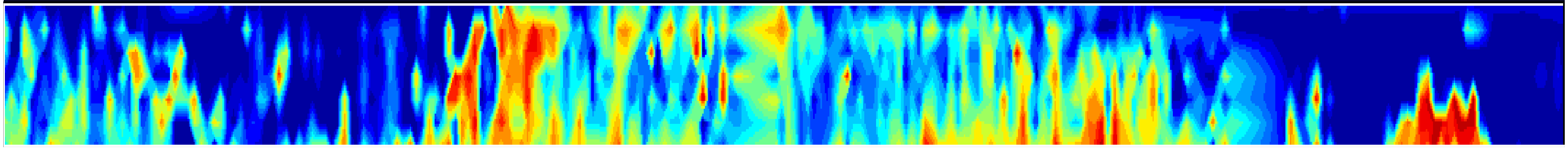
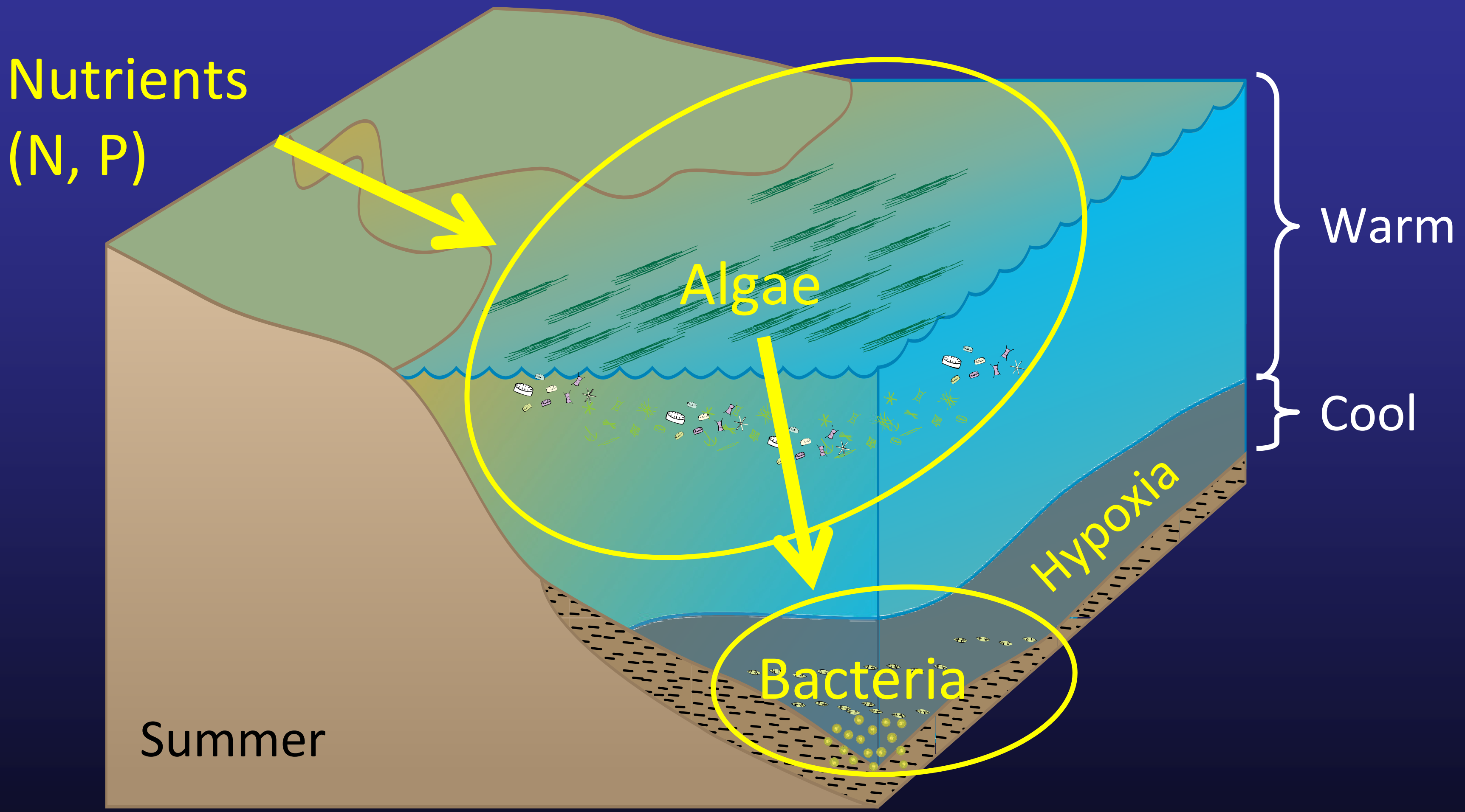
The causes and potential ecological consequences of hypolimnetic hypoxia in Lake Erie's central basin.

Tomas Höök
University of Michigan, CILER
NOAA-GLERL

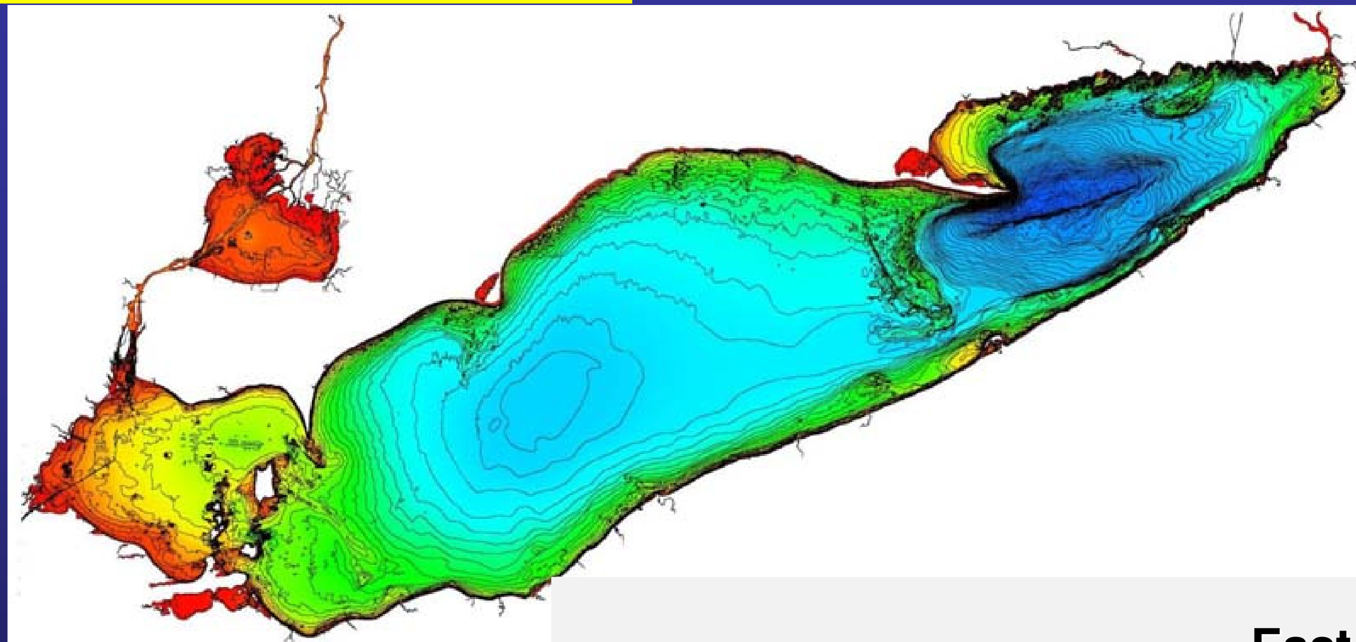


Hypoxia as a Stressor

- Cultural eutrophication as a cause of hypoxia

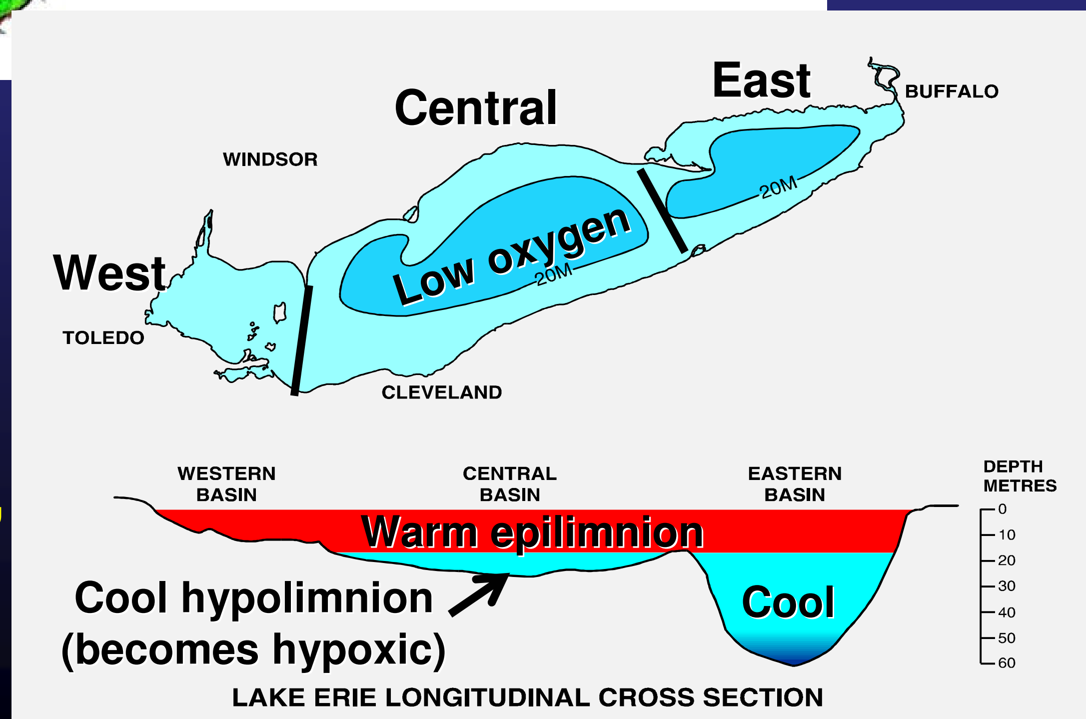


Hypoxia in Lake Erie:



Natural phenomenon

-Modified by various factors (e.g., nutrients, climate, water levels)

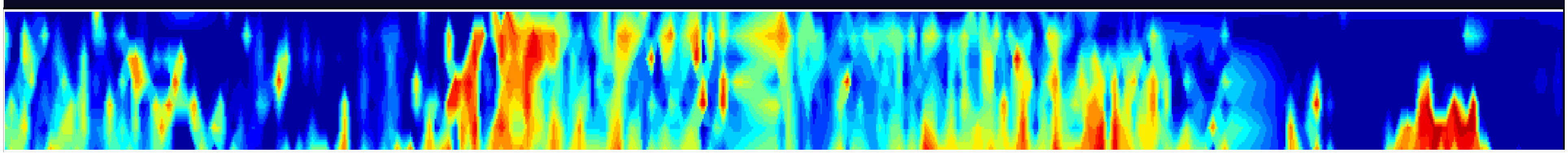


Source: Murray Charlton, NWRI

Inter-disciplinary, collaborative research projects

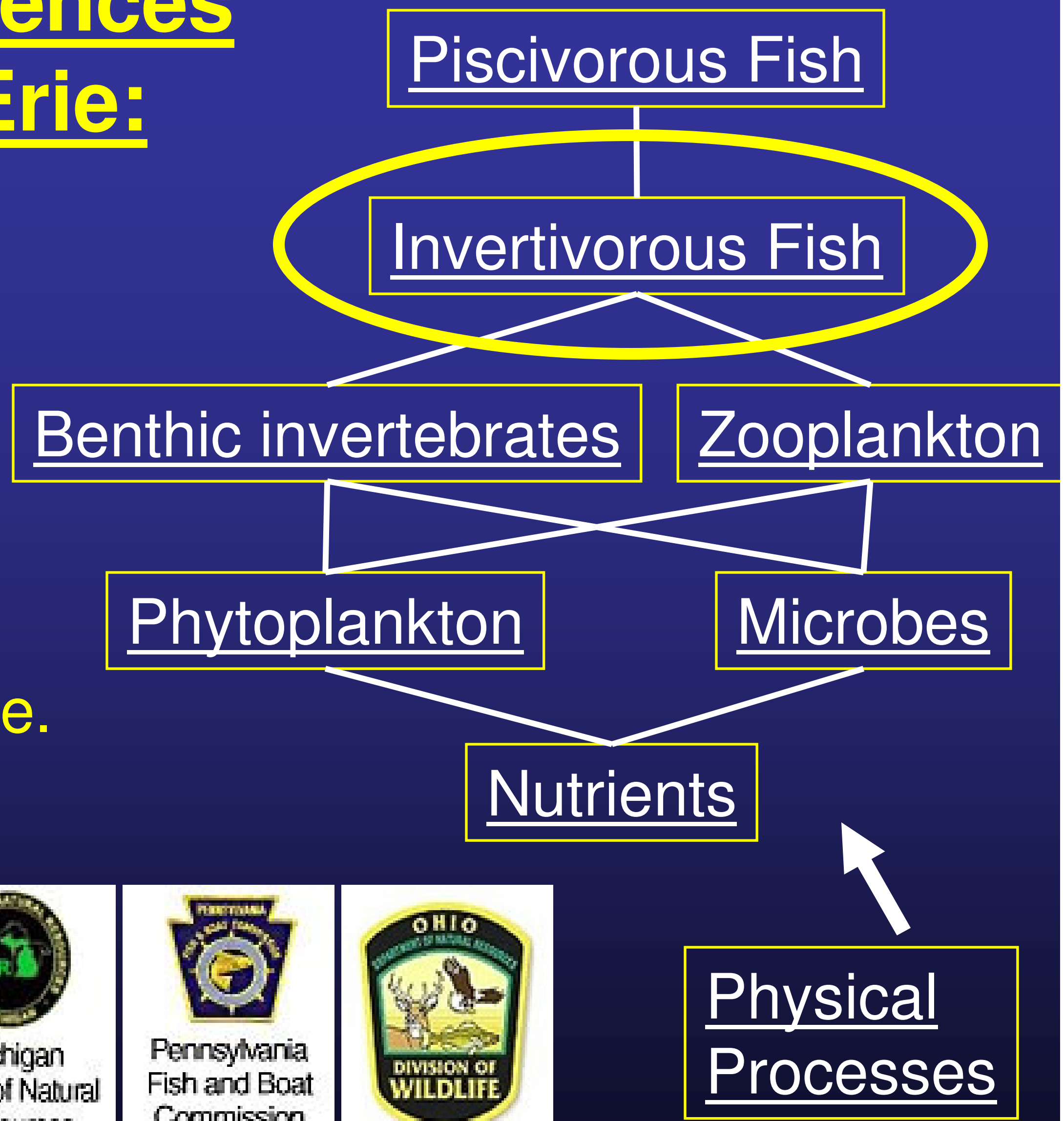
1) IFYLE (International Field Years on Lake Erie)

2) ECOFORE (Assessing the causes, consequences, and potential remedies for Lake Erie hypoxia)



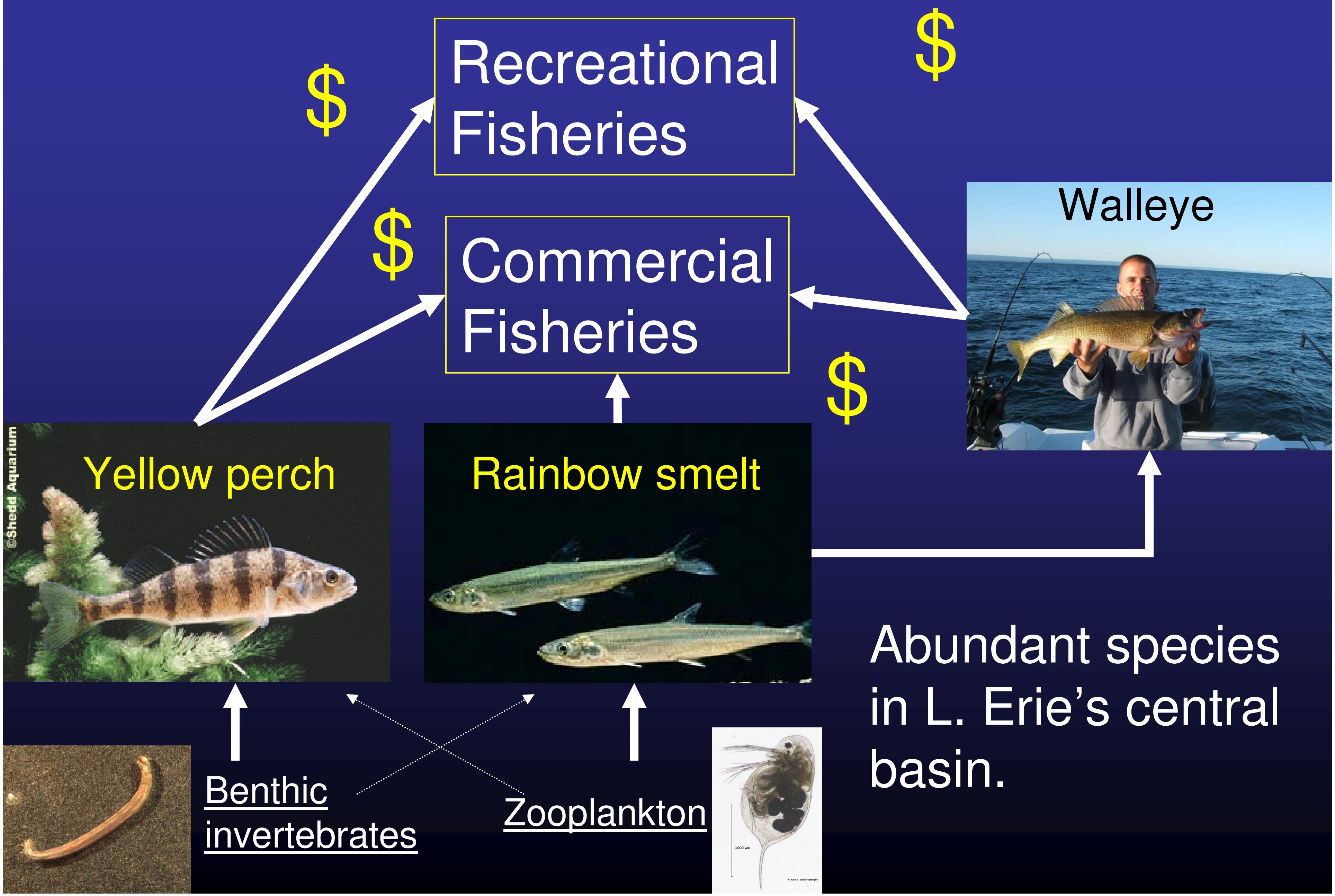
Ecological Consequences of Hypoxia in Lake Erie:

International Field Years in Lake Erie (2005 and 2007)
www.glerl.noaa.gov/ifyle
NOAA-GLERL led effort to understand the causes and ecological consequences of seasonal hypoxia in Lake Erie.

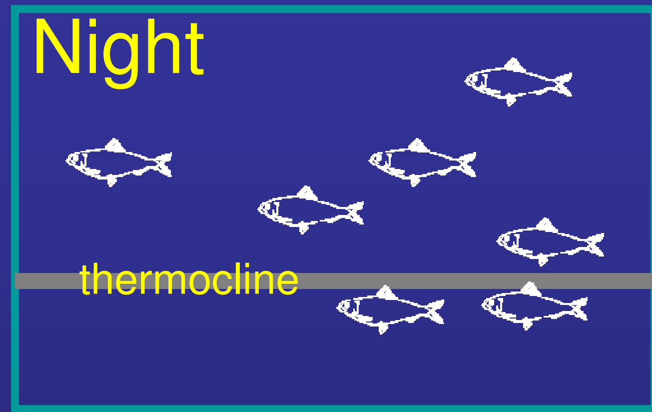


Ontario
Environment Canada
Environnement Canada
GLERL
Great Lakes Environmental Research Laboratory
Michigan Dept. of Natural Resources
Pennsylvania Fish and Boat Commission
Ohio Division of Wildlife
CILER
Cooperative Institute for Limnology and Ecosystems Research
Sea Grant Ohio Sea Grant College Program
Sea Grant New York
Sea Grant Pennsylvania
Sea Grant National Sea Grant College Program

Effects of Hypoxia on Yellow Perch and Rainbow Smelt



Effects of Hypoxia on Yellow Perch and Rainbow Smelt



Diel vertical migrations

Omnivory

Benthic invertebrates

Zooplankton

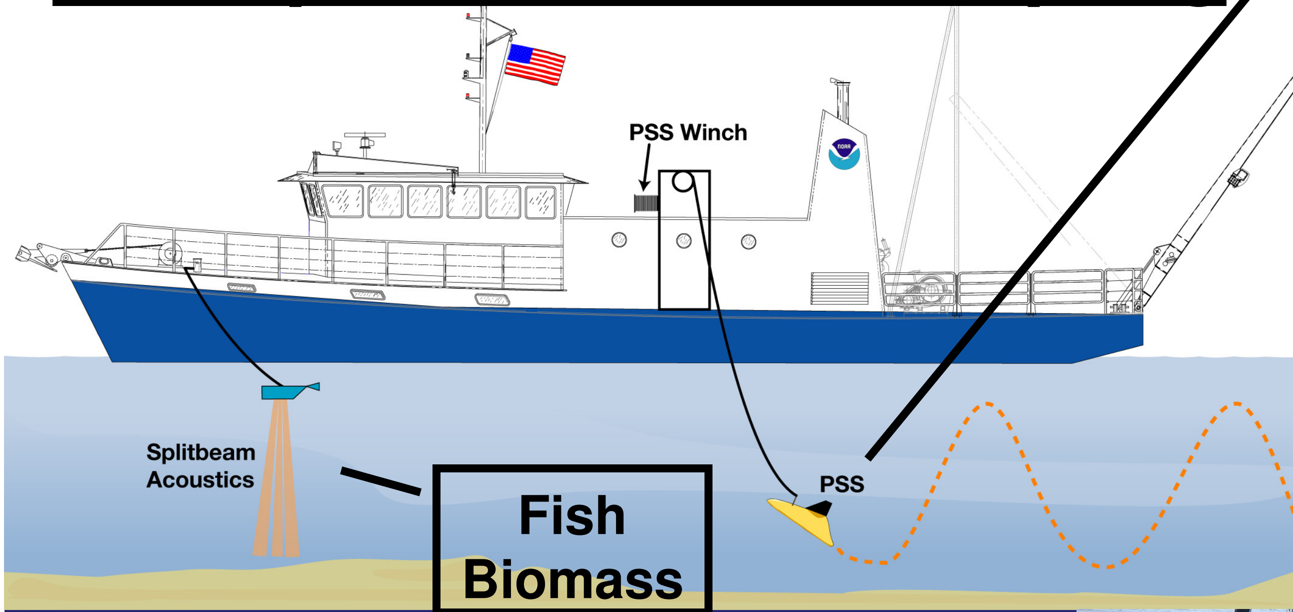
Hypoxia may alter:

-Distributions

-Diets

-Growth/Condition

24-hr paired-vessel sampling

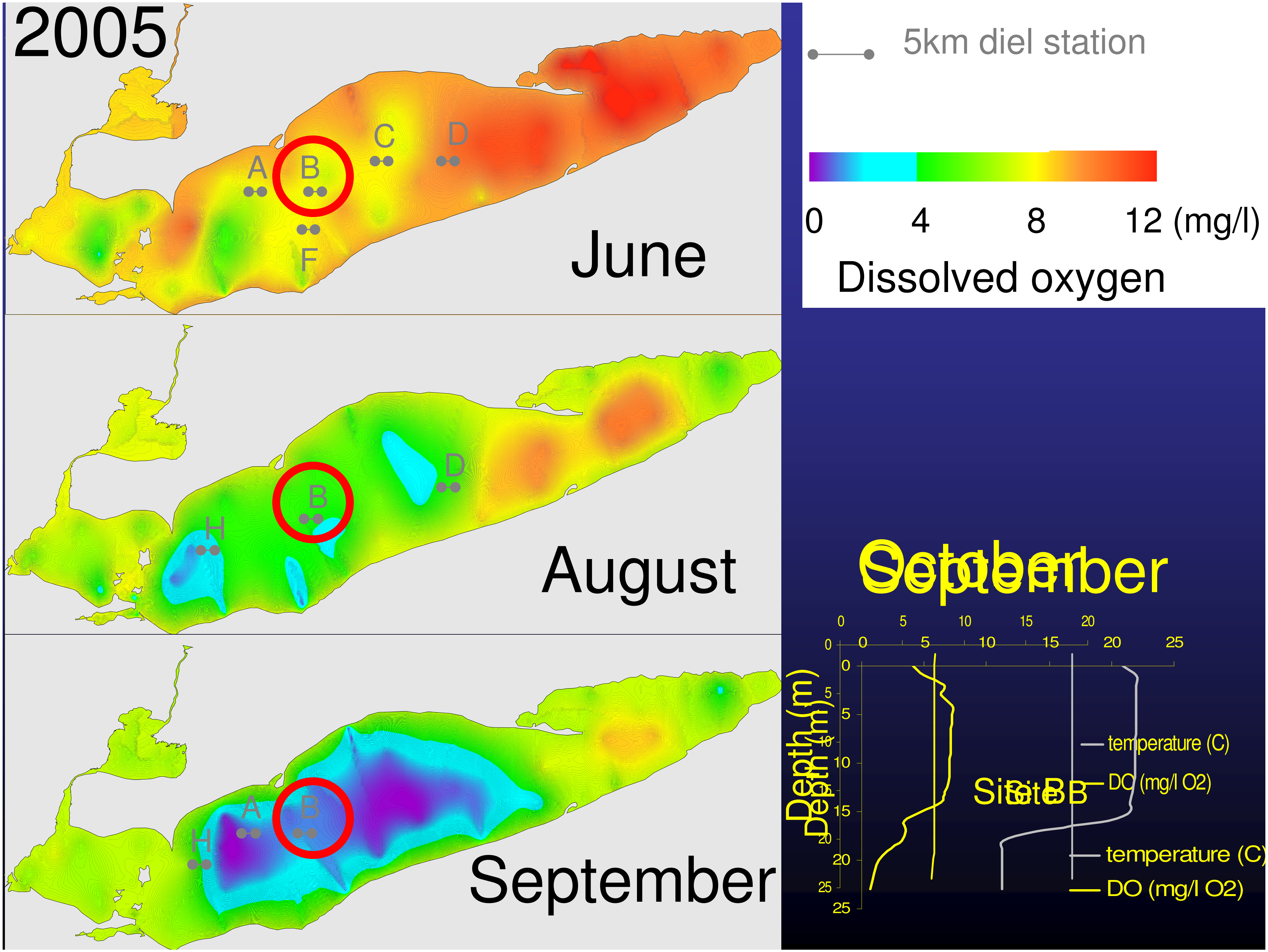


- Zooplankton
- Temperature
- Dissolved oxygen
- Light levels
- Chlorophyll *a*

-Zooplankton net and pump sampling

-Ponar grabs (benthos)

-Midwater and bottom trawling



2005
June
August
September
A
B
C
D
F
H
5km diel station
0
4
8
12 (mg/l)
Dissolved oxygen
October
September
Site B
Depth (m)
temperature (C)
DO (mg/l O2)
0
5
10
15
20
25

Effects of Hypoxia in Lake Erie.

IFYLE 2005

Strength of evidence

high

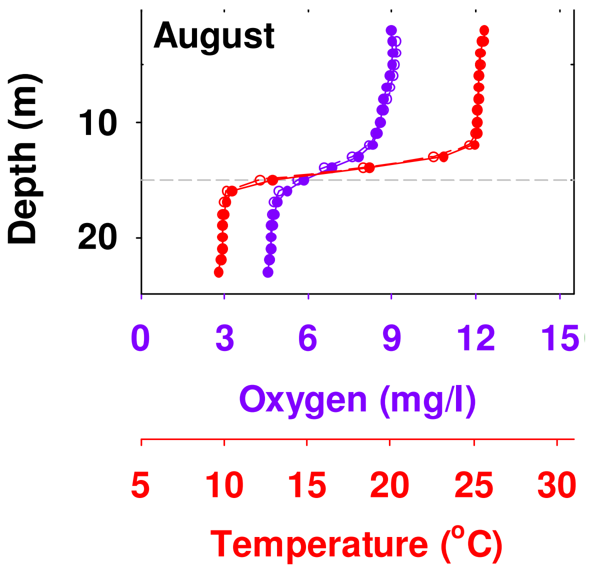
- Distributions of perch and smelt.
- Diets of perch and smelt.
- Condition/Growth of perch and smelt.

low

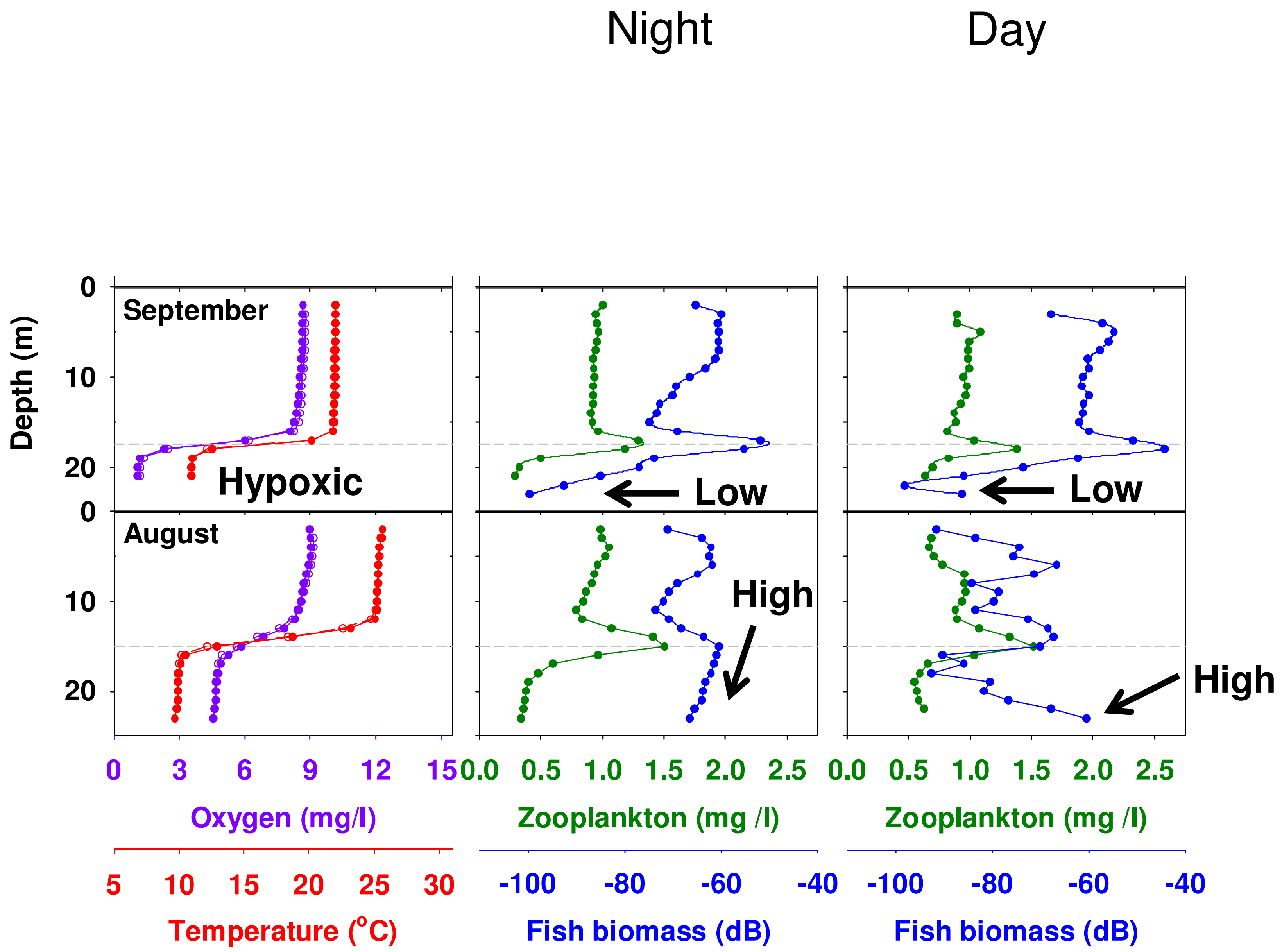
All data from Station B

Vertical Distributions of Yellow Perch and Rainbow Smelt

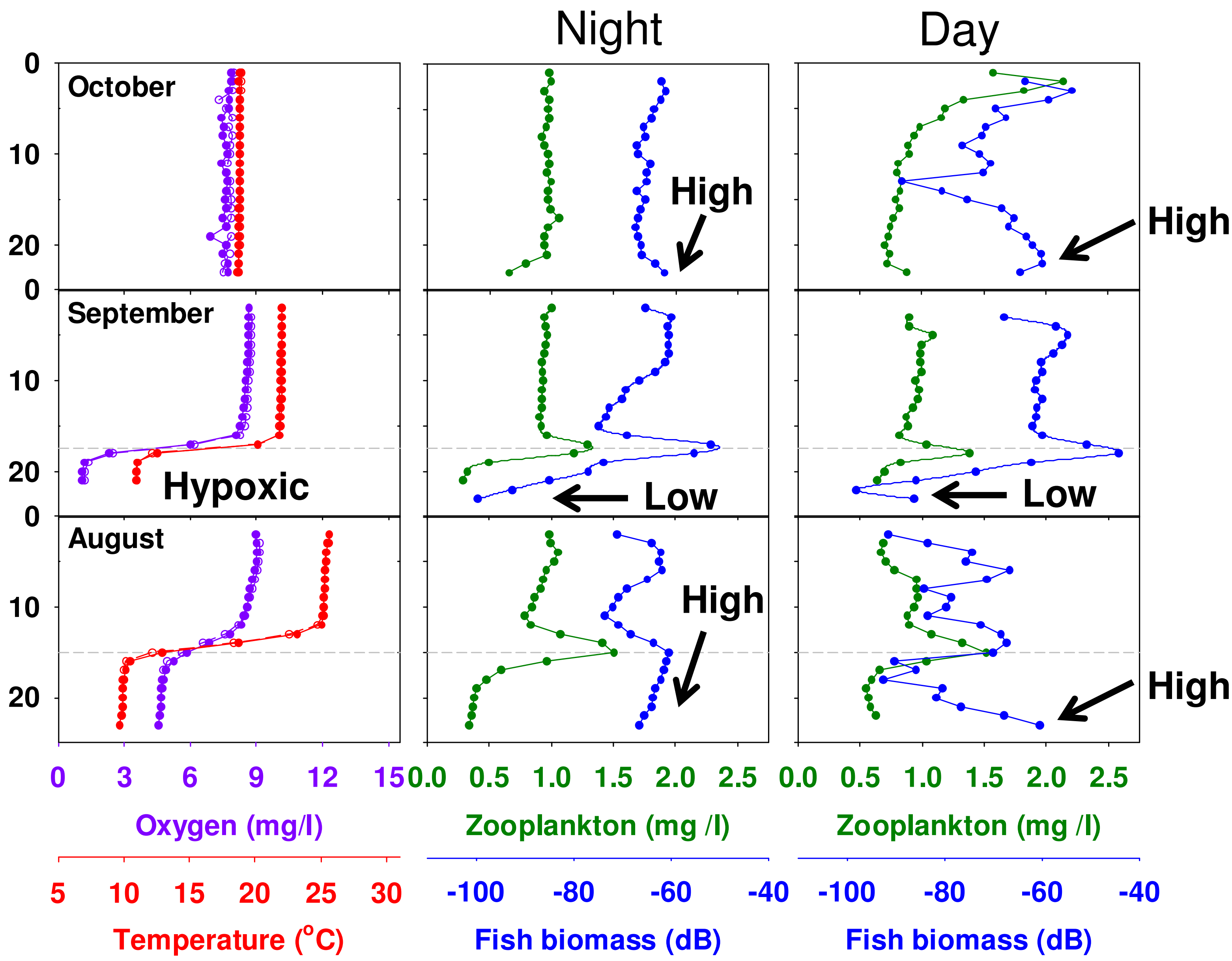
Night Day



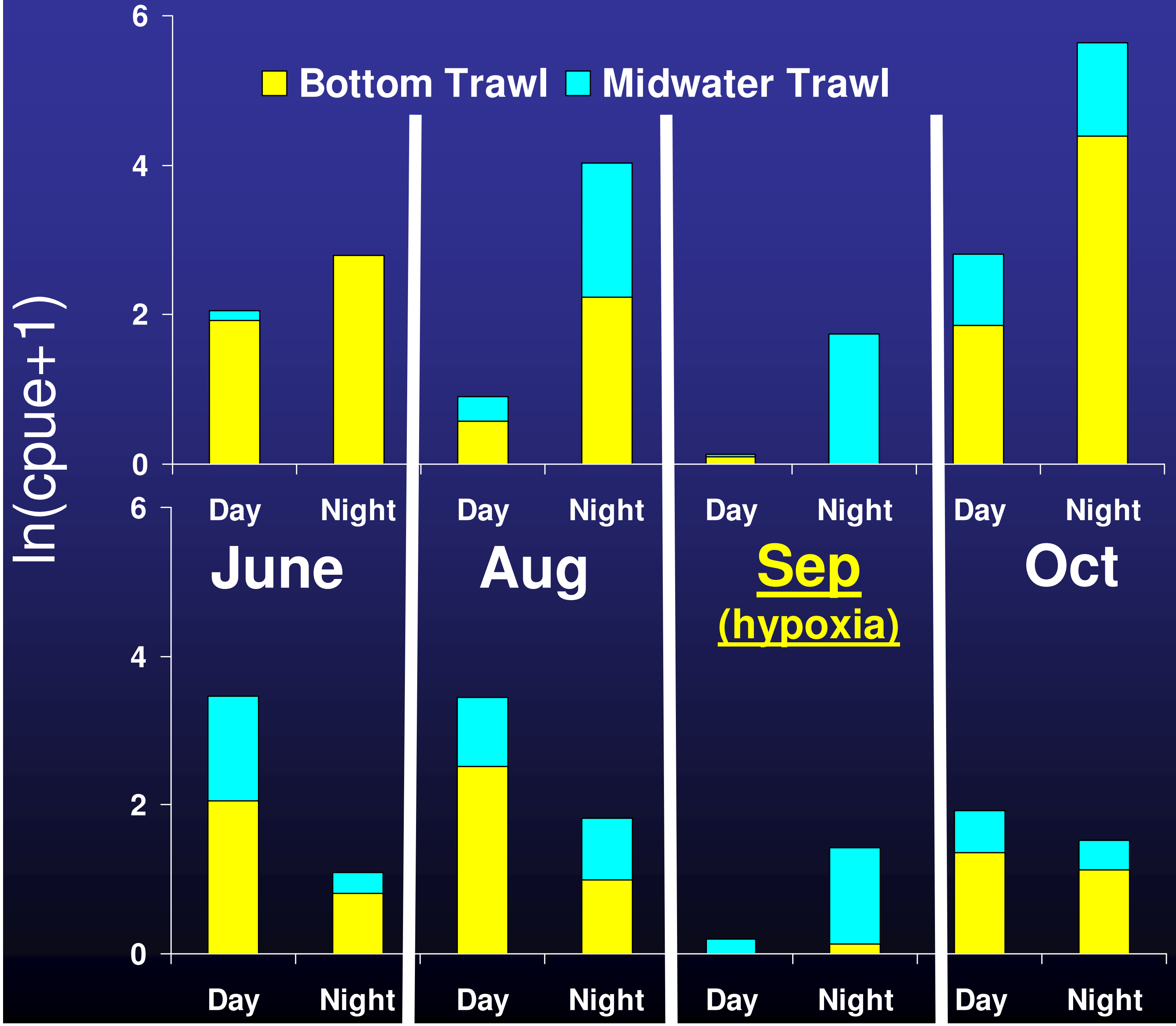
Vertical Distributions of Yellow Perch and Rainbow Smelt



Vertical Distributions of Yellow Perch and Rainbow Smelt



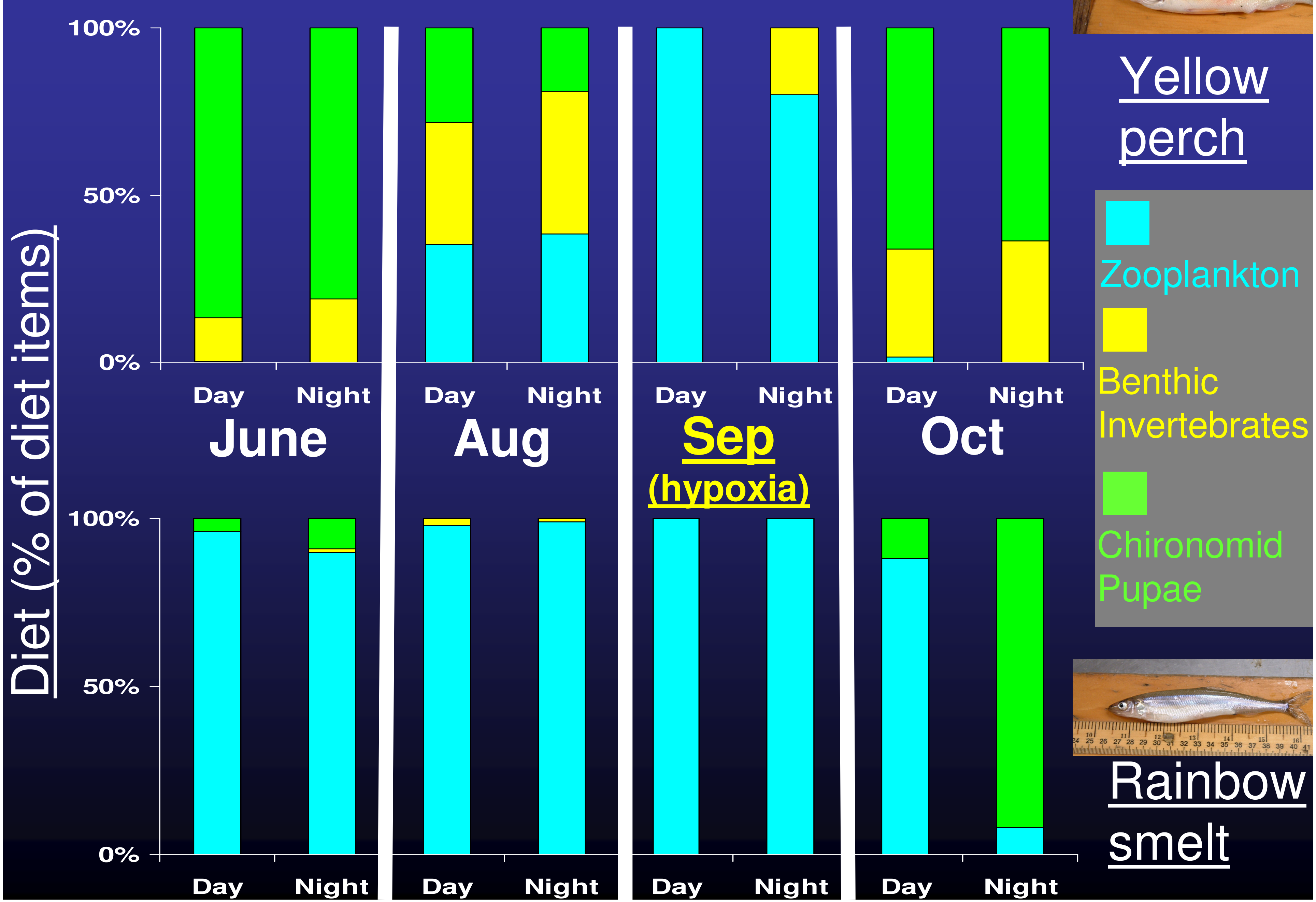
Vertical Distributions of Yellow Perch and Rainbow Smelt



Yellow perch

Rainbow smelt

Diets of Yellow Perch and Rainbow Smelt



Quantifying Growth and Condition

Traditional measures of growth and condition.

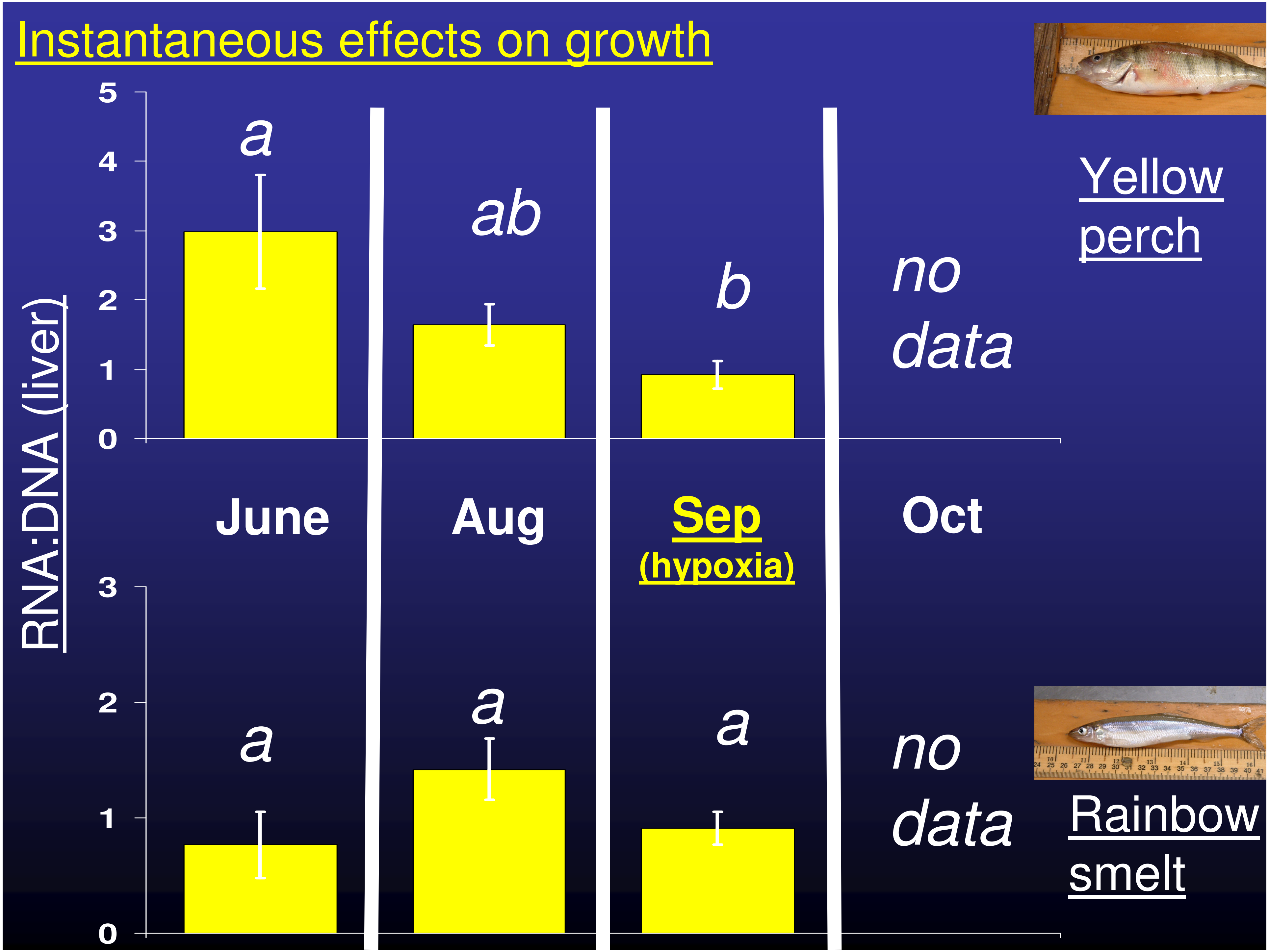
-Integrate feeding history and energetic utilization over the whole life-time of an organism.

RNA:DNA Ratios

-DNA concentrations within cells remain fairly constant.

-RNA concentrations increase as protein synthesis increases.

-A recently well-fed, growing individual should have a high RNA:DNA ratio compared to a starving individual.



Instantaneous effects on growth
RNA:DNA (liver)
5
4
3
2
1
0
a
ab
b
no data
Yellow perch
June
Aug
Sep
(hypoxia)
Oct
3
2
1
0
a
a
a
no data
Rainbow smelt

Effects of Hypoxia in Lake Erie.

- Distributions of perch and smelt.
  - Lower overall catches during hypoxia.
  - Avoid bottom waters during hypoxia.
- Diets of perch and smelt.
  - ↑Zooplankton; ↓Benthic invertebrates
  - Ration may be affected
  - Seasonal patterns may mask hypoxia effects
- Condition/Growth of perch and smelt.
  - Potential cumulative and instantaneous growth effects
  - Seasonal patterns may mask hypoxia effects

high

Strength of evidence

low

Inter-disciplinary, collaborative research projects

1) IFYLE (International Field Years on Lake Erie)

2) ECOFORE (Assessing the causes, consequences, and potential remedies for Lake Erie hypoxia)

ECOFORE 2006-2011: Assessing the causes, consequences, and potential remedies for Lake Erie hypoxia

www.sitemaker.umich.edu/ecoforelake.erie/home

- **$2.2 million from NOAA's Center for Sponsored Coastal Ocean Research**
- **Integrated Assessment (IA) Framework**
- **Multiple-model, ensemble approach**

Project goals: Create and apply models to forecast how anthropogenic (land use, invasive species) and natural (climatic variability) stresses influence hypoxia formation and the ecology of the system with an emphasis on fish production potential.

Project Components

Use a linked set of models to forecast:

I. Watershed Loading — *changes in nutrient loads to Lake Erie*

↓

II. Hypoxia — *responses of central basin hypoxia to multiple stressors*

↓

III. Ecological Effects — *potential ecological responses to changes in hypoxia*

Research Team

Watershed Team	Affiliation
Dave Allan	UM
Tom Croley	NOAA/GLERL
David Dolan	U. Wisc.
Peter Richards	Heidelberg
Changsheng He	WMU

Hypoxia Team	Affiliation
Don Scavia (PI)	UM
Joe DePinto	Limno-Tech
Dmitry Beletsky	UM
David Schwab	NOAA/GLERL
Steven Ruberg	NOAA/GLERL
Tom Johengen	UM
Henry Vanderploeg	NOAA/GLERL

Ecological Effects Team	Affiliation
Tomas Hook	UM
Larissa Sano	MCBI
Stuart Ludsin	OSU
Edward Rutherford	UM
Doran Mason	NOAA/GLERL
Stephen Brandt	NOAA/GLERL
Steve Bartell	E2, Inc
Roger Knight	OH-DNR

I. Watershed Loading

1) Estimate TP loads for all tributaries
   - Data from Heidelberg College, point sources
   - Examine sensitivity of loads to hydrologic variation

2) Quantify mass balance estimates for watersheds
   - Construct P budgets
   - Develop time sequence of P loadings
   - Compare inputs to exports

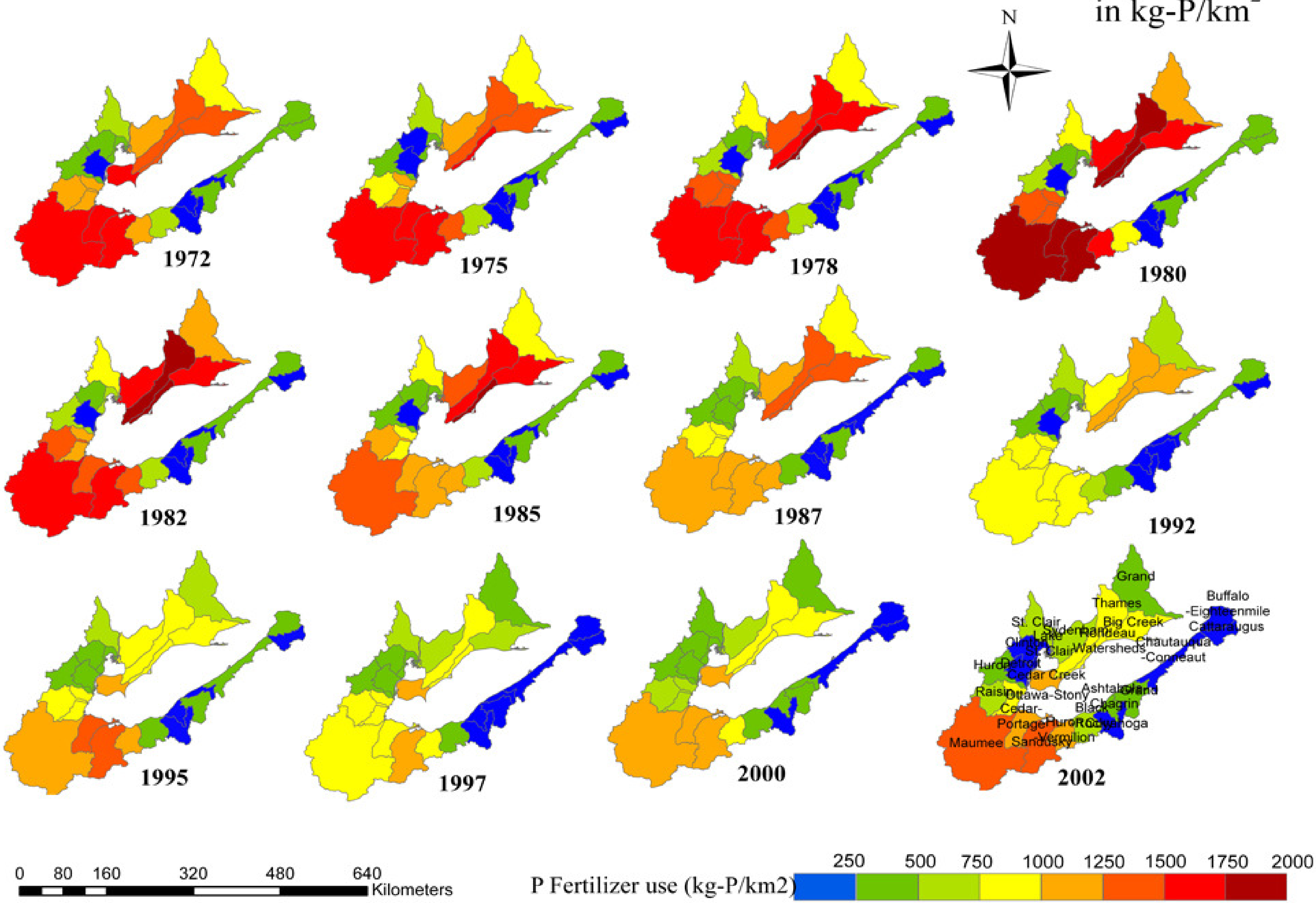
3) Evaluate conservation practices
   - Statistical analysis
   - Watershed agricultural estimates
   - Correlations between conservation and nutrient loading

4) Develop models of hydrology and nutrient export
   - Soil and Water Assessment Tool (SWAT)
   - Distributed Large Basin Runoff Model (DLBRM)

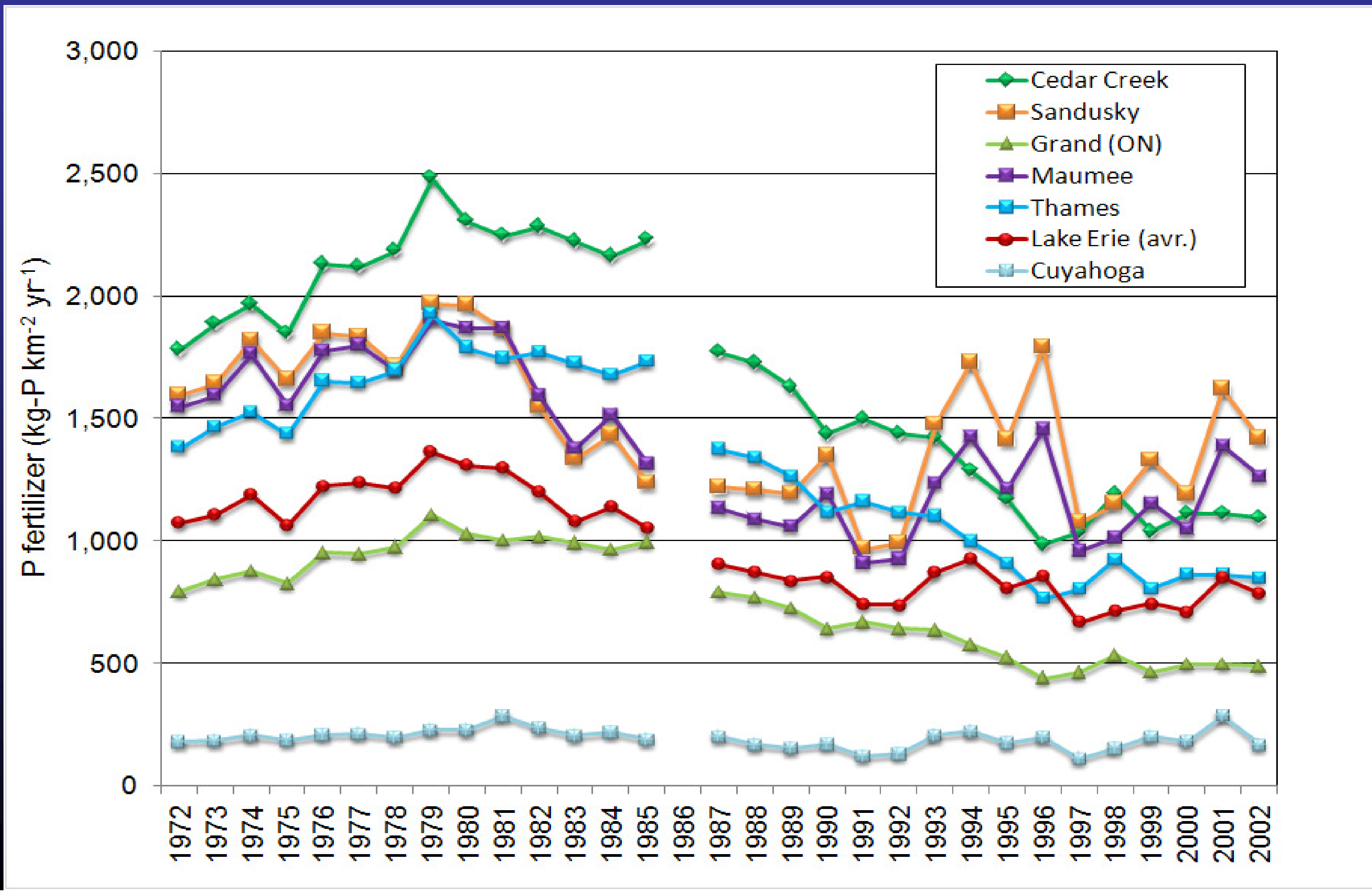
-inputs for hypoxia models

Study sites: 24 Lake Erie watersheds

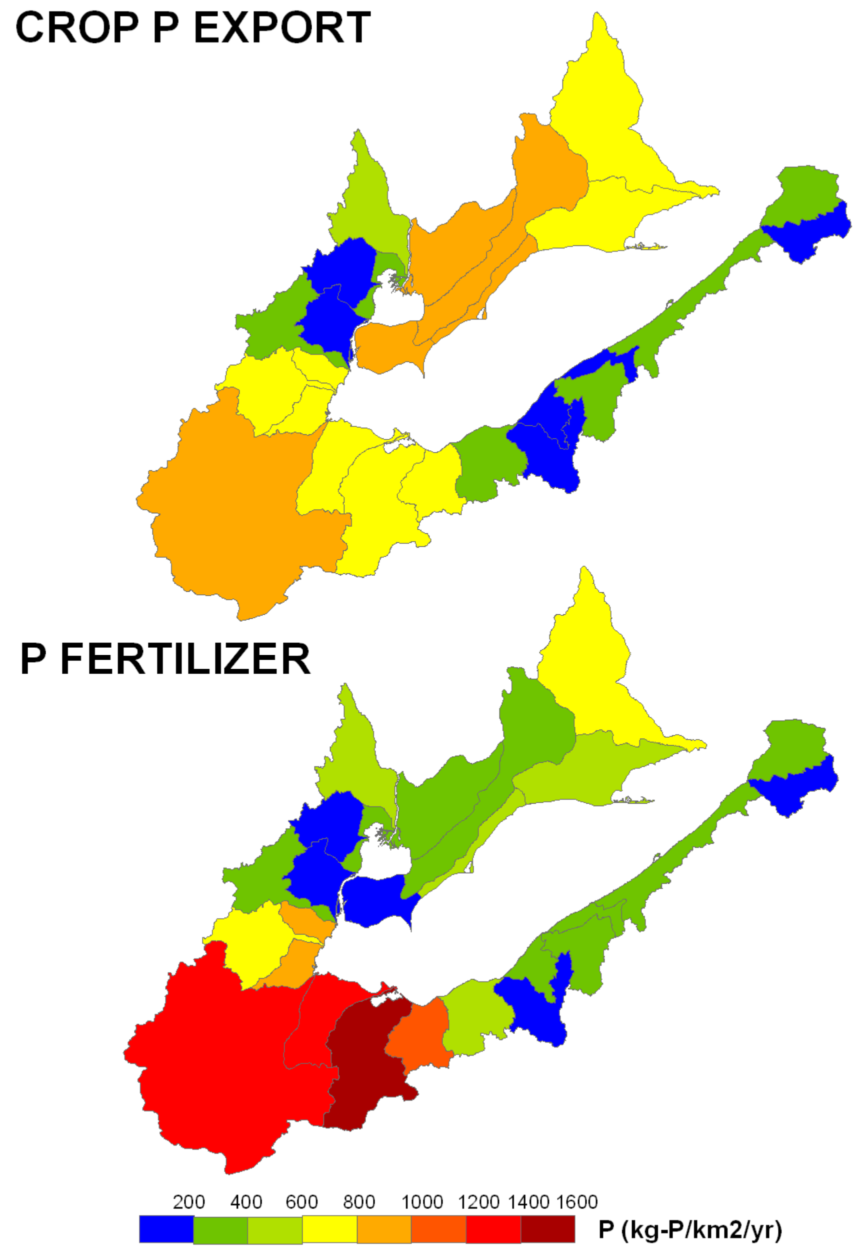
P Fertilizer use for the Lake Erie watersheds from 1972 to 2002



Historical trend in annual P fertilizer input to selected watersheds and the entire LEB from 1972 to 2002



2002
Fertilizer P input
&
Crop P harvest



II. Hypoxia Forecasting Modeling Approaches

- Models ranging in complexity
  - 1D hydrodynamics with DO consumption rates
    - Vertical thermal and mixing profiles from hydrodynamic model
    - DO mass lost from water column and sediment demand
  - 1D hydrodynamics with simple mechanistic WQ model
    - TP, Carbon, Solids mechanisms driven by central basin concentrations as boundary conditions
  - 1D hydrodynamics with simple mechanistic WQ model
    - TP, Carbon, Solids mechanisms driven by basin loads
  - 3D hydrodynamics with complex mechanistic WQ model
    - WQ framework similar to Chesapeake Bay ICM model
    - Multi-class phyto- and zooplankton, organic and inorganic nutrients, sediment digenesis, etc
    - Addition of zebra mussels

-inputs for hypoxia models

Calibrated Model Performance

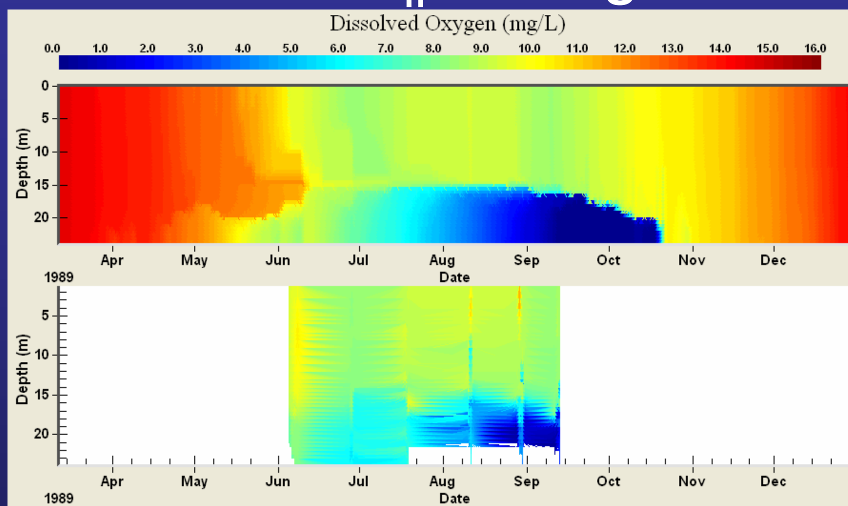
-SOD = 0.75 g/m2/d

-$WCOD_e$ = 0.0 g/m3/d

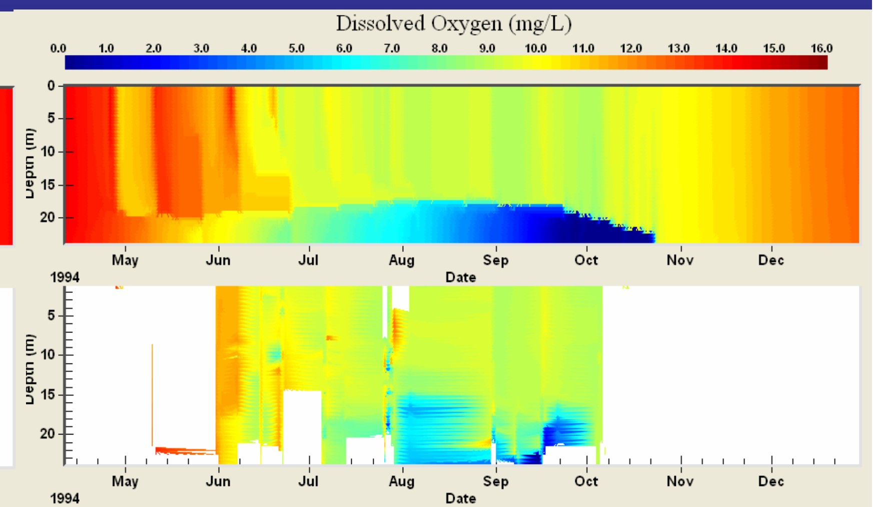
1989 $WCOD_h = 0.06\ g/m^3/d$

Model

Data



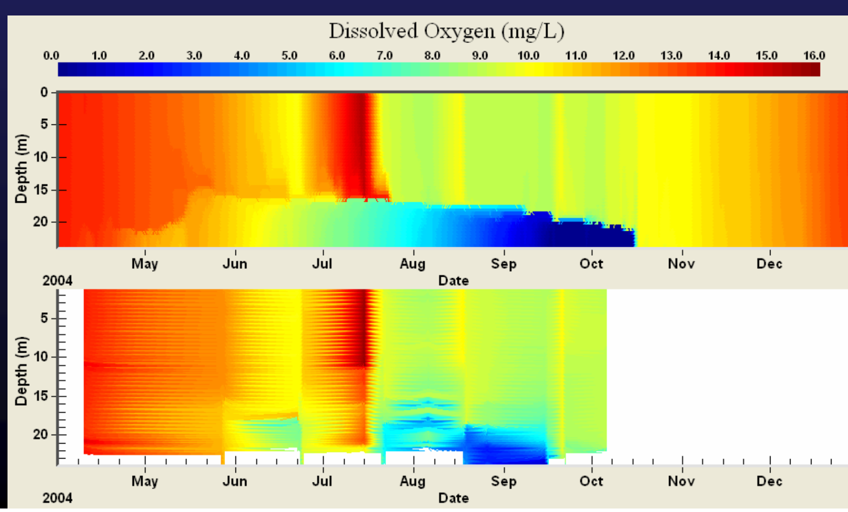
1994 $WCOD_h = 0.002\ g/m^3/d$



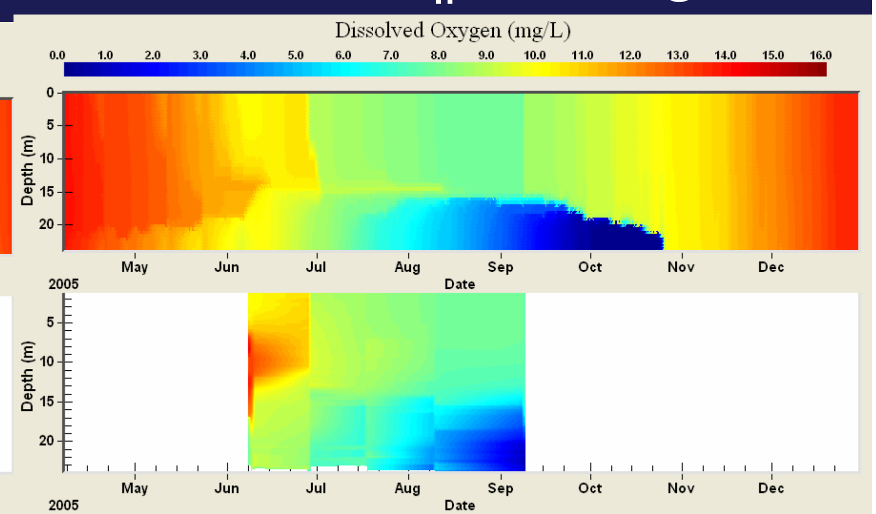
2004 $WCOD_h = 0.020\ g/m^3/d$

Model

Data

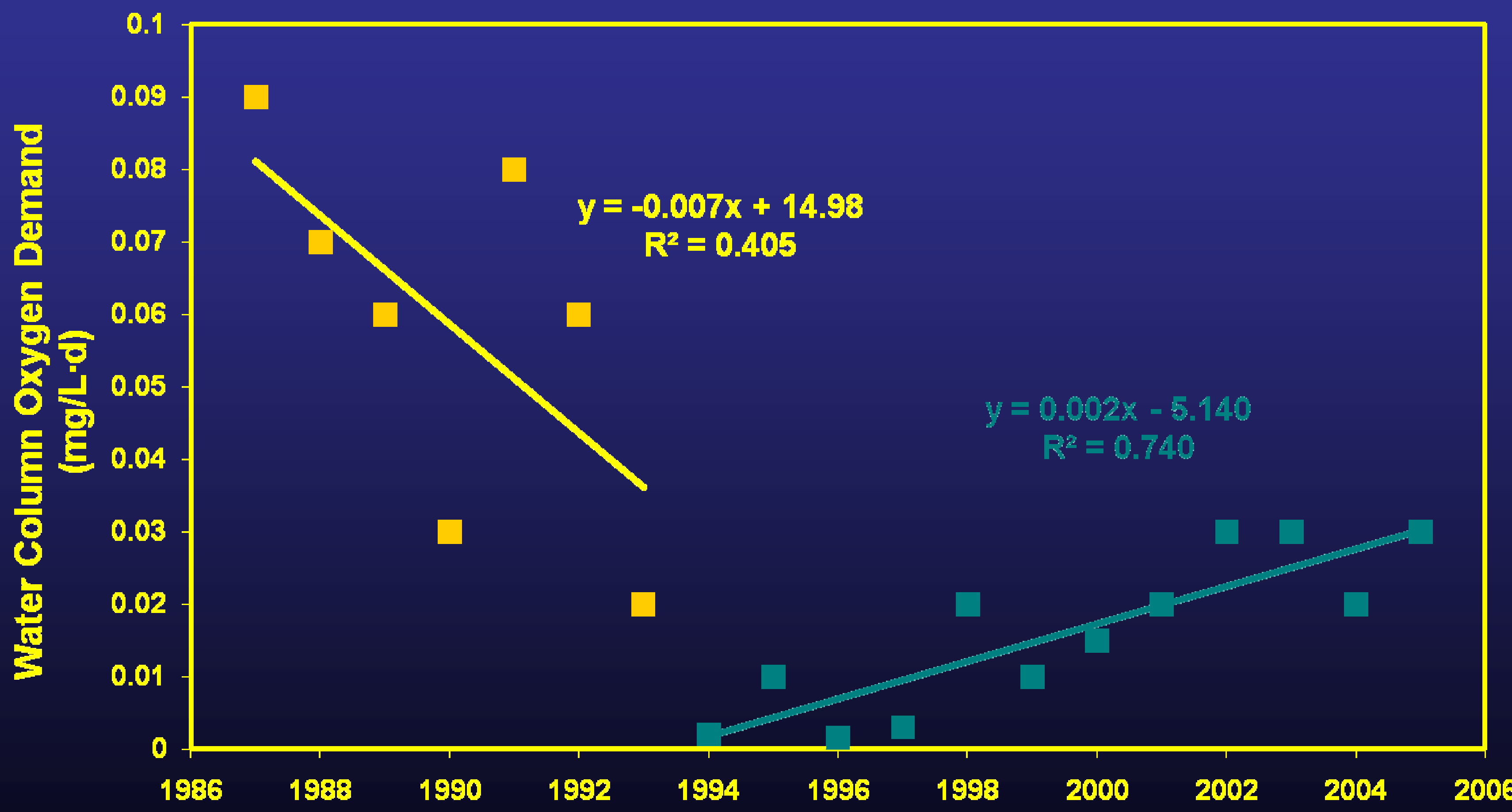


2005 $WCOD_h = 0.030\ g/m^3/d$



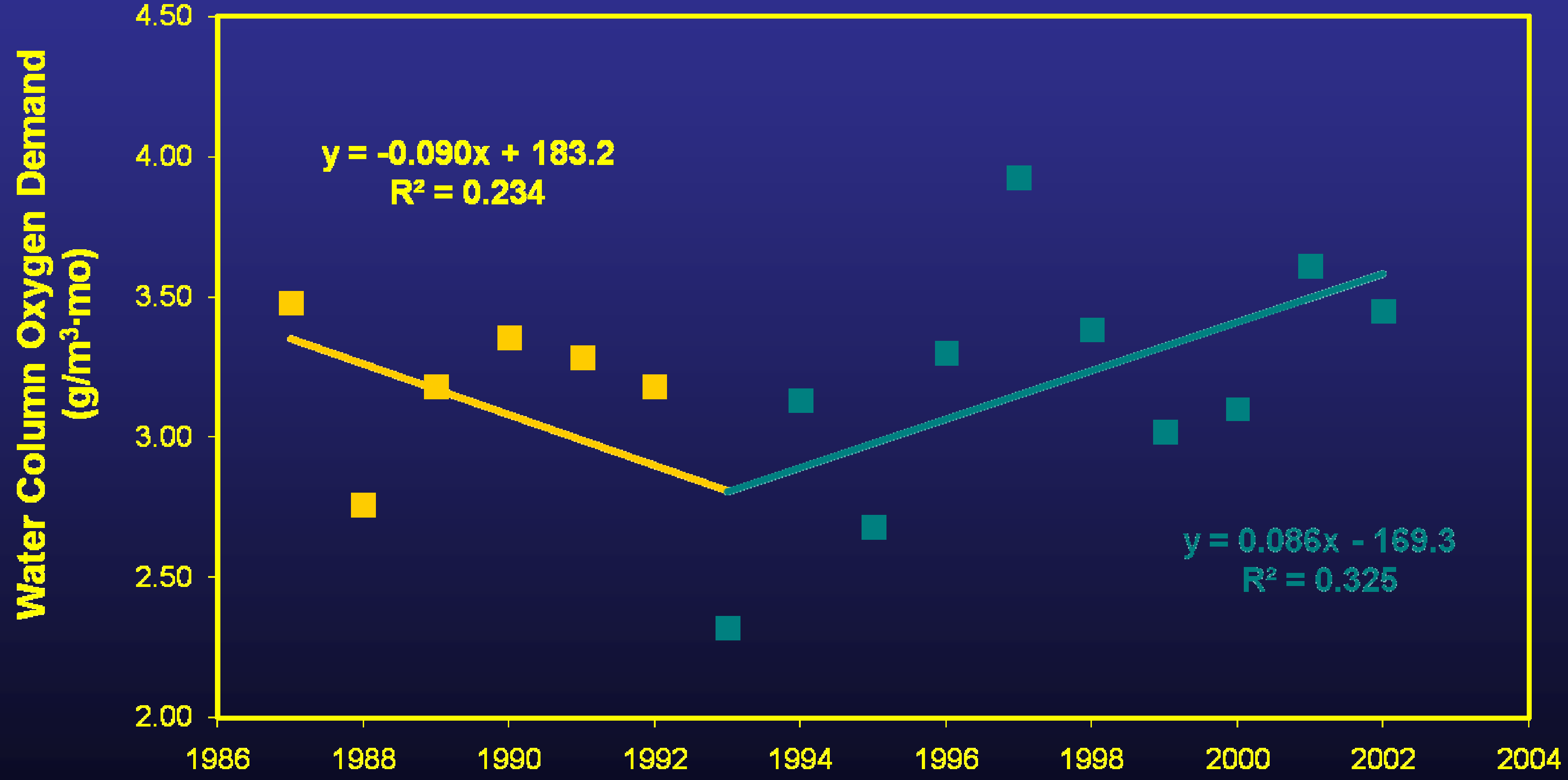
Central Basin Oxygen Depletion Rate

Using tentative alternate method, Rucinski et al. (in prep)

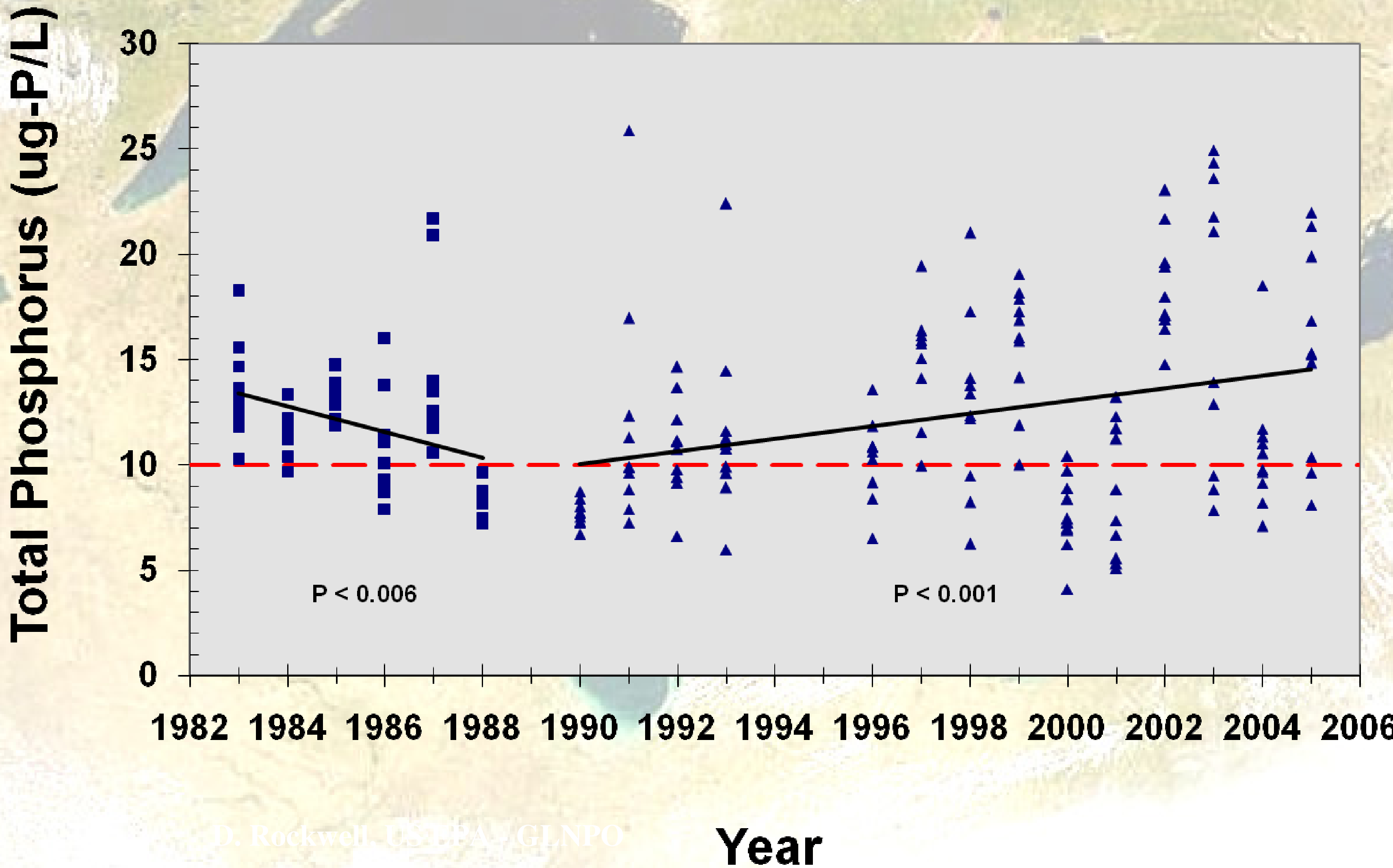


Central Basin Oxygen Depletion Rate

D. Rockwell, GLNPO, using Rosa and Burns (1987)



Central Lake Erie Total Phosphorus



III. Ecological Effects

<u>Objective</u>: develop forecasts that managers can use to guide fisheries policies in response to anticipated hypoxia impacts.

<u>Ensemble of Models</u>

- *<u>Statistical models</u>*
- *<u>Bioenergetics-based population models</u>*
  - *Growth Rate Potential (GRP)*
  - *IBM (Individual Based Bioenergetics)*
- *<u>Food-web models</u>*
  - *Comprehensive Aquatic Simulation Model (CASM)*
  - *EcoPath with EcoSim and EcoSpace*

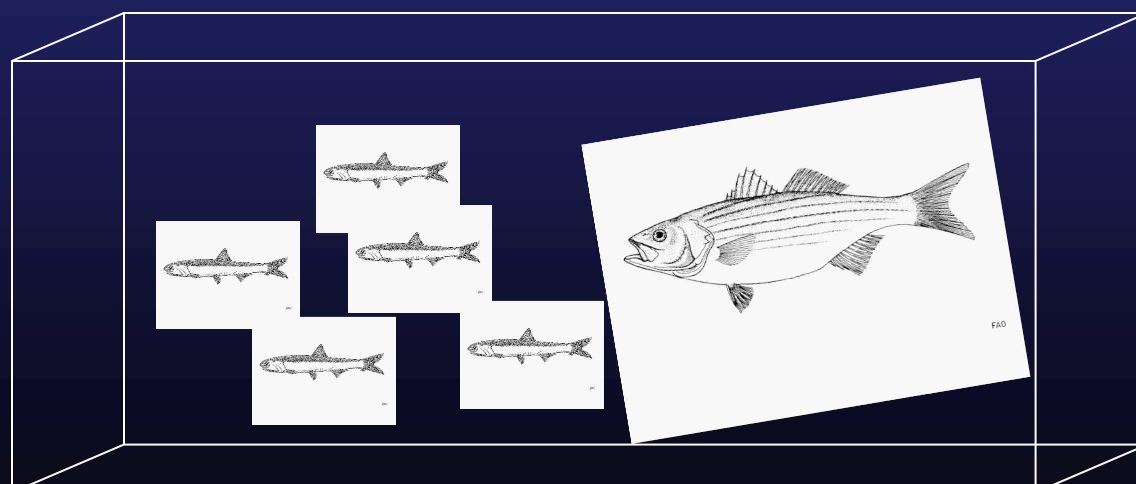
<u>Growth rate potential models (GRP)</u>

Bioenergetic Growth Rate Potential (GRP; g g^{-1} day^{-1}):

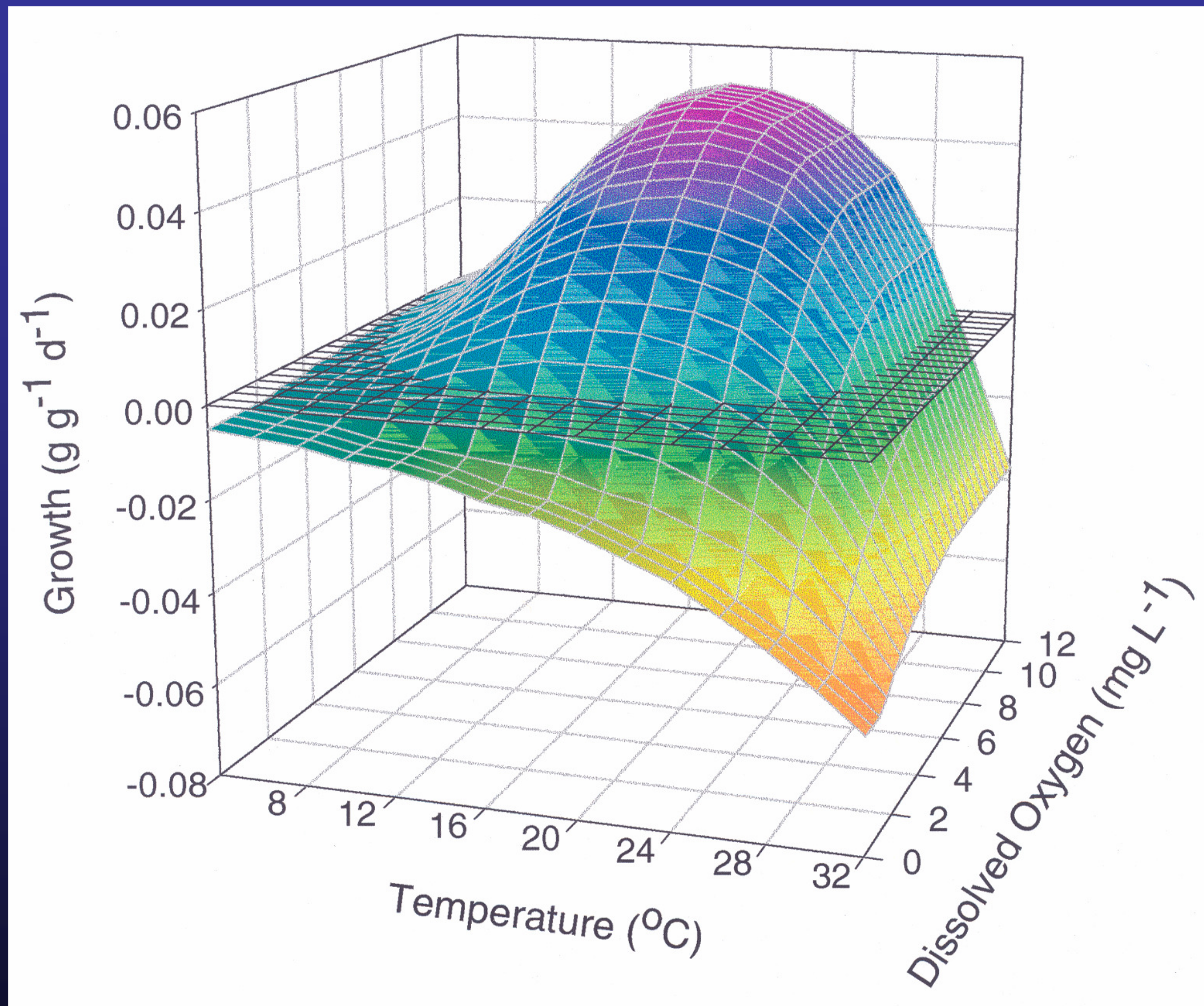
Expected daily growth rate of a fish placed in a volume of water with known conditions:

<u>Potential input variables:</u>

- prey density (prey type, prey size)
- temperature
- oxygen
- light



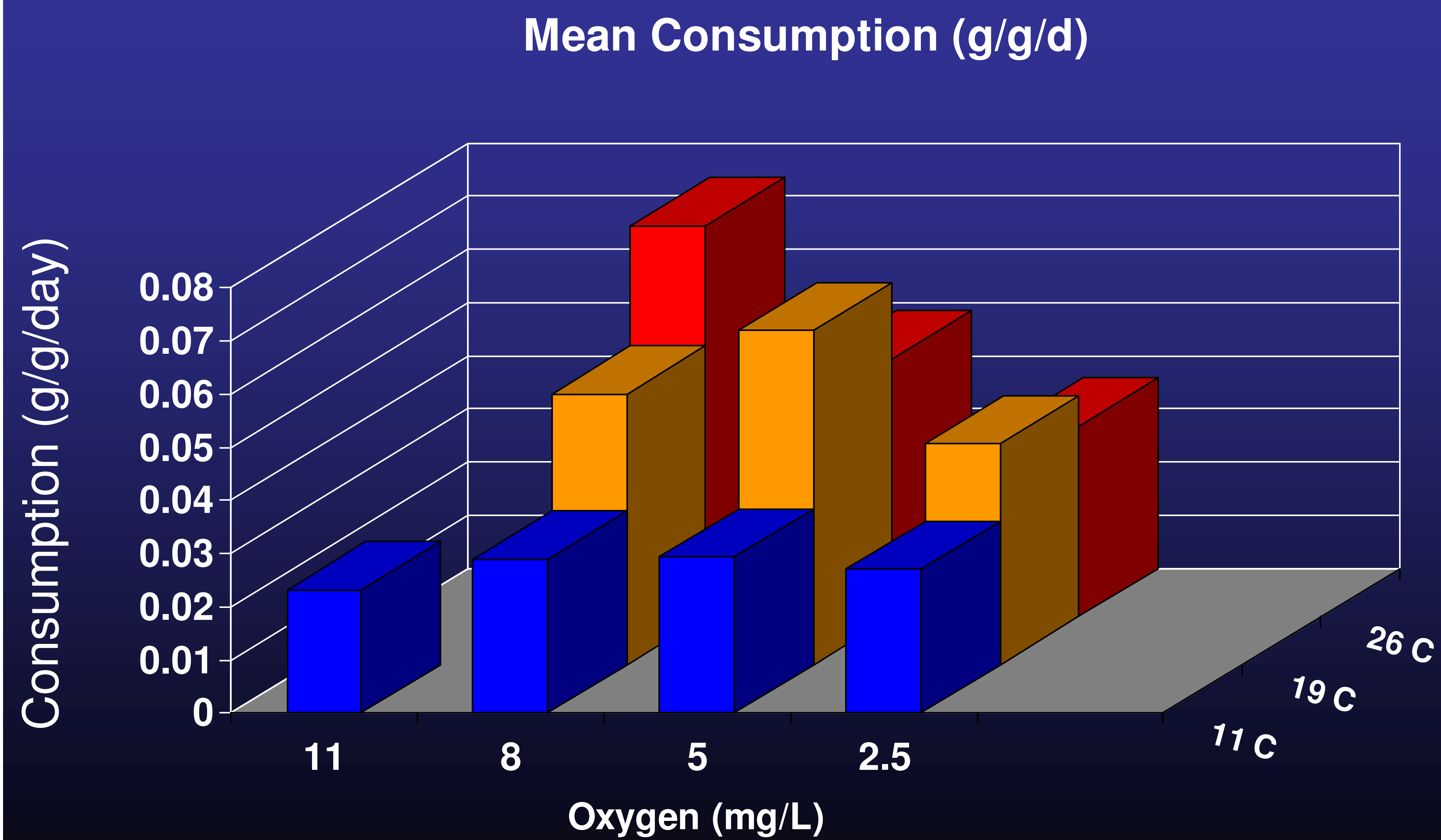
Growth rate potential models (GRP)



Effect of oxygen on consumption/growth of yellow perch not quantified.

Effect of hypoxia on consumption

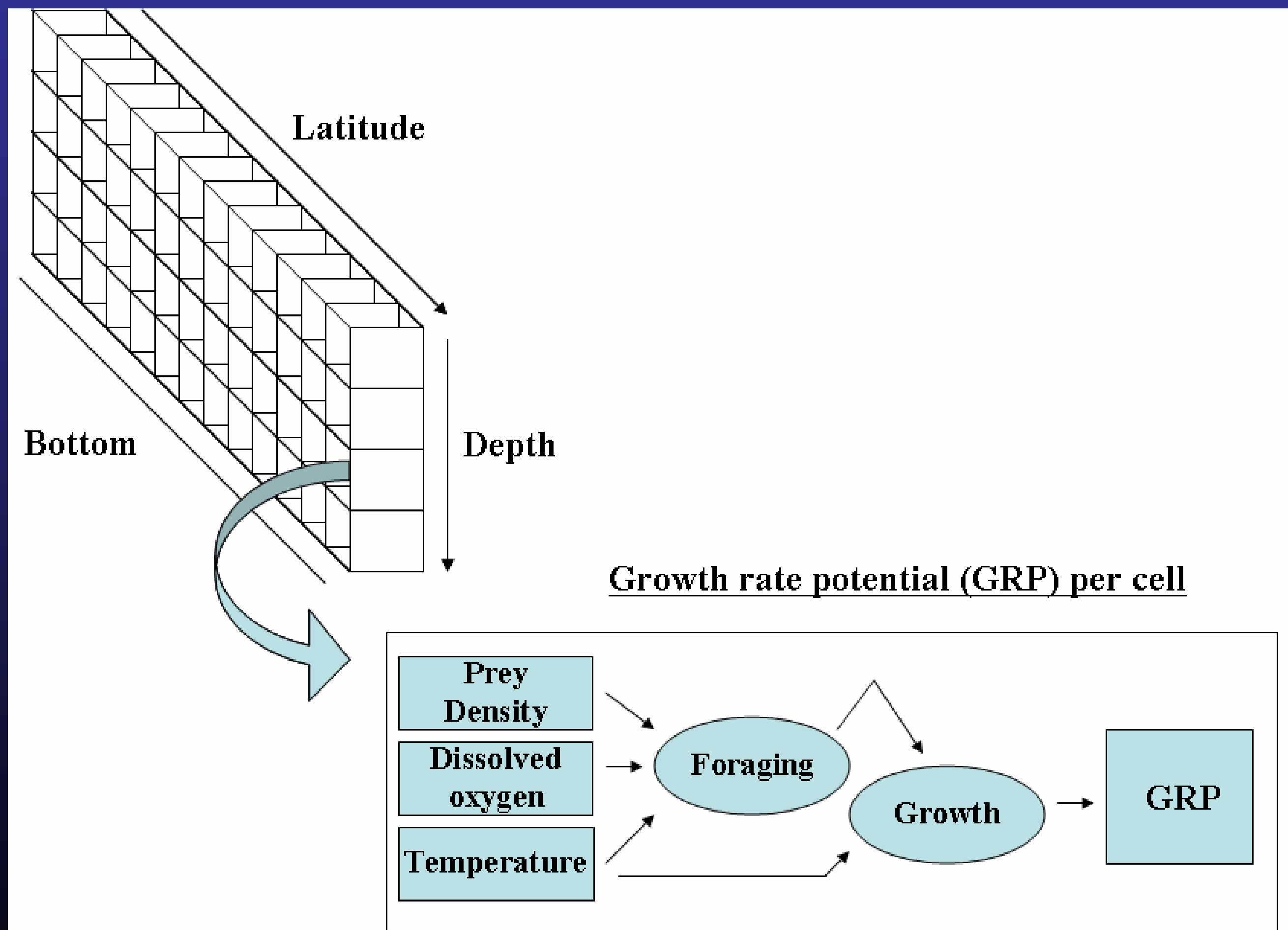
Effect of hypoxia on consumption



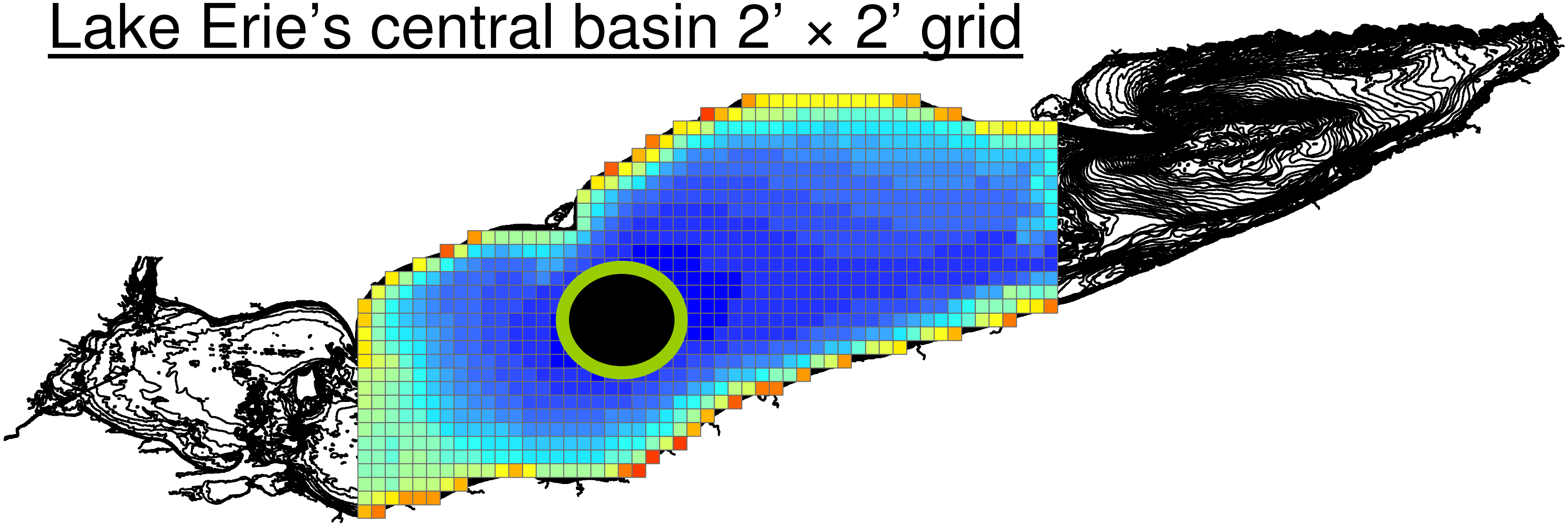
Roberts, Utrup, Höök (unpublished)

Growth rate potential models (GRP)

Spatially-explicit GRP (g g^{-1} day^{-1})



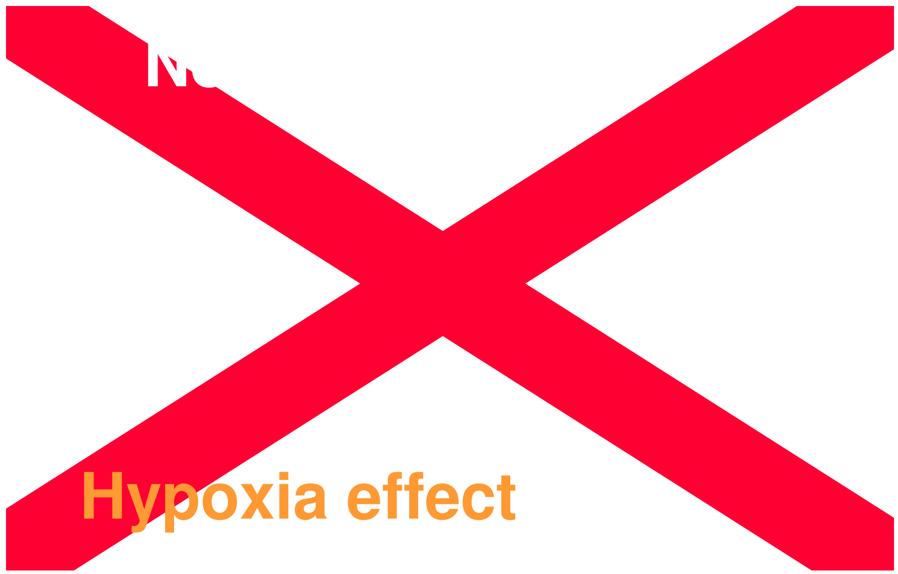
Lake Erie's central basin 2' × 2' grid



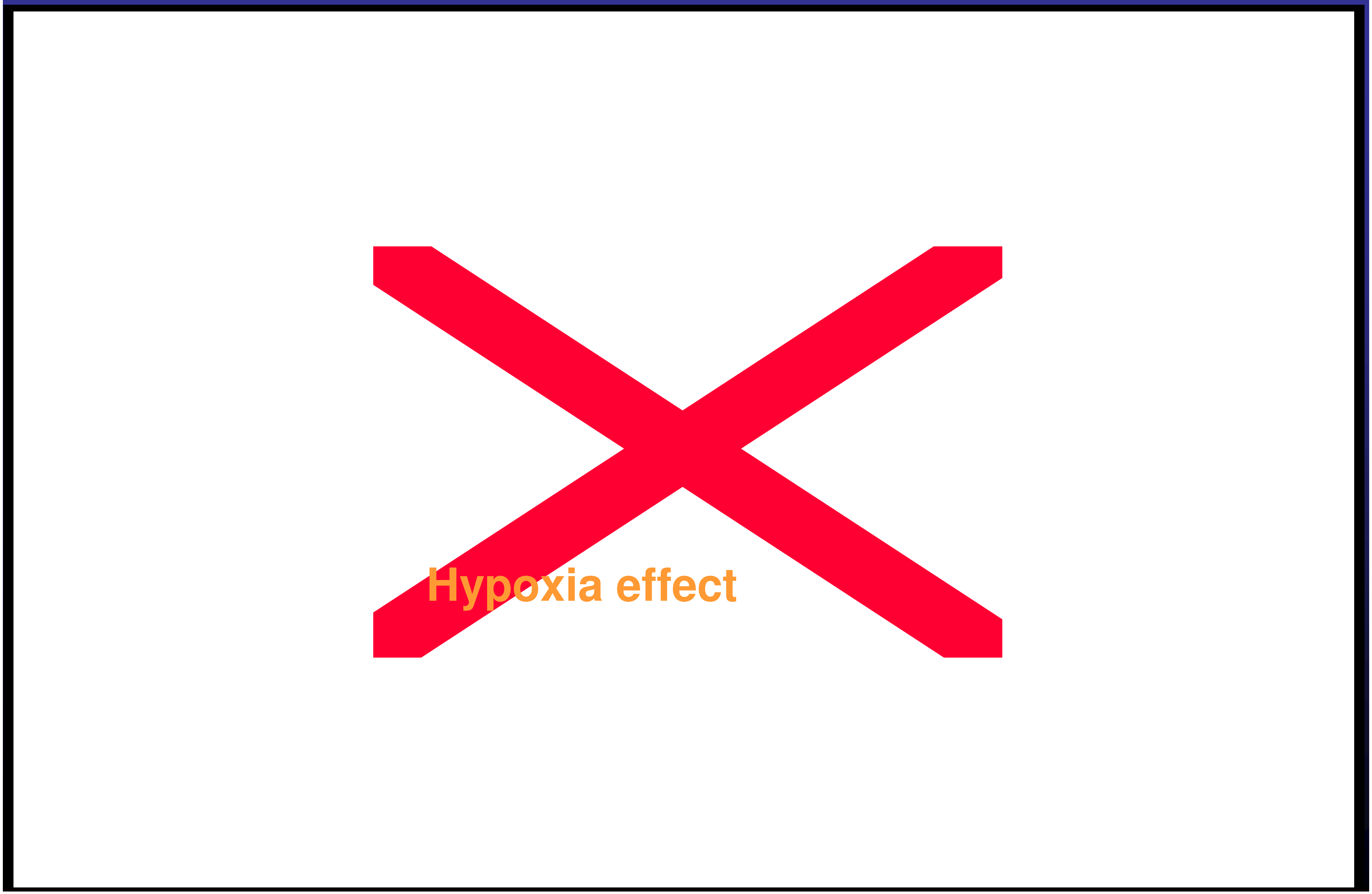
-Output from 1-D hypoxia model to populate daily mean temperatures and oxygen concentrations in bottom waters of central basin.

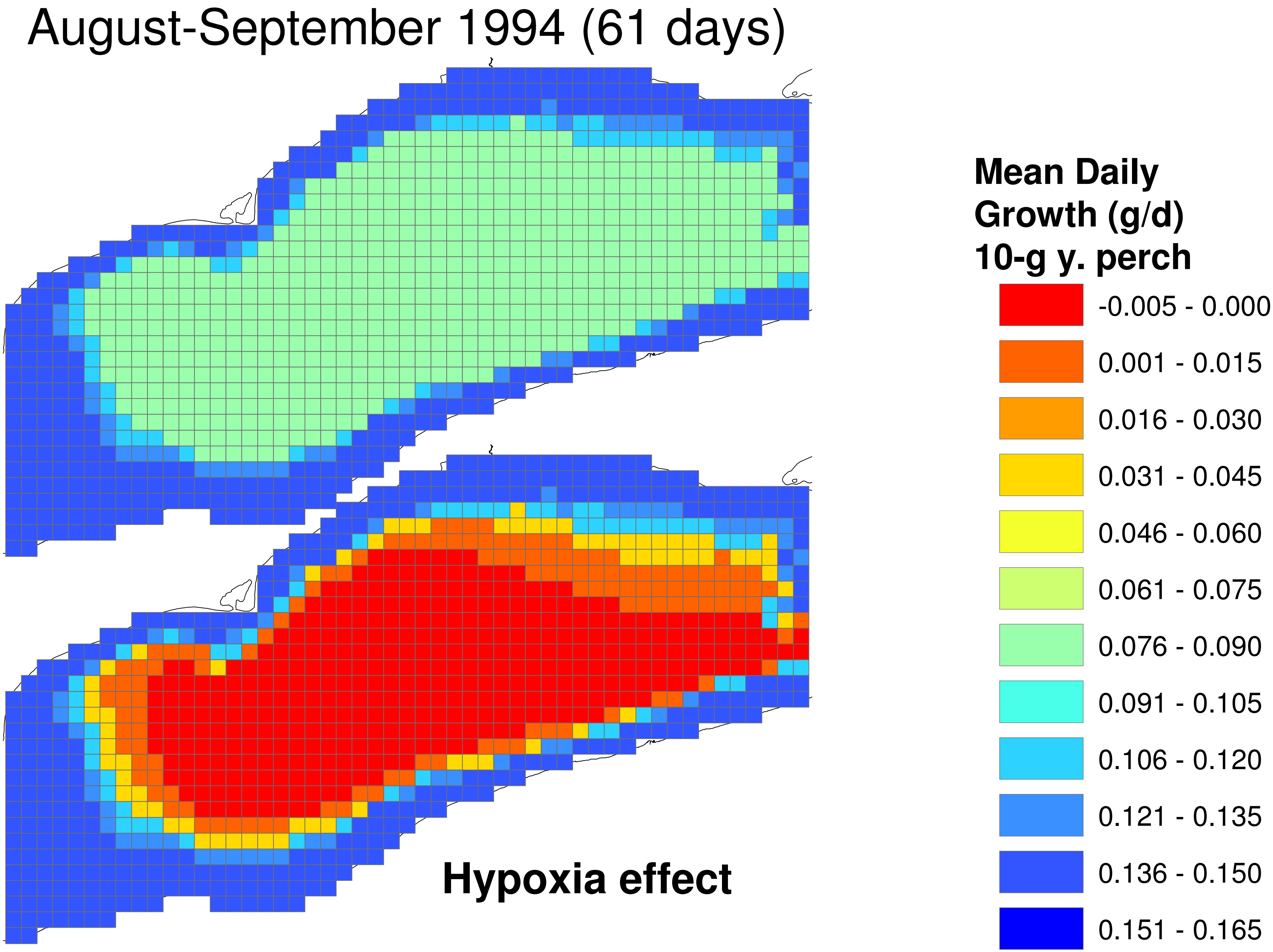
-Use these values as input for growth rate potential model.

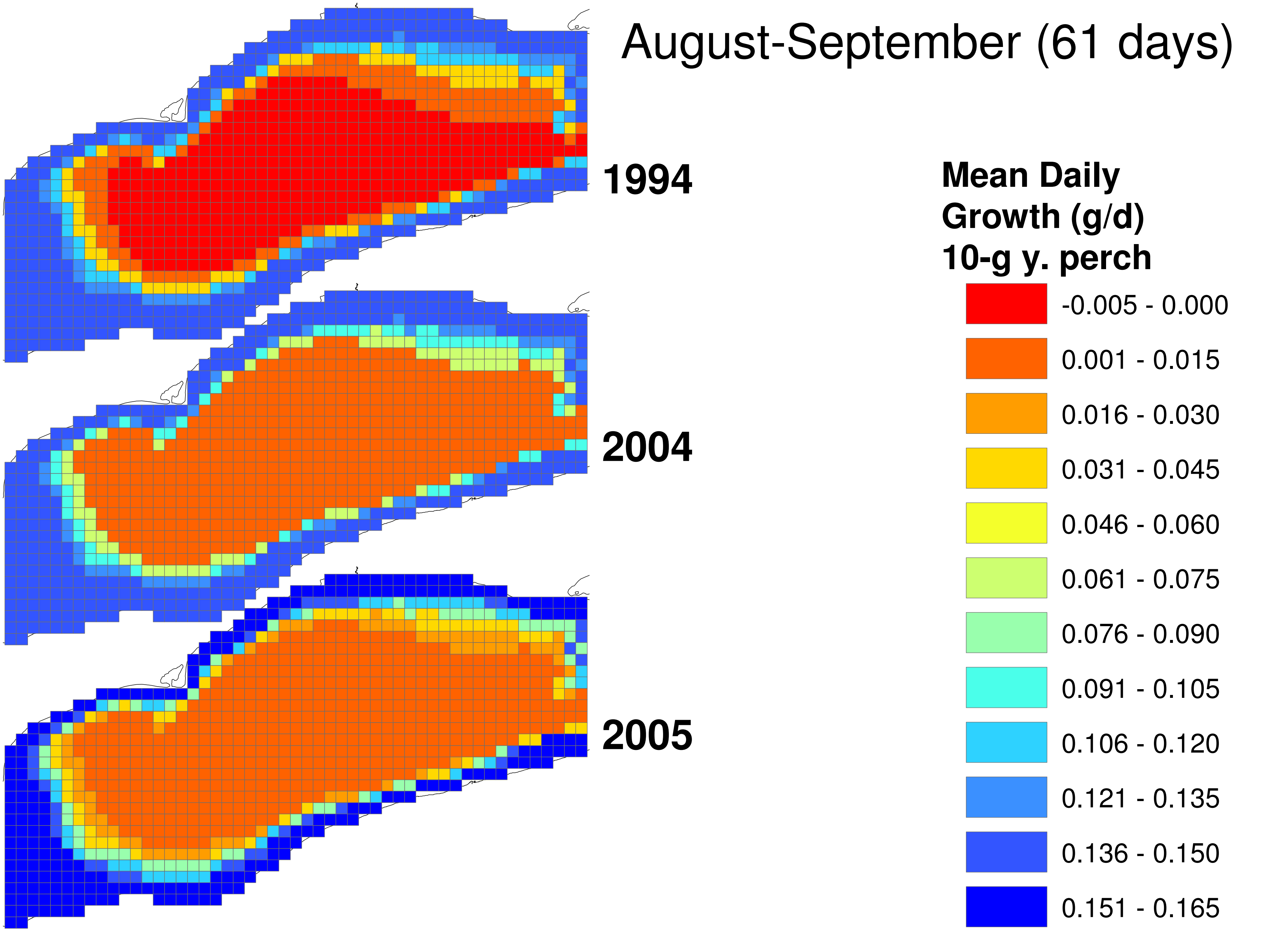
Daily consumption potential of 10-g yellow perch in hypolimnion of offshore Lake Erie during 1994



Daily growth potential of 10-g yellow perch in hypolimnion of offshore Lake Erie during 1994



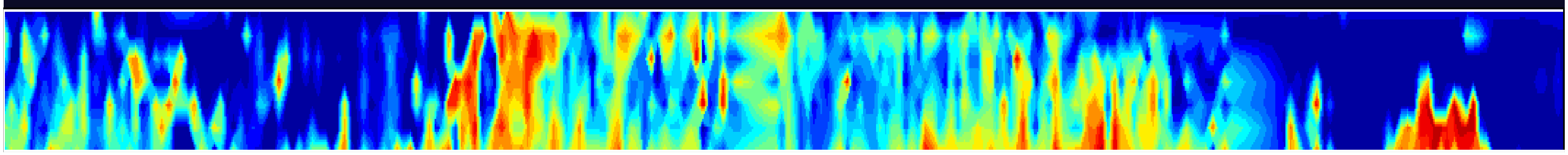

August-September 1994 (61 days)
Hypoxia effect
Mean Daily
Growth (g/d)
10-g y. perch
-0.005 - 0.000
0.001 - 0.015
0.016 - 0.030
0.031 - 0.045
0.046 - 0.060
0.061 - 0.075
0.076 - 0.090
0.091 - 0.105
0.106 - 0.120
0.121 - 0.135
0.136 - 0.150
0.151 - 0.165



August-September (61 days)
1994
2004
2005
Mean Daily
Growth (g/d)
10-g y. perch
-0.005 - 0.000
0.001 - 0.015
0.016 - 0.030
0.031 - 0.045
0.046 - 0.060
0.061 - 0.075
0.076 - 0.090
0.091 - 0.105
0.106 - 0.120
0.121 - 0.135
0.136 - 0.150
0.151 - 0.165

Conclusions

- Huge hypoxic area in central Lake Erie
- Related to P-loading from western Lake Erie
- Magnitude of hypoxia may be increasing
- Effects on fish are evident at the individual level
- Population-level effects are equivocal



II. Hypoxia

- Develop and test two types of forecasting tools
  - 1-D Limnological Model
  - 3-D Limnological Model

- Assess the relative importance of three potential causative factors:
  - *Climate*
  - *Phosphorus inputs*
  - *Dreissenid invasion*