Modeling the water quality benefits of tributary-scale oyster reef restoration

Lisa Kellogg, Mark Brush and Jeff Cornwell

Sustainable Fisheries Goal Implementation Team

December 17, 2018

VIMS | William & Mary
Virginia Institute of Marine Science

Reef Restoration - Harris Creek, MD

Tributary-scale restoration

- Creek closed to oyster harvest
- Spat on shell
  - 350 acres planted
  - 2.49 billion oysters
- Cost $28.6 million

VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Reef Restoration - Harris Creek, MD

Source: Tom Toles (2013) The Washington Post

VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Overview

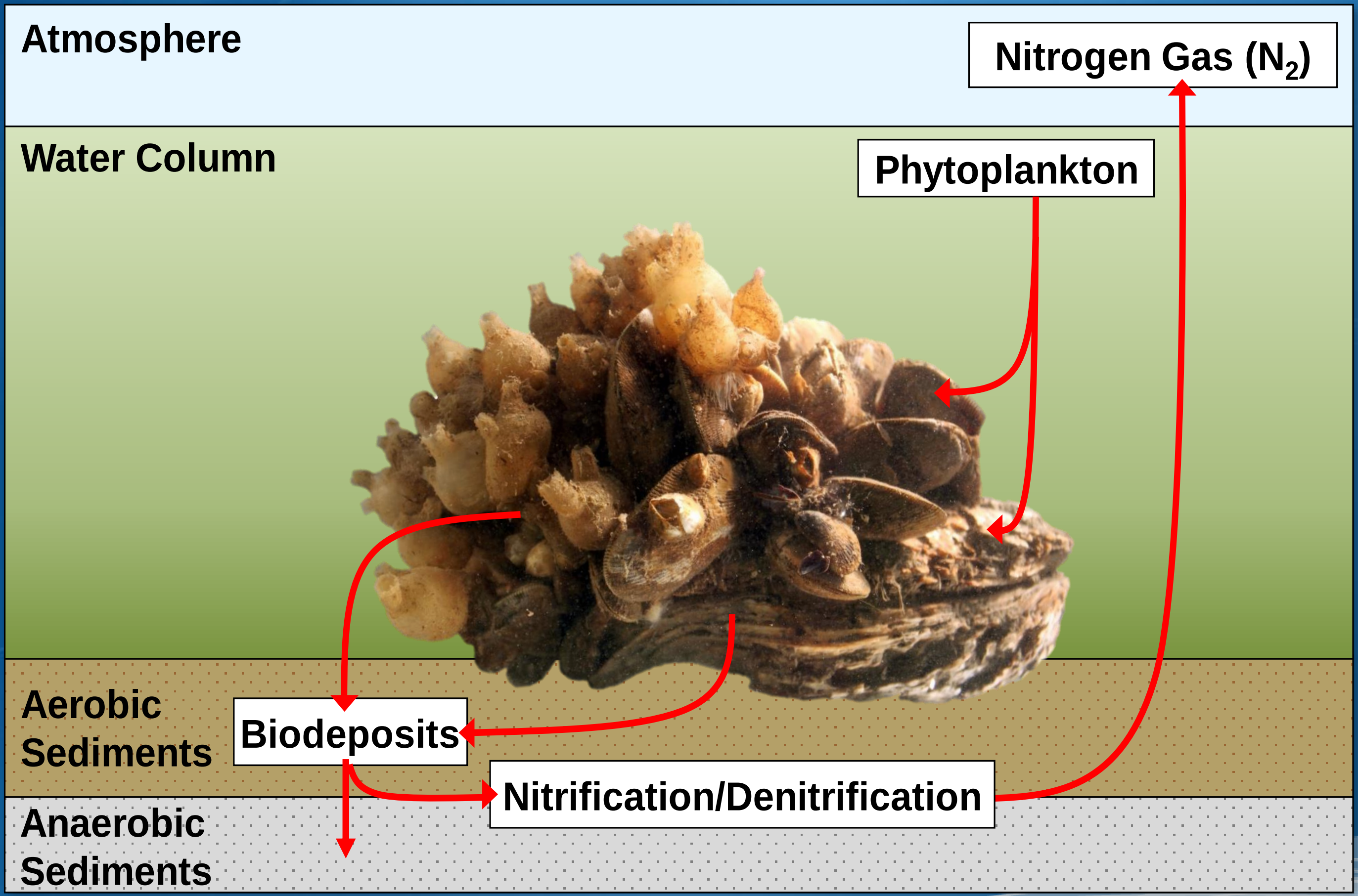
Modeling effort is part of a larger group of projects

- Integrated assessment of oyster reef ecosystem services
  - Forage for finfish
  - Habitat for macrofauna
  - Denitrification
  - TMDL-related benefits model

VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Oysters and Nutrient Cycling

Net N removal = assimilation + denitrification + burial
Net P removal = assimilation + burial

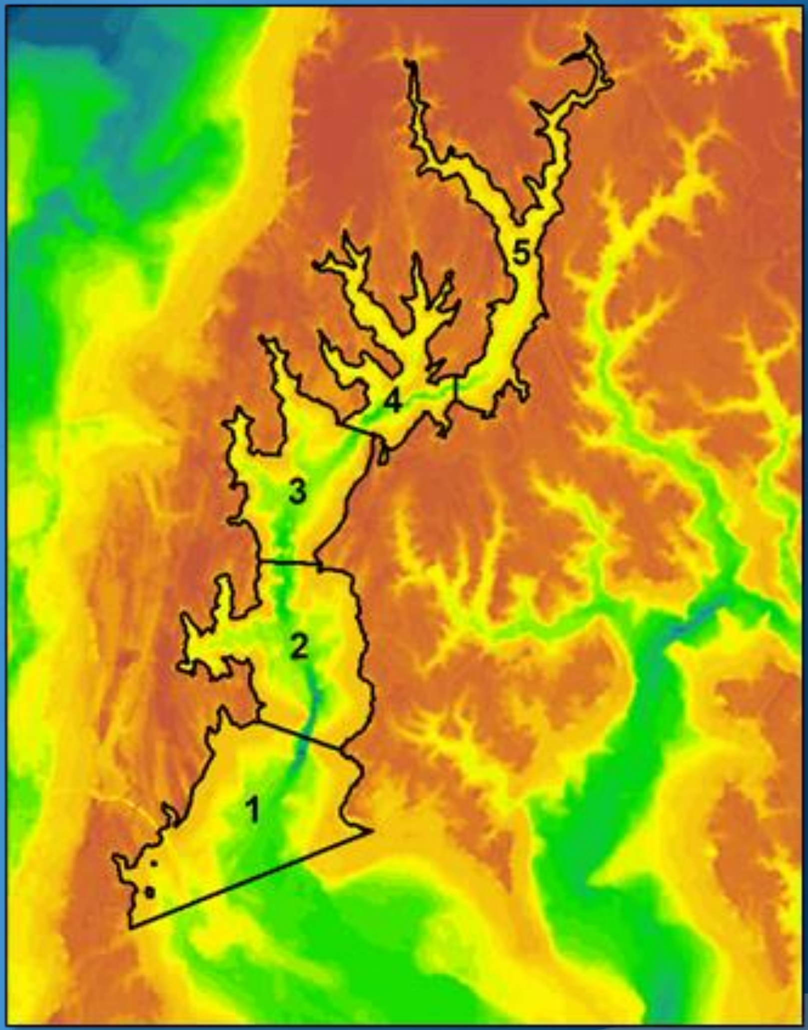


VIMS | William & Mary
Virginia Institute of Marine Science

Modeling Approach

Goals:

- Accurately estimate water quality benefits
- Allow users to run their own scenarios by altering model inputs
  - User-friendly online interface
  - Model outputs generated within seconds

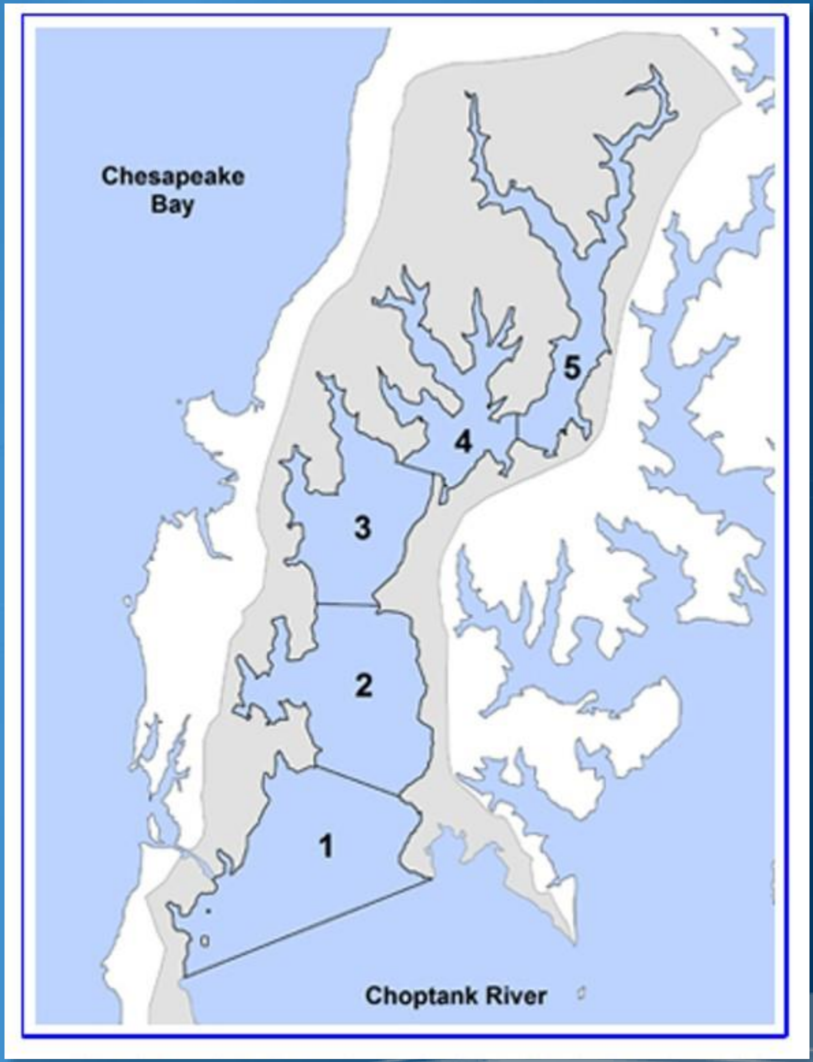


VIMS | William & Mary
Virginia Institute of Marine Science

Modeling Approach

Spatial and Temporal Resolution

- Creek divided into 5 vertically well-mixed spatial elements or “boxes”
- Simulates average annual cycle of water quality and impacts of restored reefs on the system

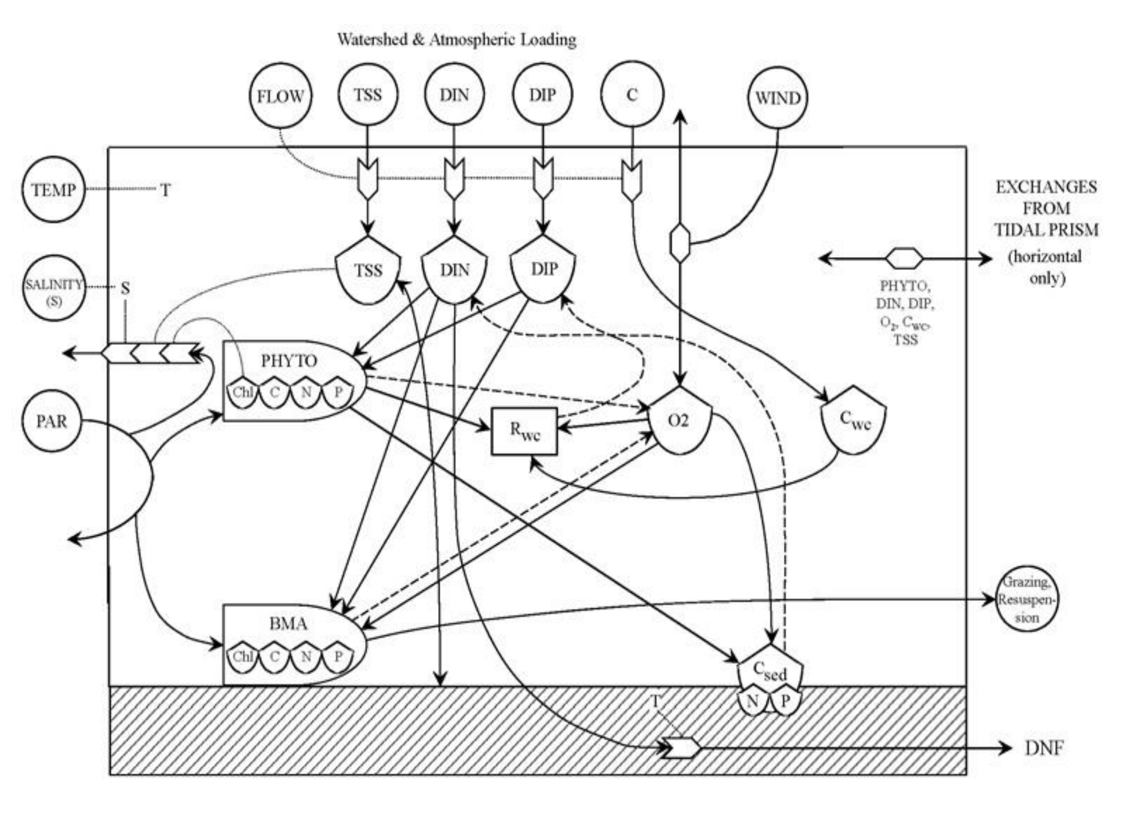


VIMS | William & Mary
Virginia Institute of Marine Science

Modeling Approach

Estuarine Ecosystem Model

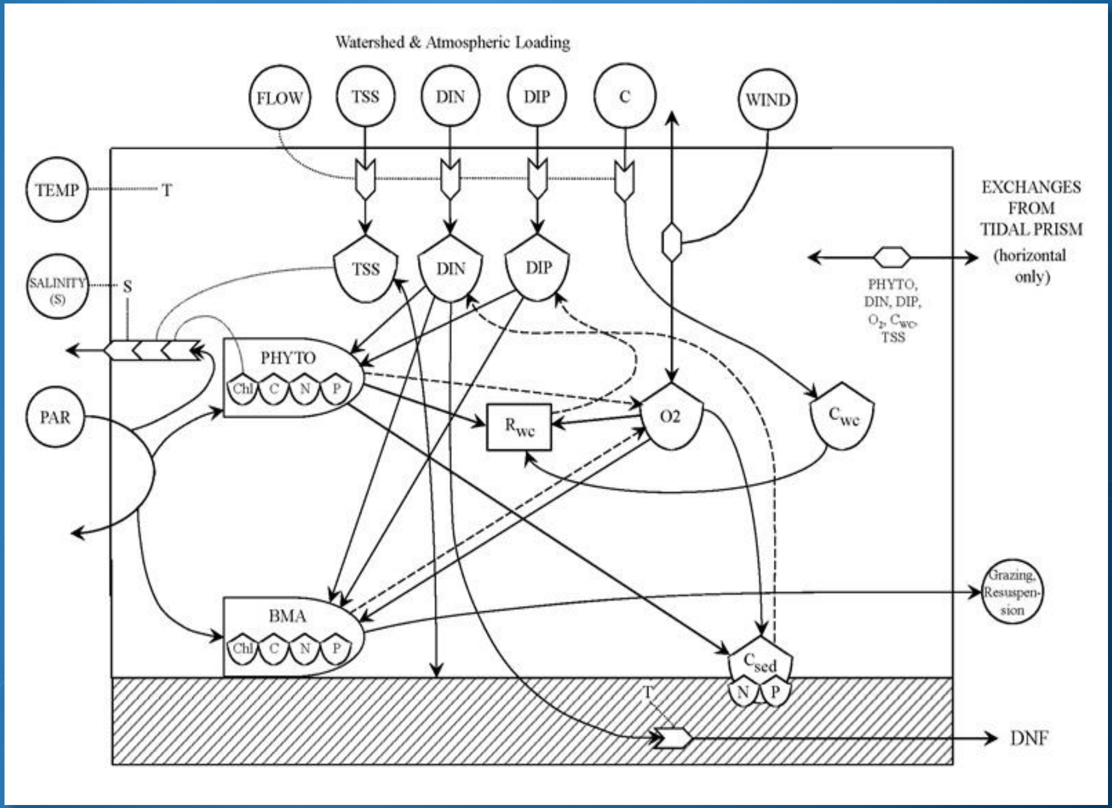
- Simulates state variables and processes of first-order importance to estuarine eutrophication
- Simulates daily concentrations over an average annual cycle
  – Chlorophyll a
  – C, N, and P in phytoplankton and benthic microalgae
  – Water column pools of TSS, DO, DIN and DIP
  – Pools of labile organic C and associated N and P in both water column and sediments



Modeling Approach

Estuarine Ecosystem Model

- Forced with daily:
  - Water temp
  - Salinity
  - PAR
  - Inputs of freshwater, TSS, DIN, DIP and C from the watershed
  - Atmospheric deposition of N
  - Mean wind speed
- Boundary conditions forced using long-term monitoring data

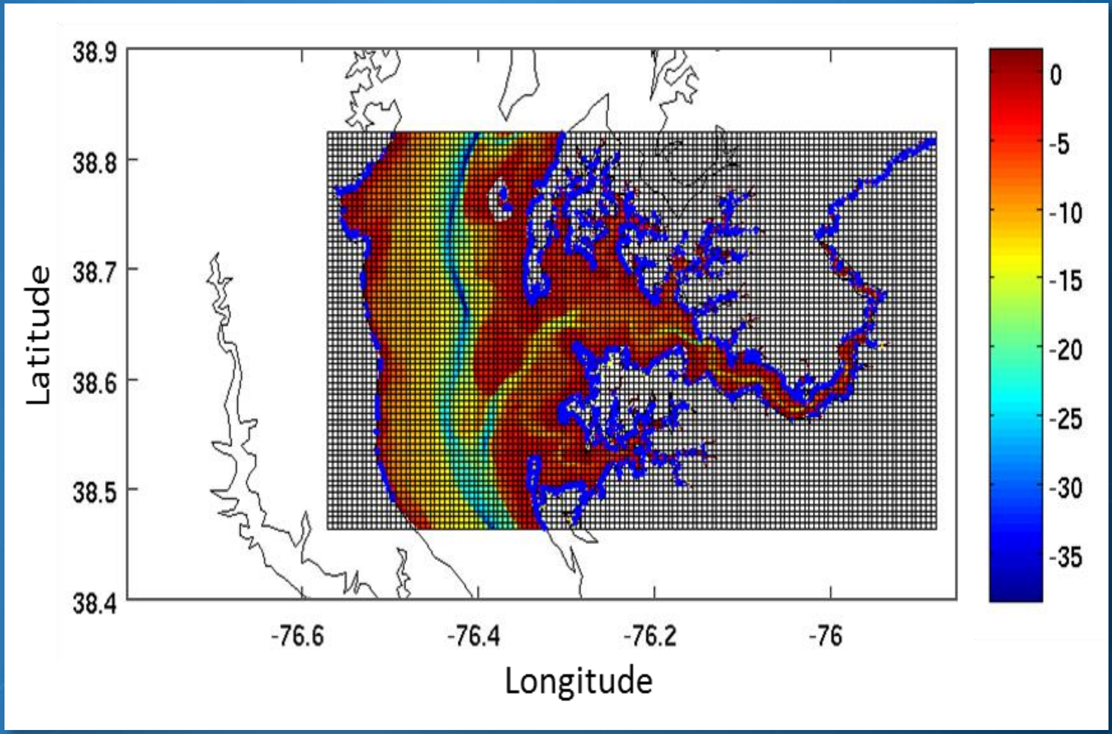


VIMS | William & Mary
Virginia Institute of Marine Science

Modeling Approach

Estuarine Ecosystem Model

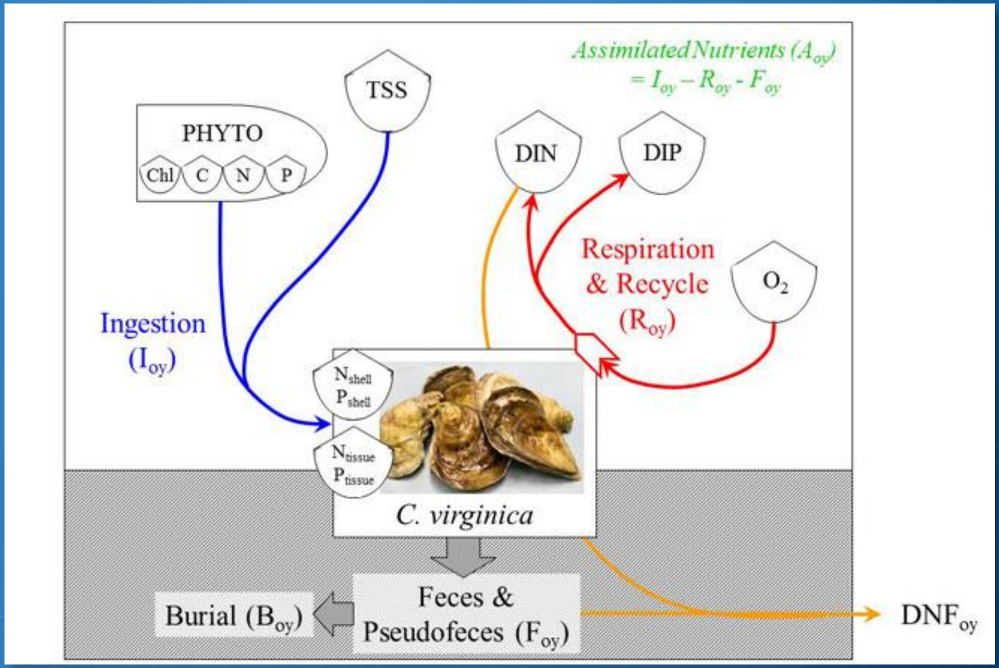
- Exchanges with the lower Choptank computed using tidal prism approach
  - Validated with ChopROMS



Modeling Approach

Oyster Sub-Model

- Computes daily growth of the average individual oyster
- Filtration is a function of individual weight, water temp, salinity, TSS and DO
- Multiplied by total oyster abundance
- Oysters draw down pools of TSS, phytoplankton biomass, and associated N and P which are assimilated into tissue and shell, buried, denitrified, or recycled

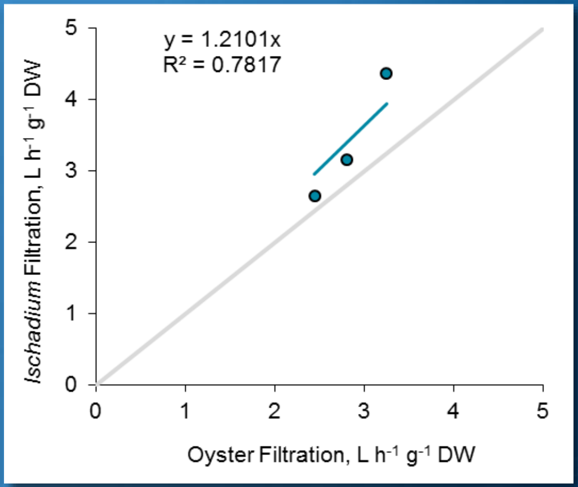


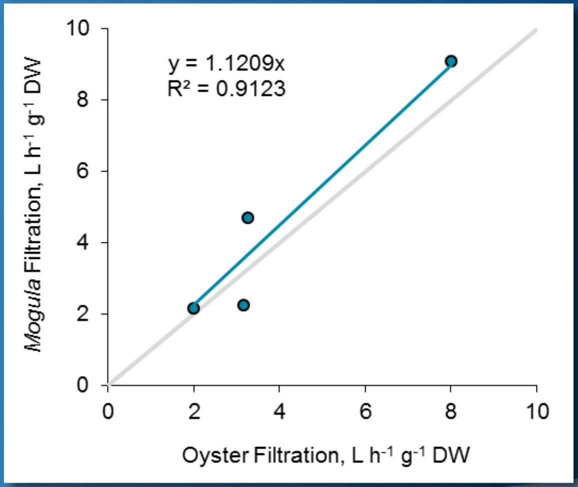
VIMS | William & Mary
Virginia Institute of Marine Science

Modeling Approach

Oyster Sub-Model

- Other filter feeders
  - Sea squirts (*Molgula manhattensis*)
  - Hooked mussels (*Ischadium recurvum)*
- Filtration rates scaled to oyster filtration
- Biomass based on seasonal data from Harris Creek



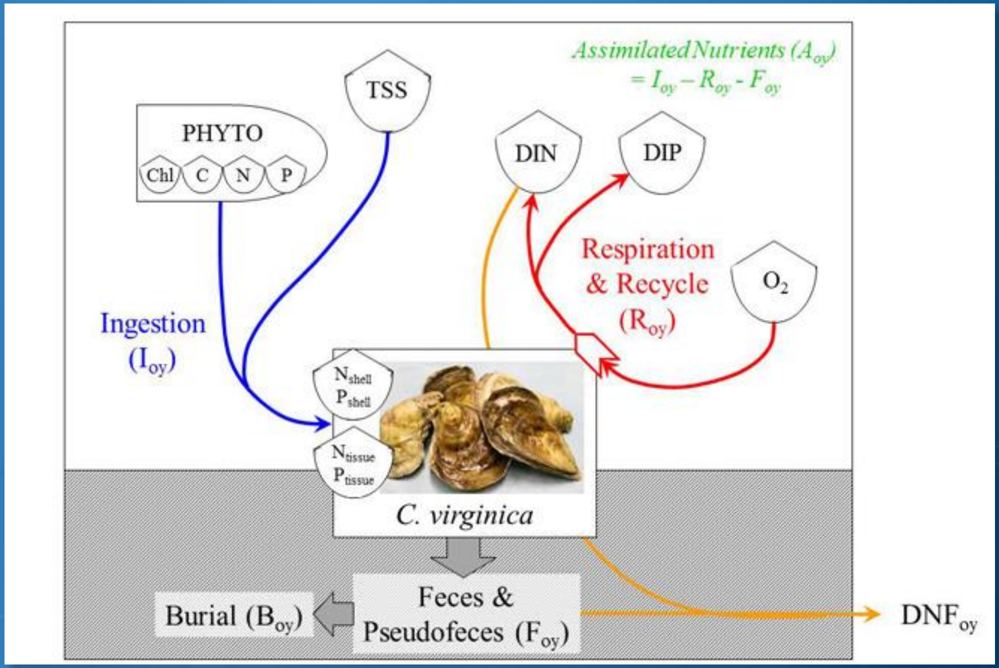


VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Modeling Approach

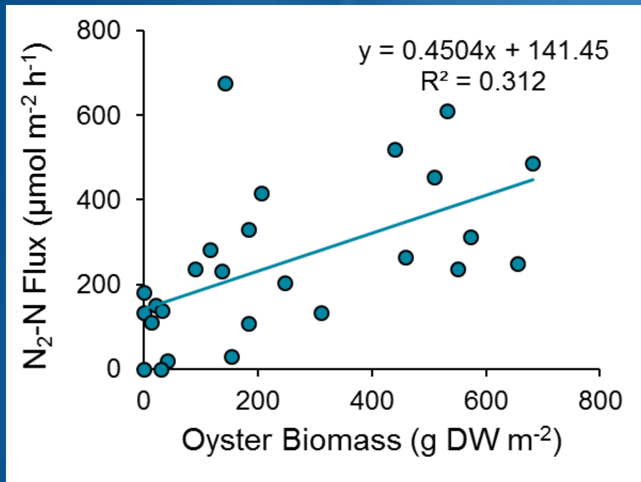
Oyster Sub-Model

- Denitrification rates based on seasonal measured values from Harris Creek and their relationship to reef community structure

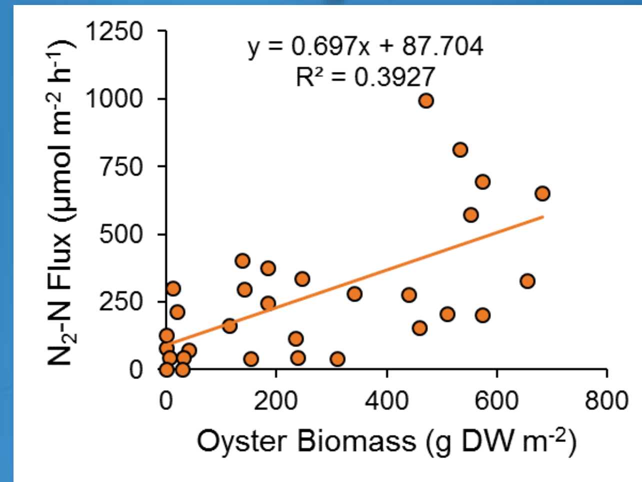


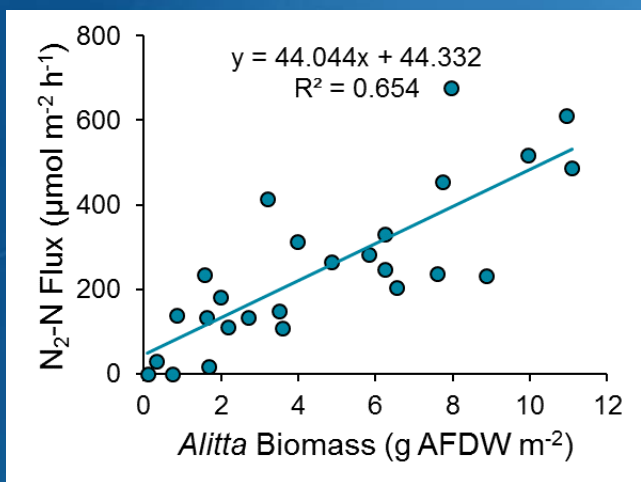
Denitrification Function

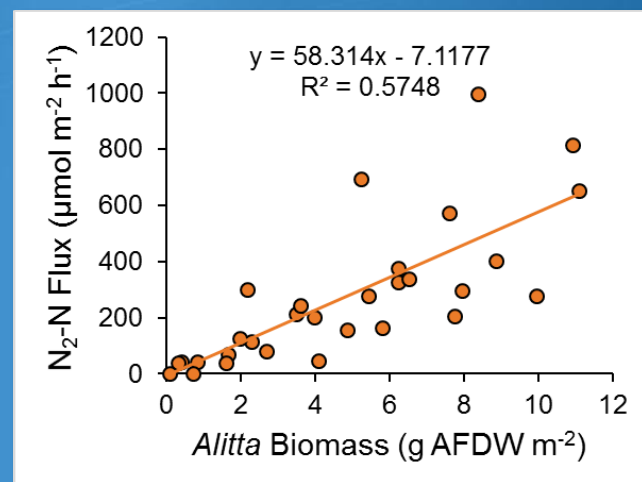
Dark



Light







VIMS | William & Mary
Virginia Institute of Marine Science

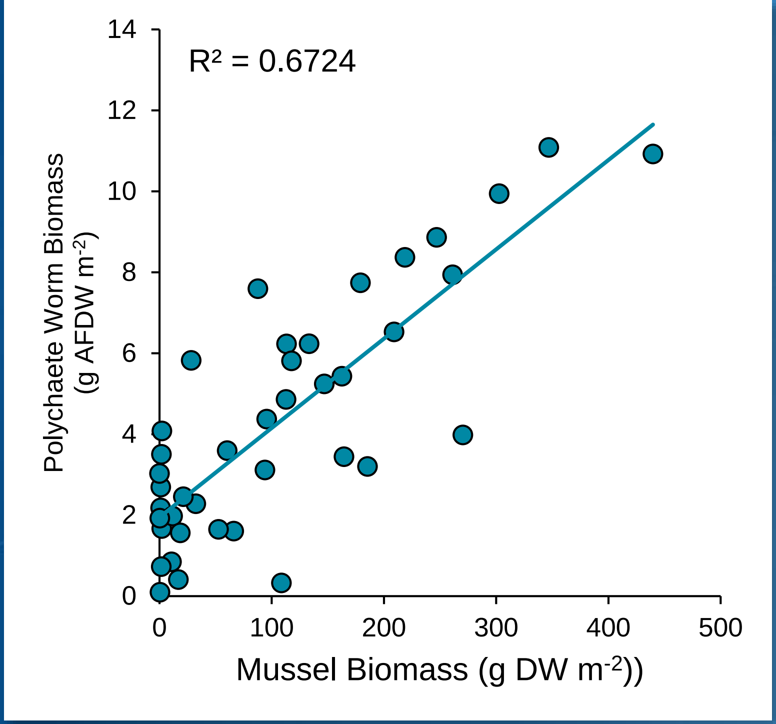
Denitrification Function

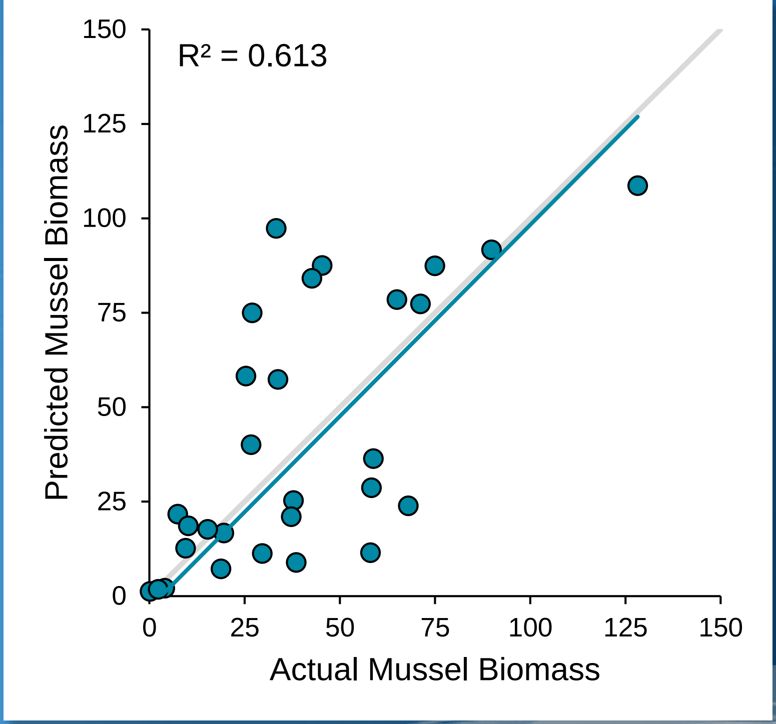
N_2 Flux = (62 * Polychaete Worm AFDW) – 40

How do you add worms to an oyster/water quality model?

Polychaete Worm AFDW = (0.12 * Mussel AFDW) + 1

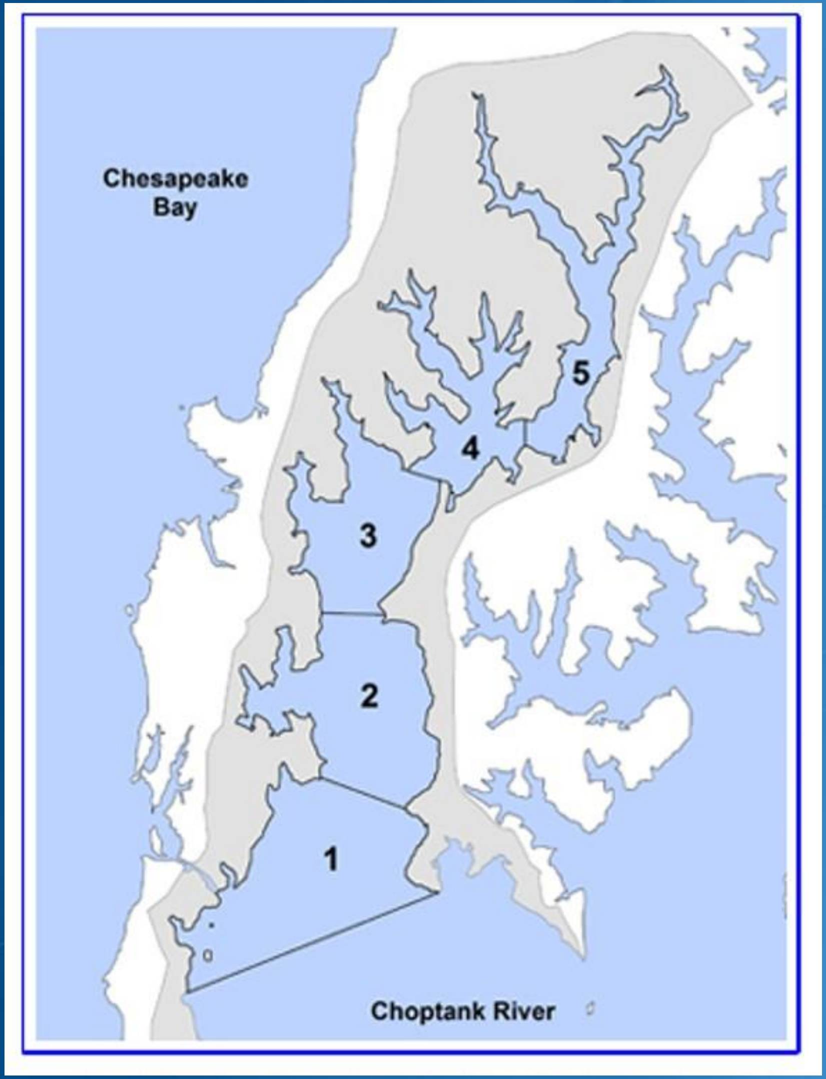
Mussel AFDW = 3 + (0.18 * Total Oyster DW) - (4.488 * Distance)





VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Model Inputs



Default values based on 2015 and 2016 oyster reef monitoring data

1. Specify the acres of restored oyster reefs in each spatial element.

Acres of Restored Reefs	Value
Oyster acres[1]	168.6
Oyster acres[2]	88.5
Oyster acres[3]	65.6
Oyster acres[4]	17.9
Oyster acres[5]	6.9

2. Specify the density of restored oysters (#/acre) in each spatial element.

Restored Oyster Density	Value
Oyster density[1]	477529
Oyster density[2]	224601
Oyster density[3]	284090
Oyster density[4]	696060
Oyster density[5]	370288

3. Specifiy the average tissue weight (g dry) of restored oysters in each spatial element.

Mean Oyster Weight	Value
Oyster DWio[1]	0.95
Oyster DWio[2]	0.87
Oyster DWio[3]	1.08
Oyster DWio[4]	1.28
Oyster DWio[5]	1.26

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

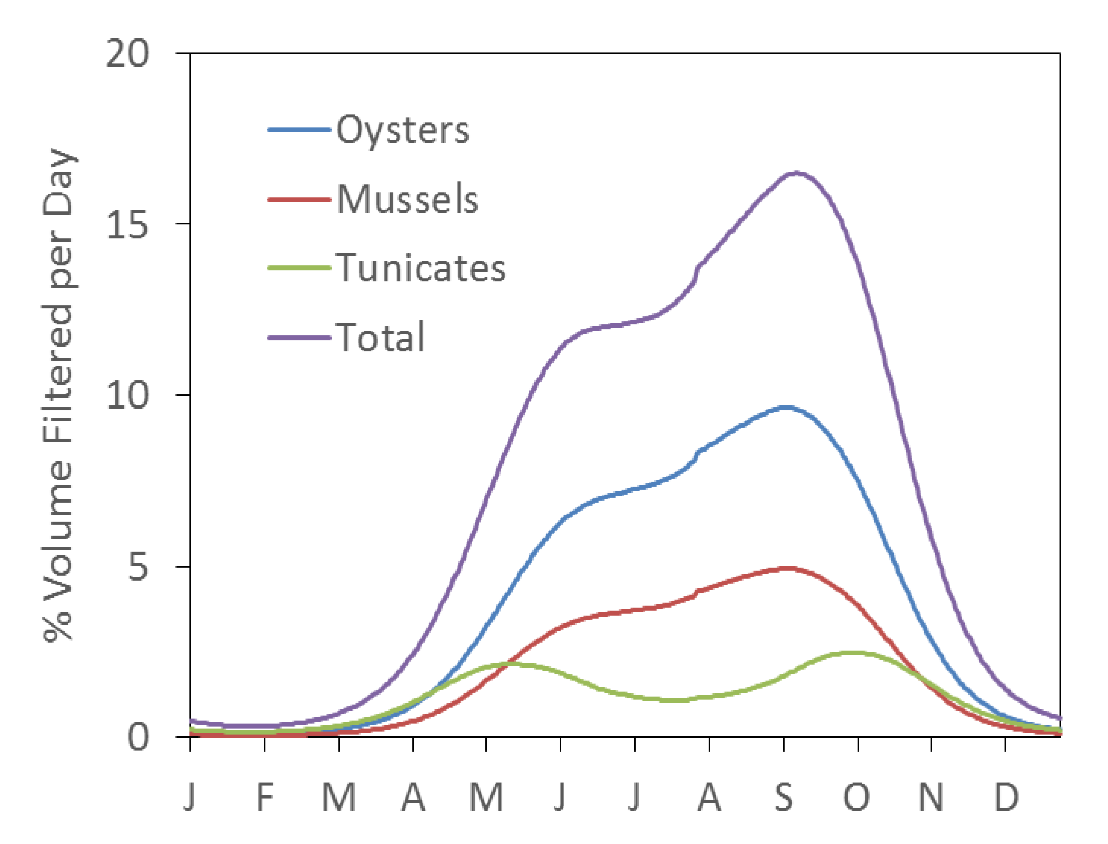
Nutrient Credits	Value
N price	0
P price	0

VIMS | William & Mary
Virginia Institute of Marine Science

Filtration Capacity

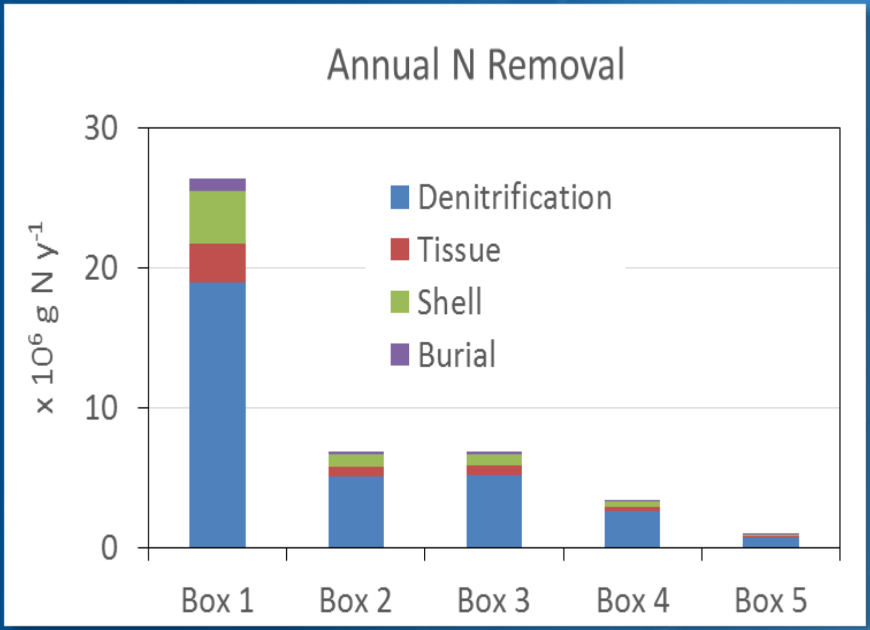
Average daily filtration:

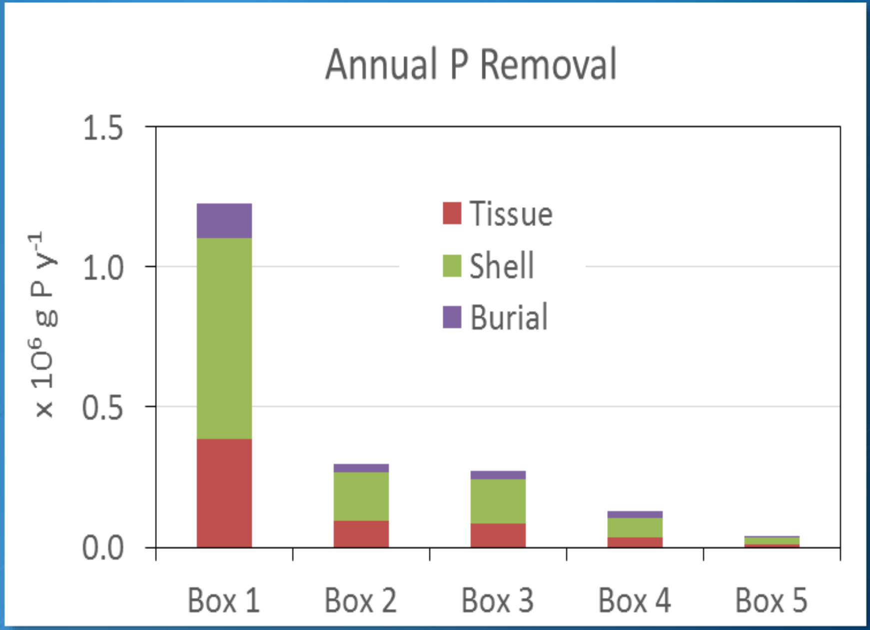
- 55% Oysters
- 29% Mussels
- 16% Sea squirts
  - Sea squirt filtration underestimated because cold water filtration not included in model



VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

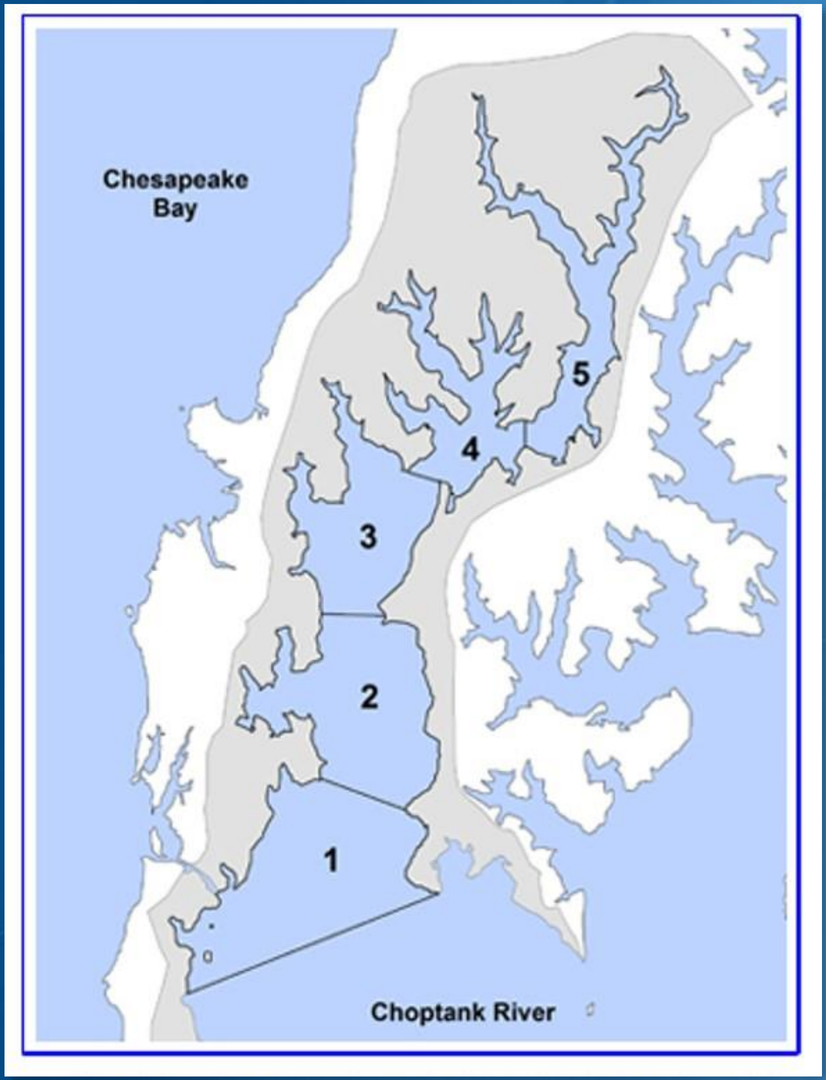
Water Quality Benefits





Box	Acres Restored	Mean Live Density, # m^{-2}	Mean Individual Mass, g DW
1	168.6	118.0	0.95
2	88.5	55.5	0.87
3	65.6	70.2	1.08
4	17.9	172.0	1.28
5	6.9	91.5	1.26

Water Quality Benefits



Percent of annual inputs removed by restored reefs			
	N	P	TSS
Watershed	208%	138%	1230%
Atmosphere	474%		
Choptank River	4.7%	8.2%	22.4%
Total	4.6%	7.8%	22.0%

Nitrogen Removal

Nitrogen removed by restoration in Harris Creek:

= 44.5×10^{6} g y^{-1}

≈ 20,000 bags of 10-10-10 fertilizer

≈ 12 stacks of fertilizer bags equal in height to the Washington Monument

VIMS | William & Mary
Virginia Institute of Marine Science

Value of Nutrient Removal

Based on MDE in-lieu annual fees for failing to achieve required nutrient reductions

- N = $17 per pound
- P = $270 per pound

MARYLAND DEPARTMENT OF THE ENVIRONMENT

Clean Water Act Section 401 Certification For the Conowingo Hydroelectric Project
FERC Project No. P-405 / MDE WSA Application No. 17-WQC-02

Certification Issued To:

Exelon Generation Company, LLC
300 Exelon Way
Kennett Square, PA 19348

(a) Payment of an in-lieu fee annually at $17.00 per pound of nitrogen and $270.00 per pound of phosphorus in accordance with payment instructions provided by MDE from time to time; *provided*, that the in-lieu fee amounts of $17.00 and $270.00 are deemed effective as of January 1, 2019 and shall be adjusted for inflation on January 1, 2020 and on January 1 of each year thereafter, based on the cumulative change in the CPI;

Source: https://mde.maryland.gov/programs/Water/WetlandsandWaterways/Documents/ExelonMD/Conowingo_WQC_04-27-18.pdf

Value of Nutrient Removal

Estimated value of Harris Creek reef restoration nutrient removal services:

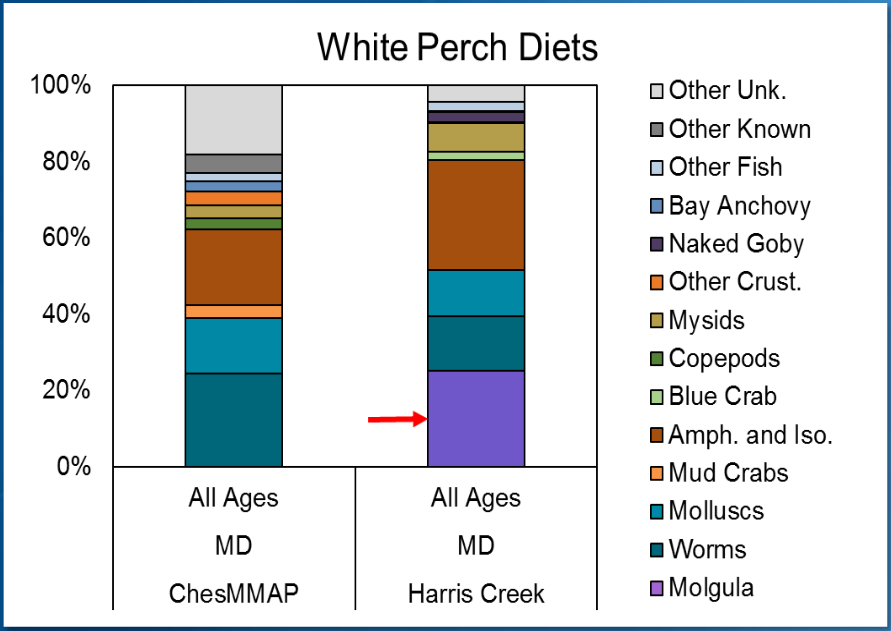
- N = $1,749,078 per year
- P = $1,277,155 per year
- Total = $3,026,233 per year

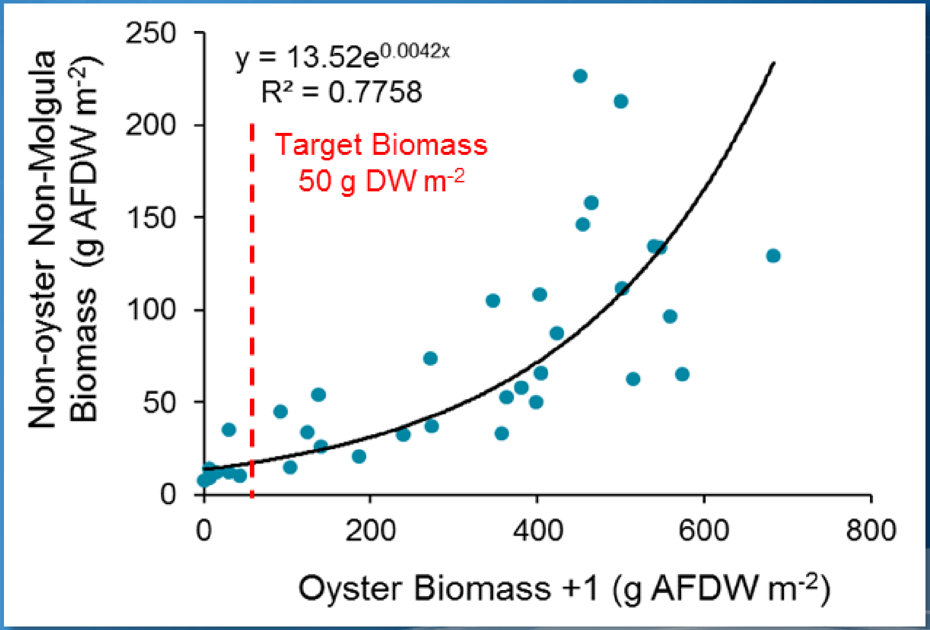
Source: Tom Toles (2013) The Washington Post

VIMS | WILLIAM & MARY
VIRGINIA INSTITUTE OF MARINE SCIENCE

Other Ecosystem Services

- Food for commercially and recreationally valuable finfish
- Habitat for other macrofauna
- Filtering fine sediments out of suspension





VIMS | William & Mary
Virginia Institute of Marine Science

Acknowledgements

VIMS

- Benthic Ecology Lab staff – Jenny Dreyer, Cate Turner, Manisha Pant, Catherine Gallway, and many others
- Field Operations staff – Jim Goins, Wayne Reisner, Graham Broadwell, Durand Ward and many others
- Eastern Shore Lab staff – Alan Birch, Edward Smith, Sean Fate and many others

UMCES Horn Point Lab

- Mike Owens, Debbie Hinkle and many others

Funding:

NOAA – National Oceanic and Atmospheric Administration – U.S. Department of Commerce

The Nature Conservancy – Protecting nature. Preserving life.

Oyster Recovery Partnership | ORP

National Fish and Wildlife Foundation

VIMS | William & Mary

Virginia Institute of Marine Science


Questions?