2009-2010
ANNUAL REPORT

Cooperative Institute for Limnology and Ecosystems Research (CILER)

NA07OAR4320006 — Year Three
Through March 31, 2010

G. Allen Burton, Director
Thomas H. Johengen, Associate Director
Christine A. McAllen, Administrator
CILER/University of Michigan
G110 Dana Building
440 Church Street
Ann Arbor, MI 48109-1041
734-763-3010
www.ciler.snre.umich.edu
Cooperative Institute for Limnology
and Ecosystems Research – CILER

Annual Report for NA07OAR4320006

Year Three: Through March 31, 2010

Table of Contents

<table>
<thead>
<tr>
<th>Table of Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CILER’s Mission</td>
<td>3</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>4</td>
</tr>
<tr>
<td>Administrative Summary</td>
<td>5</td>
</tr>
<tr>
<td>Executive Board/Council of Fellows</td>
<td>6</td>
</tr>
<tr>
<td>Summary of Research Projects-Funding</td>
<td>7</td>
</tr>
<tr>
<td>Summary of Research Projects-Theme</td>
<td>9</td>
</tr>
<tr>
<td>Project Reports</td>
<td>12</td>
</tr>
<tr>
<td>Appendices 1 Publication count</td>
<td>164</td>
</tr>
<tr>
<td>Appendices 2 Employee count</td>
<td>165</td>
</tr>
</tbody>
</table>
CILER’s Mission:

CILER’s overarching missions are to:

- To meet the needs for ecosystem and human systems research in the regions that are reflected in NOAA’s mission and objectives. CILER will foster this mission by serving as a center of excellence for scientific, education and outreach in the Great Lakes basin, and a portal to the universities of the region.

- To fully engage participants from universities throughout the Great Lakes region that carry out research, education, and outreach in order to help address NOAA’s highest priorities in the Great Lakes region.

- To engage in research that improves understanding of the fundamental physical, chemical, biological, ecological, social, and economic processes operating in the Great Lakes region and identifying the critical socio-economic drivers and feedback shaping natural resource use and conservation.

- To improve forecasts that facilitate restoration and protection of critical natural resources, help guide management decisions, and support sustainable economic development in the region.

- To disseminate scientific information for the general public, highlight NOAA research initiatives in the region, and provide training opportunities for students, teachers, and the general public.
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, Penn State University). Since the renewal of this new agreement has been in effect, CILER supported over 70 project grants that total over $7.5 million in research funding. During the past year (i.e., current reporting period) CILER administered 15 additional CI project grants totaling $3.7 million. There were 12 non-CI grants administered totaling $2.6 million. The Great Lakes Restoration Initiative resulted in a significant increase in proposal submissions both to NOAA and the U.S. Environmental Protection Agency for federal and non-federal monies. CILER will potentially be involved in 9 NOAA-related GLRI awards totaling $3.4 million for 2010-2011. Additionally, 3 GLRI proposals were submitted for non-federal funding in the amount of $1.1 million.

CILER currently conducts research that falls under five of the six different research themes: 1) ecosystem forecasting; 2) invasive species; 3) coastal observing systems; 4) protection and restoration of resources; 5) integrated assessments, and; 6) education and outreach. Research conducted under the ecosystem forecasting theme aims to develop forecasts for physical hazards, water levels, and harmful algal blooms, 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, research conducted under the education and outreach theme facilitates education and outreach activities for NOAA in the Great Lakes region.

The Regional Ocean Sciences Bowl was hosted again by CILER for 16 high school teams in the Great Lakes. This exciting competition continues to grow and consisted of a
weekend competition at the University of Michigan. The winning team participates in the national competition in Washington DC in May 2010.

CILER organized their eleventh Summer Student Fellows Program, which supported 23 undergraduate and graduate students (10 international). Over 250 applications were received for this national and international competition. Students participated on research projects with NOAA scientists within the Great Lakes. This successful program was improved and expanded for 2010. This included an online application and review system and creation of a Long Term (9-12 month) Student Fellows Program (2 students) to supplement the Summer Student Fellows Program (12 students).

**Administrative Summary:**

The administration of CILER evolved significantly during the past year. Dr. Marie Colton began as Acting Director of GLERL in January and then assumed the position as Director in October 2009. Dr. Colton reorganized the management structure and research program of GLERL and discussions were begun with Dr. Burton on how to improve the NOAA-CILER relationship to better meet the mission and goals of both organizations.

CILER’s part-time Outreach and Education position, which was supported with University of Michigan funds, was terminated. Dr. Burton discovered that UM funding of approximately $135,000 per year, as stated in the approved CILER proposal, was in fact $63,000. This resulted in a significant shortfall in funding needed to operate CILER. The School of Natural Resources and Environment (SNRE), where CILER resides, provided $100,000 as a one-time budgetary supplement following this shortfall revelation to assist CILER operations for the next 2 years.

A part-time CILER Associate Director position was created. This position was awarded to Dr. Tom Johengen, who was a previous CILER Director and a long-time CILER Research Scientist.
Executive Board/Council of Fellows:

**Executive Board:**

The Executive Board was formed, and held its first meeting on March 30, 2010. 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), Rosina Bierbaum (Dean, SNRE), Mark Banaszak-Holl (Associate Vice-President for Research UM), Allen Burton (ex-officio) and Marie Colton (ex-officio). The draft Memorandum of Agreement between NOAA and UM was approved by the Executive Board. The Council of Fellows was created and is under consideration by the Executive Board. The Council of Fellows for the new CILER provides review of the scientific direction of the new CILER, and includes directors of the Great Lakes Sea Grant programs, with additional representation by NOAA and university scientists. A meeting of the Council of Fellows is planned for June 2010.

**Tentative Member of the CILER Council of Fellows:**

Jim Diana, University of Michigan, Michigan Sea Grant Program
Brian Miller, University of Illinois, Illinois-Indiana Sea Grant Program
Steve Bortone, University of Minnesota, Minnesota Sea Grant Program
Jeffrey Reutter, Ohio State University, Ohio Sea Grant Program
David Schwab, Scientist, NOAA-GLERL
Steve Ruberg, Scientist, NOAA-GLERL
Craig Stow, Scientist, NOAA-GLERL
Edward Rutherford, Scientist, NOAA-GLERL
Summary of Research Projects-Funding

This report details project activities through the third year of the new cooperative agreement with updates covering the period through March 31, 2010. During this period CILER has administered more than 45 projects distributed as shown in Figure 1. The total funding level through year three is $7.4M.

Figure 1. Funding distribution for CILER by theme through 03/31/10.

Table 1. Breakdown of funding by Theme awarded to CILER for the current Cooperative Agreement, NA07OAR4320006, through March 31, 2010.

<table>
<thead>
<tr>
<th>Task</th>
<th>Research Theme</th>
<th>#Projects</th>
<th>Funding ($)</th>
<th>%Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Administration</td>
<td>1</td>
<td>$384,885</td>
<td>5%</td>
</tr>
<tr>
<td>II</td>
<td>Theme I: Great Lakes Forecasting</td>
<td>18</td>
<td>$2,665,344</td>
<td>36%</td>
</tr>
<tr>
<td>II</td>
<td>Theme II: Invasive Species</td>
<td>9</td>
<td>$1,674,344</td>
<td>23%</td>
</tr>
<tr>
<td>II</td>
<td>Theme III: Observing Systems</td>
<td>5</td>
<td>$794,858</td>
<td>11%</td>
</tr>
<tr>
<td>II</td>
<td>Theme IV: Protection and Restoration of Resources</td>
<td>0</td>
<td>Pending</td>
<td>0%</td>
</tr>
<tr>
<td>II</td>
<td>Theme V: Integrated Assessment</td>
<td>3</td>
<td>$1,383,535</td>
<td>19%</td>
</tr>
<tr>
<td>II</td>
<td>Theme VI: Education and Outreach</td>
<td>3</td>
<td>$497,568</td>
<td>6%</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>39</td>
<td>$7,410,278</td>
<td>100%</td>
</tr>
</tbody>
</table>
Table 2. Breakdown of subcontract funding by institution:

<table>
<thead>
<tr>
<th>Institution</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Western Reserve University</td>
<td>$170,297</td>
</tr>
<tr>
<td>Duke University</td>
<td>$93,850</td>
</tr>
<tr>
<td>E2 Engineering</td>
<td>$101,500</td>
</tr>
<tr>
<td>Grand Valley State University</td>
<td>$49,499</td>
</tr>
<tr>
<td>Heidleberg University</td>
<td>$51,936</td>
</tr>
<tr>
<td>LimnoTech</td>
<td>$124,192</td>
</tr>
<tr>
<td>Michigan State University</td>
<td>$766,122</td>
</tr>
<tr>
<td>Michigan Technological University</td>
<td>$32,999</td>
</tr>
<tr>
<td>Ohio State University</td>
<td>$113,198</td>
</tr>
<tr>
<td>Oregon State University</td>
<td>$150,000</td>
</tr>
<tr>
<td>Purdue</td>
<td>$352,086</td>
</tr>
<tr>
<td>Smithsonian</td>
<td>$102,640</td>
</tr>
<tr>
<td>State University of New York</td>
<td>$88,001</td>
</tr>
<tr>
<td>University of Minnesota</td>
<td>$51,103</td>
</tr>
<tr>
<td>University of Wisconsin</td>
<td>$94,421</td>
</tr>
<tr>
<td>University of South Florida</td>
<td>$33,248</td>
</tr>
<tr>
<td>University of Washington</td>
<td>$239,400</td>
</tr>
<tr>
<td>Upstate Freshwater Institute</td>
<td>$5,000</td>
</tr>
<tr>
<td>Wayne State University</td>
<td>$106,382</td>
</tr>
<tr>
<td>Western Michigan University</td>
<td>$60,300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,786,174</strong></td>
</tr>
</tbody>
</table>
SUMMARY OF RESEARCH PROJECTS BY THEME:

THEME I: GREAT LAKES FORECASTING

Water Quality and Fish Production in Coastal Ecosystems

Spatially-Explicit, High-Resolution Mapping and Modeling to Quantify Hypoxia Effects on the Living Resources of the Northern Gulf of Mexico

Effects and Impacts of Hypoxia on Production and Potential of Ecologically and Commercially Important Living Resources in the Northern Gulf of Mexico

Interactive effects of Hypoxia and Mercury Contamination in Great Lakes Fish.

An Integrated Approach to Monitoring and Forecasting Harmful Algal Blooms (HABs) in the Great Lakes

Statistical-Based Modeling and Prediction of Microcystis (Cyanobacteria)

Improved Understanding and Forecasting of Viral and Bacterial Sources and Transport in the Great Lakes

Beach Quality Forecasting Coordinator

Hydrodynamic Modeling in Support of Beach Closure Forecasting

Comparative Analysis of Net Basin Supply Components and Climate Change Impact on the Upper Great Lakes

Next Generation Large Basin Runoff Models

Lake Erie Hydrodynamic Modeling

Wave-current interaction and its impact on contaminant transport

Modeling Great Lakes Ice and Revealing linkages Between Lake Ice and Climate Patterns
Modeling Sea Ice-Ocean-Ecosystem Responses to Climate Changes in the Bering-Chukchi-Beaufort Seas with Data Assimilation of RUSALCA Measurements

**THEME II: INVASIVE SPECIES**

Modeling Sea Ice-Ocean-Ecosystem Responses to Climate Changes in the Bering-Chukchi-Beaufort Seas with Data Assimilation of RUSALCA Measurements

Status and Trends in Benthic Macroinvertebrates in the Great Lakes

Status of Macroinvertebrates in Lake Ontario

Status of Pelagic Crustaceans in Southern Lake MI/ Food Web Dynamics in Southern Lake Michigan

NOAA Aquatic Invasive Species Postdoctoral Research Program

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

Enhancement of the NOAA Great Lakes Aquatic Nonindigenous Species Information system (GLANSIS)

**THEME III: OBSERVING SYSTEMS**

Optical Properties of the Great Lakes

New MODIS Algorithm for Retrieval of Chlorophyll, Dissolved Organic Carbon, and Suspended Minerals in the Great Lakes

Great Lakes CoastWatch Research Assistant for NOAA CoastWatch Program Element

GLOS - Implementation of the Great Lakes Observing System

Observatory for Submerged Sinkhole Ecosystems in Thunder Bay National Marine Sanctuary

Lake Huron: Habitat Exploration, Life Inventory and Hydrologic Modeling

**THEME IV: PROTECTION AND RESTORATION OF RESOURCES**

Great Lakes Restoration Initiative - NOAA Program Support
THEME V: INTEGRATED ASSESSMENT

ECOFORE: Forecasting the Causes, Consequences and Remedies for Hypoxia in Lake Erie

MULTI-STRESSOR - Adaptive Integrated Framework: A New Methodology for Managing Impacts of Multiple Stressors in Coastal Ecosystems

Development of GIS databases for Integrated Ecosystem Assessments of Great Lakes aquatic resources

THEME VI: EDUCATION AND OUTREACH

Outreach and Education Coordination for the NOAA Center of Excellence for Great Lakes and Human Health

Regional Climate Change in the Great Lakes Webinar and Evaluation

CILER Administration Partners-for-Exellence High School Intern Summer Program
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.
Overview and Objectives

Project Background

Fishery managers in the Great Lakes and coastal marine systems need to be able to make predictions as they attempt to manage fisheries in ecosystems that are constantly changing and under multiple stressors. Problems such as habitat loss, hypoxia, harmful algal blooms, eutrophication, nonindigenous species invasions, and climate change all pose challenges to making the predictions that are needed in fishery management scenarios. For example, in the Great Lakes, recent changes in the benthic community, particularly the invasion by *Dreissena* mussels and subsequent decline of *Diporeia*, have been tied to changes in planktivorous fish distribution, abundance and production. The invasion of the predatory zooplanktions, *Bythotrephes longimanus* and *Cercopagis pengoi* may be affecting fish diet selectivity and zooplankton availability. Changes in forage fish abundance, condition, and distribution may be affecting predator fish (Pacific salmon, lake trout) condition and distribution in Lake Huron. Changes in lake whitefish condition and distribution are affecting commercial fishery harvests in Lakes Ontario, Huron, and Michigan. In Lake Erie, low productivity and forage fish abundance may be contributing to low harvests of walleye in the lake and there is evidence that watershed loadings and water quality have direct impact on fish recruitment. In the Chesapeake Bay and the Gulf of Mexico, eutrophication has caused dead zones that may affect the pelagic food webs, and, ultimately fish behavior, growth, distribution, and production. Many of these same stressors also affect water quality and human health through their influence on drinking water and recreational water use. How can management balance these impacts?

Objectives

Our overall objective is to improve our knowledge and understanding of the relationship between water quality and fish production as driven by nutrient loading, physical forcing and invasive species. Focusing research on forecasting fish growth and production will lead to a better understanding of the causes, effects, and solutions to
problems such as eutrophication, hypoxia, toxic contaminants, nonindigenous species invasions, habitat modification, and climatic variations.

**Approach**

Overall, this program combines modeling and field programs and will largely be a comparison of results from different coastal ecosystems including the Great Lakes, Gulf of Mexico, Chesapeake Bay, the Adriatic Sea, Lake Kinneret and other coastal ecosystems. Most of the field work has been completed. This program will work closely with other major programs including IFYLE, The Center of Excellence for Great Lakes and Human Health, ECOFORE, the NGOMEX, and the Multiple Stressors Program. In the Great Lakes, sampling has largely been completed and occurred seasonally in conjunction with other ongoing GLERL/CILER research projects and at stations where historical data sets are available. Special emphasis in the analyses will be placed on evaluating fisheries in Lake Erie and how physical (water currents, temperature, hypoxia, harmful algal blooms) and biological (productivity, prey concentration and types) parameters affect the production of these fisheries. Forage fish abundance and distribution will be examined relative to water depth, water temperature, and abundance of various prey such as *Diporeia*, zooplankton, and *Mysis*. Fish and zooplankton were sampled during day and night using a variety of sampling techniques including bottom and midwater trawling and fisheries acoustics. Diet information will be related to prey availability to determine selectivity and importance of major prey items. Diet information will also be used as inputs into bioenergetic models. These models will help assess fish consumption relative to prey production. Spatially-explicit bioenergetics models will help to determine what factors (i.e., temperature, fish density, prey types) are affecting fish growth in the Great Lakes. The models will also be used to help predict how changes in the Great Lakes food web may be affecting predator and forage fish production and growth. Additional modeling will occur to evaluate the effects of multiple stressors on fish and on how watershed processes affect water quality conditions and human health.

To develop forecasting models in coastal marine systems, we will utilize the wealth of physical, chemical, and biological data, collected in Chesapeake Bay during 1995-2000 as part of the Trophic Interactions in Estuarine Systems (TIES web site) project (funded as part of the National Science Foundation's Land Margin Ecosystem (LMER) program) and recently completed field programs in the Gulf of Mexico. In so doing, we primarily seek to provide ecological forecasts to agencies involved in Chesapeake Bay and Gulf of Mexico fisheries management, but fully envision that the products and approaches developed herein will benefit management in a broad class of estuaries. The comprehensive data products and forecasting tools being produced require an
interdisciplinary synthesis of physical, chemical, and biological data collected at numerous spatial and temporal scales with a variety of technologies (e.g., acoustics, CTDs, OPCs, ADCPs, remote sensing). A variety of analytical techniques, including spatially explicit bioenergetics modeling, spectral analysis, multivariate statistical modeling, and network analysis will be employed to aid this effort. We plan to continue quantifying the spatio-temporal distribution of pelagic fish biomass (e.g., bay anchovy, striped bass) in both ecosystems, as well as continue exploring the role of habitat (e.g., temperature, dissolved oxygen, prey availability) and water quality in explaining fish distributions and potential growth rates. These efforts ultimately would enhance our ability to provide ecological forecasts of how anthropogenic factors such as eutrophication can influence growth rate and habitat use of fishes in coastal systems.

This project will also examine the response of pelagic fishes (primarily sardines and anchovy) to the Po River outflow into the Adriatic Sea. Field programs will use fisheries acoustics to examine the spatial distribution of fishes across the Po River Front. Like many coastal environments throughout the world, the watersheds of the Adriatic Sea are regions of rapid population growth and changing land-use patterns. Changes in the coastal ecosystems of Croatia, Italy, and Slovenia are making the coastal zone more susceptible to environmental hazards, more costly in which to live, and of less value to the regional economy. The overall goal of this program is to cultivate a regional approach to partnerships and to environmental monitoring and forecasting in the Northern Adriatic Sea that will help mange coastal fisheries and tourism.

Predictive models developed for all four major ecosystems will be compared to determine what predictive factors are common to the ecosystems. We will also analyze similarities and dissimilarities in the effects of changes such as eutrophication, Hypoxia, nonindigenous species invasions, habitat modification, and climatic variations on the Great Lakes and a coastal marine environment. These data will help provide information on the applicability of predictive models across ecosystems, and provide a broader context for the assessing the effects of anthropogenic changes in aquatic ecosystems.

Accomplishments

Overall productivity

This work has been extremely productive and, in the last 18 months, has produced 16 scientific papers (10 peer-reviewed publications, 4 submitted papers and 2 drafted papers), a special 215 page edition of a journal with 20 papers, 7 scientific presentations
and two special sessions at major scientific meetings.

One main accomplishment was the publication in December 2009 of a dedicated issue of the Journal of Experimental Biology and Ecology on “Ecological Impacts of Hypoxia on Living Resources” (Vol. 381, Supplement 1), containing 20 peer-reviewed papers and 215 pages (Lewitus et al., 2009). S. Brandt was a co-organizer of the conference (sponsored by NOAA) and co-editor of the special issue. The primary purpose of the workshop and publications was to compare results across Lake Erie, the Chesapeake Bay and the Northern Gulf of Mexico to 1) assess the state-of-knowledge of hypoxia affects on living resources across these three ecosystems in a manner that can be used in evaluating the resource and potential economic impacts of alternative management decisions; 2) develop recommendations for selecting and applying management tools that quantify the effects of hypoxia on living resources to inform the management of hypoxia in coastal ecosystems; and 3) identify research priorities needed to further advance the state-of-knowledge of hypoxia effects on living resources for use in evaluating the resource and socio-economic impacts of alternative management decisions in coastal ecosystem impacted by hypoxia (Kidwell, et al. 2009). Indeed, these are largely the principal goals of this CILER project!

A unifying theme among the papers in this special issue is reference to the complexities in quantifying the impacts of hypoxia on living resources, and the need for food-web models to encompass indirect effects and interaction with other stressors. The papers represent the state-of-the-science in model development to quantify ecosystem responses to hypoxia, incorporating alterations in food-web structure and resultant trophic interactions, and also behavioral and physiological responses. The manuscripts exemplify the need to move beyond linear examinations of hypoxic effects on living resources towards the incorporation of indirect and frequently sub-lethal effects into models and assessments to improve our understanding of the ecological consequences of hypoxia.

Summary of results

Results relevant to this progress report include acoustic surveys in NGOMEX that found altered or reduced habitat and prey for zooplanktivorous fish during hypoxia; while habitat overlap between predator and prey was reduced during severe hypoxia, overlap was high during mild hypoxia (Zhang et al. 2009). We observed low fish biomass in hypoxic waters, with fish aggregating horizontally at the edges of hypoxic areas. Fish also aggregated immediately above hypoxic bottom waters, but only during
years of severe hypoxia. Similarly, low dissolved oxygen in Lake Erie was found to exclude fish and their zooplankton prey to areas above or adjacent to bottom water hypoxia. These hypoxia-related habitat shifts either compressed predators and prey, or allowed tolerant zooplankton species to use hypoxic waters as a refuge from fish predation (Vanderploeg et al. 2009a & b). Yellow perch also avoided hypoxic Lake Erie bottom waters by either moving horizontally away from the hypoxic zone or migrating above the oxycline, where they consumed more zooplankton than benthic macroinvertebrates, but occasionally fed in low oxygen areas (Roberts et al. 2009).

Chesapeake Bay hypoxic bottom water was found to disrupt bay anchovy diel vertical migration and access to zooplankton prey by reducing access to bottom waters and forcing fish to reside in well-oxygenated surface or nearshore waters. In turn, reduced access to bottom waters reduces spatial overlap with mesozooplankton prey, which appear to use the hypoxic zone as a refuge. Ultimately, we discuss how these hypoxia-driven changes in behavior and spatial overlap may influence food web interactions and bay anchovy recruitment in Chesapeake Bay (Ludsin et al. 2009). Additional Chesapeake Bay results from Brandt et al. (2009) found that striped bass feeding increased with dissolved oxygen (DO) but temperature had no effect on feeding. Striped bass growth was reduced at DO < 4 mg/L and was affected by the interaction of temperature and DO. Bioenergetic modeling was performed using these results. Overall results should be useful to predict changes in striped bass habitat quality in response to changes in hypoxic conditions.

Recent results from the northern Gulf of Mexico were presented during the November, 2010 Coastal and Estuarine Research Federation biannual meeting. The two talks included a growth rate potential (GRP) bionenergetics model developed for pelagic fish in NGOMEX that demonstrated hypoxia reduces high-quality fish habitat, and multiple scales of acoustic habitat mapping (split-beam acoustics, SCANFISH sensor, and DIDSON acoustic camera) that showed hypoxia reduced fish habitat quality and altered predator-prey overlap.

Other published results include field studies of fish diet and growth in various systems. European anchovies collected in the northern Adriatic Sea off the Po River delta were reported to have fuller stomachs during the day than at night, and consumption peaked for fish in the 40-59 mm size class. Although anchovy length was not related to prey size, prey electivity was apparent and copepods dominated daytime diets while bivalve larvae were more common prey at night (Borme et al. 2009). Pothoven et al. (2009) quantified the diet composition, selectivity, daily ration, and diet overlap of emerald shiner and rainbow smelt in Lake Erie to understand feeding ecology before, during, and after hypoxia. Both species are important zooplanktivores with emerald shiners primarily consuming cladocerans, while rainbow smelt fed upon a variety of prey taxa
(zooplankton, chironomids, fish), unless restricted from benthic feeding by hypoxia. Diet overlap between species was low at all times, and although rainbow smelt feeding was reduced during hypoxia, emerald shiner feeding declined throughout the sampling time, suggesting that reduced consumption may not have been linked to hypoxic conditions. Ultimately, our findings suggest that emerald shiners are as important regulator of zooplankton abundance in the Great Lakes as Rainbow smelt, given their potentially high mass-consumption rates, selectivity and diet patterns, and current high abundance. A submitted abstract for the upcoming Ecological Society of America Annual Meeting (Pangle et al., 2010) builds on diet study results for emerald shiner and rainbow smelt by developing a spatially-explicit bioenergetics-based habitat model exploring the magnitude of short- and long-term hypoxia effects based on interspecific differences in behavior, thermal requirements, and invasion history. Model results demonstrated that in the short-term hypoxia reduced habitat quality for rainbow smelt but not for emerald shiner; field observations and long-term model results support this finding. Building on previously published work by Constantini et al. (2008) quantifying growth rate potential (GRP) of striped bass during Chesapeake Bay hypoxia using a spatially explicit bioenergetics modeling framework, Brandt et al. (submitted) found that hypoxia can have both positive and negative effects on walleye GRP in Lake Erie. While inclusion of a dissolved oxygen function in the bioenergetics model reduced walleye growth rate potential relative to the model without an oxygen function (Figure 1), positive walleye growth occurred during hypoxia when altered habitat distributions compressed walleye and prey fish in the upper water column. While results from both studies suggest that hypoxia enhances short-term predation efficiency, longer term effects of
hypoxia may decrease fish growth (Constantini et al. 2008, Brandt et al. submitted). Additionally, light levels and water temperature were important factors affecting walleye growth rate potential in Lake Erie during hypoxia. Since no previous research has explored the impacts of hypoxia on walleye in Lake Erie, our results are important to evaluating whether fisheries managers should be concerned about hypoxia in Lake Erie.

Other analyses and manuscripts were completed, including laboratory and field studies of hypoxia on yellow perch growth rates. Roberts et al. (submitted) related RNA:DNA ratio to measured growth of experimental yellow perch, but the ratio was affected by temperature only, while laboratory growth rates and consumption were affected by both temperature and oxygen. The RNA:DNA ratio varied in space and time for fish collected in hypoxic and normoxic areas of Lake Erie, suggesting plasticity in responses to hypoxia. Work on prey selectivity of sculpin in the Lake Michigan was also completed (Hondorp et al. submitted). Diet data for two sculpin species confirmed prey selection of different sizes and types, with slimy sculpin favoring smaller prey such as amphipods and deepwater sculpin feeding on larger prey such as mysids. Prey partitioning reduced diet and habitat overlap between fish species. Differences in prey selection may mediate competitive interactions between slimy and deepwater sculpin directly by reducing diet overlap in areas of sympatry or indirectly by causing these fish to select different depth-habitats.

To forecast beach water quality based on watershed forcing factors, Sellinger et al. (submitted) developed a novel Early Warning System using highly-solved, spatially-explicit physical hydro-meteorological data from the surrounding watershed (precipitation, runoff, wind direction, air temperature, and biology) to parameterize a four-dimensional, data-visualization tool that predicts E. coli levels. This work was also presented during the Oceans and Human Health session at the recent 2010 Ocean Sciences Meeting. The Great Lakes are an important resource for recreational activities that involve full body contact with water, such as swimming, water-skiing, sailboarding and wading. A major concern is microbial contamination by bacteria, viruses, and protozoa as well as nutrient loading. Many sources or conditions can contribute to microbiological and nutrient contamination including combined sewer overflows after heavy rains. In this modeling effort, physical hydro-meteorological data such as precipitation, runoff, wind direction, and air temperature; as well as biological data, E.coli counts, were analyzed to determine their statistical relationship. With the aid of a four-dimensional, data visualization tool also developed during this study; a multiple-linear-regression, beach-closure forecast model was developed as a function of
antecedent rainfall, runoff, wind direction, and watershed air temperatures. This model has 67 – 75% success in forecasting water quality in both clean and heavily contaminated shoreline areas. The uses publically available data and is programmed in an exportable language so that it can be easily transferrable to any coastal watershed.

Finally, two manuscripts by Clouse et al. (drafted) based on results of interannual trawl surveys summarized diet contents for Atlantic bumper and also constructed food webs for several species of fish in NGOMEX whose trophic relationships have not been previously categorized. Results are based on the findings of a collection of 63 species. The feeding habits of these fishes are described via interannual variation in prey composition for the seven most abundant species and trophic relationships among 27 fish species. Atlantic bumper diets differed based on maturity and all fish species sampled were omnivorous, both of which reduce competition. The effect of hypoxia on fish feeding in this ecosystem was also considered.

Programmatic

The Principal Investigator convened an all-pi meeting of the scientists working on NGOMEX – (Impact of Hypoxia on Living Resources in the Gulf of Mexico) in Washington D.C. on Feb. 12-13, 2009. At that meeting, there was a series of presentations on data collected and we compiled a list of manuscripts, authors, timetables, responsibilities and data needs for the project.

Primary Goals for 2010

The primary goals for calendar year 2010 are to complete publication of the 6 manuscripts that have already been submitted or drafted (listed below). We also plan on further scientific presentations (e.g. Ludsin et al, 2010) and continued work on partnerships in the Adriatic.

A second NGOMEX (Impact of Hypoxia on Living Resources in the Gulf of Mexico) all-PI meeting is planned for June 14-15, 2010 in New Orleans, LA. The goals of this meeting are for PIs to share progress on data synthesis, make connections among various parts of the project, and inform local fishery managers of their latest results.
A special session on “Effects of hypoxia in various aquatic ecosystems” is proposed for the American Society of Limnology and Oceanography Aquatic Sciences Meeting in San Juan, Puerto Rico; February, 2011.

Publications


Papers in Review


Clouse, M., A. Adamack, S. Ludsin, D. Mason, S. Brandt, and H. Zhang. Feeding habits and trophic relationships of fish species in the northern Gulf of Mexico during summer
hypoxic events. *drafted.*


**Presentations and Scientific Sessions**


**Popular Press**

Overview and Objectives

As a direct consequence of eutrophication, there has been an alarming increase in the spatial and temporal extent of low oxygen bottom waters in estuarine and coastal waters. Although hypoxia is prevalent in many US coastal systems, such as Chesapeake Bay and the Laurentian Great Lakes, most prominent has been the advancement of hypoxia in the northern Gulf of Mexico (NGOMEX). The temporal and spatial extent of hypoxia in the NGOMEX has increased as a result of excessive nitrogen inputs from the Mississippi River. Despite this increase in hypoxia, the trophic consequences of low oxygen waters on pelagic communities remain poorly understood. Given the economic importance of the Gulf of Mexico commercial fisheries (about 20% of the U.S.’s total domestic fishery landings representing about $991 million) and recreational fishing (generating ~30% of the nation’s saltwater fishing expenditures and supporting nearly 25% of the nation’s recreational saltwater jobs), it is imperative that knowledge of the ecosystem effects of hypoxia in NGOMEX be increased.

The objectives are to:

- Conduct high-resolution mapping of the NGOMEX pelagic food web (including bacteria, phytoplankton, microzooplankton, mesozooplankton, and fish) in relation to hypoxia;
- Integrate these ecosystem measurements through a variety of models designed to assess the effects of hypoxia on NGOMEX pelagic food webs and production;
- Quantify habitat suitability for economically and ecologically important fishes; and provide tools to forecast food-web interactions, habitat suitability, and fish production in relation to hypoxia.

High-resolution mapping of the major ecosystem components of the NGOMEX will be conducted. Automation of sampling, analysis, and classification of pelagic organisms using new technologies offers a practical, cost-effective way to intensify survey efforts in the NGOMEX so that ecosystem components are sampled at the fine-scale and broad-
scale resolutions necessary to understand the effects of hypoxia. This approach will yield information on phenomena that would have been missed by a fixed or bottom-focused sampling regime, and enhance the functionality of monitoring and observations. Mapping results will be incorporated into spatially-explicit bioenergetics-based growth rate potential, size-spectrum, dynamic optimization, food-web, and statistical models to provide managers with essential information for improved ecosystem-based management of the NGOMEX, including information to quantify and forecast the ecological consequences of changes in hypoxia on the living resources of the NGOMEX. The results of this research will be highly integrated into NOAA operations and strategic planning through direct NOAA involvement, tightly integrated with other programs in the region and elsewhere, and broadly disseminated to resource managers and the scientific community through the WWW, presentations at meetings, Sea Grant Extension and peer-reviewed publications. Undergraduates, graduate students, postdoctoral scholars, and teacher interns will be involved in all aspects of this research. Researchers from CILER focus on the fish component of the living resources and food web model construction and simulations.

**Accomplishments**

Data collection and most data processing have been done during 2006 to 2008. The focus for the past year has been on analyzing the data that was collected in previous years and the preparation and submission of journal publications and the projects final report. One paper has been published and four others are in preparation. Two presentations were given at the Coastal and Estuarine Research Federation (CERF) 20th Biennial Conference 2009. The project final report will be submitted by the end of April 2010.

PIs (Hongyan Zhang and Aaron Adamack) met with other project PIs at CERF 2009 to discuss how the data collected as a part of this project could be used to advance the work being done on our new NOAA award **Effects and impacts of hypoxia on production and potential of ecologically and commercially important living resources in the northern Gulf of Mexico**

**Publications**


Zhang, H, et al. *In preparation.* Hypoxia impacts on the growth and distribution of the pelagic fish in the northern Gulf of Mexico. To be submitted to Marine Ecology Progress Series.


Adamack, AT et al. *in preparation.* *In situ* observations of fish spatial distributions in hypoxic zones.

**Presentations**


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 living resources.
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 will focus 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 will also be 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.

**Accomplishments**

Most of our work over the past several months has been focused on laying the groundwork for developing the two models that we will be building for this project.

1. September 8-10, 2009 Adamack and Zhang attended a workshop “Introduction to the Atlantis Ecosystem Model”. As a follow-up to this workshop we held a conference call (September 28, 2009) with the workshop leaders and with researchers involved with a similar project for Chesapeake Bay. Based on the material that we learned at the workshop, our discussions during the conference call and from lessons learned from a project that we are working on for Lake Erie, we’ve made the decision to switch from the Ecosim with Ecospace ecosystem based modeling platform to the Atlantis Ecosystem Model platform.

2. While attending the CERF 2009 meeting in Portland, OR (November 1-5, 2009) we had several informal planning meetings with other project PIs to plan work for the upcoming year. Also during this meeting, we met with several individuals to discuss the use of their data for model development.

3. We are currently in the process of planning an all PI meeting for mid-June 2010.

4. We are in the process of preparing bioenergetics and diet data for use in the Atlantis model.

**Publications**

None

**Presentations**

None
Overview and Objectives

The broad goal of this research is to evaluate impacts of hypoxia and mercury on long-term sustainability of fish populations. Mercury and hypoxia are two stressors of concern in the Great Lakes ecosystem. Although they commonly co-occur in aquatic systems, it is not known how effects of these two stressors might interact to impair survival, growth, and reproduction. The hypothesis of this study is that mercury-polluted fish have a reduced ability to respond to hypoxic stress. We will address this hypothesis by conducting a laboratory study to expose yellow perch to environmentally relevant levels of hypoxia and mercury. Health effects will be determined using molecular and physiological techniques. This study serves the dual purpose of 1) increasing our understanding of mechanisms underlying responses to hypoxia and mercury in fish, and 2) identifying novel molecular/physiological markers than can be used to forecast early changes to animal health. Future planned studies will include applying these novel molecular/physiological markers to evaluate and predict sustainability of fish populations.

Accomplishments

- A student technician was hired to set up a laboratory experiment to co-expose juvenile yellow perch to methylmercury and hypoxia.
- Fish were exposed to dietary methylmercury for 1 month followed by a 1 week hypoxia challenge (Summer 2009).
- Liver and brain tissues were collected from approximately 240 fish (Summer 2009).
- A student technician was hired to analyze biochemical endpoints in the collected tissues.
- Total mercury levels were measured in brain tissues from approximately 240 fish co-exposed to methylmercury and hypoxia (Fall 2009).
- NMDA receptor levels were measured in brain tissues from approximately 240 fish co-exposed to methylmercury and hypoxia (Fall 2009).
- A bioassay to assay hypoxia inducible factor (HIF) mRNA levels in yellow perch is currently being developed (Fall 2009, ongoing).
Publications

*In preparation:* JA Head, GA Burton, ES Rutherford, M Pickens, MJ Carvan, N Basu, Effects of co-exposure to hypoxia and methylmercury on NMDA receptor levels in yellow perch. To be submitted to Environmental Toxicology and Chemistry (Fall 2010)

Presentations

*Poster presentation:* JA Head, M Pickens, MJ Carvan, A DeBofsky, GA Burton, N Basu. Interactive Effects of Methylmercury and Hypoxia in Fish. Society of Environmental Toxicology and Chemistry (SETAC) annual meeting, November 2009, New Orleans.
PROJECT TITLE: AN INTEGRATED APPROACH TO MONITORING AND FORECASTING HARMFUL ALGAL BLOOMS (HABs) IN THE GREAT LAKES

Principal Investigators: Juli Dyble Bressie (GLERL), Donna Kashian (CILER), Allen Burton (CILER)

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. *Microcystis* has (again) become a dominant component of the summer phytoplankton in both Saginaw Bay and western Lake Erie after being a relatively minor component during the late 1980s and early 1990s. The toxin of highest concern in the Great Lakes in 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). These microcystin concentrations are of particular concern because they are found close to a public water supply intake in the bay. 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 in terms sample analysis and ship time. Due to limits in time and resources, 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. For example, in order to detect a bloom at a drinking water intake, there would need to be monitoring daily or every other day near the intake pipe in order to detect the presence of toxic cells. Once detected, drinking water treatment needs to be increased in order to adequately remove the toxins and it is beneficial to have advanced warning in order to prepare for this. Even if sampling could somehow
be conducted with sufficient enough frequency, processing the samples quickly enough to be responsive to a developing bloom would take a significant amount of time. Thus, there is a significant need for a HAB forecasting system that can predict the presence of blooms at significant points of interest.

We propose an integrated system of detection and modeling in order to develop a HAB forecasting model for the western basin of Lake Erie. This system would incorporate satellite imagery for the detection of blooms, a particle tracking model utilizing the hydrodynamic circulation of the basin, in situ measurements for HAB cells to determine the effectiveness of the predictive model, and public outreach to inform beachgoers and recreational water users of the presence of HAB blooms. Each of these components has been in development over the few years and this will be the first effort to incorporate them into a forecasting system.

**Accomplishments**

We built on the successes of 2008 to further refine and develop the HAB Bulletin for western Lake Erie during 2009. We put out weekly HAB Bulletins from 23 July 2009, at the start of the western Erie *Microcystis* bloom season, until 15 October 2009 when the bloom ended. Bulletins were distributed to about 40 stakeholders around Lake Erie, including the Cuyahoga County Department of Health, City of Sandusky Water Treatment Plant, City of Cleveland, City of Toledo Water Treatment Plant, and Erie County Water Authority. Managers of water utilities, beaches, recreational parks, city managers and other researchers received the HAB Bulletin. We worked in close collaboration with Sonia Joseph Joshi (GLERL) who has been developing connections with this stakeholder community in order to better determine the format, timing and information that this bulletin should contain in order to be most beneficial and we will use the feedback that she has gained to further refine the HAB Bulletin for 2010.

This project is a close collaboration with R. Stumpf, M. Tomlinson, T. Wynne (NOAA/NOS/CCMA, Silver Spring, MD). This group provided the MERIS satellite imagery for detecting the *Microcystis* blooms and then forecasts movement of the bloom 3-4 days ahead based on data from the Great Lakes Forecasting System (D. Schwab, D. Belesky) and a particle tracking model. Our group validated both the satellite detection and the forecast using ship-collected samples and found that the forecast provided an accurate model of bloom movement. Current conditions and an analysis of the forecast data is also included in each Bulletin to help provide interpretation of the imagery to stakeholders receiving it. We also collected physical, chemical and biological data that will be essential for adding a biological model of *Microcystis* growth and bloom
development to the forecast. With increased satellite resolution now available, we will also be able to provide increased spatial resolution to the forecasts as well.

(HAB bulletin sent out on 6 August 2009)

Publications


Presentations

Dyble, J., “But it is toxic? Assessing the distribution of toxic Microcystis and environmental factors controlling microcystin production,” Wayne State University, invited talk, 13 Apr 09

Dyble, J., “Cyanobacterial HABs in the Great Lakes: environmental controls, genetic diversity and impacts on human health,” *NOAA Northwest Fisheries Science Center*, 3 Jun 09

Dyble, J., “Harmful Algal Blooms”, *Eastern Michigan University, Ypsilanti, MI*, invited seminar, 23 Sept 09
Overview and Objectives

Blooms of the toxic cyanobacterium, *Microcystis aeruginosa*, annually occur throughout the Great Lakes and threaten aquatic resources and potentially human health. The current Great Lakes HAB bulletin ‘depicts’ existing *Microcystis* accumulations based on satellite imagery and relies upon multi-day projections of select physical parameters (e.g. wind velocity/direction, water movement) to predict passive bloom transport. Phytoplankton growth/loss and/or real-time responses to environmental factors are not incorporated into the bulletin and as a consequence, prediction of active *Microcystis* bloom initiation is lacking.

Objectives: 1) Construct statistical models for predicting *Microcystis* abundance and bloom potential in select, eutrophic regions of the Great Lakes, and 2) Submit (to NOAA-GLERL & UM-CILER) a report to summarize: A) the results of model validations and applications and B) identification of candidate predictors/models for integration into a ‘next generation’ Great Lakes harmful algal bloom (HAB) bulletin.

Accomplishments (to date):

1) Diverse non-parametric and parametric approaches characterized *Microcystis* abundance throughout Saginaw Bay (Lake Huron), within the context of the overall phytoplankton assemblage;

2) Key environmental factors regulating both the (holistic) phytoplankton and *Microcystis* abundance patterns were delineated;

3) Models for visualizing and predicting *Microcystis* abundance in relation to dynamic environmental constraints were developed and evaluated. Specifically, models incorporating hydrological and meteorological parameters that are easily acquired via contemporary autonomous technology were emphasized; and

4) Manuscript in preparation - intended submittal of April, 2010 to the *Journal of Phycology*:

Publications:


Presentations:


2009 (November) - Invited Seminar: University of South Carolina, Marine Sciences Program; Columbia, SC. “An ‘Enviro-Informatic’ Assessment of a Great Lakes Coastal System: Data-Driven Characterization and Modeling of Phytoplankton”
PROJECT TITLE: IMPROVED UNDERSTANDING AND FORECASTING OF VIRAL AND BACTERIAL SOURCES AND TRANSPORT IN THE GREAT LAKES

Principal Investigators:     Joan Rose, Mantha Phanikumar, MSU
                              Allen Burton, CILER

Overview and Objectives

Our research goal is to develop a risk assessment framework based on our continued examination of complex watershed systems in Saginaw Bay and in Traverse Bay. We will examine technological solutions associated with decreasing risk including membrane bioreactors and CSO abatement. We will utilize microbial source tracking tools and pathogen monitoring tool box for developing the necessary data to incorporate into the hydrodynamic and risk models. In this phase of the study we will explore the role of climate on water quality and health. Because this has had record snow falls, we plan to be in a position to follow the spring melt and water quality changes throughout the spring, summer and fall season.

Specific Tasks and Outcomes

1. Efforts will go towards the testing of the Saginaw Bay model and the Grand River Watershed models focusing on nutrients (P and N), pathogens and HABs. The models are expected to provide a scientific basis for testing hypotheses related to pathogens, HABs, muck and invasive species.

2. In 2009, we will sample key beaches and the tributaries impacting those beaches in Saginaw Bay to follow the shoreline impacts from spring to summer to fall. This will be based upon 2008 study which examined four Saginaw Bay beaches (Whites Beach, Bay City State Recreation Area Beach, Caseville County Park Beach, and Port Crescent State Park Day Use Beach) with 86 samples and over 400 analyses. Correlations detected microbial levels at each beach responded uniquely to environmental conditions with Bay City State Recreation Area water quality strongly linked to rainfall ($r = .702$ to $.855$), Whites Beach influenced by wind and wave action ($r = -.730$ to $.642$), and the other 2 beaches impacted greatest by air temperatures ($r = -.977$ to $.944$). These relationships will be further elucidated.
3. We will begin the sampling effort using the tool box approach and our portable ADCP instrument in Traverse Bay. This will include East Bay Park, Traverse City State Park and Mitchell Creek. The role of the wastewater treatment and storm water will be examined.

4. To address health risks we will build a quantitative microbial risk assessment model. This will be based on selected monitoring for pathogens, as was done for Lake Michigan (Wong et al. Water Research)

5. We will continue to work with Michigan Department of Community Health on “Water Watch”, self-reporting illness survey. Any identification of problems and we will join the State team to sample the environment.

**Accomplishments**

We have water quantity results available for the Saginaw Bay Watershed (comparisons with discharge data from USGS gauges show an excellent agreement) but the transport models will take some time. Data limitations are one of the issues we are addressing.

We made measurable progress with the modeling last year but have not tested the Saginaw Bay models yet. Saginaw Bay is a large watershed, which has led to the delay in testing the models. We are systematically testing several different issues involving scale, data limitations, and other parameters in several Michigan watersheds. We are initially testing models for smaller watersheds and then we will complete the work for larger catchments. We completed work for another important watershed that we did not include in our original work statement (Clinton River Watershed). These papers reporting results for only water quantity and model testing are in various stages of review. This year we will work on hydrologic modeling focusing mainly on transport (of indicator bacteria).

**Publications**


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 ongoing efforts of CEGLHH and other agencies with the purpose of developing and implementing a generalized approach to beach quality nowcasting and forecasting.

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**

- Hired David Rockwell for Beach Water Quality Forecasting Coordinator.
- Great Lakes Restoration Initiative
- NOAA plan for Beach Water Quality Forecasting Program proposal for Gt. Lk. Restoration Initiative. Proposal for 3.4 M over two years
- Areas of interest including Saginaw Bay River and Bay AOC, Milwaukee Wisconsin AOC, Clinton River AOC, St. Louis River Duluth Minnesota AOC, Rochester Embayment, Rochester NY AOC, and Presque Isle Erie PA AOC, Huntington Beach is near the Cuyahoga River AOC.
- 60 Hour Beach Forecasting Models proposal (Funding Opportunity Number: EPA-R5-GL2010-1; DUNS Number: 073133571) has been funded.
- Beach Model Data Base Spreadsheet has been updated, and identifies ~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.
- Formed the Great Lakes Beach Health Interagency Coordination Team comprised of three members from USEPA, USGS, and NOAA and held first joint meeting April 14, 2009.

**Membership;**
USEPA: Holly Wirick, Richard Zdanowicz, and Dr. Richard Zepp
USGS: James Morris, Sandra Morrison, and Norman Grannemann
NOAA: Richard Wagenmaker, Sonia Joseph, and Dr. David Schwab
Beach Quality Forecasting Coordinator: David Rockwell

Norman Grannemann <nggranne@usgs.gov>, Sonia Joseph <Sonia.Joseph@noaa.gov>, James Morris <jrmorris@usgs.gov>, Sandra Morrison <smorrison@usgs.gov>, David Schwab <David.Schwab@noaa.gov>, Richard Wagenmaker <Richard.Wagenmaker@noaa.gov>, Richard Zdanowicz <Zdanowicz.Richard@epa.gov>, Richard Zepp <Zepp.Richard@epa.gov>, Holly Wirick <Wirick.Holiday@epa.gov>

- Mission for Beach Health Interagency Coordination Team
  
a. 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.

b. Capitalize on the unique research capabilities of each agency in the Great Lakes region.

c. 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.

d. Develop coordinated responses to emerging issues (e.g. Great Lakes Restoration Initiative) for Beach Health in the Great Lakes through communication with each other and our beach health partners.

- Product for specific responsibility number 1.

Inventory and Document Ongoing Beach Water Quality Forecasting Activities

The International Joint Commission 2007-2009 Nearshore Priorities: Beaches and Recreational Water Quality Work Group Report, Appendix 1, is a report of Beach Water Quality Forecasting Activities in the United States and Canada. This Appendix is called the Beach Matrix and was assembled by Lori Boughton, Pennsylvania Department of Environmental Protection, Office of the Great Lakes, David Rockwell, CILER and NOAA’s CEGLHH, and Tim Feltcher, Ontario’s Ministry of the Environment.
• Product for specific responsibility number 2.
The GLRI grant proposal for 60 Hour Beach Forecasting Models represents a
general process for forecasting beach water quality and product delivery.

This plan contains the following elements.

Protocol for Identification of Appropriate Parameters to use as Independent Variables.
• Gathering Water Quality Records
• Developing a Statistical Model Relating Water Quality (E. coli) to the Parameters
• Implement A System for Routine Operation of the Model in Nowcast &
ForecastMode
• Inform users of the results of the system
• Evaluate the accuracy of the system
• Document the protocol
• Ensure protocol can be applied & sustained at any new Beach using the Forecast
Model
• Partner with EPA, USGS, NOAA, Sea Grant, State and Local Agencies, & the
GLBA.
• Review beach forecast models with USGS and Beach Managers at individual
beaches.
• Make process portable and operationally sustainable at beaches via NWS.

This plan will be tested at several beaches located in Michigan counties during 2010.

Publications
None

Presentations

National Beach Conference Huntington Beach California, April 20-22, 2009

Poster: Towards 48 Hour Beach Forecasting Models for the Great Lakes.

D. Rockwell, D. J. Schwab, S. Joseph, and R. Wagenmaker with collaborators

EPA Recreational Waters Research Forum Costa Mesa, CA. April 23, 2009
Session 3. Predictive Modeling of Pathogens and Indicators
Chaired by Dr. Richard Whitman, USGS and Dr. Richard Zepp USEPA Athen Ga.
Invited Talk

A Real-time System for Prediction of Nearshore Circulation and Pathogen Transport at Great Lakes Beaches.

D.J. Schwab and D. Rockwell

American Public Health Association annual meeting November 7-11, 2009
"Water and Public Health: the 21st Century Challenge" in Philadelphia,

Session: Your Oceans and Your Health: Public Health Surveillance, Prediction, Prevention and Preparedness

Invited Talk:

Beach Water Quality Forecasting in the Great Lakes: Using Ocean Observing Systems to Predict Public Health Issues.

D. Rockwell, D.J. Schwab, and S. Joseph

NOAA’s Oceans & Human Health Initiative, Principal Investigators Meeting, October 6-8, 2009

Invited Member of Expert Panel:
Making the Public Health and Ocean Health Connection

Dr. M. McGeehin, Dr. A. Depaola, Mr. D. Rockwell, and Dr. F. Cox

4th Annual Water Quality Forum Ottawa Co. MI. October 26th 2009

Invited Talk:
Ottawa County Beach Forecasting Model

Ocean Sciences Meeting. From Observation to Prediction in the 21th Century. Feb. 22-26, 2010

Poster: Towards a 48 Hour Beach Health Forecast Model for the Great Lakes
D. Schwab, D. Rockwell, and R. Wagenmaker

Michigan Environmental Health Association Education Conference March 24-26, 2010

Invited Talk:
Towards Real Time Data Analysis For Opening and Closing Beaches


International Association for Great Lakes Research Conference Toronto, May 17-21, 2010

Session 48. Observing System Technology To Support Great Lakes Management

Poster: Towards a 60 Hour Beach Health Forecast Model for the Great Lakes
Overview and Objectives

The Great Lakes respond very quickly to atmospheric forcing and other loadings (Klump et al., 1995). Consequently water quality managers and other planning and decision entities are increasingly calling for up-to-the-minute data on present water quality conditions or forecasts of these data that can be used to adjust or respond to quickly developing activities with environmental implications. Examples include the forecast of short term water quality conditions for the withdrawal of water for drinking water supply; short range predictions of potentially dangerous conditions at water supply intakes; the forecast of beach closings and openings from bacterial contamination from combined sewer overflow (CSO) discharges (Burton et al., 1987; Sherer et al., 1992); the knowledge of the trajectory of materials from dangerous spills; short range prediction of the impact of shoreline activities at one site or another shoreline site; and the forecasting of upwelling and downwelling events and the associated nutrient and bacterial redistributions required for toxic plankton blooms.

For these and other reasons, the Great Lakes Forecasting System (GLFS, Bedford and Schwab, 1994; Schwab and Bedford, 1994) has been developed to provide short-range operational (regularly scheduled) predictions of such conditions for the open waters of the Great Lakes. Predictions include every-six-hour nowcasts and twice-a-day short-range (48 hr) forecasts. Variables predicted include the three-dimensional velocity field, the three-dimensional temperature field, the water level distribution and the wind wave height, length, period, and direction, and resuspension, transport, and deposition of bottom sediments based on wave and current conditions (Lou et al., 2000). Predictions are made on a five-kilometer horizontal grid with twenty vertical slices comprising the vertical grid. The Princeton Ocean Model (Blumberg and Mellor, 1987) serves as the base model for the forecast system. Weather data are acquired from the National Weather Service through the NOAA PORT satellite dissemination network and objectively analyzed in near real-time to drive the nowcasts. The system has undergone extensive testing. Day-to-day evaluations are performed with the NOS water level, buoy temperature, and wave data. More extensive evaluations have occurred in hindcast comparisons with field experiment data, including the full three-dimensional current and temperature comparisons in Kuan et al. (1995) and Kuan and Bedford (1995), the surface temperature comparisons in Schwab et al. (1992), and the forecast...
comparisons in Kelley et al., (1996) and Kelley (1995). As a result of these testing activities, we concluded that the whole lake circulation features could be forecast with reasonable accuracy out to 12-24 hours.

When contrasting the information needs of water quality managers with the forecasting experience to date, three issues remain. First, the information requirements all occur with regard to activities in, near, and around the near-shore/inshore zone. It is well known that the greatest demand for lake/coastal resources is in the near-shore zone and accurate information is required in this zone. Second, the information needs of the managers are for water quality data; data not yet predicted or available in forecast form. Third, the water quality forecasts require knowledge of both point and non-point sources. This proposal is a part of the research program that focuses on point source loadings of E. coli (EC) into coastal environments from particular rivers and its impact on beach closures.

**Objective**

Develop a nested grid modeling system for Saginaw Bay, Lake Huron based upon a fully three-dimensional hydrodynamic model to provide temperature and advection fields for forecasting E. coli and Enterococci concentrations along the coasts impacted by a specific plume (ultimately pathogens).

**Accomplishments**

We employed the Princeton Ocean Model (Blumberg and Mellor 1987) for calculation of lake-scale hydrodynamic circulation in Lake Huron. For lake-scale simulations, meteorological data from the NWS surface observing stations and mid-lake weather buoys are used to synthesize overwater momentum flux and heat flux fields to drive the model. Once the lake-scale simulations are completed on a coarse grid, a nested grid with a grid size of 200 m was developed and applied to the inner Saginaw Bay. Results from the whole-lake simulations are used to specify the open water boundary conditions for the nested grid simulations. After the model was tested in the-off-line mode, it was transferred to GLERL and currently is being run operationally. Results are available at: http://www.glerl.noaa.gov/res/glcsfs/sb/

**Publications**

None
Presentations

Overview and Objectives

The objectives of this study are: 1) quantifying the uncertainty in the Upper Great Lakes Net Basin Supply’ single components and final values; 2) testing a new method for overlake precipitation estimation; and 3) recalibrating the GLERL’s model for lake evaporation with more recent data. In addition, traditional downscaling of GCM’s data will be performed for comparison with more advanced methods.

Accomplishments

We extended the Adjusted Multisensor Precipitation Estimate (Chattargee et al., 2009) to the entire Great Lakes basin for the period 2002-2007. We compared these results with the NOAA GLERL over lake precipitation estimates based on Thiessen Polygons interpolation and with the Canadian Precipitation Analysis (Fortin and Charpentier, 2008) and used these results for computing the uncertainty in GLERL’s overlake precipitation.

We analyzed the uncertainty in the NOAA GLERL's approach to river input to a lake and quantified its uncertainty.

We compared NOAA GLERL’s lake evaporation estimates for Lake Superior with evaporation data collected in 2008-2009.

We estimated the total uncertainty in NOAA GLERL's NBS using the results we produced for over-lake precipitation and river input and the estimates produced by Neff and Nicholas (2004) for evaporation.

We are presently recalibrating the GLERL model for lake evaporation.

Publications


**Presentations**


PROJECT TITLE: NEXT GENERATION LARGE BASIN RUNOFF MODELS

Principal Investigators: Brent Lofgren, GLERL
Carlo DeMarchi, Case Western Reserve University

Overview and Objectives

Adding sediment transport and water quality component to the 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 Maumee River, Sandusky River, Cuyahoga River, Grand River (Ohio).

Accomplishments

The late availability of funds (November 2009 instead of the programmed May 2009) has affected the work carried out by the project. The summer fellow hire as part of the proposal did not have the programming expertise that was expected, but she was able to produce the Rainfall erodibility maps for the AuGres-Rifle, Pigeon-Wiscoggin, Kawkawlin-Pine, Saginaw, Grand River (Michigan), and Maumee (Ohio). We hired a student at CWRU who is presently compiling the point sources in the Maumee River basin. We are also modifying the DLBRM for adding sediment transport.

Publications

None at the present date.

Presentations

None at the present date.
Overview and Objectives

The motivation for this project is to lay the groundwork for studying the relative roles of physical, chemical, and biological factors on the ecology of Lake Erie at a variety of space and time scales. Lake Erie was chosen as the target lake for several reasons including population density, availability of long term data sets, a variety of physical, chemical, and biological forcing functions (including invasive species), and a wide variety of impacts including water quality (hypoxia/anoxia), fisheries, and biological community structure. We believe that a reasonable initial approach would be to identify sources for and begin gathering data on the biological, chemical, and physical environment in Lake Erie. The data would be organized in a format that would be conducive to interdisciplinary analyses. The next step would be to develop a linked hydrodynamic/ecological model of Lake Erie including relevant physics (tributaries, advection, resuspension, etc.) and lower food web ecology. This project is intended to support the development of the Lake Erie hydrodynamic model which will eventually form the basis for the linked hydrodynamic/ecological model.

Recently, a 2 km hydrodynamic model of Lake Erie was developed based on the GLERL version of the Princeton Ocean Model (POM). Daily tributary inflows and hourly meteorology were assembled for the year 1994, 2004 and 2005 and complete hydrodynamic model simulations were accomplished. Comparison of model results with observations showed that the model was not able to simulate the observed step-function, like vertical thermal structure in the central and eastern basins. The consequences of this problem for modeling hypoxia/anoxia and for coupling ecological models with the physical model in Lake Erie are very significant, since the vertical distribution of dissolved oxygen as well as nutrients and biota in the central basin closely follow the vertical temperature profile and the development of a sharp thermocline in the lake in summer, which inhibits vertical mixing of epilimnetic and hypolimnetic waters. At the same time, the 2007 field year brought in a new set of data on thermal structure evolution. Therefore, we proposed to run the model for 2007 to help interpret the field observations as well as to continue testing the hydrodynamic model.
Accomplishments

Meteorological data from 12 land stations around Lake Erie and 3 meteorological buoys were assembled, edited and interpolated to create gridded 2 km forcing functions for the hydrodynamic model. Flow data from 22 major tributaries were prepared for the 2007 hydrodynamic model run. The model was run for 2007, and comparison of model results with new observations showed that the model failed to simulate a “bowl-shaped” thermocline, which was observed in the central basin on several occasions. We attribute this to deficiencies in the over-lake wind fields with NOAA buoys deployed primarily near the northern Shore, leaving a vast area of southern Lake Erie without wind observations.

Publications


Presentations


Overview and Objectives

It has been always recognized that current could be significantly influenced by the surface waves. It is widely known that currents are influenced by surface waves primarily by the way of surface wind stress, radiation stress, and bottom stress. Waves have a very important effect on the current structure, which play an important role in the transfer of momentum and energy across the air-sea interface and strongly impact currents and the nearshore ecosystem. As waves move into near shore regions, the subsequent energy gradients cause additional near shore circulation. The wave and current interactions are an important aspect of the hydrodynamics at the beach and coastal scales. Specifically, the wave could interact with the currents and contribute to local water level changes, momentum and vertical stratification mixing.

The Grand River is the largest tributary entering Lake Michigan. The combination of a major River, relatively simple shoreline geometry, and low-slope, regular bathymetry makes this an ideal site for developing, testing, and refining a nested-grid hydrodynamic model. There are also several highly utilized and often contaminated beaches in this area.

The wave-current based hydrodynamics-eutrophication modeling system will be useful to all users of the Great Lakes coastal waters who require the information of temperatures, currents, water levels, and waves. Wave and current physical processes have a major impact on environmental, chemical, and biological processes and influence many other types of user activities, such as water supply management, waste water management, power plant sittings, shipping, recreational and commercial boating and fishing, shoreline erosion and redistribution of sedimentary material. Planners and managers responsible for any part of the Great Lakes ecosystem that is affected by wave induced nearshore circulation, such as transport of toxic material or nutrient enrichment processes. The wave current modeling system of lake waves, water levels, water temperatures, and currents are expected to provide ecologist with a significant source of new information which should lead to considerable improvements both in the accuracy and efficiency of ecological marine forecasts for the Great Lakes.

In this past year, an three-dimensional unstructured grid Finite Volume Coastal Ocean
Model (FVCOM) has been used to investigate the wave-current interaction at the nearshore region and in particular to implement the three-dimensional effect of waves on the nearshore circulation and temperature fluctuations in the Grand River and adjacent beach areas. The ambient flow from the lake-scale Princeton Ocean Model, the real time Grand Haven river runoff data and open water boundary wave conditions drove the wave-current coupled numerical model. The nearshore wave and current unstructured grid modeling prediction system will be demonstrated at the Grand Area coastal waters near the Grand River.

**Accomplishments**

It was the firstly time to use the high resolution unstructured wave-current coupling model for the Great Lakes Region and also the first few pilot study for the whole oceanography and limnology field.

The modeling was validated using the slope experiment. The slope is 5KM wide and 10KM in length. The standard depth linearly changes from 0.5m to 20m while some experiments also were conducted with the changing depth. The typical result could be found at the figure (1): alongshore-current velocity VS incoming deep-water wave height.

The configuration of the wave-current unstructured grid model to the Grand Haven: the analysis of bathymetry, the grid generation, the modeling testing and debug, the computing environmental library installation, the output post processing.

The numerical modeling current results were obtained from the effects of wave induces radiation stress, wave-current interaction, ambient flow and river inflow at the current stage. A example of the influence of the forcing to the modeling result could be seen at figure 2.

The Nearcom, a beach model was tested and compared to the FVCOM. Some limitation was found and we decide that FVCOM is good for the nearshore modeling at the current stage.

The trajectory model was investigated and will be coupled to the Grand Haven Model later. It could help simulate the contaminant transport next step.

**Publications/Manuscripts**
“Prepared for Journal of Geophysical Research-Ocean”

Meng Xia, David J Schwab et al. (2009) The influence of wave to the plume structure and the particle transport at the Grand Haven Area of Lake Michigan
Prepared for Journal of Great Lakes Research”

Presentations


Meng Xia, David J. Schwab. The wave-current modeling for Grand River at Lake Michigan, Invited talk by Grand Valley State University (Schedule at April 16th, 2010)
Figure 1. Alongshore current velocity VS incoming deep water wave height

Figure 2. The velocity under the influence of wave, river and ambient flow
PROJECT TITLE: MODELING GREAT LAKES ICE AND REVEALING LINKAGES BETWEEN LAKE ICE AND CLIMATE PATTERNS

Principal Investigators: Jia Wang, GLERL
Dmitry Beletsky, CILER
Allen Burton, CILER

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 water surface than over 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 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. Generalized relationship between lake ice cover, lake levels, and atmospheric circulation patterns will be concluded. The second objective is to develop and test ice model of Lake Erie.
Accomplishments

A coupled Great Lakes Ice-circulation Model (GLIM) of Lake Erie was developed based on POMGL and CIOM and tested during 2003-2004 winter. Model results compared favorably with observations. A full-length paper was in press in the Journal of Great Lakes Research. Furthermore, a process study was conducted using GLIM to investigate the dynamic feature of lake ice along with measurements. This results in a paper submitted to the IAHR international conference proceedings.

We further investigate the impacts of ENSO and AO on Great Lakes ice cover using lake ice observations for winters 1963-2008 and NCEP reanalysis data to revise the previous submitted paper by Bai et al., which was submitted to Monthly Weather Review. We also examined the unique ice feature in the 2008-09 ice season as a case study and published this AGU EOS featured article.

Publications


Bai, X., J. Wang, C. Sellinger, and A. Clites. The impacts of ENSO and AO on the interannual variability of Great Lakes ice cover (submitted to MWR)

Wang, J., X. Bai, D. Wang, D. Wang, H. Hu, and X. Yang, 2010. Interannual variability of the East Asia winter Monsoon, as controlled by the Siberian High and Arctic Oscillation: Driving downwelling in the western Bering Sea. (Submitted to Aquatic Ecosystems Health and Management)


Presentations
Invited:
Wang, J., Modeling Great Lakes ice. Canadian Regional Climate Model and Diagnosis Workshop, May 23-29, Montreal

Wang, J., Development of the Great Lakes Ice-circulation Model (GLIM): Application to Lake Erie. Joint Assembly of IAPSO, IAMAS, IACS, July 19-29, Montreal, Canada (IAPSO--International Association for the Physical Sciences of the Oceans; IAMAS International Association of Meteorology and Atmospheric Sciences; IACS—International Association of Cryospheric Sciences)


Oral:
Wang, J., Seasonal, interannual, and spatial variability of Great Lakes ice cover. IAGRL, Toledo, May 18-22, 2009

Bai, X., J. Wang, and others, Impacts of ENSO and AO on interannual variability of Great Lakes ice cover. IAGRL, Toledo, May 18-22, 2009

MODELING SEA ICE-OCEAN-ECOSYSTEM RESPONSES TO CLIMATE CHANGES IN THE BERING-CHUKCHI-BEAUFORT SEAS WITH DATA ASSIMILATION OF RUSALCA MEASUREMENTS

Principal Investigators: Jia Wang, GLERL
Dmitry Beletsky, CILER
Allen Burton, CILER

Overview and Objectives

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, 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 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, 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 to 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” booms. 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**

1) Complete model-data comparison in the Bering-Chukchi-Beaufort Sea model only for a seasonal cycle
2) Complete a model run for the Bering Sea from 1990-2008
3) Implement a fine-resolution East Siberian-Chukchi-Beaufort seas model

**Publications**


**Presentations**
Oral:
Wang, J., Is the Arctic Dipole Anomaly the major driver to Arctic summer sea ice minima? JAMSTEC, Yokohama, March 19, 2009.


Wang, J. and E. Watanabe, Arctic Oscillation and Dipole Anomaly and their contribution to sea ice export: A climate modeling study for the period 1900-2010. Joint Assembly of IAPSO, IAMAS, IACS, July 19-29, Montreal, Canada

Poster:
Wang, J., et al. Is the Arctic Dipole Anomaly the major driver to record lows in Arctic summer sea ice extent? Joint Assembly of IAPSO, IAMAS, IACS, July 19-29, Montreal, Canada
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.
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. In Lake Michigan, the original program was initiated in 1980 at 40 sites in the southern basin of Lake Michigan, 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 Dreissena polymorpha, quagga mussel Dreissena bugensis, and 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 Dreissena and Diporeia over the entire lake, samples were collected in late summer at 160 sites located throughout the lake in 1995, 2000, and 2005. In Lake Huron, samples were collected at 75 sites in the main basin in 2000, 2003, and 2007, and at 33 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

Efforts in 2009 focused on counting and identifying organisms found in previously-collected samples, measuring dreissenids for biomass estimates, tabulating and analyzing data, and writing manuscripts. More specifically, organisms found in samples collected at sites in southern Lake Michigan in 2009 were counted and data entered into spreadsheets. In addition, mussels found at these sites between 1998 and 2009 were measured, and size-frequency and biomass determined. So, in addition to assessing trends in abundance, we also determined trends in biomass. A comparison of these two population parameters revealed interesting contrasts. Although mean
abundance at sites within the 16-30 m depth interval continued to increase through 2009, biomass has been stable since 2004. The population in this depth interval is dominated by small individuals (< 5 mm). While these small individuals are still increasing in number, their contribution to total biomass is minimal. In contrast, mean abundance at sites within the 30-51 m depth interval has stabilized, but biomass is still increasing. The reason for this apparent discrepancy is that the population within this depth interval is maturing, leading to an increase in mean size. The contrasting trends in abundance and biomass at these two depth interval is readily apparent in Figures 1 and 2. A manuscript documenting these trends was written and has been accepted for publication.

All mussel samples collected by divers in Saginaw Bay in 2009 were counted. Mussel abundances in 2009 agree with those found in 2008, and abundances in both years were 10-fold lower than found in 1991-1996. Reasons for this major decrease is unclear, but may be related to the establishment of gobies in the bay in 1999. We plan to obtain abundance estimates of both mussels and gobies in 2010.

Publications


Presentations

Nalepa, T. F. 2009 Recent dramatic changes in the offshore benthic community of Lake Michigan. 16th International Conference on Aquatic Invasive Species. Montreal, Quebec, April, 2009.
Overview and Objectives

Historically, the benthic community of Lake Ontario was dominated by an amphipod (*Diporeia* spp.), which together with fingernail clams (Sphaeriidae), oligochaetes, and chironomids, were the main components of the cold-stenotherm macrobenthic community occupying most of the deeper waters of all the Great Lakes (Cook and Johnson, 1974). These organisms are primarily detritivorous, dependant on surface production (particularly diatom blooms) sinking to the profundal areas.

The 1990’s were a decade of rapid transformation for the Lake Ontario benthic community. Two dreissenid mussel species *D. polymorpha* (zebra) and *D. bugensis* (quagga) were introduced in 1989 and 1991 via ballast water exchange by commercial shipping. These non-native mussels are very efficient grazers of phytoplankton and may completely cover the bottom substrate. Both US and Canadian lake-wide studies documented the rapid spread of *D. polymorpha* and *D. bugensis* in shallow (0-30 m) habitats along the entire southern coast by 1995. Between 1992 and 1995, an increase in the biomass of both species was observed, but the increase of *D. bugensis* was much greater and *D. bugensis* appeared to replace *D. polymorpha*. *D. bugensis* was also observed as deep as 85 m in 1995, indicating the species ability to spread to deep, soft substrate habitats.

The objective of this study is to examine the status of the Lake Ontario benthic community in 2009 and document if the changes observed from 1990 to 2008 are continuing. Our approach was to conduct a lake-wide spatial assessment of the benthic community along five transects in Lake Ontario during Summer, 2009. The results of the 2009 survey will be compared with similar collections made in 1990, 1994, 1995, 1997, 2003, and 2008, as well as some historical collections from the 1960s and 1970s. The roles of lake oligotrophication and *D. bugensis* competition on the decline of *Diporeia* populations will be evaluated with this time series.
Accomplishments

Two cruises were completed in 2009. The first cruise occurred during the week of August 18 to 21, 2009, when 46 benthic sites were visited. We were able to collect sediment at 44 sites. An additional 3 sites were visited on September 23, 2009. Benthic organisms were picked from all 44 samples from the August cruise. There were 28,037 invertebrates in the samples, 67% of which were dreissenids (Table 1). Amphipods were found at 13 sites. Only 5 sites had greater than 2 organisms. The greatest number of amphipods were found at station 55 which had a depth of 192 meters.

Table 1. Benthic invertebrates from 42 sites in Lake Ontario collected in August 2009.

<table>
<thead>
<tr>
<th>Long.</th>
<th>Lat.</th>
<th>Station</th>
<th>Substrate</th>
<th>Depth - m</th>
<th>Amph.</th>
<th>Worms</th>
<th>Sphaerids</th>
<th>Midges</th>
<th>Dreissenids</th>
<th>Mysis</th>
<th>Clams</th>
</tr>
</thead>
<tbody>
<tr>
<td>-79.67</td>
<td>43.34</td>
<td>2</td>
<td>Mud/Silt</td>
<td>60</td>
<td>0</td>
<td>127</td>
<td>2</td>
<td>31</td>
<td>1212</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-79.62</td>
<td>43.27</td>
<td>3</td>
<td>Mud/Silt</td>
<td>24</td>
<td>1</td>
<td>229</td>
<td>0</td>
<td>11</td>
<td>648</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-79.54</td>
<td>43.47</td>
<td>6</td>
<td>Sand</td>
<td>62</td>
<td>0</td>
<td>352</td>
<td>3</td>
<td>100</td>
<td>1028</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-79.40</td>
<td>43.59</td>
<td>9</td>
<td>Mud/Silt</td>
<td>58</td>
<td>1</td>
<td>352</td>
<td>3</td>
<td>122</td>
<td>400</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>-79.49</td>
<td>43.39</td>
<td>14</td>
<td>Mud/Silt</td>
<td>98</td>
<td>33</td>
<td>52</td>
<td>0</td>
<td>104</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>-79.36</td>
<td>43.27</td>
<td>16</td>
<td>Mud/Silt</td>
<td>66</td>
<td>0</td>
<td>143</td>
<td>1</td>
<td>103</td>
<td>47</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-79.29</td>
<td>43.38</td>
<td>19</td>
<td>Mud/Silt</td>
<td>107</td>
<td>19</td>
<td>73</td>
<td>4</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-79.01</td>
<td>43.30</td>
<td>22</td>
<td>Mud/Silt</td>
<td>11</td>
<td>0</td>
<td>618</td>
<td>42</td>
<td>16</td>
<td>39</td>
<td>0</td>
<td>58</td>
</tr>
<tr>
<td>-79.13</td>
<td>43.44</td>
<td>24</td>
<td>Mud/Silt</td>
<td>120</td>
<td>0</td>
<td>18</td>
<td>25</td>
<td>35</td>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>-79.02</td>
<td>43.61</td>
<td>26</td>
<td>Clay</td>
<td>120</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.86</td>
<td>43.78</td>
<td>28</td>
<td>Sand</td>
<td>65</td>
<td>12</td>
<td>140</td>
<td>0</td>
<td>19</td>
<td>427</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.46</td>
<td>43.89</td>
<td>31</td>
<td>Rock</td>
<td>20</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>177</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.44</td>
<td>43.78</td>
<td>32</td>
<td>Sand</td>
<td>78</td>
<td>0</td>
<td>107</td>
<td>0</td>
<td>29</td>
<td>926</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.81</td>
<td>43.60</td>
<td>33</td>
<td>Mud/Silt</td>
<td>138</td>
<td>1</td>
<td>14</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.76</td>
<td>43.46</td>
<td>34</td>
<td>Mud/Silt</td>
<td>136</td>
<td>0</td>
<td>283</td>
<td>0</td>
<td>38</td>
<td>676</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.73</td>
<td>43.36</td>
<td>35</td>
<td>Mud/Silt</td>
<td>28</td>
<td>0</td>
<td>565</td>
<td>0</td>
<td>8</td>
<td>133</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>-78.39</td>
<td>43.49</td>
<td>36</td>
<td>Mud/Silt</td>
<td>140</td>
<td>0</td>
<td>23</td>
<td>3</td>
<td>1</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-77.99</td>
<td>43.38</td>
<td>38</td>
<td>Sand</td>
<td>19</td>
<td>0</td>
<td>130</td>
<td>0</td>
<td>13</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.00</td>
<td>43.49</td>
<td>39</td>
<td>Mud/Silt</td>
<td>154</td>
<td>0</td>
<td>34</td>
<td>27</td>
<td>0</td>
<td>26</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>-78.01</td>
<td>43.59</td>
<td>40</td>
<td>Mud/Silt</td>
<td>190</td>
<td>0</td>
<td>24</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>-78.03</td>
<td>43.72</td>
<td>41</td>
<td>Mud/Silt</td>
<td>128</td>
<td>7</td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.04</td>
<td>43.84</td>
<td>42</td>
<td>Rock</td>
<td>65</td>
<td>0</td>
<td>107</td>
<td>0</td>
<td>121</td>
<td>1088</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-78.05</td>
<td>43.95</td>
<td>43</td>
<td>Sand</td>
<td>19</td>
<td>1</td>
<td>272</td>
<td>0</td>
<td>9</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-77.78</td>
<td>43.82</td>
<td>45</td>
<td>Sand</td>
<td>80</td>
<td>0</td>
<td>81</td>
<td>0</td>
<td>9</td>
<td>860</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-77.44</td>
<td>43.77</td>
<td>49</td>
<td>Rock</td>
<td>48</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
</tr>
<tr>
<td>-77.71</td>
<td>43.43</td>
<td>52</td>
<td>Mud/Silt</td>
<td>125</td>
<td>0</td>
<td>48</td>
<td>12</td>
<td>4</td>
<td>418</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>-77.44</td>
<td>43.44</td>
<td>55</td>
<td>Mud/Silt</td>
<td>192</td>
<td>36</td>
<td>10</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>-77.59</td>
<td>43.28</td>
<td>57</td>
<td>Mud/Silt</td>
<td>13</td>
<td>0</td>
<td>176</td>
<td>2</td>
<td>12</td>
<td>216</td>
<td>0</td>
<td>185</td>
</tr>
<tr>
<td>Location</td>
<td>Latitude</td>
<td>Longitude</td>
<td>Type</td>
<td>Size</td>
<td>Percent</td>
<td>Count</td>
<td>Price</td>
<td>Size</td>
<td>Weight</td>
<td>Price</td>
<td>Size</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td>-----------</td>
<td>---------</td>
<td>--------</td>
<td>---------</td>
<td>-------</td>
<td>-------</td>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>-77.16</td>
<td>43.79</td>
<td>61</td>
<td>Sand</td>
<td>54</td>
<td>0</td>
<td>150</td>
<td>3</td>
<td>33</td>
<td>1028</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-77.00</td>
<td>43.87</td>
<td>62</td>
<td>Rock</td>
<td>10</td>
<td>0</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>-76.93</td>
<td>43.73</td>
<td>63</td>
<td>Mud/Silt</td>
<td>87</td>
<td>0</td>
<td>187</td>
<td>17</td>
<td>0</td>
<td>440</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>-76.79</td>
<td>43.41</td>
<td>67</td>
<td>Sand</td>
<td>71</td>
<td>0</td>
<td>342</td>
<td>0</td>
<td>0</td>
<td>2640</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-76.71</td>
<td>43.61</td>
<td>69</td>
<td>Mud/Silt</td>
<td>185</td>
<td>0</td>
<td>13</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>-76.53</td>
<td>43.55</td>
<td>72</td>
<td>Mud/Silt</td>
<td>113</td>
<td>0</td>
<td>111</td>
<td>125</td>
<td>0</td>
<td>807</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>-76.29</td>
<td>43.63</td>
<td>73</td>
<td>Sand</td>
<td>40</td>
<td>0</td>
<td>282</td>
<td>0</td>
<td>78</td>
<td>40</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>-76.52</td>
<td>43.75</td>
<td>74</td>
<td>Mud/Silt</td>
<td>69</td>
<td>0</td>
<td>159</td>
<td>15</td>
<td>7</td>
<td>463</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>-76.36</td>
<td>43.84</td>
<td>75</td>
<td>Sand</td>
<td>32</td>
<td>3</td>
<td>133</td>
<td>3</td>
<td>12</td>
<td>350</td>
<td>0</td>
<td>41</td>
</tr>
<tr>
<td>-76.41</td>
<td>43.96</td>
<td>77</td>
<td>Mud/Silt</td>
<td>29</td>
<td>0</td>
<td>139</td>
<td>4</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>39</td>
</tr>
<tr>
<td>-76.61</td>
<td>44.14</td>
<td>80</td>
<td>Mud/Silt</td>
<td>19</td>
<td>0</td>
<td>26</td>
<td>0</td>
<td>101</td>
<td>117</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>-76.81</td>
<td>44.07</td>
<td>82</td>
<td>Mud/Silt</td>
<td>27</td>
<td>0</td>
<td>96</td>
<td>0</td>
<td>3</td>
<td>67</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>-76.73</td>
<td>43.89</td>
<td>84</td>
<td>Sand</td>
<td>37</td>
<td>2</td>
<td>326</td>
<td>1</td>
<td>0</td>
<td>1340</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>-78.31</td>
<td>43.92</td>
<td>91</td>
<td>Sand</td>
<td>22</td>
<td>0</td>
<td>223</td>
<td>45</td>
<td>140</td>
<td>109</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>-77.22</td>
<td>43.33</td>
<td>94</td>
<td>Sand</td>
<td>54</td>
<td>0</td>
<td>182</td>
<td>0</td>
<td>7</td>
<td>1248</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-79.45</td>
<td>43.23</td>
<td>1318</td>
<td>Mud/Silt</td>
<td>26</td>
<td>0</td>
<td>305</td>
<td>0</td>
<td>46</td>
<td>137</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-79.06</td>
<td>43.74</td>
<td>1330</td>
<td>Sand</td>
<td>61</td>
<td>1</td>
<td>288</td>
<td>0</td>
<td>26</td>
<td>1616</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Additional work to be completed includes slide preparation for worm and midge identification and inputting all data into Excel files.

**Publications**

None during this reporting period.

**Presentations**

None during this reporting period.
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.

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) Begin integrating data into food-web model analyses.

Accomplishments

Field sampling was done biweekly for nutrients/primary producers and monthly for zooplankton and Mysis during March-November 2009. All samples have been processed and enumerated in the laboratory and compiled into appropriate databases. A number of important observations were made, including:

1. During the spring isothermal mixing period, surface-mixed layer (SML) chlorophyll and phytoplankton biomass (carbon) and water column primary productivity decreased substantially in 2007-08 as compared to 1995-98 (66%, 87%, and 70% decrease, respectively). Smaller or no decreases were noted between 1983-87 and 1995-98 (chlorophyll 23% decrease, phytoplankton biomass 5% increase, production 22% decrease). The pronounced changes in phytoplankton parameters during spring mixing in 2007-08 were attributed to the filtering activities of the quagga mussel (Dreissinid bugensis rostriformis).
2. *Mysis* were more abundant during 1995-2002 than 2007-2008 for all seasons and depths, with average declines across seasons of 81% at 45 m and 70% at 110 m. Offshore densities of *Mysis* in 2007-2008 were similar to published densities within the same region during 1985-1989, but under differing ecosystem conditions (e.g. higher fish biomass and primary production in the 1980s). Declining spring chlorophyll levels may be altering food availability for small mysids in spring, and the decline of the benthic macroinvertebrate *Diporeia* may be increasing fish predation pressure on *Mysis* despite declining planktivore abundance.

3. TP loads decreased significantly throughout 1983-2008. The pronounced changes in TP, chlorophyll, nitrate, and Si during the spring isothermal period suggest that dreissenid mussel filtering has dramatically reduced spring phytoplankton abundance and production across the entire southern basin of Lake Michigan.

Significant effort was also put toward compiling historical datasets on key state variables. These datasets were used toward long-term analyses on the lower food web of Lake Michigan and to evaluate how invasive species have altered the structure of the food web. In particular, a grouping of papers was submitted to the Journal of Great Lakes Research for a special section on long term trends in the lower food web in Lake Michigan and results were widely presented to public interest and management audiences (see publications and presentations).

**Publications**


Presentations


Overview and Objectives

This project established a pilot partnership between NOAA and the University of Michigan-CILER to support and manage a NOAA Aquatic Invasive Species Postdoctoral Research Program.

The objective of this pilot program is to engage a competitively selected post-doctoral research scientist in biological invasion research, introduce him/her to the mission and organizational culture of NOAA, and foster new biological invasion research activities within NOAA.

Accomplishments (in chronological order)

- Six potential Host NOAA and Partner Institution were identified and commitment letters received.
- An Advisory Panel was formed.
- An Announcement of Opportunity was prepared and released via various media outlets.
- Six applications were received.
- A Review Panel consisting of six NOAA and CILER scientists was convened.
- Proposals from six applicants were reviewed and scored against criteria stated in the Announcement of Opportunity.
- The highest scoring proposal was subsequently disqualified when it was determined that the issue posed was not based on a nonindigenous species.
- The second highest scoring proposal was unanimously recommended for funding (Daniel J. Hasselman, “Population dynamics of the nonindigenous American Shad Alosa sapidissima along the west coast of the U.S. and anticipated effects of climate change on range expansion”, NOAA NW Fisheries Science Center and University of Washington, Seattle, WA).
- Notifications were made to all applicants and their sponsor institutions.
• Administrative procedures were initiated to establish the project at the University of Washington; applicant completed his Ph.D requirements in March 2010.

Publications
N/A

Presentations
N/A
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

Principal Investigators: Greg M. Ruiz, SERC
Scott Santagata (formerly SERC, resigned)
Thomas H. Johengen, CILER
David F. Reid (formerly GLERL, retired)

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(a,b)(SERC, GLERL)**

Due to sudden resignation of the original postdoc assigned responsibility for Objectives 5a and 5b, work on this objective has not progressed, but is expected to resume during CY2010 when a suitable qualified replacement is found. A no-cost extension of this project has been issued to accommodate this unforeseen delay.
Publications


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


Presentations

Santagata, S. et al. (2007). Effect of osmotic shock as a management strategy for reducing the transfer of nonindigenous 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.

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 online databases, making it unmanageable for any individual. Despite the regional importance of ANS, the Great Lakes were under-represented 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 a point mapping system, rather, species are mapped only to the level of the whole lake or adjacent watershed and this provides an inaccurate and easily misinterpreted image of the distribution of these species. In addition, GLANSIS does not presently include species that are considered native to part of the Great Lakes basin, but invasive in others parts of the basin, such as the Rusty Crawfish.

The University of Michigan (CILER) proposes to work with NOAA (GLERL ) scientists who oversee GLANSIS to 1) adapt and georectify existing species records for integration with a new point mapping system being added to GLANSIS; 2) compile information for fact sheets for identified range expansion Great Lakes ANS; and 3) assist with the development of a glossary of terms used in the database, as well as development of other educational material to enhance usability by the non-technical public.

Goals/Objectives

1) Modify existing GLANSIS species records (up to ~185 species) for integration into new point mapping system being implemented on GLANSIS;
2) Compile information and develop fact sheets for species in the Great Lakes that are considered range expansion ANS (approximately 20-25) as identified by NOAA.

3) Develop a glossary of terms associated with GLANSIS appropriate to the non-technical public to enhance their experience with and understanding of the database.

Accomplishments

Objective 1: Modify existing GLANSIS species records (up to ~185 species) for integration into new point mapping system being implemented on GLANSIS

All GLANSIS species records have been georectified to a lat-lon coordinate system. All GLANSIS fact sheets have been fully upgraded to incorporate the new point-mapping system (replacing the old watershed-based mapping system.

Objective 2: Compile information and develop fact sheets for species in the Great Lakes that are considered range expansion ANS (approximately 20-25) as identified by NOAA

A preliminary list of range expansion species was developed by 2009 students (Ling Cao and Mary Heijna). A CILER student worker to be hired for summer 2010 will complete tasks under this objective.

Objective 3: Develop a glossary of terms associated with GLANSIS appropriate to the non-technical public to enhance their experience with and understanding of the database

A glossary of scientific terms was developed by UROP student Ling Jie Gu. The glossary was reviewed by Rochelle Sturtevant, formatted for publication by GLERL webmaster Giselle Maira and linked from the main GLERL search engine page (http://www.glerl.noaa.gov/res/Programs/ncrais/nas_database.html) and accessible directly at http://www.glerl.noaa.gov/res/Programs/ncrais/glansis_glossary.html.

Publications

NOAA. 2009. GLANSIS. 
http://www.glerl.noaa.gov/res/Programs/ncrais/search_notes.html 2009. Updates to all 181 fact sheets.

Presentations

• GLANSIS Poster presented at ICAIS (April 19-23, 2009) – Montreal
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.
PROJECT TITLE: Optical Properties of the Great Lakes

Principal Investigators: George Leshkevich, GLERL
David O’Donnell (Upstate Freshwater Institute)
Thomas Johengen, CILER
Allen Burton, CILER

Overview and Objectives

This research project focuses on measurement and quantification of the optical properties of the Great Lakes. During 2007 measurements of the optical properties of Lakes Ontario and western Lake Erie were made with a suite of surface and profiling instruments along with concurrent water samples. In collaboration with the Upstate Freshwater Institute (a nonprofit organization), GLERL, and CILER, plans are for measurements in Lakes Michigan and Huron during 2008. These measurements not only document optical properties of the lakes (during mid-season), they are important for hydro-optical model development to be used for satellite retrieval of major color producing agents (chlorophyll, CDOM, SM).


Deliverables: Optical properties including but not limited to scatter, backscatter, absorption, water leaving radiance, remote sensing reflectance, and coincident measured water samples including chlorophyll, CDOM, DOC, suspended mineral, etc. for the lakes measured (Ontario, Erie, Michigan, Huron) in the MODIS and SeaWiFS ocean color bands. In addition, a journal article (or articles) will be written and submitted describing and documenting the optical properties of the lakes measured based on the measurements made.

Accomplishments

Measurements of optical properties along with coincident measured water samples including chlorophyll, CDOM, DOC, suspended mineral were made on Lakes Michigan, Huron, Erie, and Ontario during 2008.
Water samples were processed and analyzed for chlorophyll, CDOM, DOC, and suspended mineral and inherent and apparent optical properties documented for Lakes Michigan, Huron, Erie, and Ontario.

A manuscript was written and submitted documenting the optical properties and color producing agents measured on western Lake Erie during 2007.

**Publications**

O’Donnell, D.M., Effler, S.W., Strait, C.M. and Leshkevich, G.A. Optical characterizations and pursuit of optical closure for the western basin of Lake Erie through in situ measurements. (Submitted)

**Presentations**


O’Donnell, D.M., Strait, C.M., Quaring, G.F., Effler, S.W.,1 and Leshkevich, G.A. 2 Upstate Freshwater Institute, P. O. Box 506, Syracuse, NY 13214, 2 NOAA/GLERL, 4840 South State Road, Ann Arbor, 48108. *Optics Surveys of Lake Ontario: Optical Characterization and Pursuit of Closure with In Situ Instrumentation.* 53rd Conference on Great Lakes Research, University of Toronto, Toronto, Ontario, Canada. (to be presented May 2010).
**PROJECT TITLE: NEW MODIS ALGORITHM FOR RETRIEVAL OF CHLOROPHYLL, DISSOLVED ORGANIC CARBON, AND SUSPENDED MINERALS IN THE GREAT LAKES**

**Principal Investigators:** George Leshkevich, GLERL  
Robert Shuchman (Michigan Tech Research Institute  
Dmitry Pozdnyakov and  
Anton Korosov (NANSEN International Environmental and Remote Sensing Centre, St. Petersburg, Russia)  
Chuck Hatt (MTRI)  
Thomas Johengen, CILER/UM  
Allen Burton, CILER

**Overview and Objectives**

It has previously been found that the ocean ratioing algorithms for the retrieval of chlorophyll from satellite data do not work well in time or space for the Great Lakes. A fundamentally different algorithm for the retrieval of color producing agents (CPAs) from satellite data has been developed by the Altarum Institute (formerly the Environmental Research Institute of Michigan (ERIM) and currently MTRI) and the Nansen International Environmental and Remote Sensing Center (NIERSC) of St. Petersburg, Russia and tested on Lake Michigan. The algorithm operates on either SeaWiFS or MODIS data and produces estimates of chlorophyll (chl), dissolved organic carbon (doc), and suspended minerals (sm). The algorithm has undergone a preliminary validation using both dedicated and historical in situ water chemistry measurements. The algorithm presently underestimates the amount of chlorophyll, however, the algorithm successfully observes the correct seasonal trends of all three color producing agents. The present shortcoming of the algorithm lies in the fact that the hydro-optical model used in the algorithm was generated 20 years ago for Lake Ontario waters.

This proposal addresses a proposed collaboration between MTRI, NIERSC, GLERL, and CILER to further develop the algorithm so that meaningful estimates of chl, doc, and sm can result from MODIS satellite data for all of the Great Lakes, especially Lake Erie which is optically more complex. Historical radiometric observations with coincident in situ water chemistry collected by GLERL in Lake Michigan have been used to update the hydro-optical model presently used in the algorithm. Optical measurements and coincident water samples taken on Lake Erie in the summer of 2005 have allowed the development of a hydro-optical model for Lake Erie and enhanced the main hydro-optical model as will the in situ measurements made on Lake Superior during 2007.
The algorithm will then be tested with MODIS satellite data acquired coincident with field sampling. GLERL’s extensive archive of chl, doc, and sm data collected throughout the Great Lakes will serve as validation values for the new improved algorithm. The anticipated results (objective) of this proposed collaborative investigation will be a validated robust algorithm (or algorithms) for the retrieval of CPAs from all of the Great Lakes.

Proposed Work: Process optical data taken on Lake Superior during 2007 and include data taken on Lakes Ontario and Erie to modify/update the hydro-optical model. Run some MODIS images using the updated hydro-optical model to test algorithm performance. Test and validate new hydro-optical model for Lake Erie, Lake Michigan, Lake Superior and on other Great Lakes if in situ data is available.

Deliverables: The anticipated results of this proposed collaborative investigation will be a validated robust algorithm (or algorithms) for the retrieval of CPAs from all of the Great Lakes and a journal article (or articles) documenting the algorithm and results

**Accomplishments**

Data for Lakes Superior, Ontario, and western Lake is being incorporated into the hydro-optical model. Data for Lakes Michigan, Huron, Erie, and additional data for Lake Ontario has been measured and is being processed and should soon be incorporated into the hydro-optical model.

2009-2010
Assembled and created a comprehensive data base of measurements including data for Lakes Michigan, Huron, Erie, and additional data for Lake Ontario. This data is being incorporated into the hydro-optical model. Upon completion, the algorithm will be tested with MODIS data and validated with field measurements.

**Publications**
Publications can proceed when the model is completed and tested.

**Presentations**
**Development of a Robust Hydro-optical Model for the Great Lakes for the Extraction of Chlorophyll, Dissolved Organic Carbon and Suspended Minerals from MODIS Satellite Data.** 51st Conference on Great Lakes Research, Trent University,

Robert Shuchman¹, George Leshkevich², Charles Hatt¹, Dmitry Pozdnyakov³, Anton Korosov³, and Josberger, E.¹ ¹Michigan Tech Research Institute, Ann Arbor, MI ²National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, Ann Arbor, MI ³Nansen International Environmental and Remote Sensing Center, St. Petersburg, Russia.  Further Steps Towards a Chlorophyll, Dissolved Organic Carbon, and Suspended Mineral Remote Sensing Algorithm for All Laurentian Great Lakes.  52nd Conference on Great Lakes Research, University of Toledo, Toledo, Ohio, May 18-22, 2009.

Robert Shuchman¹, George Leshkevich², Charles Hatt¹, Dmitry Pozdnyakov³, and Sayers. M.J.¹ ¹Michigan Tech Research Institute, Ann Arbor, MI ²National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, Ann Arbor, MI ³Nansen International Environmental and Remote Sensing Center, St. Petersburg, Russia.  An Operational MODIS Algorithm for the Retrieval of Chlorophyll, Dissolved Organic Carbon, and Suspended Minerals for All Laurentian Great Lakes.  53rd Conference on Great Lakes Research, University of Toronto, Toronto, Ontario, Canada, (to be presented May 2010).
**PROJECT TITLE: GREAT LAKES COASTWATCH RESEARCH ASSISTANT FOR NOAA COASTWATCH PROGRAM ELEMENT**

*Principal Investigators: George Leshkevich, GLERL  
Allen Burton, CILER*

**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.

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. One of the objectives of the CoastWatch Great Lakes program is to provide access to near real-time and retrospective (two weeks) satellite observations and derived products of the Great Lakes for Federal, state and local decision making, supporting research and public use. Communications requirements and data distribution are accomplished electronically via the Internet.
Accomplishments

1. **Monitor, develop and/or improve the operational program to receive, process, analyze, and archive the CoastWatch data.** eg. Write the operational program to make the AVHRR/GLSEA images available for Google Earth.

- Completed the GLSEA 1024x1024 operational program (including IDL and Unix script).
- Google Earth (KLM) programming complete - Waiting for operating system upgrade for Google Earth implementation.

**2009-2010**
Will implement Google Earth (KLM) files when CGI libraries are installed on server by IT group.

2. **Maintain and improve the CoastWatch Great Lakes Node web server, design and develop the web site,** eg., make image gallery section on web page, check the images and links on web site.

- Created image gallery page for CW Great Lakes web site.
- Need to continue development of the image gallery page.
- Install and in process of testing Thredds/LAS server for possible use on the CoastWatch Great Lakes web site.

**2009-2010**
- Put the image gallery page online on the web site
- Wrote the C program to convert AVHRR SST images to NetCDF format (COARDS-compliant), which will be loaded in THREDDS server.
- Installed the following libraries and utilities in support of testing the Thredds/Las server:
  installed perl (v5.8.9) and related perl library
  installed LAS (v7.0.3) ( and addXML.sh )
  installed apache-tomcat (v6.0.18)
  installed thredds server
  installed ferret (v6.11)
  installed netcdf library (v4.0.1)
- Aid in analysis and planning for 2010 procurement of new Great Lakes CoastWatch web server hardware including server, memory, and peripherals.

3. **Design, modify, and develop the software to analyze and process the CoastWatch data,** eg., write programs to create kml and png files for Google Earth, write programs
to create turbidity product when the new algorithm becomes available.

-Wrote the IDL program for Ice overlay on GLSEA 1024x1024.
-Wrote the IDL program to subsize the GLSEA (from 1024 to 512) for research project.
-Modified the IDL program to process RARDARSAT image for ice classification project.
-Created GLSEA ascii file (new format).
-Waiting for operating system upgrade for Google Earth implementation
-Wrote program to calculate ice concentration data (by lake) from the NIC ice charts and post data and graphics on the CoastWatch Great Lakes web site
-Test program to derive turbidity from AVHRR Ch.1 and Ch. 2 data

2009-2010
- Wrote IDL and UNIX programs to processing RADARSAT2 images, and made the images available (.jpg format) on CW web site

4. **Participate CoastWatch related research and prepare the presentation for meetings.**

-Prepared presentations for meetings and conferences (such as: CoastWatch Node Manager Meeting 2007, Making a Great Lake Superior 2007 Conference, IAGLR 2007).

2009-2010
-Helped prepare presentations for the IAGLR 2009 Conference and other presentations (see above) and working on presentations for IAGLR 2010 Conference and 2010 CoastWatch Node Managers Meeting

5. **Assist in the mentorship of a Great Lakes summer fellow.**

-Wrote the IDL program to interpolate the MODIS true color imagery (the west end of Lake Erie) for Yellow Perch project animation.

6. **Document CoastWatch software, including path designations and data source input/output. Construct flow chart depicting data and code relationships.**

-Create flow chart and documentation for documenting the operational process of the Great Lakes CoastWatch site. Needs to be continued (completed).

2009-2010
- Updating documentation with the implementation of the Thredds/LAS server

**Publications**


**Presentations**

CoastWatch presentation to Rex Lowe’s Bowling Green University class
CoastWatch presentation to Educator House Call – On-Line Data for Classroom Use
Remote Sensing presentation at the Great Lakes International Icebreaking Conference;
CoastWatch presentation to 4 meteorologists from the White Lake NWS

Leshkevich, G.A.¹ and Liu, S.²
¹NOAA/Great Lakes Environmental Research Laboratory, and ²CILER, 4840 South State Road, Ann Arbor, MI 48108. CoastWatch Great Lakes Program After 20 Years. 53rd Conference on Great Lakes Research, University of Toronto, Toronto, Ontario, Canada (to be presented May 2010).

Leshkevich, G.A.¹ and Liu, S.²
1NOAA/Great Lakes Environmental Research Laboratory, and 2CILER, 4840 South State Road, Ann Arbor, MI 48108. CoastWatch Great Lakes Program Update: 2009. 52nd Conference on Great Lakes Research, University of Toledo, Toledo, Ohio, May 18-22, 2009.


Leshkevich, G.A.1, and Liu, S.2


PROJECT TITLE: GLOS – IMPLEMENTATION OF THE GREAT LAKES OBSERVING SYSTEM

Principal Investigators:  
Thomas Johengen, CILER  
Steve Ruberg, GLERL  
David J. Schwab, GLERL  
Allen Burton, CILER

Executive Summary

The overarching goal of this project, under the direction of the Great Lakes Observing System Regional Association, is to implement key observing system and modeling improvements that focus on four priority issue areas that affect the health, well-being and economic viability of the Great Lakes region, these being: climate change impacts; ecosystem and food web dynamics; protection of public health; and navigation safety and efficiency. Specific objectives of this implementation project are to: 1) Densify nearshore observations to improve wind/wave forecasting and circulation modeling; 2) Improve monitoring of lake heat and water balances; 3) Advance nearshore ecological forecasting; and 4) Improve water quality monitoring for Water Intakes and Public Beach users. These activities are being conducted by a collaboration of academic (University of Michigan, University Milwaukee-Wisconsin, University of Minnesota-Duluth, Great Lakes Research Consortium - SUNY–ESF partner) and federal (NOAA-GLERL) partners, with the funding and coordination of the academic partners operating under the auspices of CILER. In 2009 three additional academic partners (SUNY-Oswego, Buffalo State College, and Michigan Technological University) were added to the project to extend the number and coverage of observational assets throughout the lakes.

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. Cross-lake ferries and other vessels of opportunity have been 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. AUV/glider technologies are also being developed to enhance observational capabilities of 3-dimensional structure of thermodynamics and water quality along specified transect between permanent mooring locations.

Additional activities during 2009 included organizing a workshop to address technical/equipment issues for developing new buoy systems, as well as, system
requirements for data capture, data transfer, meta data protocols and data management issues within a centralized GLOS data center.

**Project Year Activities**
Summaries of the individual observing system activities in 2009 for each Partner are described below:

**NOAA-GLERL**
The Cleveland ReCON project is focused on providing a hypoxia and internal wave warning system to the CWD. The ReCON project develops advanced Ecosystem Forecasting Tools using network-based observing system technology. This includes research on HABs, fisheries acoustics research, expert systems ecosystem forecasting, and underwater digital video. Additional efforts are focused on Interoperability Demos with MBARI and ESONET (European Seabed Observatory Network). These software and instrumentation demos correlate with NSF Ocean Observing Initiative for network-based cabled observatories implementing interoperability standards.

**University of Minnesota-Duluth**
We have, for the second time, deployed a real-time meteorological buoy and thermistor string in the vicinity of the Duluth Water Intake. The buoy was moored in 52m of water on 28 May, 2009. The surface instrumentation package consists of an air temperature/relative humidity sensor, wind velocity sensor (a 2-D sonic anemometer with compass), barometric pressure, shortwave radiation sensor, long wave radiation sensor, and PAR sensor. The buoy also has a thermistor string, measuring water temperature in near-real time at 9 depths between 1m and approximately 25m. Engineering data include buoy orientation, buoy location (via a GPS receiver), onboard battery voltage, and instrumentation enclosure temperature. All of this data is relayed via cell phone to a computer at UMD, archived, and then served to the web for a number of applications. The data is currently being used by the National Weather Service office in Duluth, MN to improve their marine coastal forecast for the North Shore, a region of complex topography which makes modeled prediction difficult. The hope is that directly observed data from this buoy can be used to improve the accuracy of their forecasts and therefore improve marine safety in the region. Modeling efforts are focused on Lake Superior and Duluth/Superior Harbor.
The data is currently being displayed at the Great Lakes Aquarium in Duluth, MN. Patrons can explore the different measurements we make and learn about the instruments we use and why we make each particular measurement. Patrons can pick up a card directing them to the buoy website, so that the data can be accessed from home. The website is: http://www.d.umn.edu/~jaustin/UMD_buoy_2009.html. In our estimation, the main users of the buoy website are fishermen (recreational and commercial), and watersports enthusiasts (sailors, windsurfers, surfers, etc) as the North Shore is a popular tourist destination.

GLRC-SUNY ESF

Initial plans were to deploy a buoy off Oswego and Buffalo in 2009, delays in funding have forced us to work on other aspects of the project. We successfully deployed our monitoring buoy in Oneida Lake this year in conjunction with Cornell University Shackelton Point Biological Station. While this buoy does not use GLOS funding, it does provide us the opportunity to develop the website interface for the Oswego and Buffalo buoy once they are deployed. We are on version 2 of our web-interface (see www.nyglrc.org for the current version) and have had several meetings with NY Sea Grant representatives on developing educational modules for use in the Oneida Lake watershed that use this buoy interface. This information is currently being used by New York Sea Grant, Cornell University and SUNY-ESF in their Oneida Lake Educational Initiative (www.oneidalakeinfo.org) in their teacher training workshops.

After a few false starts, we have also successfully deployed our hut based system in the St. Lawrence River. This system is located on Governor’s Island off Clayton NY and initial results were presented at the St Lawrence River conference this year. It provides continual monitoring of basic water quality information (T, conductivity, pH, Chlorophyll) as well as a test bed for more advanced sensors that detect phytoplankton health, abundance of blue-green algae, and dissolved hydrocarbons such as gasoline in the water column.

Efforts are underway with Clarkson University and Environment Canada to develop a series of huts that will span the international region of the St Lawrence River.
University of Michigan Marine Hydrodynamics Lab

In response to available funding for the GLOS Open Water Subsystem, the University of Michigan’s Marine Hydrodynamics Laboratories shared with GLOS the costs of the design, fabrication and deployment of a new generation, environmental monitoring buoy as a third node in the Grand Traverse Bay Observing System. The buoy was completed and tested in the fall and winter of 2008. The buoy was deployed in April 2009 in Grand Traverse Bay north of Old Mission Point. The buoy measures wind speed and direction, water and air temperature, relative humidity as well as wave height, period and directional spectra. The directional wave package was developed by the MHL in the first step towards meeting the First-5 criteria of the National Operational Wave Observation Plan. The data is transmitted via cellular modem directly to a server at the University of Michigan, the NDBC and GLOS. In anticipation of funding for 2009, The University of Michigan’s Marine Hydrodynamics Laboratories have partnered with S-2 yachts, a Michigan cooperation headquartered in Holland, MI to manufacture a low cost environmental buoy specifically designed to meet the needs of IOOS. The MHL has also gained the support of the local communities of Little Traverse Bay, and they have agreed to fund the maintenance of the buoy once it is deployed.

University of Wisconsin-Milwaukee

Activities for GLOS are piggy-backed on the existing Great Lakes Urban Coastal Observing System (GLUCOS) operated by UWM. GLUCOS is a radio-linked network of up to 7 data acquisition buoys designed for long-term monitoring of coastal Lake Michigan with real-time data return. A very important function of the GLUCOS system has been to educate engineering students in the multidisciplinary field of underwater observatories and field instrumentation. Numerous students have worked on all aspects of the GLUCOS system – design, fabrication of components, wiring, testing, deployment and recovery, debugging and data analysis. Several students have also carried out their own projects on the system. To date GLUCOS students have written and presented 7 papers to MTS/IEEE Oceans Conferences, one of the world’s premier conferences in ocean technology.
Please note that while GLOS funding provided essential core of funding, the following work was heavily supported by funding from other sources brought in by the PI’s of the projects.

1. Measurement of the thermal bar during spring thermal stratification. From April to May, 2009, three Pioneer buoys were deployed in a west to east line at 20 m, 40m and 60m depth. Each buoy was equipped with a temperature sensor string with sensors spaced 1 meter apart, along with multiparameter sondes mounted on the anchor and on the surface float. Also part of the instrument array was a bottom station containing an upward looking sonar to measure fish and zooplankton in the water column, a remotely-controlled pan/tilt video camera, sonde, control computer and battery pack. The station is designed to ultimately connect to a buoy for real-time data transmission to shore but it was run autonomously for this experiment. The buoy array successfully measured the onset of thermal stratification indicated by the 4º isotherm known as the thermal bar. Unfortunately the data returned by the bottom station was ambiguous. An effort is currently underway to take the lessons learned from the deployment to fix the problems and improve the capabilities of the bottom station.

2. Bradford Beach Water Quality Monitoring. A single Pioneer buoy was deployed off of Bradford Beach, Milwaukee equipped with a temperature sensor string and top and bottom sondes. This buoy returned real-time data of nearshore conditions to support studies on the fate and transport of bacterial contaminants at public beaches.

3. Long-Term Monitoring of Nutrient Dynamics and Carbon Flux in Lake Michigan. An Endurance Buoy was deployed at a site 7 km north of Milwaukee Harbor on April 2009 and is still in the field at the time of this writing. The buoy is equipped with a meteorological station and a YSI sonde measuring water temperature, conductivity, pH, dissolved oxygen, and chlorophyll fluorescence. In addition, a bottom sonde, a thermistor string and a current profiler are deployed at the station. The data being collected by these sensors is being used to build a long-term nearshore monitoring dataset, with the goal of assessing the response of the nearshore zone to management actions, such as nutrient abatement, and ongoing perturbations, including climate change and invasive species. In addition to providing a long-term data set, the nearshore Endurance Buoy is being used to study gas exchange (CO₂ and O₂) between Lake Michigan and the atmosphere. The general goals of this study, which includes UW-Milwaukee graduate students, is to assess the effect of dreissenid mussels and benthic algae on carbon metabolism and energy flow in the nearshore zone, and to improve understanding of the role of Lake Michigan in the regional carbon cycle.
4. Particle Settling and Resuspension Dynamics. A Pioneer buoy is currently deployed in conjunction with an automatic sediment sampler south of Milwaukee Harbor. This buoy is returning temperature and sonde data concurrently with sediment samples to gain a more comprehensive picture of how particles move between the air, water column and the bottom.

5. The Surf Zone Station. The core electronics and instrumentation of a Pioneer buoy were mounted on a weighted aluminum frame to serve as a data acquisition platform for making measurements in the very shallow surf zone near Atwater and Bradford Beaches in Milwaukee. A 3 meter tall mast supports a radio transmitter for data transmission to shore and a 2-mile warning light for safety. Cabled to this station is a smaller weighted frame to which is mounted an acoustic doppler current profiler. This station, operational at the time of this writing, is being used to gather data on water motion to support the development of nearshore circulation models of Lake Michigan.

6. Data and Metadata Display and Archiving Technology. A comprehensive and flexible metadata database is being developed to facilitate effective cataloguing of the varied volumes of data being generated by the near-shore network. The metadata infrastructure is designed to support these primary needs: (1) The data and metadata will be made available using the DMAC transport protocols, metadata standards, and data discovery interfaces, as recommended by the IOOS Data Management and Communications Steering Team (see http://dmac.ocean.us/). This will allow the GLUCOS near-shore observing network to efficiently share its data with GLOS as a whole, as well as enabling GLUCOS to more effectively support both internal and extramurally-funded projects at the WATER Institute. (2) It will serve as a back-end to support a new GIS-based data display system that we are developing, which will support user-friendly and timely access to the data online, as well as support access at kiosks and mobile smartphones. (3) The system will permit easy access to the large body online near-shore lake, river, and stream water quality data archived at the WATER Institute, some of it dating as far back as the 1930s. GLOS funding has been crucial to the development of this critical IT infrastructure.

Michigan Technological University

In 2009 MTU installed a set of water quality sensors onto the National Park Service’s ferry boat, Ranger III, which transports visitors to Isle Royal NP in Lake Superior. The sensors recorded near surface water (approximately 2 meters depth) conditions as a function of time and location (every 30 seconds/ 200meters) during each transit and will include temperature, pH, conductivity, turbidity, dissolved oxygen, oxidation reduction potential (ORP), chlorophyll-a and total dissolved solids. The data from each Ranger
cruise was displayed in real-time on the ship and also shared with the public on a web-based portal.

In addition to the Ranger III activity, two other activities were initiated. First, a thermistor array with sensors at 1 meter spacing was placed off the breakwater on the north end of the Portage inlet. Secondly, we started to design a set of buoys that will be deployed annually at each end of the Keweenaw Waterway in Lake Superior. These buoys will be designed and built in partnership with the University of Michigan.
**PROJECT TITLE:** Observatory for Submerged Sinkhole Ecosystems in Thunder Bay National Marine Sanctuary, Lake Huron: Habitat Exploration, Life Inventory and Hydrologic Modeling

*Principal Investigators:* Thomas Johengen, CILER  
Steve Ruberg, GLERL  
Allen Burton, CILER

**Research Collaborators**


**Overview and Objectives**

**Tasks Scheduled During 2008 and 2009 Field Seasons**

Map the underwater habitat (ROV and diver mapping), evaluate the variable physico-chemical conditions for one year (continuous time-series exploration), measure the rate of groundwater discharge (Ra, Rn tracers and stable oxygen isotopes), quantify groundwater and sediment pore water nutrient chemistry (colorimetry and ion chromatography), identify the carbon composition of benthic mats and sediments (stable carbon isotopes in sediment cores), describe the fine-scale vertical organization of the microbial mats (epifluorescence microscopy, molecular characterization), identify metazoan sinkhole inhabitants (light microscopy and molecular characterization), and study mat growth (light/dark growth experiments). The proposed study is expected to provide a clear working picture of the bathymetry, physico-chemical conditions, hydrologic processes, variety and distribution of life in a range of submerged sinkhole ecosystems in this Laurentian Great Lakes Basin.

**Accomplishments**
Project data and metadata can be found at [www.glerl.noaa.gov/res/projects/sinkhole](http://www.glerl.noaa.gov/res/projects/sinkhole) collected on research cruises beginning in 2003 but primarily focused on project field years in 2008 and 2009. The chemical, physical, and biological data processed from diver and ROV samples and from instrumentation can be found on this website. Please contact Steve Ruberg at NOAA/GLERL for password to permit data downloading.

**Nutrients**

Nutrient samples were collected by [Tom Johengen’s Lab](http://www.glerl.noaa.gov/res/projects/sinkhole) from all three sinkhole locations during three different surveys. The goal was to sample the groundwater end member as well as comparative control (lake water) samples at each of the sinkhole sites. Samples were analyzed for a variety of nutrients including nitrogen, phosphorous and silicon as well as other ions such as chloride, sulfate, bromide and fluoride (Table 1). Chemical analyses helped define the signatures (i.e. source and strength) of the groundwater input and will be further examined in terms of its potential influence on observed levels of photosynthesis and chemosynthesis present within the sinkhole basins. Most chemicals showed similar levels of enrichment between groundwater and lakewater, often 4-6 times higher in concentration, except for nitrate which was depleted in the anoxic conditions.

Table 1. Chemistry results of vented groundwater and ambient lakewater for three sinkholes in the Thunder Bay National Marine Sanctuary region.
<table>
<thead>
<tr>
<th>Date</th>
<th>Site and Type of Water</th>
<th>Sample ID</th>
<th>NH4 (ugN/L)</th>
<th>SRP (ugP/L)</th>
<th>Silica (mgSiO2/L)</th>
<th>Sulfates (mg/L)</th>
<th>Chlorides (mg/L)</th>
<th>Nitrates (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/1/2008</td>
<td>El Cajon EC-a</td>
<td>EC-a</td>
<td>28.4</td>
<td>1.3</td>
<td>11.8</td>
<td>1675.7</td>
<td>41.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>6/1/2008</td>
<td>El Cajon EC-b</td>
<td>EC-b</td>
<td>37.0</td>
<td>2.5</td>
<td>12.0</td>
<td>1696.6</td>
<td>41.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - Control MI-1C-a</td>
<td>MI-1C-a</td>
<td>6.9</td>
<td>1.0</td>
<td>1.4</td>
<td>21.5</td>
<td>7.7</td>
<td>0.27</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - Control MI-2C-a</td>
<td>MI-2C-a</td>
<td>3.6</td>
<td>0.6</td>
<td>1.6</td>
<td>20.6</td>
<td>7.7</td>
<td>0.27</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - Control MI-3C-a</td>
<td>MI-3C-a</td>
<td>3.6</td>
<td>0.7</td>
<td>1.4</td>
<td>20.6</td>
<td>7.7</td>
<td>0.27</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - Control MI-4C-a</td>
<td>MI-4C-a</td>
<td>5.8</td>
<td>0.5</td>
<td>1.6</td>
<td>19.3</td>
<td>7.6</td>
<td>0.26</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-1-a</td>
<td>MI-1-a</td>
<td>17.0</td>
<td>0.9</td>
<td>4.1</td>
<td>420.7</td>
<td>12.9</td>
<td>0.21</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-1-b</td>
<td>MI-1-b</td>
<td>16.1</td>
<td>1.4</td>
<td>4.5</td>
<td>441.7</td>
<td>12.6</td>
<td>0.19</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-2-a</td>
<td>MI-2-a</td>
<td>16.1</td>
<td>2.1</td>
<td>3.9</td>
<td>1727.7</td>
<td>41.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-2-b</td>
<td>MI-2-b</td>
<td>15.6</td>
<td>1.0</td>
<td>4.0</td>
<td>417.7</td>
<td>12.6</td>
<td>0.19</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-3-a</td>
<td>MI-3-a</td>
<td>15.8</td>
<td>1.7</td>
<td>4.2</td>
<td>449.1</td>
<td>13.4</td>
<td>0.21</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-3-b</td>
<td>MI-3-b</td>
<td>15.8</td>
<td>1.7</td>
<td>4.1</td>
<td>449.1</td>
<td>13.4</td>
<td>0.21</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-4-a</td>
<td>MI-4-a</td>
<td>17.2</td>
<td>2.6</td>
<td>4.0</td>
<td>449.1</td>
<td>13.4</td>
<td>0.21</td>
</tr>
<tr>
<td>7/30/2008</td>
<td>Middle Isl - groundwater MI-4-b</td>
<td>MI-4-b</td>
<td>17.2</td>
<td>2.6</td>
<td>4.0</td>
<td>449.1</td>
<td>13.4</td>
<td>0.21</td>
</tr>
<tr>
<td>8/5/2008</td>
<td>Blue hole - groundwater BH-1-a</td>
<td>BH-1-a</td>
<td>25.3</td>
<td>1.0</td>
<td>12.6</td>
<td>1727.7</td>
<td>41.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>8/5/2008</td>
<td>Blue hole - groundwater BH-2-a</td>
<td>BH-2-a</td>
<td>25.3</td>
<td>0.9</td>
<td>11.8</td>
<td>1565.1</td>
<td>36.8</td>
<td>0.05</td>
</tr>
<tr>
<td>8/5/2008</td>
<td>Blue hole - groundwater BH-3-a</td>
<td>BH-3-a</td>
<td>17.0</td>
<td>0.6</td>
<td>14.5</td>
<td>1080.8</td>
<td>21.3</td>
<td>0.06</td>
</tr>
<tr>
<td>8/5/2008</td>
<td>Blue hole - groundwater BH-3-b</td>
<td>BH-3-b</td>
<td>17.2</td>
<td>0.5</td>
<td>13.7</td>
<td>1080.8</td>
<td>21.3</td>
<td>0.06</td>
</tr>
<tr>
<td>8/6/2008</td>
<td>Middle Isl - groundwater MI-1</td>
<td>MI-1</td>
<td>38.1</td>
<td>3.0</td>
<td>24.9</td>
<td>913.3</td>
<td>18.5</td>
<td>0.08</td>
</tr>
<tr>
<td>9/7/2008</td>
<td>Isolated sinkhole - groundwater 1a</td>
<td>1a</td>
<td>102.4</td>
<td>4.0</td>
<td>10.3</td>
<td>1962.4</td>
<td>249.2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>9/7/2008</td>
<td>Isolated sinkhole - groundwater 2a</td>
<td>2a</td>
<td>41.2</td>
<td>4.1</td>
<td>7.8</td>
<td>1080.8</td>
<td>21.3</td>
<td>0.06</td>
</tr>
<tr>
<td>9/7/2008</td>
<td>Isolated sinkhole - groundwater 3a</td>
<td>3a</td>
<td>39.3</td>
<td>1.3</td>
<td>10.5</td>
<td>1080.8</td>
<td>21.3</td>
<td>0.06</td>
</tr>
<tr>
<td>9/7/2008</td>
<td>Isolated sinkhole - groundwater 4b</td>
<td>4b</td>
<td>27.6</td>
<td>0.3</td>
<td>10.3</td>
<td>1080.8</td>
<td>21.3</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Ecosystem ecology**

**Bopi Biddanda's Lab** focused on sinkhole ecosystem ecology, characterizing the chemical, physical and hydrographic features measuring water, benthic mat and sediment metabolism providing insight into the food web linkages between sinkhole ecosystems and the lake. Because sinkhole ecosystems are microbe dominated, we developed methods to describe the abundance, diversity and activities of the microbial communities. Although the purple benthic mat consisted mostly of *Phormidium*-like cyanobacteria, microscopic examination (and molecular level phylogenetic analyses by the Nold Lab) has revealed the presence of active nematodes, tardigrades, arthropods, and various protozoa – confirming that the mats are a complex and dynamic consortia of microbial producers and protozoan+metazoan consumers. An interesting scientific finding was that the 14C-bicarbonate uptake studies of production processes showed that sinkhole ecosystems are variably supported by oxygenic photosynthesis, anoxygenic photosynthesis, and chemosynthesis along a depth gradient of decreasing sunlight. Further stable isotope tracer studies showed that the local sinkhole benthic food web is tightly linked to carbon input from the groundwater and the resulting primary production of the benthic cyanobacterial mats. Additional microscopy of
biological samples and analyses of carbon and nutrient content of water samples collected during 2009 are underway. We now have sinkhole mats growing on intact sediment cores in the lab (under simulated light and temperature, bathed by fresh groundwater) – enabling detailed microscopic analyses of the mat community.

**Microbial ecology**

Steve Nold’s Lab provided an understanding of sinkhole microbial ecology. The goal was to characterize the fine-scale vertical organization of microbial and multi-celled animal communities inhabiting sinkholes. This laboratory also determined the source of organic carbon in sinkhole sediments, a first step in understanding sinkhole nutrient cycling. After collecting and thin-sectioning sediment cores from Middle Island Sinkhole, gene sequences of the microbial inhabitants were analyzed. Two papers resulted from this work (see S.C. Nold et al. in the bibliography).

Membrane phospholipids of sinkhole inhabitants were also extracted and purified for phospholipid fatty acid analysis. These samples are currently at the Soil Science Department at the University of Wisconsin-Madison. The sample backlog at UW-Madison is substantial, and the analytical instrumentation needs upgrading before these samples can be run. Ultimately, they will be separated by gas chromatography and individual lipids will be analyzed by isotope ratio mass spectrometry for $^{13}$C content. These data will provide a comprehensive view of microbial community composition, including the metazoan and bacterial inhabitants. By illuminating patterns of $^{13}$C incorporation into individual membrane lipids, these data will also link metazoans to their food source (presumably the cyanobacterial phototrophs in this ecosystem). Another set of membrane lipids are currently awaiting analysis at the Large Lakes Observatory in Duluth, MN to investigate the possibility of anaerobic methane oxidation by methanogenic Archaea. Once complete, both studies will result in separate publications.

The source of organic carbon in sinkhole sediments was discovered by collecting sediment, phytoplankton, cyanobacterial mat, sedimenting carbon, and dissolved inorganic carbon samples from Middle Island sinkhole. The $^{13}$C and $^{15}$N content of each carbon pool was analyzed using isotope ratio mass spectrometry. We discovered that nearly all (>90%) the carbon in sinkhole sediments originates from sedimenting phytoplankton rather than cyanobacteria growing on the sediment surface. A manuscript has been composed for publication (see bibliography) and is awaiting one synthetic figure before submission.
Groundwater Isotopic Analyses

Mark Baskaran’s Lab collected a suite of water samples in around the three vents. Radioisotopes and stable isotopes of oxygen and hydrogen were analyzed in these water samples. We found the radium isotopes give the groundwater a unique isotopic signature with 100 times radium in the sinkhole groundwater than in the surrounding lake water. We will be able to quantify the amount of submarine groundwater discharge into the lake using this unique signature. The analysis of stable isotopic oxygen indicated that the sinkhole water is highly depleted in oxygen isotopic composition. The hydrogen isotopic composition also indicates similar depletion.

In addition, long diver-collected cores were obtained from the Middle Island sinkhole and are being dated using Pb-210 and Cs-137 geochronologies by Val Klump at the University of Wisconsin Milwaukee WATER Institute. Preliminary results indicate that sediment accumulation rates are considerably higher than for the depositional regions of the lake as a whole, indicating either the sinkhole is operating as a significant trap, focusing material from a wider area, and/or that productivity is high leading to high rates of deposition.

Analysis of sinkhole waters by Val Klump shows that these waters are very high in dissolved methane (400-1000 nmol L⁻¹), a bi-product of anaerobic metabolism of organic matter. Analysis of organic carbon and total nitrogen content, as well as stable isotopic composition of the Middle Island core sediment is continuing. Nitrogen remineralization appears to be significant, with as much as 60% of the total deposition being recycled back into the overlying water. Estimates of the isotopic composition of this recycled fraction indicate that it is isotopically light (δ¹⁵N ~ -0.2 ‰) relative to surface sediments (δ¹⁵N ~ +1.25 ‰), in keeping with the preferential remineralization of ¹⁴N relative to ¹⁵N (β_{obs} = 1.00164).
1. Sediment geochronology:

Based upon both Pb-210 and Cs-137 geochronologies (which are consistent with one another), the estimated sediment accumulation rate for the MI-90308-2 core is ~ 0.31 g cm\(^{-2}\) yr\(^{-1}\)

![Diagram showing excess Pb-210 and Cs-137 against years]

2. Organic carbon and total nitrogen sedimentary mass balances:

The depositional flux, the burial flux, and the recycled flux were calculated for each profile from the concentration of the two end members (in mol g\(^{-1}\) or wt. %), i.e., the concentration at the surface and the concentration at depth, when multiplied by the mass sediment accumulation rate (~ 0.31 g cm\(^{-2}\) yr\(^{-1}\)). Although more sophisticated diagenetic models have been developed, the remineralization of metabolizable organic matter in these sediments may be estimated from the well-known diagenetic expression for first order decomposition kinetics and steady state deposition and burial. By this
formulation, ~52% of the organic carbon and ~62% of the nitrogen deposited in these sediment was estimated to be remineralized and released back into the overlying water (see table and figures).

Table 1. Sedimentary organic carbon and nitrogen mass balances for Middle Island core 90308-2

<table>
<thead>
<tr>
<th>Component</th>
<th>Total C</th>
<th>Org C</th>
<th>Total N</th>
<th>OrgC:N ratio (top &amp; bottom of core)</th>
<th>δ¹⁵N (‰)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co (%)</td>
<td>8.9</td>
<td>3.77</td>
<td>0.60</td>
<td>7.1 (ave = top 3)</td>
<td></td>
</tr>
<tr>
<td>C_buried (%)</td>
<td>7.5</td>
<td>1.80</td>
<td>0.23</td>
<td>8.9 (ave = bottom 3)</td>
<td></td>
</tr>
</tbody>
</table>

Sedimentary fluxes (mol m⁻² yr⁻¹) | Est. C:N

| Input          | 9.73   | 1.33  | 7.3     | 1.25                               |
| Burial         | 4.65   | 0.51  | 9.1     | 3.60                               |
| Recycled       | 5.08   | 0.82  | 6.2     | -0.211                             |
| ƒ_r recycled   | 52%    | 62%   |         |                                    |

Middle Is. 90308-2

organic carbon (wt. %)

- OrgCo = 3.77%
- OrgC_buried = 1.80%
- Input = 9.7 mol m⁻² yr⁻¹
- Buried = 4.7 mol m⁻² yr⁻¹
- ƒ_r recycled = 52%
3. Stoichiometric (and isotopic) mass balances:

A mass balance may also be constructed using estimated C:N stoichiometries and the corresponding deposition and burial fluxes (Klump et al. 2009). The C:N stoichiometry of the recycled fraction [C:N]_R should be consistent with measurements from the core of input (C:N ~ 7.1) and burial (C:N ~ 8.9) stoichiometries and can be estimated from these equations. In this case a C:N ratio for the recycled fraction of ~6 would be required to be consistent the preferential remineralization of nitrogen (62%) relative to carbon (52%).
Similarly, the isotopic signature of recycled nitrogen which is consistent with a 62% turnover of nitrogen in these sediments may also be estimated (eqn. 7, \(-0.211 \, ^\circ/oo\)).
The anomalous dC13 profile for organic carbon, shows a lighter isotopic signal at depth in the core, as opposed to the expected heavier residual from diagenetic remineralization, as shown by the nitrogen dN15 signal. Using the same assumptions and stoichiometric analysis as above, the organic carbon dC13 profile implies a recycled fraction with an isotopic signature of -20 o/oo, i.e. heavier than the orgC deposited. A correlation with ground water inputs might be expected to generate a heavier organic carbon signature, since the dC13 of ground water carbonate is heavy (~ -1 o/oo). We do not yet have a ready explanation for the dC13 profile in this core, but some change in input, or variation in diagenetic processes, like methane production and oxidation may also be important. The groundwater inputs may be influencing the carbon isotope picture in a different way, and it is likely that there are more than one labile component of organic carbon undergoing diagenesis and remineralization (e.g. planktonic debris and in situ microbial photolithotrophic production).

4. Groundwater inputs: Is there a possible paleo-record?

Both Pb-210 and Cs-137 inventories exceed atmospheric inputs, indicating that the Middle Island sinkhole focuses material from outside the basin. is consistent with the conclusions of Nold et al (in prep.) that the Middle Island sinkhole is accumulating mostly planktonic organic carbon. Pb-210 inventories are ~13 times the atmospherically supported flux and Cs-137 inventories ~ 6 times atmospheric inputs. This implies a possible second source of Pb-210, although focusing factors (the ratio of the measured inventory to the atmospherically supported inventory) are frequently higher for Pb-210 than for Cs-137 (D. Edgington, pers. comm.).

Assuming, however, for the moment, that the additional Pb-210 excess could result from the decay of groundwater inputs of Ra-226 (a grandparent of Pb-210), and it may be possible to reconstruct a “groundwater input signal” from the excess Pb-210 record by subtracting the expected atmospheric excess Pb-210 (including focusing based upon
the Cs-137 inventory) from the total excess Pb-210 observed, and then correcting for decay since deposition. The resulting flux of Pb-210 is plotted along side historic Lake Huron water levels.

Although this is only hypothetical, it is interesting to speculate. A correlation to lake levels might reflect long term variations in the net supply to the basin, with periods of higher lake level, and therefore higher precipitation, generally correlating with higher ground water flow. This would depend largely on how responsive and closely connected this ground water system is to increased precipitation on a temporal basis. A more detailed analysis of Cs-137 inputs is underway and may refine this hypothesis.

Method Note: Sediment porosity was calculated from the weight loss upon drying at 60°C assuming a dry sediment density of 2.45 g cm⁻³. Sedimentary carbon and nitrogen content were determined on a Carlo Erba 1500 NCS analyzer interfaced to a Finnegan delta S IRMS via a Conflo II interface. Carbonate was removed for organic carbon determinations via the addition of 1:1 vol:vol 3N HCl to sediments which were then placed on a shaker overnight, removed, and dried at 60°C (Eadie, pers. comm.). All nitrogen analyses were run on untreated dry sediment.

5. Groundwater Mixing Rates:

Because radiochemical tracers decay with known and differing half-lives (100’s of years to days), they can often be used to estimate the relative ages of various processes, like mixing, simply by measuring the inherent properties found within the waters naturally. Among the tracers high in these groundwaters is radon-222, a noble gas with a 3.825 day half life. Because it is inert, i.e. non-reactive, its distribution is determined by physical processes only. Radon-222 concentrations in mixed fluids therefore, are controlled by the extent of mixing and the time over which that mixing has occurred. Due to its short half-life, radon enrichments and gradients provide strong support for active SGD venting, and in combination with conservative tracers (e.g. chloride or conductivity) can yield estimates of mixing time scales.

The chemical oxidation, scavenging or other geochemical processes for constituents like HS⁻ and Fe²⁺ are expected to occur very quickly. Microbially-mediated reactions, which depend upon biological uptake and metabolism, e.g. methane oxidation, nutrient uptake, etc. may be slower depending upon conditions. Such data can assist in calculating in situ reaction or scavenging rates for a variety of constituents.
Summary

Project lead investigator Steve Ruberg, along with Rob Paddock of the University of Wisconsin Milwaukee WATER Institute, Russ Green of the Thunder Bay National Marine Sanctuary **GIVE WEB SITE**, and Scott Kendall of the Annis Water Resources Institute collected imagery and chemical and physical mapping data at all three sinkhole locations using remotely operated vehicles. Bathymetric maps have now been produced of all three sinkhole locations. Visualization maps of dissolved oxygen, pH, temperature, and conductivity will be produced for all three sinkhole systems. Observations obtained during the summer and fall research cruises are leading to insights valuable to our understanding of these unique environments which may lead to additional investigations. For example, underwater ROV surveys coupled with PAR and conductivity sensors have now confirmed our hypothesis that the purple benthic cyanobacterial mats are restricted in their distribution to shallow sinkholes with adequate sunlight and constant groundwater availability in the near-bottom environment. Preliminary observations indicate that groundwater at the nearshore Middle Island sinkhole has a lower conductivity than the offshore Isolated system. A possible explanation is that groundwater exiting into the deeper Isolated sinkhole (93m) flows through the Silurian geologic formation known to hold more halite deposits while the shallower Middle Island system is flowing through the higher level Devonian formation. The higher salt content of the deeper formation can be attributed to the evaporation of seawater captured in rock layers of the Silurian period during the Paleozoic era. The additional exploration of a karst feature further east at a depth of 109 m showed no obvious signs of recent venting activity and no changes in water temperature or increased conductivity indicative of groundwater flow where observed.

ROV observations have led to a better understanding of the sources of groundwater in the Middle Island system. Our initial conclusion that the bowl-shaped Alcove was the primary source of groundwater is now being re-evaluated with the discovery of multiple sources around the base of the Arena walls.

In addition, Nathan Hawley deployed twelve instrumented moorings near the Middle Island and Isolated sinkholes to determine how groundwater ionic composition and physical parameters such as temperature and flow rate vary with local climate and lake conditions over the course of a nine-month multi-sensor deployment. These instrument packages will be retrieved in May 2009.
Great Lakes sinkholes were formed as groundwater erosion resulted in the collapse of karst features formed up to 400 million years ago in shallow seas. Groundwater erosion continues today and contributes to ecosystems that are unique in the Great Lakes. Groundwater chemistry, drastically different from ambient lake conditions, fuels biological reactions in two very different light environments. Groundwater with higher density and very low oxygen levels contributes to photosynthesizing cyanobacterial Oscillatoria in shallow sinkholes and sulfide oxidizing Beggiatoa in deeper aphotic sinkholes. The position of the Isolated sinkhole lower in the geologic strata results in higher chloride and sulfate levels. Low volume flow at the deeper Isolated sinkhole system results in variable groundwater layer thickness that is subject to open lake currents while high volume flows at the shallow Middle Island sinkhole sustain a nearly constant temperature and groundwater layer thickness. The reduced light in the deeper Isolated system allows the chemosynthetic Beggiatoa to dominate the benthic microbial community. Middle Island radium levels are approximately 100 times higher than ambient lake water but still well within drinking water guidelines. The sediment accumulation rate for Middle Island sinkhole is estimated at 0.31 g/cm2/year based on Pb-210 and Cs-137 geochronologies.

Middle Island ROV/Diver observations and water mass characteristics confirm that the distribution of the purple cyanobacterial benthic mats was limited exclusively to the zone of groundwater influence. These predominant blue-green algae have two modes of growth; they can either perform oxygenic photosynthesis similar to green plants or, when sulfide is present, they can perform anoxygenic photosynthesis using sulfide as the electron donor. When growing in the presence of sulfide, they synthesize a different form of chlorophyll, causing pigments to be purple rather than lake floor. Since cyanobacteria photosynthetically fix carbon dioxide, they can act as primary producers and may constitute the base of the food web in these unique ecosystems. Our observations in this and other shallow sunlit submerged sinkholes in the surrounding areas of Lake Huron confirm the presence of the purple photosynthetic cyanobacterial benthic mats whenever high conductivity, sulfate-rich groundwater is present. The occasional white bacterial strands attached to rocks at the alcove outfall are likely to be sulfur-oxidizing bacteria such as Beggiatoa. These organisms oxidize sulfide in the presence of oxygen and deposit elemental sulfur within their bodies, giving them a whitish appearance.

Questions regarding how the dominant cyanobacterial mats manage to disperse and colonize sinkholes that are small and geographically distant/isolated, as well as the significance of cyanobacterial mat production at the sinkholes to the surrounding lake
food web remain to be addressed. Interestingly, the ancestors of the cyanobacteria that currently populate Middle Island sinkhole first appeared on earth approximately 3.5 billion ybp, but are now being sustained by dissolved ions such as sulfates and carbonates deposited relatively recently (hundreds of millions of years ago).

Scientific Products

Products: The project was chosen as a “Signature Project” during 2008 by NOAA-OE and, together with NOAA’s Thunder Bay National Marine Sanctuary, we have published 3 peer-reviewed articles (MTJS 2008, Eos-AGU 2009, AEM 2010), distributed audio-video educational project CDs to school teachers and participated in live web casts to schools and the public. Learn more about this project by viewing the Project Web Page at http://www.glerl.noaa.gov/res/projects/sinkhole/, http://oceanexplorer.noaa.gov/explorations/08thunderbay, and our live web cast at http://www.oceanslive.org (choose “Underwater Sinkholes” under archives).

Peer-reviewed Research Articles:

Published:


In Review:


**Planned:**

Nold, S. C., M. J. Bellecourt*, B. A. Biddanda, S. C. Kendall, S. A. Ruberg, T. G. Sanders* and J. V. Klump: Lacustrine submerged sinkhole sediments are a sink for organic carbon. To be submitted to *Biogeochemistry*.


Nold, S.C., N.R. Maier*, and B.A. Biddanda. Photoautotrophy and chemosynthesis in Lake Huron sinkholes measured by $^{13}$C incorporation into bacterial membrane lipids. To be submitted to *Aquatic Microbial Ecology*.


**Presentations at Scientific Meetings:**

Exploration of Submerged Karst Systems in Lake Huron. 53rd Annual Conference on Great Lakes Research, International Association for Great Lakes Research.


*Denotes undergraduate student author.

**Presentations at Scientific Meetings (and presenter name):**

Laguna Bacalar Symposium, Bacalar, Quinatan Roo, Mexico, January 2009 (Sinkhole Biology - Biddanda; Physics and Chemistry - Kendall)

American Society of Limnology and Oceanography, Nice, France, January 2009 (Nold)

NABS, Grand Rapids, MI, May 2009 (Sanders)

International Association of Great Lakes Research, Toledo, OH, May 2009 (Klump)

Regional Great Lakes Biogeochemistry Conference, Kellogg Biological Station, MSU, May 2009 (Kendall)

West Michigan Regional Undergraduate Research conf., Van Andel Inst. Oct. 09 (Biddanda)

**Invited Seminars:**

Montana State University, Bozeman, October 2008 (Nold)
Wayne State University Seminar, November 7, 2008 (Ruberg)
Seminar, Kellogg Biological Station, MSU, February 13, 2009 (Biddanda)

**Outreach and Education Presentations and Products**
Web Cast:  Immersion Presents - Lake Huron Sinkholes Exploration (Ruberg, Biddanda), September 2008. Live webcast on sinkholes to schools across the nation from on board the R/V Laurentian during a cruise in TBNMS, Lake Huron. (Note: Click Archives, then Underwater Sinkholes in this website). www.oceanslive.org/portal/

Seminar, Faculty Research colloquium, College of Liberal Arts and Sciences, GVSU (October 24, 2008) (Biddanda)

Guest lecture in undergraduate class Introduction to Natural Resource Management, GVSU (October 29, 2008) (Biddanda)

Wayne State University Seminar, November 7, 2008 (Ruberg)

Dive into Lake Huron Sinkholes: An Educational CD for K-5th grade students (2008). (Biddanda and Kendall)

Classroom presentation of the educational and outreach CD to visiting K-12 students (>500) at AWRI-GVSU during 2008 (Dr. Janet Vail, GVSU)

Ocean Exploration Professional Development Workshop for Science Teachers, Shedd Aquarium, Chicago, IL. April 18 (Ruberg)

Submerged Sinkholes of Lake Huron: an Educational Outreach CD for K-12th Grade Students (2009). This revised and updated version contains teacher resources that include classroom audio Power Point presentations, activities, and other materials that bring sinkhole research into the classroom. Copies of CDs are available for distribution. (Biddanda and Kendall)

**Dissemination of Project Science to Public (Web, Newspaper, Radio and TV)**

*TV program – Discovery Channel Daily Planet September 2009:*

*Youtube clip:
Radio Interviews:

Eos-AGU Press release:

Website/Newspaper Articles:
Biddanda gets international attention for Lake Huron sinkhole research
http://www.gvsu.edu/gvnow/index.htm?articleId=36E6FB74-CD2B-DB10-E9F8627FAFA72DD8&archiveDate=01-Sep-06
http://www.thealpenanews.com/page/content.detail/id/501862.html
www.thealpenanews.com/page/content.detail/id/505831.html?nav=5004
www.thealpenanews.com/page/content.detail/id/504654.html?nav=5004
www.freep.com/article/20090510/NEWS07/905100497
www.sciencedaily.com/releases/2009/02/090224163649.htm
www.foxnews.com/story/0,2933,500124,00.html
www.wvgazette.com/News/200905030369
www.dispatch.com/live/content/science/stories/2009/03/10/sci_sink_hole.ART_ART_03-10-09_B4_EQD44NA.html
news.yahoo.com/s/livescience/20090224/sc_livescience/oddlifefoundingreatlakes
www.livescience.com/animals/090224-great-lakes-extremes.html

Other Web Sites related to our ongoing sinkhole exploration:
Sinkhole web sites at Thunder Bay National Marine Sanctuary (TBNMS):
thunderbay.noaa.gov/research/exploration2007.html
Sinkhole web site at NOAA-Ocean Explorer:
oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html
Sinkhole web site at NOAA-GLERL:
www.glerl.noaa.gov/res/Task_rpts/2006/eosruberg06-1.html
http://www.glerl.noaa.gov/res/projects/sinkhole/
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.
PROJECT TITLE: GREAT LAKES RESTORATION INITIATIVE – NOAA PROGRAM SUPPORT

Principal Investigators: Allen Burton, CILER

Overview and Objectives

CILER will assist in the execution of NOAA (~$4 million) and USEPA non-Federal CILER-directed GLRI grant implementation, provide evaluations of performance effectiveness of the awards, and assist in reporting requirements. In addition, CILER will organize and lead workshops to facilitate information exchange across relevant GLRI non-federal projects that are important for related NOAA activities. The information exchange and outreach will be further facilitated through a new web site with dissemination of highlights through existing Great Lakes listserves. Finally, undergraduate and graduate student fellows will be 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, timely and available on the internet.

Accomplishments

The interagency agreement has been signed, and funds are now at GLERL. An introduction to CILER and its purpose in this effort has been posted to the listserv.

Publications

None at this time.

Presentations

None at this time.
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.
Overview and Objectives

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

Accomplishments

WATERSHED TEAM

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

Nutrient loading efforts

Monthly and daily river export load series for the Raisin, Maumee, Sandusky, Vermilion, Cuyahoga, and Grand Rivers have been completed for the period of record. Missing data have been filled in, and the complete time series have been posted to the project website. Daily Lake Erie nutrient loading estimates for CY2005 at 26 spatial nodes have been completed. CY1976 nutrient loads have been reconstructed from archived historical data. All point source, atmospheric, and tributary data for 2006 and 2007 has been received and daily load estimates for these years are proceeding.
**N and P budgets**

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

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

Multiple databases of land use, soil, digital elevation model (DEM), hydrography, and agricultural management practices have been acquired, processed, and analyzed to develop dynamic input parameters for the DLBRM and the revised universal soil loss equation (version 2) (RUSLE2) for the 6 watersheds on the U.S. side (Grand-OH, Cuyahoga, Sandusky, Maumee, Huron-MI, and Raisin). We have acquired and processed multiple databases of land use, soil, digital elevation model (DEM), and hydrography for the Grand River – Ontario. A computer program was written to spatially link the Ontario soil attribute database with the polygon database for extracting the soil input parameters. Input parameters for the DLBRM were derived. We have also built basic model application databases (daily meteorology, land use, soils, elevation, and hydrography) for all 17 U.S. Lake Erie watersheds, and we completed DLBRM daily calibrations for five Lake Erie watersheds: Huron, Raisin, Maumee, Sandusky, and Grand (Ohio). We are now calibrating the DLBRM for the remaining 12 U.S. Lake Erie watersheds. We estimated sediment and nutrient transport for two non-Erie watersheds and are doing the same now for the Maumee watershed on Lake Erie. We are now adding transport mechanics to the DLBRM. We developed automatic near real time "Resource Shed" processing for 18 watersheds, including the five Erie watersheds mentioned previously. Resource shed maps for the last 31 days are available daily and will soon be accessible via the internet.
SWAT models have been developed, calibrated, and validated for the same 6 Lake Erie watersheds on the U.S. side being modeled by DLBRM – Huron, Raisin, Maumee, Sandusky, Cuyahoga, and Grand. Overall, the SWAT models’ performance is strong when compared to observed stream discharge, sediment loads, and nutrient loads (total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate). Currently, agricultural best management practice scenarios are being developed. Then, best management practices will be simulated by SWAT to compare their effectiveness at reducing river nutrient export loads to Lake Erie.

HYPOXIA TEAM

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

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

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

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

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

We have also begun developing the code for our level 3b model, which will be a complex hypoxia model, incorporating Dreissenids and nearshore lower food web dynamics that may be different from offshore dynamics. This model will be linked to the same 3D hydrodynamic model being used for the level 3A model. We have also compiled forcing function data (including loads of all state variables from all main tributaries) for the four master years to which this model will be calibrated and confirmed.
Additionally, we have continued to assess and incorporate uncertainty in our modeling applications. We have conducted preliminary, exploratory analyses of our level 1 model using PEST (a parameter estimation and optimization software) and WinBUGS (a Bayesian reference software). These analyses are intended to assess the variability of the calibration terms in the model.

**ECOLOGICAL EFFECTS TEAM**

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

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

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

**Empirical analyses**

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

**Bioenergetic models**

To date, we have developed bioenergetics growth rate potential models for emerald shiner, rainbow smelt, round goby, yellow perch, and walleye. We have applied these models 1) using physical, chemical and biological data collected during 2005/2007 IFYLE cruises in central Lake Erie and 2) using output from 1-dimensional hypoxia models. Analyses based on output from 1-dimensional hypoxia models suggest that hypoxia effects on habitat quality vary inter-annually and differentially affect various species and life-stages. Analyses based on measured temperatures, oxygen concentrations and prey distributions suggest that hypoxia may affect habitat quality in unexpected ways. For example, while growth rate potential modeling suggests that hypoxia will limit the availability of hypolimnetic habitat for walleye, overall walleye habitat quality may ultimately benefit as both walleye and their prey are constricted into a narrow depth range just above the hypoxic hypolimnion. Growth rate potential results have been synthesized and manuscripts have been drafted and submitted for publication. Currently, our bioenergetics modeling efforts focus on dynamic individual-based models. We have incorporated dynamic behavior and movement into growth rate potential models. In addition, we are in the process of coding a holistic individual-based model. This model includes dynamics of rainbow smelt, walleye and yellow perch. It uses output from the 3-D water quality model as input to drive dynamics of fish movement, feeding, growth etc.

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

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

Coordination and application

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

**Publications**


**Presentations**


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


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


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


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

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

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


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


spatially-explicit bioenergetics modeling approach. Oral presentation at the Michigan Chapter of the American Fisheries Society Annual Meeting, Dundee, MI.


**Awards**


**Thesis Defended (M.S.)**

**Overview and Objectives**

In 2009 we conducted our first major field work on the Bay, including an ambient water quality survey, a transect study of benthic algae and muck deposition along the beaches, trawl and seine surveys of the fishes, and a limited sampling in some of the poorly monitored, smaller tributaries. Modeling work and surveys regarding stakeholder preferences are also ongoing. At the all-PI workshop in December 2009 we decided that we would conduct our second field season of the project in 2010, rather than in 2011 as we had originally proposed. There were several reasons for this change including the need to follow a cohort of fish through their first two years, which would not have been possible with alternating-year field-efforts, and the practical consideration that graduate students with pending theses could not be “benched” for a year. The field effort for 2010 began in April and will continue into October.

**2009-10 Accomplishments and Activities**

- PI Workshop December 2009
- IAGLR session
- Ambient Water Quality Survey

We sampled key water quality parameters monthly from May to October at 13 stations in Saginaw Bay. Surface water was sampled from a total of 13 stations (10 in the inner bay, 3 in the outer bay) and 5 of these stations were ‘Master’ stations in which bottom water was also sampled. The water quality parameters measured at each station were Chlorophyll *a*, nutrients (TP, TDP, SRP, NH4, NO3, Cl, Si, PON, POC, DOC), TSS, VSS, Secchi depth, PAR profiles, temperature and DO profiles (CTD), microcystin concentrations (Master stations only), dreissenid densities (Sept only), zooplankton and microzooplankton concentrations (Master stations only) and phytoplankton cell counts. We also included measurements of microcystin concentration and geosmin concentration (a taste and odor producing compound) at drinking water intakes in the inner and outer bay.

- Nutrient (TP) and Chl *a* concentrations were highest at the station closest to the Saginaw River input.
The highest TP concentrations were in Oct 2009 for SB2, SB10 and SB14, suggesting a pulse of nutrient rich water had entered the inner bay through the Saginaw River and was moved by the counterclockwise circulation out towards the outer bay.

Chl a concentrations were the highest in Aug and Sept 2009 at the stations closest to the Saginaw River due to a large *Microcystis* bloom.

Beach and Benthic Algae Surveys - In June we found large quantities of sloughed *Cladophora* near Transect 13 and 14.

We also found *Cladophora*–based muck onshore near Transects 14 & 15, therefore we focused our surveys in southwestern portion of the inner bay.

- Overall, little muck was observed in 2009.
- In early spring we saw moderate amounts of muck which was *Cladophora*-based. By mid-summer we found minimal amounts of muck which was highly decomposed and hard to identify. In late summer, we saw low to moderate muck which was either highly decomposed or primarily macrophyte-based.
- Overall, the timing of muck deposition events tended to correspond with extreme weather events (i.e. storms or high winds), but further analysis is needed.

We found that algae growth occurred early in the season, with highest algal density found in July suggesting that we missed sampling during the time of peak growth in 2009. Therefore, we are starting our field season much earlier (i.e. mid-April) in 2010.

- The algae observed was composed primarily of *Cladophora* early in the season), with the algal community switching to a mixture of
Zygnematales (i.e. Spirogyra, Mougeotia) and other algae (i.e. Oedogonium) later in the season as density declined. The observation of early Cladophora growth also corresponds with the composition of the muck observed on shore at that time.

- Overall, highest algal density was found near Transect 13 between 2 and 3 meters depth, at an intermediate distance from the Saginaw River mouth. This finding suggests that algae growth is regulated by a trade-off between nutrient and light limitation.
- We observed that algae growing directly attached to invasive Dreissenid mussels appeared “healthier” and greener than algal growing on other substrate, thus suggesting that mussel excretion of nutrients may be important for algal growth.

In 2010, we will focus our experimental work on quantifying mussel-supplied nutrients (i.e. phosphorus) and its impact on algal growth in Saginaw Bay.

- **Fishery Survey**
  Offshore sampling for fish took place monthly May-November at 5 stations (Master sites). Data on water temperature, transparency, zooplankton density, predatory zooplankton density, and benthos were also collected each month. Sampling for larval fish took place weekly April through June. We also collected larval fish, zooplankton, benthic invertebrates and small-bodied juvenile/adult fish biweekly at four nearshore sites. Fish collected were used for species composition analysis, diet analysis, condition analysis. We have quantified abundances, size distributions, growth rates (based on daily otolith counts), and diets of larval walleye, yellow perch and lake whitefish. Diet and condition analysis has been completed for juvenile-adult walleye, lake whitefish, rainbow smelt, and is ongoing for round goby, yellow perch, white perch, shiners, and trout perch.
  - Adult walleye ate a combination of round goby, shiners, and yellow perch; age-0 walleye diets changed over the season, and included a combination of zooplankton, predatory zooplankton, benthos, and small fish.
  - Age-0 lake whitefish diets shifted from mainly zooplankton to mainly benthos between June and August.
  - We have completed processing of benthic invertebrates collected throughout 2009. While we observed some seasonal patterns in benthic invertebrates, across-site variation of benthic invertebrates appeared to be far more pronounced than temporal variation.
  - We have observed evidence of Hexagenia in benthic invertebrate samples, larval fish samples and in the diets of walleye and round gobies.
- *Bythotrephes* and *Leptodora* were the primary predatory zooplankton present. *Leptodora* numbers peaked in June and October, *Bythotrephes* numbers peaked in July.

- **Dreissenid Mussel Survey**
  We are continuing to process organisms found in benthic samples collected in Saginaw Bay in 2007, 2008, and 2009. Organisms are being picked, counted, and identified. In fall 2009, benthic samples were collected at 7 sites by divers to assess dreissenid abundances on hard substrates. All mussels were counted, identified, sized, and biomass (ash-free dry weight tissue) determined.
  - Based on 2008-2009 data, the population of dreissenids in Saginaw Bay has declined dramatically since 1991-1996. For the inner bay, mean density and biomass was only 475/m² and 1.8 g/m² in the former period compared to 8,772/m² and 17.4 g/m² in the latter.

- **Watershed/tributary nutrient modeling and monitoring**
  We developed regression models computing Total Phosphorous (TP), Soluble Reactive Phosphorous (SRP), Total Suspended Solids (TSS), Ammonia (NH4), Nitrate + Nitrite (NO3), and Total Nitrogen (TN) daily loads from the Saginaw River, and its subwatersheds. Applied it to analyze origin of TP and SRP loads. Computed daily loads for the periods 1997-2008. Computed uncertainty in TP loads estimation due to model error and input uncertainty. Developed rainfall erosivity coefficients for distributed erosion and sediment transport models to be added to the Distributed Large Basin Runoff Model (DLBRM). Presently modifying the DLBRM for including sediment and nutrient transport.

  Conducted a water chemistry sampling effort for three additional tributaries of Saginaw Bay for which there is very little historical water quality data. The tributaries included were the Au Gres River, the Kawkalin River, and the Rifle River. Hydrological models indicate that these ‘unmonitored tribs’ could account for approximately 15% of the nutrient load to the Bay. We conducted bi-weekly sampling of the tributaries from April through August. Samples were analyzed for TSM, TP, SRP, NO3, NH4, CHL, POC and PON. Data will be used to confirm flow concentration relationships for these streams and help validate prior assumptions of their contribution to overall loads to the Bay.

  Two detailed rainfall-event sampling time-series were conducted on the Rifle River. Sampling intensity was increased to frequencies of 4-6 over a 3-4 day time period.
covering the rise and fall of discharge in response to the event. The data will be used to assist in the calibration of the nutrient transport component to the DLRBM model for the whole watershed.

We participated with Limno Tech and the State of Michigan DEQ in an additional water chemistry survey of the Saginaw River. The goal of this study was to examine potential differences and bias in sampling sites used for the present study compared to typical sampling site used by the State. Specifically, the project sampling site was located just upstream of two wastewater treatment plant input sites and we were interested in quantifying the impact of these contributions on observed nutrient concentrations. Samples were collected from both sites within an hour of each other on five occasions and brought to the GLERL lab for processing and analysis. A general conclusion was that there was a significant increase in the soluble phosphorus and ammonium concentrations at the downstream DEQ site relative to the project site. Differences in TP and TSM were not significant.

- Sediment-Nutrient Interaction Studies
  Objectives included:
  - Assess the carbon and nutrient content of the sediments as well as general porosity and bulk density.
  - Quantify internal loading factors of Phosphorus under aerobic and anaerobic conditions.
  - Examine the influence of Dreissena excretion on sediment nutrient fluxes under aerobic and anaerobic conditions.
  - Identify most “hot spots” of P recycling in Saginaw Bay.
  - Internal loading of P from sediments in Saginaw Bay is correlated with anoxic/hypoxic conditions.
  - Majority of P returning from sediments occurs in sediment type observed at Site 10.

- Mussel nutrient processing experiments
  The over-arching question for this component of the project is: How do dreissenid mussels affect phosphorus (P) availability? To answer this question we have established the following goals:
  - determine phosphate and ammonia excretion rates by dreissenids as a function of seston composition, feeding rate, and temperature
  - estimate the amount of P and N that dreissenids biodeposit each in feces and in pseudofeces as a function of seston composition, feeding rate and temperature
• determine amount of P sequestered by incorporation in dreissenid tissue and shells.
• observe physical binding and breakdown and of feces and pseudofeces in the presence and absence of bay water and sediments.
• evaluate the availability of the P in feces and pseudofeces

We have been working on experimental approaches for conducting detailed nutrient mass-balanced experiments on filtering, assimilation, excretion and egesting rates. We are attempting to mass balance the energy flow in terms of both carbon and phosphorus. An additional component of these experiments will be to examine the nutrient availability of the produced feces and pseudofeces using simple remineralization experiments and conversion to soluble phosphorus.

Throughout the winter we conducted pilot experiments using lab-maintained mussels and algal cultures maintained in a high-P and low-P growth condition to assess the impact of differences in nutrient stoichiometry within the food source. A great many details had to be worked out to make these difficult experiments repeatable and produce measureable quantities of biodeposits of the kind we were looking for. We know from prior work on natural seston from ecosystems of different trophic status the rates of feeding and excretion is highly impacted. Understanding the drivers and variability in nutrient processing by mussels is key for applying these mechanisms in the updated water quality/food-web model. The laboratory experiments with cultured algae are intended to examine a range of food quality and P concentration in seston we may not observe in the few experiments we plan to carry out with natural seston.

• Hydrodynamic Modeling
Lake-wide 3D hydrodynamic model of Lake Huron was run for 1995, 1996, and 2008 on a 2 km grid. Modeled currents were saved hourly in order to validate circulation in the water quality model.

  3D nested grid modeling system for inner bay of the Saginaw Bay was developed, tested, and transferred for operations at GLERL. The model became operational since then, real-time results are available at: www.glerl.noaa.gov/res/glcsfs/sb.

Current and temperature measurements were collected by Nathan Hawley for hydrodynamic model validation.

We deployed a shallow-water vertical current profiler near the Bay City Recreation
area for approximately six weeks to obtain model verification data in the near shore area.

• Process-Based Modeling
SAGEM2 is currently being initially calibrated and applied in a diagnostic mode using data from Saginaw Bay collected by GLERL during the 1991-1996 time period. This application has been used to inform field and process research being conducted on the system during 2008-2010 through the AIF process being developed through this multi-stressor project. The model will then be fully calibrated with project data and applied to assess the relative contributions of multiple stressors (e.g., nutrients, sediments, hydrology and water levels, wind effects on circulation and sediment resuspension) to the ecosystem endpoints of concern and to make predictions of how the system will respond to a range of alternative management actions (e.g., watershed sediment and nutrient load reductions).
An additional refinement to SAGEM2 that may be necessary is the addition of a non-attached benthic alga (Spirogyra), depending on the results of this summer’s field work. We are also working with the upper food web modeling group to link SAGEM2 to an IBM fish model being developed for the system.

• Bayesian Network Modeling
A model to estimate annual TP loads and the associated uncertainty from the Saginaw River was developed. The paper detailing this work is currently in press in the journal Water Research.
  • The results of this model indicate that the Saginaw River alone rarely meets the Great Lakes Water Quality Agreement target TP load established for the whole Bay.
A model to estimate TP dynamics in the inner Bay is currently in development.

• 2010 Field Survey began in April – will continue into October.

Publications


Presentations


Project Title: Development of GIS Databases for Integrated Ecosystem Assessments of Great Lakes Aquatic Resources

Principal Investigators: Ed Rutherford, GLERL

Overview and Objectives

NOAA’s coastal and marine resources program and fisheries habitat programs require inventory and mapping of coastal habitats in order to develop management plans and policies to protect Great Lakes resources from anthropogenic stressors. A priority research area for NOAA’s ecosystems observations program is to generate and manage data and information necessary for conducting Integrated Ecosystem Assessments (IEAs) and risk analyses. An IEA is a comprehensive account of an ecosystem’s condition, stressors, and drivers, and the potential for change in response to management options. A Geographic Information System (GIS) database for Great Lakes aquatic habitats will facilitate development of IEAs and aid managers to assess threats to coastal resources and understand ecosystem structure and function. This project will incorporate available NOAA data layers on Great Lakes aquatic ecosystems to improve an existing Great Lakes habitat database, the Great Lakes GIS project (www.glfc.org/glgis). Physical habitats will be mapped and their suitability determined for key Great Lakes species. Workshops will be held with stakeholders to identify needs and information gaps for a Great Lakes Integrated Ecosystem Assessment. The GIS project will serve as a foundation for Integrated Ecosystem Assessments (IEA) and improved coordination between federal and state action agencies and ocean energy and transportation industries. The project will support extension and educational efforts to provide scientific information in advance of actions and regulations, and will assist NOAA in fostering increased understanding and partnerships among fishers, conservation and environmental groups, coastal use community, and scientists.

Objectives: (1) Refine and enhance existing landscape-scale, relational GIS databases for Great Lakes aquatic habitats to include the wealth of data collected by NOAA GLERL on physical and biological data. (2) Generate ecological habitat classifications and measures of habitat quality for selected species. (3) Develop decision support projects for coastal habitat management to help identify potential impacts of proposed lakebed alterations and coastal development (e.g., dredging, shoreline hardening, marina construction, windmill sitings) and dam removals on aquatic species and their habitats. (4) Conduct regional workshops to identify information needs and gaps missing in an Integrated Ecological Assessment of anthropogenic stressors on
coastal habitats for the Great Lakes. (5) Educate end users on database use, and develop an effective means of distributing the Great Lakes GIS databases via the Internet.

**Accomplishments**

**Objective 1:** additional data sets on bird and bat migration routes were added to the decision support tool this past year. Data from GLERL’s IFYLE cruises in 2005 and 2007 were added to the Lake Erie GIS project. A workshop was held to discuss use of the Lake Erie GIS databases for quantifying adult walleye habitat in Lake Erie. Efforts were made to secure funding to update databases on fish spawning and nursery locations throughout the Great Lakes. Discussions were held with George Leshkevich of NOAA GLERL about incorporating remotely sensed data into the lakebed tool.

**Objective 2** Ecological classifications of Great Lakes habitats are ongoing. Data were obtained from Steve Lozano of NOAA GLERL on Lake Superior and Lake Ontario substrate composition, and on Dreissenid and Diporeia densities to improve the classification.

**Objective 3** An existing decision support project to evaluate lakebed alterations was enhanced through programming of user-friendly pull-down menus and toolbars, and addition of several datasets (see Obj. 1).

**Objective 4** A regional workshop was held March 15, 2010 in Ann Arbor to identify additional information needs to improve the lakebed alteration DST.

**Objective 5** A workshop was held March 15, 2010 at University of Michigan to train stakeholders how to use the lakebed alteration decision support tool.

**Publications**

None to date.

**Presentations**

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.
Overview and Objectives

To ensure the development of useful and timely research, tools and technology, involving stakeholders in determining research priorities is essential. The NOAA Center of Excellence for Great Lakes and Human Health (CEGLHH) uses a multidisciplinary approach to translate scientific information and research into materials to aid health officials, local governments, and communities in making sound environmental decisions. In order to translate scientific materials into a concise, easily understood format and identify community needs, outreach is critical. Using Michigan Sea Grant as a model, 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.

Accomplishments

Ottawa County Volunteer Harmful Algal Bloom Sampling Program
Building on the increased education and knowledge of HABs in western Michigan and public interest in summer of 2008 weekly Harmful Algal Bloom lakewide monitoring of two Muskegon County inland lakes that are tributaries of Lake Michigan, Sonia Joseph Joshi launched a summer volunteer monitoring program for HABs in Lake Macatawa and Spring Lake in western Michigan during Summer 2009. Joseph Joshi partnered with CORE and the Macatawa Area Coordinating Council to identify volunteers to collect samples. Joseph Joshi conducted a half day training session for volunteers in water sample collection, and volunteers collected weekly samples at 8 locations for 11 weeks. Summer interns based at GLERL were responsible for processing and analyzing samples for the toxin Microcystin. Sample results from the weekly monitoring program were posted on the CEGLHH HAB Event Response Website: http://www.glerl.noaa.gov/res/Centers/HABS/index.html as well as any necessary websites in Ottawa County. Joseph Joshi worked with Adam London from the Ottawa County Health Department to create a notification letter to be shared throughout Ottawa County on the Volunteer Sampling Program. CEGLHH scientists were also
involved in this educational initiative as it provided background information on HABs in Lake Michigan tributaries and assistance to the Ottawa County Health department on decision-making. CEGLHH scientists found this program so beneficial that they would like to repeat it in 2010.

Activities:
~ Developed a summer volunteer sampling program
~ Training for volunteers
~ Product: Notification letter for Ottawa County
~ Partnered with two local volunteer organizations
~ Facilitated a partnership between NOAA, Michigan Sea Grant/ Michigan State University, and Ottawa County Health Department

Lake Erie Experimental Harmful Algal Bloom Forecast Bulletin: Assisting NOAA in Validating the First HAB Forecast in the Great Lakes while Strengthening Partnerships in Ohio

During the entire summer of 2009, the NOAA Lake Erie Experimental Harmful Algal Bloom Forecast Bulletin was released on a weekly basis providing nowcasts and 48 hour forecasts of *Microcystis* blooms in western Lake Erie. Joseph Joshi shared this Bulletin weekly with approximately 40 stakeholders in western Lake Erie/ Ohio area (activity). The stakeholders provided ‘ground-truthing’ information for us to determine the accuracy of the experimental forecast in predicting *Microcystis* blooms in specific locations in western Lake Erie. To further increase education on the the Forecast Bulletin, Joseph Joshi partnered with NOAA Public Affairs to draft a press release in September 2009 and worked hosted a “Media Call-In” hour (activity of working with media) for newspaper reporters to call in and ask questions/ speak about the Experimental HAB Forecast Bulletin. Joseph Joshi partnered with two NOAA scientists to participate in the Media Call-In and field questions/ provide scientific details on the development of the forecast as well as information on western Lake Erie harmful algal blooms. The Media Call-In generated several newspaper articles throughout the Great Lakes. Joseph Joshi was interviewed by CBC Windsor, Canada on September 18, 2009. There were several news stories from Associate Press throughout the US.
~ Associated Press, by John Flesher
(Article picked up by Chicago Tribune, New York Newsday, Detroit News, and Chippewa Herald)
forecasts-1.1455936

~ Cleveland Plain Dealer, by Michael Scott

~ Michigan Public Radio
Transcript: "Federal scientists have developed a system for forecasting the location and intensity of harmful algal blooms on the Great Lakes. The National Oceanic and Atmospheric Administration released details about the new system today. At first it will focus on Lake Erie, where the problem is the worst -- but the agency hopes to expand the system’s reach across the Great Lakes. Harmful algal blooms produce toxins that can endanger human and animal health. The ugly, smelly scum along beaches has also been found to hurt the tourism economy."

~ Port Clinton News Herald, by James Proffitt
http://www.portclintonnewsherald.com/article/20090921/NEWS01/909210307

~ Detroit Free Press, (Compiled from AP Article)
[Second section contains article]

~ Innovations Magazine, from NOAA Communications Office

Joseph Joshi partnered with the Cuyahoga County Board of Health and hosted a workshop to solicit feedback on the accuracy of the forecast bulletin and ways in which the bulletin could be improved to serve as a more effective tool for water treatment plants in western Lake Erie, this workshop was hosted in January 2010 in Lorain, Ohio as part of the Ohio Lake Erie Beach Conference. There were 51 participants in the workshop and it became very clear that central Lake Erie basin beach managers are not
as educated as western Lake Erie environmental managers are. All participants provided useful information that will be incorporated into the 2010 summer bulletins to assist in further ‘ground truthing’ of the forecast model.

Activities:
~ Facilitate information transfer between NOAA and Lake Erie end users (Ohio drinking water utilities and beach managers)
~ Ohio workshop: needs assessment/ feedback on NOAA product
~ Worked with media to develop a “Media Call-In” event
~ Partnerships with the Cuyahoga County Board of Health and the western Lake Erie Water Treatment Plant group (comprised of 38 water treatment plant operators in Ohio)

Ottawa County Water Quality Forum
Joseph Joshi continued to work with Al Vandenberg, Ottawa County Administrator and Michigan Sea Grant colleagues Dan O’Keefe, and Chuck Pistis to organize Ottawa County’s Fourth Water Quality Forum on October 26, 2009. With close to 100 participating in this year’s Forum, the full day program garnered interest from environmental health and county officials from throughout western and mid-Michigan to discuss and learn about water quality issues affecting the Grand River and Lake Michigan.

Publications


Presentations


May 7, 2009. “Great Lakes and Your Health.” Presentation at the Rouge River Water Festival in Dearborm, MI. 5th grade classrooms from all throughout the metro-Detroit area come to the festival to hear 30 minute presentations on water quality related topics.
May 19, 2009. “Great Lakes and Human Health: Communicating Water Quality “. Presentation at the International Association for Great Lakes Research Annual Meeting in Toledo, OH.

May 21, 2009. “Harmful Algal Blooms in the Great Lakes “. Presentation to the Michigan Association of Local Environmental Health Administrators in Okemos, MI.


November 9, 2009. “Partnering with tribal governments: Communicating seafood and drinking water health risks, beach quality forecasting, and harmful algal bloom research in the Great Lakes” Presentation at the American Public Health Association meeting in Philadelphia, PA.
PROJECT TITLE: REGIONAL CLIMATE CHANGE IN THE GREAT LAKES WEBINAR AND EVALUATION

Prinicpal Investigators: Brent Lofgren, GLERL

Overview and Objectives

This project was part of the effort for the mini-grant awarded to NOAA’s Great Lakes Regional Collaboration Team for climate change education. The main objectives were to improve the ability of all NOAA employees in the region to speak intelligently about climate change and be effective in conveying this information to the public. CILER’s portion of this project was carried out by student research assistant John Cawood, mentored by Brent Lofgren.

Accomplishments

John Cawood carried out an extensive literature review and prepared an annotated bibliography of publications regarding climate change impacts in the Great Lakes region.

The project culminated in the presentation of a webinar regarding the science of climate change and its impacts to all of the NOAA employees in the Great Lakes region who wished to participate. John played a large role in the preparation of the presentation for this, as well as providing extensive logistical and technical assistance, including setting up the site for the webinar, registering participants, and monitoring and relaying questions during the live webinar.

There was also a follow-up webinar regarding communication of climate science information to public audiences. Although this webinar was entirely prepared and presented by Susan Buhr, John again played a large logistical and technical role.

Publications


Presentations
Project Title: CILER Administration Partners for Excellence High School Intern Summer Program

Principal Investigators: Thomas Nalepa, GLERL  
Allen Burton, CILER

Overview and Objectives

As part of a partnership with the Science Department of the Ann Arbor Public Schools, the Great Lakes Environmental Research Laboratory (GLERL), in conjunction with the Cooperative Institute for Limnology and Ecosystems Research Institute, University of Michigan (CILER), sponsor 2-4 high school interns to work at GLERL for the summer. All applicants go through a preliminary selection process by the school system and final selections are made after interviews by GLERL/CILER staff. Applicants must compose an essay that conveys their interest in the internship, and their experience and qualifications. In addition, applicants must be recommended by their science teachers. Each intern is assigned to a GLERL/CILER scientist who is responsible for defining specific tasks and duties. The intern performs routine research tasks that may include laboratory set-up, experiment preparation, data analysis, data coding, and computer input.

Accomplishments

Two interns were selected for summer 2009. One intern worked on a project with Tom Nalepa (GLERL), and the other worked with Donna Kashian (CILER). The former involved measuring mussels from Lake Michigan to generate size-frequency distributions, while the latter involved processing sediment samples for the collection of zooplankton ephippial eggs.

Publications

None

Presentations

None
APPENDIX 1: Publication count.

<table>
<thead>
<tr>
<th></th>
<th>CILER Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer Reviewed</td>
<td>16</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>7</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CILER Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer Reviewed</td>
<td>10</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>10</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CILER Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer Reviewed</td>
<td>19</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Non-Peer Reviewed</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>17</td>
<td>0</td>
</tr>
</tbody>
</table>
APPENDIX 2: Employee Count by category from FY2007 to FY2009, by year.

Summary of Joint Institute Staff by Head Count 2009-2010 (Includes subcontracts)

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>B.S.</th>
<th>M.S.</th>
<th>Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research Scientists</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Visiting Scientists</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Postdoctoral Research Fellows</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>Research Support Staff</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Administrative</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>High School Students</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Undergraduate Students</td>
<td>38</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>28</td>
<td>0</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>146</td>
<td>22</td>
<td>40</td>
<td>44</td>
</tr>
<tr>
<td>Located at NOAA Lab</td>
<td>52-GLERL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obtained NOAA employment</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>