Behavioral cues for small coastal pelagic species in the California Current: results from a fully-coupled end-to-end ecosystem model.

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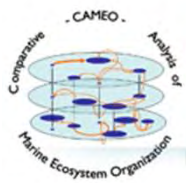

CAMEO
COMPARATIVE ANALYSIS OF MARINE ECOSYSTEM ORGANIZATION

PICES Meeting, Khabarovsk, 21 October 2011

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Motivation

Much emphasis on climate to fish linkages

- Global change issues
- Bottom-up, middle-out, top-down controls

Increasing pressure for ecosystem-based considerations in management

- Full array of interactions within an ecosystem, including humans (instead of single species)

Development of end-to-end ecosystem models

- Multi-species, individual-based, physics to fish
- Proof of principle, continuation of NEMURO effort

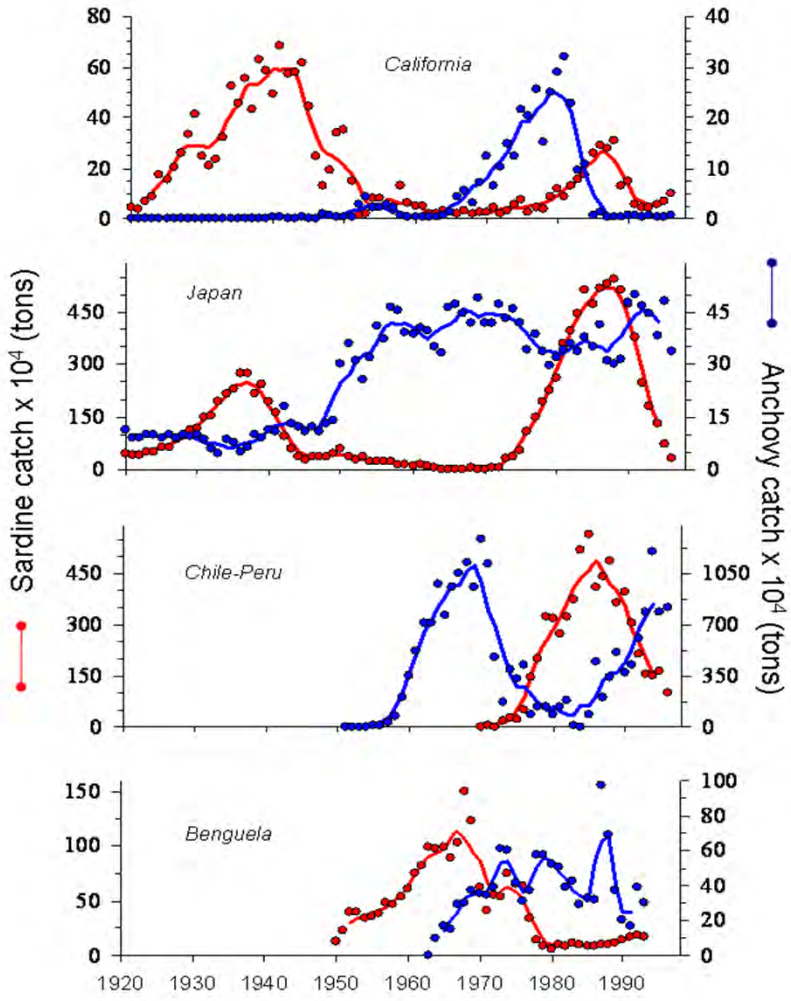
Proof of Principle

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



Source: Schwartzlose et al., 1999

End-to-End Ecosystem Model Components

(NEMUROMS.SAN)

Sub-Model 1: 3-D ROMS for ocean circulation

Sub-Model 2: NEMURO for NPZ

Sub-Model 3: Multiple-species IBM for fish

Sub-Model 4: Fishing fleet dynamics

Today: progress to date

- Solved many numerical and bookkeeping issues
- Implemented different behavioral cues for movement
- Next is to add more realistic biology

Fully-Coupled Model Within ROMS Framework

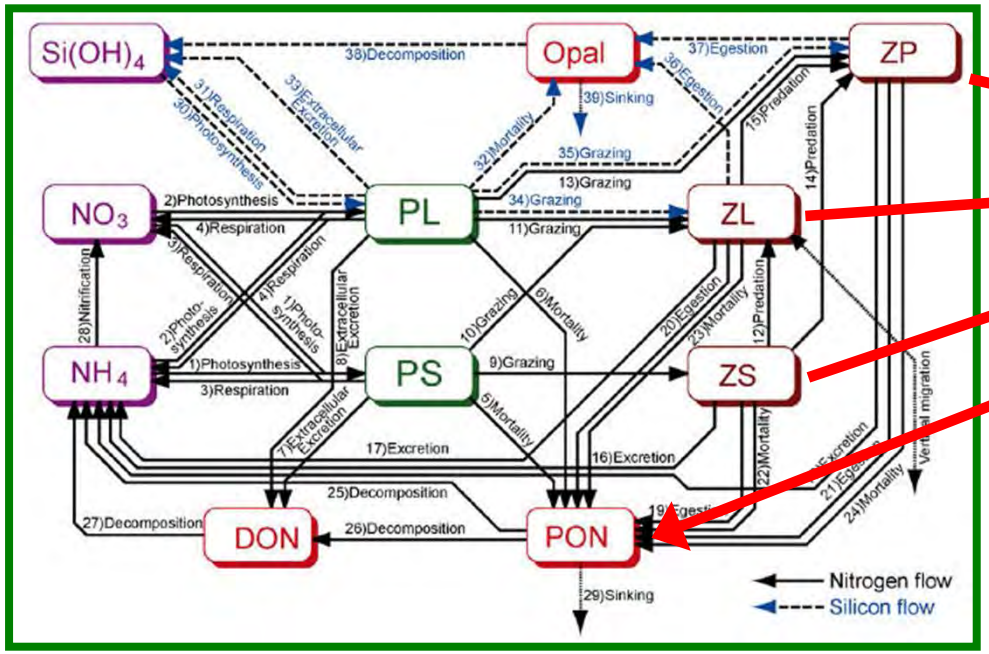
Climate Coupling

Regional Ocean Circulation Model

NPZ Component (multiple)

Floats Component

Data Assimilation



Fish IBM

Sardines

Anchovies

Predators

Fishing Fleet

3-D ROMS for Ocean Circulation

California Current Grid

- 30 km horiz. Resolution
- 42 vertical levels

Run duration

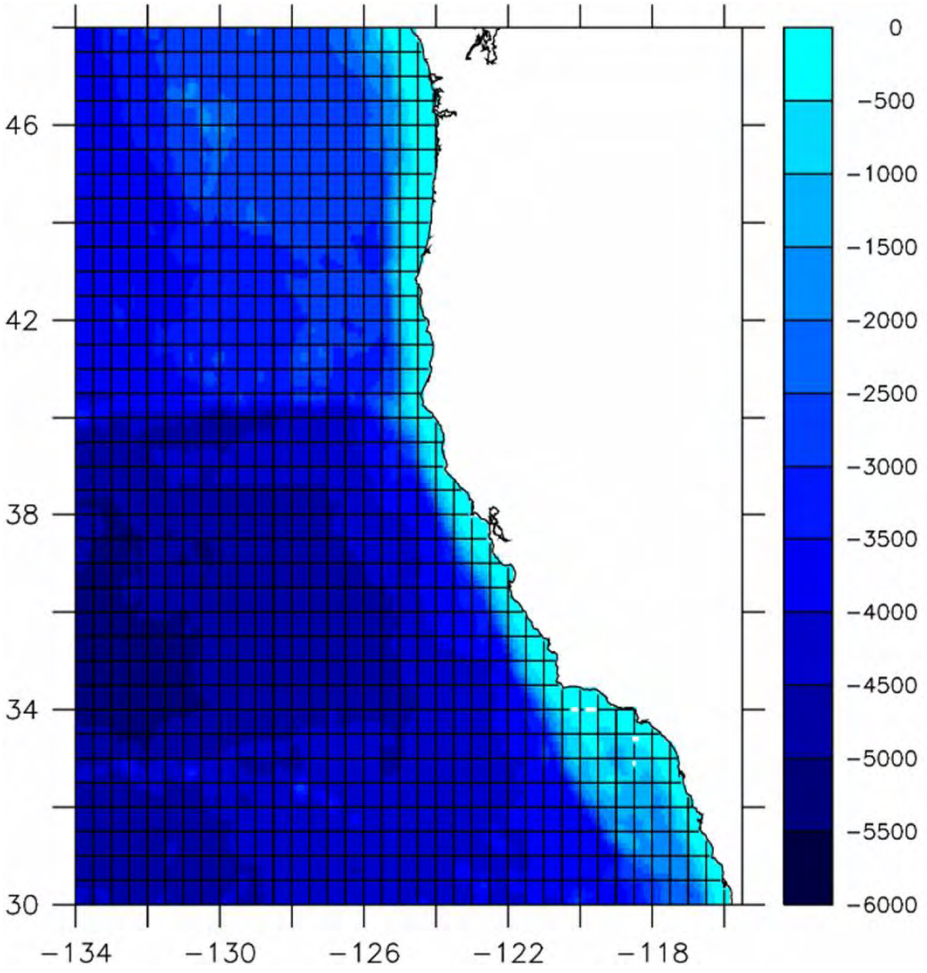
- 20 years (1985-2005)
- Hourly time step

BC/IC: SODA-POP

- Monthly SSH, U, V, T, S
  (Carton et al., 2000)

Surface forcing: CORE2

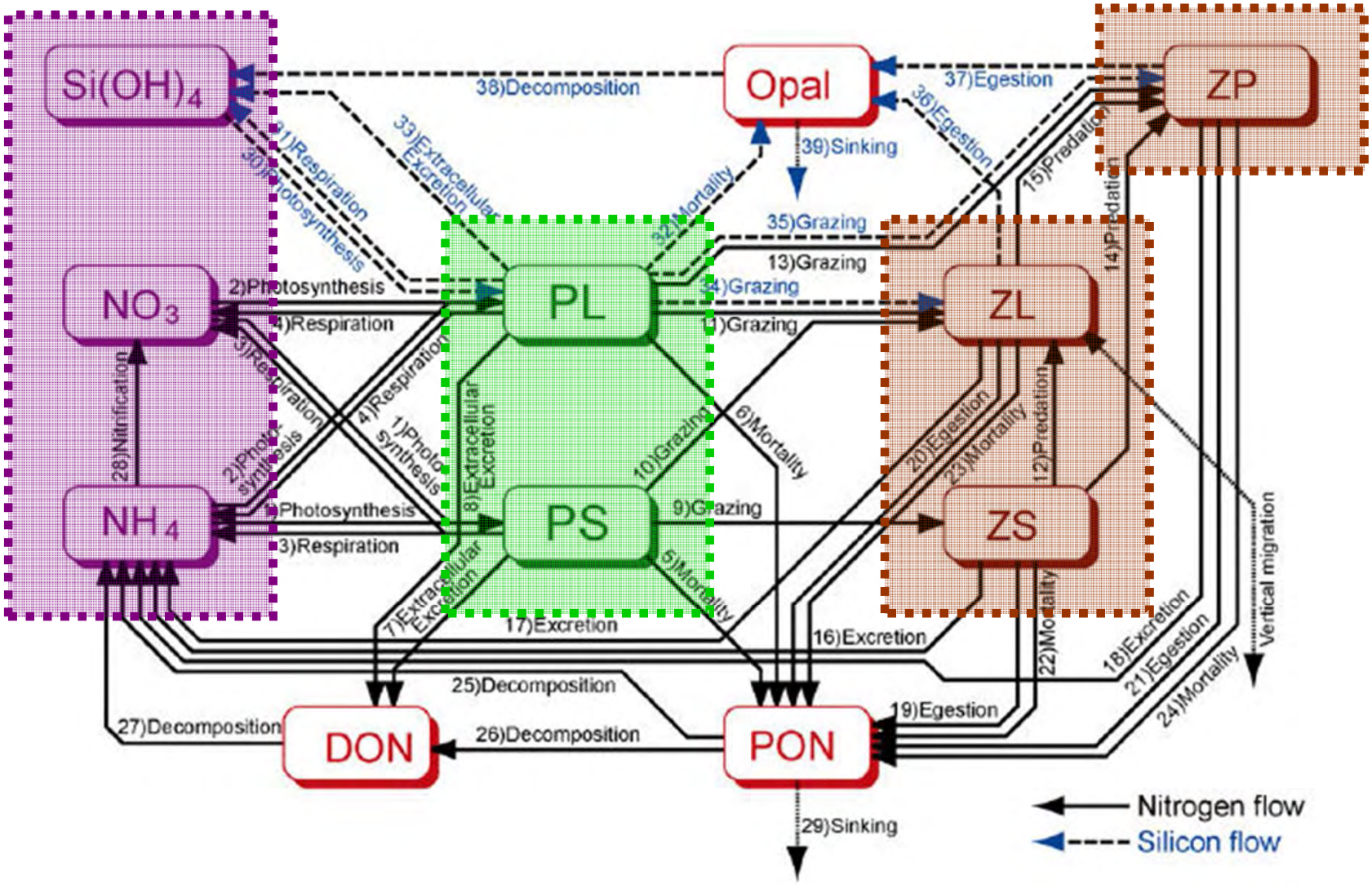
- 6-hrly wind stress, heat fluxes
- Daily radiation, monthly E-P
  (Large and Yeager, 2008)



ROMS grid and bottom topography (m)

NEMURO for Lower Trophic Levels

(Nutrients, Phytoplankton, and Zooplankton)



Fish IBM: Species Types

Individual-based model (IBM)

- Natural unit in nature
- Allow for complicated life history
- Conceptually easier movement
- Super-individual approach (Sheffer et al., 1995)

Sardines and anchovy (full life-cycle)

- Egg, yolk sac, larva, juvenile, subadult, adult
- Growth, mortality, reproduction, movement
- Competitors for food (P and Z from NEMURO)

Predator species (e.g., albacore)

- Consumption and movement only
- Relative biomass to scale mortality

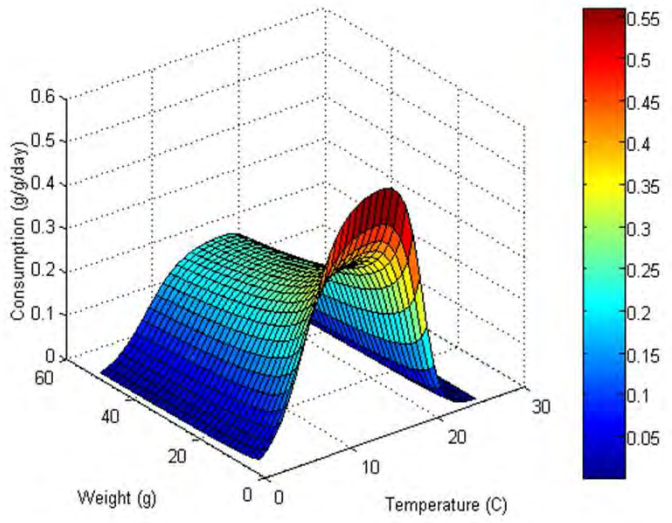
Fish IBM: Growth and Mortality

Growth:

- Bioenergetics for weight
- Consumption from multi-species functional response
- At maturity, allocate energy to growth or reproduction

Mortality:

- Natural (temperature and stage dependent)
- Predation (predator species dynamics, vary in space/time)
- Fishing (fishing fleet dynamics, vary in space/time)



Maximum consumption: f(W, T)

$$C_j = \frac{C_{MAX} \cdot \frac{PD_{ij} \cdot v_{ij}}{K_{ij}}}{1 + \sum_{k=1}^{n} \frac{PD_{ik} \cdot v_{ik}}{K_{ik}}}$$

Holling Type II feeding curve

Fish IBM: Movement

Eggs, yolk-sac, and larvae moved by physics

- Vertical position assumed at 50 m depth

Juveniles and adults moved by behavior

- Day-to-day vs. seasonal migrations
- Kinesis for sardines and anchovies

  (Happiness-based behavior; Humston et al, 2004)
- Fitness for predator species

  (Maximized growth behavior; Railsback et al., 1999)

Each fish has continuous x, y, and z position

- Mapped to 3-D grid at each time step to determine cell location and local conditions

Fishing Fleet

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

- Num. of ports: 6 (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

Fish IBM: Movement - Kinesis

- Used for sardines and anchovies
- Sum of random and inertial velocities (happiness)
- Horizontal is done once a day; vertical is done hourly
- Possibility to combine multiple cues (food, temperature)

Inertial:

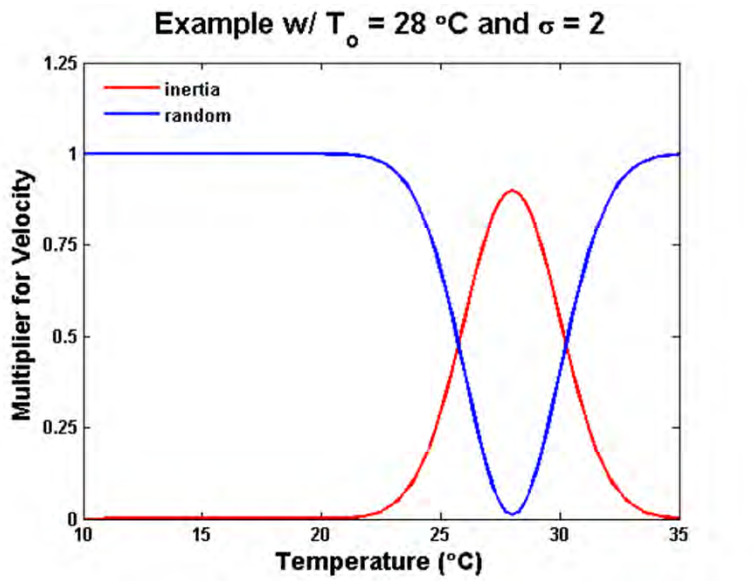
$f(V_{t-1}) = V_{t-1} \cdot \text{multiplier}$

Random:

$g(\varepsilon) = \varepsilon \cdot \text{multiplier}$

Velocity:

$f(V_{t-1}) + g(\varepsilon)$



Environmental Cues for Movement (Kinesis)

Coastal pelagic species 1 ("anchovy-like")

- Feeds on large zooplankton (ZL)
- Initially distributed inshore

Coastal pelagic species 2 ("sardine-like")

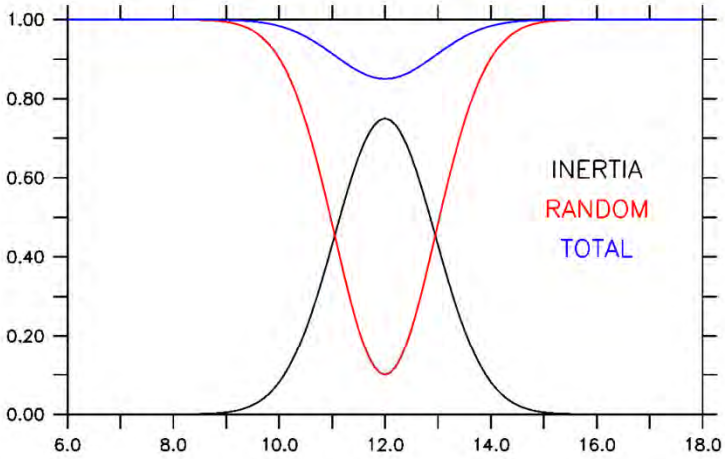
- Feeds on small zooplankton (ZS)
- Initially distributed offshore

Behavioral cues (horizontally and vertically)

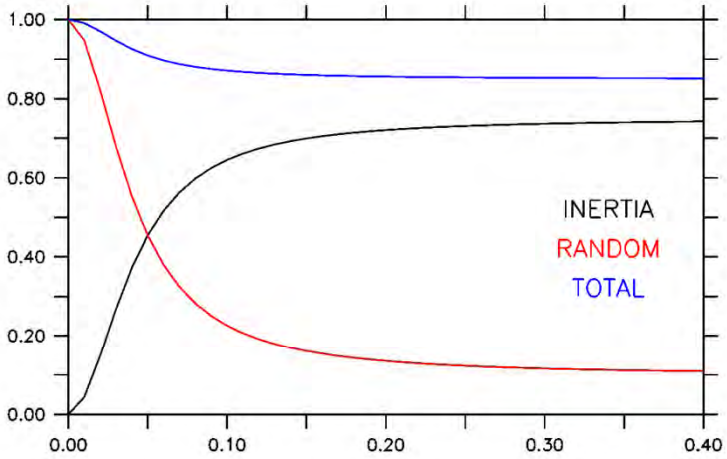
- Optimal temperature of 12ºC with σ of 3ºC
- P-value for random-inertia transition of 0.05
- Combination of temperature and p-value using cue with larger random component

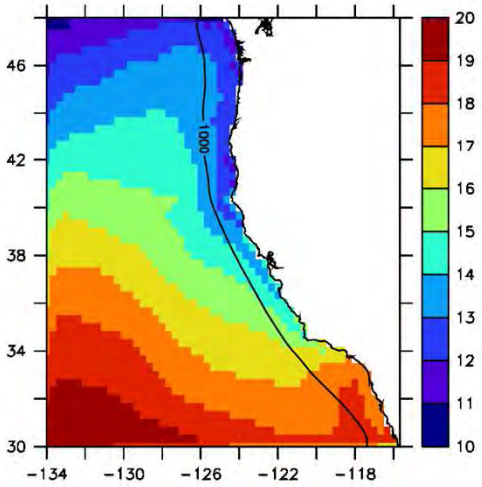
Environmental Cues for Movement (Kinesis)

Temperature (°C) - Gaussian

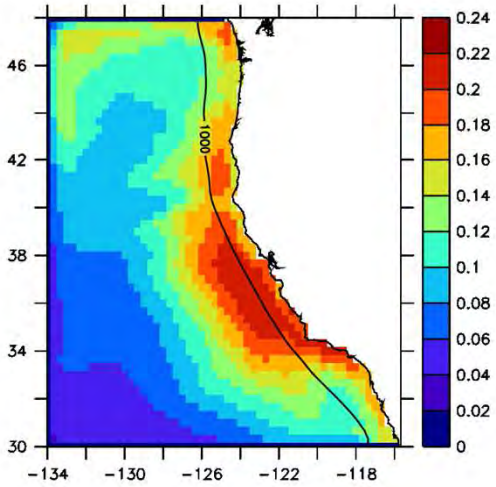


P-Value (C/C_{max}) – Holling Type III

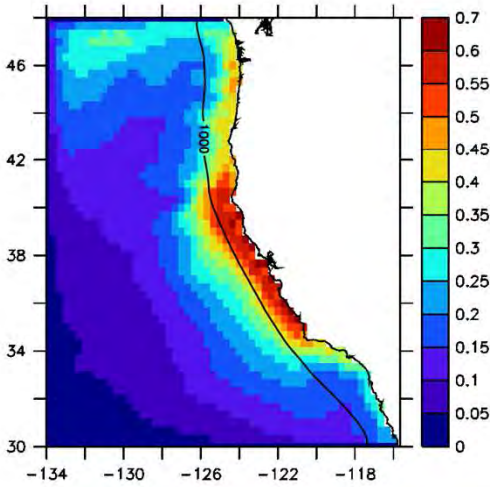




Mean SST (1985-2005)

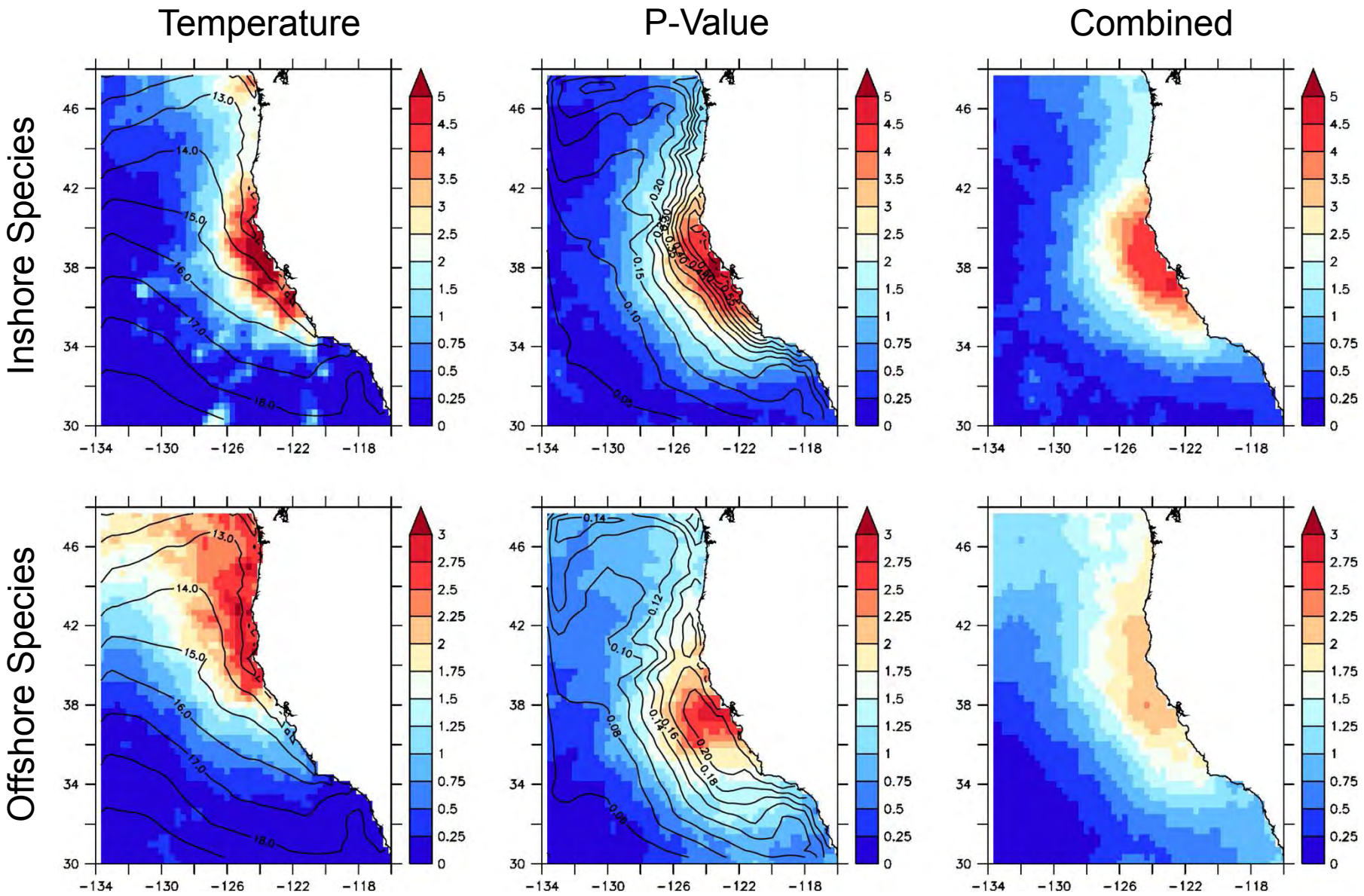


Mean ZS (1985-2005)



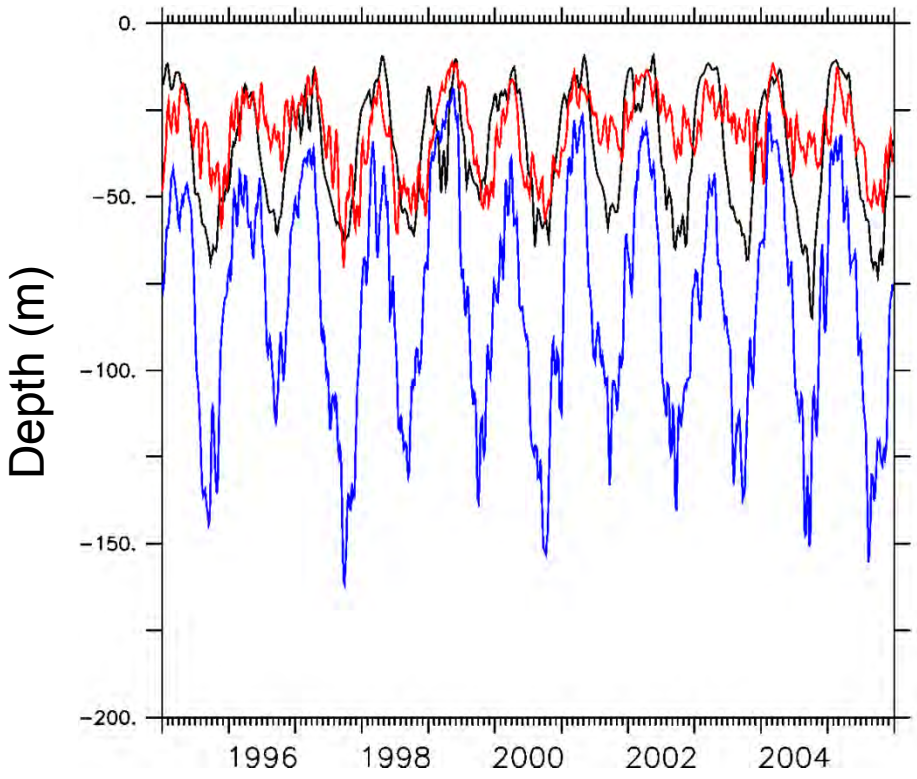
Mean ZL (1985-2005)

Adult Stage: Mean Biomass Distribution (1995-2005)

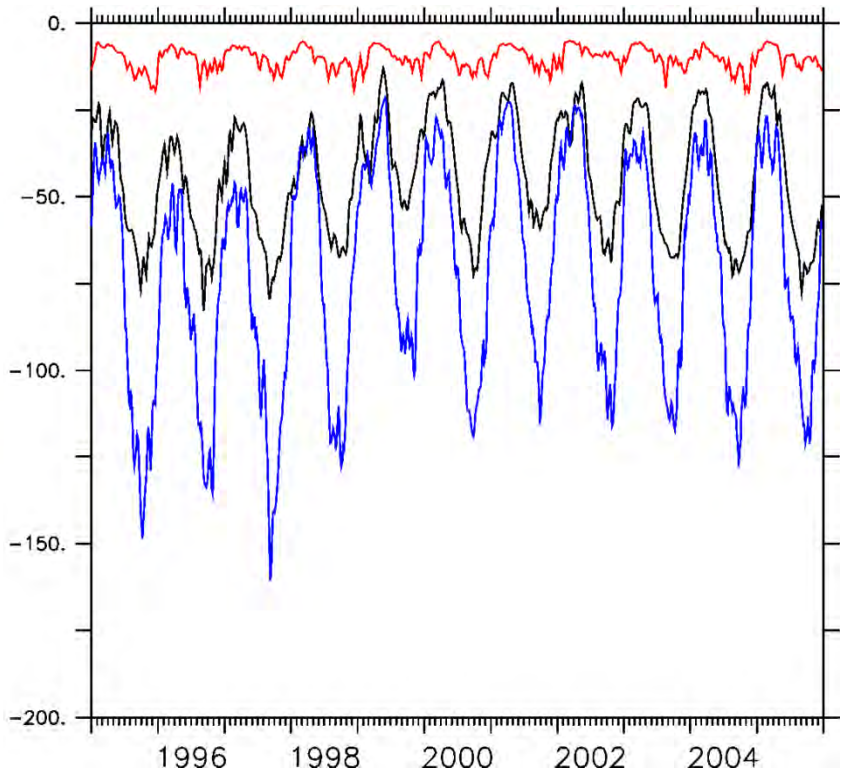


Adult Stage: Vertical Distribution (1995-2005)

Species 1 (ZL feeder)

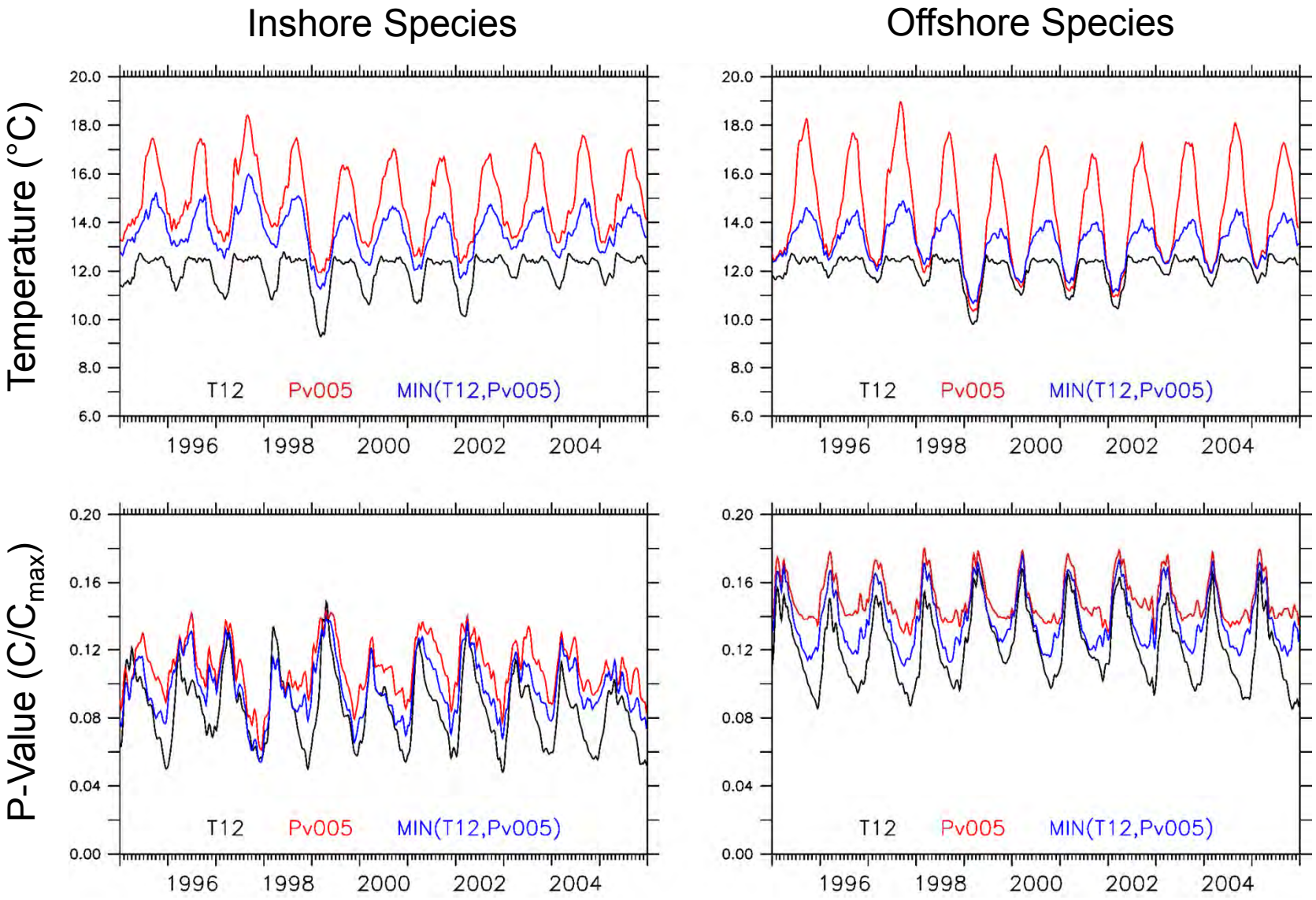


Species 2 (ZS feeder)



Temperature P-Value Combined

Adult Stage: Environmental Conditions (1995-2005)

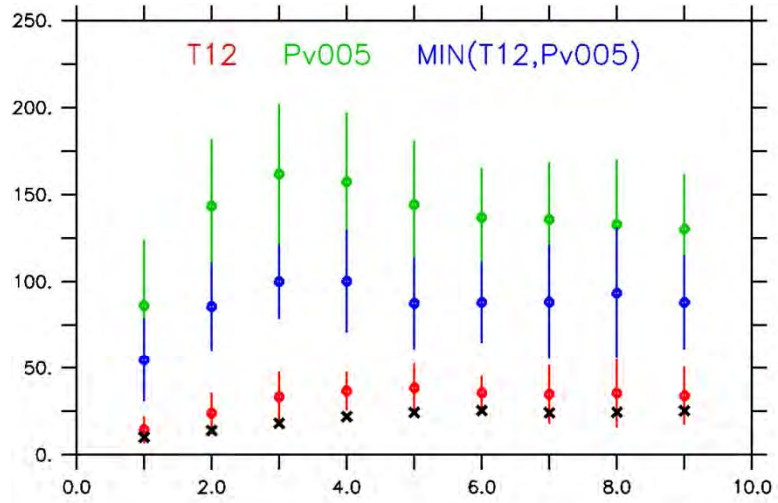


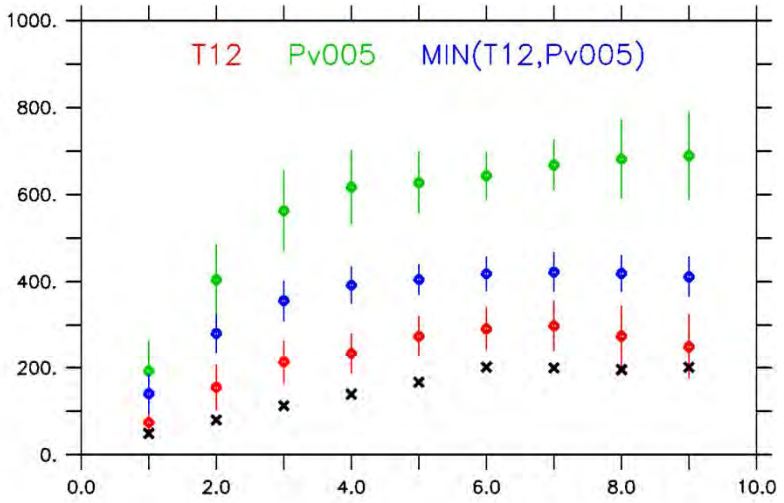
Adult Stage: Bioenergetics Variables (1995-2005)

Inshore Species

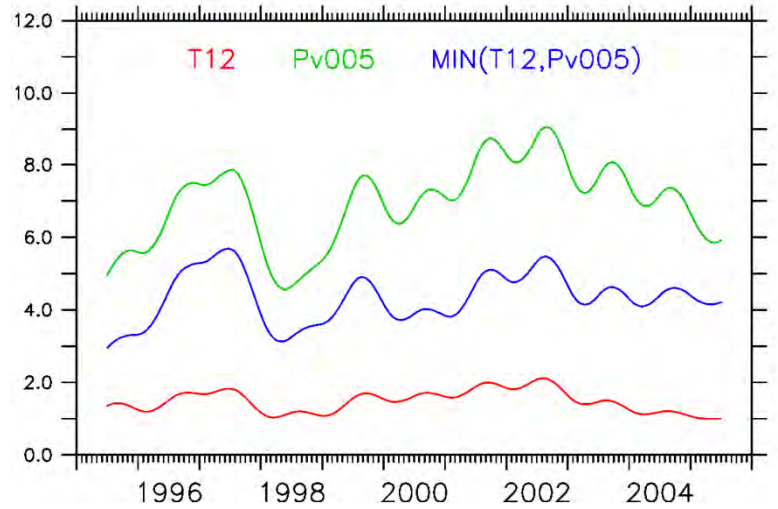
Offshore Species

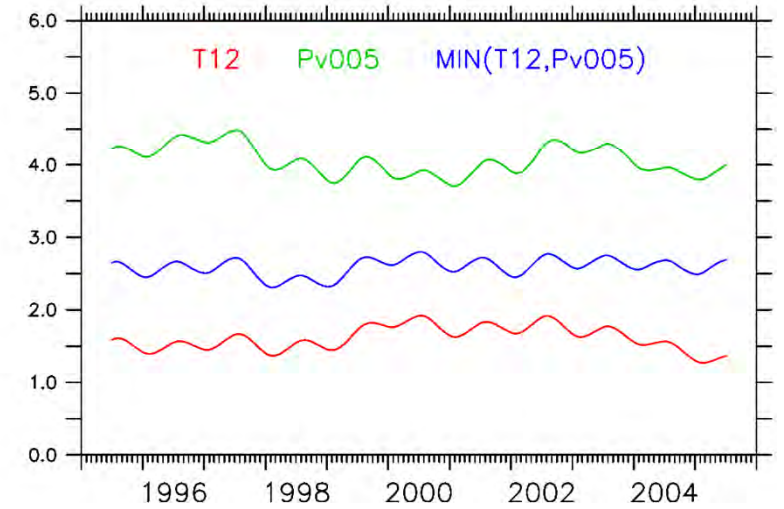
Weight (g)





Norm. Biomass





Next Steps: Sardines and Anchovies

It can be done – proof of principle

- 1 day to run 20 years with 20,000 individuals
- Target: 500,000 super-individuals

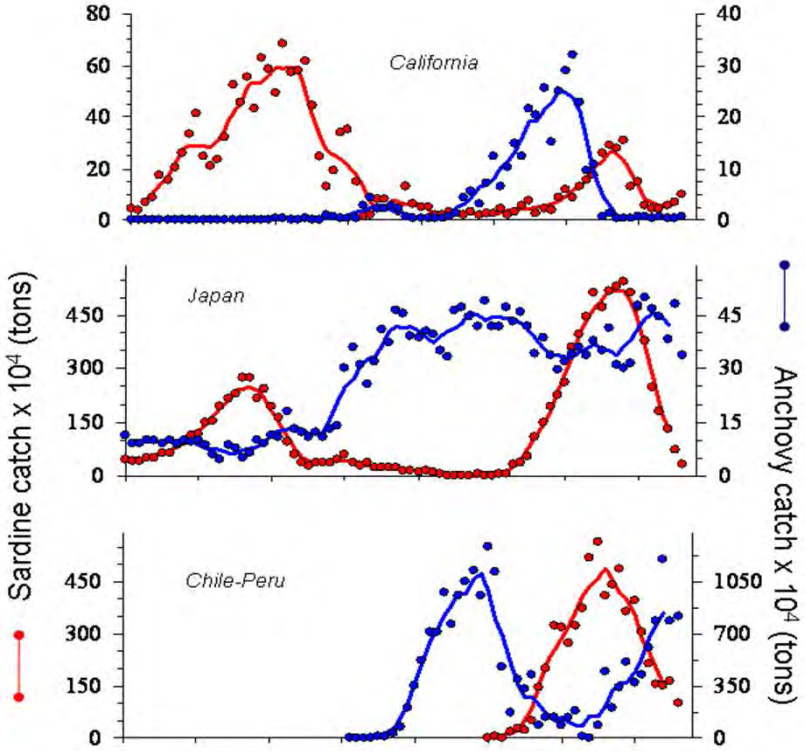
Can we calibrate and validate this model?

- Very challenging: Physics, NPZ, Fish
- Cues for horizontal and vertical behavior
- Feedback to NEMURO (additional mortality term)

Is it useful?

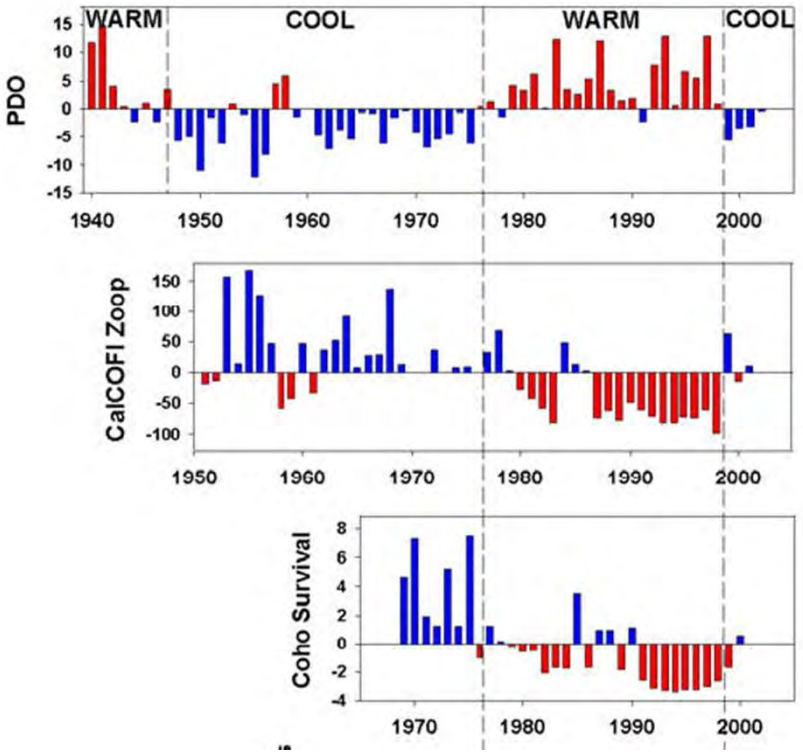
- Need to increase biological realism
- Investigate causes for low-frequency cycles
- Parallel effort in Japan to provide ecosystem contrast

Next Leaps: Other Fish Species



Sardine/Anchovy Shifts

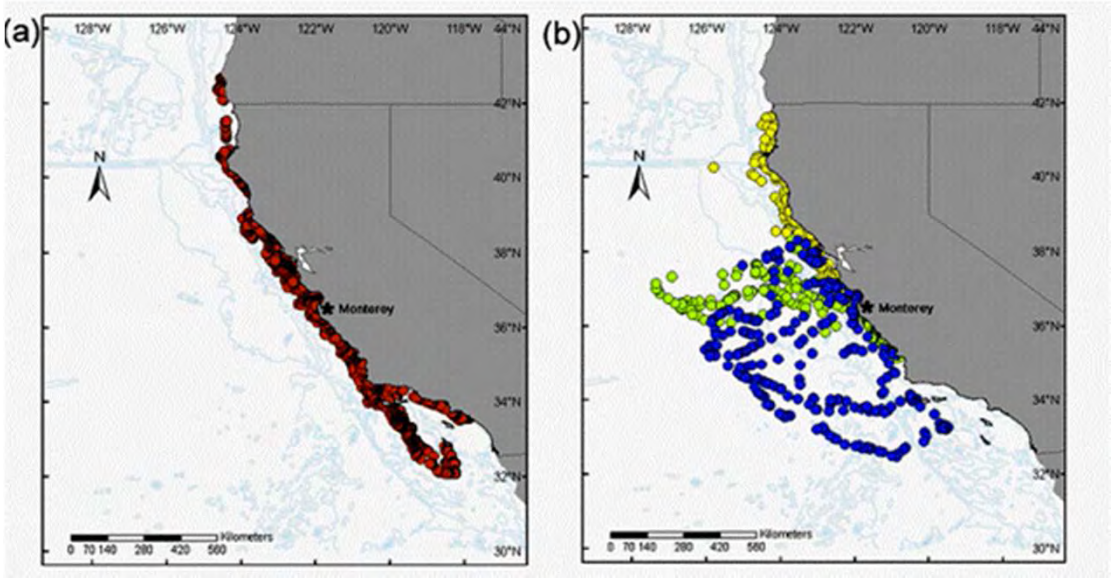
(Schwartzlose et al., 1999)



Coho Salmon Survival

(Peterson and Schwing, 2003)

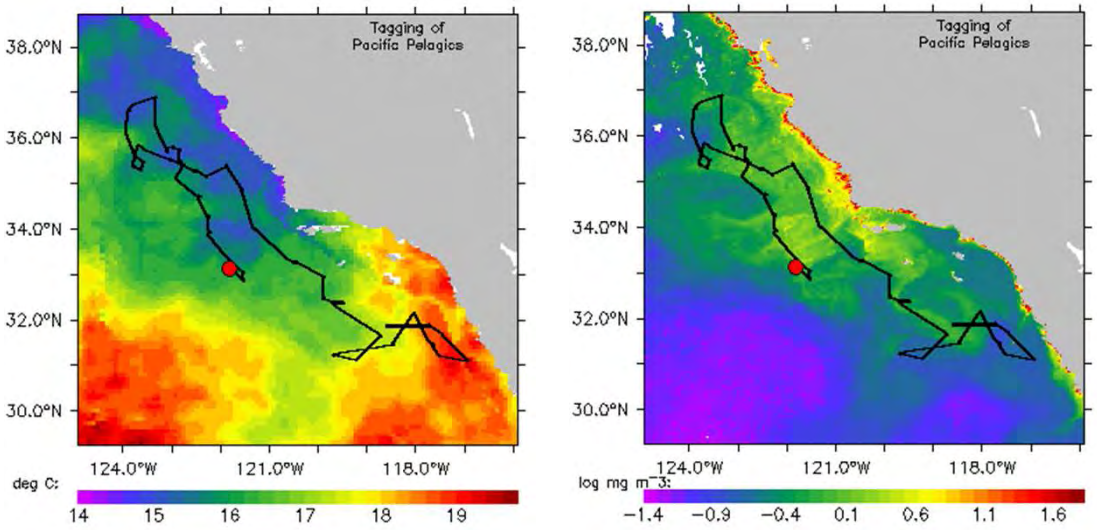
Next Leaps: Apex Predators



California Sea Lion foraging patterns

2004 vs. 2005

(Weise et al., 2006)



Shortfin Mako Shark

Aug-Nov 2010

(TOPP website)