Reduced complexity models as an alternative approach for ecosystem analysis

Mark J. Brush

Integrated Trends Analysis Team meeting
June 2015

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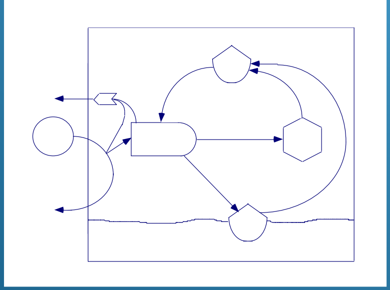
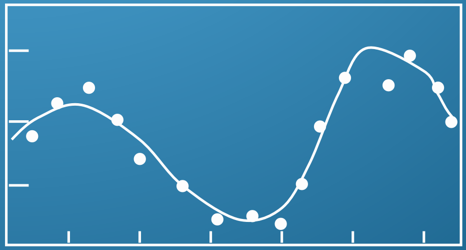
VIRGINIA INSTITUTE OF MARINE SCIENCE





Outline

1. Overview of reduced complexity modeling approach

2. Recent examples: estuarine response to …

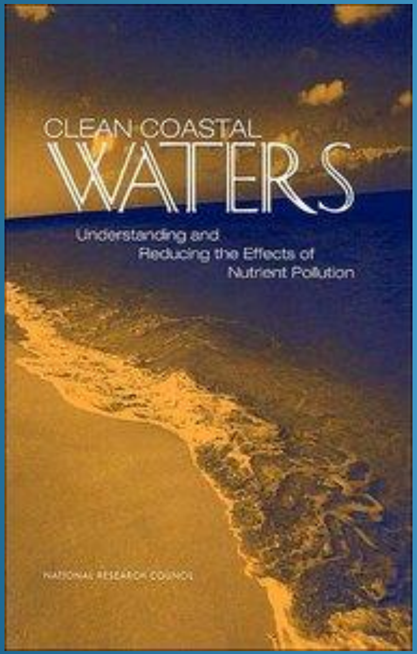
   Nutrient loading
   Climate change
   Restoration
   Aquaculture

3. Online implementation

4. Potential for analyzing long-term trends in water quality

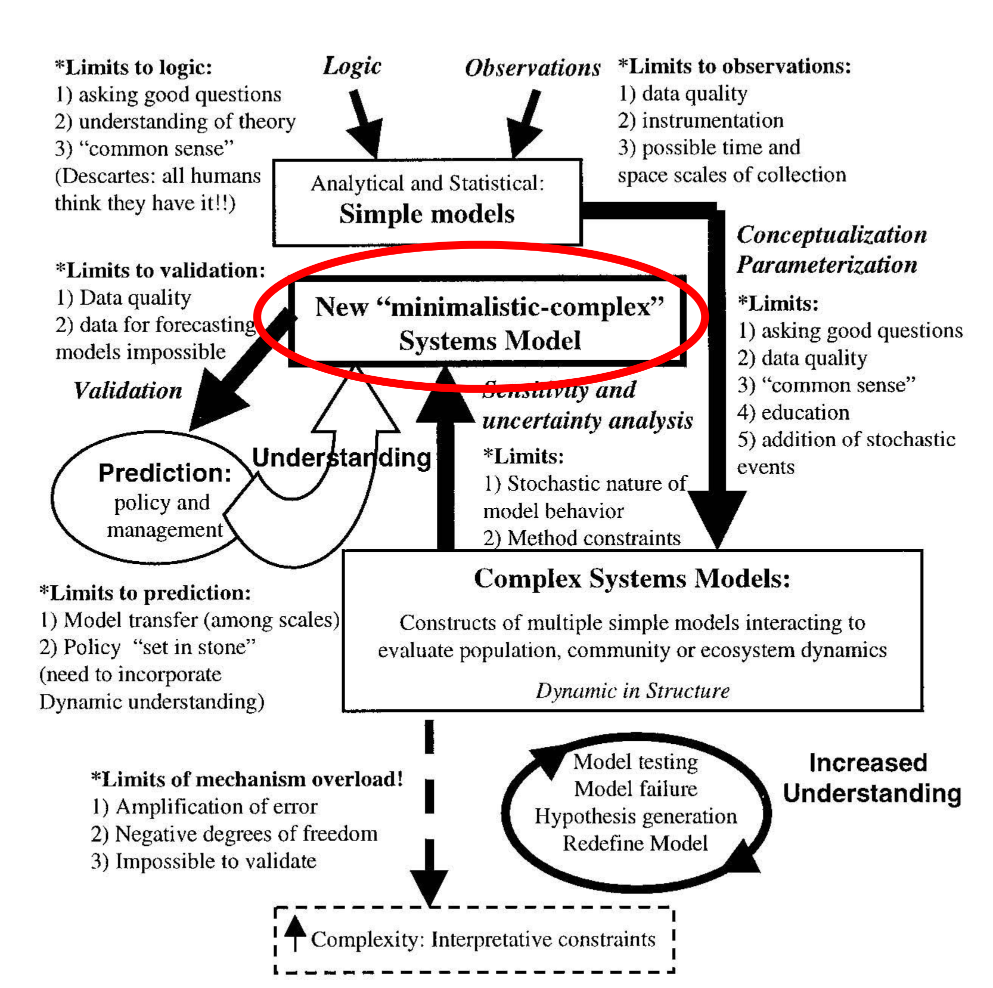
Modeling Approach

National Academy of Sciences' Committee on Causes and Management of Coastal Eutrophication (NRC 2000):



- Development of a reasonable accurate model accessible to managers to predict sources of nutrients in the landscape
- Simple frameworks for characterizing the sensitivity of estuarine response

Duarte et al. (2003)
"The limits to models in ecology"

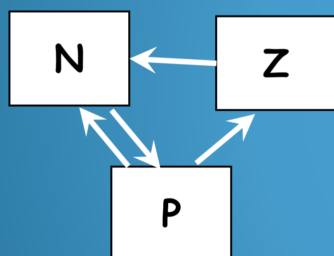


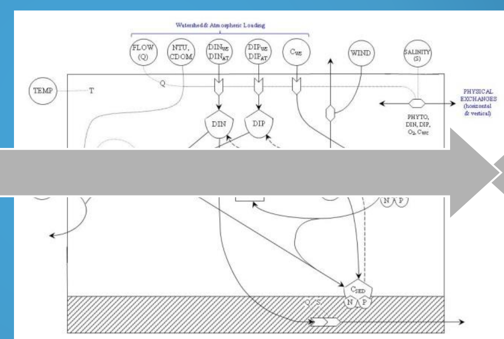
Modeling Approach

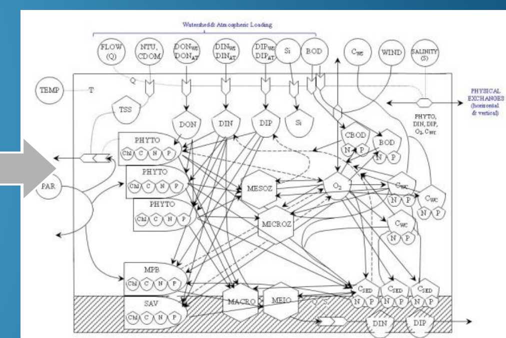
A range of models exist from simple to complex:

Reduced Complexity:

Biological Complexity:

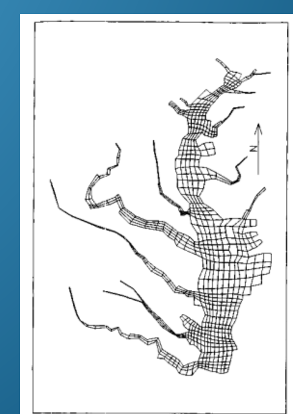






Spatial Resolution:

1 box



Empirical Formulation of Key Rate Processes

Cole & Cloern: Estuarine phytoplankton productivity

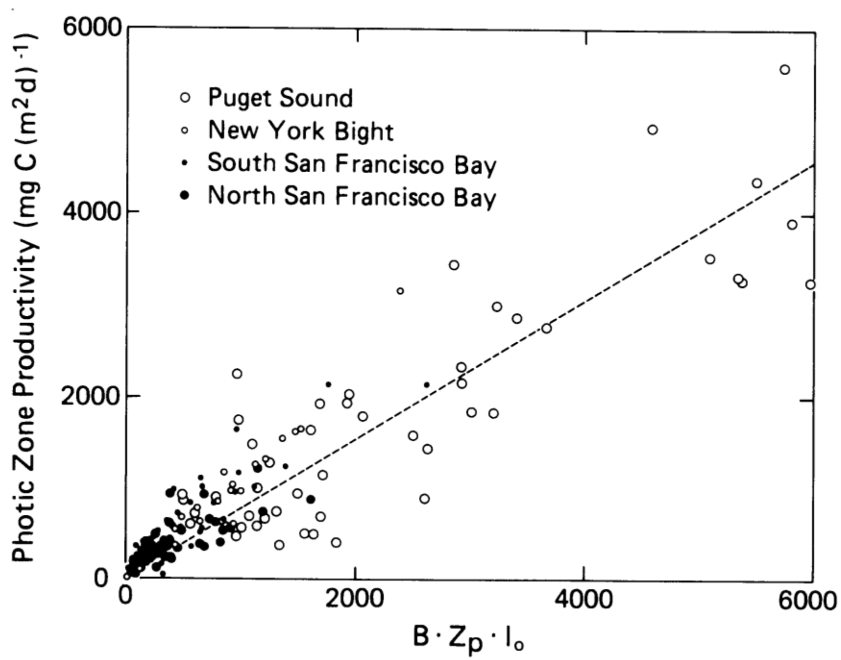
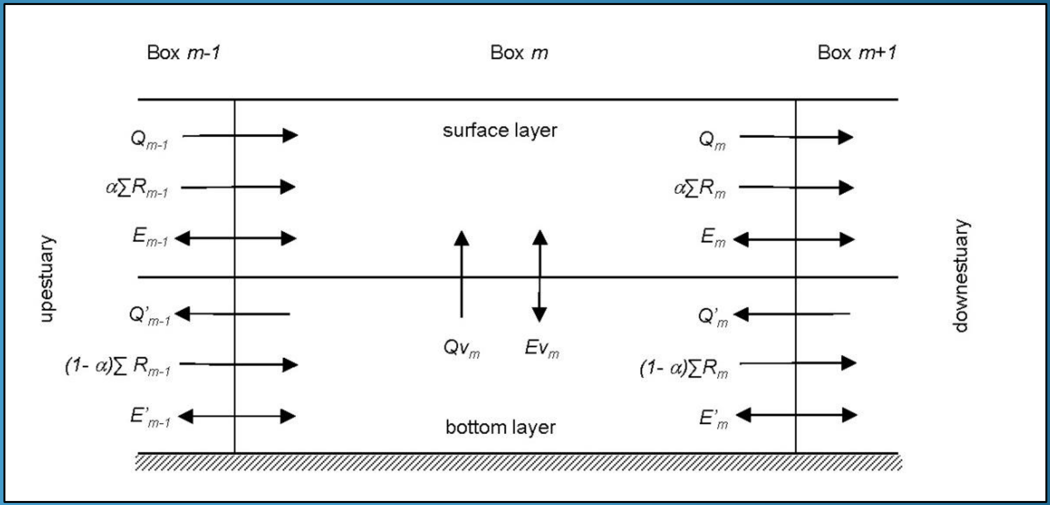


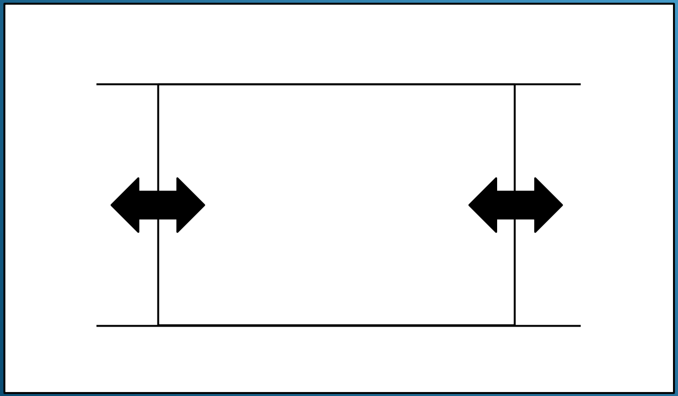
Fig. 2. Regression of photic zone productivity against the composite parameter $B Z_P I_o$ for 211 incubation experiments. $P = 150 + 0.73\,(B Z_P I_o)$; $r^2 = 0.82$; S_{yx} (standard error of the estimate) = 410

Model "Physics"

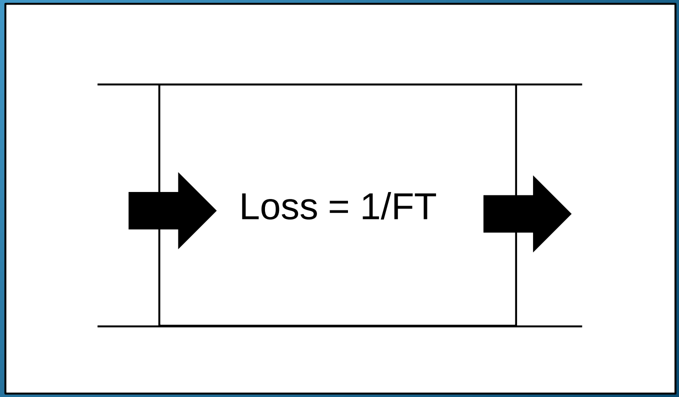
Salinity – Freshwater Box Model



Tidal Prism Model

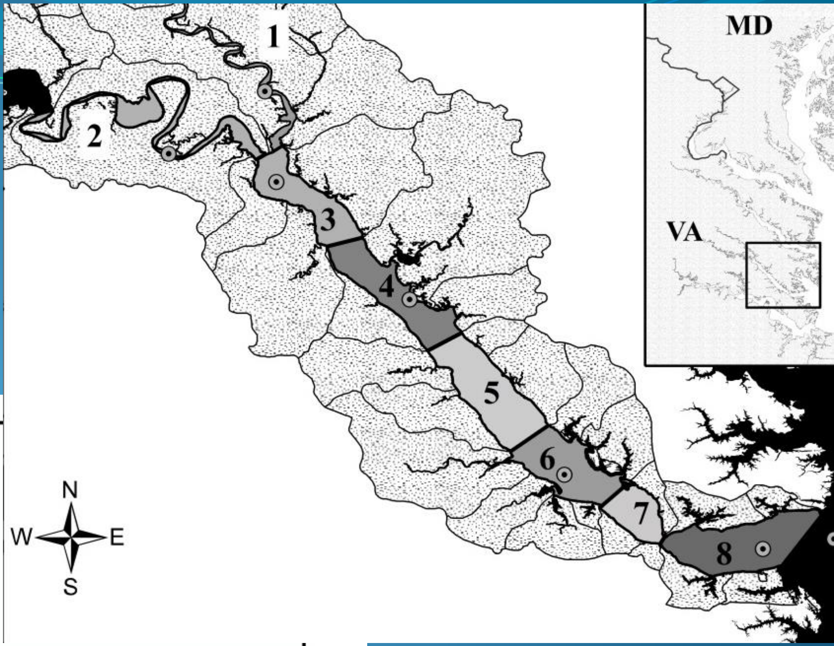


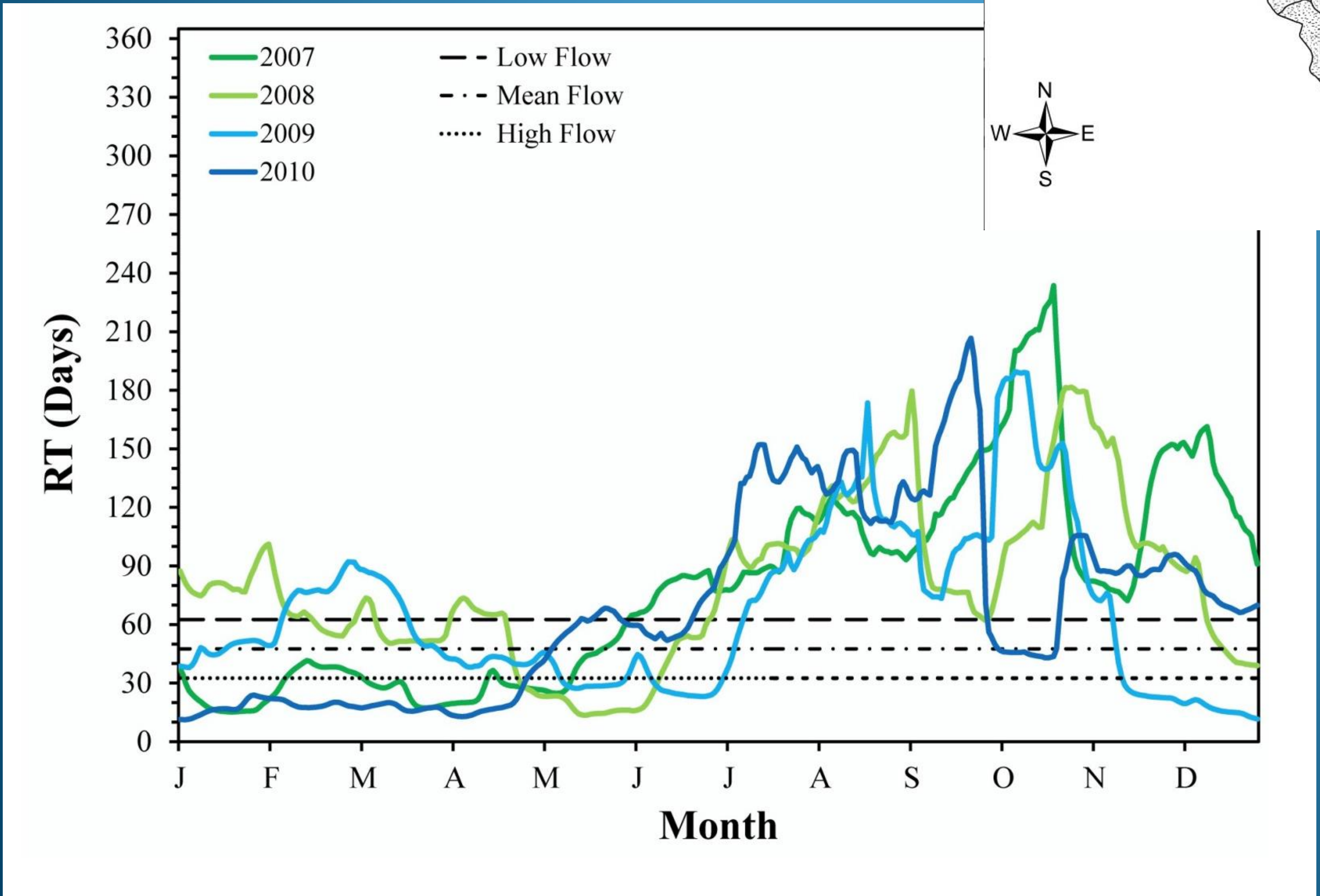
Simple Flushing



York River Flushing Time

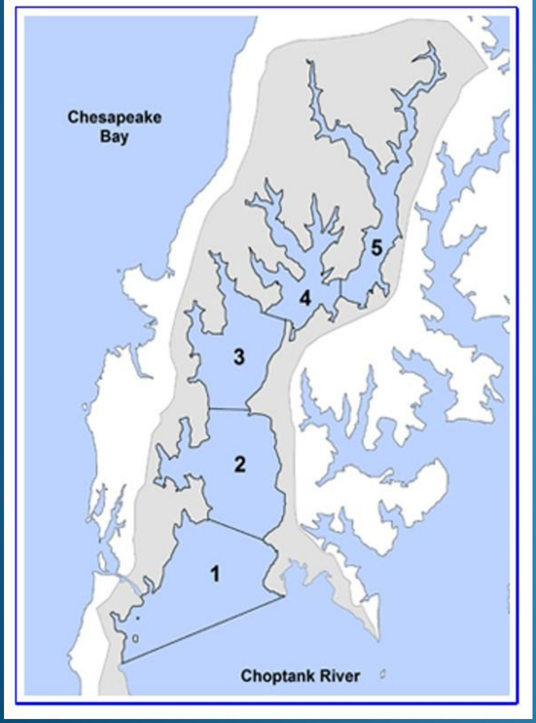
Lake Ph.D. (2013)

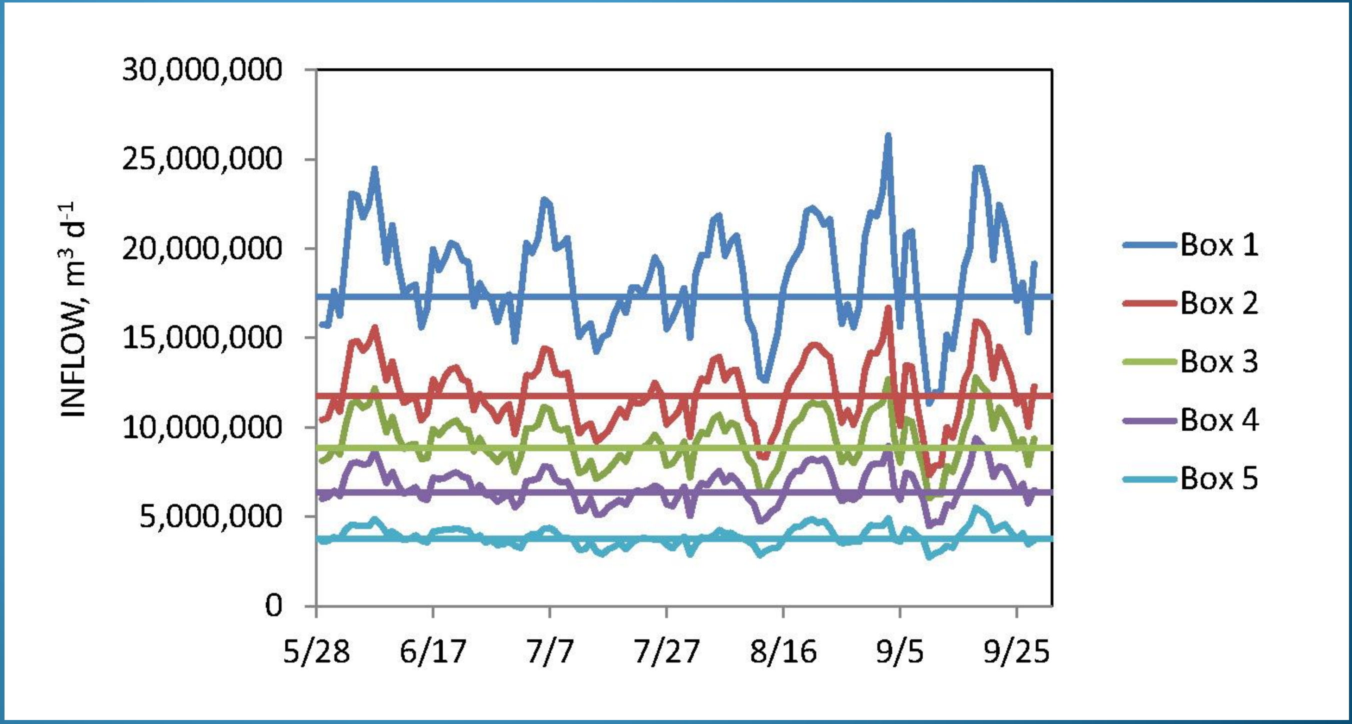




Harris Creek: Tidal Prism vs. ROMS

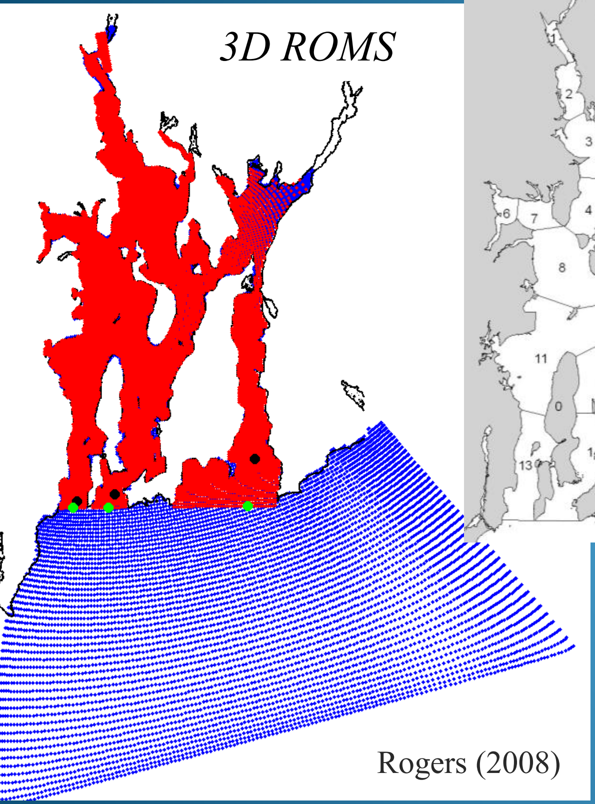
Brush and Kellogg (2014)

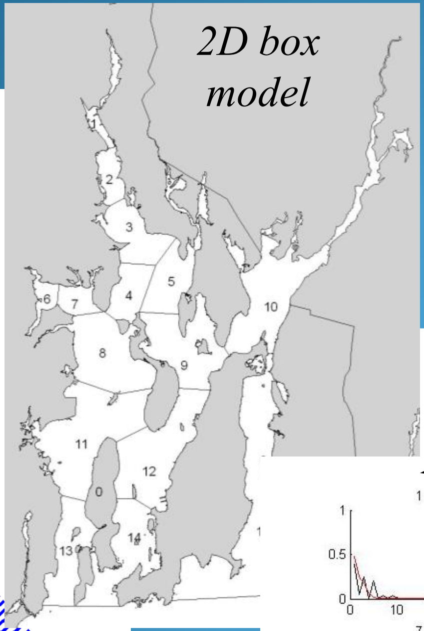


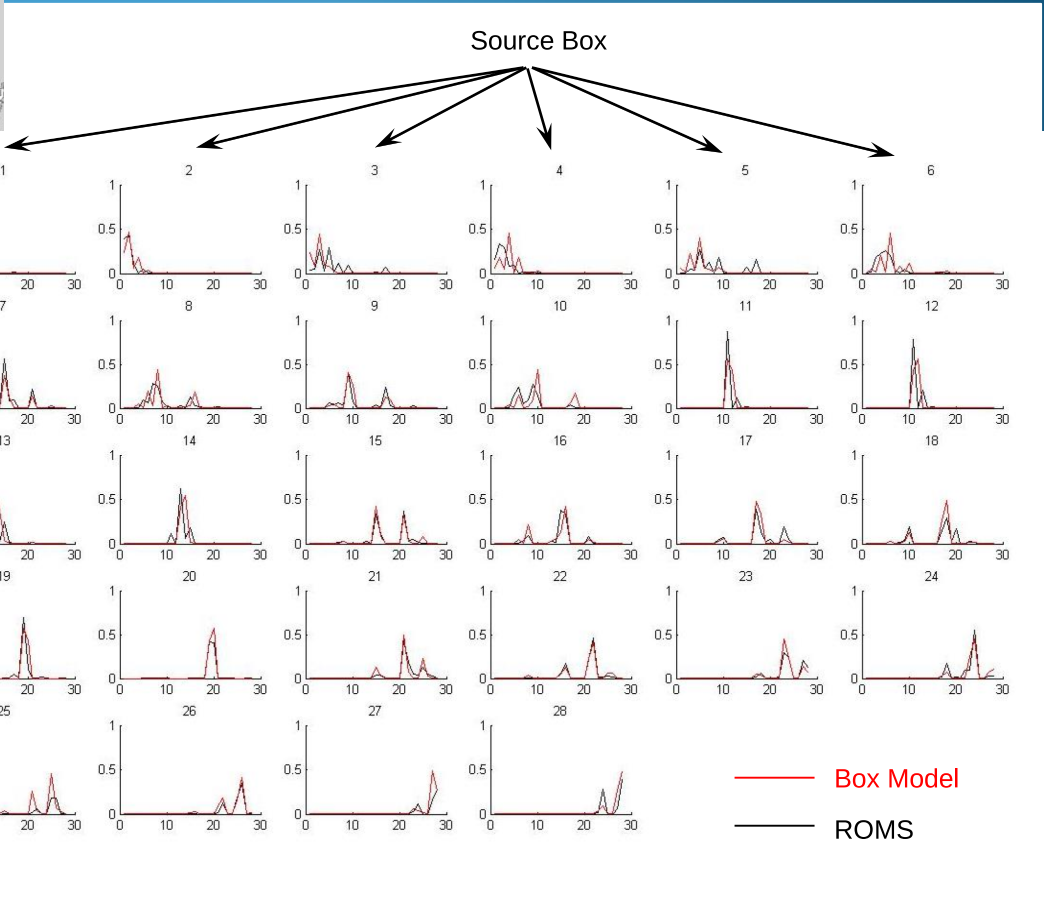


Narragansett Bay: OBM vs. ROMS

2006

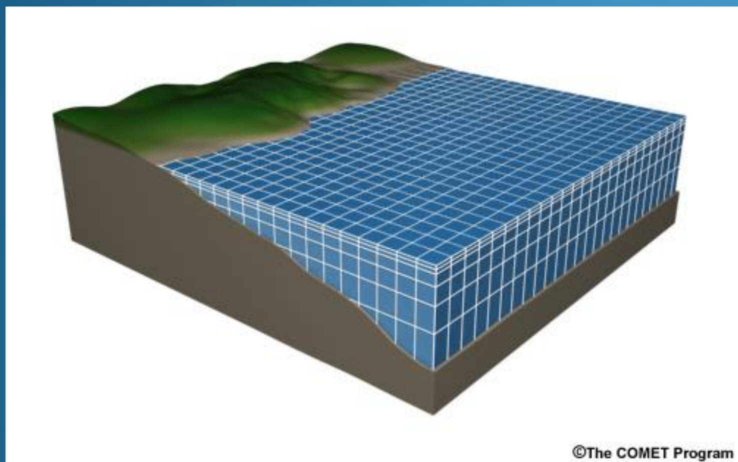


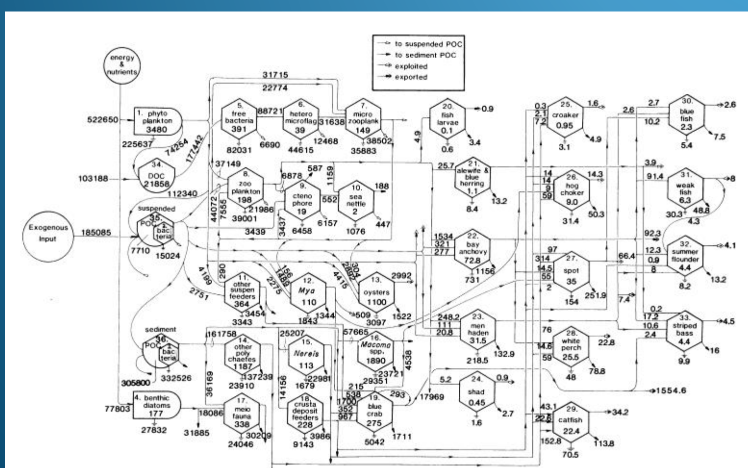




ROMS output from D. Ullman;
Comparison by J. Vaudrey

What this model isn't:

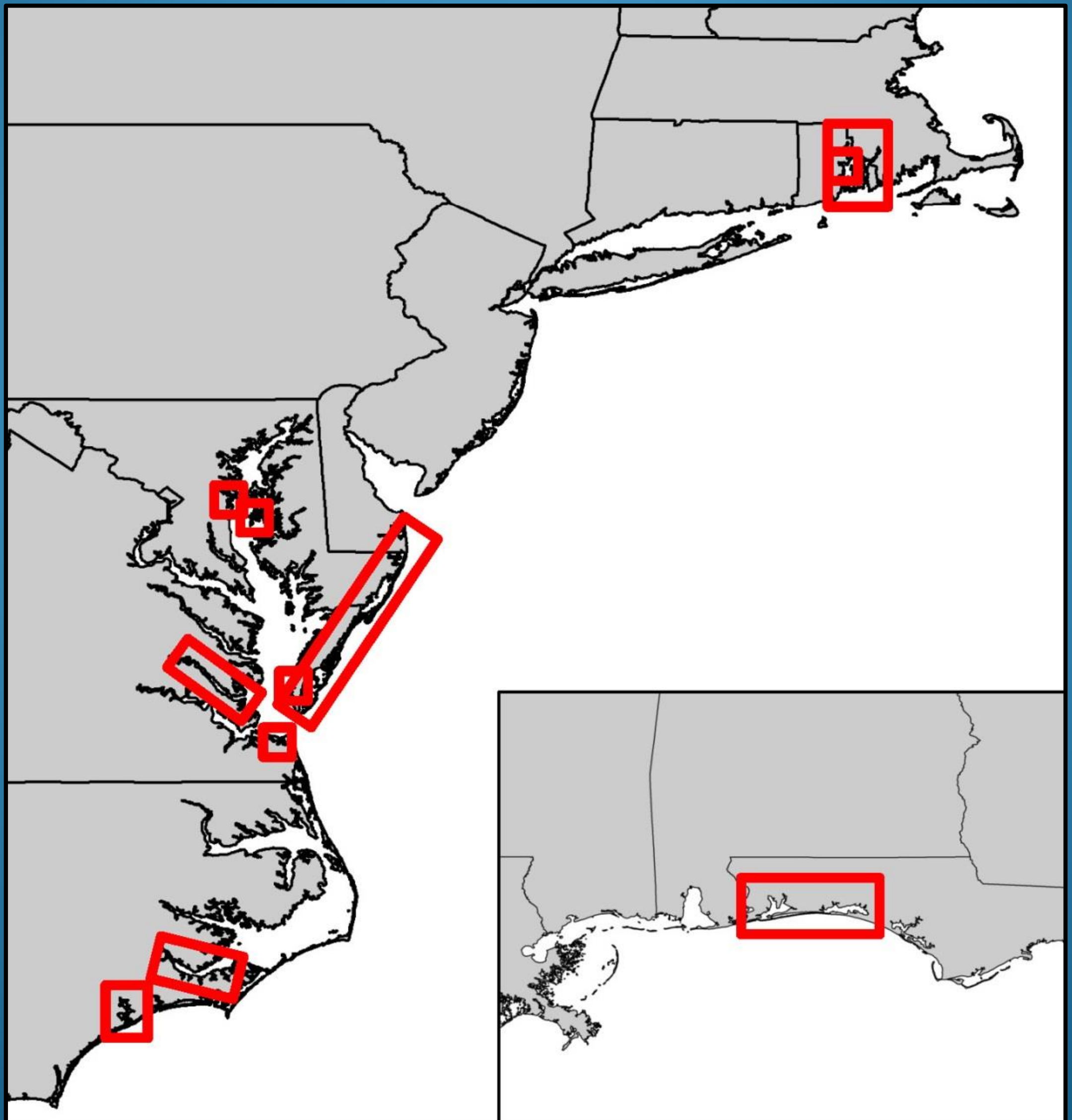




What this model is:

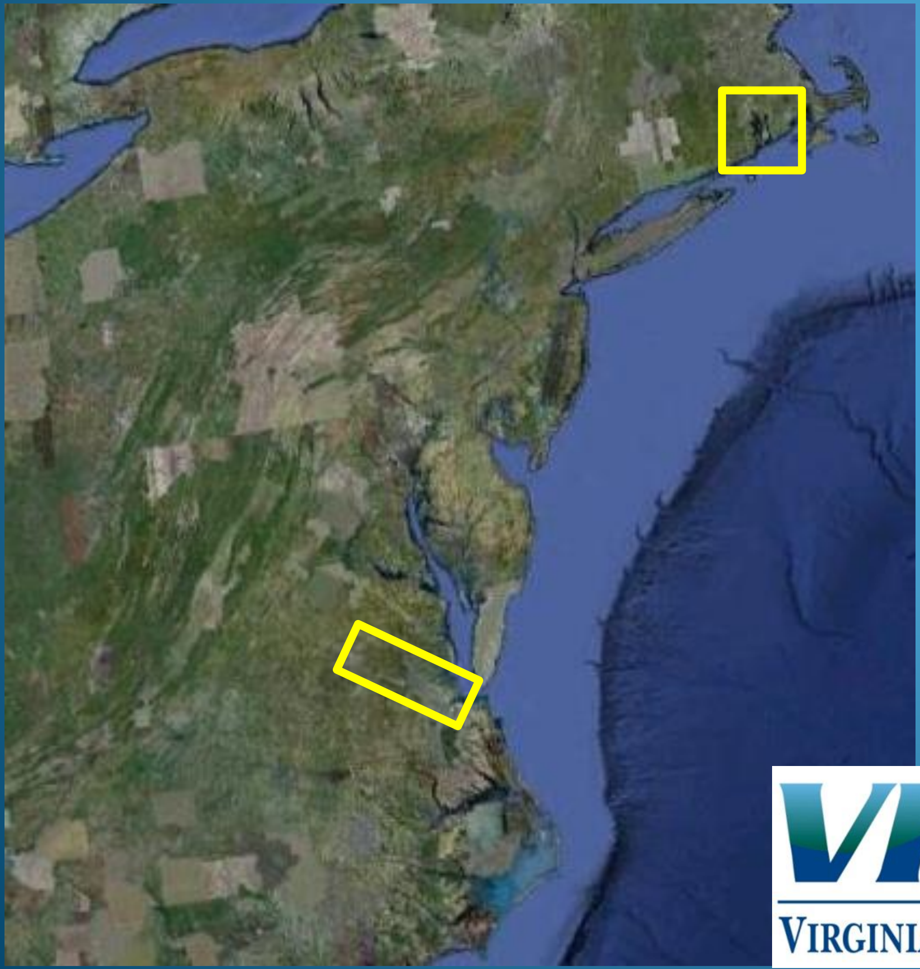
- Reduced complexity
- Modular (easy addition of state variables)
- Management-focused
- Fast running (~ seconds to minutes)
- Quickly applied (~1.5-2 weeks per system)
- Accessible GUI, web-deployable

Current Model Implementation



Hypoxia in the York River Estuary, VA

(with a comparison to upper Narragansett Bay, RI)



York River analysis from:
Lake (2013 – PhD), Lake et al. (2013), Lake and Brush (2015)

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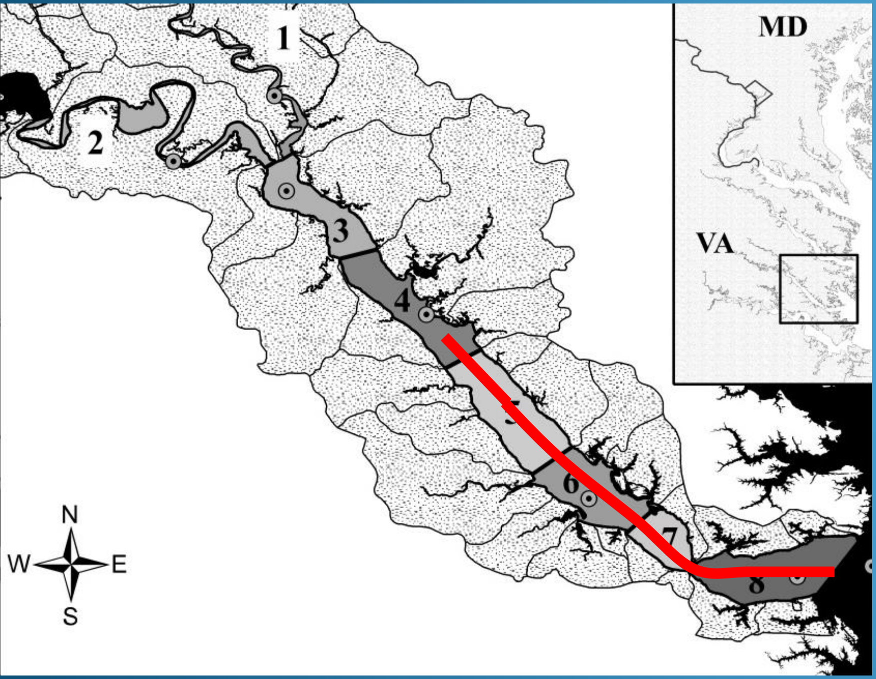
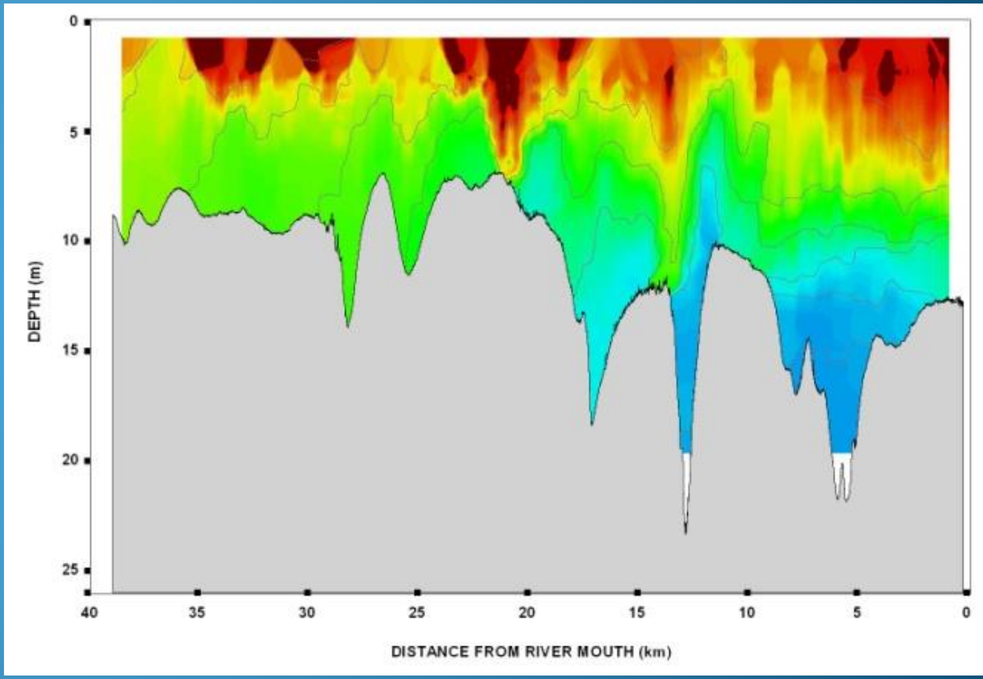
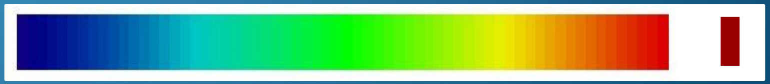
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

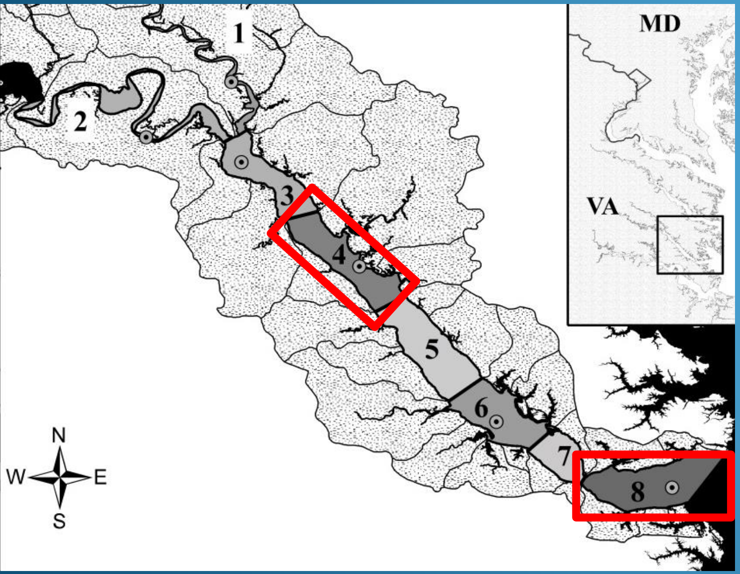
Hypoxia in the York River, VA

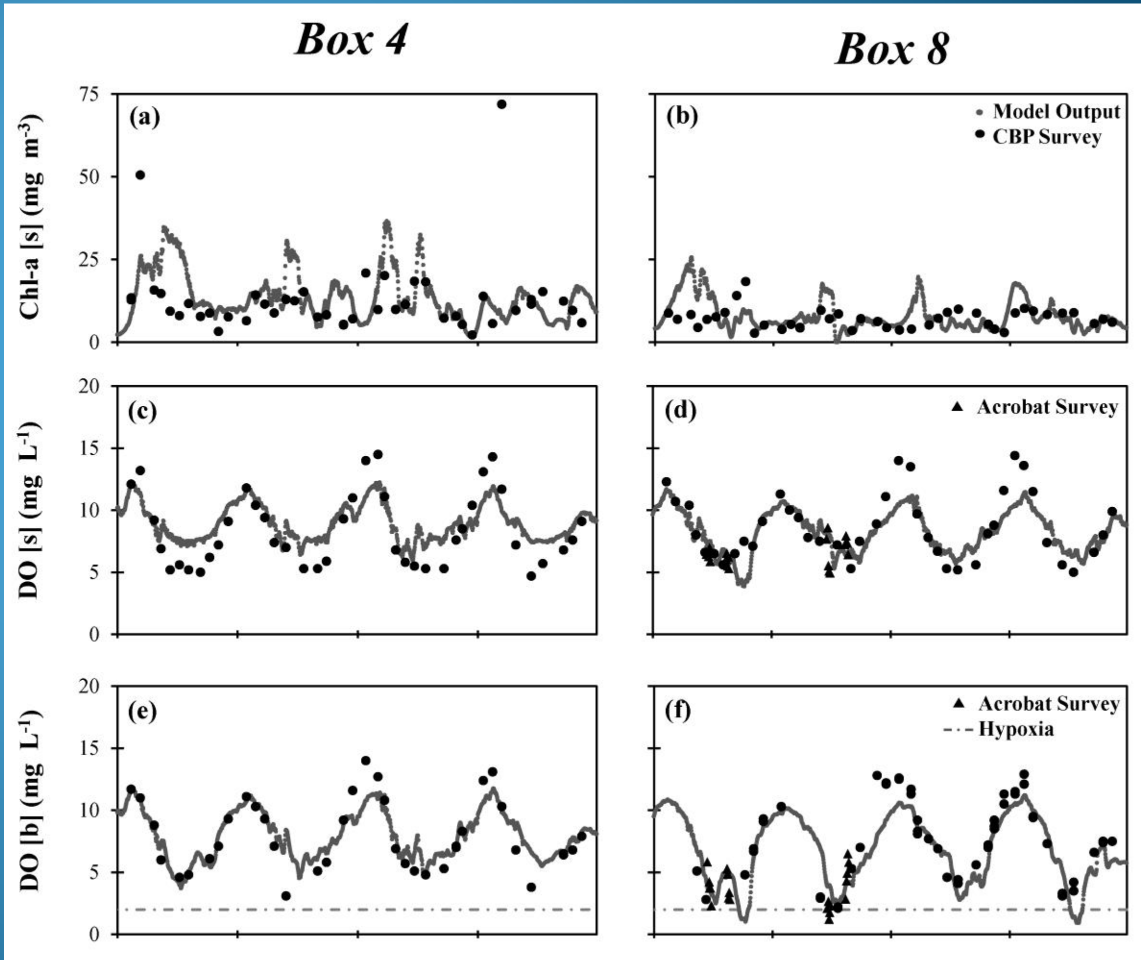






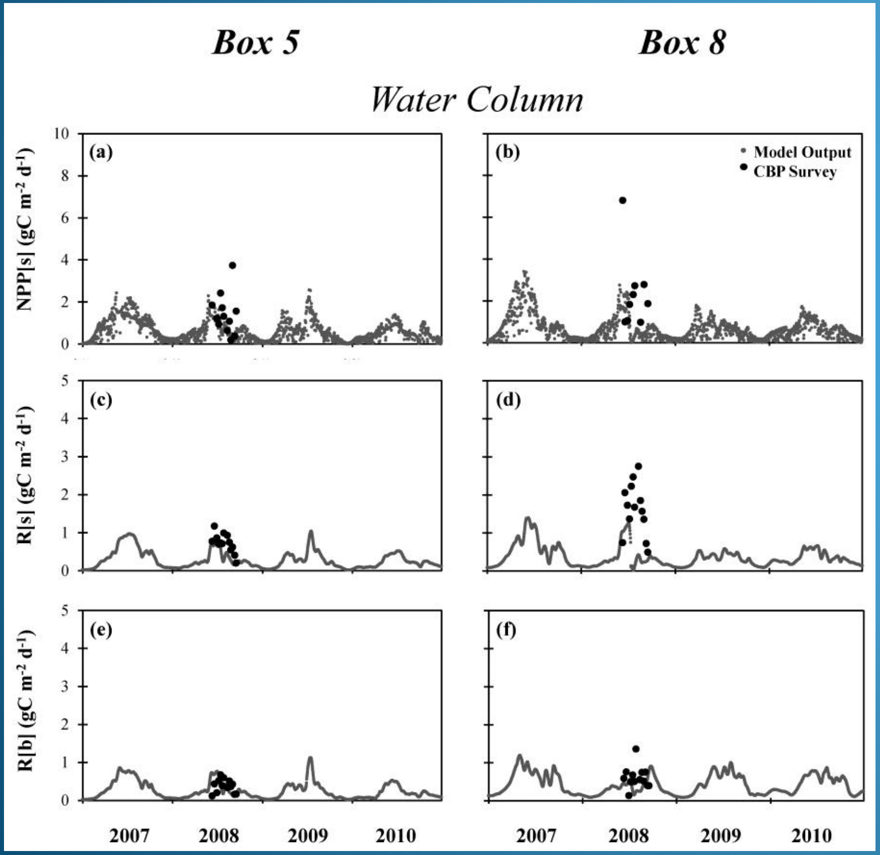
York River Calibration: Stocks

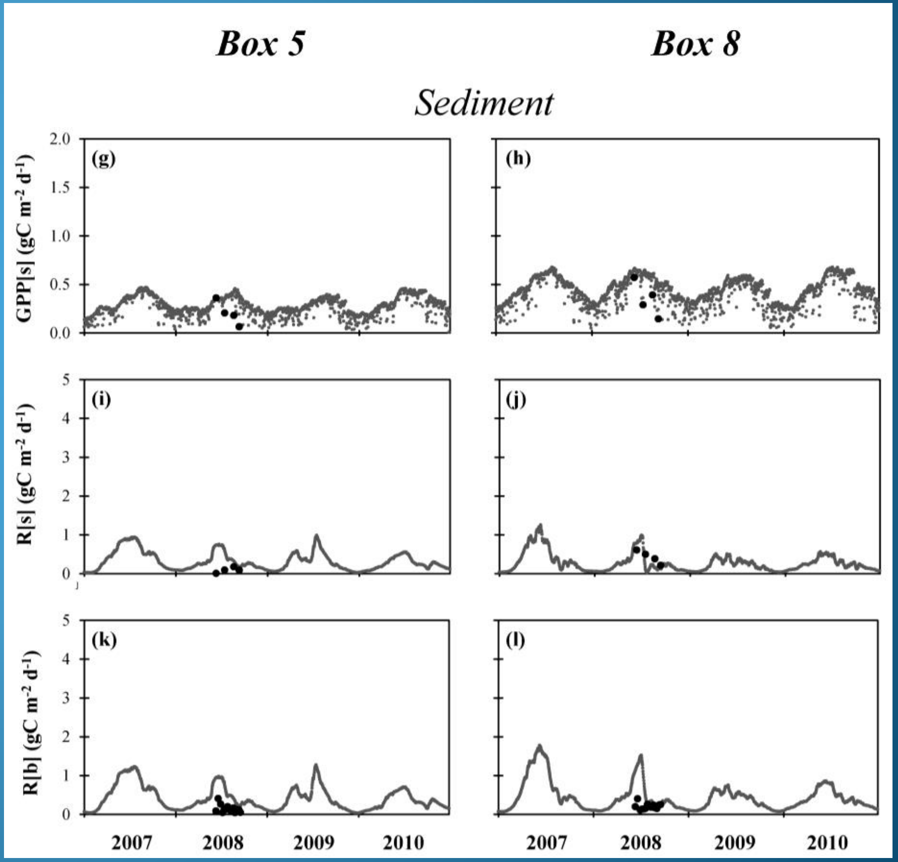




Data: Chesapeake Bay Program and VIMS

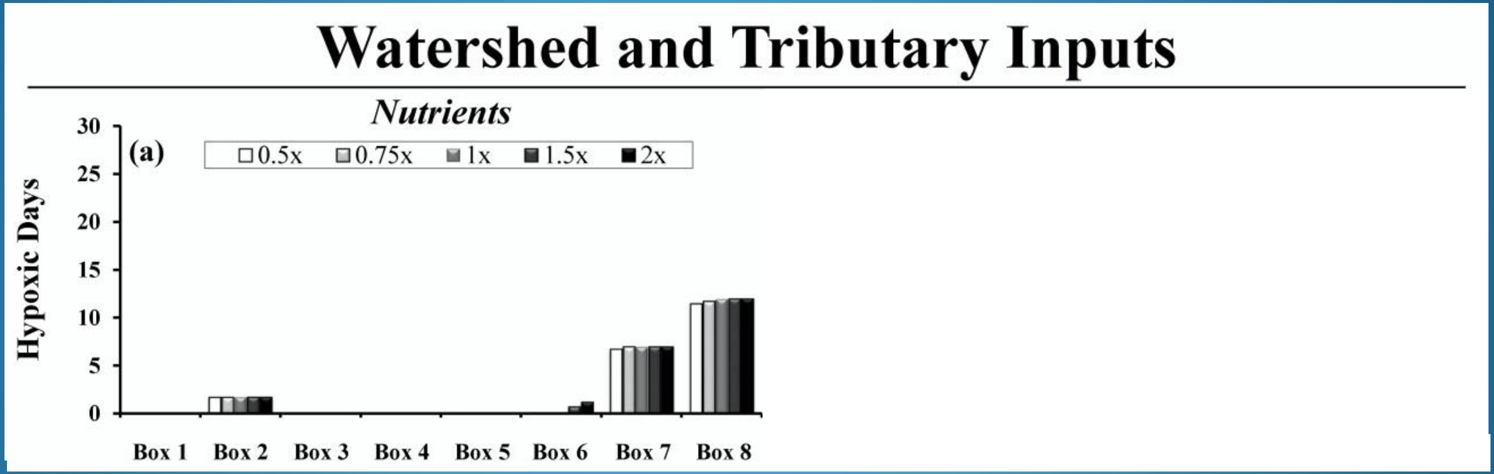
York River Calibration: Rates

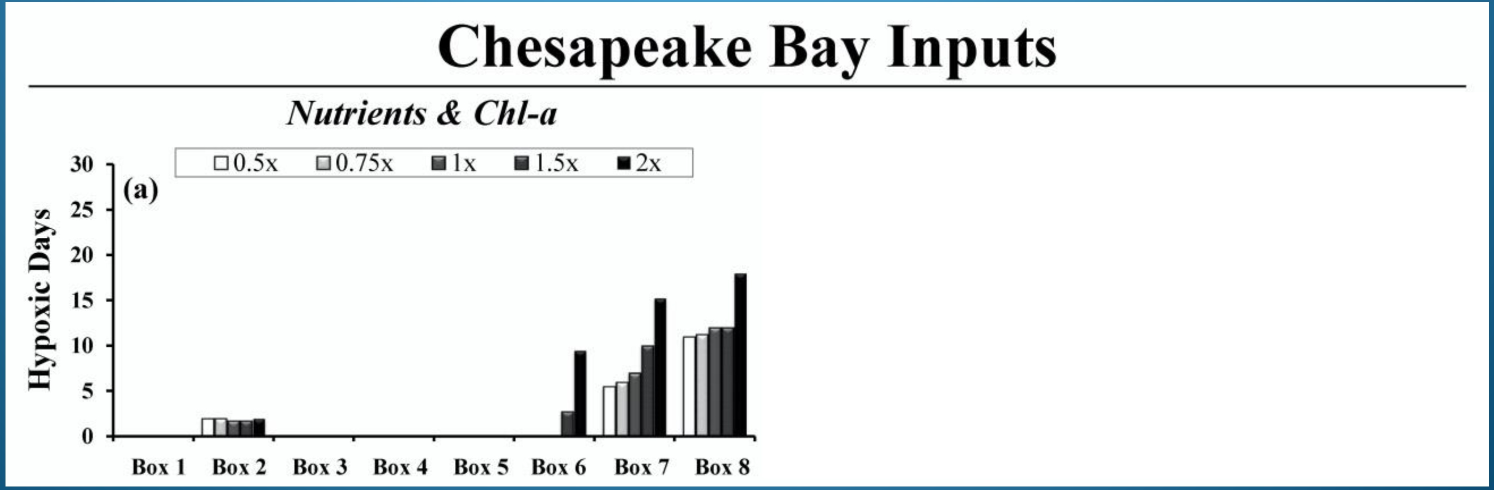




York River Loading Scenarios

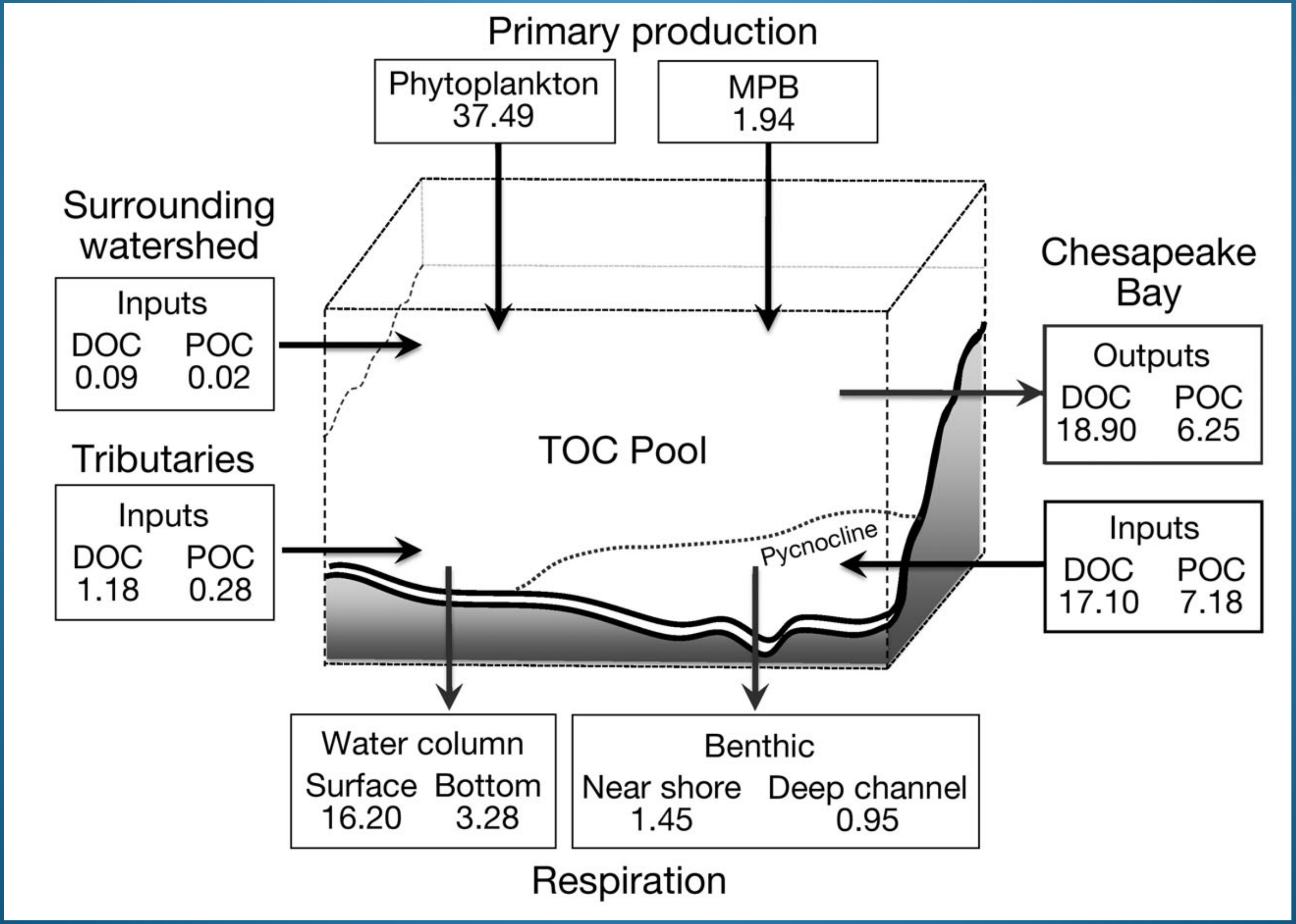
Number of Hypoxic Days (< 2 mg l^{-1})





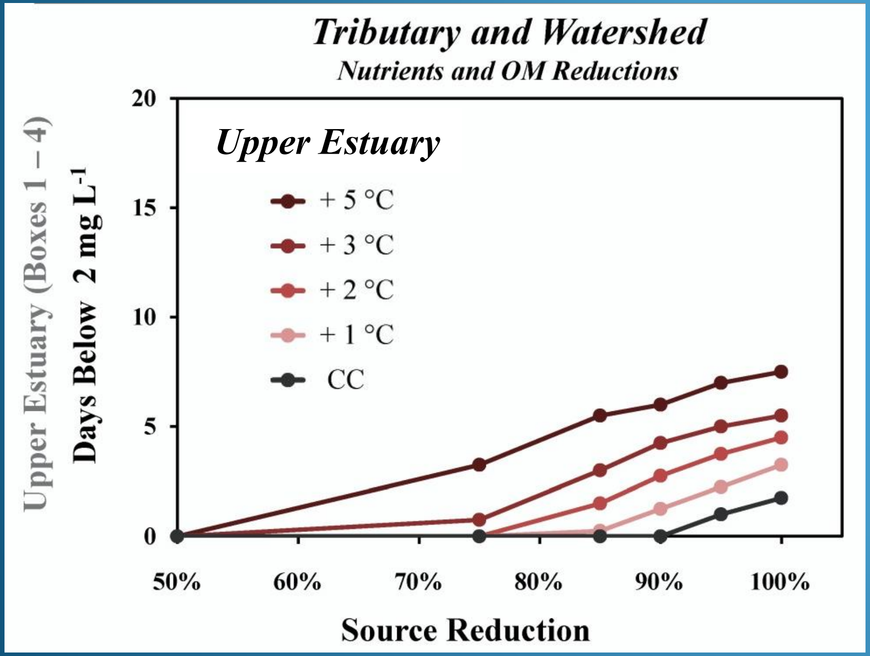
York River External Inputs

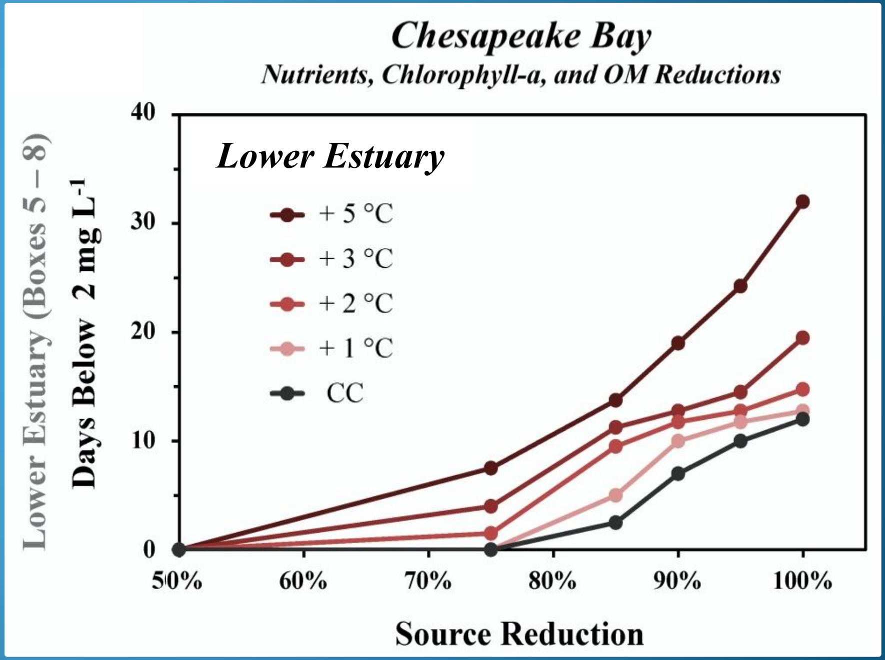
Carbon Sources & Sinks (x 10^9 g C summer^{-1})



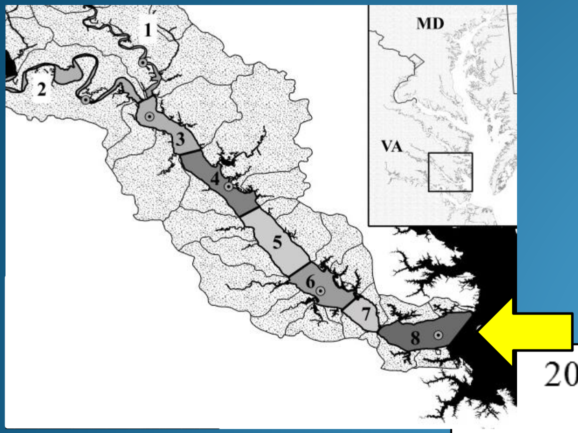
York River Climate Scenarios

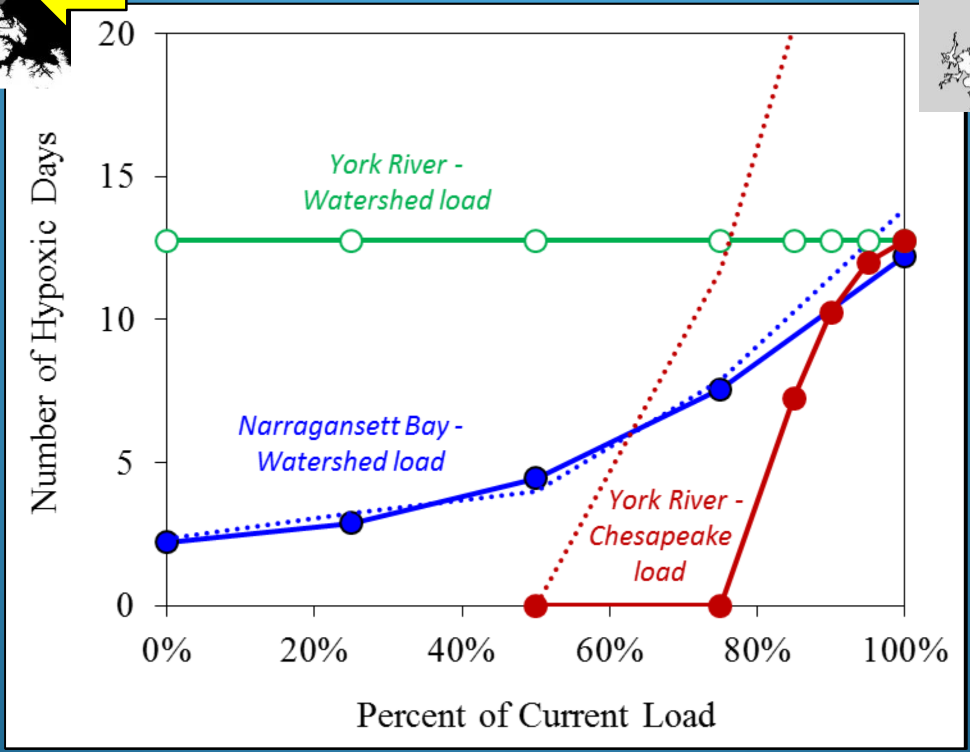
Number of Hypoxic Days (< 2 mg l^{-1})

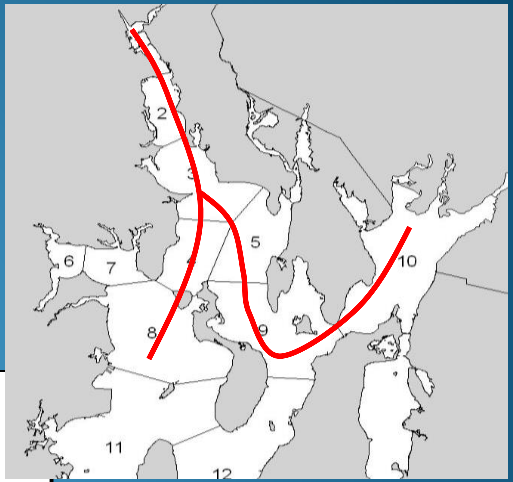


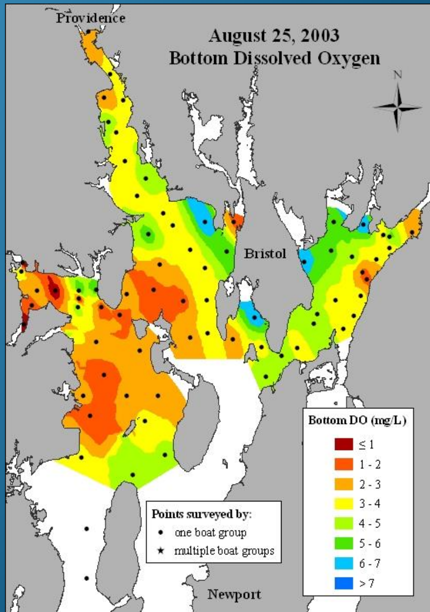


Cross-System Comparisons

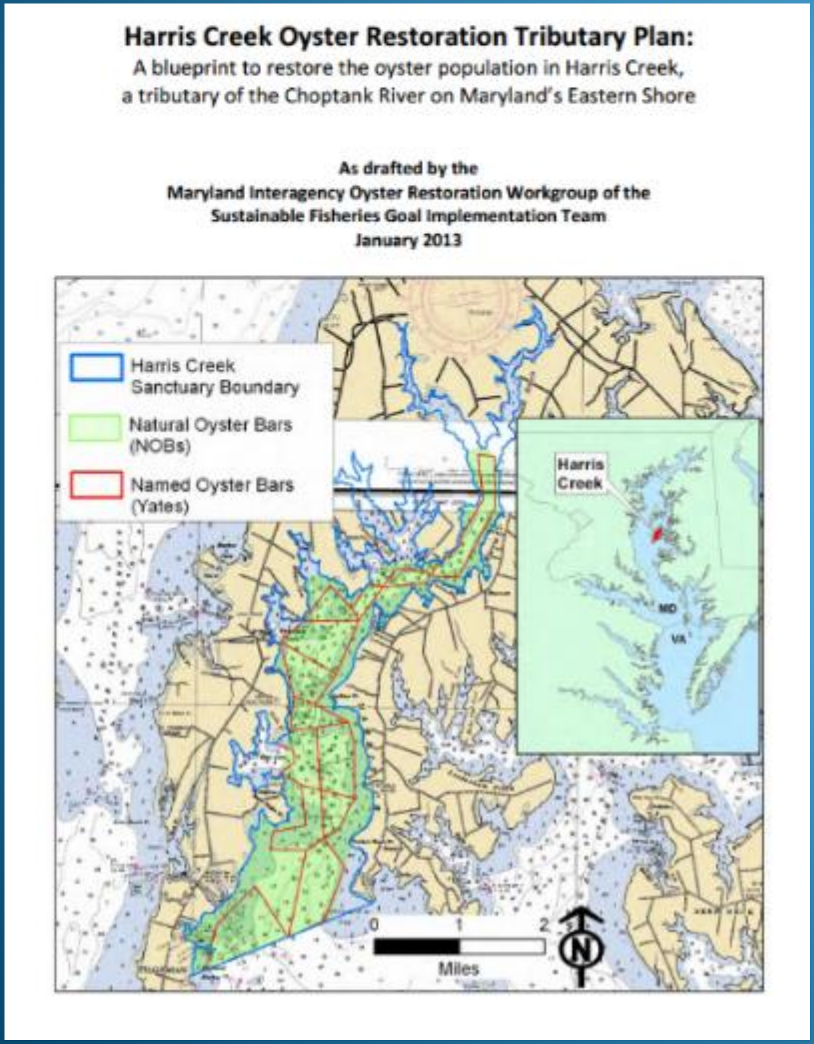








Harris Creek Oyster Restoration



188 acres planted to date
~1.2 billion oysters

Goal

- User-friendly, web accessible model

User-Defined Inputs

- Restored acreage, density, & mean weight

Outputs

- Volume filtered
- TSS, Chl-a, and nutrients filtered
- N and P assimilated in tissues and shells
- N removed via denitrification
- N and P burial
- Economic value of N and P removal

Model Forcing

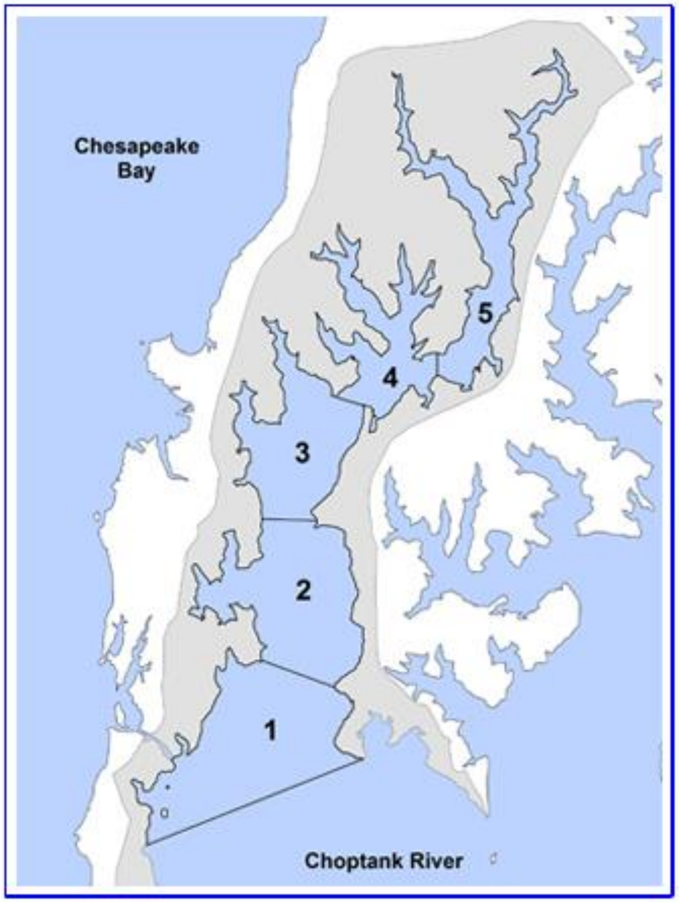
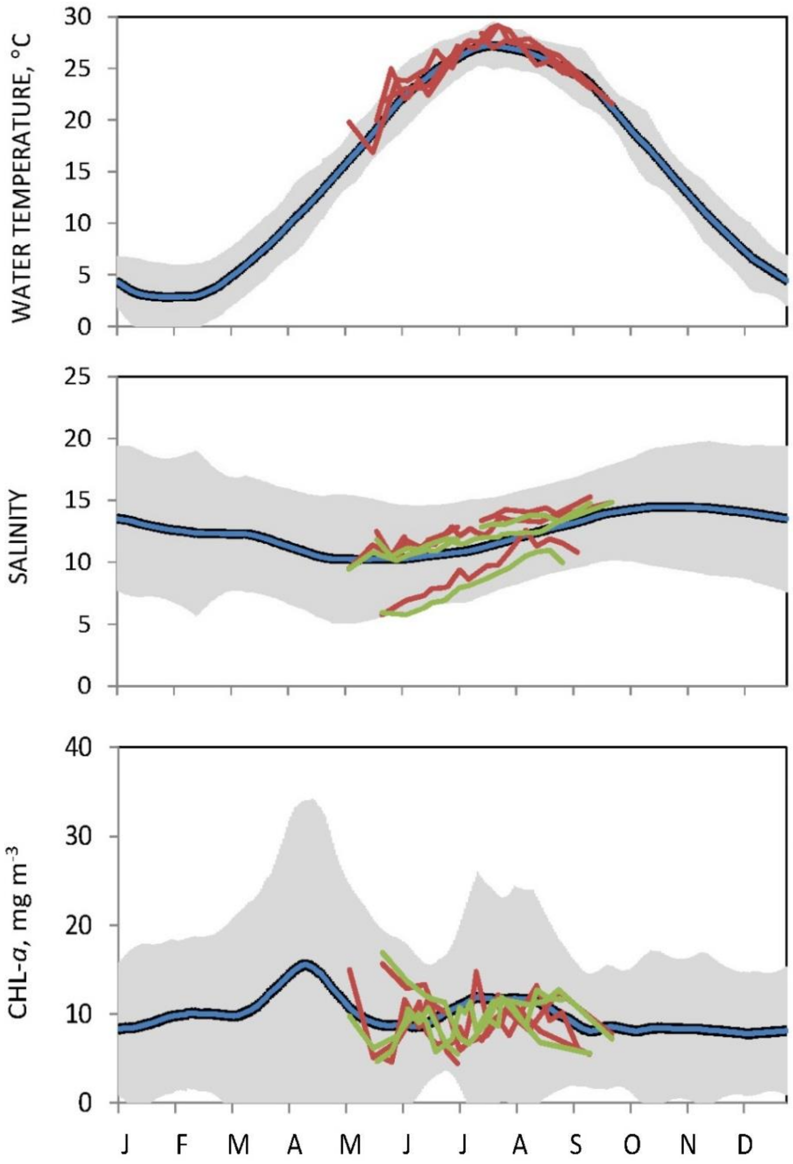
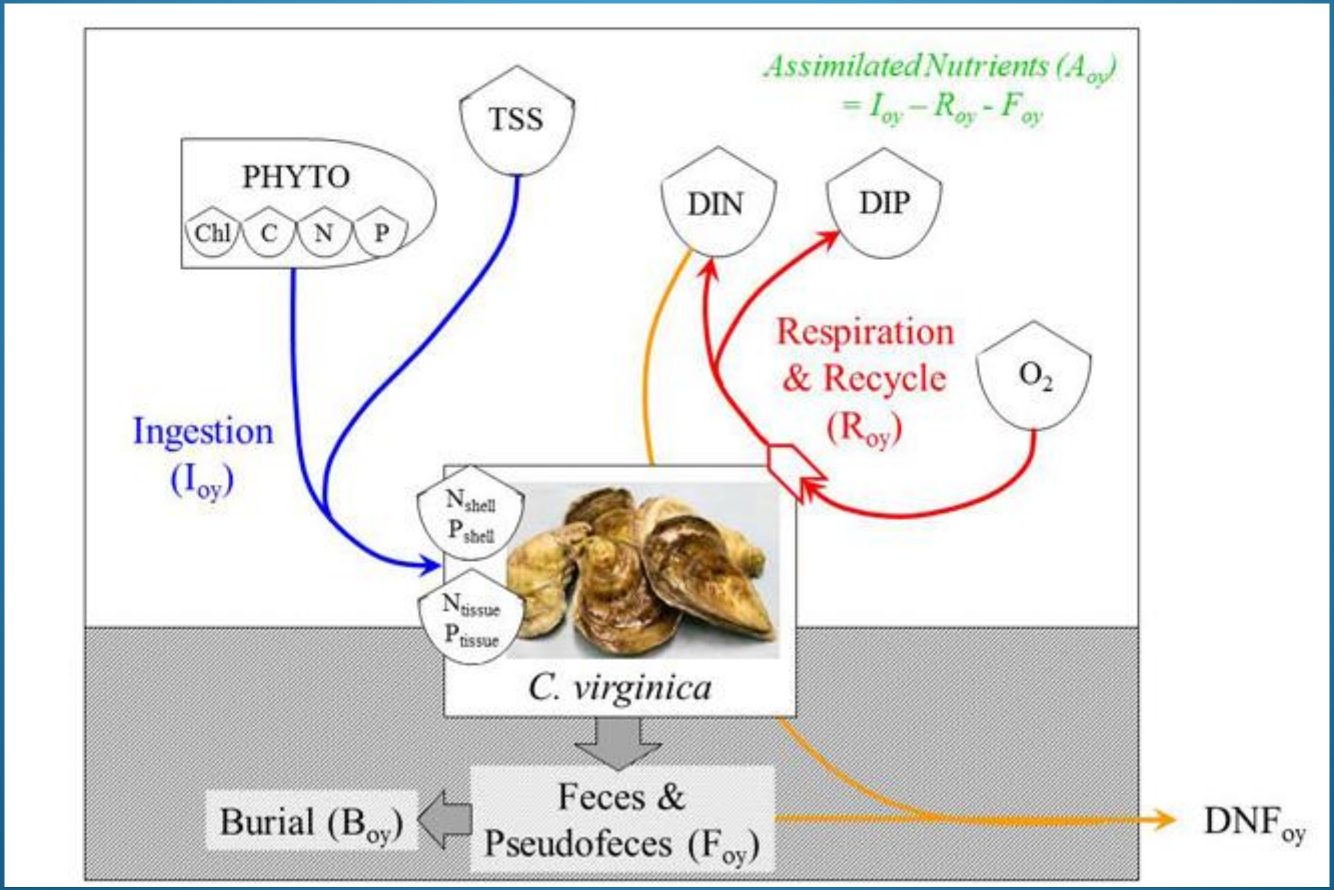


Fig. 1: Spatial elements (1-5) of the Harris Creek model. Watershed boundary is shown in light grey.

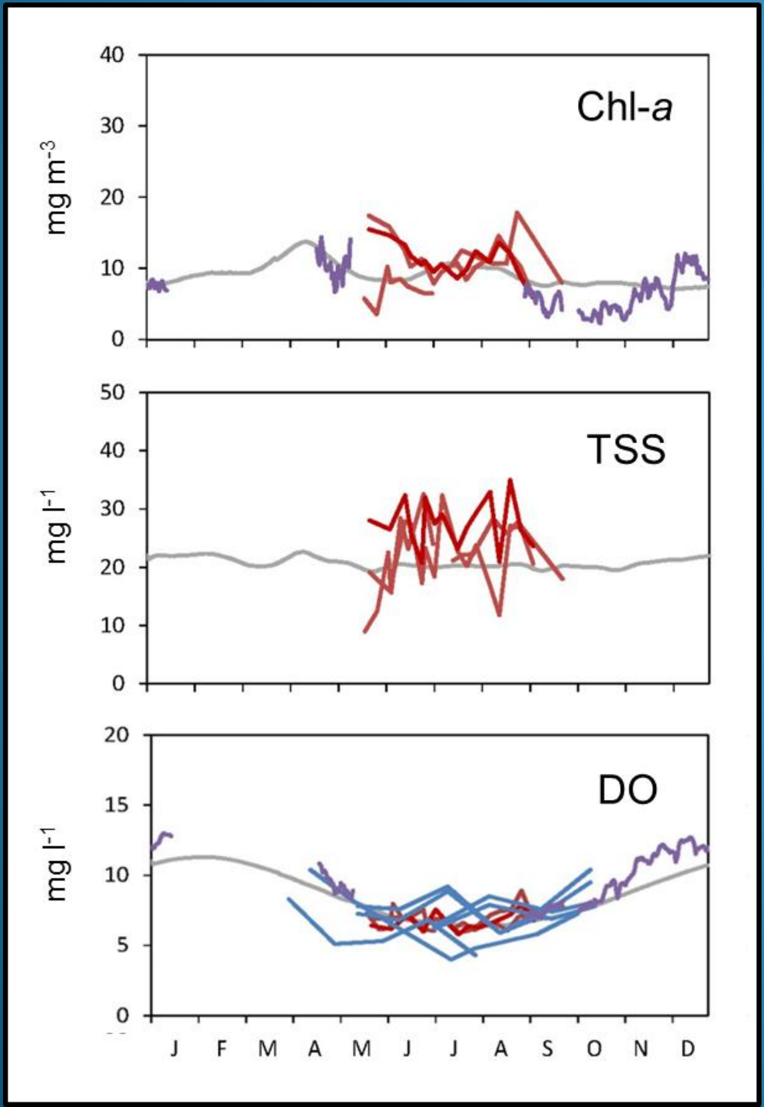


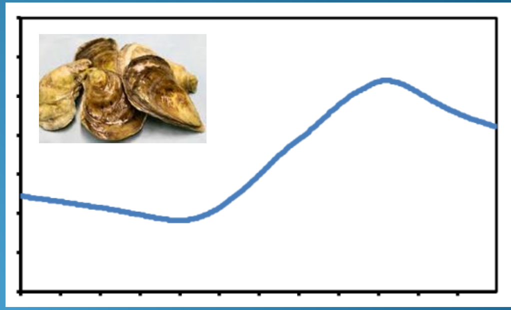
Oyster Submodel

Net N removal = assimilation + denitrification + burial - recycling



Calibration of Water Quality and Oyster Growth





Expected growth (Liddel 2008):
0.62 – 0.80 g DW y^{-1}

Table 3. Modeled annual oyster growth using default values for restored acres, density, and oyster size.

Box	Growth, g DW y^{-1}
1	0.70
2	0.69
3	0.78
4	0.71
5	0.34

Simulated Oyster Functions

Table 1. Predicted oyster impacts on water quality

Volume filtered, % d^{-1}	0 – 11.2
mean	3.5
% change due to oysters	
Chl-a	-4.0
TSS	-6.3
DO	0.1
Secchi	4.3

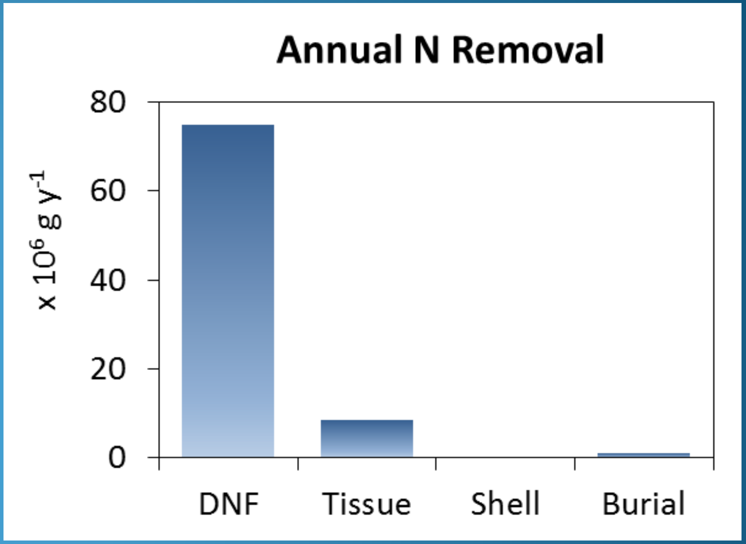
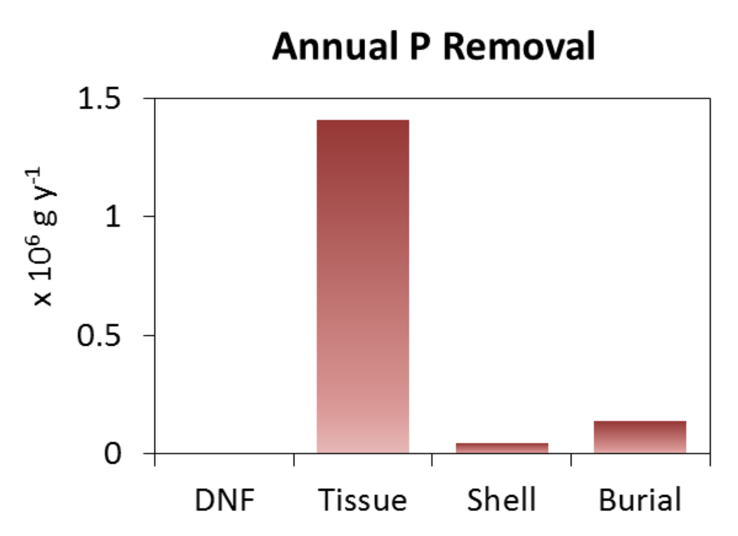


Table 2. Percent of inputs removed by oysters

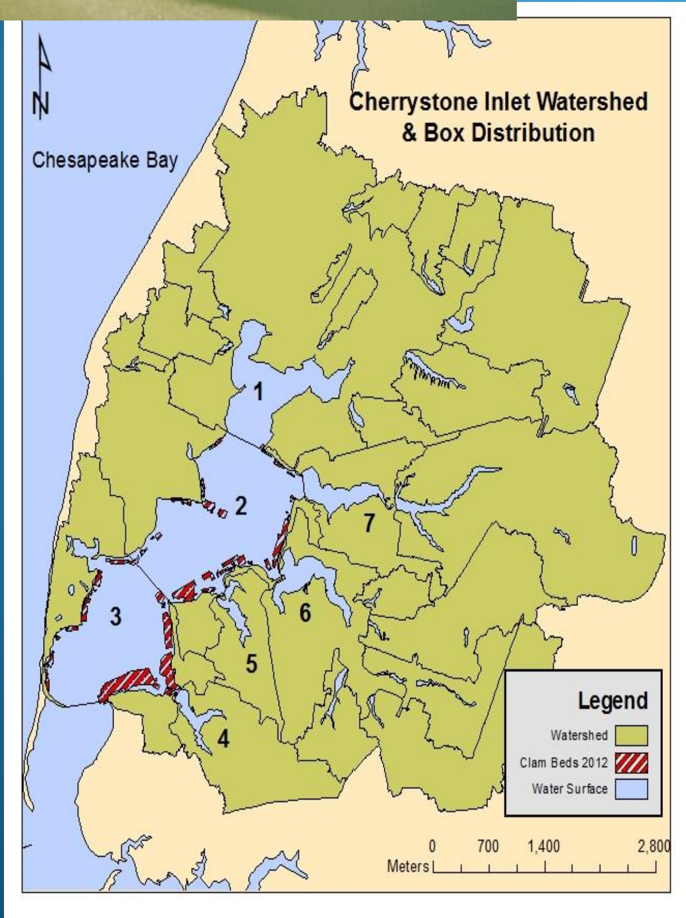
	N	P	TSS	C
Watershed	365	112	1059	116
Atmosphere	437			
Chesapeake	6.2	6.6	11.9	5.6
NPP				9.6
Total	6.0	6.2	11.8	3.4

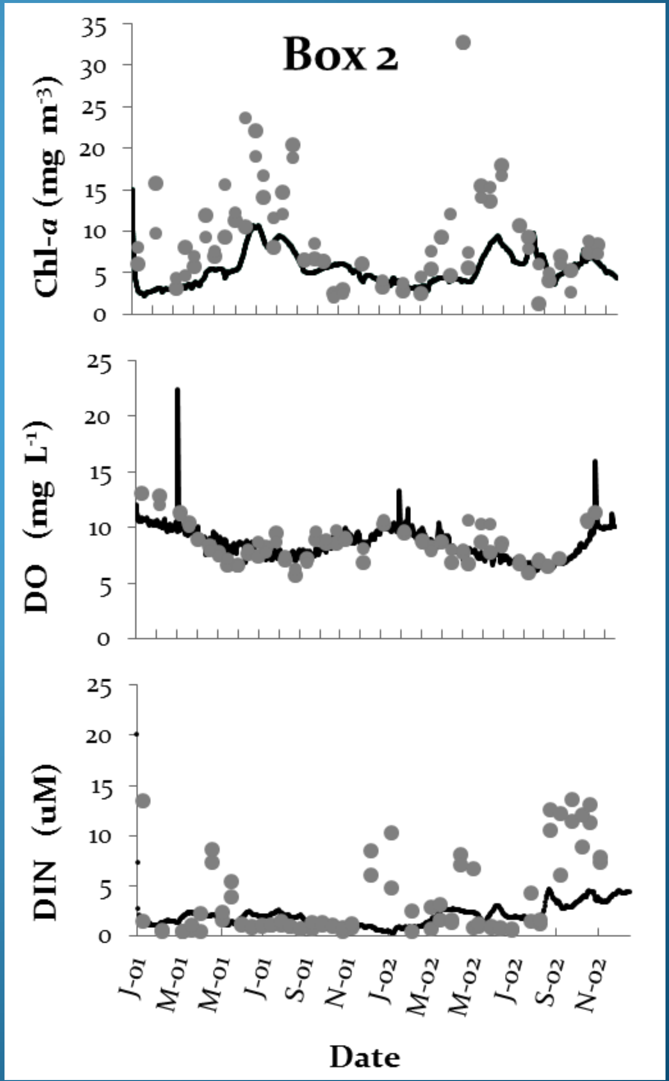


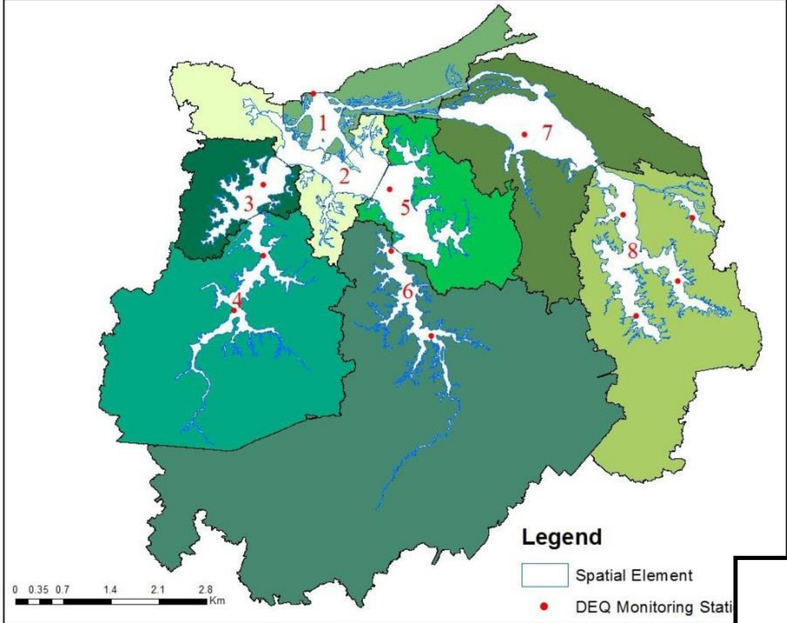
Hard Clam Aquaculture

Cherrystone Inlet, VA

Kuschner (2015) – M.S.



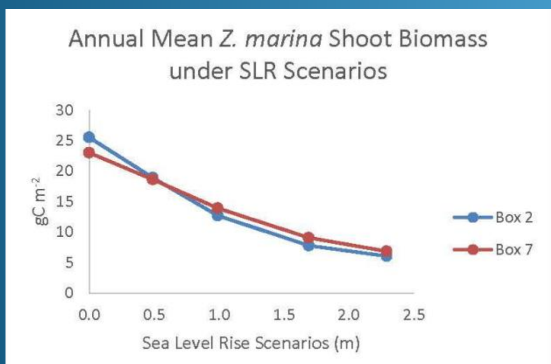


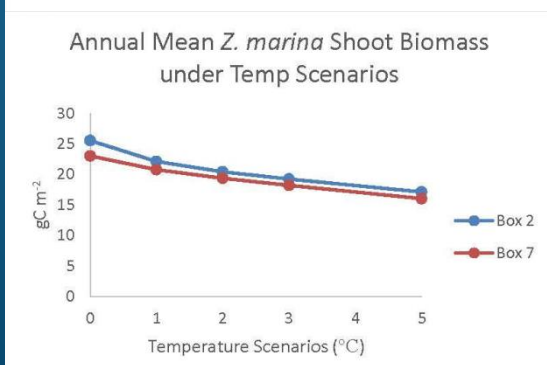


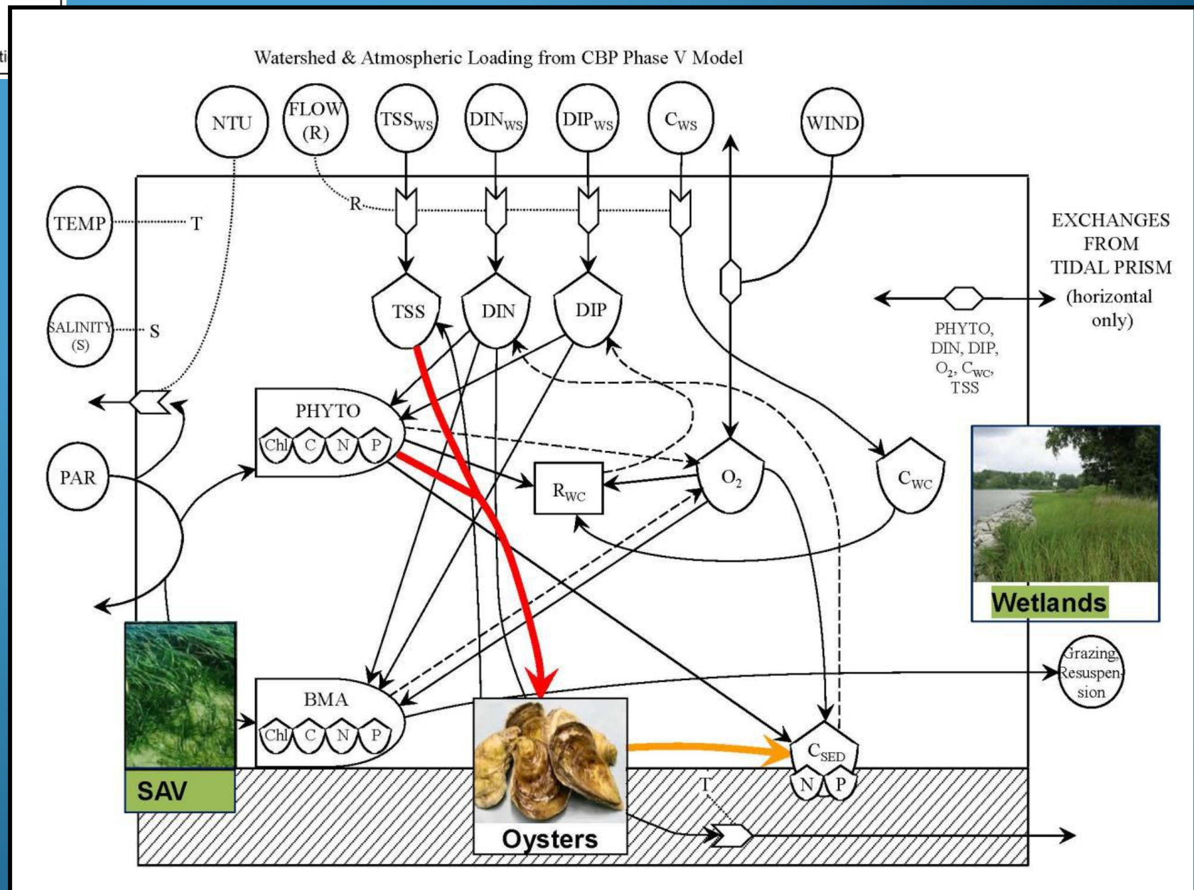
Sustainability of Restoration under Climate Change

Lynnhaven River, VA

Skeehan (2015) – M.S.







Online Models

www.vims.edu/research/departments/bio/programs/semp/models/index.php

Systems Ecology and Modeling Program

- Introduction to Modeling
- Introduction to Systems Ecology
- People
- Research Interests
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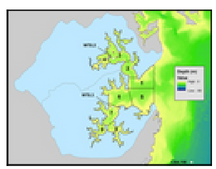
Coastal Systems Ecology and Modeling Program

Online Models

- West-Rhode River Estuary (MD) Restoration Model (v.2, October 2013):



- DCERP Estuarine Simulation Model (v.1, December 2013):
  - Complete 2007-2010 model
  - 2010 model only (faster running)

- Narragansett Bay EcoOBM (v.1, February 2014):
  - Complete 2001-2010 model (coming soon)

Online run time:
< 1 min for 1 year

The Harris Creek Oyster Restoration Model

Drs. Mark J. Brush and M. Lisa Kellogg
Virginia Institute of Marine Science
June 2014

Introduction

The Harris Creek model simulates water quality and ecosystem dynamics in five well-mixed boxes (Fig. 1). A diagram of the model is given on the next page (Fig. 2).

The model runs over an average annual cycle based on forced water temperature, salinity, and boundary conditions using Chesapeake Bay Program (CBP) data for 1985-2012, and monthly watershed loading from the CBP Phase V watershed model for 1985-2005.

The user can conduct runs under various restoration scenarios and export output on the following pages. The model was constructed with funding from the National Fish and Wildlife Foundation and Oyster Recovery Partnership.

Contact for questions:
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VIMS | William & Mary
Virginia Institute of Marine Science

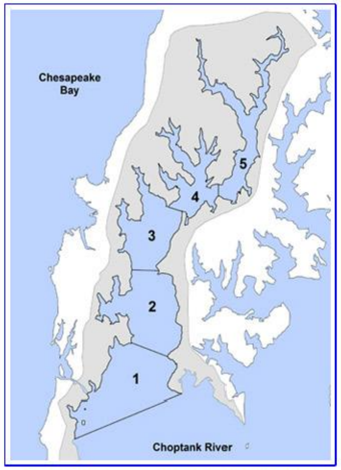


Fig. 1: Spatial elements (1-5) of the Harris Creek model. Watershed boundary is shown in light grey.

Skip to Scenario Analysis

Next Page

The Harris Creek Oyster Restoration Model

Previous Page

Running Model Scenarios and Obtaining Output

This page enables the user to conduct simulation analyses of restoration scenarios in each spatial element of Harris Creek. Enter the acres of restored reefs, restored oyster density, and mean oyster size in the tables below. Spatial element is shown in brackets. Clicking the "U" in the upper left corner of each table will restore default values.

1. Specify the acres of restored oyster reefs in each spatial element.
2. Specify the density of restored oysters (#/acre) in each spatial element.
3. Specify the average weight (g dry weight) of restored oysters in each spatial element.

Acres of Restored Reefs	
Oyster acres[1]	98.39
Oyster acres[2]	67.59
Oyster acres[3]	38.16
Oyster acres[4]	10.65
Oyster acres[5]	11.01

Restored Oyster Density	
Oyster density[1]	468311
Oyster density[2]	287114
Oyster density[3]	211160
Oyster density[4]	92733
Oyster density[5]	688309

Mean Oyster Weight	
Oyster DWo[1]	0.98
Oyster DWo[2]	0.73
Oyster DWo[3]	0.89
Oyster DWo[4]	0.76
Oyster DWo[5]	0.76

4. Optional: Specify the value of nutrient removal ($/pound):

Nutrient Credits	
N price	0
P price	0

Use the buttons below to run, pause, stop, and resume a model run. Model output is plotted and available for export on the following pages. Water quality graphs are cumulative (results of multiple runs will be plotted along with previous results). "Restore" will clear all previous runs.

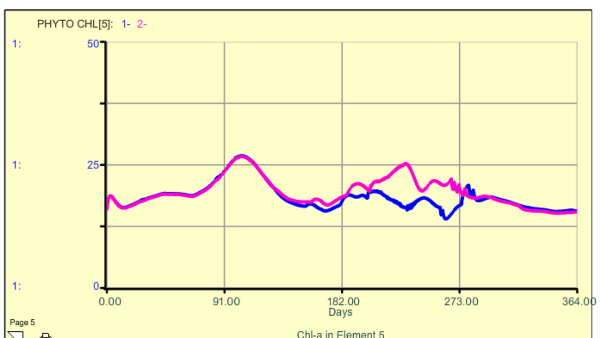
Run | Pause | Stop | Resume | Restore

Next Page

The Harris Creek Oyster Restoration Model

Phytoplankton chl-a (ug/l):

The graph shows output for simulated chlorophyll-a over an average annual cycle from Jan 1 (day 0) to Dec 31 (day 364). Click the tab in the lower left corner to scroll through results for each spatial element; element number is displayed in brackets after the parameter name in the upper left corner.

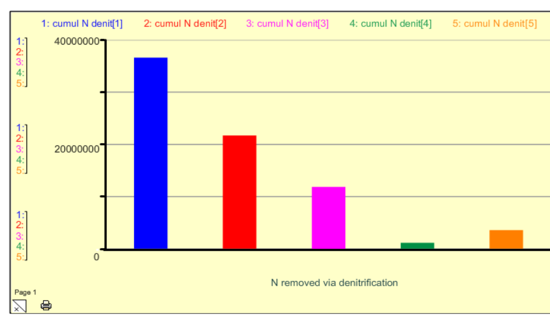


Return to Model Output Dashboard

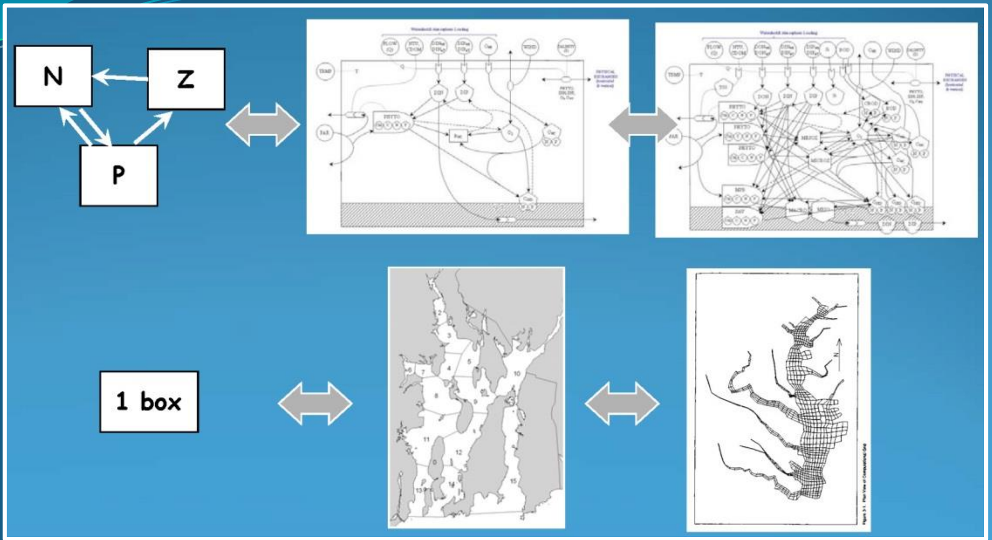
The Harris Creek Oyster Restoration Model

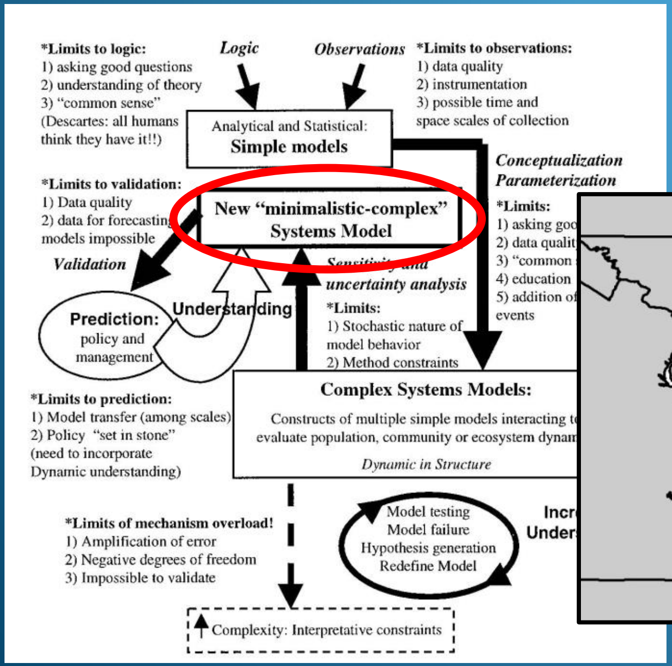
N removed via denitrification (g/y):

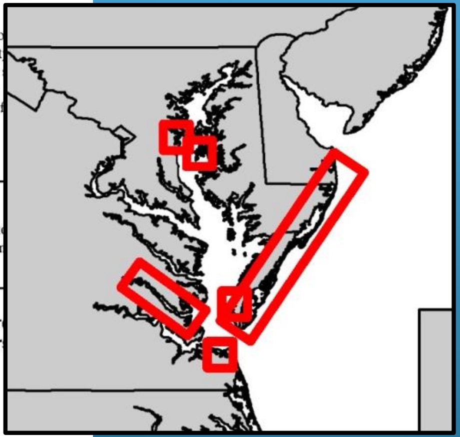
The graph below shows the total annual removal of N via denitrification associated with restored oyster reefs; Spatial element number is shown in brackets across the top of the graph.



Return to Model Output Dashboard







What this model is:

- Reduced complexity
- Modular (easy addition of state variables)
- Management-focused
- Fast running (~ seconds to minutes)
- Quickly applied (~1.5-2 weeks per system)
- Accessible GUI, web-deployable