Climate induced fluctuation of Japanese sardine, its influence on marine ecosystem and human being

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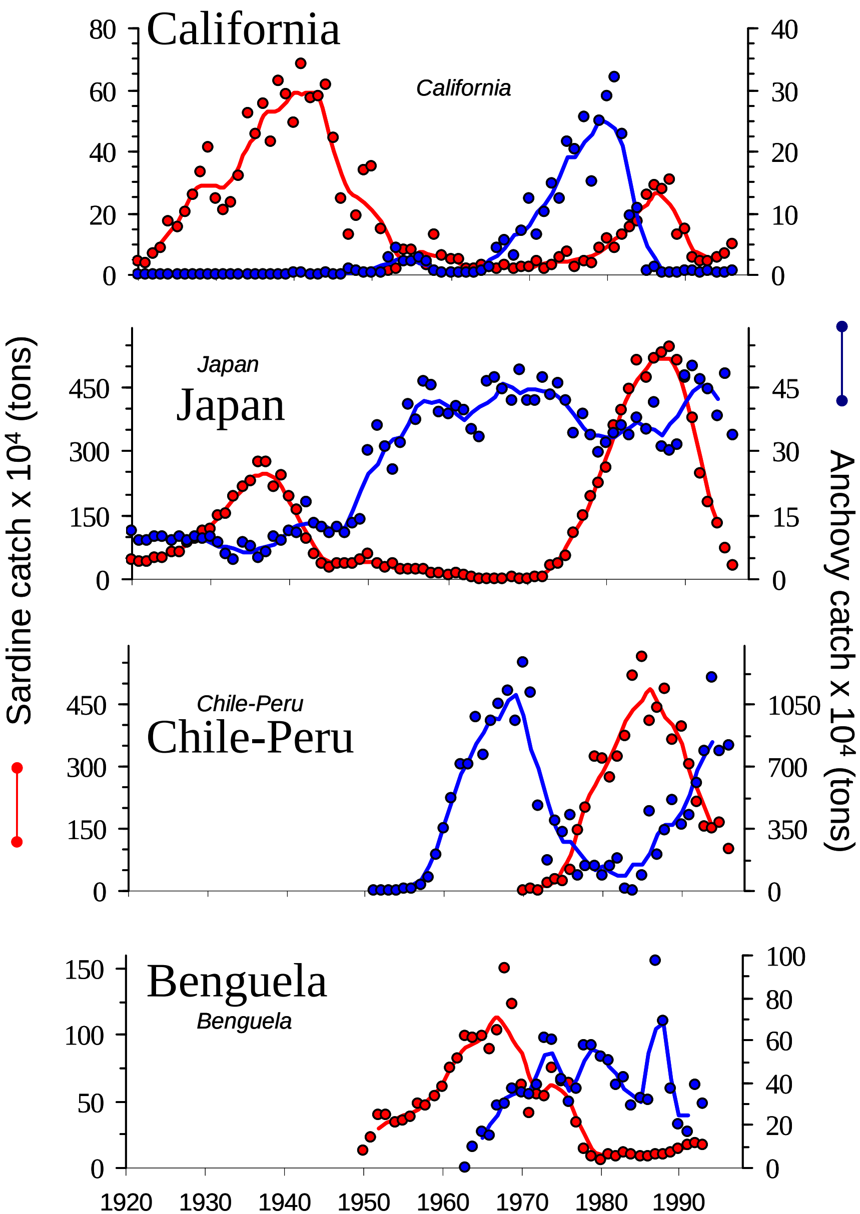
Today's contents

1. fluctuation of Japanese sardine
2. multi trophic level ecosystem model
3. density dependent effect
4. influence on human being

Introduction



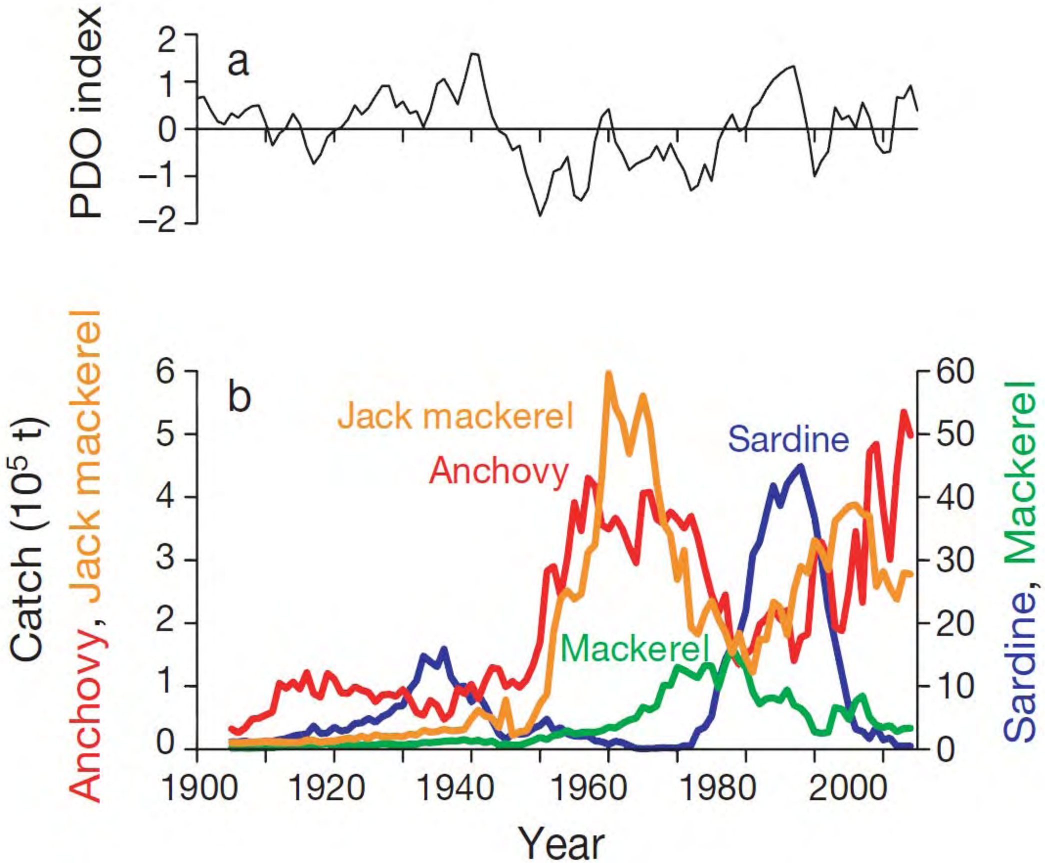
Courtesy of Lluch-Cota & Chavez

Sardine & anchovy shows alternation in many places.

During 20th century, it showed synchronicity in the whole Pacific.

Therefore, the fish species alternation seems one of the distinctive phenomena which climate variability is acting an important role.

1. Fluctuation of Japanese sardine



Takasuka et al. (2008), MEPS

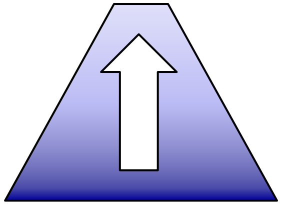
In Japan, sardine shows the largest fluctuation in the small pelagic fish.

Three groups
1) sardine
2) mackerel
3) anchovy, jack mackerel, saury, squids
show species alternation responding to the large scale climate regime shift (e.g. PDO).

Mechanisms of marine ecosystem regime shift

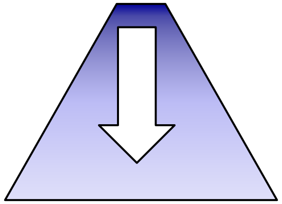
1. **bottom-up control**

Environmental change trigger changes in physical conditions and food availability, hence ecosystem structure (Lluch-Belda et al. 1992; Ware and Thomson, 2005, etc.).



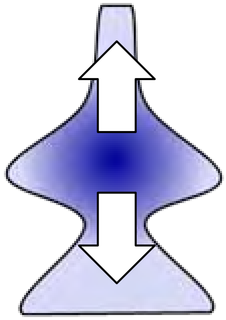
2. **top-down control**

Environmental change modified predation from the top predators and change the ecosystem structure.
Fishers are one of top predators targeting large fish species.
The mean trophic level of the catch has been decreasing worldwide as a result of `fishing down marine food webs' (Pauly et al., 1998, 2000).



3. **Wasp-waist control**

One or several dominant species can play a structuring role in ecosystem dynamics (Cury et al., 2000, 2003, etc.).
Climate change influence on the dominant species, hence affect both higher and lower trophic levels.



Influence of Japanese sardine on zooplankton

<u>Tadokoro et al. (2005)</u>

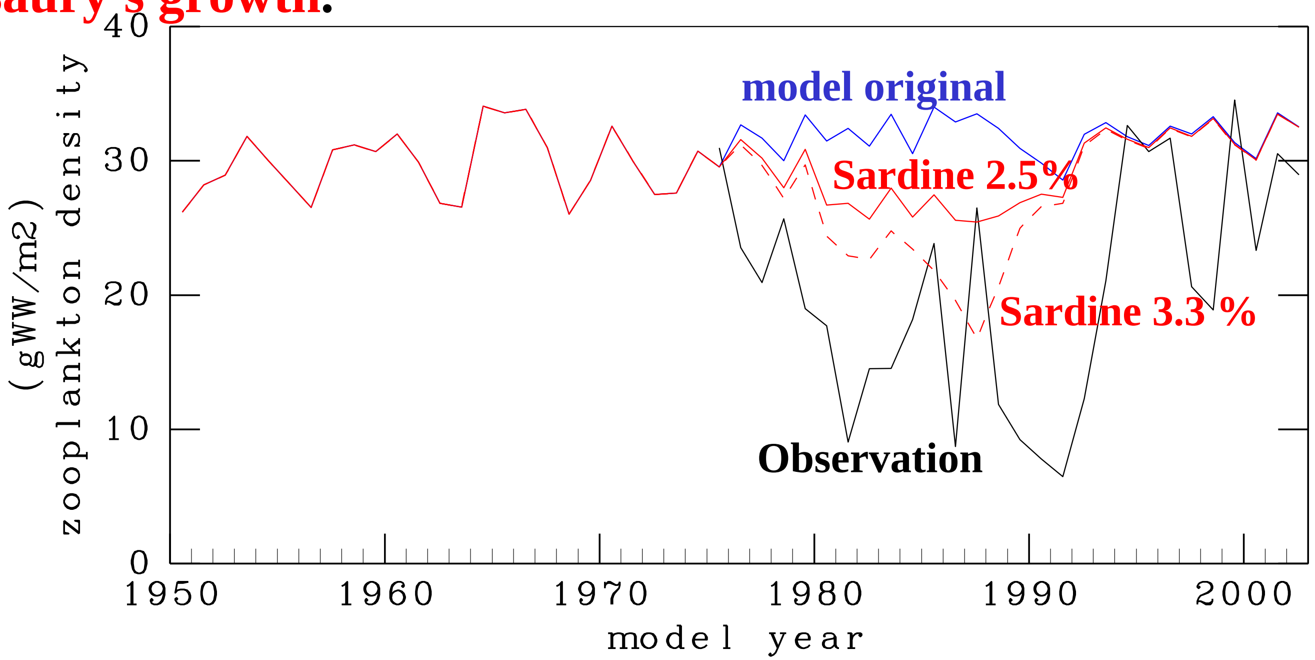
At their peak in 1984, sardines consumed 32–138% of the daily Neocalanus production during summer.

Predation pressure on Neocalanus by Japanese sardine is likely to affect interannual variation in mesozooplankton biomass.

<u>Ito et al. (2007):</u> simple three ocean domain box model

Predation pressure on large copepods from sardine is needed to reproduce decrease of large copepods in 1980's.

Model result suggeted this decrease of prey zooplankton influenced on Pacific saury's growth.



Ito et al. (2007), Ecol. Model.

2. Multi-trophic-level ecosystem model

Japanese sardine seems the dominant species playing a structuring role in ecosystem dynamics in the western North Pacific.

However, Japanese sardine widely migrate from subtropical to subarctic and its habitat area also varies according to the regime shift.
The mechanism of habitat area variation is still unclear.
Moreover, species interaction is much difficult to understand.

Therefore, our strategy is
1. develop a sardine migration model,
2. develop a multi-trophic-level ecosystem model, and

investigate the impact of Japanese sardine.

Step 1: development of migration model

(Okunishi et al., 2009, Ecol. Model.)
(Okunishi et al., 2012, Fish. Oceanogr.)
(Okunishi et al., in press, Clim. Change)

Climatlogical physical field

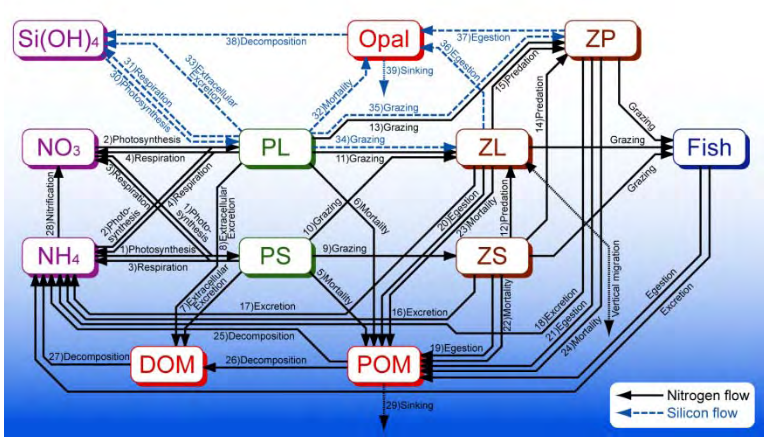
satellite derived
sea surface current
sea surface temperature

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.)

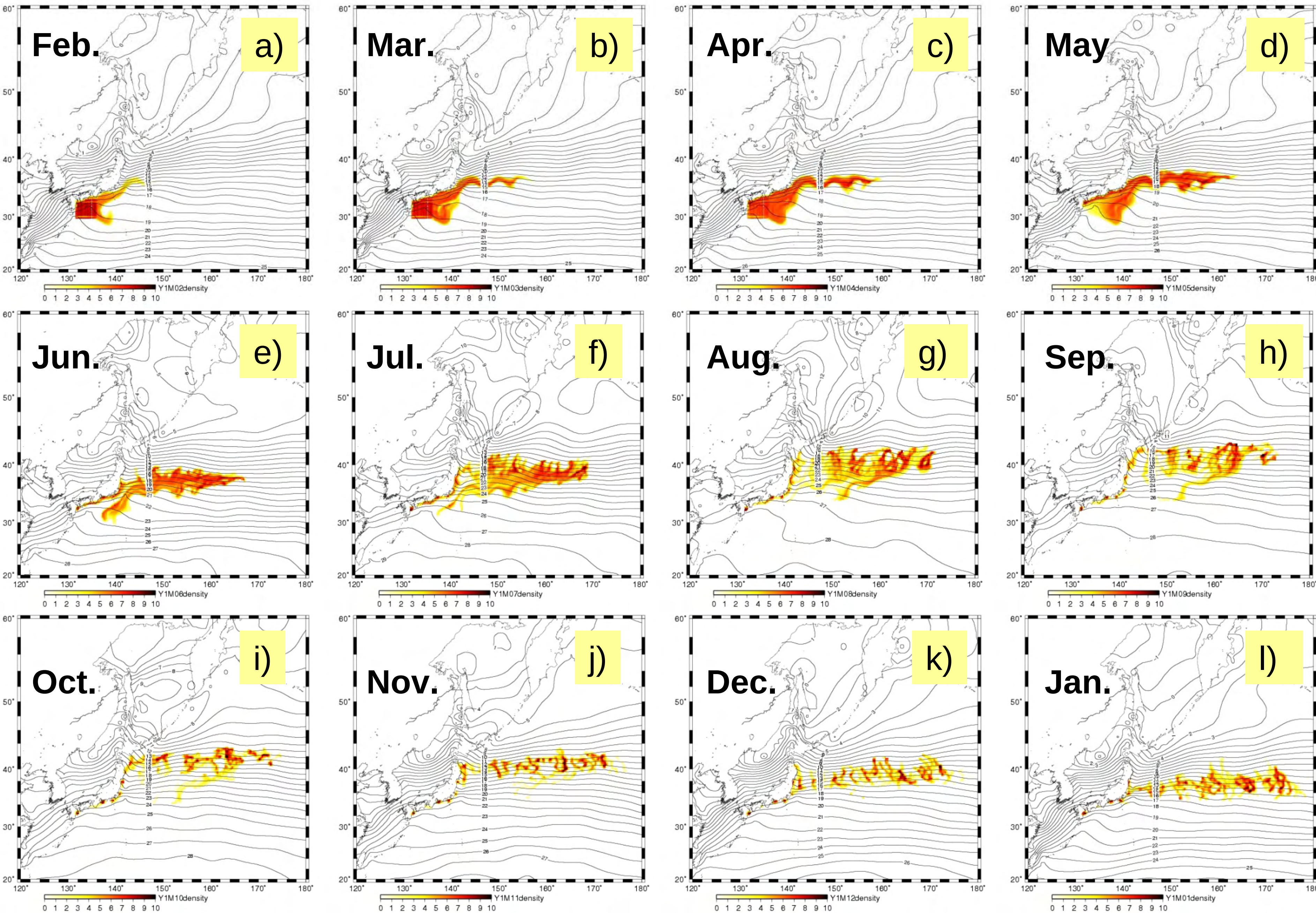
Challenge 1: reproduce realistic migrations

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.

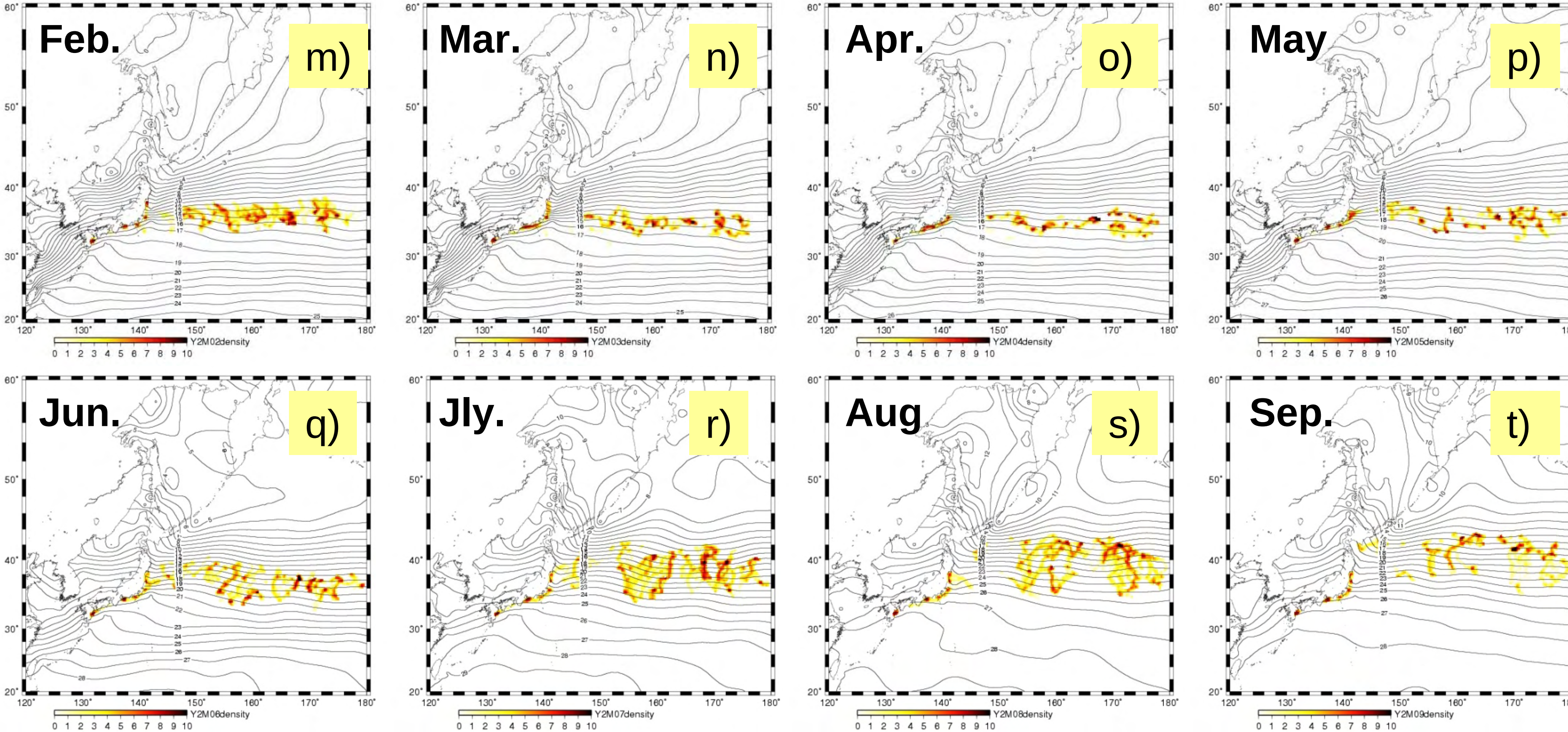
Feeding migration (age-0)

Okunishi et al. (2009)



feeding migration (age 1+)

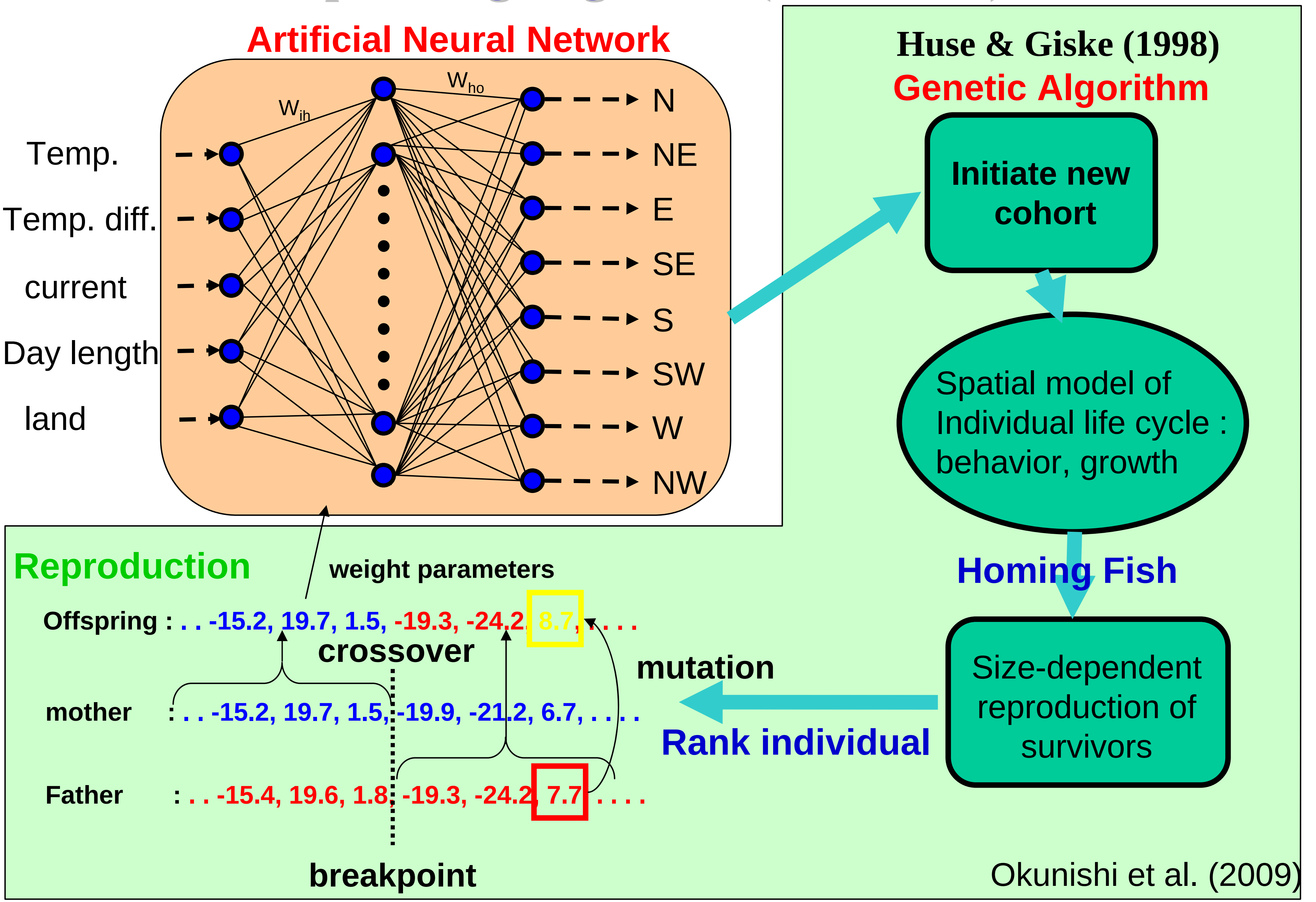
Okunishi et al. (2009)



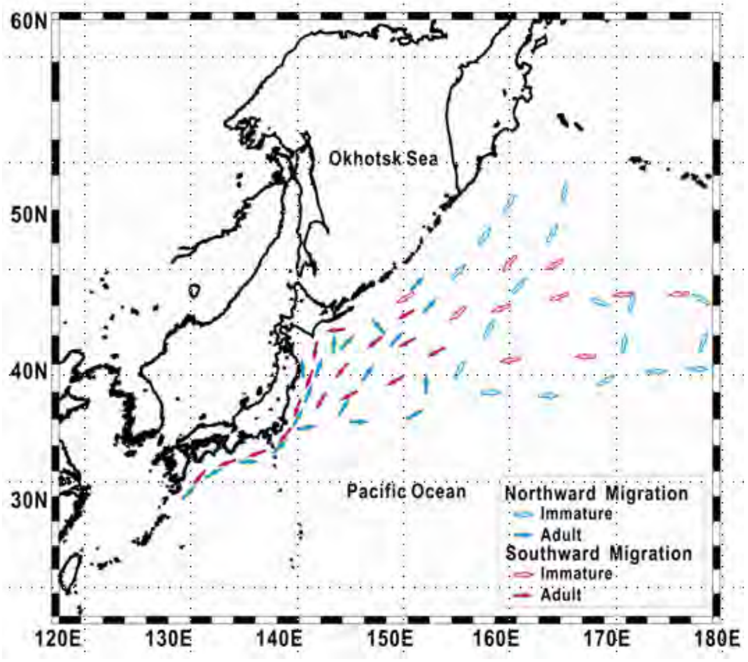
general pattern of feeding migration are reproduced by the fitness (optimal growth) migration algorithm.

Okunishi et al. (2009)

Spawning migration (ANN+GA)

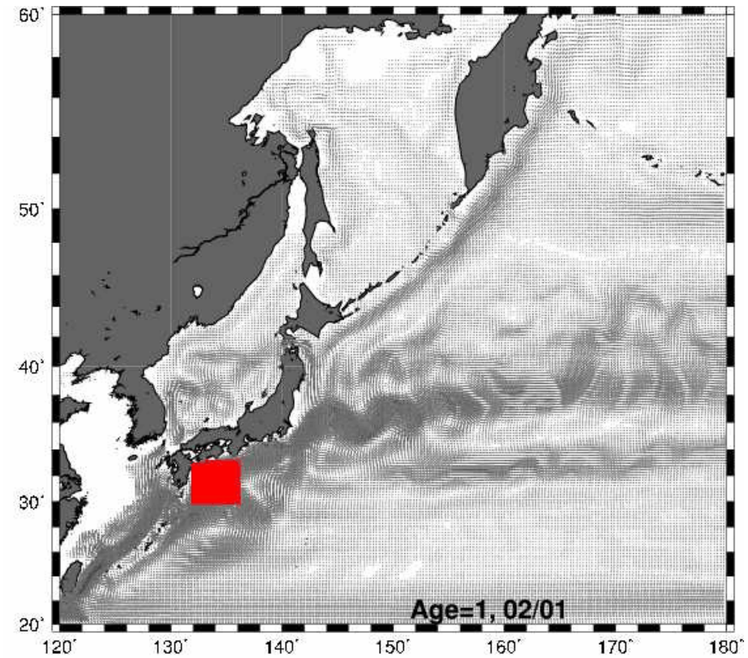


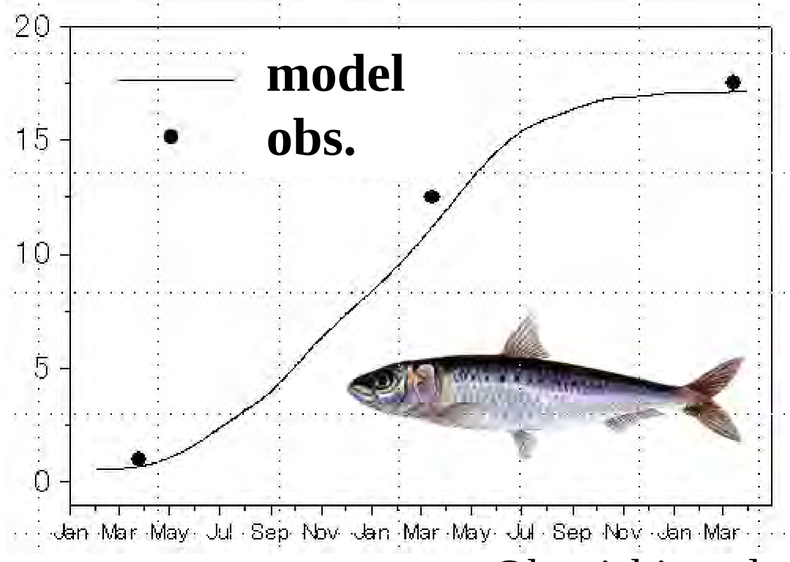
Sardine migration (GA+ANN+BP)



Schematic picture of sardine migration

Kuroda (1991)



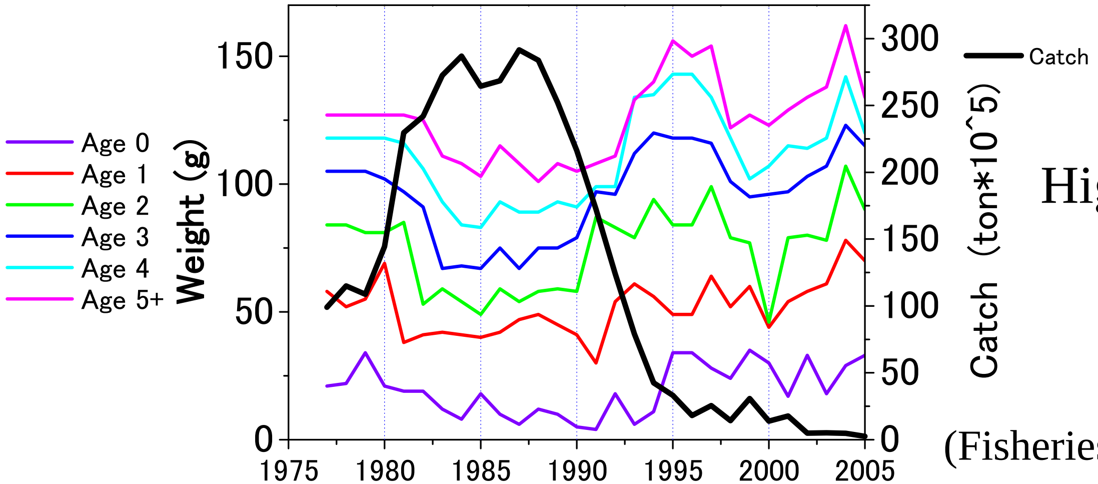


Realistic migration and growth are reproduced.

Okunishi et al. (2009)

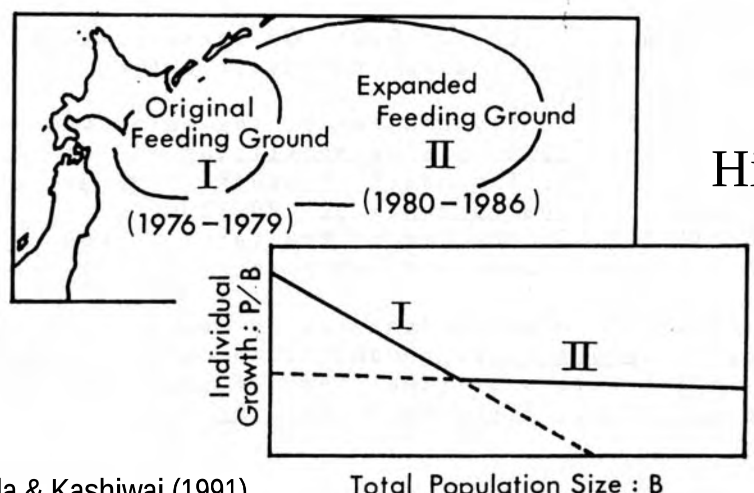
3. Density-dependence effect

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.

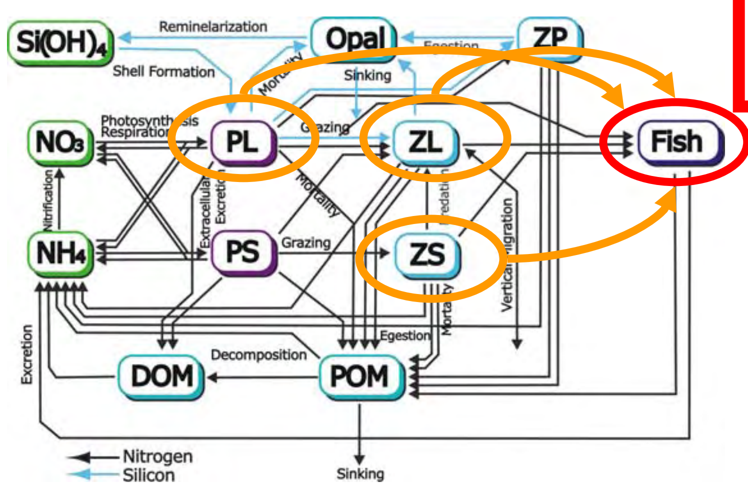
LTL Ecosystem Model NEMURO

1/4 x 1/6
prey plankton density

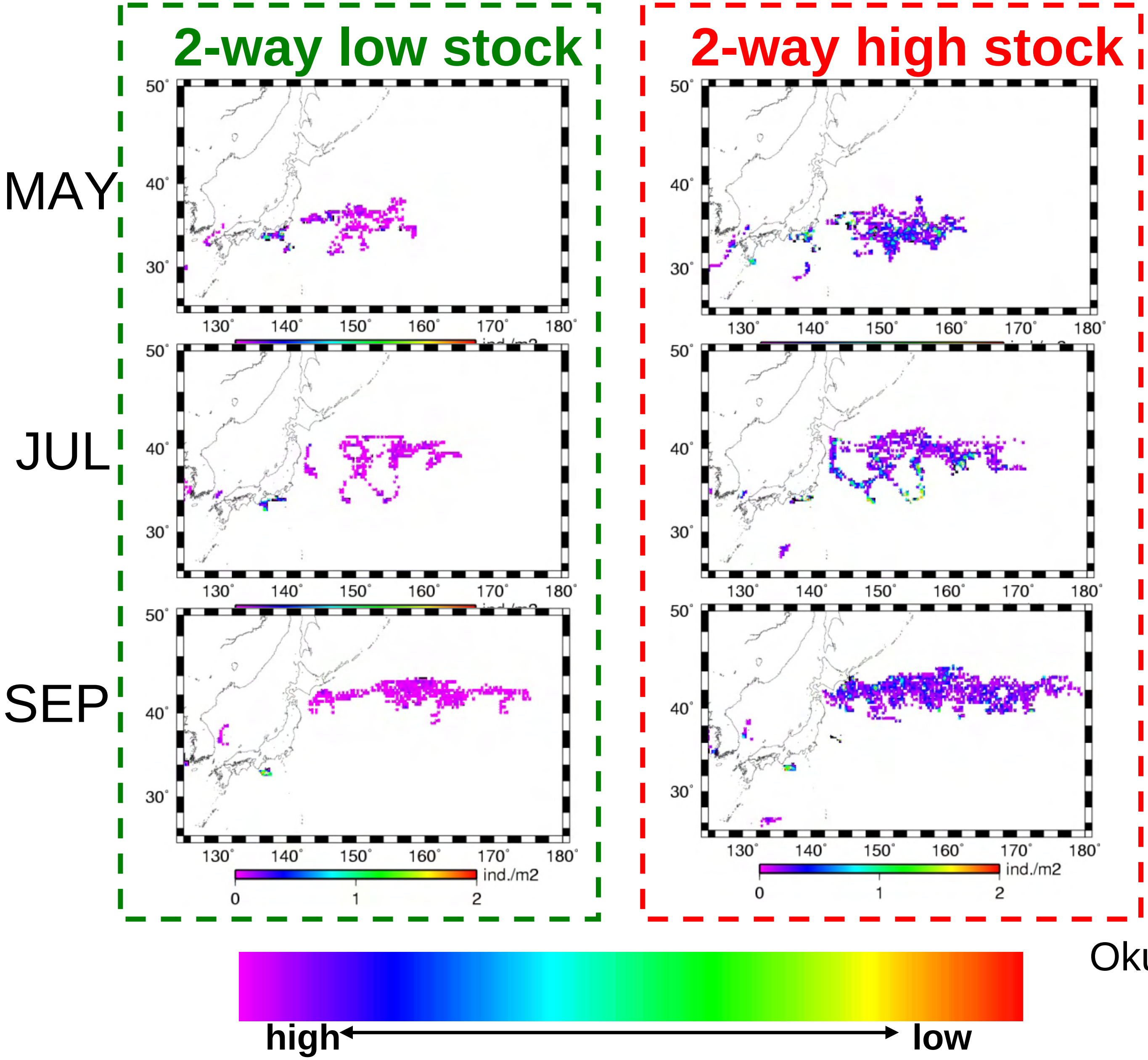
2-way

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

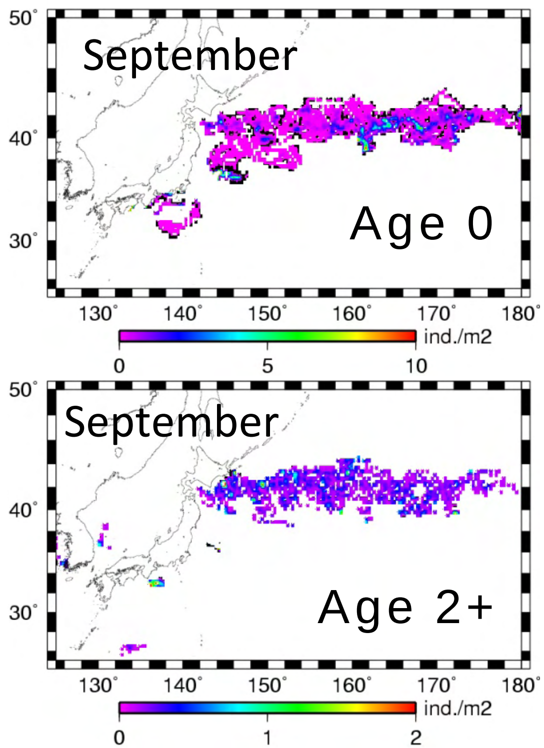
Model results explicitly support the density dependent effect hypothesis.

Okunishi et al. (in prep.)

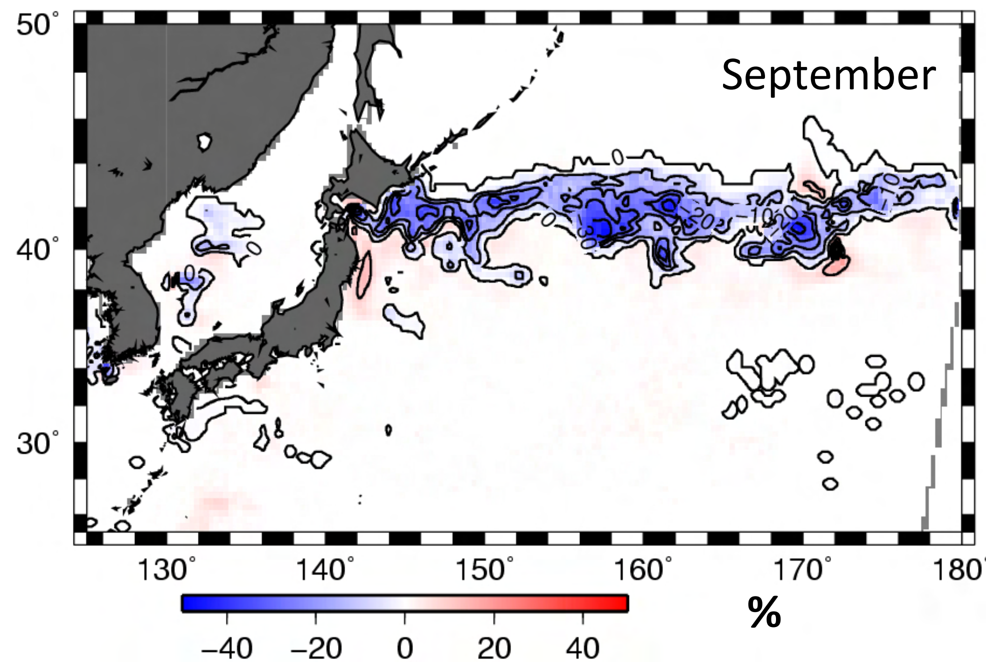
Density dependent effect on prey density

Okunishi et al. (in prep.)

Geographical Distributions



Anomaly of Forage density (PL + ZS + ZL)

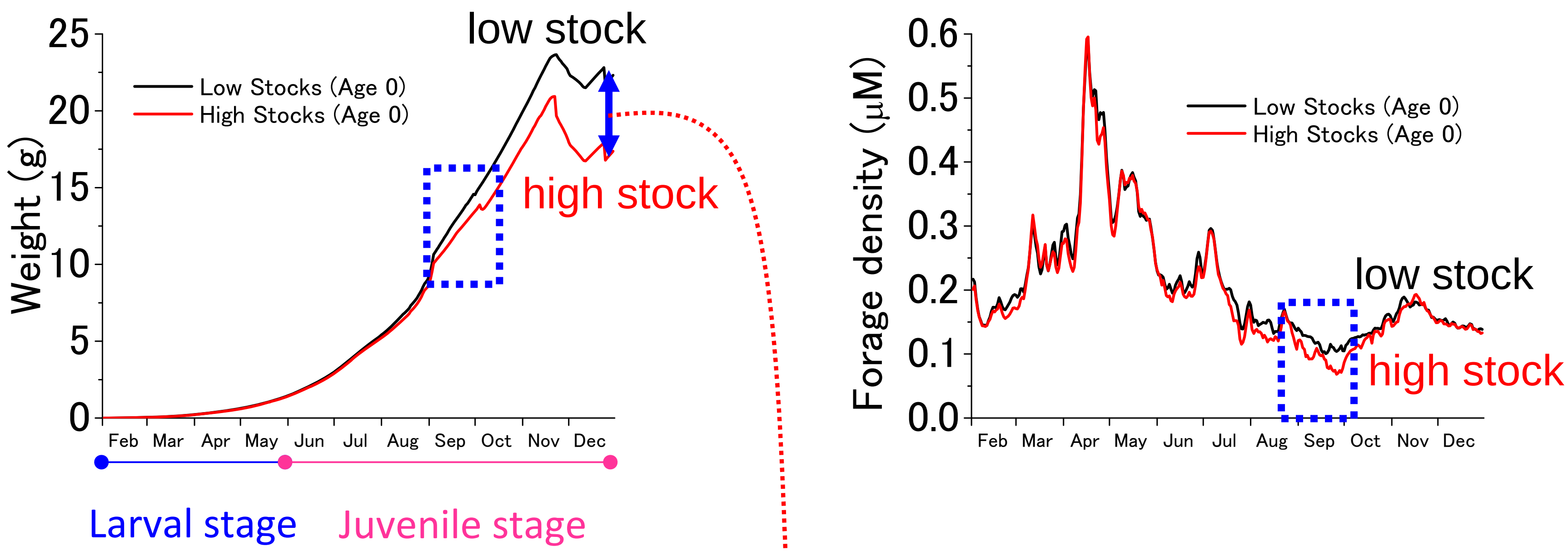


S3 (High stocks) - S2(Low stocks)

- 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-dependence.
- The model reproduced the expansion of sardine distribution by the effect of density-dependence.
- 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.

- Japanese sardine seems the dominant species playing a structuring role in ecosystem dynamics in the western North Pacific.
- Large fluctuation of Japanese sardine also influences on human being.

4. Influence on human being

Purse Seine Fishery; the main producer of sardine, mackerel and anchovy

- One of the biggest fisheries sectors in Japan.
- In the mid ’80s, about 72 operation units harvested 2.0-2.4 million tons/year.
- Managed by license from the Minister (5 years).

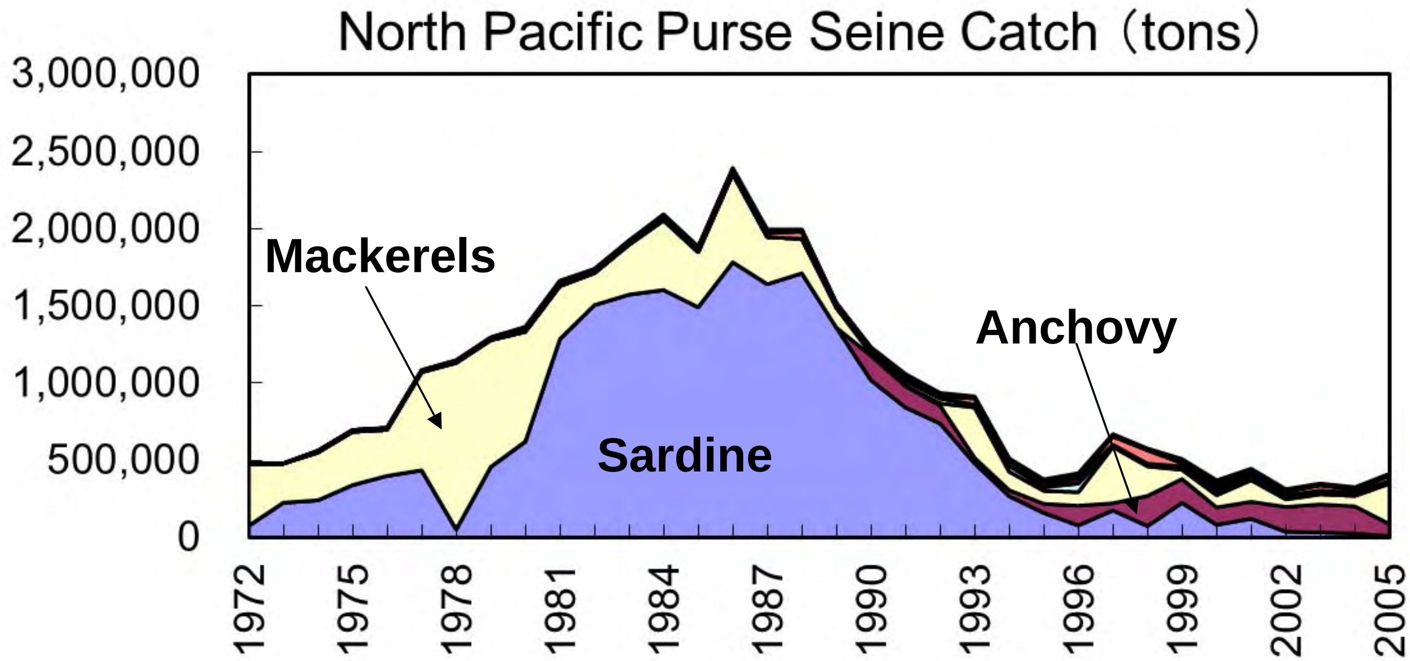
Main ship (net ship): 135t type

2* Transportation ship: 330t type

Search ship: 99t type

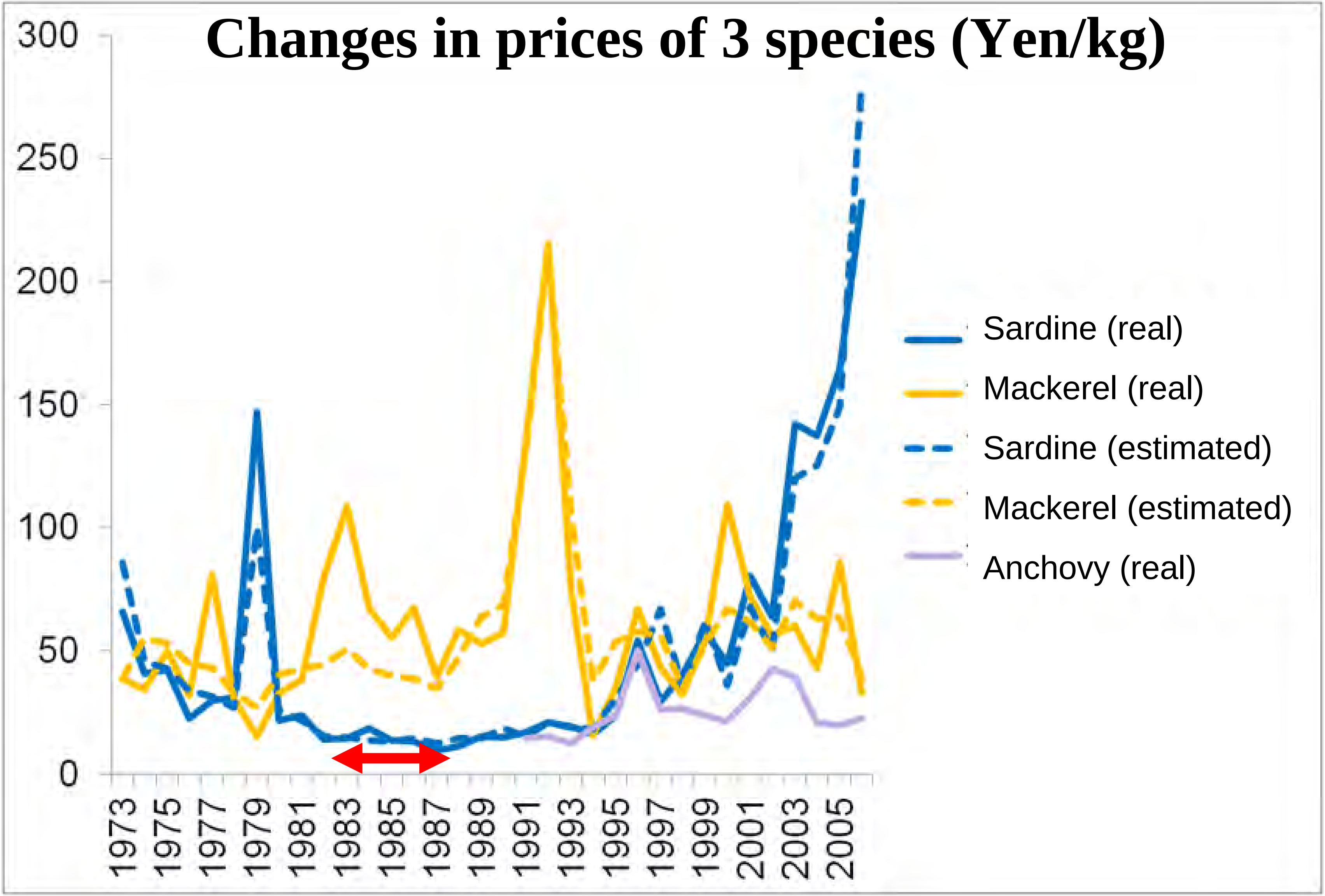
http://www.souhou.jp/fukushima

4. Influence on human being



- The peak in catch value was 1983 (JPY 67.3 billion).
- The peak in catch volume was 1986 (2.4 mill. tons).
- During '83 and '86, so many fish in the sea with low price in the market, and decreasing total income.
- Total number of nets (operation units) are regulated by licenses.

4. Influence on human being

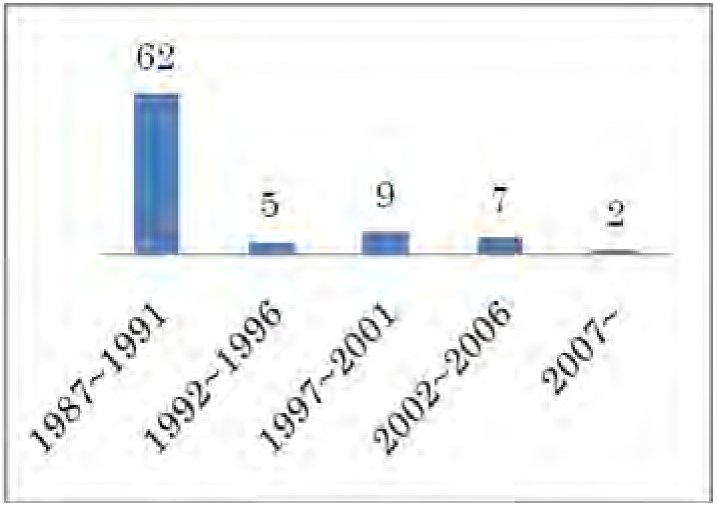


courtesy of Dr. Makino

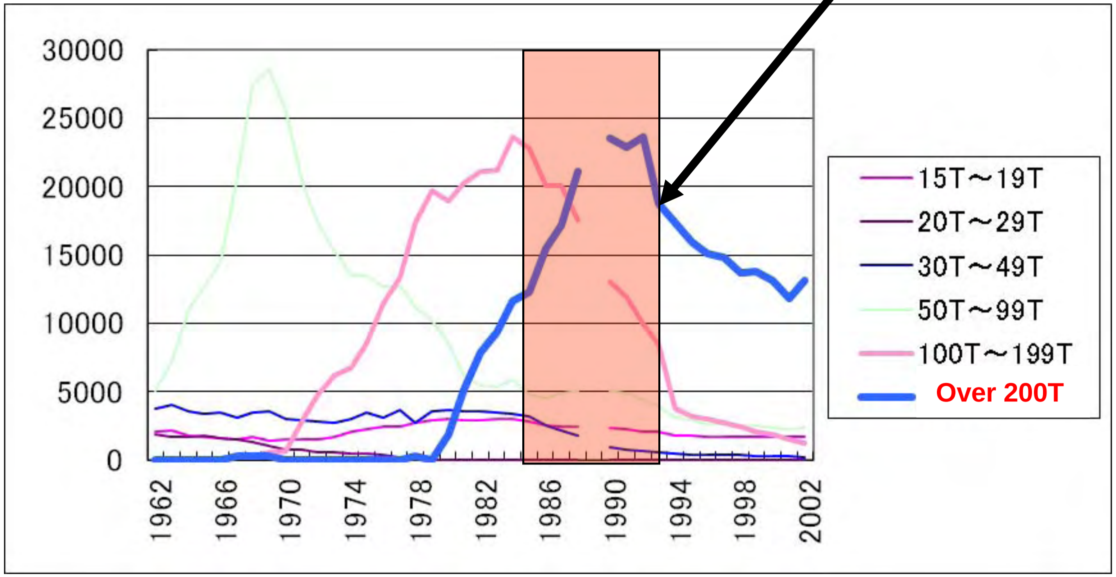
4. Influence on human being
Purse seiners' response

- They constructed many large-scale transport ships since the around the peak in catch volume (1986).
- Also the Japanese economy was in the economic bubble, and banks were very happy to lend money for purse seiners (Depreciation period was about 3-4 years at that time!)

Transport ship: 330t type



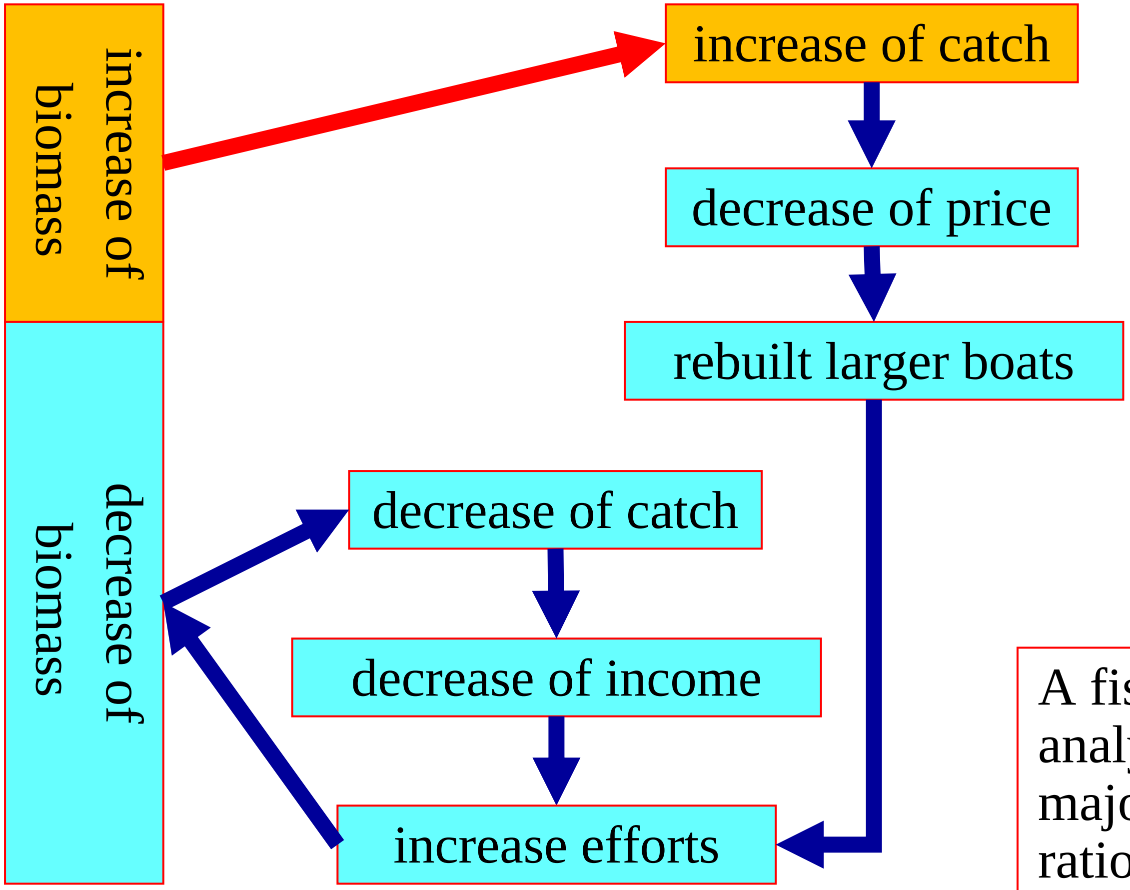
Number of vessel construction by the license period.



Total gross tonnes of transport ships by size class

courtesy of Dr. Makino

Summary for influence on human being



After the stock collapse, fishermen had to continue to catch sardine to refund.

As a result, excess catch of Japanese sardine accelerated the decrease of Japanese sardine and the economy of the fishery ports was damaged.

A fisheries management model analysis showed that there was no major decrease of self-sufficiency ratio of fish even if the building of the larger fisheries boats had been limited.

Summary

1) Large fluctuation of Japanese sardine seems to influence on zooplankton abundance

2) Large fluctuation of Japanese sardine seems to influence on sardine's weight decrease by the effect of density-dependent.

3) Large fluctuation of Japanese sardine seems to influence on expansion and reduction of sardine's distribution by the effect of density-dependent.

4) Japanese sardine seems the dominant species playing a structuring role in ecosystem dynamics in the western North Pacific.

5) Large fluctuation of Japanese sardine also influences on human being. Human's response may amplify the fluctuation. Appropriate management is important!

Disclaimers

However, our knowledge on species interaction including human being is still limited.

Disclaimers

1) We can put explanations on the past phenomena, however, we are still not able to predict future.

2) Species interactions (prey-predator) and fish behavior controlling factors are keys to understand ecosystem responses to the climate variability.

3) Model oriented field observations and laboratory experiments will accelerate model developments.

4) Since our management and prediction skills seems still immature, careful and continuing monitoring is needed.

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