A multi-trophic level ecosystem modeling for understanding mechanism of the small pelagic fish species alternation

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Today's contents

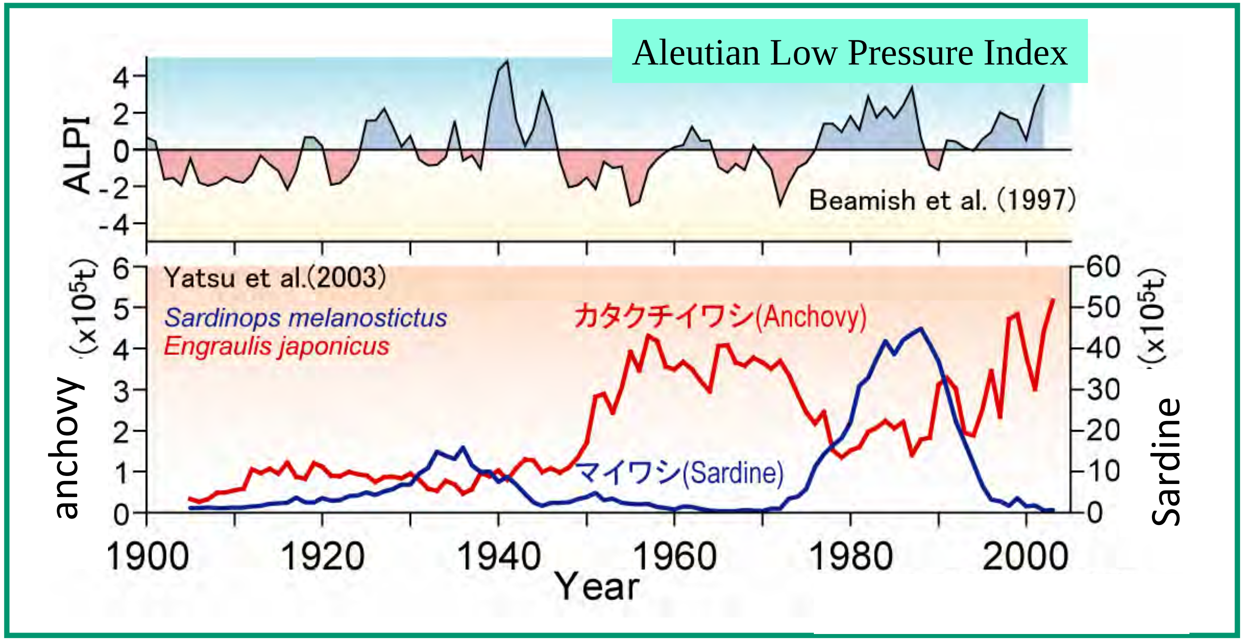
1. multi-trophic level ecosystem model of sardine
2. density depent effect
3. predator's effect
4. response to future climate forcing

Background

Sardine are extensively fished in five of the world's coastal regions, off Japan and in the California, Humboldt, Benguela, and Canary current systems.

Regimes of high abundance of sardine have alternated with regimes of high abundance of anchovy in each of the five regions of the world where there taxa co-occur.

As the Japanese system, the stock fluctuations of sardine and anchovy are related to interdecadal North Pacific ocean/climate variability (Yasuda et al., 1999).



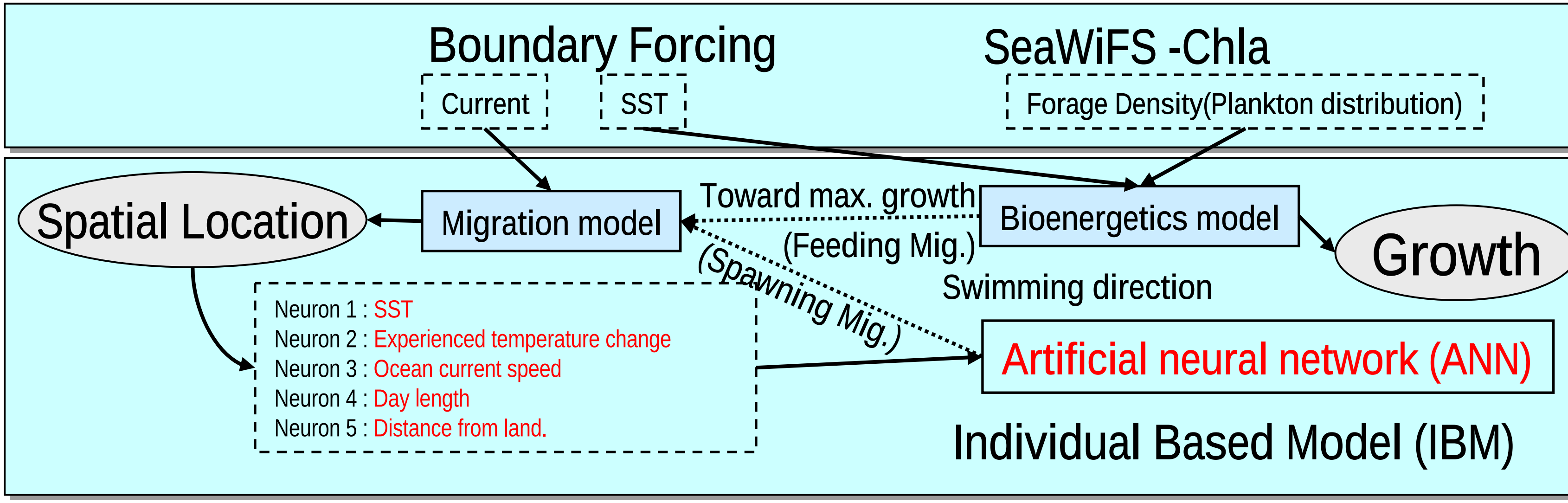
Our challenge

- For the comprehensive understanding of the dynamics of pelagic ecosystem responses to climate variability, we need a model which enable to represent realistic prey condition, fish growth and fish distributions.

- To represent the fish distribution, we developed a horizontally two-dimensional sardine migration model.

- To understand the mechanism of fish species alternation associated with climate regime shifts, we developed a multi-trophic level ecosystem model including Japanese sardine by couplling physical (OGCM), biochemical-plankton (Lower Trophic Ecosystem Model) and fish models (sardine migration model).

Fish Migration Model for Japanese Sardine (Okunishi et al., 2009)



Bioenergetics Model

Time change in body weight

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

- C: feeding
- R: respiration
- S: specific dynamics action
- F: egestion rate
- E: excretion rate

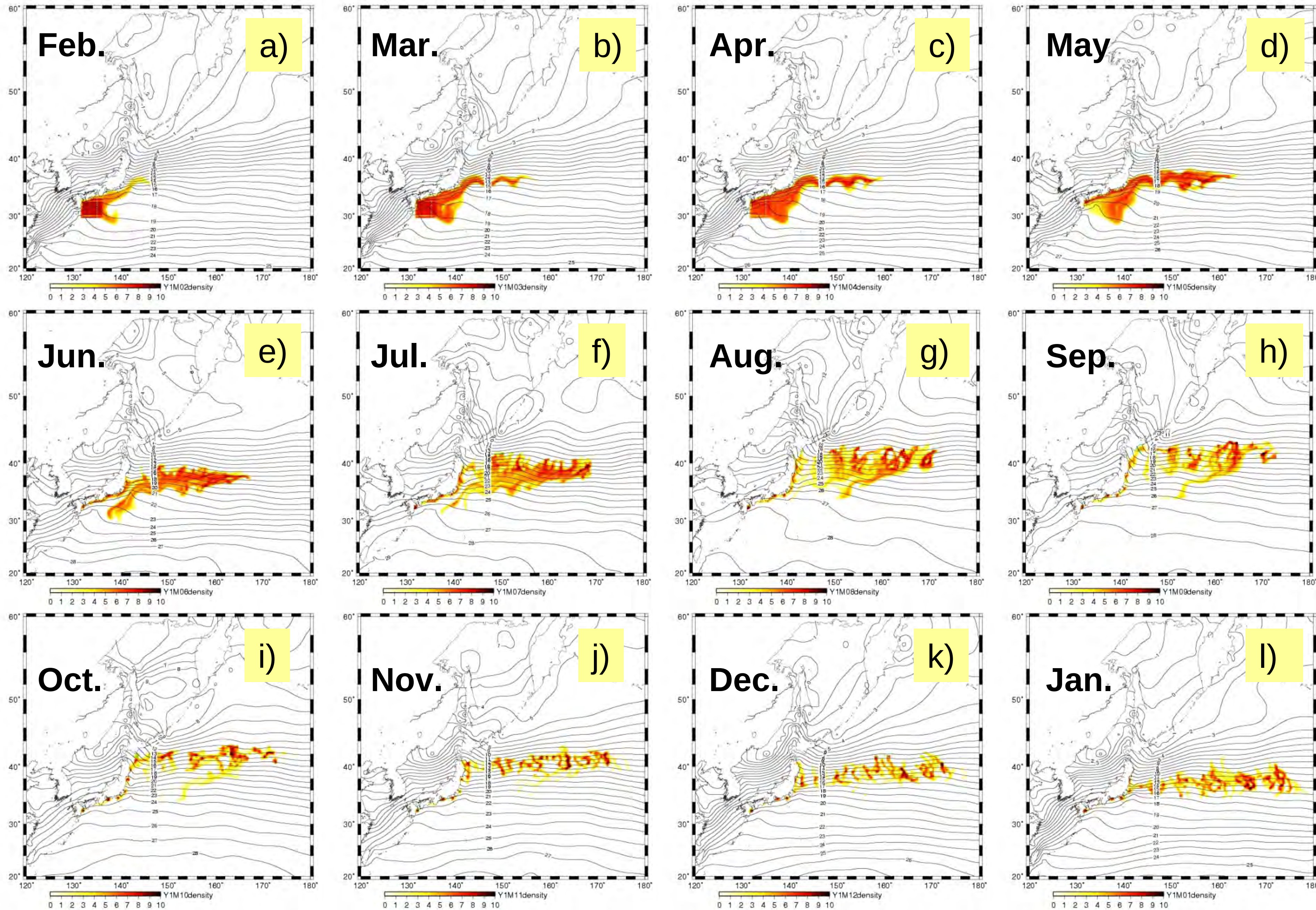
Migration Model (Lagrangian Model)

$$\frac{dx}{dt} = U_1 + (U_2 \text{ or } U_3) + R$$

- advection (U_1)
- Feeding Migration: toward max. growth rate (U_2)
- Spawning Migration: Artificial neural network(ANN) + Genetic algorism (GA) (U_3)
- Dispersion (R)

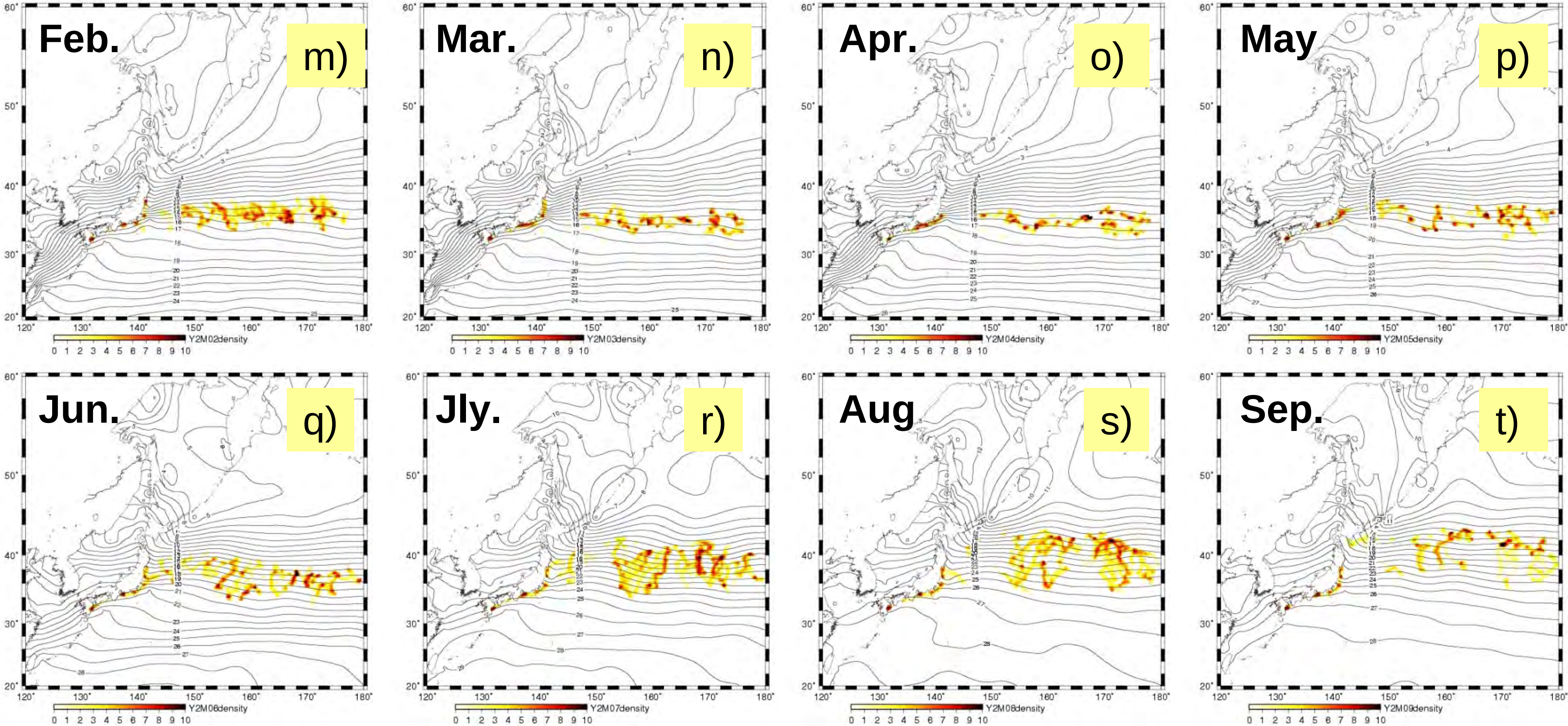
Feeding migration (age-0)

Okunishi et al. (2009)



feeding migration (age 1+)

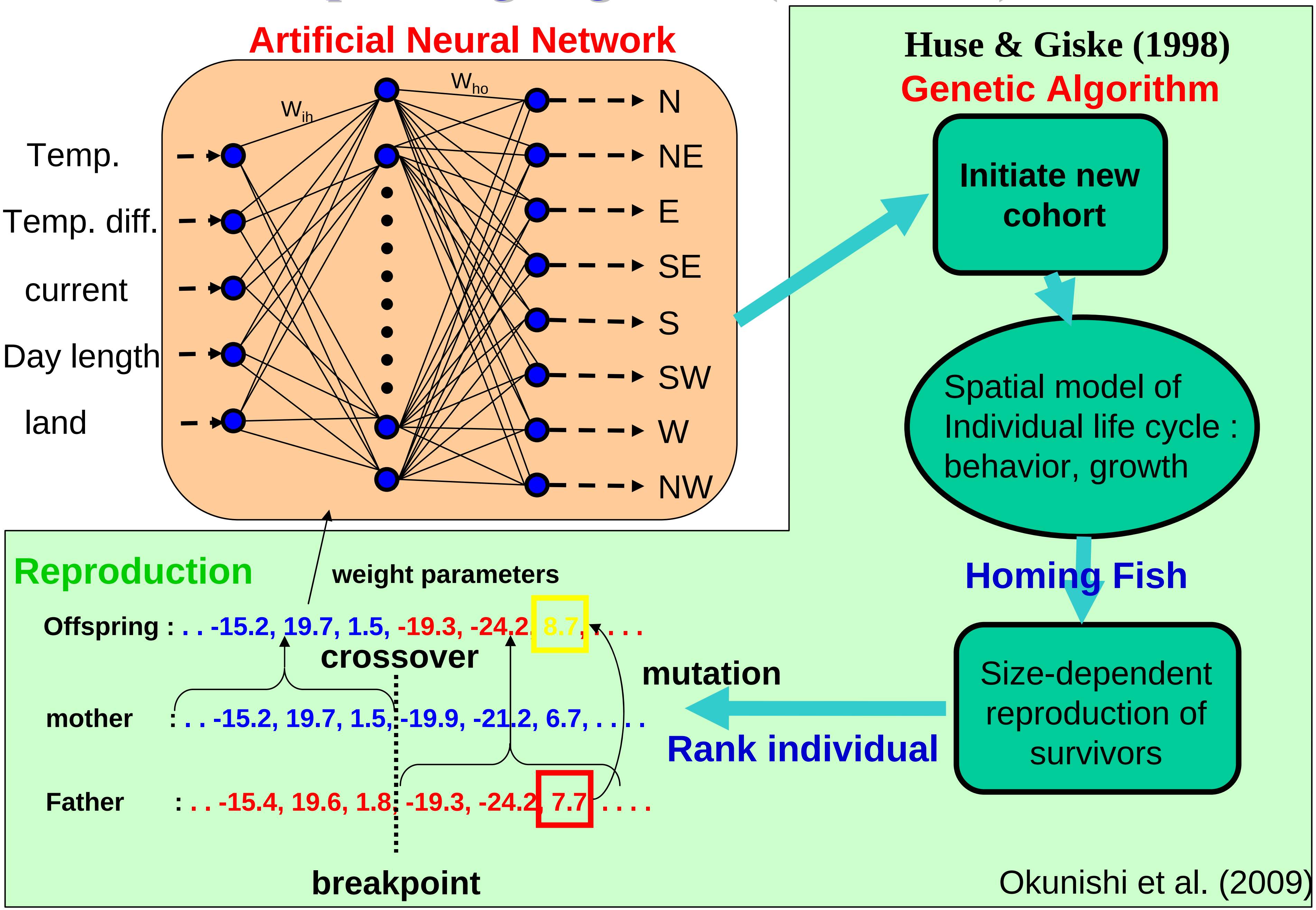
Okunishi et al. (2009)



general pattern of feeding migration are reproduced by the fitness (optimal growth) migration algorithm.

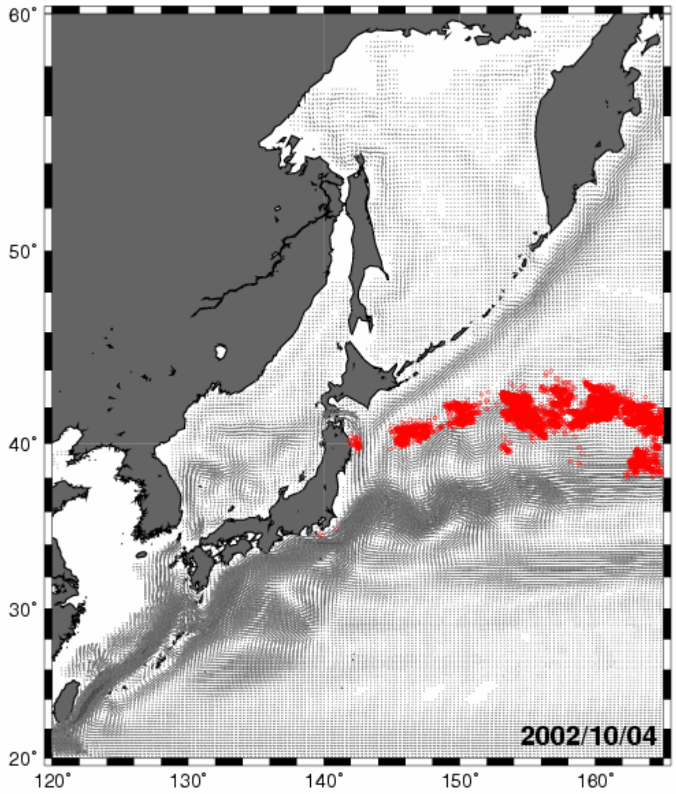
Okunishi et al. (2009)

Spawning migration (ANN+GA)



Spawning migration (initial guess: first generation)

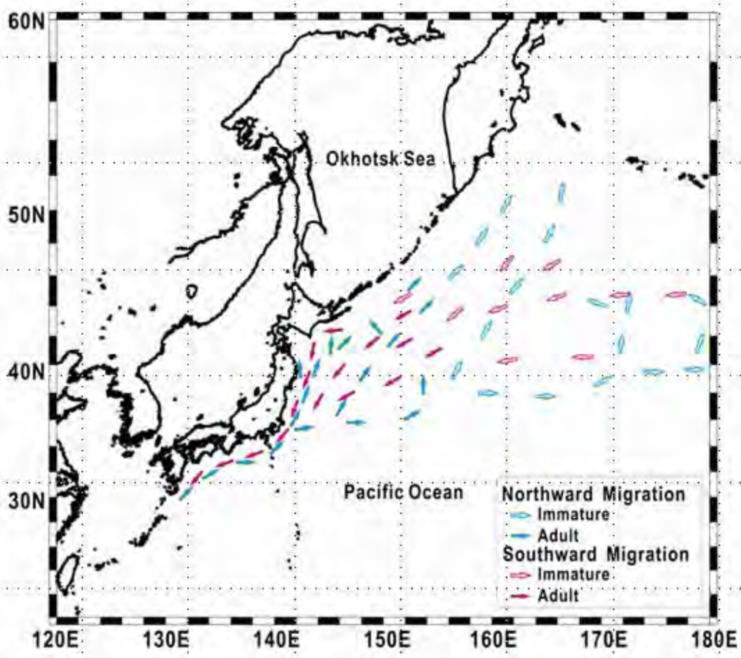
1. Neural Network parameters are tuned using training data with backward propagation method (BP).
2. Initial value Neural Network parameters were set to 30% white noise fluctuation from BP training data.



Okunishi et al. (accepted)

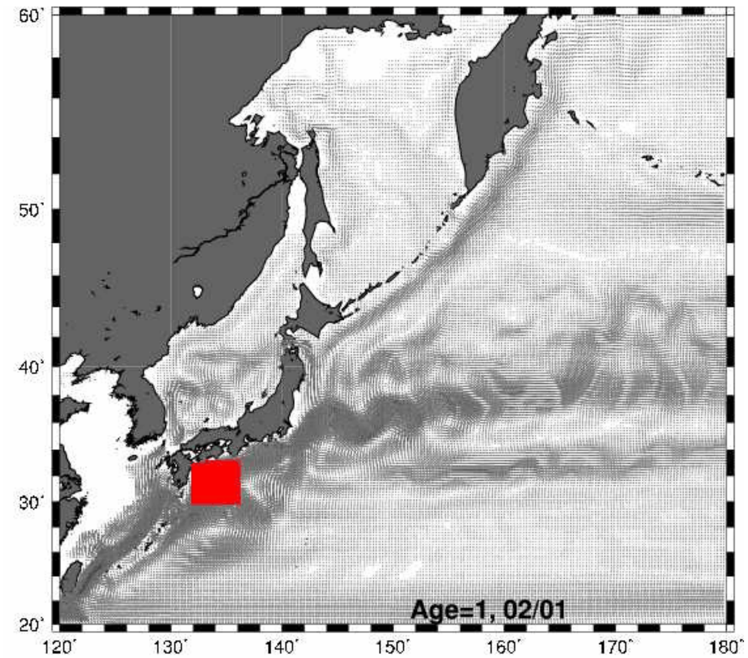
Neural Network parameters were optimized by iteration with genetic algorithm.

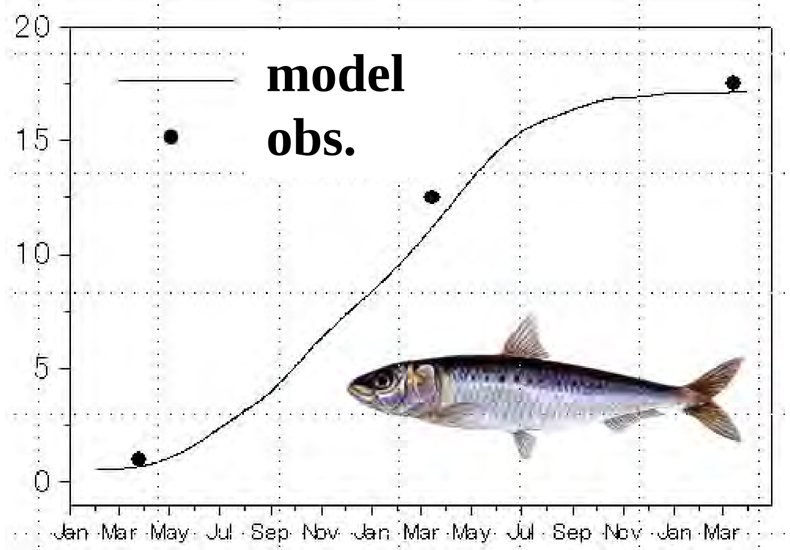
Sardine migration (GA+ANN+BP)



Schematic picture of sardine migration

Kuroda (1991)



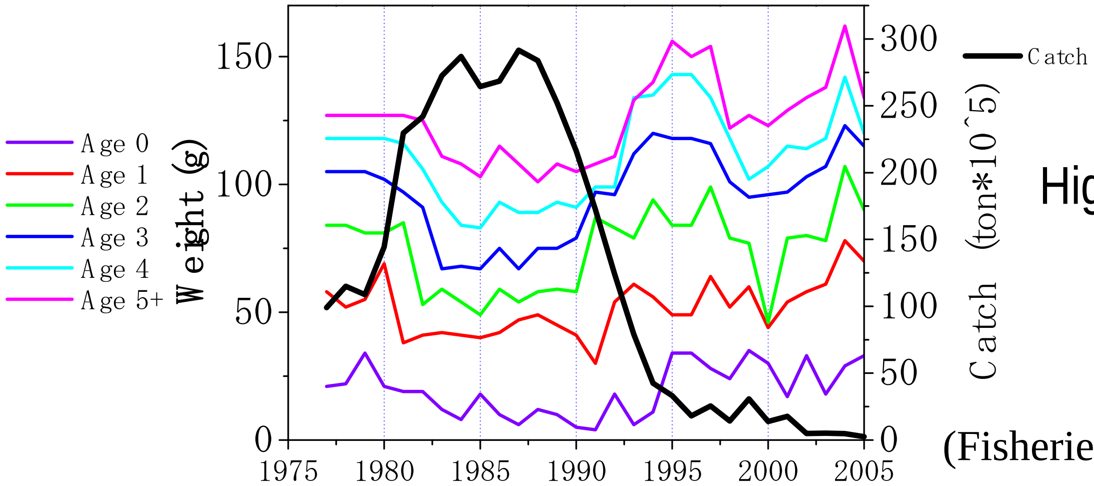


Realistic migration and growth are reproduced.

Okunishi et al. (accepted)

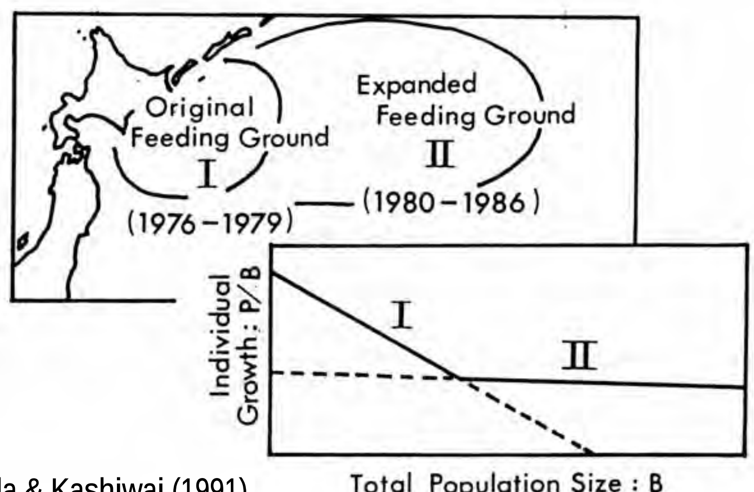
Q1: Density-dependence effect?

Weights & Catches of the Japanese sardine



High Stocks => Decreasing weight (small size)

(Fisheries Agency, 2004)



Wada & Kashiwai (1991)

High Stocks => Expanding feeding ground

These seem to be the effects of density-dependence.

multi-trophic-level ecosystem model of Japanese sardine

Climate Model MIROC 3.2

1/4 x 1/6
Climatological Physical fields
SST, V, Kz, etc.

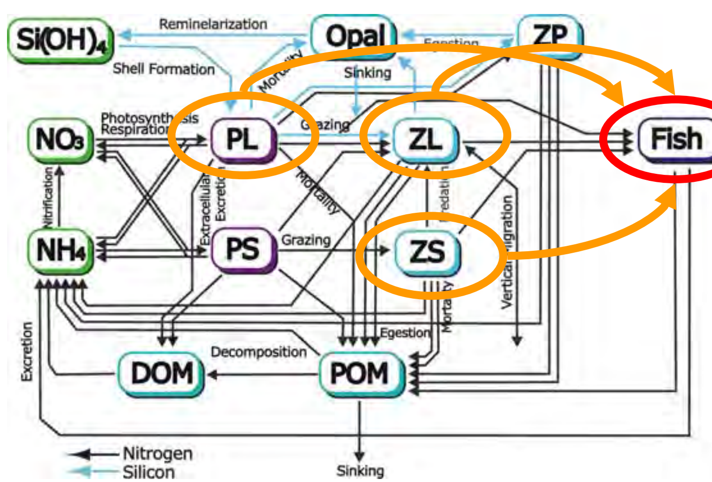
LTL Ecosystem Model
NEMURO

1/4 x 1/6
prey plankton density

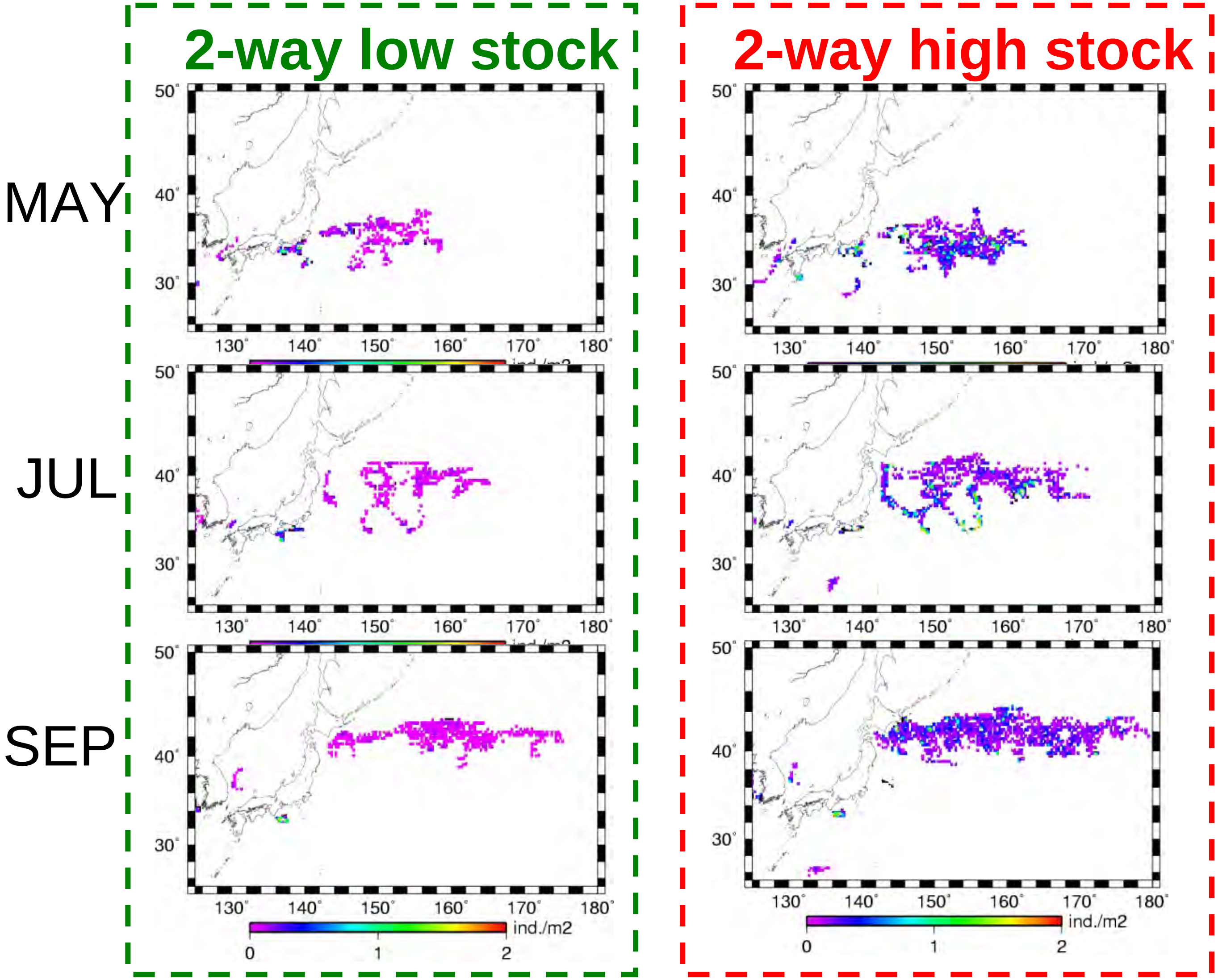
2-way

Sardine Migration Model
(Okunishi et al., 2009)

growth: NEMURO.FISH
migration: fitness+GA
population: size dependent mortality



Geographical Distributions of Adult fish (Age = 2+)

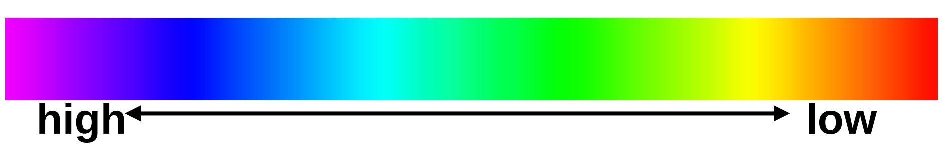


stock increase

prey decrease

expansion of habitat area

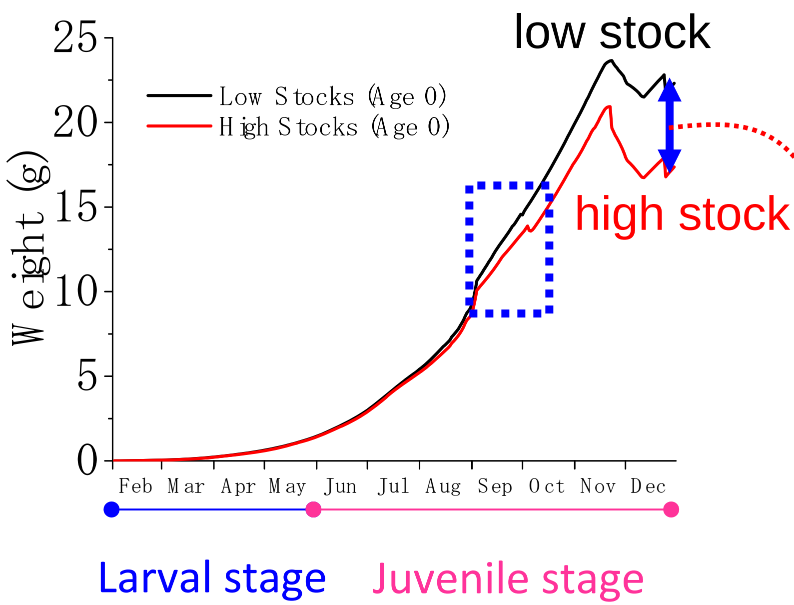
Model results explicitly support the density dependent effect hypothesis.

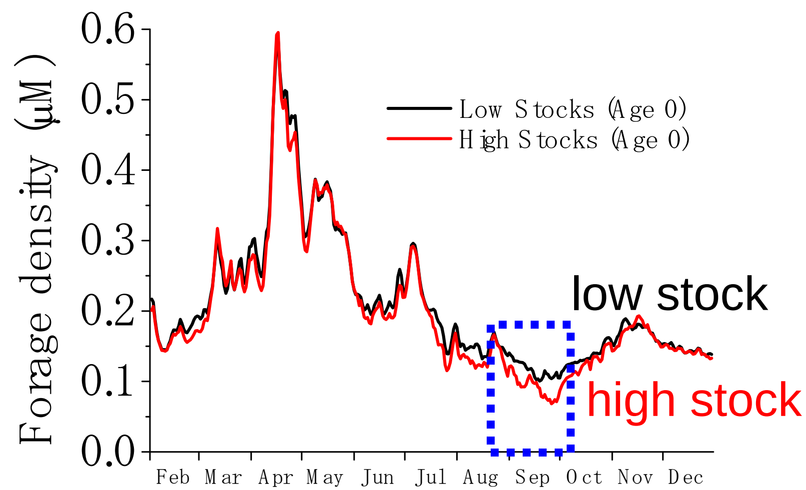


Okunishi et al. (in prep.)

Density dependent effect on fish weight

Okunishi et al. (in prep.)





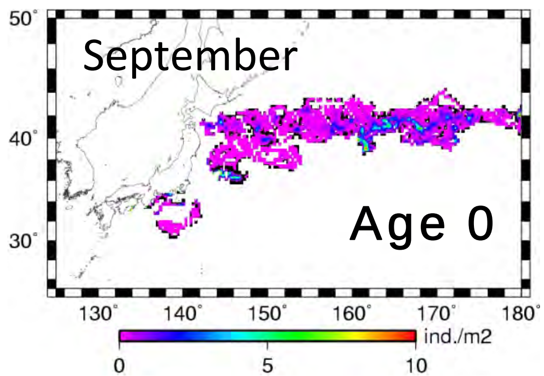
Difference in age-1 weight between high & low stock experiments is 4.9g.
This difference is similar order with observation (4.0 g).

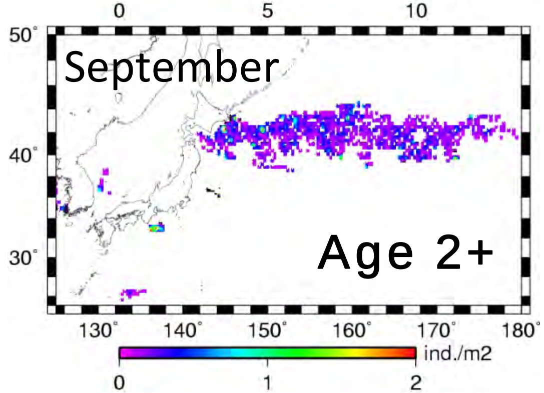
In early autumn, Age 0 fish has slower growth rate under the scenario of high standing stock because forage density becomes significantly low.

Density dependent effect on prey density

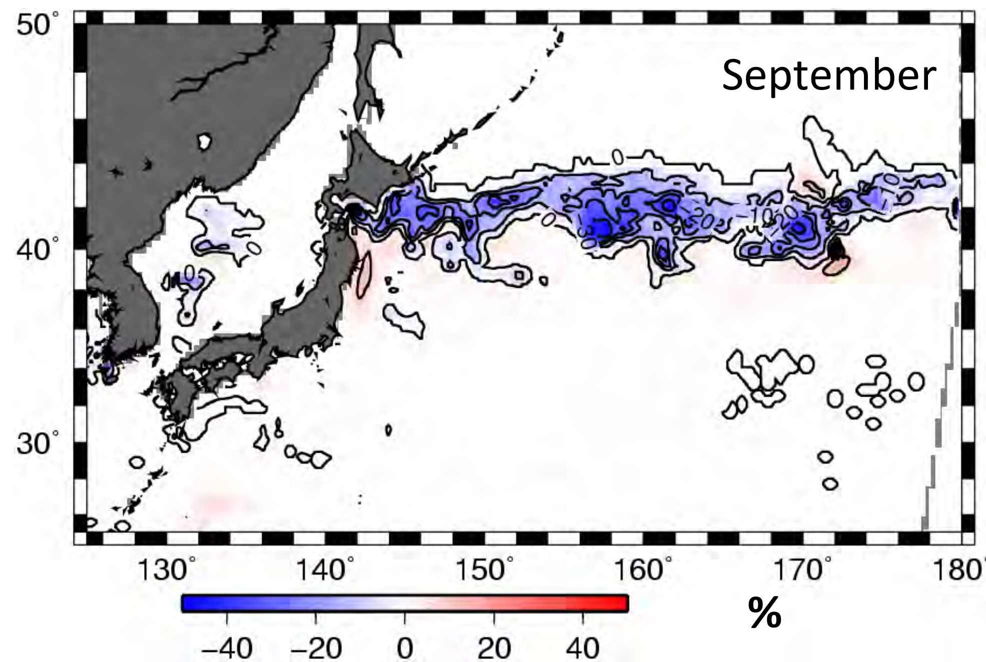
Okunishi et al. (in prep.)

Geographical Distributions





Anomaly of Forage density (PL + ZS + ZL)



S3 (High stocks) - S2(Low stocks)

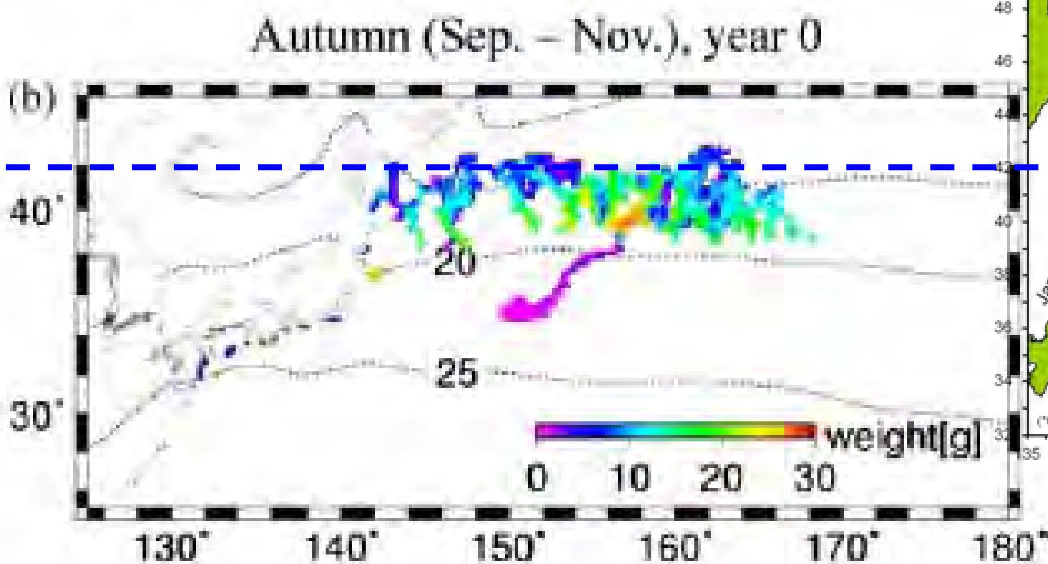
- Forage density is lower by 10 to 20 % in the Mixed water and Oyashio regions in the high stock simulation than that in the low stock simulation due to high grazing pressure of adult sardine.
- The deceleration of growth at Age 0 fish becomes remarkable in the Mixed Water and Oyashio regions in early autumn.

Summary for density dependent effect

- The model reasonably reproduced fish weight decrease by the effect of density-dependent.
- The model reproduced the expansion of sardine distribution by the effect of density-dependent.
- 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.

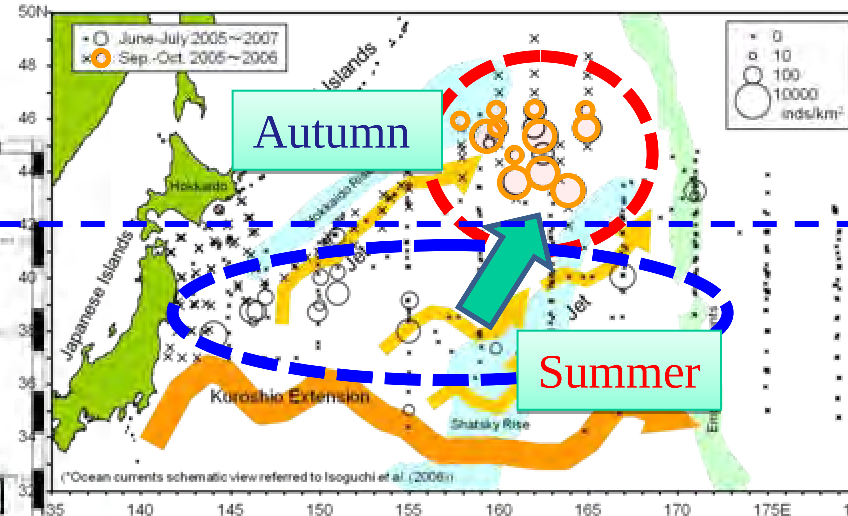
Q2: Predator's effect ?

The model reasonably reproduced realistic sardine migration. However,



The model simulated migration is limited south of 42N.

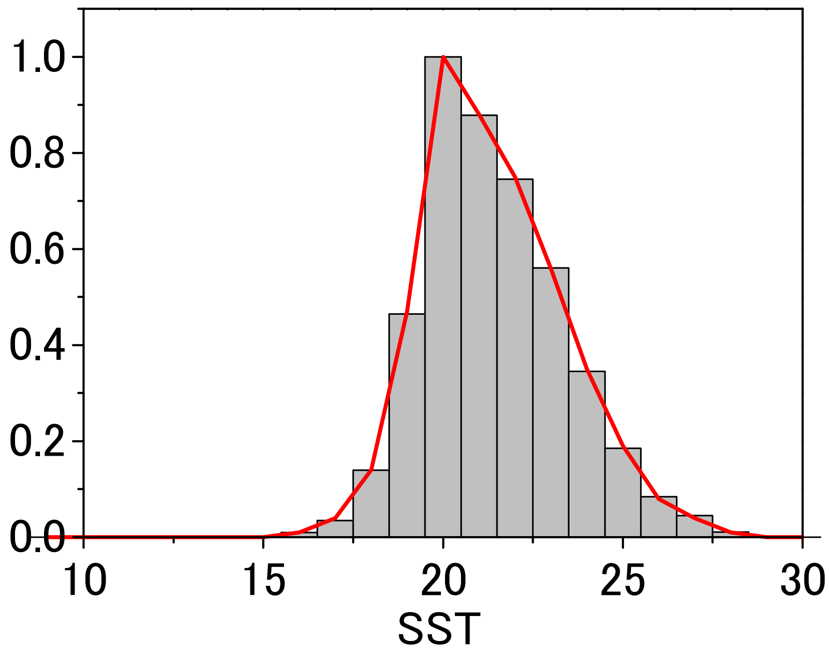
Observation data shows fish (Age 0) distribute in the subarctic waters of SST 12-14 degC in autumn.



Hypothesis

Sardine makes feeding migration with escaping from predators such as skipjack tuna.

modeling the predation risk from skipjack tuna



Skipjack frequency as a function of SST in May in the around Japan from catch data.

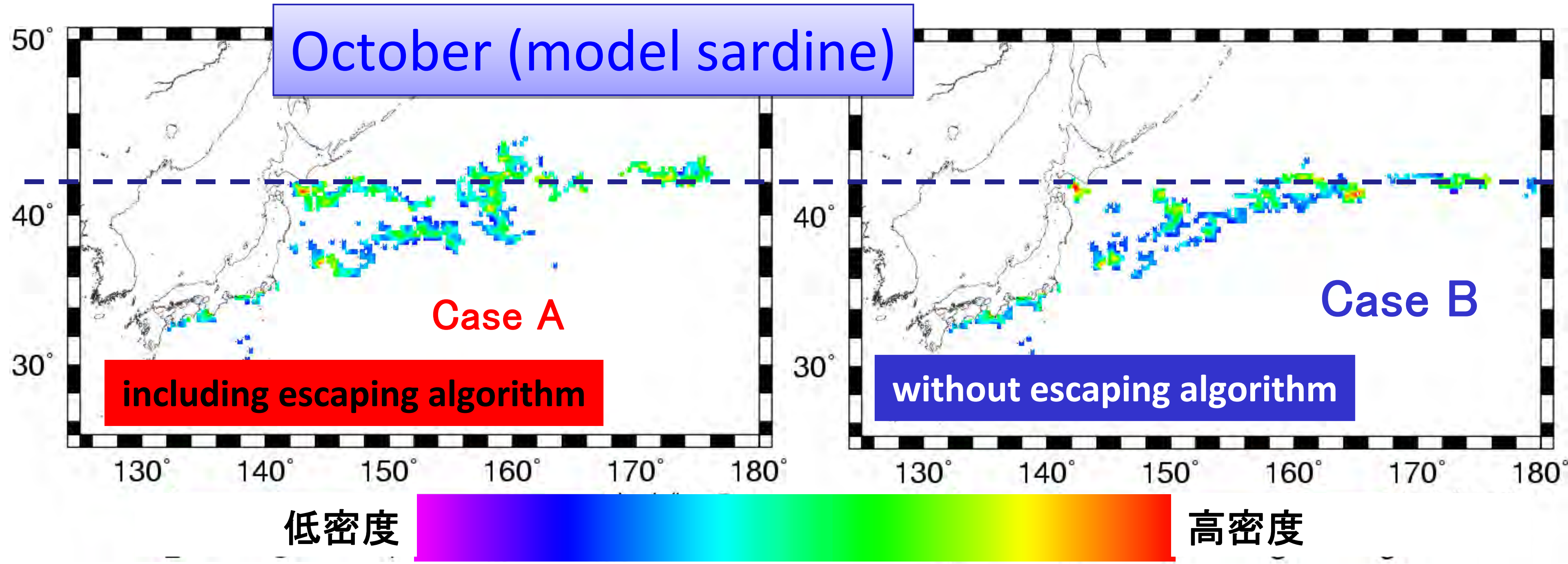
We assumed predation risk has the same type function of SST.

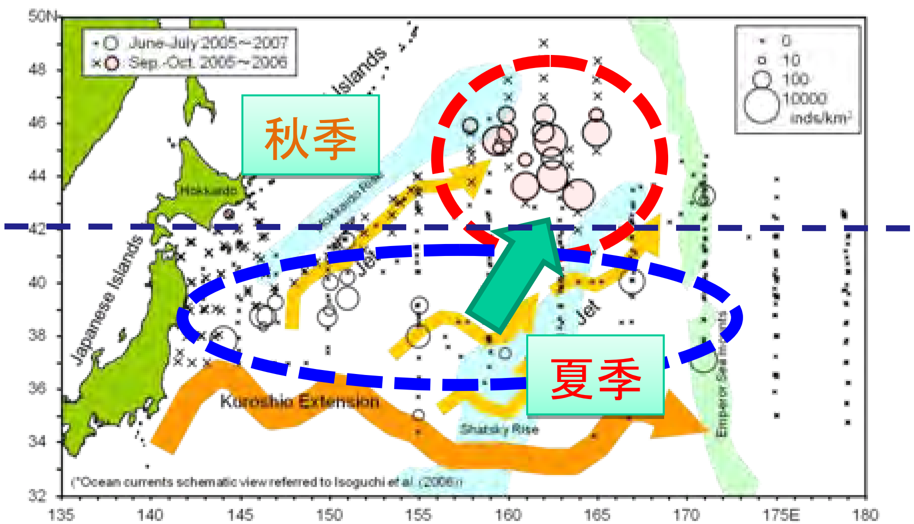
Feeding migration : toward high fitness regions

Case A : **fitness = Growth Rate * (1-Predation Risk)**

Case B : **fitness =Growth Rate**

predator's effect on migration





By including effects of predators, the model reproduced northern migration.

Summary for predator's effect

- The model reasonably reproduced northern migration of Japanese sardine when escaping behavior from a predator is considered.
- (Figure is not shown) The northern migrated sardine showed higher wet weight than ones distributed in the south.
- (Figure is not shown) The growth difference becomes apparently at about 80-days old.
- It seems that the advection determine the larval position and the high growth larvae success to the northern migrations.

Summary

We developed a multi-trophic level ecosystem model including Japanese sardine by coupling to a fish bioenergetics model to a lower trophic level.

Model results suggest the possibility that

1) The density dependent effect may be acting for growth and distributions of Japanese sardine and prey plankton density.

2) Predators existence may affect migration routes of Japanese sardine and hence their growth.

3) (Figures were not shown) Japanese sardine may shift the main spawning grounds to the north-eastward and migrate further north under future climate.

Disclaimer

However, we don't know actual mechanism controlling sardine migration. Moreover, it is difficult to evaluate the modeled migration since there is few tag release data.

Disclaimers

1) Another migration algorithm (e.g. kinesis) may be appropriate for sardine.

Please see Okunishi-san's poster D2-6277

2) Bioenergetics parameters must be improved.

3) Species interactions must be take into account.

4) These improvements may totally change the results of this study.

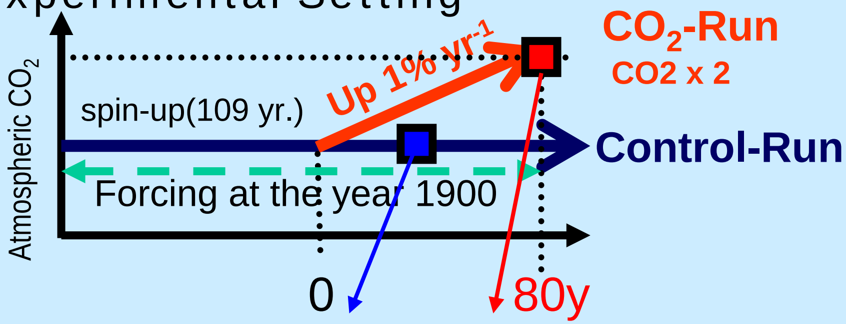
For questions

Q3. Response to future climate change

High resolution climate Model: MIROC

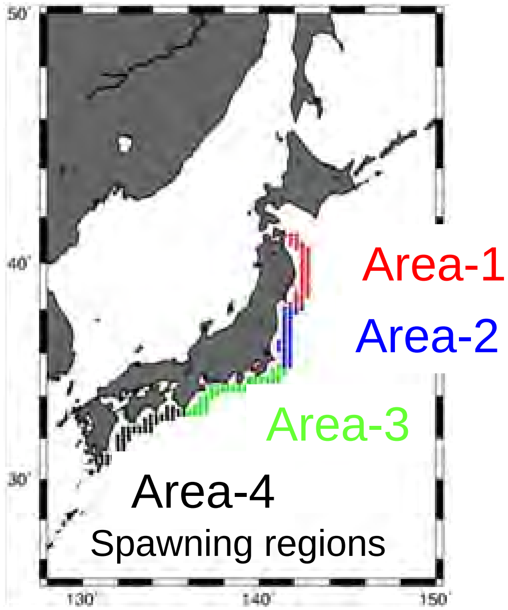
MIROC 3.2 (The CCSR/NIES/FRCGC Coupled Ocean-Atmosphere GCM)
Horizontal Resolution (Ocean Part): 1/4×1/6

Experimental Setting



Analysis Period: Control-Run (46-55y), CO_2-Run (76-85y)

Predicted Physical Fields for off-line Eco. Model
from Sakamoto et al., (2005) GRL.



Simulations by using 10 year physical fields

Period :

Larvae stage – Adult stage in summer, Age 1 (22 months)

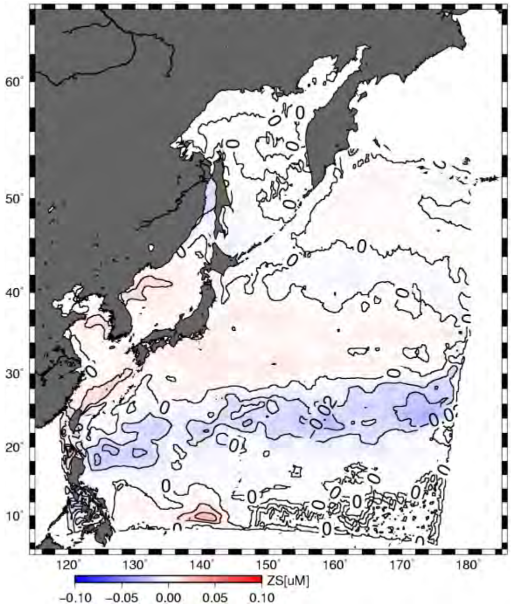
Spawning condition

SST: 15- 21°C

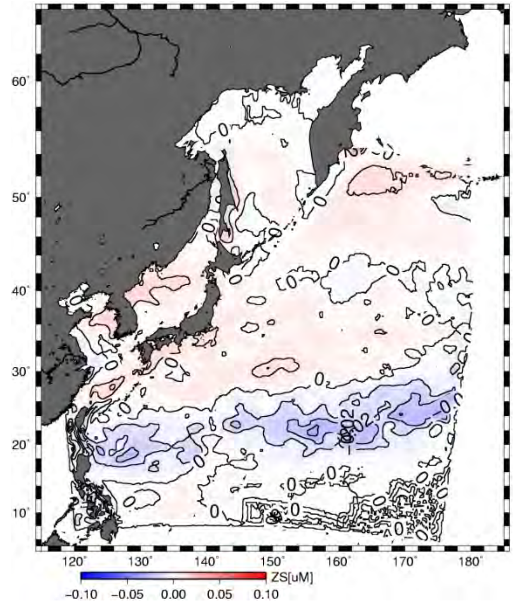
Dec – Apr

Projected Impact on small-zooplankton (CO_2 – Control)

Jan



Feb



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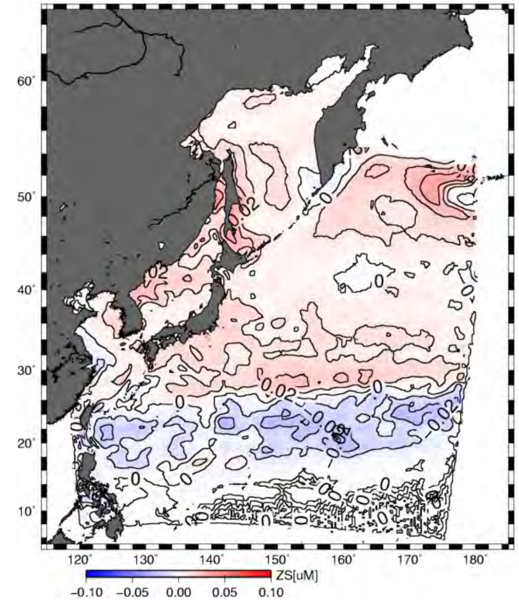
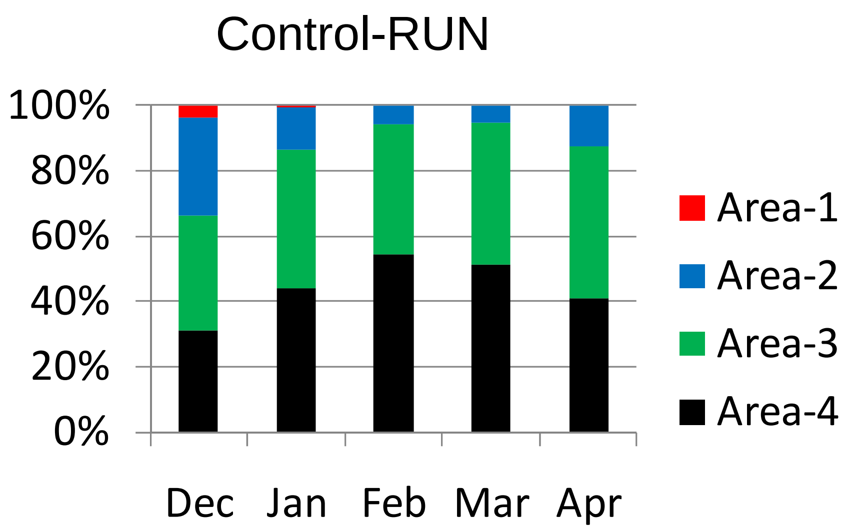


Hashioka et al. (2010)
Okunishi et al. (submitted)

Spawning grounds

Okunishi et al. (submitted)



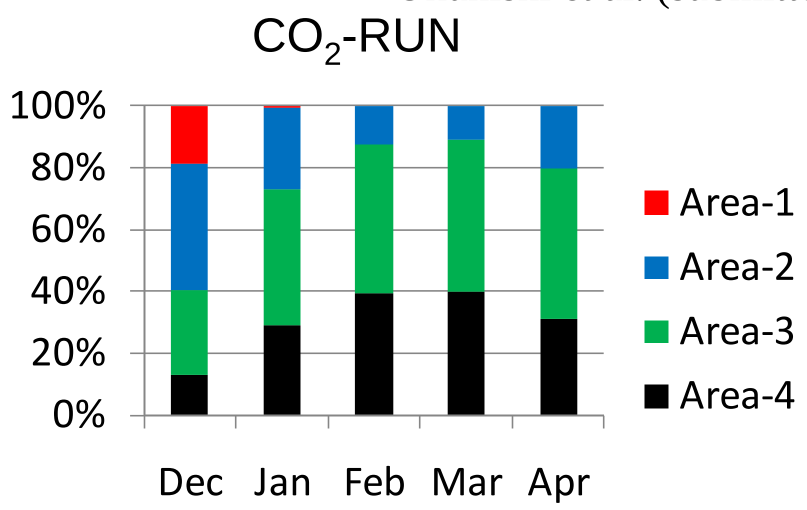
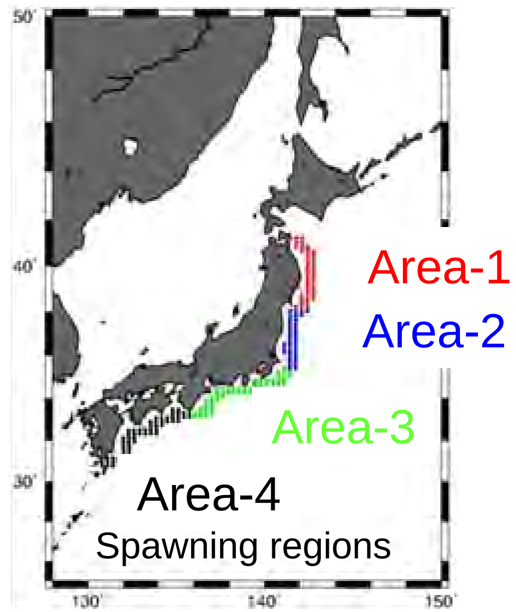


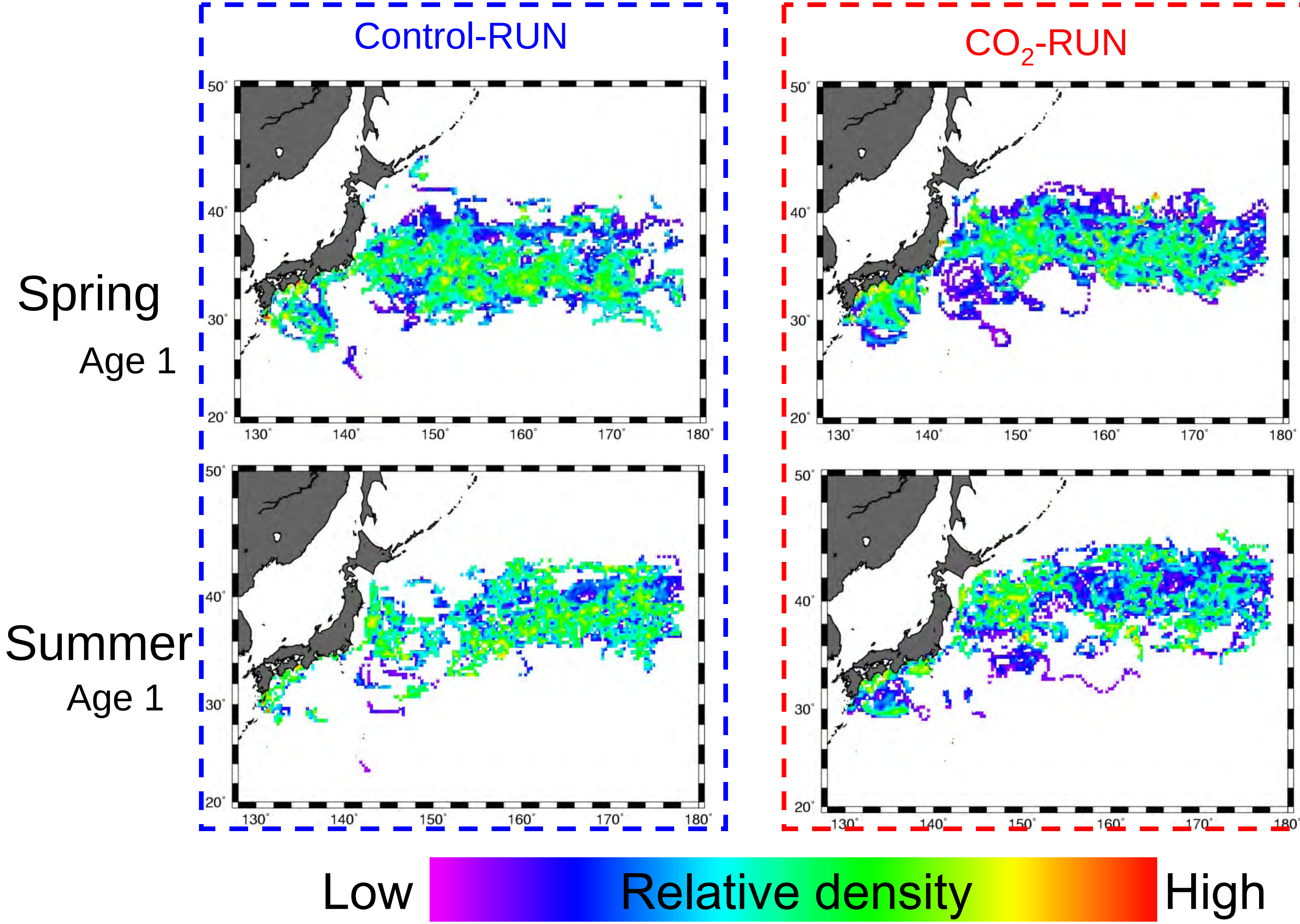
Fig. Proportion of hatched numbers in the four spawning regions

Projection

Spawning grounds shifts to north-eastward.



Change in Geographical Distribution



Okunishi et al. (submitted)

Summary

We developed a multi-trophic level ecosystem model including Japanese sardine by coupling to a fish bioenergetics model to a lower trophic level.
We demonstrated possible impacts of global warming on migration pattern and growth of Japanese sardine.

Model results suggest the possibility that

1) The current main population of Japanese sardine in Tosa Bay may be face collapse under the global warming condition.

2) However, Japanese sardine would shift spawning ground toward north regions, and succeed in recruitment.

3) Geographical distributions of Japanese sardine can be altered directly through climate-induced changes in temperature variations. But, the impact on the change in geographical distribution would be not large.