# Coupling across individuals, populations and human systems in marine ecosystem models

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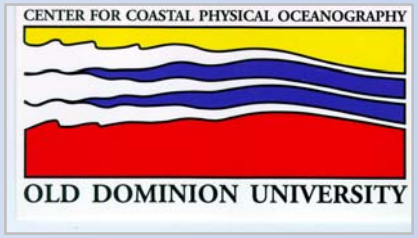




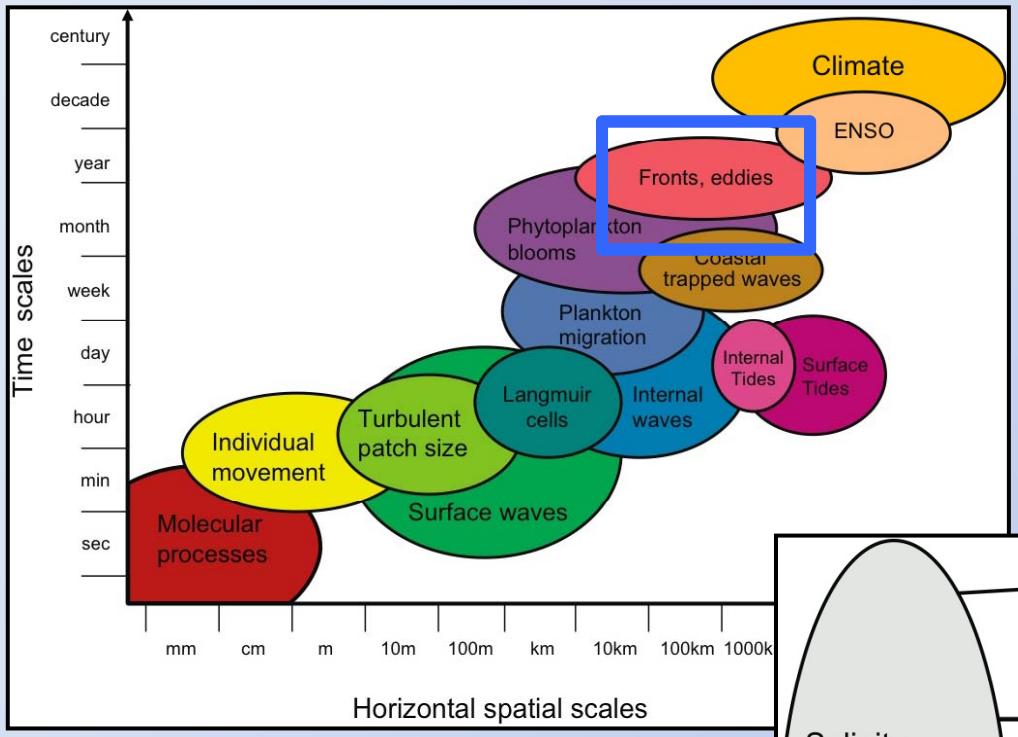
# Outline of Lecture

- Scales and relevance to model development
- Individual-based models – sequence of complexity
- Food web models
- Coupling of human-natural system models
- Indicate important and exciting directions and opportunities for marine ecosystem modeling

# Scales of Processes

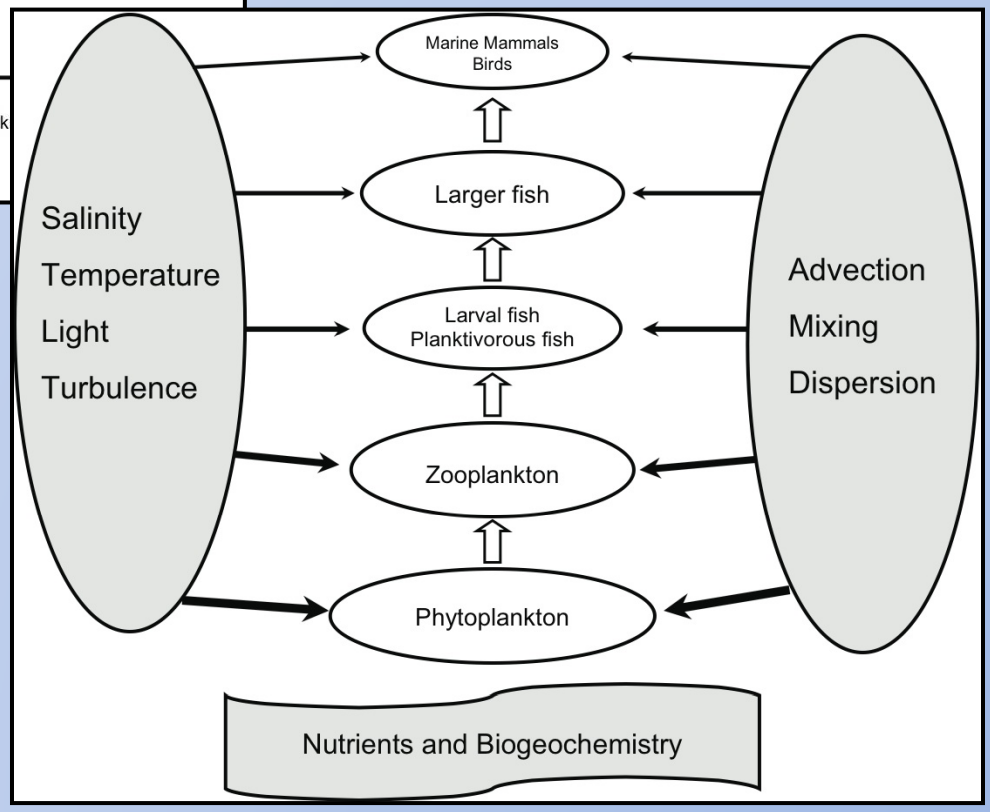
- View that marine ecosystems operate along a continuum defined by space and time has underpinned much of model development

- View has evolved to one in which marine ecosystem variability and population recruitment result from the integration of processes across all space and time scales and includes direct as well as indirect interactions




Processes at smaller scales are parameterized

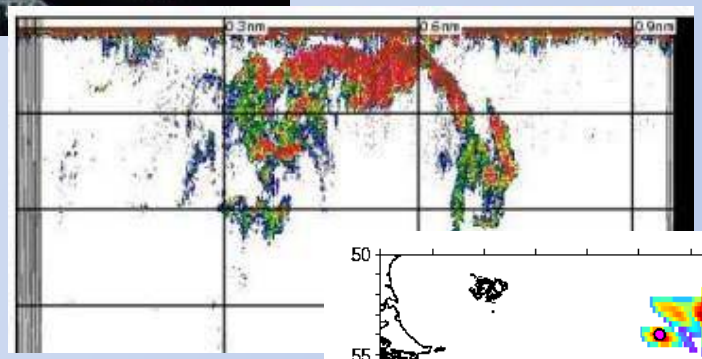
Processes at larger scales are boundary conditions

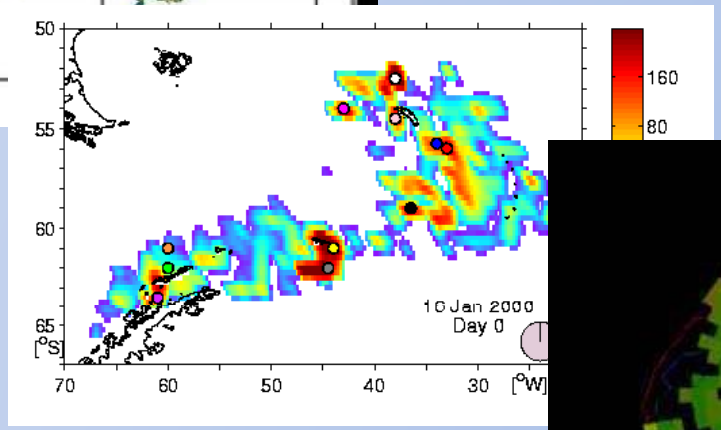


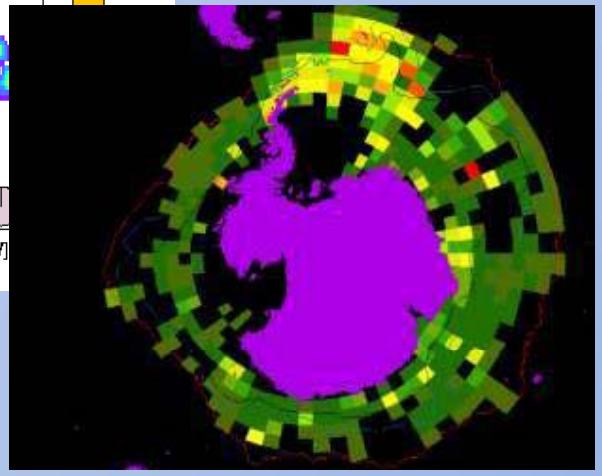

Studies of marine ecosystems require integration of the environmental drivers and biological responses

# Scales of spatial variation

Scale of aggregation depends on view of system

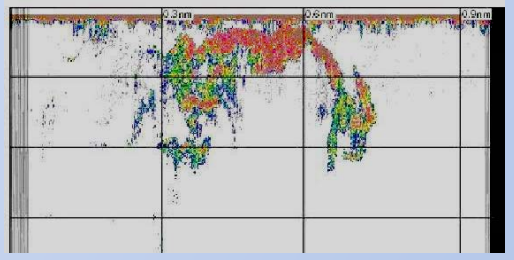


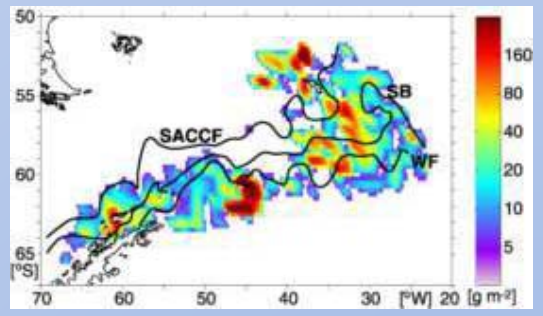


Each scale requires a different model and/or approach

# Structure modifies the operation of the ecosystem






Scale of aggregations - exploited by different predators

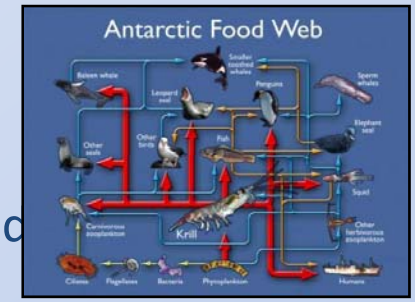
Krill are important to different parts of the food web because of a spatial structure that covers many scales

Longevity and overwinter survival allows spatial and temporal transfer

Makes energy available to predators

# Advection

Autochtonous – Allocthonous proc



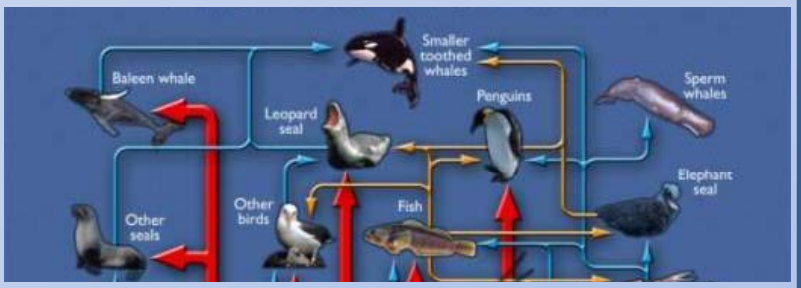

Displaces production

Disconnects

Production - Mortality

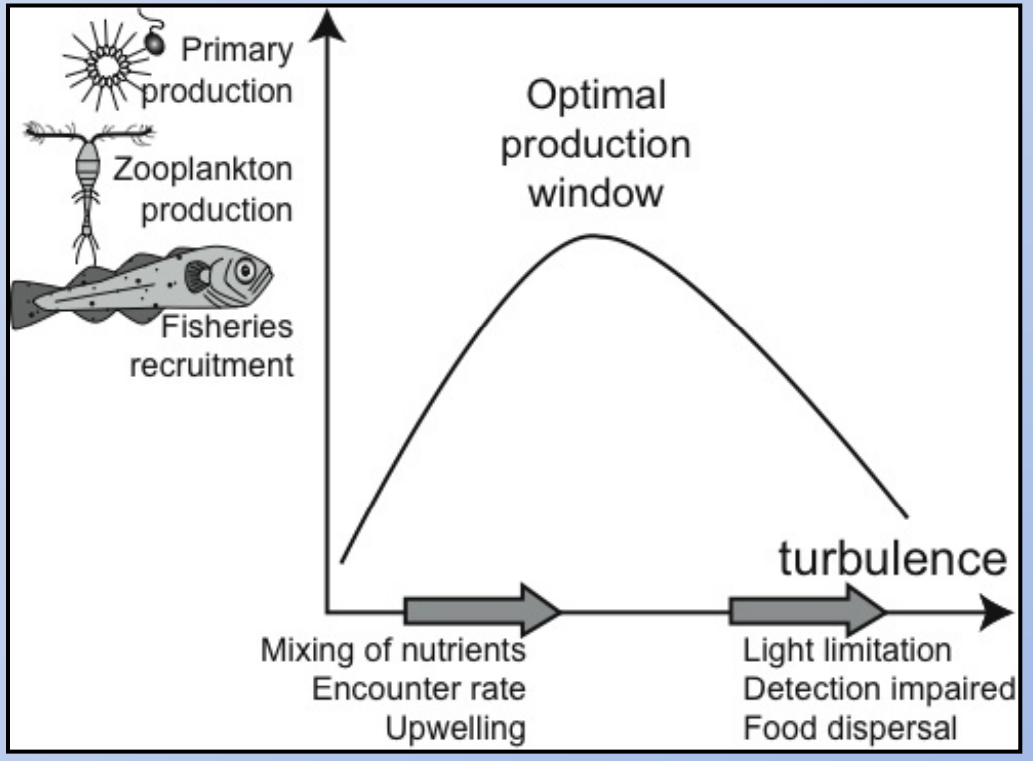
Production - Export






# Scales of Processes

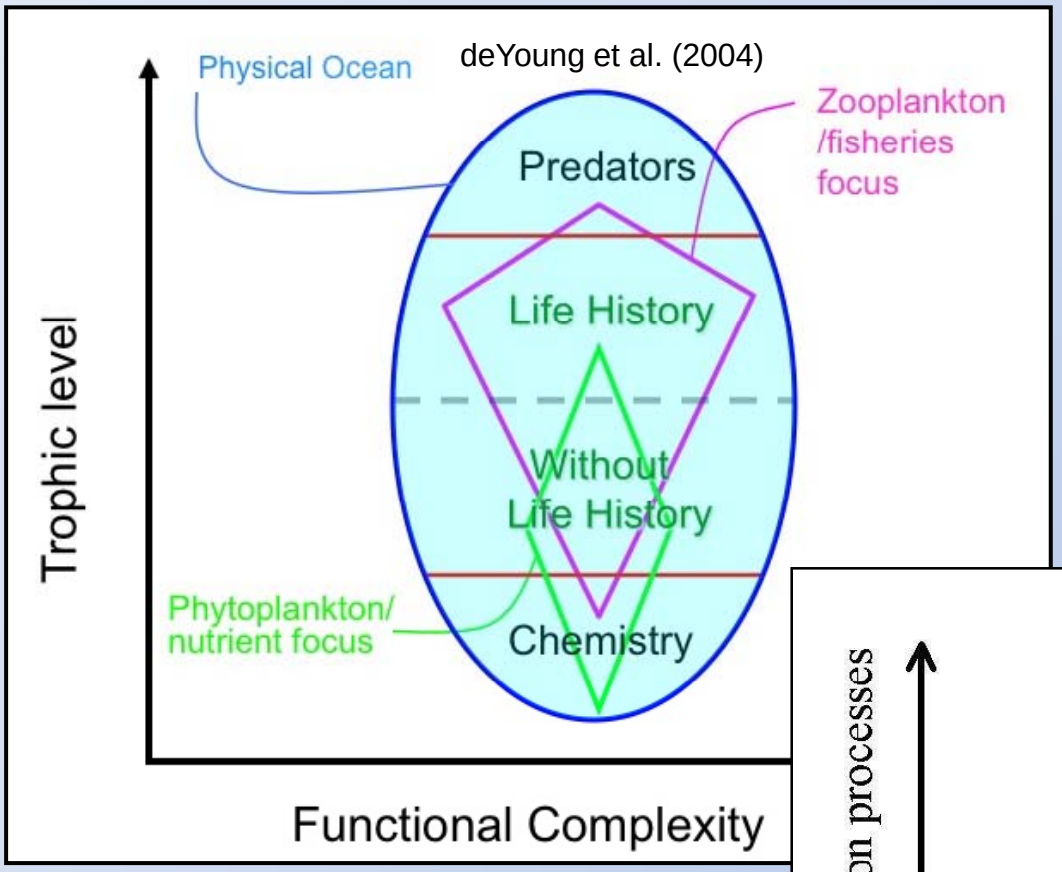
- Models pick out key scales and follow these through system
- Multiple optima in ecosystems and have begun to understand interactions that produce these



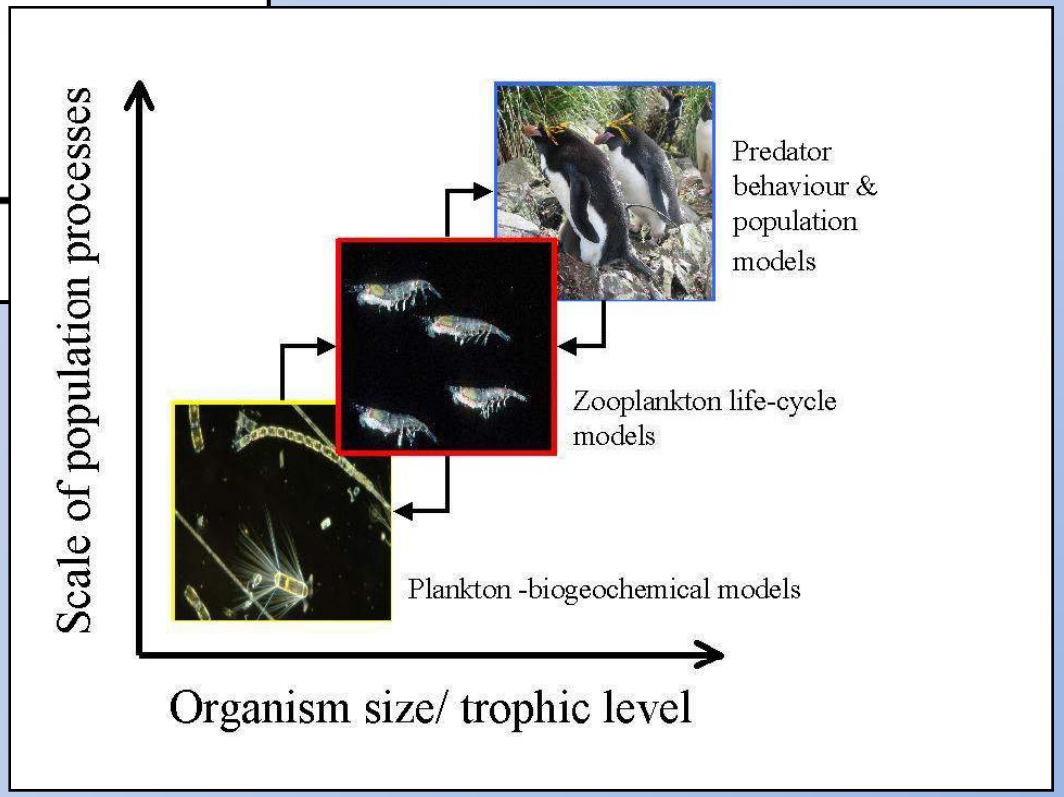
# Modeling Approach

Target species
Trophic Level
Population

Top Down vs. Bottom up




Top down and bottom up controls operate simultaneously but relative effect of each is variable



# Modeling Approaches

- Species
  - Lagrangian models, individual-based models (IBMs)
  - Track individual particle in circulation field
- Food web models
  - combine species and population
  - evaluate top down versus bottom up control

# Individual-based Models

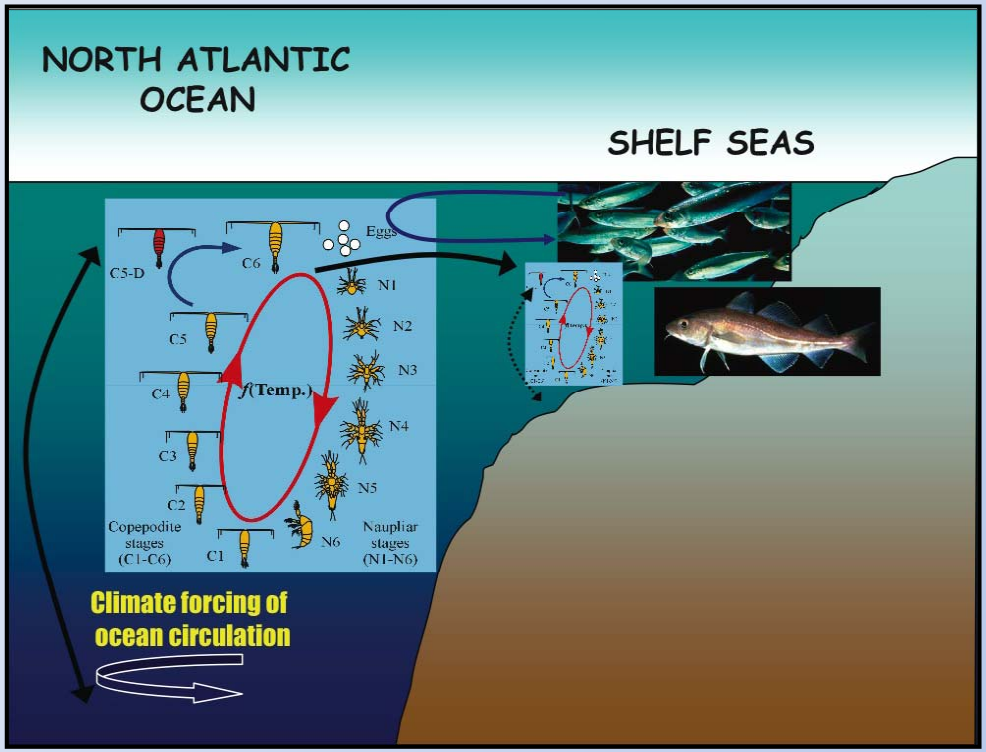
- Grimm (1999, Ecol. Mod.) suggested two reasons to use IBMs

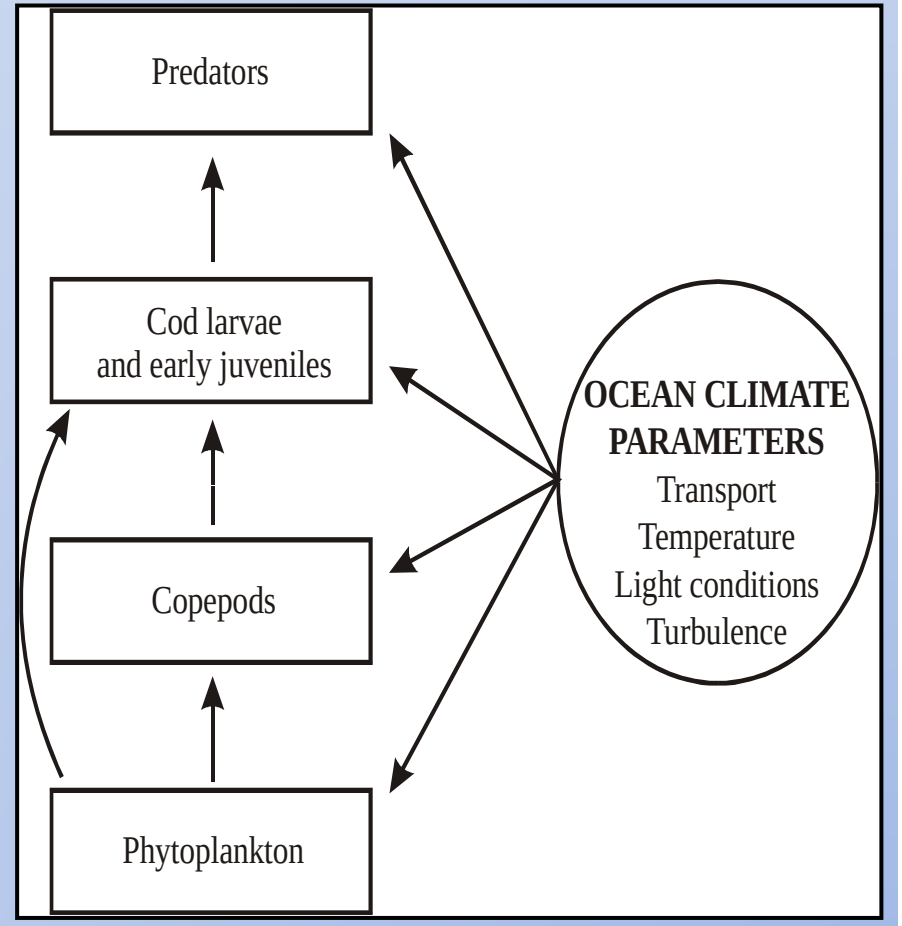
  - "*study problems that cannot be addressed with state variables*" (pragmatic)

  - "*study is driven by suspicion that much of what we have learned from state variable models about theoretical issues…e.g., regulation etc., would have to be revised if the discreteness, uniqueness, life cycles and variability of the individuals were to be taken into account*" (paradigmatic)

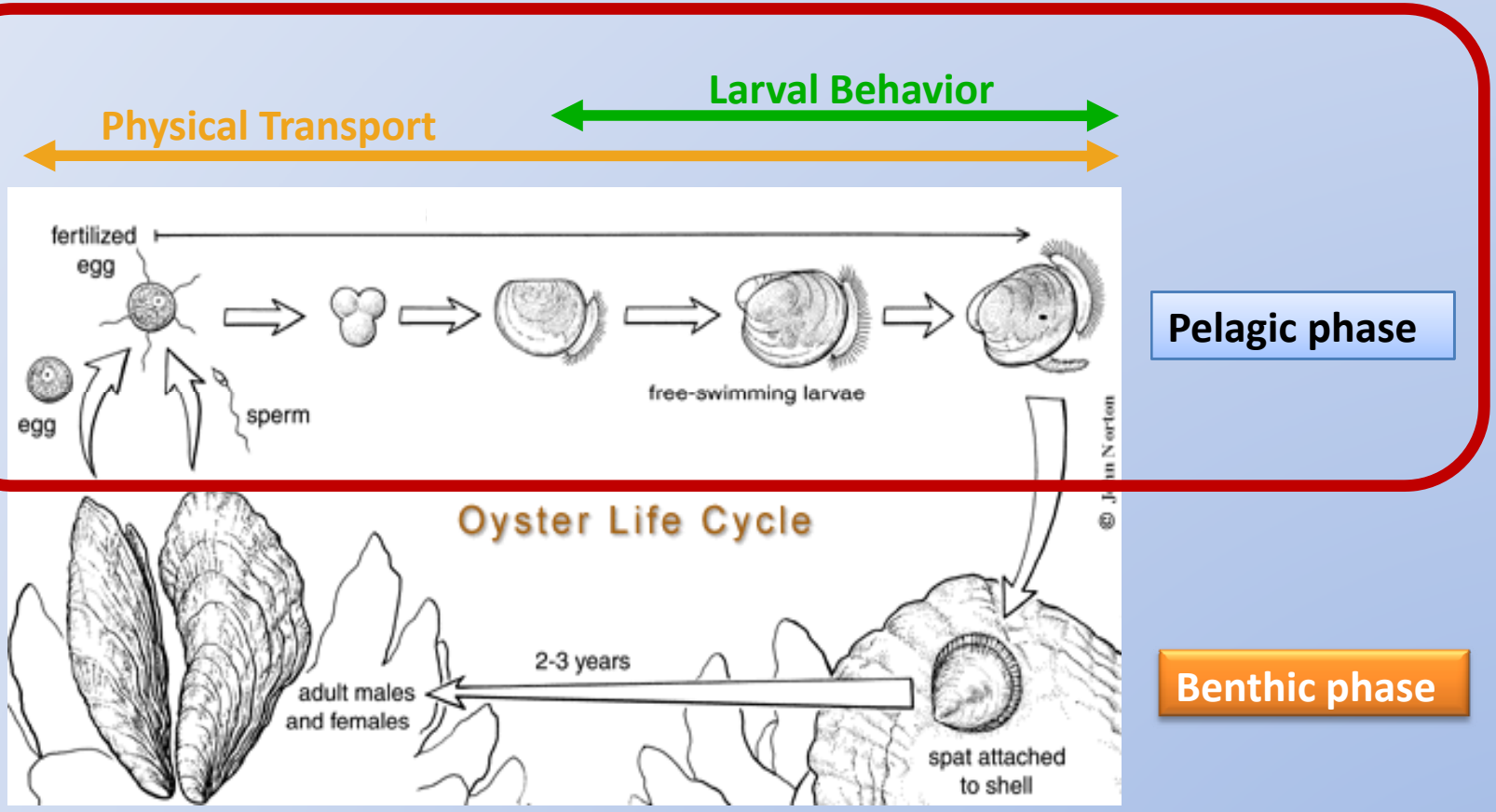
- Most marine applications fall into the pragmatic category because marine organisms experience unique trajectories during their planktonic drift stages and after they develop full swimming capabilities

# Development of conceptual frameworks for recruitment that encompass multiple scales



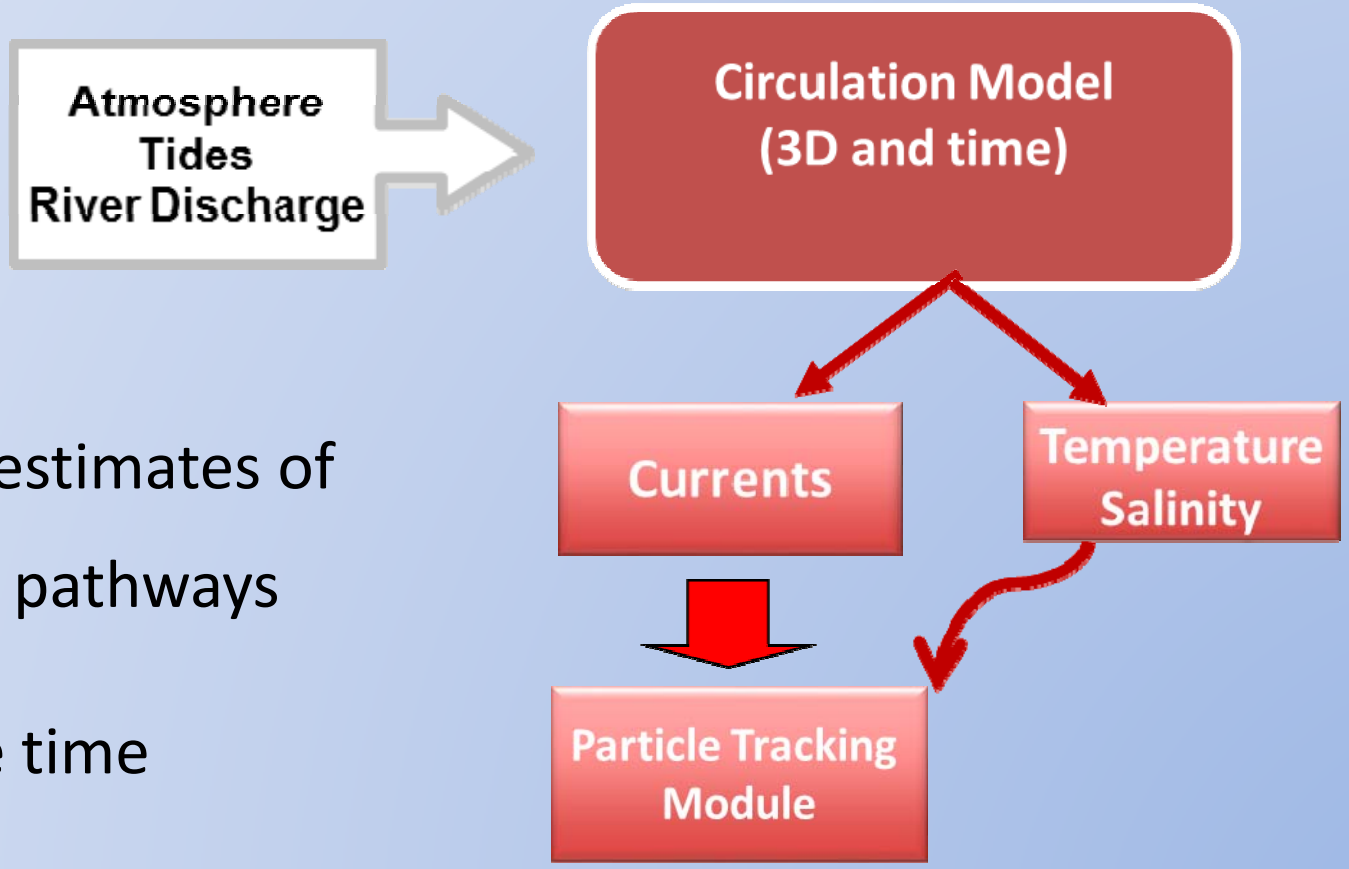

Knowledge of interactions have resulted in additional hypotheses about physical-biological controls on recruitment




© John Norton (http://www.mdsg.umd.edu)

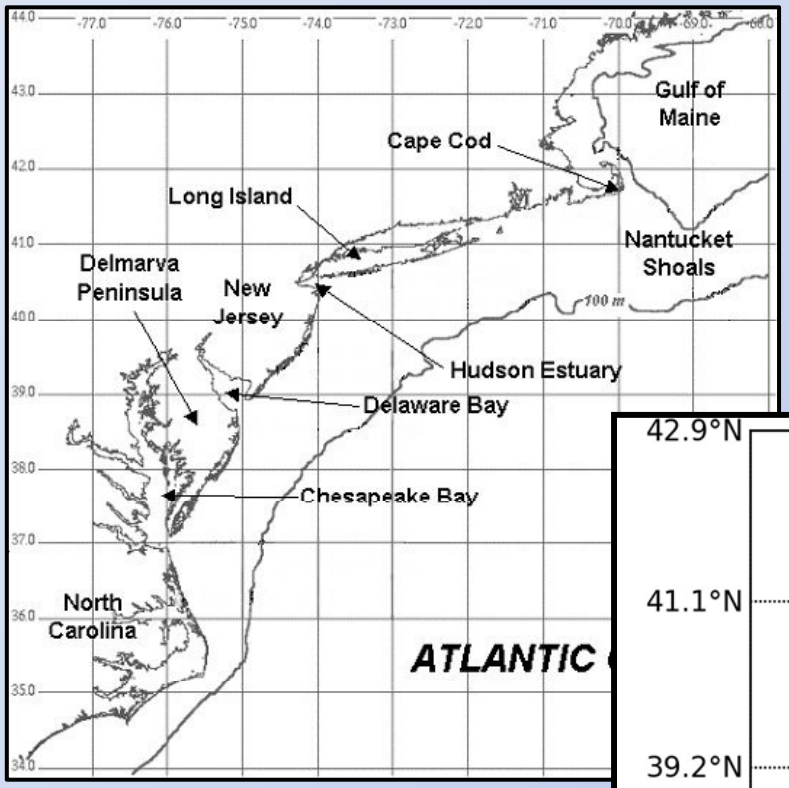
Organism with pelagic life phase – oyster
Larva grows, migrates, transport by currents
Recruitment, exchange between reefs

# IBM – Passive Particle

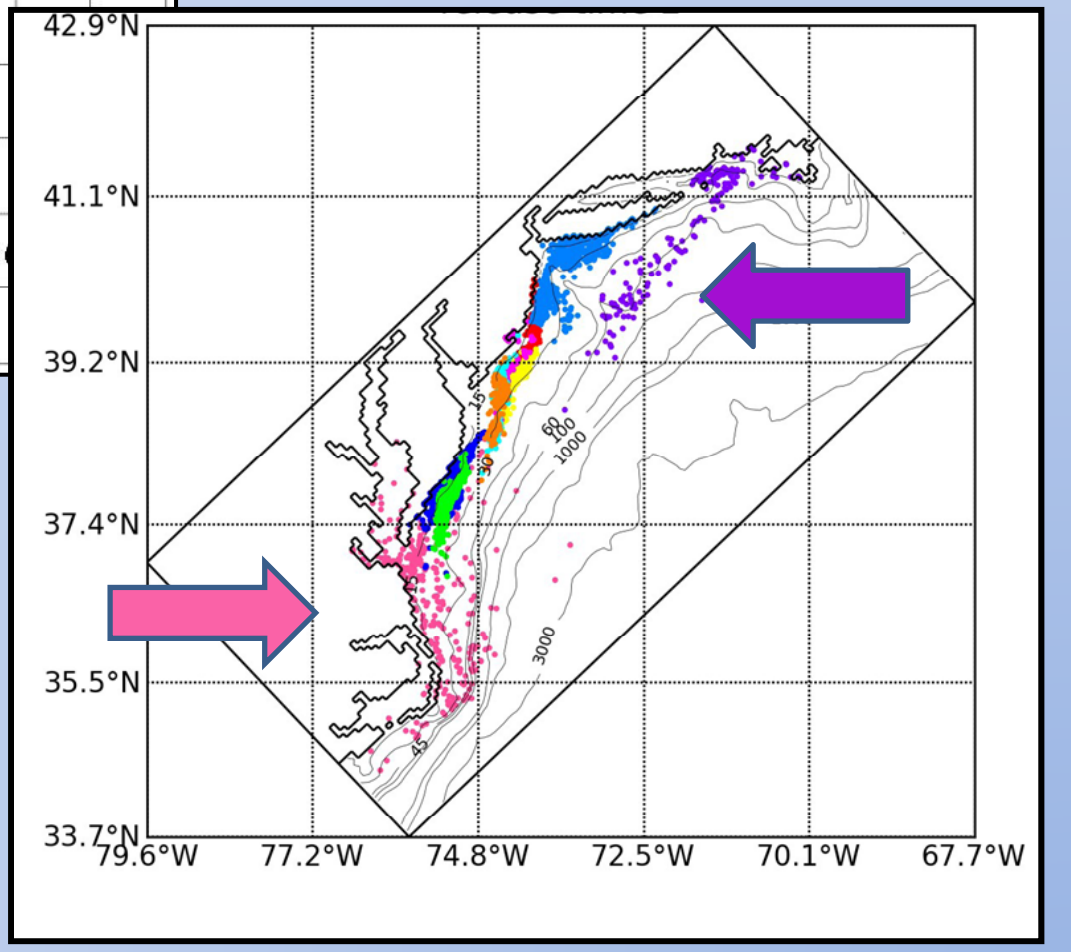



Provides estimates of

transport pathways
exchange
residence time



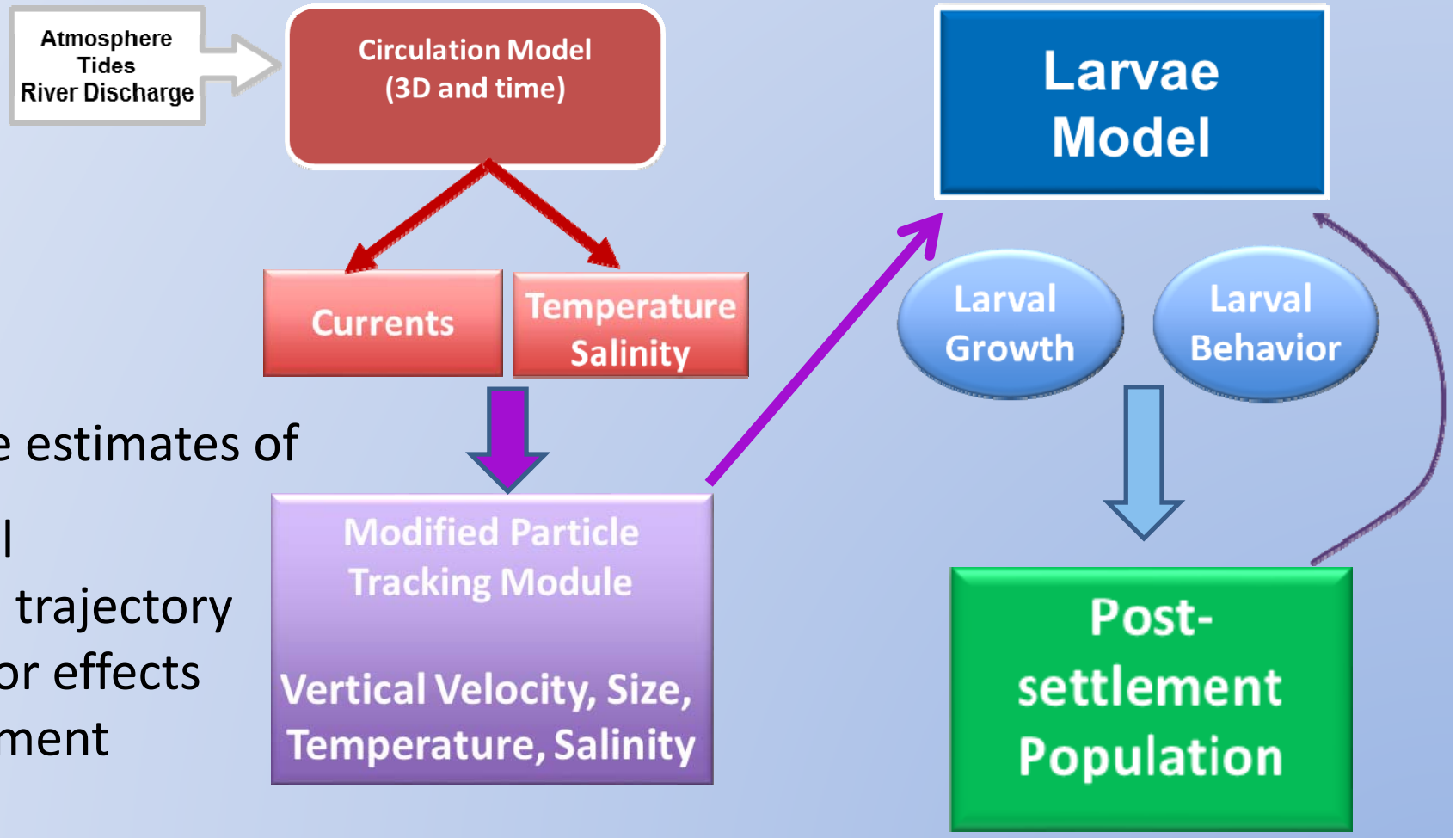

Movement of particles along the US continental shelf




Transport

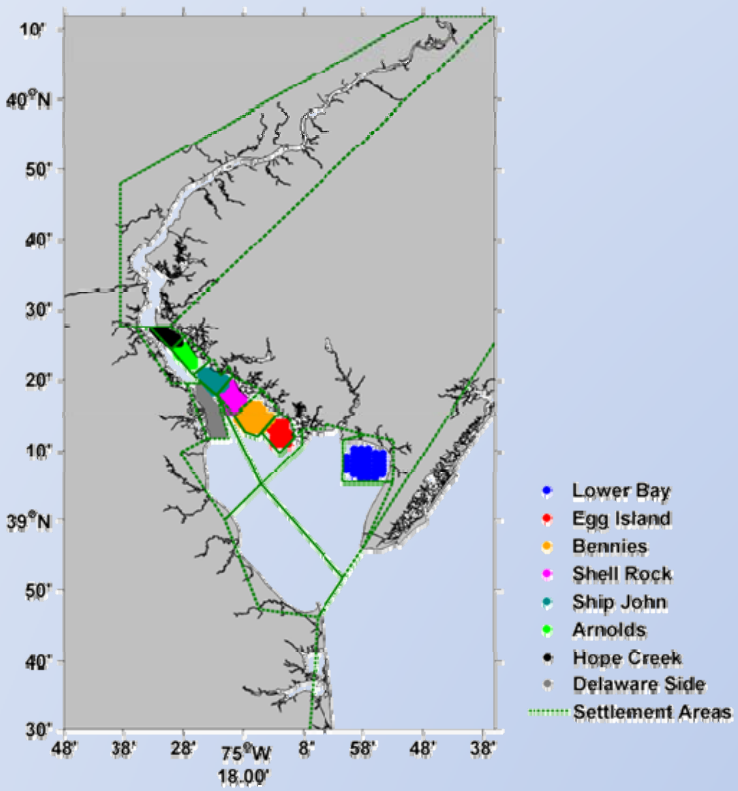
North-south
Across-shelf
Bay-to-bay

# IBM – Growth and Behavior




Provide estimates of

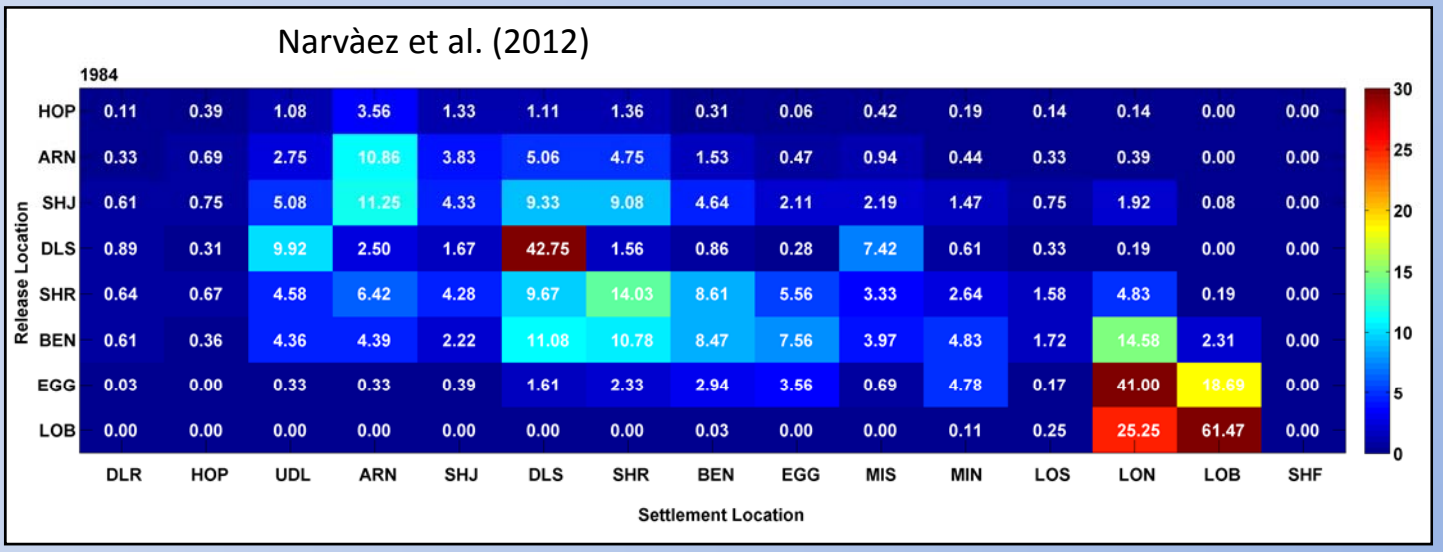
survival
growth trajectory
behavior effects
recruitment




# Population Connectivity Matrix

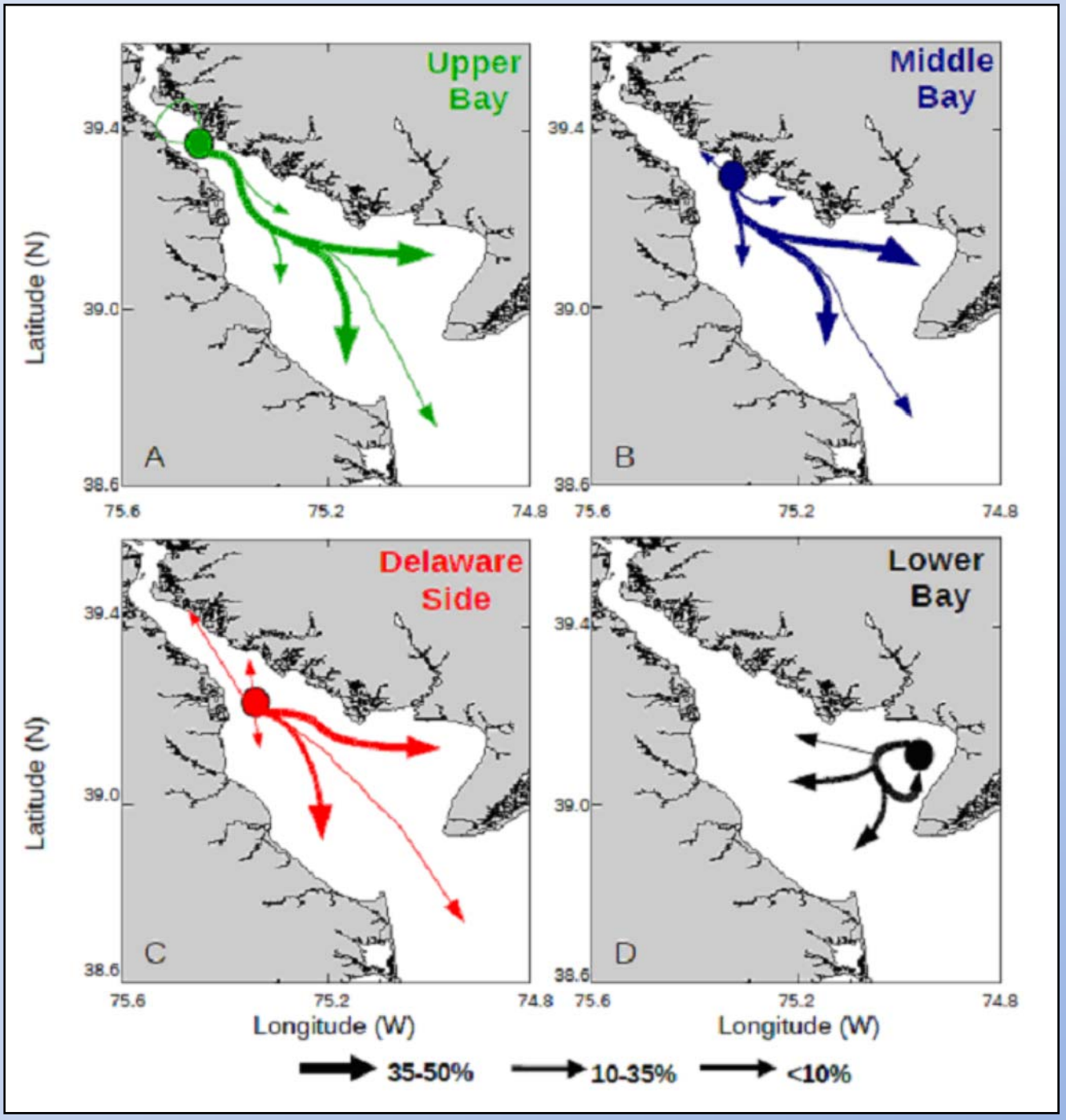
Allows determining connection between spawning and settlement areas

Narvàez et al. (2012)



Identify Source/sink Regions

Genetic Exchange?




Narvàez et al. (2012)

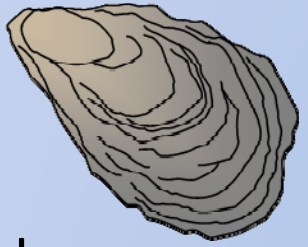
Individual Genetics:

- Based on parental genotype
- Offspring created by meiosis

Larvae can:

- Experience mortality
- Remain within source population
- Disperse
  - circulation, larval growth, behavior

Larva exchanges genetic material

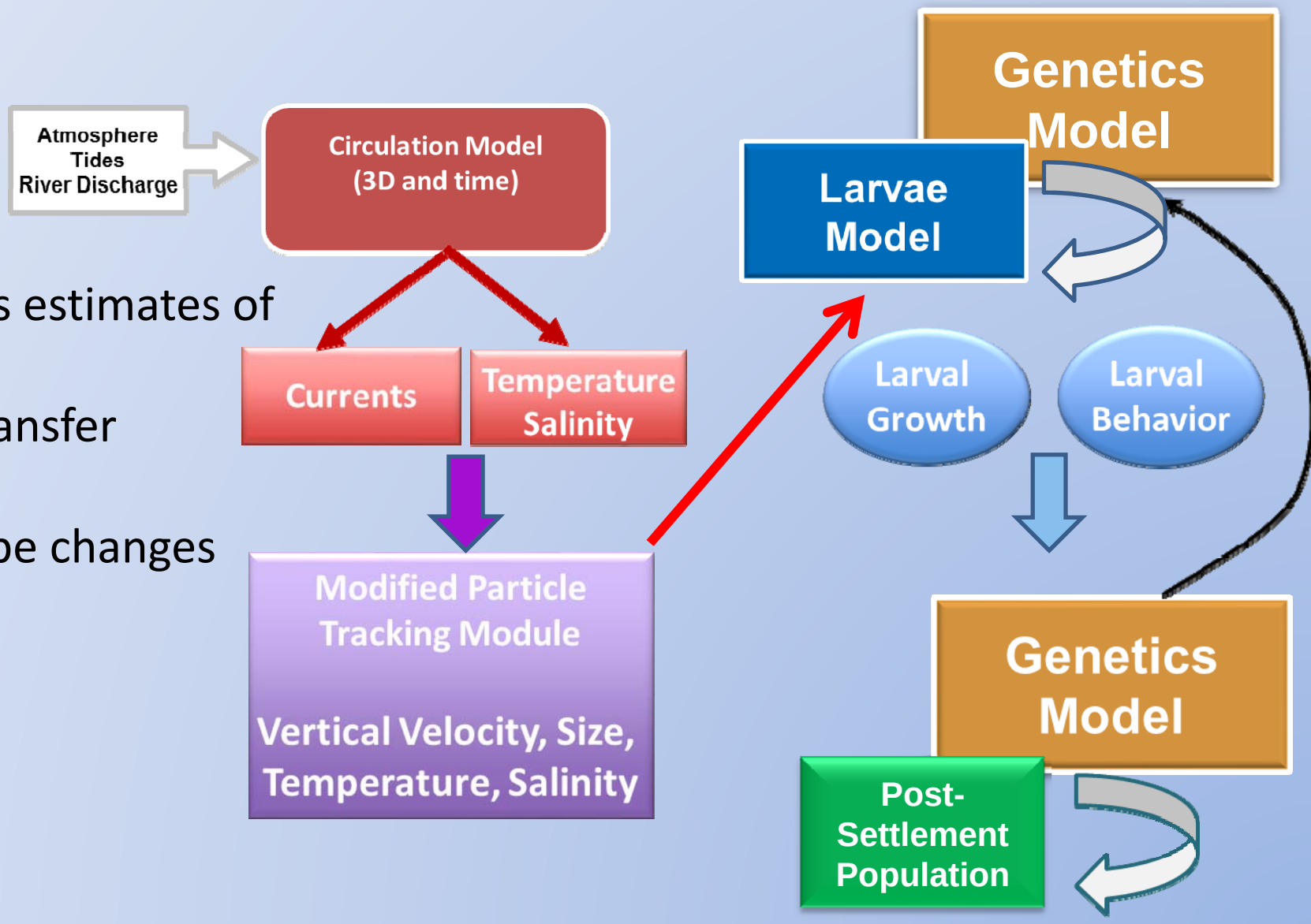


Recruits will:

- Grow
- Experience mortality or fishing
- Change sex
- Spawn

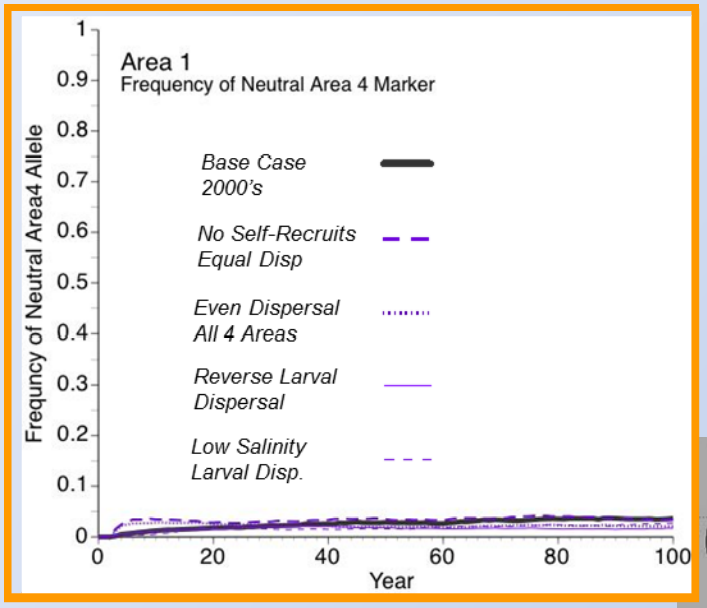
Adult provides larva and genetic structure

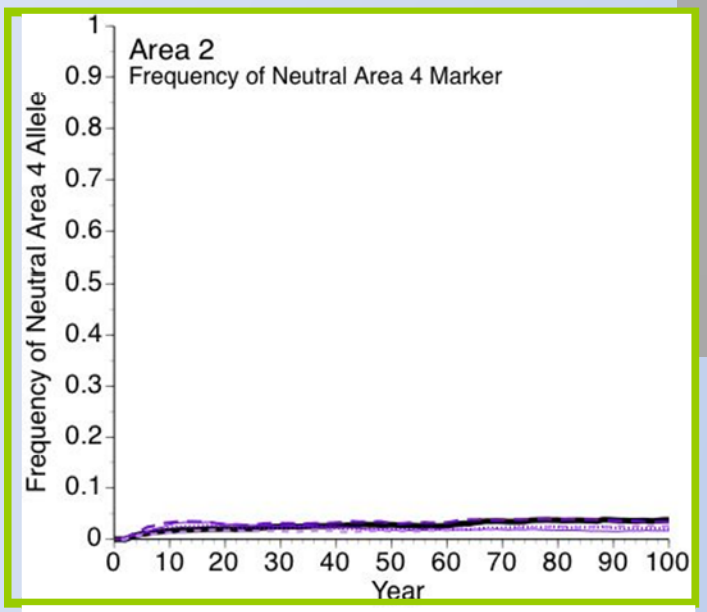
# IBM – Genetics Framework

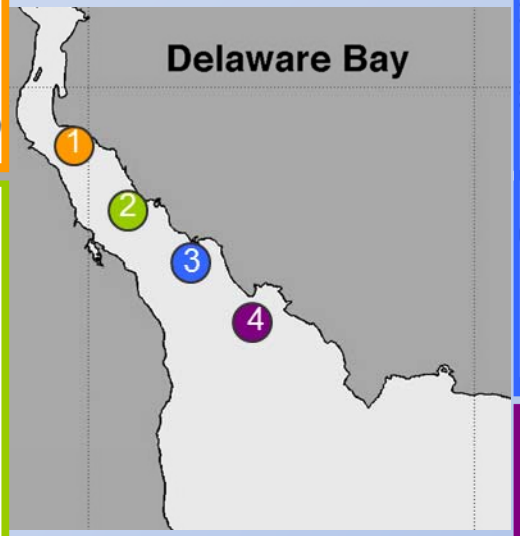


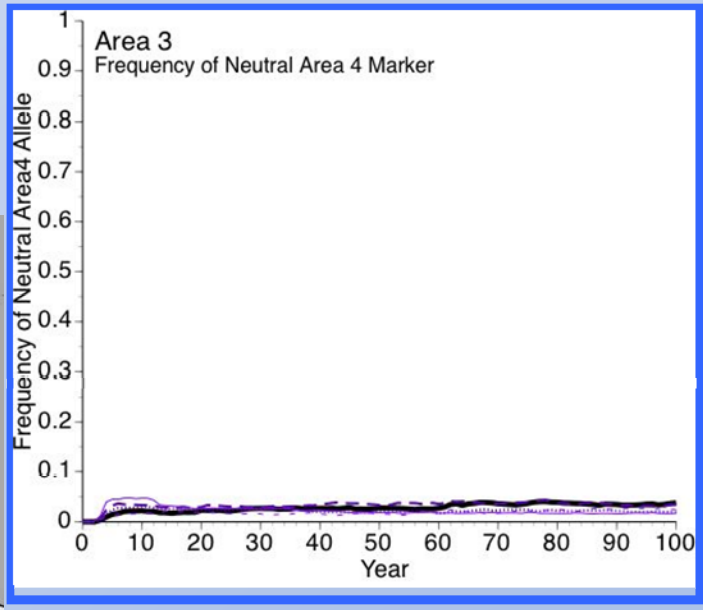

Provides estimates of

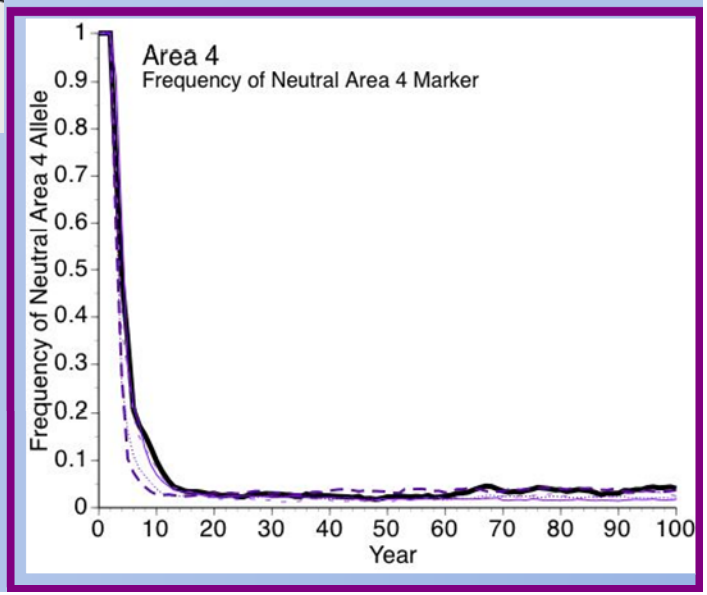
Gene transfer
Traits
Genotype changes



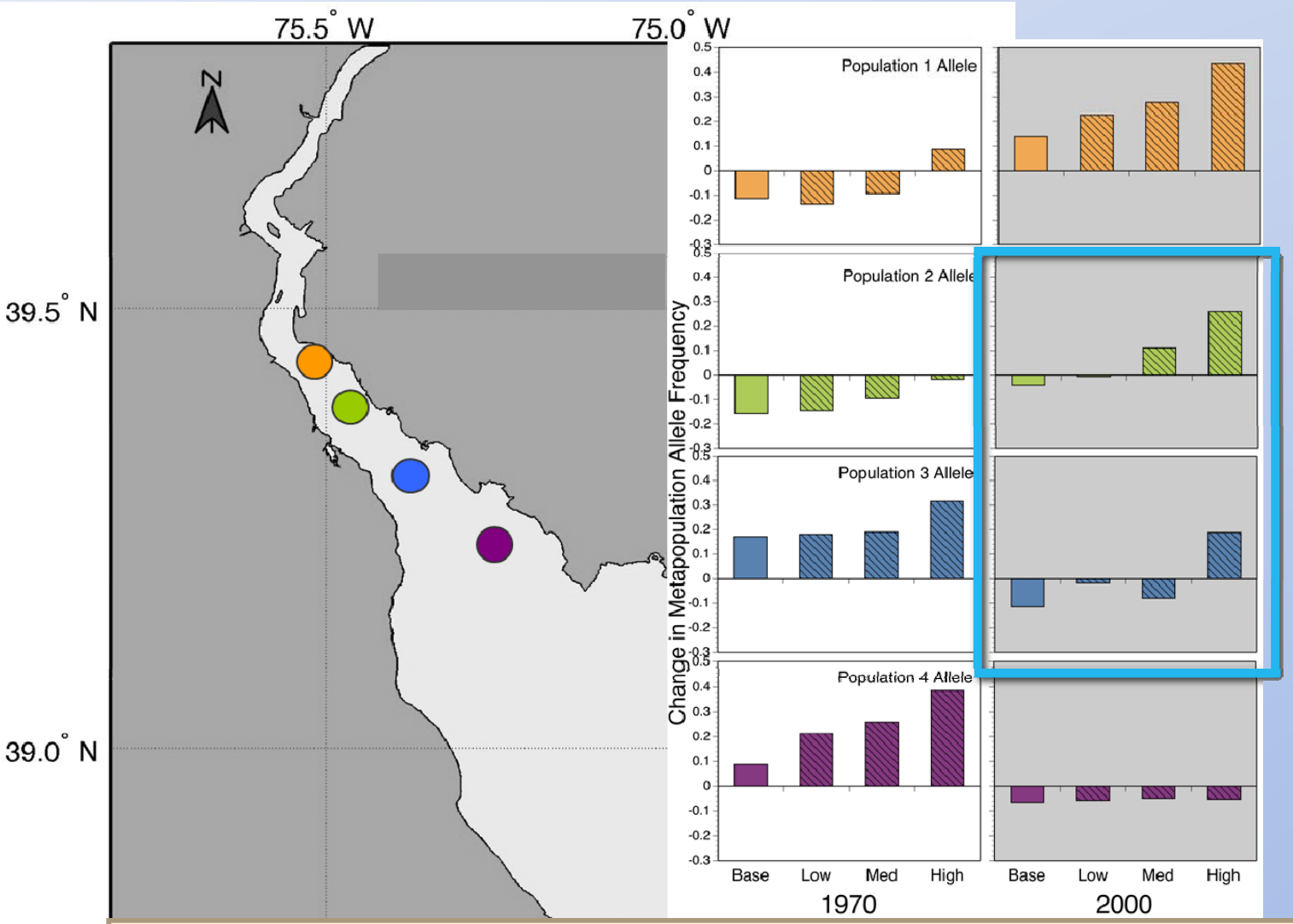




Munroe et al. (2013)




MPAs:

Can alter source:sink locations

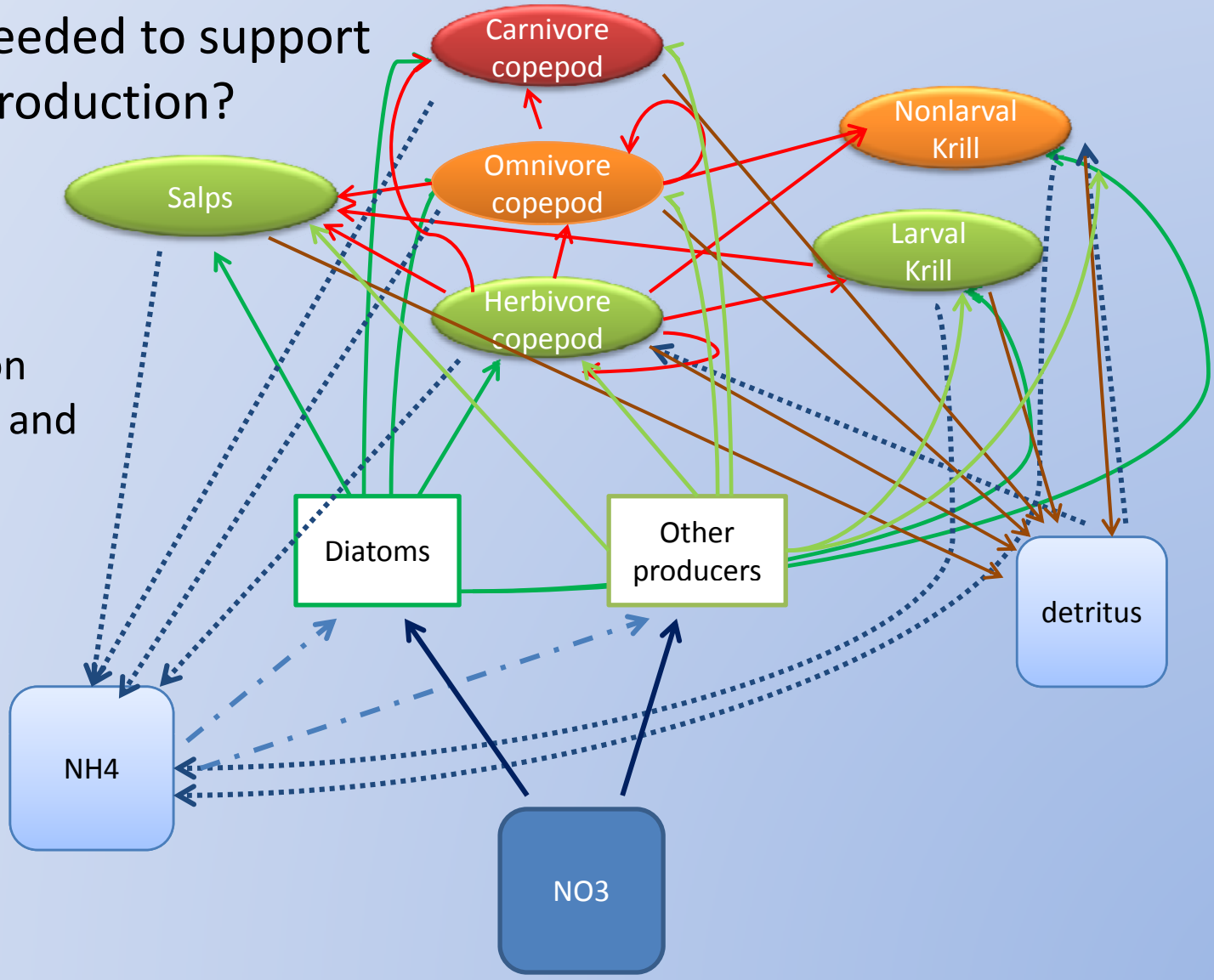
Munroe et al. (in press)

What role do MPAs play in genetic connectivity?

# Bottom –up view of the lower food web

What is needed to support primary production?

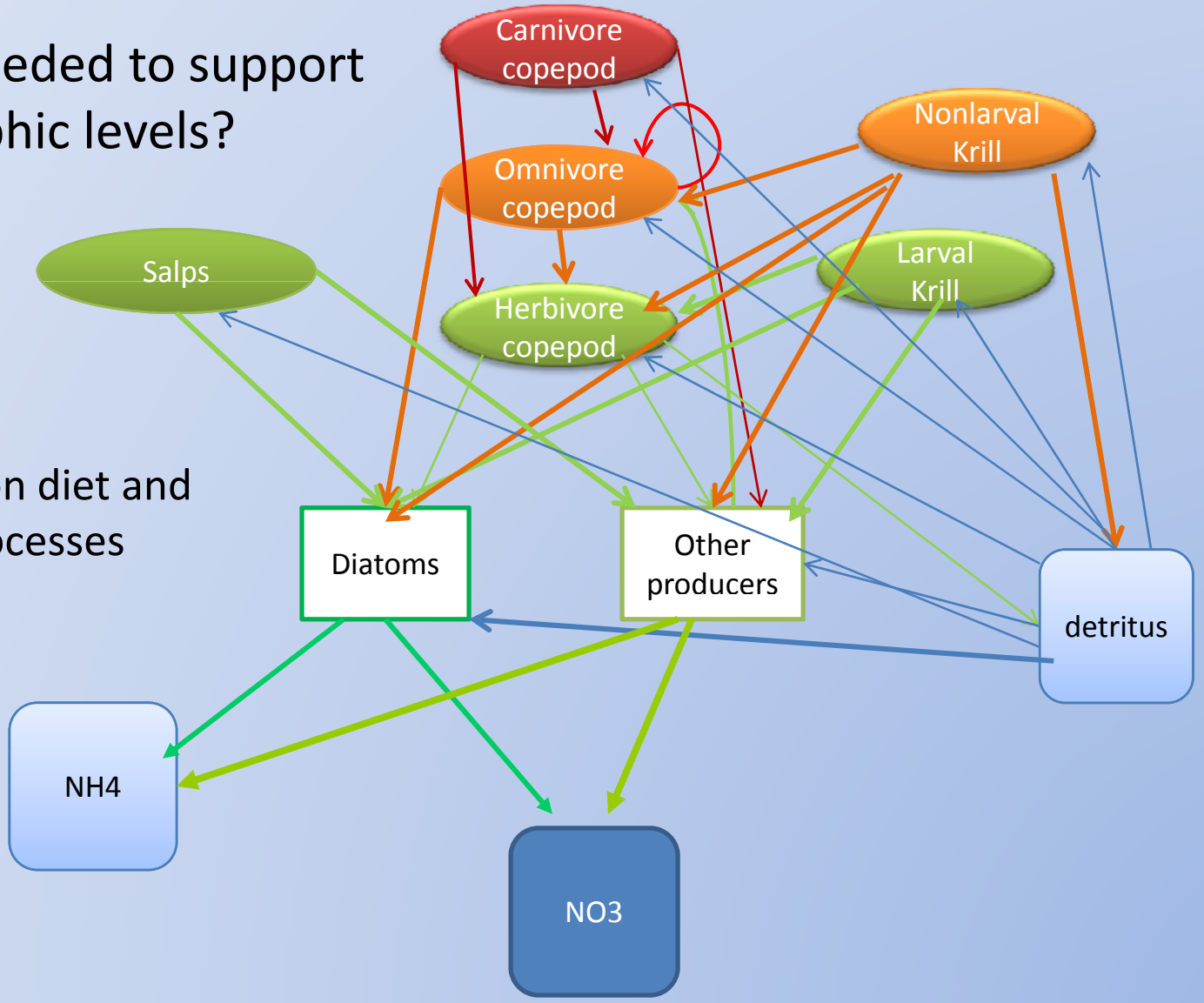
Emphasis on production and export



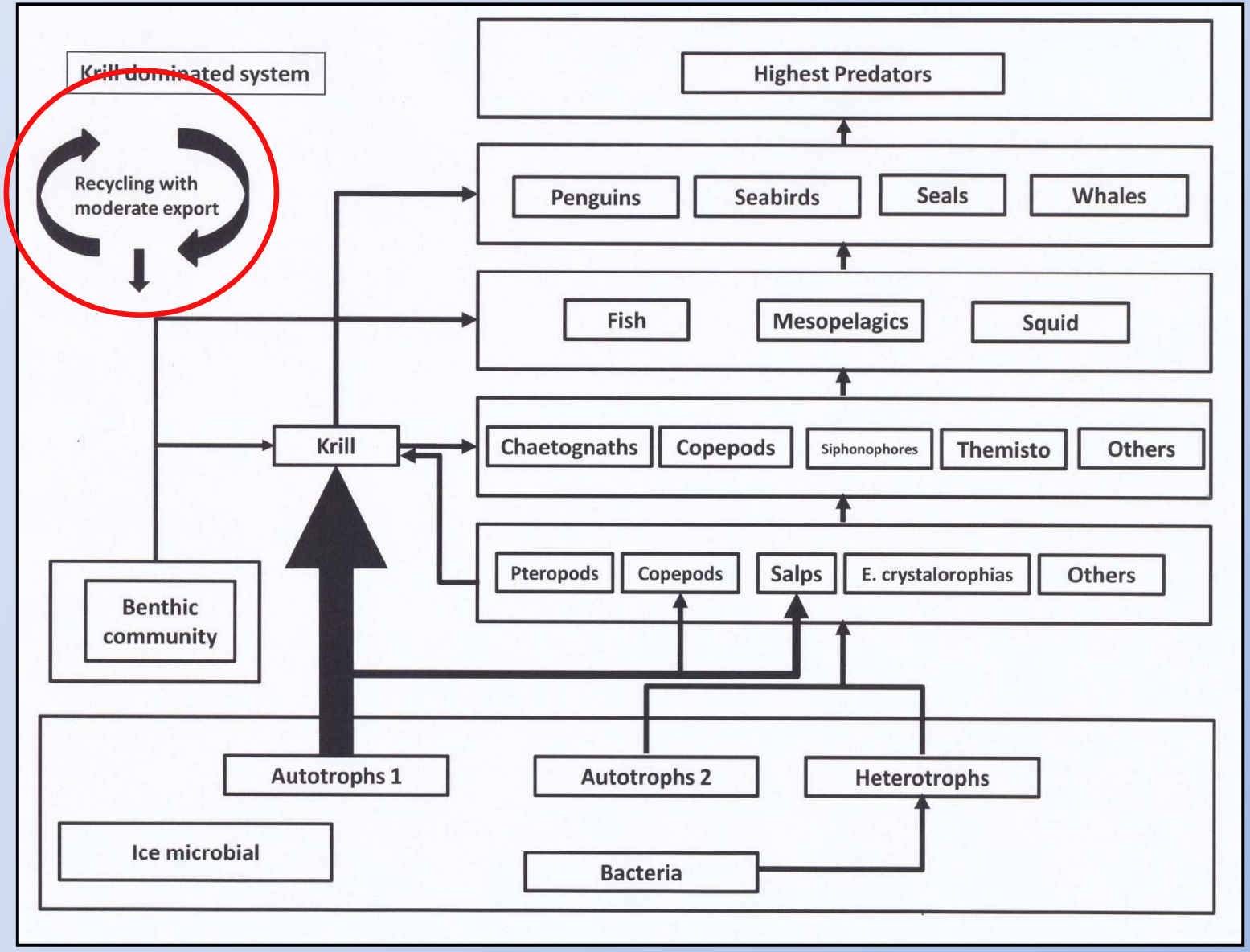
# Top-down view of the lower food web

What is needed to support upper trophic levels?

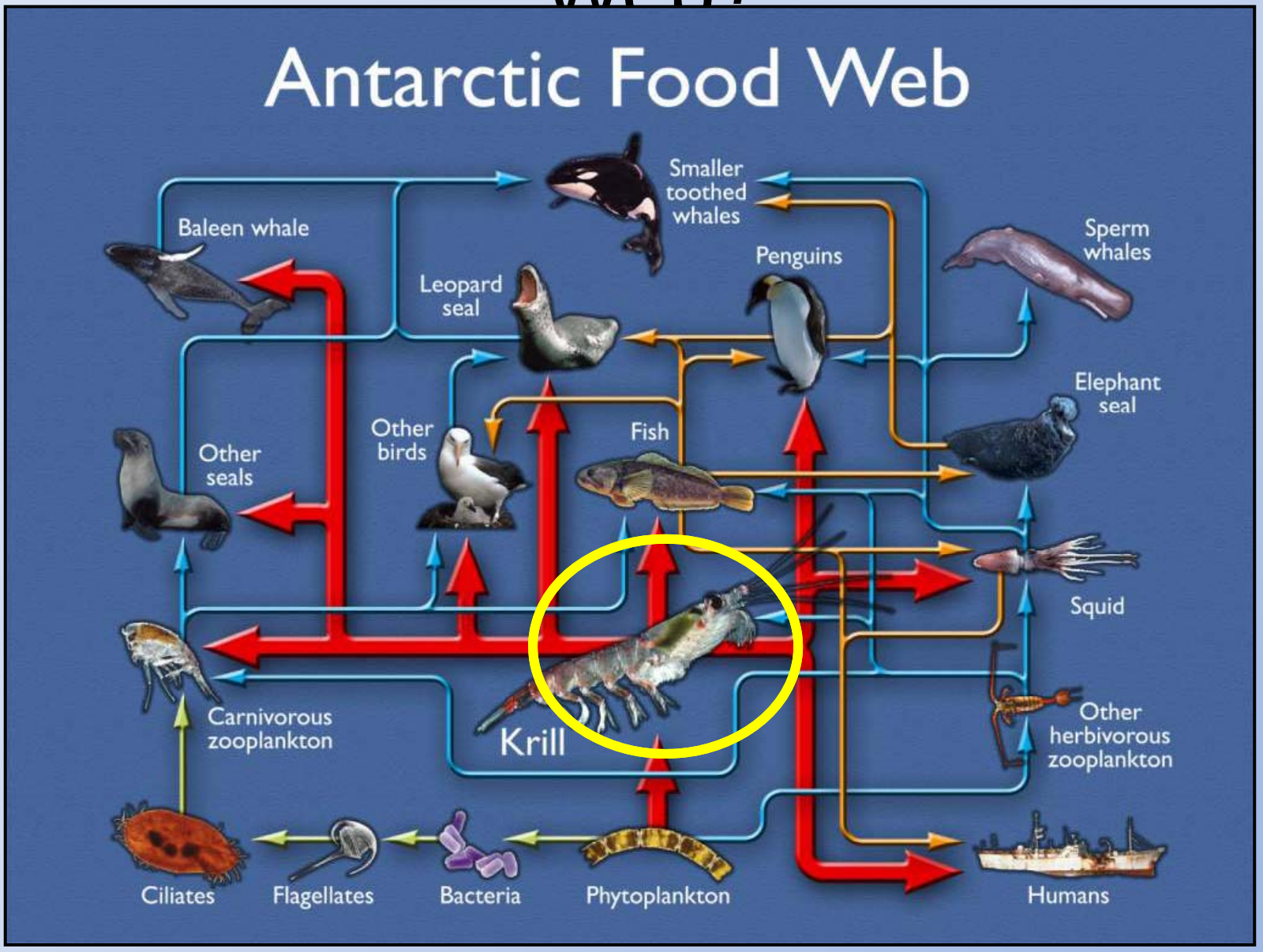
Emphasis on diet and feeding processes



# Couple Food Webs and Biogeochemcial Cyclin



# What is a Southern Ocean Food Web?

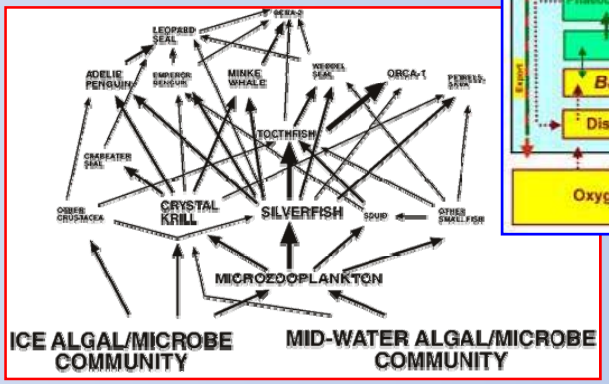


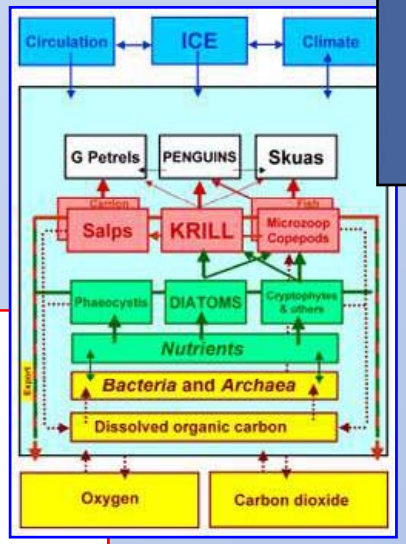
# Range of Food Webs

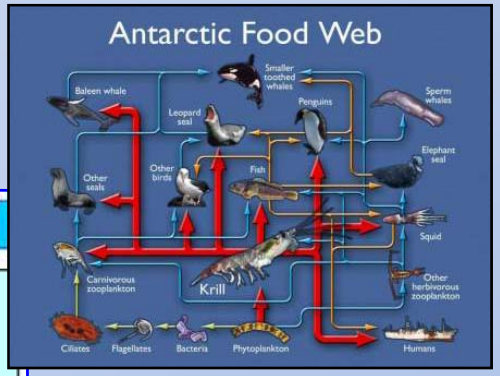
Sub Antarctic

Seasonal length

High Antarctic



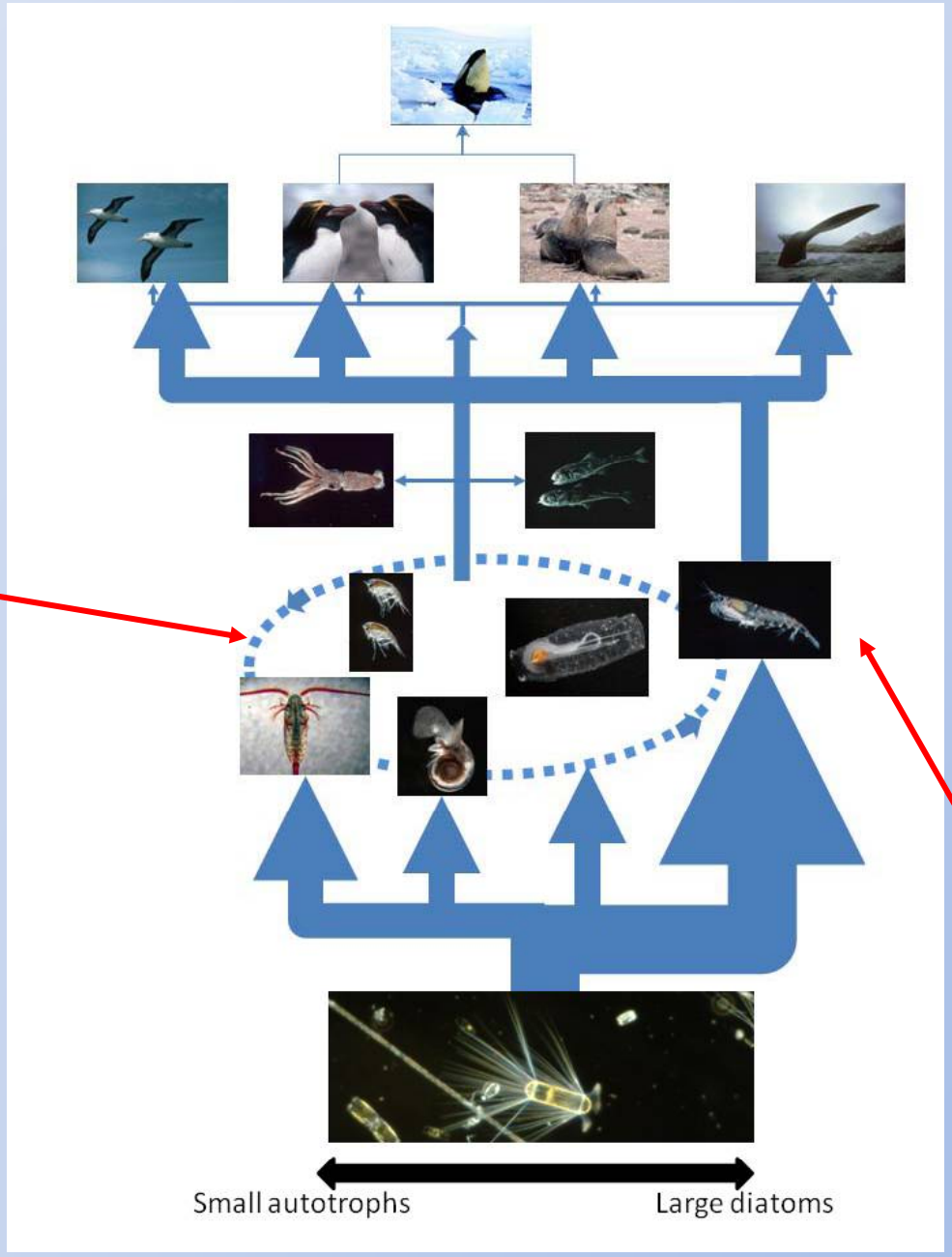




Differences due to
Circulation
Sea-ice
Biogeochemistry
Production
Seasonality

Low Production

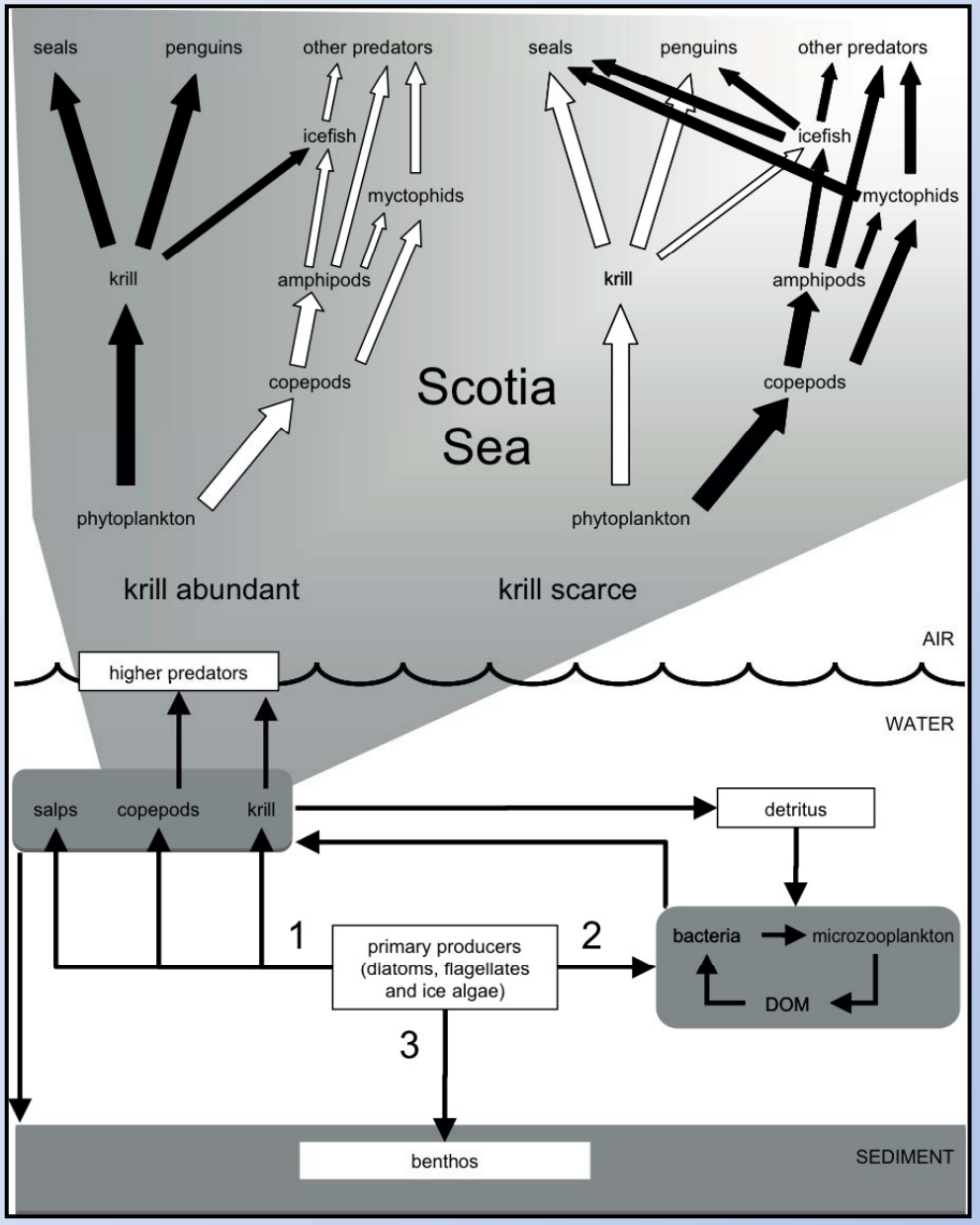
High Production

A range of alternative pathways of energy flow through the zooplankton and nekton communities are crucial in maintaining food web structure




Antarctic krill provide efficient energy transfer to highest trophic levels

Murphy et al. (2013)



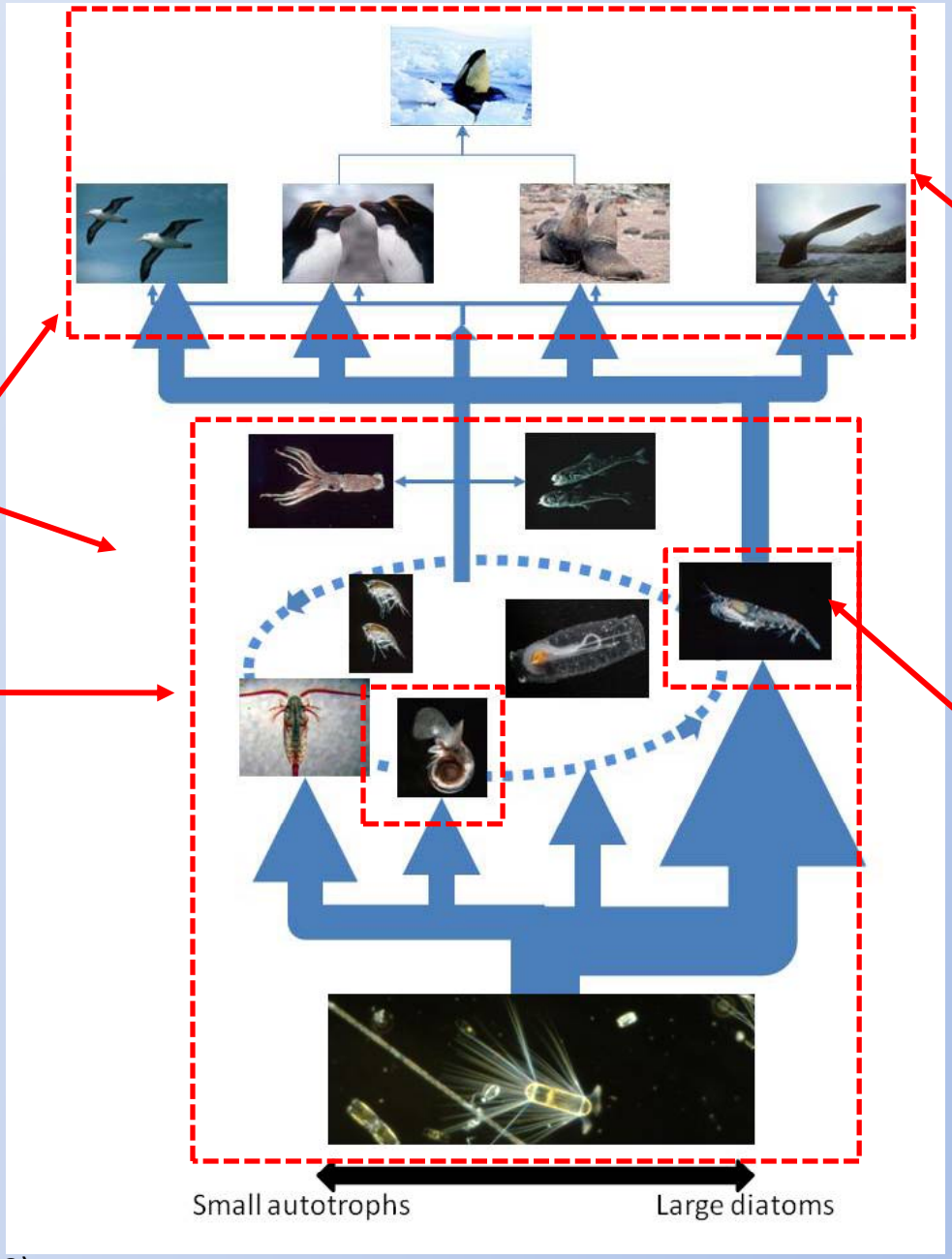

Alternative food web structures

Implications for production and maintenance of predators

Understand the causes for change and key processes

Habitats change and life cycles disrupted

Warming and pH impacts physiology and adaptive capacity




Historical impacts of harvesting (e.g. whale numbers increasing)

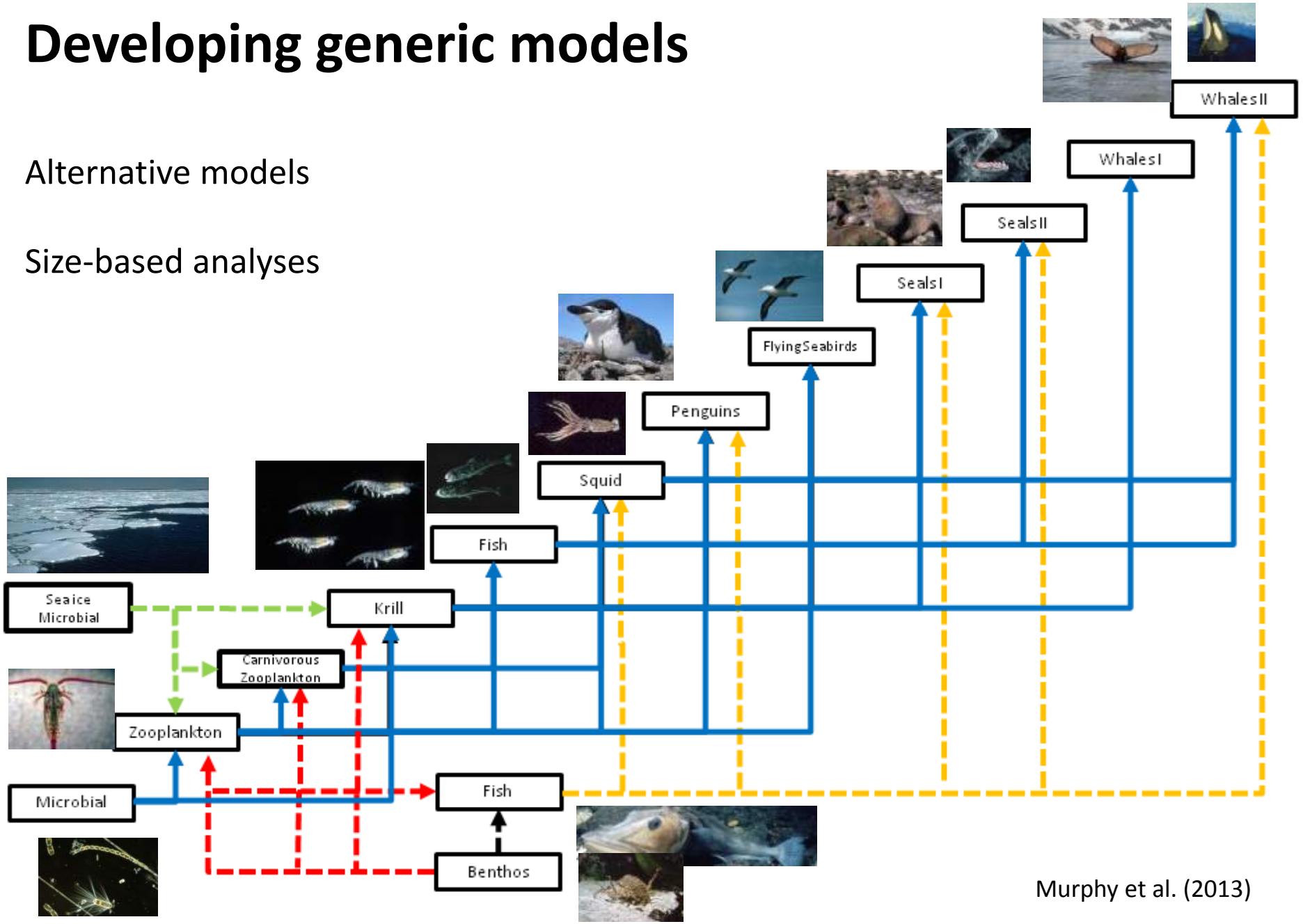
Current fishing impacts food web interactions

Murphy et al. (2013)

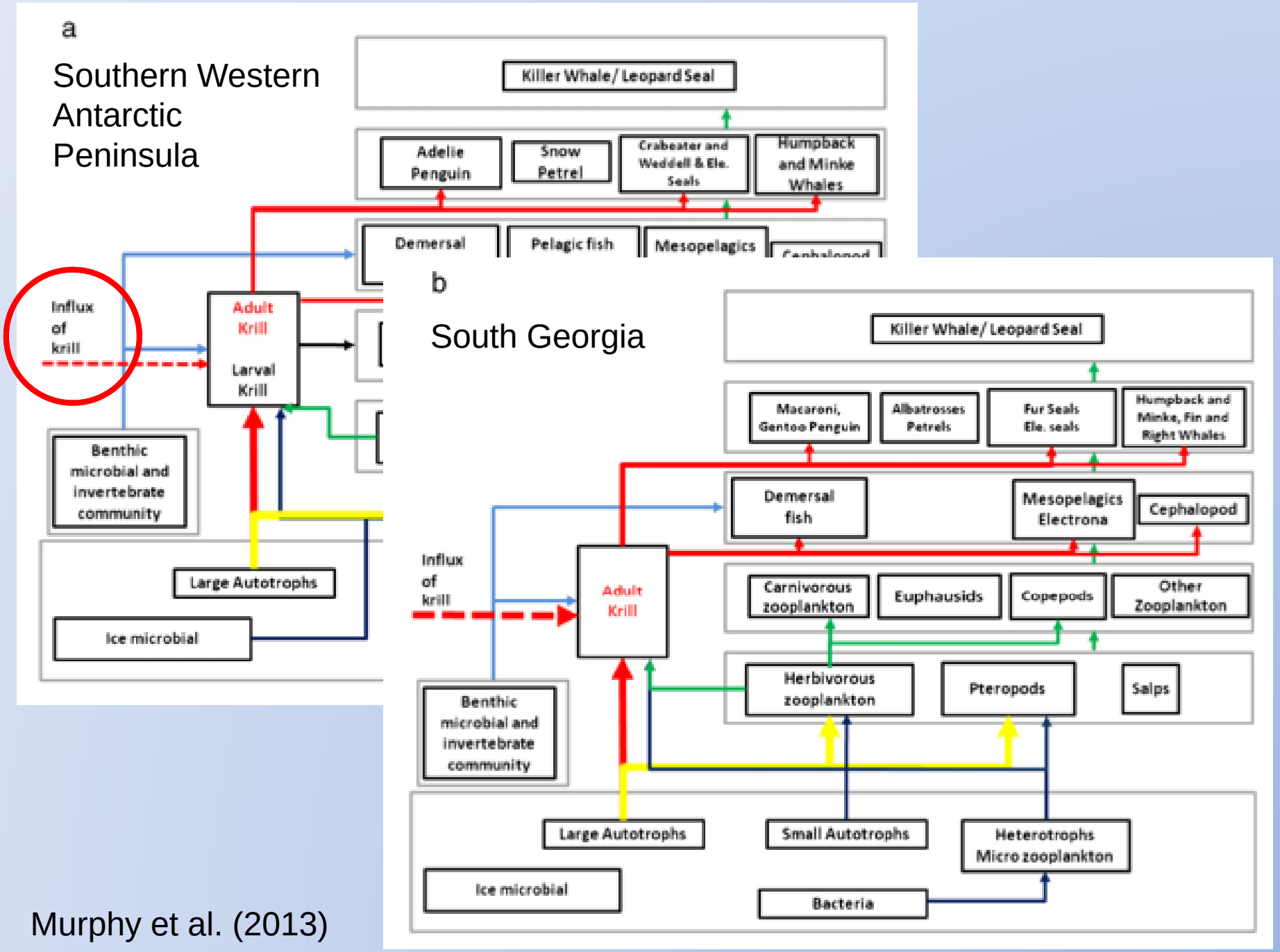
# Developing generic models

Alternative models

Size-based analyses




Murphy et al. (2013)



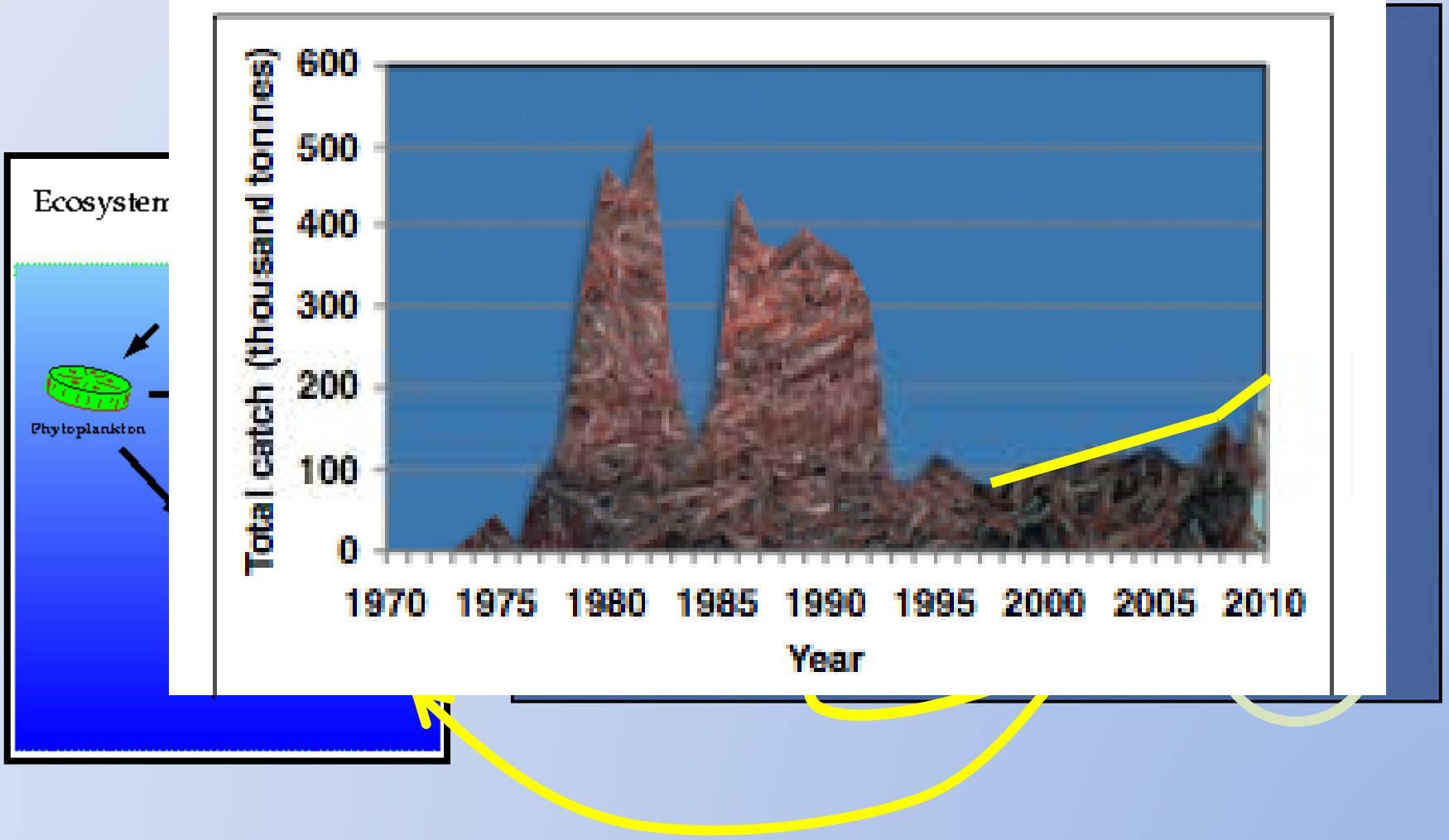

Murphy et al. (2013)

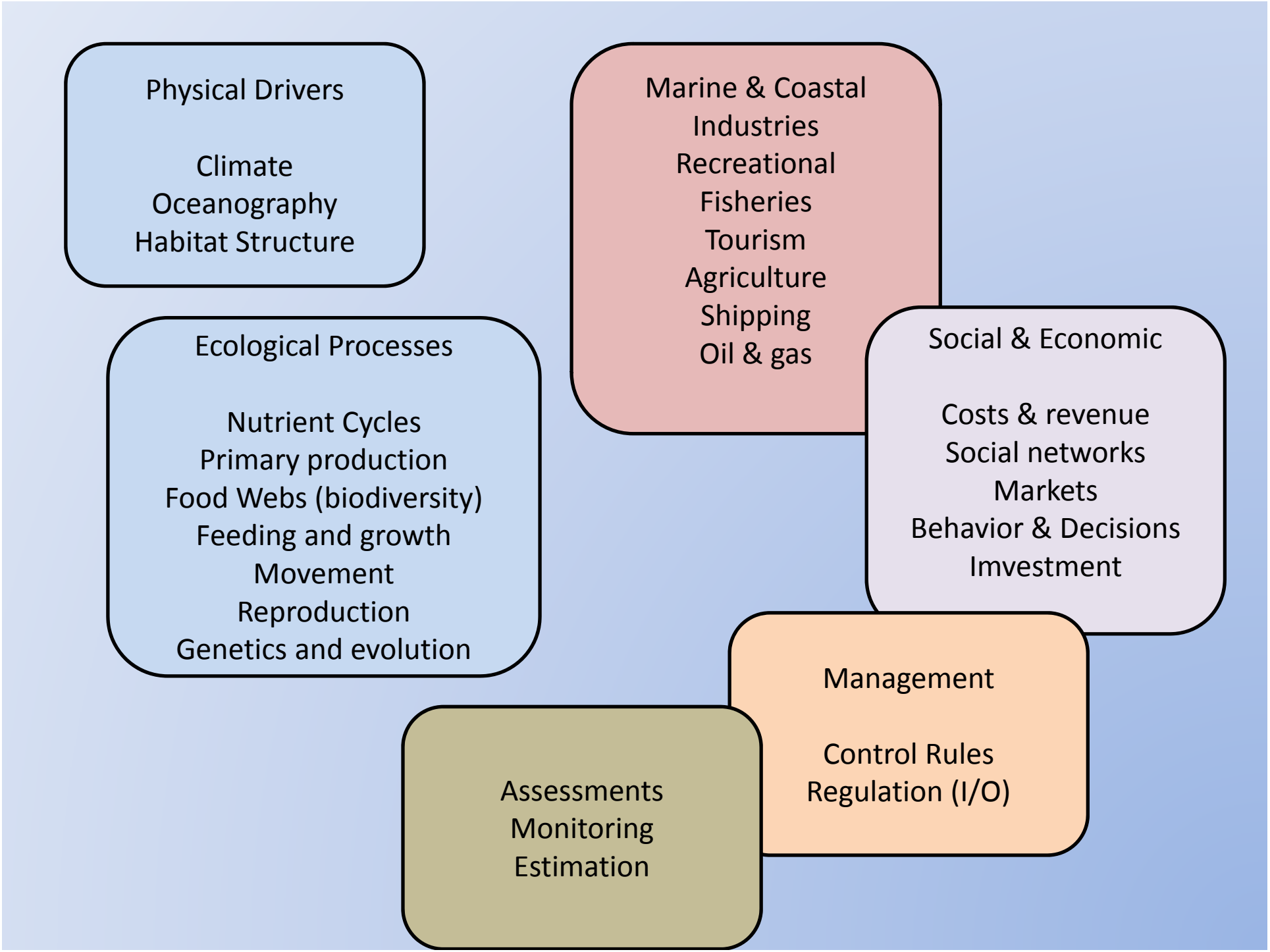
| Biomass (g C $m^{-2}$) | Predator group with doubled biomass | Surplus/deficit production (%) |
|---|---|---|
| 1.6 | Initial values in Table 1 | -9 |
| 3.2 | Initial values in Table 1 | +46 |
| 3.2 | Cephalopods | +14 |
| 3.2 | Off-shelf pelagic fish | +33 |
| 3.2 | On-shelf pelagic fish | +19 |
| 3.2 | Benthic fish | +8 |
| 3.2 | All fish and cephalopods | -1 |
| 3.2 | All seabirds and marine mammals | +33 |
| 3.2 | All fish, cephalopods, seabirds and marine mammals | -5 |

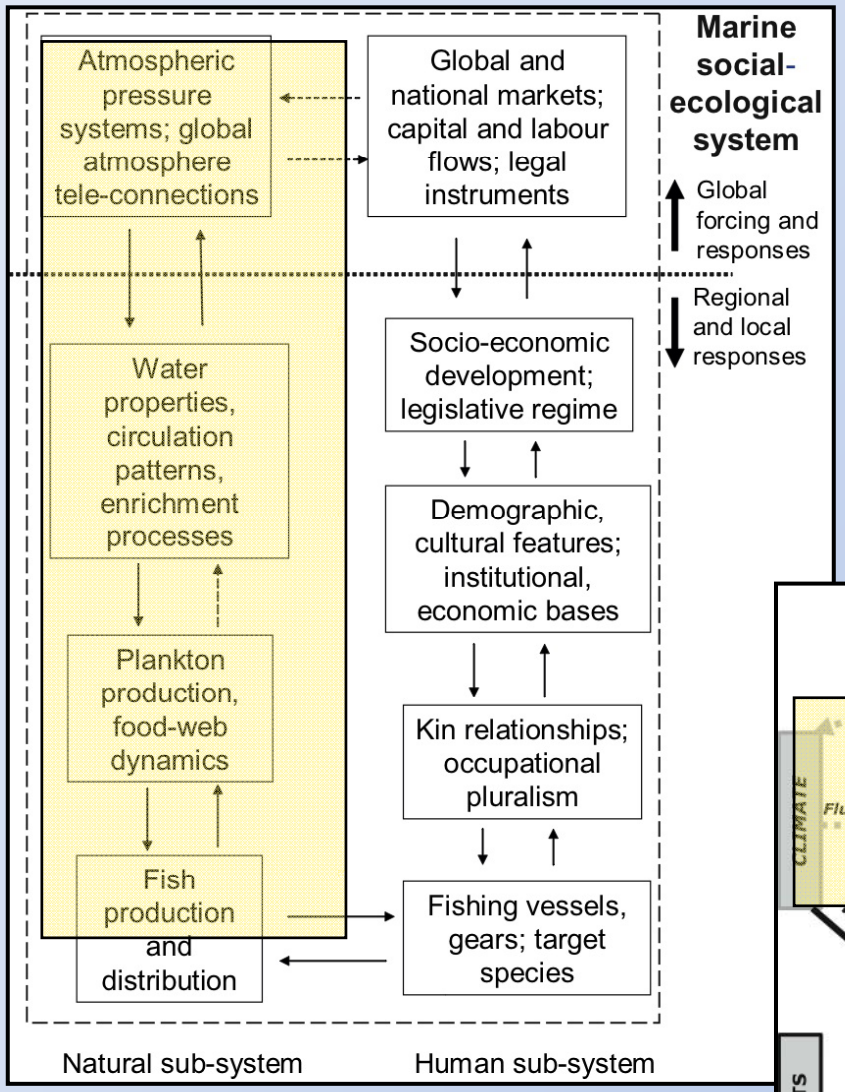
Ballerini et al. (submitted)

Southern western Antarctic Peninsula

# Relevance?

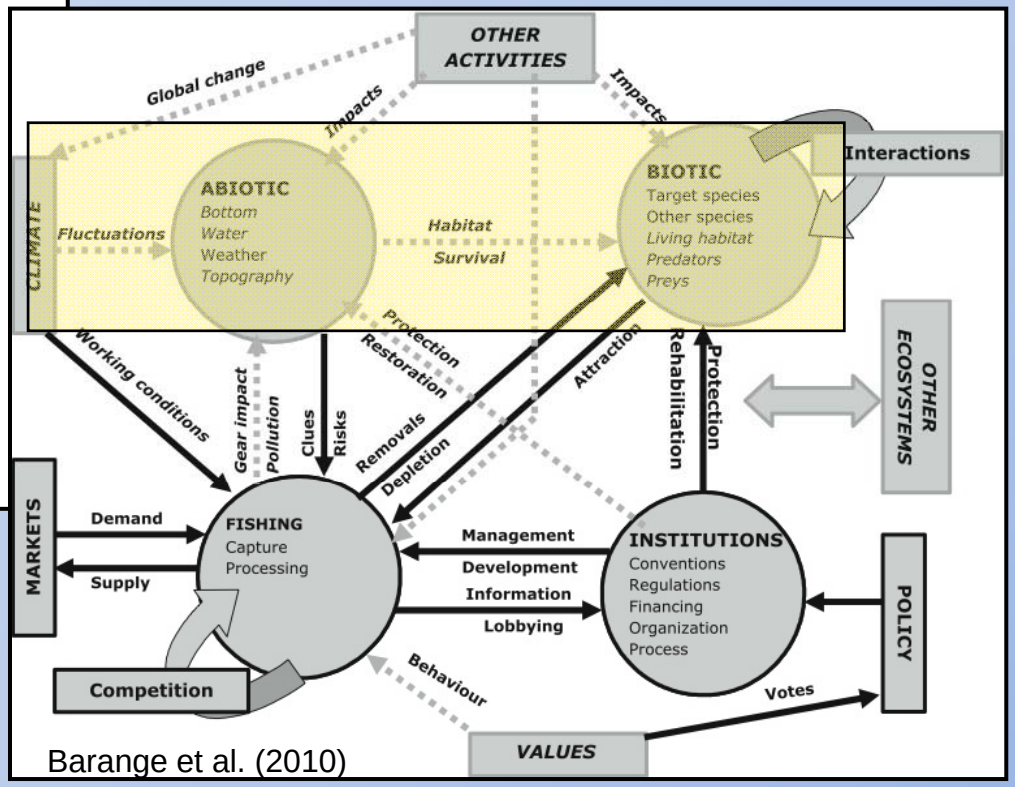

Ecosystem
Phytoplankton
Total catch (thousand tonnes)
600
500
400
300
200
100
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


Physical Drivers
Climate
Oceanography
Habitat Structure
Marine & Coastal
Industries
Recreational
Fisheries
Tourism
Agriculture
Shipping
Oil & gas
Ecological Processes
Nutrient Cycles
Primary production
Food Webs (biodiversity)
Feeding and growth
Movement
Reproduction
Genetics and evolution
Social & Economic
Costs & revenue
Social networks
Markets
Behavior & Decisions
Imvestment
Management
Control Rules
Regulation (I/O)
Assessments
Monitoring
Estimation




Perry et al. (2010)

# Understanding has evolved to recognize that need to include humans as part of the marine food web

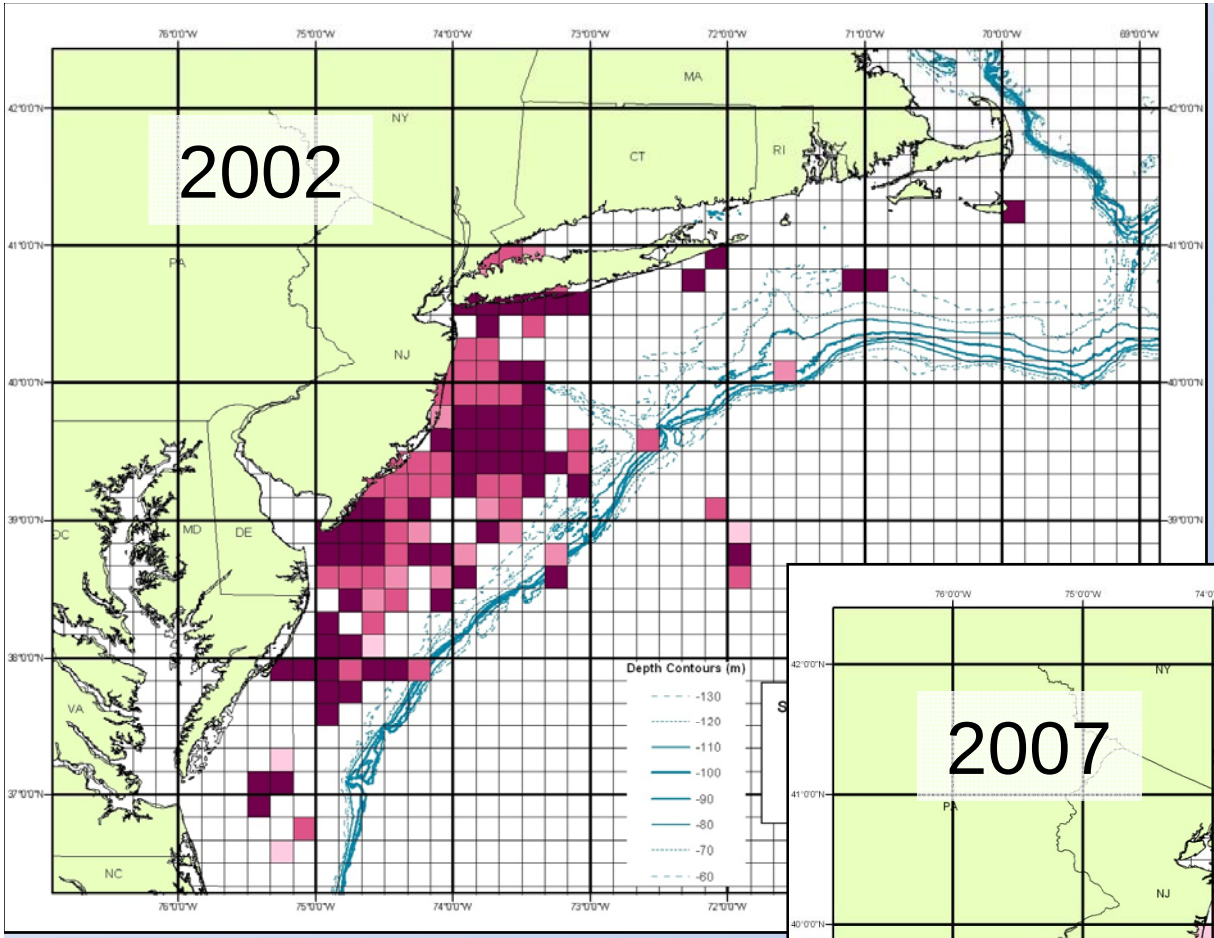


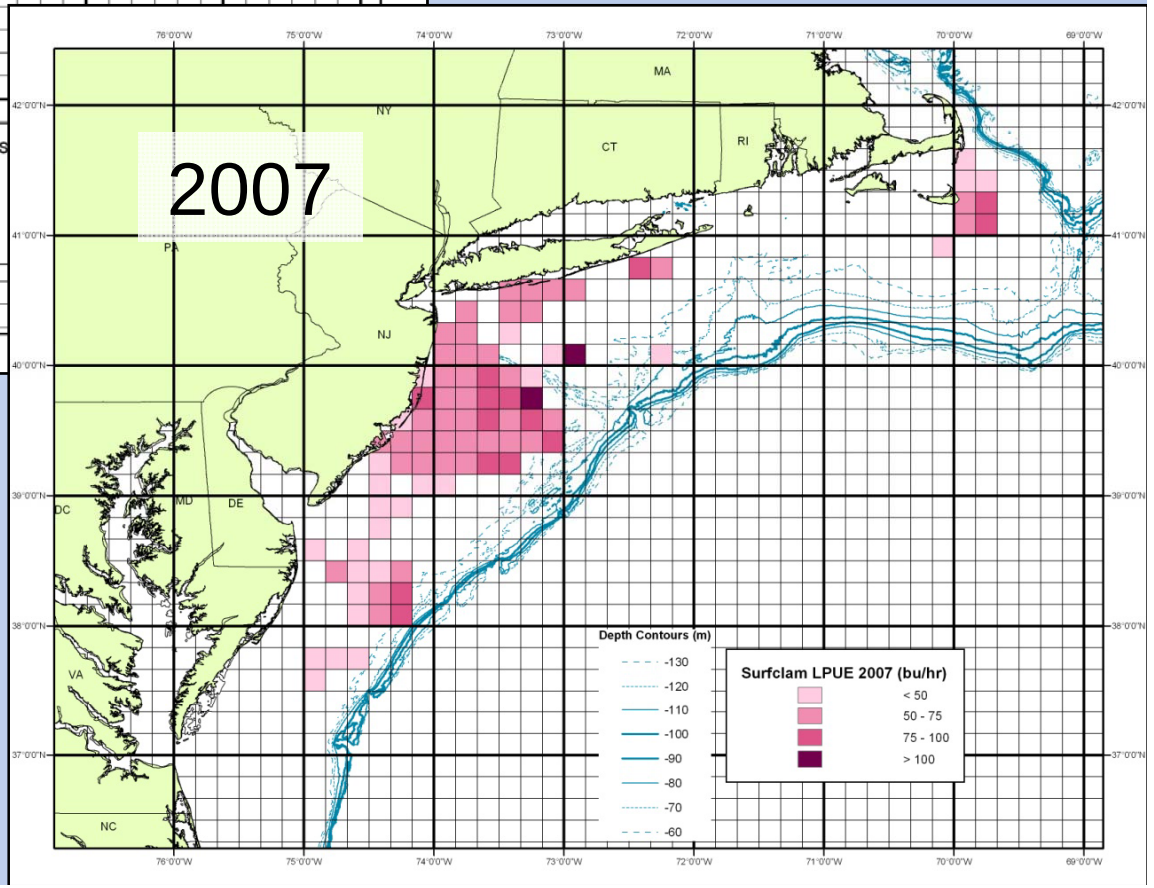

Barange et al. (2010)

Importance of top predators including humans

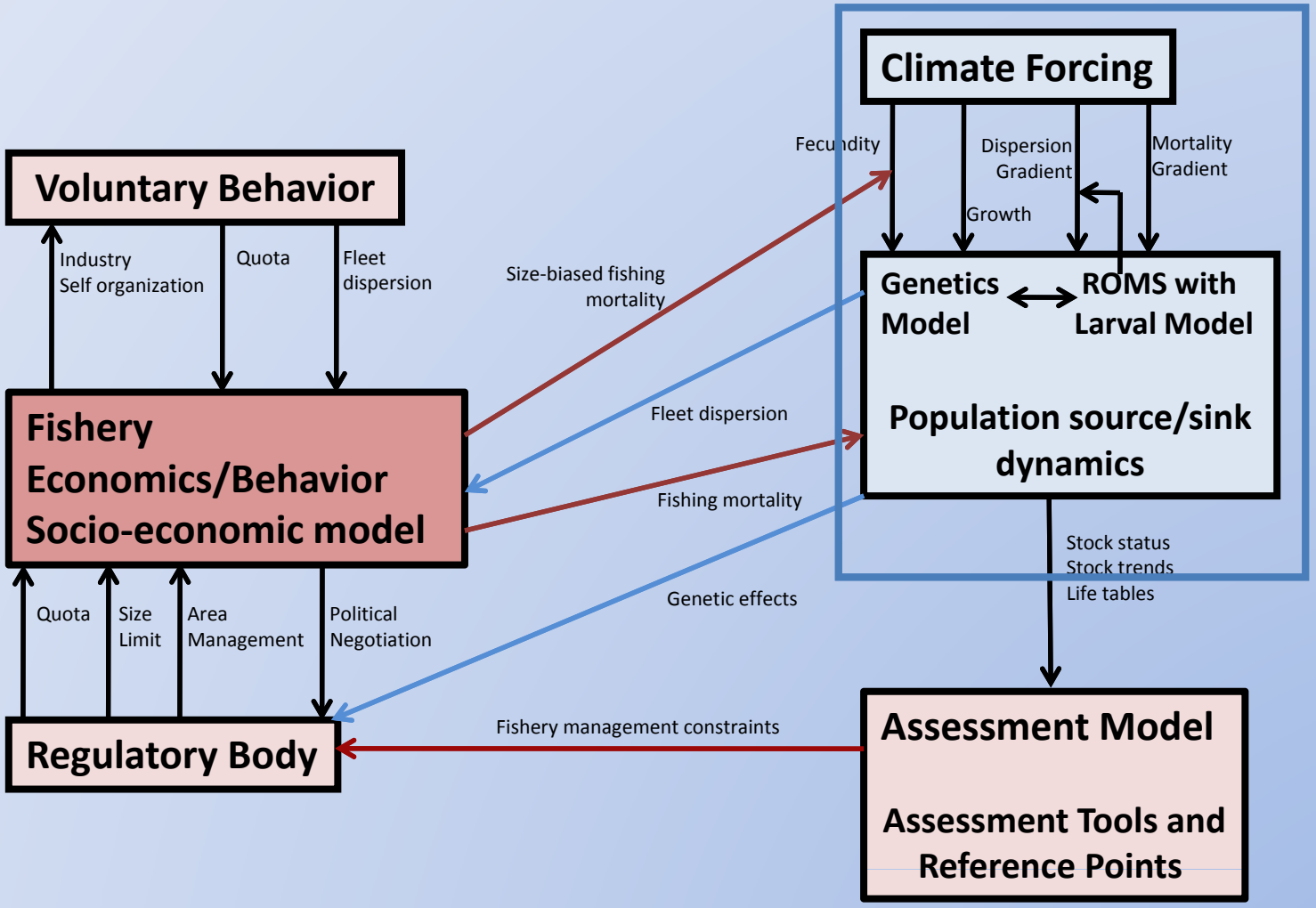
# Surfclam Landings

## US East Coast Mid-Atlantic Bight

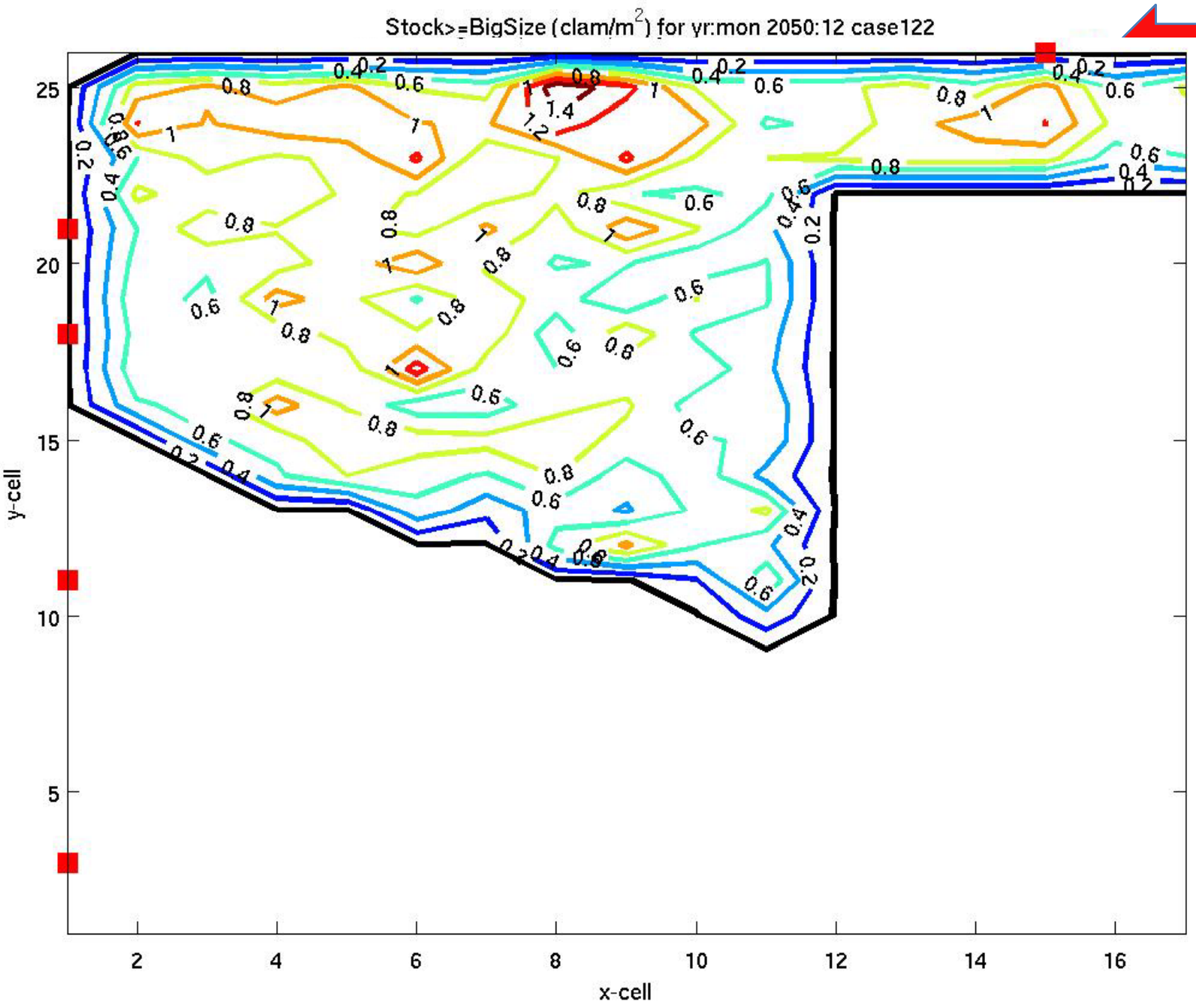


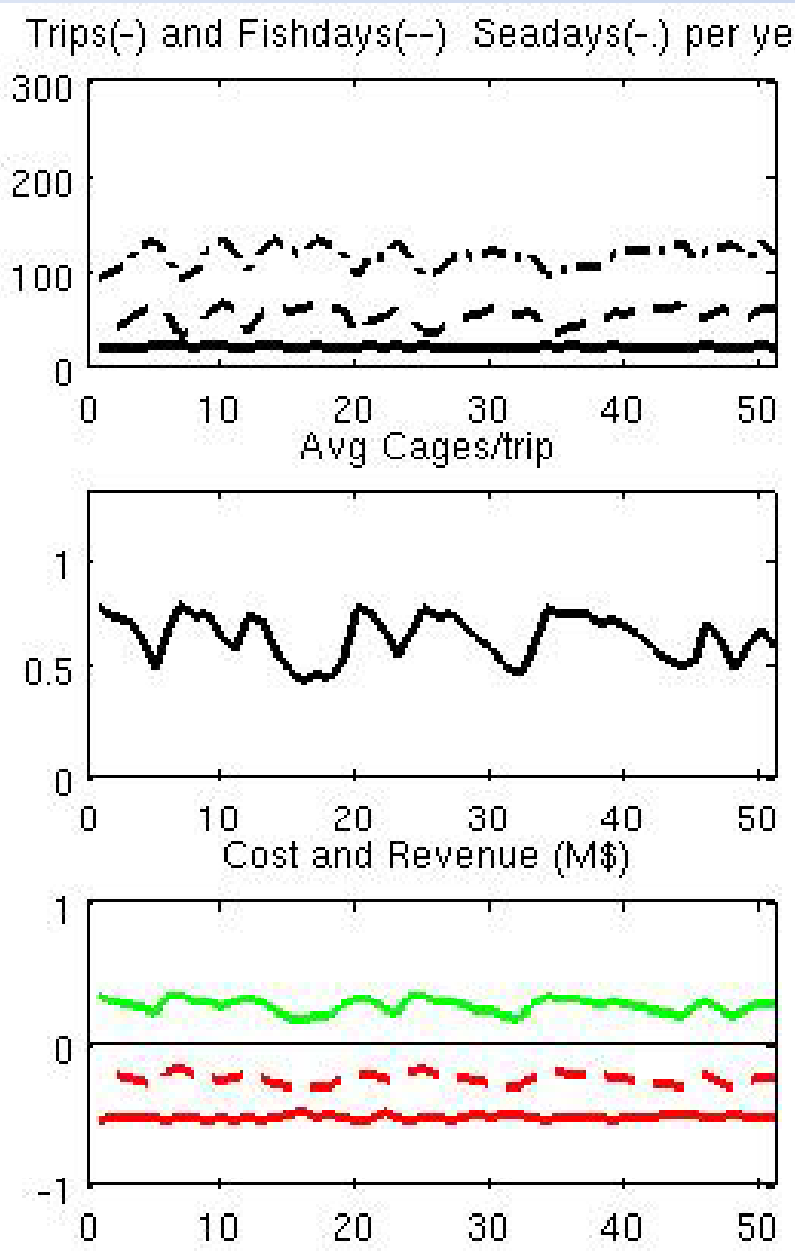



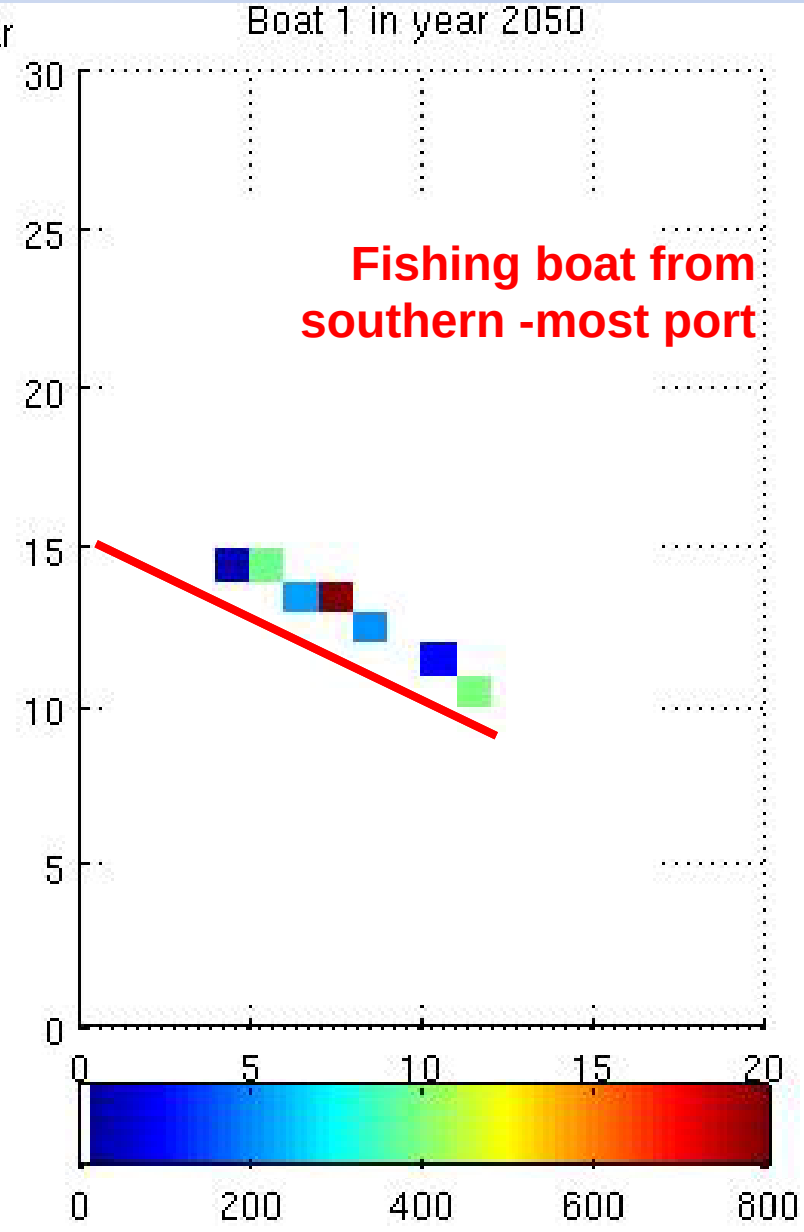

- Reduction in abundance
- Northward population shift



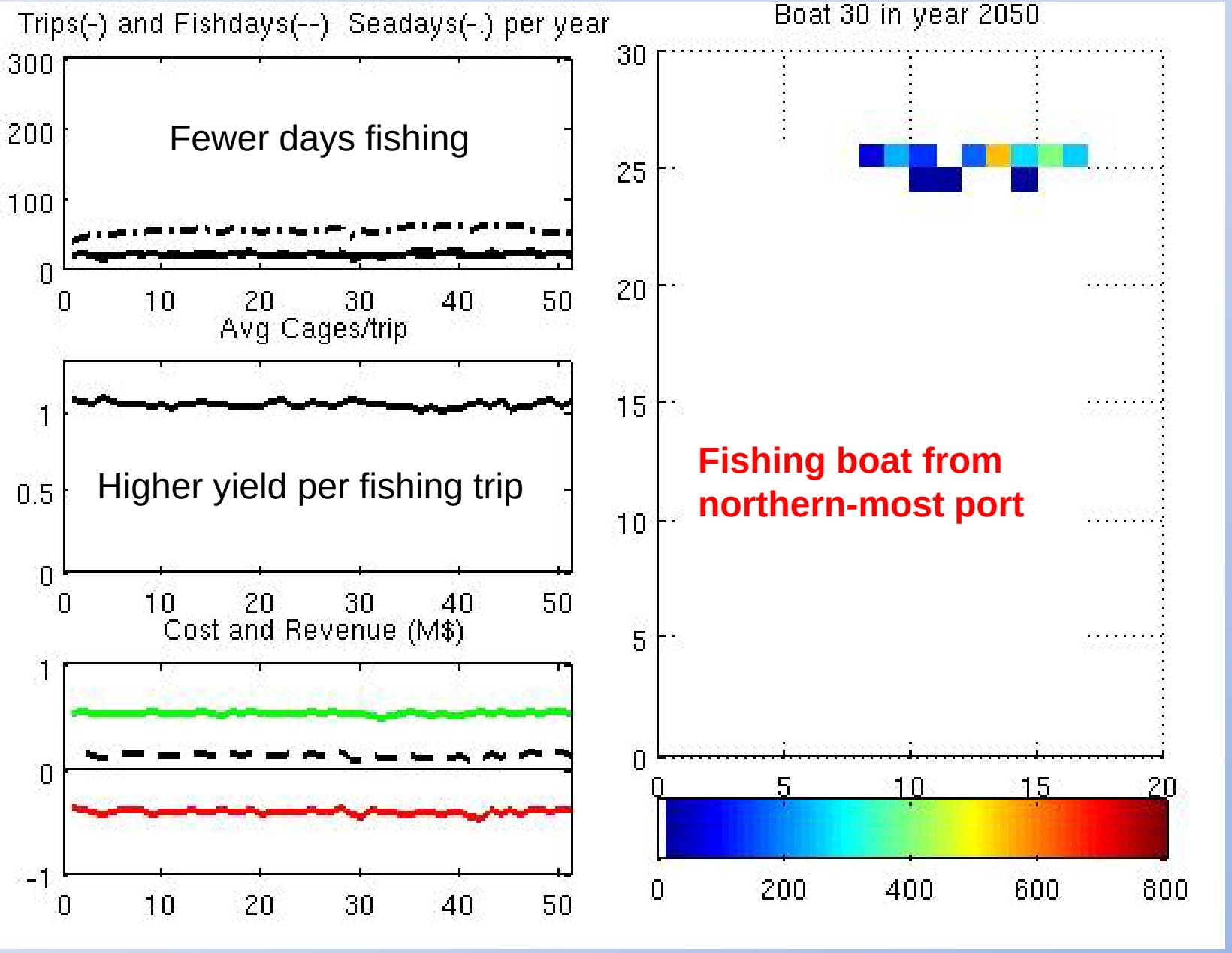

Framework for coupled climate-ocean-surfclam-fishery economics model


Stock>=BigSize (clam/m$^2$) for yr:mon 2050:12 case122
y-cell
x-cell
25
20
15
10
5
2
4
6
8
10
12
14
16




**Fishing boat from southern -most port**


Trips(-) and Fishdays(--) Seadays(-.) per year
300
200
100
0
Fewer days fishing
0 10 20 30 40 50
Avg Cages/trip
1
0.5
0
Higher yield per fishing trip
0 10 20 30 40 50
Cost and Revenue (M$)
1
0
-1
0 10 20 30 40 50
Boat 30 in year 2050
30
25
20
15
10
5
0
0 5 10 15 20
0 200 400 600 800
Fishing boat from northern-most port

# Summary Comments

- Ecosystems result from interactions across multiple scales
- Comparative studies provide insights beyond those from single system study
- Target species approach allows picking out key processes - compare with other systems
- Top predators, including humans, are integral parts of food web
- Physical, biological, observational, and observational communities focused on integrated research programs

# Summary Comments

- Need for physical, biological, observational, and observational communities focused on integrated research programs
- Management of natural marine resources must include climate change and address extensive socio-economic implications
- Development of a community that can work at the interface between natural and human sciences

# Future Directions

## Next challenge

Provide **meaningful** forecasts and projections
of marine population variability and response to
climate change and human impacts

| | | |
|---|---|---|
| Climate (JGOFS & IMBER) | Heat Distribution/ Biogeochemistry | Budgets/ Elemental cycles |
| Weather (GLOBEC & IMBER) | Synoptic patterns/ Population dynamics | Events/ Species |

## Human-ocean-human interactions

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# How to build and use individual-based models (IBMs) as hypothesis testing tools

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# Scale issues in marine ecosystems and human interactions

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these issues of ecosystem processes and human interactions, and their appropriate scales.

**Key words:** fisheries, inter-discipline, management, natural science, scales, social science, space, time

# Thanks


**Photos by D. Costa**