Towards coupling sardine and anchovy to the NEMURO lower trophic level model

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Participants in the Tokyo Workshop

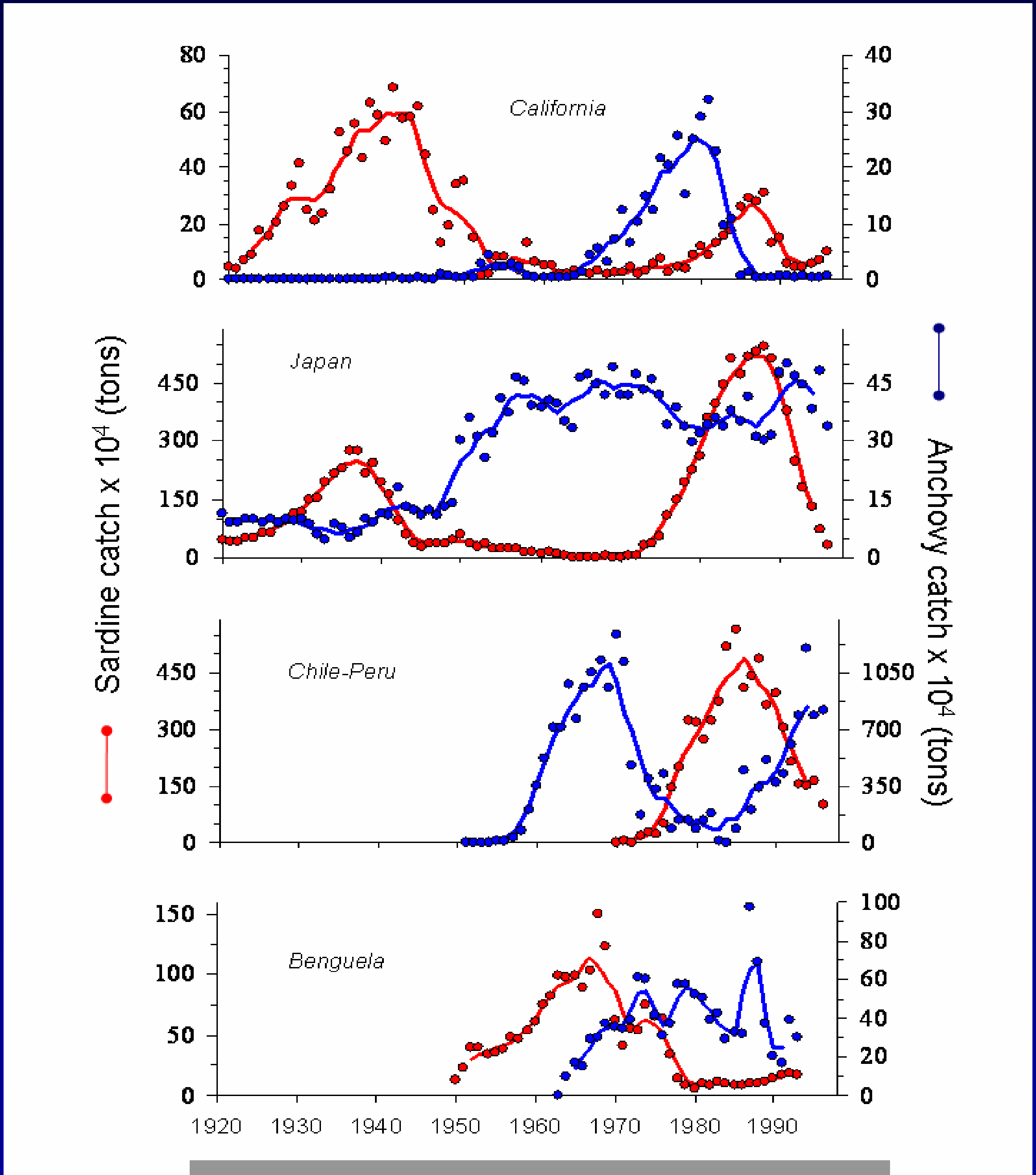
Introduction

- Sardine – anchovy population cycles
  - well-studied
  - teleconnections across basins
- Recently, increased focus on the spatial aspect of the population cycles
  - contraction/expansion
  - shifts
- Top-down versus bottom-up controls

Workshop

- *"Global comparison of sardine, anchovy and other small pelagics: building towards a multi-species model"*
- November 14-17 2005 in Tokyo, Japan
- Support: Japanese Fisheries Research Agency (FRA), Tohoku National Fisheries Research Institute, PICES, GLOBEC, Asia Pacific Network (APN), Inter American Institute for Global Change research (IAI)

Workshop

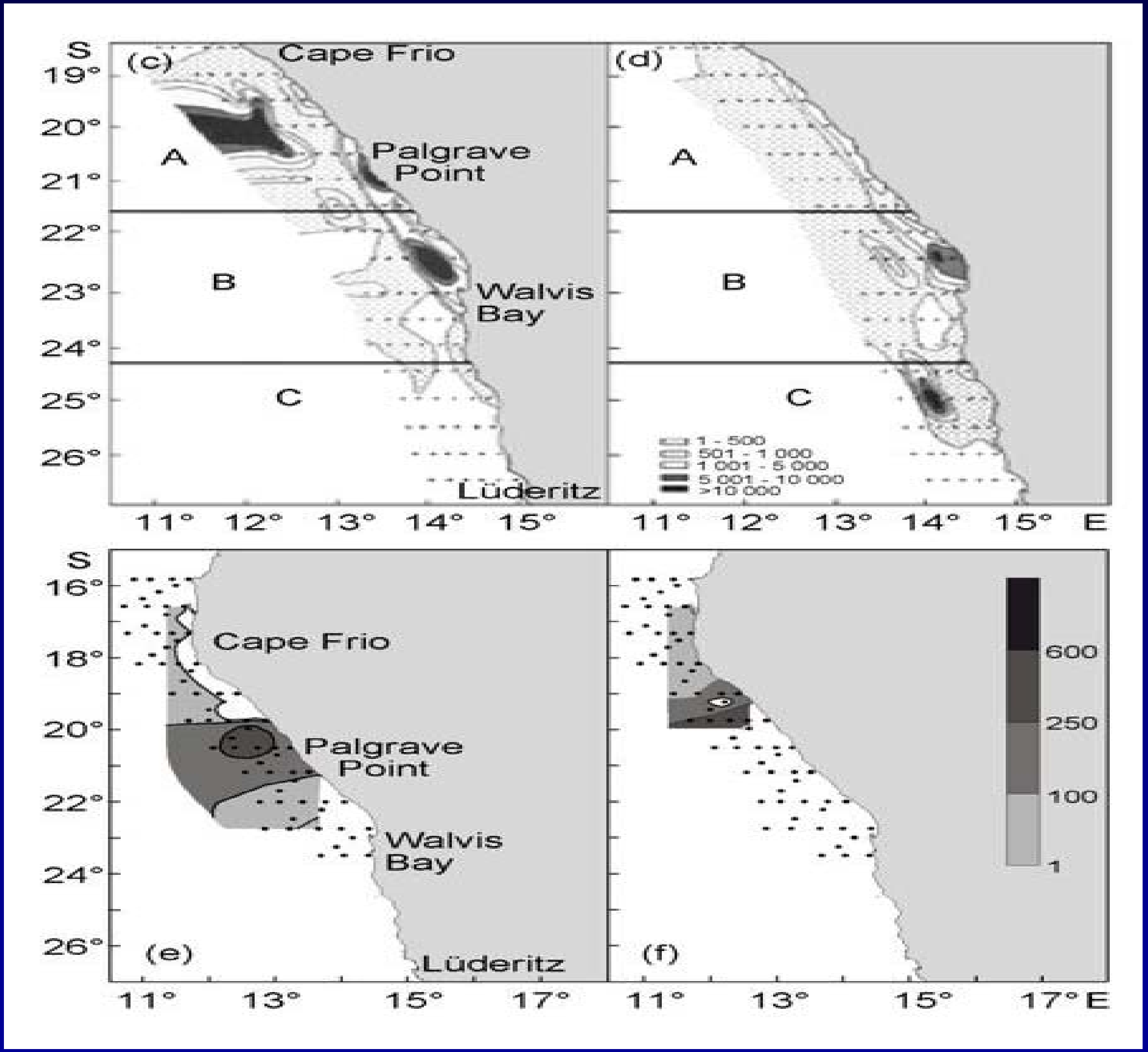


Provided by: Salvador E. Lluch-Cota
Source: Schwartzlose et al., 1999

Sardine Anchovy

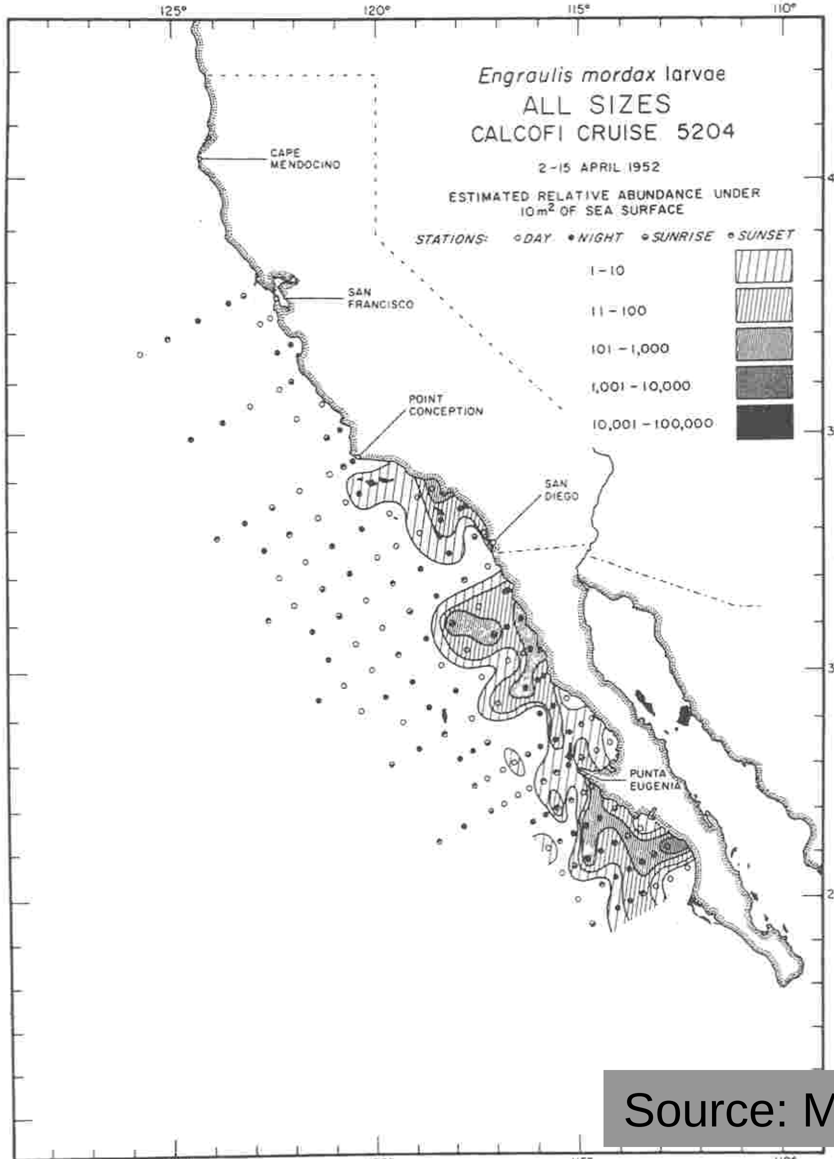
1971

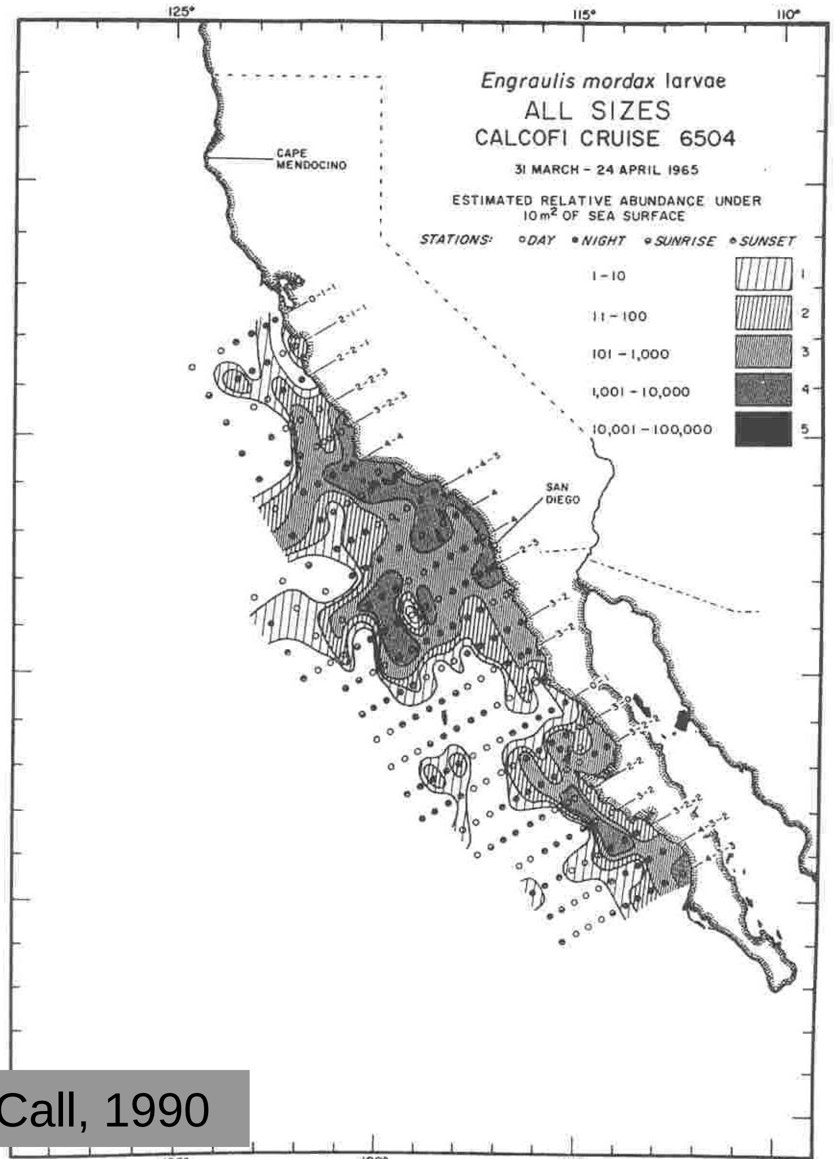
2004



Provided by: Carl van der Lingen
Sources: King, 1997; E. Stenevik, pers com

California Current

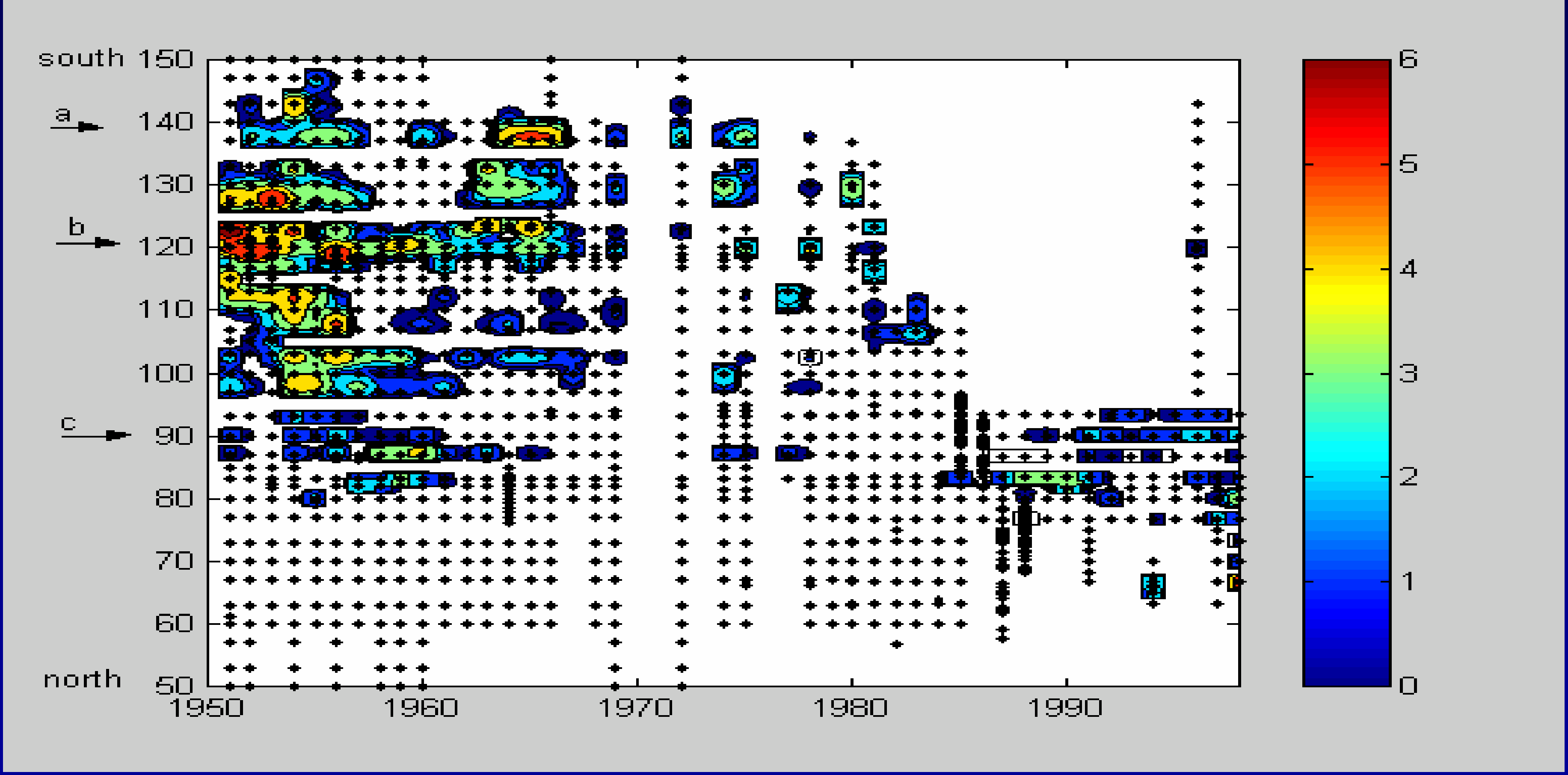




Source: MacCall, 1990

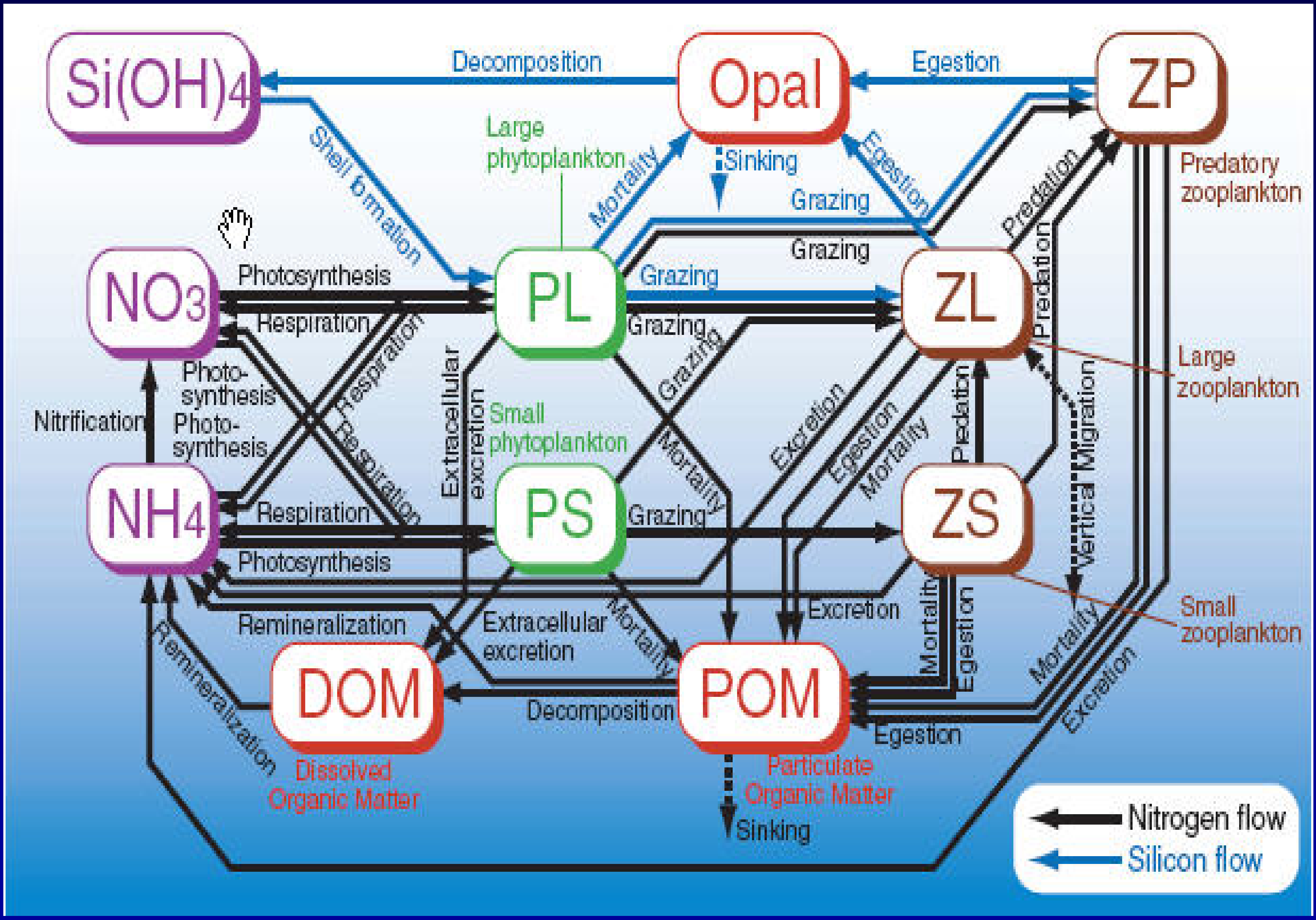
California Current

Sardine egg distribution



Source: Agostini, unpublished

Model 1: NEMURO



Model 2: NEMURO.FISH

$$\frac{dW}{dt} = \left[C - (R + S + F + E) - H\right] \cdot \frac{CAL_z}{CAL_f} \cdot W$$

Zoop from NEMURO

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

W = weight (g ww)
C = consumption (1/day)
R = respiration
S = SDA
F = egestion
E = excretion
H = reproduction

Depend on W and temperature

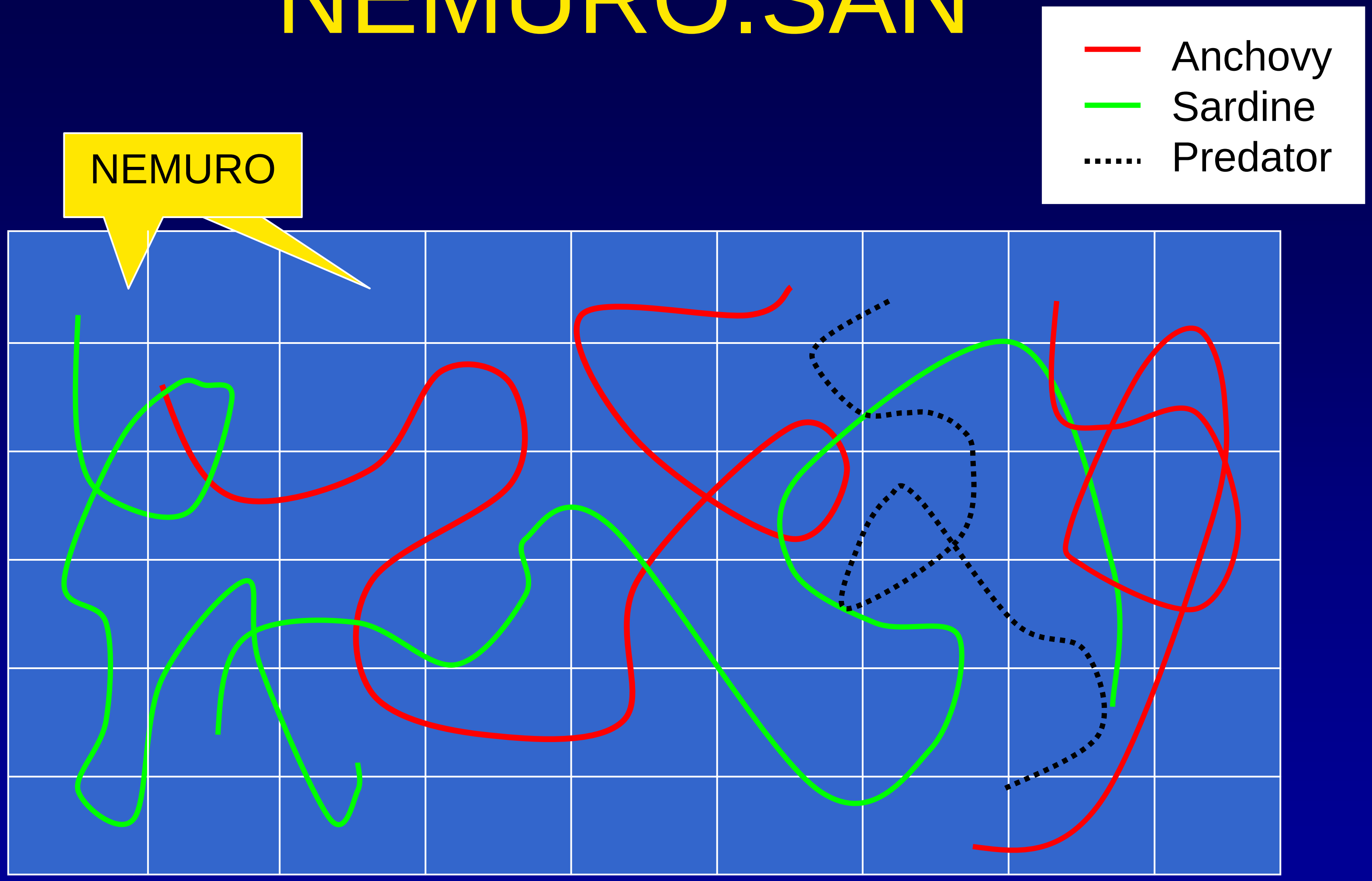
PD = prey density (1=ZS; 2=ZL; 3=ZP)
V = vulnerability
K = feeding efficiency

Now: NEMURO.SAN

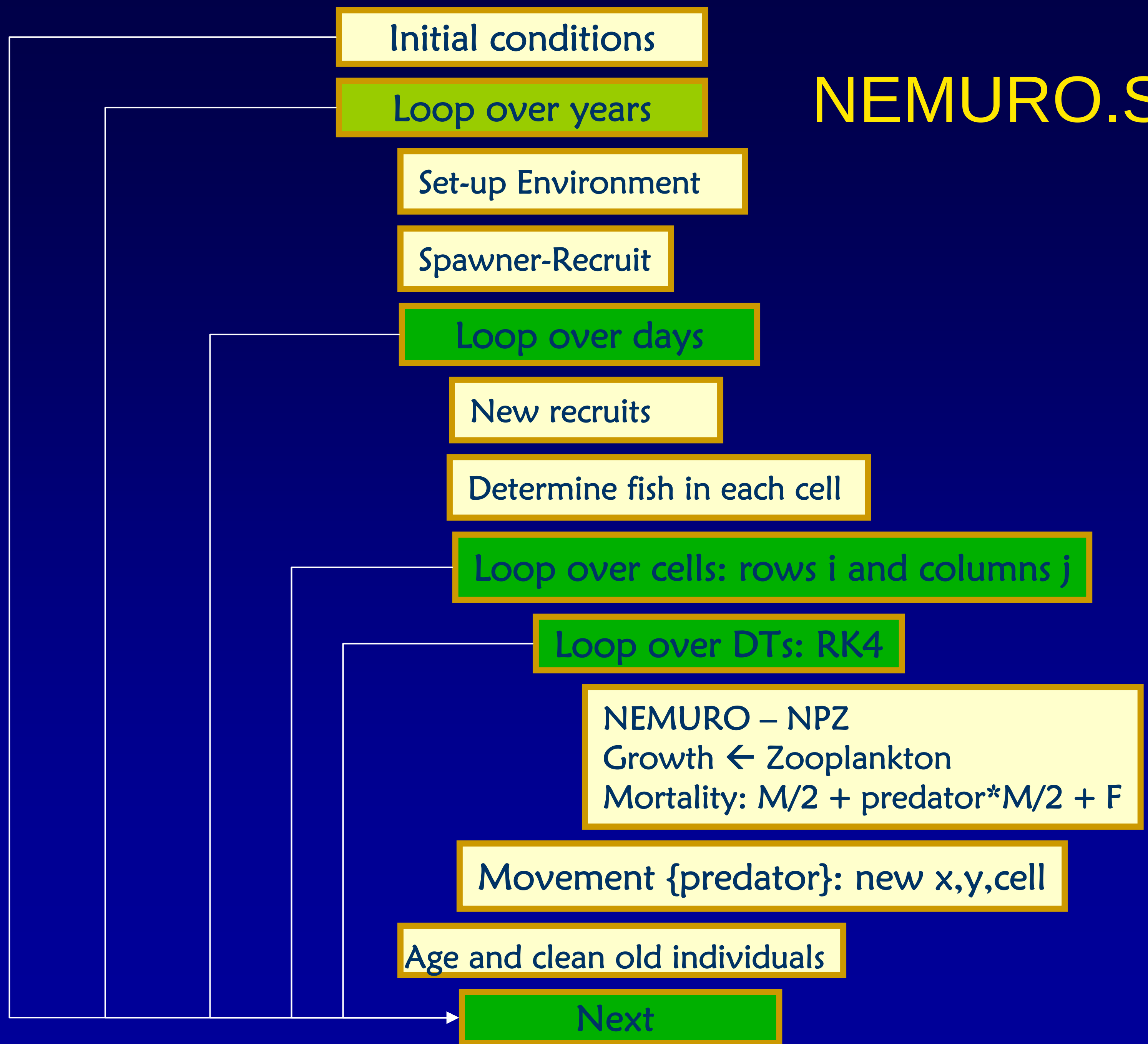
- Biological extensions:
  - Two species (sardine and anchovy)
  - Individual-based
  - Full life-cycle
  - Dynamic predator on sardine and anchovy

- Spatial extensions
  - Grid of cells

NEMURO.SAN



NEMURO.SAN


Initial conditions
Loop over years
Set-up Environment
Spawner-Recruit
Loop over days
New recruits
Determine fish in each cell
Loop over cells: rows i and columns j
Loop over DTs: RK4
NEMURO – NPZ
Growth ← Zooplankton
Mortality: M/2 + predator*M/2 + F
Movement {predator}: new x,y,cell
Age and clean old individuals
Next

NEMURO.SAN: Growth

$$\frac{dW}{dt} = \left[C - (R + S + F + E) - H\right] \cdot \frac{CAL_z}{CAL_f} \cdot W$$

Zoop from NEMURO

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

Mortality to NEMURO

W = weight (g ww)
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Depend on W and temperature

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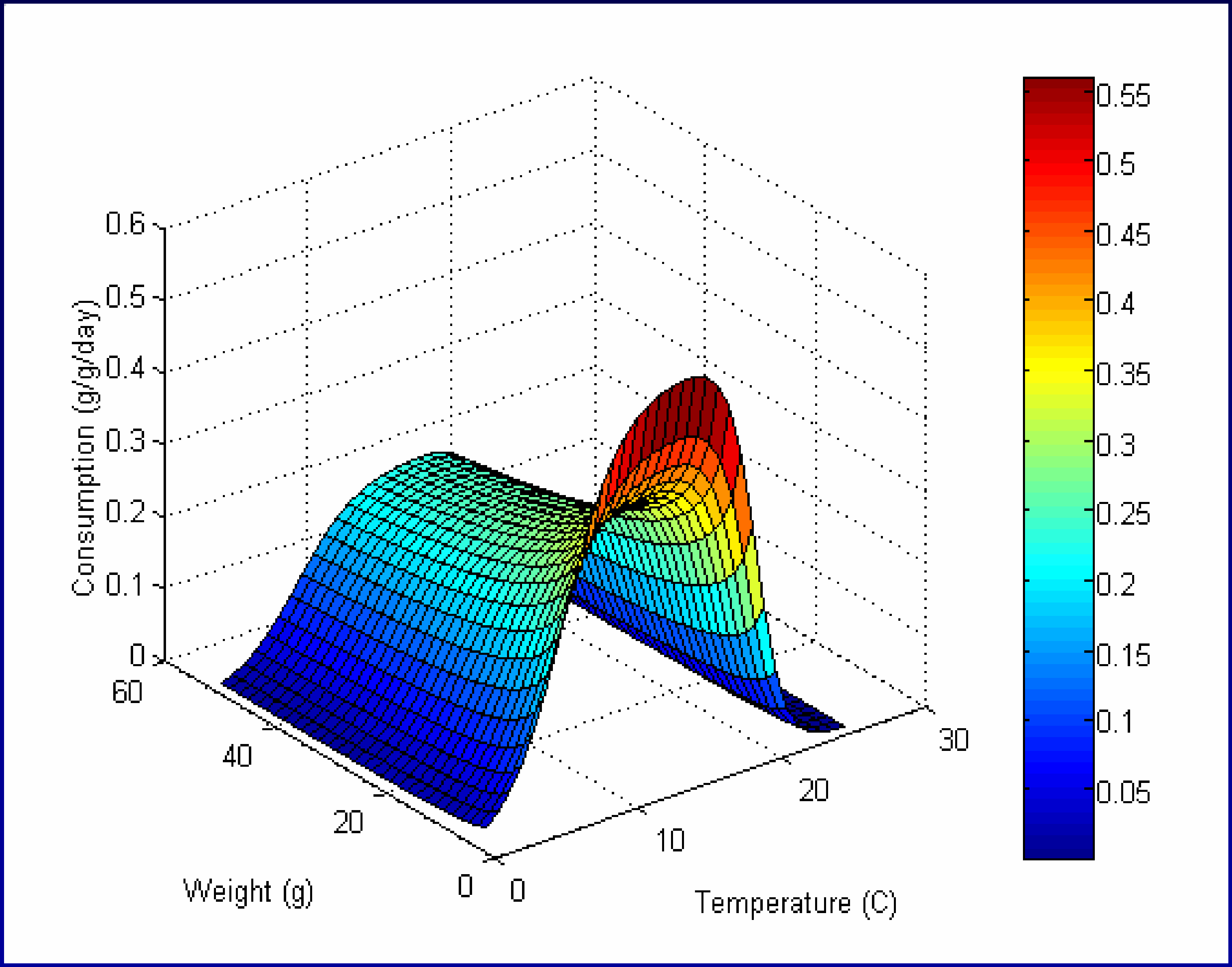
Maximum Consumption



Bioenergetics

Process	Anchovy	Sardine
Cmax	$1.65*W^{0.67} * T1$	$0.2*W^{0.256} * T2$
Respiration	$0.086*W^{0.81} * Q10 * ACT$	$0.0033*W^{0.23} * Q10 * ACT$
Egestion	0.2 * C	0.16 * C
Excretion	0	0.1 * (C-Eg)
SDA	0	0.175 * (C-Eg)

Bioenergetics- Feeding

K values Anchovy Sardine	Age 1-2	Age 3-5	Age 6+
Small Zoop	0.09 0.2	0.04 0.2	0.02 0.2
Large Zoop	0.6 1.0	0.08 1.0	0.06 1.0
Predatory Zoop	0.3 0.4	0.2 0.4	0.08 0.4

NEMURO.SAN: Mortality

- Fishing
  - Age-specific
- Egg to age-1
  - Implicit in spawner-recruit relationship
- Natural:
  - Constant
  - Predator-dependent

Predator-dependent

- Individuals of a third species
  - Do not grow or die
  - Move based on neighboring cell with highest prey biomass (anchovy + sardine)

- Each day compute predator biomass in each cell

- Daily mortality rate of anchovy and sardine individuals in a cell is proportional to predator biomass in that cell

NEMURO.SAN: Reproduction

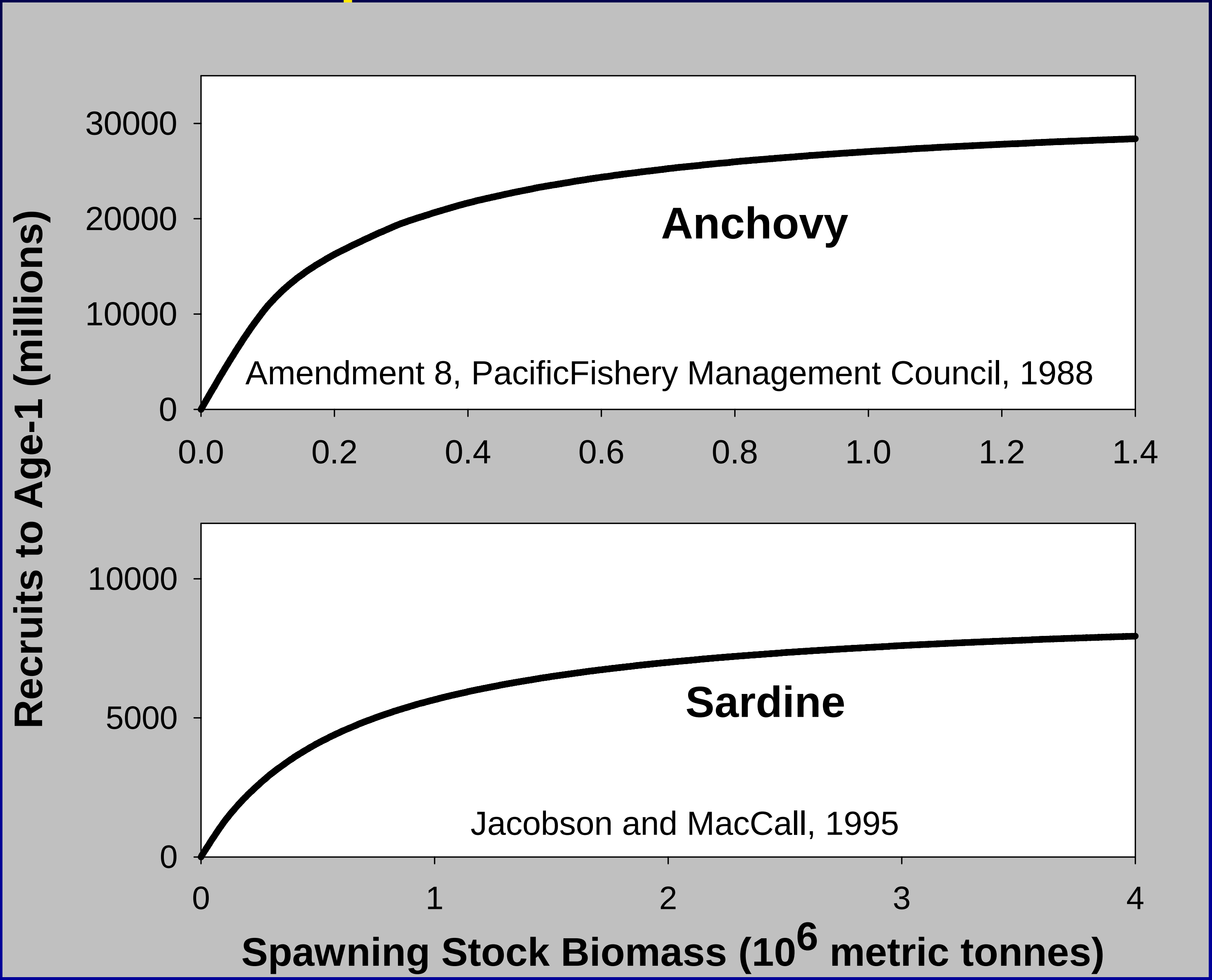
- Option 1: Follow eggs through yolk-sac, larval, and juvenile stages
  - Better for investigating YOY effects
  - Must specify density-dependence

- Option 2: Spawner-recruit relationship
  - Aggregate YOY stages
  - Easier to code

Reproduction

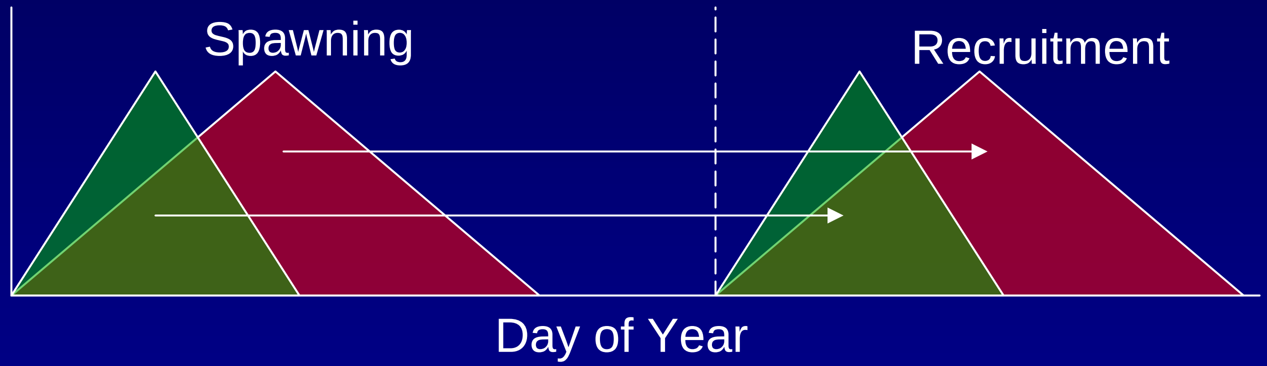
- Spawning season:
  - Anchovy: January 1 – May 30
  - Sardine: January 1 – Sept 7
- Compute SSB at beginning of spawning season
- Individuals mature at age-2 (after seeing second January 1 birthday)

Spawner-Recruit



Recruitment

- Add new individuals one year after each day of spawning season



- Initial values:
  - 10.5 g for anchovy and 35.7 g for sardine
  - Anchovy placed near coast at mid-latitude
  - Sardine placed at southern edge

NEMURO.SAN: Movement

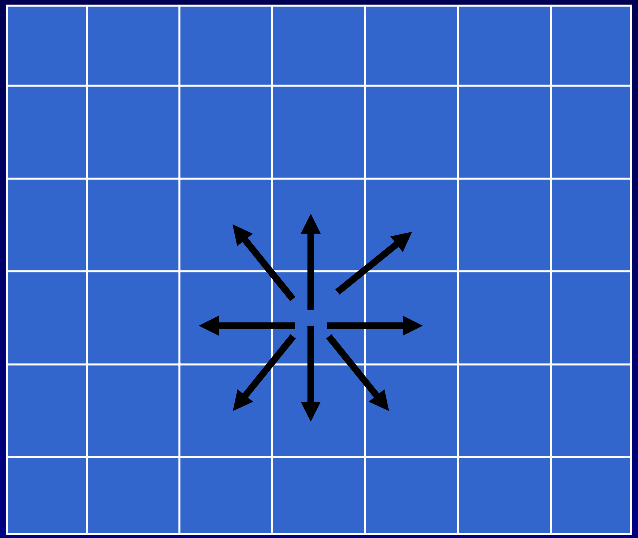
- Each individual has a continuous x and y position

- Position mapped to grid to determine cell location

- Three candidate approaches:
  - Neural network with genetic algorithm (Huse and Giske 1998)
  - Kineses (Humston et al 2004)
  - Fitness (Railsback et al 1999) - Today

Fitness-based Movement

- Evaluate cells in neighborhood



- For each cell, project weight and survival to next spawning season

- $Fitness_{ij}$ = Survival * ($W_{projected}$/W_{target})

Fitness-based Movement

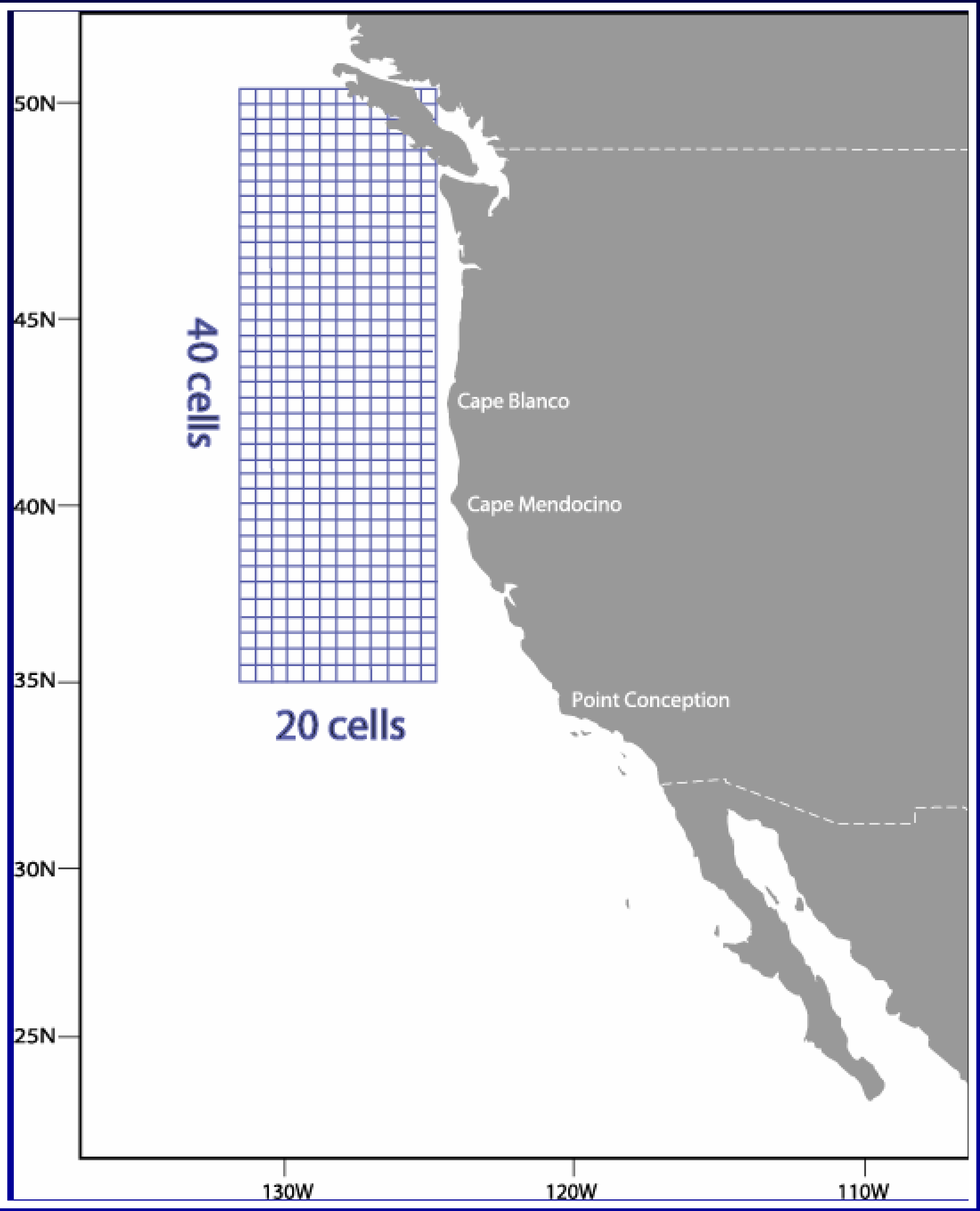
- Select cell with highest fitness
- Increment x and y by travel distance in direction of selected cell (8 directions)
  - Anchovy 2000 m, sardine 5000 m, predator 500 m
- Plus an equal random component

Numerical Details

- 4^{th} order Runge-Kutta for each timestep in a day
- Movement is daily and predator sees yesterday's locations of anchovy and sardines
- 1000 super individuals per age class per species, and removed when reach age-10 (Scheffer et al. 1995)

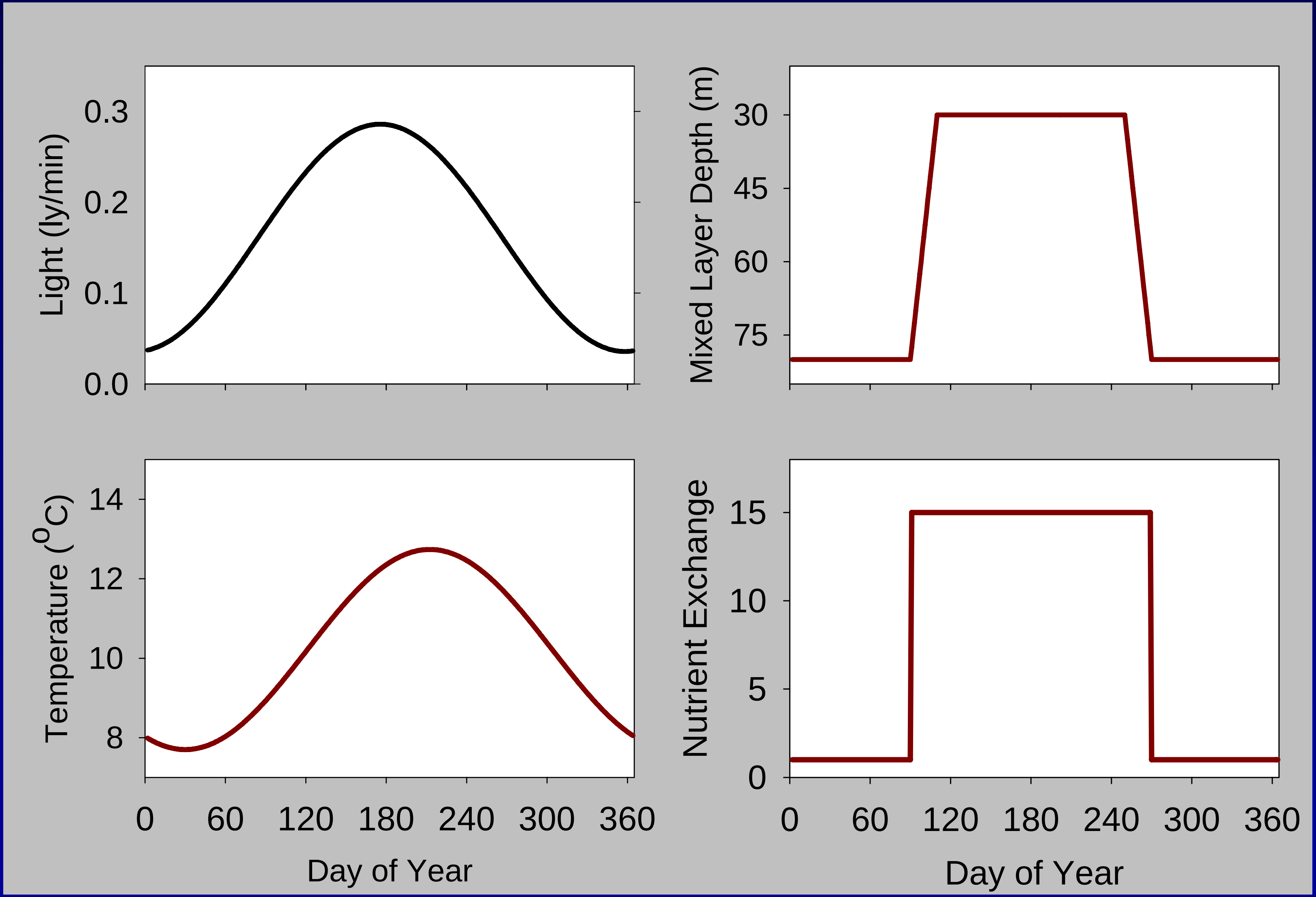
California Current Version

- Very preliminary – meant to answer the question: “Can we do it?”
- 40 cells in x-direction x 20 in y-direction
- West coast Vancouver Island version of NEMURO (Rose et al. in press) in top right corner

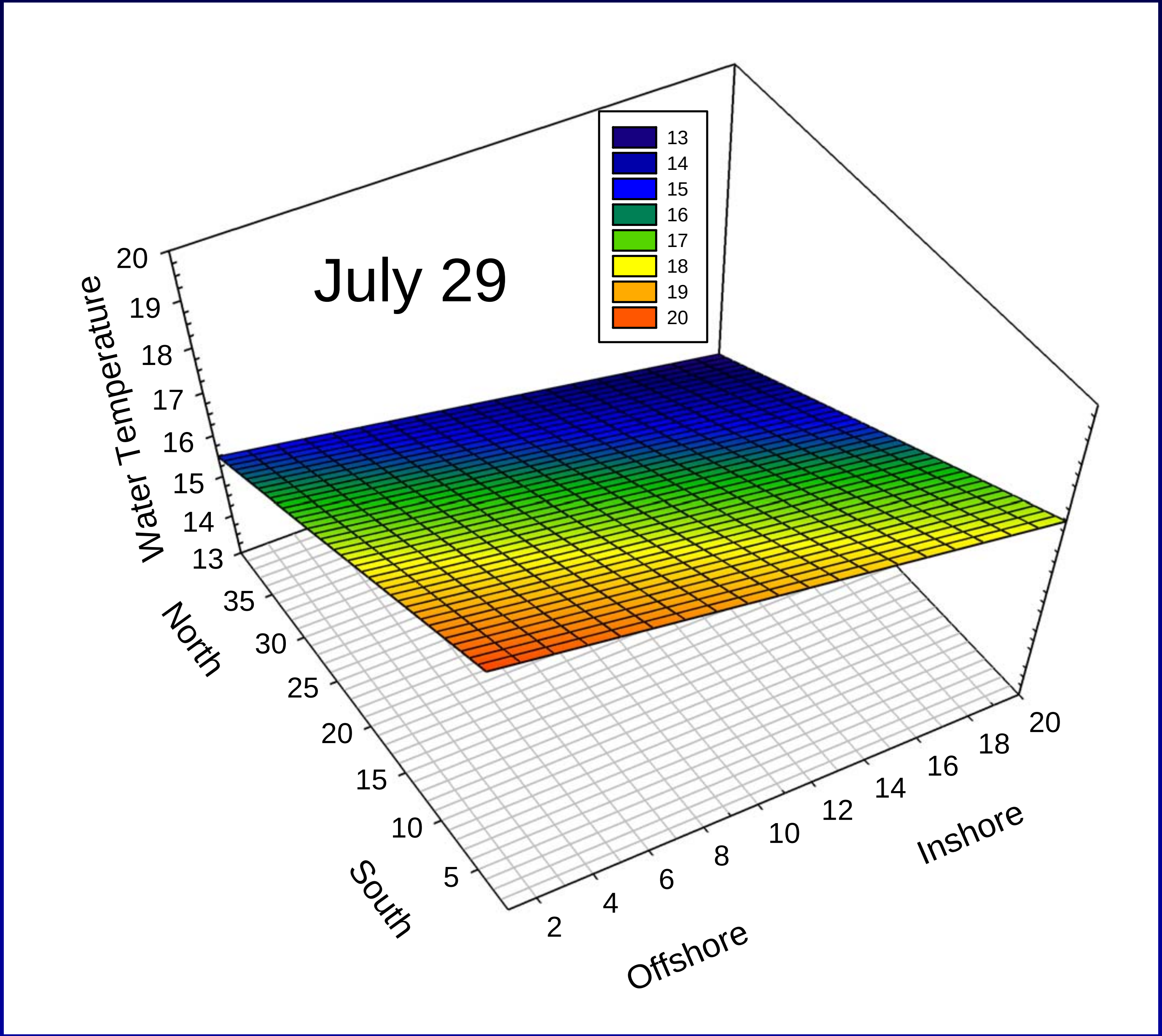


California Current

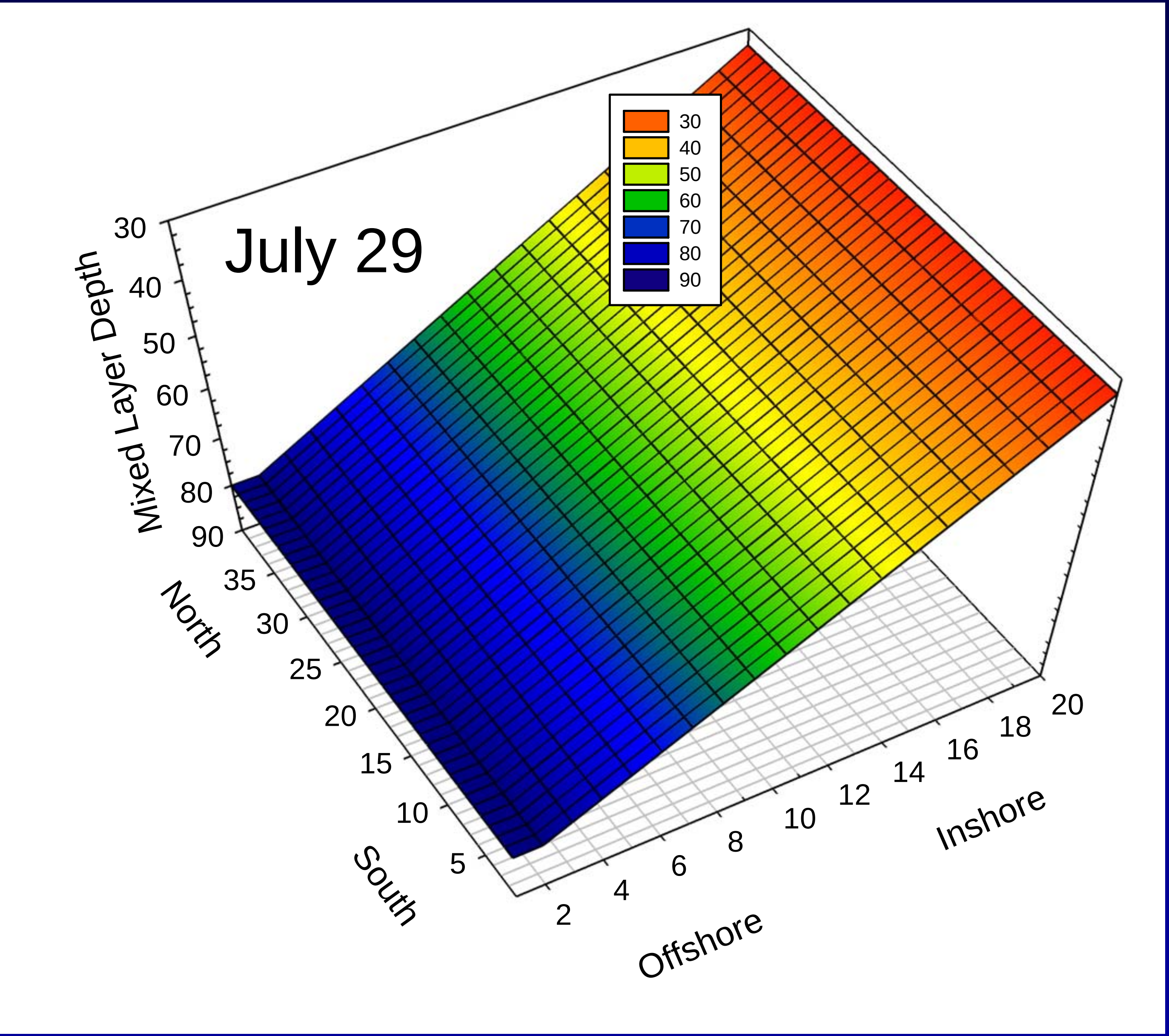
WCVI Environmental Variables



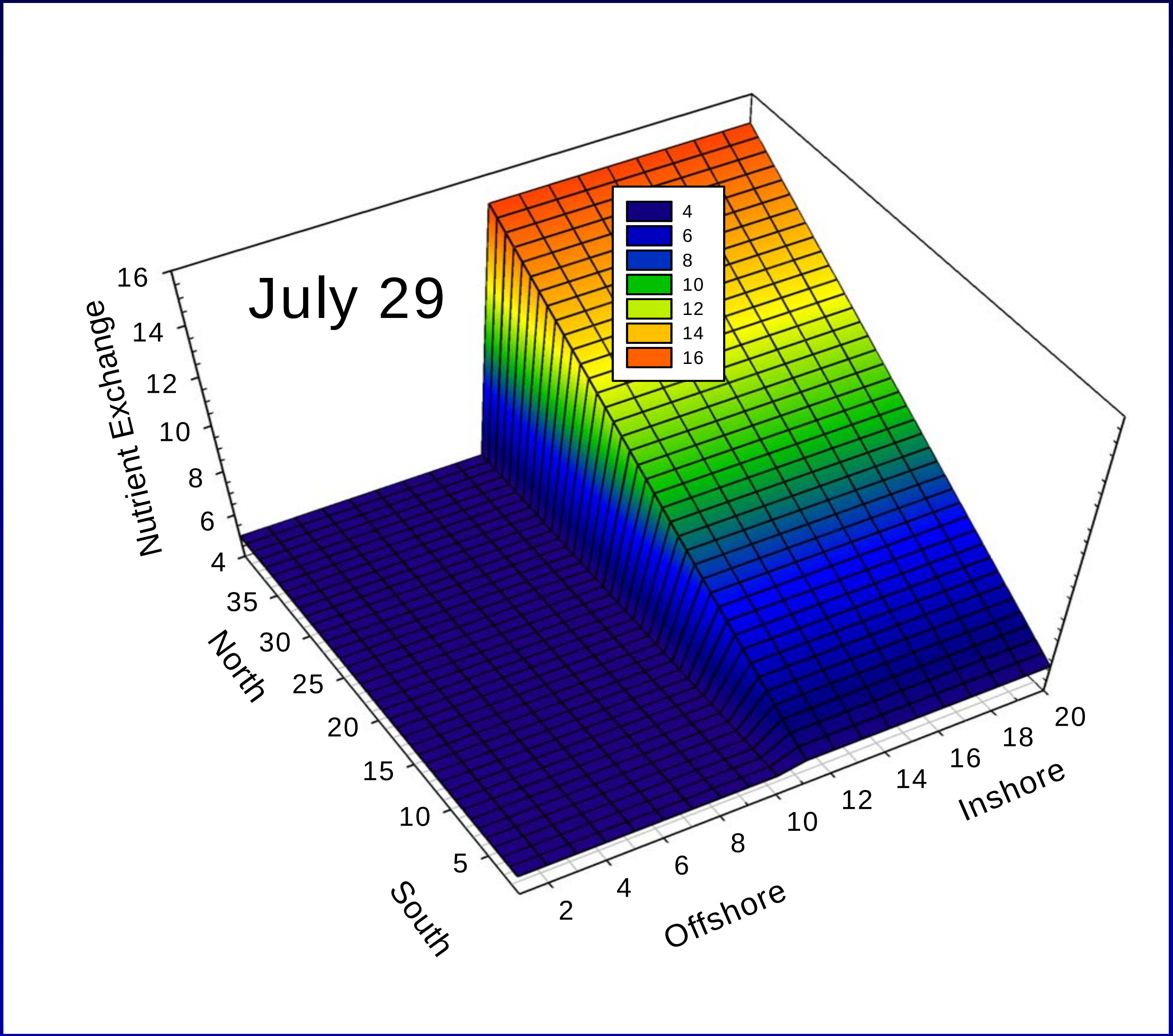
Temperature



Mixed Layer Depth

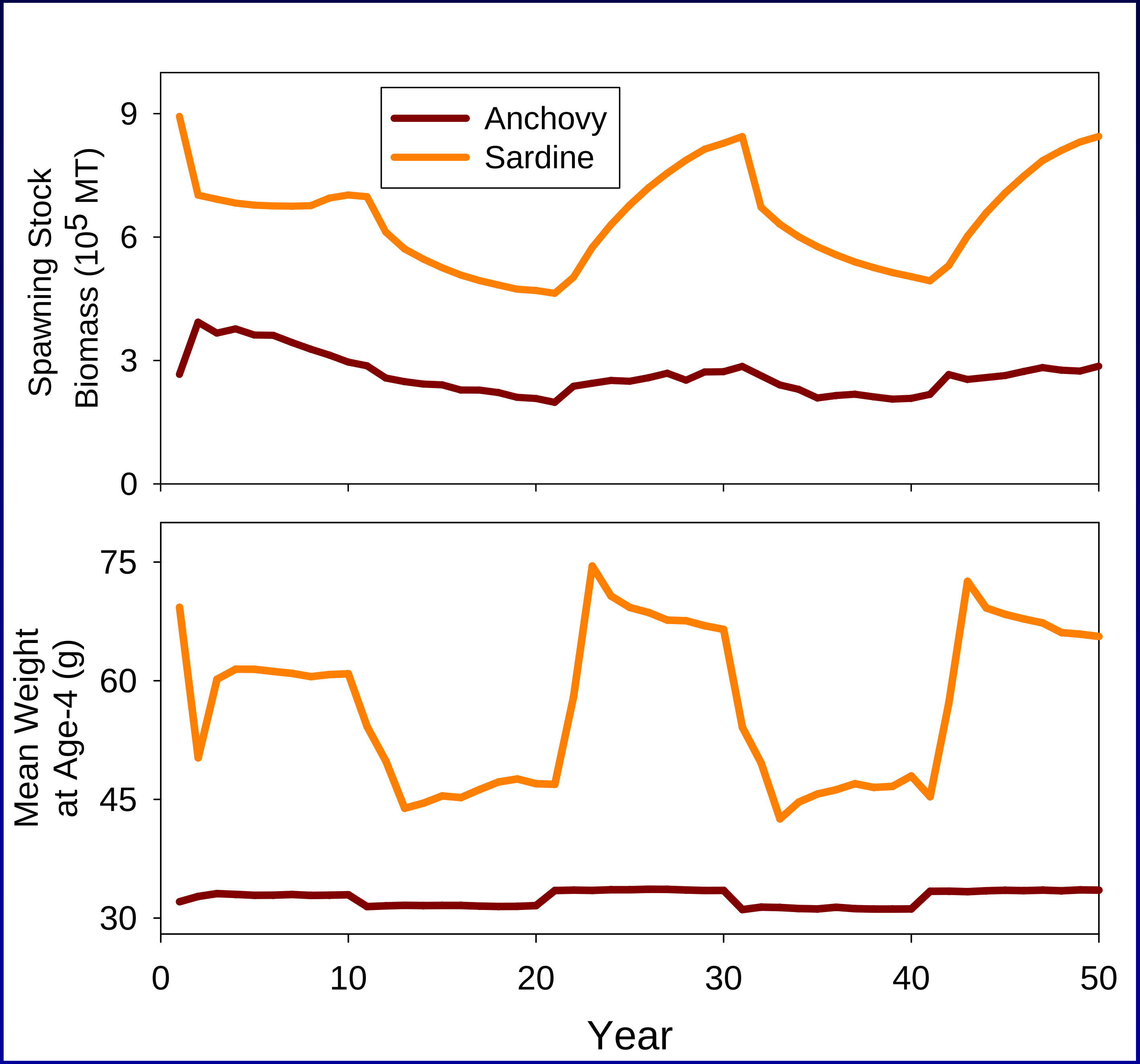


Nutrient Exchange



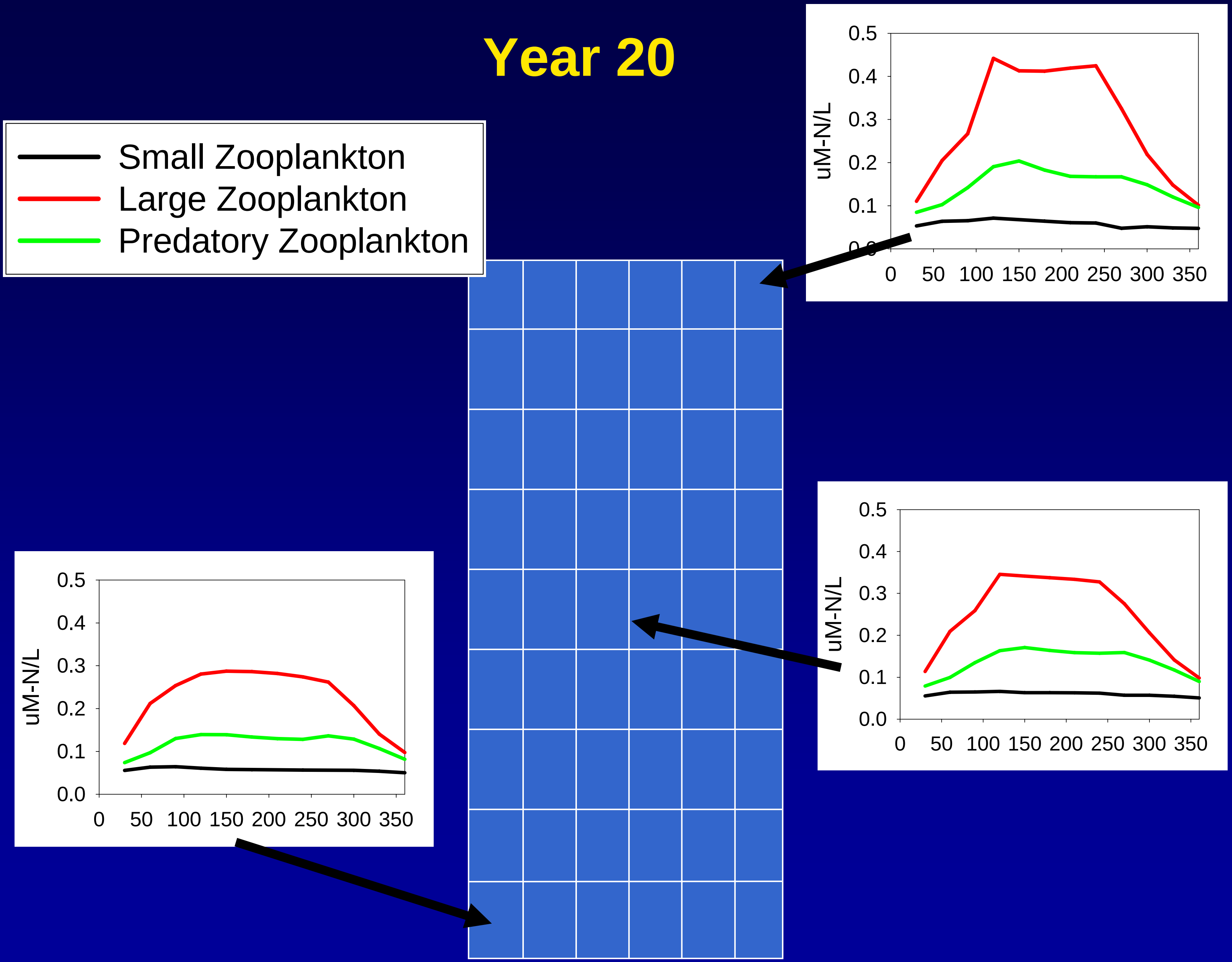
Baseline Simulation

- Conditions: Years 1-10: spin-up
  11-20: warm (+2^{O} C)
  21-30: cold (-2^{O} C)
  31-40: warm (+2^{O} C)
  41-50: cold (-2^{O} C)
- Outputs:
  - Annual SSB and mean weight at age-4
  - NEMURO zooplankton concentrations at 3 cells in year 20
  - Daily bioenergetics of two individuals over their lifetime
  - Spatial maps of fish biomass on July 20 for six of the years



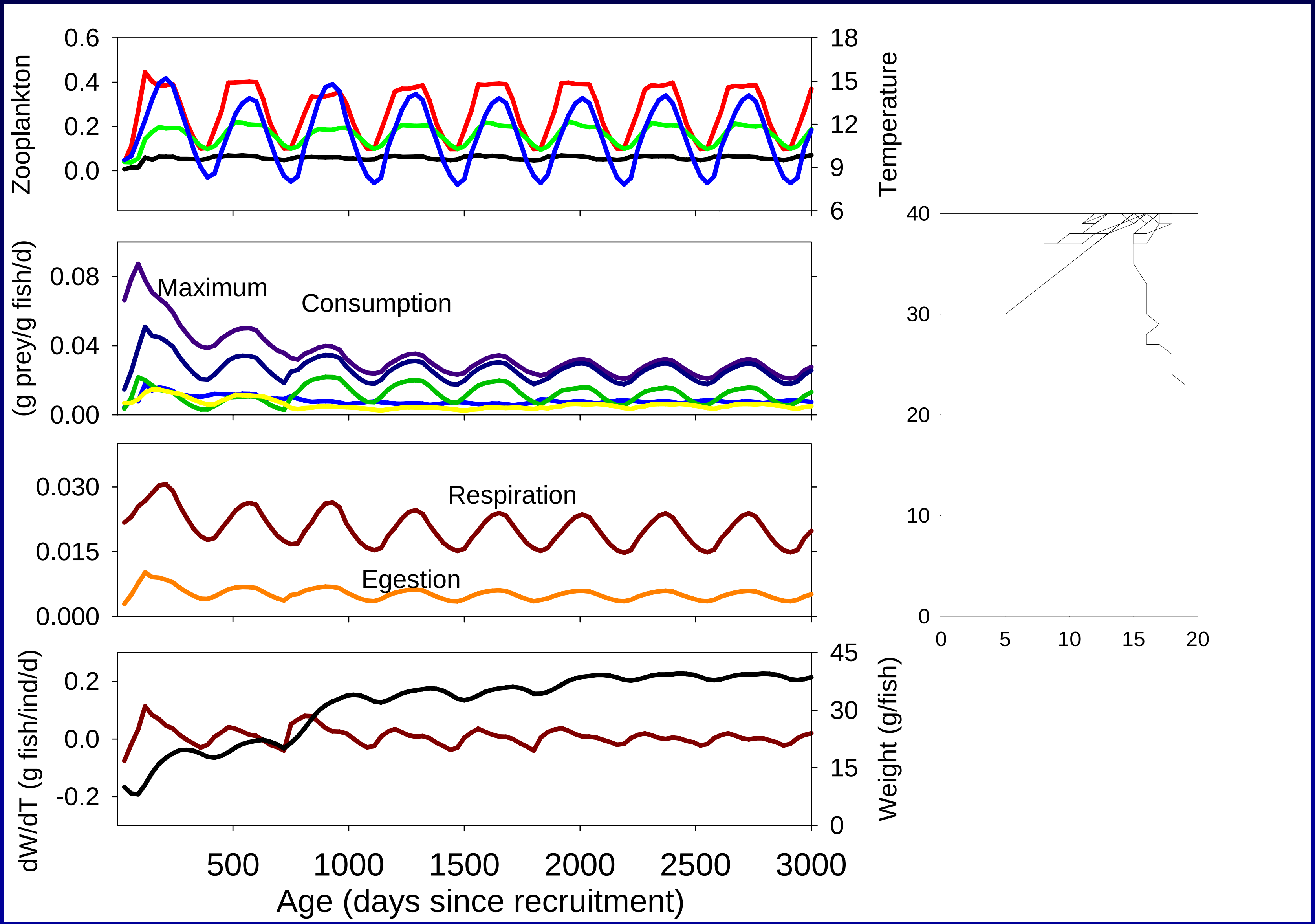
Spawning Stock Biomass (10^5 MT)
9
6
3
0
Anchovy
Sardine
Mean Weight at Age-4 (g)
75
60
45
30
0
10
20
30
40
50
Year

Year 20

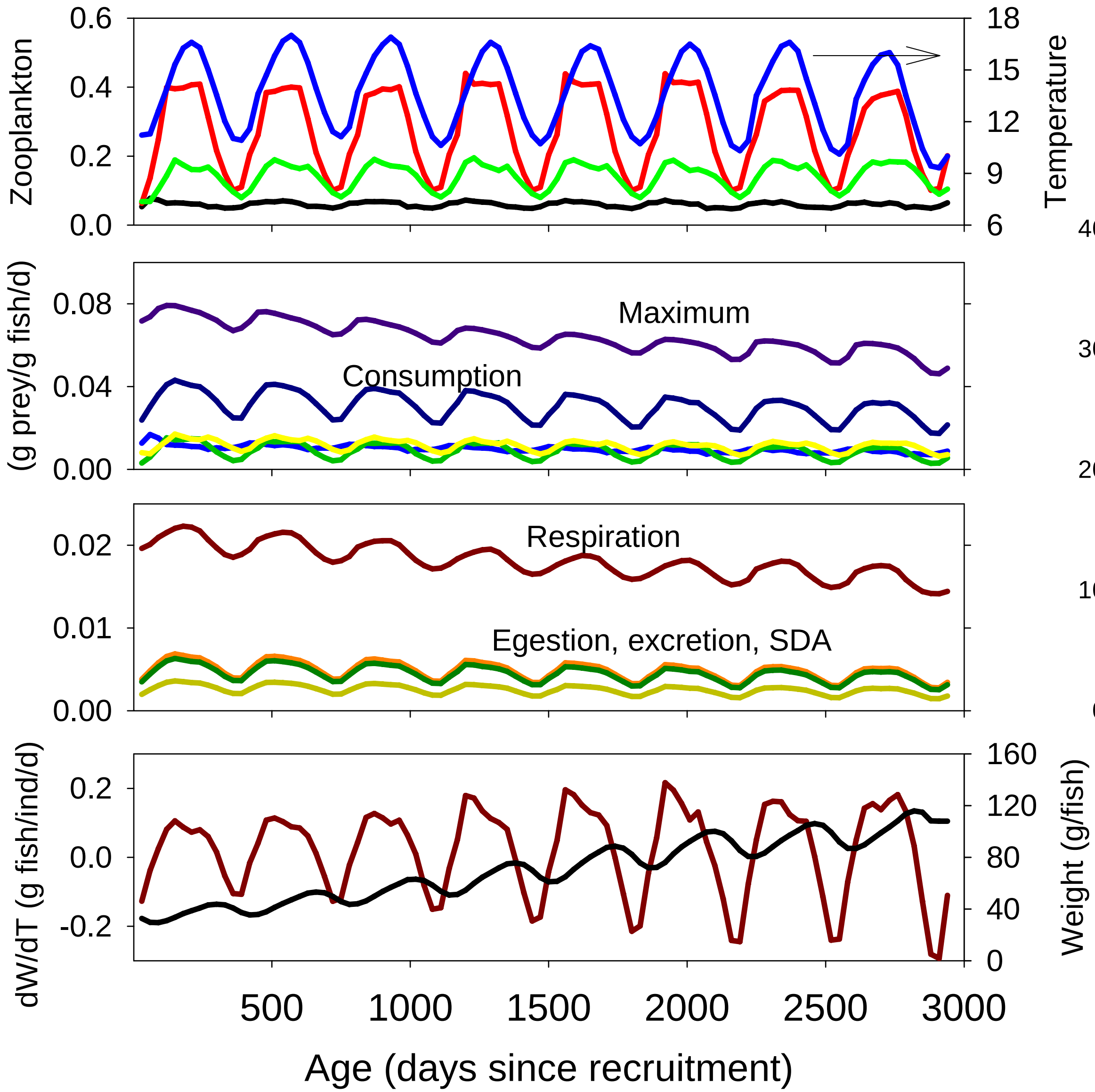


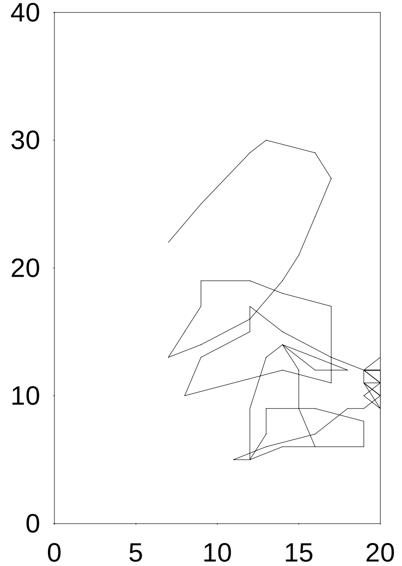
Small Zooplankton
Large Zooplankton
Predatory Zooplankton
uM-N/L
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350

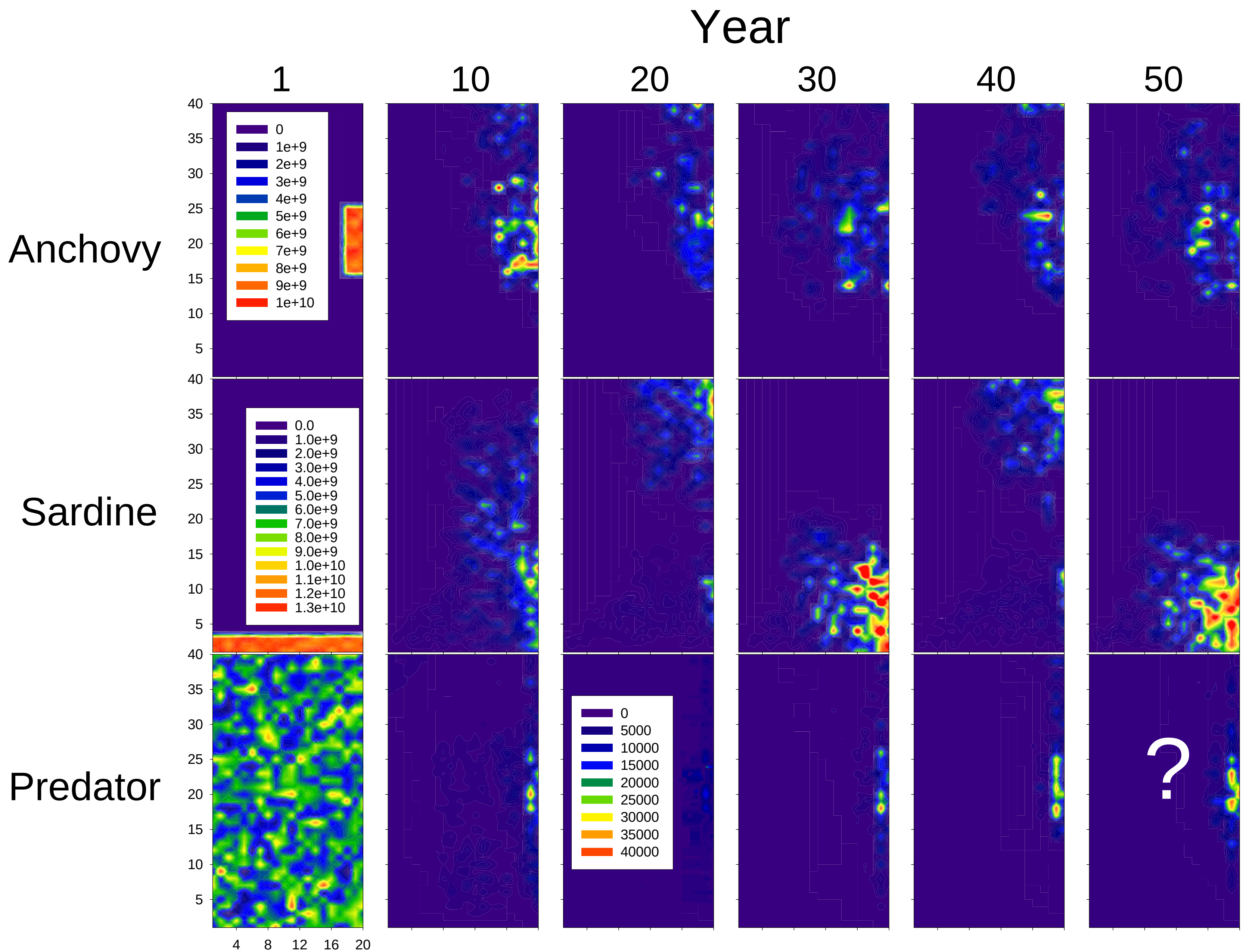
Anchovy #10 (John)



Sardine #10060 (Bernie)







Year
1
10
20
30
40
50
Anchovy
Sardine
Predator
0
1e+9
2e+9
3e+9
4e+9
5e+9
6e+9
7e+9
8e+9
9e+9
1e+10
0.0
1.0e+9
2.0e+9
3.0e+9
4.0e+9
5.0e+9
6.0e+9
7.0e+9
8.0e+9
9.0e+9
1.0e+10
1.1e+10
1.2e+10
1.3e+10
0
5000
10000
15000
20000
25000
30000
35000
40000
?

Concluding Remarks

- Presented an idea for the next generation in NEMURO family of models – credit goes to the Tokyo workshop participants

- Demonstrated it is feasible and some of its features and capabilities
  - Two species and individual-based
  - Full life cycle
  - Spatially-explicit

Next

- Option 1:
  (a) Stop, call it theoretical (include predator-prey?)

- Option 2:
  (a) Continue and develop a more rigorous California Current version (biology and physics)
  (b) Then apply to other locations (Benguela, Japan) for geographical comparison