Development of a climate-to-fish-to-fishers model: proof-of-principle using long-term population dynamics of anchovies and sardines in the California Current

RUTGERS UNIVERSITY
MARINE & COASTAL SCIENCES

Ecosystem Studies of Sub-Arctic Seas
ESSAS

CAPaBLE

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UC San Diego

INSTITUTO ESPAÑOL DE OCEANOGRAFÍA

DoD HPC Modernization Program
SOLVING THE HARD PROBLEMS

CAMEO
COMPARATIVE ANALYSIS OF MARINE ECOSYSTEM ORGANIZATION

LSU
OCEANOGRAPHY & COASTAL SCIENCES
LOUISIANA STATE UNIVERSITY

APN
Asia-Pacific Network for Global Change Research

North Pacific Marine Science Organization

THE UNIVERSITY OF CALIFORNIA
LET THERE BE LIGHT
1868

INTER-AMERICAN INSTITUTE FOR GLOBAL CHANGE RESEARCH
IAI

NOAA HPCC
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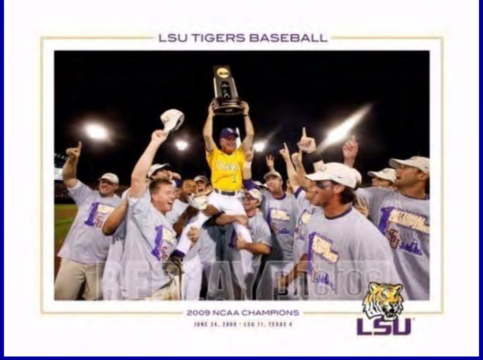

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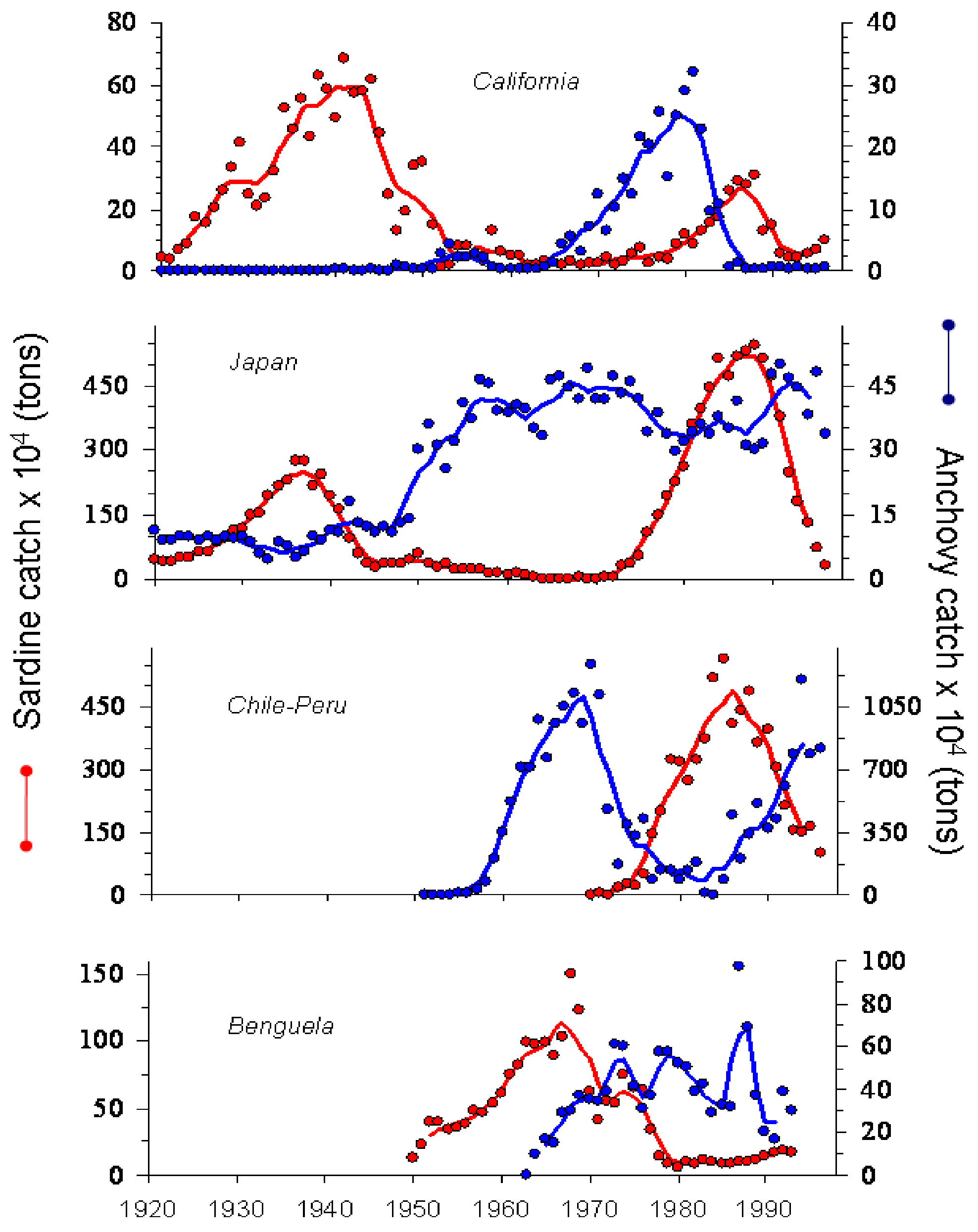
Introduction

- 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
- Continuation of the NEMURO effort
  - Multi-species, individual-based, physics to fish model
  - Proof of principle

Proof of Principle

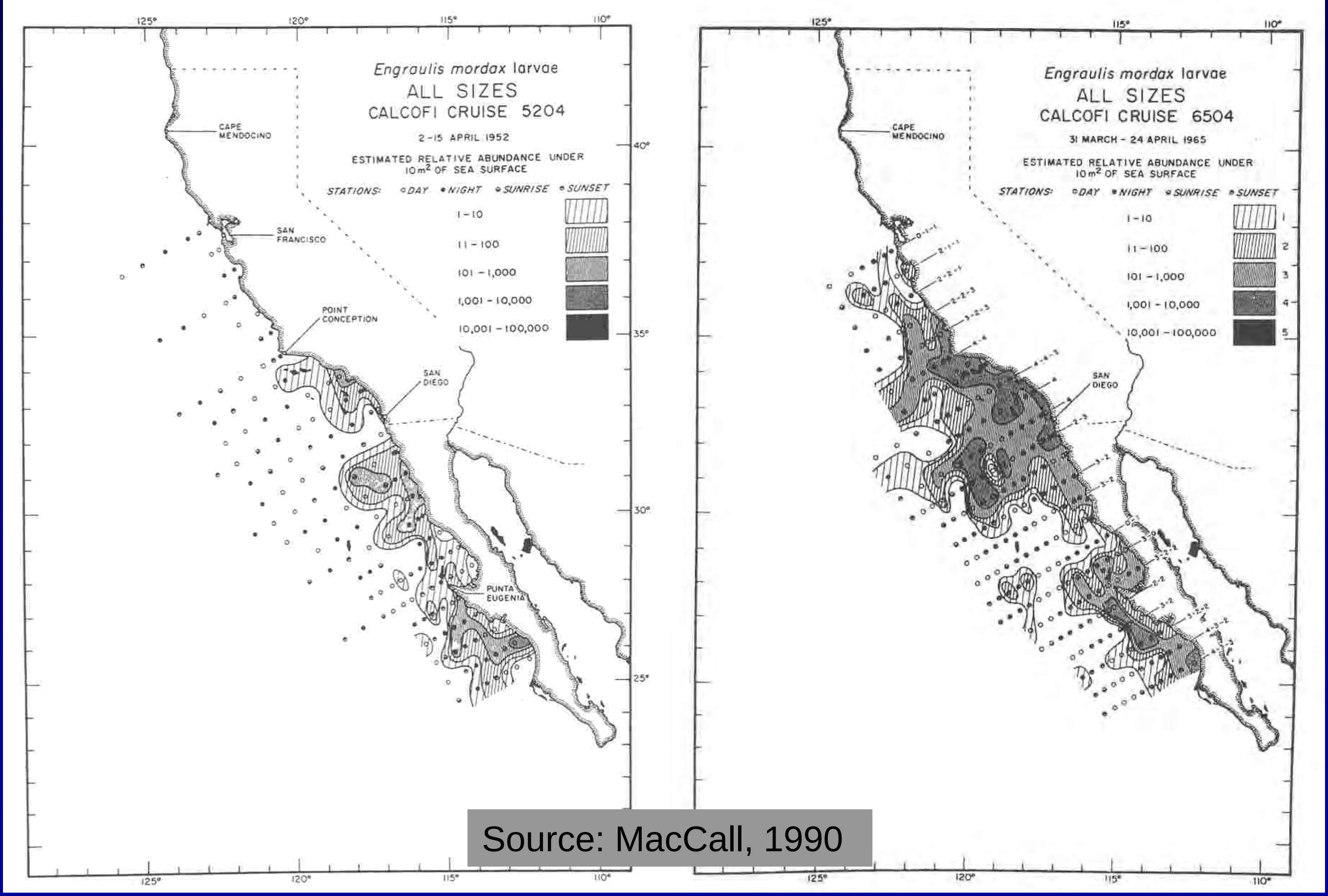
- Sardine – anchovy population cycles
  - well-studied
  - teleconnections across basins

- Good case study
  - Forage fish tightly coupled to NPZ
  - Important ecologically and widely distributed
  - Cycles documented in many systems
  - Recent emphasis on spatial aspects of cycles

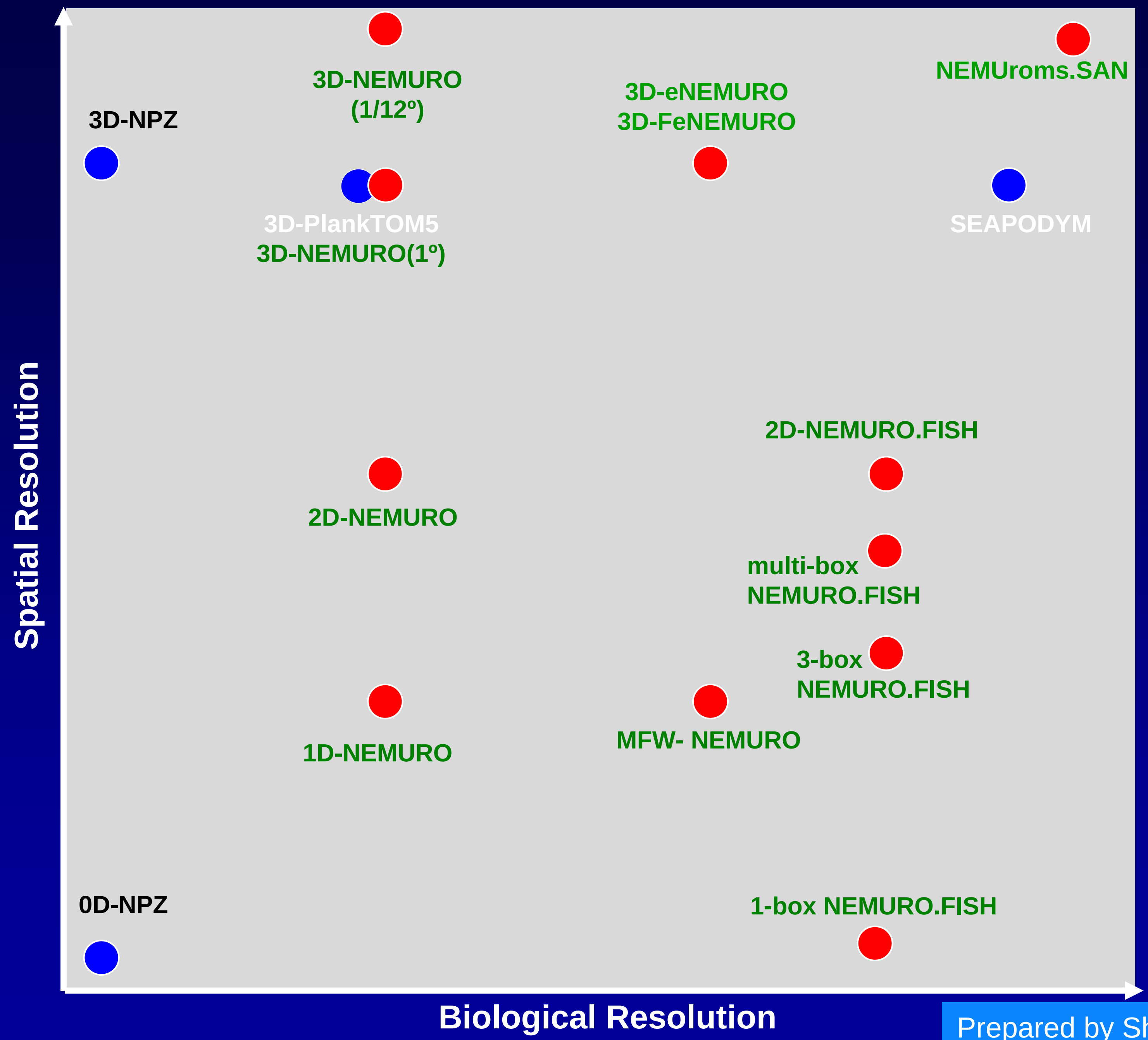


Provided by: Salvador E. Lluch-Cota
Source: Schwartzlose et al., 1999

California Current



Source: MacCall, 1990



Prepared by Shin-ichi Ito


MARINE and
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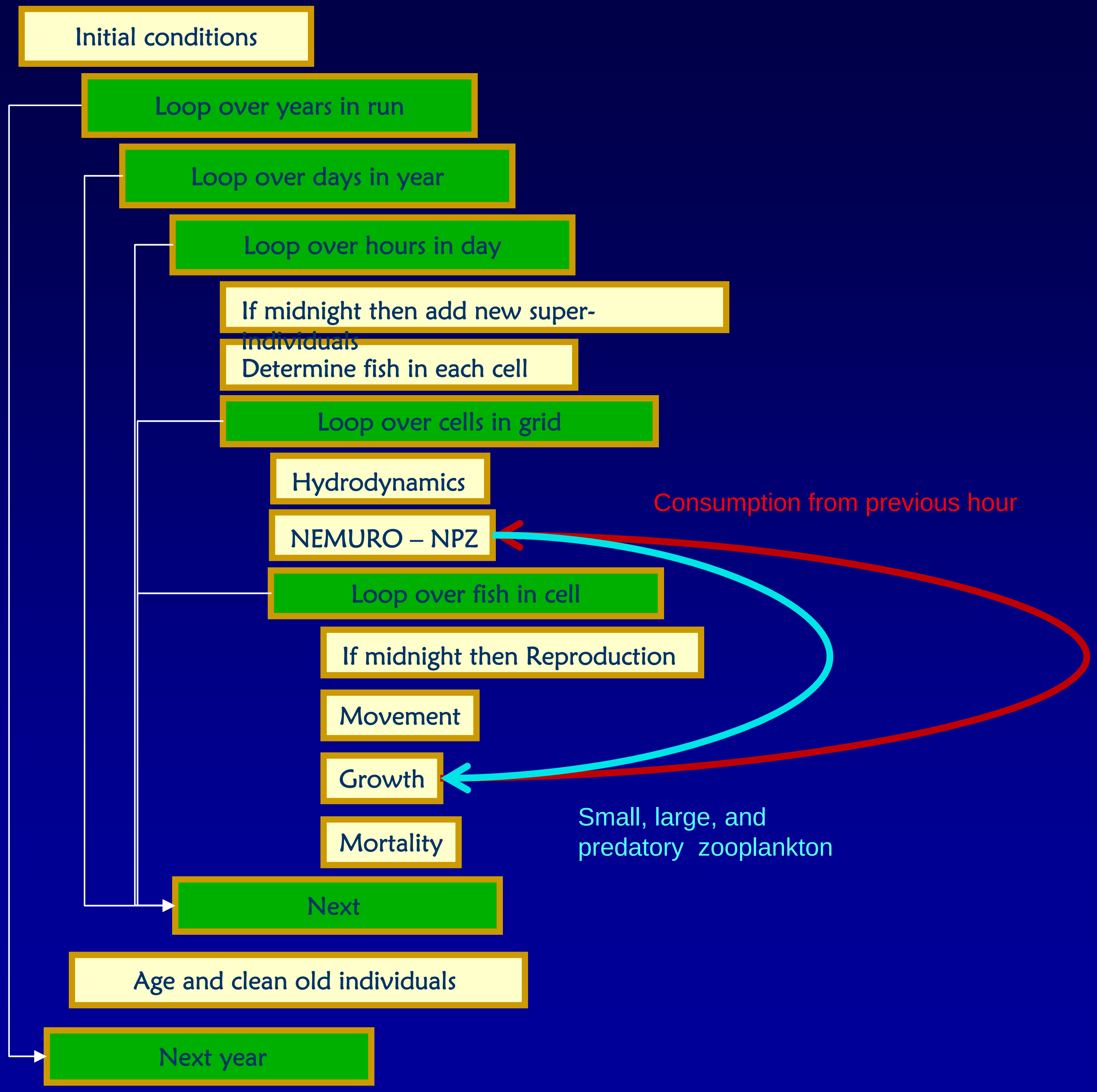
Why IBM for Fish

- Natural unit in nature
- Allows for local interactions and complex systems dynamics
- Easier representation of
  - Complicated life histories
  - Plasticity and size-based interactions
- Conceptually easier to model movement

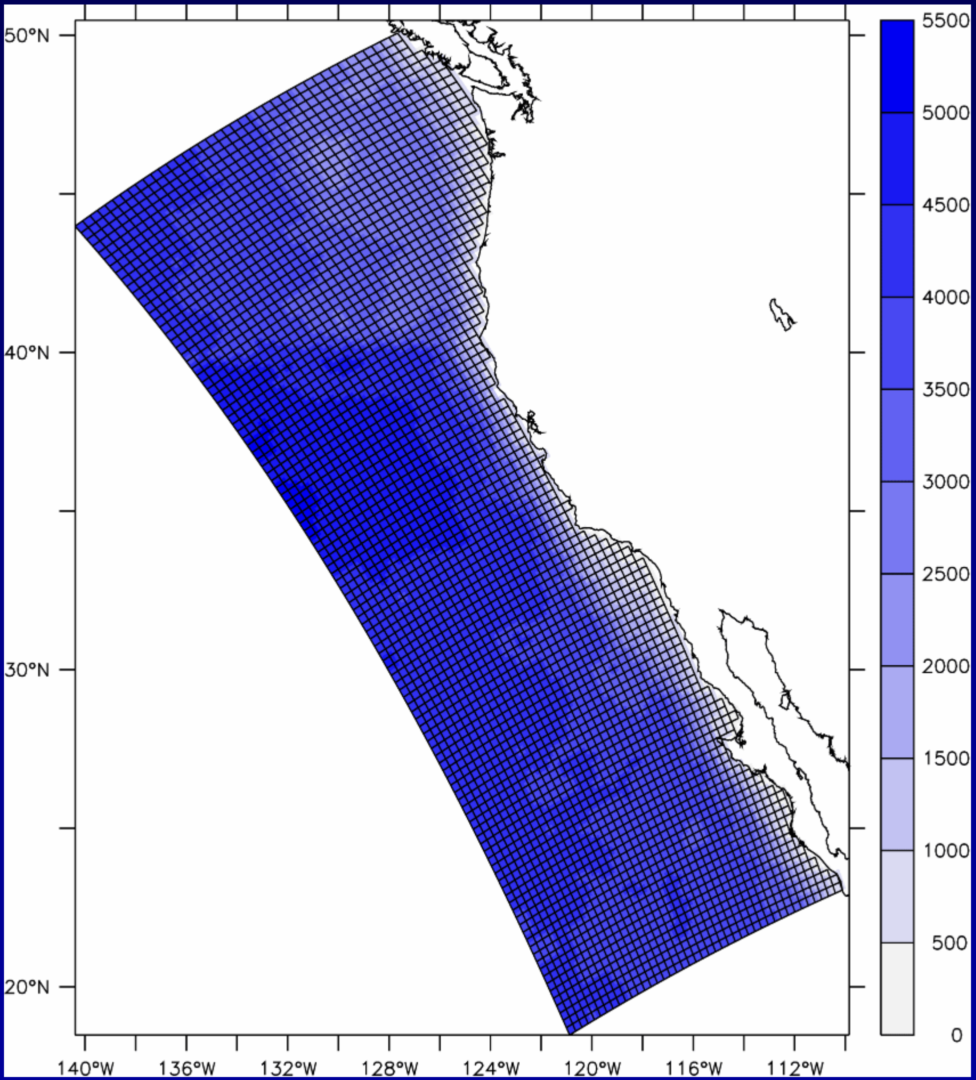
NEMUroms.SAN

- Model 1: 3-D ROMS for physics
- Model 2: NEMURO for NPZ
- Model 3: Multiple-species IBM for fish
- Model 4: Fishing fleet dynamics
- Today: progress to date
  - Solved many of the numerical and bookkeeping
  - Next is to add realistic biology


Initial conditions
Loop over years in run
Loop over days in year
Loop over hours in day
If midnight then add new super-individuals
Determine fish in each cell
Loop over cells in grid
Hydrodynamics
Consumption from previous hour
NEMURO – NPZ
Loop over fish in cell
If midnight then Reproduction
Movement
Growth
Small, large, and predatory zooplankton
Mortality
Next
Age and clean old individuals
Next year

Model 1: ROMS

- Grid:
  44x114 horizontal grid
  30 km resolution
  30 vertical levels
- Run duration: 40 years (1960-2000)
- Hourly time step

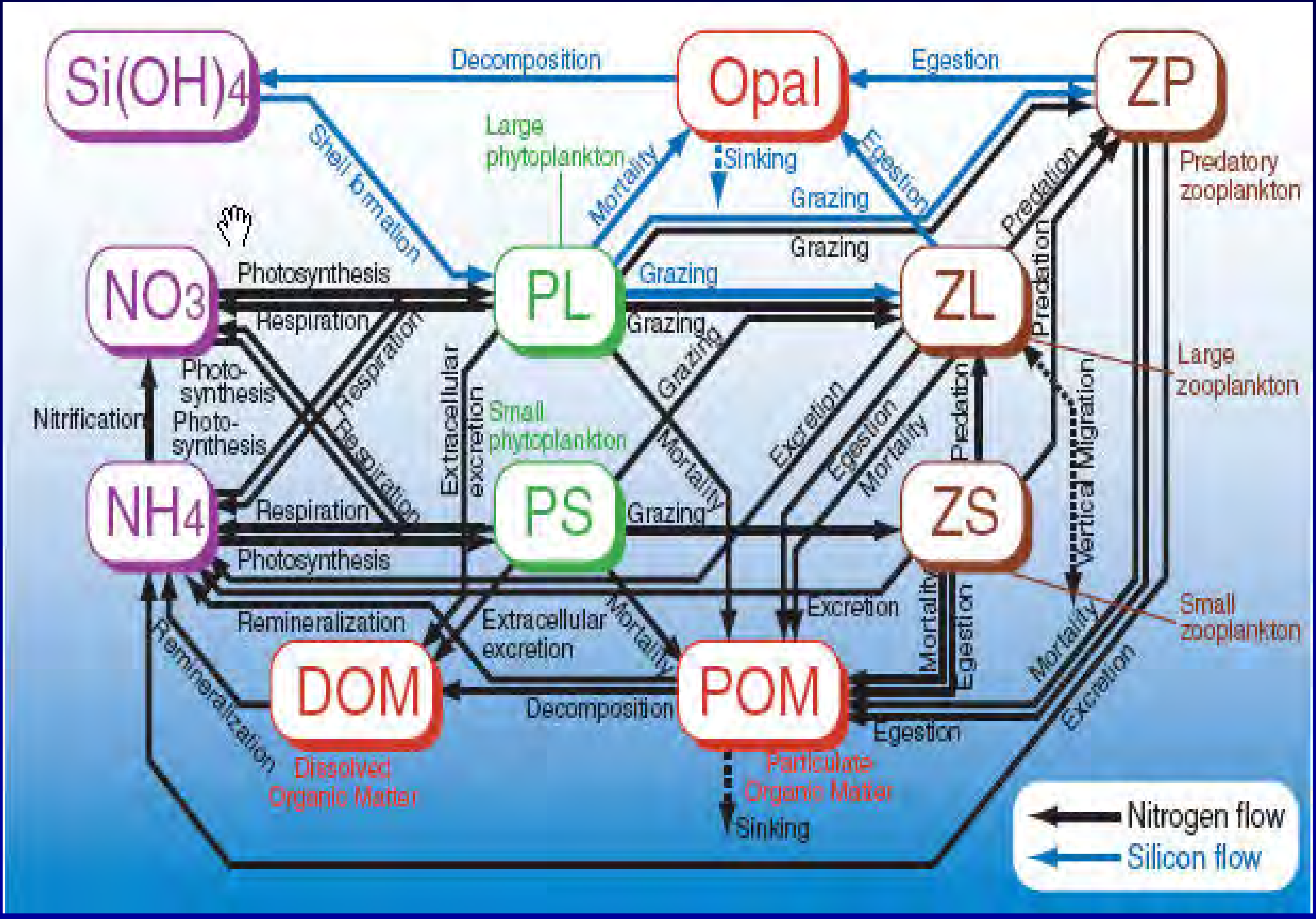


Model 1: ROMS

- Boundary and initial conditions
  - SODA-POP (1958-2006)
  - Monthly surface elevation, velocity, temperature, and salinity fields
  - Carton et al. 2000

- Surface forcing
  - CORE2 (1958-2006)
  - 6-hour wind and heat fluxes
  - Daily radiation fluxes
  - Monthly precipitation
  - Large and Yeager 2008

Model 2: NEMURO



Model 3: Fish IBM

Species Types

- Sardines and anchovy – fully modeled
  - Individual: reproduction, growth, mortality, movement
  - Competitors (food, space)
  - Predator-prey (eat each other)

- Predator - only for spatially-dynamics mortality
  - Movement only
  - Relative biomass to scale mortality

- Fishing fleet
  - Movement based on engineering, economics, behavior

Fish IBM: Full members

- Life cycle framework
  - Easy to say, creates bookkeeping challenge
  - Cannot keep adding new fish to the model

- Four vital processes:
  - Growth and development
  - Reproduction
  - Mortality
  - Movement

Fish IBM: Growth

- Compute change in weight each time step
- Bioenergetics-based
- Consumption determined by multispecies functional response
  - NEMURO zooplankton in the cell
  - Other individual fish in the neighborhood
- Once mature, allocate energy to growth or reproduction

Fish IBM: Development

- Eggs, yolk-sac larvae, larvae
  - Temperature-dependent stage durations

- Birthday on January 1 of each year
  - Juvenile to subadult on first January 1
  - Subadult to adult with maturity at second birthday

Fish IBM: Reproduction

- Two strategies
  - Capital and income
  - Hybrid that allows switching
- Beginning and ending temperatures (or days)
- Check energy to initiate a batch
  - Capital using condition
  - income using yesterday’s weight change
- Batches develop based on temperature
- Accumulate eggs each day and locations of spawners

Fish IBM: Mortality

- Other natural
  - Constant rates by stage (e..g., 0.05/day)
- Starvation: too skinny
- Fish eating fish
- Predator-dependent (species type 2)
- Fishing
  - Constant
  - Fishing fleet dynamics

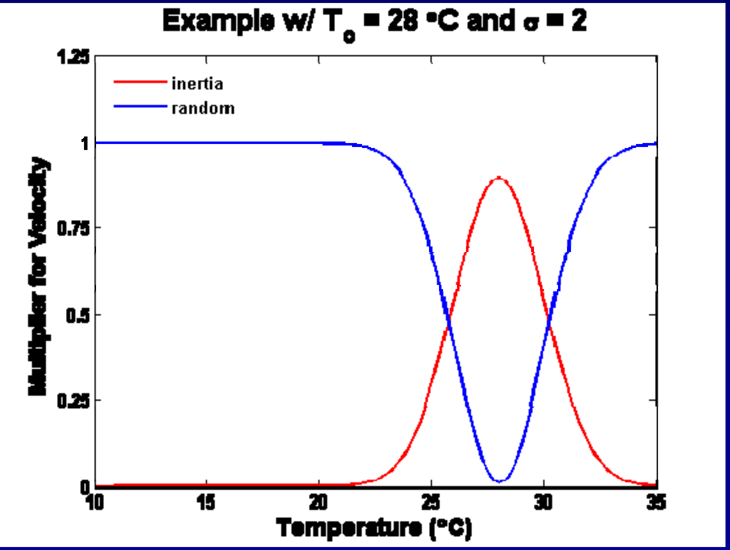
Fish IBM: Movement

- Eggs, yolk-sac, and larvae move by physics
  – assumed at surface for now
- Juveniles and adults move by behavior
  – Day-to-day
  – Seasonal migrations
- Each individual has a continuous x, y, and z position
- Position mapped to 3-D grid every hour to determine cell location and local conditions

Fish IBM: Kinesis Option for Movement (Humston et al. 2004)

- X and Y velocities of each individual is computed hourly based on kinesis behavior (response to temperature)

- Kinesis is the sum of random and inertial velocities (happiness)



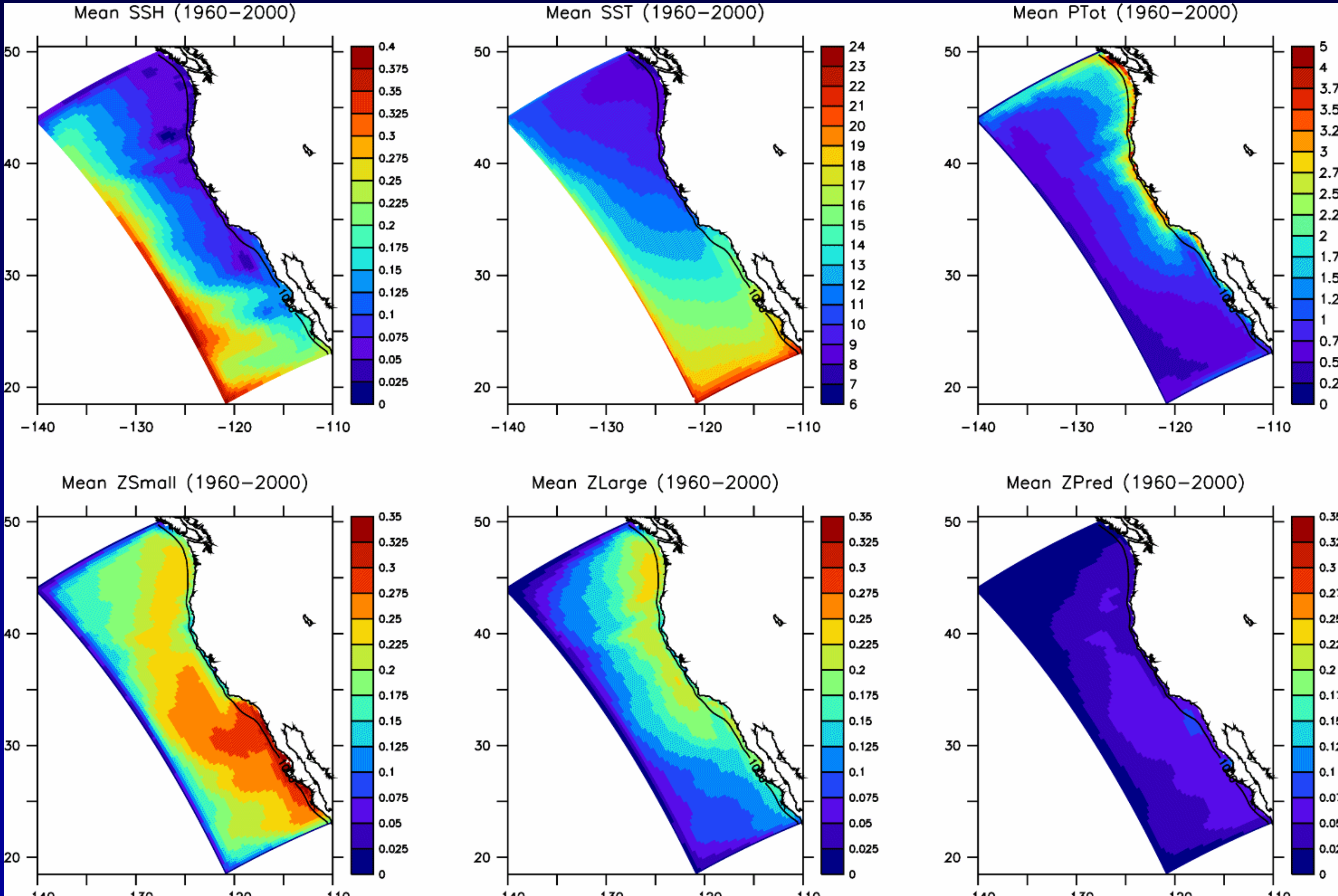
- Horizontal done 24 times a day using first hour's conditions; vertical is hourly

Density-Dependence

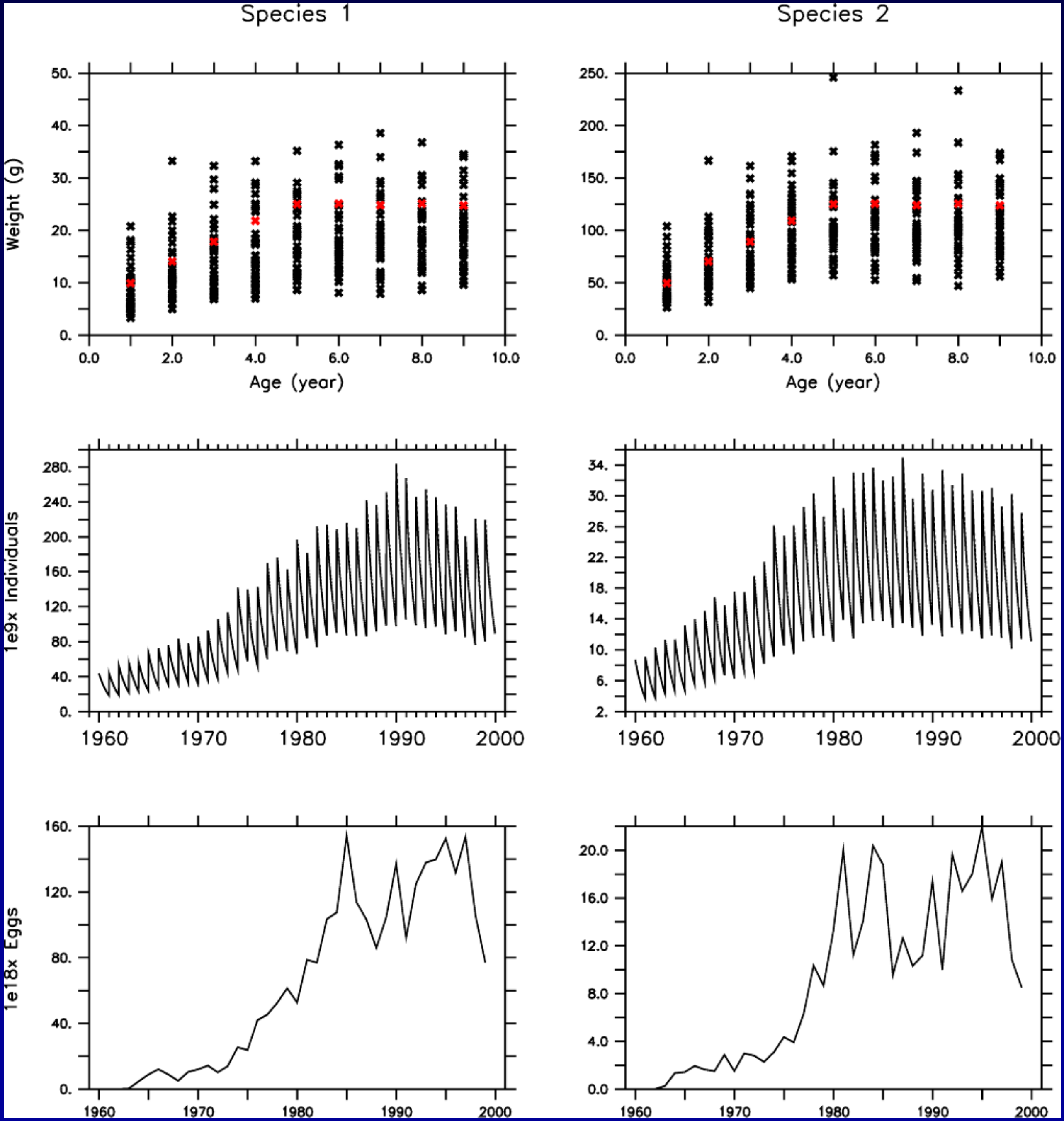
- Growth via feedback effects on prey
  - Starvation
  - Fecundity
- Other possibilities:
  - Maturation (mediated through growth)
  - Mortality via predation (movement only species) and fishing
- Movement
  - Spreading out under high abundances
  - Costs of inferior habitats?

Numerical Details

- Major numerical and bookkeeping challenges
- See Kate Hedstrom talk in workshop
- We are working within ROMS source code, using the available particle tracking features
- Solving everything simultaneously
- Using super-individual approach (Scheffer et al. 1995)



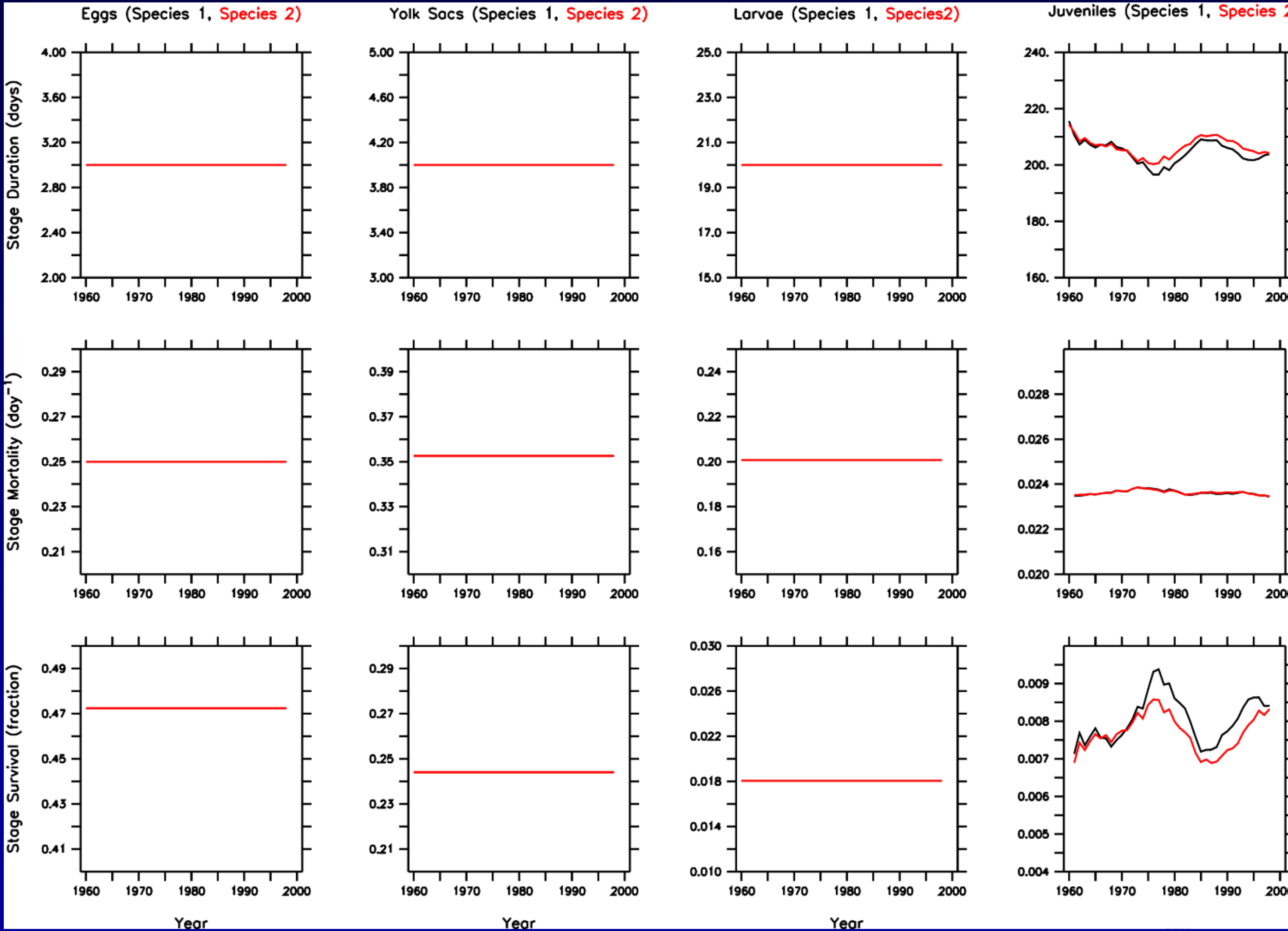
Mean SSH (1960–2000)
Mean SST (1960–2000)
Mean PTot (1960–2000)
Mean ZSmall (1960–2000)
Mean ZLarge (1960–2000)
Mean ZPred (1960–2000)



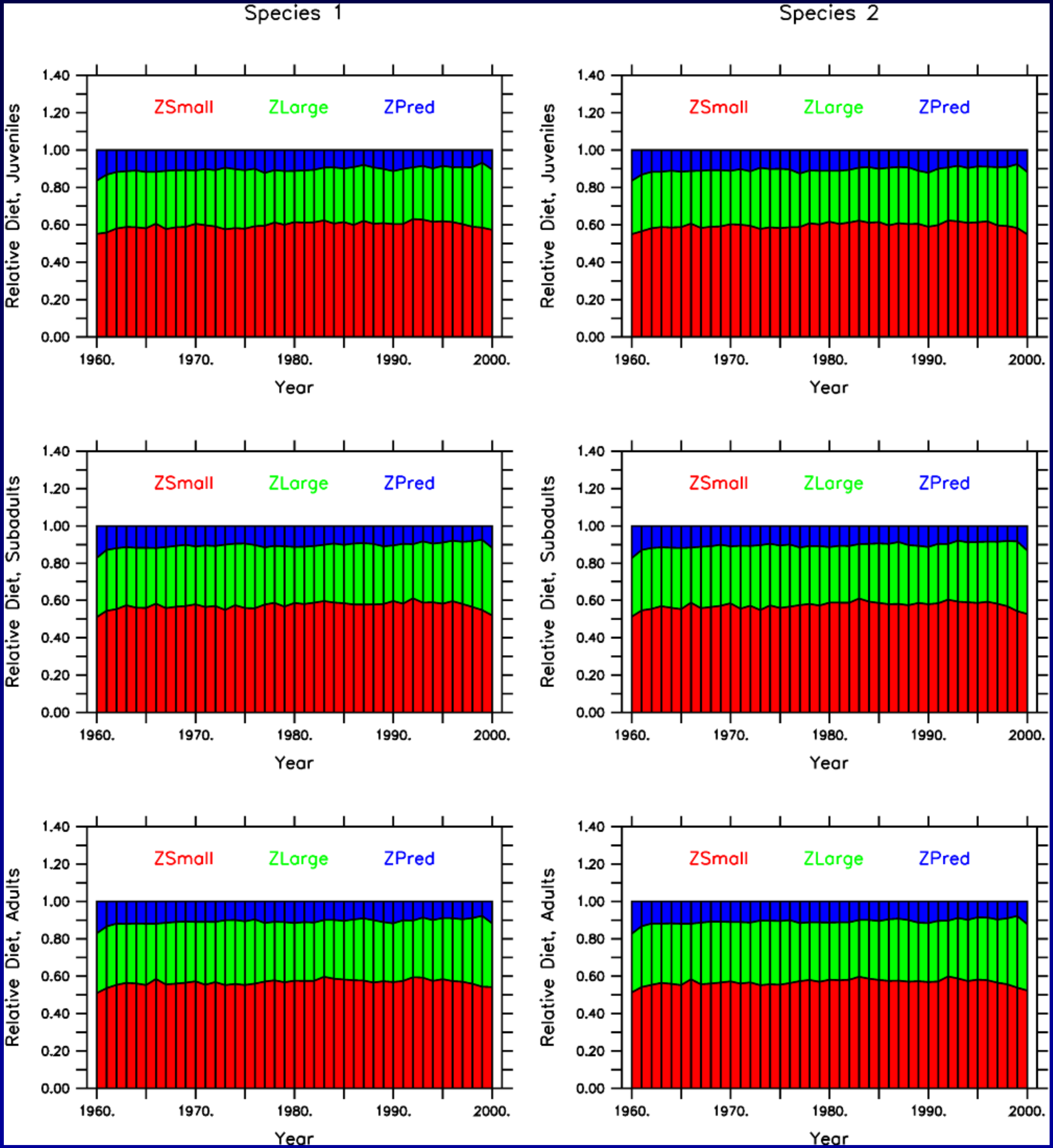
Mean weight on January 1

Subadults and Adults every 5 days

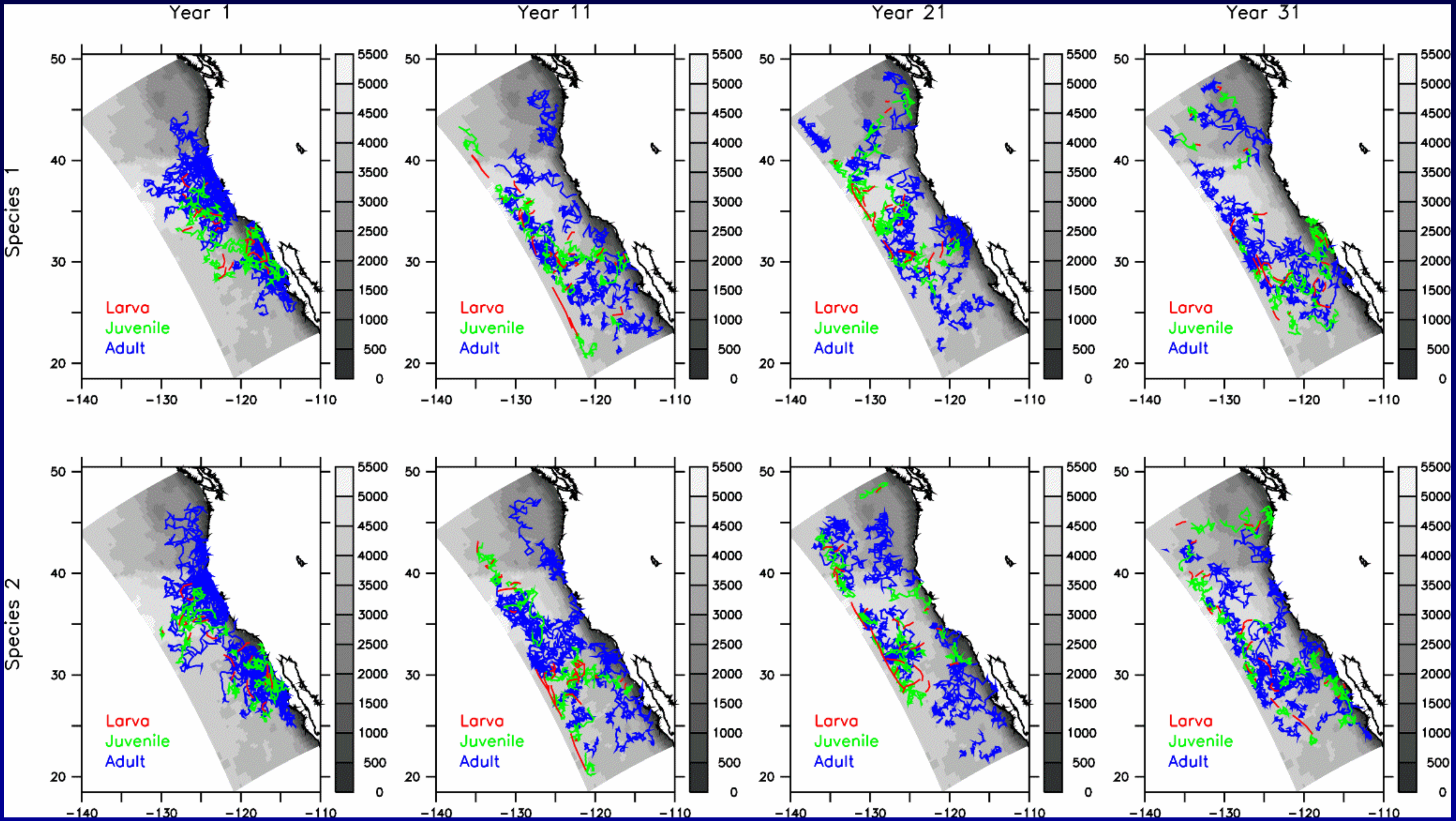
Total eggs produced



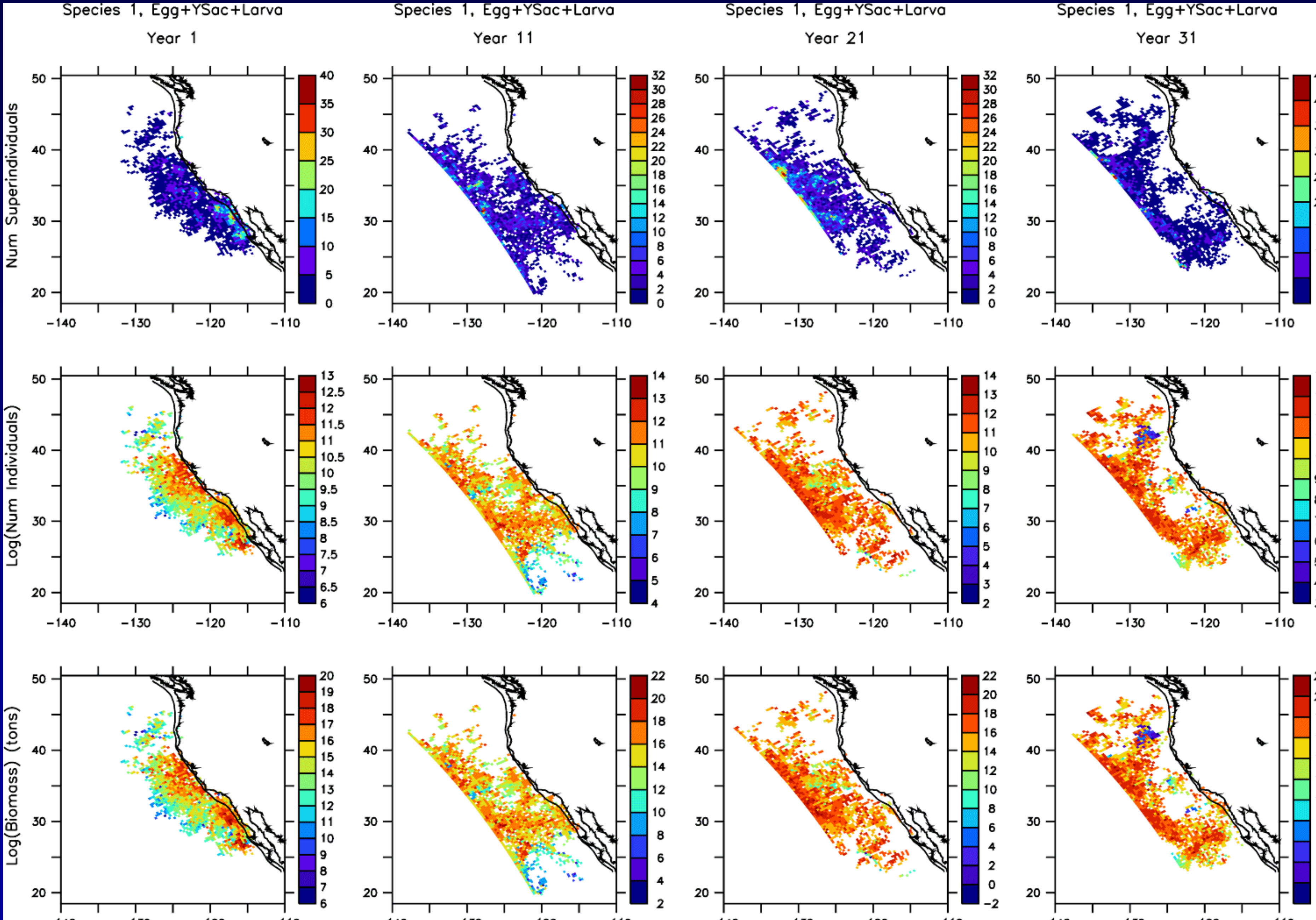
Eggs (Species 1, Species 2)
Yolk Sacs (Species 1, Species 2)
Larvae (Species 1, Species2)
Juveniles (Species 1, Species 2
Stage Duration (days)
Stage Mortality (day^{-1})
Stage Survival (fraction)
Year
Year
Year



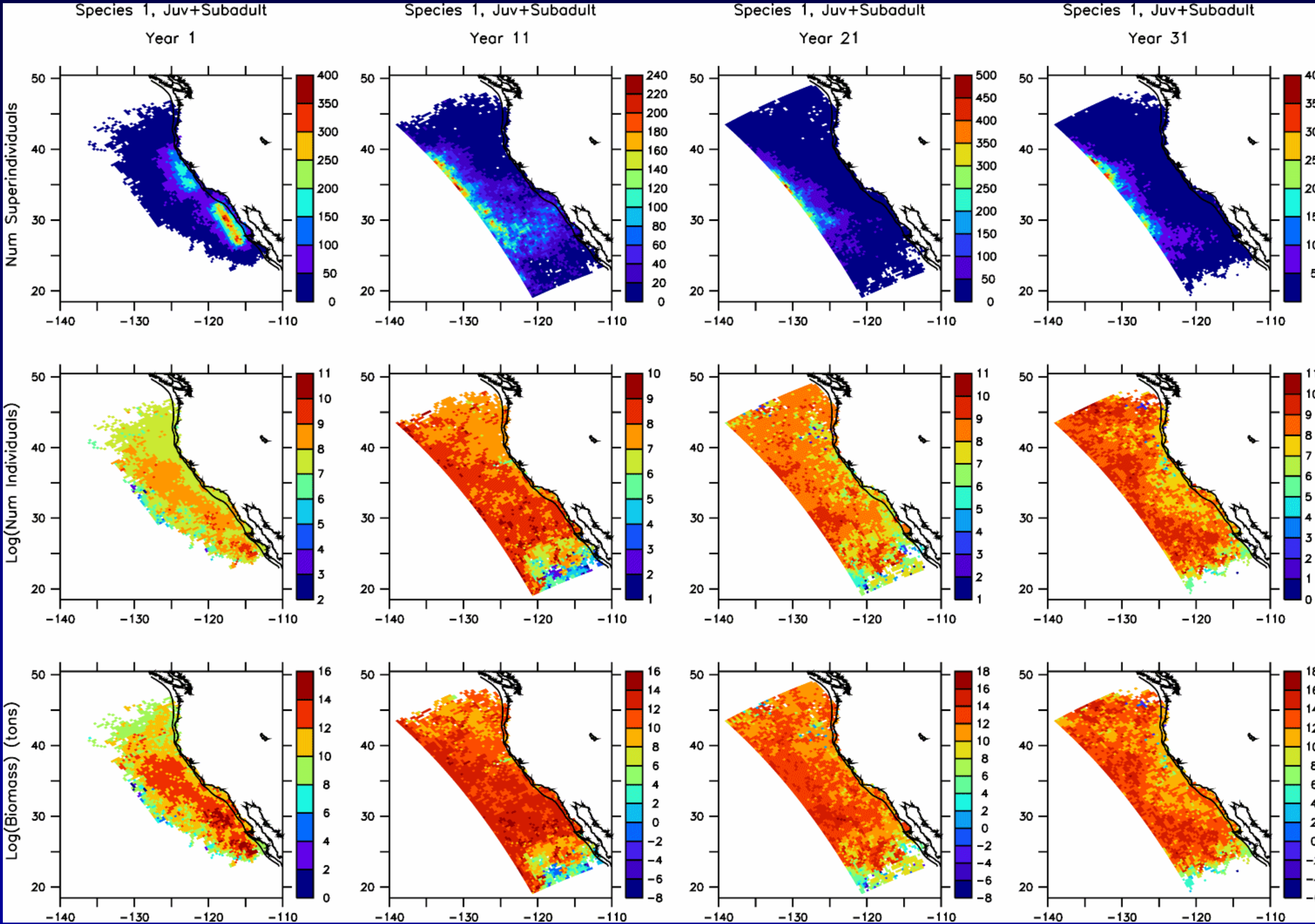
Annual average based on 5-day snapshots



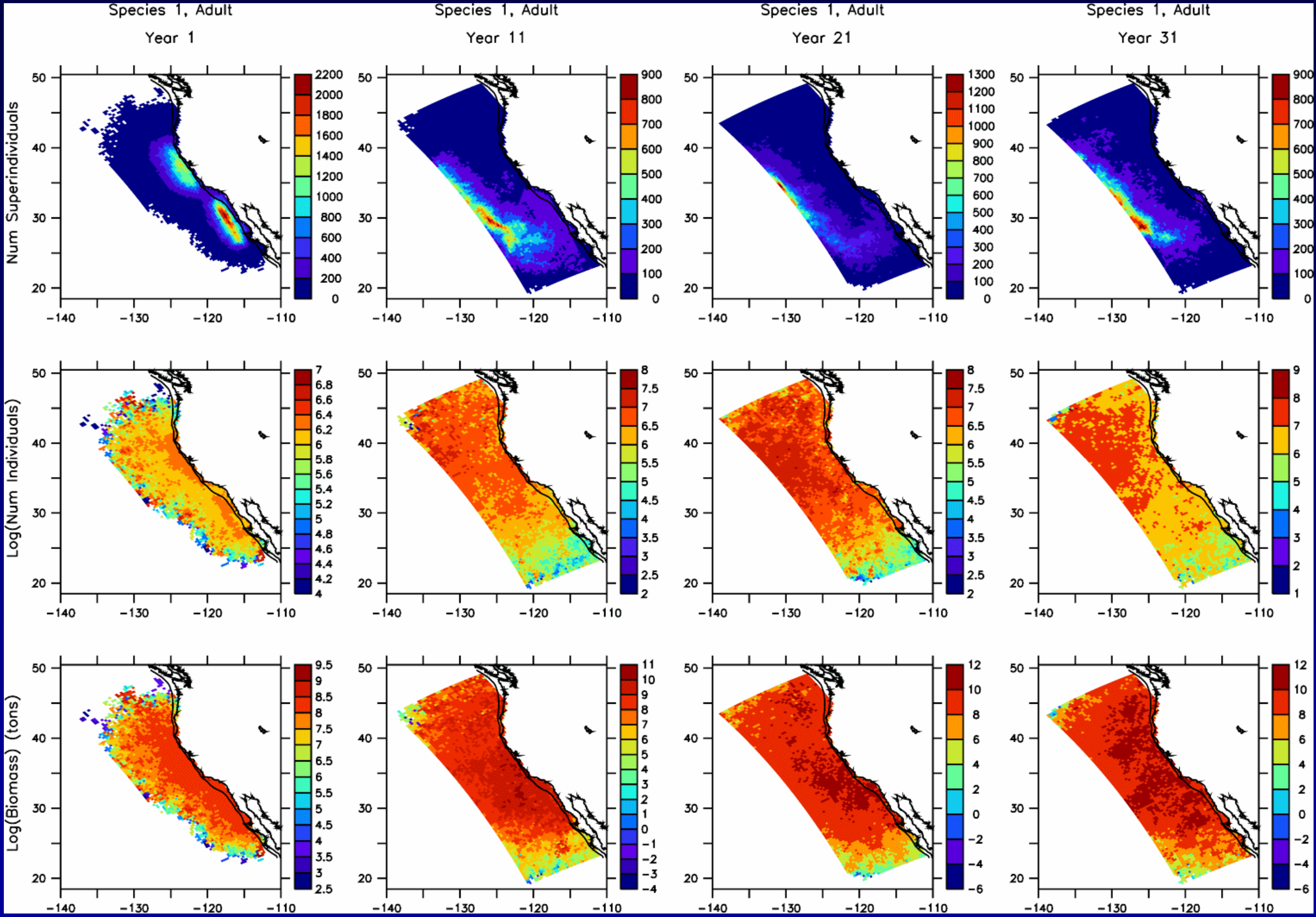
Locations every 5 days for one year
Grey shading shows bottom topography



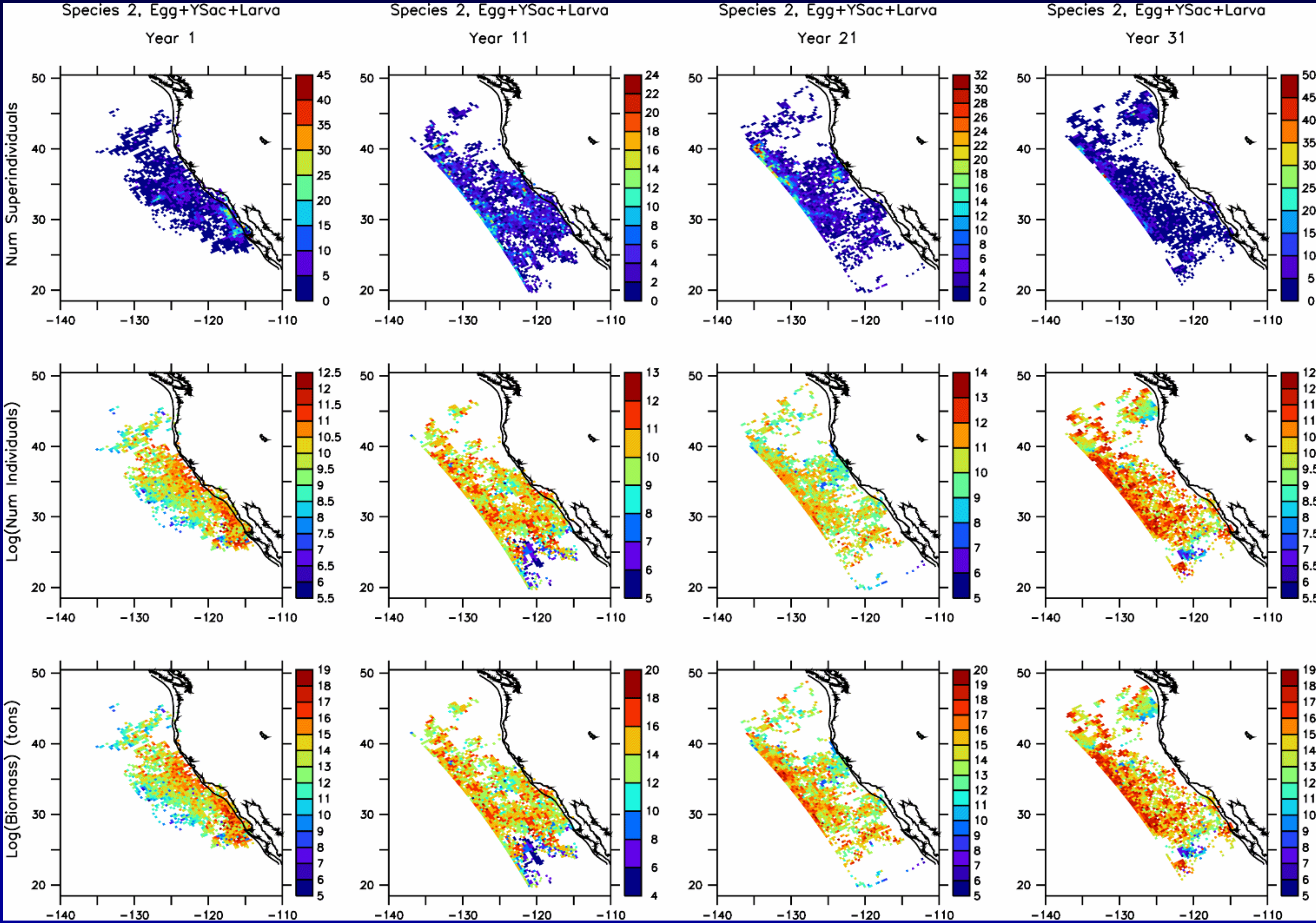
Species 1, Egg+YSac+Larva
Year 1
Species 1, Egg+YSac+Larva
Year 11
Species 1, Egg+YSac+Larva
Year 21
Species 1, Egg+YSac+Larva
Year 31
Num Superindividuals
Log(Num Individuals)
Log(Biomass) (tons)

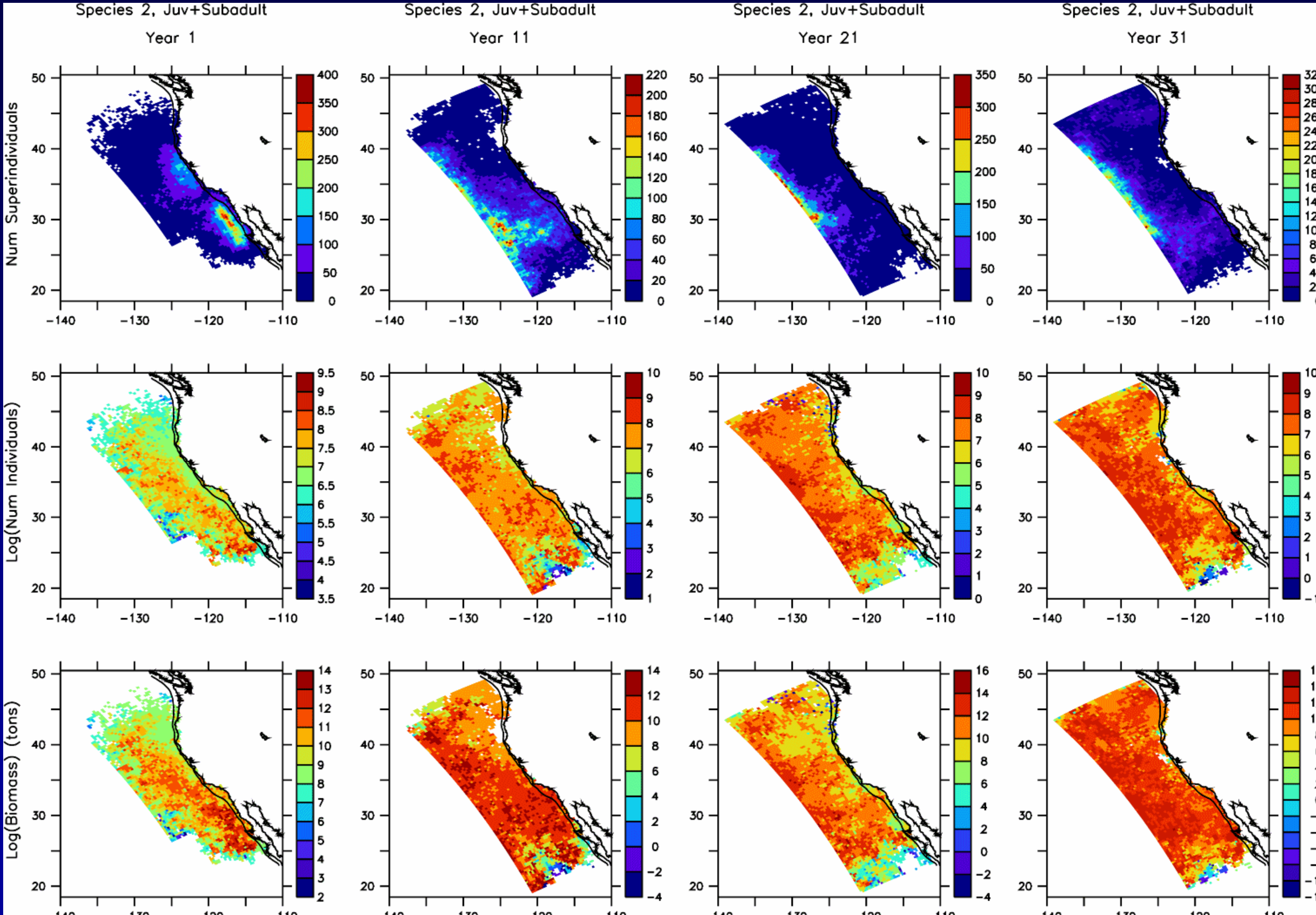


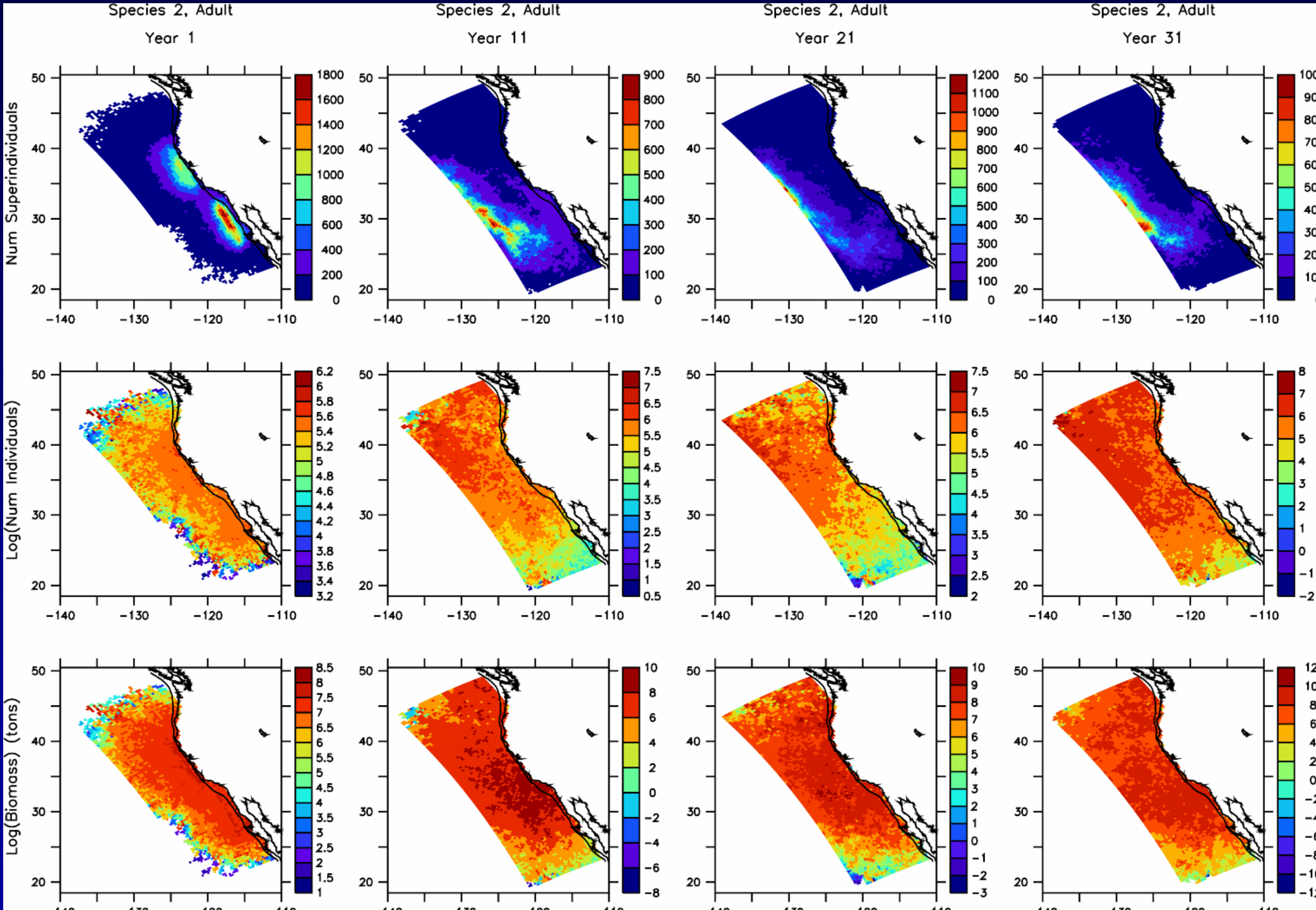
Species 1, Juv+Subadult
Year 1
Species 1, Juv+Subadult
Year 11
Species 1, Juv+Subadult
Year 21
Species 1, Juv+Subadult
Year 31
Num Superindividuals
Log(Num Individuals)
Log(Biomass) (tons)



Species 1, Adult
Year 1
Species 1, Adult
Year 11
Species 1, Adult
Year 21
Species 1, Adult
Year 31
Num Superindividuals
Log(Num Individuals)
Log(Biomass) (tons)

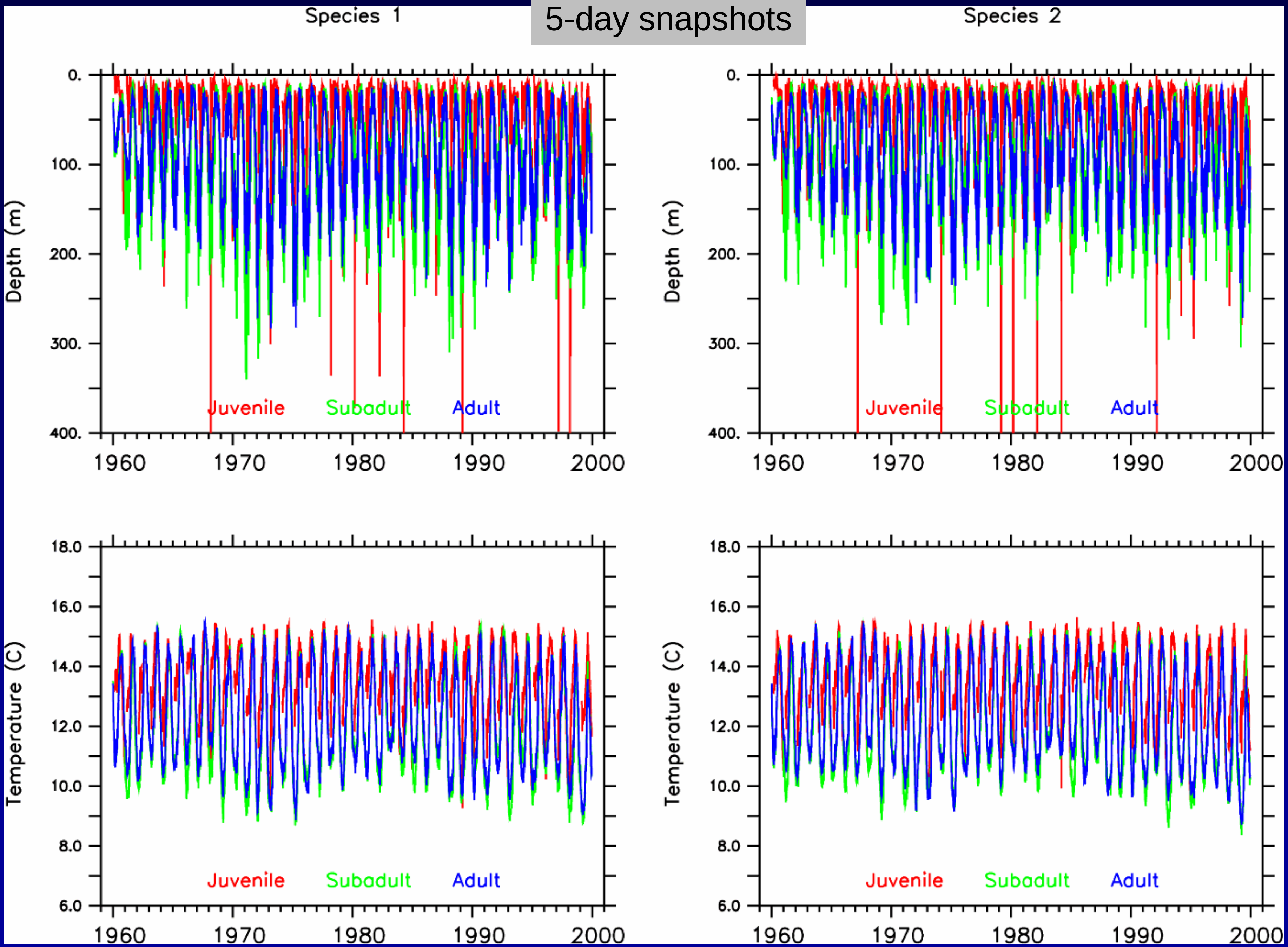

Species 2, Egg+YSac+Larva
Year 1
Species 2, Egg+YSac+Larva
Year 11
Species 2, Egg+YSac+Larva
Year 21
Species 2, Egg+YSac+Larva
Year 31
Num Superindividuals
Log(Num Individuals)
Log(Biomass) (tons)


Species 2, Juv+Subadult
Year 1
Year 11
Year 21
Year 31
Num Superindividuals
Log(Num Individuals)
Log(Biomass) (tons)
50
40
30
20
−140
−130
−120
−110



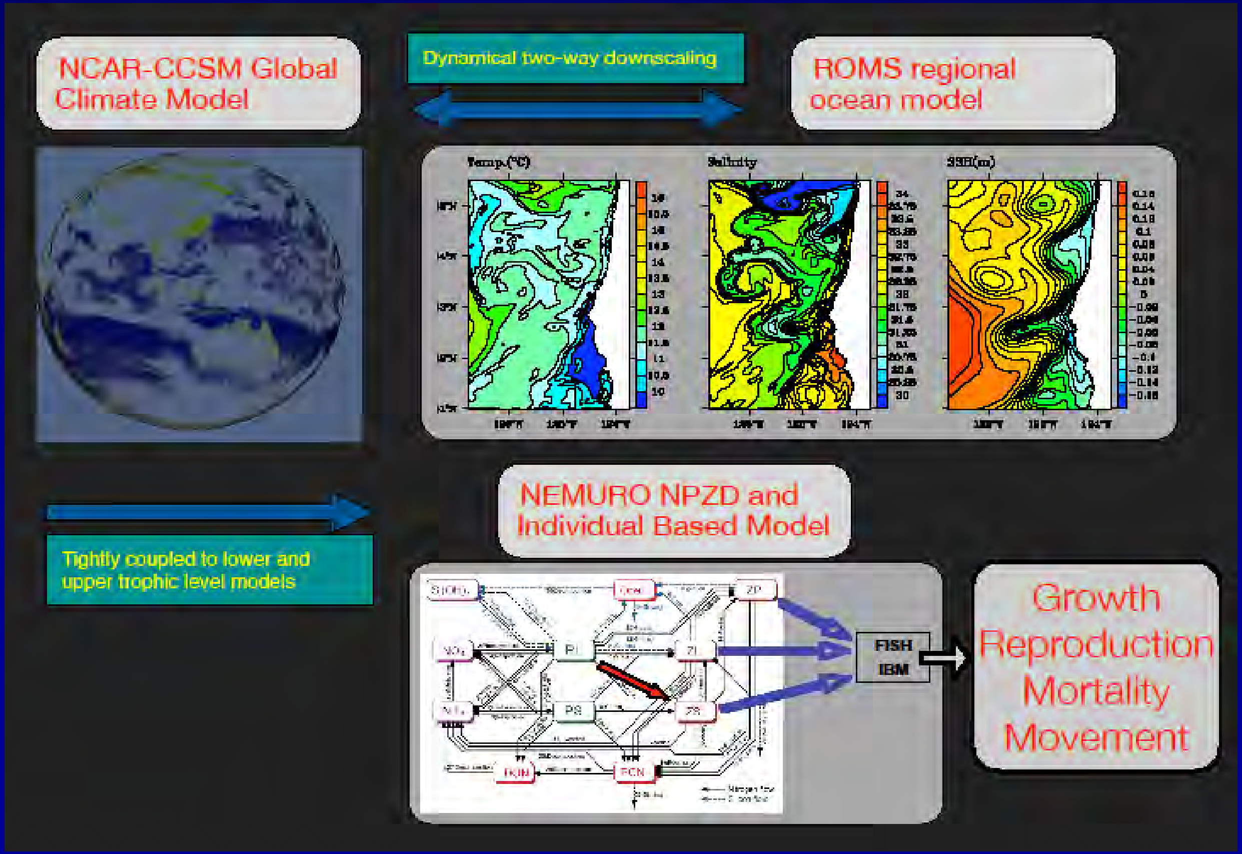
Species 2, Adult
Year 1
Species 2, Adult
Year 11
Species 2, Adult
Year 21
Species 2, Adult
Year 31
Num Superindividuals
Log(Num Individuals)
Log(Biomass) (tons)
50
40
30
20
−140
−130
−120
−110
1800 1600 1400 1200 1000 800 600 400 200 0
900 800 700 600 500 400 300 200 100 0
1200 1100 1000 900 800 700 600 500 400 300 200 100 0
1000 900 800 700 600 500 400 300 200 100 0
6.2 6 5.8 5.6 5.4 5.2 5 4.8 4.6 4.4 4.2 4 3.8 3.6 3.4 3.2
7.5 7 6.5 6 5.5 5 4.5 4 3.5 3 2.5 2 1.5 1 0.5
7.5 7 6.5 6 5.5 5 4.5 4 3.5 3 2.5 2
8 7 6 5 4 3 2 1 0 −1 −2
8.5 8 7.5 7 6.5 6 5.5 5 4.5 4 3.5 3 2.5 2 1.5 1
10 8 6 4 2 0 −2 −4 −6 −8
10 9 8 7 6 5 4 3 2 1 0 −1 −2 −3
12 10 8 6 4 2 0 −2 −4 −6 −8 −10 −12

5-day snapshots



Next Steps

- Investigate the causes of low-frequency cycles in sardine and anchovy
  - remember that from the introduction!!!!
- Parallel effort in Japan to provide a contrast
- Ultimately,



Next Steps

- It can be done – proof of principle

- Computing:
  - ShaRCS at UC-Berkeley
  - 128 CPUs (Xeon 2.4 GHz, 272 nodes, 8 cores/node, 3 GB/core)
  - -40-year run at 30-km resolution, hourly, with 20,000 super-individuals takes 2.25 days

  - Also access to ARSC DoD Supercomputing Resource Center (Fairbanks) and NOAA's Jet at Earth Systems Research Lab (Boulder)

Next Steps

- It can be done – proof of principle
  - UC Shared Research Computing Services (ShaRCS) - Berkeley
  - 128 CPUs (Xeon 2.4 GHz, 272 nodes, 8 cores/node, 3 GB/core)
  - 40-year run with 20,000 super-individuals takes 2.25 days

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- So it is useful?
  - Now we will add biological realism

- Can we calibrate and validate this model?
  - Very challenging: Physics, NPZ, Fish
  - We have a plan