Framework for a Coupled Ecological-Economic Model of the Chesapeake Bay Watershed

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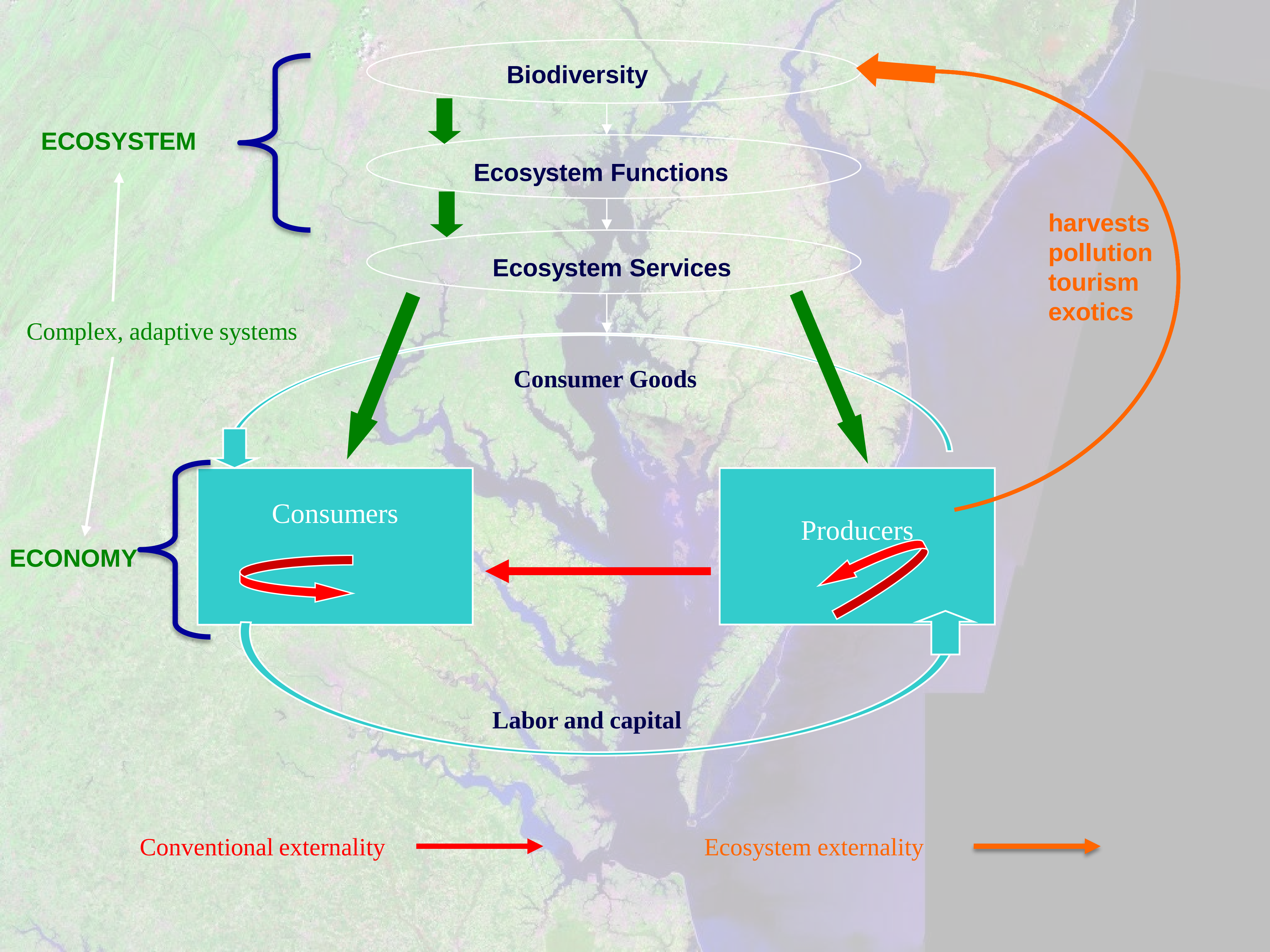
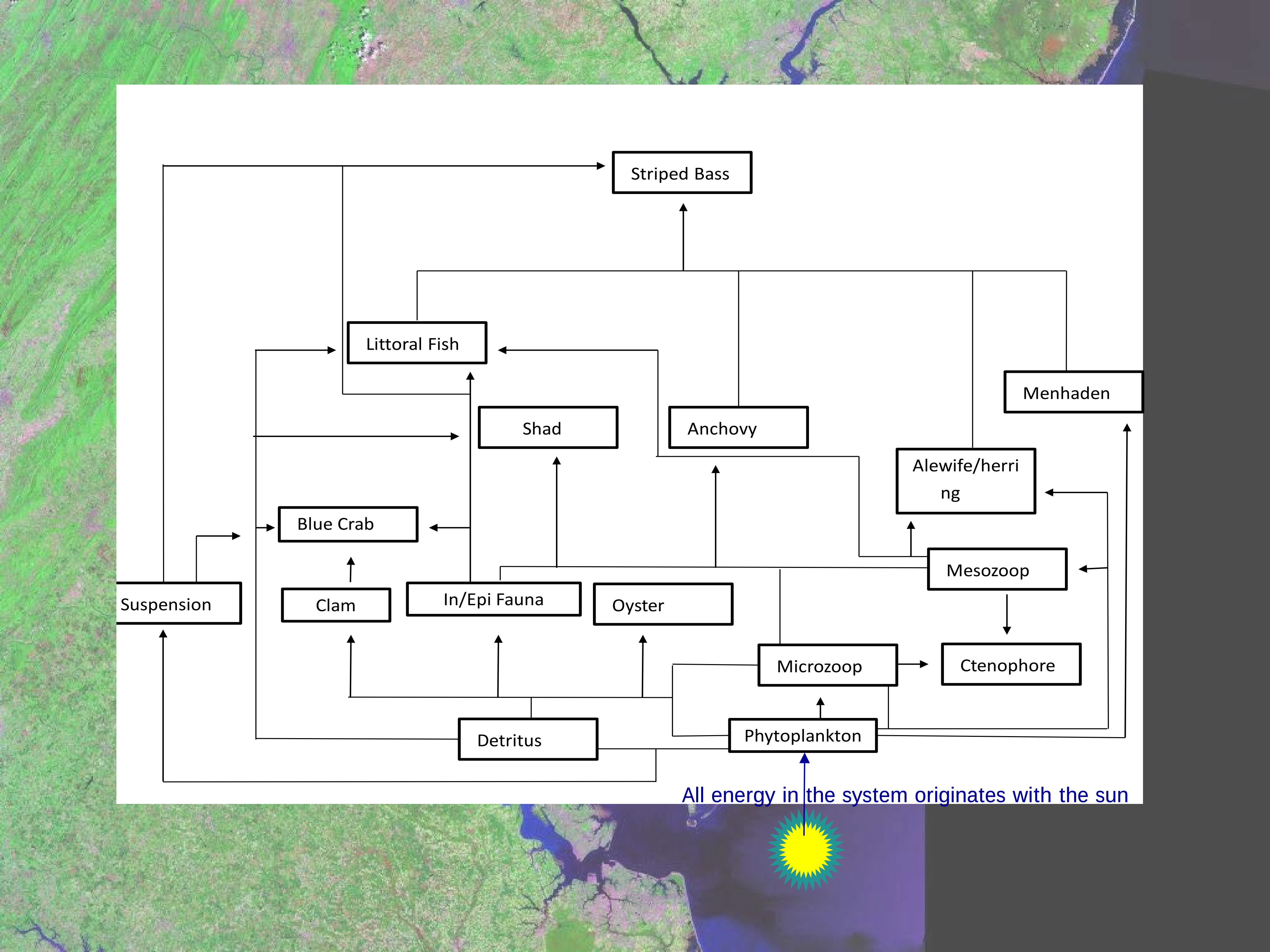
Chesapeake Bay Program
A Watershed Partnership


Biodiversity
Ecosystem Functions
Ecosystem Services
ECOSYSTEM
Complex, adaptive systems
Consumer Goods
harvests
pollution
tourism
exotics
ECONOMY
Consumers
Producers
Labor and capital
Conventional externality
Ecosystem externality

Economy and Ecosystem Analogies

Economy	Ecosystem
industries	species
firms	individual plants and animals
maximize profits	maximize net energies
quantities	biomasses
dollar prices	energy prices
firms demand inputs	predators demand biomass
firms supply outputs	prey supplies biomass
market exchange	biomass transfers
macro outcomes	population densities


Striped Bass
Littoral Fish
Menhaden
Shad
Anchovy
Alewife/herri
ng
Blue Crab
Mesozoop
Suspension
Clam
In/Epi Fauna
Oyster
Microzoop
Ctenophore
Detritus
Phytoplankton
All energy in the system originates with the sun

Objective function and conditions for optimality in the adaptive general equilibrium calculations:

1) net energy for an individual flatfish

$$R_{18} = (e_{02} - e_{1802})x_{1802} + (e_{16} - e_{1816})x_{1816} - r_{18}(x_{1802} + x_{1816})$$
$$-.5r_{18}(x_{1802}{}^{2} + x_{1816}{}^{2} + x_{1802}x_{1816}) - b_{18} - d_{1813}e_{18}(1 + t_{18}e_{1318})(x_{1802} + x_{1816})^{.5}$$

2) four optimality conditions for flatfish

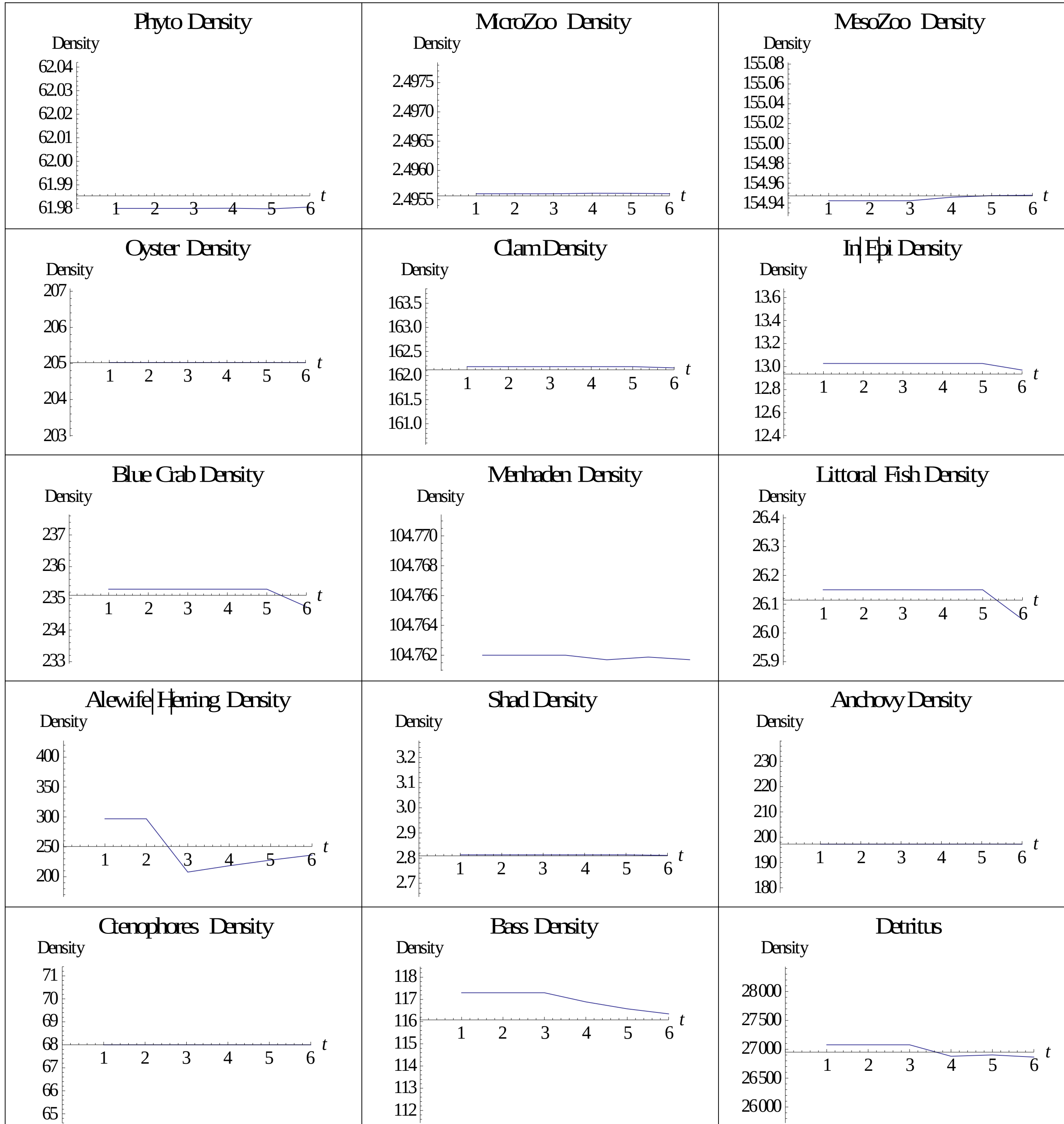
$$\partial R_{18} / \partial x_{1802} = (e_{02} - e_{1802}) - r_{18} - .5r_{18}(2x_{1802} + x_{1816}) - .5d_{1813}e_{18}(1 + t_{18}e_{1318})(x_{1802} + x_{1816})^{-.5} \le 0$$
$$[\partial R_{18} / \partial x_{1802}]\, x_{1802} = 0 \qquad x_{1802} \ge 0$$

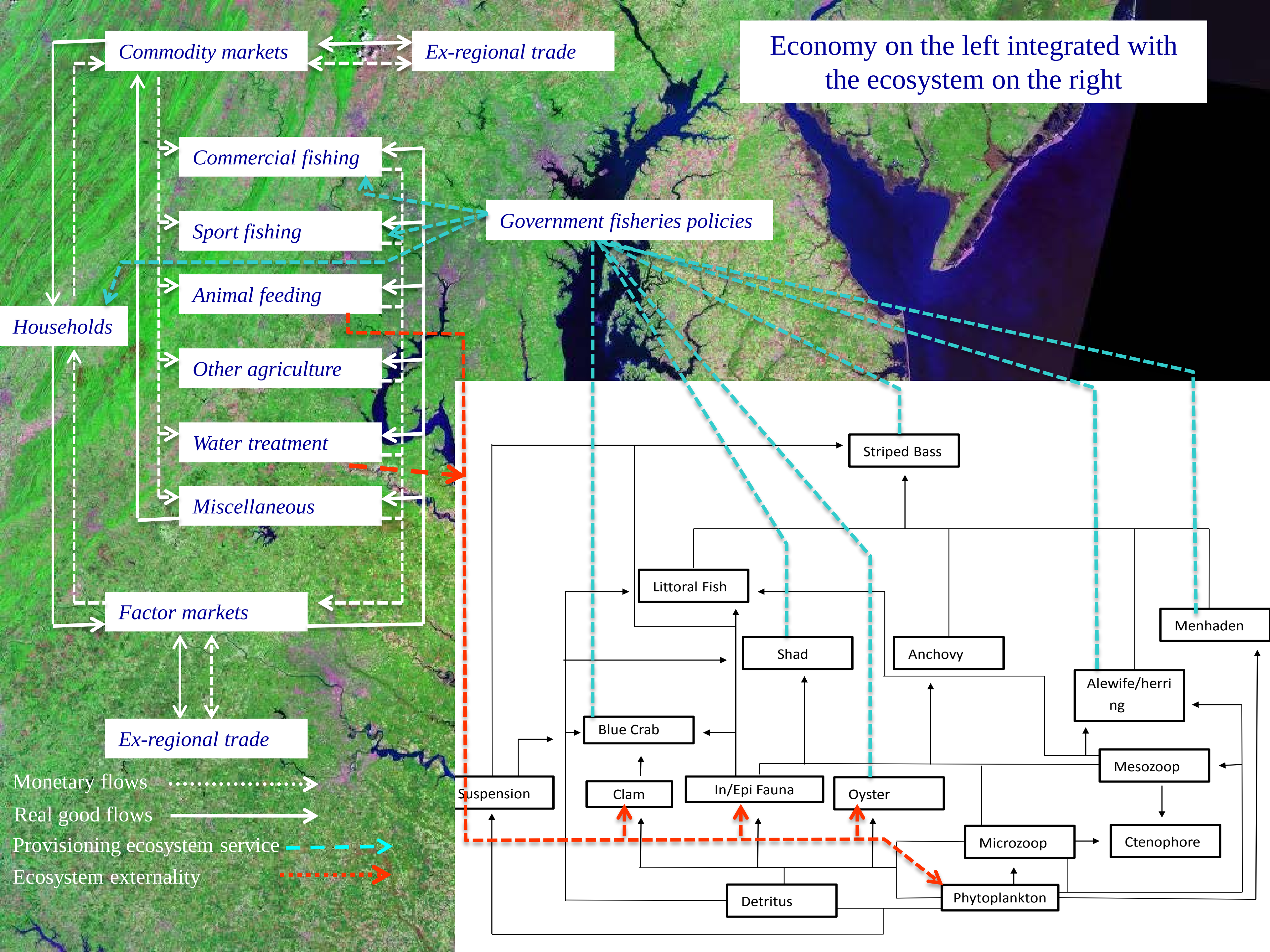
$$\partial R_{18} / \partial x_{1816} = (e_{16} - e_{1816}) - r_{18} - .5r_{18}(2x_{1816} + x_{1802}) - .5d_{1813}e_{18}(1 + t_{18}e_{1318})(x_{1802} + x_{1816})^{-.5} \le 0$$
$$[\partial R_{18} / \partial x_{1816}]\, x_{1816} = 0 \qquad x_{1816} \ge 0$$

$$N_{18}x_{1802} - N_{02}d_{0218}(x_{0201} + x_{0299})^{.5} \le 0$$
$$e_{1802}[N_{18}x_{1802} - N_{02}d_{0218}(x_{0201} + x_{0299})^{.5}] = 0 \qquad e_{1802} \ge 0$$

$$N_{18}x_{1816} - N_{16}d_{1618}x_{1699}^{.5} \le 0$$
$$e_{1816}[N_{18}x_{1816} - N_{16}d_{1618}x_{1699}^{.5}] = 0 \qquad e_{1816} \ge 0$$

Some population dynamics following a one period, 30% harvest of alewife/herring.




Economy on the left integrated with the ecosystem on the right
Commodity markets
Ex-regional trade
Commercial fishing
Sport fishing
Animal feeding
Other agriculture
Water treatment
Miscellaneous
Households
Government fisheries policies
Factor markets
Ex-regional trade
Monetary flows
Real good flows
Provisioning ecosystem service
Ecosystem externality
Striped Bass
Littoral Fish
Shad
Anchovy
Menhaden
Alewife/herring
Blue Crab
Mesozoop
Suspension
Clam
In/Epi Fauna
Oyster
Microzoop
Ctenophore
Detritus
Phytoplankton

Ecosystem Externalities

Externality	Effect	Species directly impacted	Species indirectly impacted
Nitrogen/ Phosphorus	Reduced water clarity	sea grass	menhaden, alosines, blue crab
	Oxygen depletion	sea grass, blue crab, oyster, striped bass, menhaden	menhaden, alosines, blue crab, striped bass
	Reduced water quality	oyster, striped bass, menhaden, alosines	striped bass
Chemicals	Habitat loss	oyster	crab
	Reduced water quality	oyster, striped bass, menhaden, alosines	striped bass, crab
Sediment	Reduced water quality	sea grass, oyster	menhaden, alosines, blue crab
Fishery	Habitat destruction	sea grass	menhaden, alosines, blue crab
	Population loss	blue crab, oyster, striped bass, menhaden, alosine	blue crab, striped bass
Spawning habitat loss		American shad	striped bass
Increased temps	Disease	oyster	blue crab

Ecosystem Services – Commercial Fishing

	Total Catch (million lbs)	Total Revenue (million $)
Striped bass	4.687	9.165
Alosine (alewife, shad, blueback herring)	0.98	0.332
Blue crab	111.95	131.227
Eastern oyster	1.819	10.615
Menhaden	448.997	35.231

Ecosystem Services – Commercial Fishing

	Striped bass	Shad	Blueback Herring and alewife	Blue crab	Eastern oyster	Menhaden
Regulations	-commercial license -minimum/maximum size -annual TAC -annual individual quota	-moratorium	-moratorium	-commercial license -minimum size -location -daily quota -gear -life cycle-stage -season	-harvest method-specific license -location -minimum size -annual TAC -daily individual quota	-TAC
Regulator	Marine Resources Commission	Marine Resources Commission	Marine Resources Commission	Marine Resources Commission	Marine Resources Commission	Atlantic States Marine Fisheries Commission

In the Economy: Regulated Fishery

$TAC_i^t = a_i + b_i N_i^t$ -- total allowable catch is set

$H_i^t = d_i E_i^t N_i^t$ -- harvest depends on aggregate effort and fish

minimize $wL_i^t + r\overline{K}_i^t$ -- minimize cost of effort

subject to

$$E_i^t = \varphi_i \left[\delta_i L_i^{t\,\frac{\sigma_i - 1}{\sigma_i}} + \left(1 - \delta_i\right) \overline{K}_i^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{(\sigma_i - 1)}}$$

Ecosystem Services – Recreational Fishing

2011 Striped Bass	Catch (millions of lbs)	Angling days (millions)
For-hire charter boats	0.9362	0.1911
Private/rental boats	2.8337	3.2345
Shore	0.0314	2.2925

Recreational Fishing – supply side

$$PVC_{RF} = \left(\varphi_{RF}\right)^{-1} QD_{RF}\left[\delta_{RF}^{\sigma_{RF}} W^{1-\sigma_{RF}} + \left(1-\delta_{RF}\right)^{\sigma_{RF}} R^{1-\sigma_{RF}}\right]^{1/\left(1-\sigma_{RF}\right)}$$

$$\left(\varphi_{RF}\right)^{-1} = \Delta^{F}\left(\varphi_{RF}^{0}\right)^{-1}$$

$$\Delta^{F} = 1 + \varepsilon_{F}^{RF}\Delta^{N}$$

$$\Delta^{N} = \left(\sum_{\substack{sport\\fish}} Annual\ \%\ change\ in\ biomass\right) \Big/ \#\ sport\ fish$$

Recreational Fishing – demand side

- Challenge to mesh the trip level, non-market demand models of Massey, Newbold and Gentner (2006) and Gentner, Steinback, and Lee. 2012.
- Plan to nest the non-market demand component in an upper level utility function in the CGE in the same fashion as typically made for labor-leisure choices.

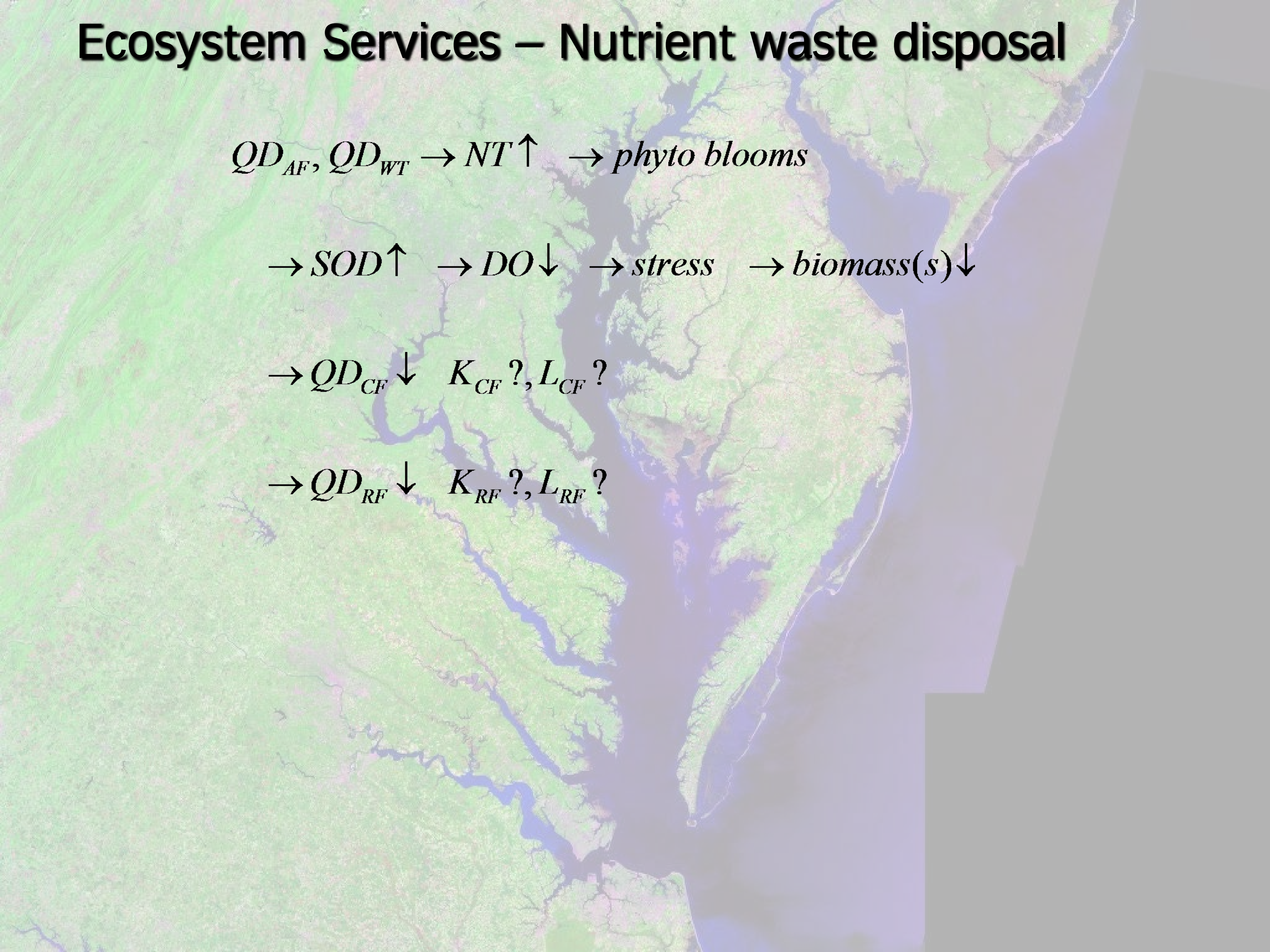
Ecosystem Services – Nutrient waste disposal

$$QD_{AF}, QD_{WT} \rightarrow NT\uparrow \quad \rightarrow phyto\ blooms$$

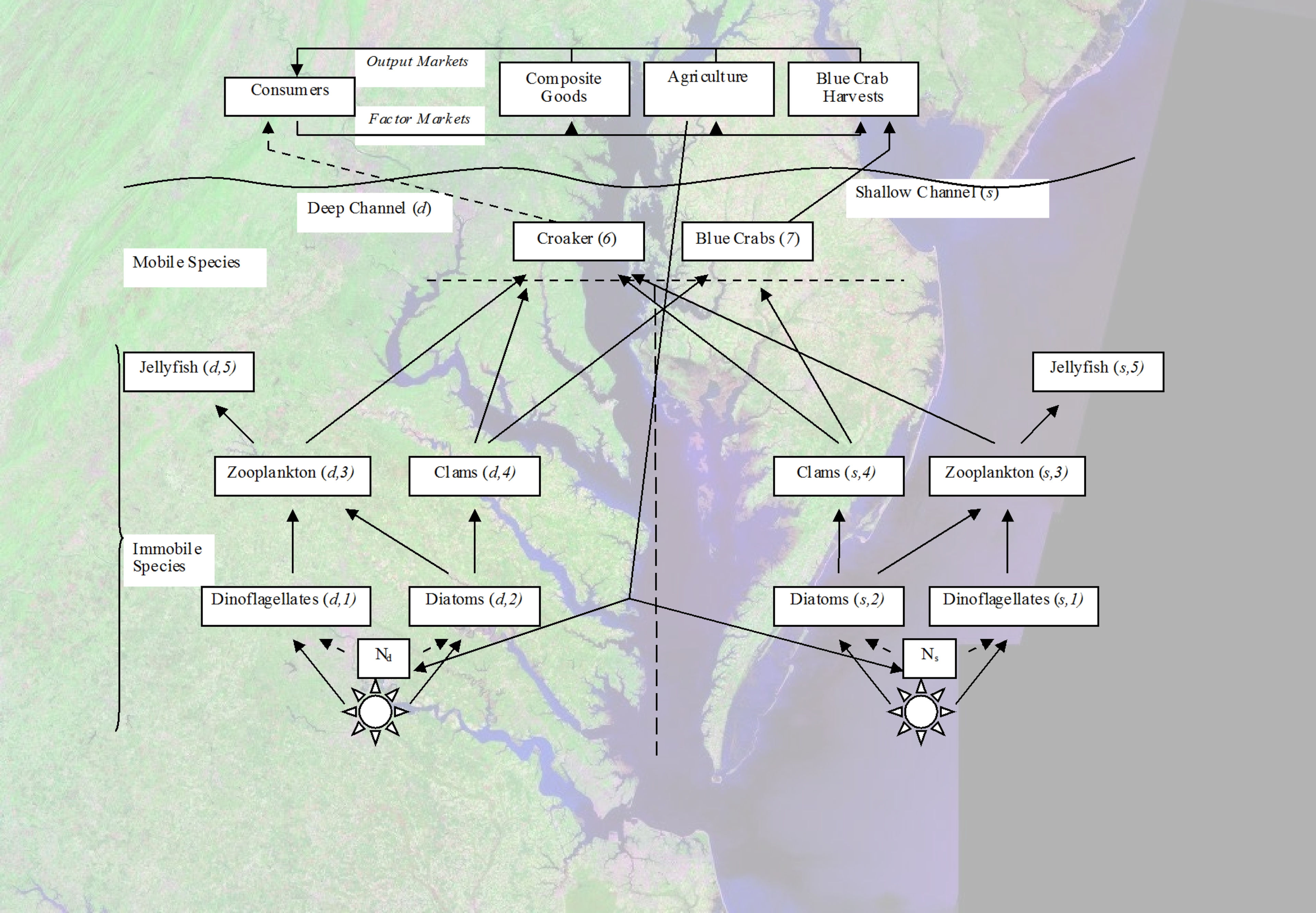
$$\rightarrow SOD\uparrow \quad \rightarrow DO\downarrow \quad \rightarrow stress \quad \rightarrow biomass(s)\downarrow$$

$$\rightarrow QD_{CF}\downarrow \quad K_{CF}?, L_{CF}?$$

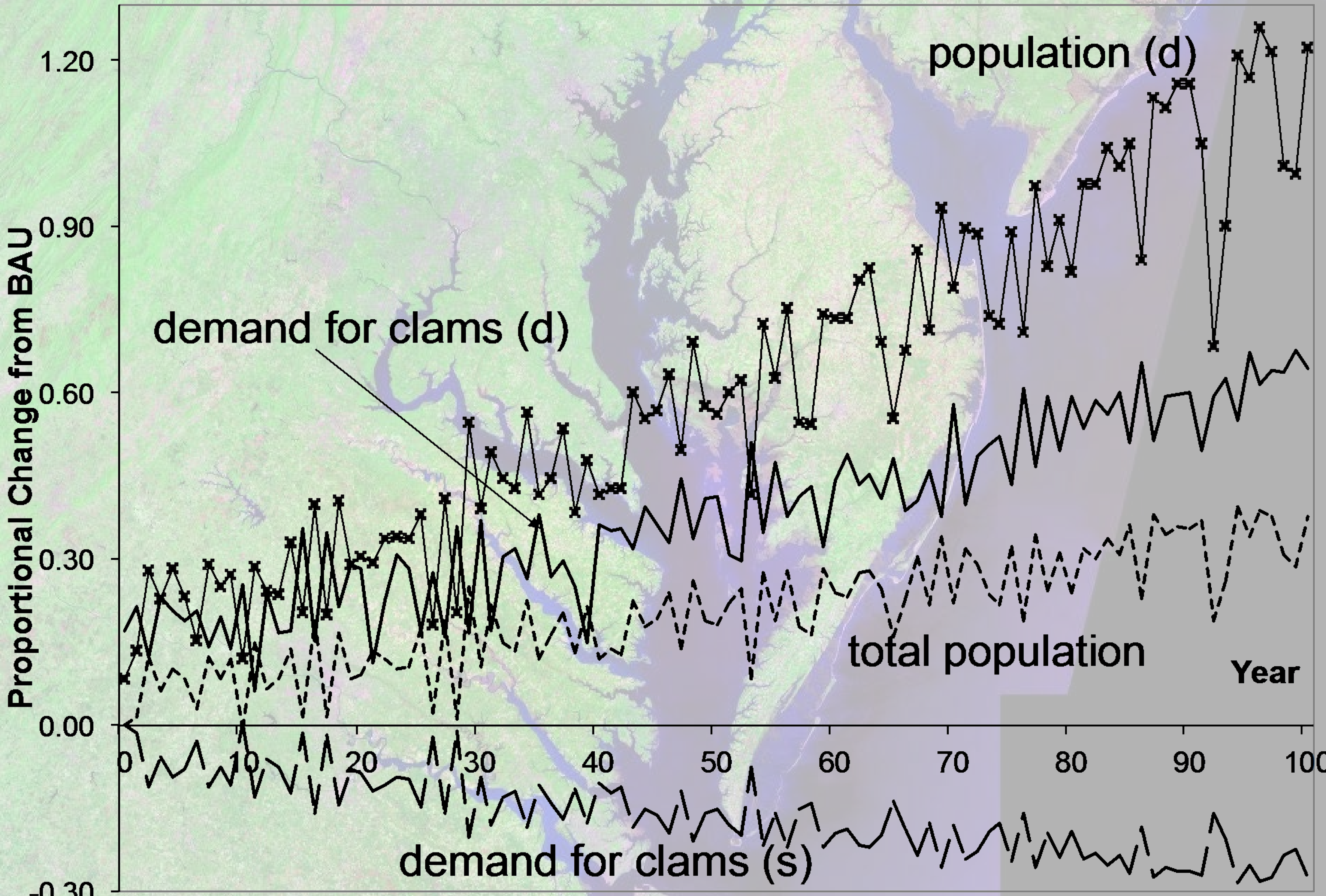
$$\rightarrow QD_{RF}\downarrow \quad K_{RF}?, L_{RF}?$$



Neuse Estuary & Hypoxia



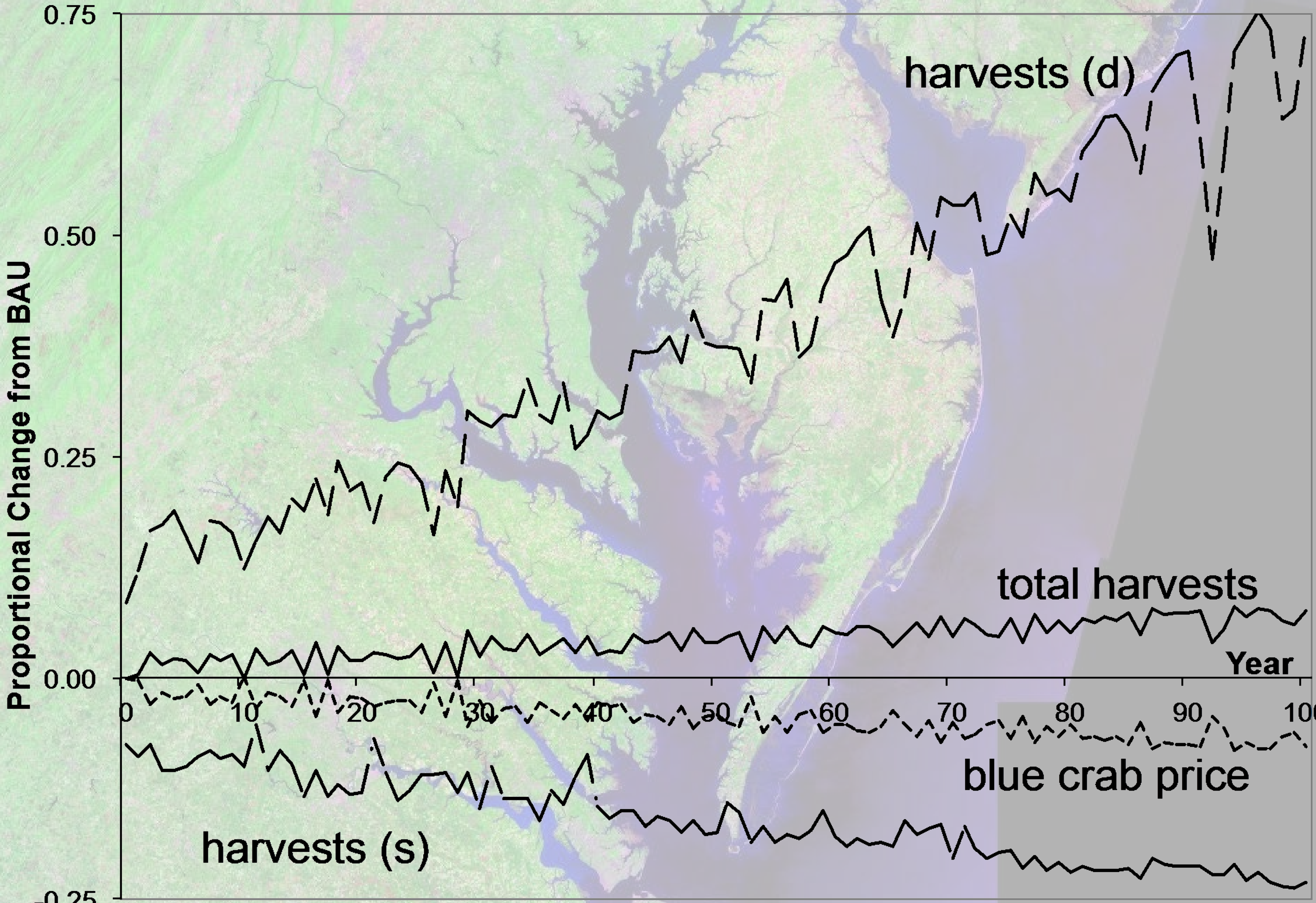
Neuse– Blue Crab Consequences



Neuse– Ecological Consequences

Scenario			No Increase in Agriculture Costs	1% Increase in Agriculture Costs	10% Increase in Agriculture Costs
Variable	**Variable Type**	**Species**	**% Change From BAU**	**% Change From BAU**	**% Change From BAU**
n^d_1	Deep populations	Dinoflagellates	−20.0800%	−20.0800%	−20.0800%
n^d_2		Diatoms	51.0257%	51.0257%	51.0257%
n^d_3		Zooplankton	−8.8283%	−8.8283%	−8.8283%
n^d_4,		Clams	82.2926%	82.2926%	82.2926%
n^d_5		Jellyfish	−6.9873%	−6.9873%	−6.9873%
n_6 (n^d_6) (n^s_6)	Populations (deep) (shallow)	Croaker	8.0706% (30.1607%) (−7.1604%)	8.0706% (30.1607%) (−7.1604%)	8.0706% (30.1607%) (−7.1604%)
n_7, (n^d_7,) (n^s_7)		Blue crab	27.4328% (91.3994%) (−2.5262%)	27.4329% (91.3994%) (−2.5262%)	27.4331% (91.3998%) (−2.5260%)

Neuse– Blue Crab Economic Consequences



Neuse– Economic Consequences

Scenario		No Increase in Agriculture Costs	1% Increase in Agriculture Costs	10% Increase in Agriculture Costs
Variable	**Variable Type**	**% Change From BAU**	**% Change From BAU**	**% Change From BAU**
I	Income	3.194E−6%	3.754E−5%	3.336E−4%
R	Capital price	6.137E−6%	7.213E−5%	6.409E−4%
P_C	Composite price	3.193E−6%	3.753E−5%	3.335E−4%
P_A	Agriculture price	4.155E−6%	1.0000%	10.0005%
P_B	Crab price	−5.8380%	−5.8381%	−5.8381%
Q_C	Composite output	5.354E−6%	−0.0001%	−0.0009%
Q_A	Agriculture output	4.489E−6%	−0.8916%	−8.2212%
H	Crab harvest	5.6373%	5.6372%	5.6367%
(H^{deep})	(Deep)	56.5770%	56.5768%	56.5793%
$(H^{shallow})$	(Shallow)	−18.6235%	−18.6235%	−18.6275%
T	Crab season	−0.6034%	−0.6035%	−0.6042%
(T^{deep})	(Deep)	46.6725%	46.6723%	46.6756%
$(T^{shallow})$	(Shallow)	−23.2483%	−23.2483%	−23.2535%
K_B	Crab capital	−0.6034%	−0.6035%	−0.6046%
L_B	Crab labor	−0.6034%	−0.6035%	−0.6040%
K_C	Composite capital	2.70 E−6%	-0.0001%	-0.0012%
L_C	Composite labor	8.23 E−6%	-0.0001%	-0.0006%
K_A	Agriculture capital	2.7 E−6%	0.0994%	0.9565%
L_A	Agriculture labor	8.23 E−6%	0.0995%	0.9570%

Cumulative Welfare (Million $)		
Agricultural Cost Scenario	**Discount Rate 0**	**Discount Rate 0.03**
0	10.88	2.42
1%	−241.07	−78.90
10%	−2412.70	−779.81

Summary

- Model use is in assessment of policies
- Weighs ecological and economic outcomes
- Tracks ecological consequences
- Tracks economic consequences
  - Provides aggregate welfare
  - Provides stakeholder specific welfare measures