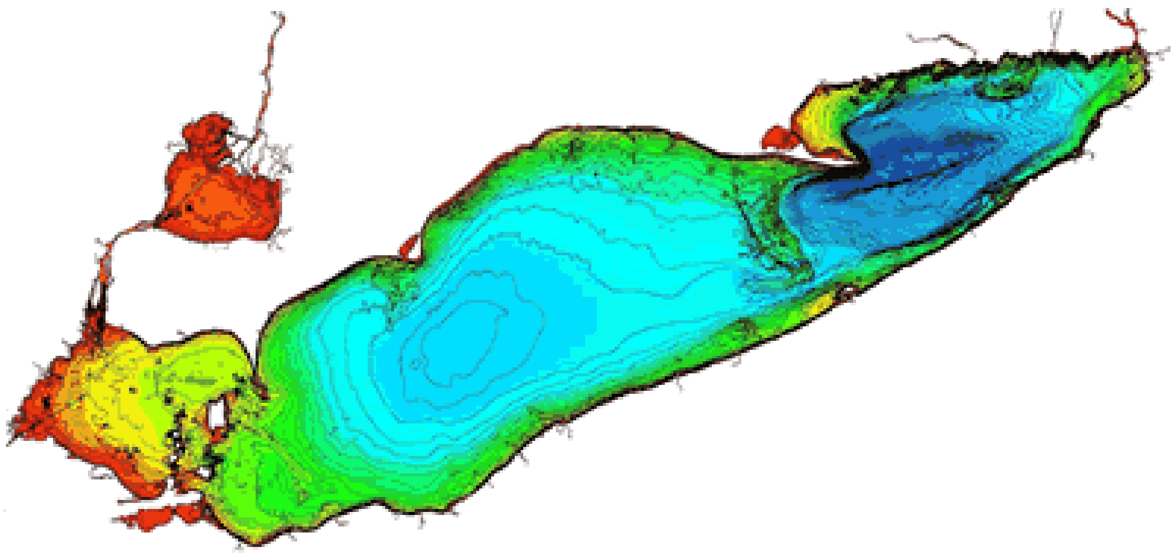
Lake Erie Research Planning Workshop

March 4-5, 2004
GLERL/NOAA Ann Arbor, MI



Workshop Organizers:

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Lake Erie Research Planning Workshop Report

Introduction

A report from the Presidents Committee on Environmental and Natural Resources on ecological forecasting (CENR, 2001) stressed the nation's need for developing forecasts of ecological change. To meet this need, NOAA has proposed development of an Ecological Forecasting Service for coastal managers (NOAA, 2003), which would formalize partnerships among all NOAA line offices, universities, and other federal agencies. Both documents identify the widespread societal and economic value that such ecological forecasts could provide to the country, including 1) improved decision-making for coastal stewardship, 2) mitigation of potentially hazardous human activities, 3) reduced impacts of natural hazards, 4) enhanced communication between scientists and managers, and overall, 5) more effective prioritization of science, particularly across disciplines.

The long-term goal of these efforts is to produce improved and enhanced ecosystem forecasts (both ecological and environmental) that would benefit coastal communities, including the Great Lakes. Some environmental forecasting already exists (e.g. Great Lakes Forecast System - http://coastwatch.glerl.noaa.gov/) providing forecasts of lake thermal structure, wind fields, and waves. Enhanced ecosystem forecasts would predict patterns of biological and chemical variables as well as natural and human-induced changes (extreme natural events, climate change, land and resource use, pollution, invasive species, fisheries impacts and interactive effects) to the system across a variety of spatial and temporal scales (Figure 1).

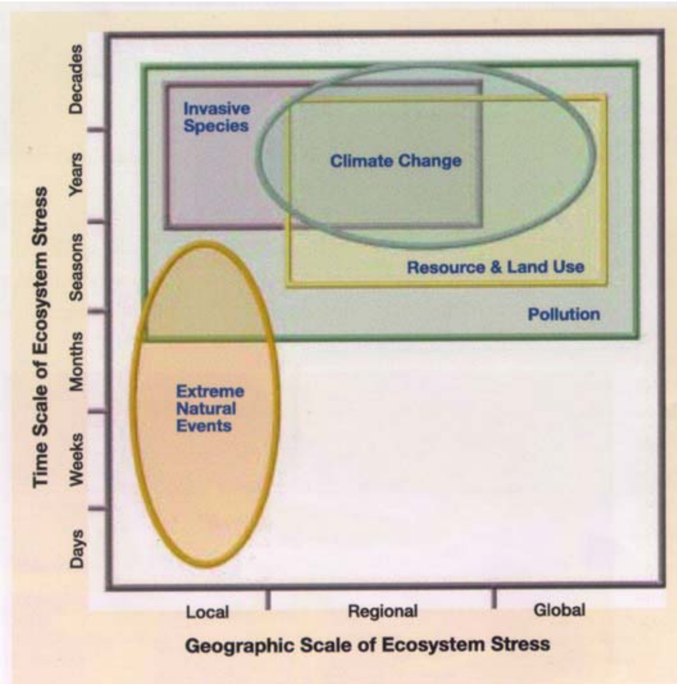

Figure 1. Time and space scales affected by five identified causes of ecosystem change (CENR 2001). In the Great Lakes, all of these perturbations interact in complex ways.

Great Lakes Forecasting

It is now well recognized that continued and new water quality and ecosystem health issues persist within the Great Lakes that are of concern to the user community and researchers, and which remain a challenge to Great Lakes resource management. Clearly, development of systems to provide reliable forecasts of the Great Lakes ecosystem and/or modular components of chemical, biological, or physical subsystems would help resource agencies choose among potential management options. Improved hydrodynamic models are already providing reliable information on lake circulation, transport of nutrients, and system-wide thermal structure in these coastal systems. Improved understanding of how these ecosystems work, including fundamental changes in nutrient dynamics and food webs, the importance of episodic events, and land-lake coupling need to be incorporated into a next generation of lake management tools.

To develop reliable forecasts of ecological changes, we need to:

1) increase understanding of ecosystem composition, structure, and functioning;

2) expand ecosystem monitoring and apply advanced scientific information to make these complex data widely available; and

3) develop and improve forecast and interpretative tools that use a scientific basis to assess the results of management and science policy actions (CENR, 2001).

The Great Lakes region is ideal for conducting ecosystem-forecasting research for several reasons. First, these systems continue to experience numerous anthropogenic perturbations, including overfishing, land-use changes, eutrophication and subsequent oligotrophication, and exotic species invasions (Smith 1972, Makarewicz and Bertram, 1991; Mills et al., 1993). Second, the Great Lakes have an economically important user base, who have needs for predicting impacts of excess nutrient loads, anoxia, microbial contamination, harmful algal blooms, invasive species, and extreme natural events (e.g., storms, water level change). Third, this region has pioneered novel management strategies that have provided a testing ground for new science and management. For example, the Great Lakes region led the nation in developing successful nutrient control and contaminant cleanup strategies during the 1970s (DePinto et al., 1986), and more recently, has agreed to adopt ecosystem-based approaches for the management of its fisheries (Great Lakes Fishery Commission, 2001). Finally, the Great Lakes region has a long history of interagency partnerships in monitoring/assessment and research, which has led to an extensive accumulation of physical, chemical, and biological data, and predictive models.

To improve our ability to provide reliable ecosystem forecasts in the Great Lakes, NOAA's Great Lakes Environmental Research Laboratory (GLERL) has been working toward development of an integrated (multi-agency), multidisciplinary research program for Lake Erie (GLERL, 2003). Four attributes make Lake Erie ideal for piloting the development of an ecosystem-forecasting framework. First, although Lake Erie is a large system, it is small relative to other coastal marine systems and the other Great Lakes. In turn, comprehensive, yet cost-effective, field sampling can be performed to test hypotheses (i.e., tractable questions can be asked). Second, a wealth of historical monitoring and research data has been compiled for this system, which can be used immediately for model parameterization/calibration, validation, and ecological scenario testing. Third, several predictive physical and biological models exist for Lake Erie (Maumee River watershed-hydrology model, Croley, 2002; Lake Erie hydrodynamics model; Schwab and Beletsky, 1998), or are ready to be tailored to Lake Erie (lower trophic level model; Bierman et al. in review). Finally, Lake Erie has experienced a wide array of simultaneous anthropogenic stresses, including habitat destruction, overfishing, altered nutrient regimes (both eutrophication and oligotrophication), chemical pollution, and invasive species introductions.

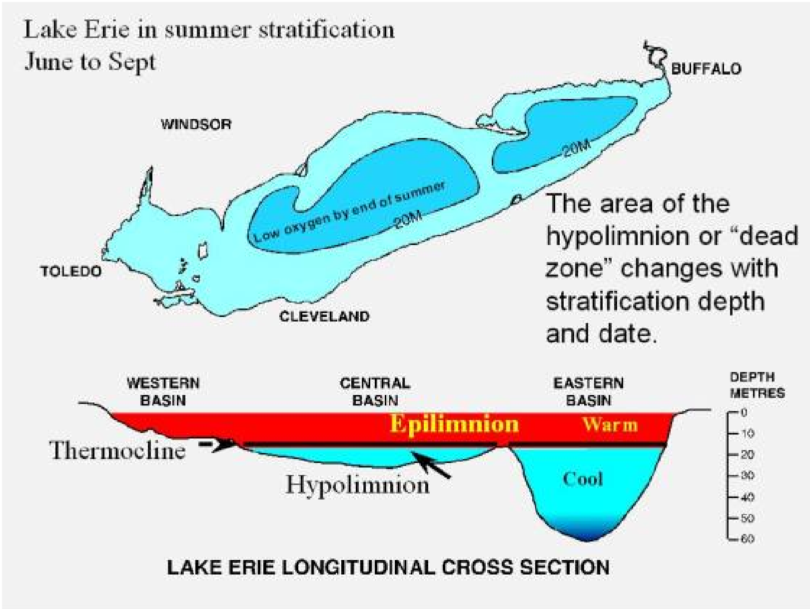

Figure 2. Lake Erie during summer stratification. The blue region in the central basin corresponds to the region of seasonal hypoxia. Figure from Murray Charlton.

As a major step in developing this Lake Erie program, GLERL hosted this large (over 50 attendees, Appendix 1), international workshop on March 4-5, 2004 (agenda, Appendix 2) to identify and discuss three important Lake Erie issues that GLERL scientists thought were within the existing capabilities of the laboratory: 1) anoxia and hypoxia, 2) harmful algal blooms (HABs), and 3) coupling physics with fish forecasts.

This workshop also provided an opportunity:

- ✓ for GLERL scientists to learn about ongoing programs by U.S. and Canadian agencies and academics,
- ✓ to discuss facilitation of communication and collaboration among GLERL and the other, ongoing research programs in Lake Erie, and
- ✓ for improving the focus and approach of GLERL’s Lake Erie coordinated research program whose long-term goal is the development of models and other tools to better understand and forecast changes in the Lake Erie ecosystem.

At the workshop, invited presentations were given by five major Lake Erie research agencies summarizing their ongoing or planned Lake Erie research programs (Appendix 3). These were followed by an invited summary presentation on each of the three focus issues (Appendix 3). Subsequently, attendees were divided into three workgroups (Anoxia and hypoxia, Harmful algal blooms (HABs), and Fish recruitment) in order to:

- ✓ identify research hypotheses for the issues,
- ✓ identify the critical processes,
- ✓ identify ongoing and planned activities, and
- ✓ identify potential contributions from GLERL areas of interest, including
    - o Hydrology: land-use modeling, hydrologic modeling
    - o Hydrodynamics: current and wave modeling
    - o In-situ observation systems: meteorological data, currents and waves, biosensors
    - o Ice
    - o Sediment: accumulation, resuspension, and sediment-water exchange
    - o Carbon and nutrient cycling
    - o Ecology: lower food web, benthic, and fisheries
    - o Remote sensing

Several areas of potential and immediate collaboration were identified and mechanisms to implement them were initiated. Summary workgroup reports are included in this document (Appendix 4-6)

Background Information on Focus Issues

Issue: Hypoxia and anoxia

Hypoxia is generally defined as 2 mg O_2/L and is considered stressful for all organisms, however concentrations below 4 mg O_2/L are stressful for most species of fish. Anoxia is defined as the absence of oxygen, not only deadly for all biota, but a condition that initiates different microbial and geochemical reactions, the most pernicious is the release of phosphorus from the large inventories in the sediments. Restoration of year-round aerobic conditions in the bottom waters of the central basin was one of the goals of the 1972 GLWQA.

The central basin hypolimnion of Lake Erie generally exhibits hypoxia, and occasionally anoxia, at the end of the summer. Near-equilibrium saturation of O_2 (13 mg O_2/L) occurs during the late winter – early spring when vigorous mixing occurs within the isothermal water column (Wetzel, 2001). Isolation of the hypolimnion to reaeration occurs as thermal stratification becomes established. The reservoir of O_2 within the hypolimnion begins to be consumed during the decomposition of settling and sedimentary organic matter. Resultant O_2 concentrations are directly related to the volume of the hypolimnion (the inventory of O_2 available) and inversely related to the amount of organic material available for decomposition.

Binational phosphorus reduction strategies designed to achieve this end were based on modeling. Although state-of-the-art at the time, the models used in the 1970s to set nutrient input levels were relatively simple by present standards. Even so, they proved successful in forecasting lake response to phosphorus abatement into the early 1990s, although incidences of hypoxia and anoxia have continued with some interannual variability (Charlton and Milne, 2004). There is a strong argument to be made that low dissolved oxygen levels in the central basin, however, are primarily due to Lake Erie's bathymetry (Figure 2). Specifically, summer thermal stratification results in a hypolimnion that is only a few meters thick with a low reservoir of oxygen. In turn, interannual variability in oxygen levels in the shallow hypolimnion can be influenced by anything that affects the thermal structure (i.e., warm winters, early or late spring warm-ups, intense spring storms, lake level fluctuations, etc,), as well as changes in the food web, productivity, and nutrients. A cause of current concern is that recent data imply that lake phosphorus concentrations are increasing from the low values in the early 1990s (Figure 3).

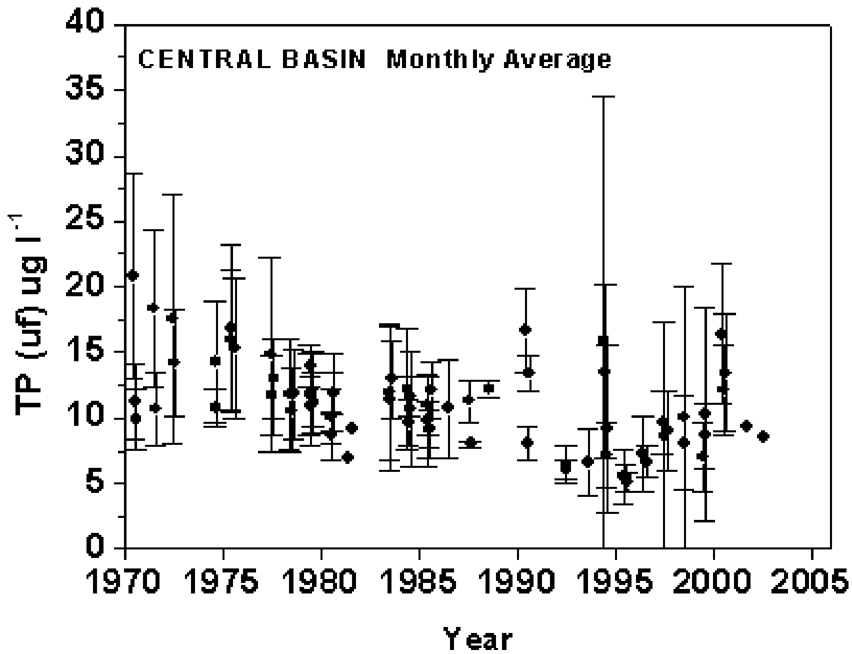

Figure 3. Lake Erie central basin total Phosphorus concentration. Data from Charlton and Milne, 2004.

Issue: Harmful algal blooms (HABs)

During the past 15 years, the rate of species invasion into the Great Lakes has accelerated with substantial impacts on food webs and cycling of nutrients (Mills et al. 1993, Vanderploeg et al. 2002). The benthic food web and associated processes are very different from the 1980s and earlier. The most obvious example of these changes resulted from the introduction of zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*, respectively) in the late 1980s. This new component of the food web fundamentally altered energy transfer and nutrient cycling in the lakes and has been identified as a primary cause of the appearance of hazardous algal blooms (Vanderploeg et al. 2001).

The importance of HABs in Lake Erie has fluctuated. During the 1960s and 1970s, the massive blooms (and subsequent die offs) of filamentous algae (primarily *Cladophora*), stemming from cultural eutrophication, were viewed as a critical issue, especially to beachfront property owners. By contrast, during the 1980s and much of the early 1990s, the importance of HABs as an issue diminished, likely owing to phosphorus abatement programs that limited blue-green algae production. Interestingly, HABs have once again become a very important issue in the lower Great Lakes in recent years, including western Lake Erie. In particular, the cyanobacterium now involved, *Microcystis*, is much more toxic than *Cladophora*, and has demonstrated the potential to jeopardize human health and drinking water quality.

Currently, there are projects focused on understanding the role of allochthonous nutrient inputs and exotic dreissenid mussels in causing the recent occurrence of HABs in areas such as western Lake Erie. In addition, different strains of toxins in Great Lakes cyanobacteria are much more toxic than others; thus a low abundance of cyanobacteria that is highly toxic could be equally as "threatening" as a high abundance of cyanobacteria that is of low toxicity. Hence, understanding factors that control the magnitude and timing of HABs in aquatic systems is critical, especially if we hope to begin to forecast HABs.

Issue: Fish and Physics

The objectives of Lake Erie fisheries management agencies have been developed over many years and are outlined in *Fish-community Goals and Objectives for Lake Erie* (see www.glfc.org). Although the list of objectives is both diverse and lengthy, among the major Lake Erie issues of concern identified by workgroup participants, which included Lake Erie resource managers, are recent trends in the ecologically and economically important walleye (*Sander vitreus*) and yellow perch (*Perca flavescens*) fisheries (i.e., both have been fluctuating unpredictably). Essentially, Lake Erie fishery management agencies desire an ability to reliably forecast future recruitment of these species, both in the short- and long-term.

One potential weakness of the current forecasting strategies for these species is that they lack consideration of physical processes. In large part, this is due to an insufficient understanding of how physical processes, both internal (water levels, lake circulation) and external (climate, watershed-borne river inputs) to the system, influence growth and survival of these species, and hence future fisheries production. As such, a major goal of GLERL's workshop was to begin to set the foundation to allow for the coupling of physical processes with forecasts of fish production.

The need for such linkages between physical components of the ecosystem and fisheries production was made obvious by long-term limnological data collected by the Ohio Department of Natural Resources-Division of Wildlife and the Ontario Ministry of Natural Resources. Specifically, data were provided to suggest that predictable "water masses" occur in western Lake Erie (Figure 4), which appear to derive from discharge from individual rivers (or a mixing of river plumes). These water masses appear to have unique characteristics, both physical (e.g., temperature, water clarity, and dissolved oxygen) and biological (e.g., zooplankton) that are recurrent on an annual basis. In turn, it was speculated that the different habitat qualities of these water masses would differentially support fish production (biomass and growth).

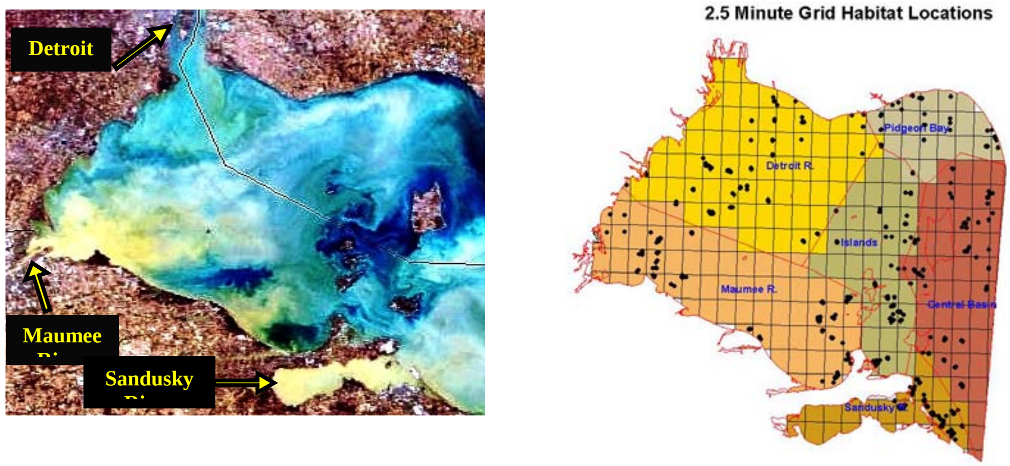

Figure 4. Figure 4. Satellite image of the complex mixing of river and lake waters in western basin (NOAA CoastWatch image from March 21, 2003). Measured limnological data (e.g., water temperature, dissolved oxygen, and water clarity) were used in cluster analyses to identify predictable habitat zones that could influence biological production **(**J. Tyson, ODNR-DOW, unpub. data). There is a striking correspondence to the instantaneous satellite image.

Development of coupled physical-biological-chemical models that could describe the timing, magnitude, and persistence of these water masses would be of value to fisheries management because these models could allow agencies to begin to explain spatial variation in fish growth and habitat use. Current data also point toward the need for understanding linkages between watershed land use and aquatic habitat (water mass development), given that allochthonous inputs from the watershed appear critical to driving physical, chemical, and likely biological conditions in Lake Erie.

<u>Summary of Workshop Recommendations - (for details, see Appendices)</u>

General

1. The need for collaboration and coordination among agencies is critical. Efforts to build useful forecasting models will fail in the absence of inter-disciplinary approaches. Efforts aimed at maximizing integration, collaboration should be supported.

2. Improve 3D circulation and wave models for Lake Erie. Higher nearshore resolution is required for the HABs and fisheries issues, accurate thermal structure in the central basin is required for DO depletion forecasting.

3. Support efforts to improve remote sensing algorithms. Remote sensing critical to all components, and vital to circulation model validation

4. Encourage the development of a user-friendly database that would provide general access to the large inventory of historical data.

5. Support the synthesis of existing Lake Erie data.

6. Continued efforts to bring scientists from multiple disciplines together to focus on specific issues… develop the framework for forecasting.

7. Support an annual meeting to coordinate sampling among agencies/scientists. This way, redundancy can be reduced and we could maximize information collected (ships might have room for additional researchers).

Issue Specific: Anoxia and Hypoxia

1. Support rerunning older ecosystem models, updated to include the effects of dressenids

2. Estimate the level of P loading needed to achieve acceptable DO levels (>4 mg/L) in the central basin

3. Run ecosystem models with that P load to provide a first estimate of other consequences caused by the further P reduction

4. Design sampling (e.g., remotely deployed sensor arrays) and modeling strategy (e.g., hindcasting thermal structure) to determine whether DO depletion is stable, growing, or shrinking.

5. Support work on the overall impact of dressenids on DO depletion

6. Support work on populations and distributions of dressenids and their role in the cycling of carbon and nutrients

7. Support measurements of settling and accumulation rates of organic matter for the whole lake

8. Verify that current estimate of phosphorus and organic carbon loads from tributaries, particularly the Detroit River, are accurate.

9. Attempt to quantify the ecological consequences of central basin hypoxia

Issue Specific: Hazardous Algal Blooms

1. Support efforts to quantify the relative roles of dressenids and phosphorus in *Microcystis* production.

2. Identify the species composition of HABs blooms and the toxicity associated with each species

3. Explore the growth, transport and decay of HABs blooms (community structure, spatial extent, duration)

4. Identify the conditions conducive to HABs bloom initiation and develop an early forecast product

5. Support specific algorithm development for HABs tracking by satellite

6. Demonstrate operational bloom detection and prediction system coupled with GLERL's Great Lakes Coastal Forecasting System.

Issue Specific: Coupling Fish and Physics

1. Support development of a coupled physical-biological model, which will initially predict water mass characteristics (i.e., fish habitat), and eventually could be used to forecast fish distributions and growth.

2. Use historical data (satellite, shipboard) to define attributes, transport, and persistence of water masses in the western basin.

3. Use extant three-dimensional circulation models to also define attributes, transport, and persistence of water masses in the western basin.

Next Steps - Potential GLERL contributions:

- Use historical data to help define attributes, predictability, persistence of water masses (this is interesting question in own right—analogous to fronts in estuarine systems)
    - Great Lakes Forecasting System (Schwab, Bedford)
    - Use it to look for water masses (based on temperature alone)
    - Are water masses definable in spring, based on temp?
    - How transient are the masses?
    - Use GLFS to track water movement through lake
- Daily Remote Sensing (AVHRR) (Leshkevich)
    - Do remotely sensed images agree with GLFS masses?
    - Discrepancies may be due to river discharge effects (not included in GLFS)
    - Use historical discharge data to see if we can explain discrepancies (Croley)
- Limnological data collections (OMNR, ODNR, EPA, CCIW, EC, UT, USGS)
    - Secchi depth, TSS, chlorophyll *a*, oxygen, temperature
    - Use collections during spring to explore water mass persistence and definability
- Dreissenid Condition (Nalepa & Schloesser)
    - Do we see spatial variation in dreissenid condition, which may indicate differences in water masses (temperature, plankton quality)

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Appendix 2. Workshop agenda

Lake Erie Research Planning Workshop

Thursday, March 4

10:00	Welcome – logistics and goals	Brian Eadie
10:15	Program presentation 1: Millennial Group	Jan Ciborowski
10:35	Program presentation 2: CCIW	Murray Charlton
10:55	Program presentation 3: EPA – GLNPO	Paul Horvatin
11:15	Program presentation 4: GL Fish Comm	Allison Niggemeyer
11:35	Program presentation 5: NOAA – GLERL	Dave Schwab
11:55	General discussion	
12:15	Lunch	
1:00	Presentation - HABs issues and status	Gary Fahnenstiel
1:20	Presentation - Hypoxia issues and status	Murray Charlton
1:40	Presentation - Fisheries issues and status	Roger Knight
2:00	Charge to workgroups (below)	
2:15	Workgroup deliberations	
3:30	Break	
5:30	Adjourn	

Friday, March 5

8:00	Plenary – brief workgroup reports on progress/questions
8:30	Reconvene workgroups - continue discussions and draft report
10:30	Break – attendees are welcome to participate in any workgroup
12:30	Lunch
1:30	Workgroup presentations (15 minutes each)
2:15	General discussion
3:00	Adjourn

Appendix 3. Summaries of workshop presentations

Summaries of presentations given by each of the major Lake Erie research groups follow. Click on the bolded link to see view the actual PowerPoint presentation.

Jan Ciborowski, presenter: Lake Erie Millennium Network

This presentation focused on 1) acquainting participants with the history and goals of the Lake Erie Millennium Network, 2) presenting some preliminary findings from the 2001 Millennium Conference, 3) communicating some preliminary results from the collaborative, multidisciplinary EPA-funded Lake Erie Trophic Status project (lead PI: G. Matisoff), and 4) describing planned Millennium Network activities for 2004. Although a wide variety of research topics and results were presented, understanding the roles of stochastic weather events, exotic species (e.g., dreissenid mussels), and the "benthification" of Lake Erie in driving 1) the dearth of pelagic primary production in central and eastern Lake Erie, 2) the recent increase in total water-column phosphorus concentrations without seeming increases in phosphorus loading, 3) the recent reduction in water-column chlorophyll *a* concentrations despite more total available phosphorus, and 4) the continued prevalence of anoxia in the central basin were portrayed as being critical research needs. For this reason, planned 2004 Millennium Network activities will focus on mapping Lake Erie habitat, including watersheds and dreissenid mussels, as well as collecting information (e.g., hypolimnion thickness) to understand what is driving low oxygen events. Additional information about the Lake Erie Millennium Network can be found at http://zeus.uwindsor.ca/erie2001/working.html.

Murray Charlton & Vi Richardson, presenters: Environment Canada (EC), Canadian Centre for Inland Waters (CCIW) and National Water Research Institute (NWRI)

Discussed, were issues most important to NWRI and CCIW researchers, as well as proposed research plans for 2004. A wide array of issues were deemed important to these agencies, including 1) exotic species' effects, 2) fluctuating fisheries, 3) ability to accurately estimate nutrient loading, 3) the occurrence of blue-green algae (HABs), 4) the continued prevalence of anoxic events in the central basin, and 5) contaminants. However, during 2004, these agencies' will focus on collecting information to help understand how allochthonous materials (sediments, nutrients, contaminants) are distributed, and then processed, once deposited on the lake. To do so, rigorous lakewide monitoring of physical, biological, and chemical variables will be conducted during 2004. Ideally, a comparison of 2004 monitoring results with those gathered during earlier decades will help to determine how dreissenid mussels have altered bioavailability, sedimentation rates, retention times, and inter-basin exchange of allochthonous materials. Details on variables to be sampled and sampling schedules (including during future years) can be found in the presentation itself.

Paul Horvatin, presenter: U.S. Environmental Protection Agency (EPA) – Great Lakes National Program Office (GLNPO)

Most of this presentation focused on outlining the various ongoing EPA-GLNPO monitoring programs in the Great Lakes. For Lake Erie, these include 1) lakewide monitoring of water quality variables (biological, physical, and chemical) during spring and summer (1983-present), 2) occasional monitoring of contaminants deposition (ongoing program with EC) and bioaccumulation in fish, 3) annual monitoring of beach water quality and closings, and 4) seasonal (June through September) monitoring of dissolved oxygen levels in the central basin.

In so doing, a few important, recent trends were presented, including a increase in water-column total phosphorus concentrations, a decrease in persistent bioaccumulative toxics (PCBs, OC pesticides, PAHs) in air, precipitation, and fish (although urban levels of PCBs, PAHs, and some pesticides are higher), an increase in beach closings in recent years, and the continued prevalence of anoxia in the central basin despite continued reductions in phosphorus loading relative to the 1970s. Other topics briefly described were the sampling design and goals of the EPA-sponsored Lake Erie Trophic Status project (lead PI: G. Matisoff), an EPA modeling effort to help understand the relative contribution of physical, chemical, and biological factors to the reestablishment of hypoxia in central Lake Erie, and bi-national (U.S. and Canada) monitoring plans for the Great Lakes through 2008.

Allison Niggemeyer, presenter. Great Lakes Fishery Commission (GLFC)

This presentation had three objectives: 1) to describe the history of the bi-national (U.S. and Canada) GLFC, 2) to explain the role of the GLFC in funding fisheries-related research, and 3) to summarize the various ongoing GLFC-sponsored Lake Erie fisheries research programs. In essence, the two primary objectives of the GLFC are to formulate and implement a comprehensive program to eradicate (or minimize) sea lamprey populations in the Great Lakes and (briefly) to advise the governments of Canada and the U.S. on matters relating to sustaining fisheries production in the Great Lakes. In so doing, the GLFC has the duties of sponsoring fisheries-related research, and ensuring that subsequent information is communicated for use by management agencies, policy makers, and the public. The science program itself consists of three research programs (Sea Lamprey Assessment, Fisheries Research, and Restoration Act), which each has unique goals and funding levels (see the presentation itself for further details). However, all funded research projects (regardless of program) ultimately must provide information to help the GLFC achieve the milestones outlined in the *Strategic Vision of the Great Lakes Fishery Commission for the First Decade of the New Millennium*. See the presentation itself for details on ongoing GLFC-sponsored Lake Erie projects, as well as the 13 Lake Erie research objectives.

David Schwab, presenter: National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory (NOAA-GLERL)

The sole focus of this presentation was to briefly acquaint participants with ongoing Lake Erie research projects at NOAA-GLERL, all of which have been funded internally. Overall, there are 13 Lake Erie projects that will be ongoing during CY2004, spanning a diversity of topics, including invasive species, water quality (hypoxia/ anoxia), fisheries, and biological community structure (HABs). Six of these projects began during CY2003, as part of a Lake Erie pilot program. Descriptions of many of these projects can be found at GLERL's Lake Erie website (http://borris.glerl.noaa.gov/res/region/glbasin/erie.html), as well as in Dr. Schwab's presentation.

Synopses of individual presentations explaining the three focal issues—anoxia, harmful algal blooms (HABs), and fisheries—are provided below. Click on the bolded link to see view the actual PowerPoint presentation.

Gary Fahnenstiel (NOAA-GLERL), presenter: HABs issues and status

This presentation provided a brief history of HABs as in issue (both worldwide and in Lake Erie), described a few projects that have begun to explore HABs related issues in the Great Lakes, and provided a few preliminary findings regarding HABs production in western Lake Erie. The details are summarized below.

Production of harmful algal blooms (toxic algae; cyanobacteria in freshwater systems) has been an issue that has caught the public's eye in recent years in both freshwater and marine systems worldwide. Largely, this concern emanates from potential effects that HABS can have on human health, fisheries (shell- and fin-fish) production, marine mammal health, local economies, aquatic system aesthetics, and ecosystem functioning. Hence, understanding factors that control the magnitude and timing of HABs in aquatic systems is critical, especially if we hope to begin to forecast HABs.

The importance of HABs in Lake Erie has fluctuated. During the 1960s and 1970s, the massive blooms (and subsequent die offs) of filamentous blue-green algae (primarily *Cladophora*), stemming from cultural eutrophication, were viewed as a critical issue, especially to beachfront property owners. By contrast, during the 1980s and much of the early 1990s, the importance of HABs as an issue diminished, likely owing to phosphorus abatement programs that limited blue-green algae production. Interestingly, HABs have once again become a very important issue in the lower Great Lakes in recent years, including western Lake Erie. In particular, the cyanobacterium now involved, *Microcystis*, is much more toxic than *Cladophora*, and has demonstrated the potential to jeopardize human health and drinking water quality.

Currently, there are three projects that have begun to explore factors regulating HABs in the Great Lakes, including Lake Erie. In particular, these projects have focused on understanding the role of allochthonous nutrient inputs and exotic dreissenid mussels in causing the recent occurrence of HABs in areas such as western Lake Erie. Although past NOAA-GLERL research has implicated selective-feeding by dreissenid mussels as the cause for recent *Microcystis* outbreaks, preliminary field data collected during 2004 also suggests that episodic inputs of phosphorus from the Maumee River also might be responsible. In addition, ongoing research by Dr. Fahnenstiel has focused on identifying different strains of toxins in Great Lakes cyanobacteria, and the factors that promote one strain over another. Apparently some strains are much more toxic than others; thus a low abundance of cyanobacteria that is highly toxic could be equally as "threatening" as a high abundance of cyanobacteria that is of low toxicity.

Murray Charlton (NWRI, EC): Anoxia/Hypoxia Issues and Status

This presentation provided a context to understand the ever-increasing concern over the continued occurrence of a "dead zone" (area of low oxygen) in central Lake Erie during summer/fall. The Lake Erie "dead zone" is thought to be an artifact of enhanced phosphorus loading (cultural eutrophication) during the 1970s, and was theorized to decline with implementation of nutrient abatement programs. In fact, given the current (post-1990) loading levels of phosphorus into Lake Erie, anoxia/hypoxia should no longer be a problem. This, however, is not the case; recent levels of anoxia/hypoxia are in the range of those observed during the height of eutrophication. Interestingly, Dr. Charlton hypothesizes that the "dead zone" might not be strictly regulated by phosphorus loading effects, but may actually be a "natural" artifact of a shallow hypolimnion in the central basin. Thus, the expectation by scientists (and ultimately the public) that low oxygen events should not occur in Lake Erie might be unrealistic. Regardless, Dr. Charlton's presentation highlights the need to understand what is driving oxygen levels in Lake Erie, because this understanding will guide future expectations regarding the "dead zone", and hence, how the system is managed.

Roger Knight, presenter: Ohio Department of Natural Resources, Division of Wildlife

This presentation provided some background on the Lake Erie fish community, including recent trends in the economically important walleye and yellow perch fisheries (i.e., both have been fluctuating unpredictably), and described several of the objectives of Lake Erie fisheries management agencies, which are outlined in *Fish-community Goals and Objectives for Lake Erie* (see www.glfc.org) and also are outlined in both Roger Knight's and Allison Niggemeyer's presentations. Most importantly, however, this presentation provided a potential research focus that would be value to Lake Erie fisheries management agencies, and of likely interest to the workshop participants. Specifically, data were provided to suggest that predictable, "water masses" occur in western Lake Erie, which appear to derive from discharge from individual rivers (or a mixing of river plumes), and have unique characteristics, both physical (temperature, Secchi depth, and dissolved oxygen) and biological (e.g., zooplankton). In turn, it was speculated that the different habitat qualities of these water masses would differentially support fish (including growth). Ultimately, this presentation hinted that development of coupled physical-biological-chemical models that could describe the timing, magnitude, and persistence of these water masses would be of value to fisheries management because these models could begin to allow agencies to begin to explain spatial variation in fish growth and habitat use. In addition, this presentation pointed toward the need for understanding linkages between watershed land use and aquatic habitat (water mass development), given that allochthonous inputs from the watershed appear critical to driving physical, chemical, and likely biological conditions in Lake Erie.

Appendix 4. Workgroup Report - Anoxia and hypoxia

Anoxia Breakout Group

Participants: Keith Bedford, Bopi Biddanda, Murray Charlton, Jan Ciborowski, Kevin Czajkowski, Joseph DePinto, Brian Eadie, Paul Horvatin, Ora Johannsson, Margaret Lansing, Luis Leon, Steve Lozano, Gerry Matisoff, Peter Richards, Vi Richardson, John Robbins, Steve Ruberg, Ralph Smith

Workgroup Chair: Brian Eadie

A. Spatial and temporal extent of anoxia

<u>Identify key issues</u>
Has the area of hypoxia/anoxia or rate of oxygen depletion increased? If so why?
Central basin hypoxia never went away after nutrient load reductions; is it remediable?
How low does the load need to be in order to achieve elimination of anoxia in central basin?
Would cleanup of tributaries ameliorate anoxia in central basin?
What are the drivers of hypoxic conditions in general? C, N, P ? Are zebra mussels important?
Implications of management activities in terms of the lake hypoxia generation

<u>Needs/Projects</u>
Diagnostic/Sensitivity analysis, work existing models for initial calculations to guide research plans
Look at management implications in terms of the lake hypoxia generation
Go back into models before initiating field program, evaluate data and sampling needs first
Use fine scale hydrodynamic model to hindcast the volume of the hypolimnion
How much of variance in hypolimnetic O_2 is explained by that volume estimation
Can we use models to identify spatial resolution necessary for sampling?
What spatial resolution of BOD, and SOD do the models require in the central in western basins
Model comparison exercise, look at results of different teams, compare performance,
Hindcast the thermal regime as surrogate to determine extent of anoxic area in central basin, validate model first

B. Zebra mussels

<u>Identify key issues</u>
How do zebra mussels alter availability of organic carbon for microbial activity?
Do zebra mussels cause perturbations in the oxygen budget with fluctuations in their population densities?
Do zebra mussels increase or decrease sediment resuspension? Existing models can answer this, Diane Foster Ohio State
Zebra mussel veliger settlement = new sedimentation flux, model implications

<u>Needs/Projects</u>
Estimates of materials zebra mussels are processing; fate of phosphorus and Carbon
Grid initiating: distributions of zebra mussels for models
Characterize dynamics of changing large-scale populations of zebra mussels (see European literature)
Benthic algae – are they an important temporary nutrient sink

C. Sources and characteristics of organic matter and nutrients

<u>Identify key issues</u>

What are the sources of organic carbon? Autotrophic, rivers, recycling, zebra mussel repackaging
Is sewage loading a factor (aging plants, increased flow?)
How labile are these various materials?
Would a carbon mass balance be possible, from existing data?
Can we trace the sources of the organic carbon in the lake?

<u>Needs/Projects</u>

Characterize transport of organic matter and nutrients
Analysis of current tributary inputs
Tracers: CDOM from tributaries across lake, sterols as markers for sewage tracking,
Determine relationship of types of organic matter to oxygen demand
Direct organic carbon measurements? measure BOD in water column, relate to presence of OC, not all C is the same. need data to determine correct approach
Carbon lability: more difficult to measure
Count and size bacteria, DOC
Foodweb structure related to oxygen demand, shifts in LE at end of summer

D. Primary productivity

<u>Identify key issues</u>

How well can we estimate primary production from sporadic ship measurements? (Regions of large gradients confound)
Improved characterization of types of phytoplankton
What spatial and temporal resolution is needed?
Zebra mussels confound (light penetration, temperature regime, thermocline structure

<u>Needs/Projects</u>

Determine the fraction of primary production that settles out
Determine the types of plankton that settle out
Characterize transport of organic matter from tributaries
Measure benthic production in hypolimnion (Hunter Carrick)
Central basin respiration and productivity differs from eastern basin or deep lakes
Need respiration measurements in water column
Measurements of respiratory quotient (often assumed to be 1)

<u>E. Internal Processes</u>

<u>Identify key issues</u>

Episodic events: storm frequency, resuspension events, wave events, hindcasting could yield better statistics for box models and sampling protocols
Resuspended component integrated: Considerations for ground-truthing in modeling, large reservoir of phosphorus but what actually gets into system? Many factors: e.g. thickness of layers, deep biological mixing by chironomids, episodic nature of resuspension events, integrated bedload contributions

Linkage between water column and sediments is strong in LE relative to other lakes
Characterize Mayfly bioturbation

Needs/Projects
-Plankton Community Structure, top down control of microbial processes should be measured
- characterize linkages between water column and sediments
C, N, Si recycling from sediments to water column
Diffusive flux exchange process independent of resuspension flux
C, N, Si recycling from sediments to water column due to resuspension processes
Coping with heterogeneity of bottom substrate, consolidation of substrate, how can you measure compactness?
Sediment trap can provide flux estimates ?
In situ measurements of bottom shear, shear strength necessary to resuspend sediments   Flume: Shear stress? Other possible tools?
Relate shear stresses/resuspension to benthic community
Evaluate taxonomic structure and condition of benthic community
Fluorescent or synoptic ways of determining types of phytoplankton present; ground truth with microscopic measurements
Link water quality models and hydrodynamic models
Fate of primary producers throughout year, over-winter storage? Annual cycle: how to address e.g. winter loading rates, is this important?
Carbon budget: balances throughout water column, include heterotrophic component, at what times is lake net heterotrophic, what times is lake net autotrophic, relationship to anoxic zone

F. Phosphorus bioavailability

Identify key issues
Have there been changes in bioavailability of phosphorus?
Differences between watersheds, tributaries, geological factors, seasonal differences in input and use of phosphorus

Needs/Projects
Evaluate bioavailability of phosphorus in tributaries (direct measurements, chemical surrogates)
How much algal growth is stimulated by non-point sources
How much does best management practices improve run-off?
Ultimately couple with watershed model,
What are the human impacts on the lake, determine best management practices for agricultural purposes, land-use planning,
What does bioavailability mean in the lake?
Look at sediment mass balances, how much does particulate load move, consider sediment-layering implications,

G. Public perceptions

Identify key issues
Drinking water taste
Not enough fish for recreational fishing
Dead zone, algal blooms, low water levels, sense that Lake Erie is in trouble

Aesthetic quality of lower tributaries

H. Modeling

Identify key issues
Revise existing models from phosphorus load reduction and LMMB projects
Add new pieces as needed
Run models for several years, not single season
Use models to assist in when, where, and how to sample

Appendix 5. Workgroup Report – Harmful algal blooms (HABs)

Core Group: Gary Fahnenstiel, Tim Granata, Bob Heath, Peter Lavrentyev, George Leshkevich, Rex Lowe, Allison Niggemeyer, David Raikow, Ace Sarnelle, Dave Schwab, Jeff Tyson, Hank Vanderploeg, Glenn Warren, Greg Lang

Workgroup Chair: Gary Fahnenstiel

Focus on *Microcystis* (cyanobacteria) – *Microcystis* blooms lend themselves to ecological prediction. Need to account for at least 'other' algae for selective feeding. Algae associated with taste and odor problems and beach closings have different generation mechanisms than Microcystis. Complicated relationship between *Microcystis* abundance (& relative abundance) and ZM density & phosphorus levels (Raikow et al. L&O 49:482-487).

Science Issues
The interaction of phosphorus and ZM in promoting *Microcystis* abundance. Are ZM important in western basin of Lake Erie? ZM set the stage, nutrients trigger bloom?

Toxicity – *Microcystis* abundance or toxin level? In-situ strain identification can be used to forecast potential toxicity. Time scale of forecast. Forecast products?

Time and space scales and duration of blooms. Location, duration and magnitude of nutrient sources? Observations and data limitations.

Effect of size and timing of blooms on rest of food web and fisheries?

External versus internal nutrient loading in predicting blooms. Resuspended phosphorus not contributing to bloom? Resuspension events introduce "seed" population to water column?

Role of physical forcing? High air temps coupled with low winds (low mixing) lead to higher toxic BG abundance.

Relationship of other cyanobacteria blooms (*Aphanizomenon*) and *Microcystis*

Societal Issues
Does *Microcystis* affect shoreline/beaches? Health effects of toxin production. Beach closings. Any related to BG algae blooms?

Taste and odor problems.

Prioritization of controlling nutrient sources.

Issue (1): The interaction of phosphorus and ZM in promoting *Microcystis* abundance. Are ZM important in western basin of Lake Erie? ZM set the stage, nutrients trigger bloom?

Importance/Justification:
We believe phosphorus and ZM are the dominant factors in controlling *Microcystis* growth. phosphorus can be controlled; ZM can't.

Needs/Projects:

Experimental work. Manipulate phosphorus levels and ZM abundance – mesocosm approach.

Measurements of key processes, gains and losses controlling *Microcystis* population. In lake or mesocosm.

Knowledge of nonindigenous mussels (NIM) densities and biomass. Temporal and spatial distribution. Understanding of mussel filtering relative to seston quality (with and without Microcystis).

Hindcast: satellite imagery, ground-truthing. Gather historic phosphorus and phytoplankton data (Culver). Can we characterize past Microcystis blooms on Lake Erie prior to MODIS? Modeling exercise?

Issue (2): Toxicity – Microcystis abundance or toxin level? In-situ strain identification can be used to forecast potential toxicity. Time scale of forecast. Forecast products?

Importance/Justification:
Public health issue. May or may not have ecological significance. Bioaccumulation effects. Impacts on water treatment plants.

Needs/Projects:
Strain identification (what's there). Genetics of individual colonies.

Toxin gene production potential.

Environmental regulation of toxin production.

How does toxicity interact with ZM? Do ZM select for particular strains?

Relationship of toxin levels to beach closings and drinking water standards. Can we develop criteria or indices with respect to forecasts?

Issue (3): Time and space scales and duration of blooms. Location, duration and magnitude of nutrient sources? Observations and data limitations.

Importance /Justification:
Need to know time and space scales, extent and duration, of these blooms in order to characterize them.

Needs /Projects:
Remote sensing. Satellites and/or other platforms (aircraft, AUV, ROV), moorings. Algorithm refinement/validation…chlorophyll, primary production.
Ground truthing. Cruises vs. moorings.
Coupling with modeling.

Issue (4): Effect of size and timing of blooms on rest of food web and fisheries?

Importance /Justification:
Alteration of food web. Impact on sport fisheries.

Needs /Projects:
Cruises and trawls during blooms. Observation of major components (zooplankton, dreissenids).
Processes…energy efficiency and transfer, especially at bottom of food web. Need trophic dynamic model; emphasis on grazing and decomposition.
Bioaccumulation of toxins in different food web components.
Rate of attenuation of toxins in water, food web. Advection, persistence of this 'toxic' water mass.

General Algal Bloom Outbreak Forecasting.
What conditions promote bloom outbreak/development? Need water temp, nutrients, Maumee discharge load (and transport), meteorology (air temp, wind, solar radiation), turbidity, currents, spring ZM abundance. But what will be in bloom? Where will bloom be? Dutch experience. Potential users – water intake managers, public.

Bloom Detection and Subsequent Growth Forecasting.
Multi-spectral satellite imagery. Generate 2 real-time maps of 1) general chlorophyll and 2) estimated cyanobacteria index (e.g. BG reflectance). Needs: MODIS imagery, (2x per day, 530-560 band), chlorophyll algorithm, cyanobacteria algorithm). *Expected products available summer 2004.*
In-situ (same day) ground truthing: water samples, moorings, AUVs. Gary F. and Tom B. will coordinate/conduct sampling and analysis. *Begin summer 2004 in conjunction with satellite products.*

Trajectory tracking of bloom (once detected).
Subsequent trajectory tracking and growth dynamics with knowledge/forecast of in-situ water and met conditions. *2005-2006?*
Begin to generate database of bloom initiation conditions.

Long-term, seasonal forecasting.
Need ZM densities, predicted nutrient loads.

Appendix 6. Workgroup report: Coupling Fish and Physics

Core Group: Joe Atkinson, Dima Beletsky, Tom Bridgeman, Mike Bur, Hunter Carrick, Tom Croley, Bob Haas, Tim Johnson, Roger Knight, Marten Koops, Stuart Ludsin, Doran Mason, Chris Mayer, Tom Nalepa, Ed Rutherford, Don Schloesser, Mike Thomas

Day 2 participants: Joe DePinto, Ora Johannsson, Scott Peacor, Hank Vanderploeg,

Workgroup Chair: Stuart Ludsin

Important Lake Erie fisheries issues and research needs have been previously defined (see Niggemeyer's and Knight's presentations). Thus, this workgroup focused more specifically on developing the ideas presented earlier by Knight. Specifically, Knight suggested that having the ability to model (describe, predict) fish habitat (e.g., temperature, oxygen, food) in three dimensions would be of value to fishery management agencies, allowing them to begin to understand why fish are distributed as they are and grow as they do throughout the lake. In addition, Knight mentioned the potential existence of water masses that are seemingly predictable in both space and time.

Initially, the workgroup began to work towards identifying what would be needed to develop a 3-dimensional, coupled biological-physical model to describe/predict water masses (fish habitat). However, the realization came quickly that such an undertaking could not be accomplished in the short term (certainly not within 1-2 years). Further, the workgroup realized that concept of water masses is currently based on snapshots of data—August limnological collections. Because most Lake Erie fishes (e.g., yellow perch, walleye, and many prey fishes) are likely more vulnerable to mortality as eggs and larvae during spring and early summer (i.e., prior to August), as compared to older life stages, the group thought a better first step would be to determine whether predictable water masses even exist during spring/summer (i.e., during egg and larval stages). Only after the water mass concept has been demonstrated to occur in spring/summer, would it be worthwhile to tackle the second, more complex objective (building predictive models and applying them to fisheries management questions; i.e., ecological forecasting).

As such, much of the second day of the workgroup session was spent identifying the sort of information that would need to be assembled or collected to quantify the predictability, persistence, and appearance of water masses in western Lake Erie during spring and early summer. Ultimately, the workgroup felt that a lot could be learned using extant information, including Great Lakes Forecasting System temperature predictions, daily remotely sensed images (AVHRR), and a diversity of limnological data collected by universities and agencies (e.g., ODNR, OMNR, U.S.E.P.A., U.S.G.S., GLERL, EC). Ultimately, this effort helped identify how GLERL scientists could work with others to achieve this end.

Long-term research objective:

- Develop a coupled physical-biological model to help explain and/or forecast fish distributions, growth
- 3-D hydrodynamics/circulation model
- Pertinent physical variables (temp, dissolved oxygen, water clarity)
- Pertinent biological variables (food—zooplankton, benthos)
- Daily time step (seems most important for fish)
- Spatial resolution—whatever can be modeled efficiently by oceanographers

- Incorporate water mass ideas (predictability, persistence per R. Knight's presentation)
- Initial focus on west basin (high fisheries production, small, much historical data)
- Model would ultimately be coupled to watershed/river hydrology models to explore influence of land-use alteration, climate change, and water-flow policies

Short-term research objective:

Two stage effort:

1. Model the physical environment (during spring—when larvae are produced)
    a. Major questions to address:
    b. Are water masses truly identifiable?
    c. How variable are water masses in space and time?
    d. What characteristics best define water masses (temperature, water clarity, oxygen)?
    e. How do attributes of water masses co-vary with one another?
        i. Could be useful for helping to tease out the mechanisms influencing fish
2. Apply physical, descriptive model to fisheries objectives
    a. Hindcast to explain spatial distribution of growth/abundance
    b. Forecast to explore role of land-use change, climate change on recruitment to fishery