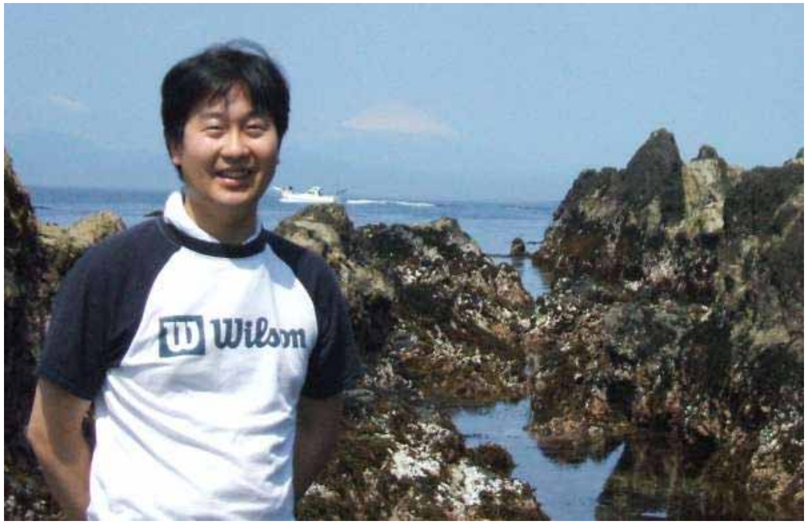
Comparison of migration algorithms for Japanese sardine (*Sardinops melanostictus*) in the western North Pacific



Takeshi Okunishi (NRIFS, FRA)

& Shin-ichi Ito (TNFRI, FRA)

Today's contents

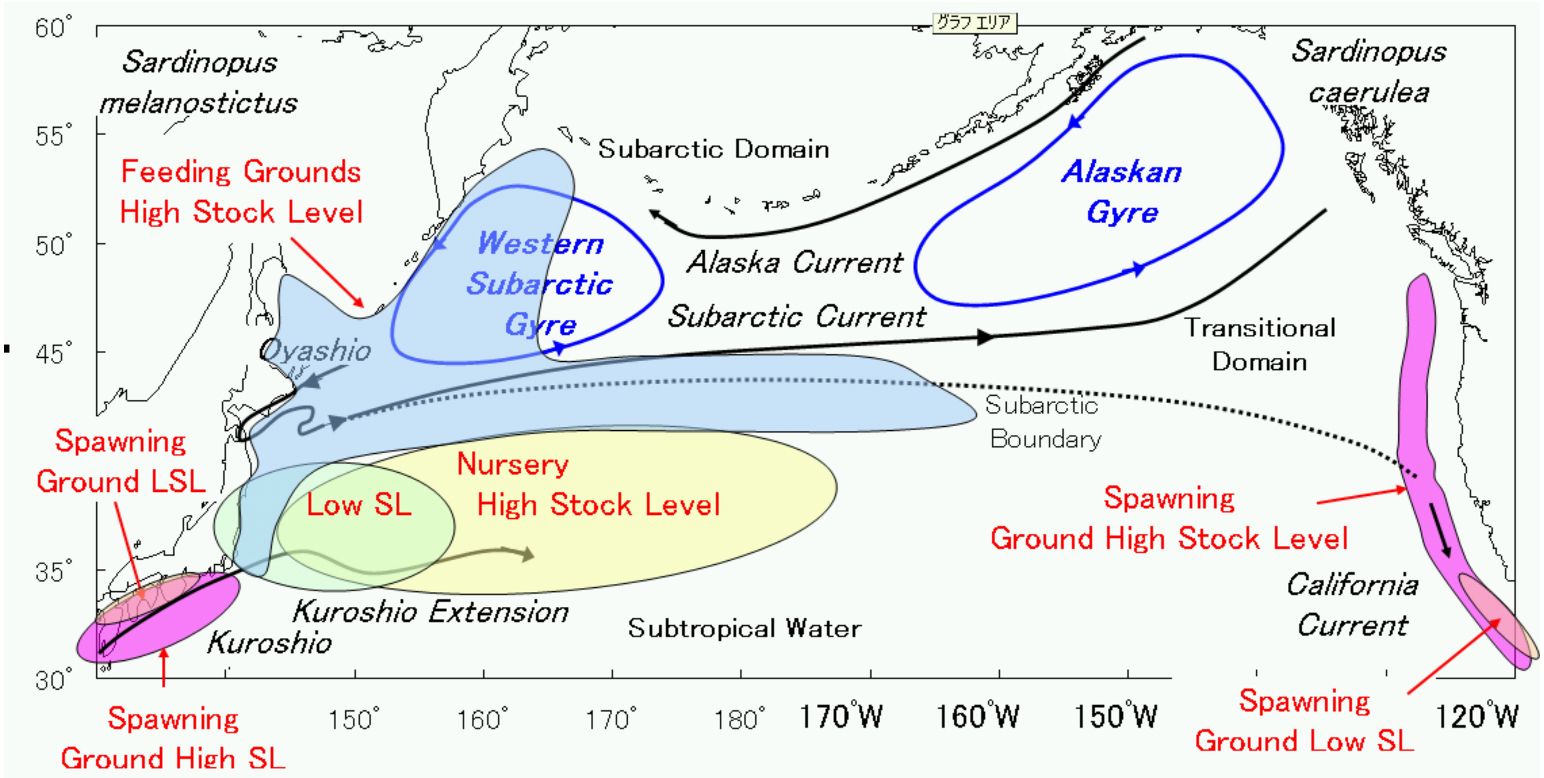
1. fitness + neural network
2. fitness + escaping from predator
3. kinesis & extended kinesis

FRA Fisheries Research Agency

NEMURO MAFIA

SUPRFISH POMAL

Introduction



Courtesy of Dr. A. Yatsu

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.)

Climatlogical physical field

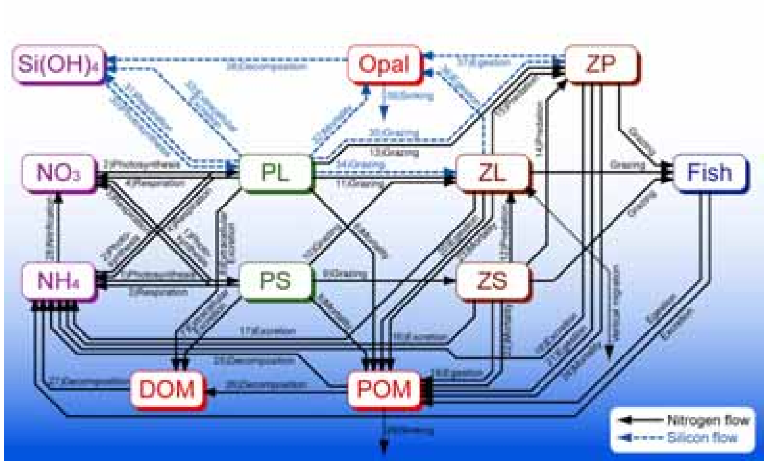
satellite derived
sea surface current
sea surface temperature

Climatlogical 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.)

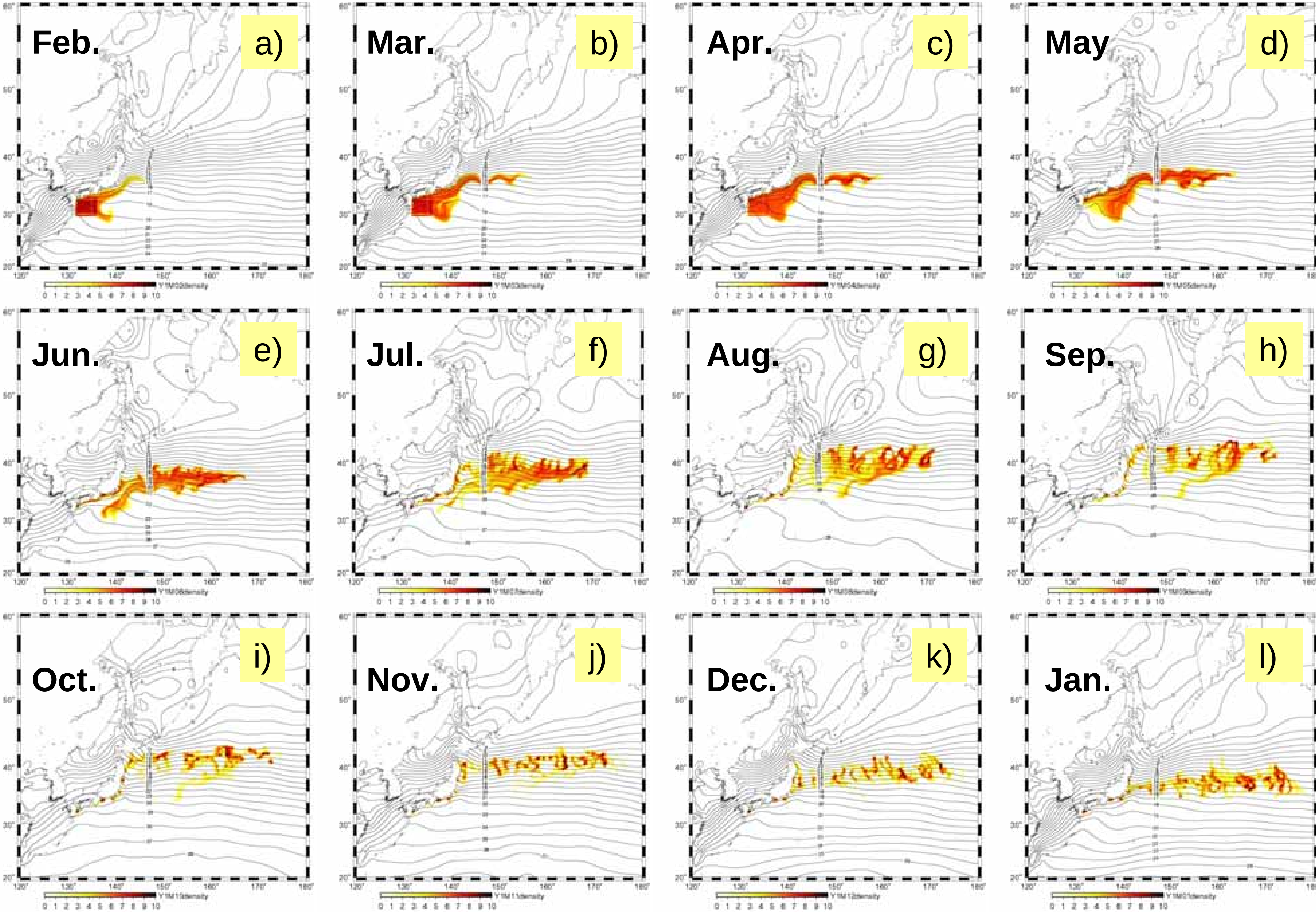
migration algorism

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.

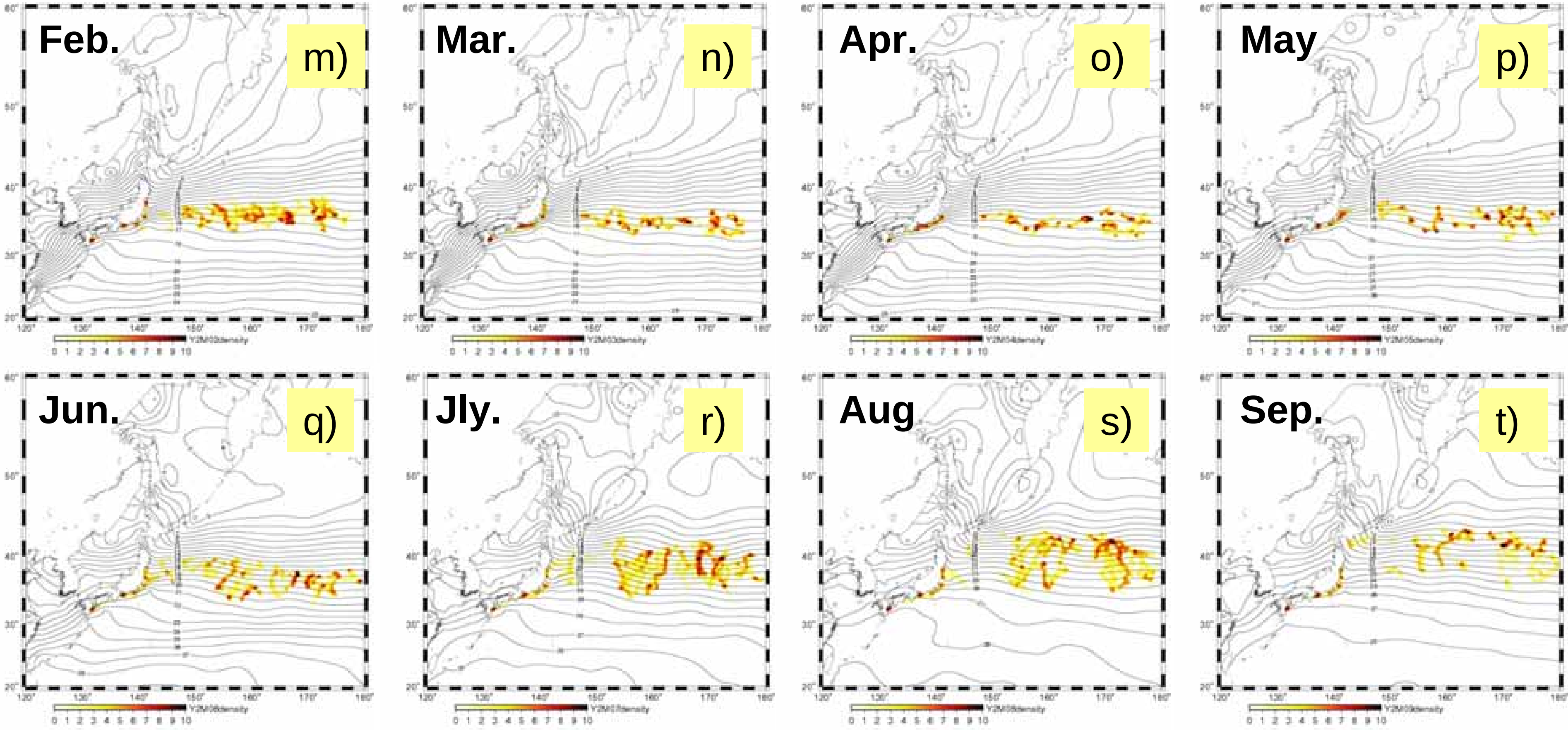
Feeding migration (age-0)

Okunishi et al. (2009)



feeding migration (age 1+)

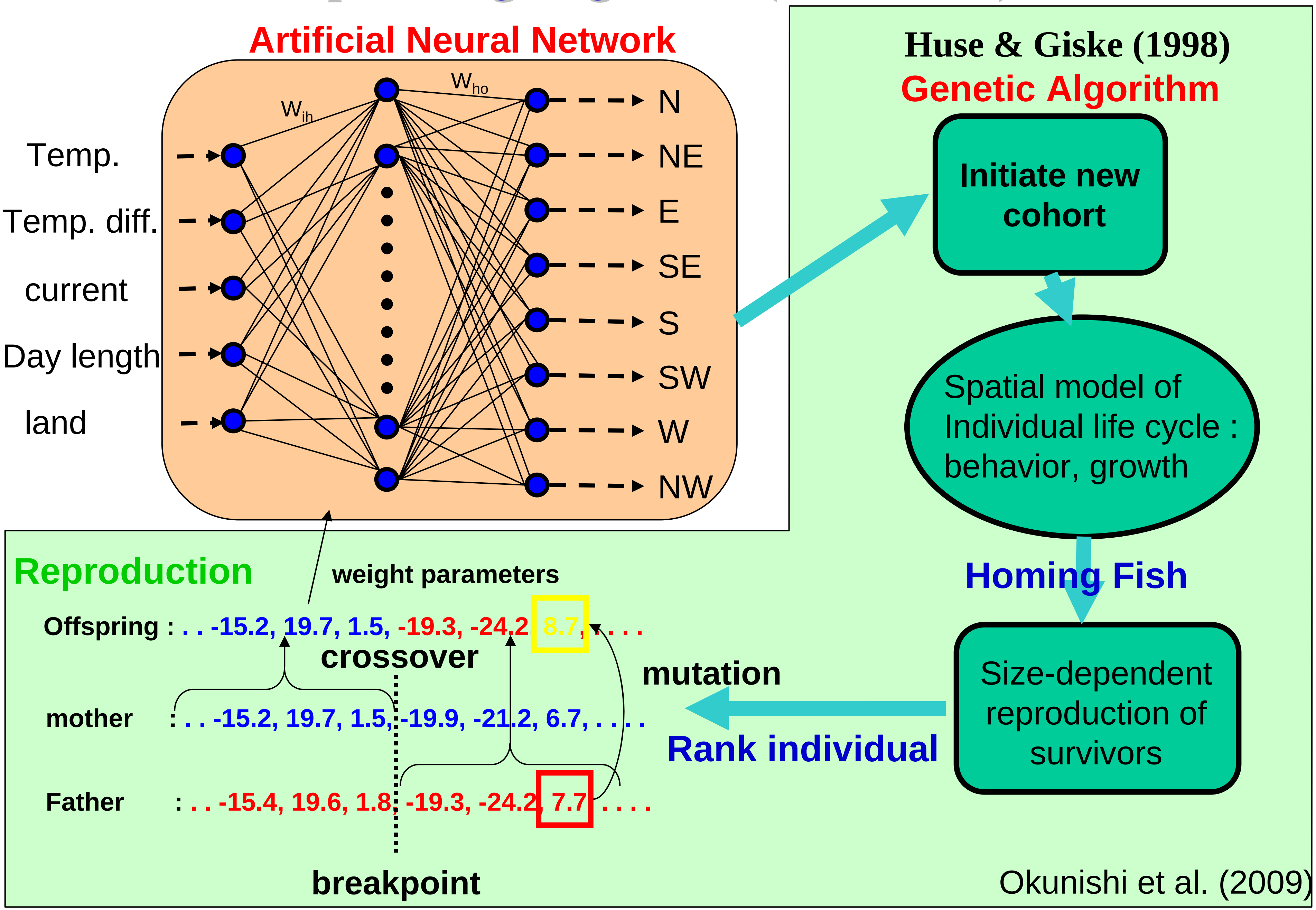
Okunishi et al. (2009)



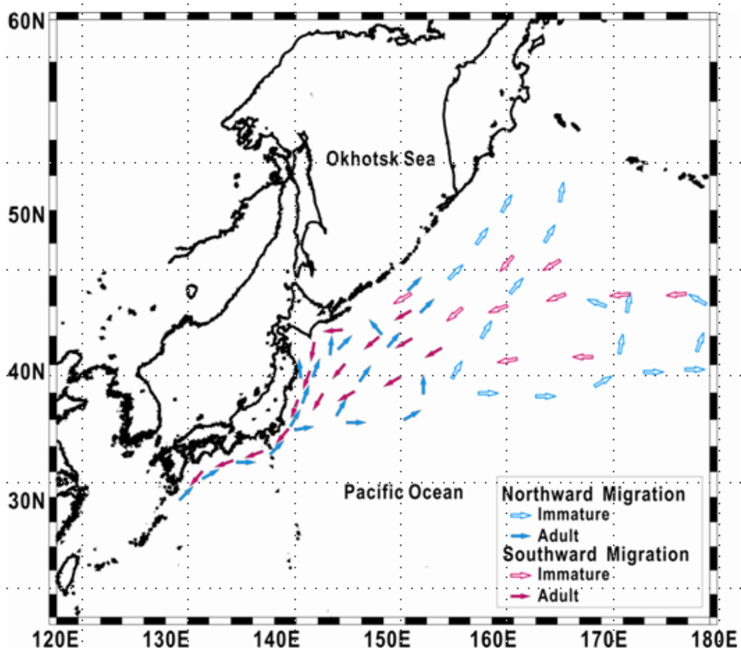
general pattern of feeding migration are reproduced by the fitness (optimal growth) migration algorithm.

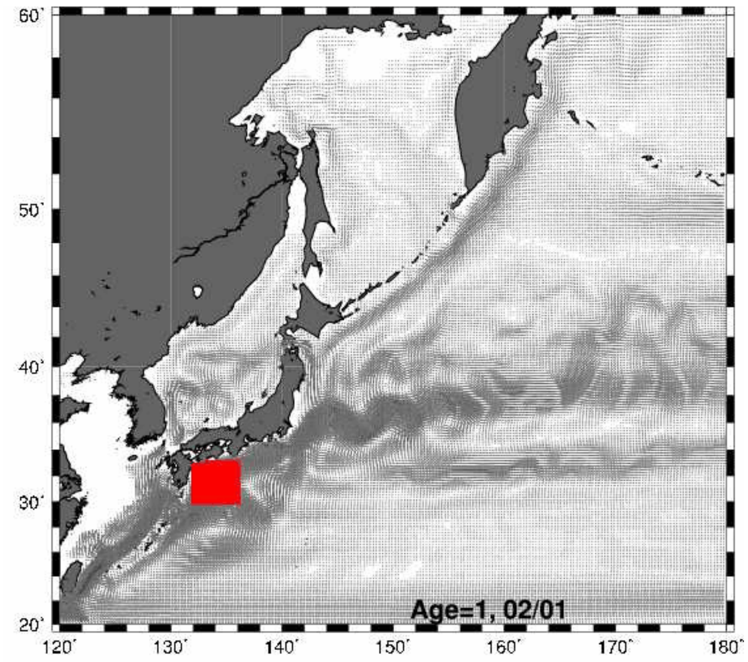
Okunishi et al. (2009)

Spawning migration (ANN+GA)



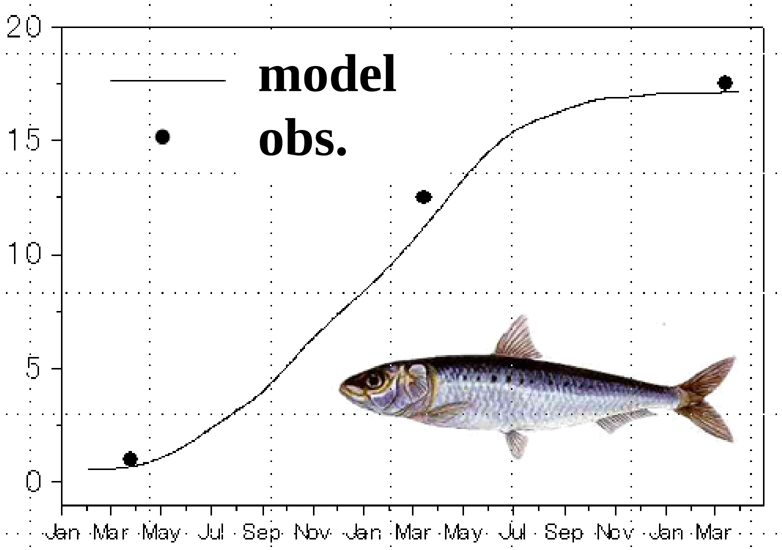
Sardine migration (GA+ANN+BP)





Schematic picture of sardine migration

Kuroda (1991)

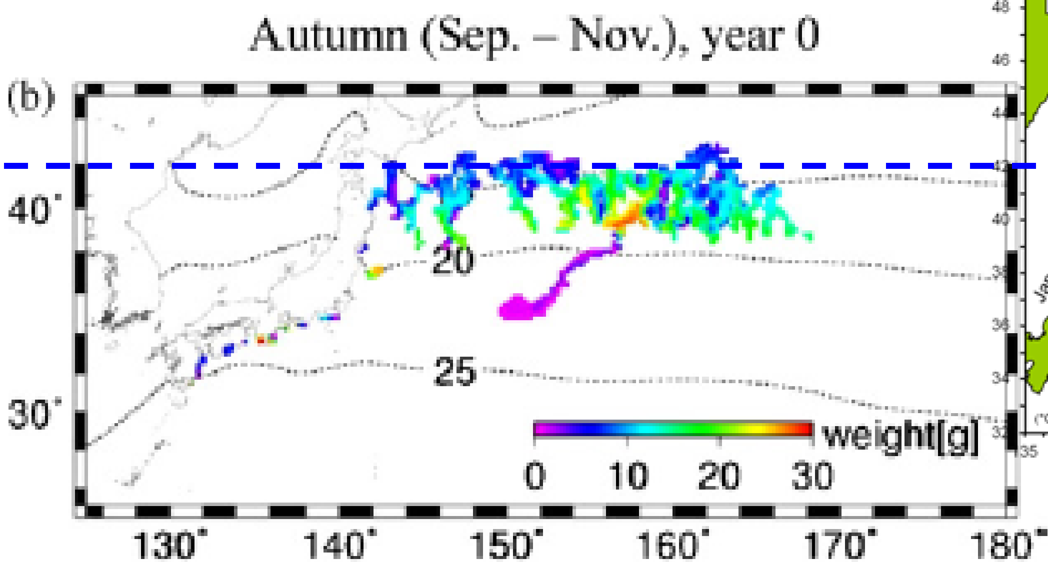


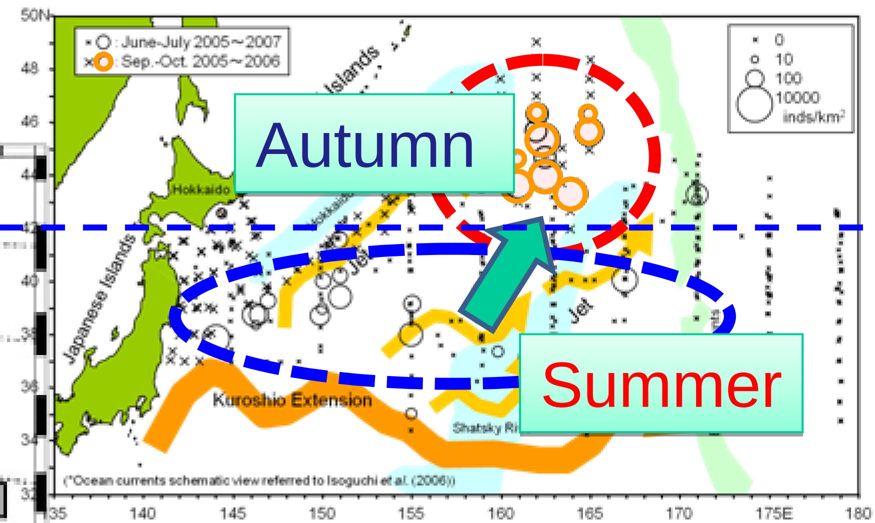
Realistic migration and growth are reproduced.

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 blow 15 degree Celsius, in autumn.

Multi-trophic level ecosystem model

3D- Lower Trophic Ecosystem Model (NEMURO)

OGCM

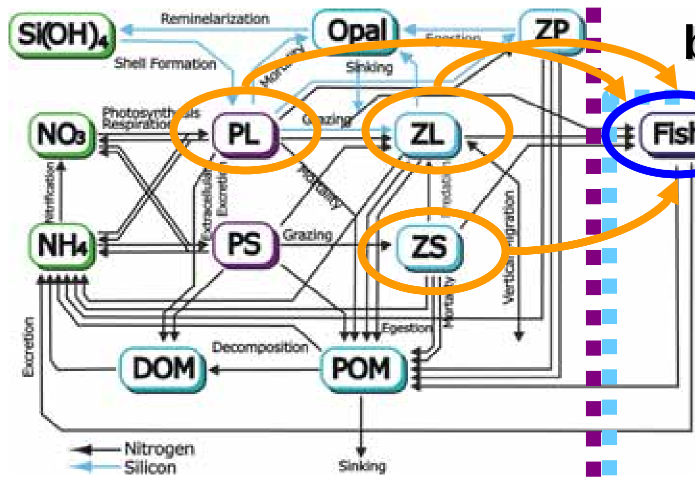
Ocean General Circulation Model(OGCM) 1/4×1/6

(COCO by CCSR)

Forcing at the year 1900

Simulated

Velocity Field
Temperature
Salinity
Vertical Diffusivity,
Solar Radiation
etc..



Forcing

Sardine Migration Model

based on Okunishi et al (2009)

2D - Individual Based Model (IBM)

Lagrangean 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

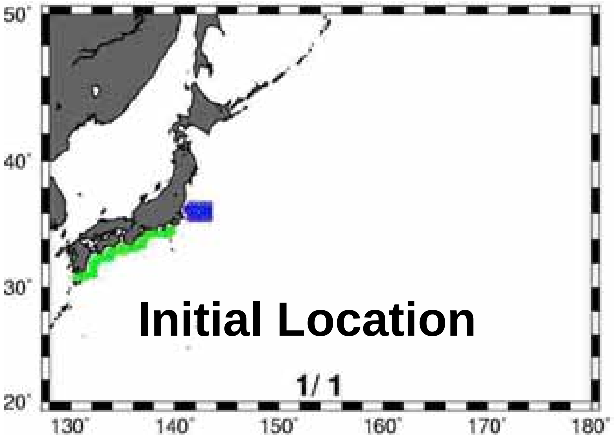
for simulating growth

- **SST** from Climate model
- **Forage density** from NEMURO

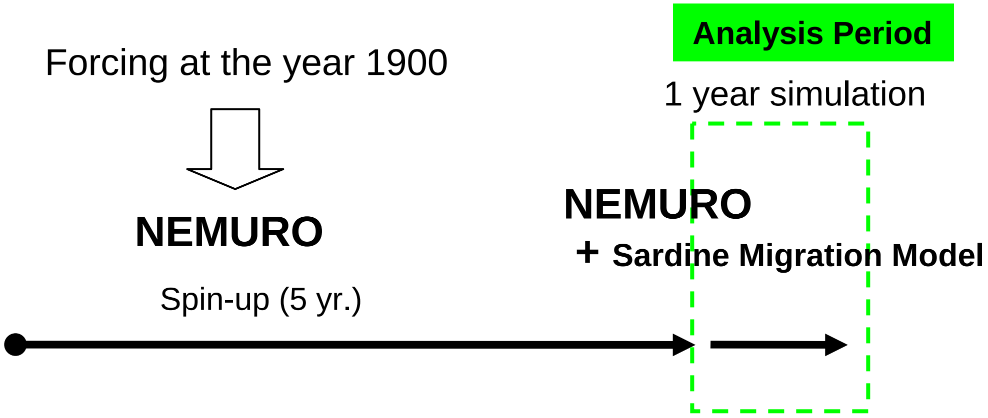
<Population>

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.

Escaping behavior from skipjack tuna



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



<Mortality rate>(Size dependency)

Early larvae: 0.075 / day
Late larvae : 0.01 / day
Juvenile– Adult: 0.001/day

Feeding Migration

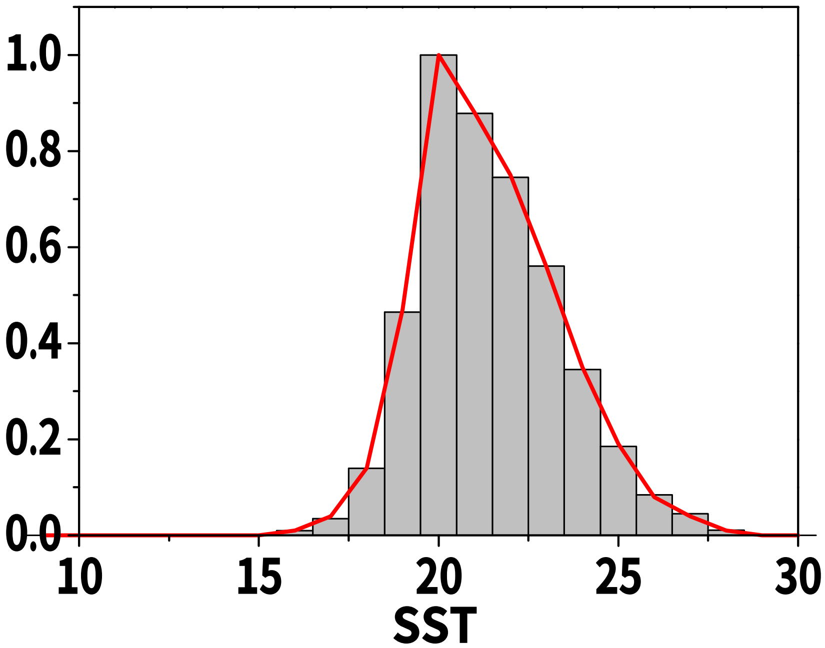
Case A :

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)

Predation Risk from Skipjack Tuna



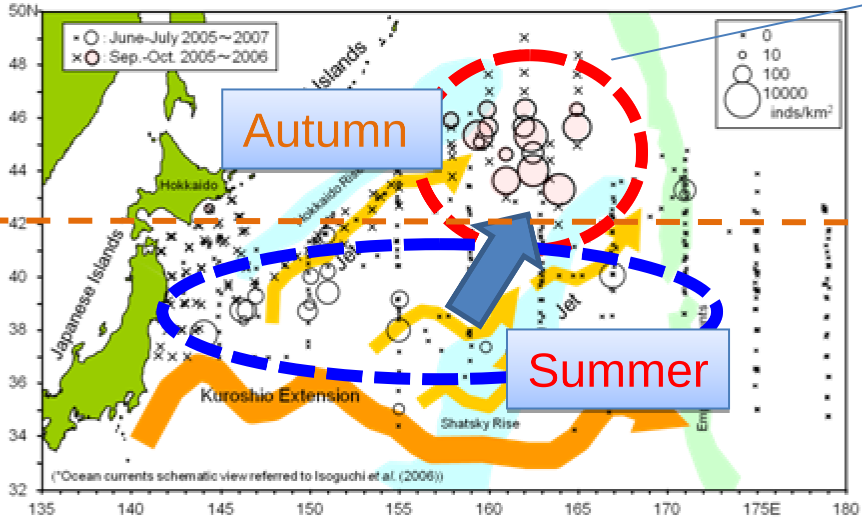
An example of histogram of skipjack catch as a function of SST (May).

Feeding migration : toward high fitness regions

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

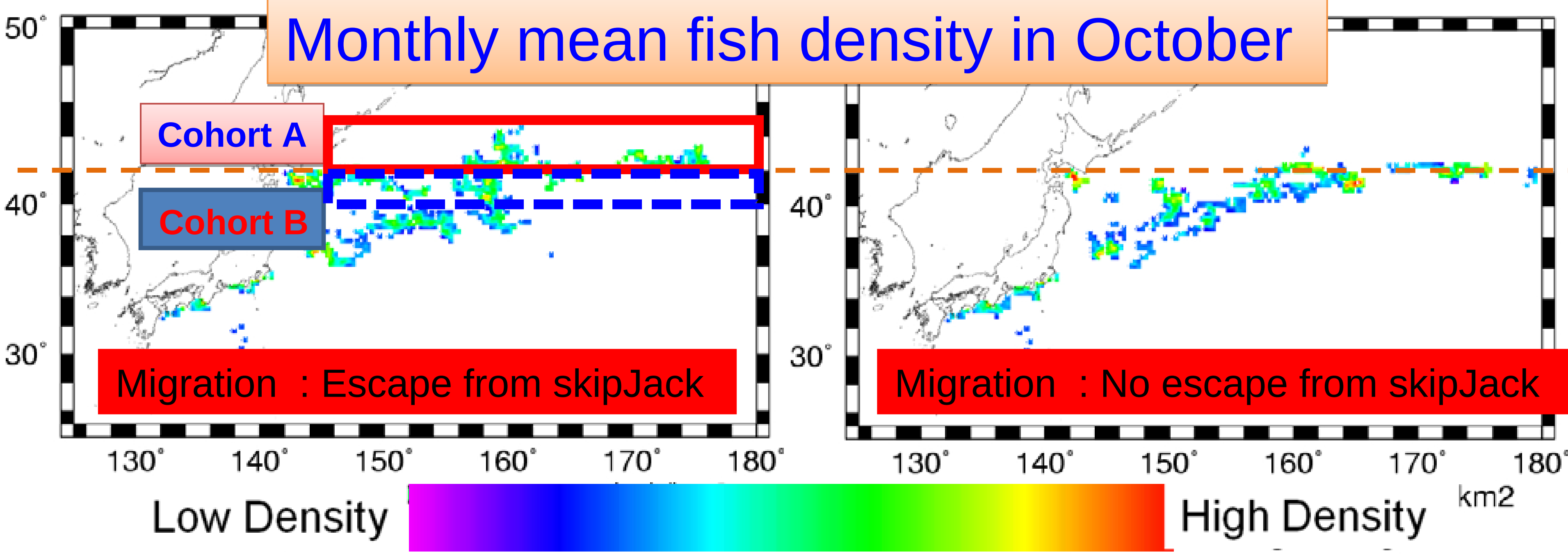
Case B : **fitness =Growth Rate**

Observation data shows fish (Age 0) distributes in the area which SST is12-14 degC in autumn.



When the escaping behavior is included, sardine migrates to the north of the Subarctic Boundary.

Monthly mean fish density in October



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

Case B : **Habitat index =Growth Rate**

Q2: Is escaping behavior controlling the sardine migration.

Kinesis algorism (Humston et al, 2000)

swimming velocity

$St = f(S_{t-1}) + g(\theta)$

$f(S_{t-1})=S_{t-1} \times H_1 \times HI$ depending on previous speed

$g(\theta)= \varepsilon(\theta) \times (1 - H_2 \times HI)$ random component

$H_1=0.75$, $H_2=0.9$, HI: habitat index

$|\varepsilon|$: maximum sustained swimming velocity =5 Body Length ($m\ s^{-1}$)

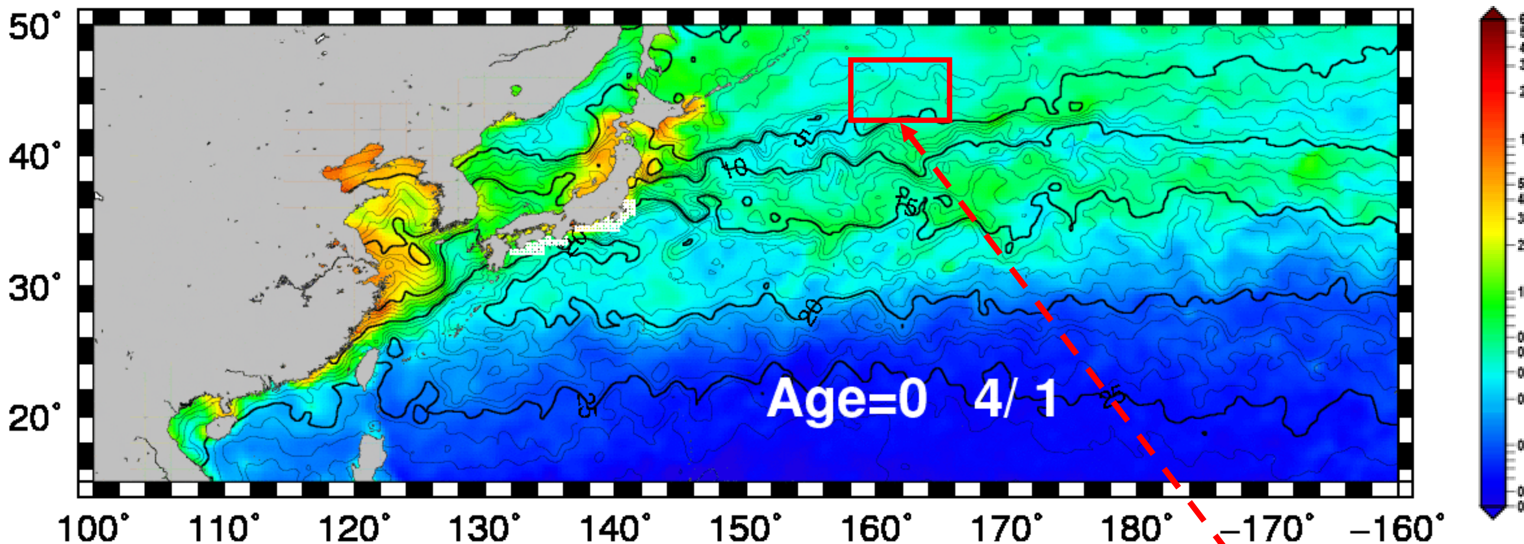
extended Kinesis algorism (Okunishi et al, accepted to F.O.)

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

$$S_t = S_{t-1} - (S_{t-1} - |\varepsilon| / |S_{t-1}| \times H_3) \times HI$$

$H_3=0.5$ keep the direction but slowdown

e.g. 2006 April spawned cohort



Chl-a (mg m^{-3})

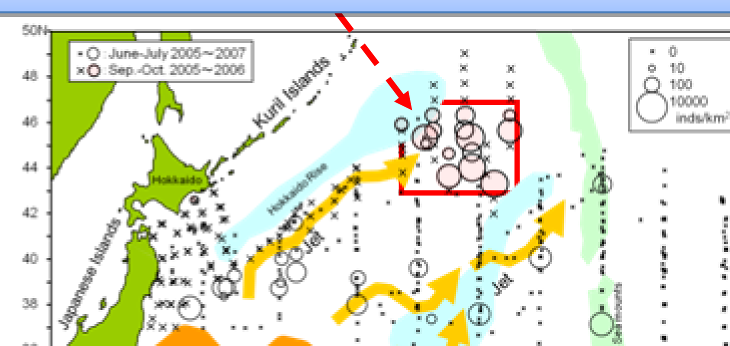
BL < 1 cm BL 1-3 cm BL 3-5 cm

BL 5-7 cm BL 7-9 cm BL > 9 cm

migration to the north of the Subarctic Boundary was reproduced.

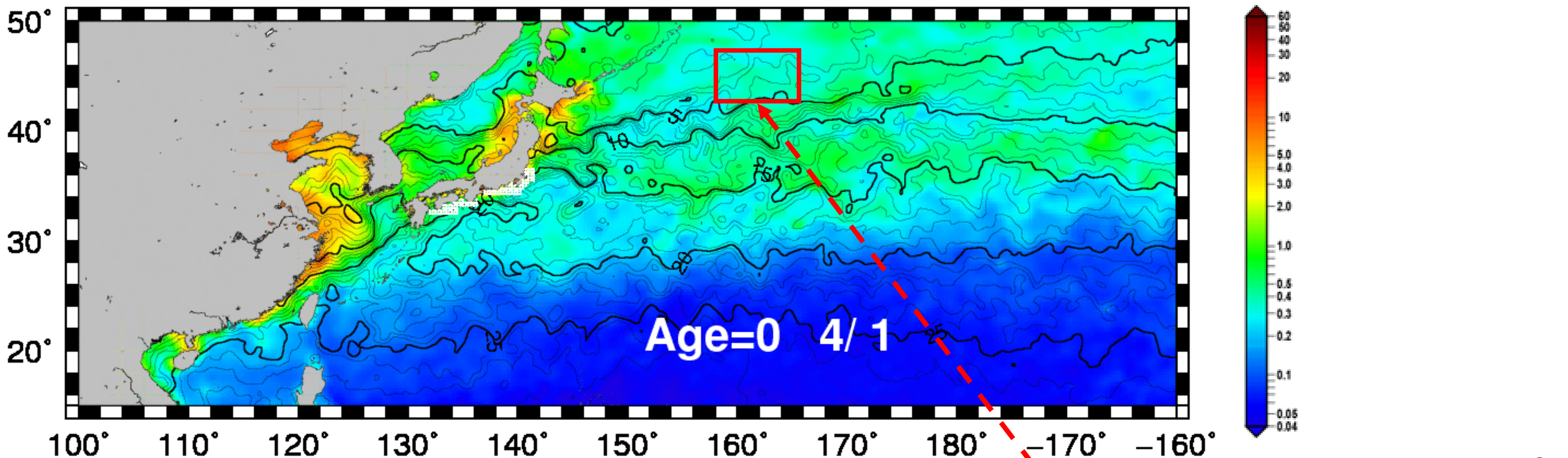
•dots shows fish and color is changed according to the growth.

•tone is Chl-a, contour is temp.



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

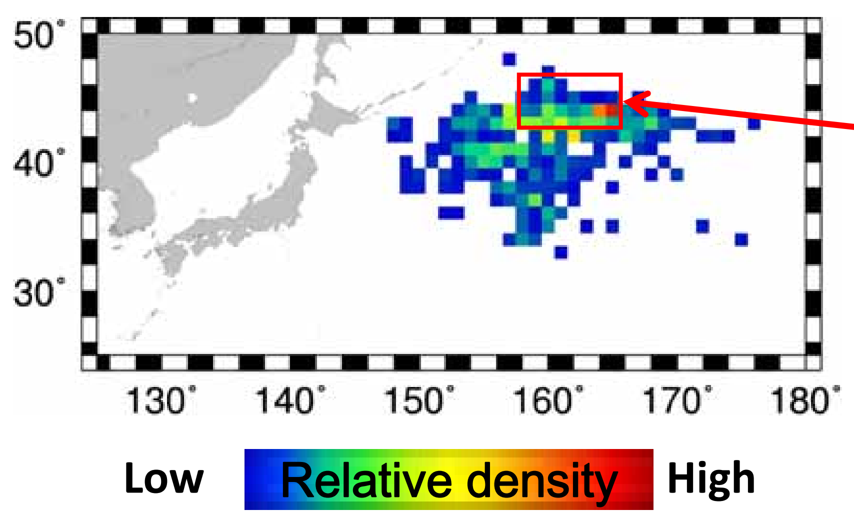
e.g. 2006 April spawned cohort

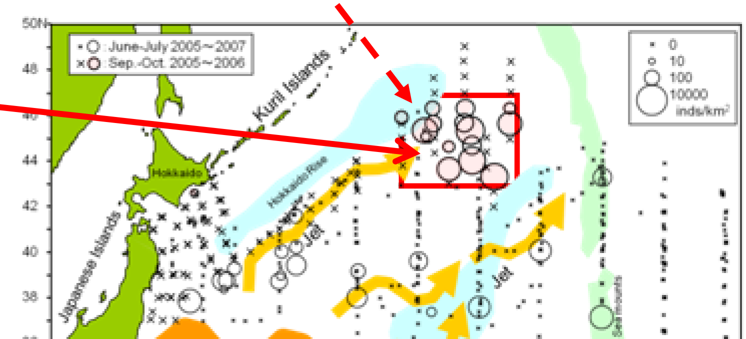


○ BL < 1 cm ● BL 1-3 cm ● BL 3-5 cm

● BL > 9 cm

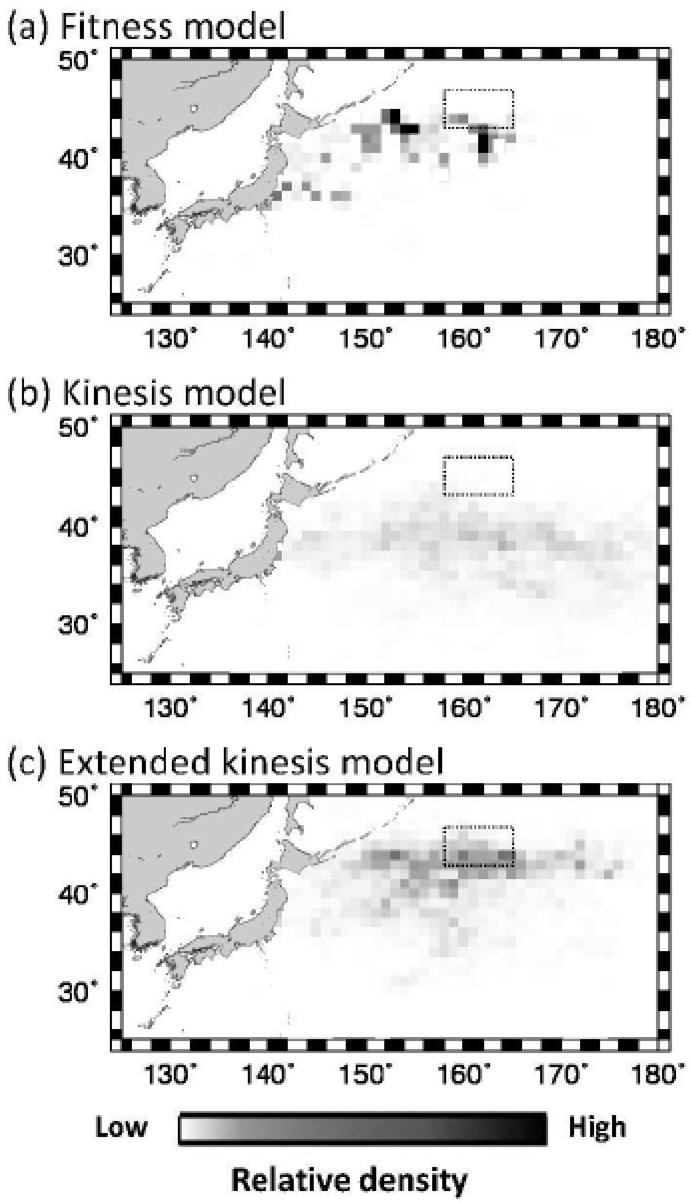
A.V. density in 2006 (Sep.-Oct.)





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

Comparison of three algorisms



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

Okunishi et al. (accepted to F.O.)

Summary

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.