A migration model of Japanese sardine using artificial neural network

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Purposes of this study

• The stock has exhibited dramatic changes.

• The stock fluctuation is related to interdecadal North Pacific ocean/climate variability (Yasuda et al., 1999).

• To produce a forecast of climate impacts on the production and distribution of Japanese sardine, we developed a horizontal 2D-model coupled fish bioenergetics.

• A key is how to reproduce the spawning migration of Japanese sardine.
Spawning Migration

- Adult fish return to spawning grounds along the Pacific coast of Japan during autumn and winter.

Presumed northward migration (Feeding migration) and southward migration (Spawning migration) according to Kuroda (1991).
A migration model of Japanese sardine

**Model (Individual Based Model)**

- **Bioenergetics Model**
- **Lagrangian Model**

**Transport & Movement**

\[ x^{n+1} = x^n + (U_1 + [U_2 \text{ or } U_3]) \cdot \Delta t + R \]

- **U_1**: Passive transport (ocean current)
- **U_2**: Feeding migration (Search for local optimal habitats)
- **U_3**: Spawning migration (using an Artificial neural networks)

Swimming speed = 3 Body Length s\(^{-1}\)

**R : Diffusion**

\[ R = r \cdot \sqrt{2 \cdot \Delta t \cdot D} \]

- r : normal random number (-1 ~ 1)
- D : diffusion coefficient

**Data**

- SST: Monthly mean SST on World Ocean Atlas 2005 (WOA05)
- Chl-a: monthly climatology Chl-a concentration on the SeaWiFS
- Zooplankton Biomass = 0.3 * Phytoplankton Biomass

**Graph**

- **Model**
- **Observation**

**Fork Length (cm)**

- Hatch: Feb.- Apr.
Bioenergetics Model for Sardine

The bioenergetics sub-model is based on the model of the North Pacific Ecosystem Model for Understanding Regional Oceanography For Including Saury and Herring; NEMURO.FISH (Megrey & Kishi, 2002)

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

- **C**: consumption
- **R**: respiration (loses through metabolism)
- **S**: specific dynamic action (digesting food)
- **E**: excretion
- **F**: egestion

change of weight
Domain in the model
Hypothesis for spawning migration

• Japanese sardine can recognize geographical orientation
  (using solar orientation or magnetic fields),
  changes in temperature,
  current speed,
  day length,
  the difference between coastal region and ocean region.

• They use these information for orientation cues.
An orientation during spawning migration was modeled using ANN.
The fish move according to the direction decided by weights in ANN.

1. Case 1: the weights are trained with standard back propagation method with training data.

2. Case 2: genetic algorithm (GA) is used to adjust the weights.

3. Case 3: the weights of ANN is decided by a combination method of both cases 1 and 2.
Case 1: trained with standard back propagation method

- The temporal-spatial input and output data were extracted from the trajectories as leaning data.

## Leaning data

### Ideal migration routes

SST
- Temperature change experienced
- Current speed
- Day length
- Distance from land
- Direction

Training Method: Back Propagation method (+Gradient Descent method)

Decide the weights of ANN
Results in Case 1

Predicted monthly mean of relative sardine density during spawning migration

- Most fish don’t return to the spawning ground.
- The weights don’t possess structures permitting proper handling with the unexperienced input information.
- Because the weights are derived by learning with only the few training data.
The Genetic Algorithm - Concept

Input data

ANN

Reproduction

Offspring: ..., -0.5, 0.1, 0.4, -0.3, 0.2, 0.7, 0.3, ...

Mother: ..., -0.5, 0.1, 0.4, -0.8, -0.2, 0.7, ...

Father: ..., -0.4, 0.1, 0.8, -0.3, 0.2, 0.7, 0.8, ...

crossover

Weight parameters

mutation

breakpoint

Spatial model of Individual life cycle: behavior, growth

Generation loop

Initiate new cohort

Homing Fish

Size-dependent reproduction of survivors

Rank individual
The experiments using ANN + GA

- Case 2: the GA is used to adjust the weights
  - Initial weights are randomly \((-1 \sim 1)\).
  - The simulation was carried out for 300 generations.

- Case 3: the weights are decided by a combination method both of Cases 1 (BP: training) and 2 (GA)
  - The weights are initiated randomly however based on the results in Case 1.
  - The weights are set at up to 30% above or below Case 1’s values by using normal random number.
  - The simulation was carried out for 300 generations.
Case 2: GA

Most fish cross the Kuroshio Extension, and migrate to the spawning ground.

- Homing rate: 99.6%
- Average FL: 16.94 cm

Case 3: GA+BP

In Case 3, the model can reproduce most realistic spawning migration.

- Homing rate: 99.6%
- Average FL: 16.89 cm

Predicted monthly of mean relative sardine density during spawning migration
Summary

• To simulate reliable spawning migration, ANN system is useful.

• We are strongly in favor of integrating both standard back propagation and the GA to find optimum the weights of ANN.

• Japanese sardine may be able to return to their spawning grounds using the environmental information, such as the changes in temperature, current speed and day length for orientation cues.