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Coastal Fisheries Ecosystem Modeling: Applications in the Chesapeake Bay

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March 12, 2012

Coastal Ecosystem Modeling Workshop

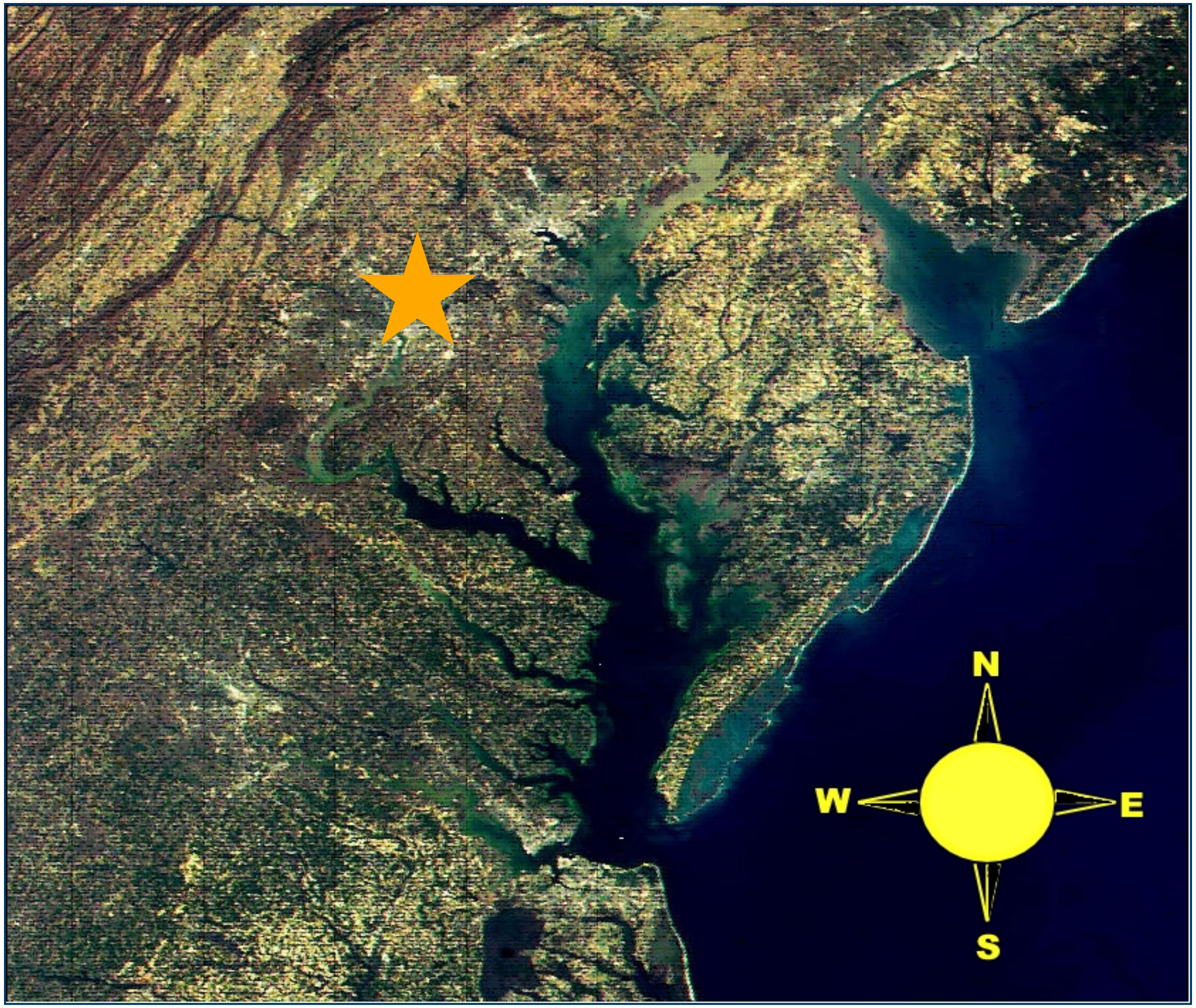
Tom's River, NJ

NOAA CHESAPEAKE BAY OFFICE

Overview

- Chesapeake Bay and its issues
- Why ecosystem modeling for the Chesapeake and in general
- How ecosystem modeling is being used in the Chesapeake
  - Multi-species management
  - Eutrophication/water quality/habitat
  - Invasive species
- Concluding thoughts

Chesapeake Bay



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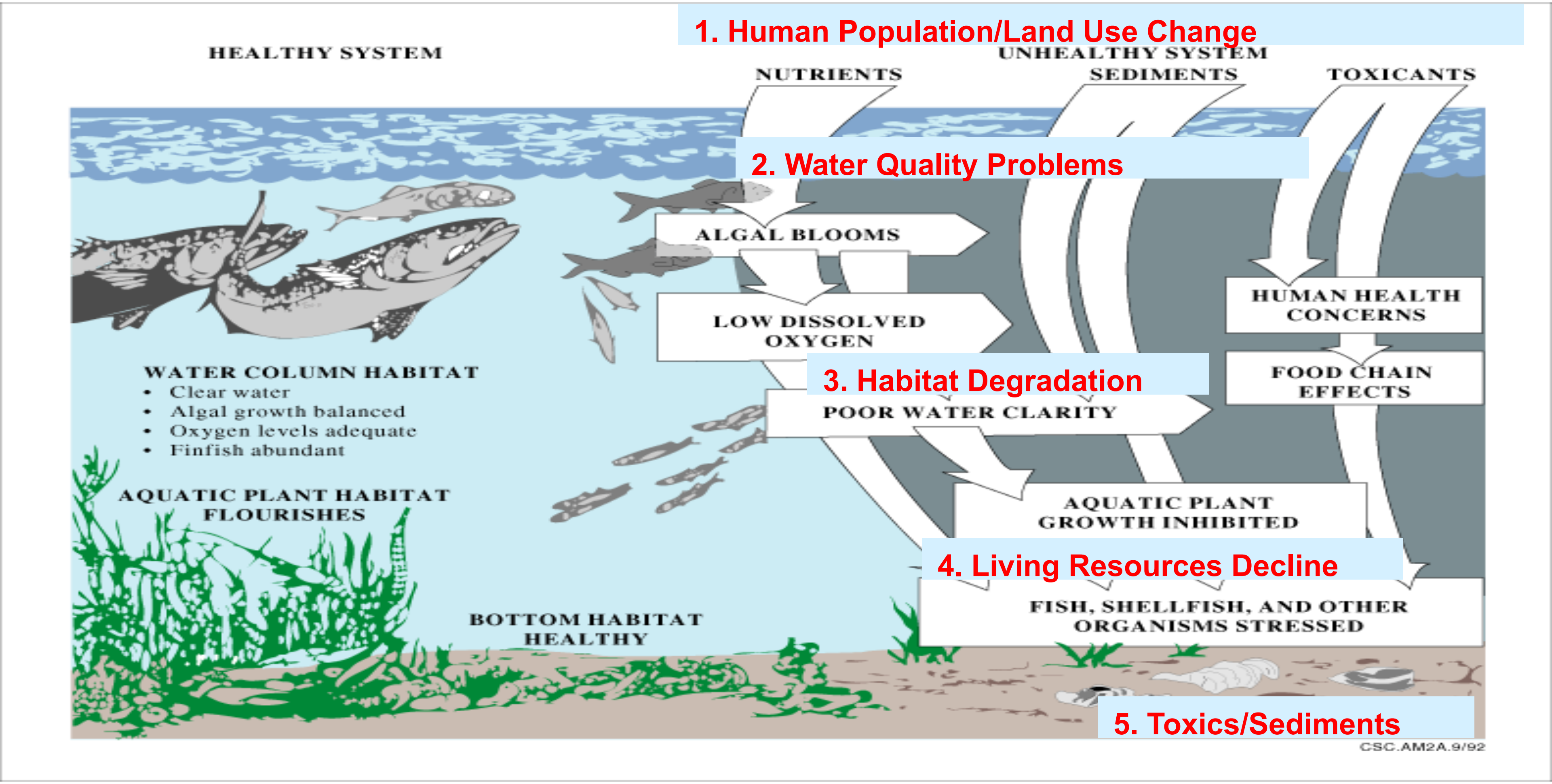
Problems in the Chesapeake Bay



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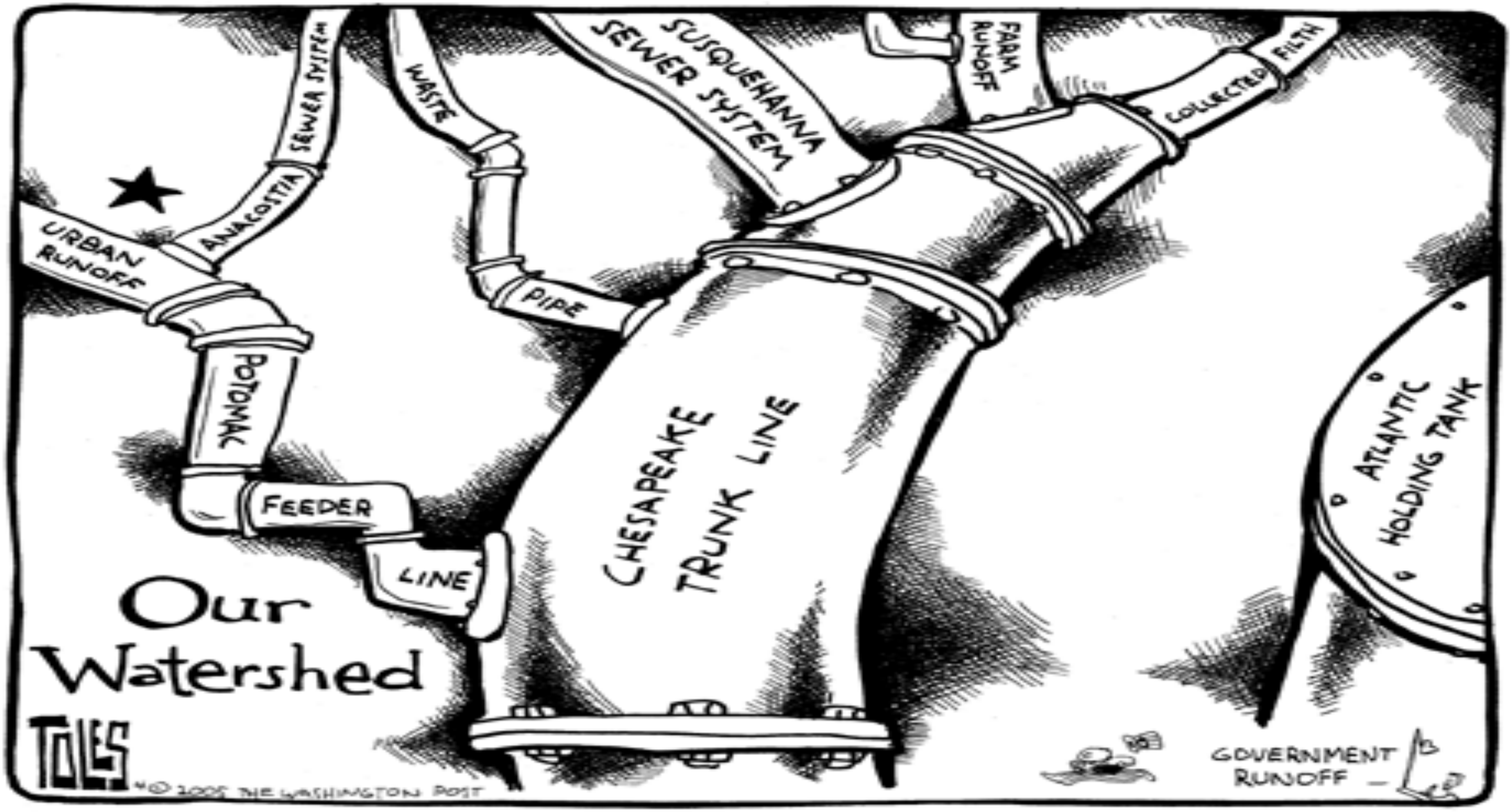
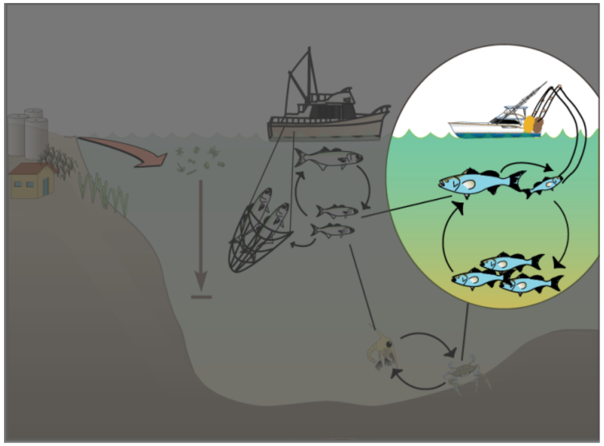
Problems in the Chesapeake Bay



Changing View of Fisheries Management

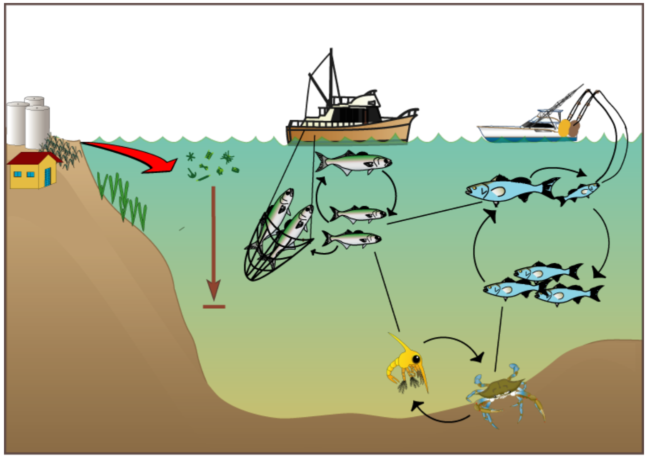


Single-species/sector management

- Simplified view of system
- Tactical decision-making
- Manage by reference points and benchmarks

Ecosystem/Multi-species management

- Complex view of system
- Strategic decision-making
- Manage by considering alternative scenarios



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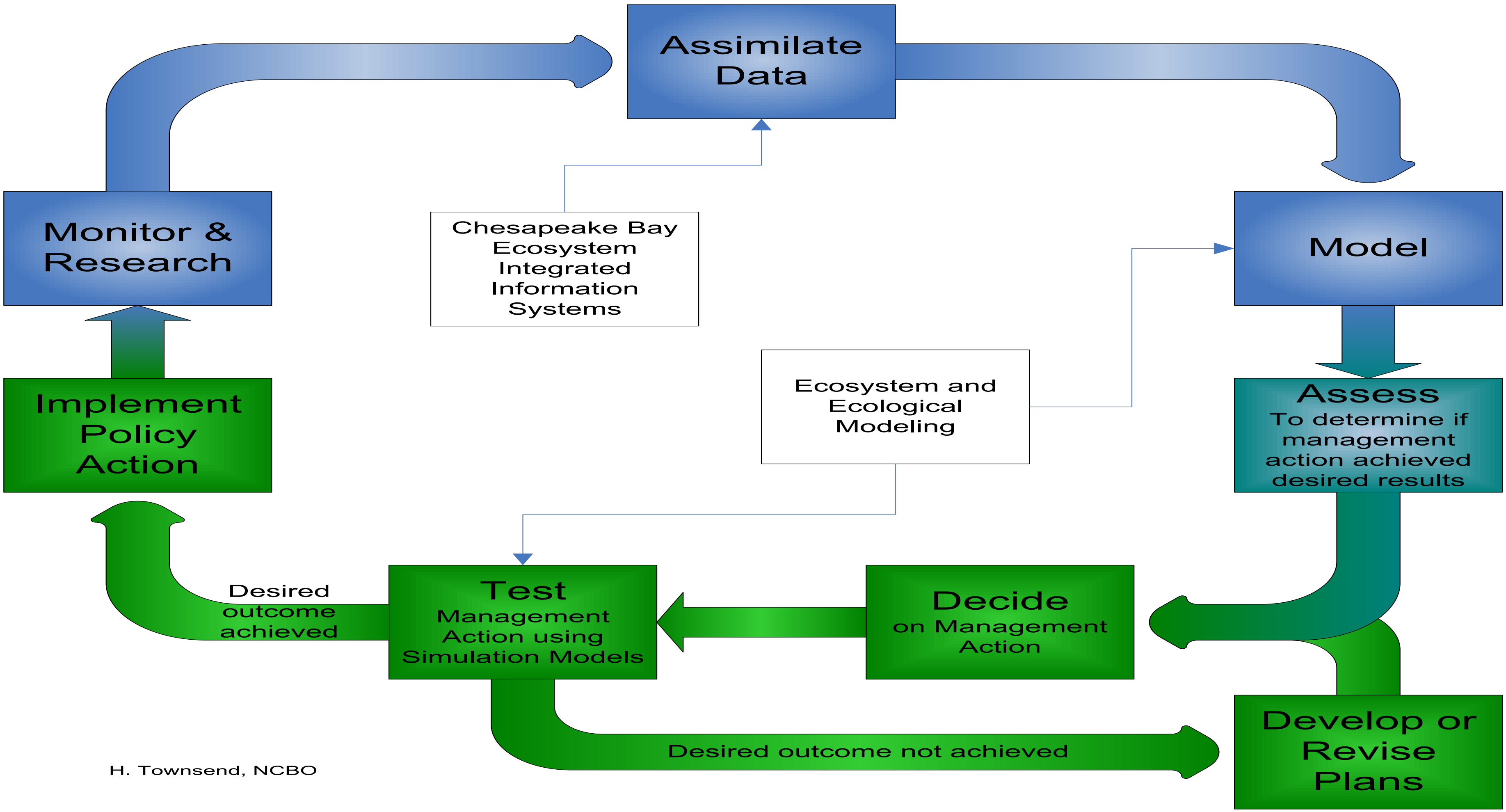
Adaptive Resource Management Approach



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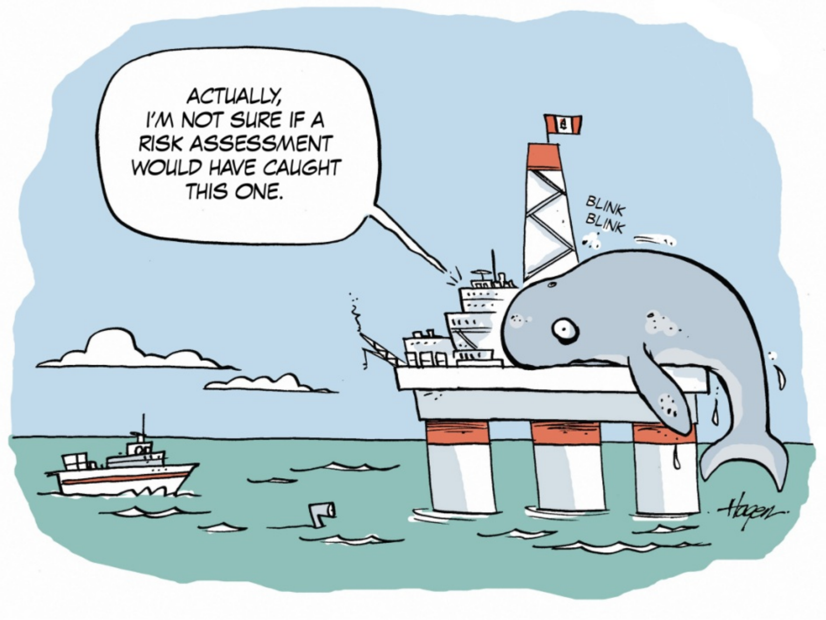
Role of Ecosystem Models in EAM: IEA

Indicator Development



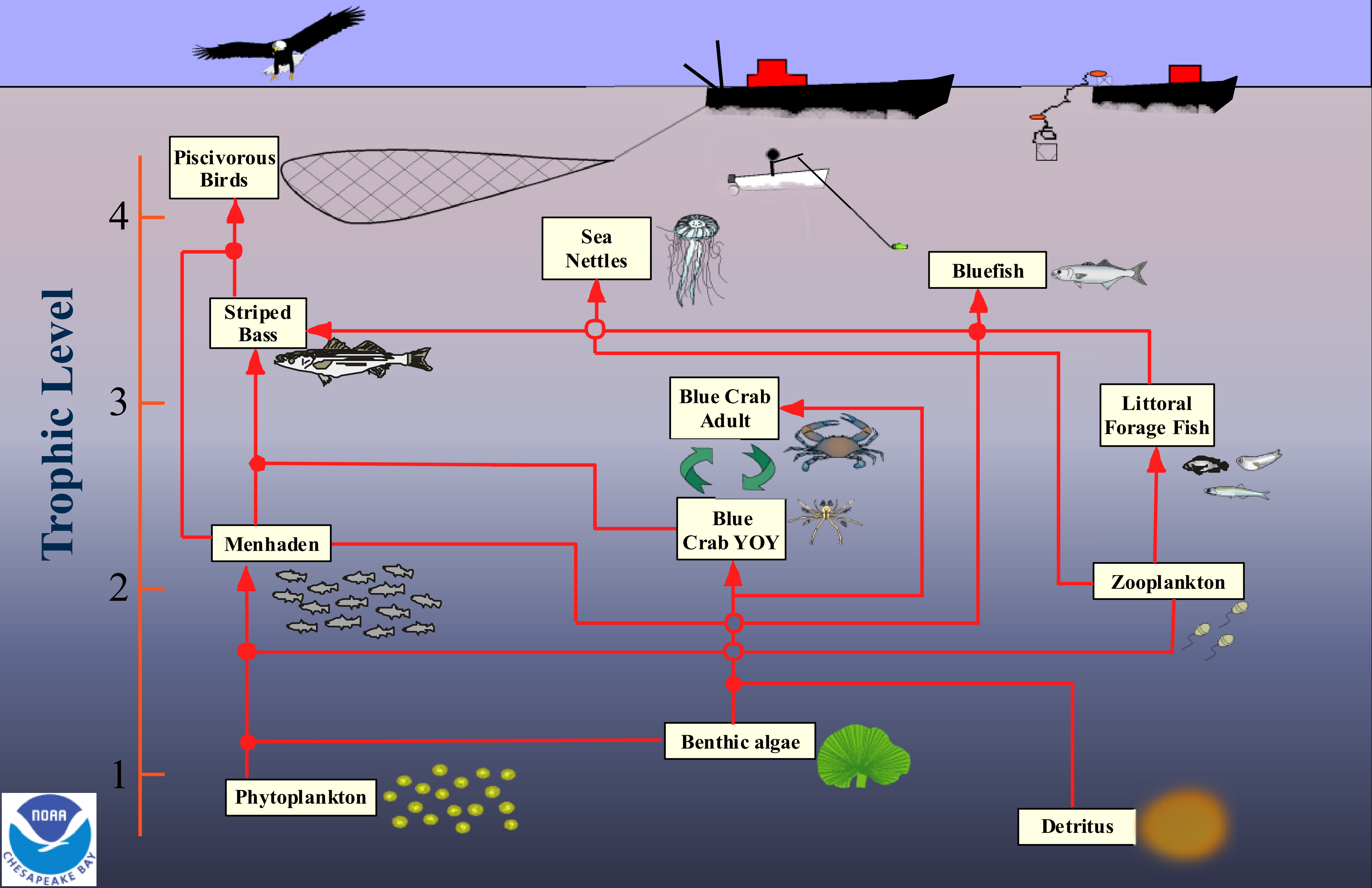
Risk Analysis

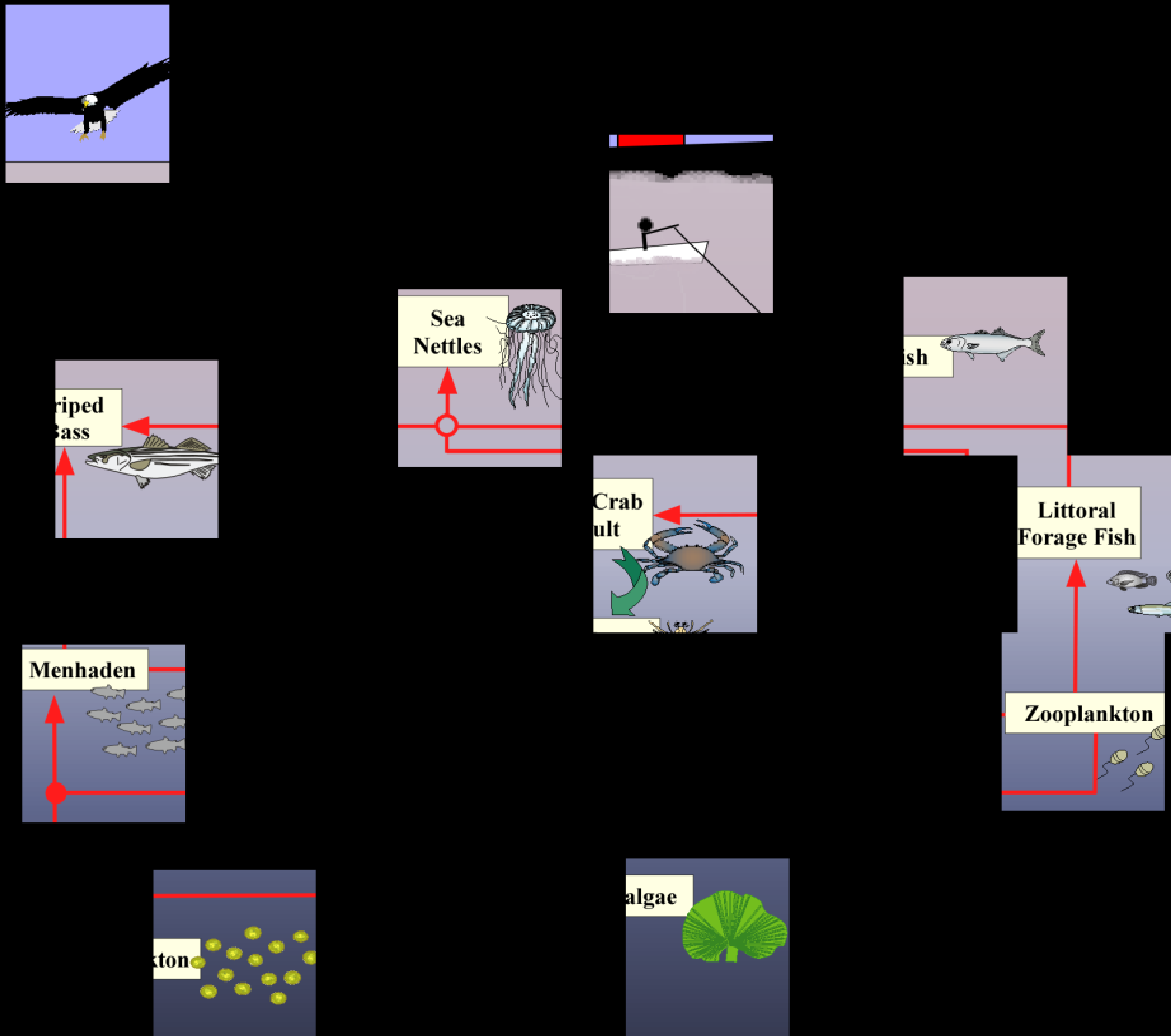
Management Strategy Evaluation

Consider trade-offs in goods and services provided by the ecosystem

IEAs – Levin et al 2009

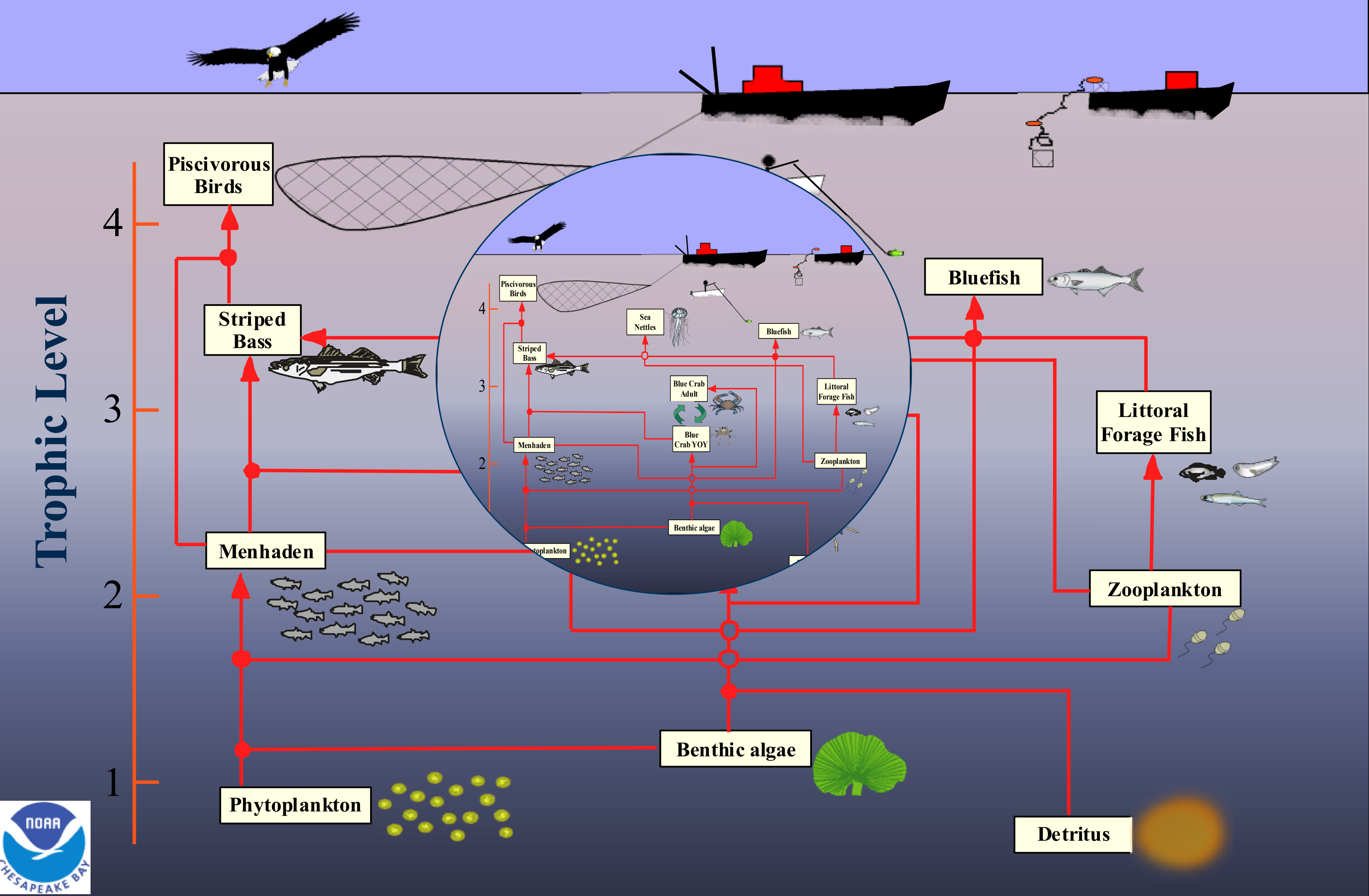
Chesapeake Bay Ecosystem





Sea
Nettles
Menhaden
Littoral
Forage Fish
Zooplankton
algae

Chesapeake Bay Ecosystem



Overview of Chesapeake Bay Fisheries Ecosystem Model

Ecopath module has been completed.

- 45 trophic groups (58 in extended model)
- 218 diet links
- 1950 model gives a snapshot of what the Chesapeake was like 50 yrs ago. Original model simulated to 2002, now extending it to 2009

Ecosim module

- Calibrated using time series data; 100+ data sets and assessments
- 50 yr simulations with a nutrient loading forcing functions, attempts to replicate the current status and dynamics of the Chesapeake
- Simulations can be run to explore policy options (i.e., fisheries management plans) and familiarize people with ecosystem approaches.

Time series data

Drivers

Fishing mortality rates

Fleet effort

Biomass (force)

Time forcing data (e.g., prim. prod., SST)

Validation

Biomass (relative, absolute)

Total mortality rates

Catches

Average weights

Diets

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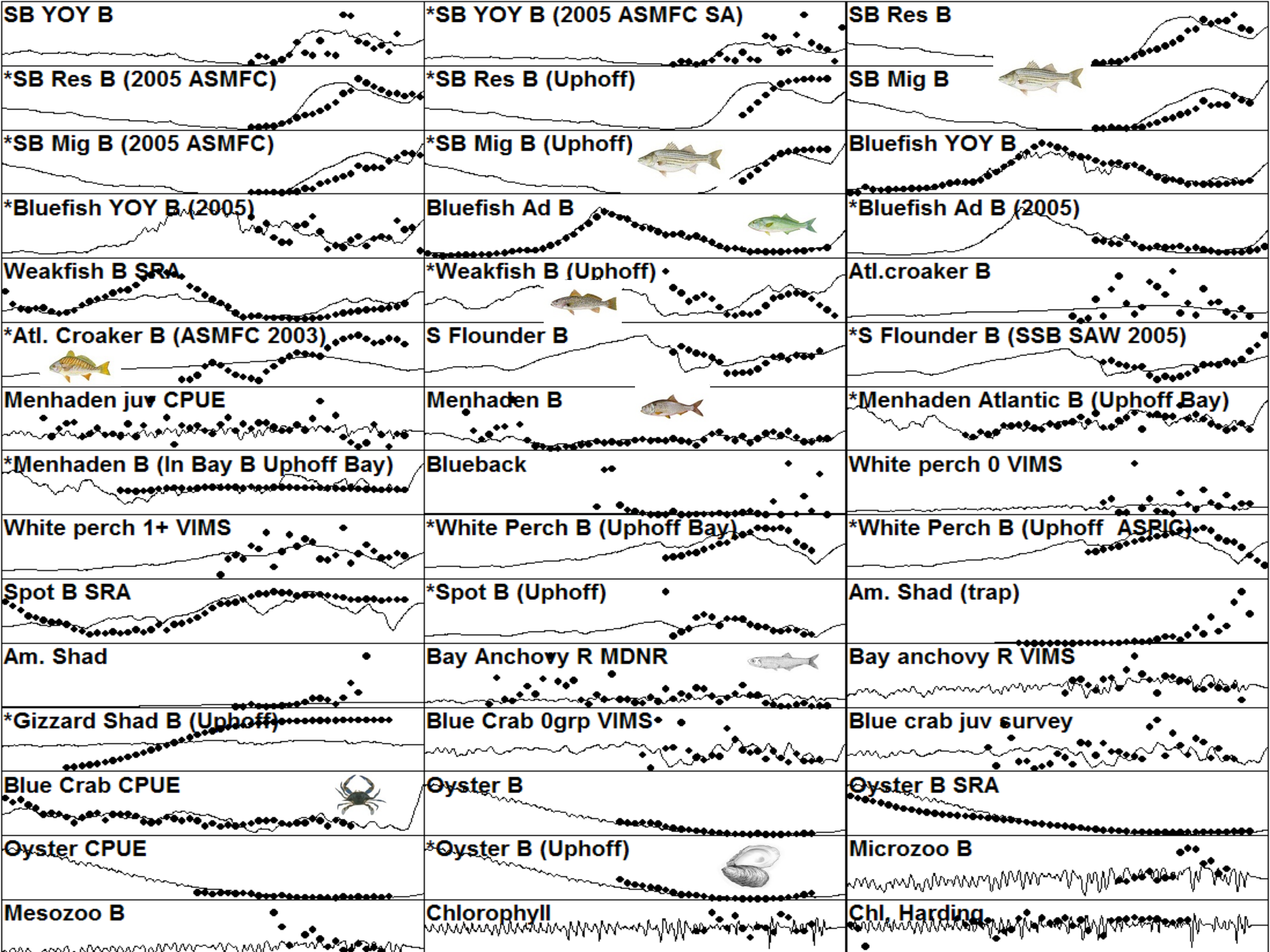
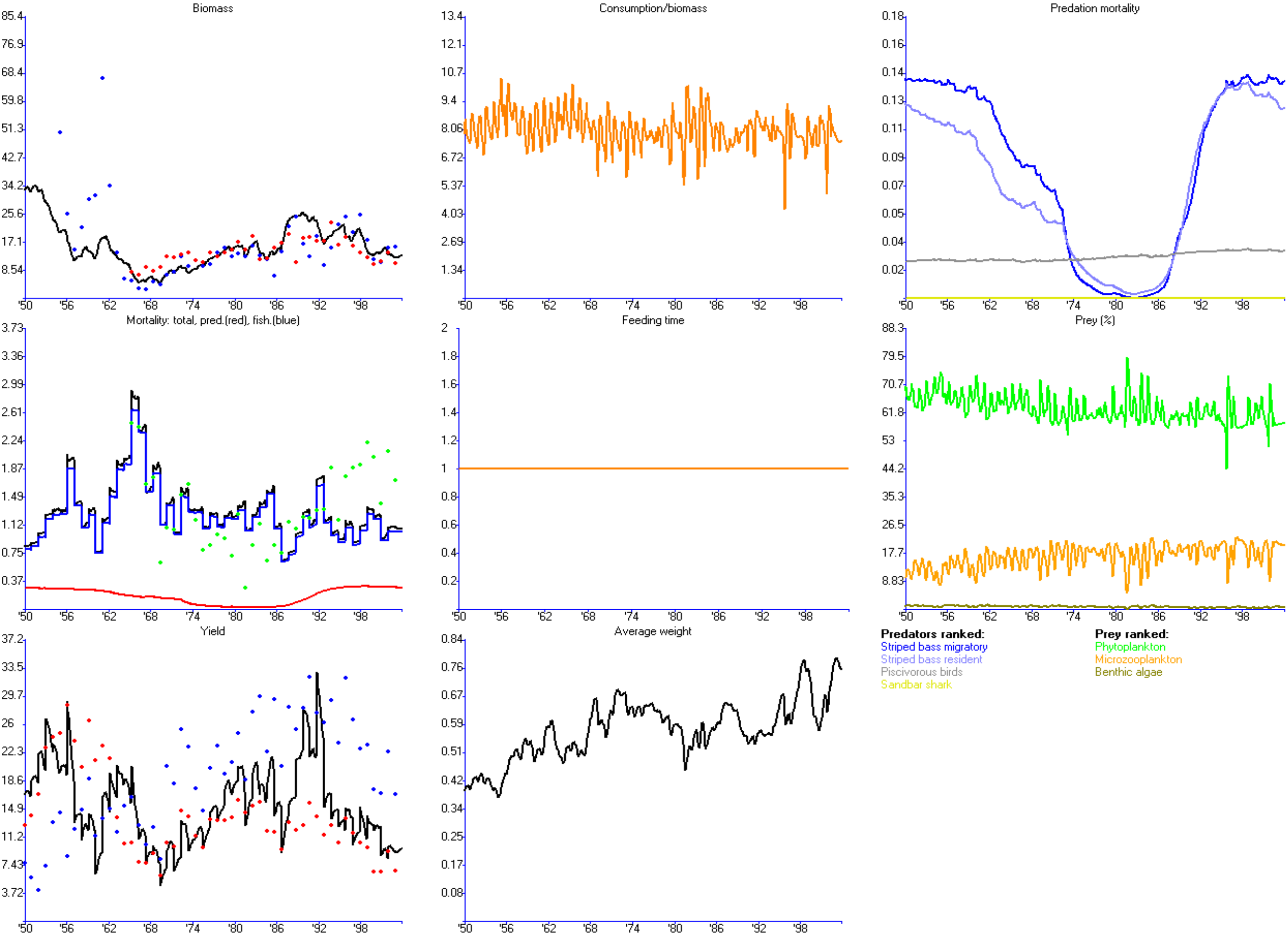
Data Pedigree

Sequenc	groupName	Biomass	ProdBiom	ConsBiom	Diet	Catch
1	Striped bass YOY	0.023	1.8	22.869		0
2	Striped bass resident	2.100	0.6	4.793		0.463
3	Striped bass migratory	1.617	0.35	2.3		0.427
4	Bluefish YOY	0.016	5.65	18.111		0
5	Bluefish adult	0.240	0.589	3.3		0.089
6	Weakfish YOY	0.026	4	13.525		0
7	Weakfish Adult	0.489	0.685	3.1		0.286
8	Atl. croaker	1.670	0.916	5.4		0.542
9	Black drum		0.19	2.1		0.024
10	Summer flounder		0.52	2.9		0.209
11	Menhaden 0-1	16.444	1.5	15.86		0.242
12	Menhaden adult	30.000	0.8	7.8		15.3
13	Alewife and herring		0.75	9.4		1.58
14	American eel		0.25			0.065
15	Catfish		0.28	2.5		0.091
16	White perch YOY	0.003	2	19.921		0
17	White perch adult	0.300	0.5	4.2		0.073
18	Spot		1	5.8		0.456
19	American shad	0.400	0.7	3.5		0.203
20	Bay anchovy	3.400	3	10.9		0
21	Other flatfish		0.46	4.9		0
22	Gizzard shad		0.53	14.5		0
23	Reef assoc. fish		0.51	3.1		0
24	Non reef assoc. fish		1			0
25	Littoral forage fish		0.8			0
26	Sandbar shark	0.024	0.23	1.4		0.001
27	Other elasmobranchs	0.500	0.15			0
28	Piscivorous birds	0.300	0.163	150.6		0
29	Non-piscivorous seabirds	0.121	0.511	365		0
30	Blue crab YOY	1.580	5	12.057		0
31	Blue crab adult	4.000	1	4		3.45
32	Oyster YOY	3.280	6	8.965		0
33	Oyster 1+	20.400	0.15	2		1.266
34	Soft clam		0.45			0.073
35	Hard clam	4.200	1.02			0.071
36	Ctenophores	3.400	8.8			0
37	Sea nettles	0.583	5			0
38	Microzooplankton		140			0
39	Mesozooplankton	10.300	25			0
40	Other suspension feeders	6.000	2			0
41	Other in/epi fauna		1			0
42	Benthic algae		80			0
43	SAV	419.000	5.11			0
44	Phytoplankton	27.000	160			0
45	Detritus	1.000				0


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

Menhaden adult



Multi-species management

- What-if scenarios with striped bass moratorium
- Menhaden management and impacts on predators

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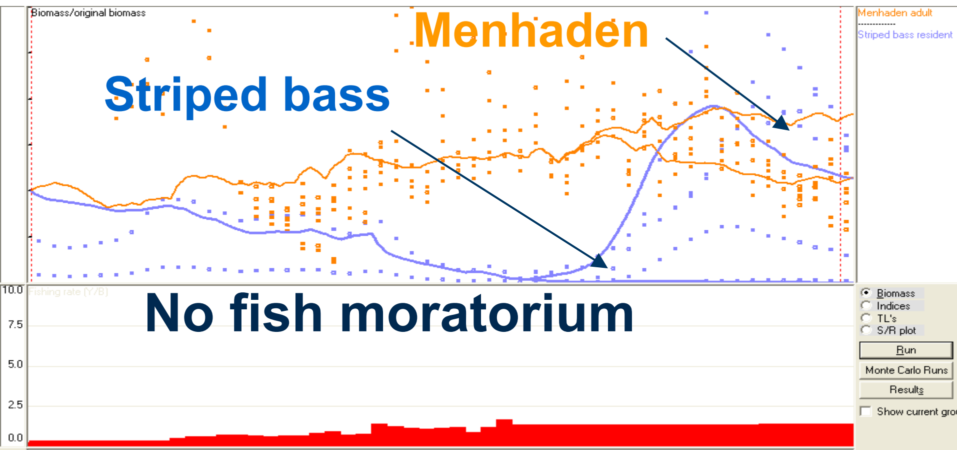
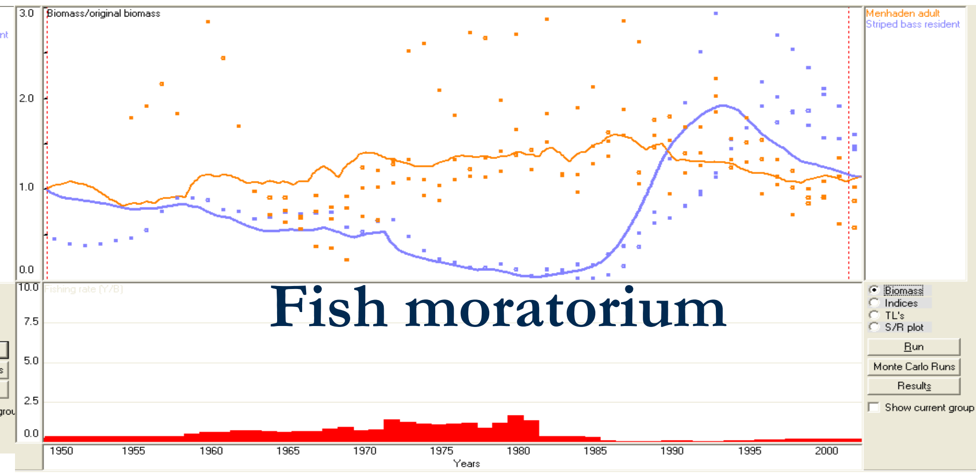
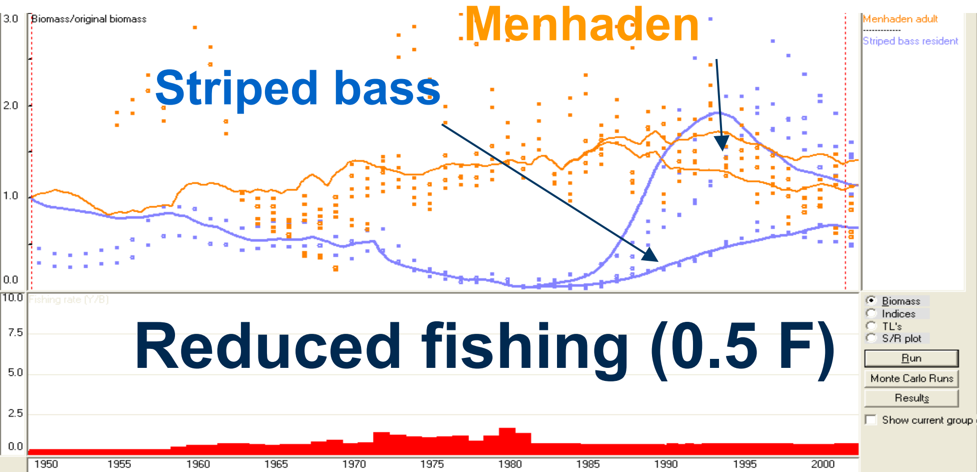
Multi-Species: Different Fishing Mortality for Striped Bass







With increased F, striped ↓ and menhaden ↑ (top-down effect)

Projections for Menhaden and Predators

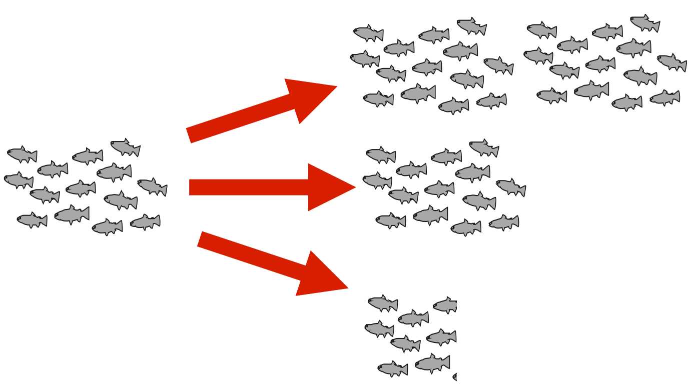
Use simulations to project long-term consequences (25 years) of current management strategies and potential strategies

Run Simulation Scenarios

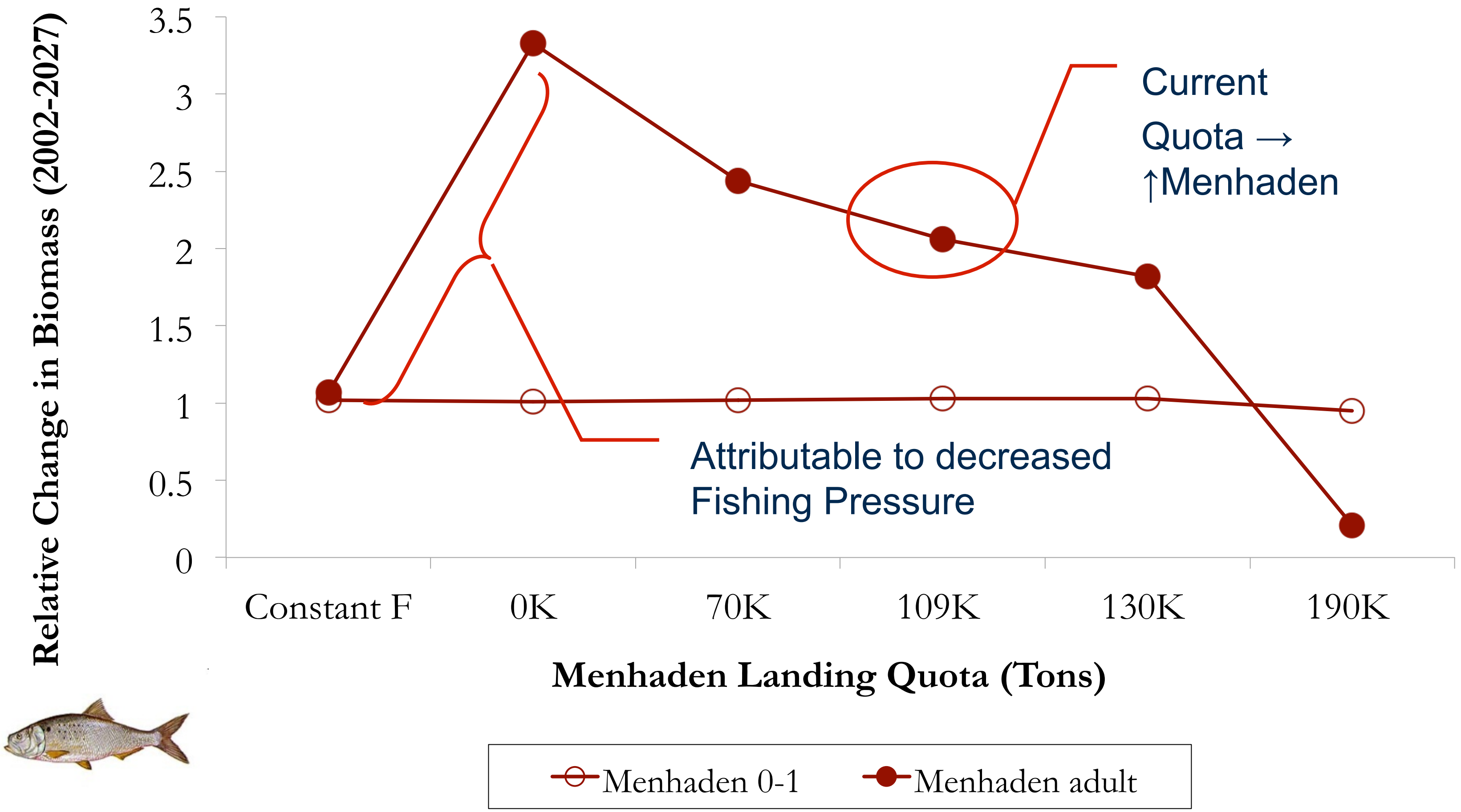
- Run 5 Menhaden strategies
  - Quota → 0K MT, 70K MT, 109K MT, 130K MT, 190K MT

Output to measure: Relative change in Biomass for Menhaden and its predators

- Relative Change = $B_{Future}/B_{Current}$



Menhaden Management Effects on Menhaden



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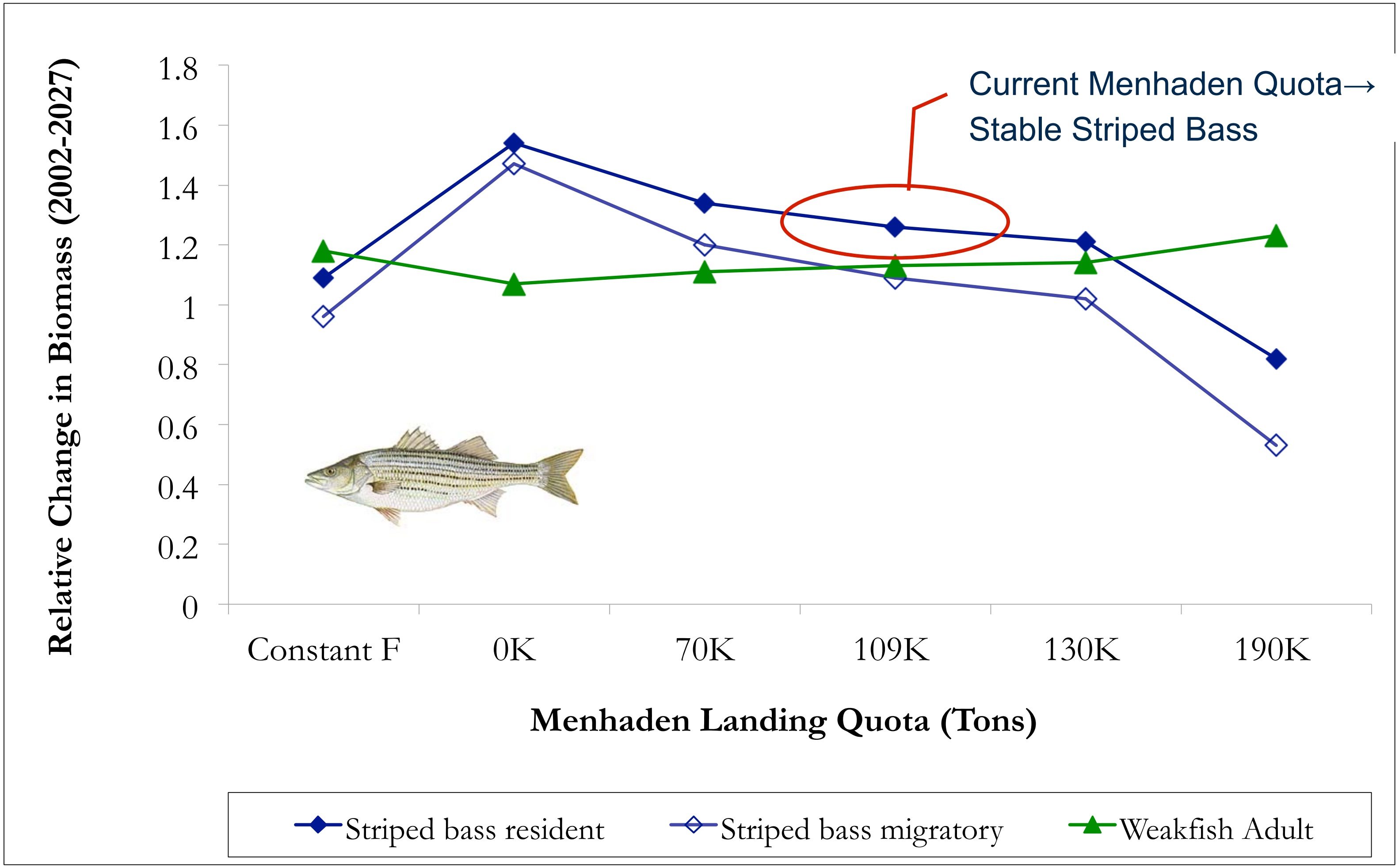
Menhaden Management Effects on Predators



Water Quality and Habitat

- Decreases in nutrient loading: effects on fish
- Decrease in nutrient loading: effects on habitat → fish
- Using fish to influence water quality

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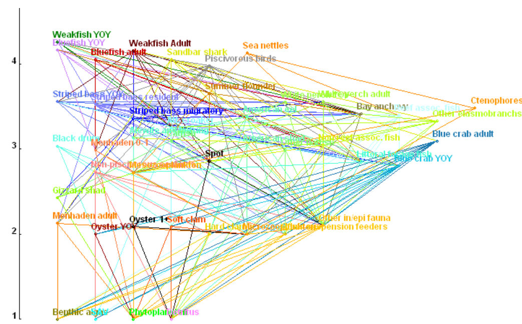
Methods - Inputs and Links to EwE

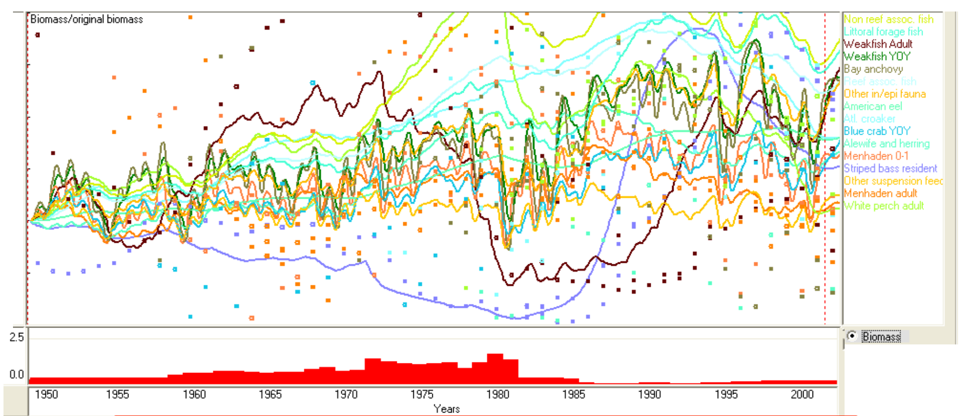


Monitoring (B)

Stock assessment (F, C)

Literature (DC)

Input



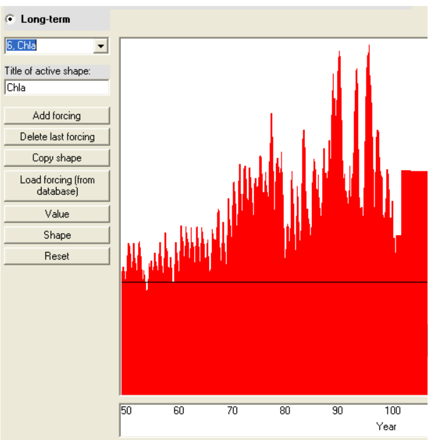
Mediation

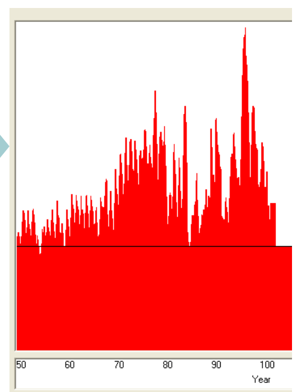
Forcing

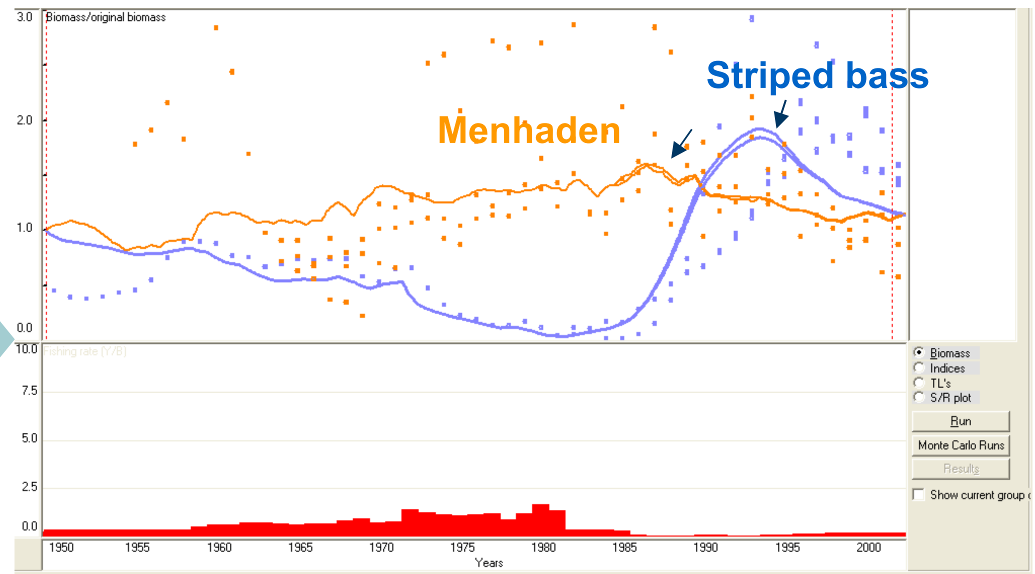
Habitat and water quality (e.g., SAV, DO)

Management scenarios

Results – Nutrient Reduction







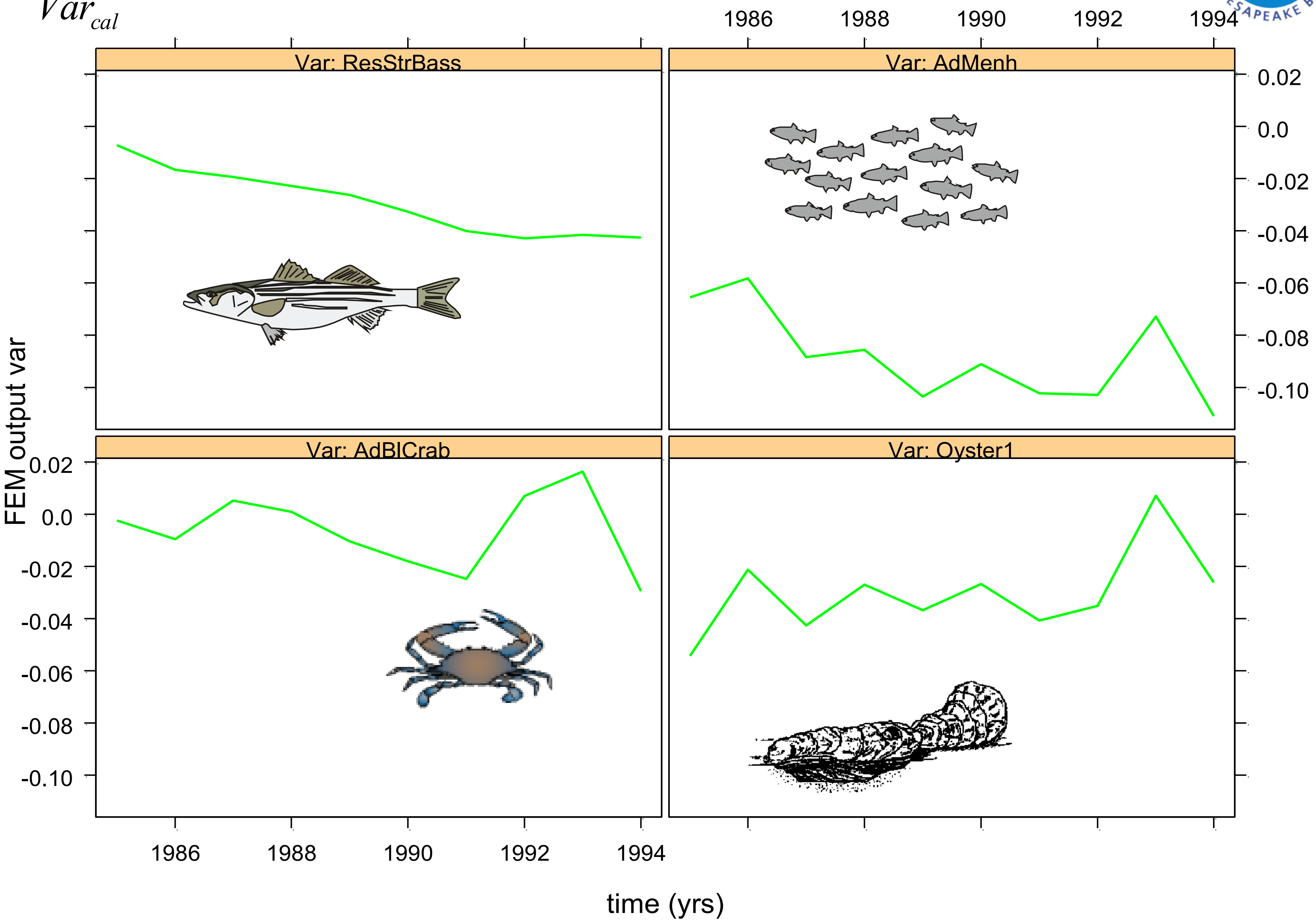
Forcing function for primary production (1985-1994) was adjusted according to WQM output under CTS

Nutrient☒ → phytoplankton↓ → Menhaden↓ → SB☒

(bottom-up effect)

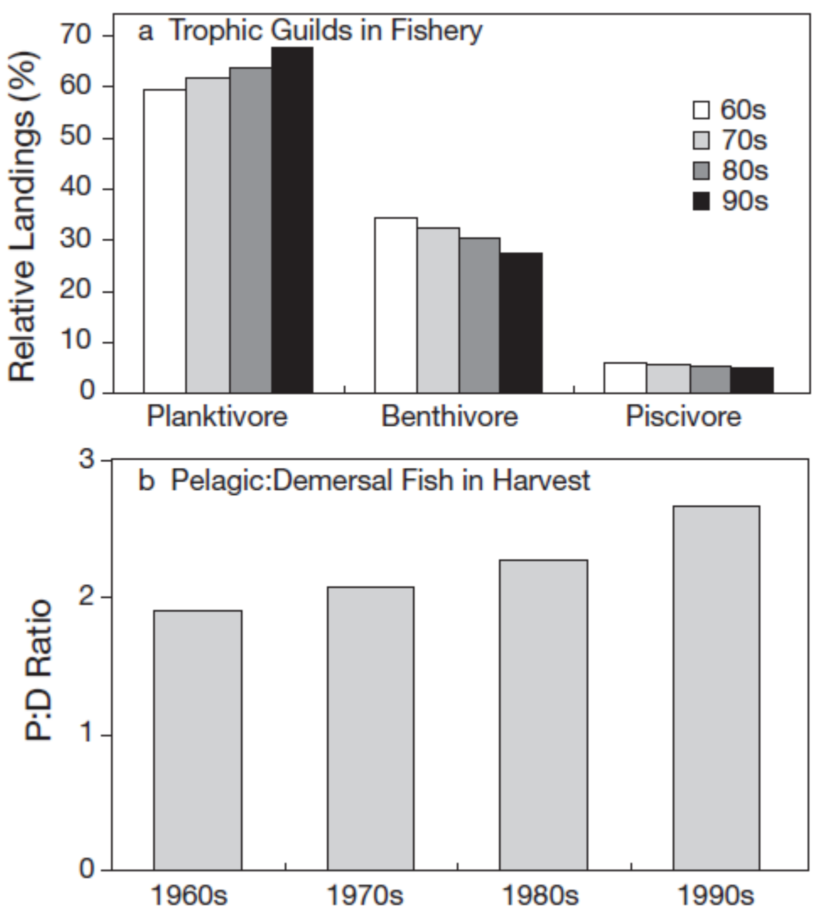
$$\frac{Var_{trib} - Var_{cal}}{Var_{cal}}$$

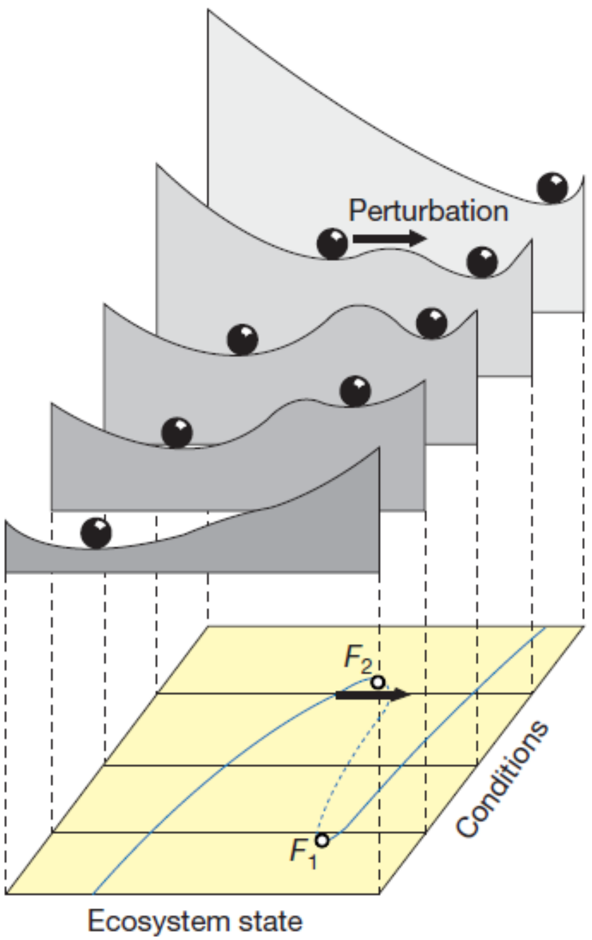
Annual relative difference in FEM state variables



Trophic Structure Issues

Kempr et al 2005

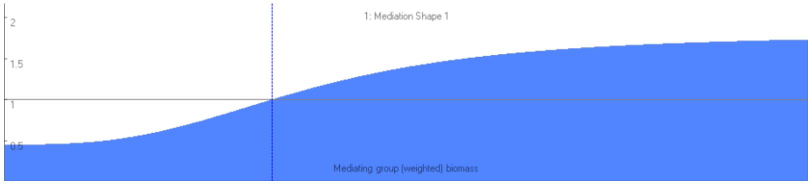




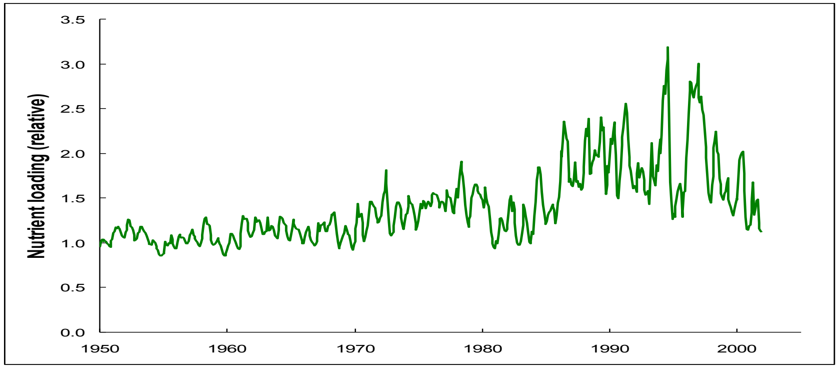
Scheffer et al 2001

Habitat: Mediation and forcing function in EwE

Mediation Function



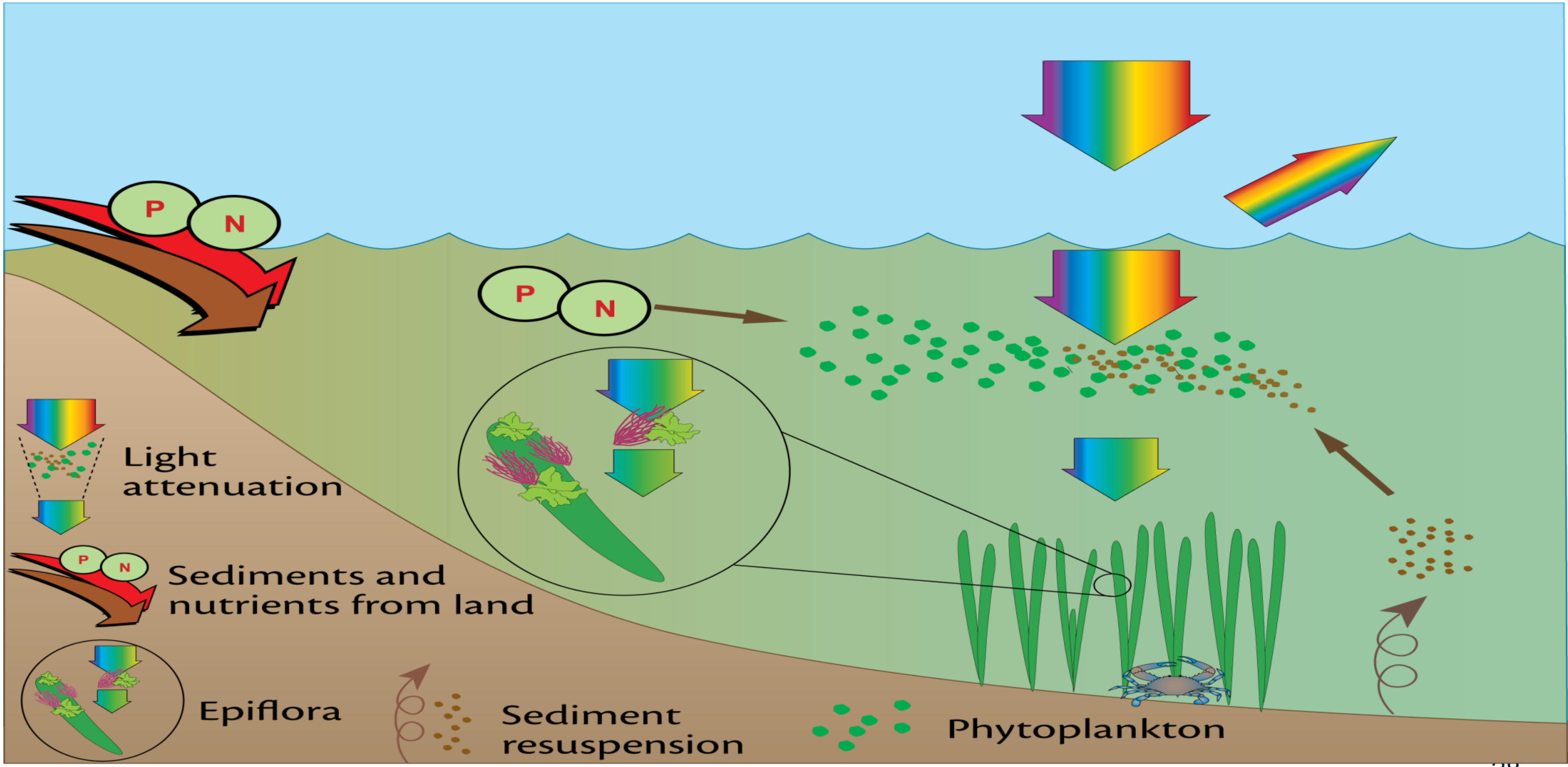
$$Q_{ij} = \frac{a_{ij} v_{ij} B_i B_j T_i T_j S_{ij} \dfrac{M_{ij}}{D_j}}{v_{ij} + v_{ij} T_i M_{ij} + a_{ij} M_{ij} B_j S_{ij} \dfrac{T_j}{D_j}}$$



Forcing Function

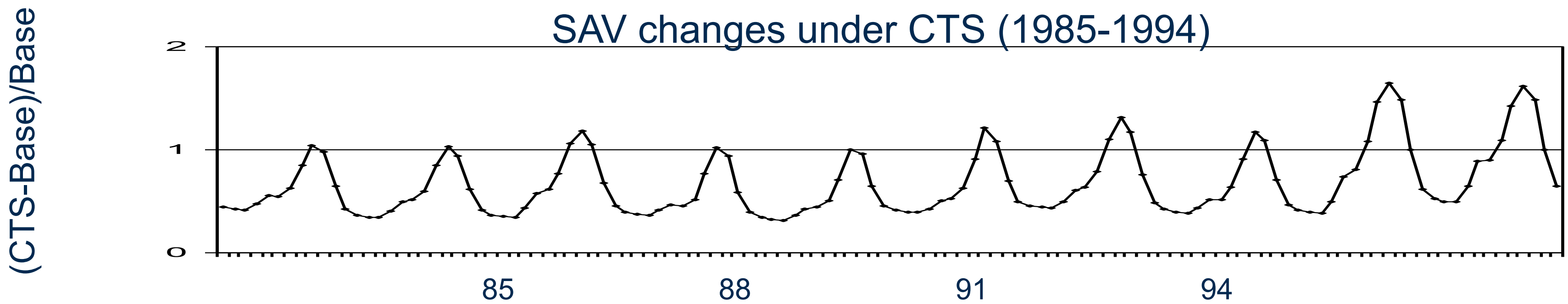
— Forced variability in production to fit with physico-chemical or climate based trends

Incorporating Habitat



Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Center for Environmental Science.

SAV Enhancement due to Nutrient Management



$$C_{ij} = \frac{a_{ij} v_{ij} B_i B_j}{2v_{ij} + a_{ij} B_j}$$

a_{ij}: effective search rate

v_{ij}: Vulnerability

Bi: Prey biomass

Bj: Predator biomass

$S_{ij} = f\ (SAV_t / SAV_{1950})$

Forcing function

$M_{ij} = f\ (SAV_t / SAV_{1950})$

Mediation function

$$C_{ij} = \frac{a_{ij} S_{ij} v_{ij} B_i B_j}{2v_{ij} + a_{ij} S_{ij} B_j}$$

$$C_{ij} = \frac{a_{ij} v_{ij} M_{ij} B_i B_j}{v_{ij} + v_{ij} M_{ij} + a_{ij} B_j}$$

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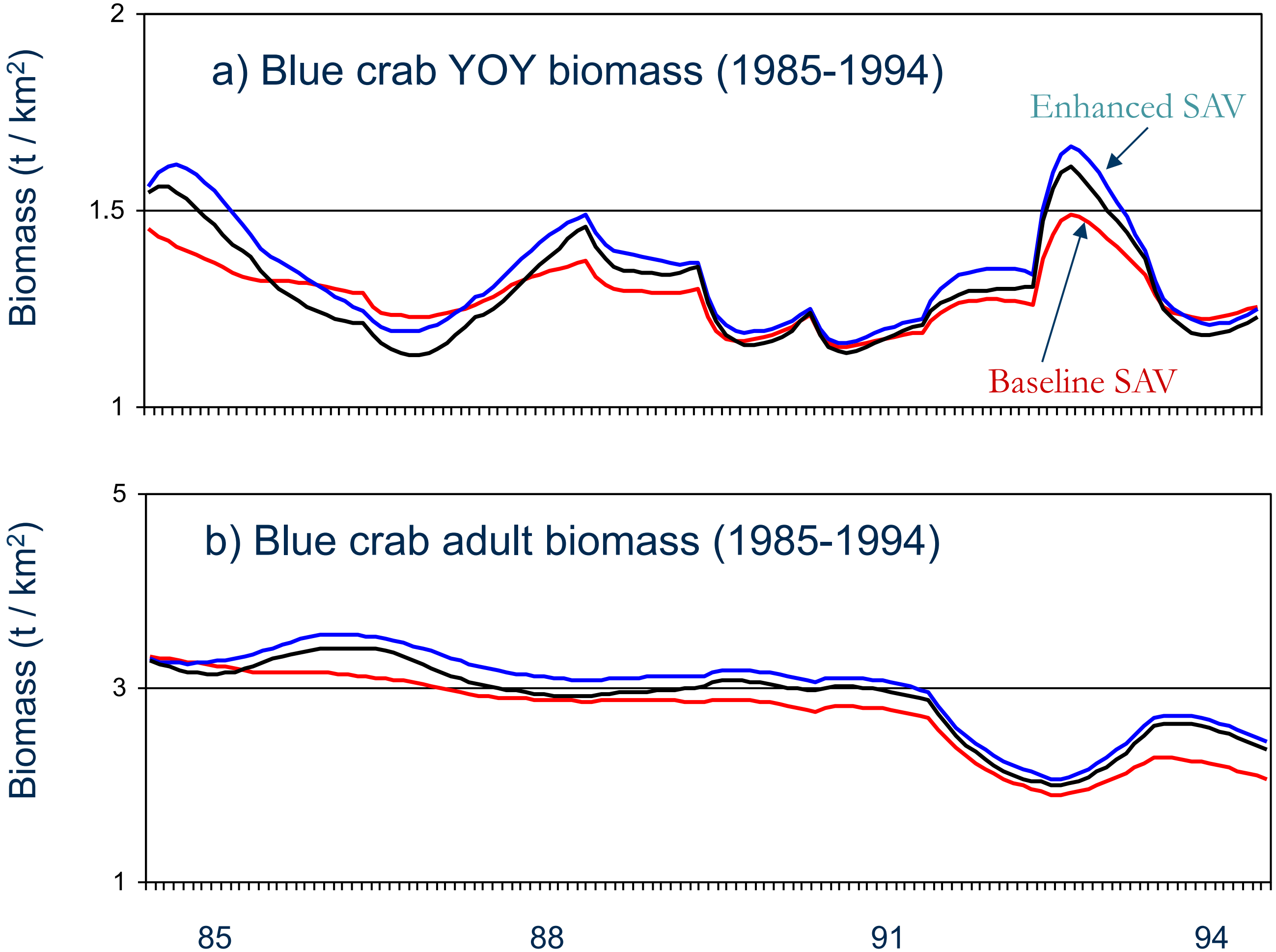
Effect of SAV enhancement



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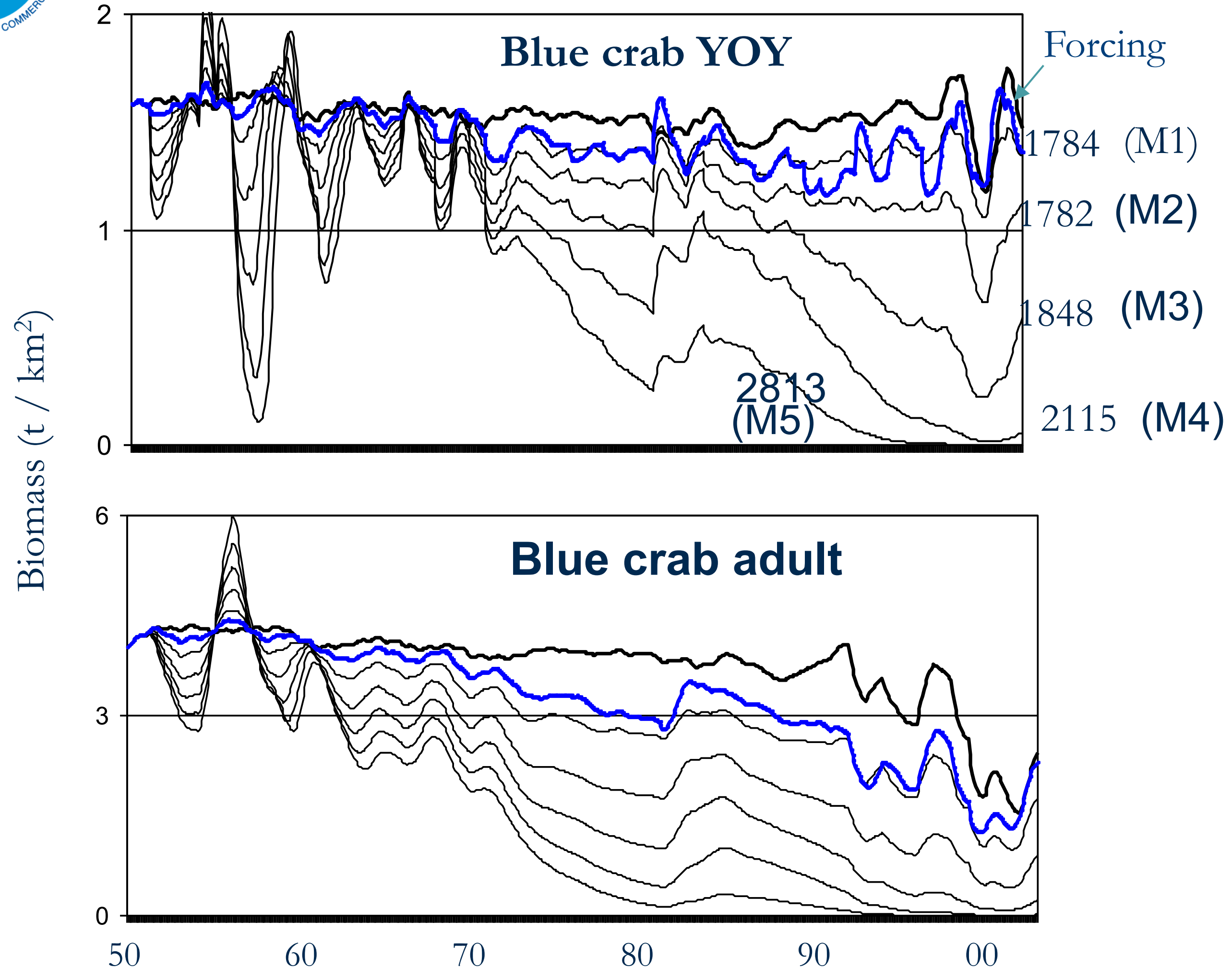
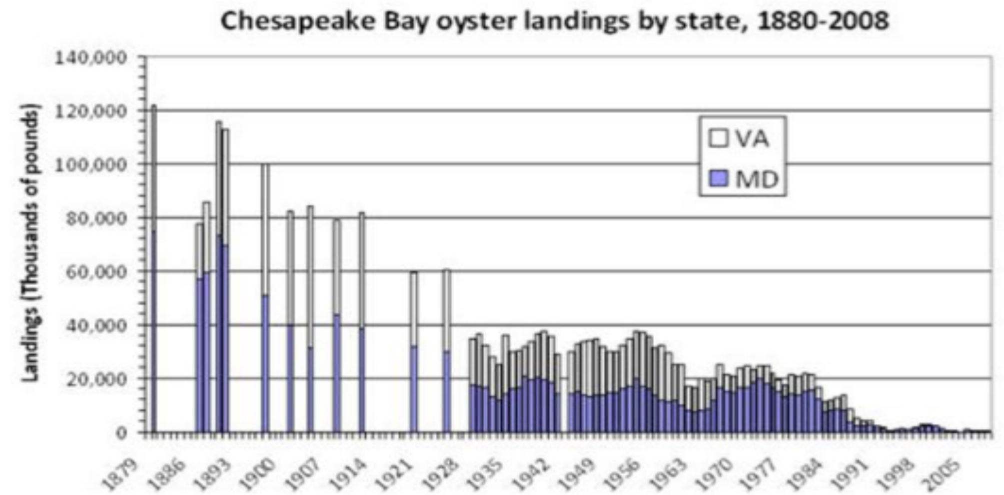
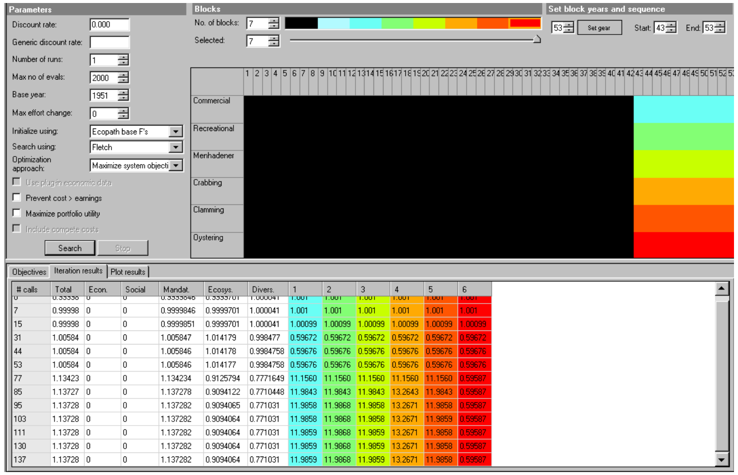
Comparison of Forcing and Mediation Functions



Effects of Oysters on WQ: Policy Optimization





Notion: Oysters improve water quality. However oyster stocks are drastically reduced.

To maximize oyster stocks what changes in fishing policy would have had to have been made from 1992-2002.

Used EwE policy optimization search

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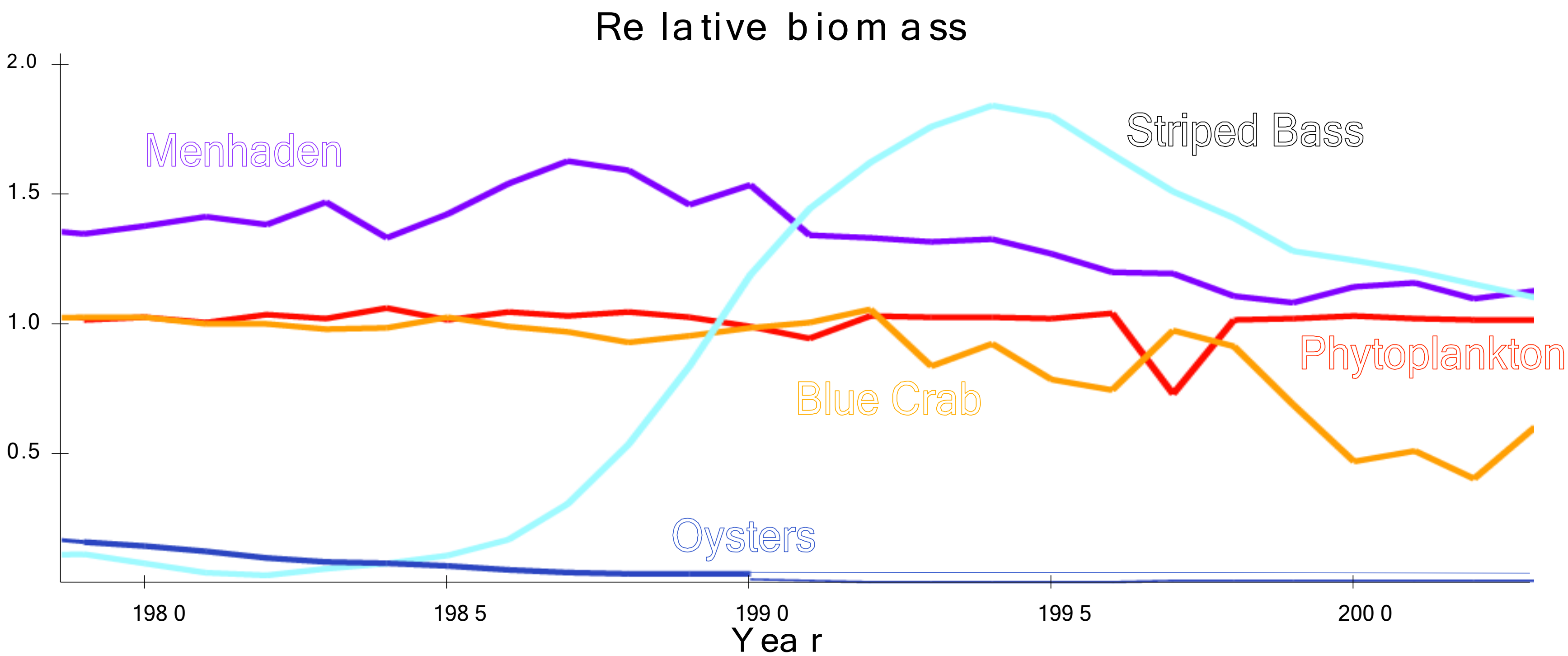
Policy Optimization - Baseline



The baseline run was done in which the historical fishing policy was kept constant. Policy Optimization runs were standardized to the baseline.

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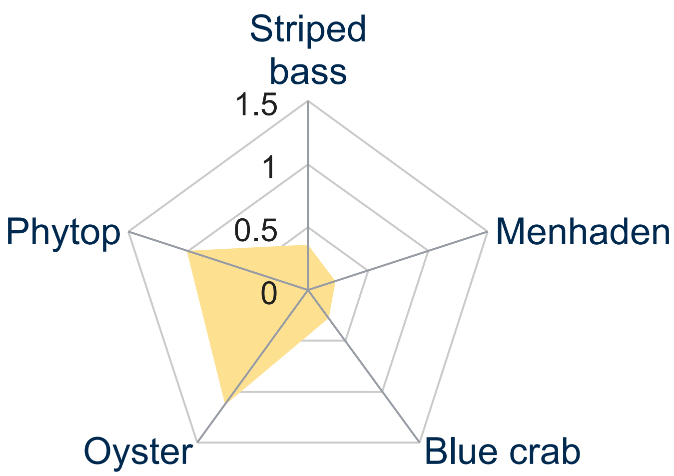
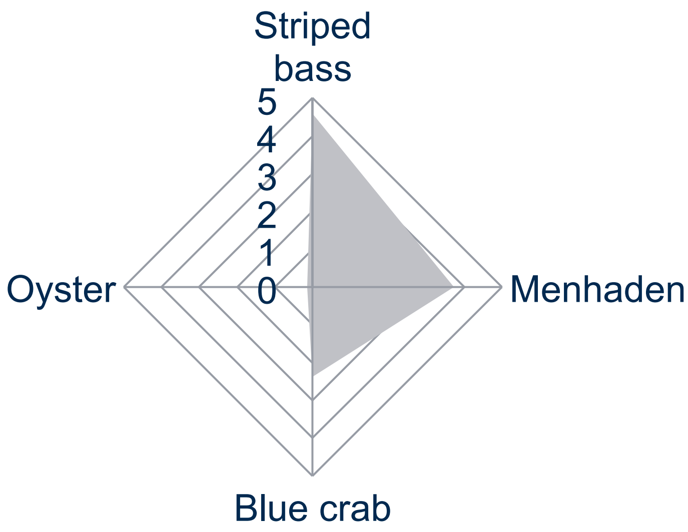
Policy Optimization – Maximize Oyster

Biomass



Catch



Very extreme changes in policy (i.e., catch) result in only moderate changes in Oyster biomass.

Chesapeake Bay – Blue Catfish

- Applied fisheries ecosystem models (using EwE) to generate quantitative estimates of the impacts of BCF on other species.
- Ran management scenarios to understand how fisheries and water quality management can be used to regulate BCF
- Used ecosystem model to guide research and monitoring directions

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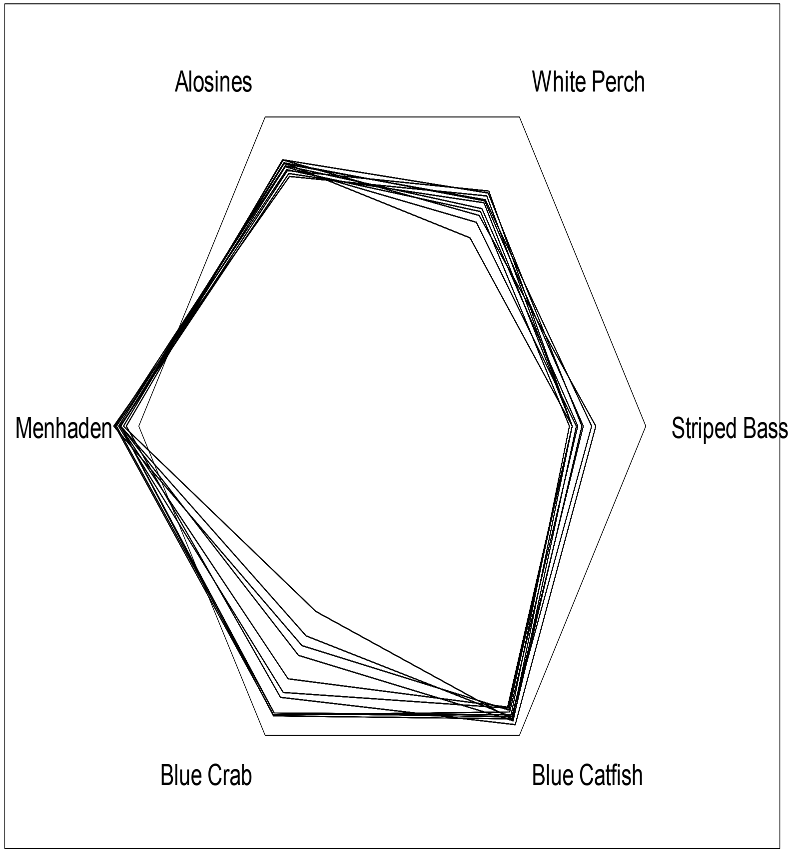
Impact of Invasives

% Biomass Change, SQ: Status Quo



Baseline Scenario

- Hypothetically maintain status quo in current fishing regulations and effort
- 20-yr projection of changes in Biomass of key species

Baseline Major Impacts

- White Perch
- Alosines
- Blue Crabs
- Striped Bass
- Croaker

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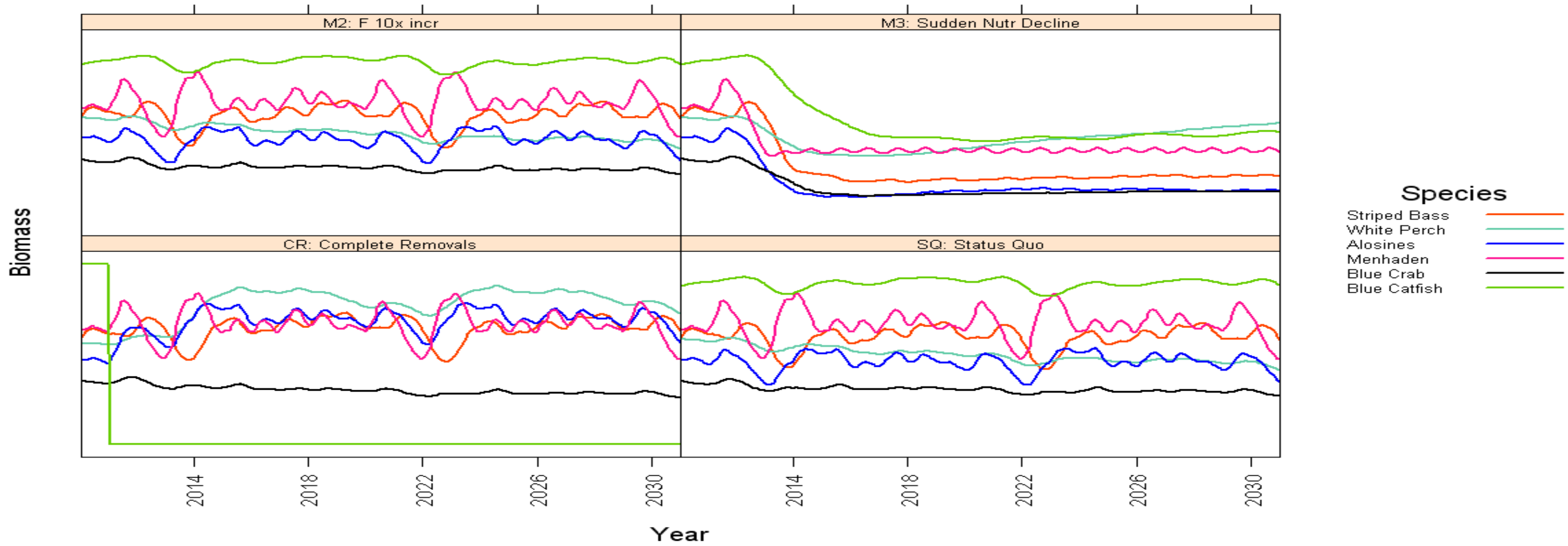
Apply Model and Assess Utility



Increasing exploitation rates had little affect on blue catfish populations.

An overwhelming control of the system through different levels of nutrient inputs.

Perhaps habitat has more of an influence than fishing?

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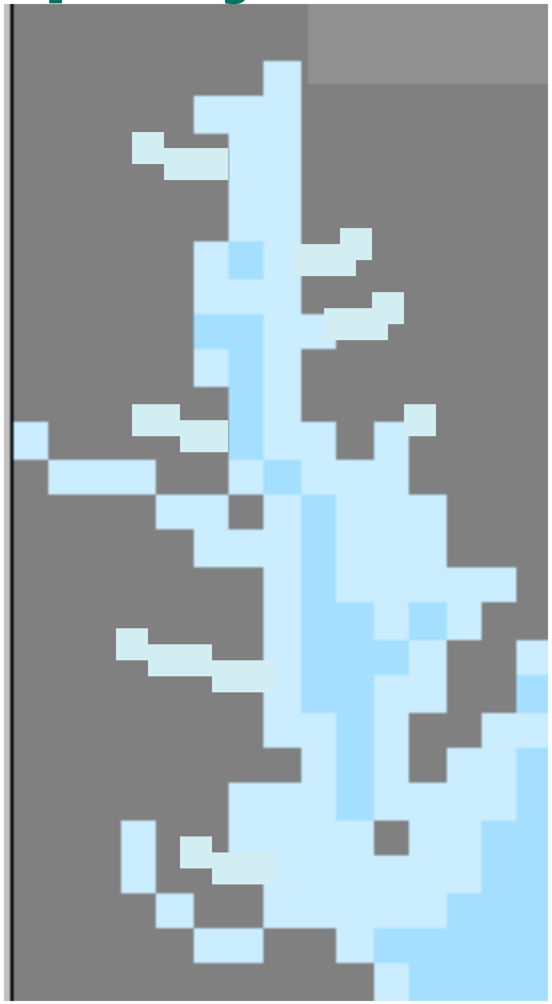
Refine Model – Include habitat and seascape/water quality



Longer Term…

Finer spatial scale evaluation of BCF in the Chesapeake Bay system. Model would be completed using the Ecospace option within EwE.

Ecospace model could provide…

-Spatially specific predator and prey interactions.

-Better understanding impacts of BCF impacts on anadromous species.

-Recommendations on where tributary specific removal campaigns may be effectively applied.

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Oyster Reef Ecosystem Model

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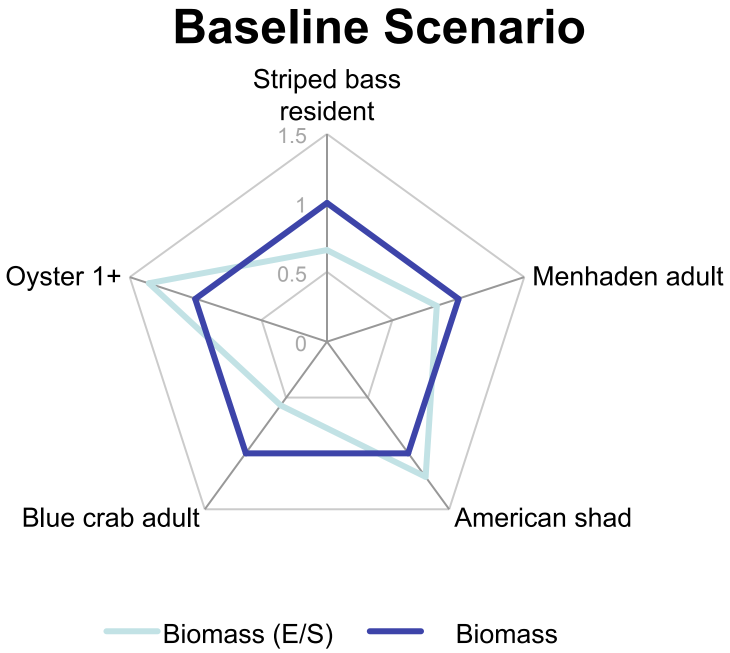
CONCLUDING THOUGHTS

Turn complex model output into meaningful information for resource management



Overall take-home points

— CBFEM is being used for exploring policy options in ecosystem-based fisheries management plans

— The development of this tool and other approaches will (I hope) help to get a grip on this “Ecosystem Jell-O”. EwE’s quick run-time allows for rapid exploration policy implications and environmental effects.

— The process of developing this model and exploratory analysis has helped to organize and synthesize data (from disparate sources) on trophic interactions and population trends. This effort helps identify gaps and needs for future research and monitoring.

— In the not-too-distant future, we will use multiple models to aid with the understanding “Ecosystem Jell-O”, continue towards EAM, and understanding how human society’s behavior influences the sustainability of natural resources.

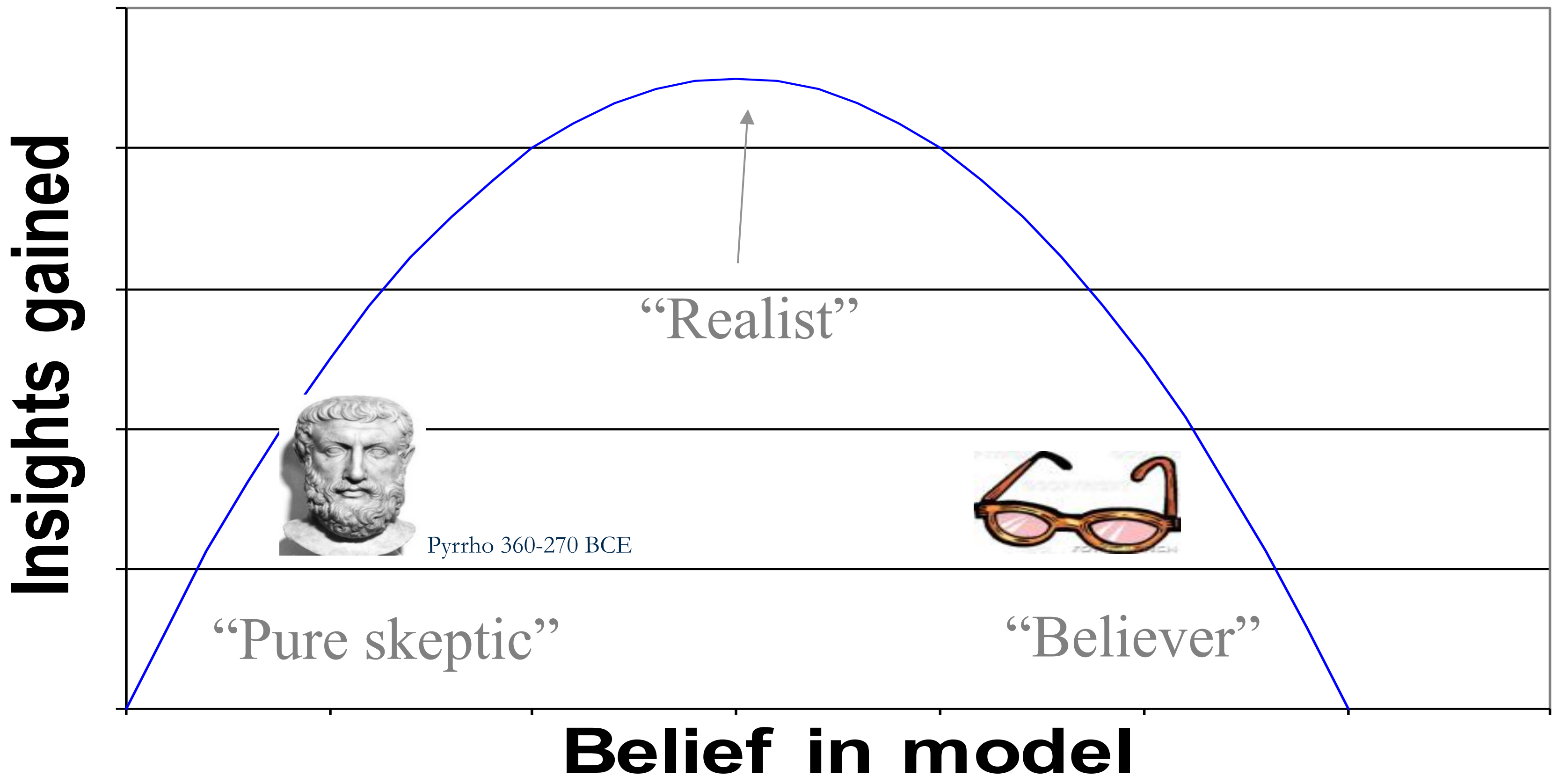
Conclusions – What we have for moving forward

1) Adequate fisheries dependent and independent monitoring programs?
   - For some species and in some areas
   - Improved integration necessary
2) Regular analysis of trophic interactions,
   - Chesapeake Bay Trophic Interactions Laboratory Services
3) An ecosystem/food-web modeling and analysis program
   - NCBO Food Web/Ecosystem Modeling Program

Conclusions – What we need for moving forward

1. Zooplankton/phytoplankton monitoring, and remotely sensed chl-a data.
2. Monitoring and research of non-target species that potentially have a large impact on trophic structure (e.g., jellyfish, cownose rays, piscivorous birds).
3. Detection systems for invasive species and research on the impact of invasives (e.g., blue catfish).
4. Research on methods to augment or improve stomach content analysis (e.g., fatty acid signatures, stable isotopes).

Conclusions



Extra slides

Conclusions

Historic perspective analyses

With increased Striped Bass F, Striped Bass biomass decreased and Menhaden biomass increased (top-down). With decreased nutrient loading, both Menhaden and Striped Bass biomass decreased (bottom-up).

The blue crab biomass could be enhanced under CTS when the effective search rate of BC YOY's predators or the vulnerability of BC YOY to its predators was mediated by SAV

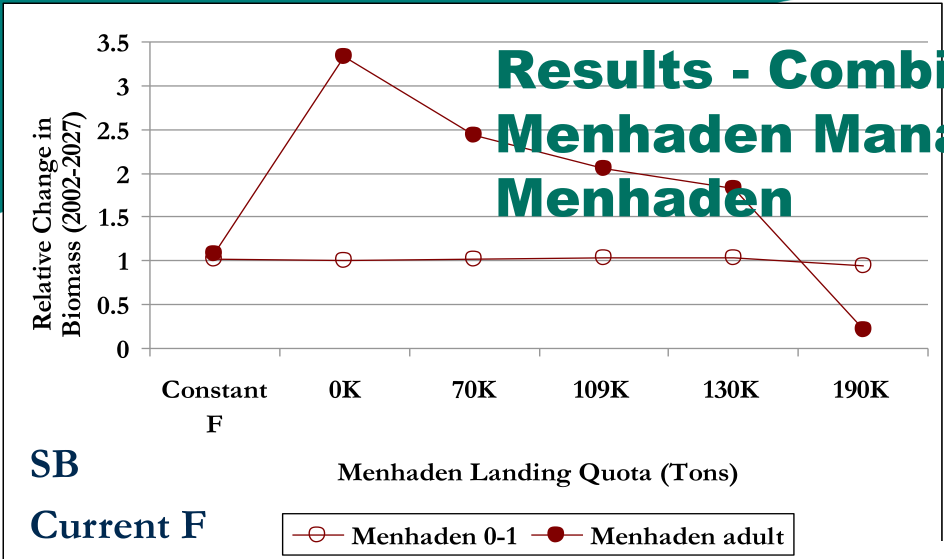
Future projections

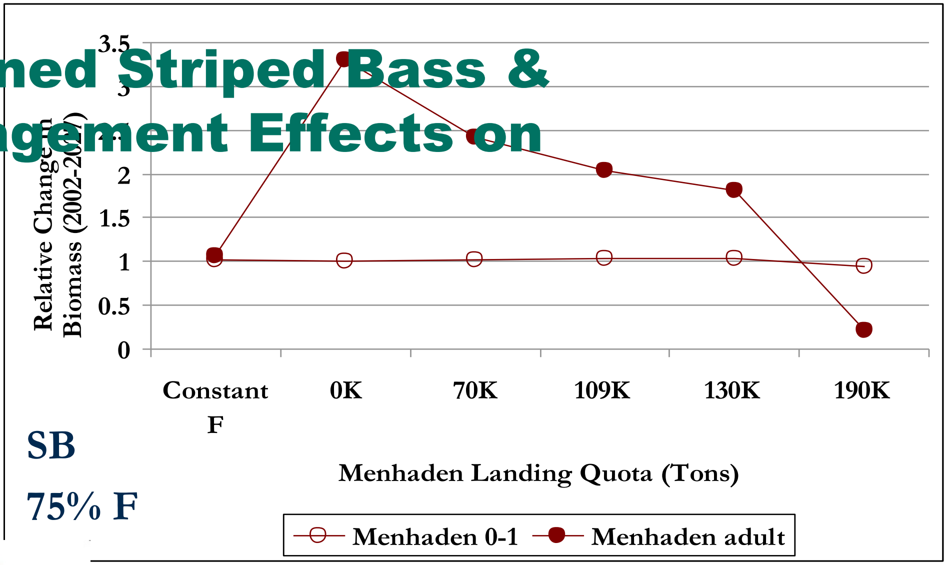
If modeled Striped Bass F accurately reflects reality, then

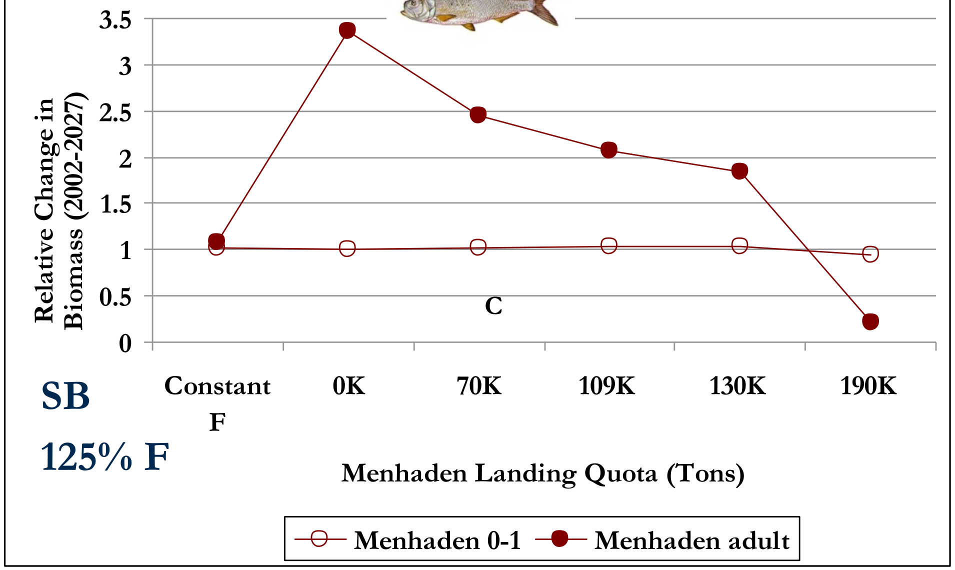
- Current Quota → ↑Menhaden, & ↓Striped Bass F has negligible effect on Menhaden, relative to increases in quota
- ↑Quota → ↓Striped Bass
- & ↑Menhaden quota has similar effect on striped bass as ↓Striped Bass F

Science, Service, Stewardship

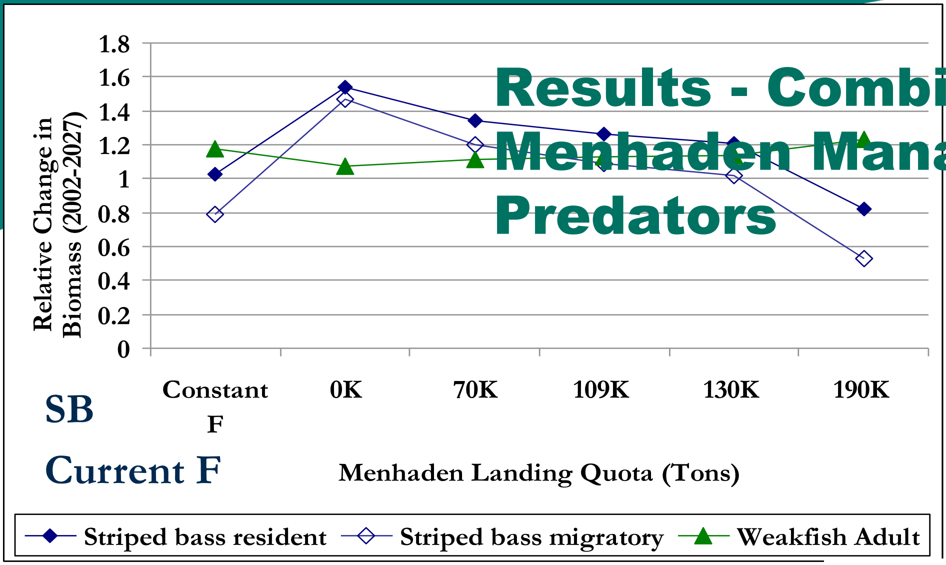
Results - Combined Striped Bass & Menhaden Management Effects on Menhaden

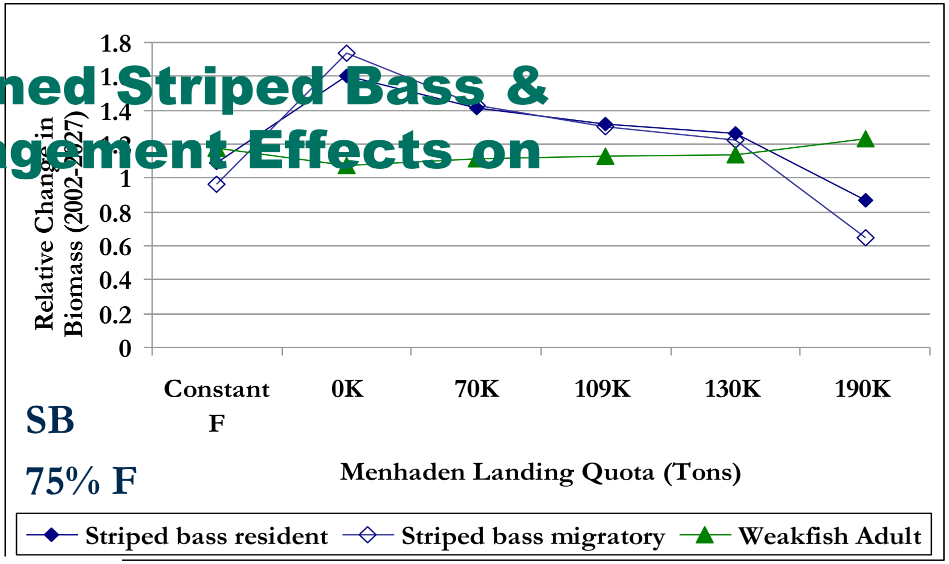


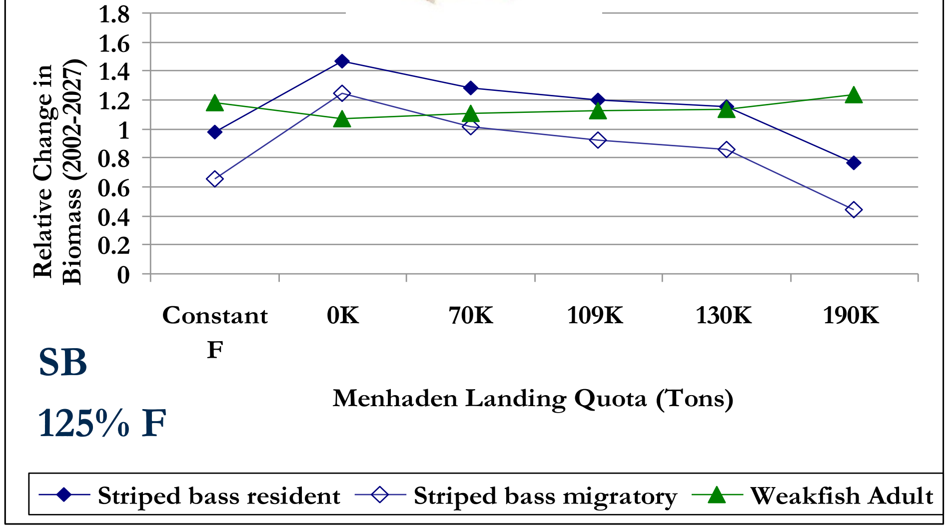




Results - Combined Striped Bass & Menhaden Management Effects on Predators







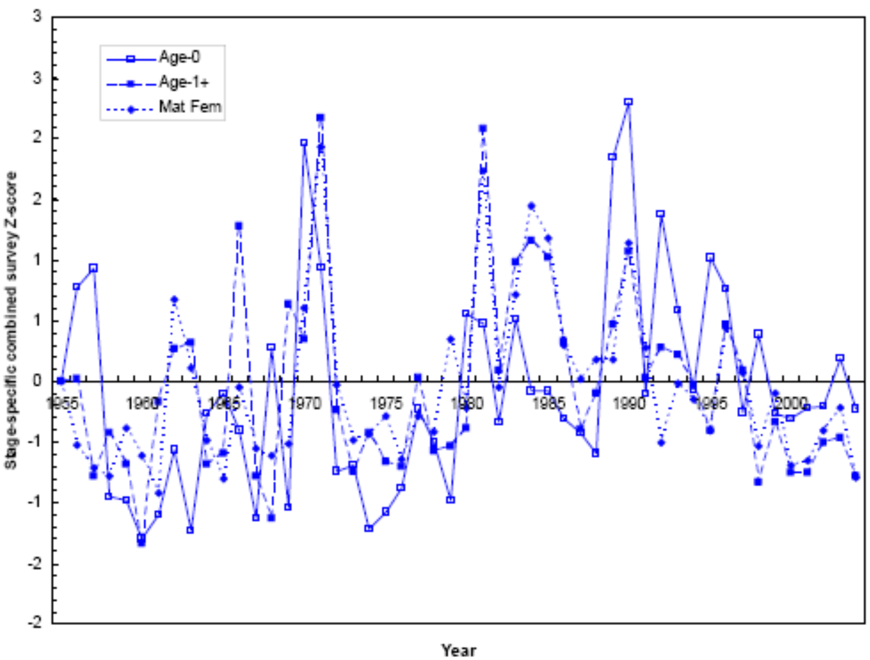
Parting Shot

"The considerable uncertainties in the predictions provided by ecosystem/multispecies models notwithstanding, decisions have to be made and actions implemented to ensure sustainable and optimal utilization of marine living resources. These decisions must be informed by the best available scientific advice and, in the context of EAF, this scientific advice must include ecosystem considerations. Ecosystem models, adhering as far as possible to the best practices described here, will frequently be the best sources of such information and can lead to advice that rests on explicit and principled arguments. **In their absence, managers and decision-makers will have no choice but to fall back on their own mental models which may frequently be subjective, untested and incomplete, a situation which clearly needs to be avoided.**"

Importance of Blue Crab

Important component of the estuarine ecosystem

— Seagrass beds are important nursery areas for juveniles



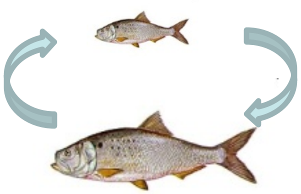
Combined survey Z-scores from 4 fisheries-independent surveys

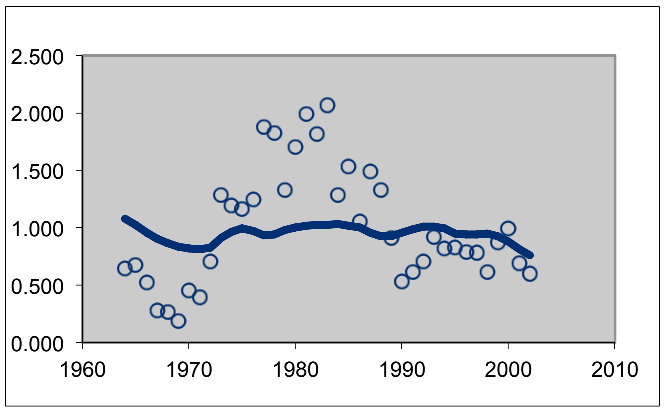
(Miller et al., 2005)

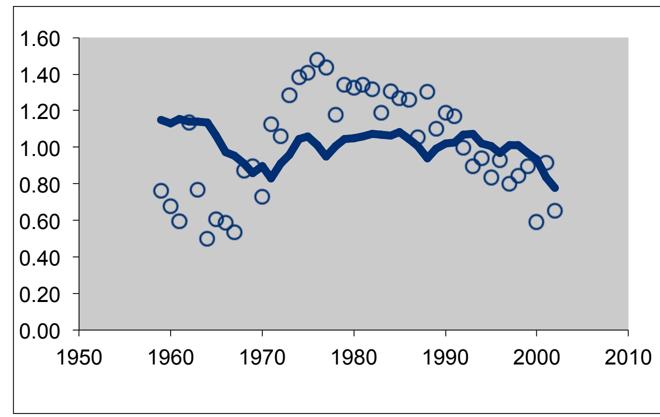
Ecosystem Models to Estimate Food-Web and Habitat Effects on Natural Mortality

	Adult Menhaden	Juvenile Menhaden
		

Simple Stock Assessment







Simple Model with Predation and Habitat Effects