Fisheries variability and its physical drivers

(From physics to fish and from weather to climate)

Cisco Werner
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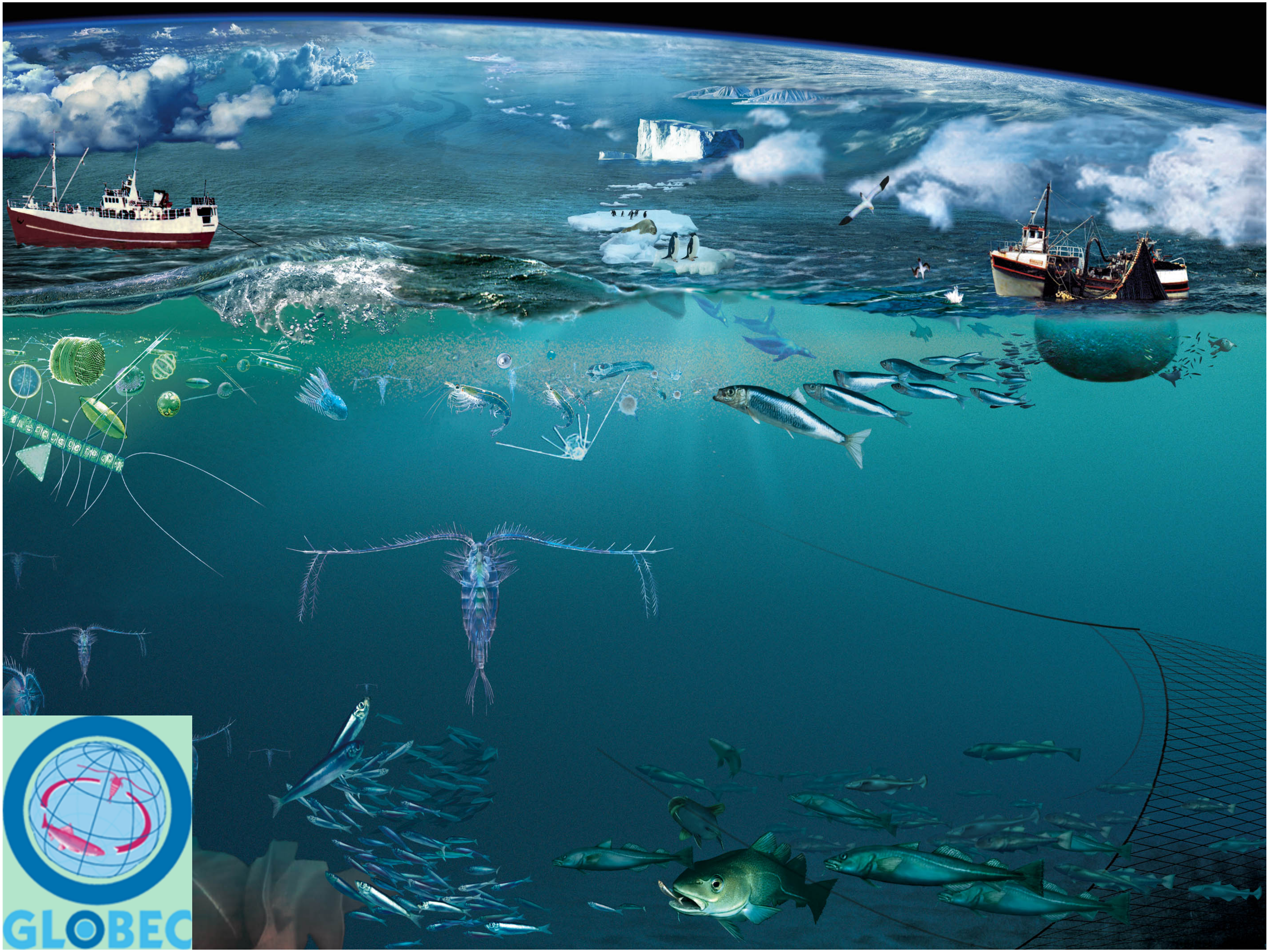

GLOBEC

Questions (from Agenda)

- To what extent have the linkages between climate and fisheries been made (and verified)?
- What mechanisms must be captured by climate models to diagnose fisheries fluctuations?
- What information can ecosystem models provide for prominent fisheries issues?
- What information can present global scale models provide for coastal regions?

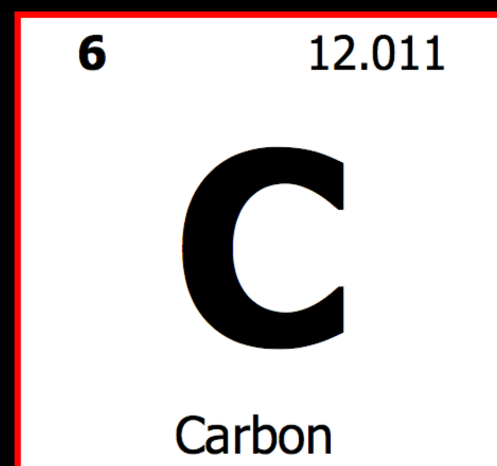
Climate/ "JGOFS"	Heat Distribution/ Biogeochemistry	Budgets/ Elemental cycles
Weather/ "GLOBEC"	Synoptic patterns/ Population dynamics	Events/ Species

JGOFS Goals

- To determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associated biogenic elements in the ocean…

- To develop a capacity to predict on a global scale the response to anthropogenic perturbations, in particular those related to climate change

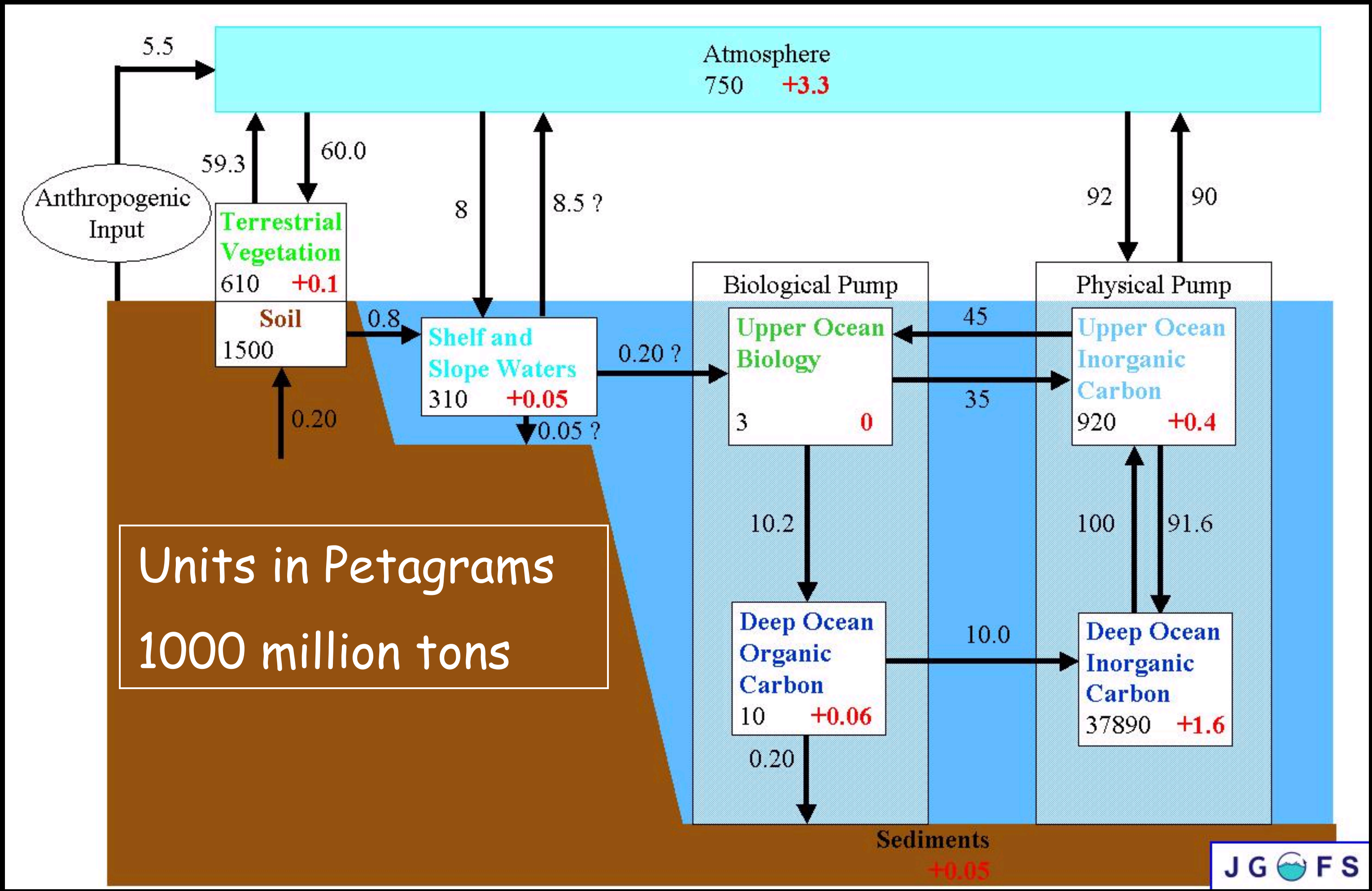
  [A set of models that express
  our understanding of the processes
  controlling large-scale carbon fluxes.]



Hardy's (1924) web untangled into functional groups

Yamanaka et al. (2005)

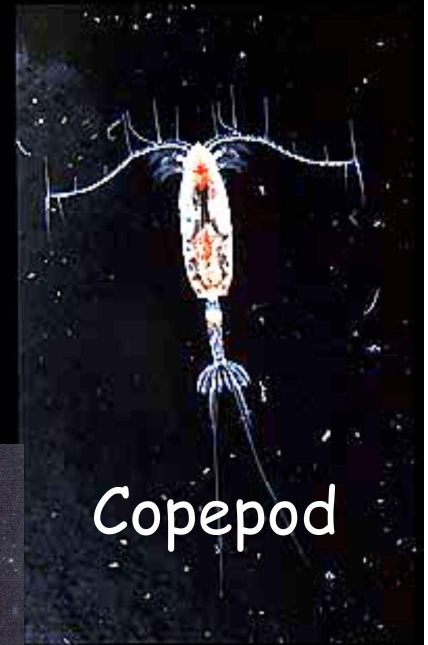
What is the role of ocean biology in determining the fate of anthropogenic CO_2?

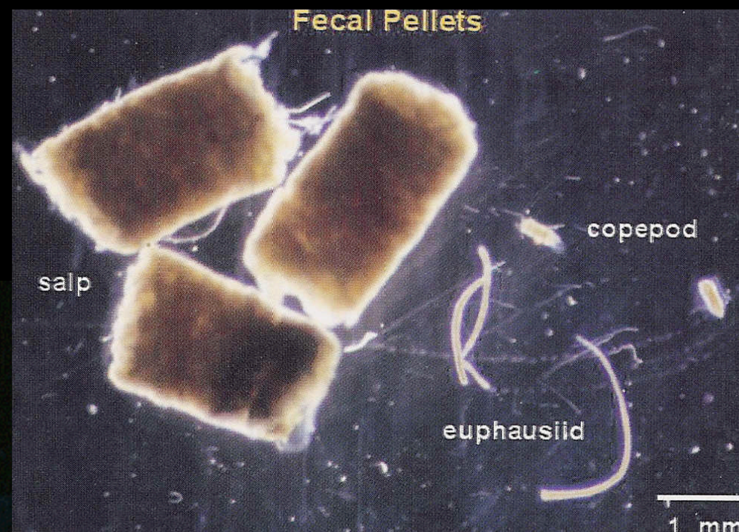


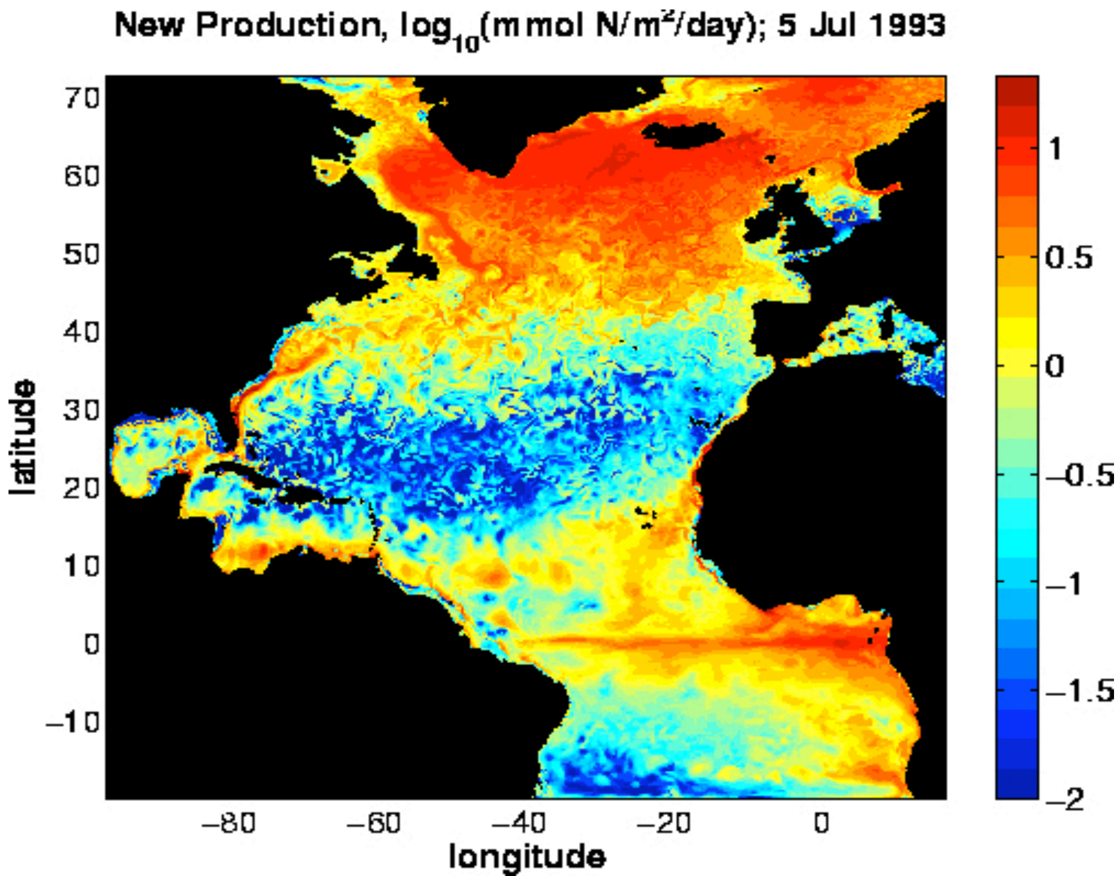
[Average annual fluxes between pools of carbon with standing stock in the black in the box and extra input from anthropogenic input in red.]

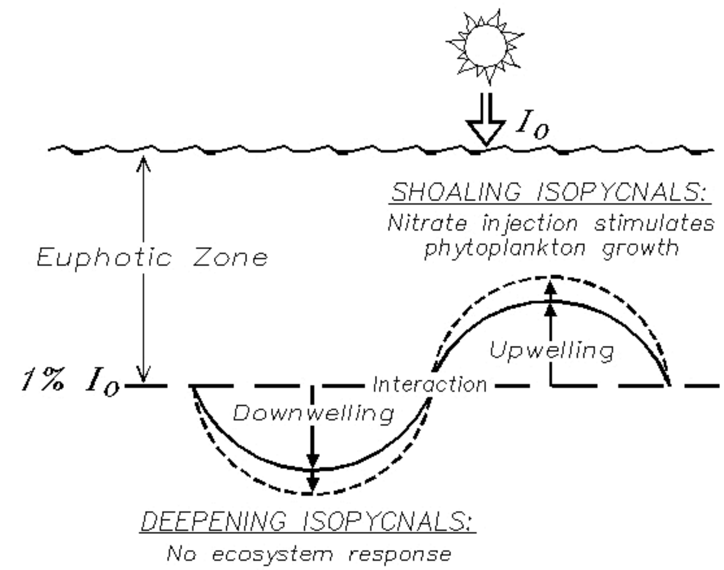
Species composition (not just biomass) affect sedimentation rate of sinking particles and flux of organic matter to the deep ocean

Ducklow, Steinberg and Bruessler (2001)





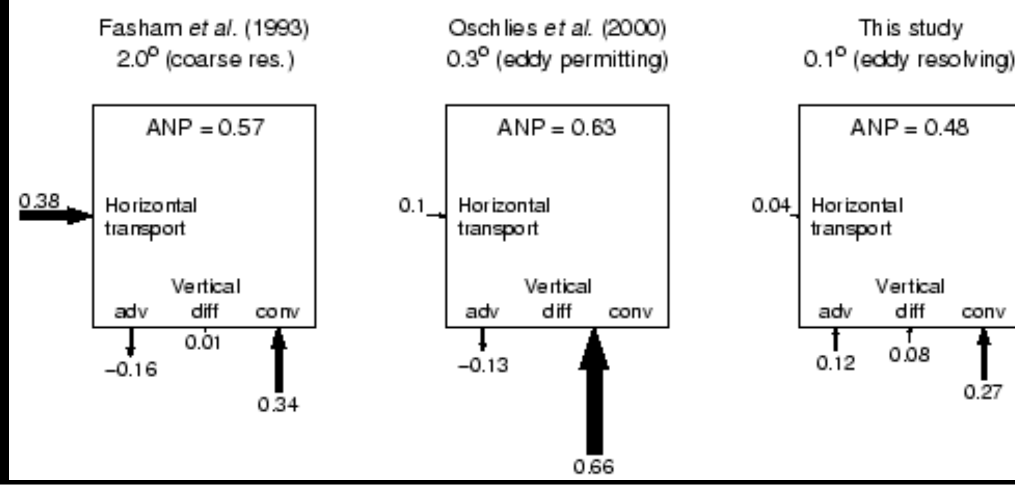




(McGillicuddy et al.)

New Production at BATS: Three Models, Three Different Nutrient Transport Pathways

Simulated Nitrate Budgets at BATS (euphotic zone integral)



"Challenges"

- Resolution: non-convergence of physics, biology and BGC, i.e., the solution depends on grid size and on (evolving) functional groups or lack thereof. [Rigidity of model structure – diversity.]

- Making models more complex does not result in improvements (e.g., Friedrichs et al.; Denman).

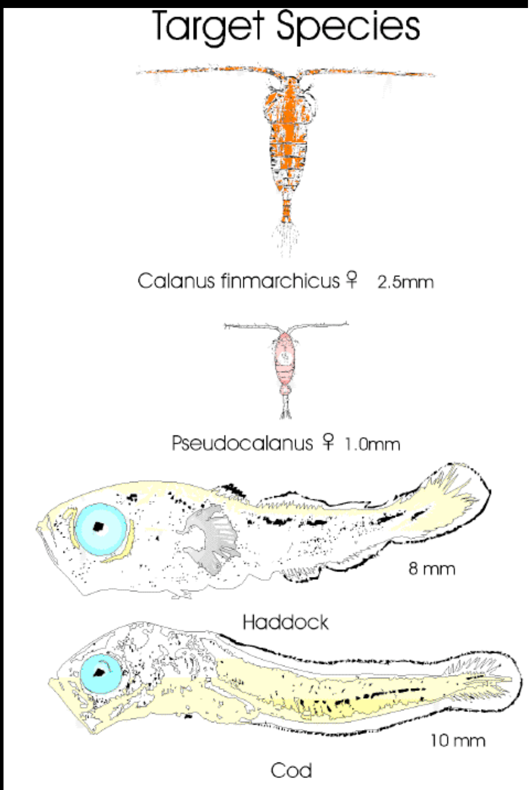
- "Too many" parameters - difficult (impossible?) to determine them and their spatial and temporal dependence, although formal fitting methods help.

- Prediction

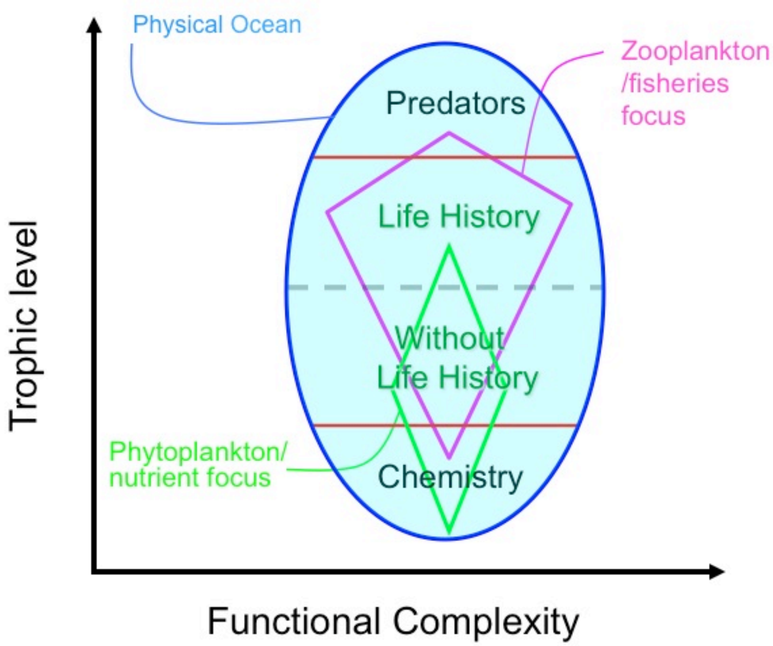
GLOBEC Goals

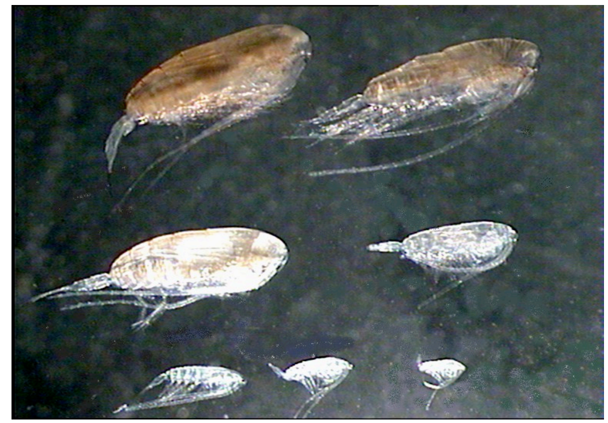
- To advance our understanding of the structure and function of the global ocean ecosystem, its major subsystems, and its response to physical forcing so that
- a capability can be developed to forecast the responses of the ecosystem to global change.

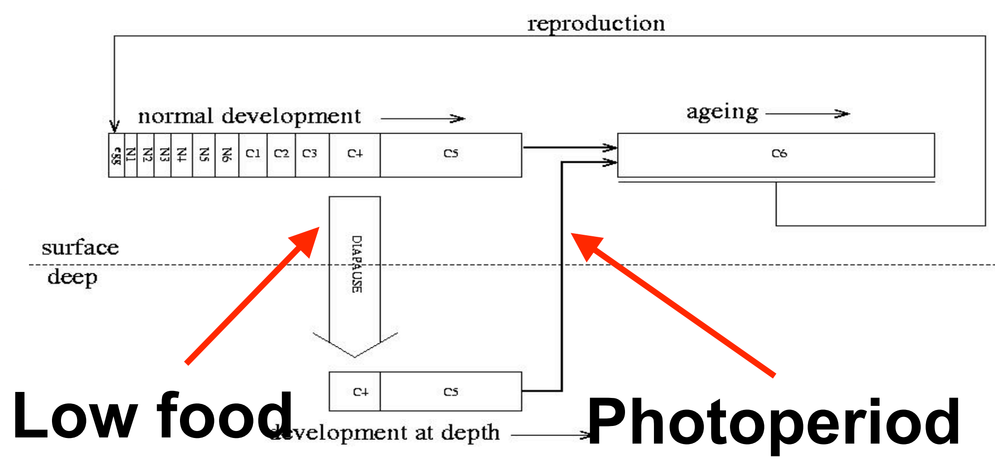
[Physical-biological interactions:
from key (target) species to ecosystems from individuals to populations.]



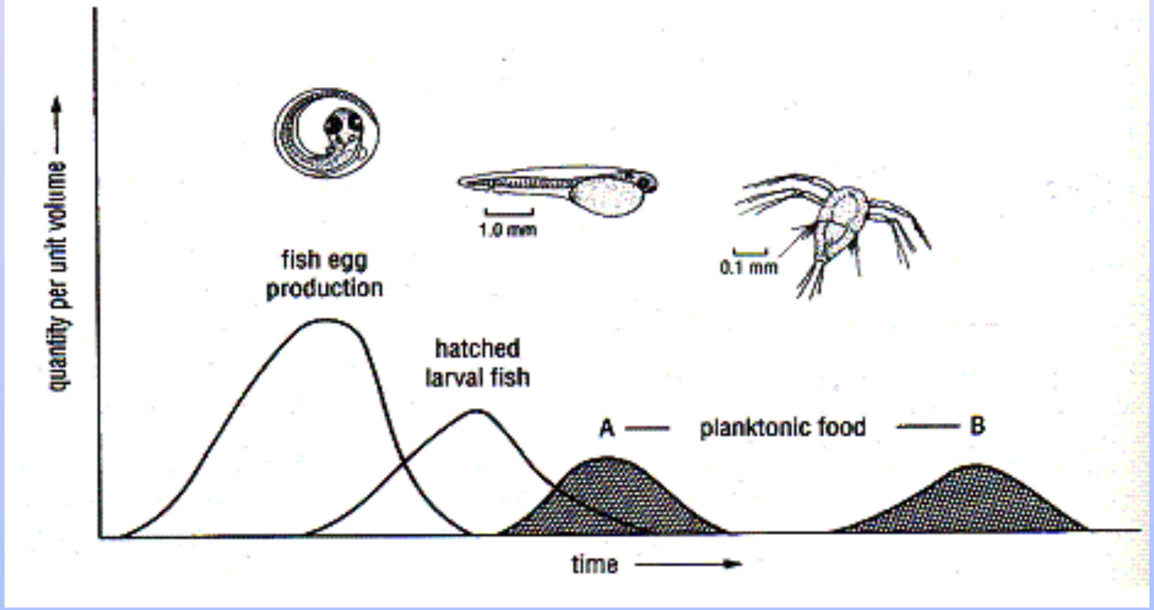
Target species

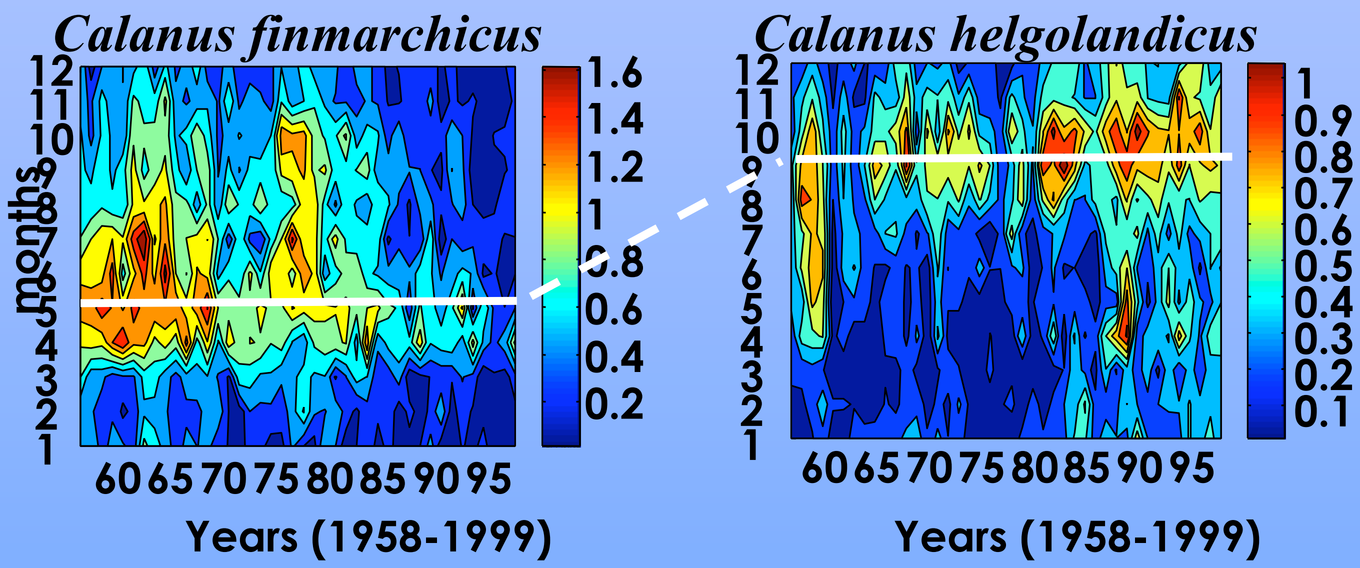






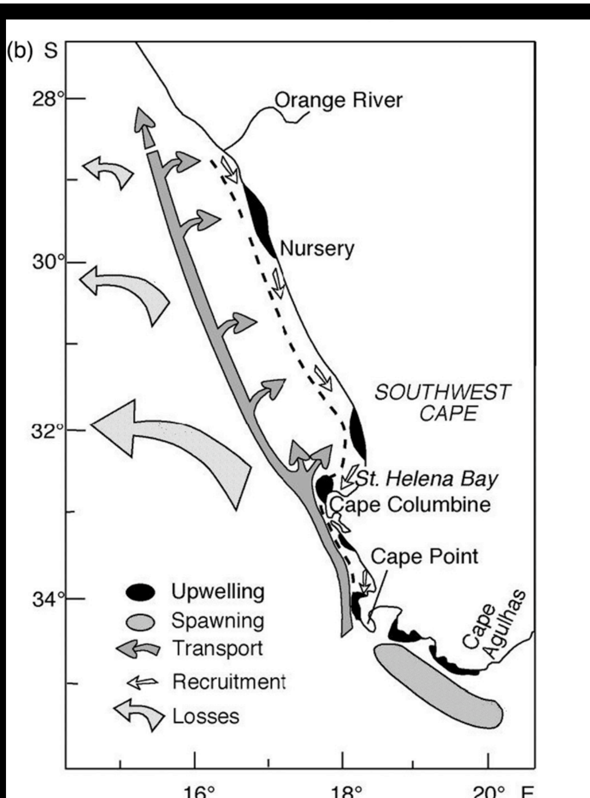
Long-term changes in the abundance of two key species in the North Sea

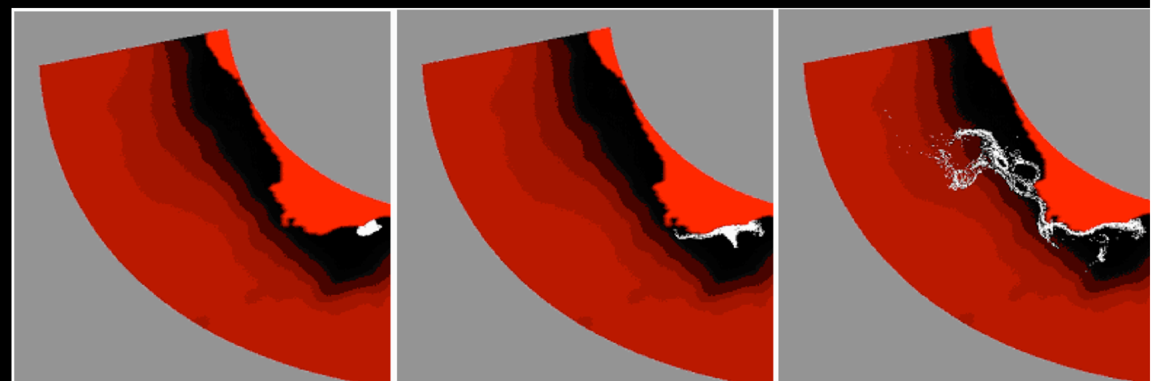


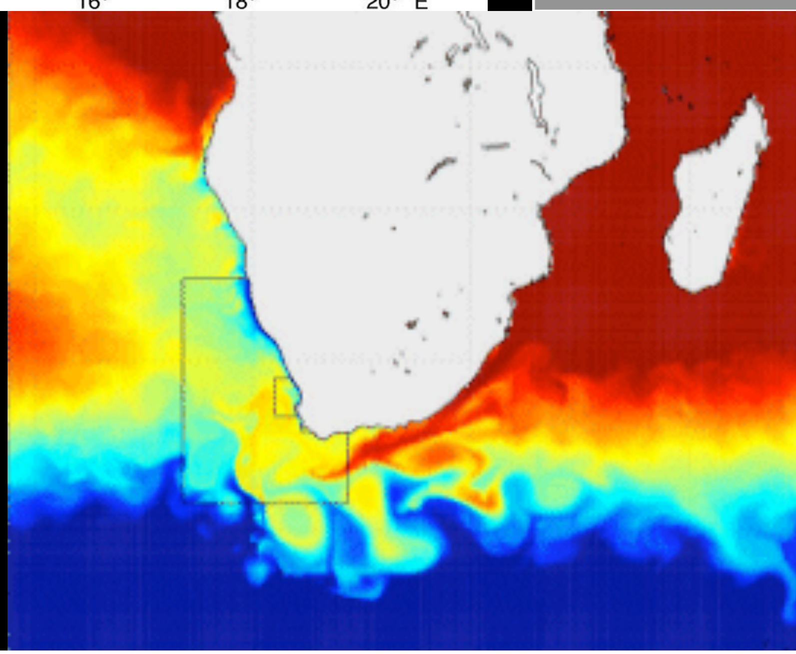


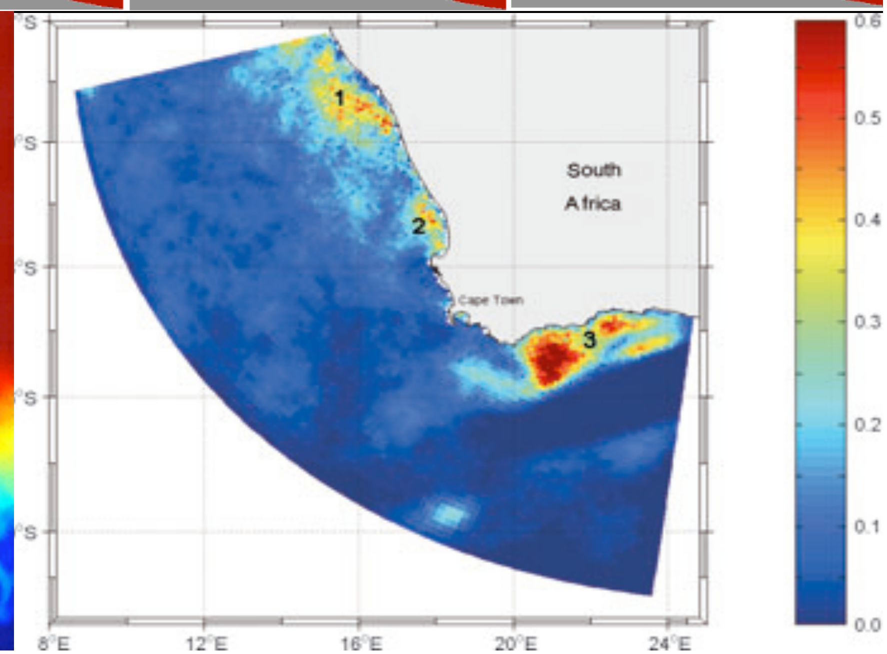
(Beaugrand)

Benguela Upwelling System: retention & dispersal using Individual Based Models (IBMs)



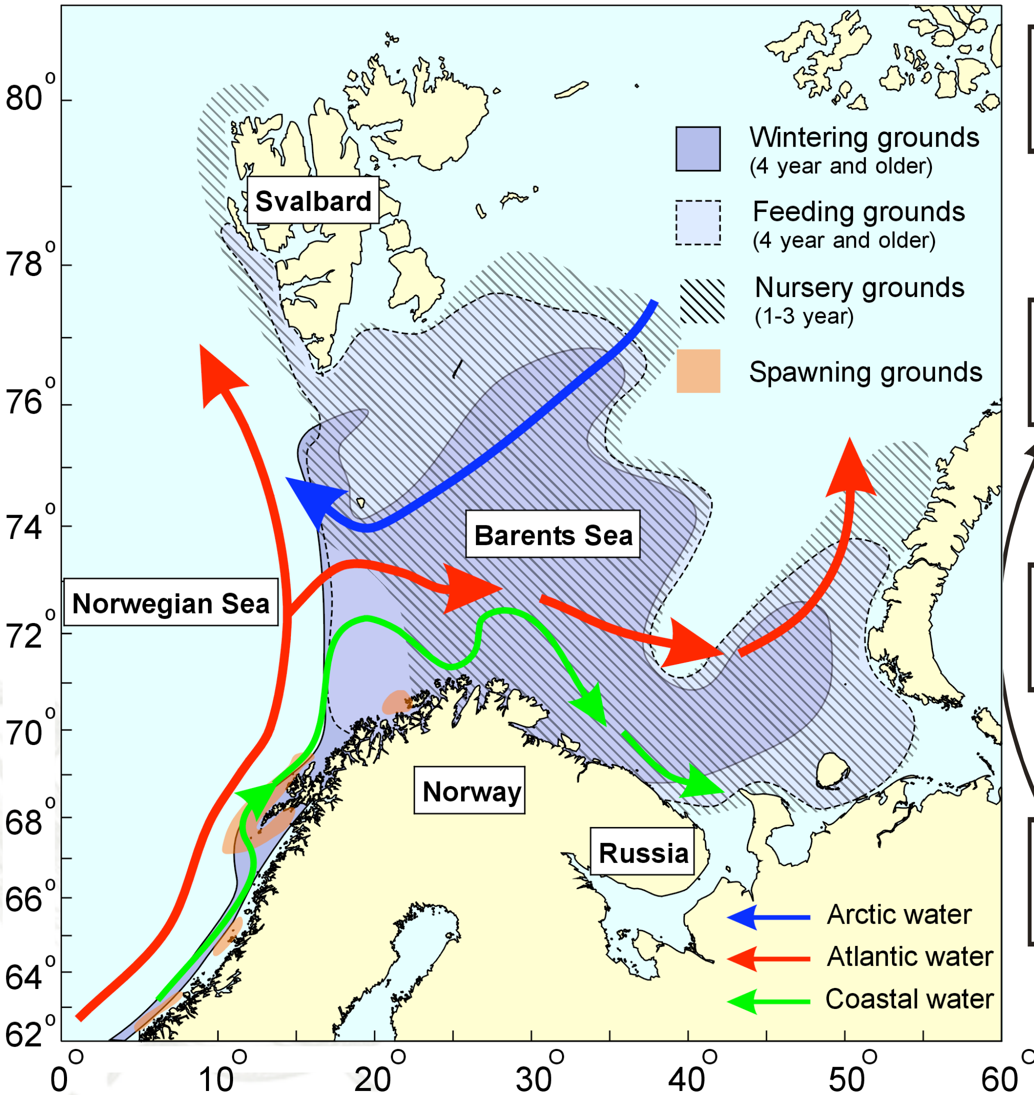


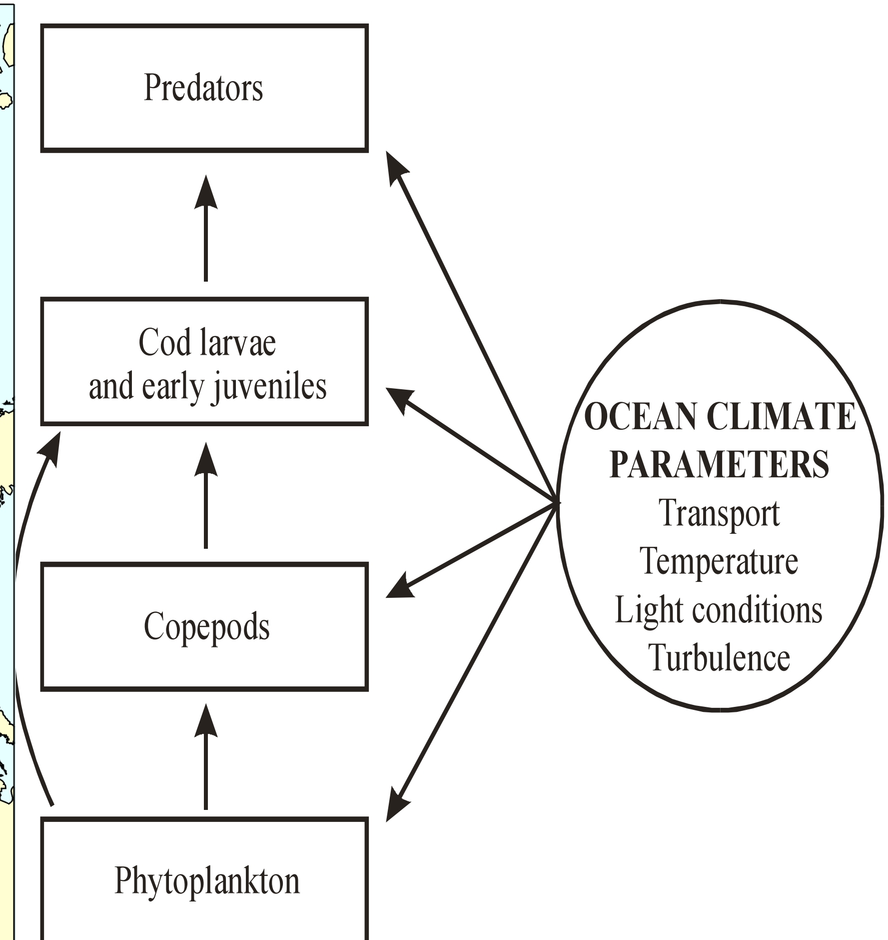




Mullon, Lett. Parada, Rpy, et al.

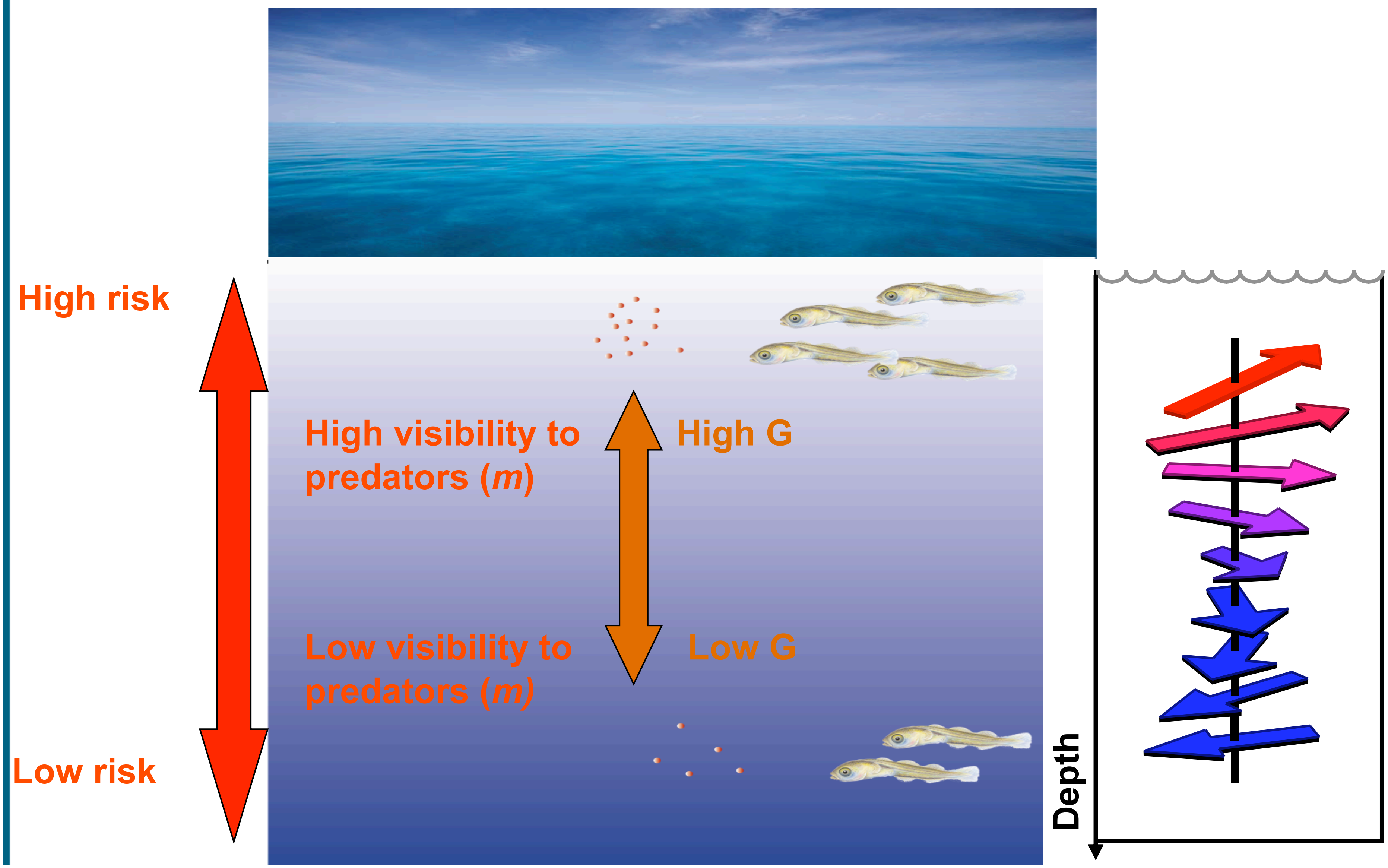
Spawning and nursery grounds





Trophic transfer

Too eat or be eaten



(T. Kristiansen)

Recruitment

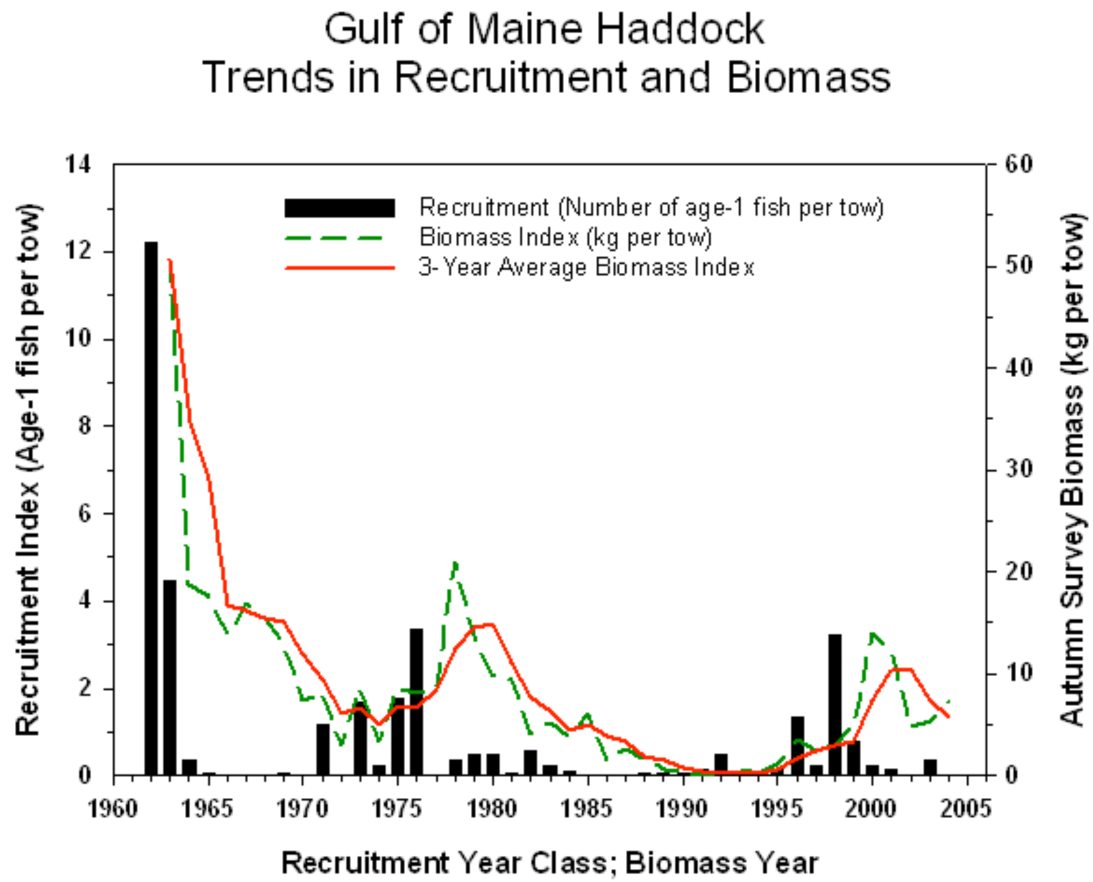


Figure 2.6. Trends in recruitment (age 1) and biomass for Gulf of Maine haddock.

“Challenges”

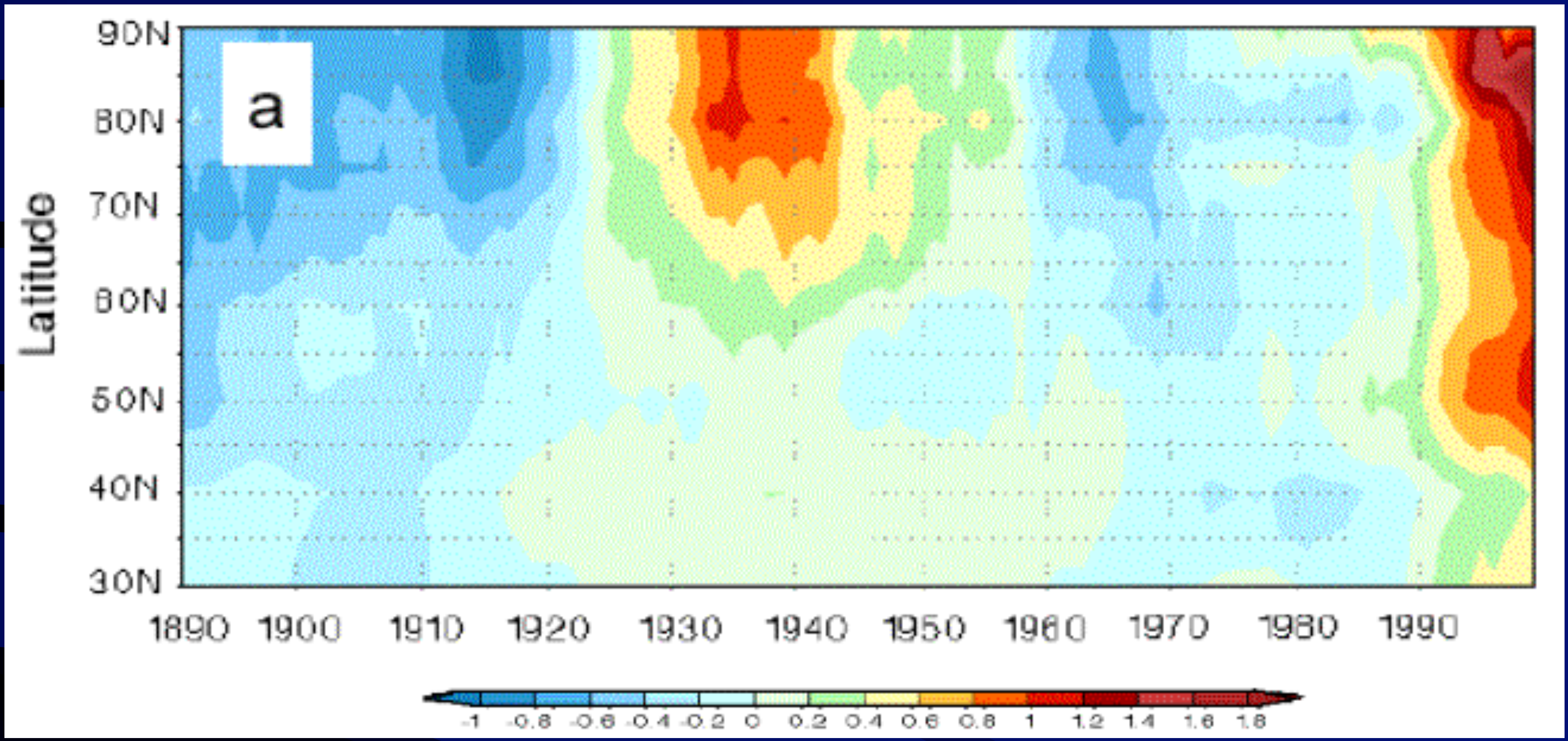
- How do we get from individuals (or target species) to populations?
- How do the interactions among individuals happen? Density dependence?
- How to impose behavior?
- Rigidity of model structure; full life cycles. Size-structured models?
- Prediction

Question (from Agenda)

- To what extent have the linkages between climate and fisheries been made (and verified)?

The 1920s and 1930s Warming

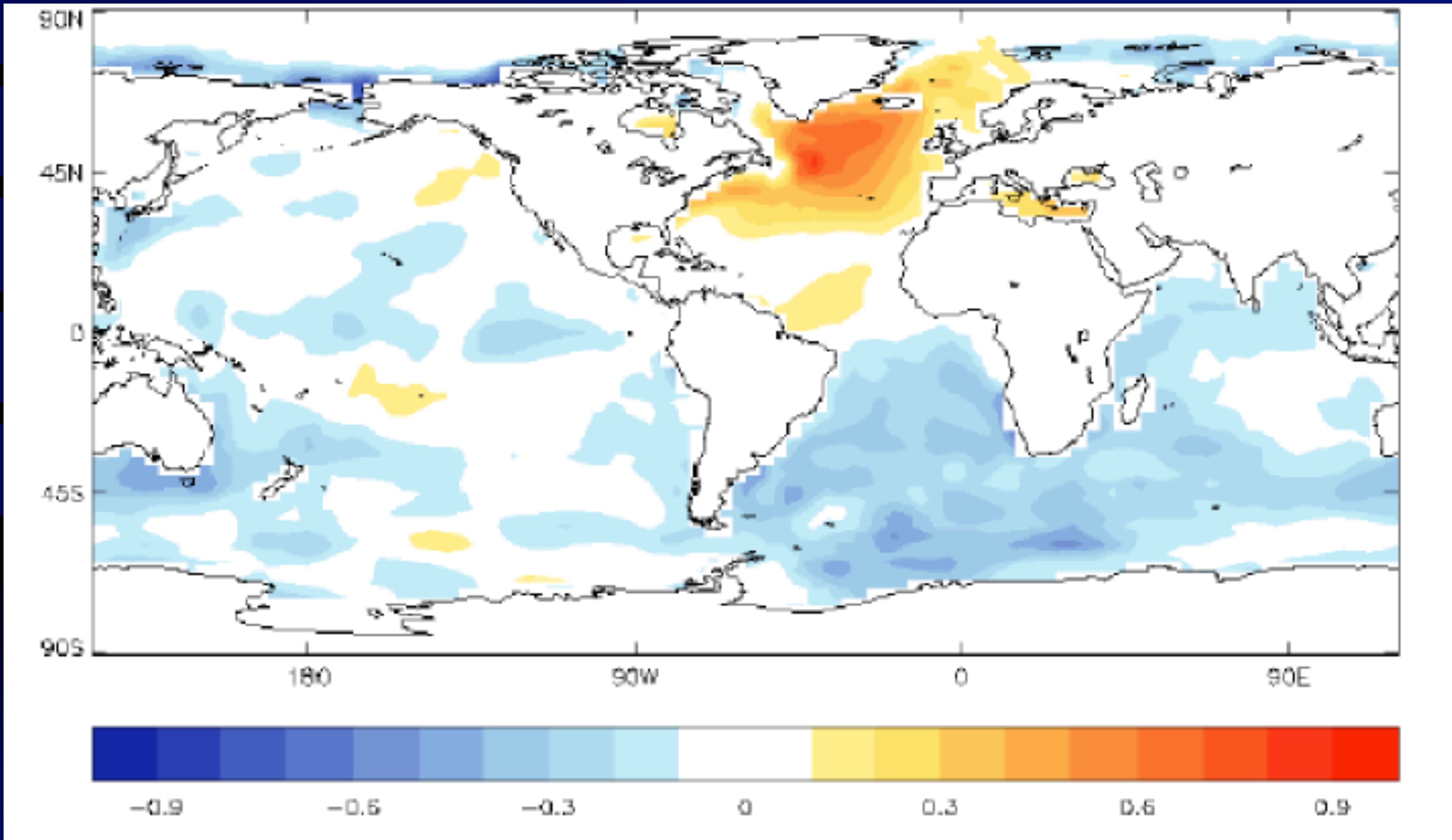
From Ken Drinkwater (IMR, Norway)



During the 1920s and 1930s there was rapid warming of the atmosphere and oceans primarily north of 60ºN that produced temperatures as warm or warmer than the present.

Johannessen et al. 2004. Tellus

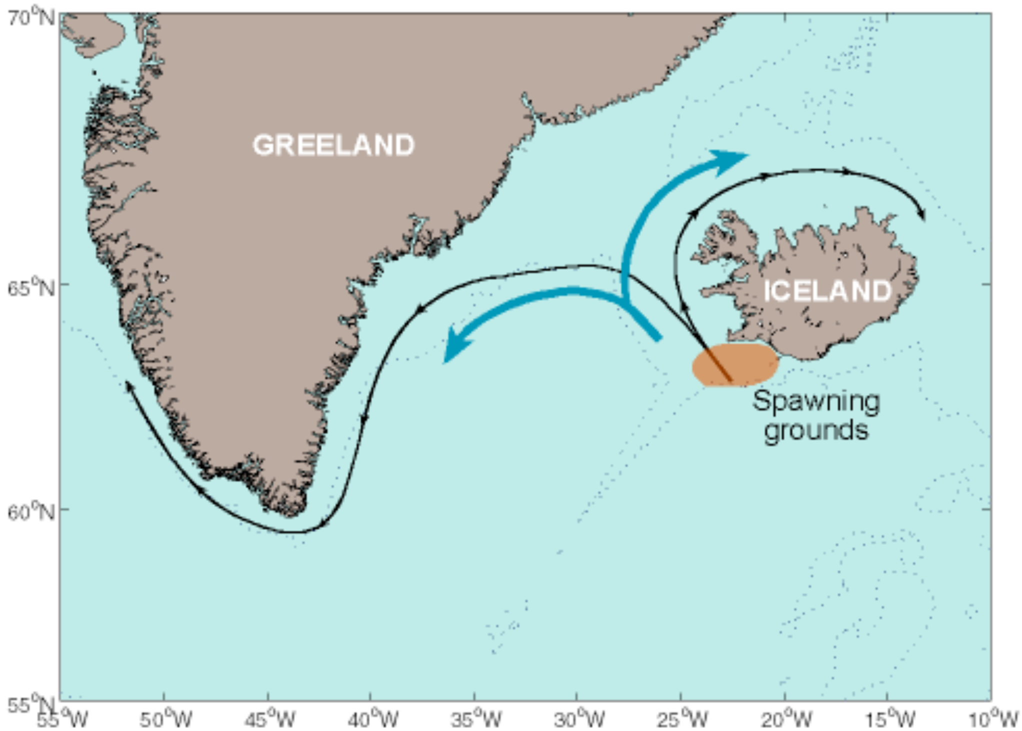
Warming was concentrated in the Northern North Atlantic



Sea Surface Temperature Change (1930-60 vs 1961-90)

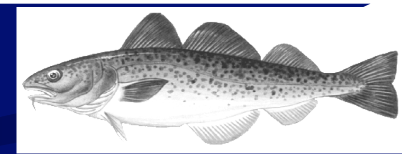
West Greenland-Iceland Connection for Atlantic cod

Under certain conditions cod larvae drift from Iceland to West Greenland

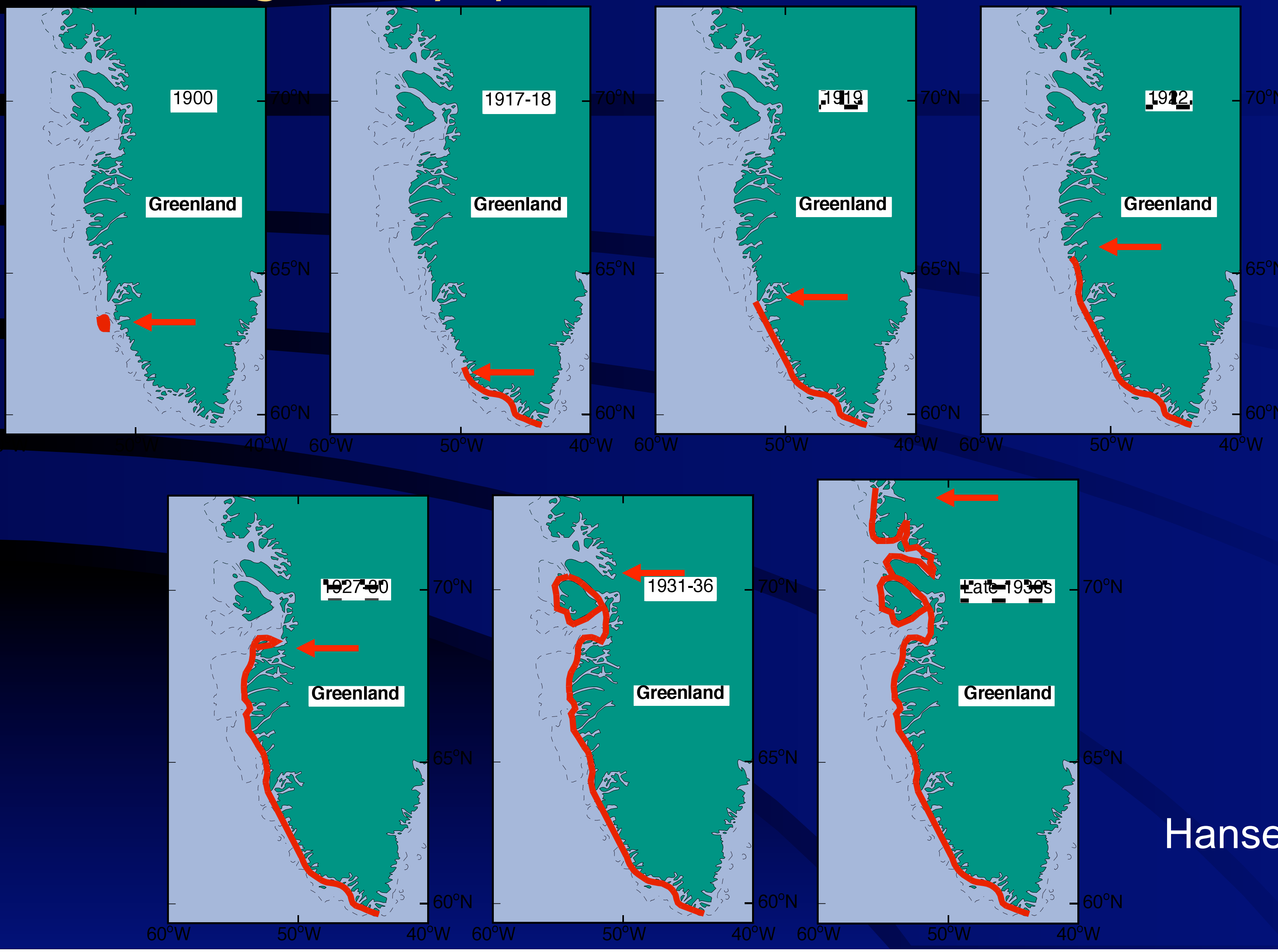


Conditions in 1920s resulted in the drift of larvae from Iceland to West Greenland and their survival.

West Greenland



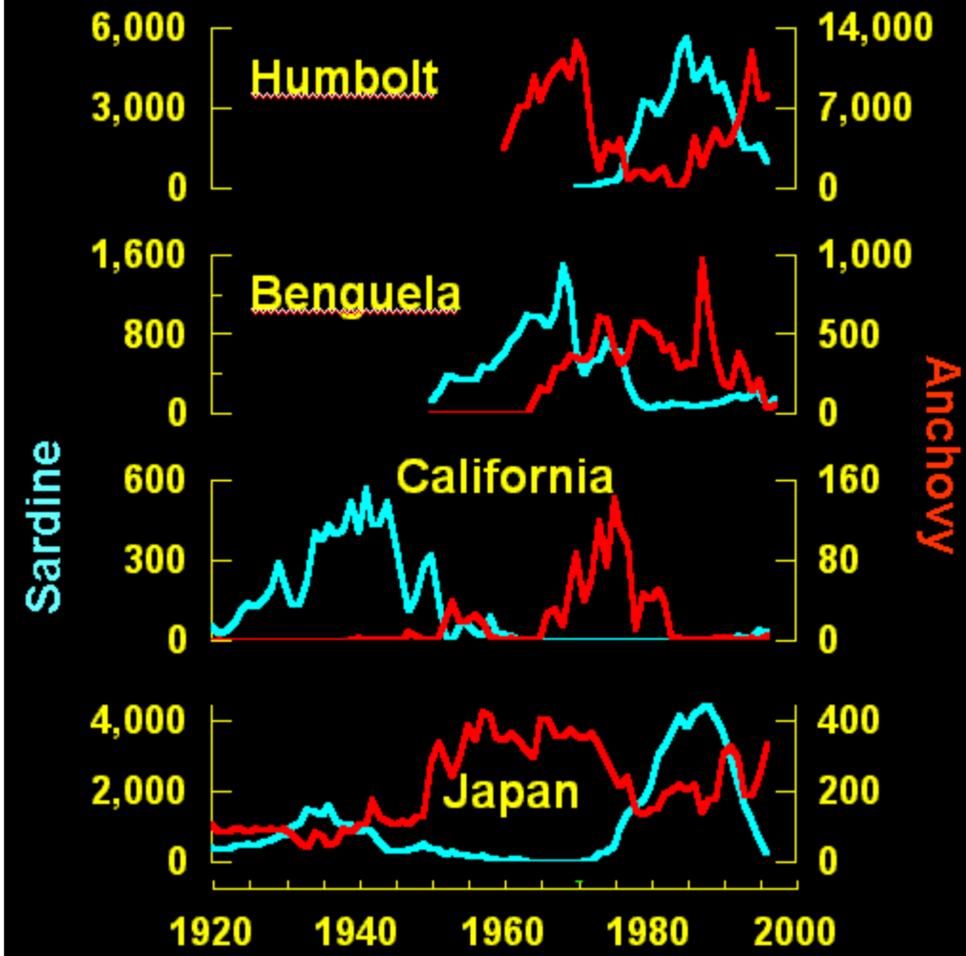
The cod gradually spread northward.



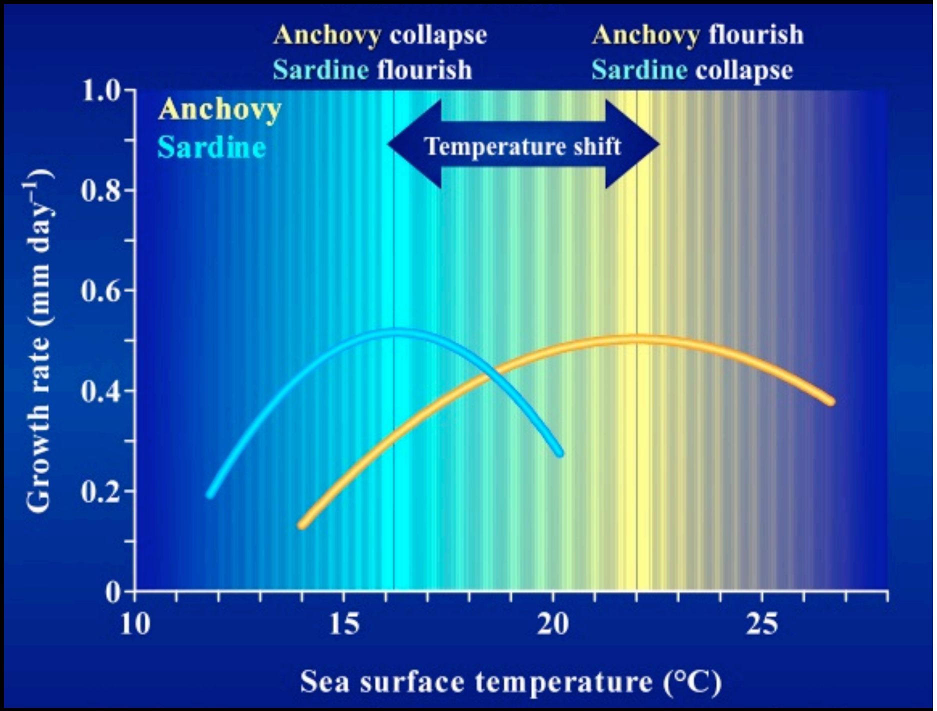
Hansen, 1940

Long time-scales, climate?

Basin-scale Synchronies and Asynchronies



Lluch-Cota et al.

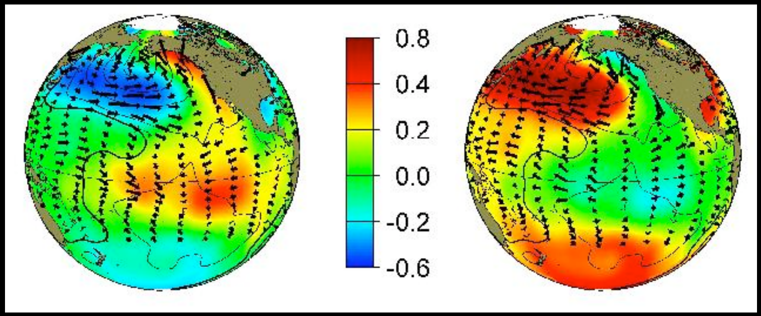


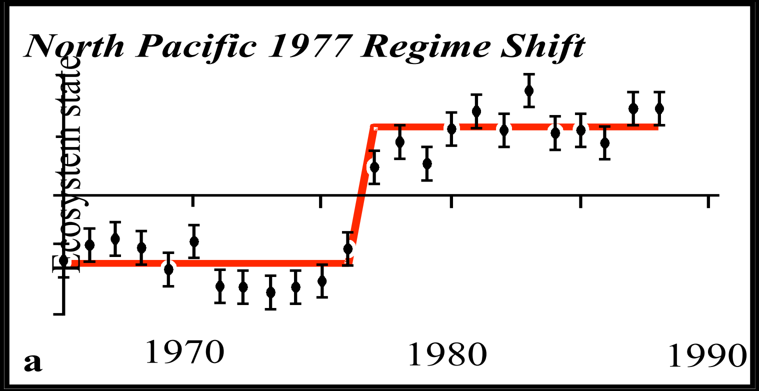
Takasuka et al.

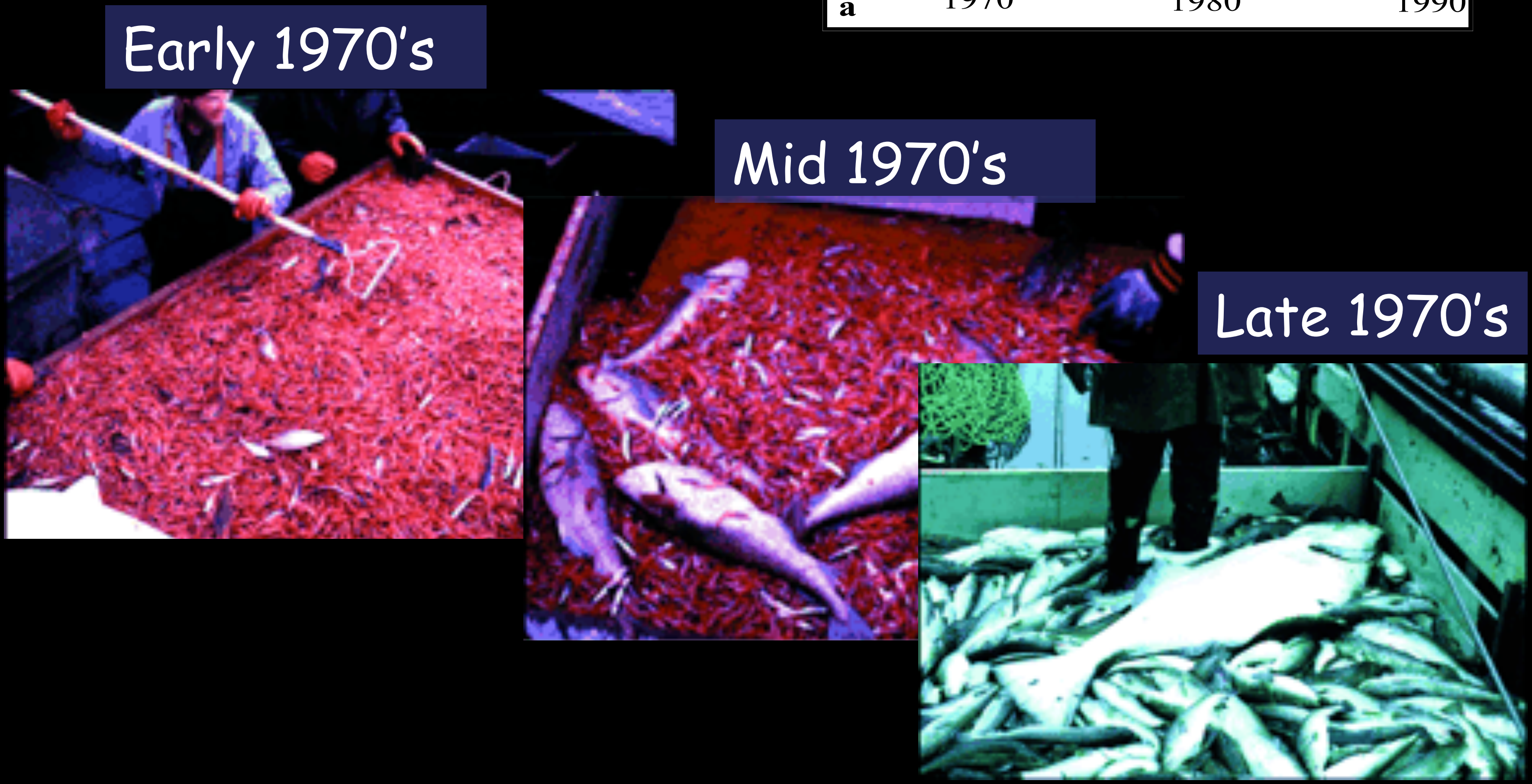
Question (from Agenda)

- What mechanisms must be captured by climate models to diagnose fisheries fluctuations?

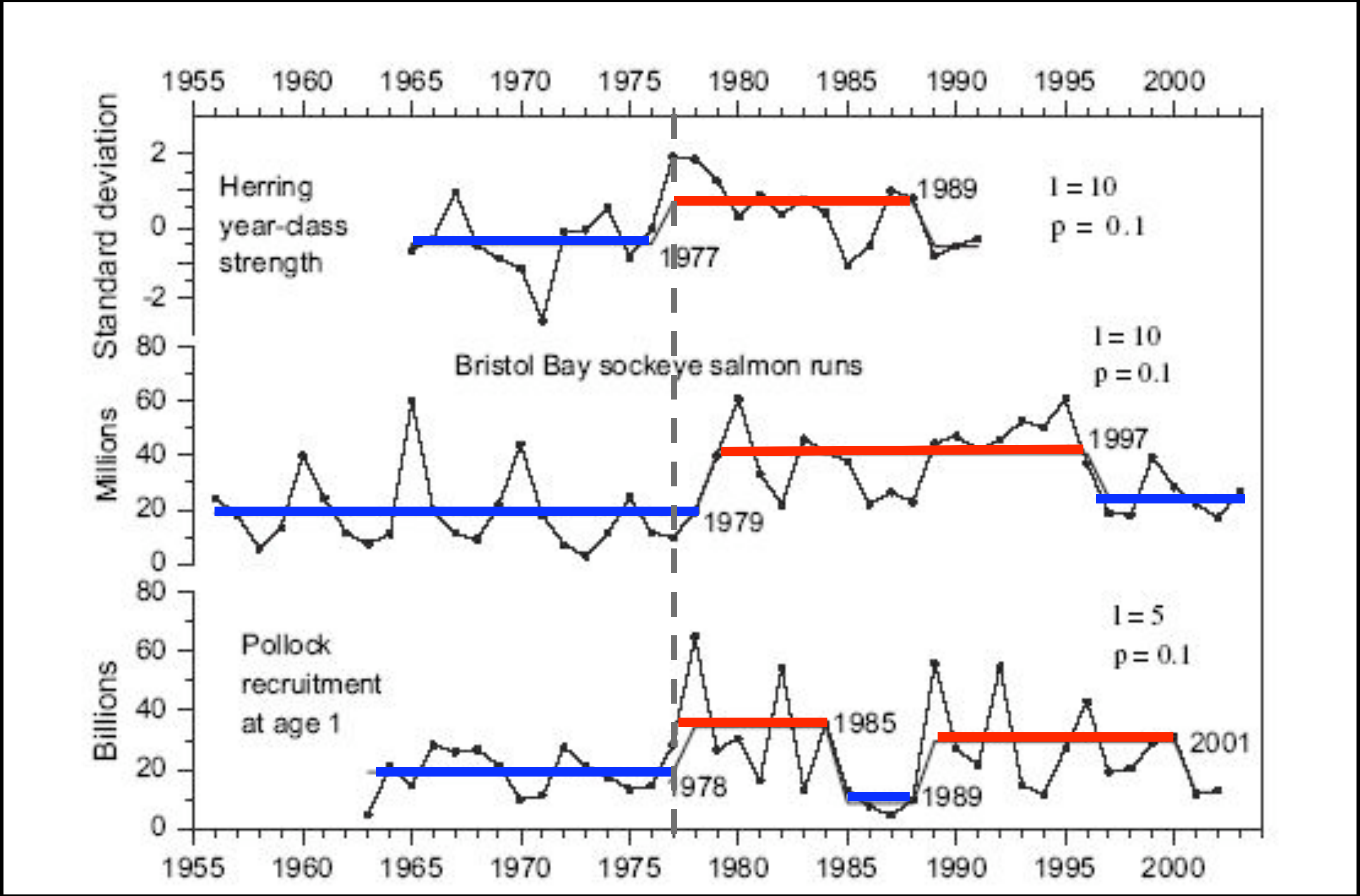
Regime Shifts and the Pacific Decadal Oscillation







"Regimes" evident in fish stocks

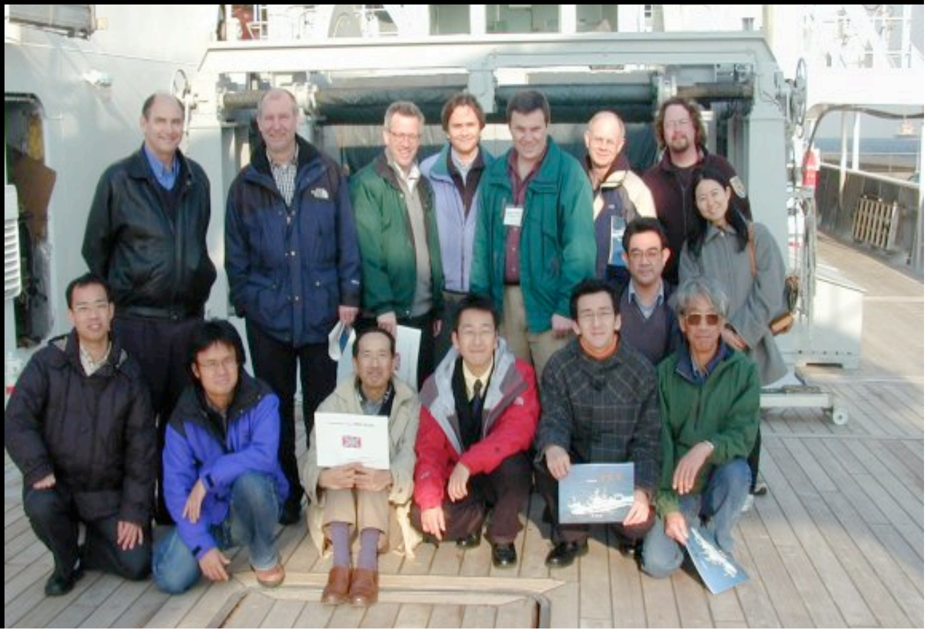


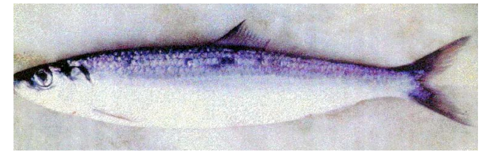
(Rodinov and Overland, 2005)

NEMURO & NEMURO.FISH

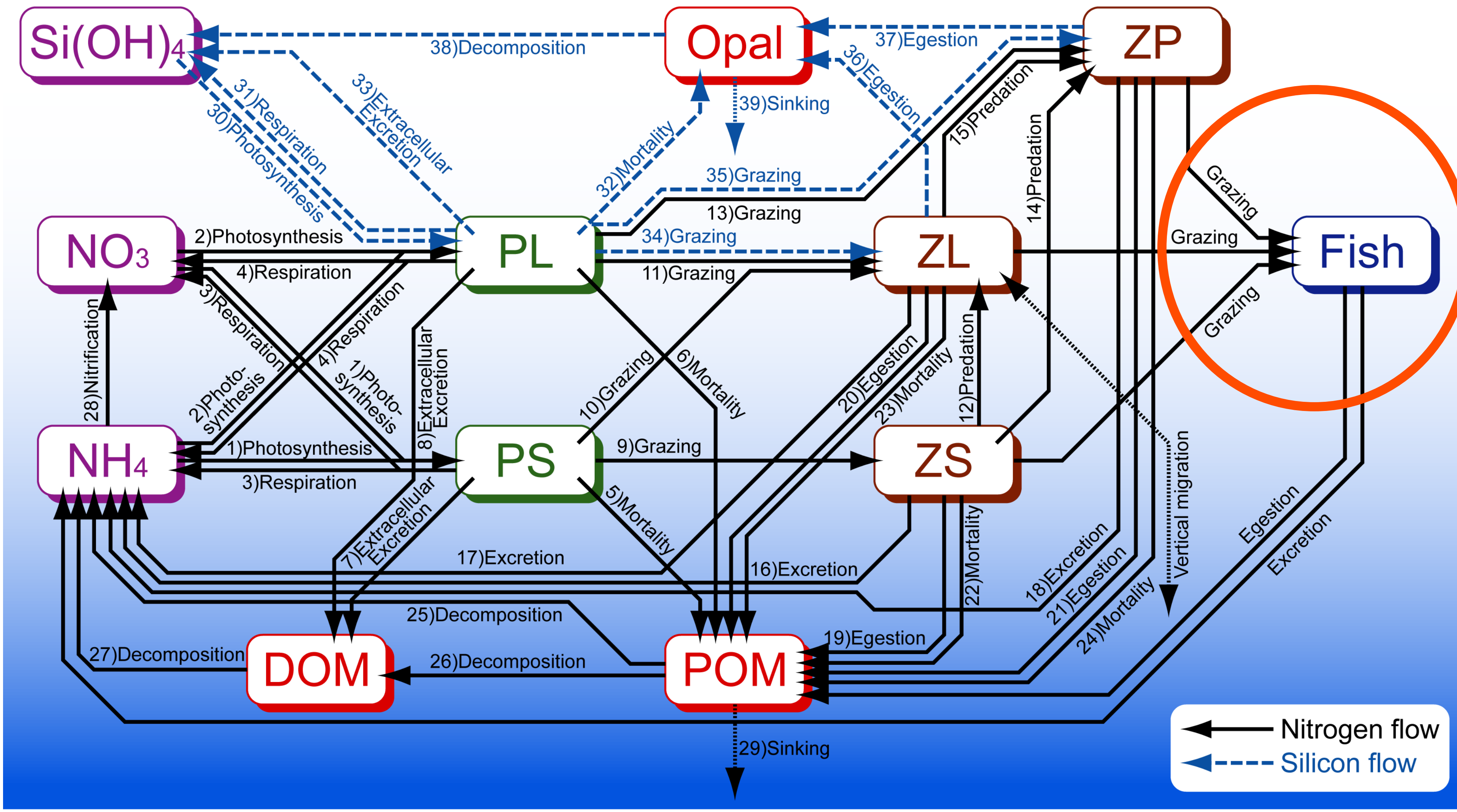
North Pacific Ecosystem Model for Understanding Regional Oceanography

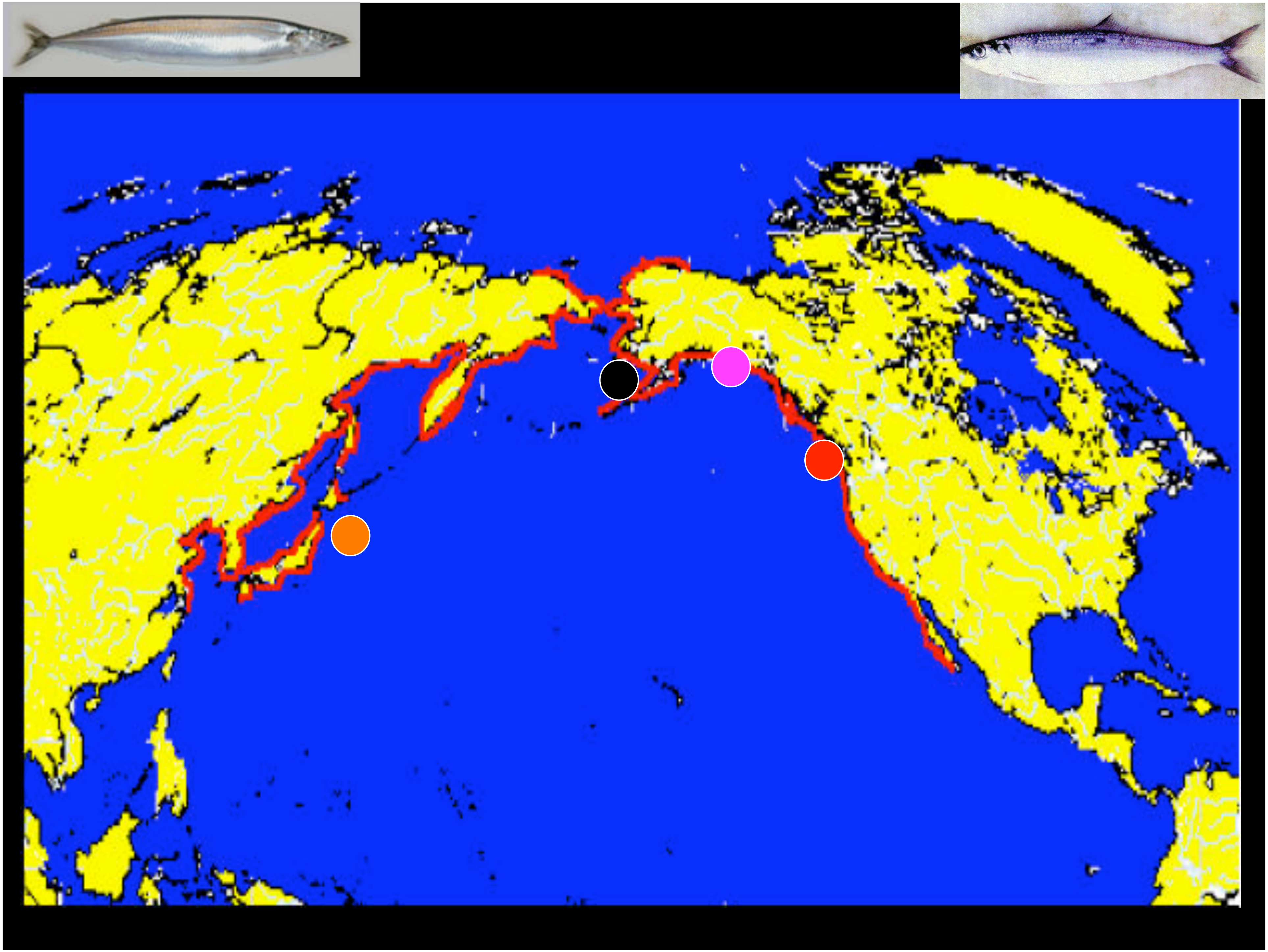
A consensus conceptual model … representing the minimum trophic structure and biological relationships … thought to be essential in describing ecosystem dynamics in the North Pacific

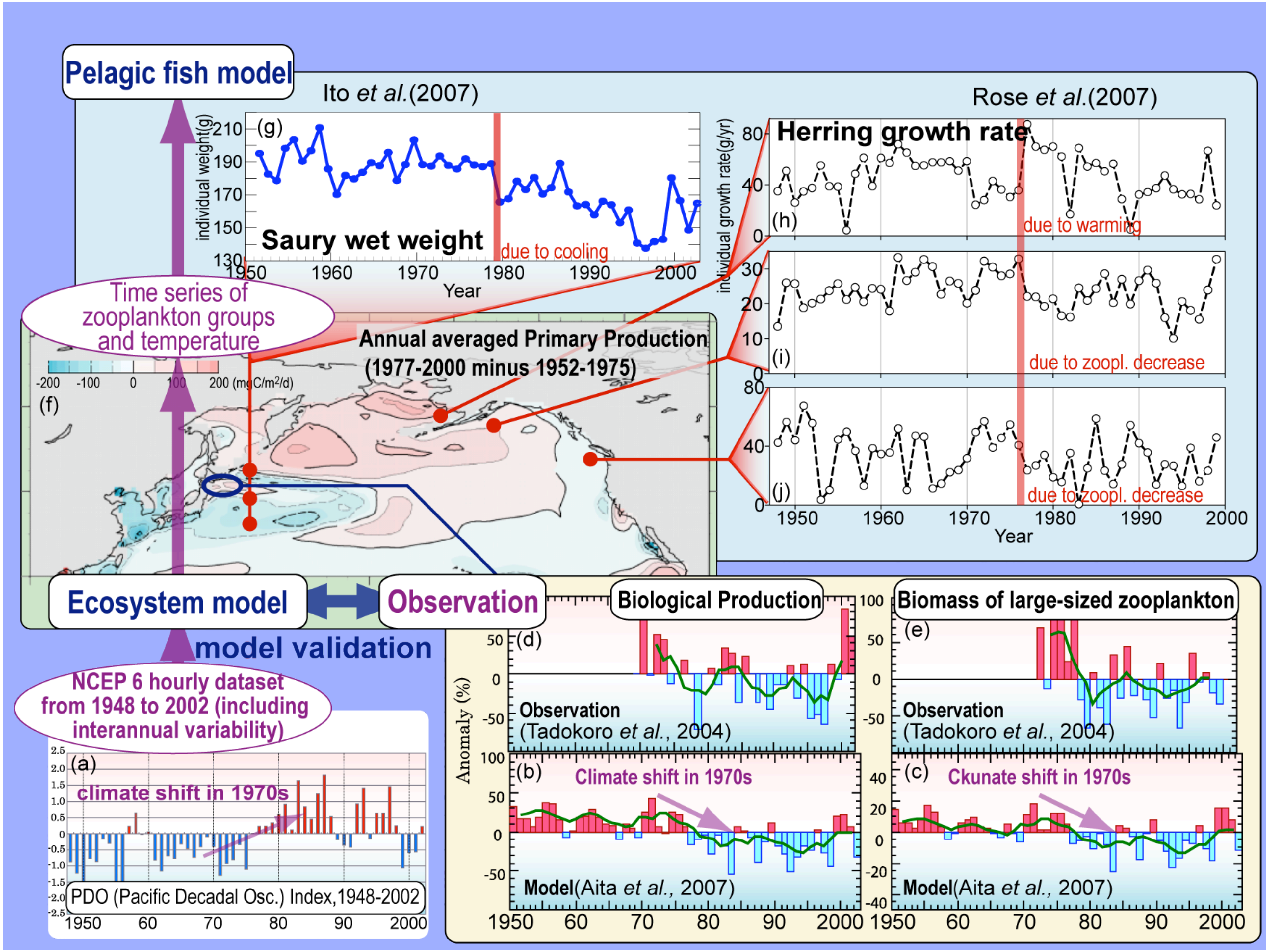




NEMURO.FISH
NEMURO.For Including Saury and Herring







Pelagic fish model
Ito et al.(2007)
Rose et al.(2007)
(g)
Saury wet weight
individual weight(g)
due to cooling
Year
Herring growth rate
individual growth rate(g/yr)
(h)
due to warming
(i)
due to zoopl. decrease
(j)
due to zoopl. decrease
Year
Time series of zooplankton groups and temperature
Annual averaged Primary Production (1977-2000 minus 1952-1975)
(mgC/m2/d)
(f)
Ecosystem model
Observation
model validation
NCEP 6 hourly dataset from 1948 to 2002 (including interannual variability)
(a)
climate shift in 1970s
PDO (Pacific Decadal Osc.) Index,1948-2002
Biological Production
Biomass of large-sized zooplankton
(d)
(e)
Anomaly (%)
Observation (Tadokoro et al., 2004)
Observation (Tadokoro et al., 2004)
(b)
Climate shift in 1970s
(c)
Ckunate shift in 1970s
Model(Aita et al., 2007)
Model(Aita et al., 2007)

Question (from Agenda)

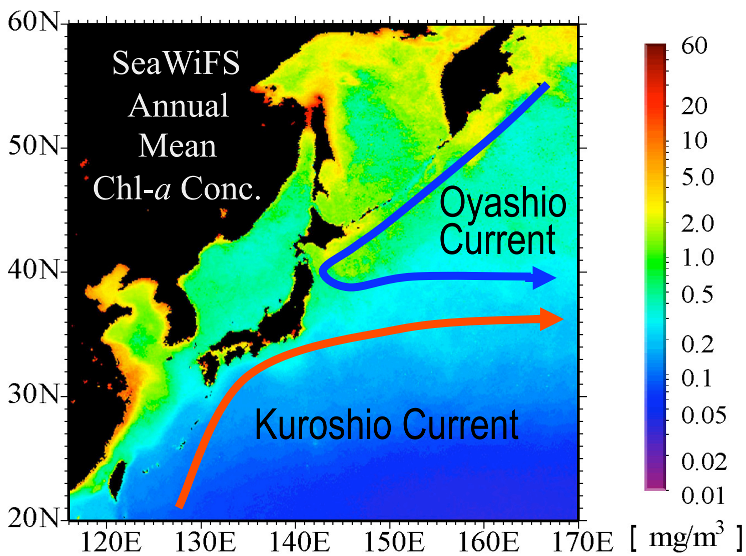
- What information can ecosystem models provide for prominent fisheries issues?

An attempt at a future scenario

Hashioka and Yamanaka (2007), *Ecological Modelling*

CCCC/PICES/APN: NW Pacific response to G.W. (T. Hashioka and Y. Yamanaka)

To predict the response of the lower-trophic level ecosystem to global warming, we conducted and compared the present-day and global warming experiments, using a 3-D NEMURO in the western North Pacific.



Model Domain (20-60°N, 115-170°E)

< Setting of our model >

Ocean General Circulation Model

- CCSR Ocean Component model (Hasumi *et al.*, 2002)
- Horizontal resolution: 1° x 1° degrees

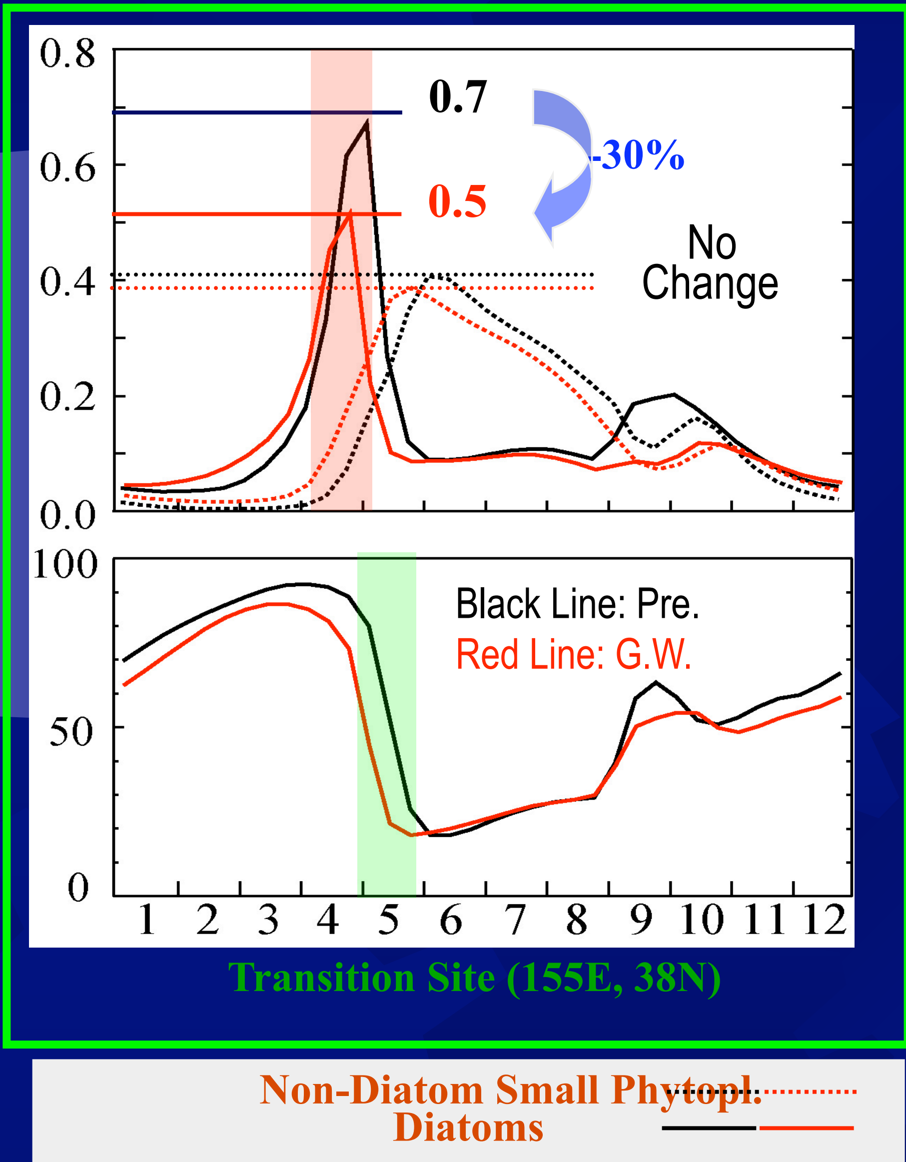
Ecosystem Model

- 15-Compartment model extended from NEMURO (Yamanaka *et al*., 2004)

Boundary conditions for present-day sim.

- Monthly mean climatology from data-sets of OMIP and WOA 01

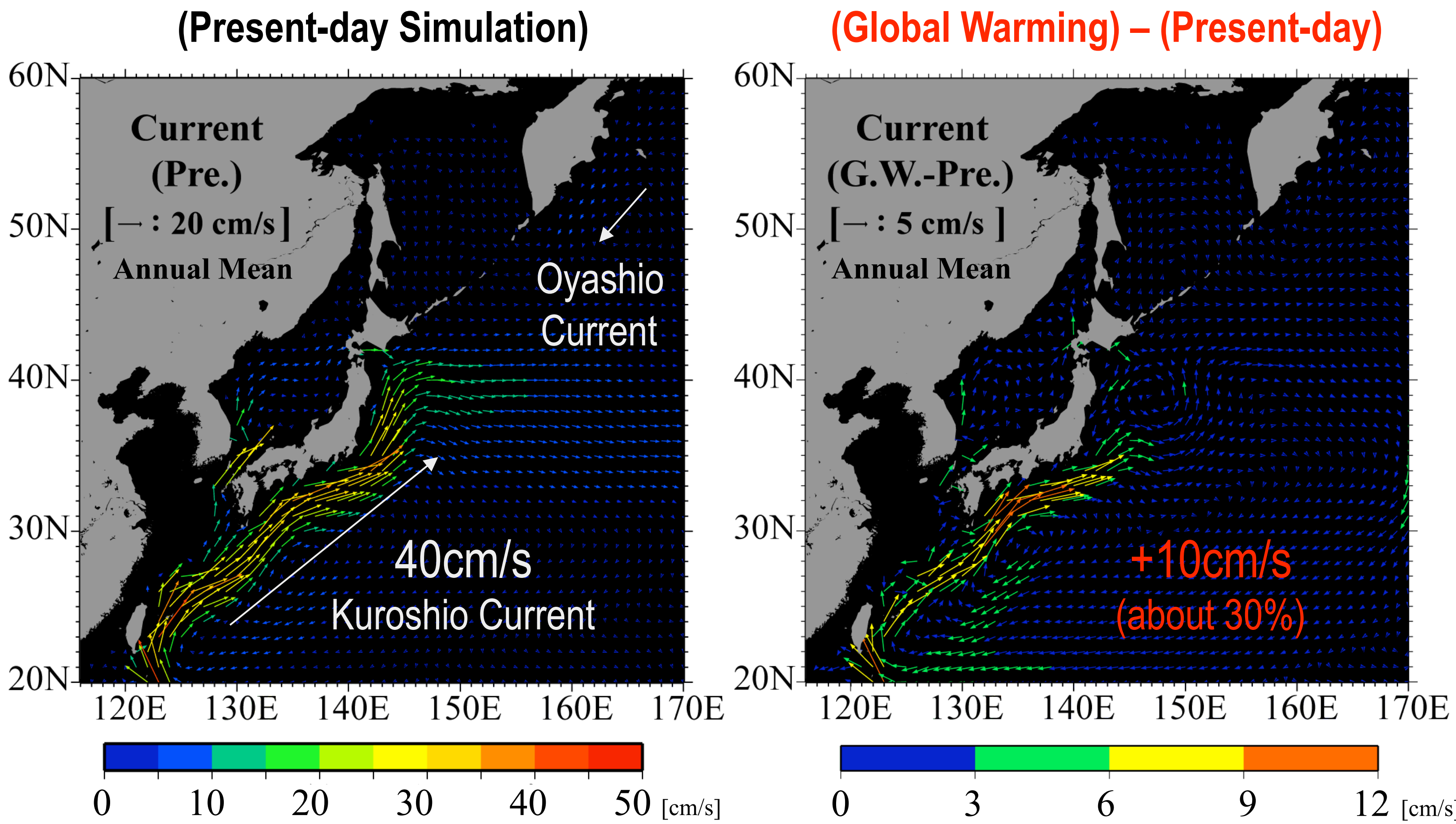
Change in Seasonal Variations (0-20m)



- * The biomass change at the transition site is the largest due to the large change in MLD.

- * The onset of the spring bloom is Predicted to occur half a month earlier.
- * The maximum biomass in the spring bloom is predicted to decrease by 30%.
- * The change in the dominant group appears notably at the end of the spring bloom.

Change in Flow Field @ 100m

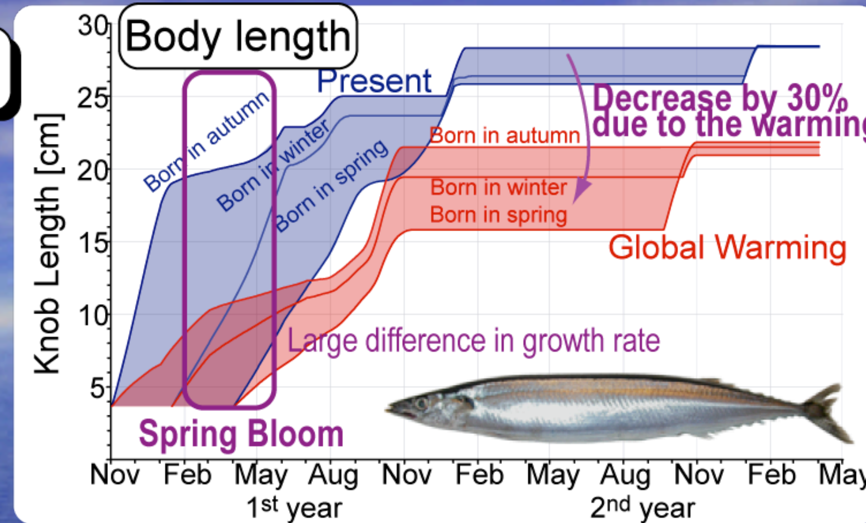


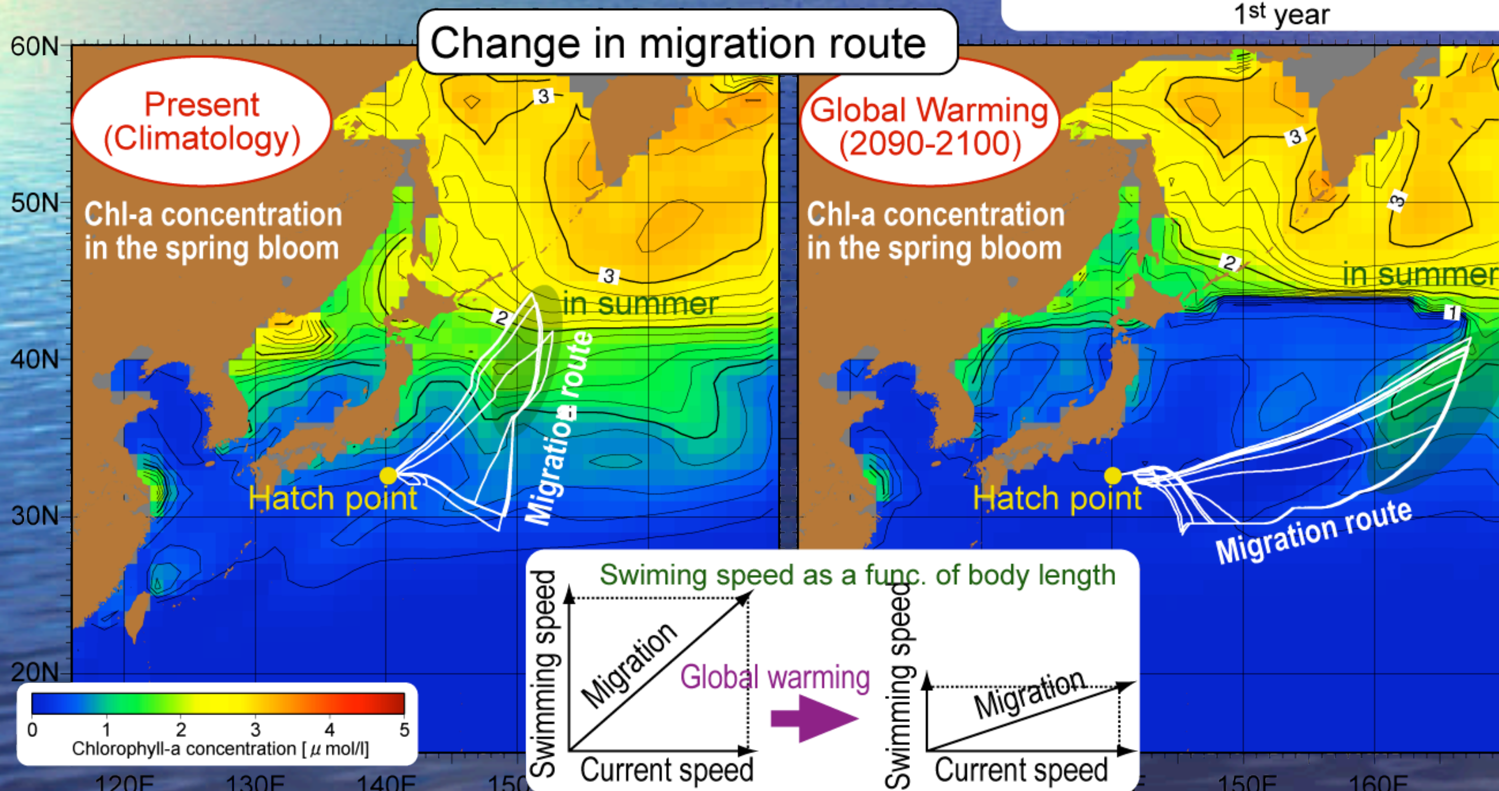
Increase in the Kuroshio Current from 40cm/s to 50cm/s at its maximum. associated with global warming.

Hashioka and Yamanaka, 2007 (*Special Issue of NEMURO in Ecological Modeling*)

Future Pacific saury simulated by NEMURO.FISH

The weak spring bloom leads Pacific saury to slow growth rate and to shift offshore migration route advected by Kuroshio extension. Japanese fishery would use large catching boat to obtain smaller size of Pacific saury in future (?).

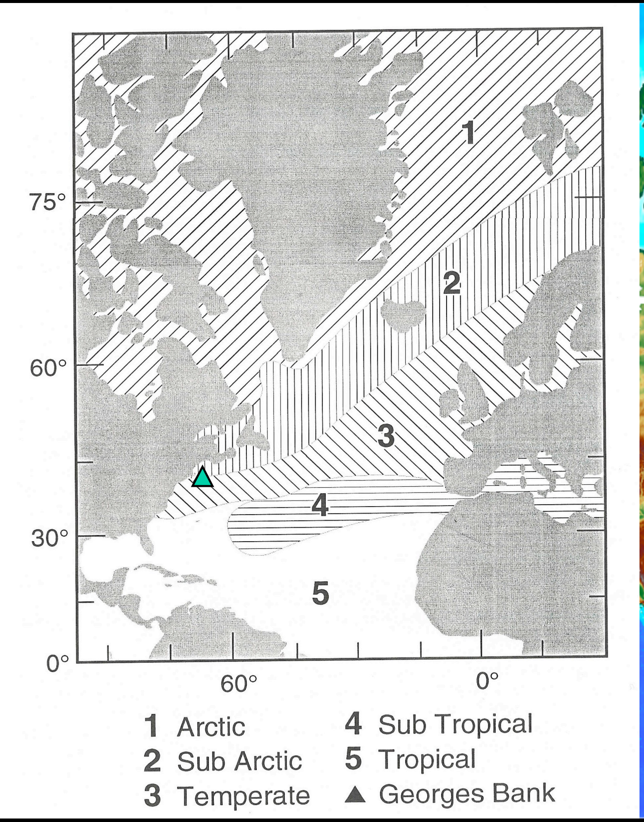


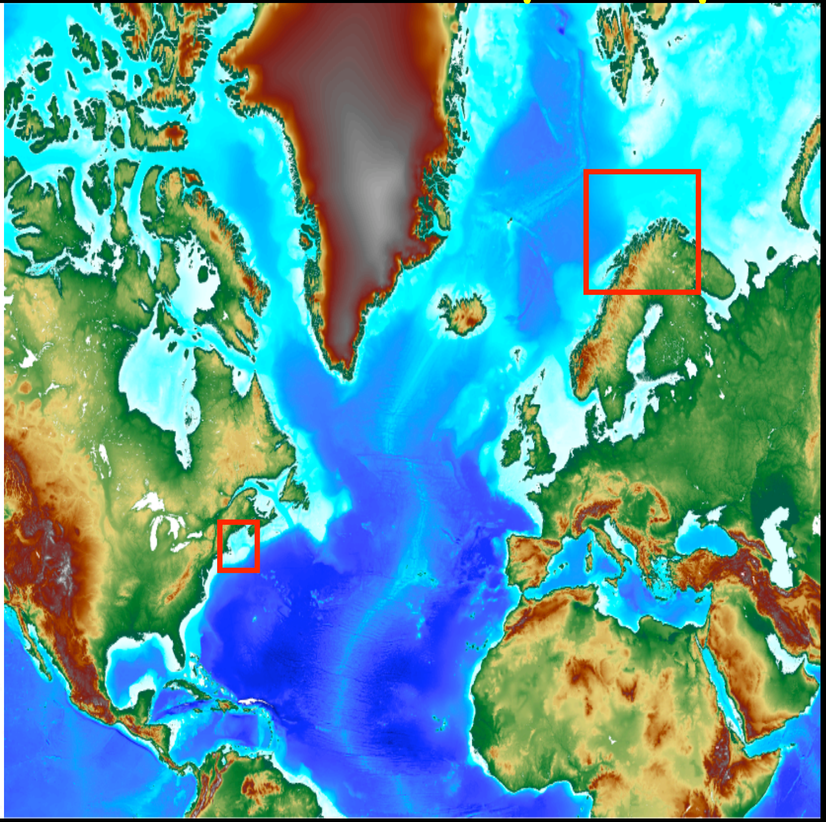


Question (from Agenda)

- What information can present global scale models provide for coastal regions?

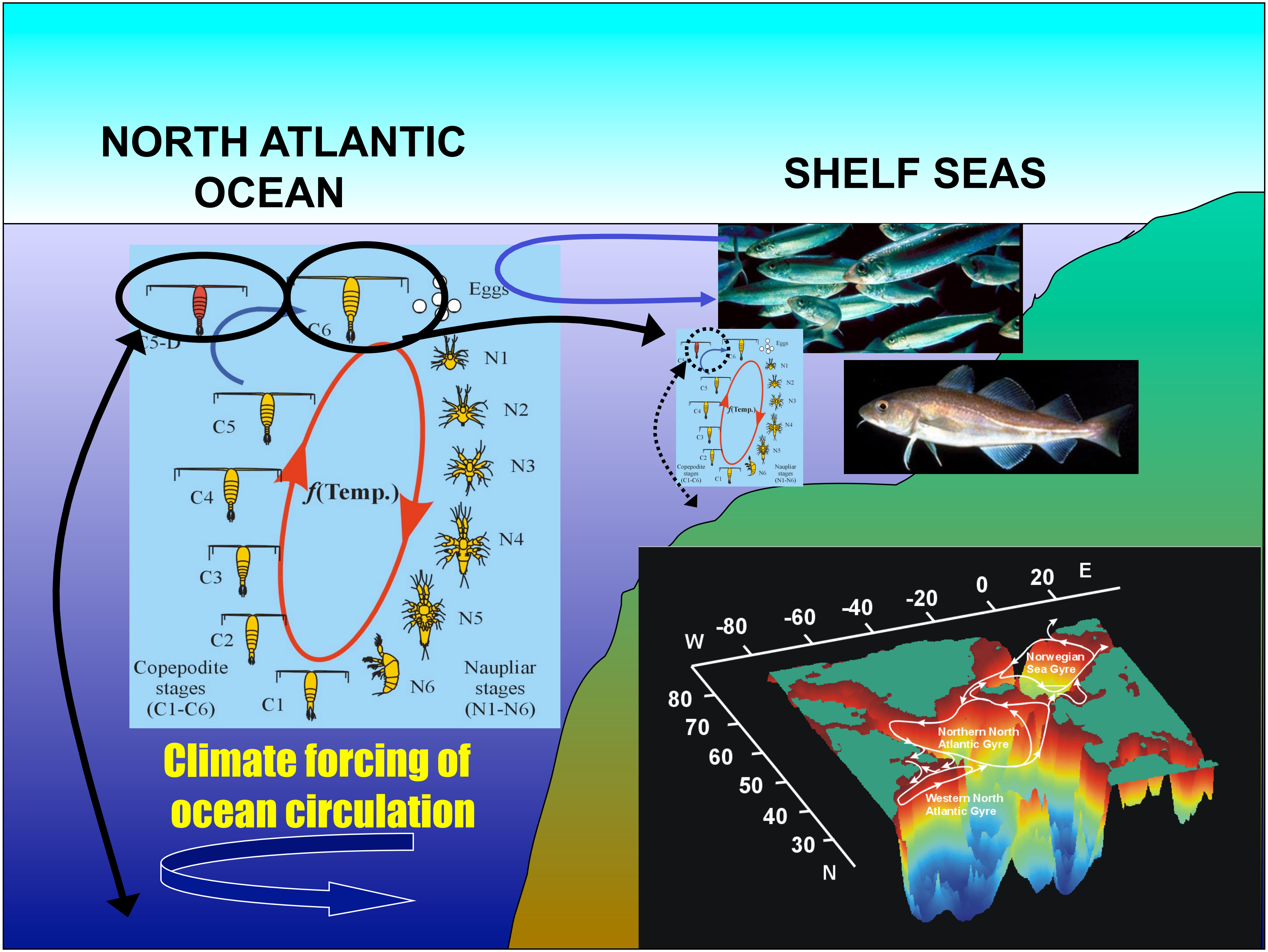
Linking basin- and coastal ocean models: the need to downscale (and eventually couple)





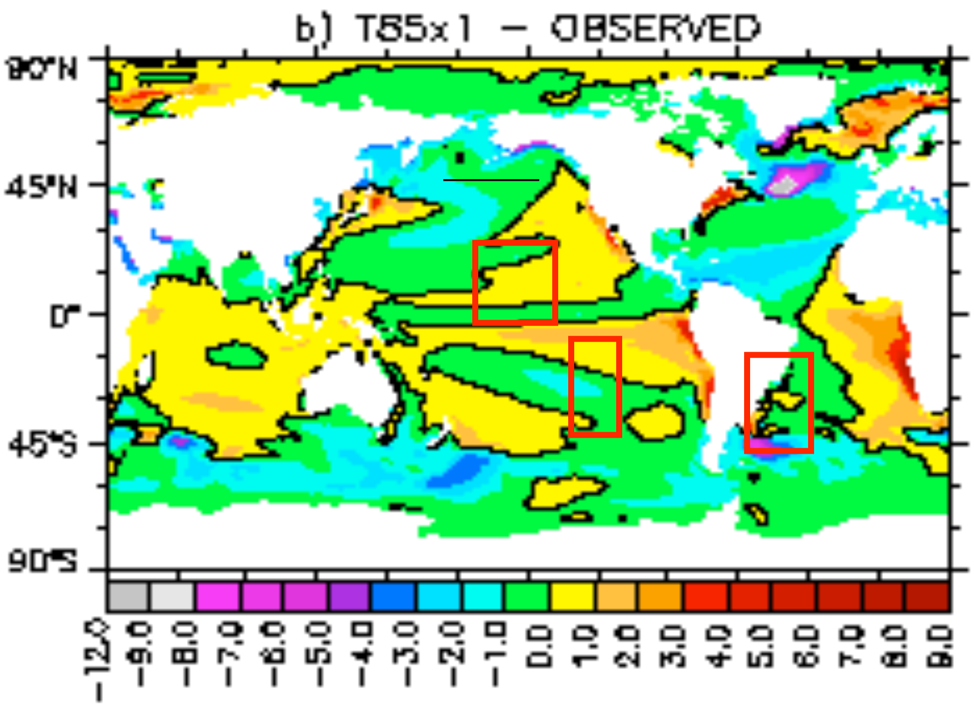
Georges Bank vs. Barents Sea
(Comparative Analysis)

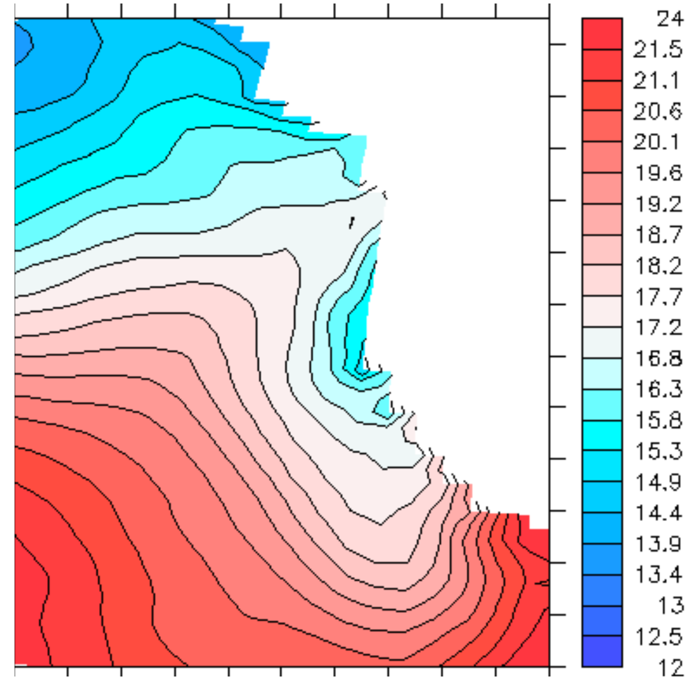
Temperature (Growth rate increases with temperature)
Turbulence (Increases encounter between predator and prey)
Food (Preferred prey)
Light (Visual predators like cod, need light to forage)
Retention/advection (Large scale physical features)

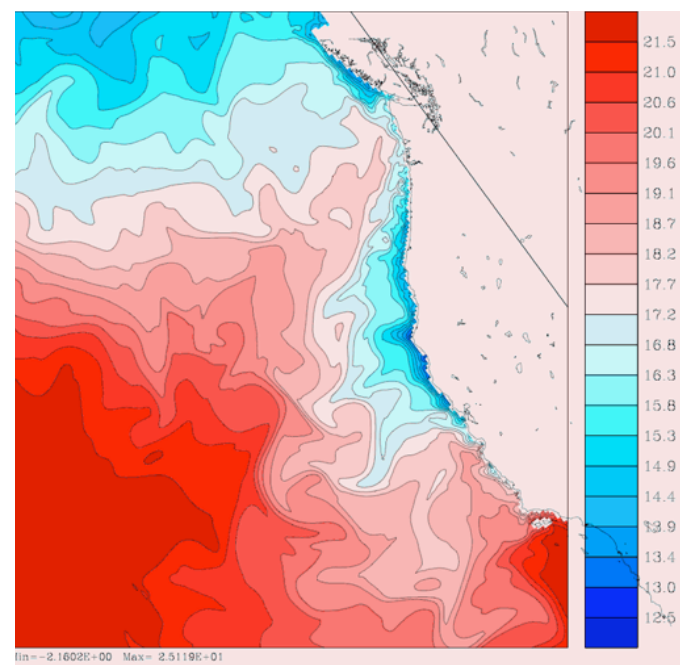


NORTH ATLANTIC OCEAN
SHELF SEAS
Eggs
C6
C5-D
C5
C4
C3
C2
C1
N1
N2
N3
N4
N5
N6
f(Temp.)
Copepodite stages (C1-C6)
Naupliar stages (N1-N6)
Climate forcing of ocean circulation
W
-80
-60
-40
-20
0
20
E
80
70
60
50
40
30
N
Norwegian Sea Gyre
Northern North Atlantic Gyre
Western North Atlantic Gyre

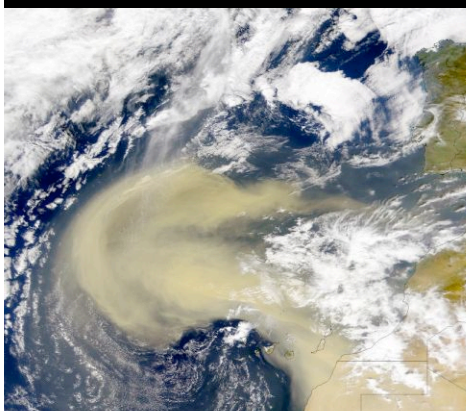
OCEAN NRCM
Motivation : CCSM3
SST BIAS







Linking ocean models to other Earth System components



Land vegetation, $2xCO_2$, atmosphere-ocean interaction

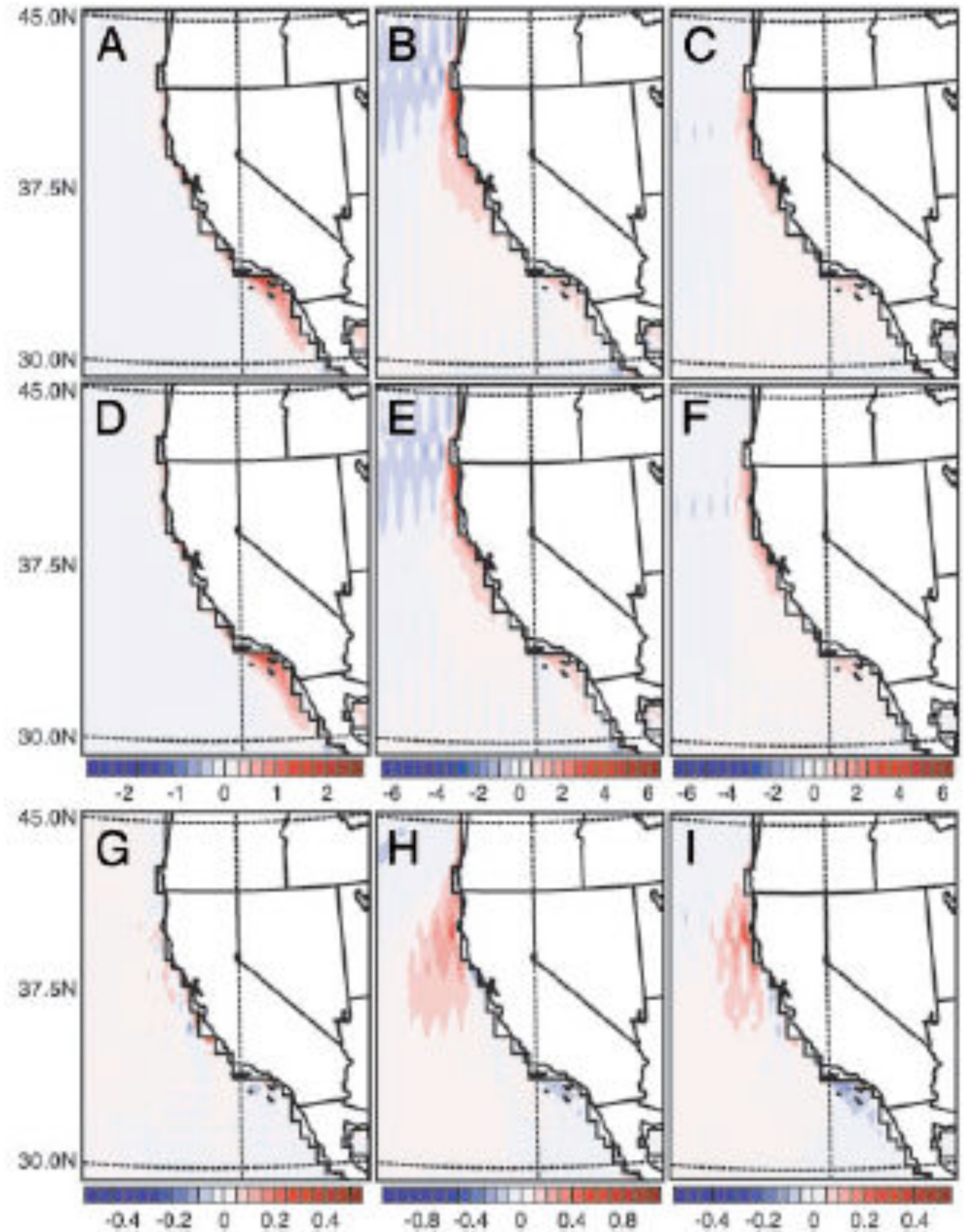


Fig. 2. Simulated California Current wind-stress curl. (*A*) May curl in the

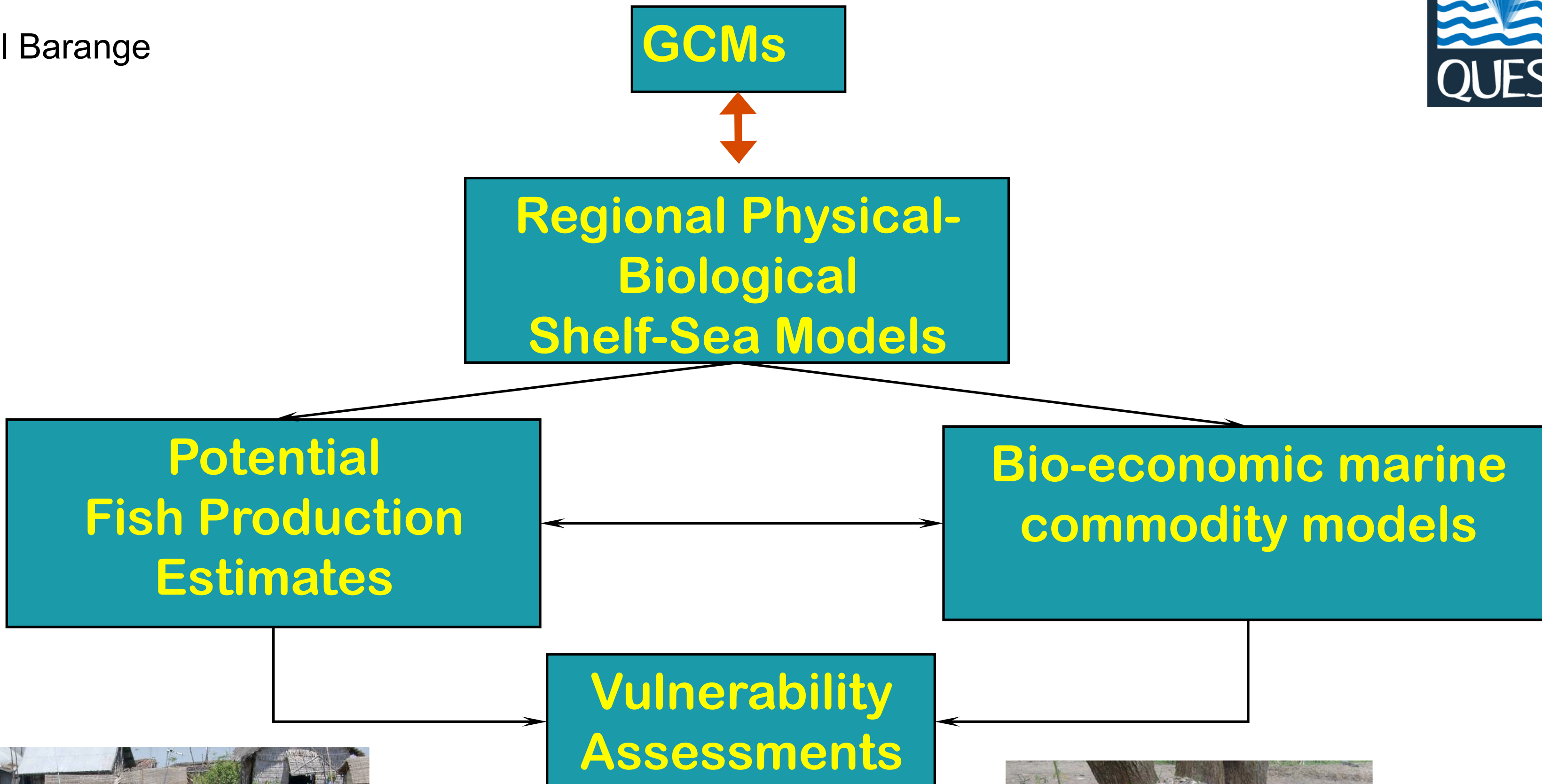
Simulated wind-stress curl

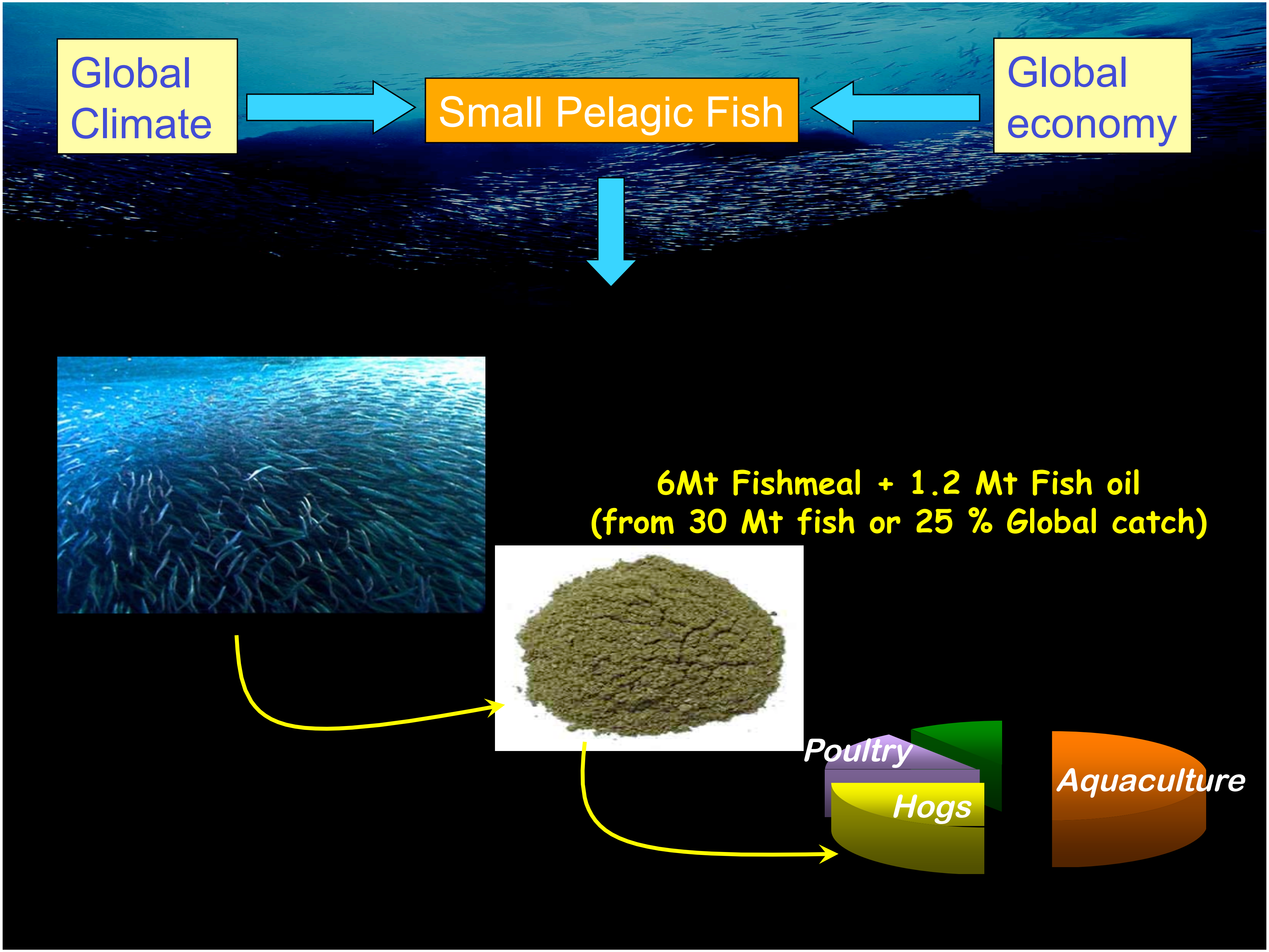
(Diffenbaugh)

Fig. 2. Simulated California Current wind-stress curl. (*A*) May curl in the $2XCO_2$+VEG case. (*B*) August curl in the $2XCO_2$+VEG case. (*C*) September curl in the $2XCO_2$+VEG case. (*D*) May curl in the $2XCO_2$ case. (*E*) August curl in the $2XCO_2$ case. (*F*) September curl in the $2XCO_2$ case. (*G*) May curl anomalies calculated as $2XCO_2$ − CONTROL. (*H*) August curl anomalies calculated as $2XCO_2$ − CONTROL. (*I*) September curl anomalies calculated as $2XCO_2$ − CONTROL. Units are 10^{-7} N/m^3. Continental areas in the RCM are shown in white. Two coastlines are shown. The jagged line represents the RCM coastline. The smooth line represents the actual coastline. RCM grid boxes are 40×40 km.

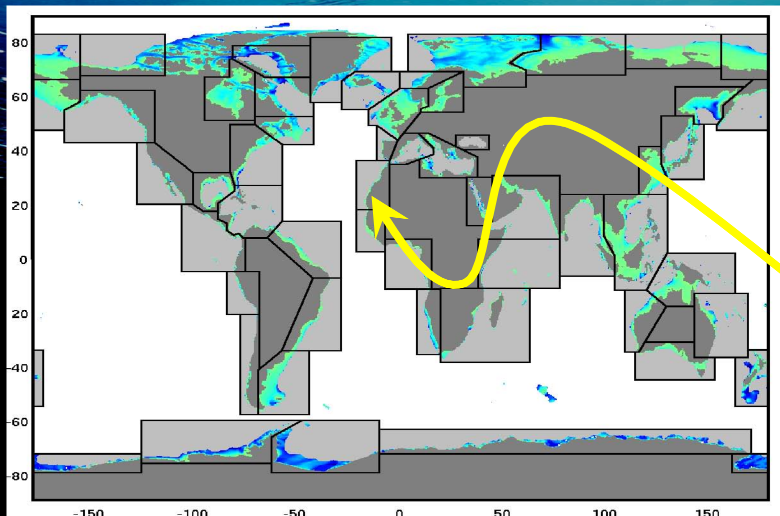
The QUEST_Fish model

From
Manuel Barange



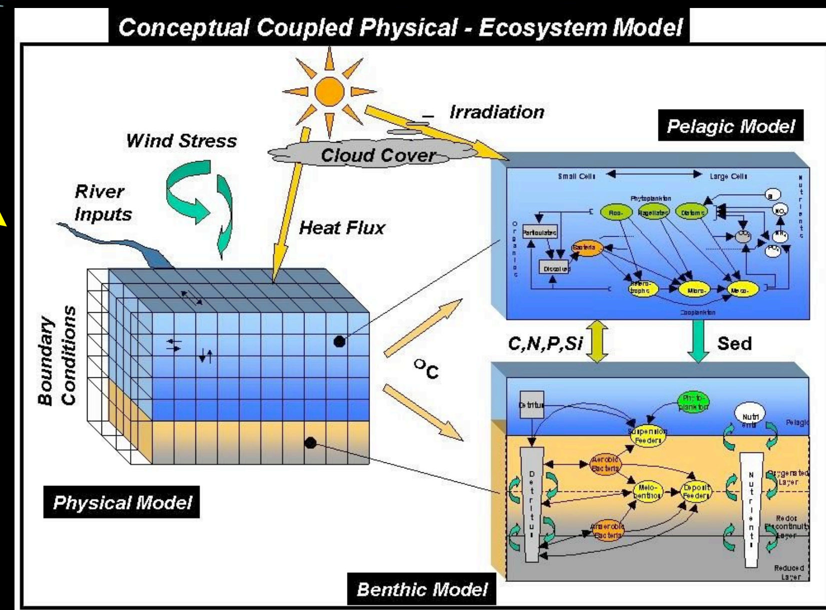

Global Climate
Small Pelagic Fish
Global economy
6Mt Fishmeal + 1.2 Mt Fish oil
(from 30 Mt fish or 25 % Global catch)
Poultry
Hogs
Aquaculture

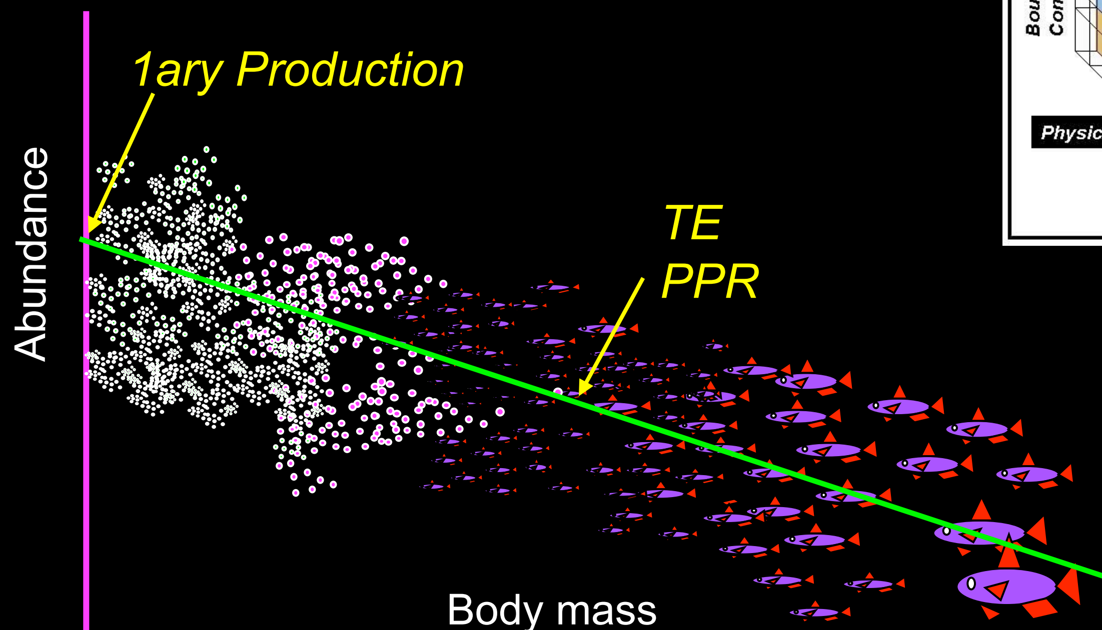
Climate Change forcing scenarios and predictive planktonic ecosystem responses



Couple the shelf seas to the global ocean

Model pelagic/ benthic dynamics as driven by regional hydrodynamics

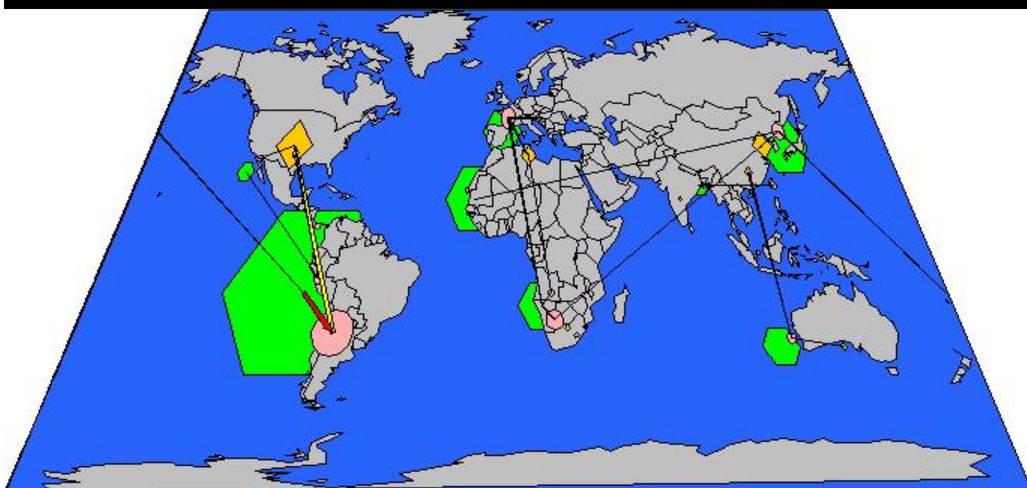


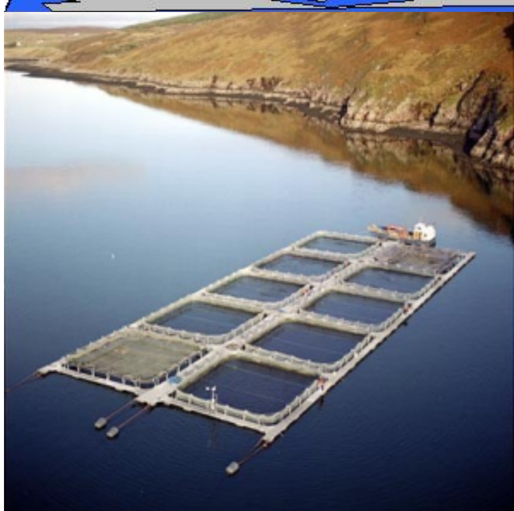


Impacts and Consequences of Global Environmental Change on the fishmeal-based global food markets

Future vulnerability of national economies and global fishmeal and food markets to effects of climate change and other drivers on fisheries

Bio-economic models





Implications for aquaculture via feed substitution

Exposure (E) → **Potential Impacts (PI)**

Sensitivity (S) → **Potential Impacts (PI)**

Potential Impacts (PI)

+

Adaptive Capacity (AC)

=

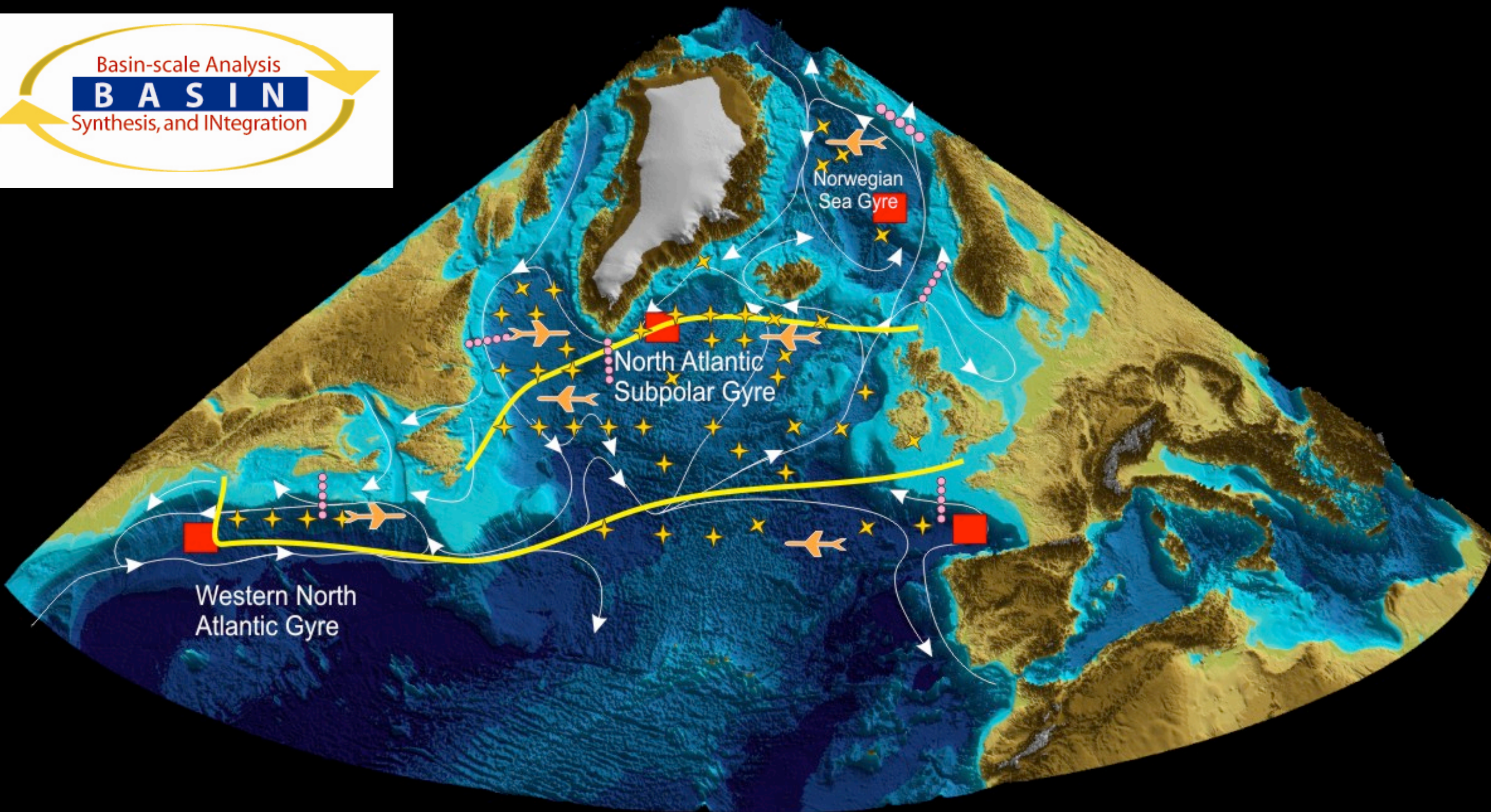
VULNERABILITY
V =*f* (PI, AC)

Summary

- Important advances have been made in the approaches to studying marine ecosystems
- Challenges in linking across scales and across biogeochemistry-individual species-populations (end-to-end)
- Predictions (on "ecological" space & time scales)
- Need to couple:
  - open ocean and coastal regions
  - ocean-land-atmosphere
  - Human dimension

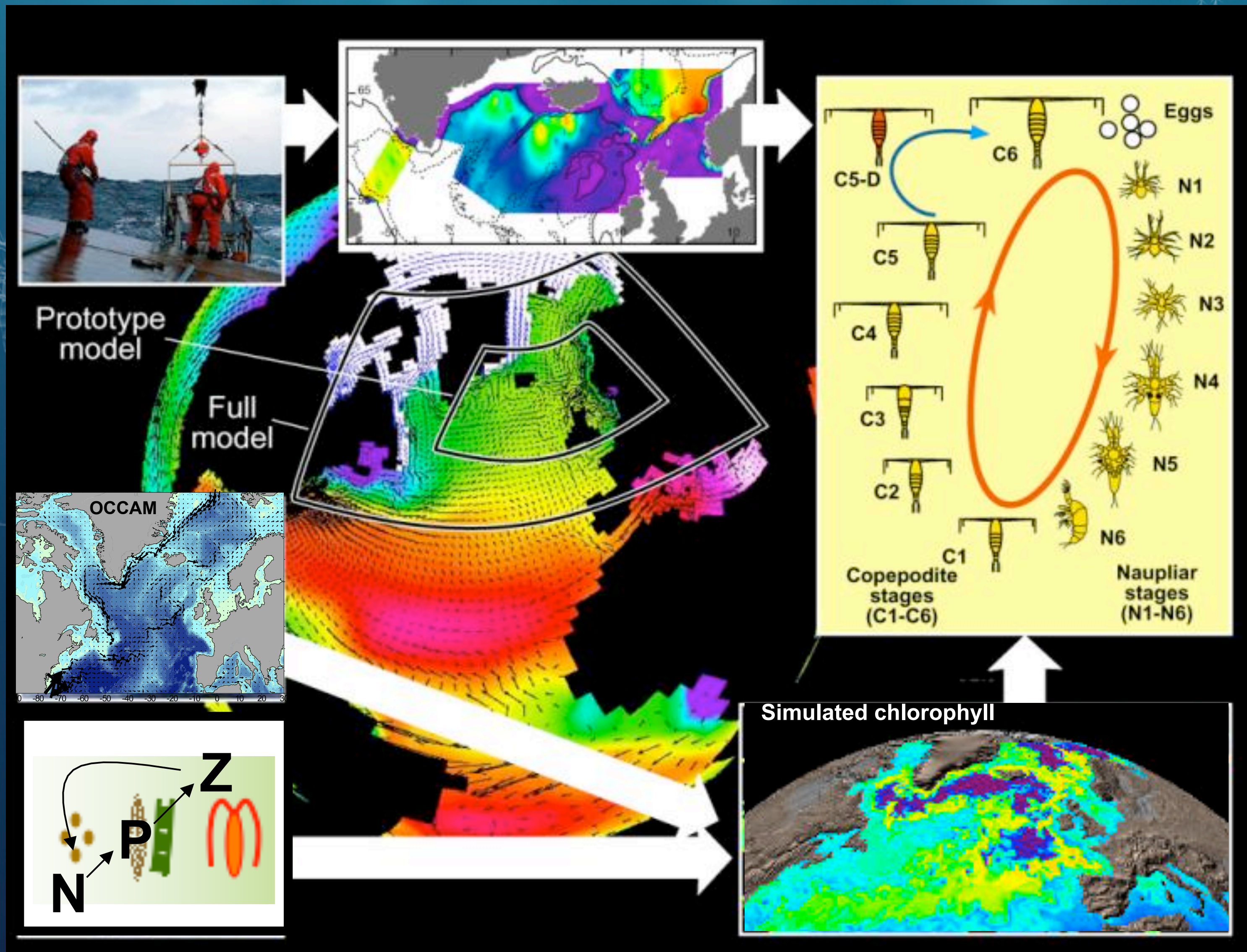
BASIN Study Area and a conceptualization of the Instrumentation.

Basin-scale Analysis
BASIN
Synthesis, and INtegration



BASIN Aim

To understand and simulate the impact of climate variability and change on key species of plankton and fish, as well as community structure as a whole, in the North Atlantic and to examine the consequences for the cycling of carbon and nutrients in the ocean and thereby contribute to ocean management.


Prototype model
Full model
OCCAM
N
P
Z
Eggs
C5-D
C6
N1
N2
C5
N3
C4
N4
C3
N5
C2
N6
C1
Copepodite stages (C1-C6)
Naupliar stages (N1-N6)
Simulated chlorophyll

(from M. Heath)