Comparison of migration algorithms for Japanese sardine (Sardinops melanostictus) in the western North Pacific

Today's contents
1. fitness + neural network
2. fitness + escaping from predator
3. kinesis & extended kinesis

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Introduction

Japanese sardine makes a large migration between Kuroshio (subtropical) region and Oyashio (subarctic) region. However, the migration pattern is still unclear.

  e.g. How far they migrate to the offshore?
  What environmental factors are controlling their migration?
Development of migration model
(Okunishi et al., 2009, Ecol. Model.)

Climatological physical field
- satellite derived
- sea surface current
- sea surface temperature

Climatological SeaWiFS Chl-a
- convert to prey plankton density

Sardine Migration Model
- growth: NEMURO.FISH
- migration: fitness
- neural network

Megrey et al. (2007a, Ecol. Model.)
Ito et al. (2004b Fish. Oceanogr.)
migration algorithm

1. Feeding migration: Fitness algorithm toward the most preferable place growth index estimated by the bioenergetics model was used for measure

2. Spawning migration: Artificial neural network (ANN) migration direction was learned using ANN with five environmental factors as input signals SST, SST change, current, day length, land to seek optimal parameter of ANN, Genetic algorism was used.
Feeding migration (age-0) Okunishi et al. (2009)
The general pattern of feeding migration are reproduced by the fitness (optimal growth) migration algorithm.

Okunishi et al. (2009)
Spawning migration (ANN+GA)

Artificial Neural Network

Reproduction

- Offspring: ..., -15.2, 19.7, 1.5, -19.3, -24.2, 8.7, ...
- Mother: ..., -15.2, 19.7, 1.5, -19.9, -21.2, 6.7, ...
- Father: ..., -15.4, 19.6, 1.8, -19.3, -24.2, 7.7, ...

weight parameters

crossover

mutation

Rank individual

Homing Fish

Size-dependent reproduction of survivors

Spatial model of Individual life cycle: behavior, growth

Initiate new cohort

Huse & Giske (1998)

Genetic Algorithm

Okunishi et al. (2009)
Schematic picture of sardine migration
Kuroda (1991)

Realistic migration and growth are reproduced.

Okunishi et al. (2009)
Q1: Migration across the Subarctic Boundary

Observation data shows fish (Age 0) distributes in the northern waters of SST 12-14 degC in autumn.

However, the model did not simulate the habitat of high latitude region, which is low SST below 15 degree Celsius, in autumn.
Multi-trophic level ecosystem model

3D- Lower Trophic Ecosystem Model
(NEMURO)

Sardine Migration Model
based on Okunishi et al (2009)

2D - Individual Based Model (IBM)

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 >
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.

OGCM
Ocean General Circulation Model (OGCM)
1/4×1/6
(COCO by CCSR)

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

Forcing
Escaping behavior from skipjack tuna

Feeding Migration

Case A:
Fish swims by searching optimal habitats (Max, growth rate) and escapes from high predation risk (by skipjack tuna).

Case B:
Fish swims by searching a optimal habitats (Max, growth rate)

Analysis Period
NEMURO + Sardine Migration Model

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

Mortality rate (Size dependency)
Early larvae: 0.075 / day
Late larvae: 0.01 / day
Juvenile—Adult: 0.001/day
An example of histogram of skipjack catch as a function of SST (May).

Feeding migration: toward high fitness regions

Case A: \( \text{fitness} = \text{Growth Rate} \times (1-\text{Predation Risk}) \)

Case B: \( \text{fitness} = \text{Growth Rate} \)
When the escaping behavior is included, sardine migrates to the north of the Subarctic Boundary.

Observation data shows fish (Age 0) distributes in the area which SST is 12-14 degC in autumn.

Monthly mean fish density in October

Migration: Escape from skipJack

Migration: No escape from skipJack

Cohort A

Cohort B

Case A: $HI = \text{Growth Rate} \times (1 - \text{Predation Risk})$

Case B: Habitat index = Growth Rate
Q2: Is escaping behavior controlling the sardine migration.

Kinesis algorism (Humston et al, 2000)

swimming velocity

\[ S_t = f(S_{t-1}) + g(\mathbb{B}) \]

\[ f(S_{t-1}) = S_{t-1} \times H_1 \times H_I \] depending on previous speed

\[ g(\mathbb{B}) = \mathbb{B} \times (1 - H_2 \times H_I) \] random component

\[ H_1 = 0.75, \ H_2 = 0.9, \ H_I: \text{habitat index} \]

\[ |\mathbb{B}|: \text{maximum sustained swimming velocity} = 5 \text{ Body Length} \ (\text{m} \ \text{s}^{-1}) \]

Extended Kinesis algorism (Okunishi et al, accepted to F.O.)

add component of better condition compared with previous (HIn > HIn-1)

\[ S_t = S_{t-1} - (S_{t-1} \times |\mathbb{B}| / |S_{t-1}| \times H_3) \times H_I \]

\[ H_3 = 0.5 \] keep the direction but slowdown
In situ observation of sardine juvenile (Kawabata et al., 2008)

Migration to the north of the Subarctic Boundary was reproduced.

dots shows fish and color is changed according to the growth.
tone is Chl-a, contour is temp.
e.g. 2006 April spawned cohort

A.V. density in 2006 (Sep.-Oct.)

In situ observation of sardine juvenile (Kawabata et al., 2008)
Comparison of three algorithms

Only extended kinesis model can reproduced northern migration of sardine without escaping behaviour.

Okunishi et al. (accepted to F.O.)
1) Feeding migration seems easier to imitate. Spawning migration was trained by ANN+GA.

2) All of fitness, kinesis, extended kinesis reproduced reasonable feeding migrations of Japanese sardine.

3) Only escaping behavior or extended kinesis reproduced northern migration across the Subarctic Boundary. Need biological information to model fish behavior.

Extended kinesis algorism seems good except that kinesis type algorism includes random components and need ensemble runs.

Interaction between species is still difficult to model it. We need high technical observation methods to observe fish behaviour regarding species interaction.