The impact of density-dependent processes on growth of Japanese sardine (Sardinops melanostictus)

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5. Graduate School of Environmental Science, Hokkaido University
Japanese sardine habitats

Feeding Grounds High Stock Level

Spawning Ground Low SL

Spawning Ground High Stock Level

Spawning Ground High Stock Level

Nursery Mixed Water region

Low SL

High Stock Level

Kuroshio Extension

Subtropical Water

Kuroshio

Oyashio

Western Subarctic Gyre

Oyashio region

Mixed Water region

Oyashio

Subarctic Domain

Alaska Current

Subarctic Current

Alaskan Gyre

 Transitional Domain

Subarctic Boundary

Sardinops caerulea

Sardinops melanostictus

Courtesy of Dr. A. Yatsu
Back Ground

Weights & Catches of the Japanese sardine

These seem to be the effects of density-dependence.

Wada & Kashiwai (1991)

High Stocks => Expanding feeding ground

High Stocks => Decreasing weighs (small size)

These seem to be the effects of density-dependence.
Questions

• **When** would the deceleration of growth start in their life history?
  – Larval stage (Winter-early Spring) ?
  – Juvenile stage (late Spring -Winter) ?

• **Where** would the deceleration of growth occur?
  – Kuroshio Current region ?
  – Kuroshio Extension region ?
  – Mixed Water region ?
  – Oyashio region ?
Objective

• To investigate the impact of density-dependent processes on growth and distribution of Japanese sardine,
• we carried out a multi-trophic level ecosystem model including Japanese sardine under scenarios of high and low standing stocks.
Ecosystem Model

3D- Lower Trophic Ecosystem Model (NEMURO)

Sardine Migration Model
(Okunishi et al, E.M. accepted)

Climate Model
MIROC 3.2 (The CCSR/NIES/FRCGC Coupled Ocean-Atmosphere GCM)
Horizontal Resolution (Ocean Part): 1/4 × 1/6

Forcing at the year 1900
Simulated
Velocity Field
Temperature
Salinity
Vertical Diffusivity,
Solar Radiation etc..

Climetological physical fields

Lagrangian Model
for simulating migration
• Sea surface current from climate model
• Fish swim by searching for local optimal habitats during feeding migration.
• Adult fish is strongly oriented in homeward direction during spawning migration.

Bioenergetics Model
for simulating growth
• SST from Climate model
• Forage density from NEMURO

<Population & Mortality>
1. Super-individuals were used to allow the IBM to represent the sardine population.
2. The internal number in a super-individual is reduced due to mortality.
3. Mortality rate
   Early larvae: 0.075 / day (Kuroda, 1991)
   Late larvae: 0.01 / day (Kuroda, 1991)
   Juvenile–Adult: 0.001/day (Kawai, 1987)
Experimental Setting

Initial Location

Age 0  Spawning regions (Larvae)
Age 1  Wintering places (Juvenile)
Age 2+ Spawning regions (Adult)

Initial Condition

<table>
<thead>
<tr>
<th>Particle number (Model)</th>
<th>Age 0</th>
<th>Age 1</th>
<th>Age 2+</th>
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<tbody>
<tr>
<td>High Stocks and Low Stocks</td>
<td>9,000</td>
<td>5,200</td>
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<table>
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<tr>
<th>Stock abundance in particle[10^6 individual / particle]</th>
<th>Age 0</th>
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<tr>
<td>High Stocks (1978-1989)</td>
<td>93.3</td>
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<td>21.9</td>
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<td>Low Stocks (1990-1998)</td>
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<th>Initial weight (g)</th>
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<td>High Stocks and Low Stocks</td>
<td>1.5 x 10^-3</td>
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Forcing at the year 1900

NEMURO Spin-up (5 yr.)

Analysis Period

1 year simulation

NEMURO + Sardine Migration Model

Scenarios

High stocks 1978-1989
Low stocks 1990-1998

3 Case Simulations

Simulation 1 (S1): 1-way model, Low stocks
Simulation 2 (S2): 2-way model, Low stocks
Simulation 3 (S3): 2-way model, High stocks
One-way model

Environmental Data

From Climate Model
- Ocean Current
- Sea surface temperature

From Climate Model
- Sea surface temperature

From NEMURO
- Forage density

Sardine Migration Model

Lagrangian transport model

Spatial location

Bioenergetics model

Growth

Swimming directions by Habitat Index
(Feeding migration periods)

Swimming directions by ANN
(Spawning migration periods)

Environmental information
- Neuron 1: SST
- Neuron 2: Experienced temperature change
- Neuron 3: Ocean current speed
- Neuron 4: Day length
- Neuron 5: Distance from land.

NEMURO is not affected by the Sardine migration model.
**Experimental Setting**

**Initial Location**
- Age 0: Spawning regions (Larvae)
- Age 1: Wintering places (Juvenile)
- Age 2+: Spawning regions (Adult)

**Initial Condition**

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**Forcing at the year 1900**

**Simulation 1 (S1):** 1-way model, Low stocks
**Simulation 2 (S2):** 2-way model, Low stocks
**Simulation 3 (S3):** 2-way model, High stocks
Two-way model

Environmental Data

From Climate Model
- Ocean Current
- Sea surface temperature

From Climate Model
- Forage density

Sardine Migration Model
- Lagrangean transport model
- Spatial location

Bioenergetics model
- Swimming directions by Habitat Index
  (Feeding migration periods)
- Swimming directions by ANN
  (Spawning migration periods)

Growth
- Artificial neural network (ANN)

Environmental Information
- Neuron 1: SST
- Neuron 2: Experienced temperature change
- Neuron 3: Ocean current speed
- Neuron 4: Day length
- Neuron 5: Distance from land.

NEMURO is affected by the Sardine migration model.

PL, ZL, ZS decrease

POM, NH4 increase
**Experimental Setting**

- **Initial Location**
  - Age 0: Spawning regions (Larvae)
  - Age 1: Wintering places (Juvenile)
  - Age 2+: Spawning regions (Adult)

- **Initial Condition**
  - Particle number (Model)
    | Age 0  | Age 1  | Age 2+ |
    |--------|--------|--------|
    | High Stocks and Low Stocks | 9,000  | 5,200  | 9,000  |

- **Stock abundance in particle [10^6 individual / particle]**
  - Age 0  | Age 1  | Age 2+ |
  - High Stocks (1978-1989) | 93.3   | 34.6   | 21.9   |
  - Low Stocks (1900-1999)   | 5.9    | 1.9    | 3.2    |

- **Initial weight (g)**
  - Age 0  | Age 1  | Age 2+ |
  - High Stocks and Low Stocks | 1.5 x 10^{-3} | 18    | 40    |

- **Scenarios**
  - High stocks: 1978-1989
  - Low stocks: 1990-1998

- **Forcing at the year 1900**
  - Spin-up (5 yr.)

- **3 Case Simulations**
  - Simulation 1 (S1): 1-way model, Low stocks
  - Simulation 2 (S2): 2-way model, Low stocks
  - Simulation 3 (S3): 2-way model, High stocks
Geographical Distributions of Adult fish (Age = 2+)

• High Stocks ⇒ Low Forage density ⇒ Expanding feeding ground

- Under the scenario of high standing stocks, the occupied regions by adult sardine cover widespread areas.
- The impact of density-dependent on distributions is strong.
- Model results appear to provide support for the hypothesis of density-dependent habitat selection.

The distributions have expanded in the east-west direction.
In early autumn, Age 0 fish has slowly growth rate under the scenario of high standing stocks because forage density becomes significantly low.
In early autumn

- Forage density is lower by 10 to 20% in the Mixed water and Oyashio regions in the S3 than that in S2 due to high feeding pressure of adult sardine.
- The deceleration of growth at Age 0 fish becomes marked in the Mixed Water and Oyashio regions in early autumn.
Summary

- The model reproduced the expanding distributions by the effect of density-dependent.

  - When would the deceleration of growth start in their life history?
  - Where would the deceleration of growth occur?

- Model results suggest that the deceleration of growth of sardine starts at the juvenile stage in the Mixed Water and Oyashio regions.

- The effect of density-dependence among trophic levels and fish seems to be one of the most important factors which determine the geographical distribution of adult sardine and growth of young sardine.