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)
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Source: Agostini, unpublished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

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

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

- 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

Zoop from NEMURO
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
Loop over cells: rows i and columns j
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

Initial conditions
Set-up Environment
Spawner-Recruit
Loop over years
NEMURO.SAN
**NEMURO.SAN: Growth**

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

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**Zoop from NEMURO**

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\]

**Mortality to NEMURO**
Maximum Consumption
## Bioenergetics

<table>
<thead>
<tr>
<th>Process</th>
<th>Anchovy</th>
<th>Sardine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cmax</td>
<td>$1.65W^{0.67} * T1$</td>
<td>$0.2W^{0.256} * T2$</td>
</tr>
<tr>
<td>Respiration</td>
<td>$0.086W^{0.81} * Q10 * ACT$</td>
<td>$0.0033W^{0.23} * Q10 * ACT$</td>
</tr>
<tr>
<td>Egestion</td>
<td>$0.2 * C$</td>
<td>$0.16 * C$</td>
</tr>
<tr>
<td>Excretion</td>
<td>0</td>
<td>$0.1 * (C-Eg)$</td>
</tr>
<tr>
<td>SDA</td>
<td>0</td>
<td>$0.175 * (C-Eg)$</td>
</tr>
</tbody>
</table>
## Bioenergetics- Feeding

<table>
<thead>
<tr>
<th>K values</th>
<th>Age 1-2</th>
<th>Age 3-5</th>
<th>Age 6+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchovy</td>
<td>0.09</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Sardine</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Small Zoop</td>
<td>0.09</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Large Zoop</td>
<td>0.6</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Predatory Zoop</td>
<td>0.3</td>
<td>0.2</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>
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

**Anchovy**

- Spawning Stock Biomass (10^6 metric tonnes)
- Recruits to Age-1 (millions)

**Sardine**

- Spawning Stock Biomass (10^6 metric tonnes)

Amendment 8, PacificFishery Management Council, 1988

Jacobson and MacCall, 1995
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\textsuperscript{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

- Cape Blanco
- Cape Mendocino
- Point Conception

40 cells

20 cells
WCVI Environmental Variables

- **Light (ly/min)**: 0.0, 0.1, 0.2, 0.3
- **Mixed Layer Depth (m)**: 30, 45, 60, 75
- **Temperature (°C)**: 8, 10, 12, 14
- **Day of Year**: 0, 60, 120, 180, 240, 300, 360
- **Nutrient Exchange**: 0, 5, 10, 15

Diagrams showing the variations of these variables over time.
Temperature

July 29

Water Temperature

North                         South
Mixed Layer Depth

July 29
Nutrient Exchange

July 29
Baseline Simulation

- **Conditions:** Years 1-10: spin-up
  - 11-20: warm (+2°C)
  - 21-30: cold (-2°C)
  - 31-40: warm (+2°C)
  - 41-50: cold (-2°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)

Anchovy
Sardine

Year
Mean Weight at Age-4 (g)

Spawning Stock Biomass (10^5 MT)

Anchovy
Sardine

Year
Year 20

- Small Zooplankton
- Large Zooplankton
- Predatory Zooplankton
Sardine #10060 (Bernie)

- Zooplankton
- Maximum
- Consumption
- Respiration
- Egestion, excretion, SDA
- Change in weight with temperature
- Weight over time

Age (days since recruitment)
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