Dynamically coupled food-web and hydrodynamic modeling with ADH-CASM for sessile benthic invertebrates: a case study from the Chesapeake Bay

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Environmental Issues in the 21st Century

- Environmental/Water resource issues becoming more complex

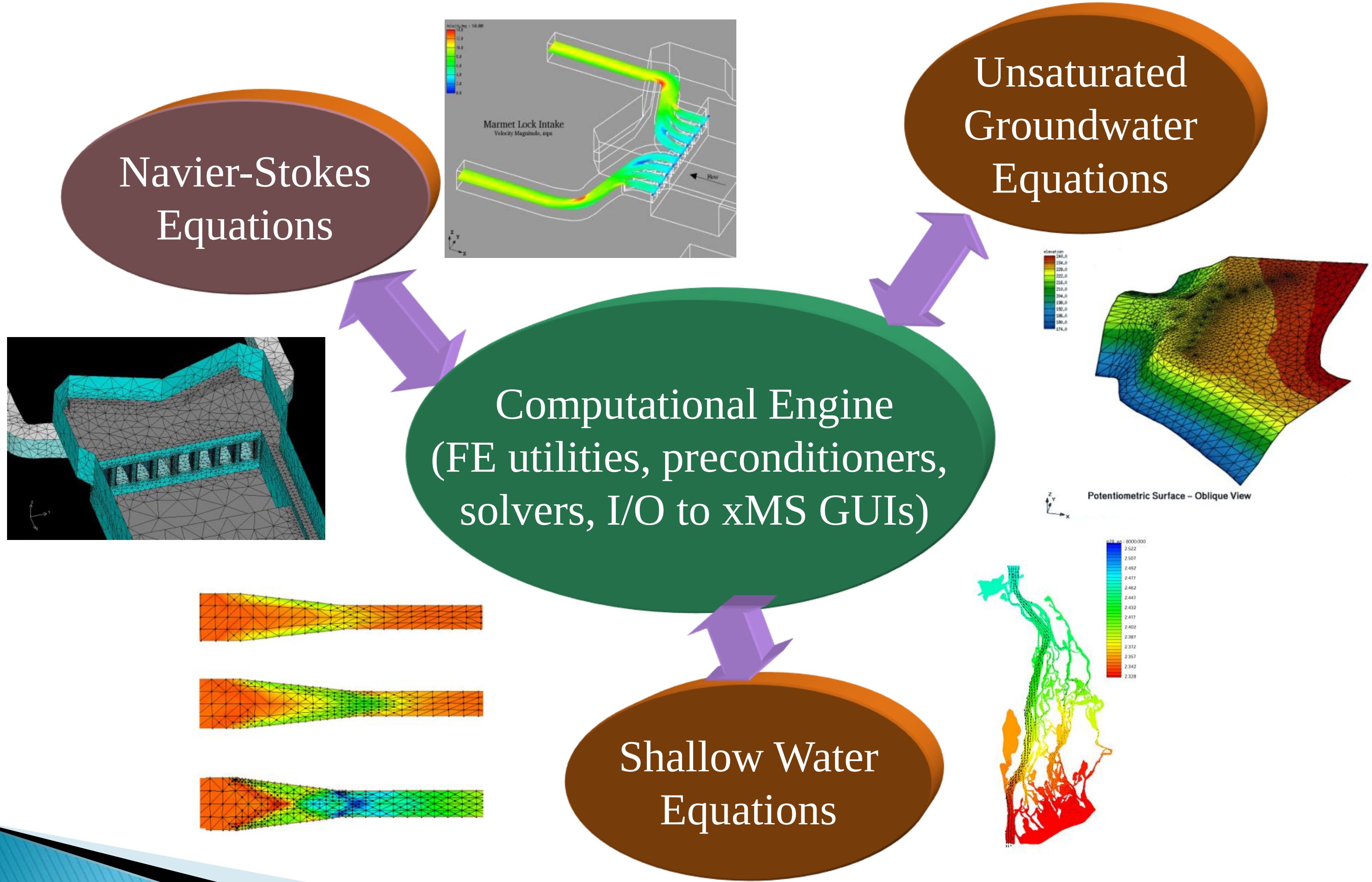
- Require holistic approaches to understand system

- Coupled hydrodynamic-ecological models
  - Links fine scale hydrodynamics to ecological systems (e.g., food webs, fish behaviors, etc)

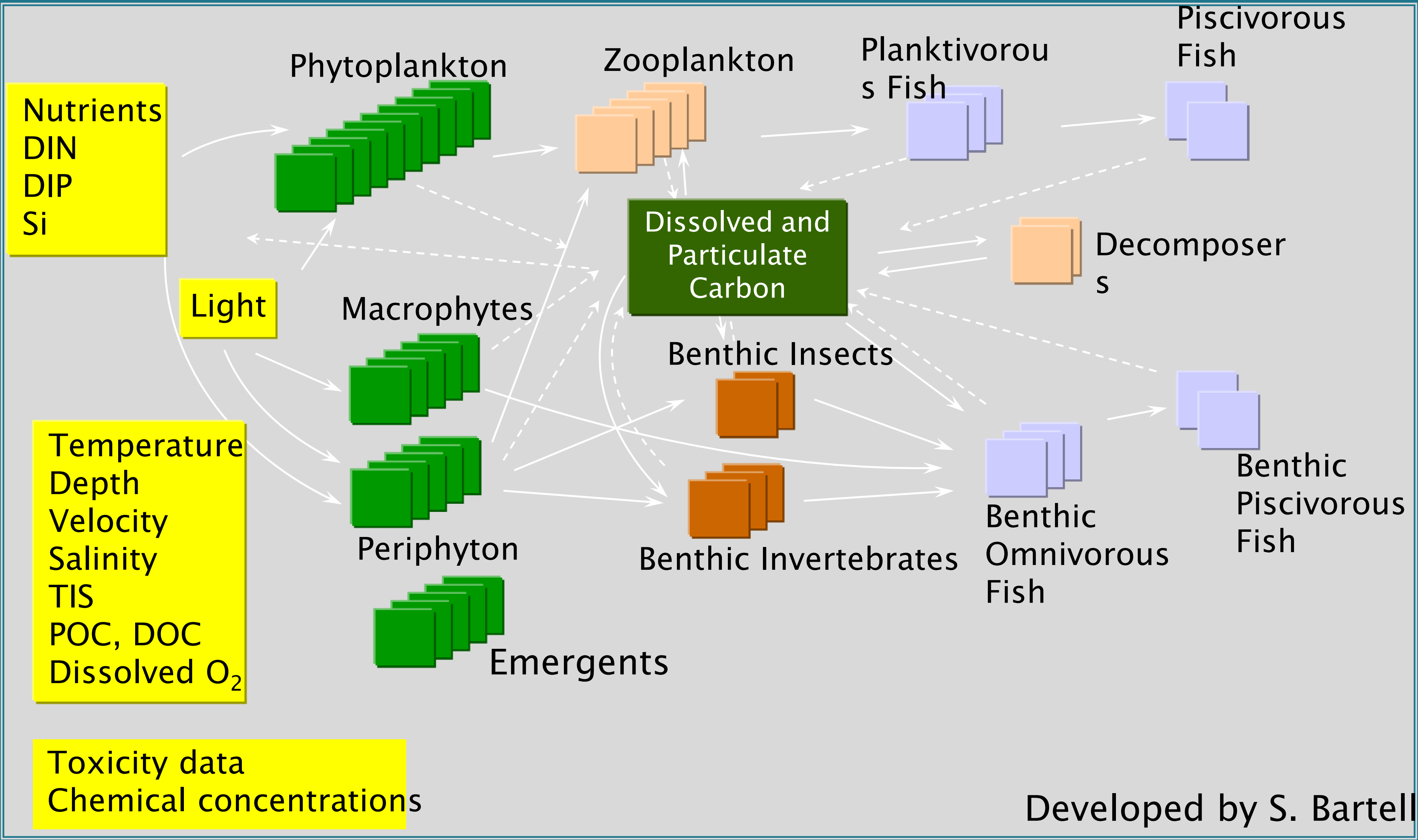
Benefits of coupled Eco-Hydro approaches

- Dynamic feedback between constituent transport and biota (uptake and nutrient cycling)
- Spatially-explicit
- Embraces temporal variability of flow, water quality and ecosystem dynamics

Adaptive Hydraulics Overview



Comprehensive Aquatic Systems Model (CASM) Overview



ADH-CASM Outputs

Hydrology
- velocity
- depth, elevation
- salinity

Geomorphology
- sediment transport, deposition
- substrate variability
- channel structure

Biogeochemistry
- dissolved oxygen
- DIN, DIP, DOC
- particulate carbon, TSS
- water clarity

Habitat
- physical-chemical characteristics
- biological (e.g., SAV, emergents)

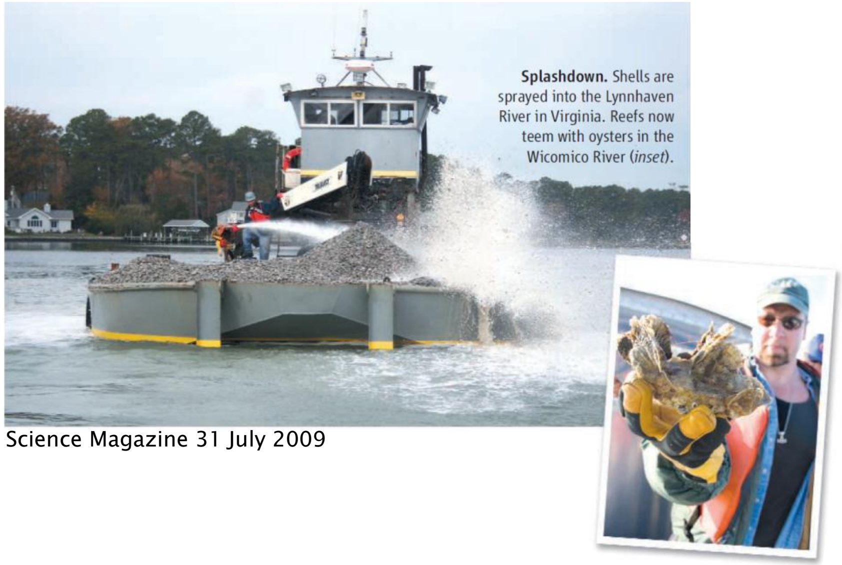
Biota
- phytoplankton
- periphyton
- SAV
- emergent aquatic plants
- zooplankton
- benthic invertebrates
- omnivorous fish
- piscivorous fish

Chesapeake Bay Oysters

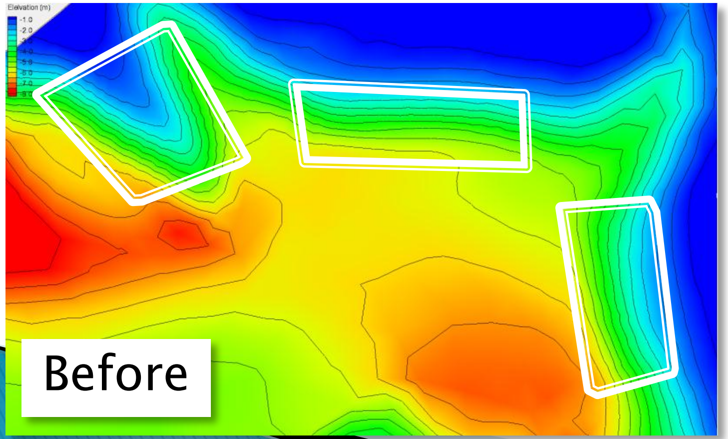
- Oyster populations at 1% of historic levels
- Oyster fishery is $100+ million/annually
- Oyster reefs provide tremendous environmental benefits (water quality, biodiversity, storm protection, etc)
- Different viewpoints on how to restore oysters and maintain fishery

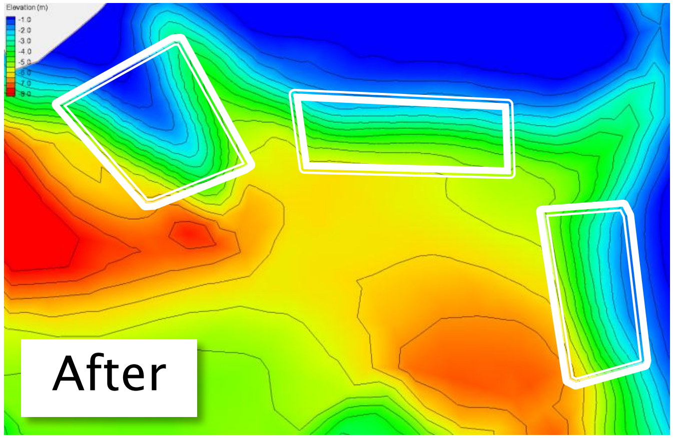
Brief History of the Great Wicomico River Oyster Restoration

- 2004: 9 reefs were restored with additions of shell and spat-on-shell
- Reefs were restored as low- and high-relief reefs
- Subtle changes in bathymetry, even with high-relief reefs (see below)
- Oysters density was ~5x greater on high-relief reefs



Science Magazine 31 July 2009



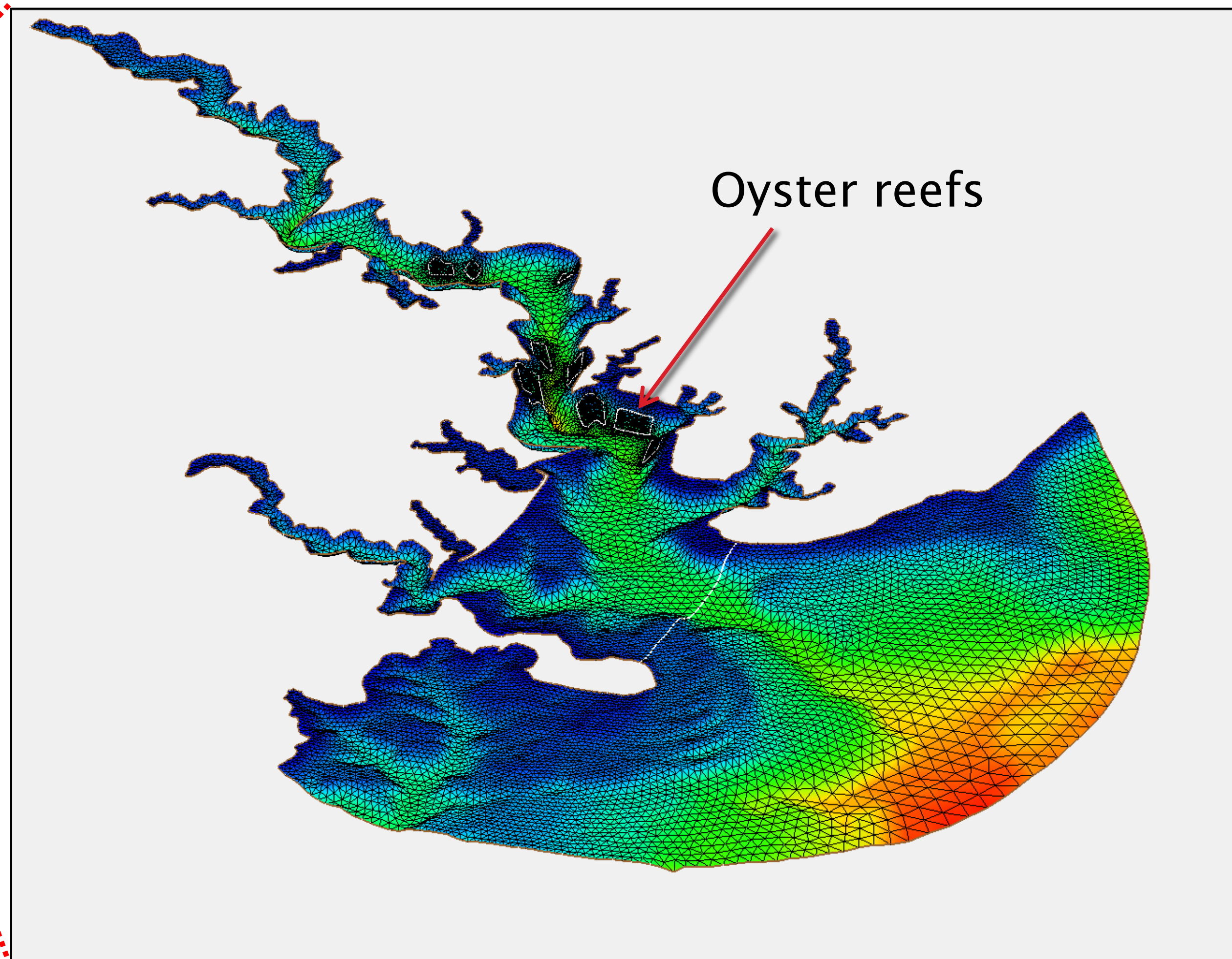


What effect do oysters have on the water quality in the vicinity of the reef?

- Modeling scenarios
  - pre-construction (no structure + no function)
  - reefs (structure + no function)
  - reefs + CASM (structure + function)

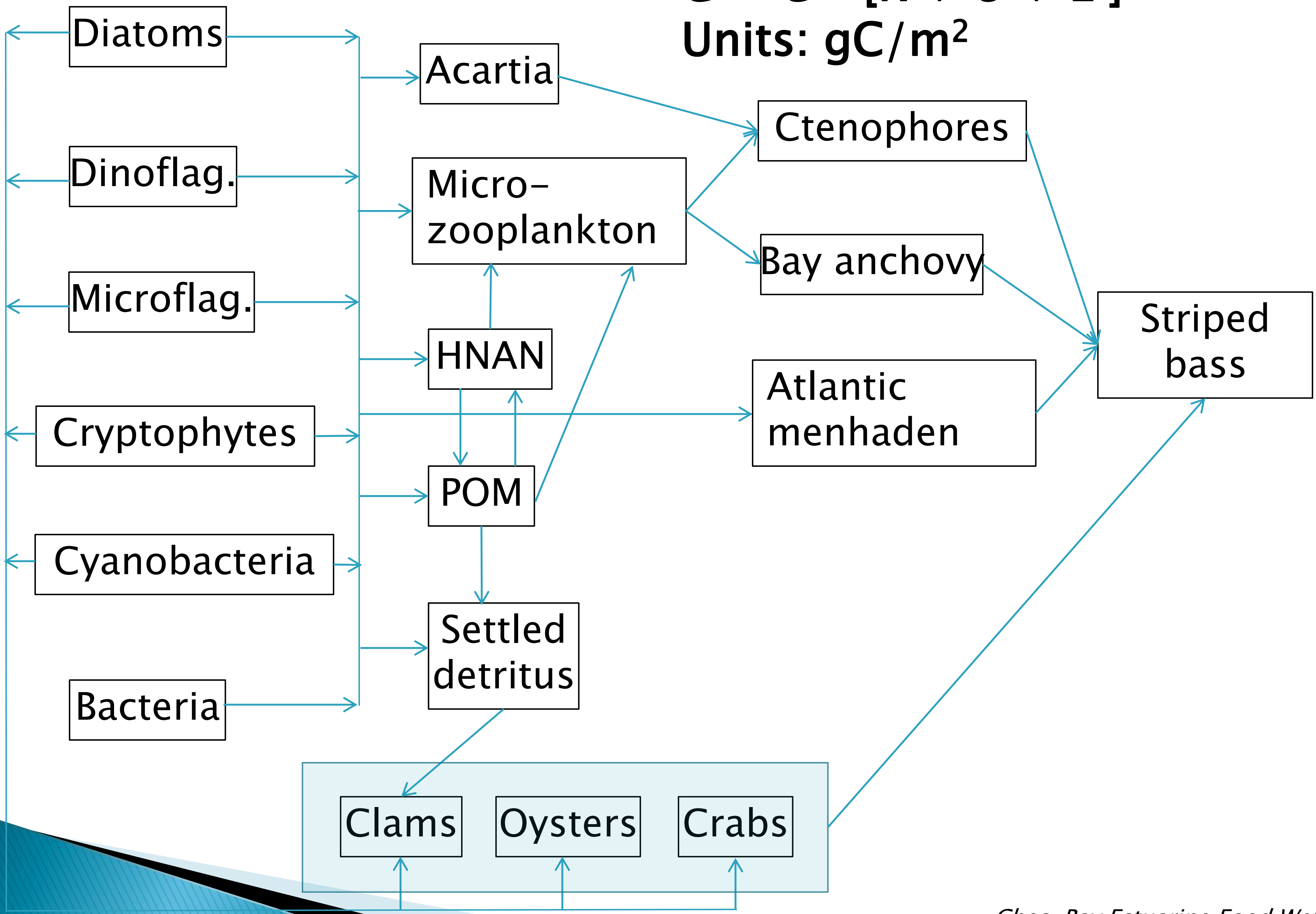
Bivalve and Flow

Great Wicomico River ADH mesh



$$G = C - [R + U + E]$$

Units: gC/m²



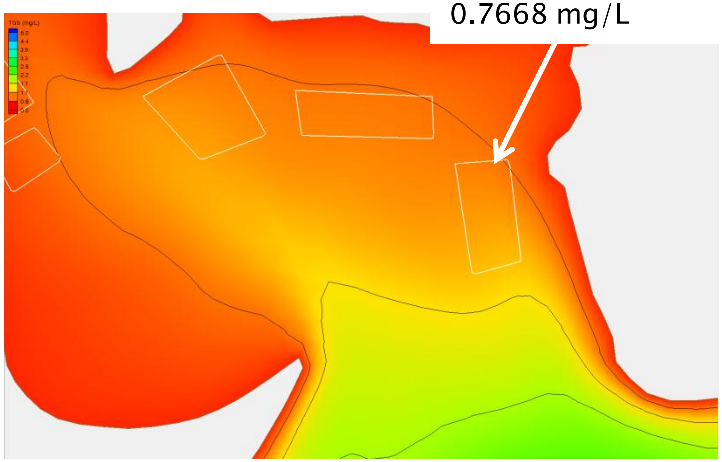
Ches. Bay Estuarine Food Web
Bartell et al 2003

Results

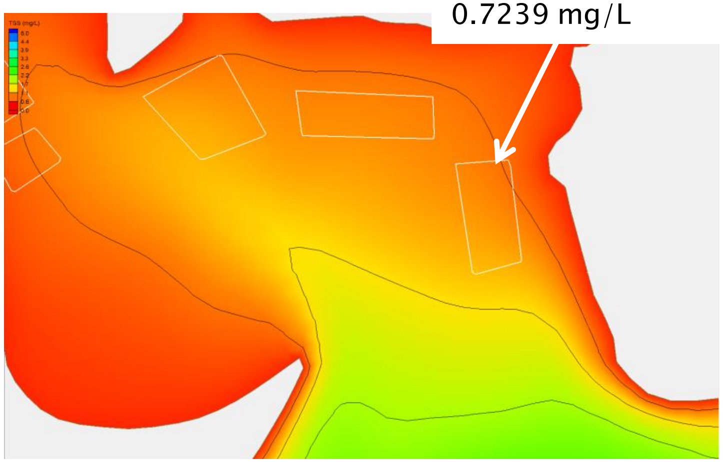
TSS Reduction – filtration

- No CASM
- With CASM

Avg. TSS day 160:
0.7668 mg/L



Avg. TSS day 160:
0.7239 mg/L



~5.6% reduction in TSS

Discussion

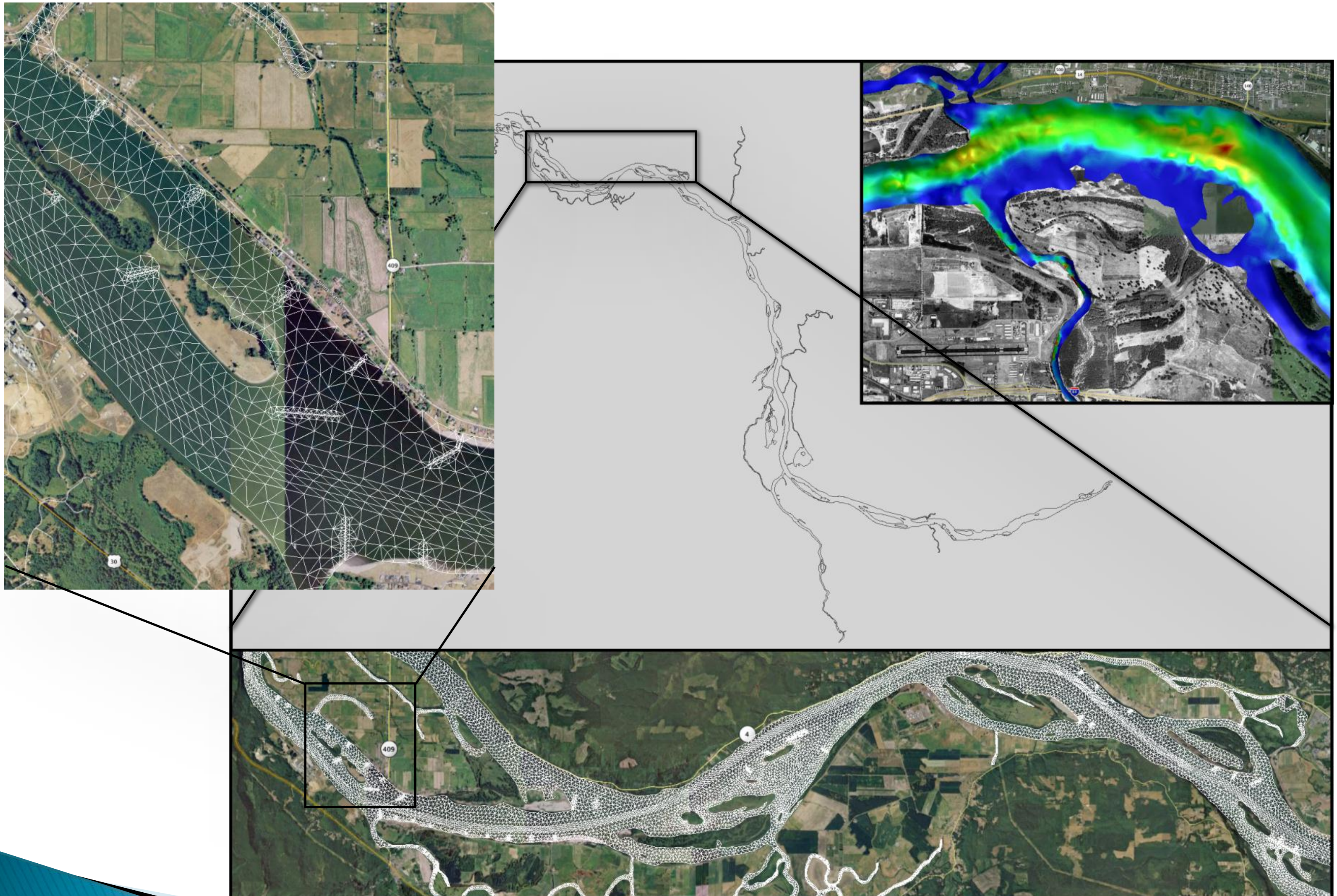
- Coupling models result in direct benefits out (e.g., TSS reductions and nutrient uptake)

- Captures critically system processes, such as feedback loops and interspecies dynamics

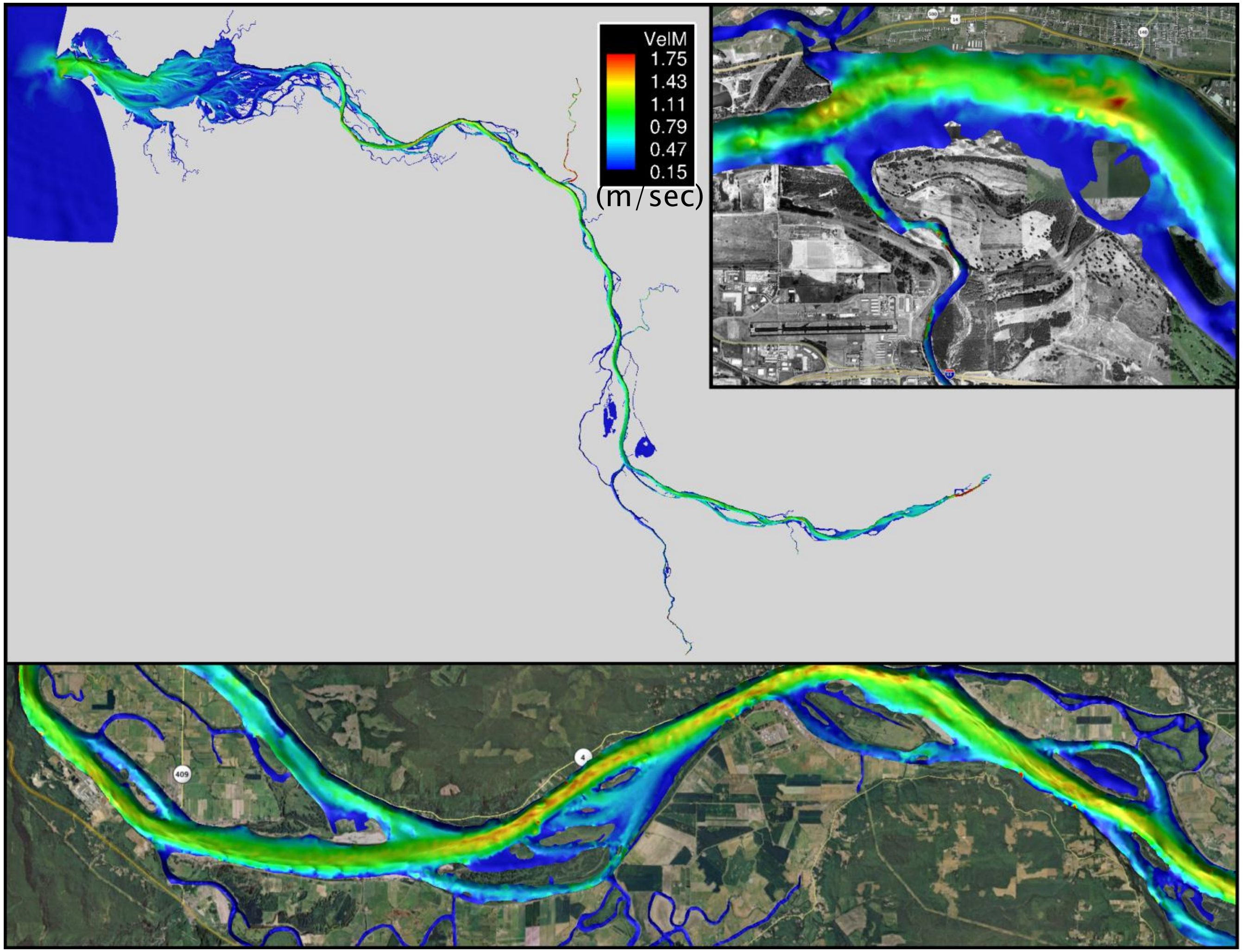
Other uses for coupled modeling

- Ecosystem services
- How management affects multiple levels of trophic structure (e.g., salmonids to plankton)
- Examine future conditions (SLC, ocean acidification)
- Addresses issues across scales

Fish Passage (Reach Level)



Fish Passage (System Level)



Benefits

- Holistic approach
  - System dynamics for ecosystem restoration, sea level change, water chemistry
- Food web can be developed for any system
  - Data intensive, but can use surrogates to identify future research needs

Management implications

- Scenario analysis for multiple management strategies (rotational harvest, sanctuary, etc), hydrologic scenarios and/or climatic regimes
- Can develop system-level risk assessments
- Provides mechanism for visualizing dynamic feedback loops

Acknowledgments

- Dave Schulte (USACE – Norfolk)
- Gaurav Savant (ERDC – CHL)
- Jessica Kozarek (UMN – SAFL)
- Dave Smith (ERDC– EL)
- Susan Conner (USACE – Norfolk)
- R. Andrew Goodwin (ERDC – EL)

Questions?

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Basic Food Web Structure

Basic Features

- Bioenergetic (carbon currency) systems model
- Biota
  - 4 producer guilds, each with 10 species: phytoplankton, periphyton, macrophytes and emergent aquatic plants.
  - 8 consumer guilds – include zooplankton, benthic invertebrates, fish and bacteria; 10 populations possible for each guild
- Trophic interactions
  - Prey preference, assimilation efficiency, handling efficiency
- Habitat quality
  - Depth, current velocity, dissolved oxygen, salinity
- Biogeochemistry (DIN, DIP, Si, DO, POC, DOC)

Why do we need CASM?

- Few differences in the *depth-averaged* hydrodynamics and constituent transport
- Oyster reef structures modify the micro-environment – does not translate to large differences throughout the water column
- Movie