Estimating the fisheries economic benefits of the Chesapeake Bay TMDL using a fisheries-based ecosystem model

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Overview

- Objective and Approach
- Ecosystem models and trophic structure
- Scenario development
  - Exploratory efforts
  - Current approach
- Preliminary results and communication of results

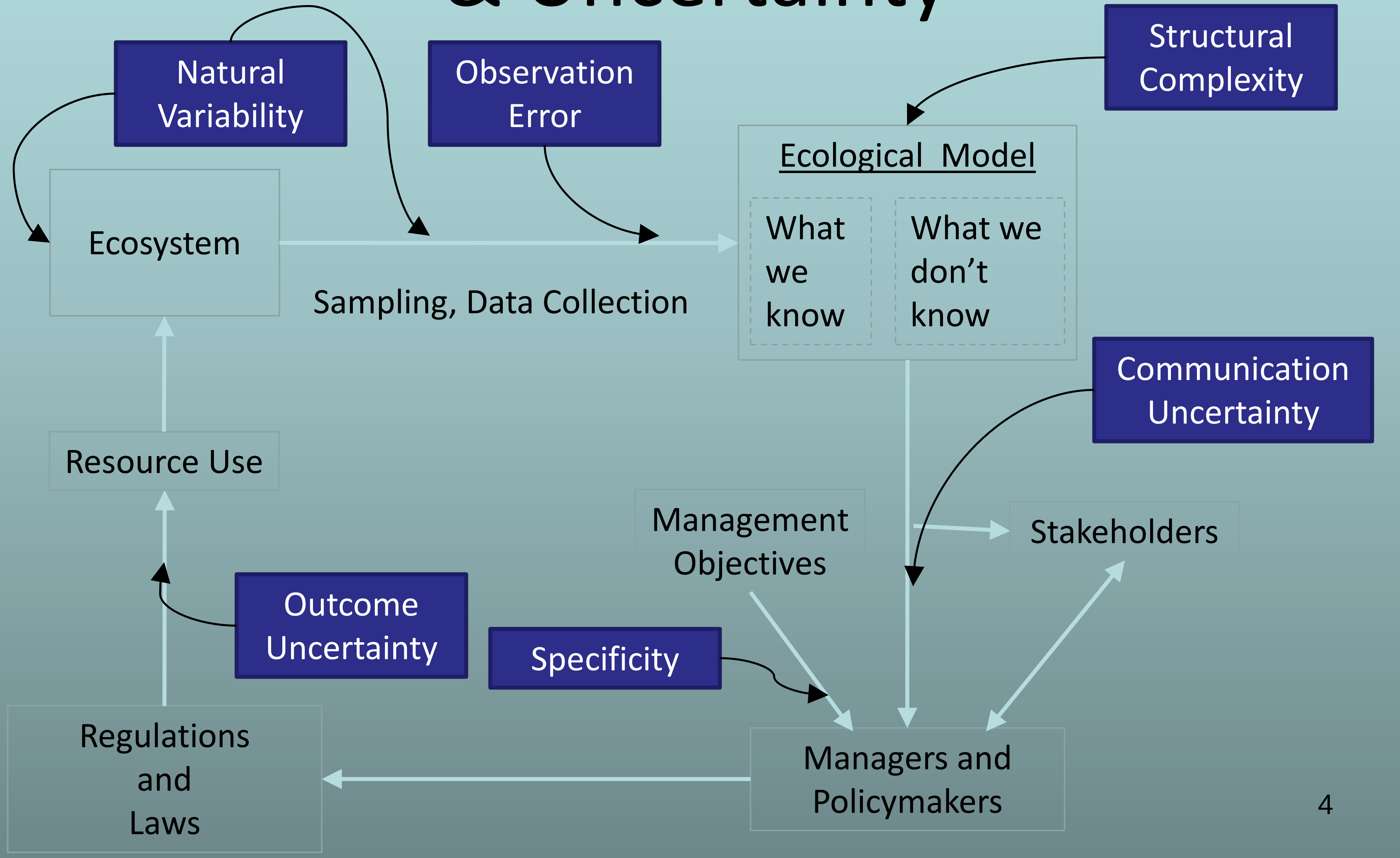
Objective & Approach

The purpose of this analysis is to assess the impacts of eutrophication on the major fisheries of the Chesapeake Bay and estimate the potential economic benefits to the fisheries associated with reduced nutrient loading prescribed in the Total Maximum Daily Load (TMDL) regulations for the Bay.

The focus of this presentation is on the ecological and fisheries management aspects of this analysis. Economic modeling is not discussed.

We are using an open loop management strategy evaluation in a fisheries focused ecosystem model.

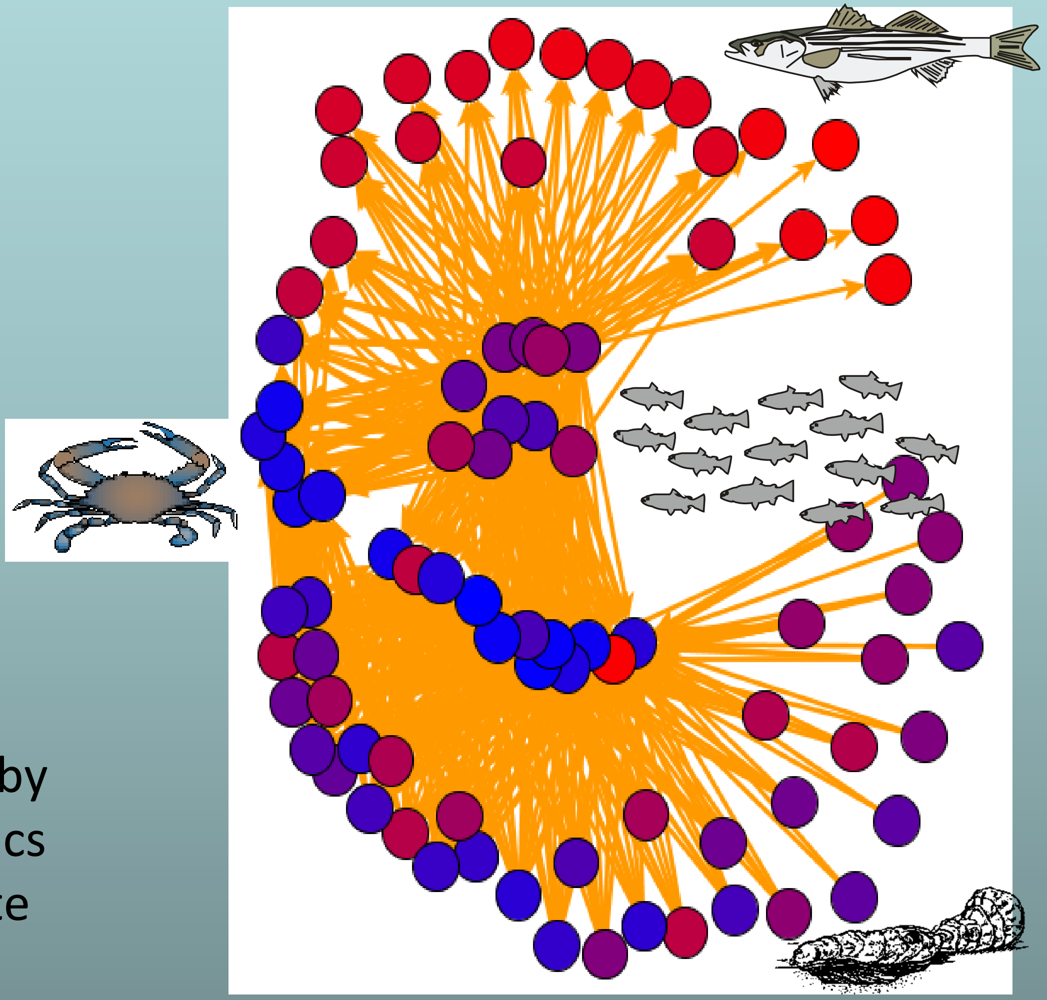
Management Strategy Evaluation & Uncertainty



Why use ecosystem models?

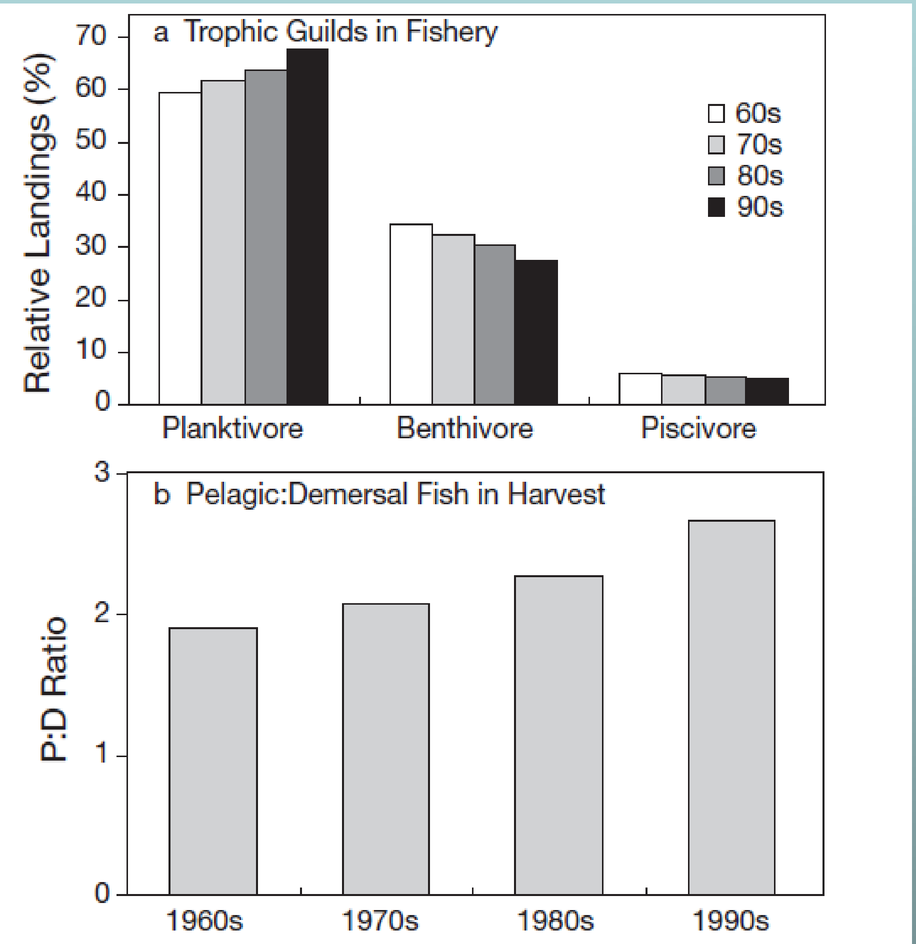
Ecosystem interactions are complex

- Responses to management actions may be non-linear
- Ecosystem models help to keep track of trade-offs in resource management decisions
- Most single species/stock assessment models driven by internal population dynamics – not feasible to incorporate biogeochemistry (e.g., N)



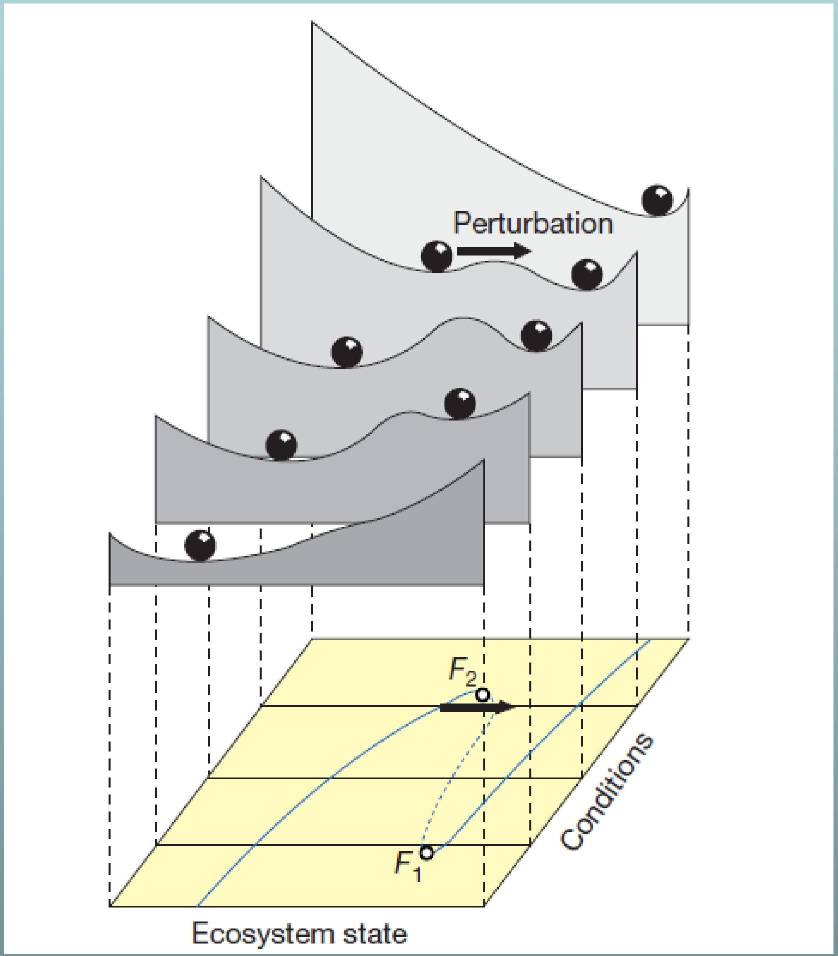
Trophic Structure Issues

Kemp et al 2005



Benthic-Pelagic Shift

Scheffer et al 2001



Stability vs. Hysteresis

The Chesapeake Bay Fisheries Ecosystem Model (CBFEM)

A Fisheries Food-Web Model

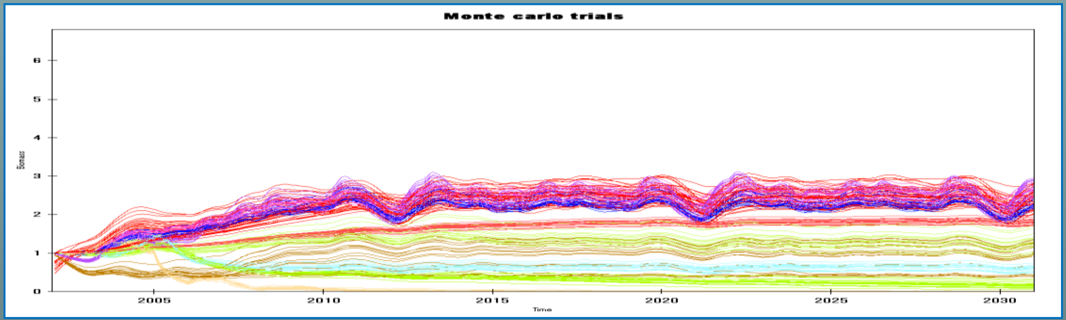
Incorporating:

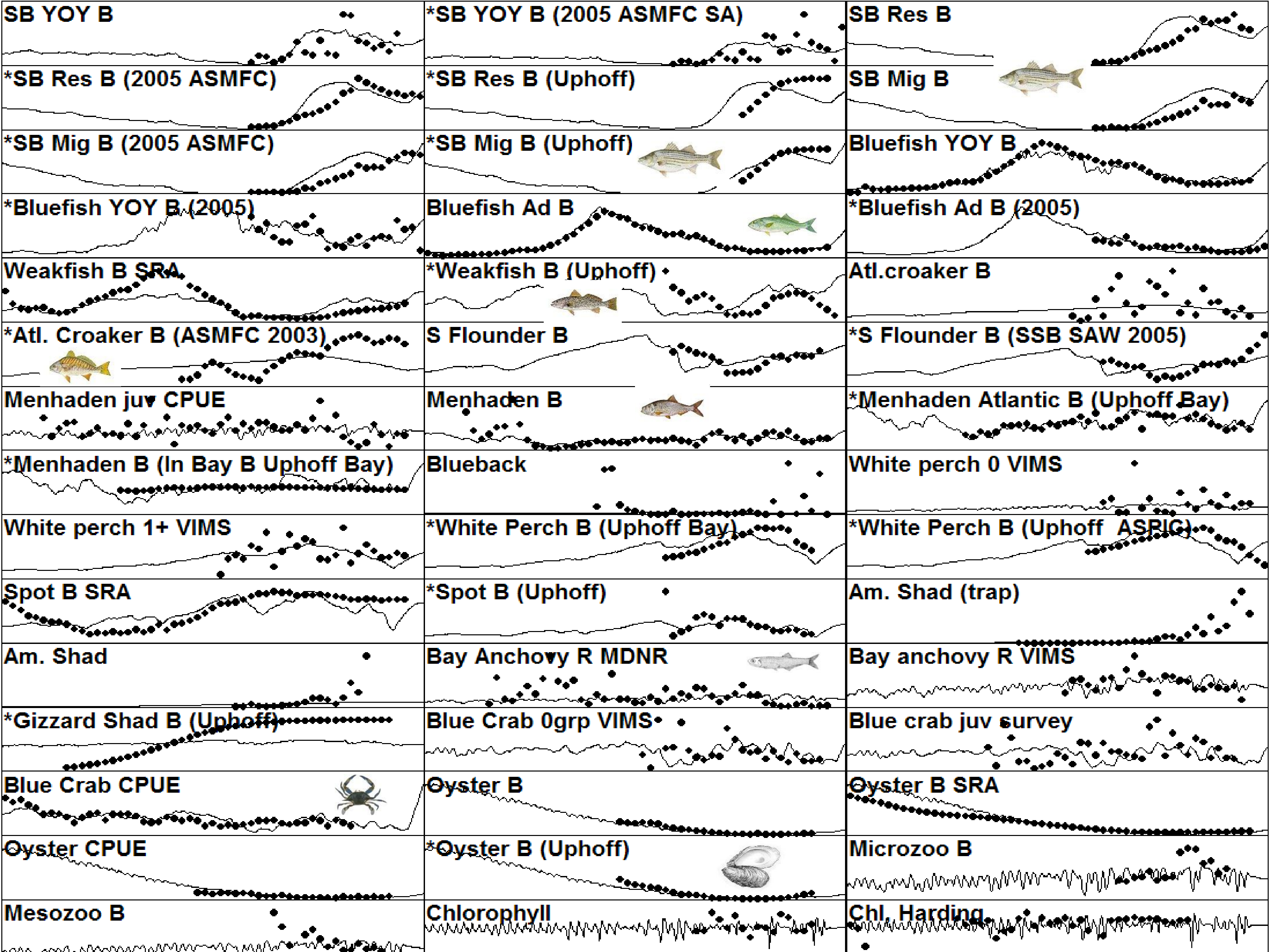
Biological environment
✓Primary production forcing
✓Trophic interactions
✓Recruitment relationships
✓Age/stage structure

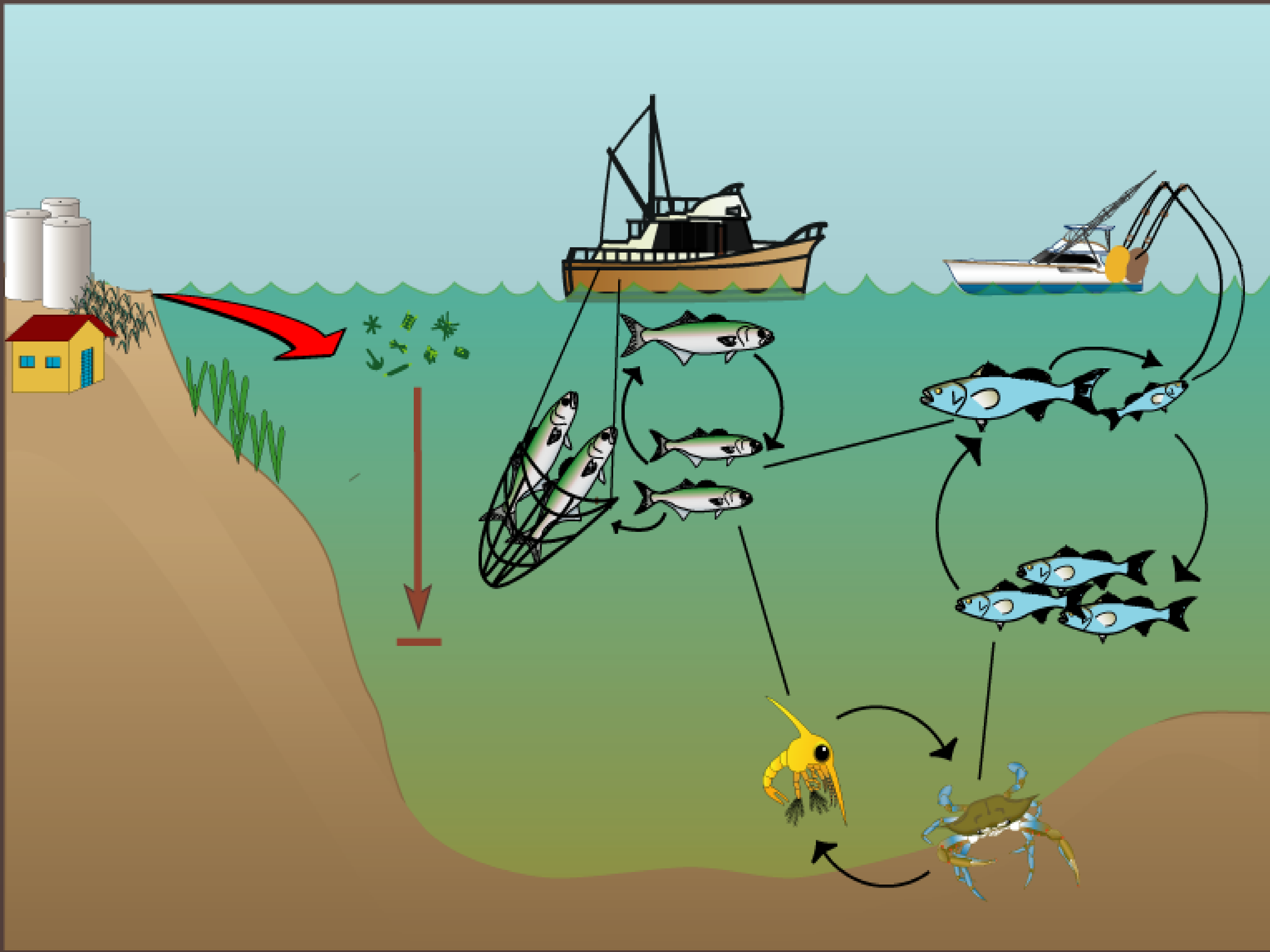
Fisheries
✓Multiple sectors

Physical environment
✓Forcing functions
✓Mediation functions

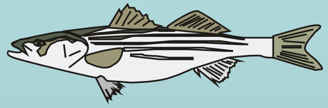
Nutrient Inputs
✓Currency is Biomass
✓Relative changes in nutrients to force primary production

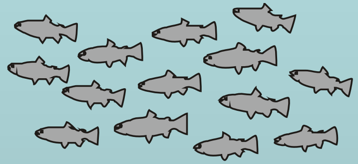


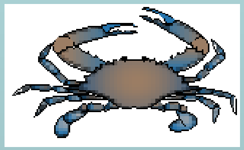

SB YOY B
*SB YOY B (2005 ASMFC SA)
SB Res B
*SB Res B (2005 ASMFC)
*SB Res B (Uphoff)
SB Mig B
*SB Mig B (2005 ASMFC)
*SB Mig B (Uphoff)
Bluefish YOY B
*Bluefish YOY B (2005)
Bluefish Ad B
*Bluefish Ad B (2005)
Weakfish B SRA
*Weakfish B (Uphoff)
Atl.croaker B
*Atl. Croaker B (ASMFC 2003)
S Flounder B
*S Flounder B (SSB SAW 2005)
Menhaden juv CPUE
Menhaden B
*Menhaden Atlantic B (Uphoff Bay)
*Menhaden B (In Bay B Uphoff Bay)
Blueback
White perch 0 VIMS
White perch 1+ VIMS
*White Perch B (Uphoff Bay)
*White Perch B (Uphoff ASPIC)
Spot B SRA
*Spot B (Uphoff)
Am. Shad (trap)
Am. Shad
Bay Anchovy R MDNR
Bay anchovy R VIMS
*Gizzard Shad B (Uphoff)
Blue Crab 0grp VIMS
Blue crab juv survey
Blue Crab CPUE
Oyster B
Oyster B SRA
Oyster CPUE
*Oyster B (Uphoff)
Microzoo B
Mesozoo B
Chlorophyll
Chl. Harding



Modeled Fisheries Stocks for Outputs







- Oysters
- Striped bass
- Menhaden
- Blue crab
- Alosines
- Atlantic croaker
- Black drum
- Bluefish
- Butterfish
- "Panfish"
- Reef associated fish
- Sandbar shark
- Smooth dogfish
- Spiny dogfish
- Summer flounder
- Weakfish
- White perch
- Catfish: Blue, White, Channel & Flathead

Scenario development - Initial

- Model exploration was focused on using the model to explore Chesapeake Bay tidal water designated uses for living resources as described in the TMDL report
- Used habitat and mediation functions
- In progress

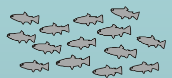
Chesapeake Bay tidal waters designated uses

Tidal water designated use	Chesapeake Bay habitats and communities protected
Migratory fish spawning and nursery	Migratory and resident tidal freshwater finfish during the late winter/spring spawning and nursery season in tidal freshwater to low- salinity habitats.
Shallow-water Bay grass	Underwater Bay grasses and fish and crab species that depend on the shallow-water habitat provided by underwater Bay grass beds.
Open-water fish and shellfish	Diverse populations of sport fish, including striped bass, bluefish, mackerel and sea trout, as well as important bait fish such as menhaden and silversides in surface water habitats within tidal creeks, rivers, embayments, and the mainstem Chesapeake Bay year-round.

Chesapeake Bay tidal waters designated uses

Tidal water designated use	Chesapeake Bay habitats and communities protected
Deep-water seasonal fish and shellfish	Animals inhabiting the deeper transitional water column and bottom habitats between the well-mixed surface waters and the very deep channels during the summer months (e.g., bottom-feeding fish, crabs and oysters, as well as other important species, including the Bay anchovy).
Deep-channel seasonal refuge	Bottom-sediment-dwelling worms and small clams that serve as food for bottom-feeding fish and crabs in the very deep channels in summer.

Forcing and mediation functions: habitat

Ecological group	Species	Response
Mobile, Pelagic predators	Striped Bass 	Habitat squeeze
Mobile, Pelagic forage fish	Menhaden	Refuge or Predation
Less mobile, benthic invertebrates 	Blue Crabs 	Jubilees/ Direct mortlaity
Sessile, benthic invertebrates	Oysters 	Direct Mortality
Potential Ecosystem Interrupter	Sea Nettles and Ctenophores 	Release

Forcing and mediation functions: habitat

$$C_{ij} = \frac{a_{ij} * \ v_{ij} * \ B_i * P_j * \ T_i * \ T_j * S_{ij} * M_{ij}/D_j}{v_{ij} + \ v_{ij} * T_{ij} * M_j + \ a_{ij} * \ M_{ij} * \ P_j * \ S_{ij} * \ T_j/D_j}$$

- C_{ij} is the consumption of predator *i* on prey *j*,
- a_{ij} is the effective search rate for predator *i* feeding on a prey *j*,
- v_{ij} base vulnerability expressing the rate with which prey move between being vulnerable and not vulnerable,
- B_i prey biomass, and
- P_j predator abundance (N_j for split pool groups discussed later, and B_j for other groups).
- T_i represents prey relative feeding time,
- T_j predator relative feeding time,
- S_{ij} user-defined seasonal or long term forcing effects,
- M_{ij} mediation forcing effects, and
- D_j represents effects of handling time as a limit to consumption rate

Initial Scenario results

- Initial model exploration was using habitat and mediation functions to explore Chesapeake Bay tidal water designated uses for living resources showed little effect of TMDLs as compared to no TMDL action
  - These effects would probably be observed on a model with finer spatial scale – like the Chesapeake Atlantis Model
- Led to developing three simple eutrophication response scenarios

Scenario Development – Current Approach

TMDL implementation scenarios		Eutrophication Response		Fisheries Management
No Action		Agricultural Model		Regulated, Open Access
Constant baseline				- Maintain current Fs
Trib Strategies	×	Agricultural-Microbial Shunt	×	- Calculate new Fs
				Maximize profits
TMDL		Microbial Shunt		- By species - Ecosystem-wide

Scenario Development – Current Approach

TMDL implementation scenarios		Eutrophication Response		Fisheries Management
No Action Constant baseline Trib Strategies TMDL	×	Agricultural Model Agricultural-Microbial Shunt Microbial Shunt	×	Regulated, Open Access - Maintain current Fs

TMDL Implementation Scenarios

- No Action
  - Loads increase steadily over time
- Constant Baseline
  - Loads held constant at current levels
- Tributary Strategies
  - Loads reduce over time
- TMDL – full implementation
  - Loads reduce over time and more rapidly than under Trib Strategies

Eutrophication Scenarios

1) Agricultural Model

   increased N loads results in proportional increases in primary productivity, and result increases in secondary productivity and fisheries

2) Agriculture-Microbial shunt model

   increases in N loads above a certain threshold level results in energy and matter being shunted away from primary producers to microbial pathways that do not contribute to fishery production at higher trophic levels.

3) Microbial Shunt

   Scenario 2- Scenario 1

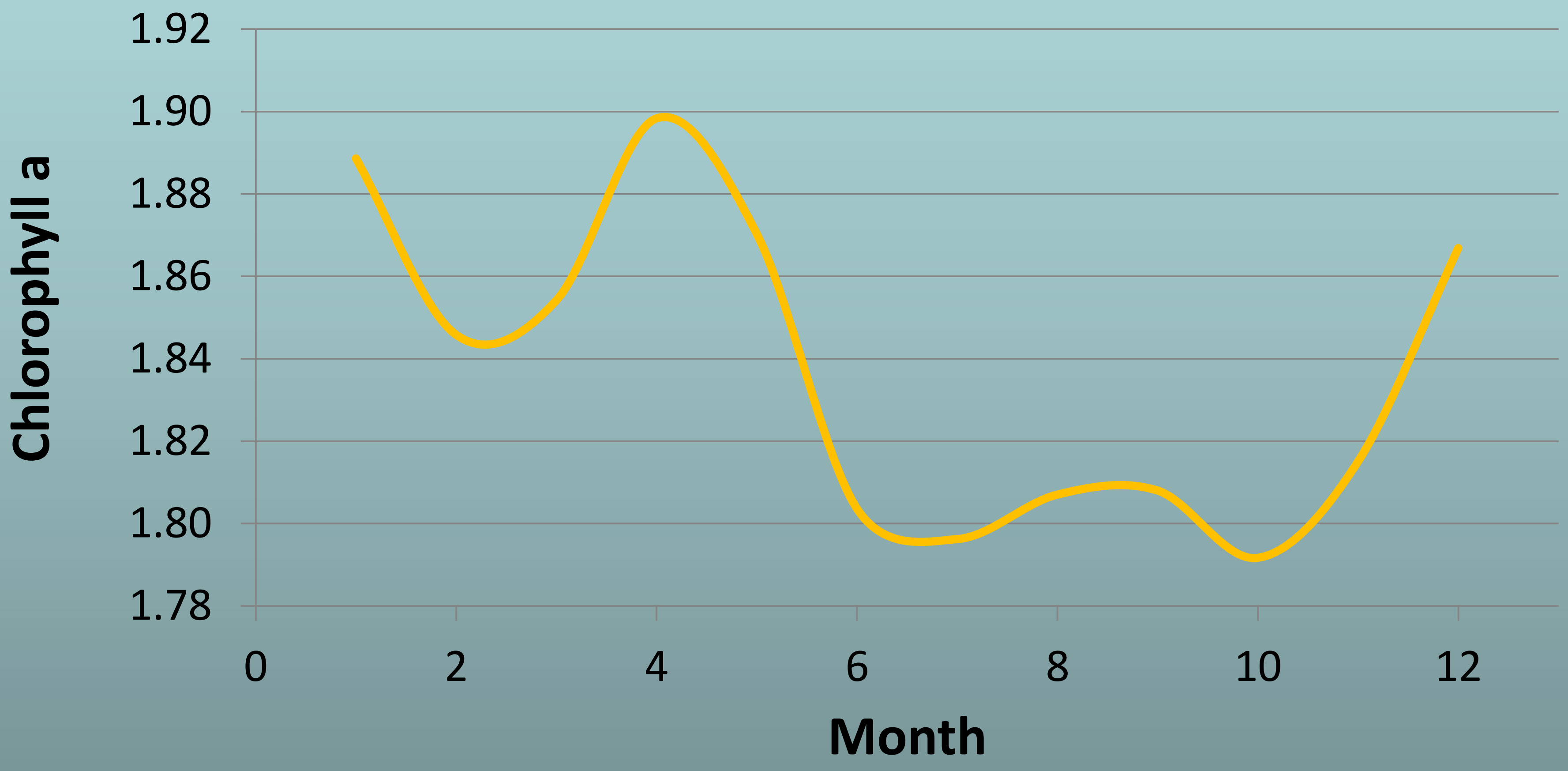
Management Scenarios

- Open Access
  - Maintain current Fs
  - Calculate new Fs – based on changes in F_{MSY}
- Maximize profits
  - By species
  - Ecosystem-wide

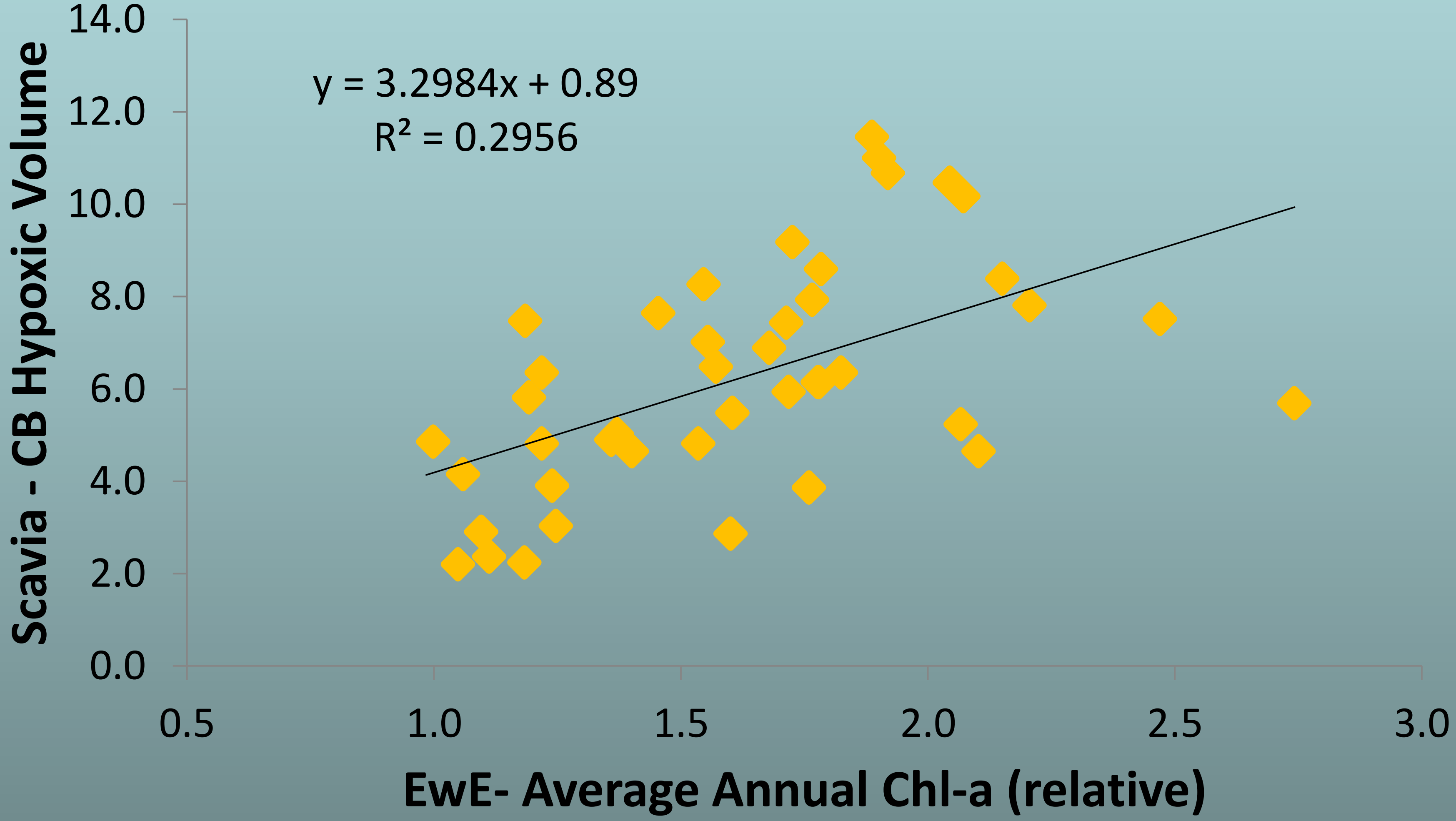
Nitrogen loadings for TMDL scenarios

Year	No Action	Constant Baseline	Trib Strategies	TMDL
2010	248	248	248	248.0
2011	254.3	248	244.2	242.7
2012	260.5	248	240.4	237.4
2013	266.8	248	236.6	232.1
2014	273.1	248	232.8	226.7
2015	279.3	248	229.0	221.4
2016	285.6	248	225.2	216.1
2017	291.9	248	221.4	210.8
2018	298.1	248	217.6	207.7
2019	304.4	248	213.8	204.6
2020	310.7	248	210.0	201.5
2021	316.9	248	206.2	198.4
2022	323.2	248	202.4	195.3
2023	329.5	248	198.6	192.2
2024	335.7	248	194.8	189.1
2025	342	248	191	186

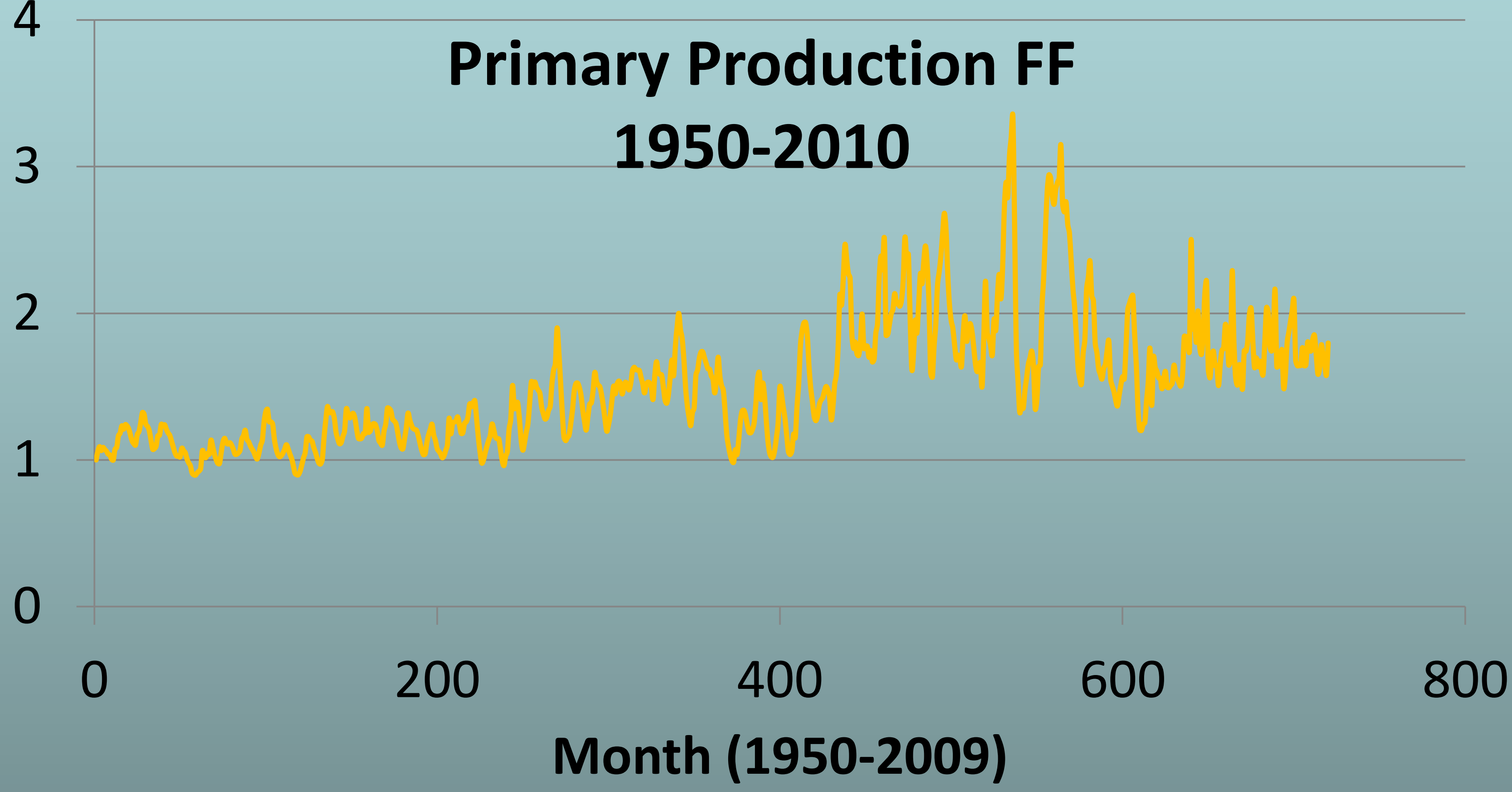
Seasonal Pattern in Chlorophyll a



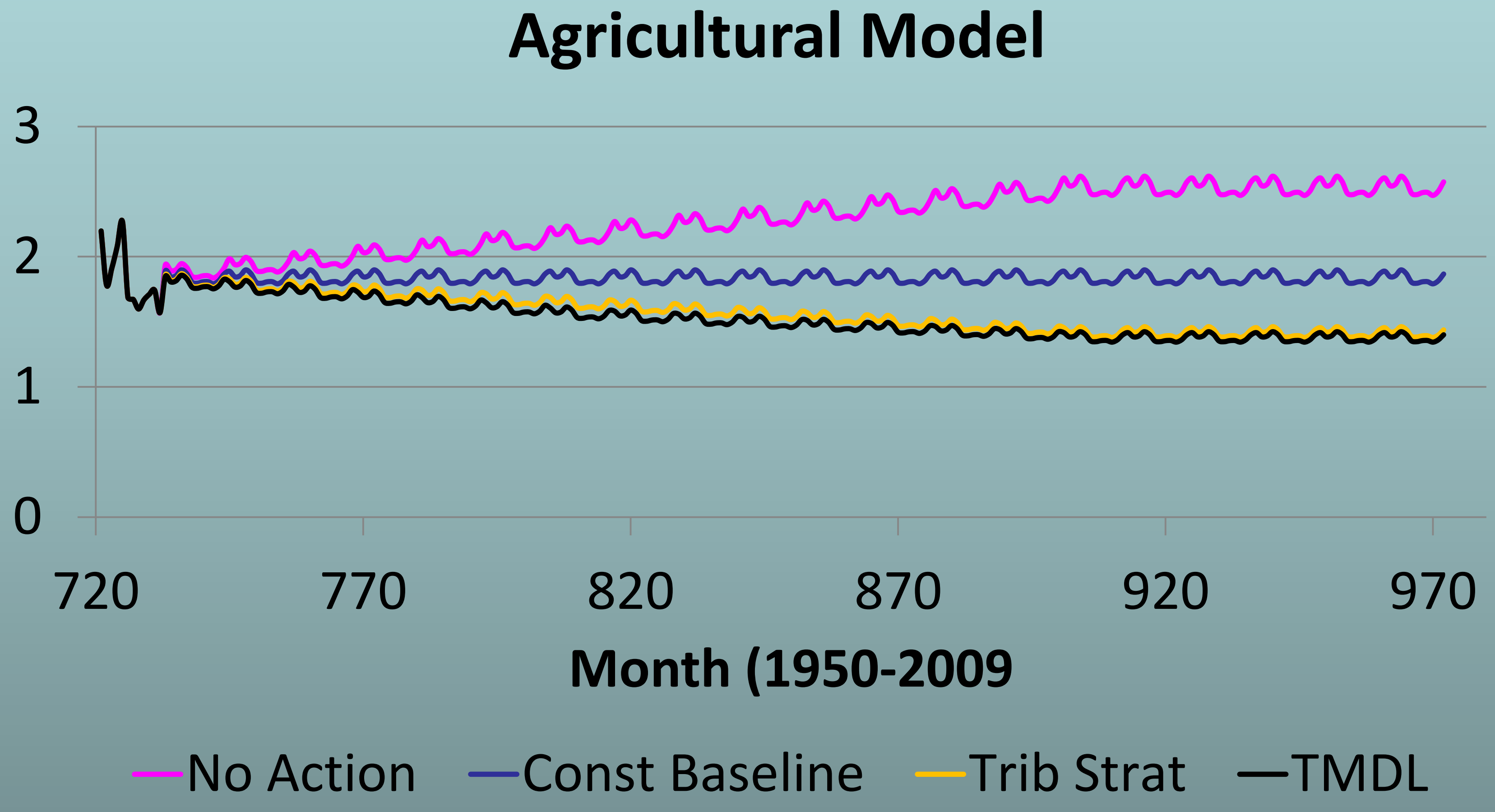
Chlorophyll a – Hypoxic Volume



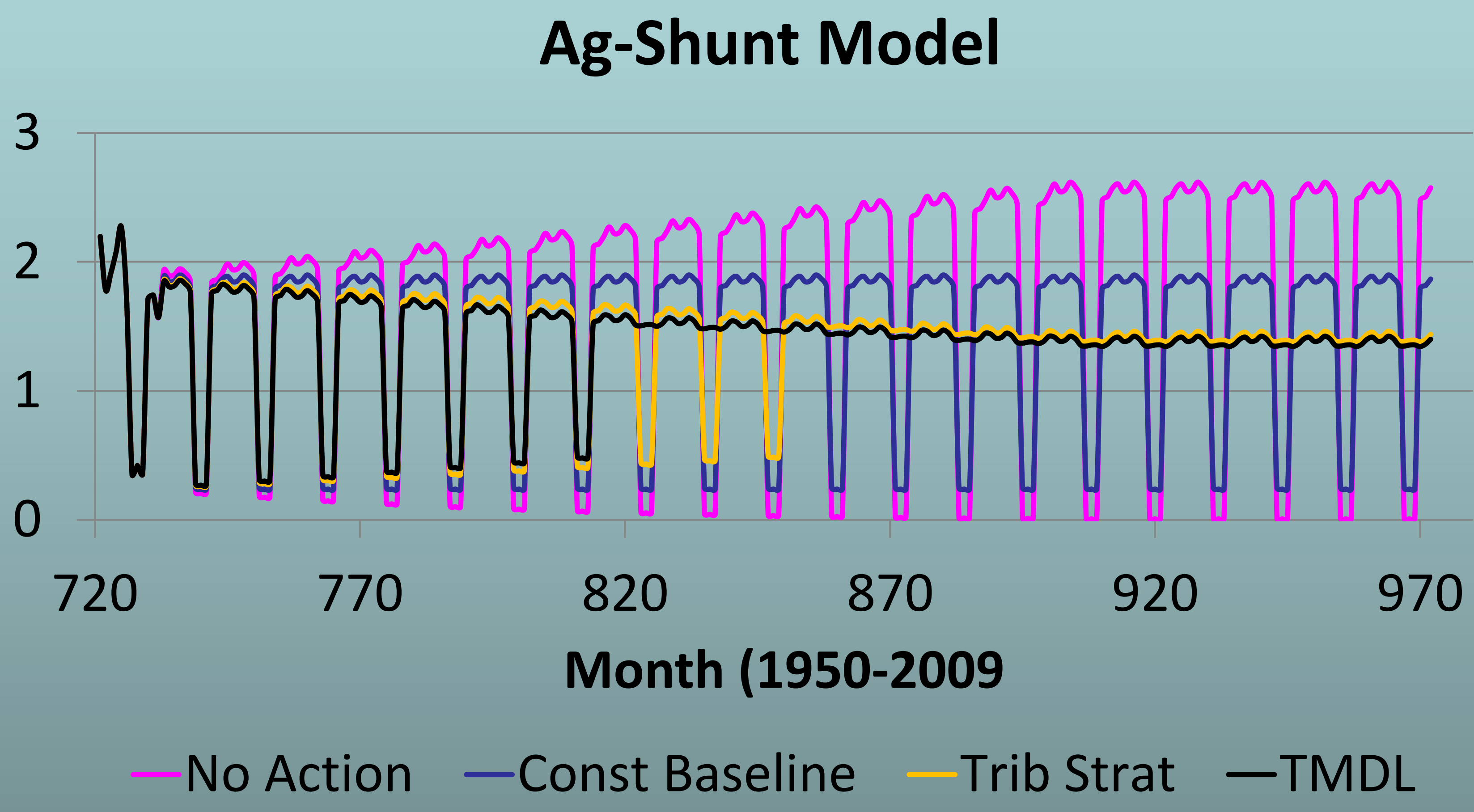
Forcing Functions



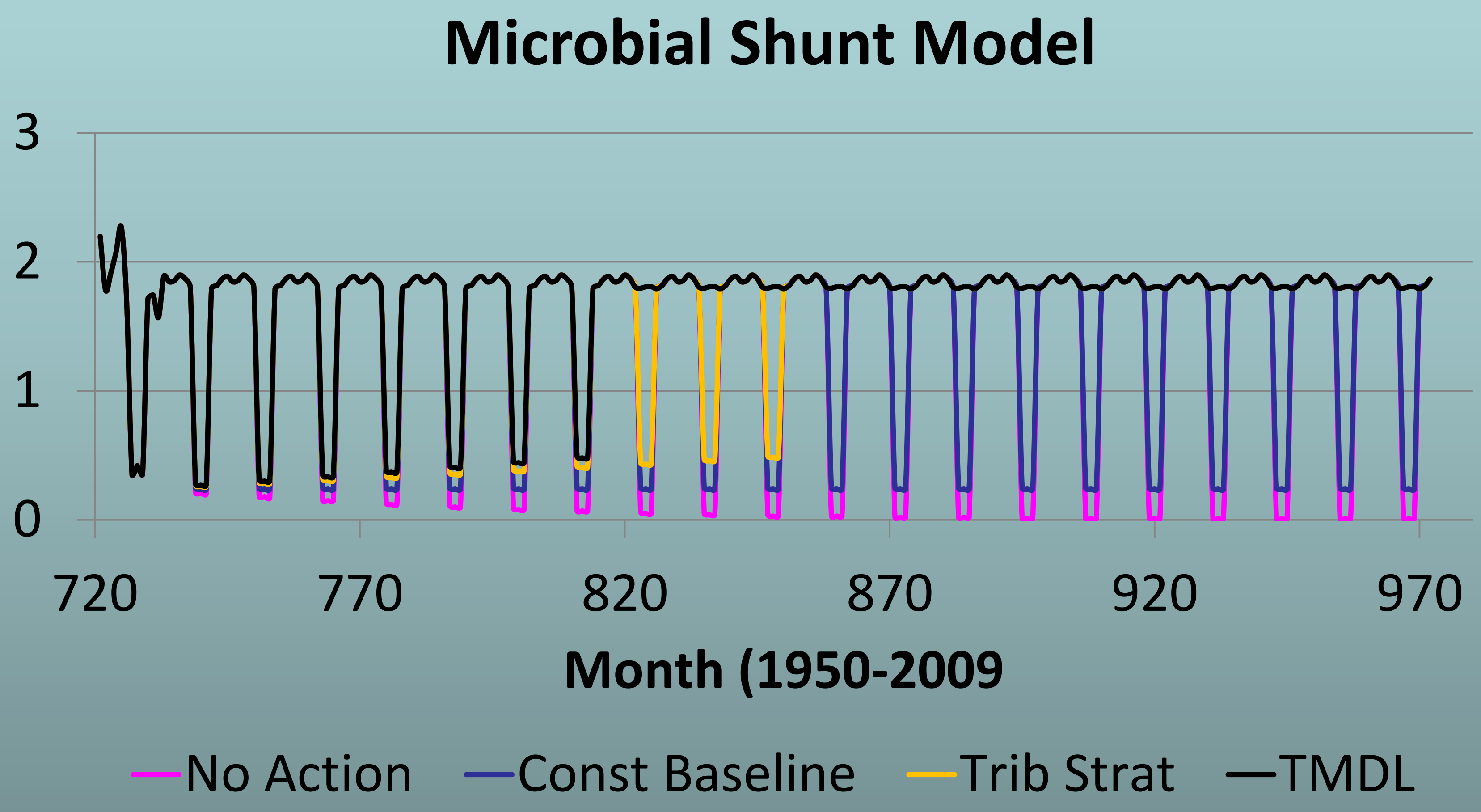
Forcing Functions



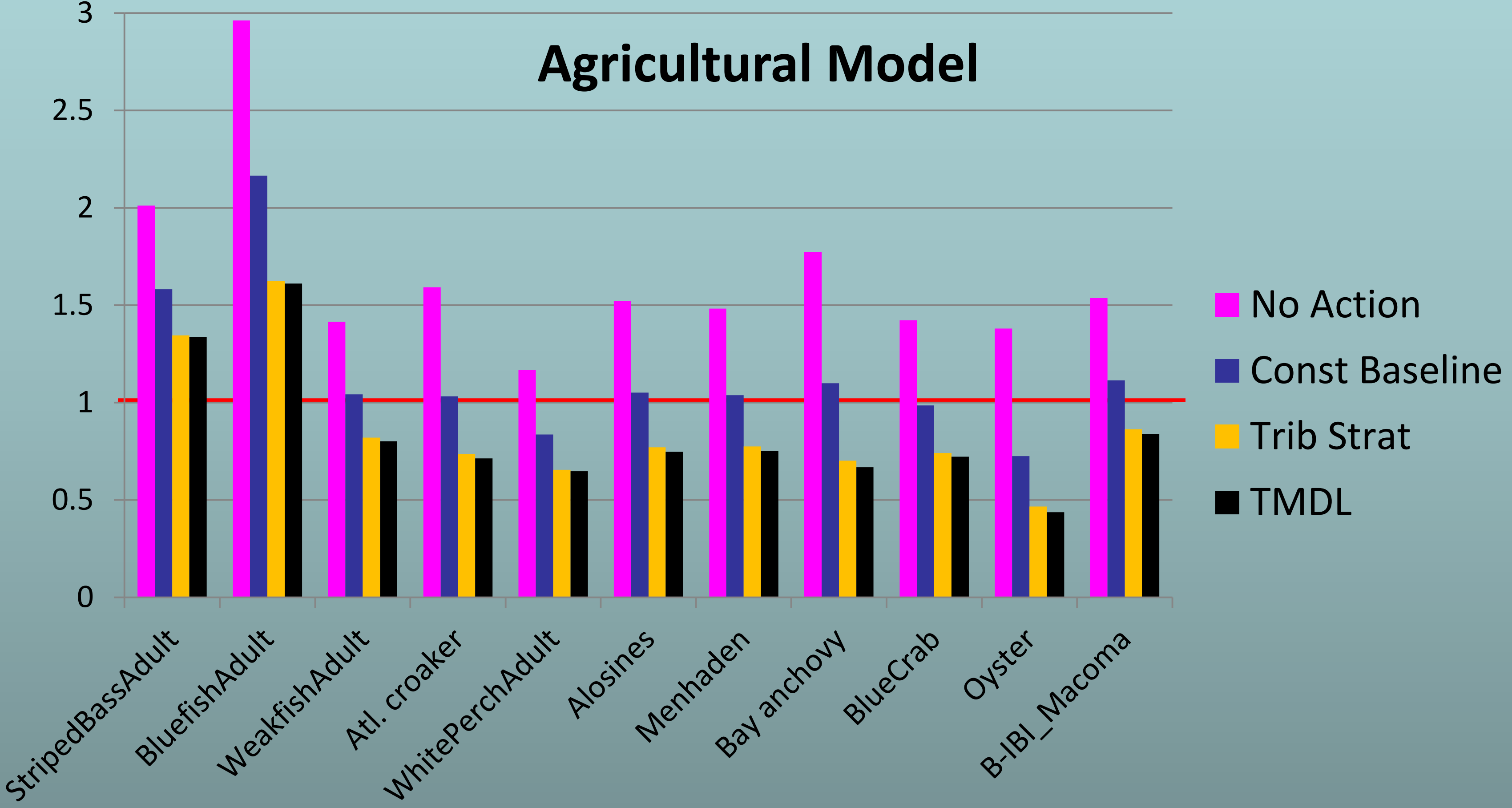
Forcing Functions



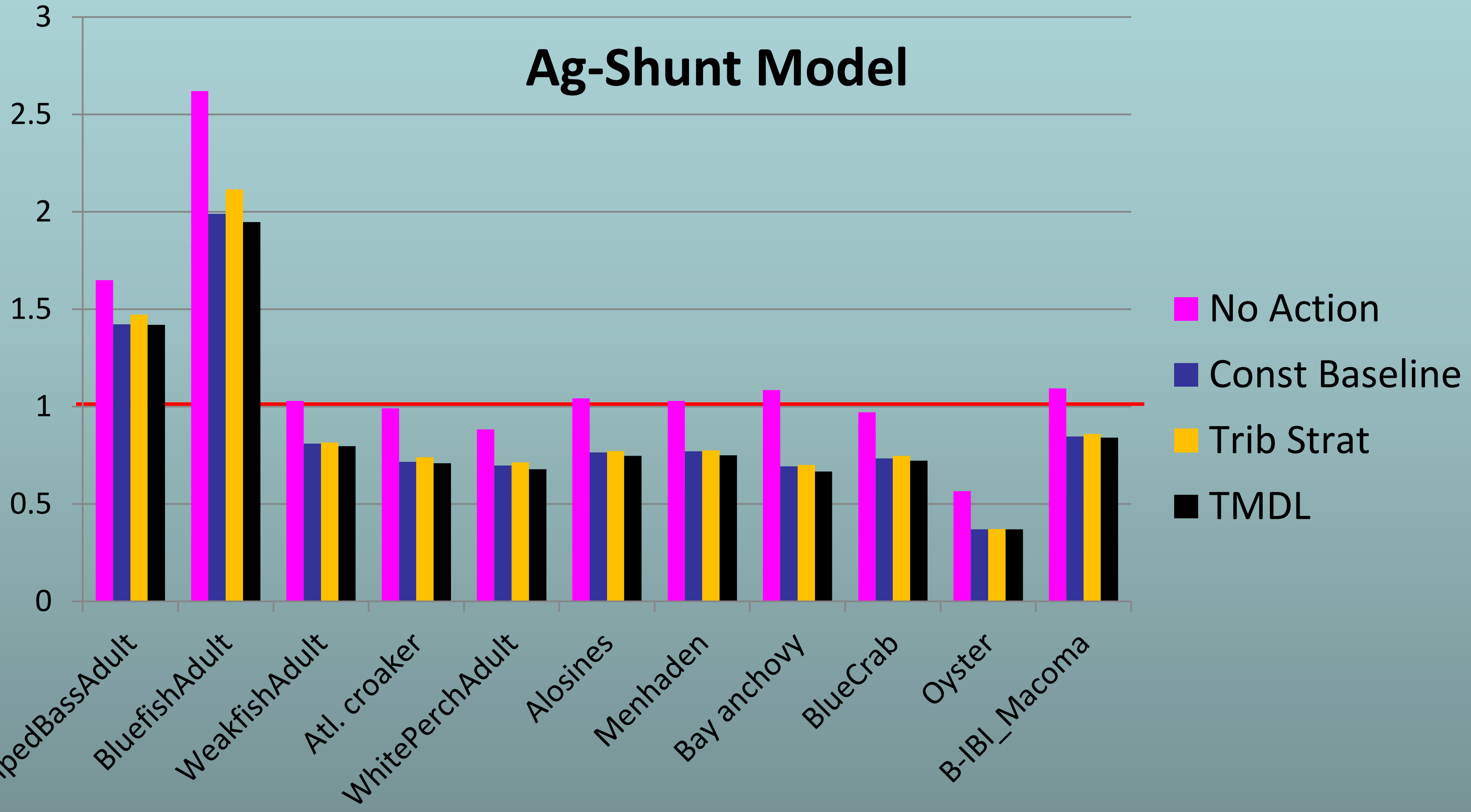
Forcing Functions



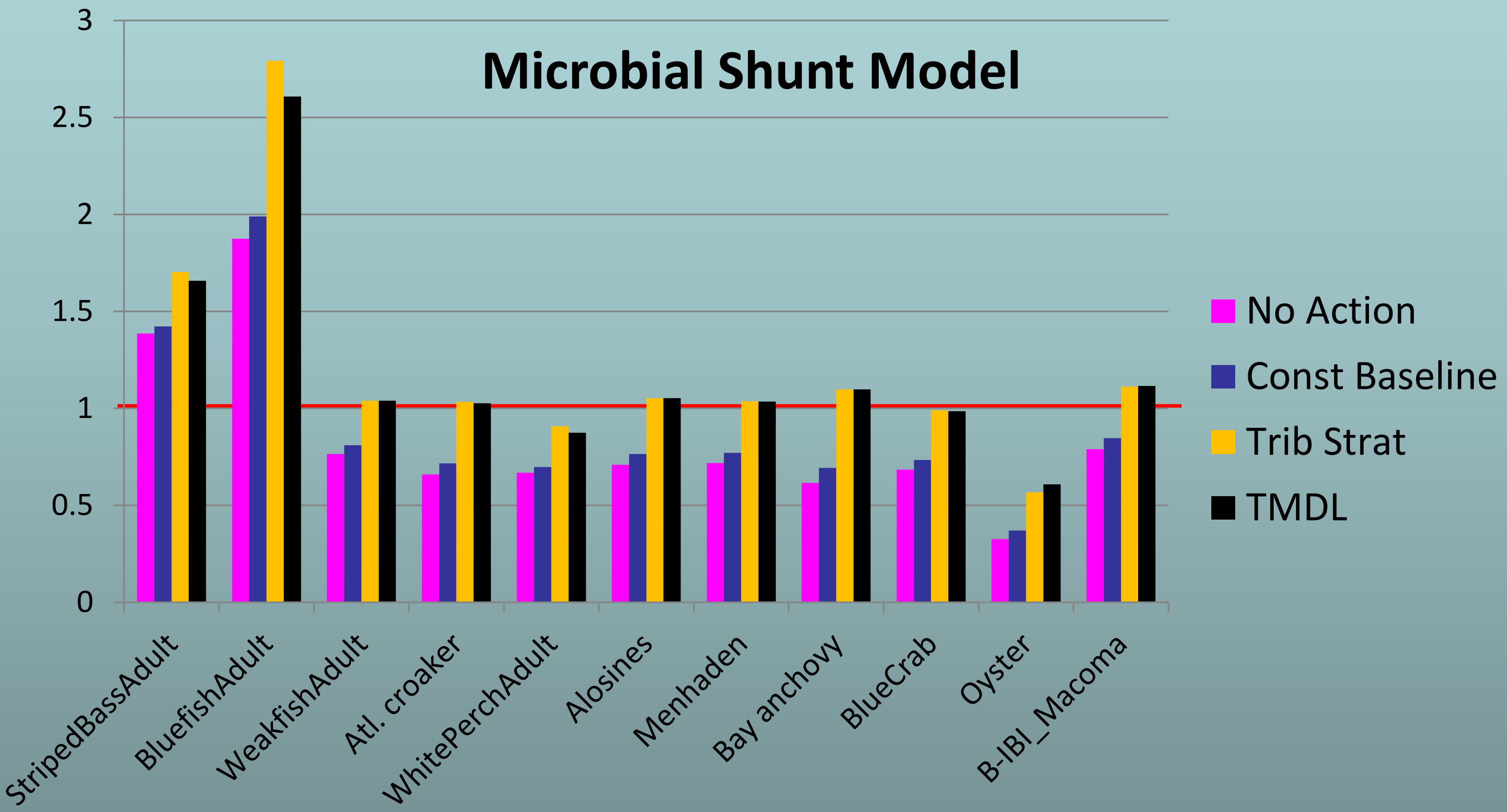
Results – Constant F



Results – Constant F

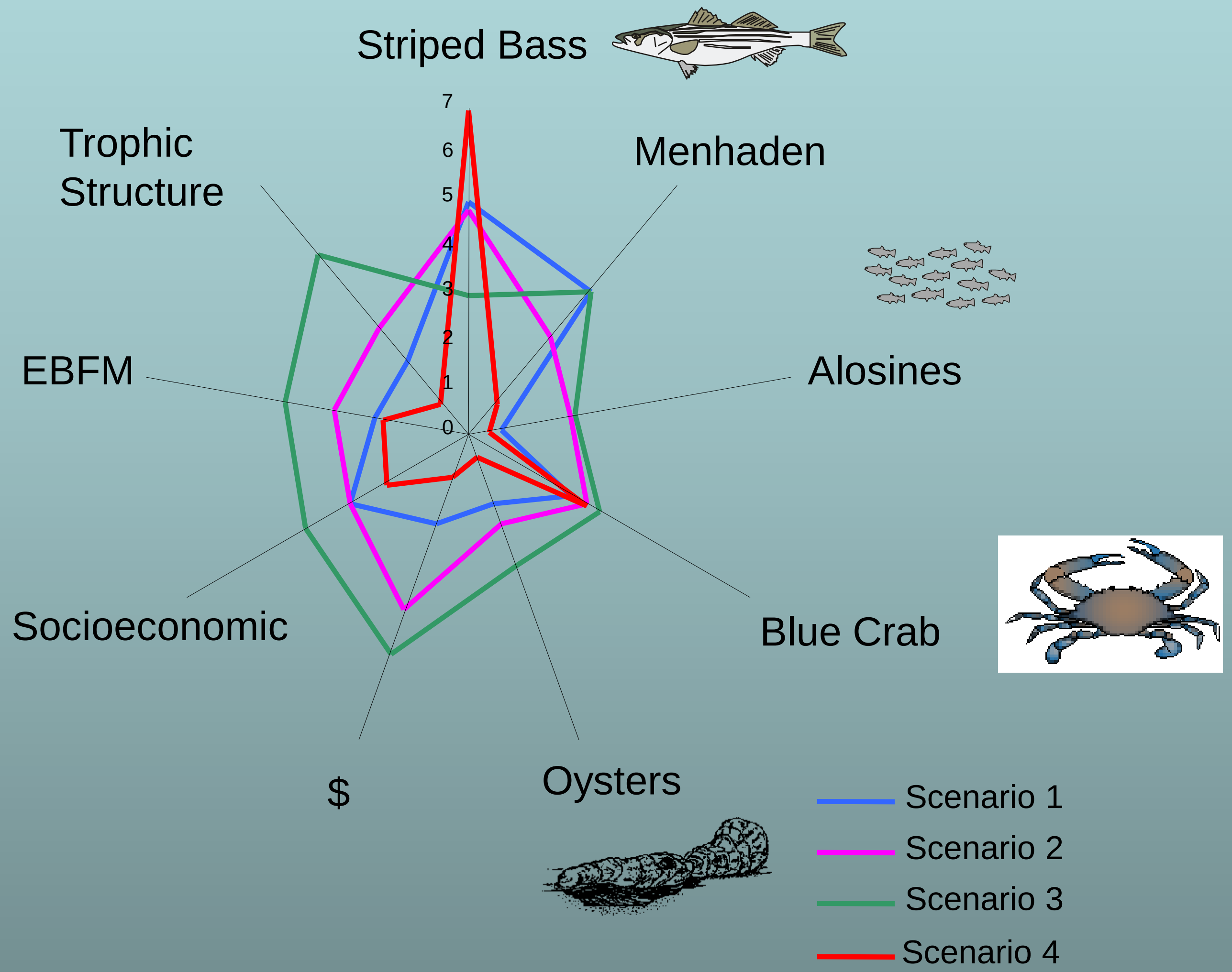


Results – Constant F



Example Outputs – Tradeoffs

Hypothetical



For Illustrative Purposes Only -- Not Based on Actual Modeling Results

Summary

- Providing ecological and fisheries information to assess benefits of TMDL to fisheries
- By linking water quality model output to fisheries-focused ecosystem models and ecosystem model output to economic models
- Using two complementary modeling systems (CAM and CBFEM)
- CBFEM will be during this year. Chesapeake Atlantis Model will be ready for use next year.

For more info contact:

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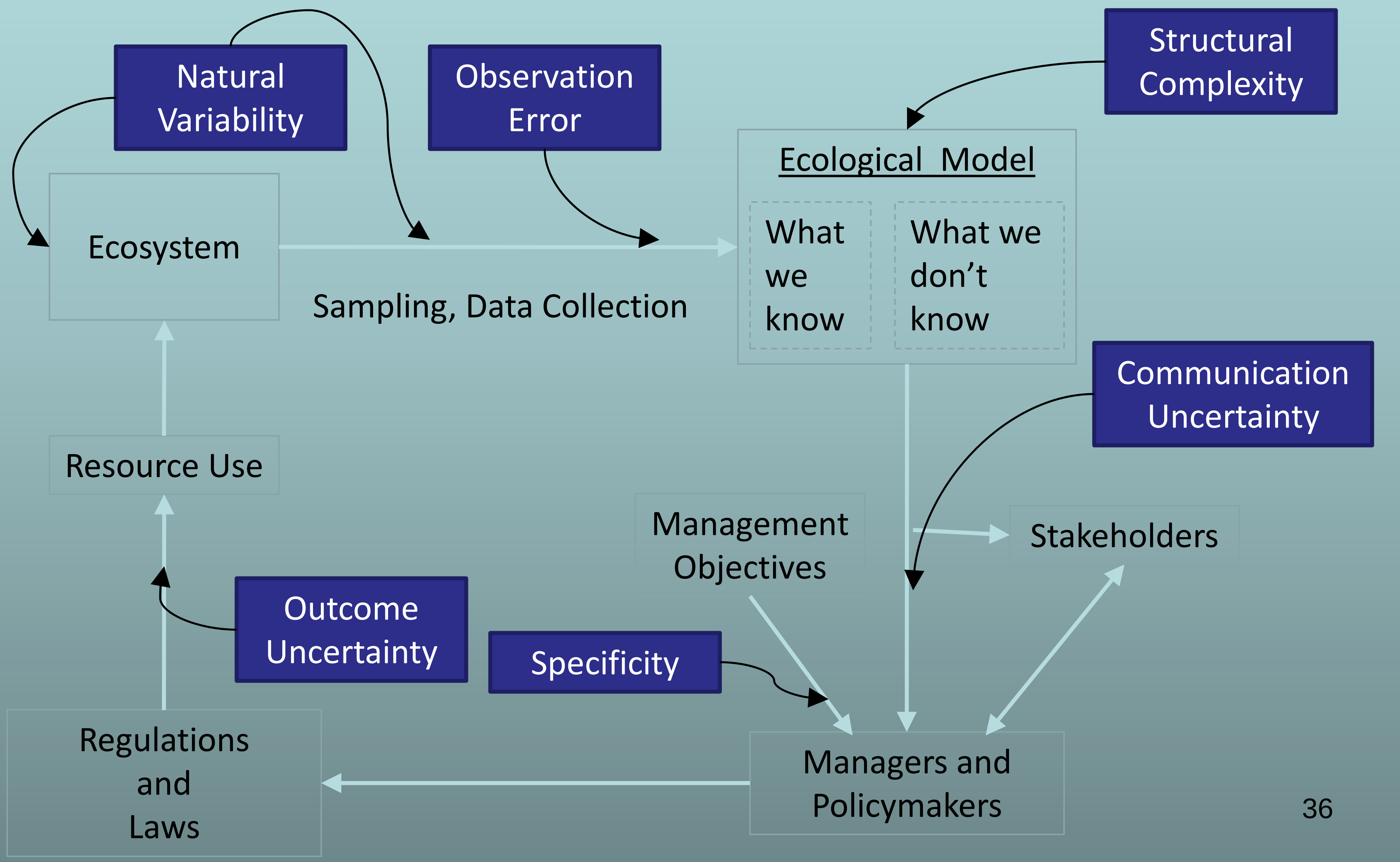
Extra Slides

Uncertainty



Plan to accomplish objectives

- For different TMDL scenarios, use nutrient outputs of the EPA Chesapeake Bay Program Eutrophication Model Suite to drive fisheries-focused ecosystem models:
  - Chesapeake Atlantis Model (CAM)
  - Chesapeake Bay Fisheries Ecosystem Model (CBFEM)
- Use ecosystem model outputs – biomass and catch of key species – to inform economic surveys and models
- Work iteratively with economists to provide outputs as needed for different stages of benefits assessment (i.e., focus groups, stated preference surveys, economic models)

The Chesapeake Atlantis Model (CAM)

A Holistic Ecosystem Model

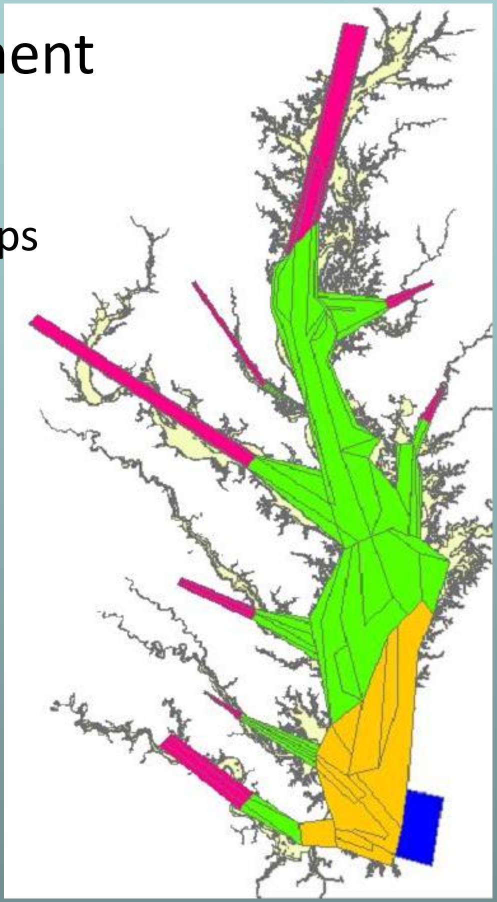
Incorporating:

Biological environment

- ✓Primary production
- ✓Trophic interactions
- ✓Recruitment relationships
- ✓Age structure
- ✓Size structure
- ✓Life History

Fisheries

- ✓Multiple sectors
- ✓Gears
- ✓Seasons
- ✓Spatially explicit



Physical environment

- ✓Geology
- ✓Chemistry
- ✓Circulation & currents
- ✓Temperature
- ✓Salinity
- ✓Water clarity
- ✓Climate variability

Nutrient Inputs

- ✓Currency is Nitrogen
- ✓ NH3
- ✓ NO2
- ✓ Si
- ✓ D.O

Model Complementarities

CAM

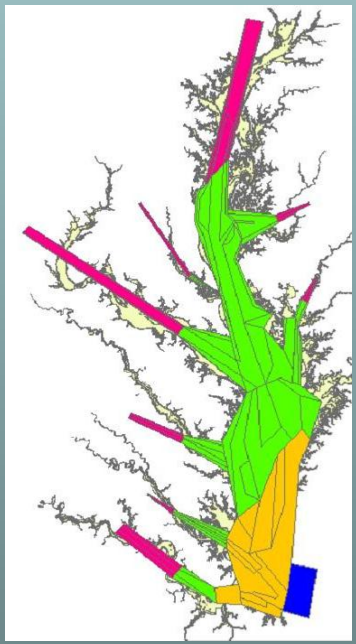
- More realism
  - Direct coupling of water quality and fisheries food webs
  - Spatially resolved
- Slower run time
  - Few runs
  - No long-term projections

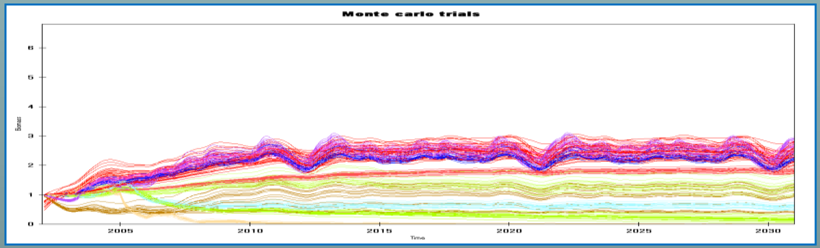
CBFEM

- Less realism
  - Forcing and mediation functions to connect WQ and fish
  - Not currently spatially resolved
- Quicker run time
  - Sensitivity analysis
  - Climate projections

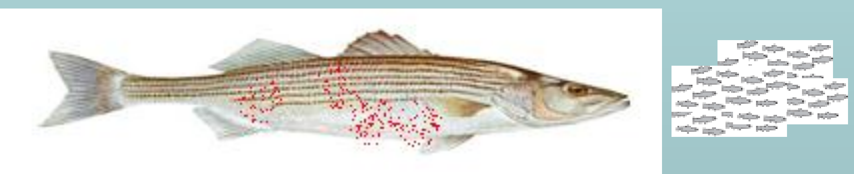
Why use multiple ecosystem models?

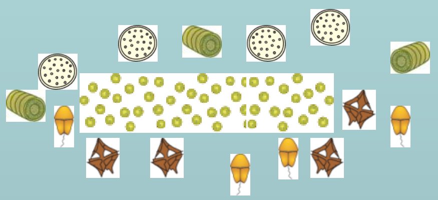
- Using multiple models is a standard approach for dealing with uncertainty in model parameters and structure
- Models can have complementary strengths

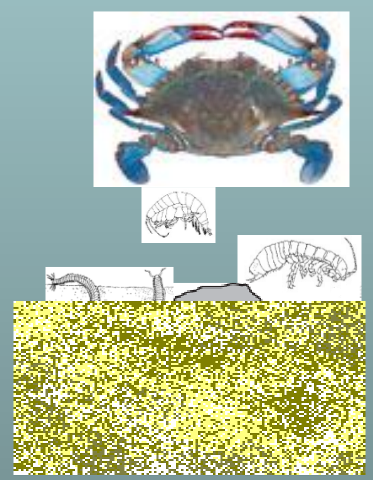




Forage/Prey - Issues







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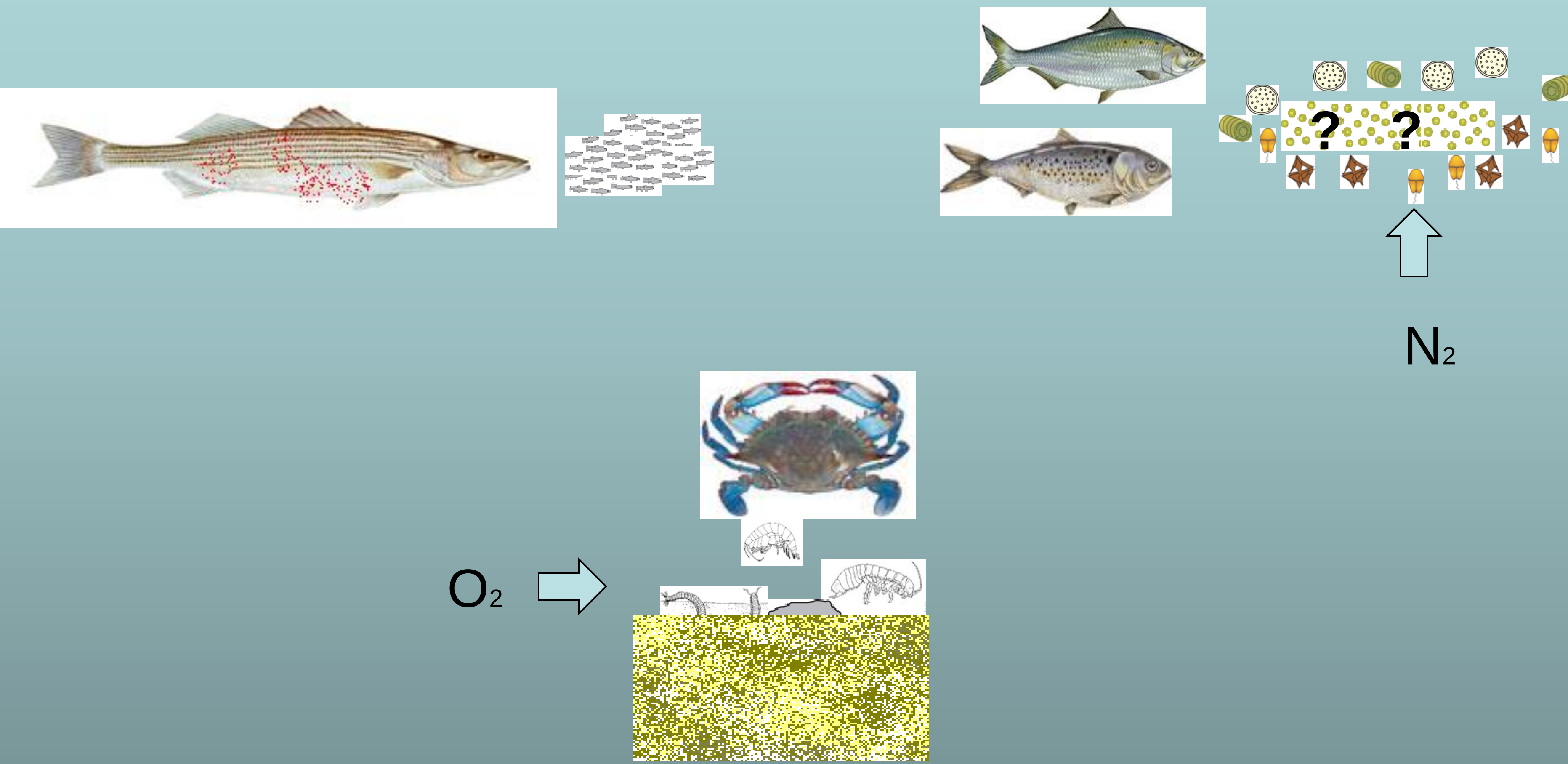

FY12 Milestones

- Quarter 1 – Generate initial CBFEM outputs for TMDL scenarios for use in focus group questions
  - 4 TMDL scenarios: status quo (least improvement), moderate improvement, high level improvement, maximum improvement (all WIPs met)
- Quarter 2 – Incorporate forcing and mediation functions in CBFEM, provide revised outputs for stated preference surveys
- Quarter 3 – Biomass output from CAM
- Quarter 4 – Incorporate key fisheries in CAM and begin linking to economic models

Trophic Structure