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

- Atmospheric deposition
- Land-use
- Productivity
- Phytoplankton
- Photic zone heterotrophy
- Flux to bottom
- O$_2$ coupled stoichiometrically
- Benthic C
- Benthic heterotrophy
- Denitrification
- Temp, Light, Boundary Conditions
- Chl, N, P, Salinity

**Physics**
- Surface layer
- Deep layer
- Bottom sediment

**Processes**
- Temp, Light, Boundary Conditions
- Chl, N, P, Salinity

**Only 17 constants and coefficients**
Ecology

Empirical Formulation of Key Rate Processes

robust across many systems

Primary Prod : Respiration

Benthic Remin. : Primary Prod

Denitrification

Production: BZI → with a modification for 2 layers

Cole & Cloern: Estuarine phytoplankton productivity

Fig 2: Regression of photic zone productivity against the composite parameter BZlz for 211 incubation experiments. 
\[ P = 150 + 0.73(BZl_z), \ r^2 = 0.82, \ S_e (\text{standard error of the estimate}) = 410 \]

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

- 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
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

- River 1 = Moshassuck + Woonasquatucket
- River 2 = Blackstone + Ten Mile + Bucklin Point WWTF
- River 3 = Pawtuxet
- River 4 = Taunton + (est. Mt. Hope and Sakonnet)
- River 5 = Hunt
- River 6 = Palmer

Width of arrows indicate relative magnitude of volume input.
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.
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 = \( \frac{\text{mod}_+ \cdot \text{obs}_+}{\text{mod}_+ \cdot \text{obs}_+} \)
false alarm rate = \( \frac{\text{mod}_+ \cdot \text{obs}_-}{\text{mod}_+ \cdot \text{obs}_-} \)

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Skill – ROC, whole model

> 0.5 = skilled; 1 = perfect skill

Oxygen - buoy data

ROC area = 0.89; data n = 6037; threshold n = 19

O2 buoy 0.89

Oxygen - CTD areal avg.

ROC area = 0.8; data n = 207; threshold n = 19

O2 CTD 0.80

Phytoplankton - buoy data

ROC area = 0.69; data n = 3733; threshold n = 19

Phyto buoy 0.69

Nitrogen

ROC area = 0.88; data n = 328; threshold n = 19

N survey 0.88

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Skill – by element (just $O_2$ shown)
Sediment Rates

blue = model
green = core data

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

denitrification  Sed N regeneration  Sed Oxygen demand  Sed P regeneration

field data responsive to N reductions

hypoxia map: W. Prell, D. Murray, C. Deacutis
Phytoplankton – 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.

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(in review)

Managed Nutrient Reduction Impacts on Nutrient Standing Stock Concentrations, Metabolism and Hypoxia in Narragansett Bay
Phyto – 15% to 30% reduction

Oxygen – alleviation of hypoxia

Nitrogen – reduction

N reduction can come from other sources, not just WWTF
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, O₂ – 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*