

Ecological Responses to Low Oxygen Events in Central Lake Erie

Primary Investigators: Stuart Ludsin

Co-Investigator: Hank Vanderploeg, Tom Nalepa, Scott Peacor, Steve Ruberg, Joann Cavaletto, Terry Miller, Dave Fanslow, Greg Lang, Jim Liebig, Nancy Morehead, Steve Pothoven - NOAA GLERL, Patrick M. Kocovsky, USGS Great Lakes Science Center/Lake Erie Biological Station, Sandusky OH)



Figure 1. Dissolved oxygen profile in central Lake Erie during July through October 2003. Data source: NOAA-GLERL's central basin buoy, Steve Ruberg.

Overview

A prominent feature of Lake Erie's central basin is the area of severe hypoxia/anoxia (aka the "dead zone") that recurs annually during late summer. Although the size of the dead zone declined with reduced phosphorus inputs during the mid-1980s, current levels of oxygen depletion are on par with those observed during the preceding period of severe cultural eutrophication, which is of concern to both Lake Erie resource management agencies and user groups. At present, several GLERL scientists have proposed to explore the physical and biological factors that regulate the timing, magnitude, and duration of low oxygen events in Lake Erie (i.e., submitted NOAA COP proposal). However, minimal effort will be put forth toward understanding the impacts, if any, the dead zone can have on biological components of the ecosystem, especially higher trophic levels. Herein, we propose to use a combination of sophisticated sampling technologies (fish acoustics; towed plankton survey system with numerous sensors, PSS), in combination with traditional sampling (plankton net/pump sampling; benthic Ponar sampling; bottom and mid-water trawling), to explore whether reduced oxygen availability influences 1) the normal diel-migration pattern and of benthic macroinvertebrates, zooplankton, and fish, and 2) the feeding and potential growth response of planktivorous rainbow smelt and benthivorous lake whitefish, both of which are of commercial importance. With the help of Patrick Kocovsky (USGS-Lake Erie station), we also will explore how fish community structure (i.e., species richness/diversity, species composition/abundance) varies with oxygen availability in the central basin, and explore round goby foraging on dreissenid mussels in the "dead zone" region. Further, the pilot data collected herein will be used to explore whether the dead zone allows *Bythotrephes* to persist in such high numbers in central Lake Erie by providing a refuge from planktivorous fish predation. In addition to meshing nicely with other GLERL efforts in central Lake Erie (e.g., proposed NOAA COP project, continued

development of the central basin buoyed observing system), our findings will serve as the basis of future proposals (internal and external) aimed at delineating linkages between oxygen availability and higher trophic level production and community structure in Lake Erie. Certainly, this knowledge would be invaluable to future ecological forecasting efforts.

Methods

Field surveys will be conducted at in Lake Erie's central basin, nearby the NOAA-GLERL central basin buoy, such that we have a continuous, real-time record of physical (e.g., temperature, dissolved oxygen, turbidity) and biological (e.g., chlorophyll) data at our sampling station. We will sample two transects, one in deeper waters (in close proximity to the NOAA-GLERL's buoy) that becomes hypoxic/anoxic (< 2 mg/l;) during late summer and one in shallower water in an area that remains near normoxic in the hypolimnion (> 4 mg/l) year-around. In this way, we seek to use the year-around, high-oxygen transect as a control, which we could contrast with our seasonal, low-oxygen area.

We will sample physical and biological attributes, including chlorophyll a, benthic macroinvertebrates, zooplankton, and fish. Sampling will occur, using a NOAA-GLERL vessel, on three occasions: one in mid- to late July (just after thermocline setup, but before severe hypoxia occurs); one in late August (height of reduced oxygen availability in hypolimnion); and one in late September (after fall turnover, and re-aeration of bottom waters) (see Figure 1). Real-time temperature and oxygen data, provided from the GLERL buoy system, will allow us to time our sampling accordingly. On each occasion, we will sample on a diel basis (every 6 h; 0000, 0600, 1200, and 2400) over a 48-h period, which will allow us assess whether behavior (e.g., vertical migration, fish foraging) is influenced by oxygen availability; one transect will be sampled per day.

At each transect (and during each diel sampling period), we will use GLERL's undulating Plankton Survey System (optical plankton counter, CTD, fluorometer, and PAR sensor; PSS)—with an oxygen sensor and pH sensor mounted to it for this project—to determine the fine-scale distribution of dissolved oxygen, pH, temperature, sediments, photic depth, chlorophyll a, and zooplankton. Simultaneously, we will collect information on the vertical and horizontal distribution of pelagic fishes, using GLERL's new BioSonics DT-X acoustics system. In this way, we will generate a continuous record of physical (temperature, oxygen, light levels) and biological (zooplankton, forage fishes) variables that could be used to model (and map) the growth rate potential (GRP; see below) of several fishes.

Subsequent to continuous collections with acoustics gear and the PSS, mid-water trawling (31' x 31' trawl) and bottom trawling (N = 2 tows per transect, for each gear and sampling period) will be conducted to collect pelagic fishes for gut content analysis, as well as to determine fish species composition (n = two replicate tows per gear per transect per sampling period). These collections will be supplemented by the Ohio Department of Natural Resources (Kevin Kayle, Fairport Harbor, OH station), which has agreed to provide us with bottom trawl, temperature, and bottom oxygen information, as well as fish samples for diet analysis, collected in areas nearby our sampling locations (ODNR's sampling occurs monthly during the last two weeks of May through September at ~ 40 stations). Finally, as we explain below, sampling of benthic

macroinvertebrates, zooplankton, and physical variables will occur at the start and finish of each transect.

At present, little is known about the central basin benthic macroinvertebrate community. To characterize its response to reduced oxygen availability, Ponar sampling will be conducted at the start and end of each transect ($n = 6$ replicates per transect per sampling period). Beyond learning whether short-term shifts in composition, abundance, and behavior (e.g., vertical migration) occur, owing to reduced oxygen availability, this sampling will provide insight into whether hypoxia indeed reduces availability of important macroinvertebrate prey for benthic feeding fishes, as hypothesized by previous researchers (Hartman 1972, Leach and Nepszy 1976, Laws 1981).

To quantify effects of oxygen availability on zooplankton community behavior (i.e., vertical migration) and composition, we will use a combination of vertical net tows (64- μ m mesh; $n=4$ replicates per transect per sampling date) and pumping (samples from the hypolimnion, metalimnion, and epilimnion will be integrated separately). Pumping will be vital for determining zooplankton enumeration in the thin hypolimnion, which cannot be effectively sampled with vertical net tows. At each site, cladoceran zooplankton will be identified to species, and copepods will be identified as calanoids, cyclopoids, or nauplii. For some critical samples, full taxonomic identification will be conducted. For the predatory invader, *Bythotrephes*, and its prey (e.g., *Daphnia*, *Bosmina*), we will quantify variation in summer zooplankton productivity by identifying individuals to species, sexing them, and calculating egg ratios.

We will use mid-water and bottom trawl data, collected in both the dead zone and adjacent control area, to quantify how hypoxia affects the fish community. Chi-square contingency analysis and analysis of variance will be used to compare species richness and species relative abundance between treatment (hypoxic) and control areas before, during, and after a low-oxygen event. Comparisons also will be made over the diel cycle ($n = 4$ sampling periods), as well as between gear types (bottom versus mid-water trawls), to understand the influence of oxygen availability on fish community dynamics (behavior). Correlation analyses between fish community attributes (e.g., species relative abundance, species richness) and the suite of physical and biological data (e.g., dissolved oxygen, temperature, pH, PAR, chlorophyll, zooplankton) also will be conducted. These analyses will provide a first look at if and how fish communities, and individual species within communities, react to hypoxic conditions in the dead zone.

Stomach contents of juvenile and adult rainbow smelt, lake whitefish, and round gobies, collected via mid-water and bottom trawling, will be analyzed in the laboratory ($n = 10$ diets per species per transect per sampling period). We will identify, measure, and count all food items found in stomachs under a dissecting microscope with an image analysis system. Cladoceran zooplankton will be identified to genus, and copepods will be identified as calanoids, cyclopoids, or nauplii. We will identify benthic invertebrates to family and fish to genus (or species, if possible). Zooplankton length and abundance information in diets will be used to calculate diet biomass and daily consumption, which then will be used to generate an index of gut fullness (e.g., diet biomass to fish mass). We also will quantify selectivity for zooplankton taxa (Pothoven

and Vanderploeg 2004), and attempt to estimate consumption of Bythotrephes. The vertical structure of zooplankton and fishes will allow us to determine the role of anoxia in influencing fish selectivity, particularly Bythotrephes.

Bioenergetics-based, spatially-explicit growth rate potential (GRP) modeling (Brandt et al. 1992, Mason et al. 1995) will be used to assess how the suite of habitat features (e.g., oxygen levels, temperature, food resources), collected by the PSS, interact to influence growth of rainbow smelt and lake whitefish. This type of modeling uses a grid-based (location by depth) approach to predict the physiological growth response of a fish to a suite of environmental conditions. In essence, the spatial maps produced will provide a species-specific measure of habitat quality in the central basin (along each transect). A foraging model will define consumption as a function predator size, temperature, zooplankton (for rainbow smelt), and benthic macroinvertebrate (for lake whitefish) availability. Previously published diet data from Lake Erie, as well as diet data collected herein, will be used to develop the consumption models. Previously developed bioenergetics models for these species will be used to calculate GRP as a function of consumption and prevailing physical conditions. Snapshots (maps) of consumption and growth rate potential will be calculated for each transect during each sampling period, which will allow us to assess the potential influence of oxygen availability.

Finally, we are proposing to deploy a remotely operated, underwater video system below the central basin buoy in order to characterize diel migration patterns of fish, and possibly larger invertebrate species. A video camera will be moored to one of Nathan Hawley's tripods, which is 2 m on each side and stands ~1.5 m tall, on the bottom such that we can document fish habitat use (and migration patterns) before, during, and after a low-oxygen event. We will cover the tripod with plastic netting (similar to what has been used in coral reef systems) such that it simulates an artificial reef, which should attract fish to this site. Streamed video will be recorded every 10 min from 3 h before sunrise to 3 h after sunset, and still images will be taken hourly over the entire 24-h period, to document diel habitat use. The camera will be mounted on a pan/tilt system, which will allow us to view a 360° cone around the structure. Stills will then be digitized to assess fish biomass in the hypolimnion before, during, and after a low-oxygen event, as determined from buoy data.

Expectations

We are optimistic that this effort will provide insight into whether low-oxygen events in central Lake Erie play a role in structuring higher trophic levels (e.g., benthic macroinvertebrates, zooplankton, fish), including their ecological interactions. Although it has been suggested that reduced oxygen availability has historically limited several important recreational and commercial fishes in the central basin by limiting access to vital thermal and foraging habitat, little mechanistic support exists to justify this hypothesis (but see Ludsin et al. 2001). In addition, we are optimistic that this effort will shed insight into why central Lake Erie is a stronghold for Bythotrephes, which has been implicated in the reduction of native crustacean zooplankton prey in Lake Erie (Johannson et al. 1999). In fact, Bythotrephes biomass is greater in central Lake Erie than anywhere else in the Great Lakes (Figure 3). Although numerous possibilities exist to explain this phenomenon, we will explore whether Bythotrephes is using low-oxygen (< 4 mg/l)

areas as a refuge from predation by planktivores (e.g., rainbow smelt) that cannot tolerate low oxygen levels. Thus, although this work is largely exploratory, it also is hypothesis-driven, and indeed may help us understand the potential effects oxygen availability can have on both Lake Erie's valued fisheries and the persistence of exotic species. In turn, because ecological understanding is pivotal for developing reliable predictive models, this effort will be of value to future ecological forecasting efforts.

2005 Plans

1. Sample, on three dates (pre-, during, post-hypoxia setup), both physical (temperature, oxygen, turbidity, PAR, total and soluble-reactive phosphorus) and biological (chlorophyll, benthic macroinvertebrates, zooplankton, fish) attributes along a two transects in the central basin: one that remains normoxic year-round (control region) and one that becomes seasonally hypoxic/anoxic (< 2 mg/l) in the hypolimnion (treatment region).
2. Use diel sampling (4 collections per date) to characterize the vertical migration behavior of benthic macroinvertebrates, zooplankton, and fish before, during, and after a low oxygen event.
3. Use contingency analyses to quantify how fish community structure (e.g., species richness/diversity, species composition/abundance) varies with oxygen availability in central Lake Erie.
4. Quantify diets of a planktivore (rainbow smelt) and two benthivores (lake whitefish and round gobies) to determine how feeding behavior (e.g., consumption, prey selectivity) changes with reduced oxygen availability.
5. Use bioenergetics-based, spatially-explicit modeling to quantify the potential growth response of, and help understand the distribution of, rainbow smelt and lake whitefish to reduced oxygen events.
6. Provide preliminary estimates of Bythotrephes predatory impact on the zooplankton community in central Lake Erie.

References

Aku, P. M. K., and W. M. Tonn. 1997. Changes in population structure, growth, and biomass of cisco (*Coregonus artedii*) during hypolimnetic oxygenation of a deep, eutrophic lake, Amisk Lake, Alberta. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2196-2206.

Aku, P. M. K., and W. M. Tonn. 1999. Effects of hypolimnetic oxygenation on the food resources and feeding ecology of cisco in Amisk Lake, Alberta. *Transactions of the American Fisheries Society* 128:17-30.

Aku, P. M. K., L. G. Rudstam, and W. M. Tonn. 1997. Impact of hypolimnetic oxygenation on the vertical distribution of cisco (*Coregonus artedii*) in Amisk Lake, Alberta. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2182-2195.

- Barbiero, R. P., R. E. Little, and M. L. Tuchman. 2001. Results from the US EPA's biological open water surveillance program of the Laurentian Great Lakes: III. Crustacean zooplankton. *Journal of Great Lakes Research* 27:167-184.
- Bertram, P. E. 1993. Total phosphorus and dissolved oxygen trends in the central basin of Lake Erie, 1970-1991. *Journal of Great Lakes Research* 19:224-236.
- Brandt, S.B., D.M. Mason, and E.V. Patrick. 1992. Spatially-explicit models of fish growth rate. *Fisheries* 17(2): 23-35.
- Breitburg, D.L., L. Pihl, and S.E. Kolesar. 2001. Effects of low dissolved oxygen on the behavior, ecology and harvest of fishes: a comparison of the Chesapeake Bay and Baltic-Kattegat systems. Pages 241-268 in N.N. Rabalais and R.E. Turner, editors. *Coastal hypoxia: consequences for living resources and ecosystems*. American Geophysical Union, Washington, DC.
- Caddy, J. 1993. Toward a comparative evaluation of human impacts on fishery ecosystems of enclosed and semi-enclosed seas. *Reviews in Fishery Science* 1:57-96.
- Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8:559-568.
- Carr, J. F., and J. K. Hiltunen. 1965. Changes in the bottom fauna of western Lake Erie from 1930 to 1961. *Limnology and Oceanography* 10:551-569.
- Coutant, C.C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. *Transactions of the American Fisheries Society* 114:31-62.
- Diaz, R. J., and R. Rosenberg. 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review* 33:245-303.
- Hartman, W. L. 1972. Lake Erie: effects of exploitation, environmental changes and new species on the fishery resources. *Journal of the Fisheries Research Board of Canada* 29:899-912.
- Johannsson, O.E., D.M. Graham, D.W.E. Einhouse, and E.L. Mills. 1999. Historical and recent changes in the Lake Erie zooplankton community and their relationship to ecosystem function. Pages 169-196 in M. Munawar, T. Edsall, and I.F. Munawar, editors. *State of Lake Erie (SOLE) - Past, Present and Future*. Backhuys Publishers, Leiden, The Netherlands.
- Ketchum, B. H. 1969. Eutrophication of estuaries. Pages 197-209 in *Eutrophication: Causes, Consequences, Correctives*. National Academy of Sciences, Washington, DC.

- Lang, C., and O. Reymond. 1996. Reversal of eutrophication in four Swiss lakes: evidence from oligochaete communities. *Hydrobiologia* 334:157-161.
- Laws, E. A. 1981. *Aquatic Pollution, an Introductory Text*. John Wiley and Sons, New York.
- Leach, J. H., and S. J. Nepszy. 1976. The fish community in Lake Erie. *Journal of the Fisheries Research Board of Canada* 33:622-638.
- Ludsin, S.A., M.W. Kershner, K.A. Blocksom, R.L. Knight, and R.A. Stein. 2001. Life after death in Lake Erie: nutrient controls drive fish species richness, rehabilitation. *Ecological Applications* 11:731-746.
- Marcus, N.H. 2001. Zooplankton: responses to and consequences of hypoxia. Pages 49-60 in N.N. Rabalais and R.E. Turner, editors. *Coastal hypoxia: consequences for living resources and ecosystems*. American Geophysical Union, Washington, DC.
- Mason, D.M., A. Goyke, and S.B. Brandt. 1995. A spatially explicit bioenergetics measure of habitat quality for adult salmonines - comparison between Lakes Michigan and Ontario. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1572-1583.
- Naiman, R. J., J. J. Magnuson, D. M. McKnight, and J. A. Stanford. 1995. *The Freshwater Imperative: a Research Agenda*. Island Press, Washington, DC.
- Nürnberg, G. K. 1995. The anoxic factor, a quantitative measure of anoxia and fish species richness in central Ontario lakes. *Transactions of the American Fisheries Society* 124:677-686.
- Patalas, K. 1972. Crustacean plankton and the eutrophication of St. Lawrence Great Lakes. *Journal of the Fisheries Research Board of Canada* 29:1451-1462.
- Pothoven, S.A., and H.A. Vanderploeg. 2004. Diet and prey selection of alewives in Lake Michigan: seasonal, depth, and interannual patterns. *Transactions of the American Fisheries Society* 133:1068-1077.
- Rabalais, N.N., and R.E. Turner. 2001. Hypoxia in the northern Gulf of Mexico: description, causes and change. Pages 1-36 in N.N. Rabalais and R.E. Turner, editors. *Coastal hypoxia: consequences for living resources and ecosystems*. American Geophysical Union, Washington, DC.
- Rosa, F., and N. M. Burns. 1987. Lake Erie central basin oxygen depletion changes from 1929-1980. *Journal of Great Lakes Research* 13:684-696.
- Tonn, W. M., and J. J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin lakes. *Ecology* 63:1149-1166.
- Verdonschot, P. F. M. 1996. Oligochaetes and eutrophication: an experiment over four years in outdoor mesocosms. *Hydrobiologia* 334:169-183.

Wannamaker, C.M., and J.A. Rice. 2000. Effects of hypoxia on movements and behavior of selected estuarine organisms from the southeastern United States. *Journal of Experimental Marine Biology And Ecology* 249:145-163.

Wetzel, M.A., J.W. Fleeger, and S.P. Powers. 2001. Effects of hypoxia and anoxia on meiofauna: a review with new data from the Gulf of Mexico. Pages 165-184 in N.N. Rabalais and R.E. Turner, editors. *Coastal hypoxia: consequences for living resources and ecosystems*. American Geophysical Union, Washington, DC.