A Review of the EcoGEM Modeling Approach as applied to Narragansett Bay, RI

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Motivation, Rationale & Objectives

As part of a NOAA Coastal Hypoxia Research Program project:

Apply a novel, reduced complexity, parsimonious ecological model to predict hypoxia in Narragansett Bay.

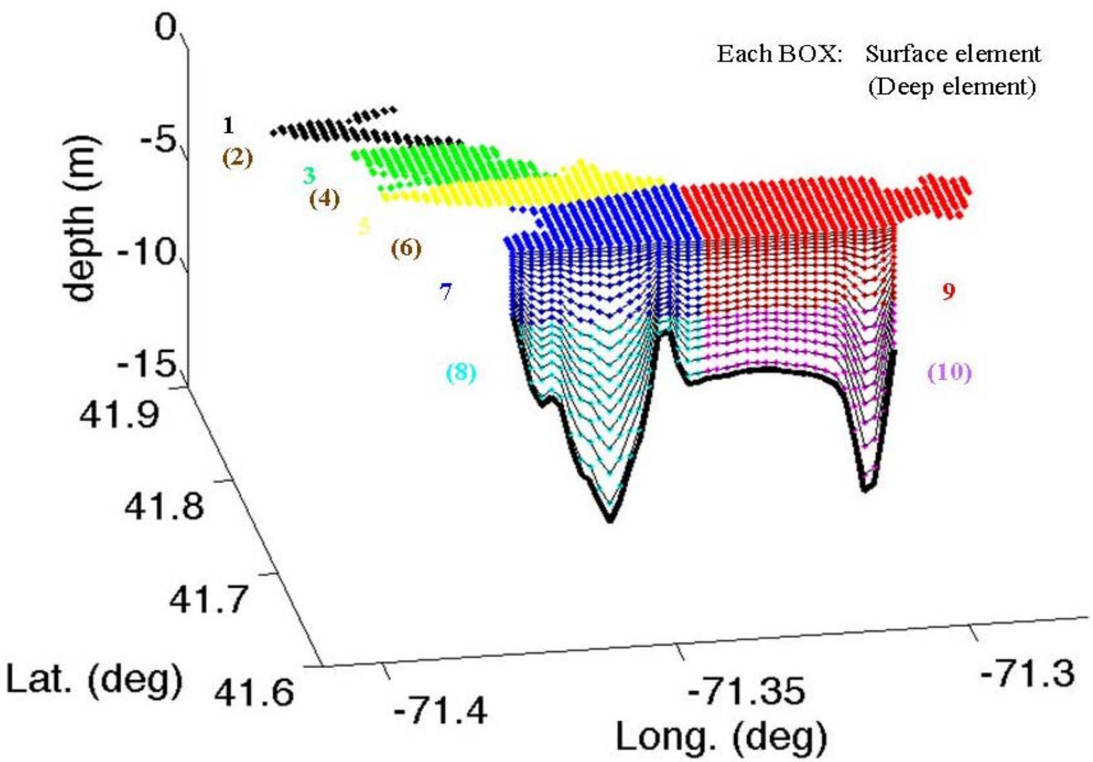
Implement within a fast running, coarse boxed scheme linked to a fine resolution hydrodynamic model.

Simulate responses to nutrient reductions and climate change.

Make the model available for direct use by managers.

linking ROMS to EcoGEM

Highly resolved hydrodynamic model (ROMS) linked to a coarse boxed scheme.



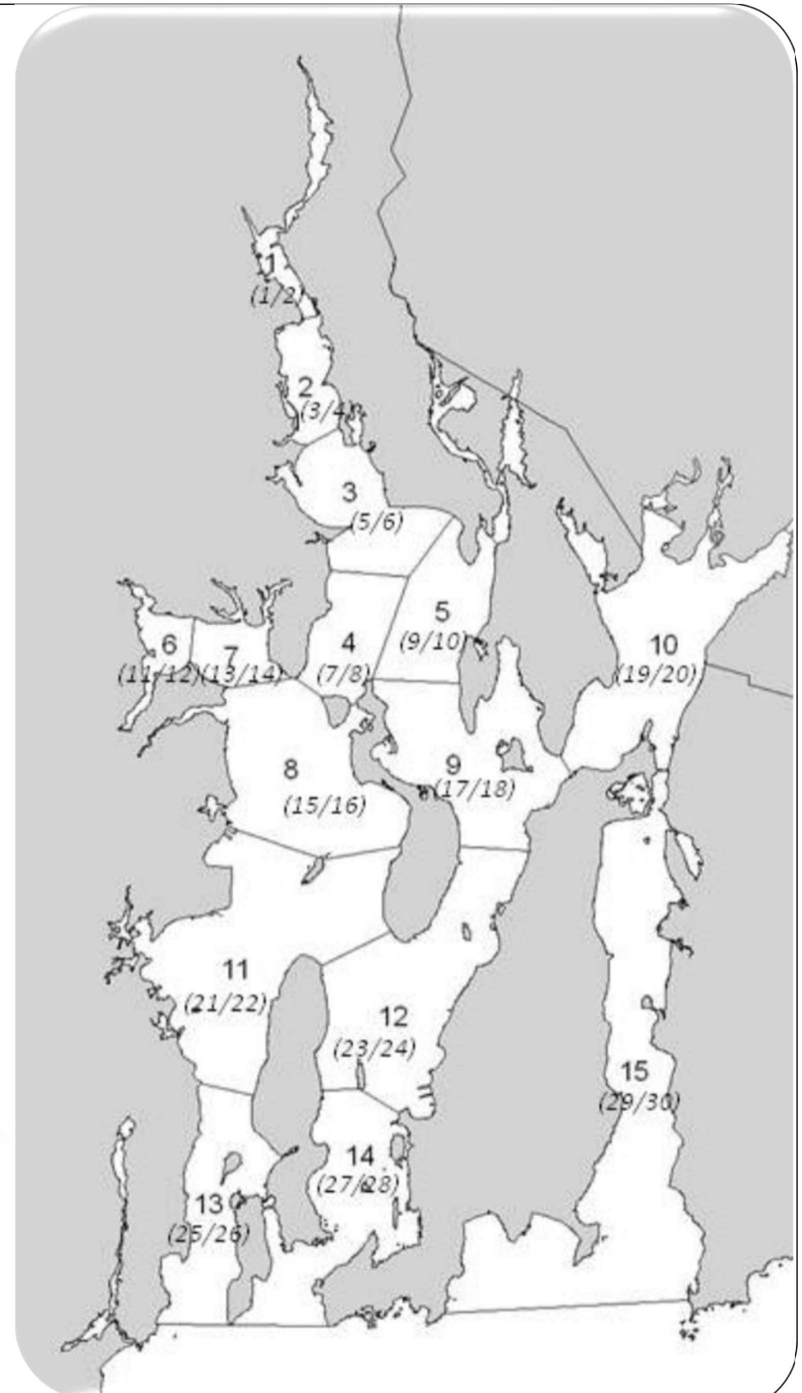


figure courtesy of Dave Ullman, URI

linking ROMS to EcoGEM

Dye initialized in an element at 12am each day, allowed to mix for 24h, fate of dye yields exchange coefficient for the day. Gross Exchange Matrix (GEM) is a 3-d array detailing exchange among all elements for each day.

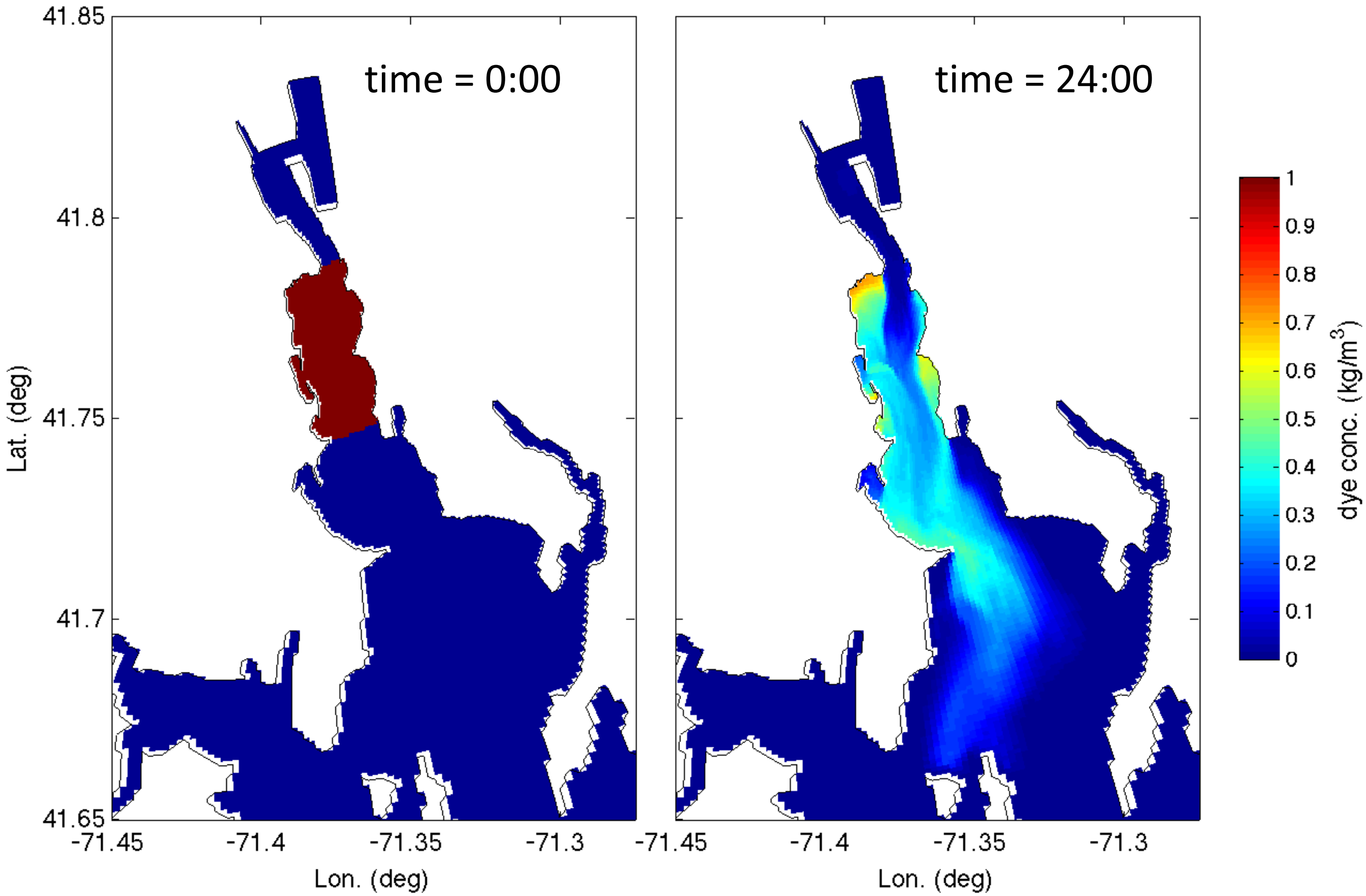
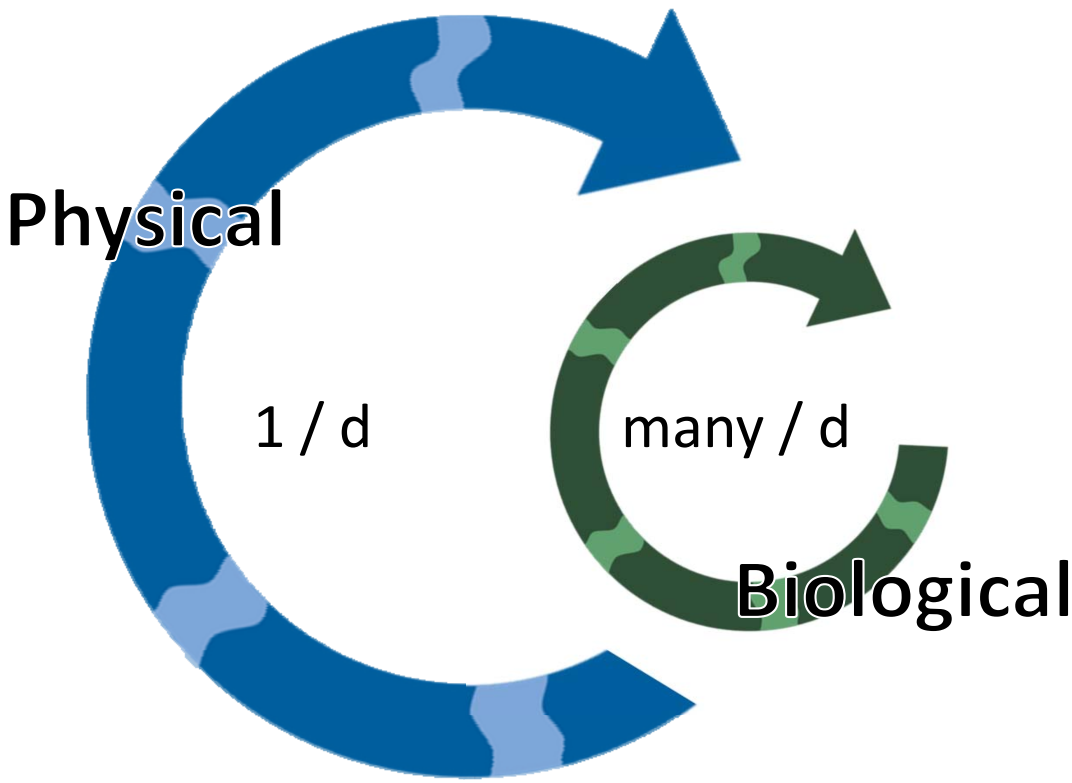


figure courtesy of Dave Ullman, URI

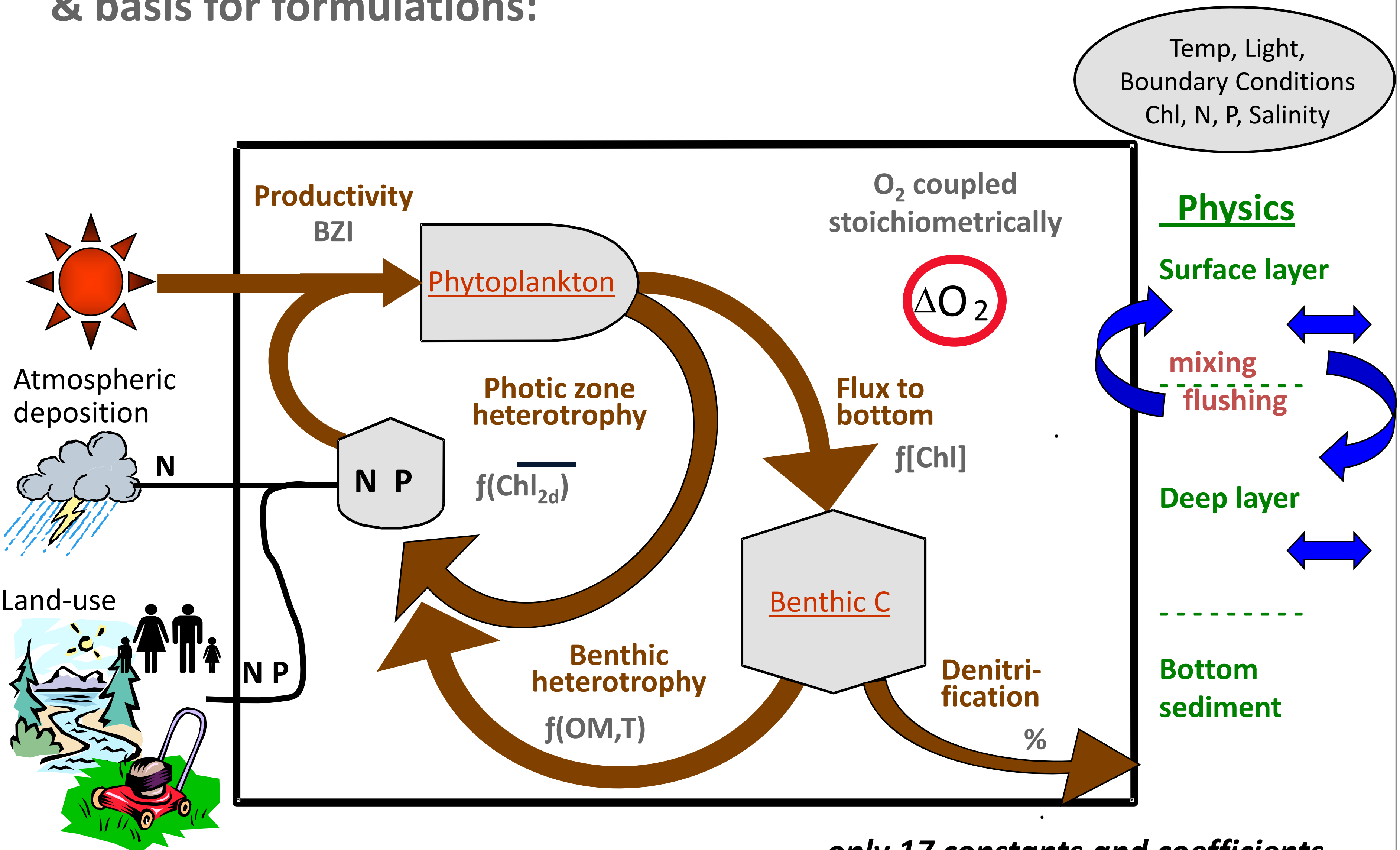
linking ROMS to EcoGEM

Structure of program:

- boxes are mixed at start of each day
- biology state variables are formulated as differential equations
- biology is allowed to integrate for 24 h (Runge-Kutte 3,4 integration scheme)



Processes of the model
& basis for formulations:



only 17 constants and coefficients

Ecology

Empirical Formulation of Key Rate Processes

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robust across many systems

Production: BZI → with a modification for 2 layers

Cole & Cloern: Estuarine phytoplankton productivity

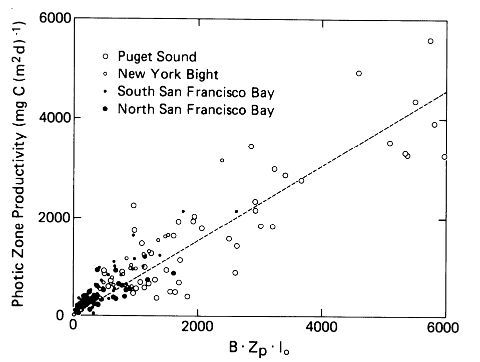
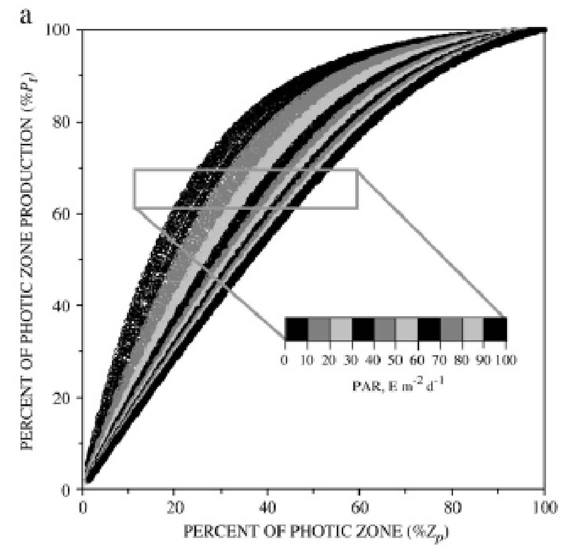
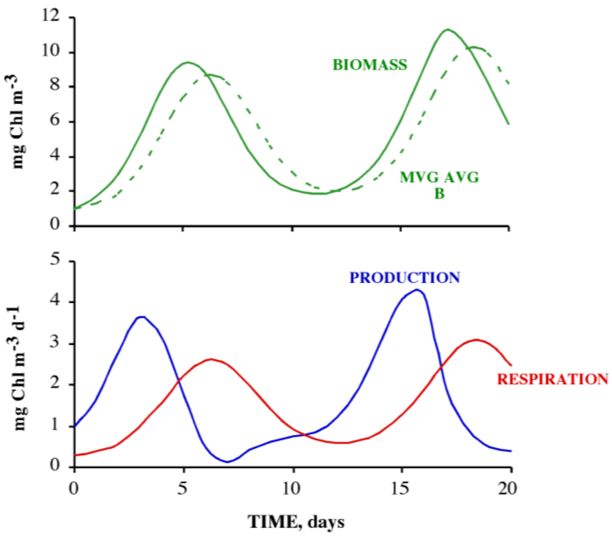


Fig. 2. Regression of photic zone productivity against the composite parameter $B Z_P I_o$ for 211 incubation experiments. $P = 150 + 0.73 (B Z_P I_o)$; $r^2 = 0.82$; S_{yx} (standard error of the estimate) = 410



Primary Prod : Respiration



Benthic Remin. : Primary Prod

Scott W. Nixon

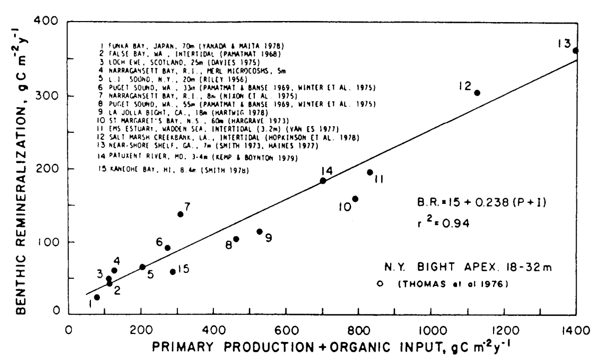


FIGURE 2. The relationship between the amount of organic matter fixed and imported and the amount of organic matter metabolized on the bottom over an annual cycle in a variety of coastal marine systems.

Denitrification

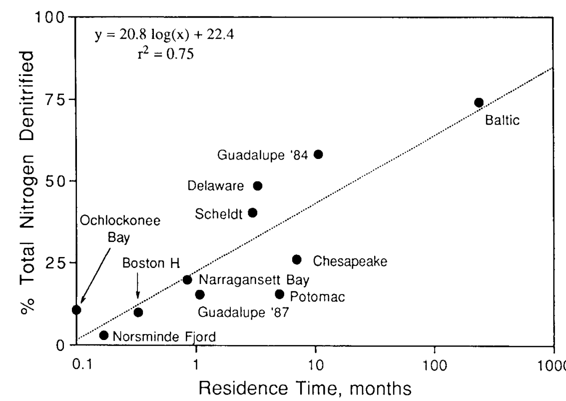


Figure 4. The fraction of total nitrogen input from land and atmosphere that is denitrified in various estuarine systems as a function of mean water residence time. Data sources as in Figure 1. The estimate for Delaware Bay is almost certainly too high because it is based on summer measurements only (see Table 5). Anoxic bottom waters over parts of Chesapeake Bay and the Potomac estuary may reduce the fraction of total N input that is denitrified.

Forcing Conditions

ROMS forcing functions described by Dave Ullman

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light from Eppley Labs, Newport, RI

wind from T.F. Green Airport

for exchange of oxygen with the atmosphere

precipitation from T.F. Green Airport

for nutrient loads from wet and dry deposition

water temperature from ROMS

Boundary Conditions

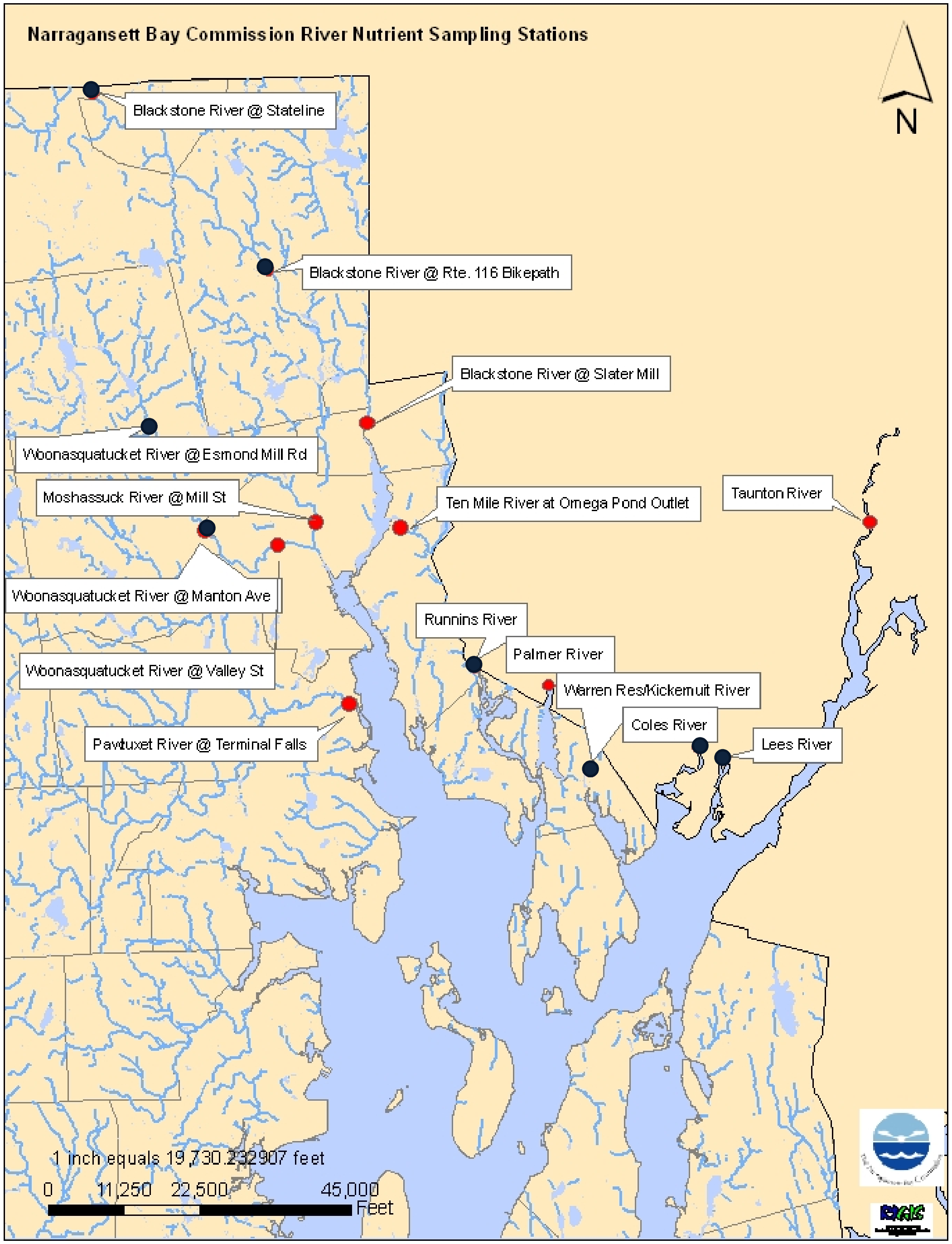
assume salt = 0 ppt in rivers

benthic carbon is not transferred among elements

N and P = river concentration * flow (m^3)

phytoplankton = surface buoy data at boundary

oxygen = surface buoy data at boundary

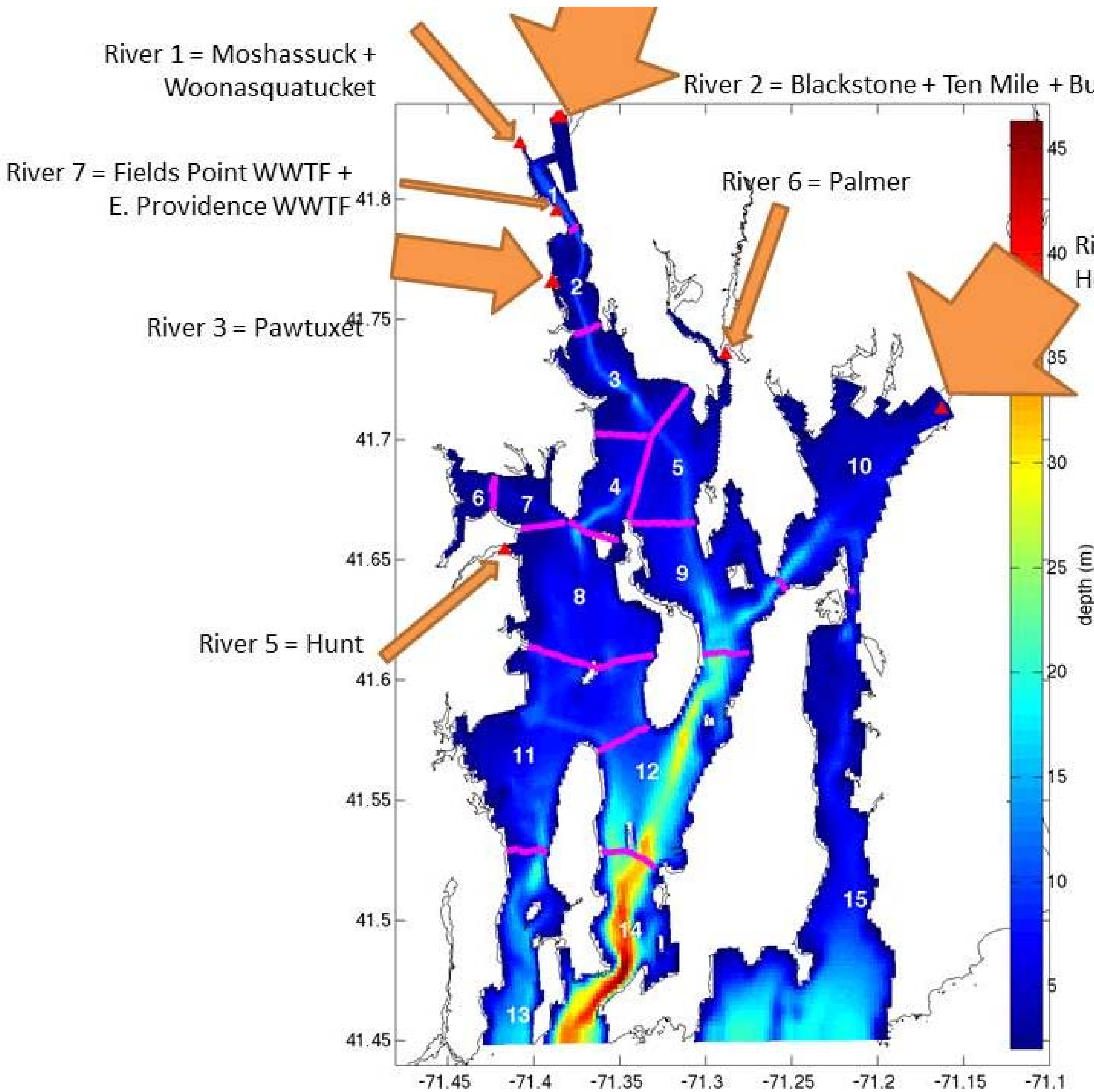


boundary conditions

N and P

concentration from NBC data (•) or WWTF data – linear interpolation between dates for missing days

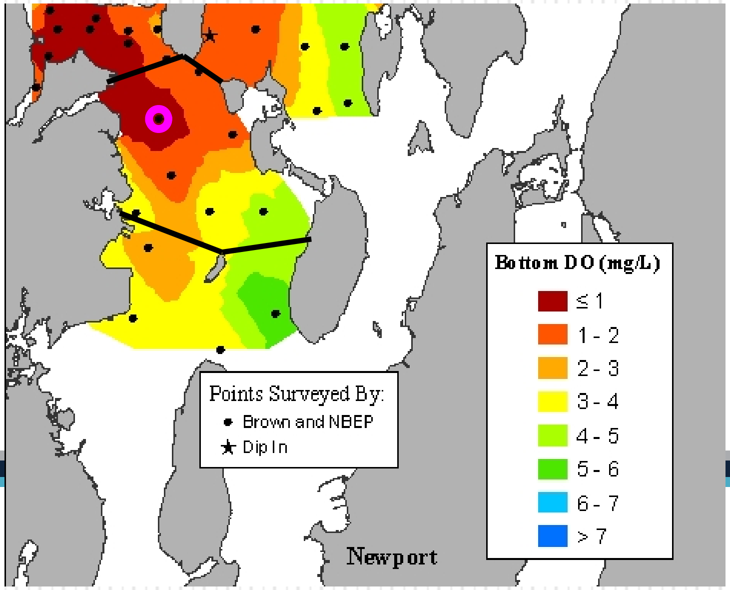
flow from ROMS model, partitioned based on USGS river flow data *boundary conditions*



width of arrows indicate relative magnitude of volume input

skill

Skill Assessment



Data Discrepancy

Model predicts a box-wide, daily average. Field data are not strictly comparable:

- buoys – a fixed location, 15 minute data (can get daily average)
- CTD surveys – many locations, but infrequent (can get box-wide average)
- nutrient and productivity surveys – few locations, few dates

A "perfect skill" is not expected and is highly unlikely.

skill

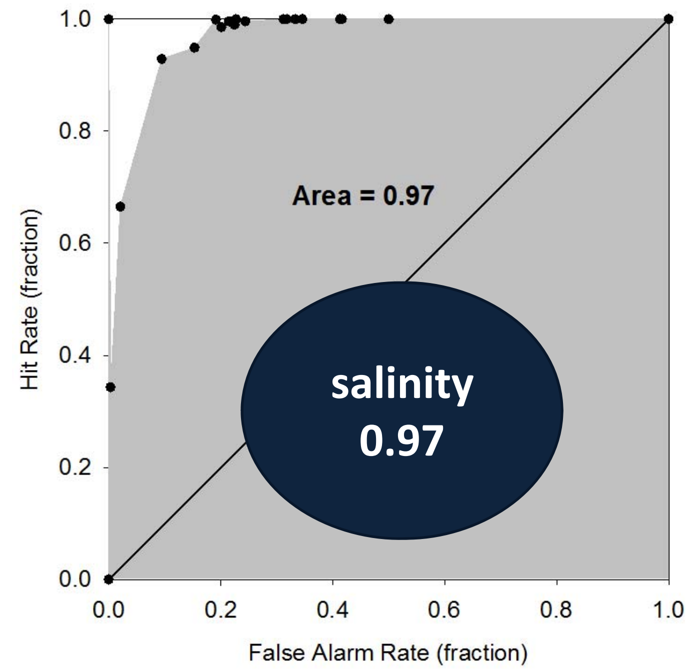
Relative Operating Characteristic (ROC) curve

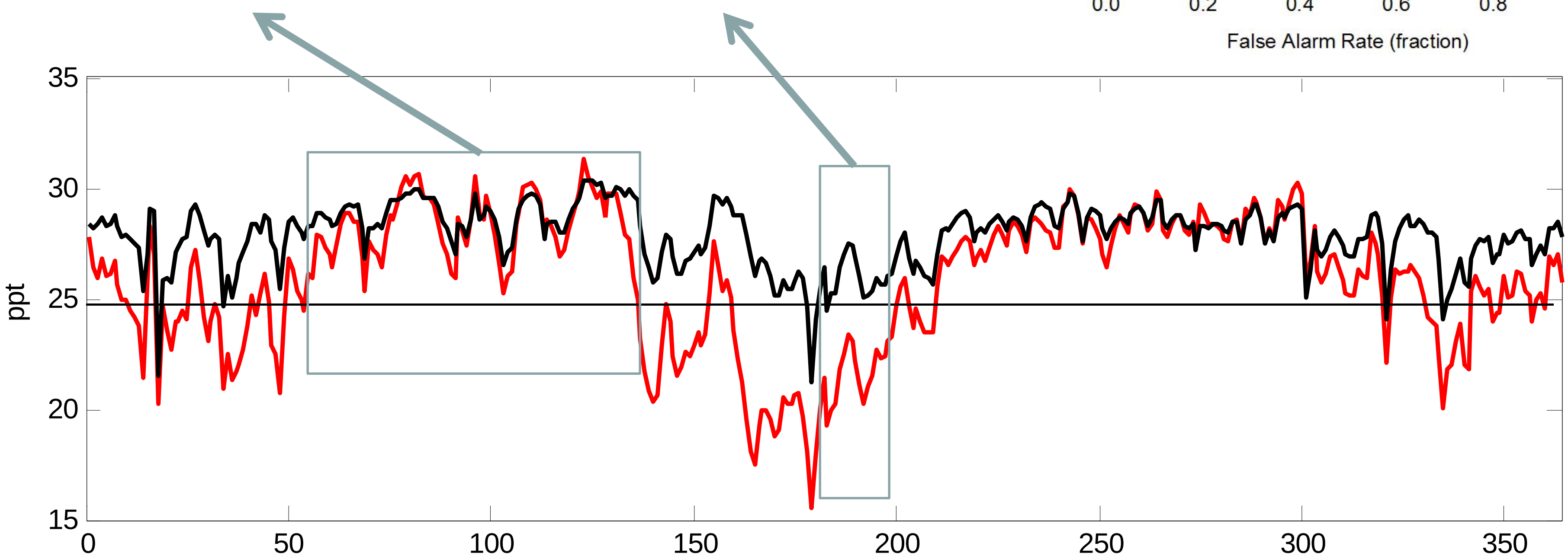
- used for evaluating models in many fields
- compares the "hit rate" to the "false alarm rate"
- > 0.5 = skilled; 1 = perfect skill
- ***evaluates all elements at once – whole model***

thresholds every 5.4 ppt, yielding 20 evaluations

hit rate = $mod_+ obs_+$

false alarm rate = $mod_+ obs_-$





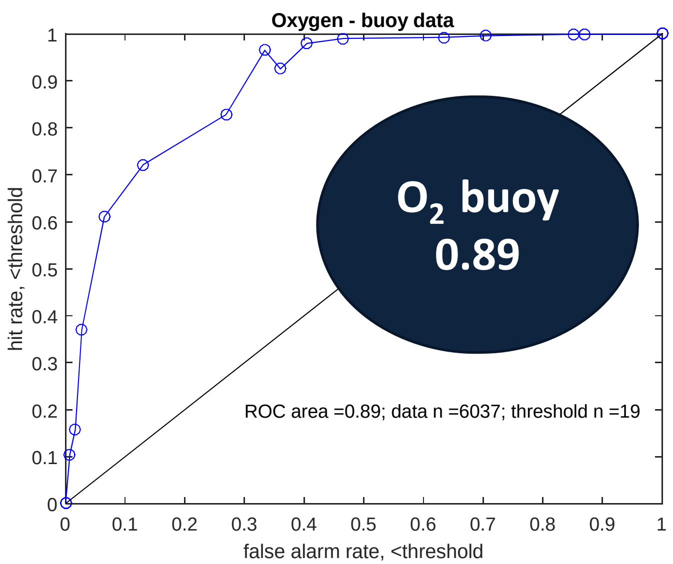
Mason, S. J., and N. E. Graham. 1999. Conditional probabilities, relative operating characteristics, and relative operating levels. Weather and Forcasting **14: 713-725.**

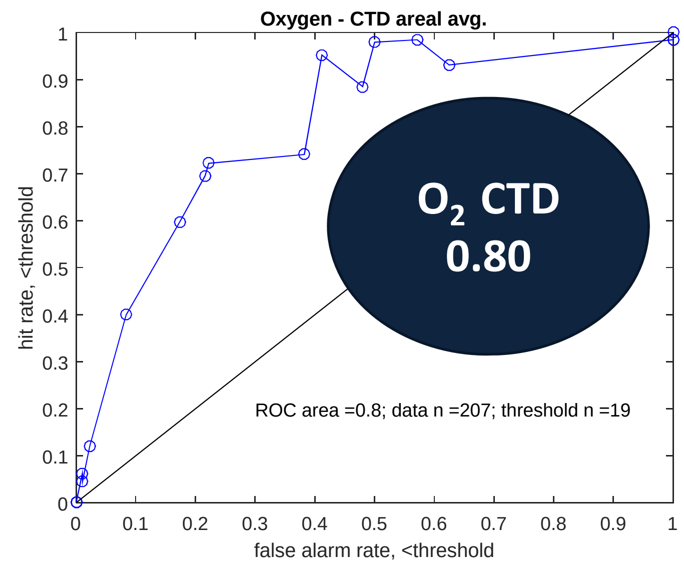
Sheng, Y. P., and T. Kim. 2009. Skill assessment of an integrated modeling system for shallow coastal and estuarine ecosystems. J. Mar. Syst. **76: 212-243.**

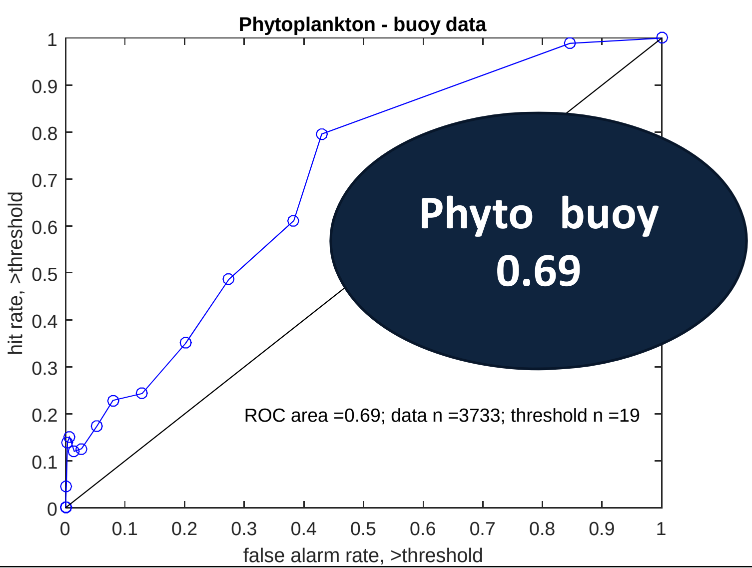
skill

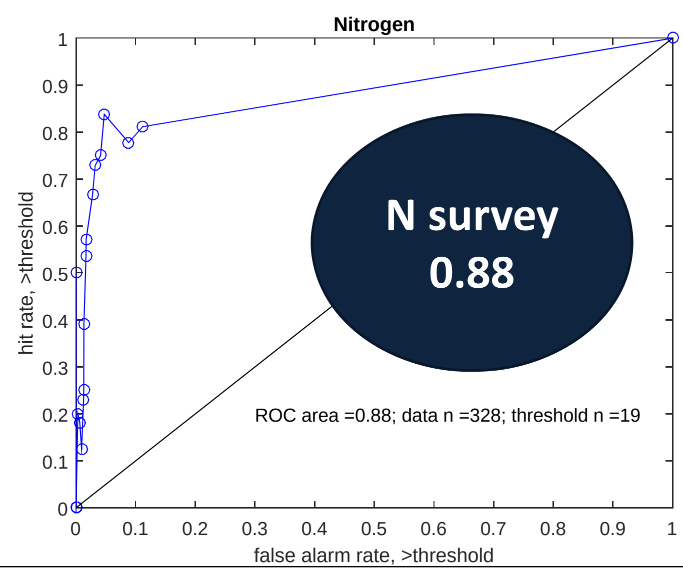
Skill – ROC, whole model

> 0.5 = skilled; 1 = perfect skill



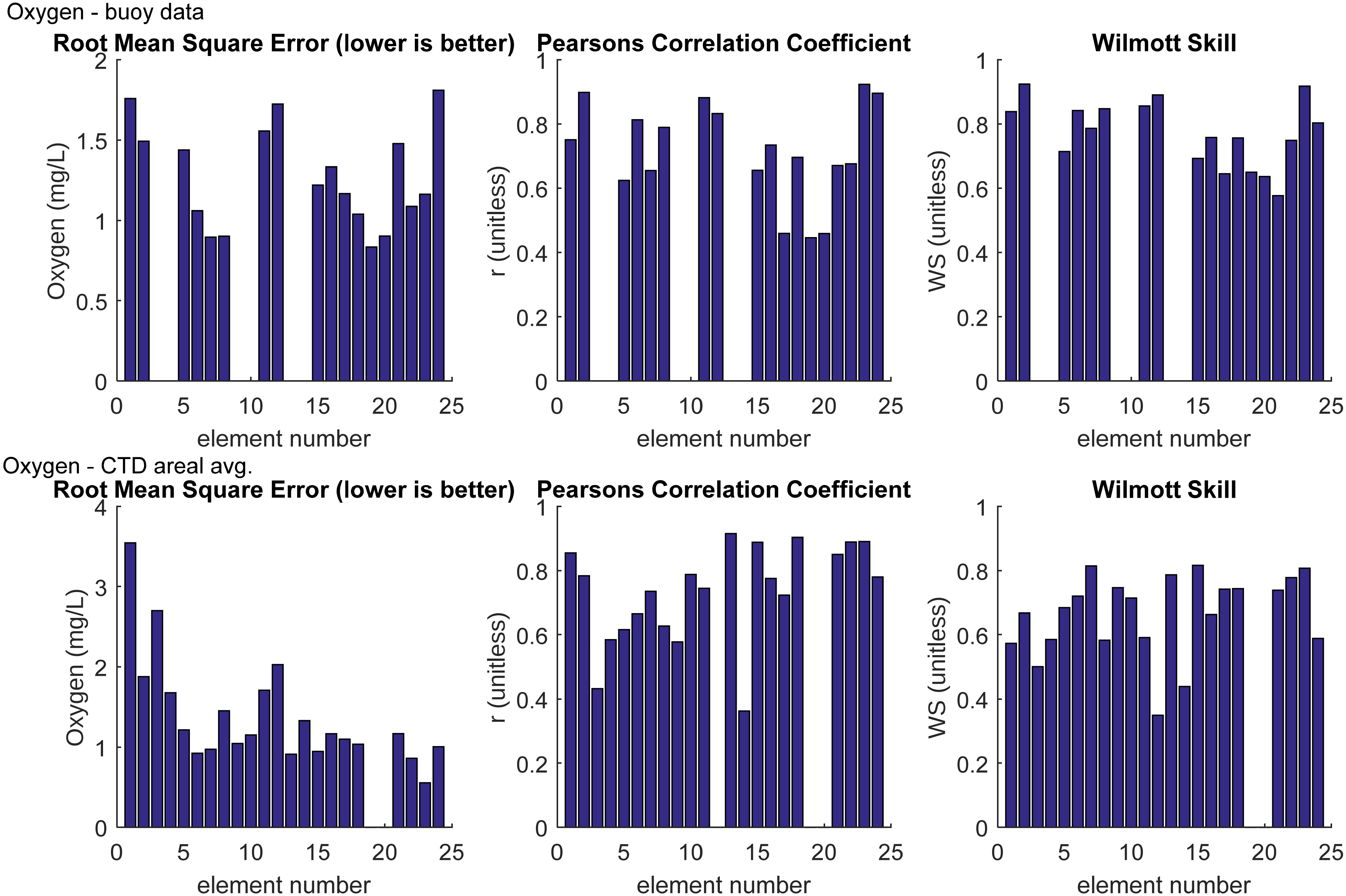






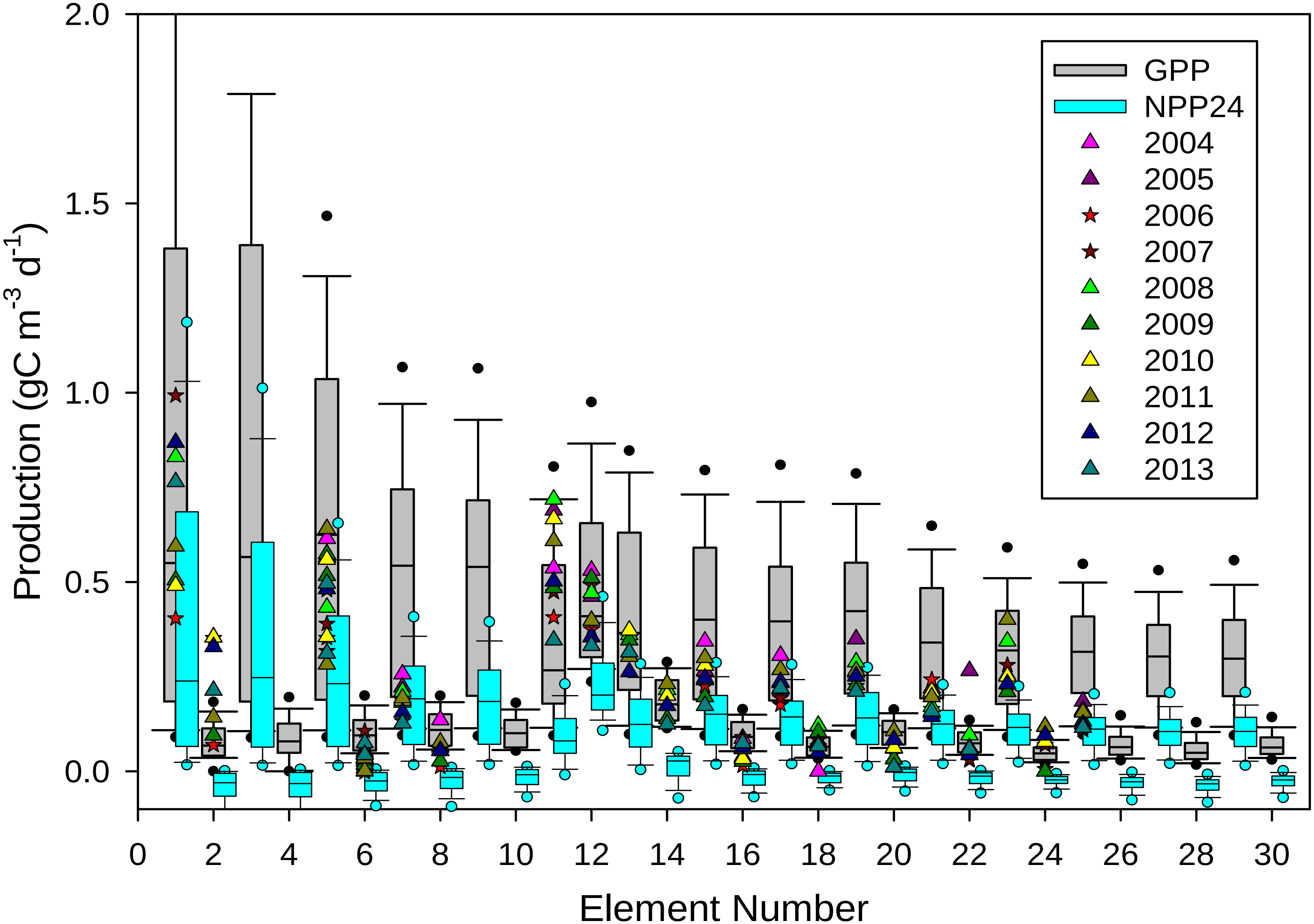
skill

Skill – by element (just O_2 shown)



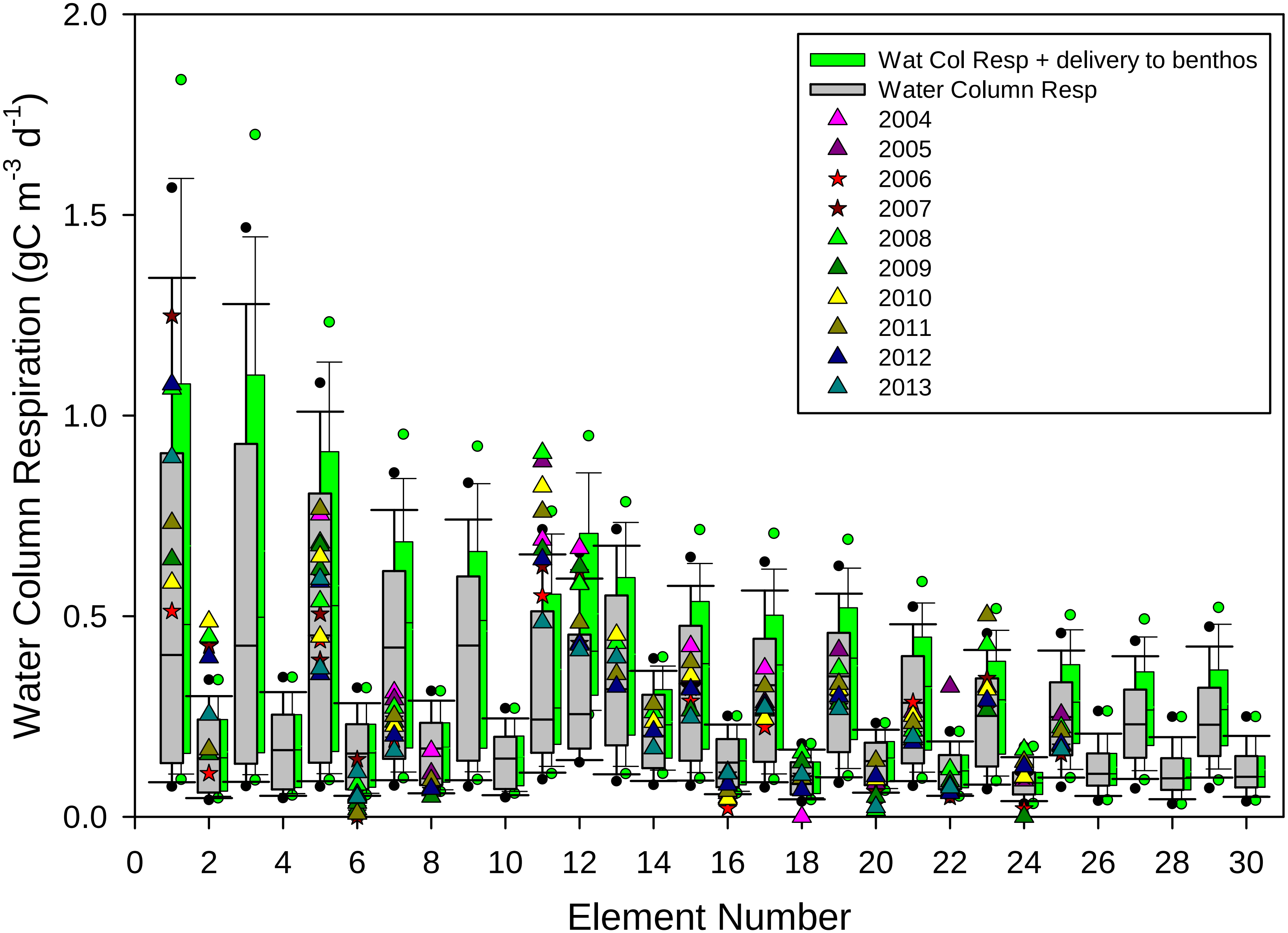
skill

Water Column Production



skill

Water Column Respiration

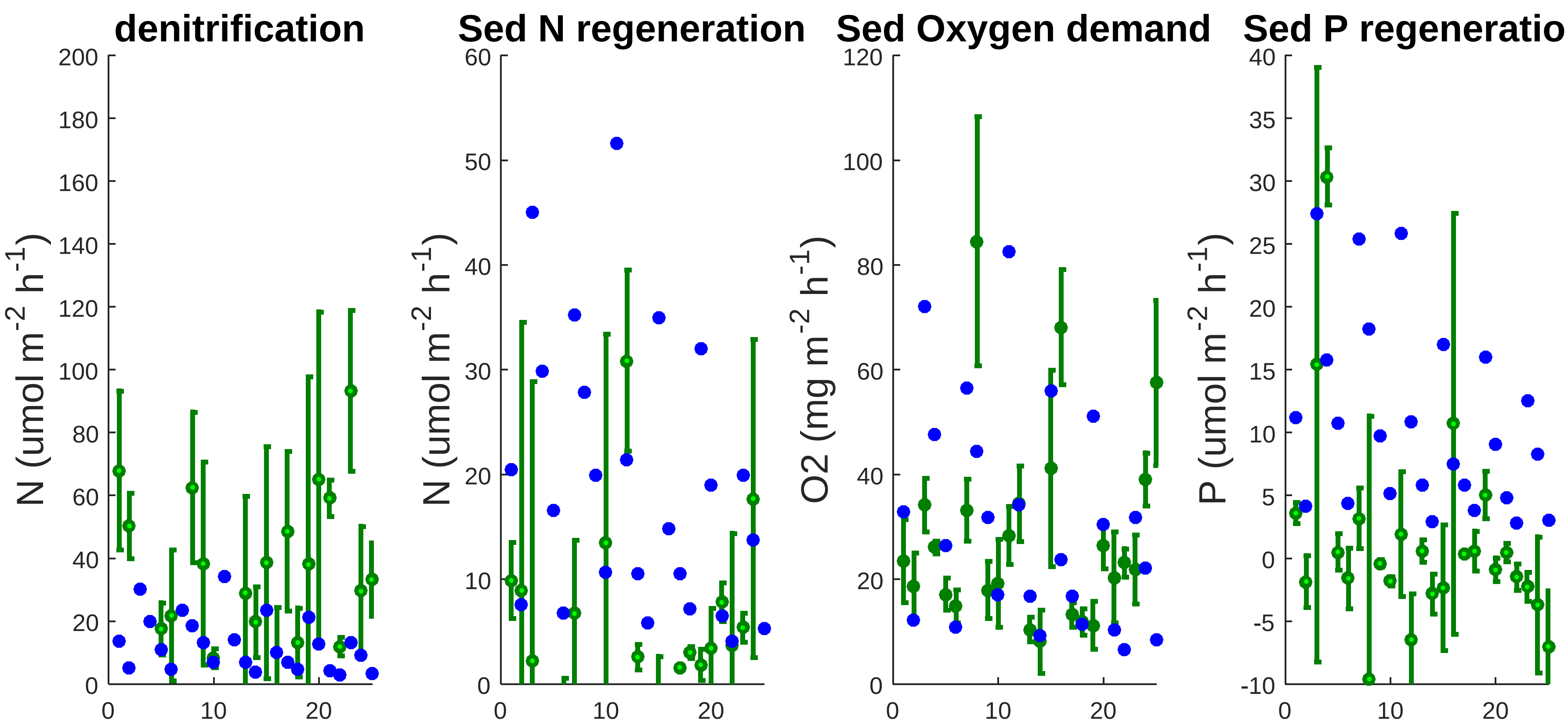


skill

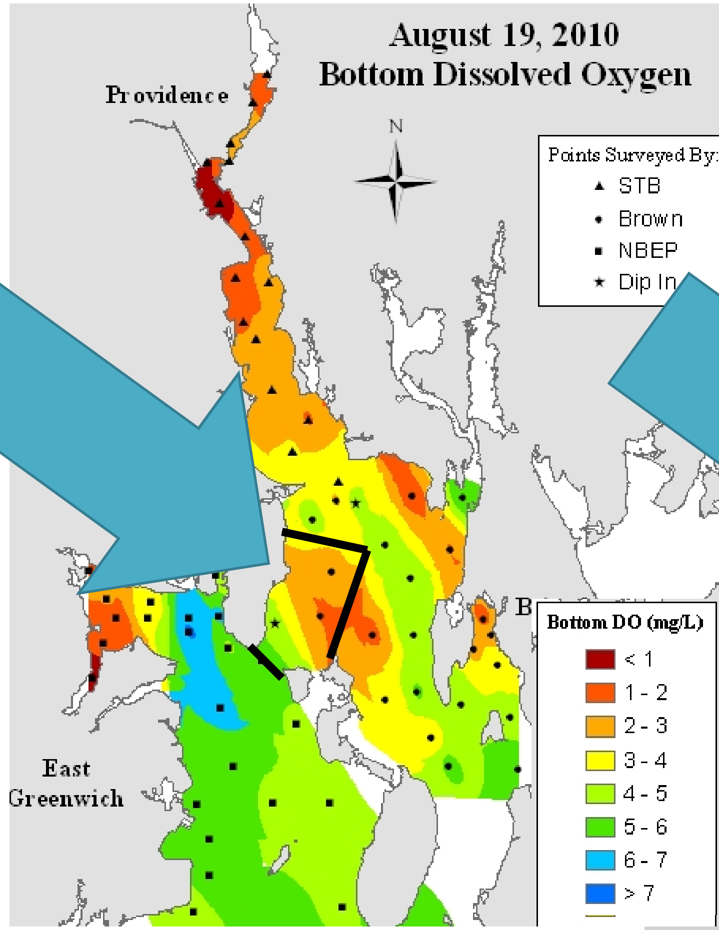
Sediment Rates

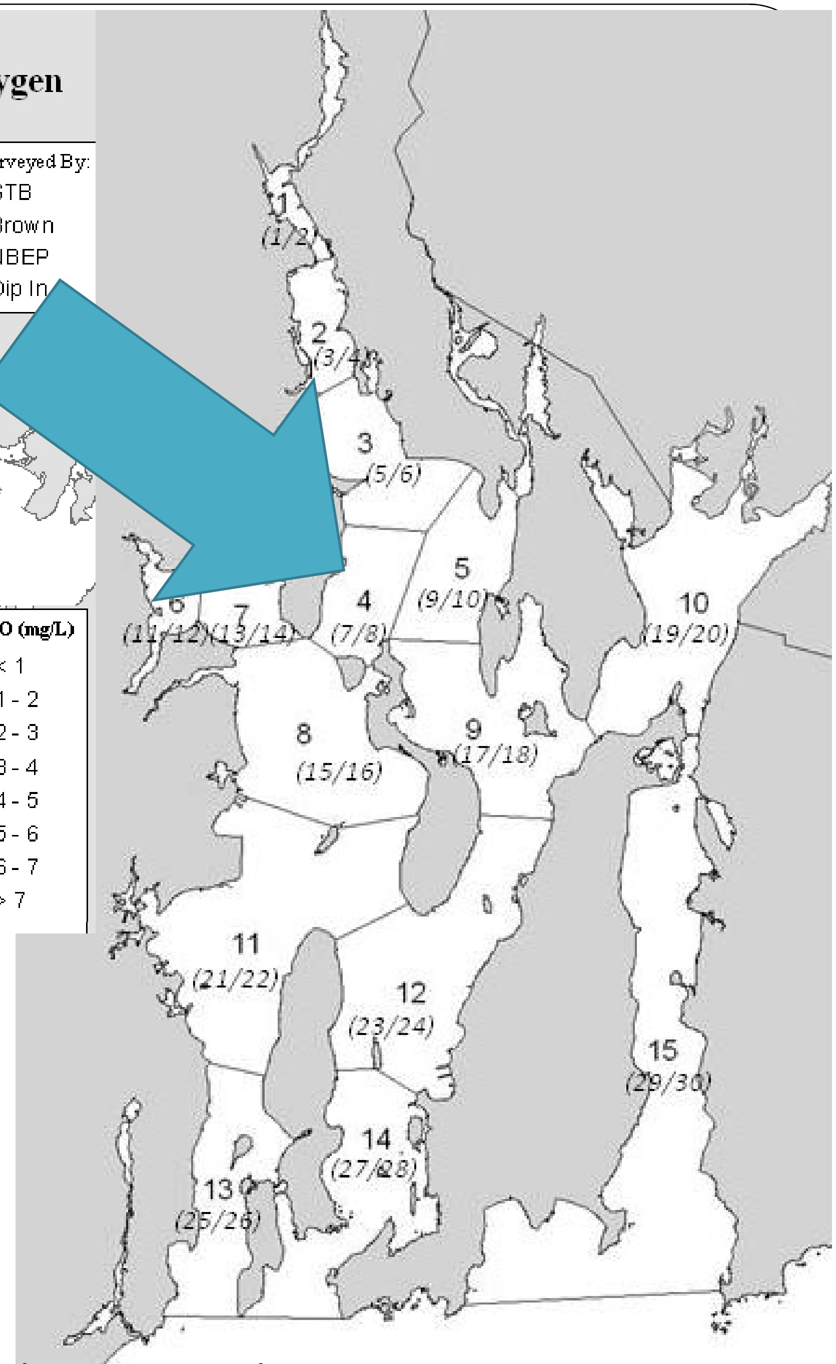
blue = model
green = core data

only 25 data points, from 2005 & 2006
model data are from corresponding element on corresponding day



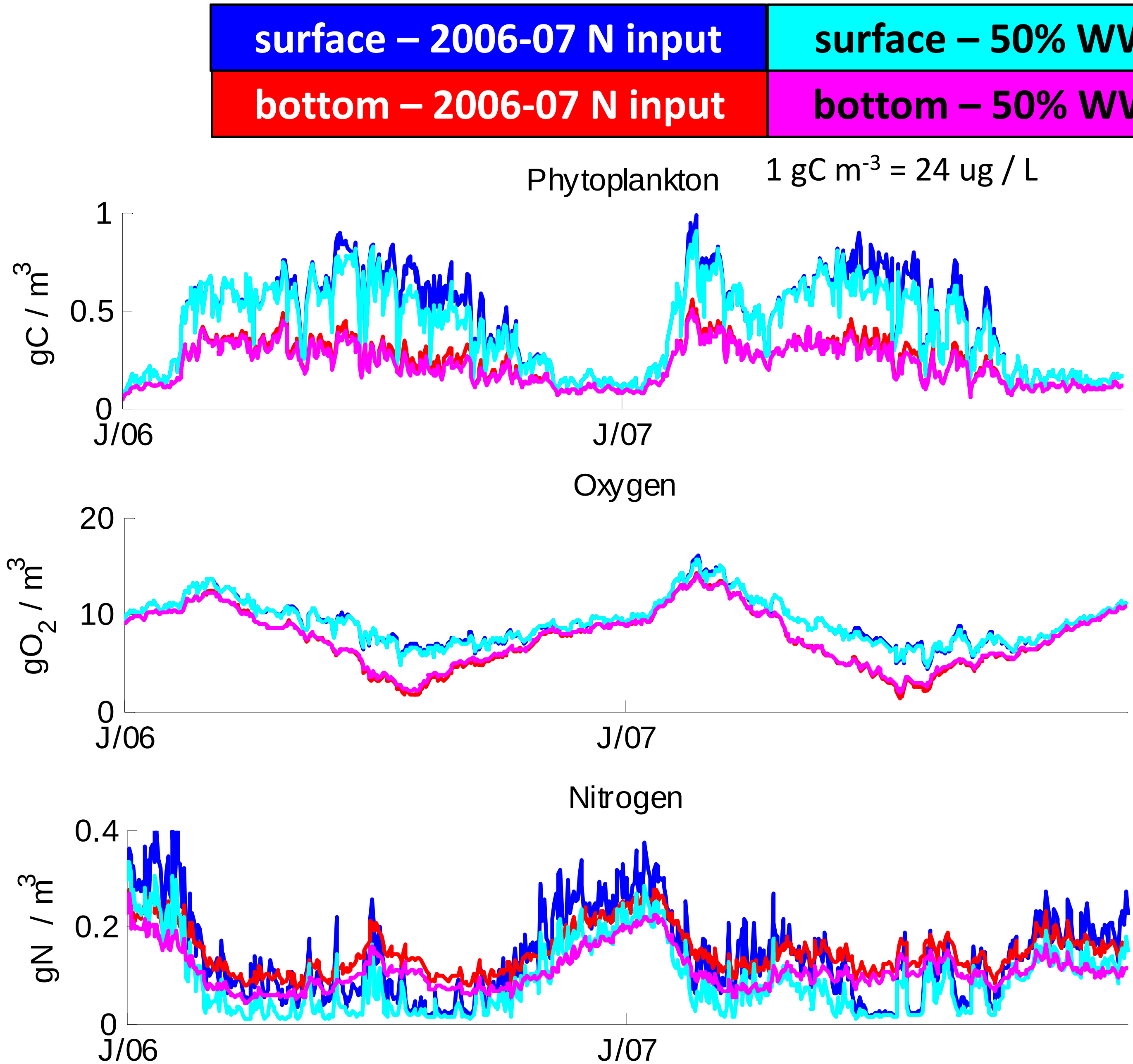
data from: Fulweiler, R.W., S.W. Nixon, B.A. Buckley, and S.L. Granger. 2007. Reversal of the net dinitrogen gas flux in coastal marine sediments. *Nature* 448, no. 7150: 180-82.





field data
responsive to N reductions

hypoxia map: W. Prell, D. Murray, C. Deacutis
Brown U. - http://www.geo.brown.edu/georesearch/insomniacs/index.html



Phyto – 10% to 15% reduction

Oxygen – no change

Nitrogen – reduction

Model predictions match field data collected after the 50% reduction was achieved in spring of 2013.

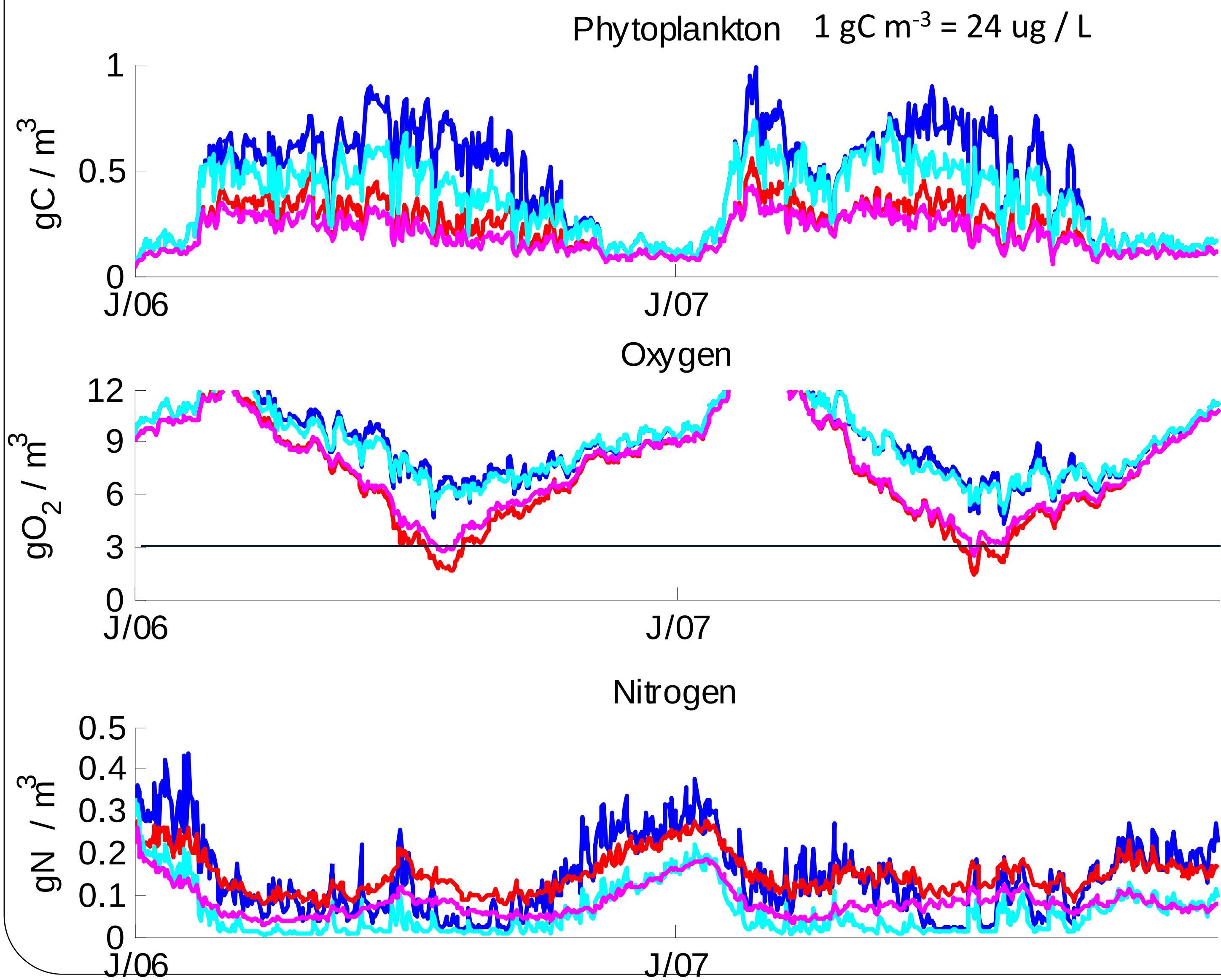
Candace Oviatt[1], Leslie Smith[2], Jason Krumholz[3], Catherine Coupland[1], Heather Stoffel[1], Aimee Keller[4], M. Conor McManus[1], and Laura Reed[1]

(in review)

Managed Nutrient Reduction Impacts on Nutrient Standing Stock Concentrations, Metabolism and Hypoxia in Narragansett Bay

surface – 2006 N input	surface – 75% WWTF DIN
bottom – 2006 N input	bottom – 75% WWTF DIN

N reduction can come from other sources, not just WWTF



Phyto – 15% to 30% reduction

Oxygen – alleviation of hypoxia

Nitrogen – reduction

Model suggests…

- Larger N reductions needed before alleviation of hypoxia.
- Oxygen in the model is sensitive to N input.

What EcoGEM can and cannot do…

Cannot utilize new physical forcings to get at effects of changes in river flow or stratification – need ROMS for this.

2006 and 2007 were good years in terms of differences – so able to predict new years by “bracketing”.

-- need to apply appropriate nutrient reduction, relative to ‘06-’07

-- if boundary conditions for the year are available, use

This model can be used to explore the effects of nutrient reductions and temperature changes associated with climate change.

What is needed to apply EcoGEM in LIS…

have

- water column field data (nutrients, chlorophyll, oxygen, light) – buoy & survey
- benthic carbon
- productivity & respiration (buoy and incubations)
- wind, rain
- N & P loading estimates (Vaudrey et al., USGS, LISS, CTDEEP, NYSDEC)

need

- physical exchange coefficients from ROMS or FVCOM (or other)
- benthic rates (flux of N, P, O_2 – including denitrification)
- light (PAR) at surface, daily
- *C to Chl (high variability)**
- *C to N in sediment**

* *model can be run with default values, site specific data is useful*