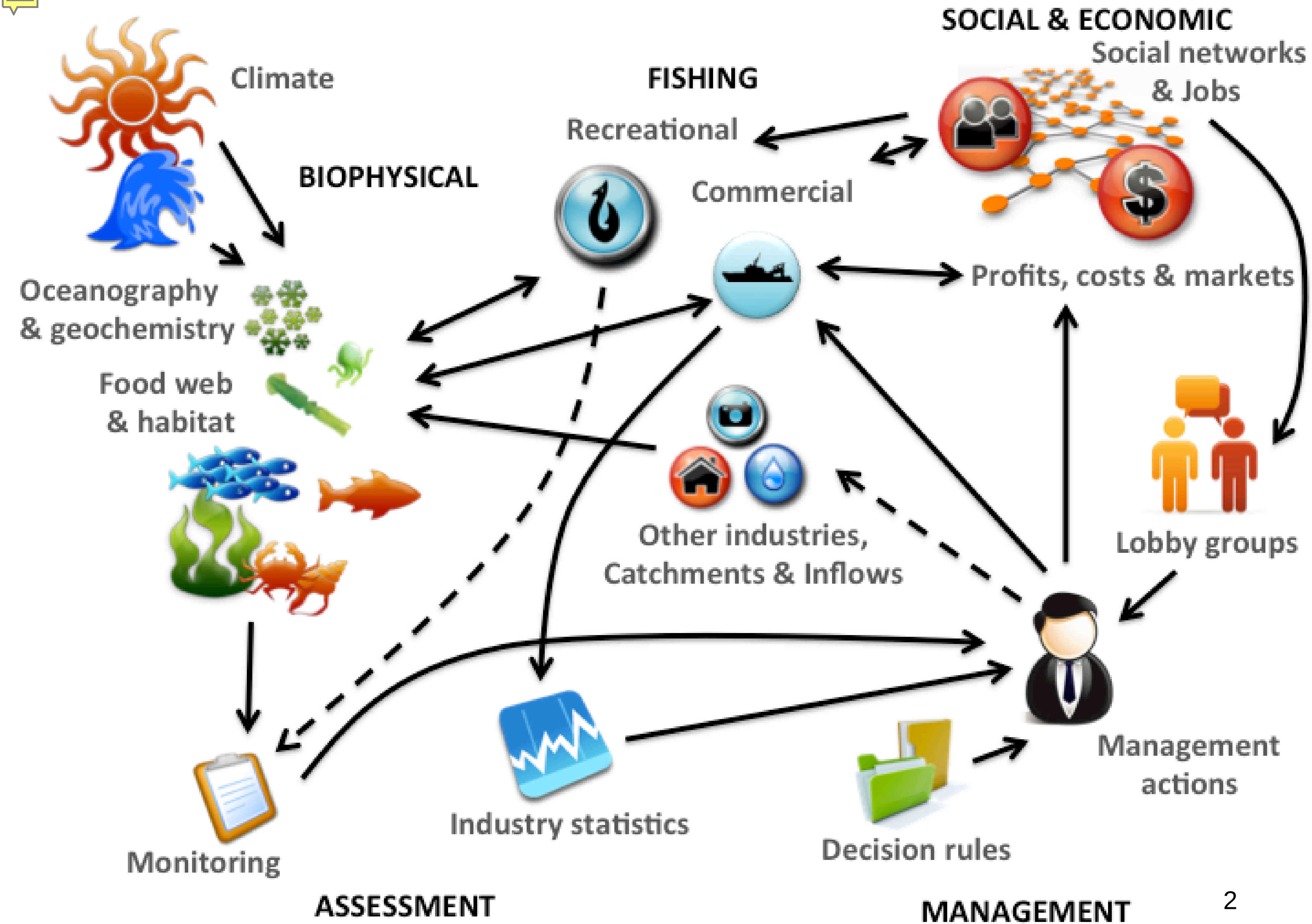
Predicting the Cumulative Effects of Multiple, Simultaneous Stressors Using the Chesapeake Atlantis Model

Tom Ihde, ERT, Inc.
for the NOAA Chesapeake Bay Office

WQ-GIT, 11 July, 2016


SOCIAL & ECONOMIC
Social networks
& Jobs
Climate
FISHING
Recreational
BIOPHYSICAL
Commercial
Oceanography
& geochemistry
Profits, costs & markets
Food web
& habitat
Other industries,
Catchments & Inflows
Lobby groups
Management
actions
Industry statistics
Decision rules
Monitoring
ASSESSMENT
MANAGEMENT

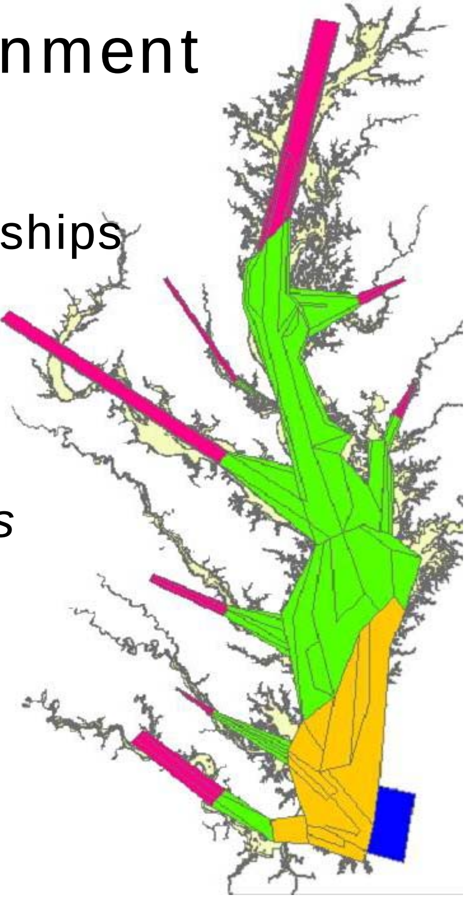
Atlantis Applications

The Atlantis Model

"End-to-End" Approach

Factors Influencing Included:

Biological environment
✓Primary production
✓Trophic interactions
✓Recruitment relationships
✓Age structure
✓Size structure
✓Life History
✓Habitat also refuge
SAV, Marsh, Oysters



Physical environment
✓Chemistry
✓Circulation & currents
✓Temperature
✓Salinity
✓Water clarity
✓Climate change

Fisheries
✓Multiple sectors
✓Gears
✓Seasons
✓Spatially explicit

Nutrient Inputs
✓Currency is Nitrogen
✓Oxygen
✓Silica
✓3 forms of detritus
✓Bacterial nutrient cycling

The Chesapeake Atlantis Model

Visualization *of* Management Strategy Outcomes

Management Strategy Outcomes & Key Actions

Water Quality-Goal Implementation Team (GIT):

- ✓Visualize, improve understanding of ecosystem services of attainment of TMDL or a range of levels of attainment
- ✓The simulation of all other Outcomes in the context of the TMDL conditions for the Bay
- ✓Demonstrate and quantify the benefit of improved monitoring, and filling of data gaps

STAR:

- ✓ Development and testing of ecological indicators

Climate Resiliency & Adaptation:

- ✓Visualize likely impacts of expected temperature increase and salinity change
- ✓Support development of research agenda – identify most critical data or research gaps
- ✓Visualize future realizations for public, stakeholder, and local engagement
- ✓Simulate implementation of priority adaptation actions
- ✓Develop and test climate resilience indicators to assess adaptation action effectiveness

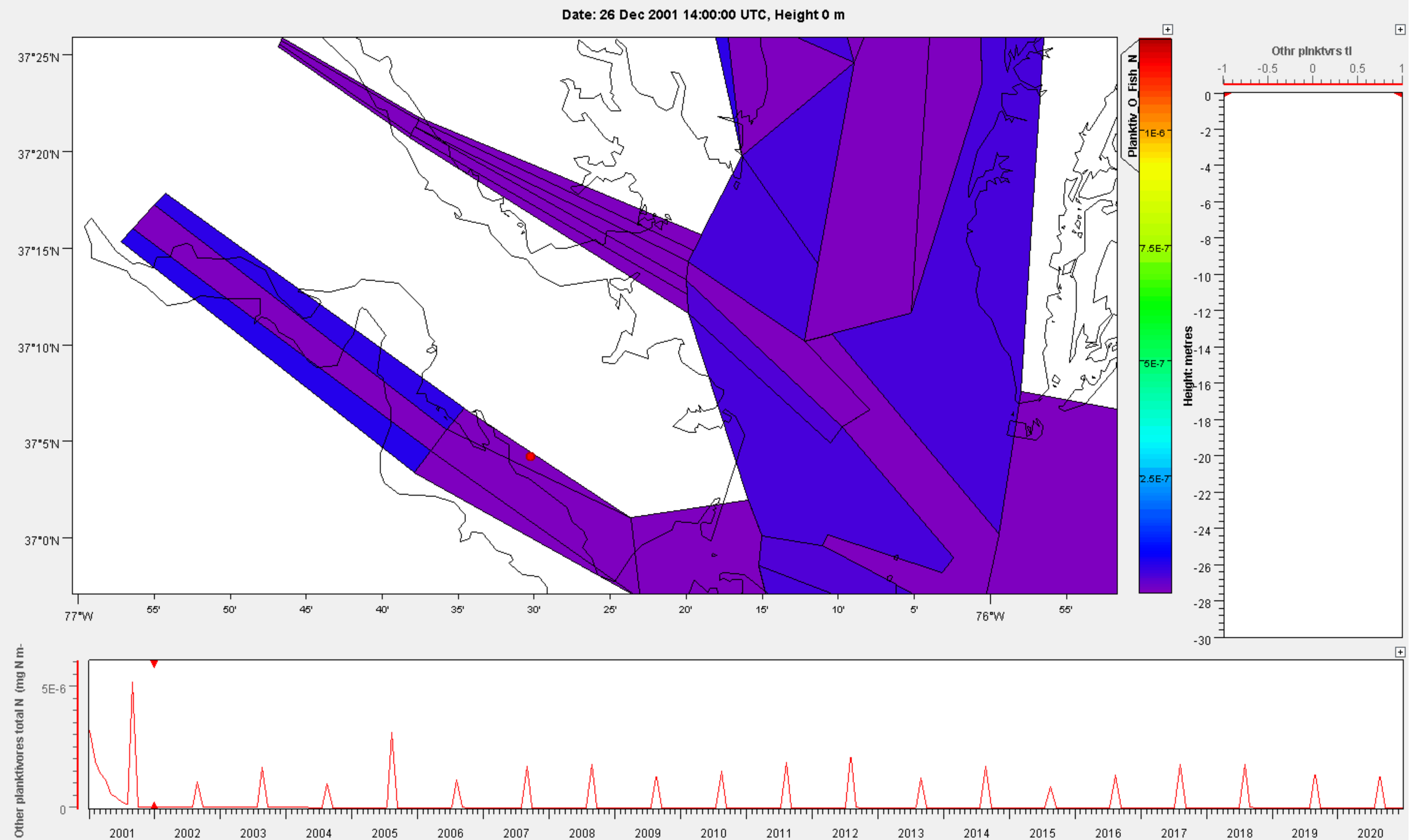
Habitat-GIT:

- ✓Visualize range of attainment for SAV Outcome: acreage benefits, water clarity benefits and restoration benefits
- ✓Fish Passage: Visualize benefits (& ecosystem services) of restored populations
- ✓ Wetlands outcome – range of attainment, simulate ecosystem services

Sustainable Fisheries-GIT:

- ✓Blue crab – ecosystem effects of varying abundance; harvest sectors allocation
- ✓Oyster restoration – visualize benefits of restoration
- ✓Fish habitat – visualize effects of loss or gain
- ✓Forage – simulate predator population effects of loss or gain of forage groups

System Changes Over Space and Time

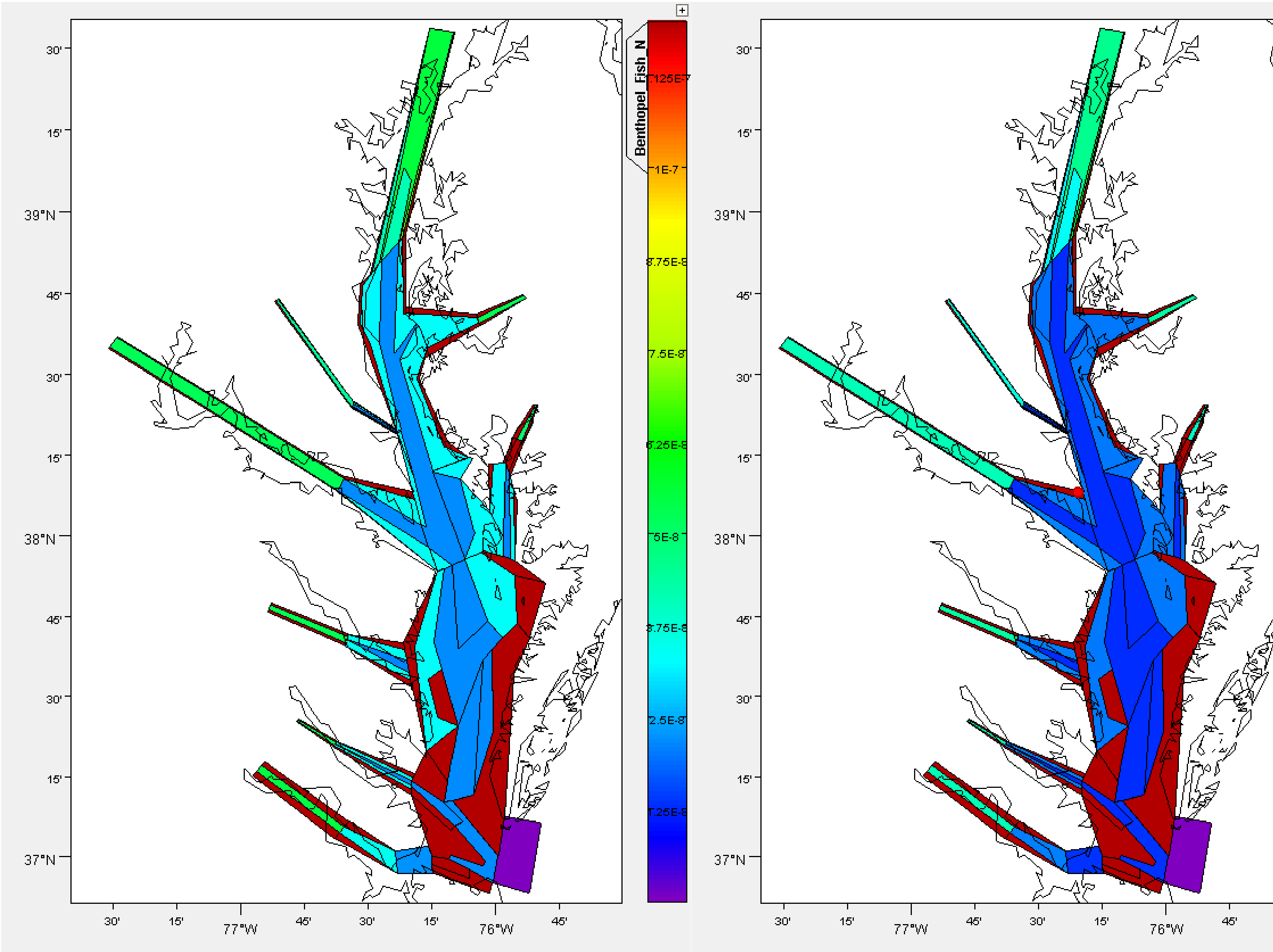


Bay Anchovy – High Marsh Biomass Scenario

Striped Bass

Current Conditions

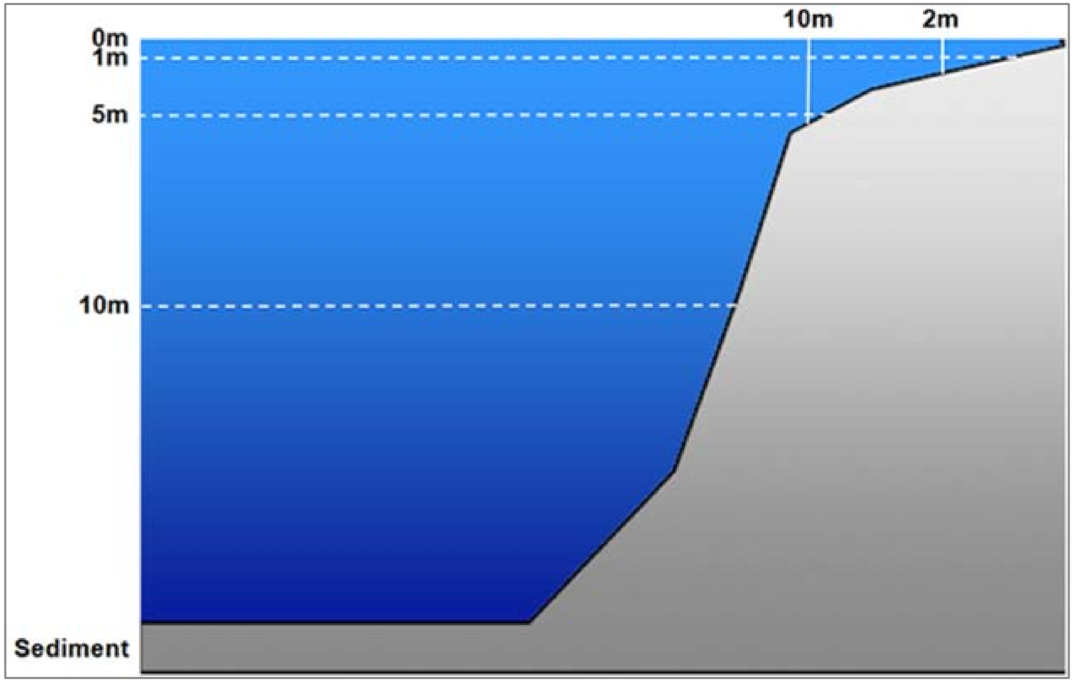
Temperature increase & Habitat Loss

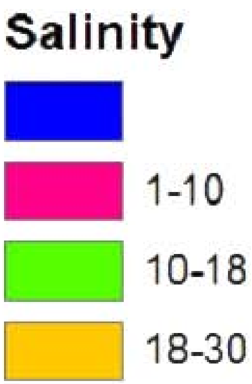


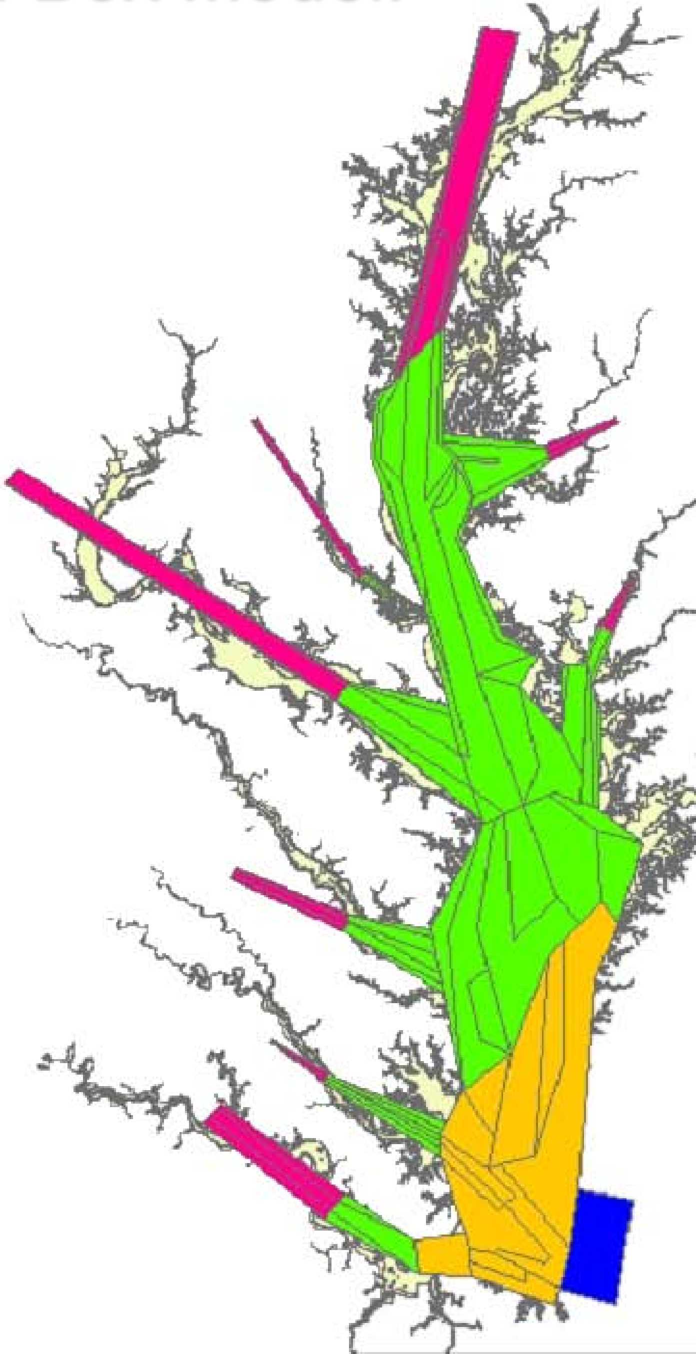
The Chesapeake Atlantis Model

Design

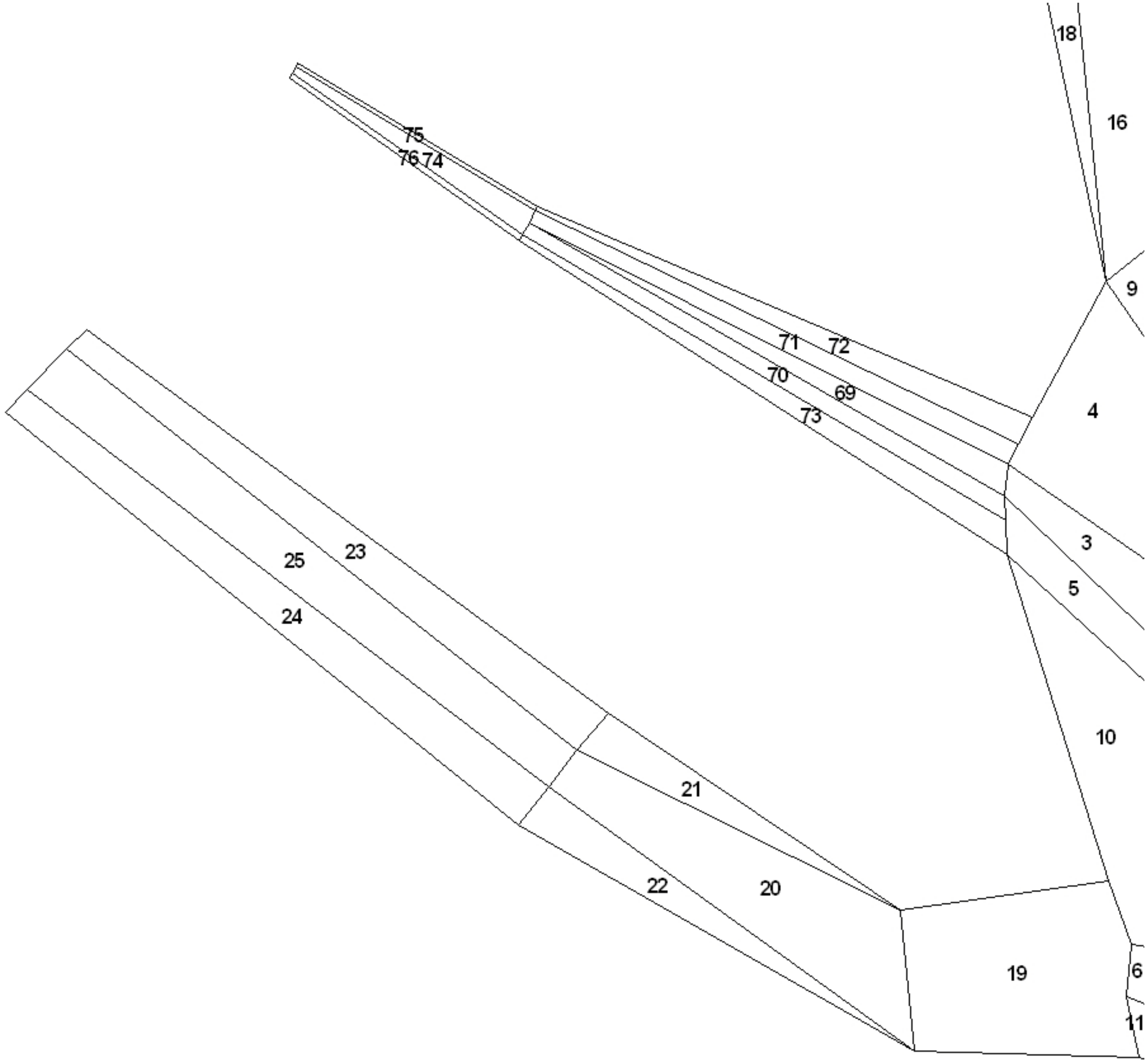
CAM Design: 3-Dimensional Box Model:







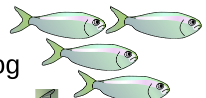
CAM: River Box Structure



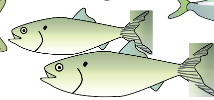
Ecological Groups: Federal fisheries, Forage, Protected, Habitat

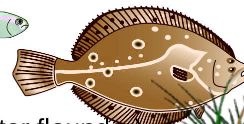
Finfish

- **Alosines** (Amer.Shad, Hickory Shad, Alewife & Herring)
- Atlantic Croaker
- **Bay anchovy**
- Black drum
- **Bluefish**
- **Butterfish**, harvestfish ("Jellivores")
- Catfish
- Gizzard shad

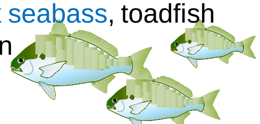


- **Littoral forage fish**: silversides, mummichog
- **Menhaden**
- Striped bass

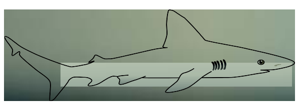




- **Summer flounder**
- Other flatfish (hogchoker, tonguefish, window pane, winter flounder)
- **Panfish**:
    Euryhaline: Spot, silver perch; FW to 10ppt: yellow perch, bluegill
- **Reef assoc. fish**: spadefish, tautog, black seabass, toadfish
- Spotted hake, lizard fish, northern searobin
- Weakfish
- White perch

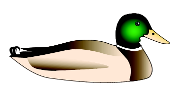


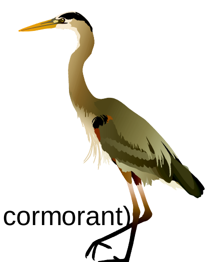
Elasmobranchs



- Cownose ray
- Dogfish, smooth
- **Dogfish, spiny**
- Sandbar shark

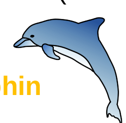
Birds





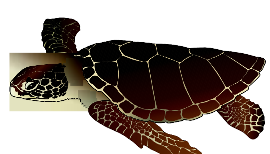
- **Bald Eagle**
- Piscivorous birds (osprey, great blue heron, brown pelican, cormorant)
- Benthic predators (diving ducks)
- Herbivorous seabirds (mallard, redhead, Canada goose, & swans)

Mammals



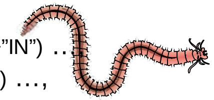
- **Bottlenose dolphin**

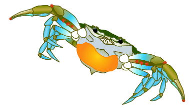
Reptiles



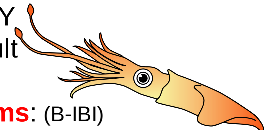
- **Diamond-back Terrapin**
- **Seaturtles**

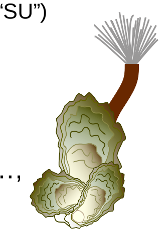
Invertebrates



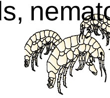


- **Benthic feeders**: (B-IBI "CO"+"IN") …,
- **Benthic predators**: (B-IBI "P") …,
- **Benthic suspension feeders**: (B-IBI "SU")
- Blue crab YOY
- Blue crab adult

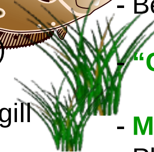


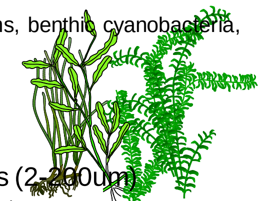


- **Brief squid**
- **Macoma clams**: (B-IBI)
- **Meiofauna**: copepods, nematodes, …,
- **Oysters**

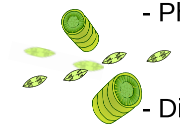


Primary Producers

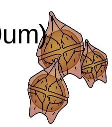




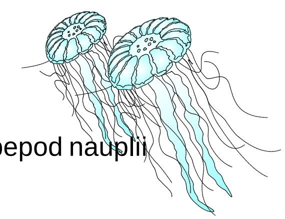
- Benthic microalgae ("microphytobenthos" benthic diatoms, benthic cyanobacteria, & flagellates)
- **"Grasses:"**
    SAV – type varies with salinity
- **Marsh grass**
- Phytoplankton – Large: diatoms & silicoflagellates (2-200um)
- Phytoplankton – Small: nannoplankton, ultraplankton,
    aka "picoplankton" or "picoalgae" (0.2-2um),
    cyanobacteria included (2um)



- Dinoflagellates (mixotrophs) (5-2,000um)



ZooPlankton



- Ctenophores
- Sea nettles

- Microzooplankton (.02-.2mm): rotifers, ciliates, copepod nauplii
- Mesozooplankton (.2-20mm): copepods, etc.

Detritus

- Carrion
- Carrion (sediment)
- Labile
- Labile (sediment)
- Refractory
- Refractory (sediment)

Bacteria (.2-2 um [.002 mm] - feed microzooplankton food chain)

- Benthic Bacteria (sediment)
- Pelagic Bacteria: (free-living)

Images courtesy of ian.umces.edu/imagelibrary/

Outline

Stressors / system changes:

- Habitat loss:
  - Marsh, SAV
- Water column factors:
  - Nitrogen & Total Suspended Solids
- Climate forcing:
  - Temperature increase

Simulation results

Next Steps

Habitat Scenario Assumptions

- 50% loss of Marsh
  (area & biomass)

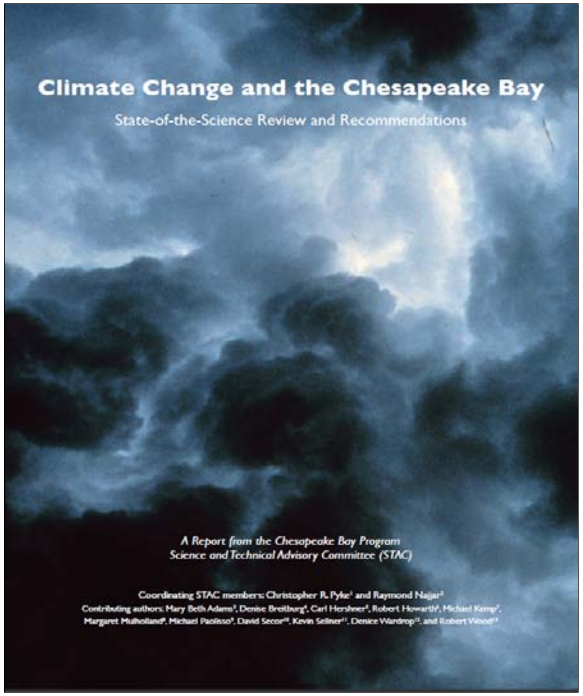
  Due to multiple, interacting factors:
  - shoreline armoring
  - subsidence
  - sea level rise
- 50% loss of Seagrass

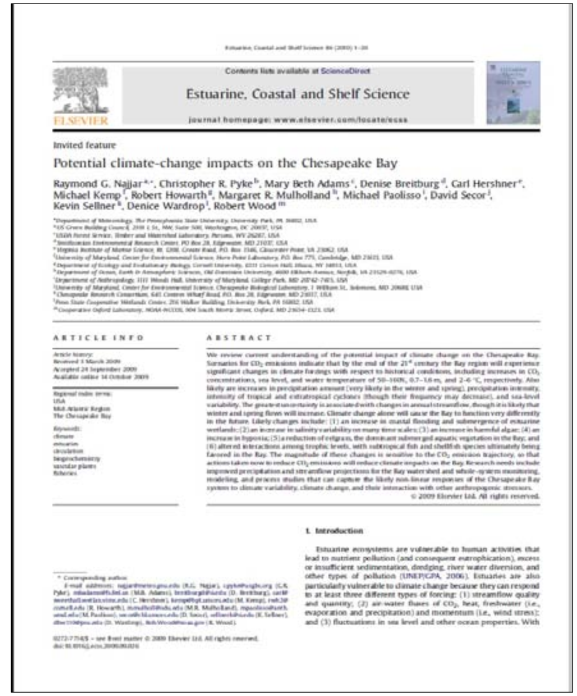
Water Column Habitat Assumptions

"TMDL" = Total Maximum Daily Loads of Nitrogen & turbidity – full attainment:

- Nitrogen
  - 25% reduction
- Turbidity (total suspended solids)
  - 20% reduction

Climate Change Assumptions





Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Invited feature

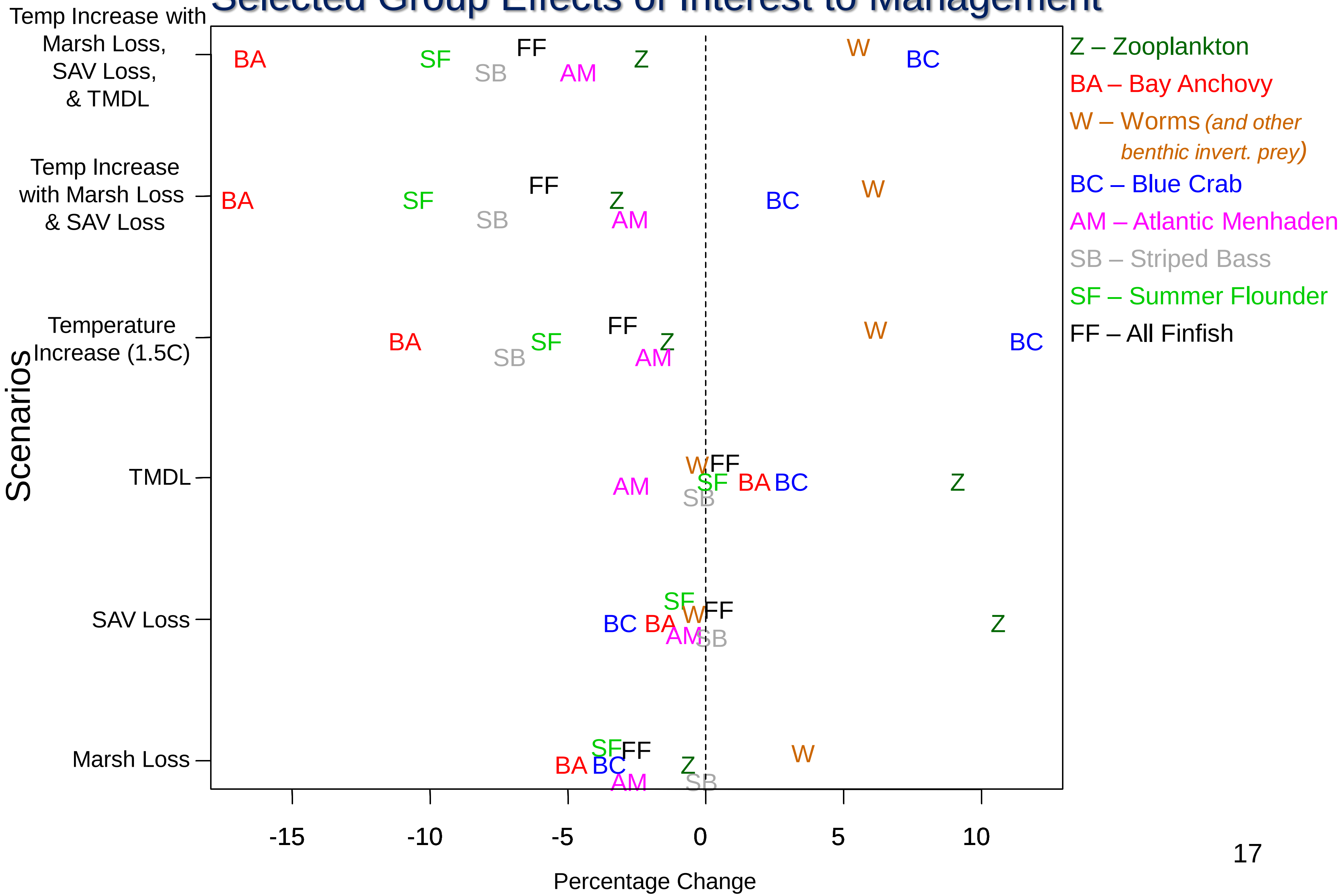
Potential climate-change impacts on the Chesapeake Bay

Raymond G. Najjar[a,*], Christopher R. Pyke[b], Mary Beth Adams[c], Denise Breitburg[d], Carl Hershner[e], Michael Kemp[f], Robert Howarth[g], Margaret R. Mulholland[h], Michael Paolisso[i], David Secor[j], Kevin Sellner[k], Denice Wardrop[l], Robert Wood[m]

- Najjar et al. (2010); IPCC AR4 (2007)
- 50 years from now:
  - ✓ Increased water temperature (1.5°C)
  - ✓ Salinity (+/- 2 ppt)

Sensitivity To Environmental Factors

Selected Group Effects of Interest to Management



Summary

- Temperature increase produces relatively strong effects on production compared to losses of marsh, SAV, or the TMDL water quality improvements
- Modeling other stressors without expected temperature increase could be misleading
- Reasonable trends can be predicted modeling a single stressor *if* happen to choose the dominant stressor
- Risk is relatively large for some important Chesapeake managed fish (~10 % loss in production)

Next…

- ✓ Test sensitivities, explore current hypotheses: pred-prey mismatches; shifts in state of system; DO
- ✓ Verify trends with other models where possible
- ✓ Add other effects of climate change:
  - allow movement preferences for changing climate conditions (temperature, salinity)
  - shifts in timing of migration & spawning
- ✓ Acidification effects

Thanks to:

NOAA OFFICE OF SCIENCE AND TECHNOLOGY
NATIONAL MARINE FISHERIES SERVICE

NOAA HABITAT CONSERVATION
NATIONAL MARINE FISHERIES SERVICE

National Science Foundation
WHERE DISCOVERIES BEGIN

Center for Coastal Resources Management
Virginia Institute of Marine Science

CSIRO Marine and Atmospheric Research

Northwest Fisheries Science Center
NOAA Fisheries Service

Northeast Fisheries Science Center