Multi-trophic level ecosystem modeling for understanding the mechanism of small pelagic fish species alternation associated with climate regime shifts

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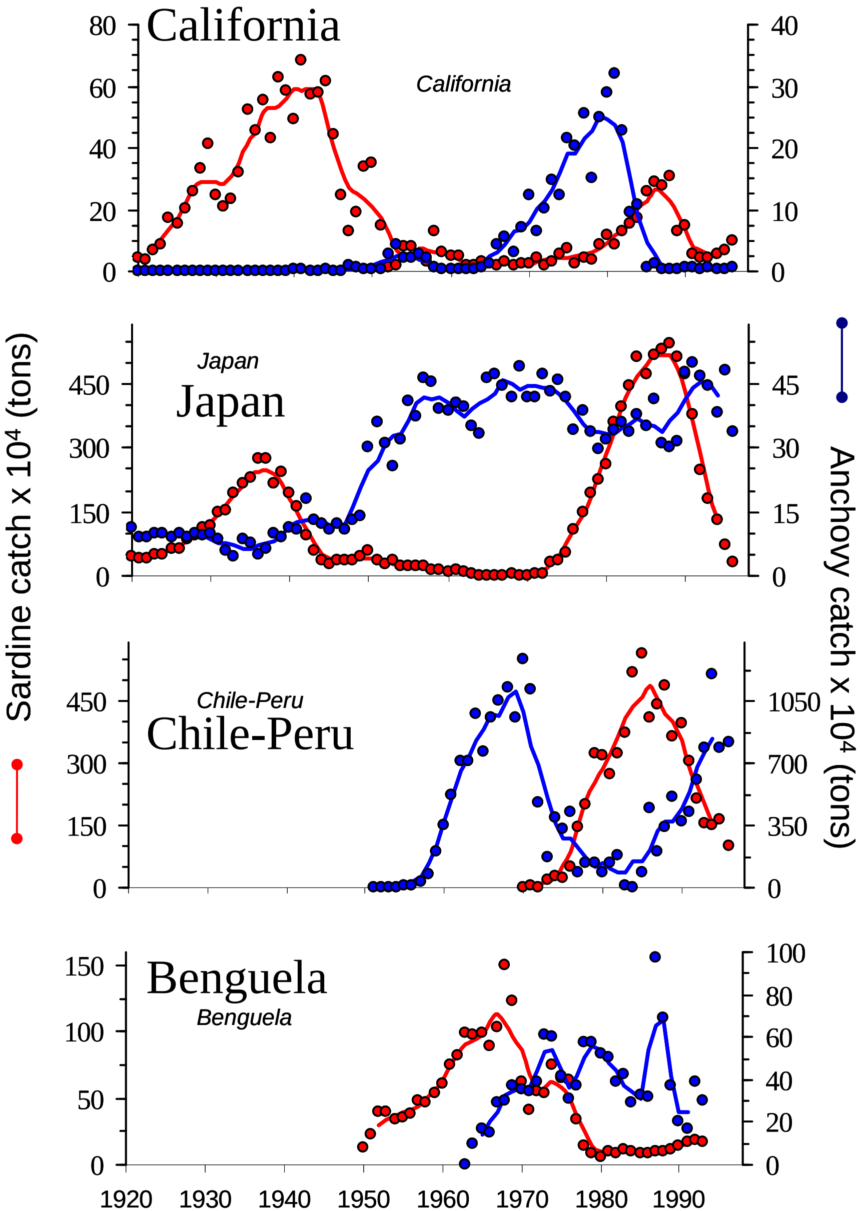
Today's contents

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

Introduction



Courtesy of Lluch-Cota & Chavez

Sardine & anchovy alternation is one of the distinctive phenomena climate variability acting an important role.

However, the responses of those fishes depends on regional marine ecosystem structures.

Therefore, our strategy is
1. develop a multi-trophic-level ecosystem model which can be applied to each regions, and
2. investigate regional responses to climate forcing.

As a first step, we developed a model for Japanese sardine.

Step 1: development of migration model

(Okunishi et al., 2009, Ecol. Model.)

Climatlogical physical field

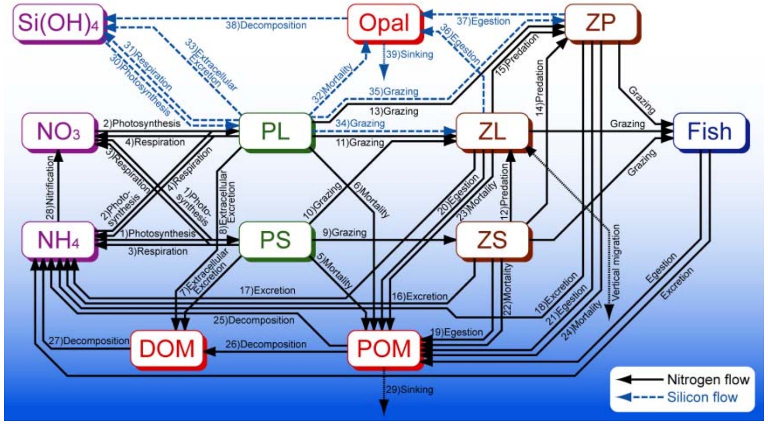
satellite derived
  sea surface current
  sea surface temperature

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.)

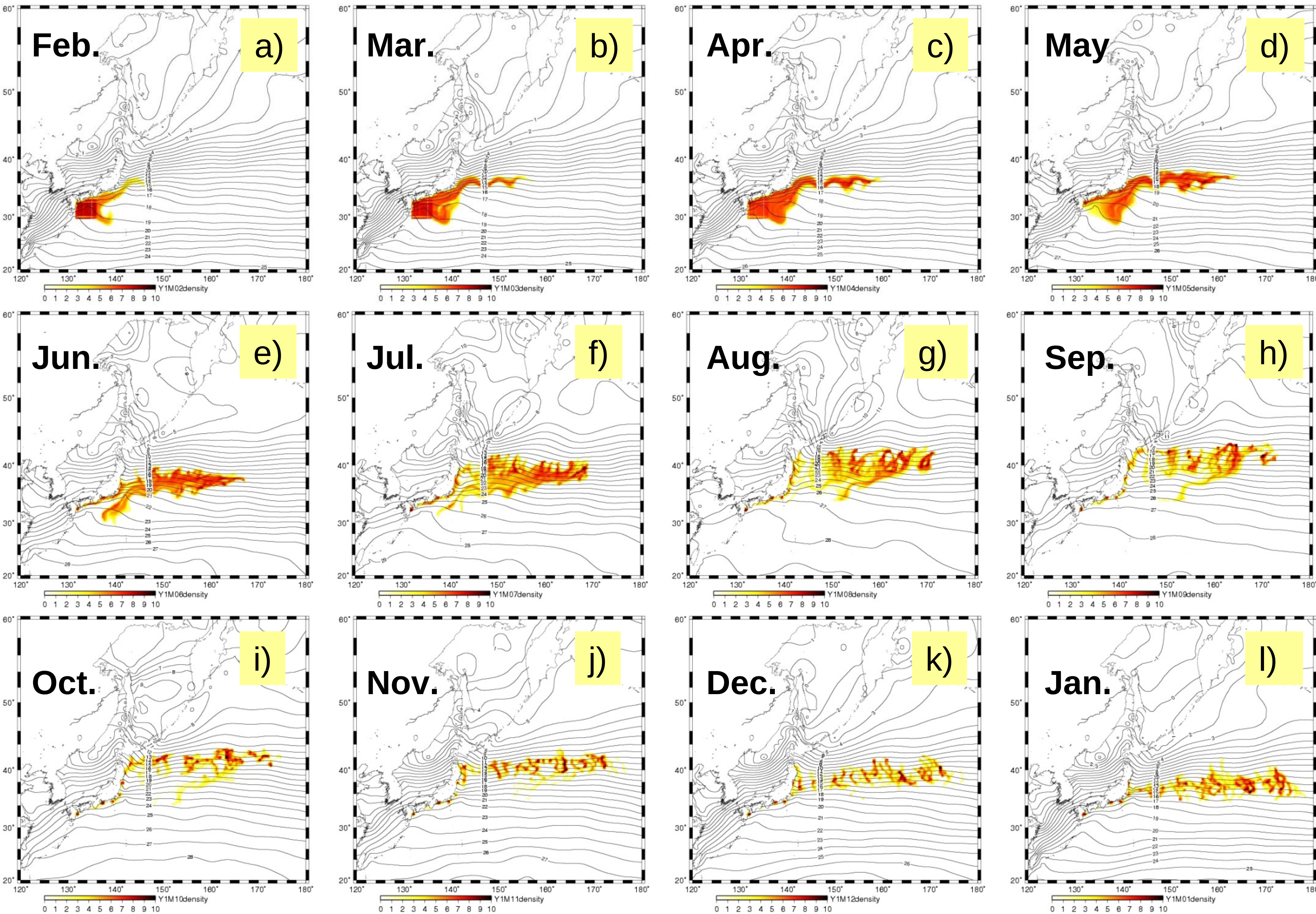
Challenge 1: reproduce realistic migrations

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.

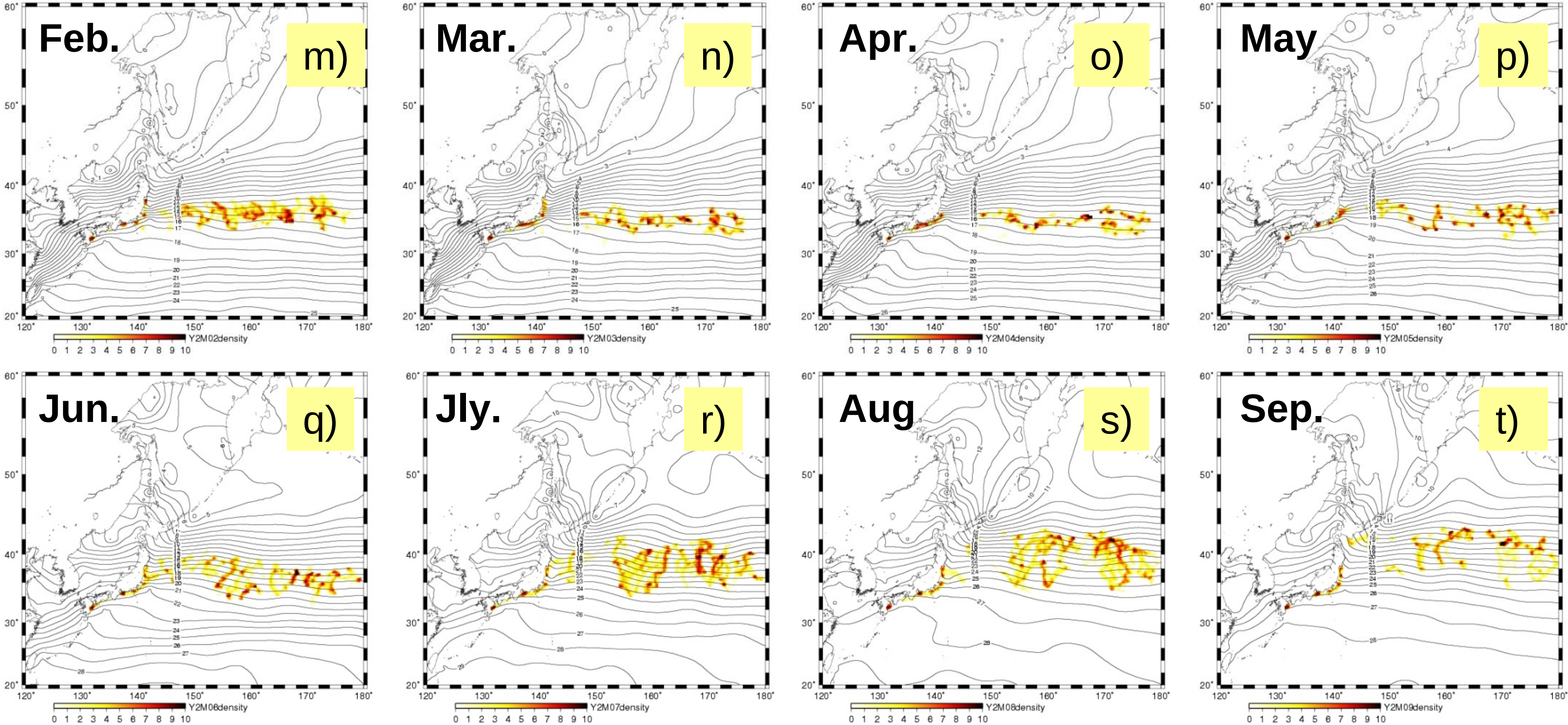
Feeding migration (age-0)

Okunishi et al. (2009)



feeding migration (age 1+)

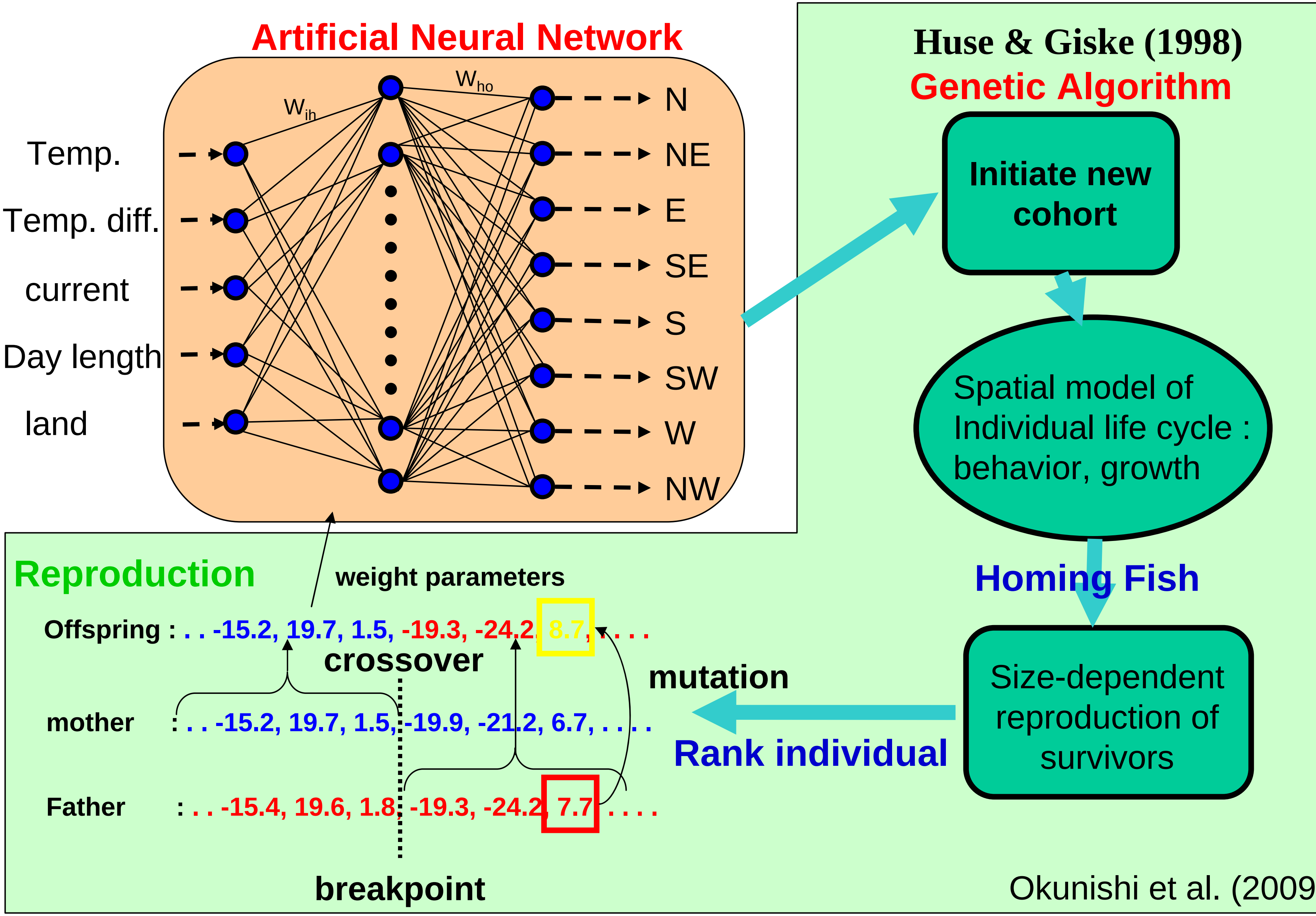
Okunishi et al. (2009)



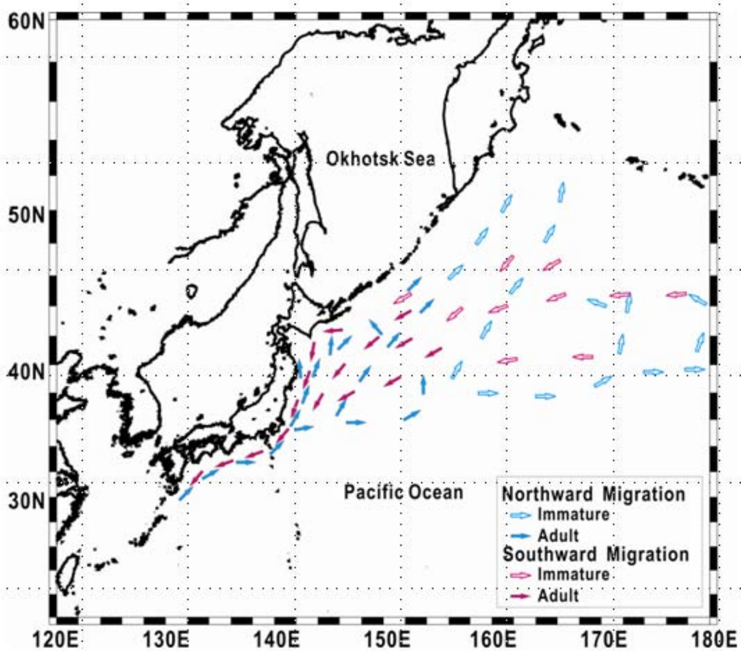
general pattern of feeding migration are reproduced by the fitness (optimal growth) migration algorithm.

Okunishi et al. (2009)

Spawning migration (ANN+GA)

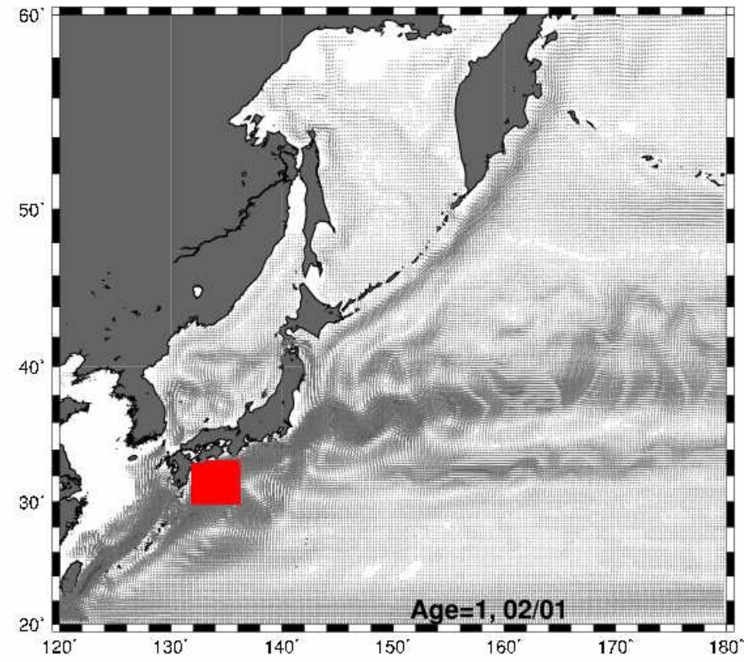


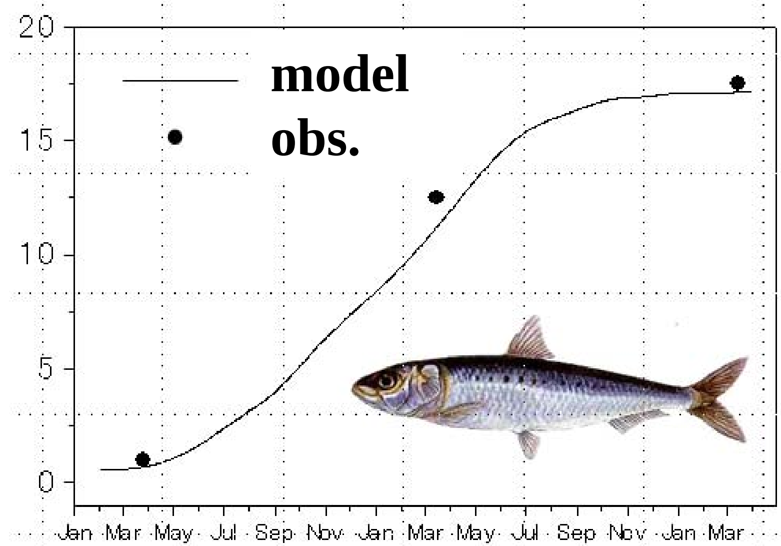
Sardine migration (GA+ANN+BP)



Schematic picture of sardine migration

Kuroda (1991)



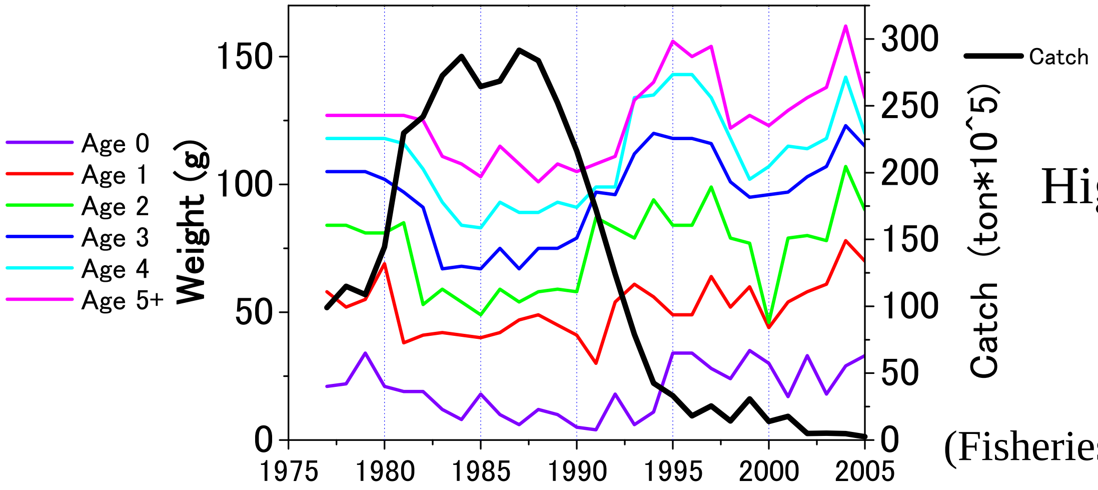


Realistic migration and growth are reproduced.

Okunishi et al. (2009)

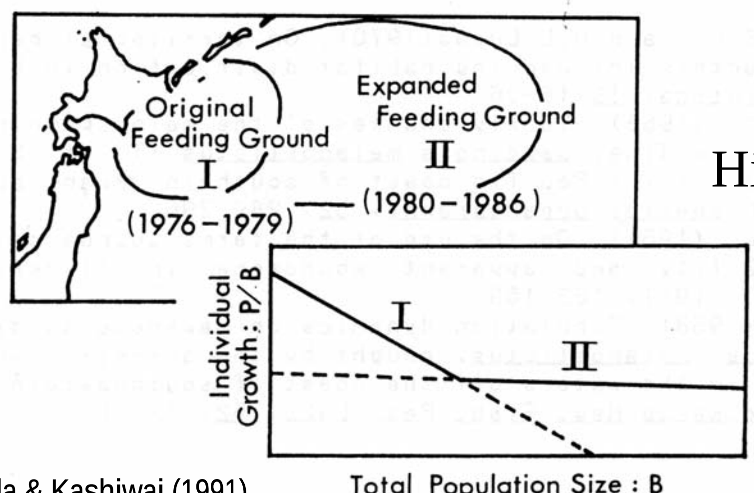
Q1: Density-dependence effect?

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.

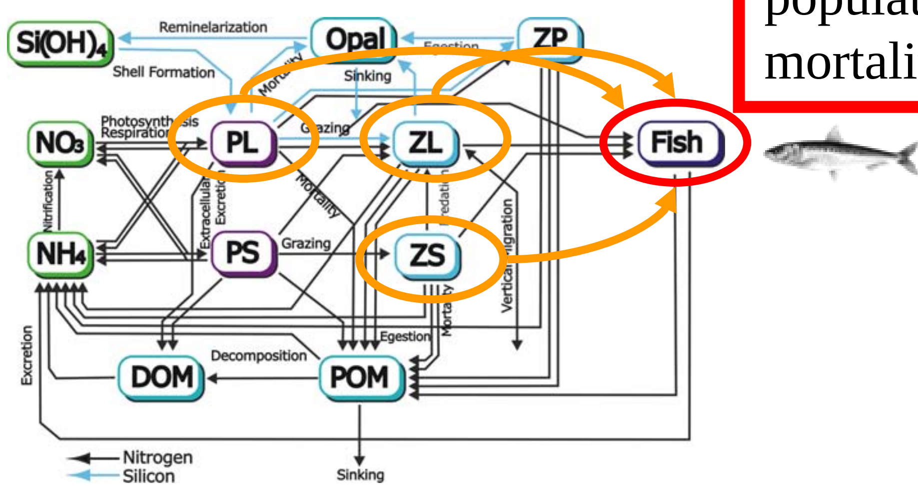
LTL Ecosystem Model NEMURO

1/4 x 1/6
prey plankton density

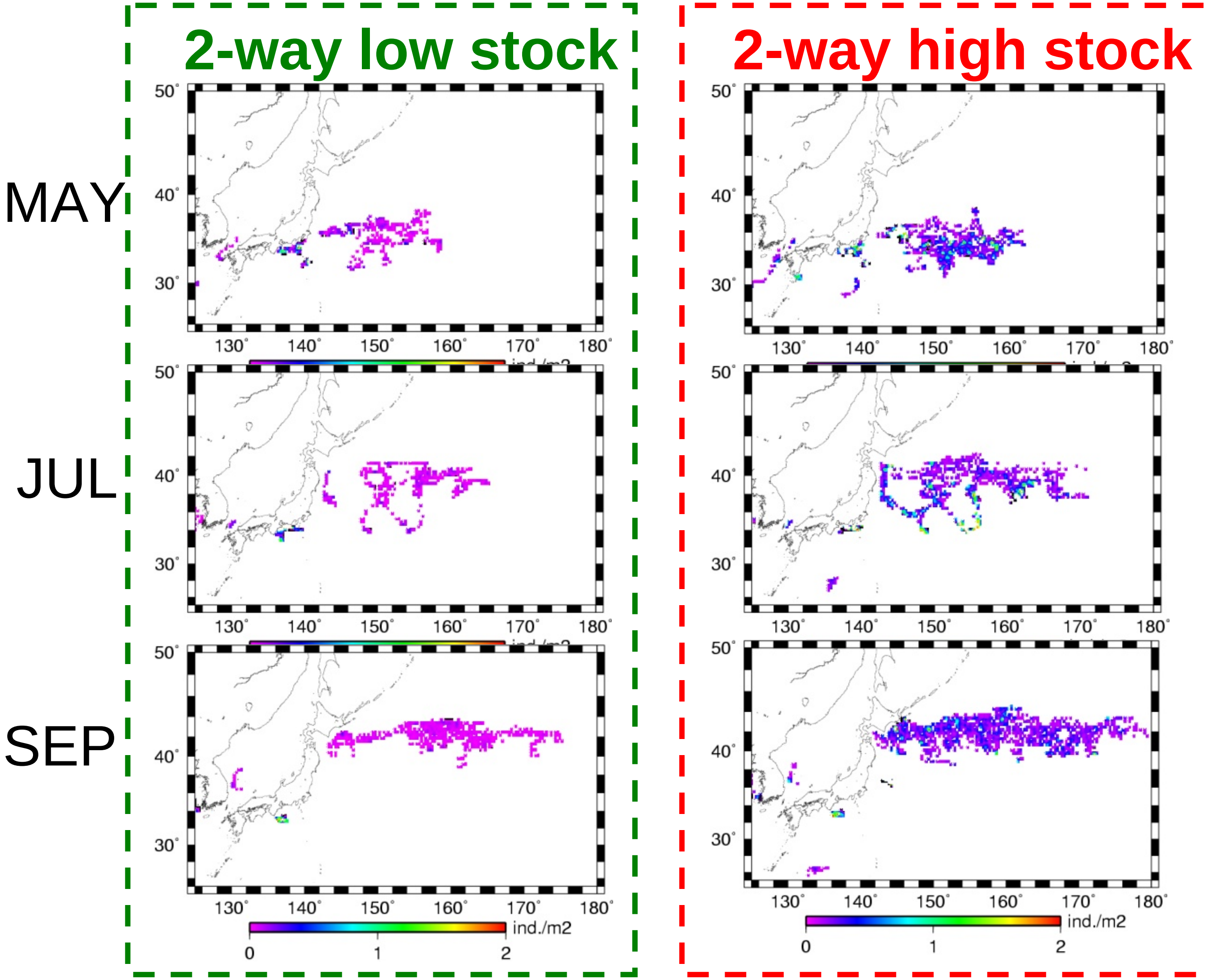
2-way

Sardine Migration Model (Okunishi et al., 2009)

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



Geographical Distributions of Adult fish (Age = 2+)

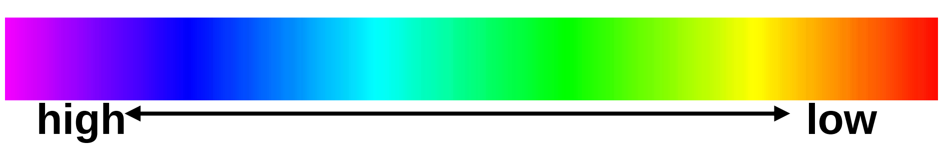


stock increase

prey decrease

expansion of habitat area

Model results explicitly support the density dependent effect hypothesis.

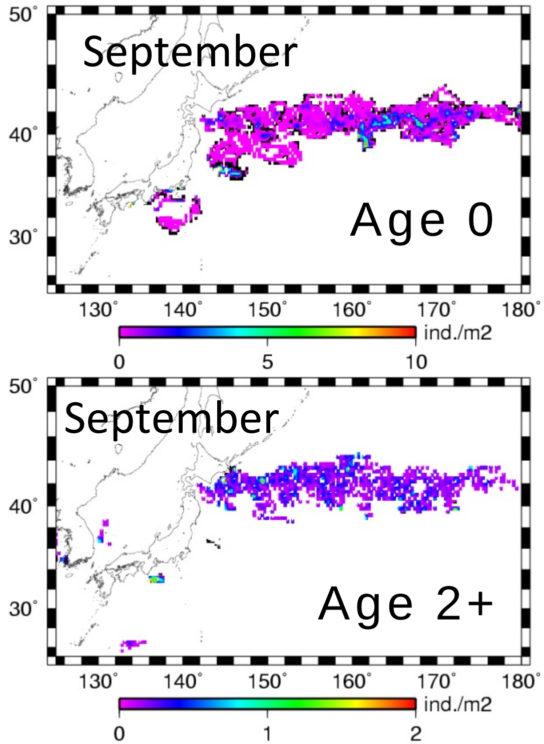


Okunishi et al. (in prep.)

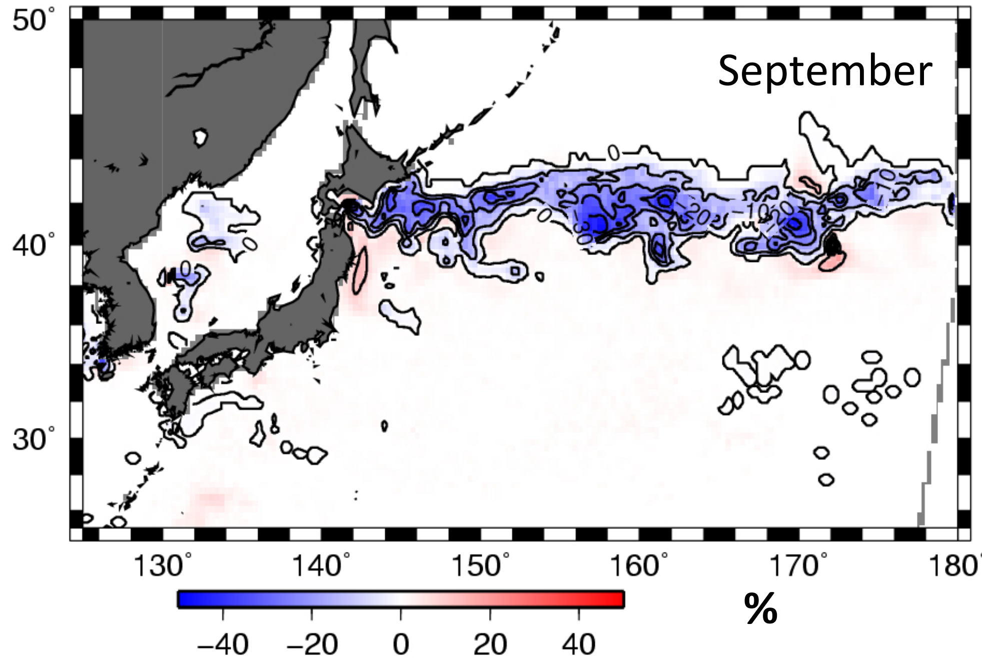
Density dependent effect on prey density

Okunishi et al. (in prep.)

Geographical Distributions



Anomaly of Forage density (PL + ZS + ZL)

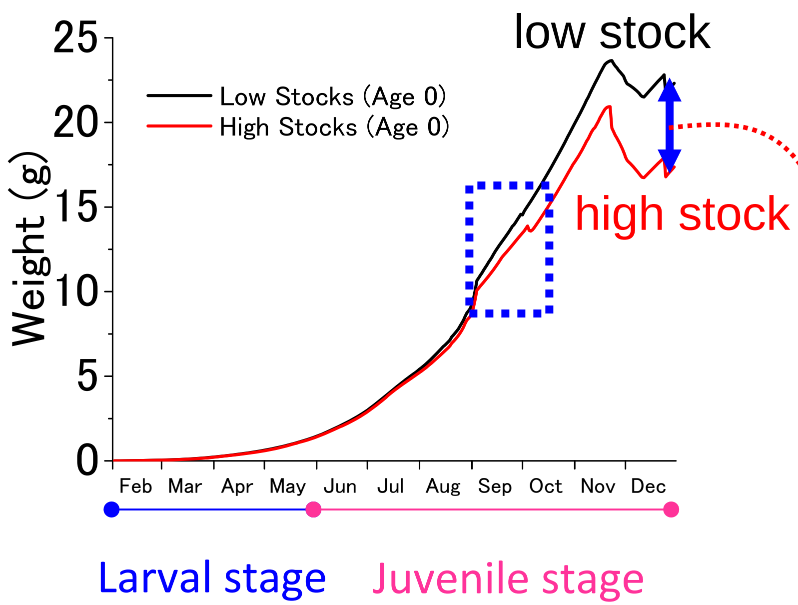


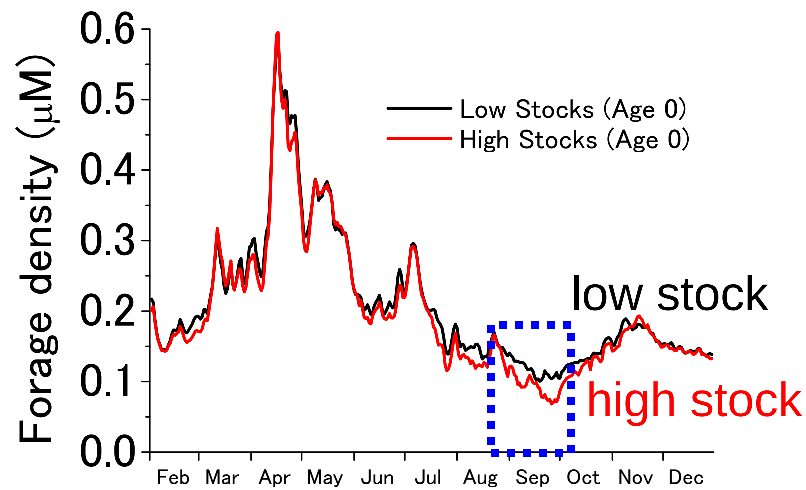
S3 (High stocks) - S2(Low stocks)

- 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.

Density dependent effect on fish weight

Okunishi et al. (in prep.)





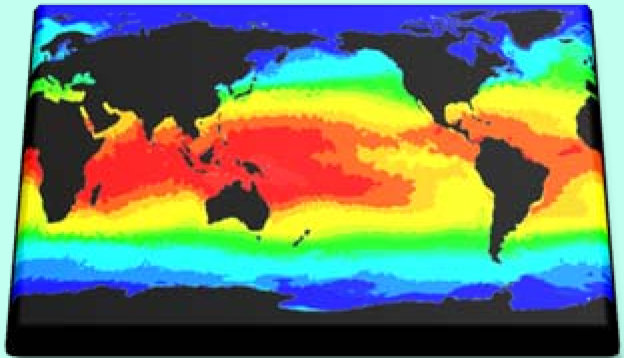
Difference in age-1 weight between high & low stock experiments is 4.9g.
This difference is similar order with observation (4.0 g).

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

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.

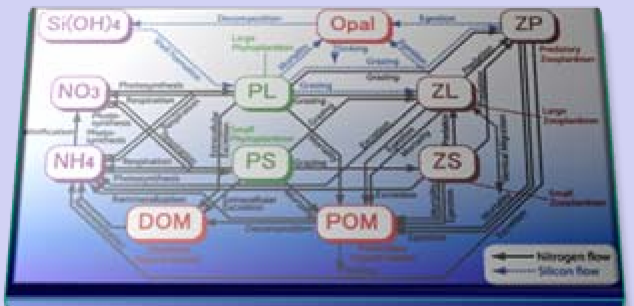
Q2: Decadal alternation is a bottom up control?



IcedCOCO4.3
Eddy permitting with Sea-Ice
1/4° x 1/6° with 51 vertical levels .
46 years historical run (1959-2004) by CORE forcing.

offline coupling

5days mean T, S, U, V, SH, SWA, A_{HV} and frequency of convective adj.



3D-NEMURO
Nitrogen and Silicon cycles with
2 types of phytoplankton and
3 types of zooplankton.
46 years historical run (1959-2004)

Fish migration model

The model carried out for 7month during egg and juvenile each years populations from 1965 and 1995

Three mortality scenarios

Case I Mortality rate : Size dependency (Bigger is better)

BL < 0.6 cm : 0.1 / day

BL = 0.6-10 cm : 0.075 / day

BL = 5-10 cm : 0.01 / day

BL > 10 cm : 0.001 /day

Case II Mortality rate : Size and Growth rate dependency

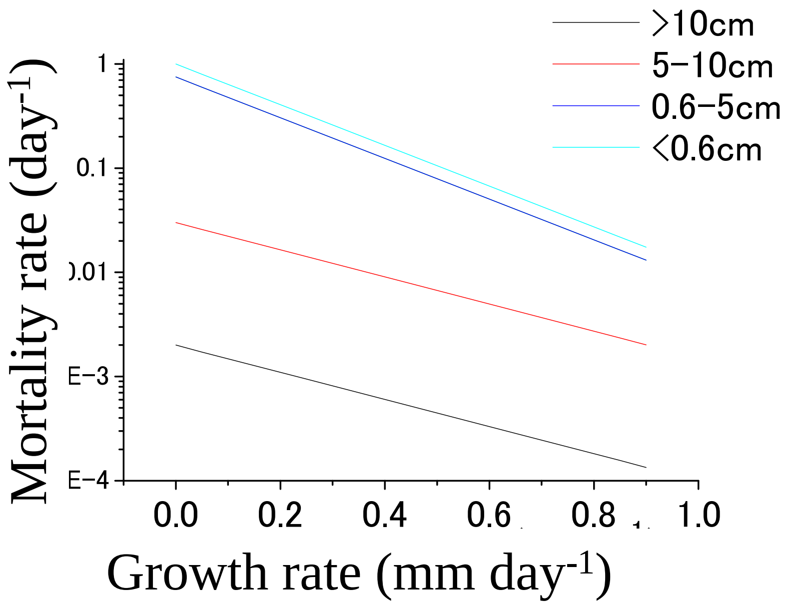
(Bigger is better + Growth-mortality)

Case III Mortality rate : Size and Growth rate dependency

+ Predation risk by Skipjack

(depending on SST and stock of Skipjack)

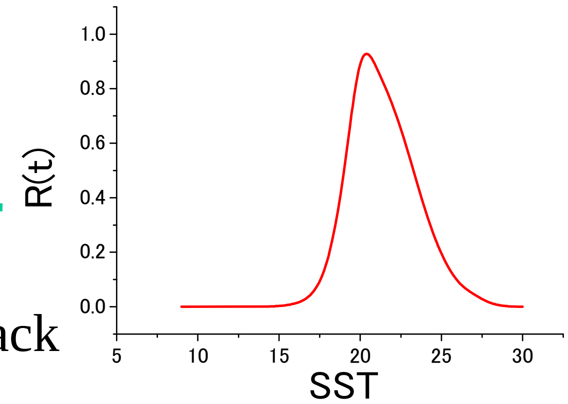
Case II



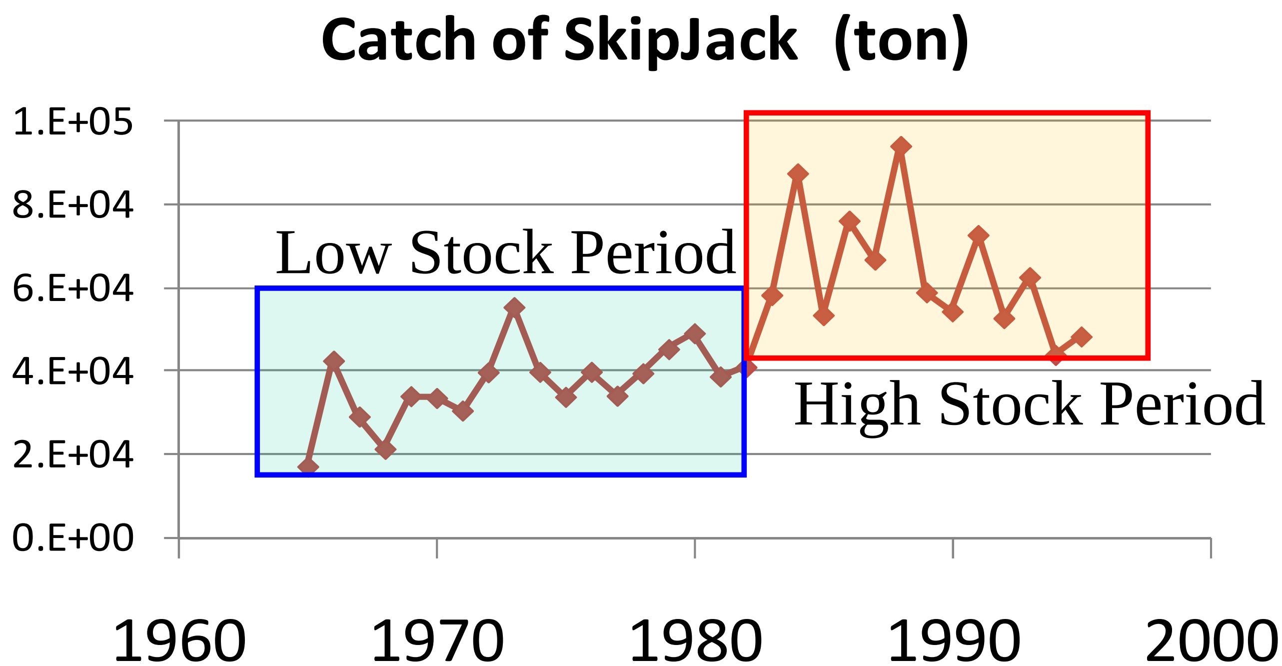
Case III

Mortality rate =Size dependent function
+growth rate dependent function
+Predation by Skipjack [R(t) * f(s)]

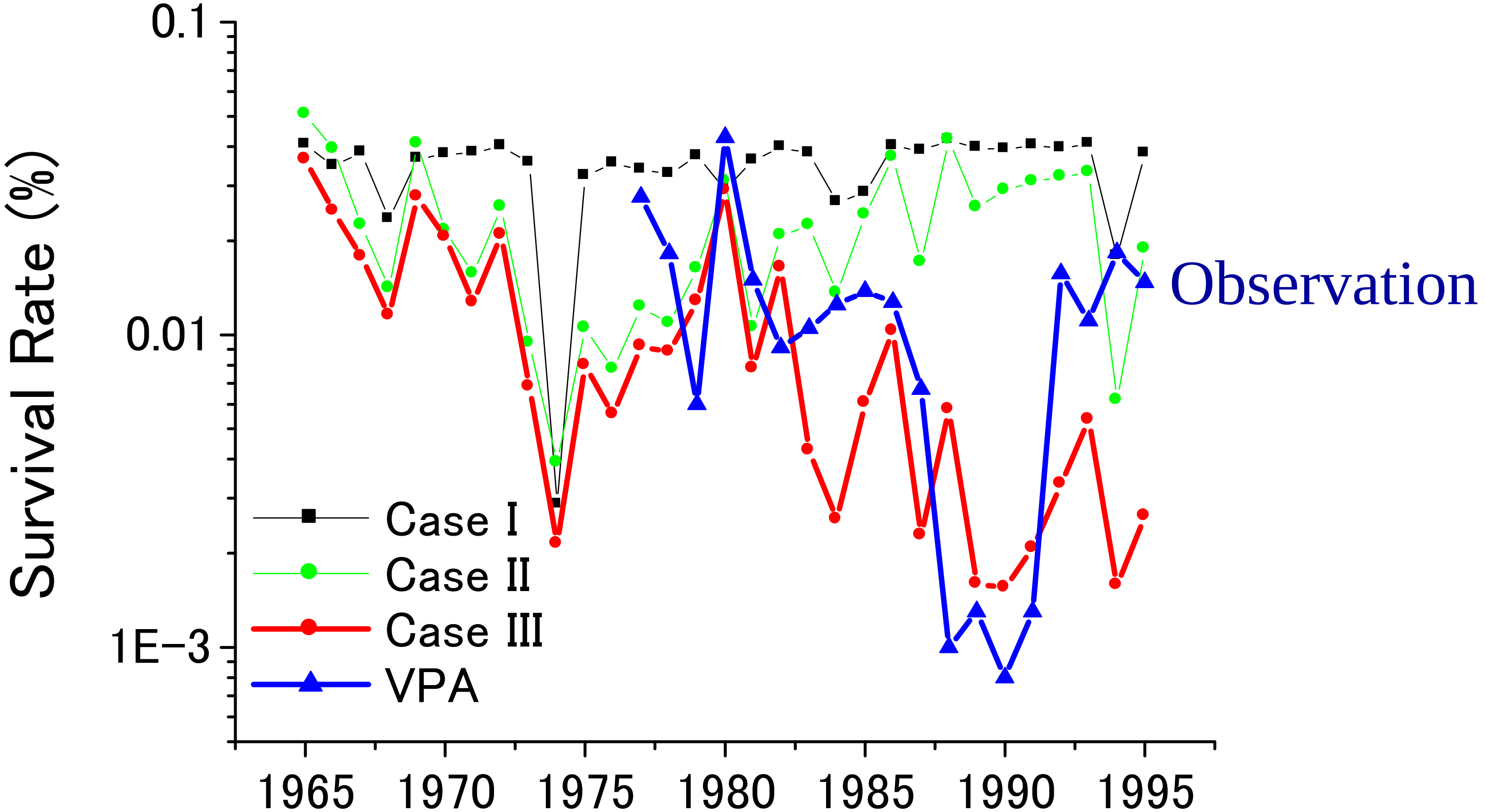
R (t) is predation risk of SST dependency
estimated from catch data



f(s) is encounter probability depending stock of Skipjack
f(s) =1. : High Stock period (1965-1982)
f(s) =1/20 : Low Stock period (1983-1995)



Result: Survival rate (recruits/egg)

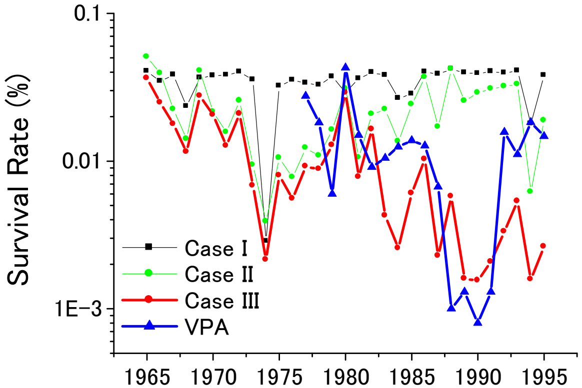


Case I Bigger is better: low variability

Case II Bigger is better + Growth-mortality: cannot reproduce collapse of stock

Case III (Bigger is better+Growth-mortality+Predation risk):
collapse of stock was reproduced
($R=0.662$, $p<0.005$)

Simple population dynamics model



Recruitment number in the coupled model was used for a simple population model.

$$N_{0,y} = R_{0,y} \exp(-F_{0,y})$$: Fish number at Age 0

$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M)$$

a: age

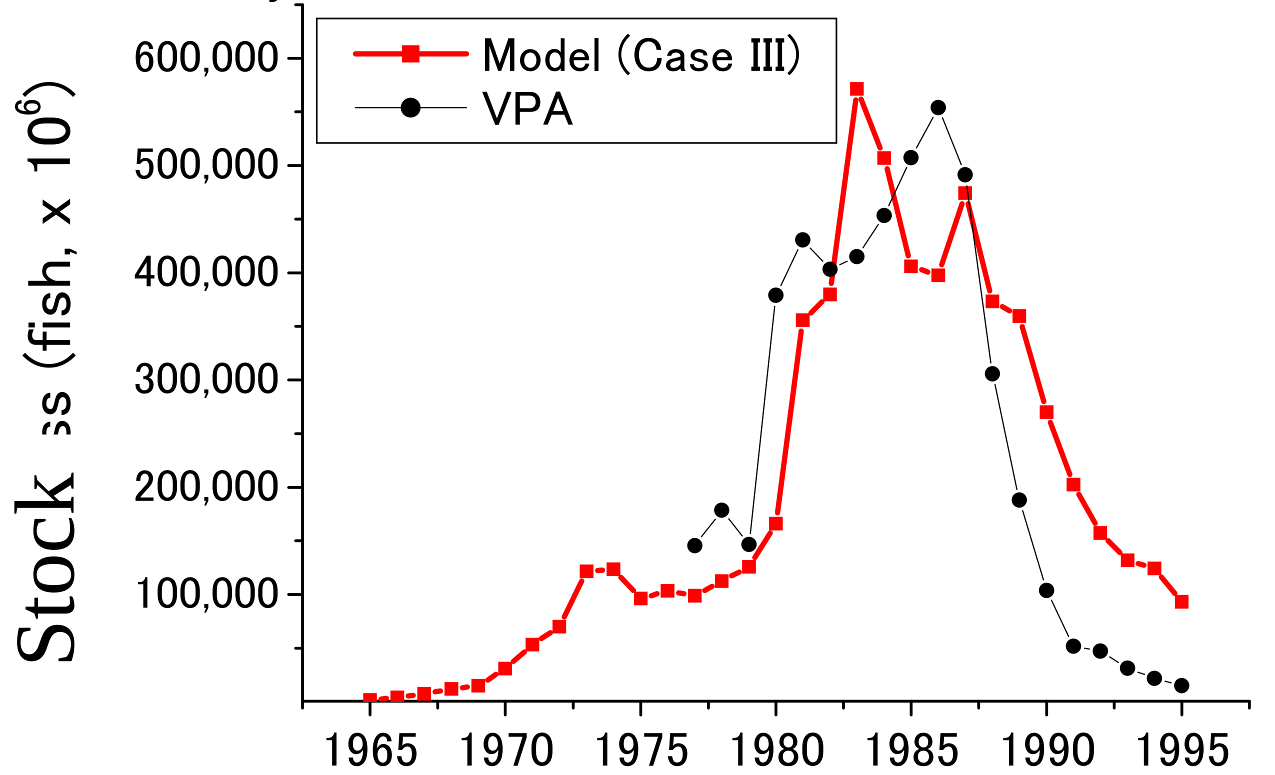
y: year

$F_{a,y}$ Fishery coefficient by fishing data

M Natural Mortality $= 0.4$ year^{-1}

Result: stock of Japanese sardine

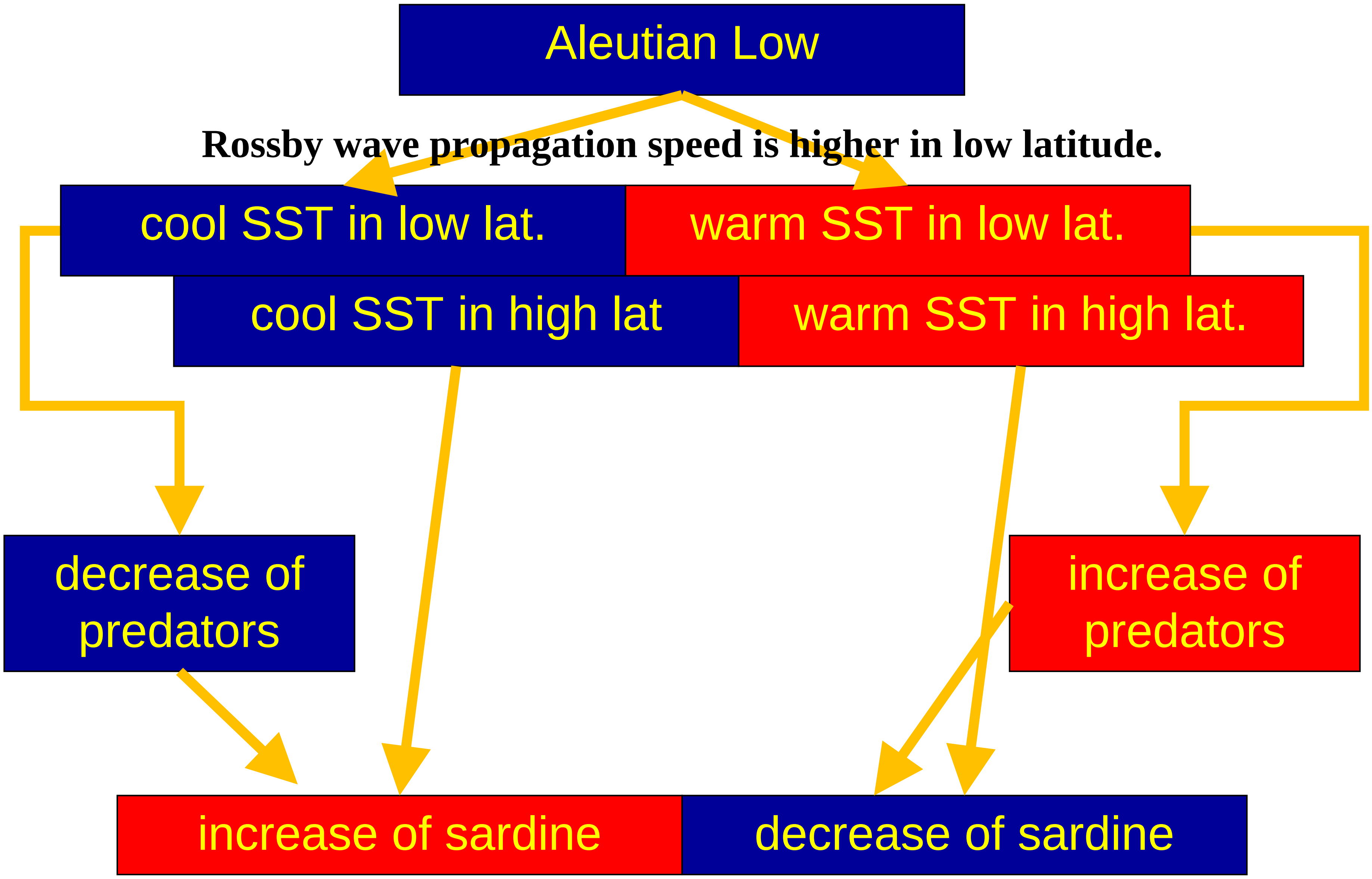
$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M)$$



The predation of top-predator may be one of important factors controlling the survival rate.

However, the effect of predation by skipjack tuna is the add-hoc parameterization.

Delayed double punch hypothesis



Summary

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

1) Modeling approaches seem powerful tools to investigate ecosystem responses to climate forcing.

2) Dynamic linkage between trophic levels must be included in the model. Density-dependent effect may be acting for growth and distributions of Japanese sardine and prey plankton density.

3) Predatory fish effects seem an important factor controlling sardine stock fluctuations.

4) (not shown today) We tested several migration algorithms (including escaping from predatory fish, kinesis algorithm) and investigated responses to future climate.

Disclaimers

However, we are still facing information gaps to improve models realistic.

Disclaimers

1) We must develop techniques to enable tag and release observations of small pelagic fishes.

2) Bioenergetics parameters must be improved.

3) Species interactions must be take into account.

4) More realistic forcing (data assimilated reanalysis) must be used.

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

Our knowledge improved, then model and hence our comprehensive understandings will be improved.