An Overview of Biogeochemical Modeling in ROMS

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With help from Enrique Curchitser, Kenny Rose, Jerome Fiechter and others

Outline

- Simple NPZ model
- ROMS options
- BEST-BSIERP project
- CAMEO project

Annual Phytoplankton Cycle

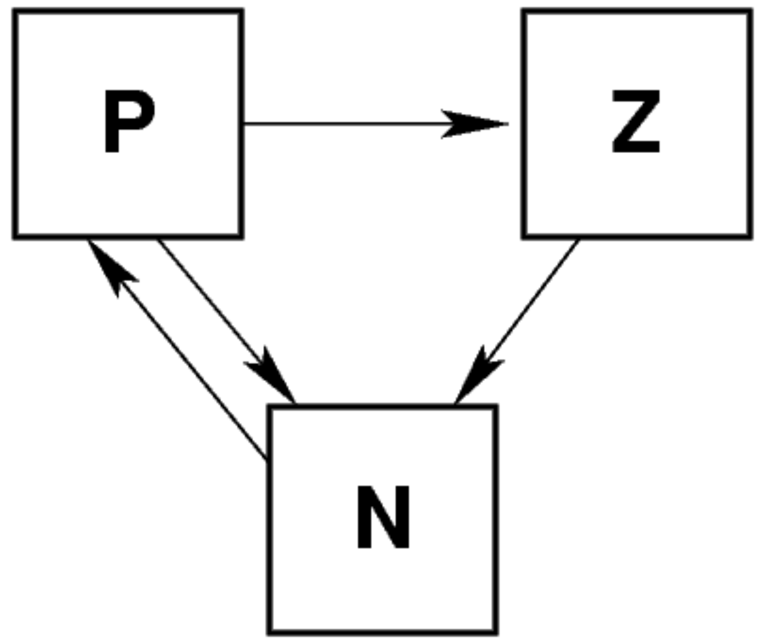
- Strong vertical mixing in winter, low sun angle keep phytoplankton numbers low
- Spring sun and reduced winds contribute to stratification, lead to spring bloom
- Stratification prevents mixing from bringing up fresh nutrients, plants become nutrient limited, also zooplankton eat down the plants

Annual Cycle Continued

- In the fall, the grazing animals have declined or gone into winter dormancy, early storms bring in nutrients, get a smaller fall bloom
- Winter storms and reduced sun lead to reduced numbers of plants in spite of ample nutrients
- We want to model these processes as simply as possible

Franks et al. (1986) Model

- Simple NPZ (nutrient, phytoplankton, zooplankton) model
- Three equations in the three state variables
- Closed system - total is conserved



The Equations

P Change = nutrient uptake - mortality(P) - grazing

$$\frac{dP}{dt} = \frac{V_m N P}{K_s + N} - mP - Z R_m (1 - e^{-\Lambda P})$$

Z Change = growth efficiency * grazing - mortality(Z)

$$\frac{dZ}{dt} = \gamma Z R_m (1 - e^{-\Lambda P}) - gZ$$

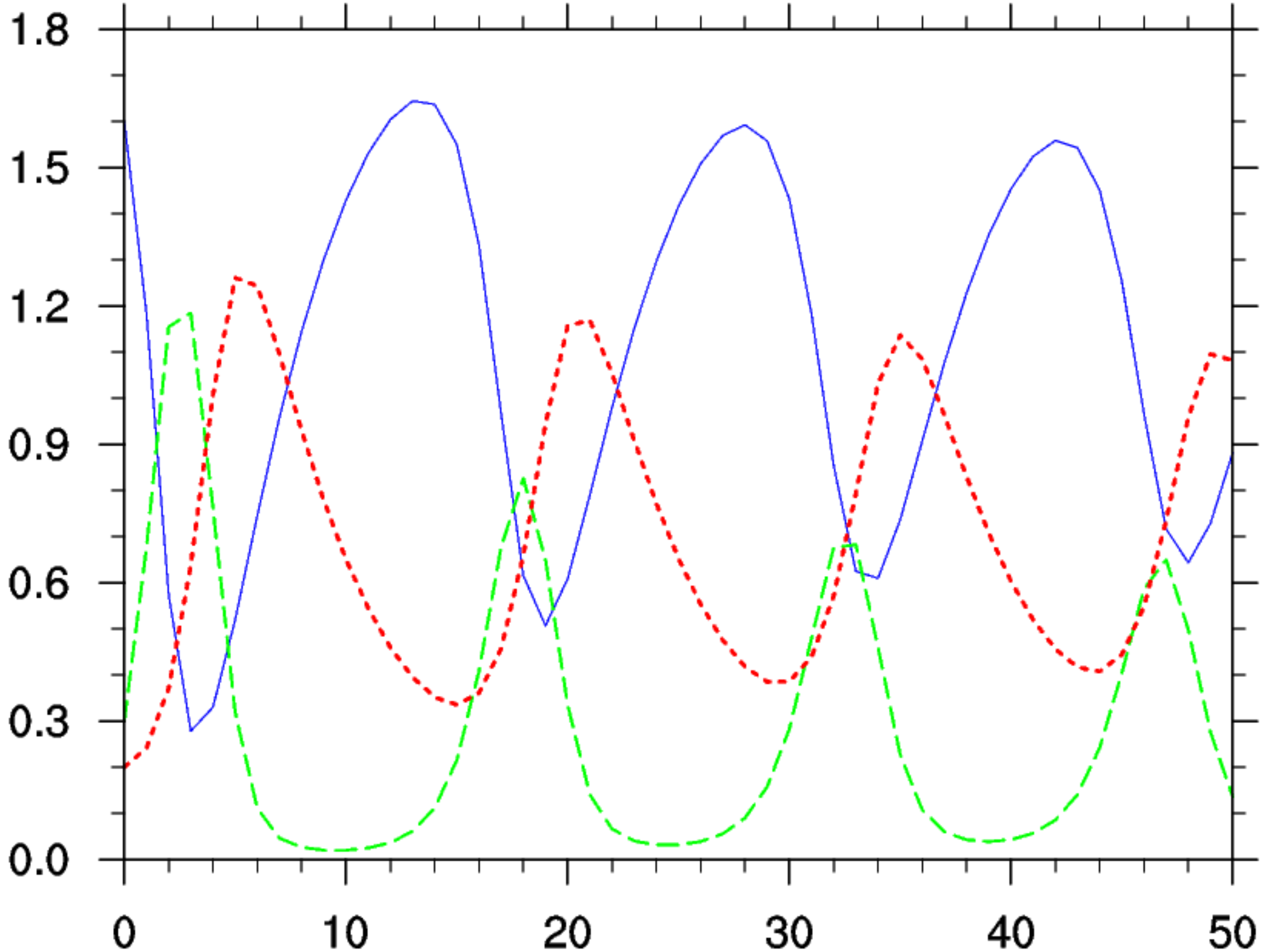
N Change = - nutrient uptake + mortality(P) + mortality(Z) + (1 - growth efficiency) * grazing

$$\frac{dN}{dt} = -\frac{V_m N P}{K_s + N} + mP + gZ + (1 - \gamma) Z R_m (1 - e^{-\Lambda P})$$

Goal

- Initial conditions are low P, Z, high N
- We want the model to produce a strong spring bloom, followed by reduced numbers for both P and N
- Hope to find a steady balance between growth of P and grazing by Z after the bloom

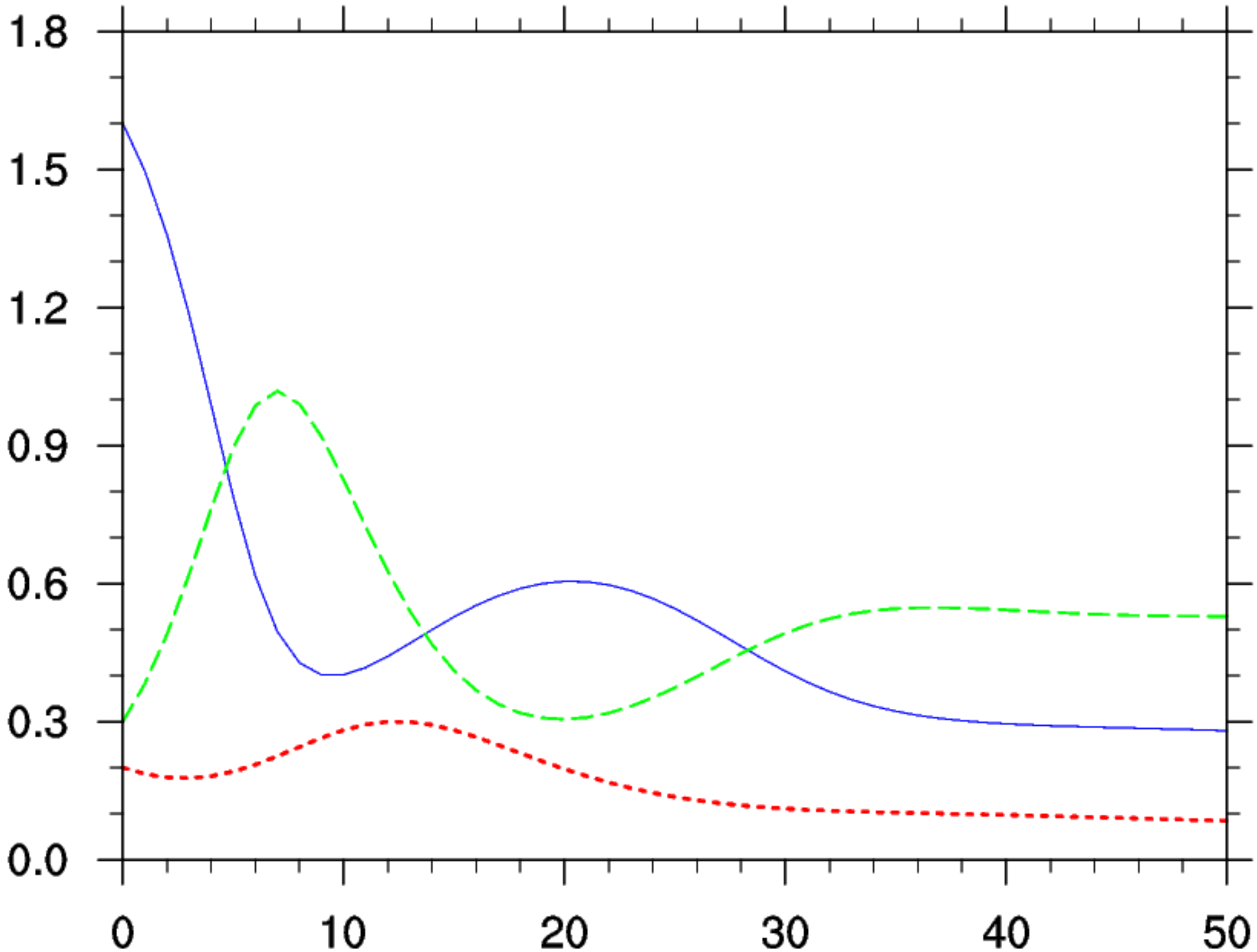
Original Franks Model



NPZ Results

- **There's more than one way to damp the oscillations**
  - Change initial conditions
  - Change grazing function
  - Change mortality constant
- **It's not clear if any of these methods is "right"**
- **Current practice is to add detritus falling out of the mixed layer (NPZD model)**

Simple NPZD Attempt



NPZD Summary

- The Franks model is attempting to describe the ocean mixed layer at one point
- Next is a 1-D vertical profile of the biology, including light input at the surface
- Final goal is a full 3-D model with the physical model providing temperature, currents, seasonal cycle, etc.
- Each component is advected and diffused in the same manner as temperature

More Modern Models

- **Seven, ten, or more variables**
  - Large and small zooplankton
  - Large and small phytoplankton
  - More (specific) nutrients
  - Detritus
- **Models are tuned for specific regions, specific questions**

ROMS Biology Options

- **NPZD_Franks**
- **NPZD_Powell**
- **NPZD_iron**
- **Fennel**
- **Multiple phytoplankton-class model (ECOSIM)**
  - Four phytoplankton classes
  - Internal carbon and nitrate for each
  - No zooplankton
- **NEMURO**

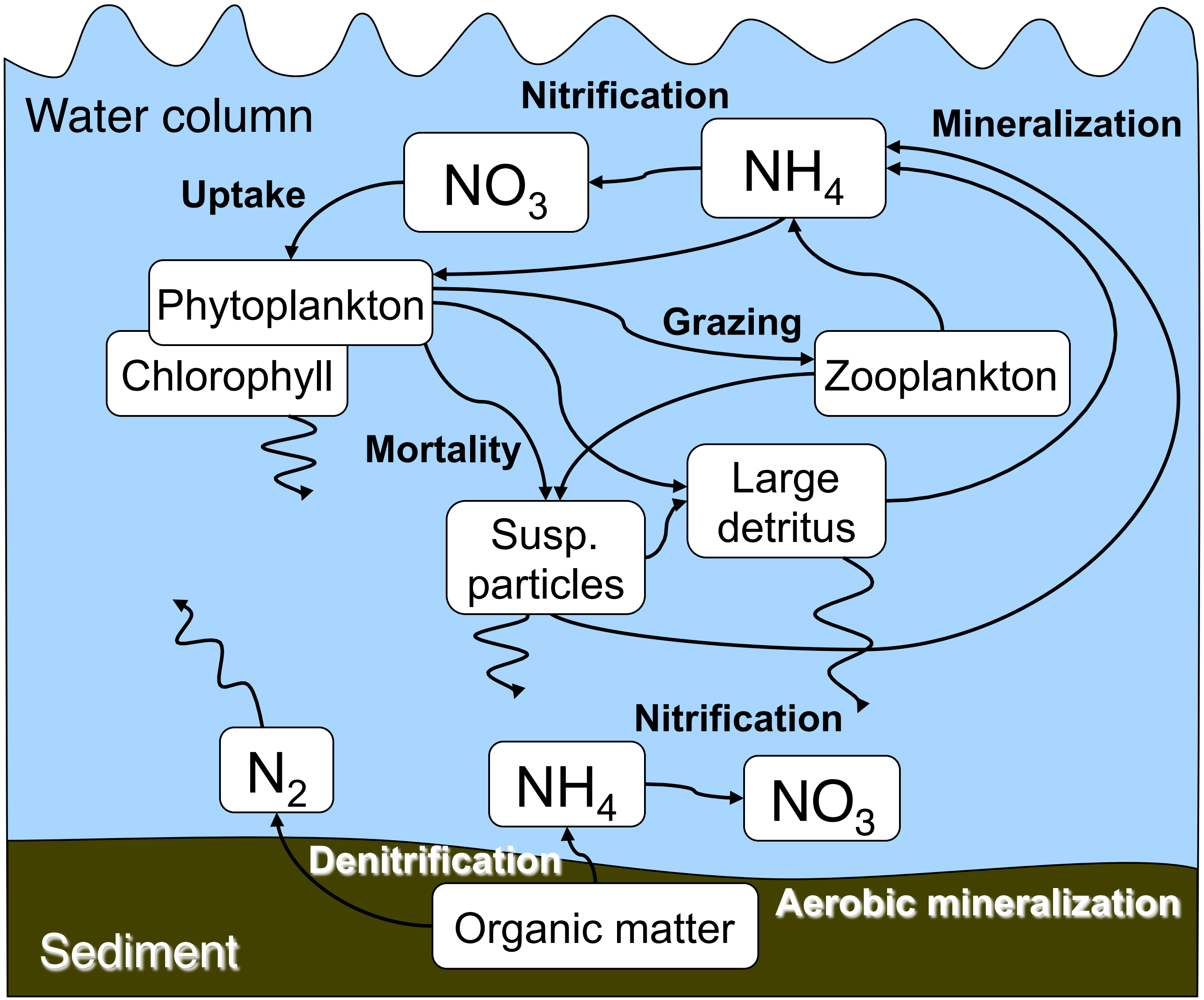
Non-trunk Options

- CoSiNE
- GOANPZ (Gulf of Alaska)
- BESTNPZ (Bering Sea)
- Darwin – 80-100 phytoplankton with random parameters

Fennel's Model

- Fasham-type model
- In shallow coastal waters, the sinking particles hit the bottom where nutrient remineralization can occur
- Add a benthos which contributes a flux of NH4 as a bottom boundary condition
- Her goal is to track the nitrogen fluxes and extrapolate to carbon

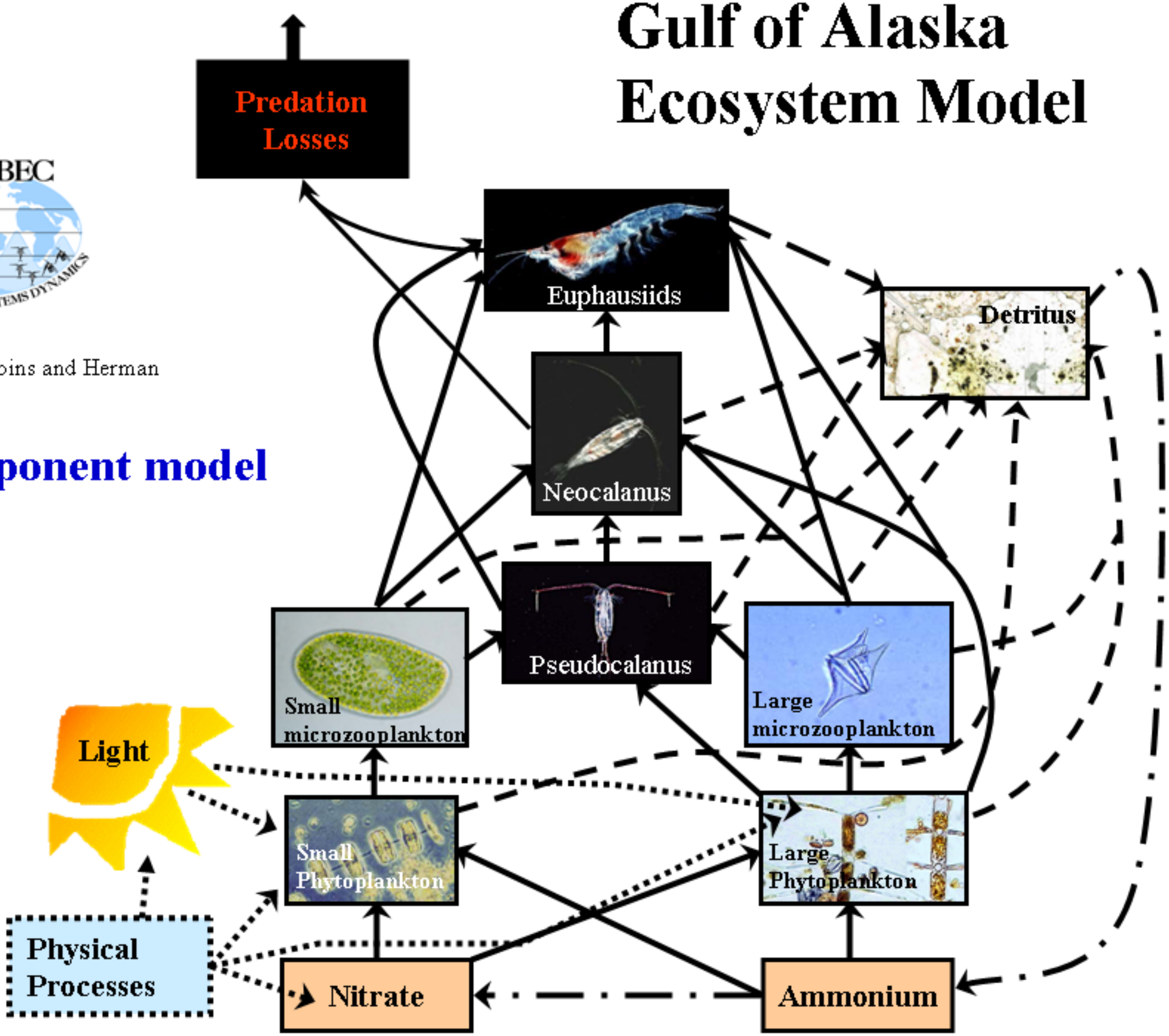
Katja Fennel's Model



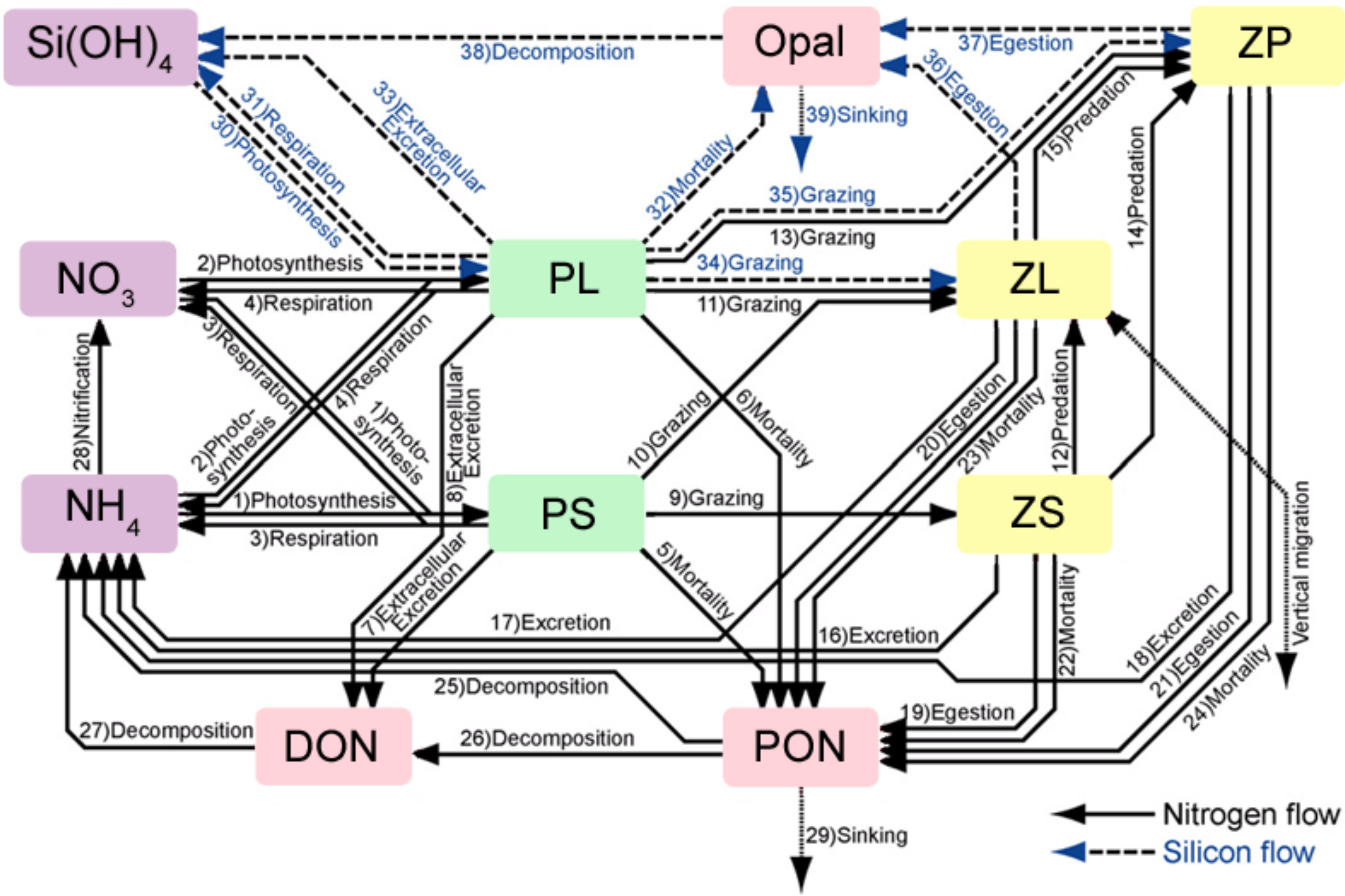
Gulf of Alaska Ecosystem Model

Hinckley, Dobbins and Herman

10 Component model



NEMURO


Si(OH)4
Opal
ZP
38)Decomposition
37)Egestion
36)Egestion
39)Sinking
31)Respiration
30)Photosynthesis
33)Extracellular Excretion
32)Mortality
35)Grazing
15)Predation
14)Predation
NO3
PL
ZL
2)Photosynthesis
4)Respiration
13)Grazing
34)Grazing
11)Grazing
3)Respiration
4)Respiration
2)Photo-synthesis
1)Photo-synthesis
8)Extracellular Excretion
10)Grazing
6)Mortality
20)Egestion
23)Mortality
12)Predation
28)Nitrification
NH4
PS
ZS
1)Photosynthesis
3)Respiration
9)Grazing
5)Mortality
7)Extracellular Excretion
17)Excretion
16)Excretion
22)Mortality
18)Excretion
21)Egestion
24)Mortality
Vertical migration
25)Decomposition
27)Decomposition
DON
26)Decomposition
PON
19)Egestion
29)Sinking
Nitrogen flow
Silicon flow

What’s Next?

- **“How can you call it an ecosystem model if you stop at euphausiids?”**

  – Kenny Rose

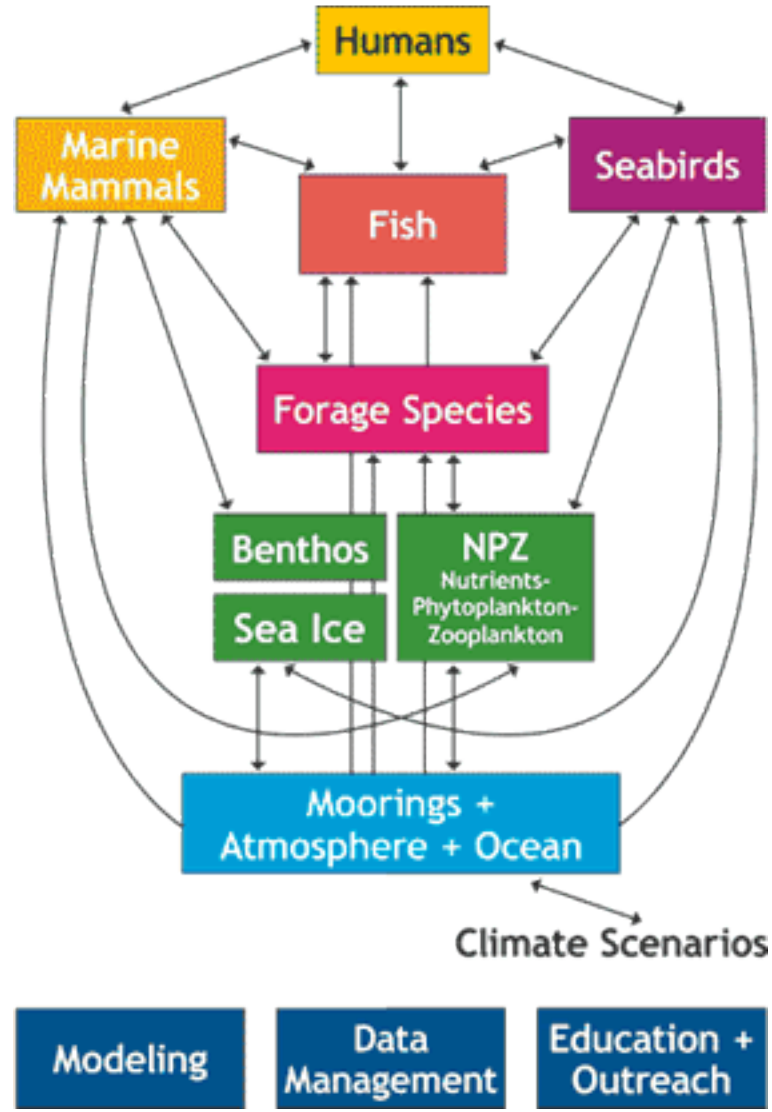
BEST-BSIERP

- **Goal is to understand the Bering Sea ecosystem**
- **About 100 PIs, observations and modeling**
- **Get the current conditions right, then move on to forecast**
  - Use IPCC scenarios
  - Physical model (Monday's talk)
  - NPZ model – start with Gulf of Alaska model, then add components for Bering
  - FEAST fish model
  - Economic models

BEST-BSIERP

- **Focal fish here is pollock**
- **“How can you get the pollock right without salmon?”**

  –Tom Weingartner



Changes in Fish Composition

- When they happen, is it overfishing or is it climate change?
- Goal is to model the complete range of processes from climate to fisheries to get both top-down and bottom-up effects
- Can we do it?

End-to-End Models

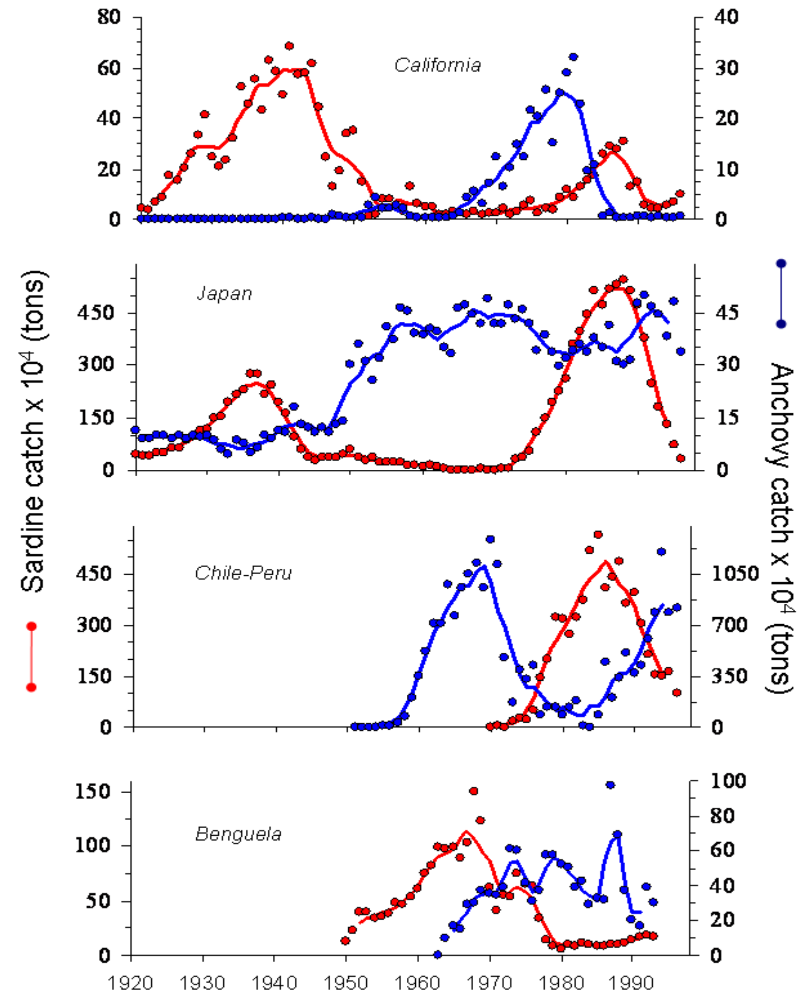
- **They are coming! BEST-BSIERP is one example of how to do it**
- **They are primarily built from existing stand-alone components**
- **NPZ and fish models meet at zooplankton**
  - Closure for getting phytoplankton right
  - Fish food

Some Problems

- **Zooplankton biomass vs. stages**
- **Functional groupings**
  - Diet shifts in fish
  - Prey selection by zooplankton
- **New organisms**
  - Jellyfish
  - People
- **Validation**

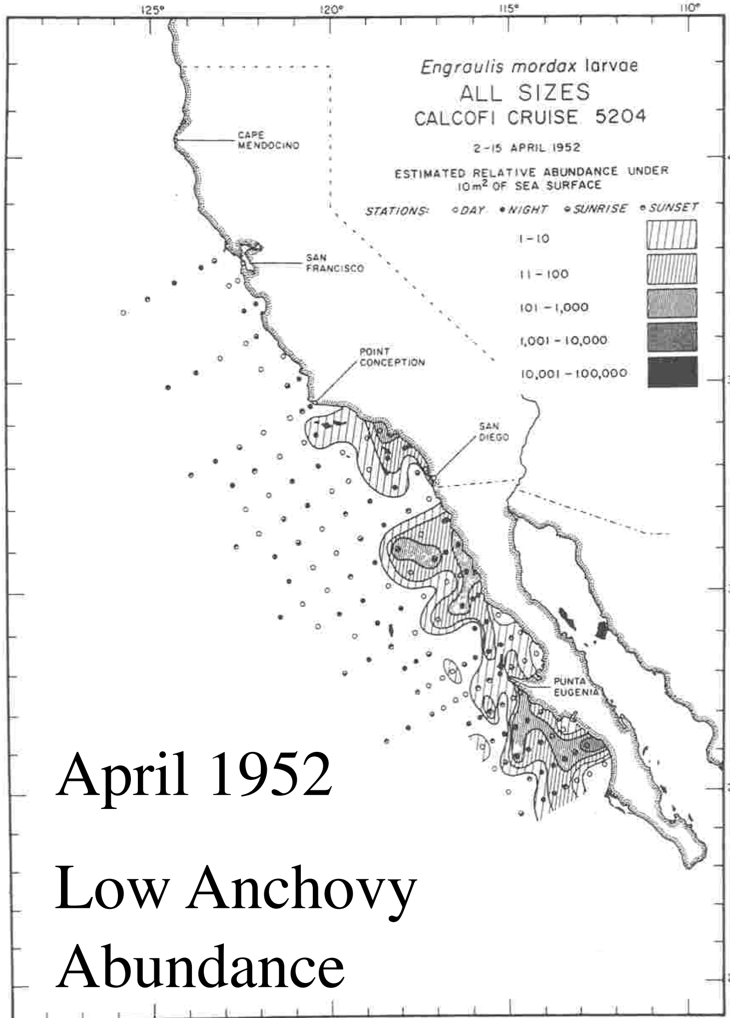
A Simpler Problem?

- **Sardine – Anchovy cycles**
  - Well-studied species with population cycles observed in many systems
  - Teleconnections across basins
- **Good case study**
  - Forage fish tightly coupled to NPZ
  - Important ecologically and widely distributed
  - Low frequency variability



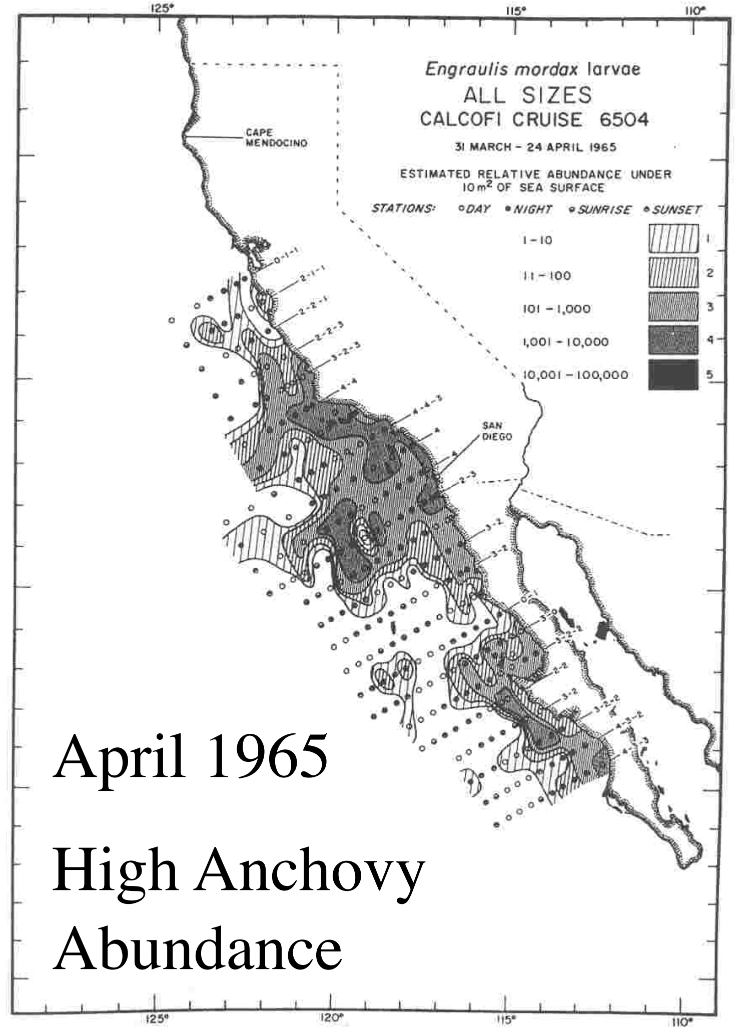
Provided by: Salvador E. Lluch-Cota
Source: Schwartzlose et al., 1999

Californian Anchovy Larval Abundance



April 1952

Low Anchovy Abundance



April 1965

High Anchovy Abundance

Source: MacCall, 1990

CAMEO Model Components

- Community Earth System Model (CESM)
- Regional Ocean Modeling System (ROMS) with NEMURO NPZ
- Superindividual model of sardines and anchovies (Rose)
- California and Mexican sardine fishery (Haynie)

Fish (and Fishers) Project

- **With:**
  - Jerome Fiechter (UCSC)
  - Kenny Rose (LSU)
  - Enrique Curchitser (Rutgers)
  - Alan Haynie (NOAA-AFSC)
  - Miguel Bernal (IEO, Spain)
  - Salvador Lluch-Cota (CIBNOR, Mexico)
  - Others…

Full Life Cycle

- **Superindividuals**
- **Reproduction**
- **Growth**
- **Movement**
  - Feeding and spawning
- **Mortality**
  - Fishing
  - Predators
  - Starvation

Many Challenges

Behavior should include spawning and feeding migrations, predator avoidance, etc.

Growth requires knowledge of bioenergetics – grow or make eggs?

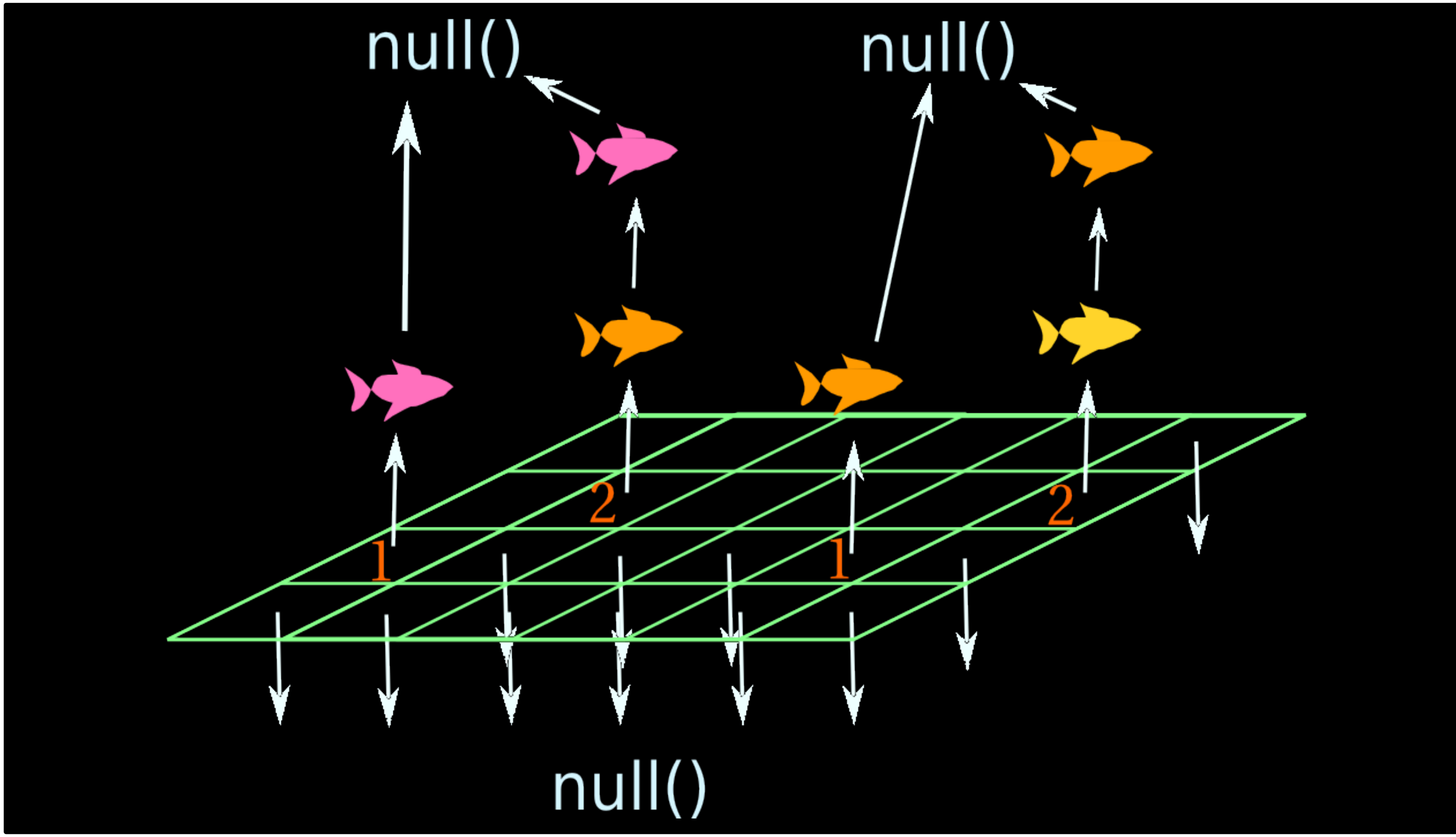
Mortality from starvation – don't all starve at once

Spawning new superindividuals in bounded memory space

Methods

- “Fish” as modified floats
- Fixed number of fish per species per yearclass
- Limit number of yearclasses, killing off too old fish
- Feedback to NPZ-type model, NEMURO for now (PICES)
- Fish-eat-fish and fishing fleets require knowledge of fish in i,j space

fish_list



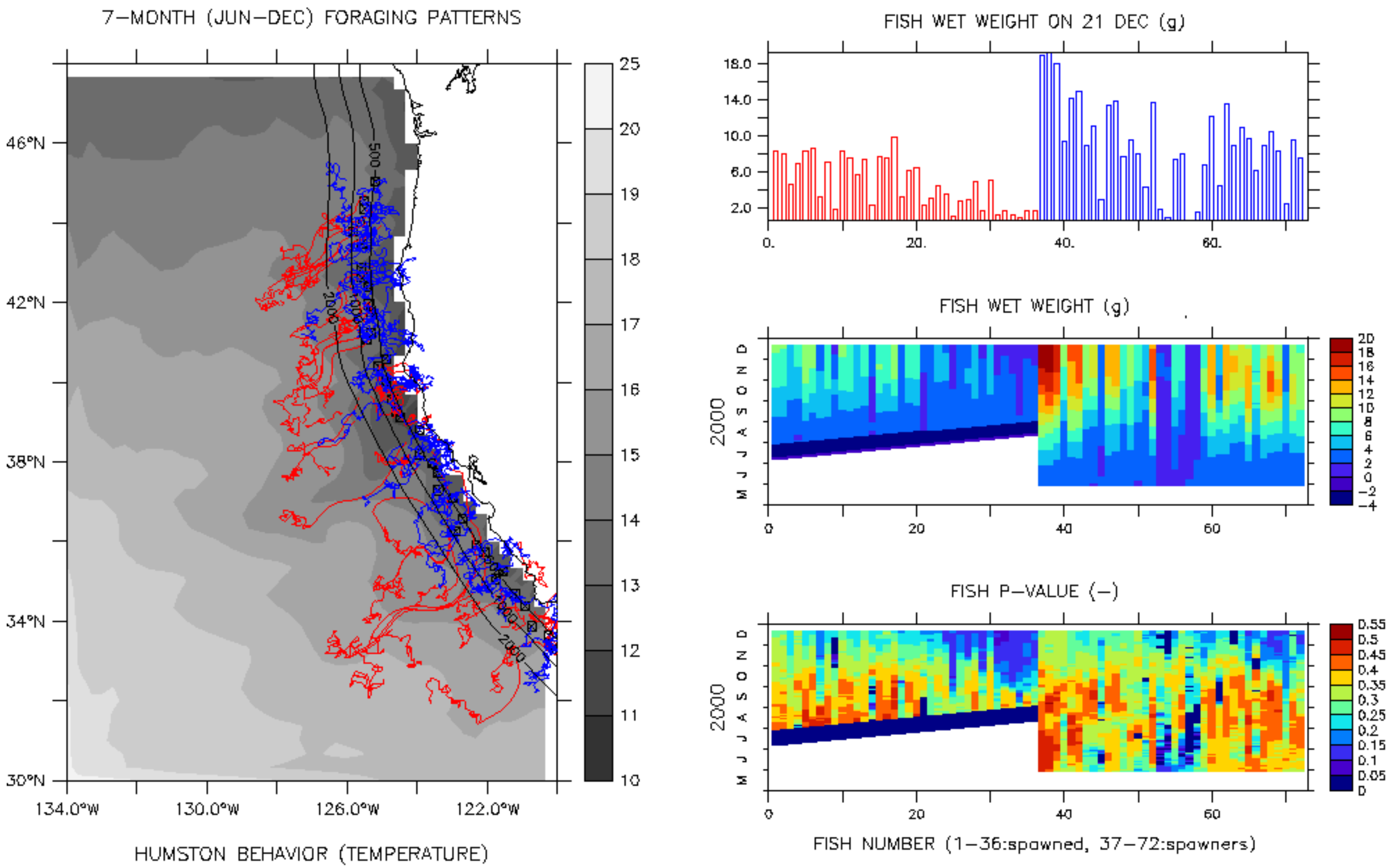
Fish Growth

- **Compute change in weight**
- **Bioenergetics-based**
- **Consumption determined by:**
  - Zooplankton in cell (NEMURO)
  - Other individual fish in the neighborhood
- **Once mature, allocate energy to growth or reproduction**

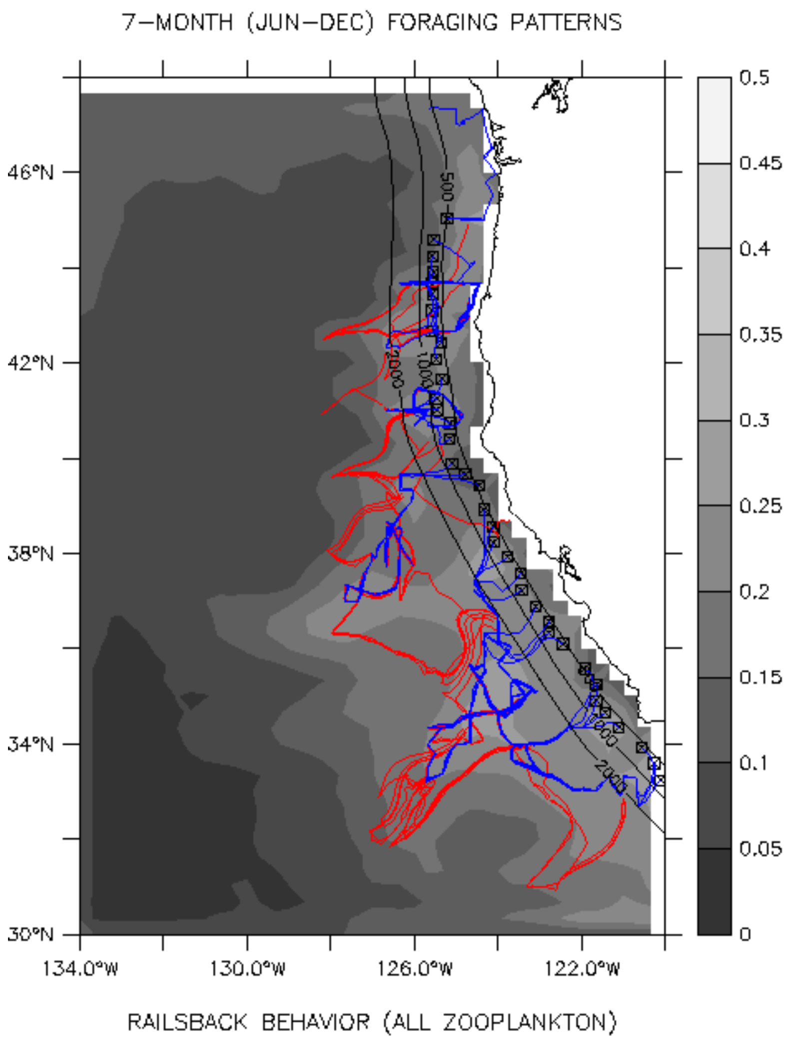
Movement

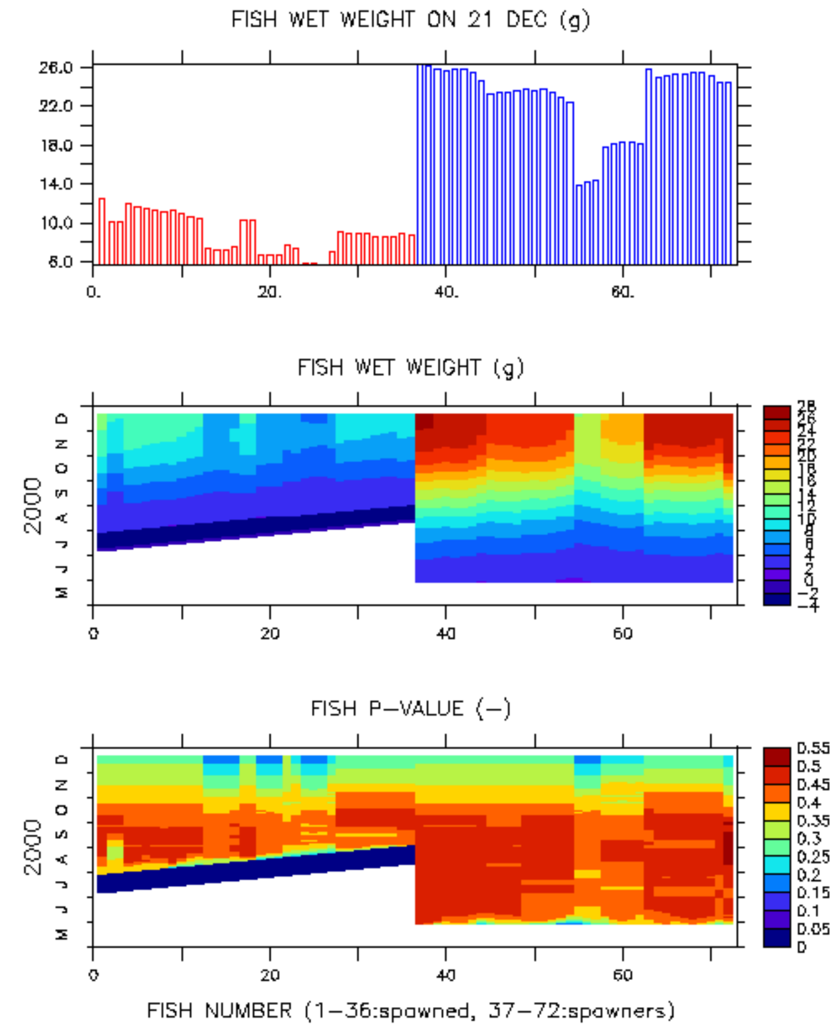
- **Eggs, yolk-sac and larvae are moved by the currents**
- **Juveniles, sub-adults and adults move by behavior**
- **Two choices (for now):**
  - Kinesis (Humston et al., 2004), sum of random plus moving to better temperature
  - Railsback, look for food

Using Humston Behavior



Using Railsback Behavior





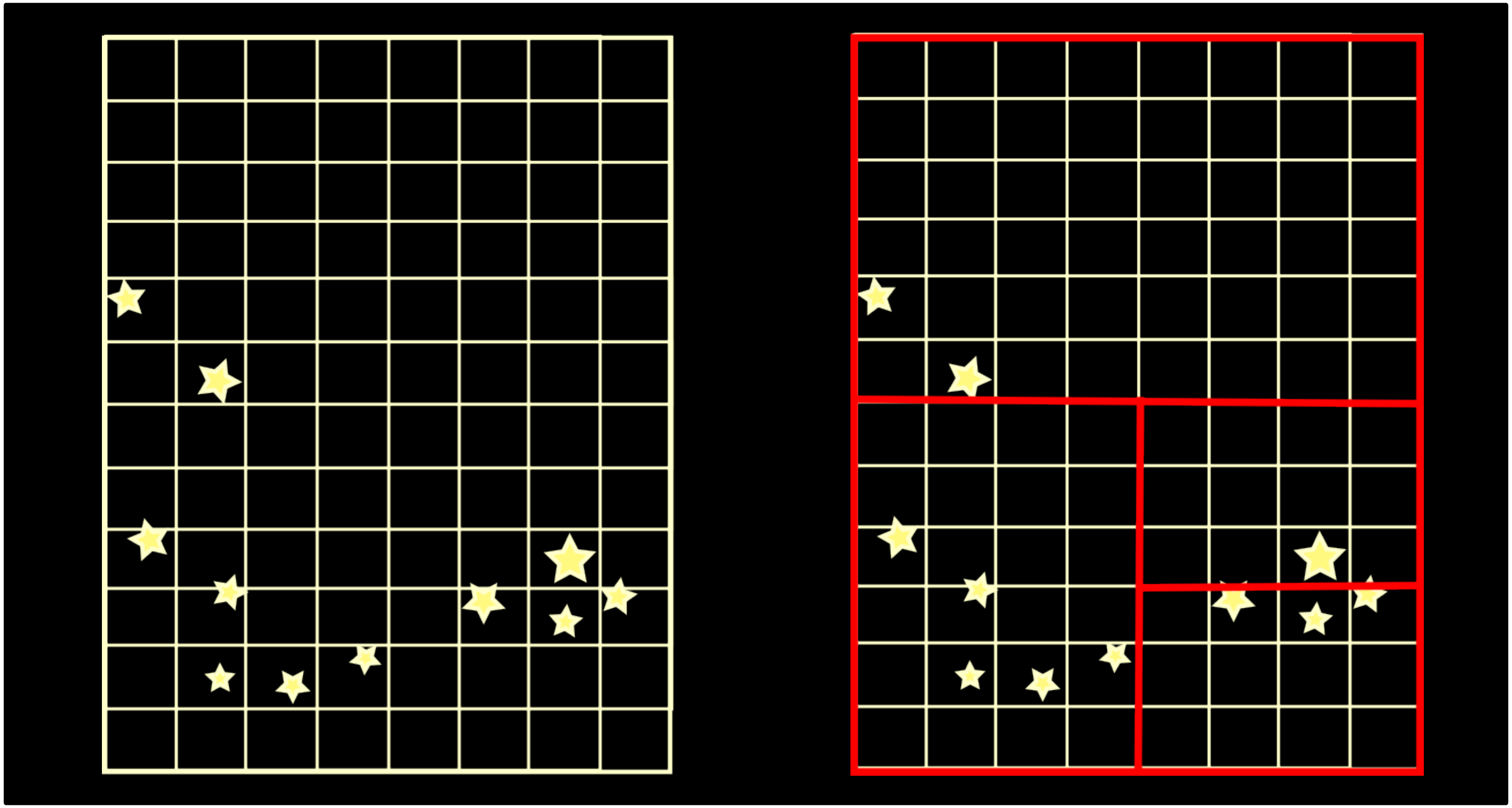
Create new Superindividuals

- **Fixed number per day of spawning – spawning happens in a fixed time window**
- **Find out how many adults spawn that day, how many eggs**
- **Could have:**
  - No eggs
  - Fewer cells with eggs than new SIs
  - More cells with eggs than new SIs

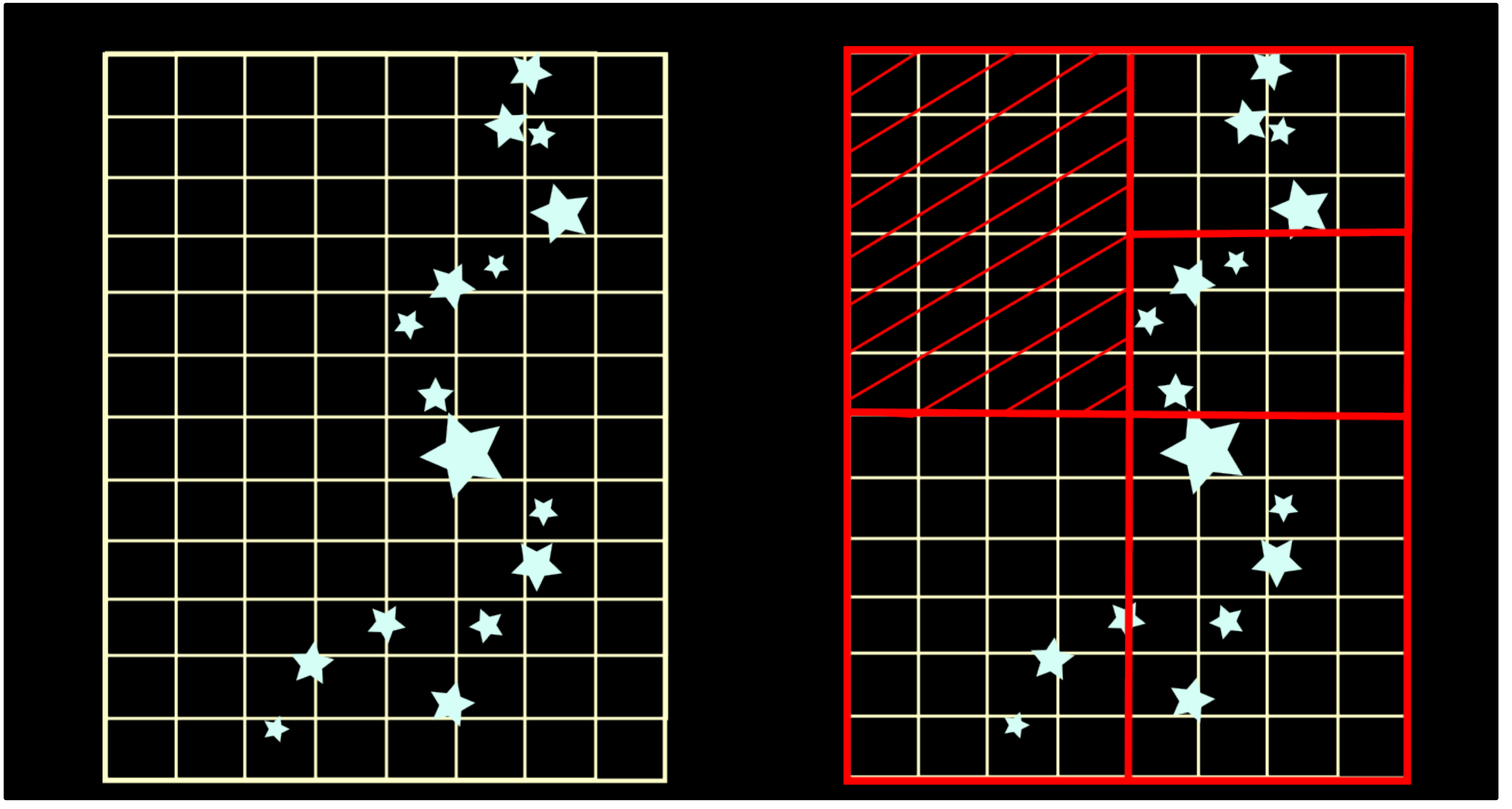
Bisection

- Master node builds an egg array with all of the eggs in each cell
- Array is for the entire grid
- Successively divide up domain in i,j directions until available superindividuals are filled
- Toss out empty partitions
- Keep a sorted (by egg count) linked list of partitions

Bisection



Another Example



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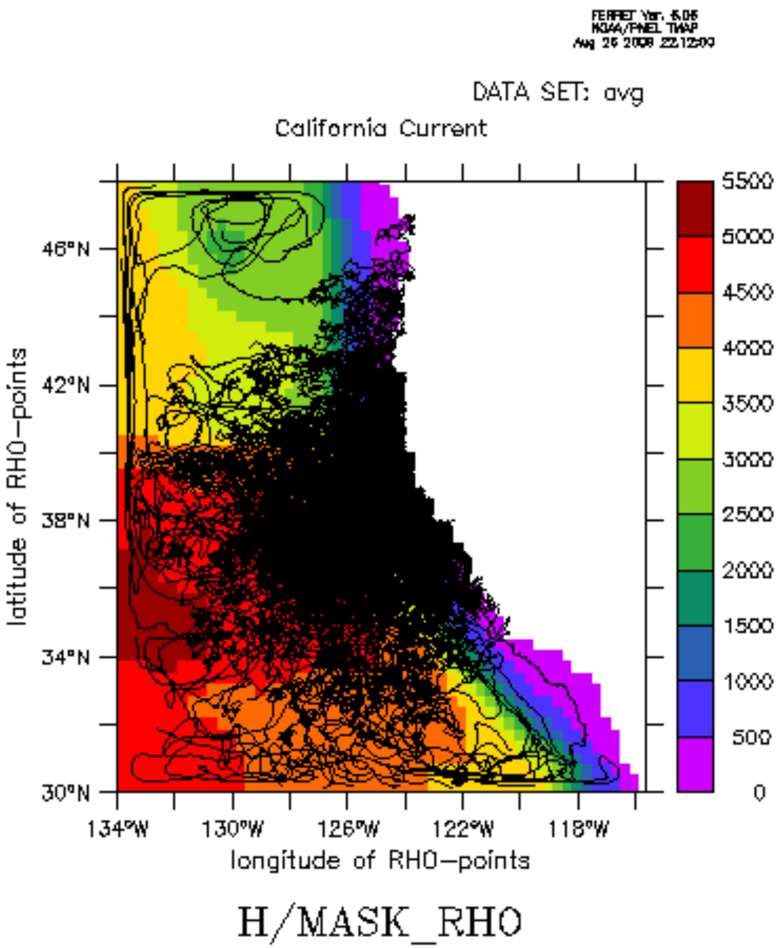
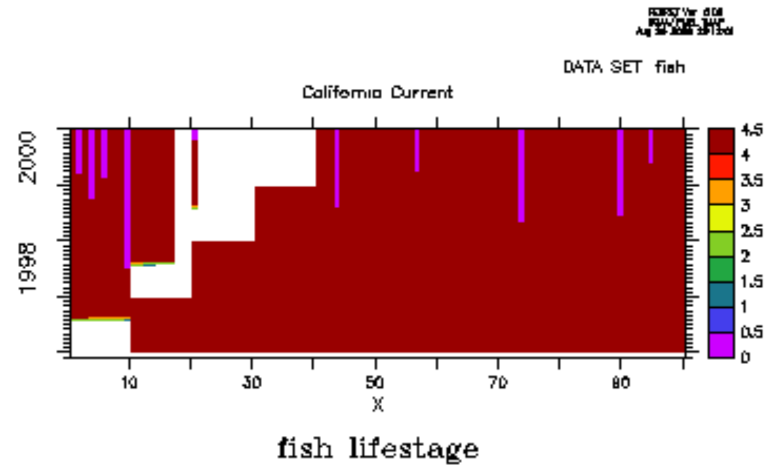
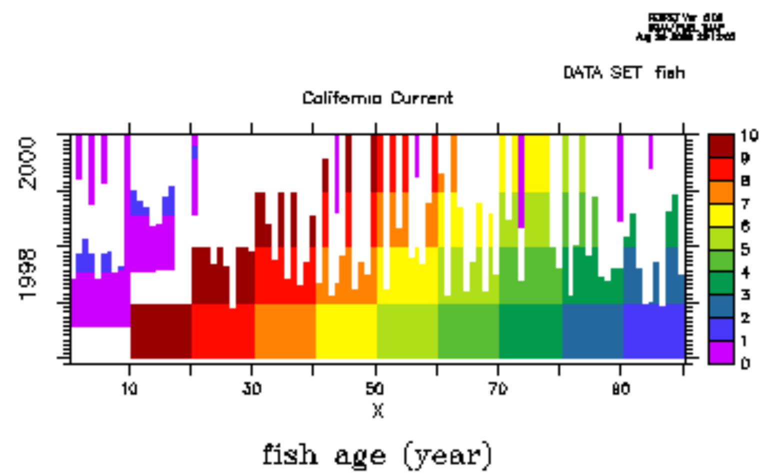
Test of Spawning







Mortality

- **Starvation – bioenergetics are coming**
- **Predator – not full lifecycle:**
  - Modeled on albacore
  - Migrate in to feed, spawn elsewhere
- **Fishing fleets**

Fishing Fleet

- **Targeting sardines only in the California Current**
- **Movement based on engineering, economics, behavior (evaluated once daily in model)**
- **Maximize revenue based on expected CPUE**

Fishing Fleet

-Six ports: (CA(3), OR(1), WA(2))

- Num of boats per ports: 10-30

- Average catch per boat: 40-60 tons

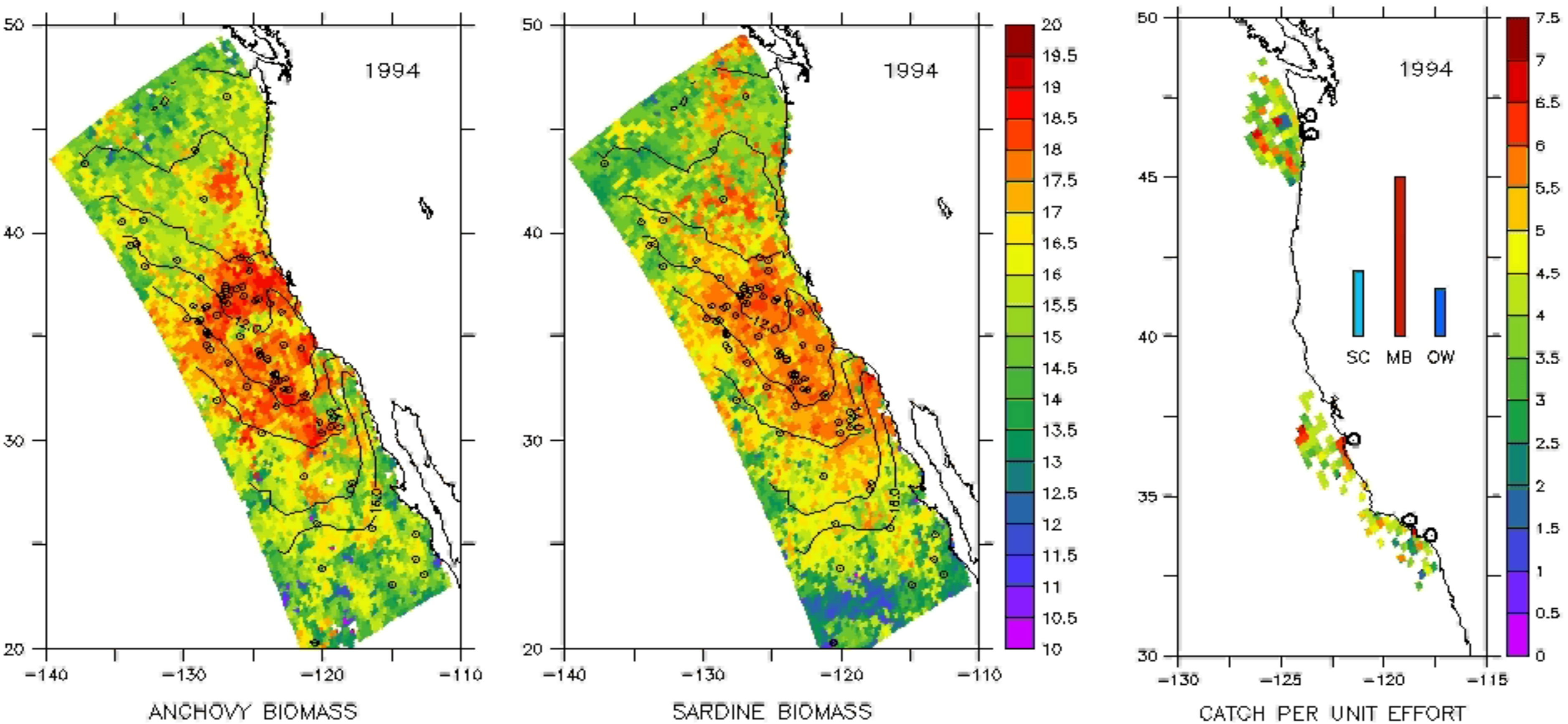
- Boat motoring speed: 20 km/h

-Time to fish/process catch: 2 hours

- Average price for catch: 0.1-0.15 $/kg

NEMUROMS.SAN (1994-2004)

Fully coupled ROMS + NEMURO + Fish + Predators + Fleet
(20,000 individuals; 1,000 predators; 100 fishing boats)



Future Fish Plans

- **Tuning of bioenergetics and behavior**
  - Warm/cold behavior switch
  - Make them look like sardines and anchovies
- **Name this thing!**
- **Write some papers**

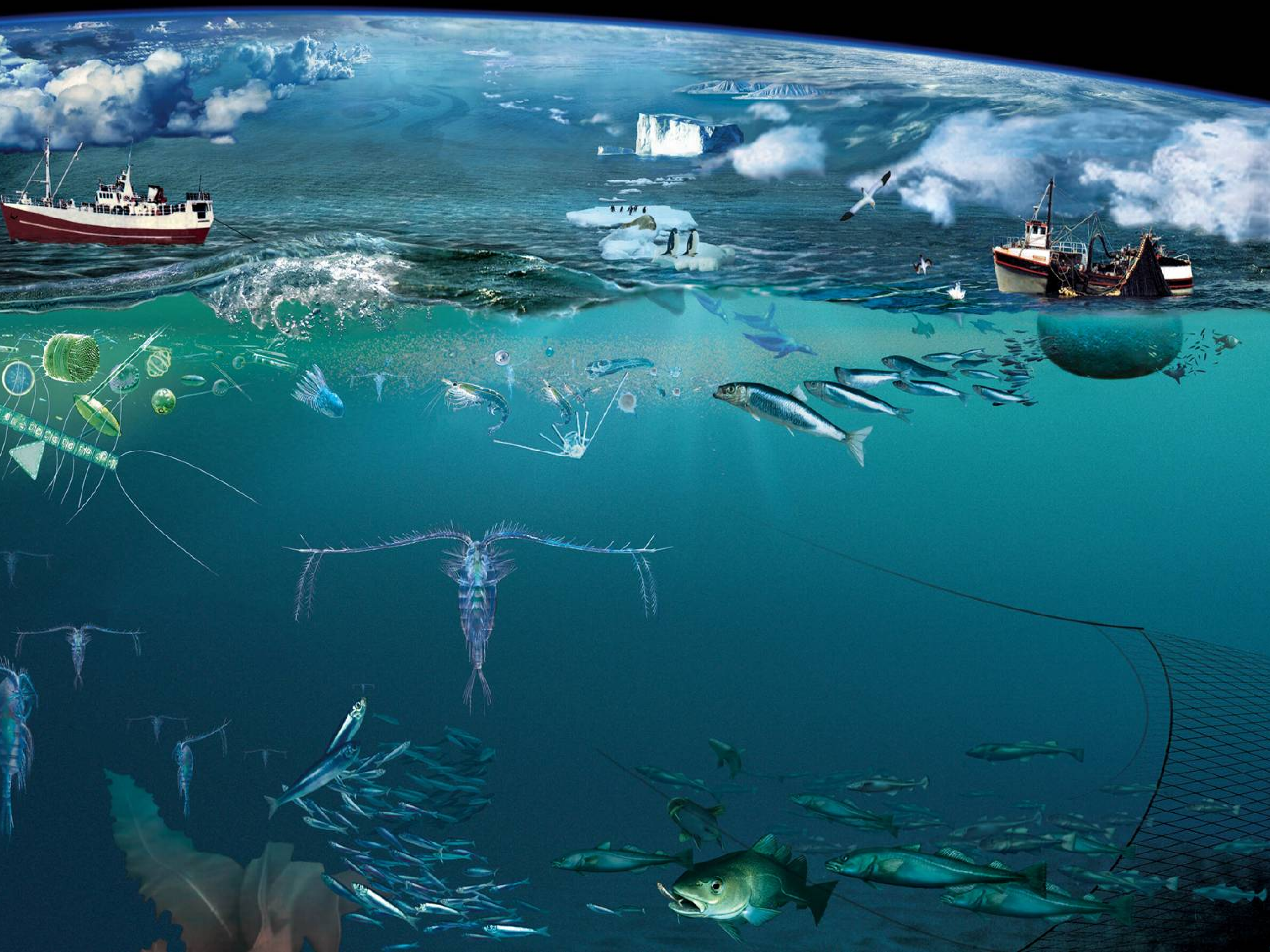
Summarizing

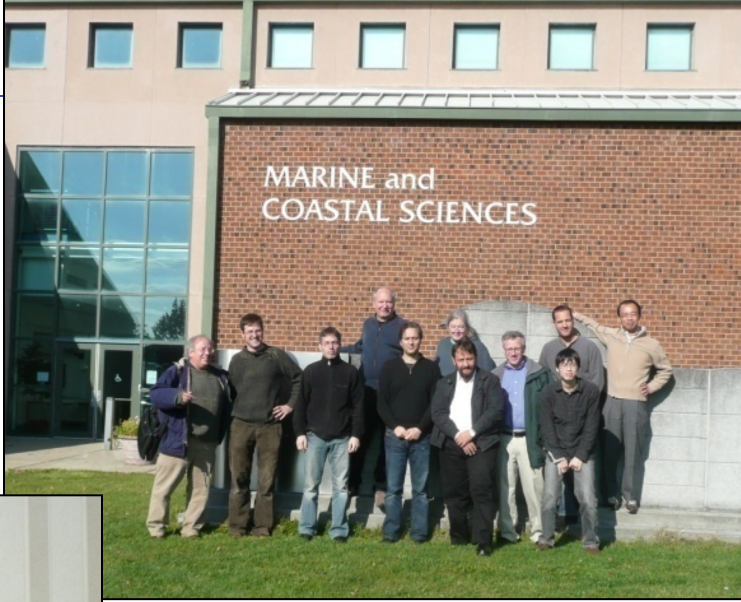
- We have developed a new approach to regional downscaling of climate models that maintains the important feedbacks in the system.
- The new resolved physical scales are closer to what is needed for biology.

- We are developing an individual based model for fish and fishers which is tightly coupled to the physics and lower trophic level models.
- Feedbacks in the biological models may also be important.

Some further thoughts

- End-to-end models are coming. The multi-scale problem exists in biology as well, and needs to be addressed.
- Due to the complexity, different approaches are likely to be better suited for certain problems.
- Models will not be too useful in a data vacuum. We need the same big-picture approach to observations as is being used in the development of complex models.





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