3rd International Symposium: Effects of Climate Change on the World's Oceans
Session 4: Regional models for predictions of climate change impacts: Methods, uncertainties and challenges

Regional models for projections of climate change impacts on small pelagic fishes in the western North Pacific

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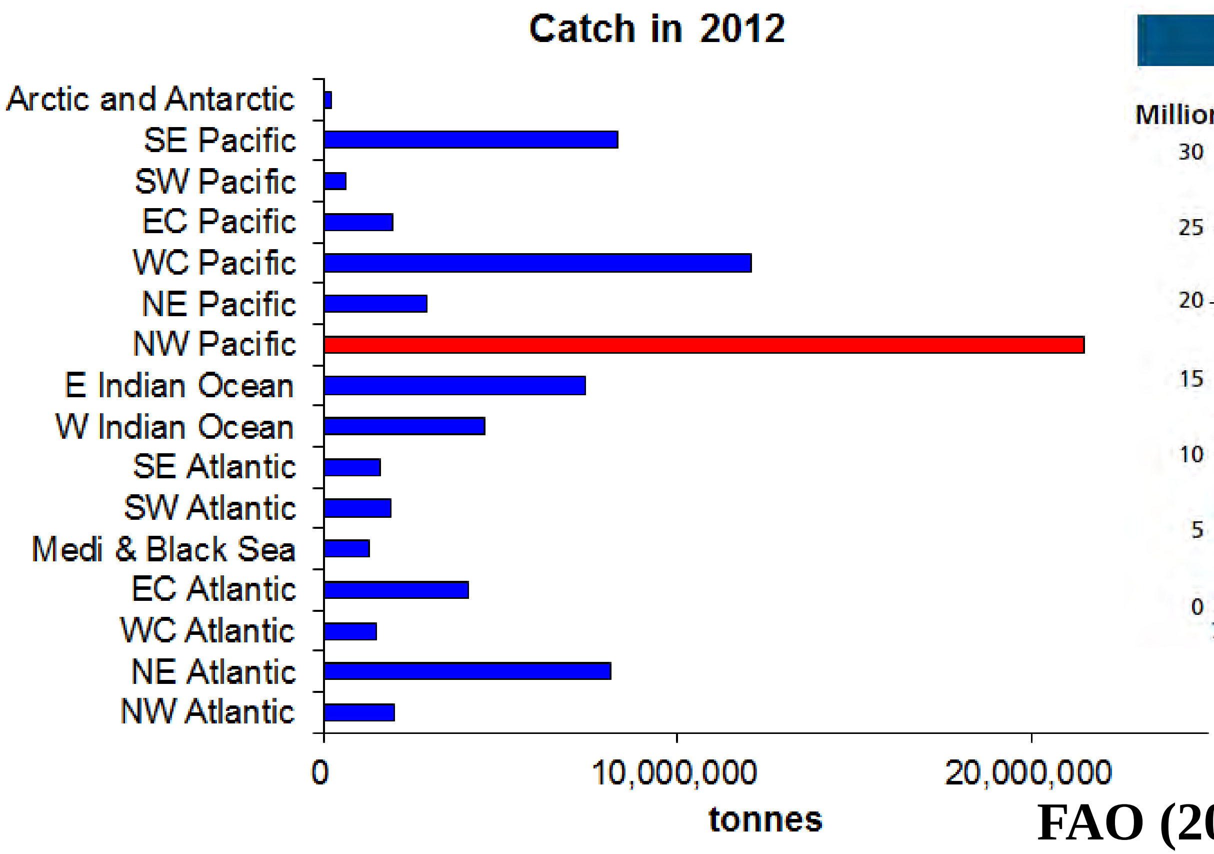
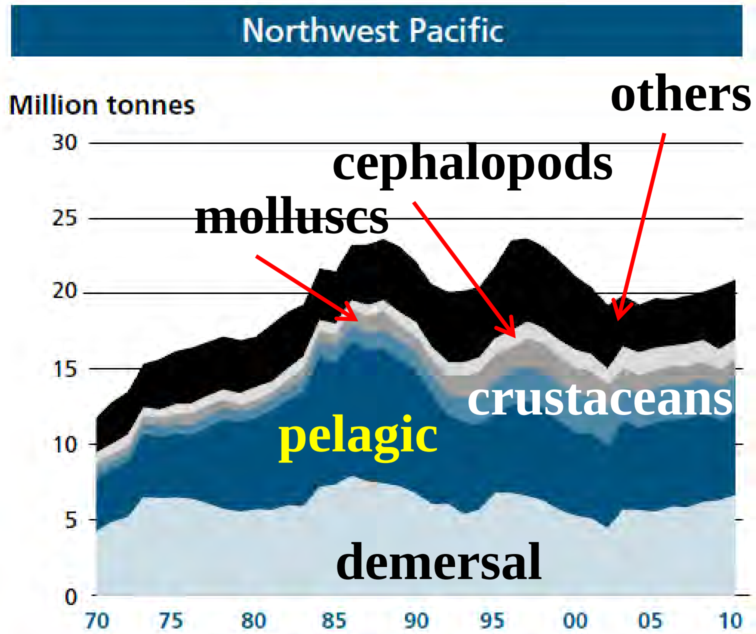
2. How to model small pelagic fish
3. example: Japanese sardine
4. example: Pacific saury
5. caveats & challenges
6. conclusion

1. Western North Pacific



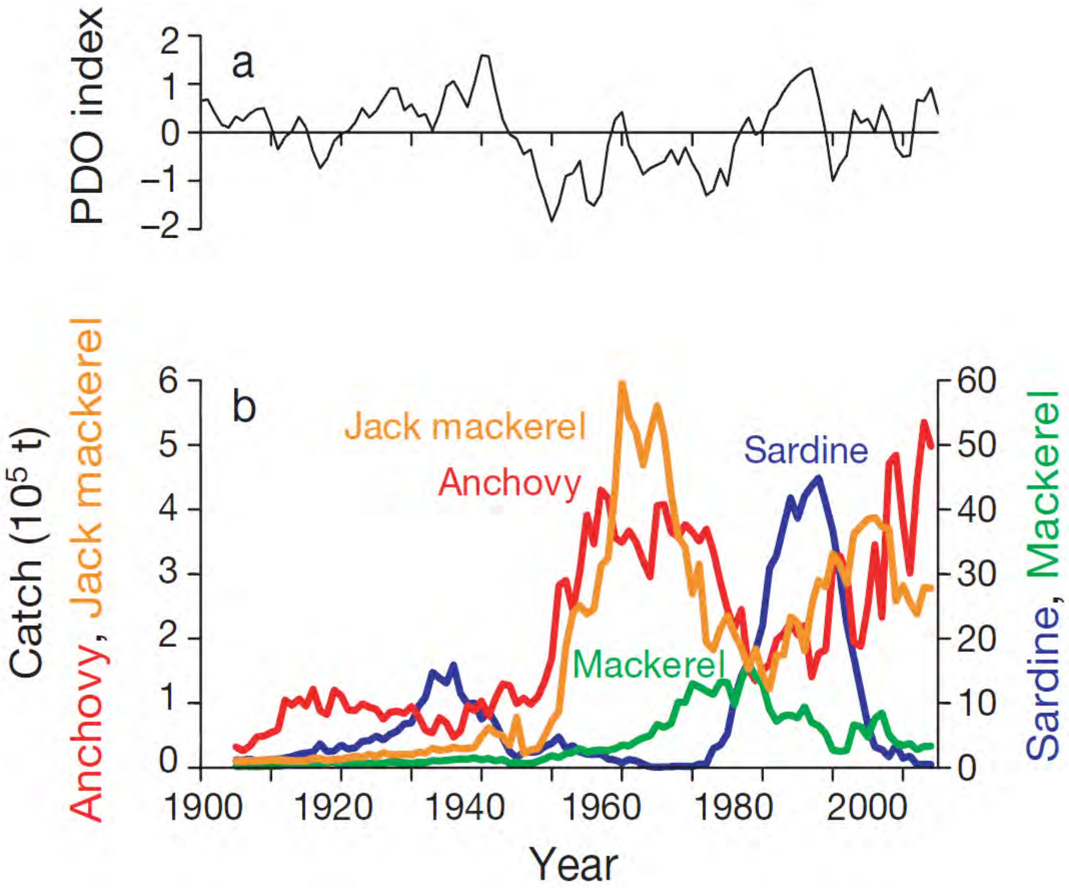
FAO (2014)



FAO (2012)

- Although the area of WN-Pacific occupies only 6 % of the world ocean, WN-Pacific products 25 % of catch of the world.
- Not only continental shelf but also offshore catch is quit large.

1. small pelagic fish in western North Pacific

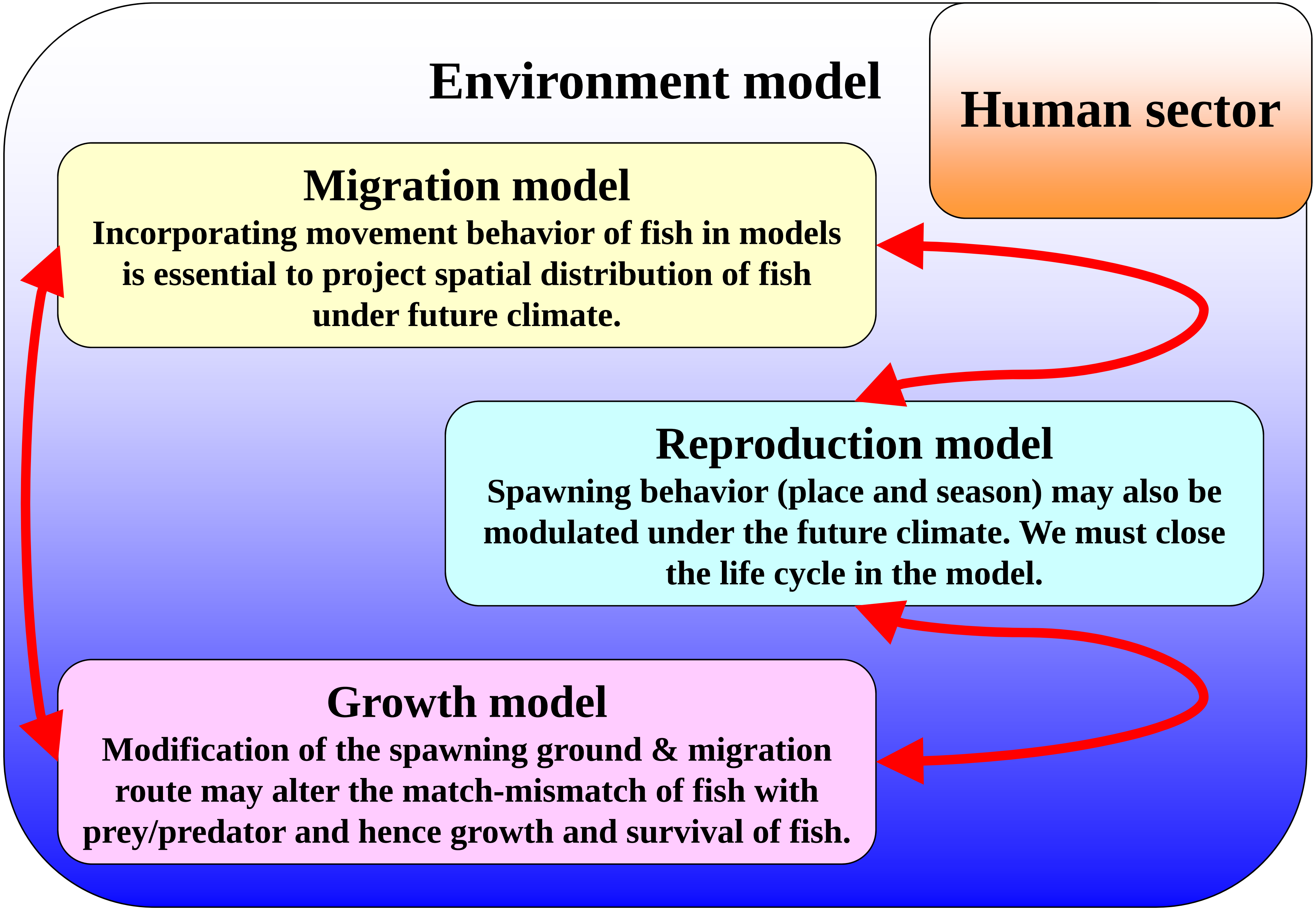


Takasuka et al. (2008)

Small pelagic fish in WN-Pacific have shown clear species alternations corresponding to basin-scale climate variability.
A big question is how the small pelagic fish in the WN-Pacific responses to climate change. It is an important issue related to the future world food security.

How to model the small pelagic fish response to climate change?

key elements to project fish responses

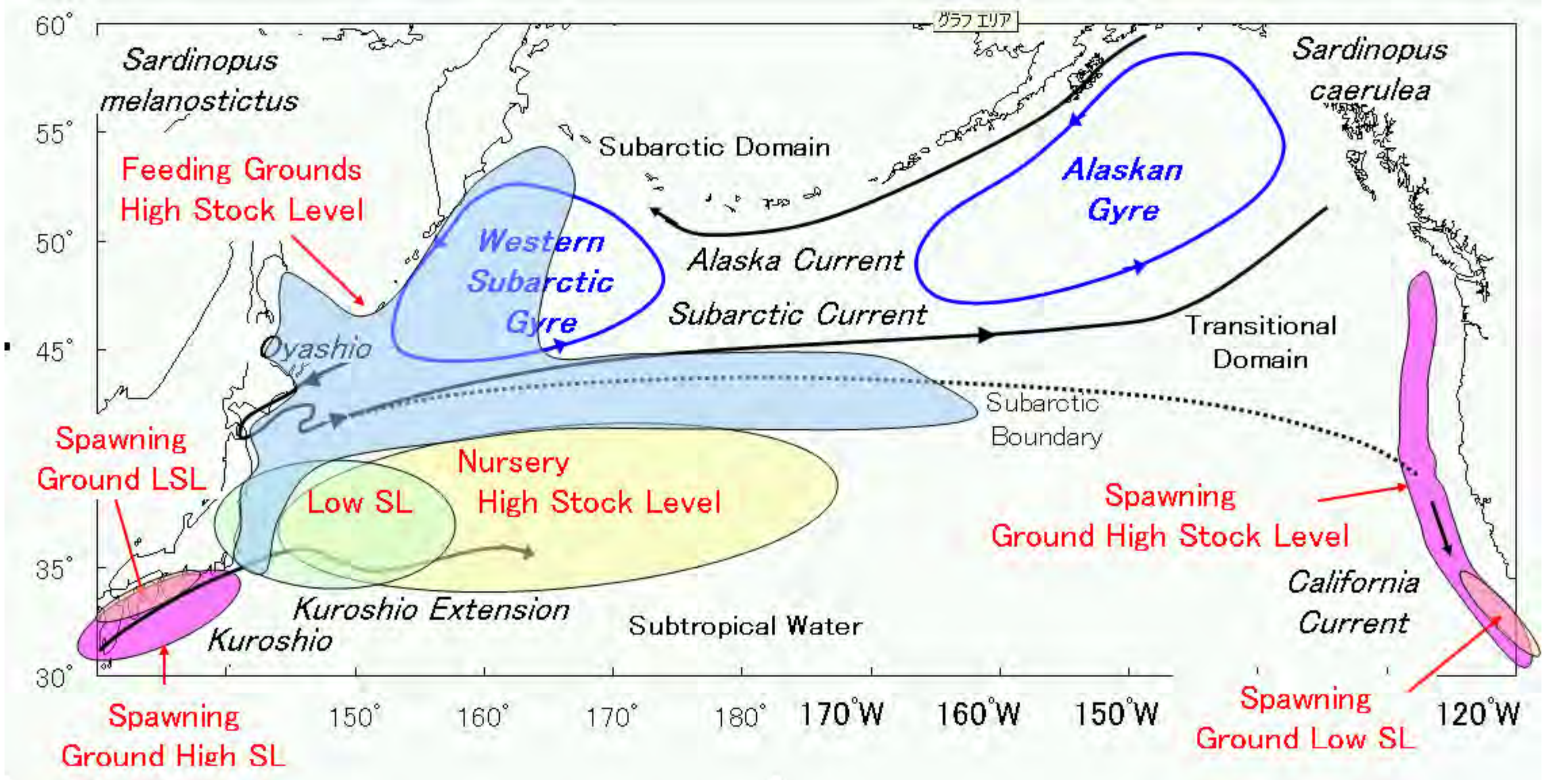


How to model the small pelagic fish response to climate change?

example 1: Japanese sardine

photo from http://abchan.job.affrc.go.jp/

Japanese sardine (*Sardinops melanostictus*)



Yatsu & Kaeriyama (2005)

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

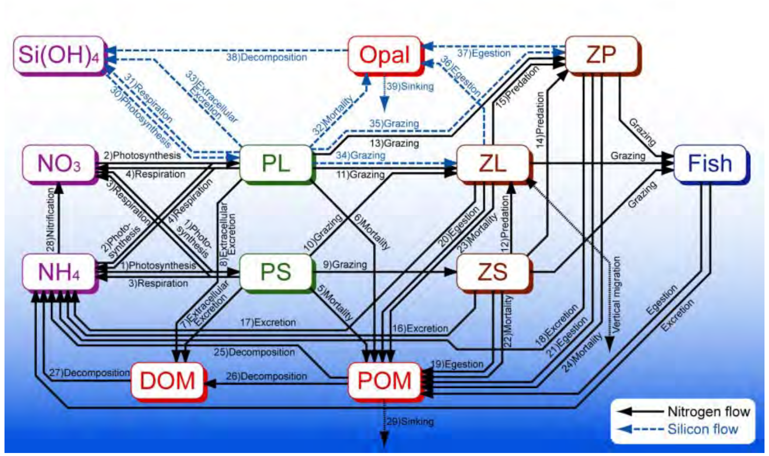
satellite derived
sea surface current
sea surface temperature

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.)

growth model

Bioenergetics model (Wisconsin model) is major solution.

Ney (1993)

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

change of weight

C: consumption

R: respiration
(loses through metabolism)

S: specific dynamic action
(digesting food)

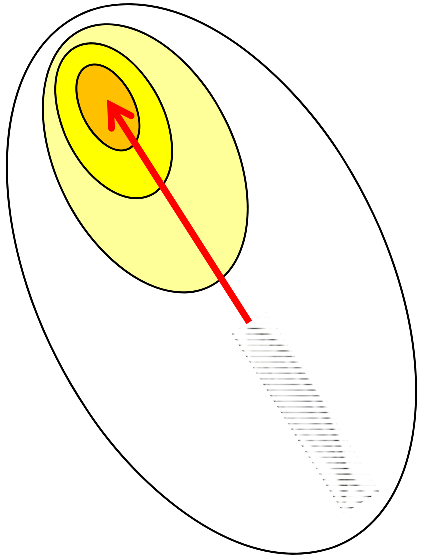
F: egestion

E: excretion

P: egg production

The model is not simple.
Each term is a function of weight, water temperature, prey density, etc.

migration algorism



<u>1. Feeding migration</u>: Fitness algorithm

Toward the most preferable place.

Growth index estimated by the bioenergetics model was used for measure.

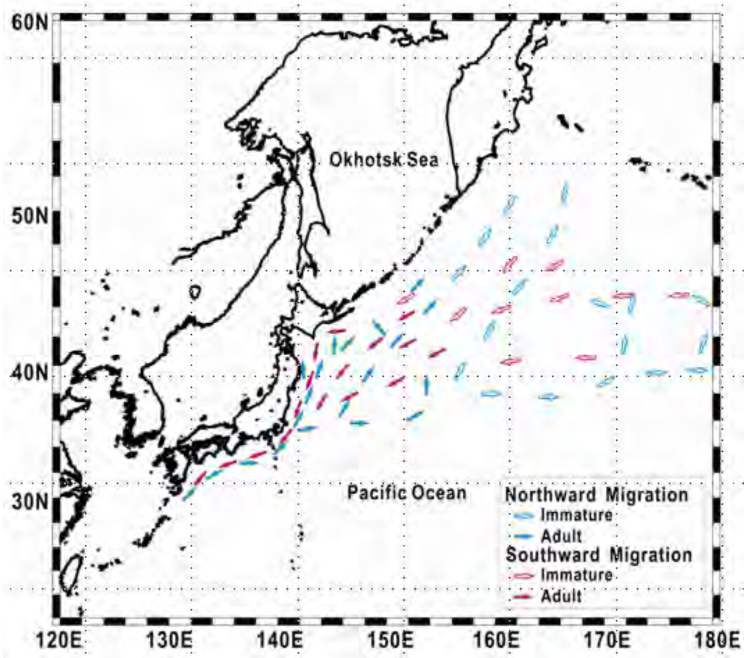
<u>2. Spawning migration</u>: Artificial neural network (ANN)

Migration direction was learned using ANN with five environmental factors as input signals

SST, SST change, current, day length, land.

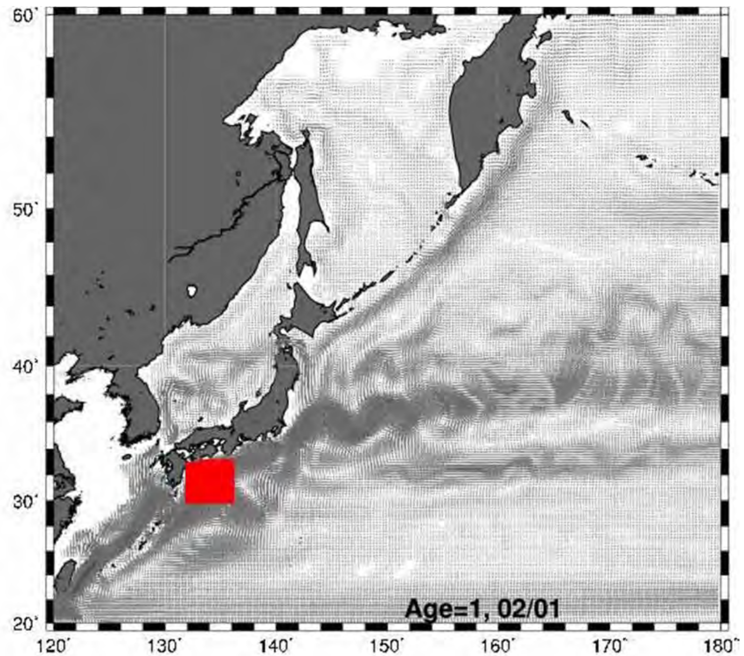
To seek optimal parameter of ANN, Genetic algorism was used.

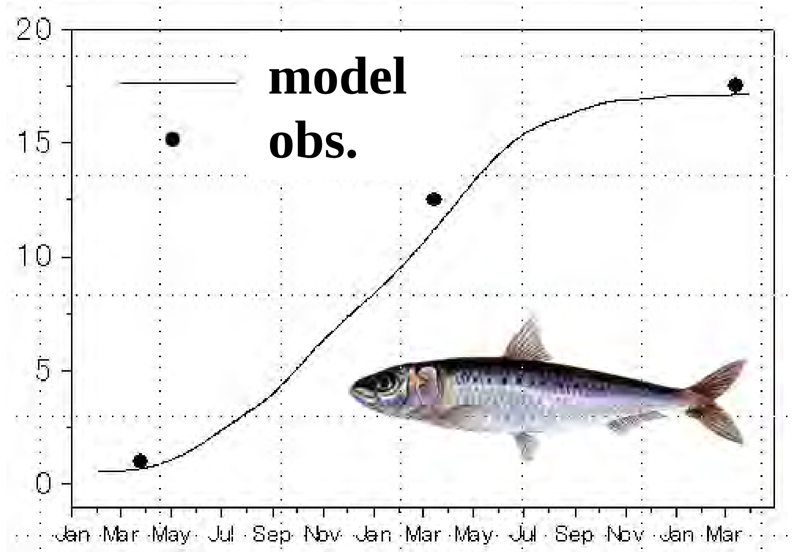
Sardine migration model



Schematic picture of sardine migration

Kuroda (1991)



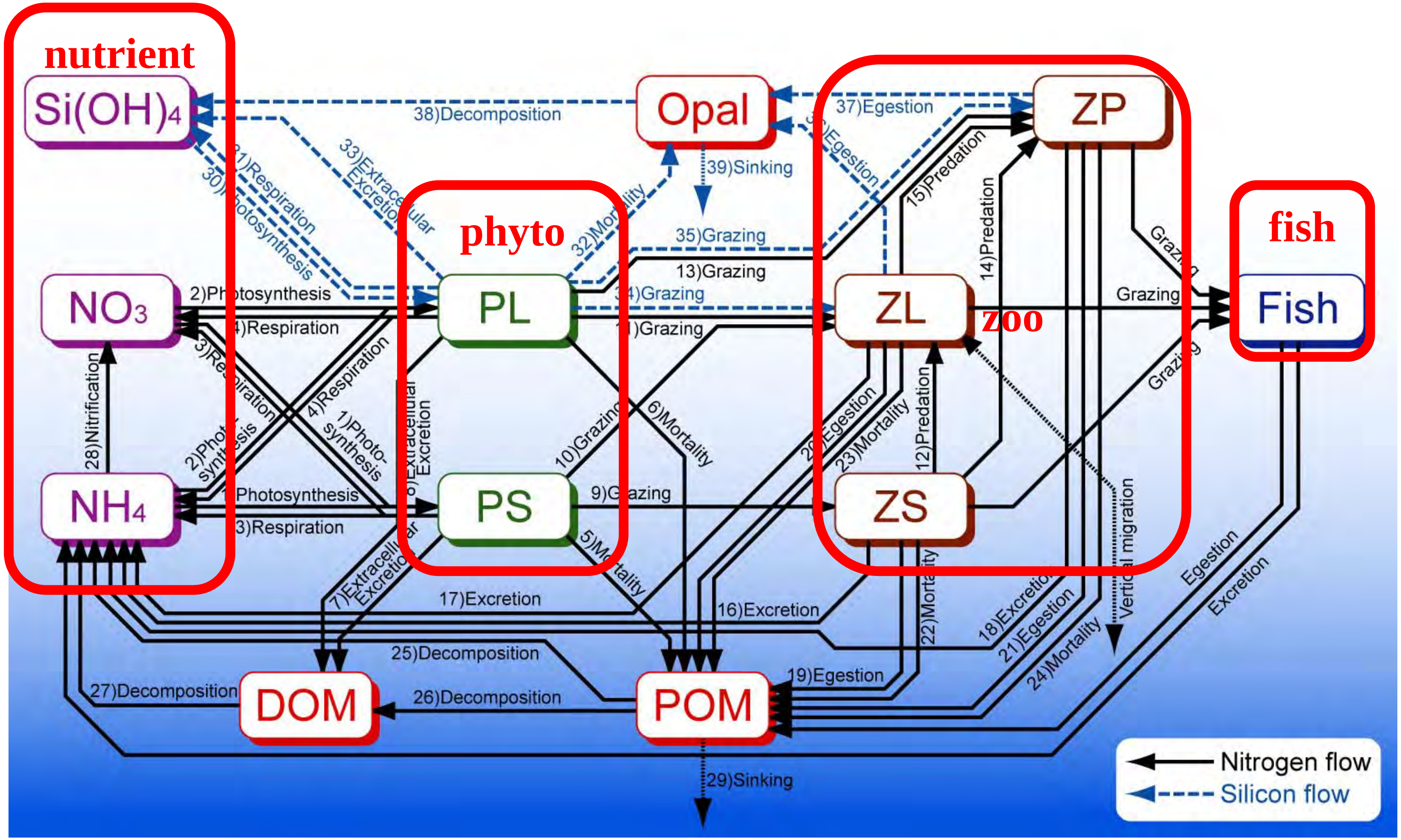


Okunishi et al. (2009), Ecol. Model.

Realistic migration and growth are reproduced.

Fish growth model coupled to NPZD ecosystem model

NEMURO.FISH



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

Q1. Response to future climate change

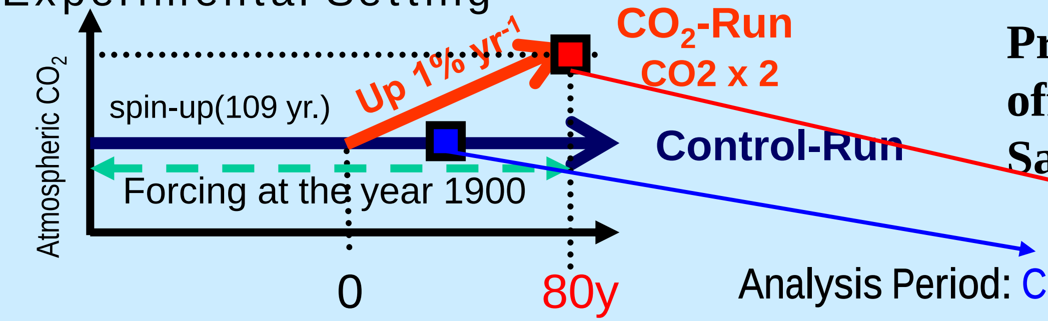
Climate model

Okunishi et al. (2012), Climatic Change

MIROC 3.2 (The CCSR/NIES/FRCGC Coupled Ocean-Atmosphere GCM)

Horizontal Resolution (Ocean Part): 1/4 x 1/6 degree

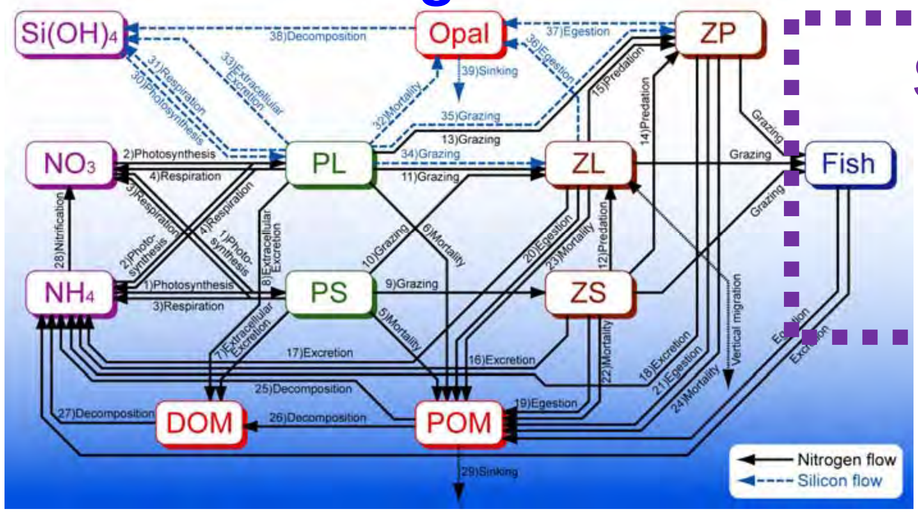
Experimental Setting



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

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

NPZD + fish growth model



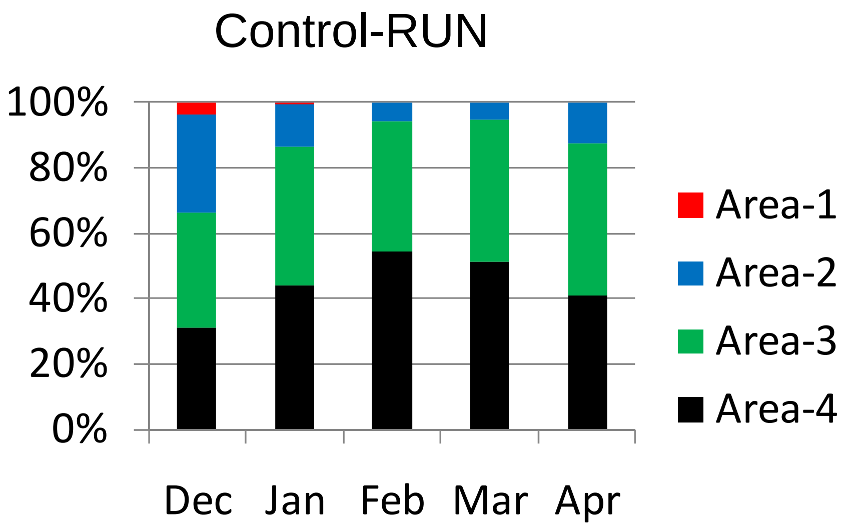
Sardine Migration Model

Okunishi et al. (2009)

We will focus on spawning ground and pre-mature adult distribution.

Spawning grounds

Okunishi et al. (2012), Climatic Change



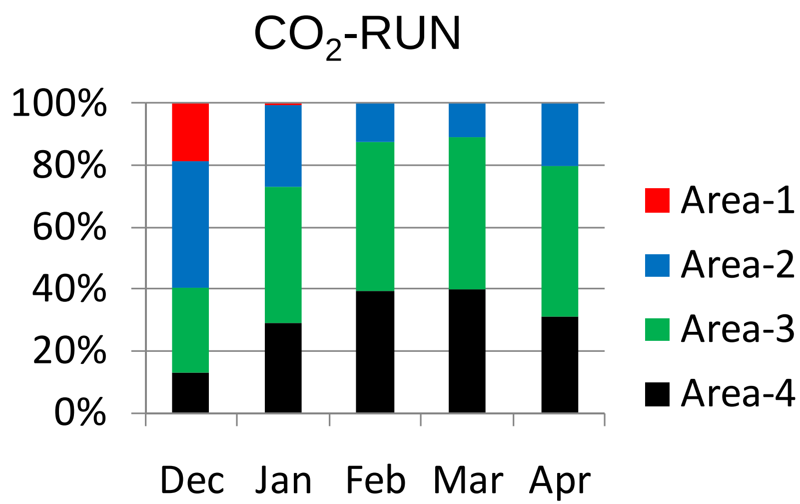
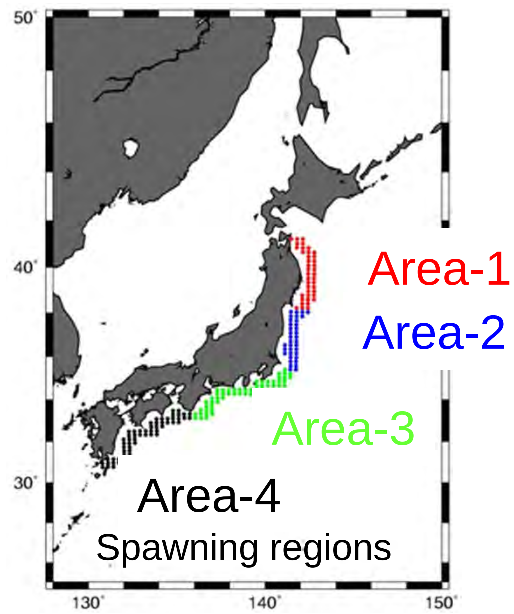


Fig. Proportion of hatched numbers in the four spawning regions

Spawning condition: SST 15- 21°C
Dec – Apr

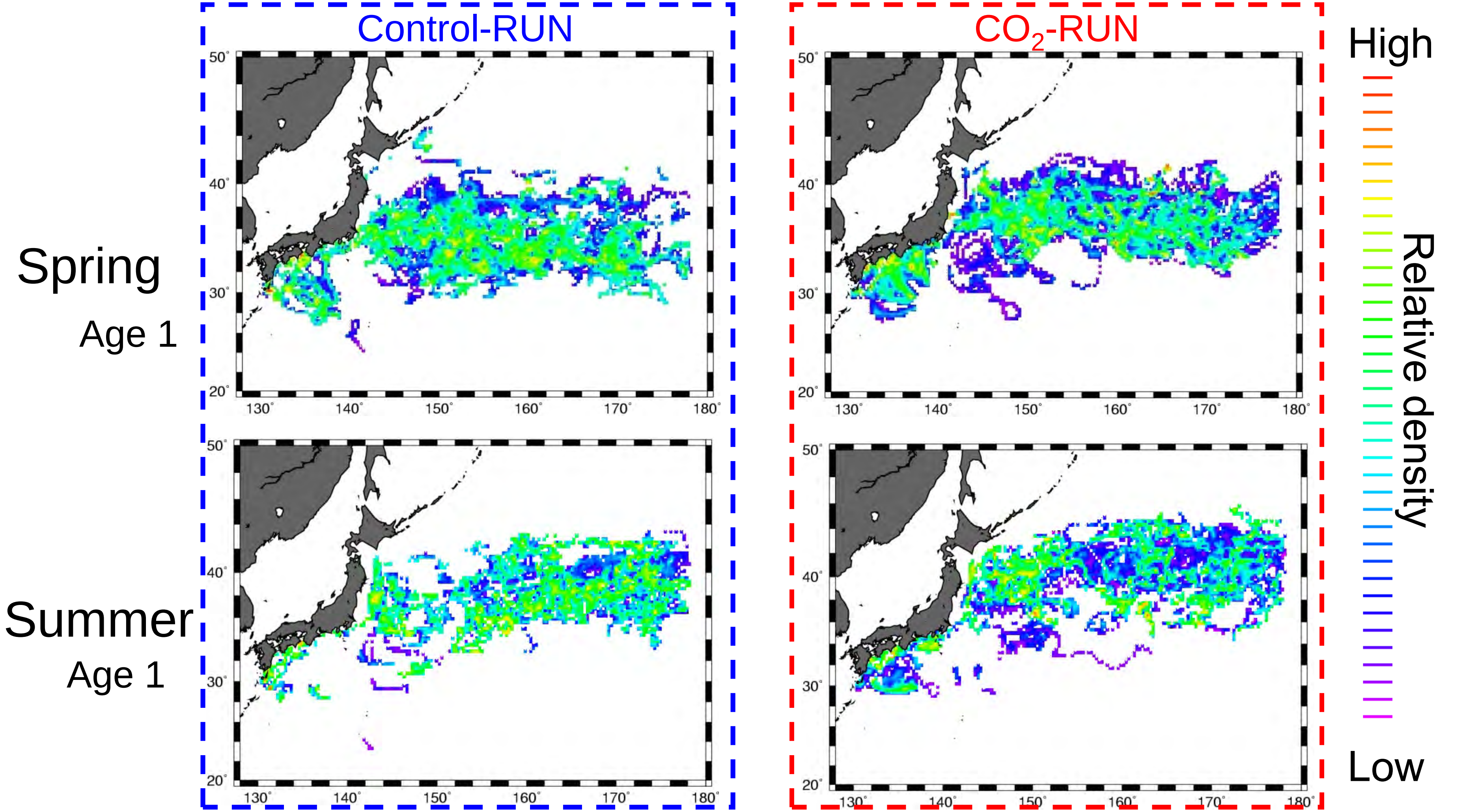
Projection

Spawning grounds shifted to north-eastward.



Change in geographical distribution

Okunishi et al. (2012), Climatic Change



Projection: **The distribution shifted northward. The size of sardine did not change since they compensate food by northern migration.**

How to model the small pelagic fish response to climate change?

example 2: Pacific saury

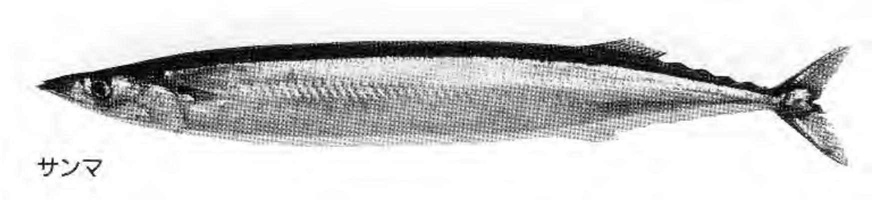
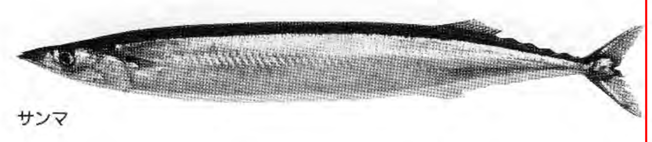


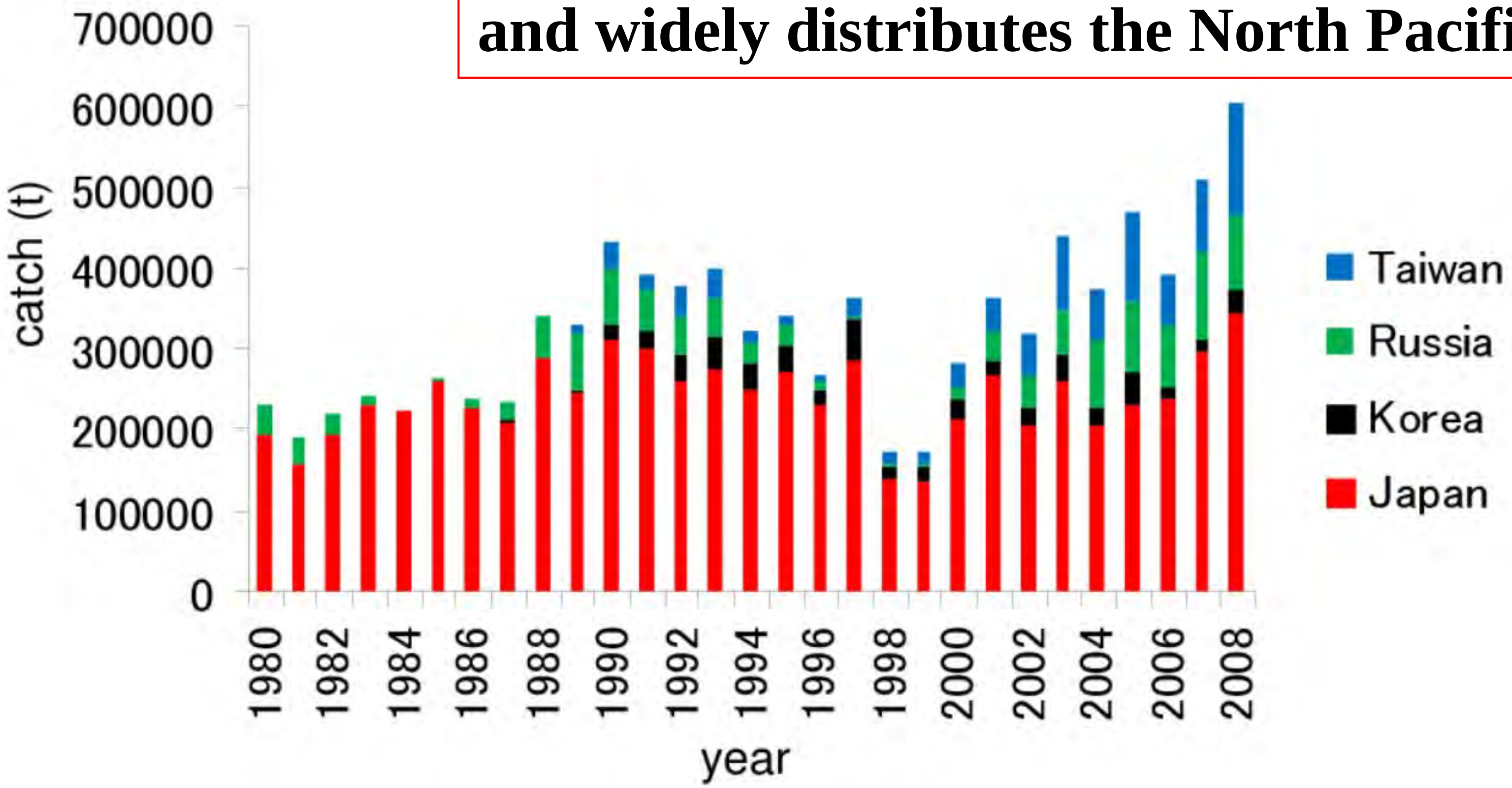
photo from http://abchan.job.affrc.go.jp/

In the sardine example, an eddy permitted climated model was used.
In the saury example, an eddy resolving regional model is coupled.

Pacific Saury

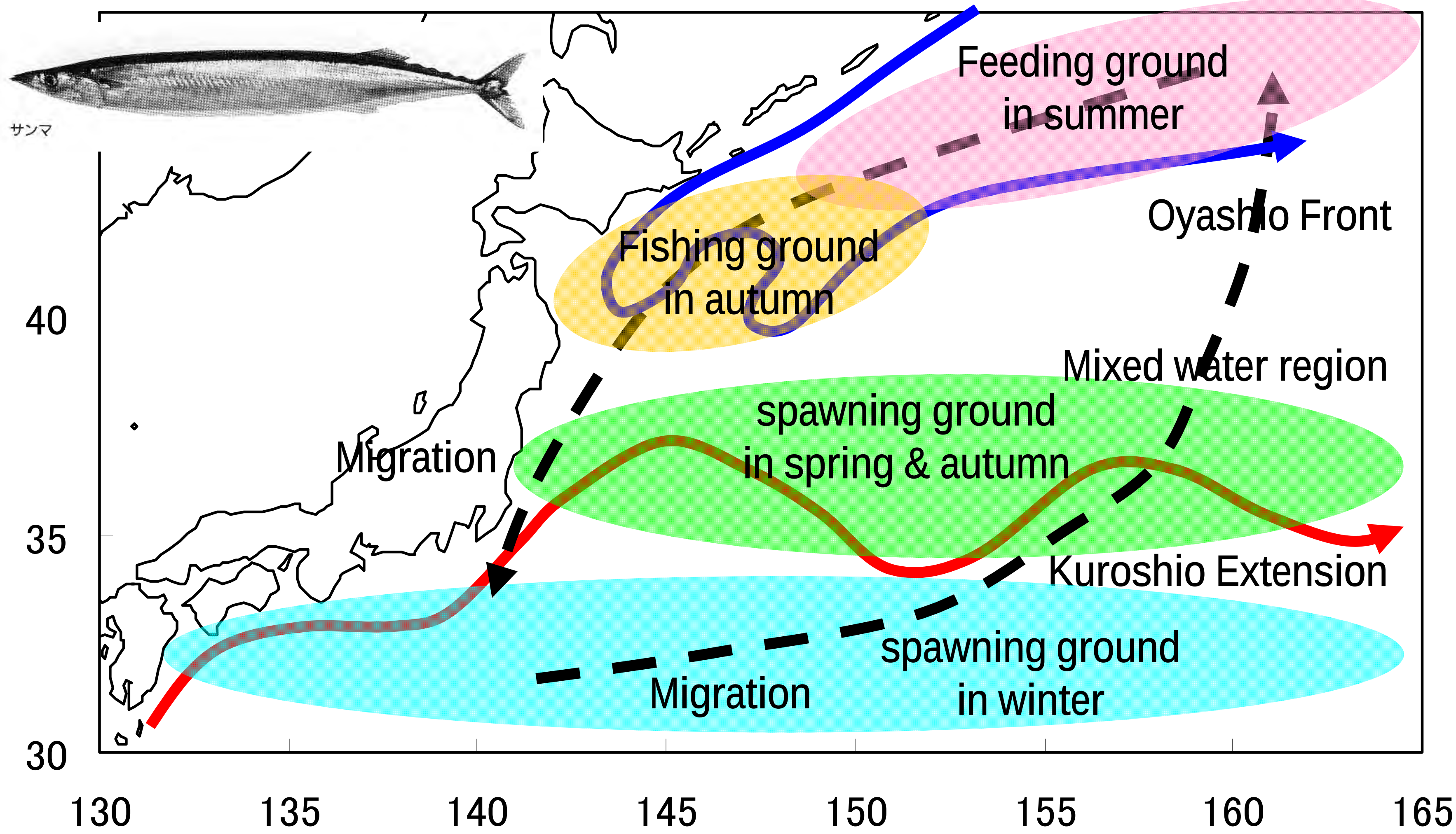


Pacific saury is one of the dominant small pelagic fish in the northwestern Pacific and widely distributes the North Pacific.



Ito et al. (2013, ICES-JMS)

Life History of Pacific Saury with Oceanographic Features

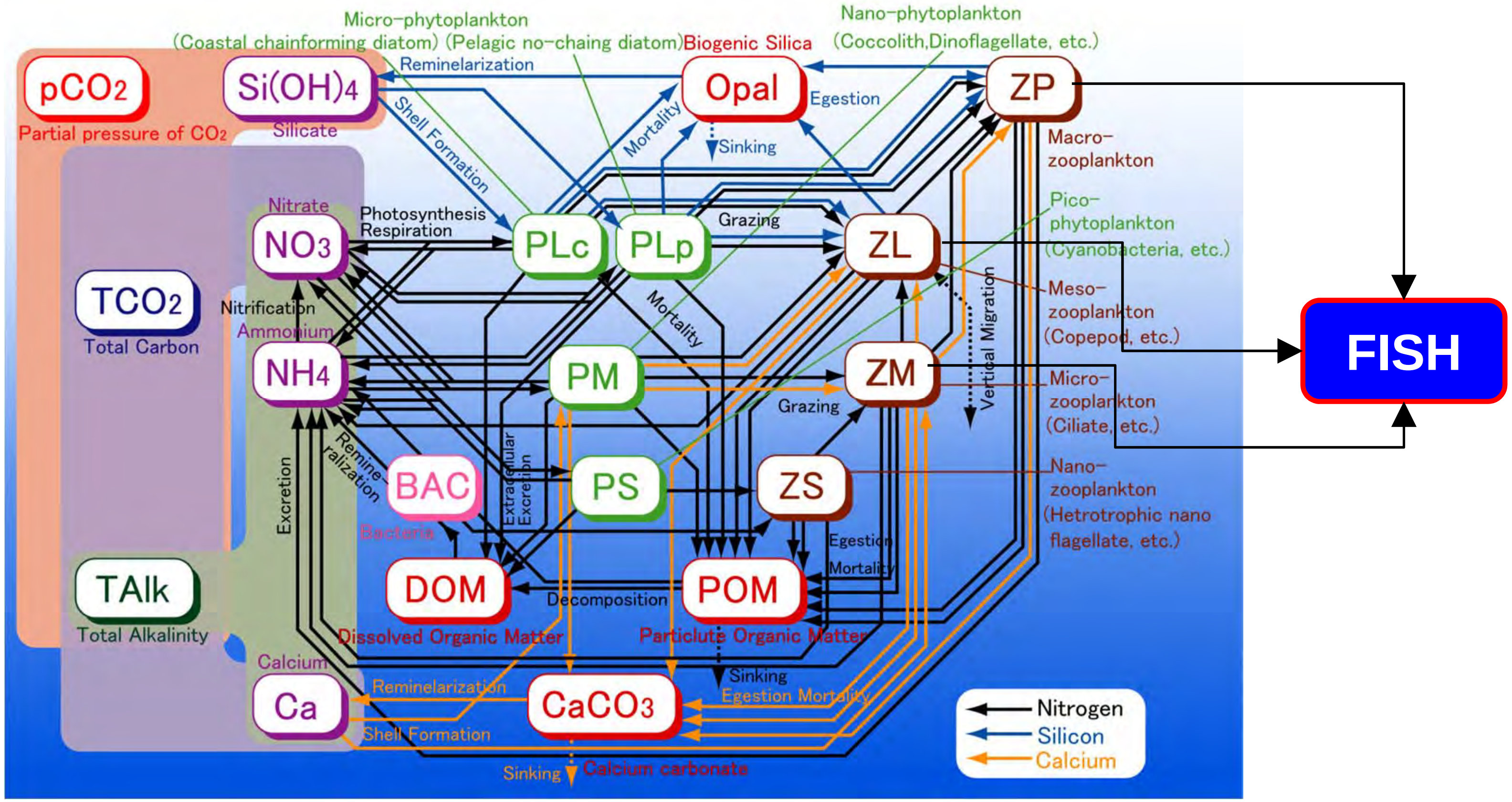


Modified from Ito et al. (2004a, Fish. Oceanogr.)

Pacific saury is one of the dominant small pelagic fish in the northwestern Pacific and widely distributes the North Pacific.

eNEMURO

extended North Pacific Ecosystem Model for Understanding Regional Oceanography



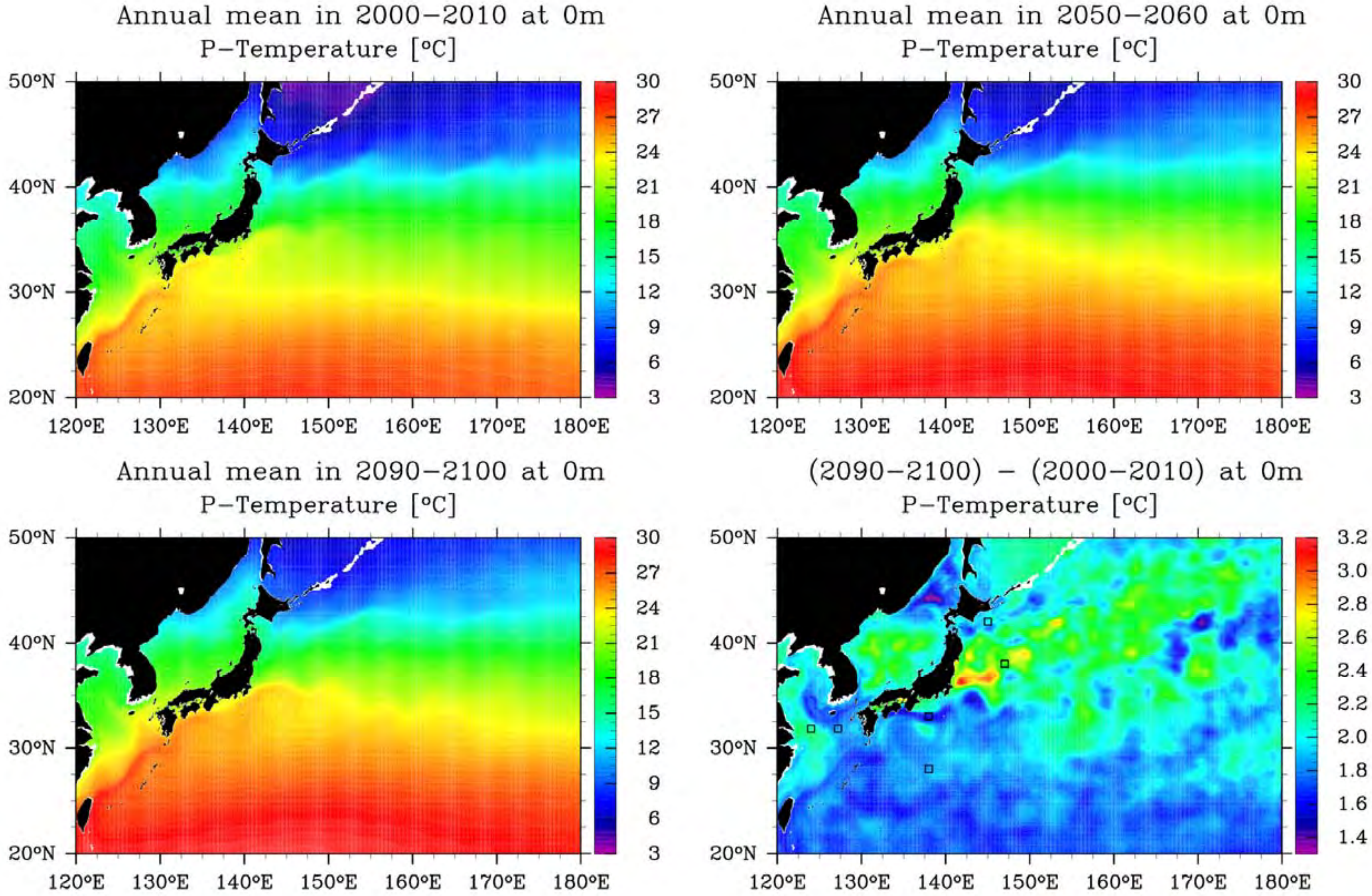
Courtesy of Prof. Naoki Yoshie

Coupled to C-HOPE (1/16 degree horizontal resolution model).
Forced by MIROC-high output with A1B scenario.
Fitness feeding migration and larvae fitness spawning migration.

CHOPE-eNEMURO (Global warming exp.)

Komatsu et al. (in prep.)

SST

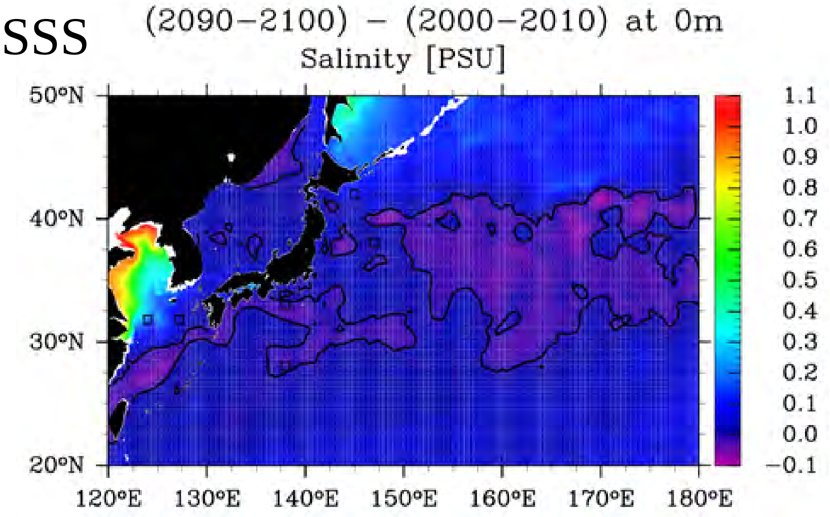


SST increased more than 2.5℃ in the mixed water region.

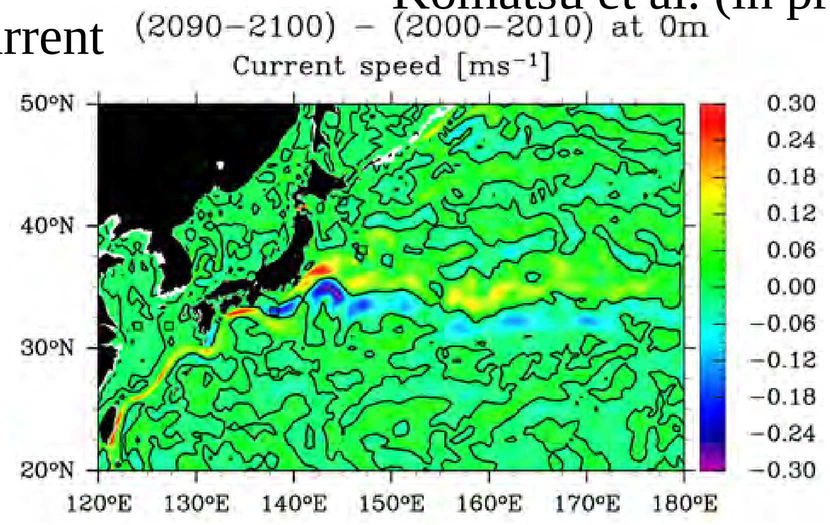
CHOPE-eNEMURO (Global warming exp.)

Komatsu et al. (in prep.)

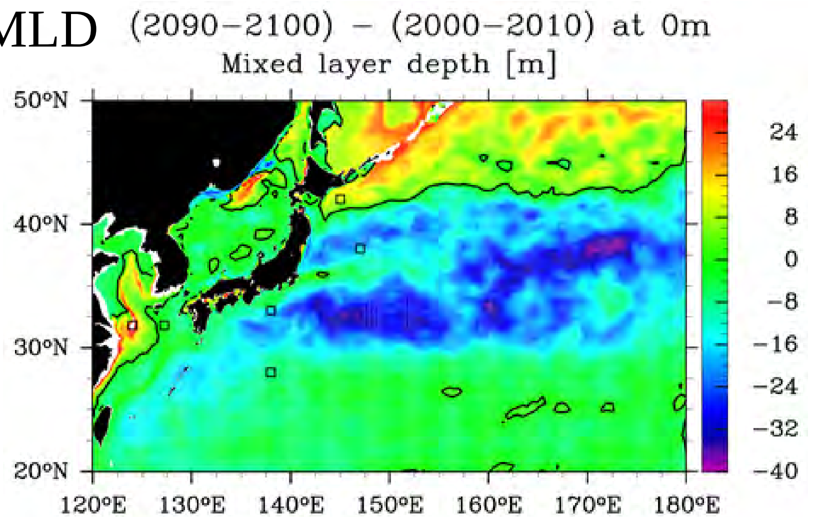
SSS



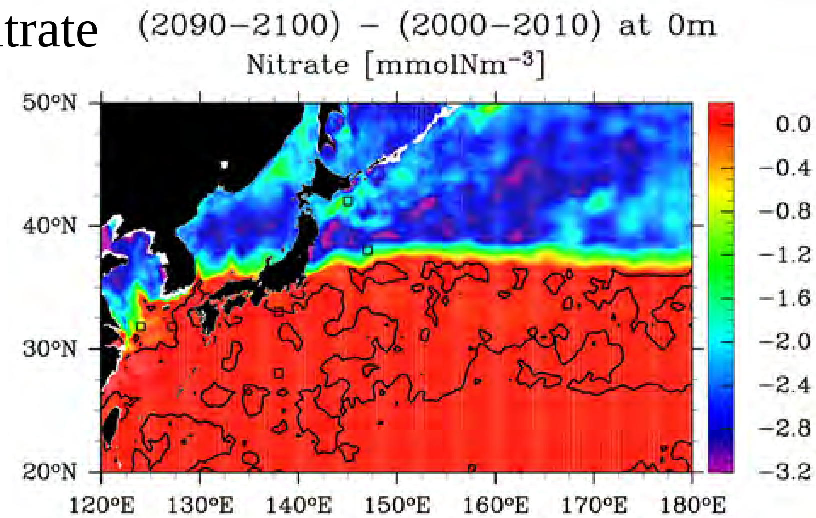
current



MLD



Nitrate

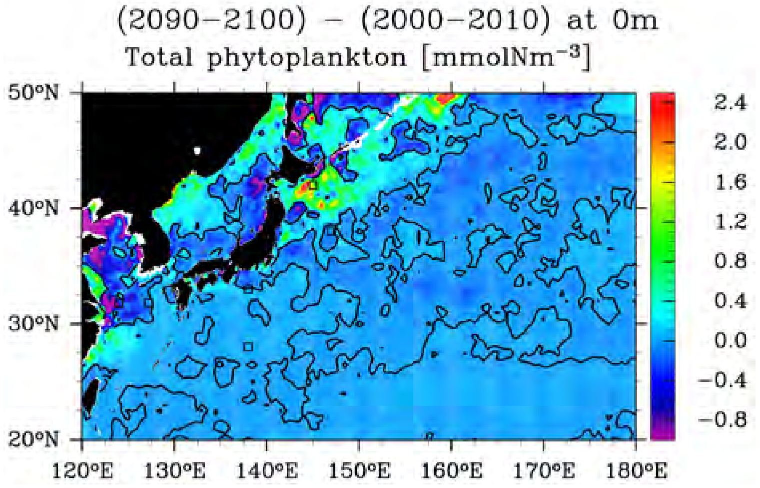


Decrease in salinity, spin up of Kuroshio,
Decrease in MLD and nutrient concentration in the mixed water region and subarctic area.

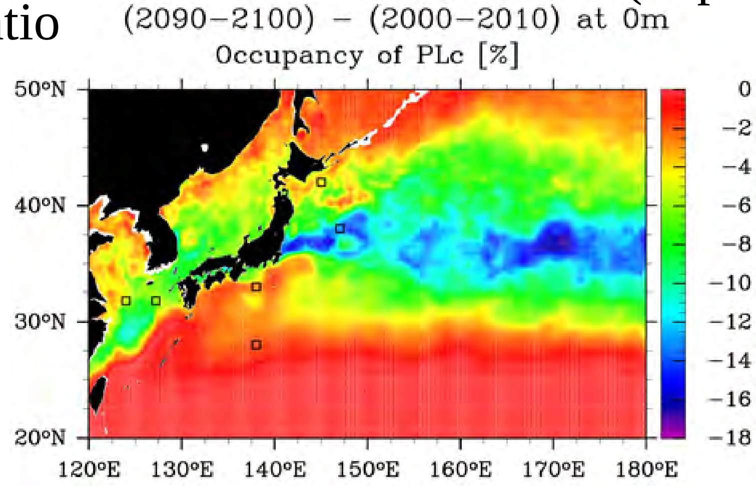
CHOPE-eNEMURO (Global warming exp.)

Komatsu et al. (in prep.)

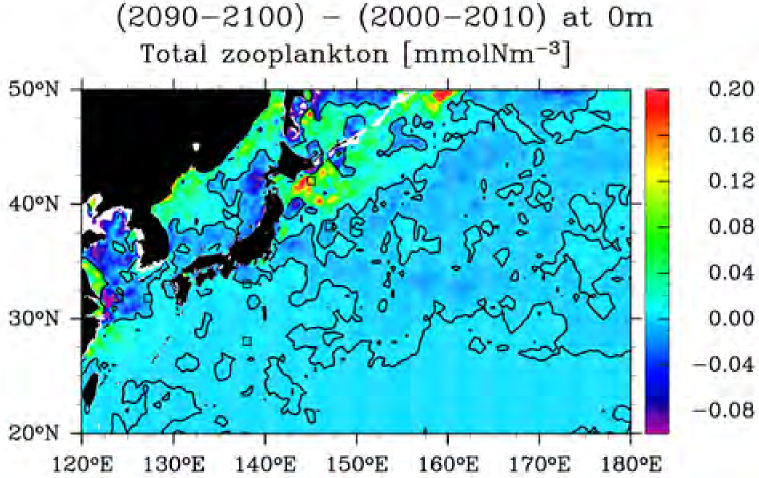
Total phyto.



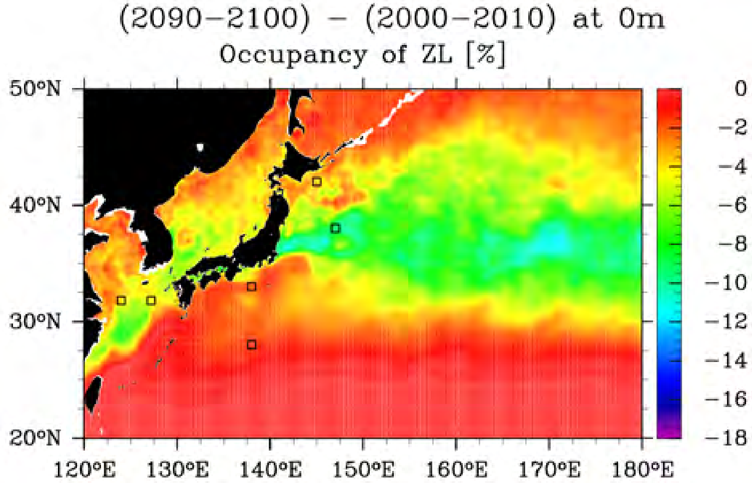
PLc ratio



Total zoo.



ZL ratio

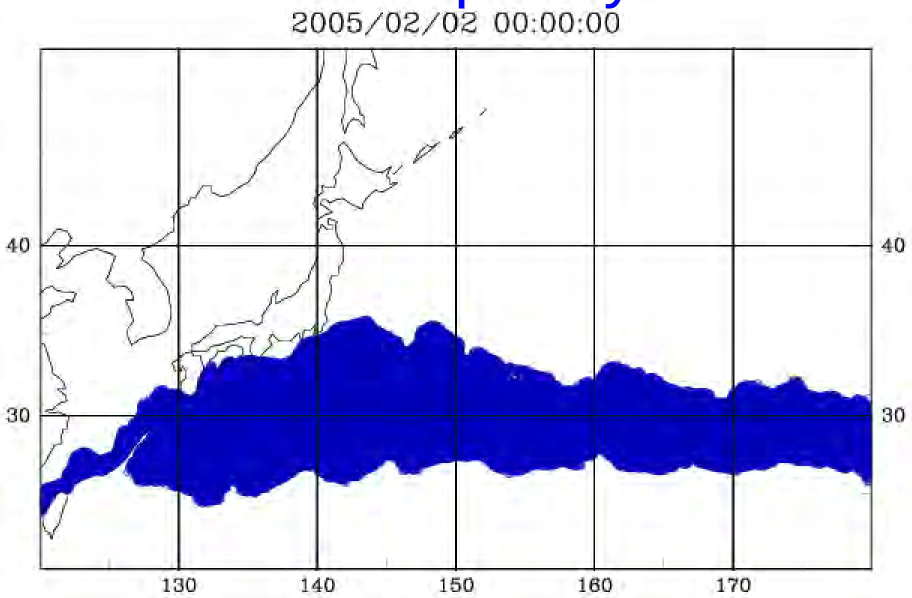


Planktons decreased in almost all area except for a part of Oyashio region.
Large diatom and zooplankton decrease especially in the mixed water region.

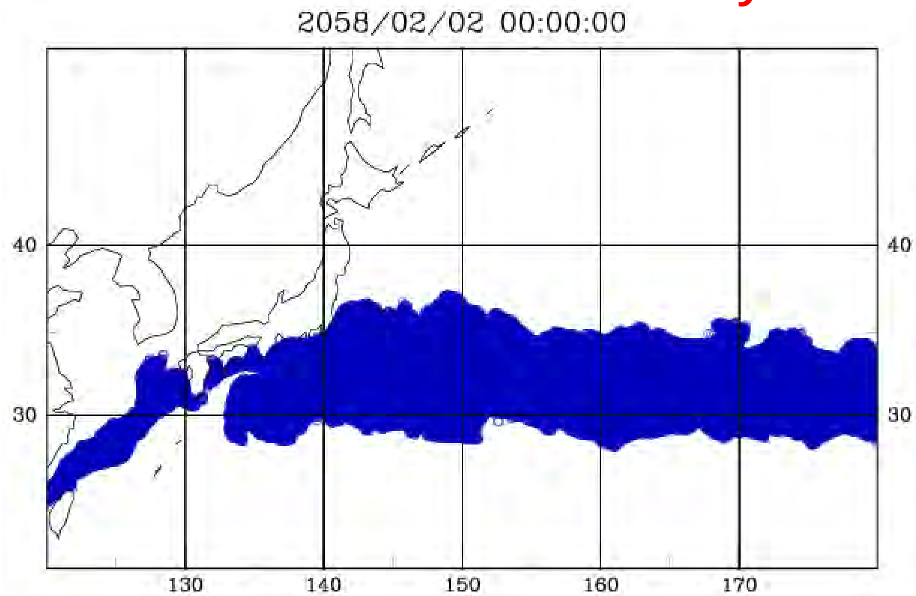
Projection of spawning ground of saury

Based on Takasuka et al. (2014) and Iwahashi et al (2006), spawning ground was set to the region which sea surface temp. is between 17.8 and 21.6 degC.

contemporary



middle of 21st century

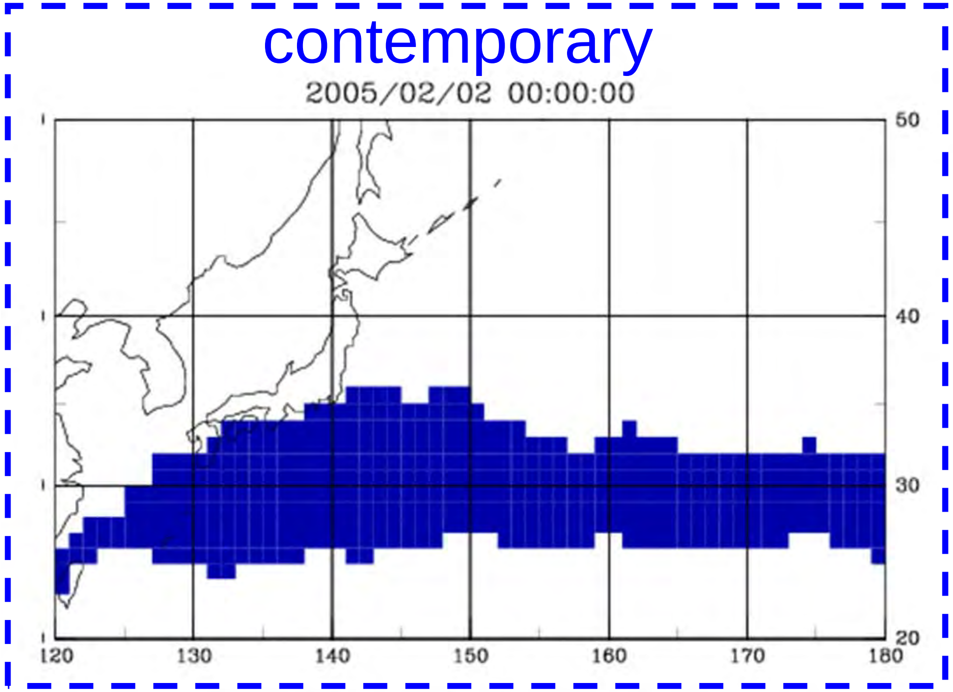


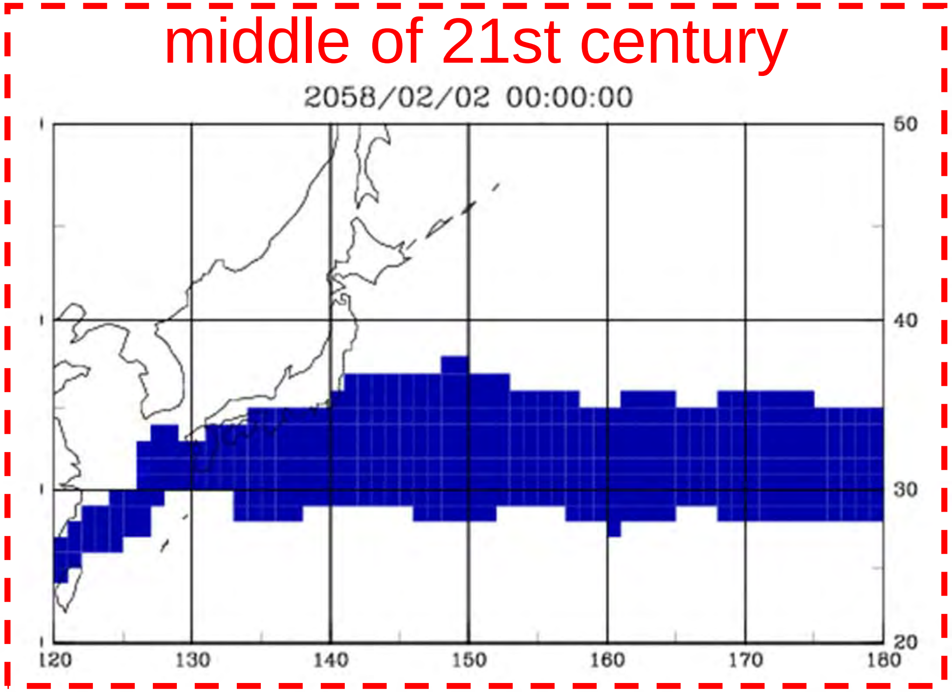
Projection

The spawning ground was shifted northward about 2 degree in latitude.

Projection of migration of Pacific saury

example for saury spawned on Feb. 2nd





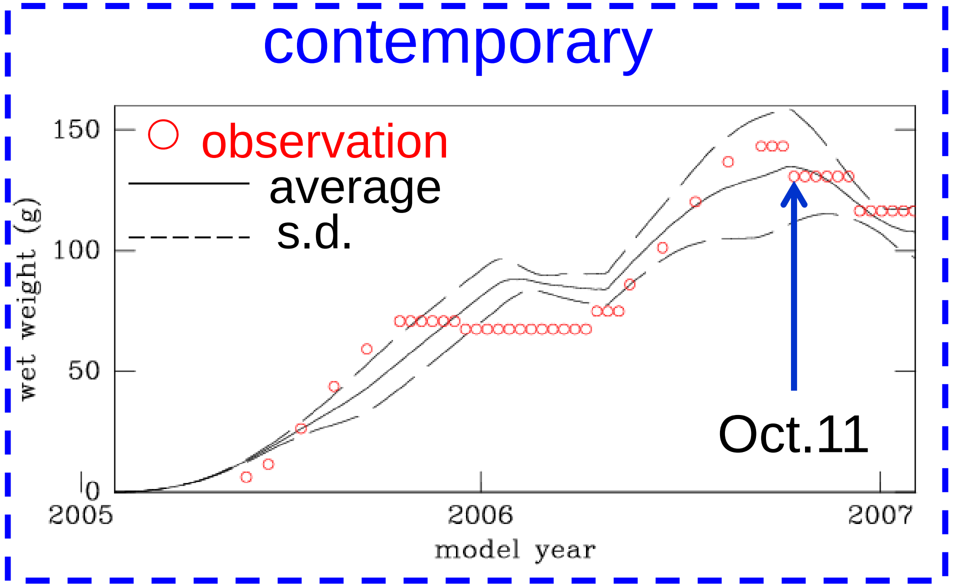
Projection

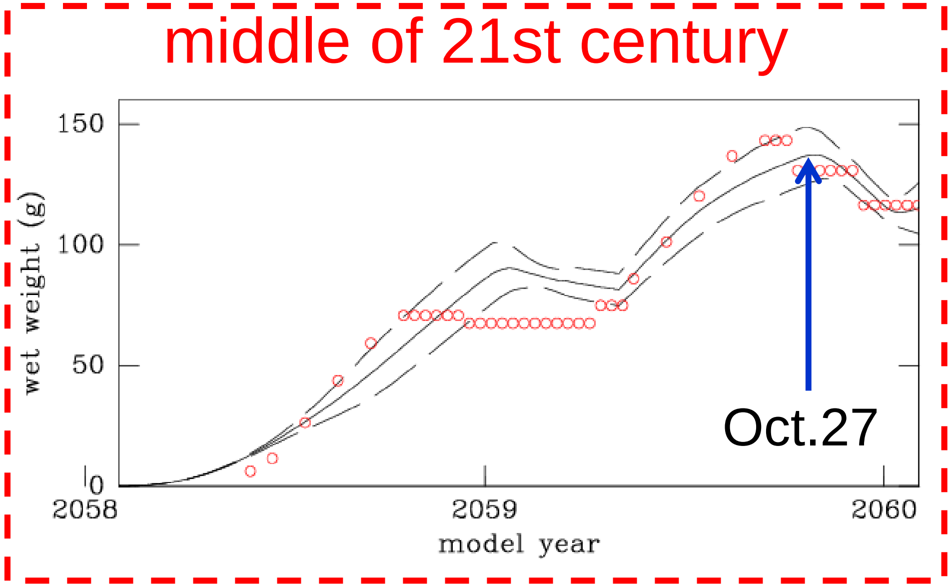
The migration route was shifted northward.

Migration to the fishing ground (Japan coast) was delayed.

Projection of growth of Pacific saury

example for saury spawned on Feb. 2nd





Projection

The timing of maximum weight was delayed.

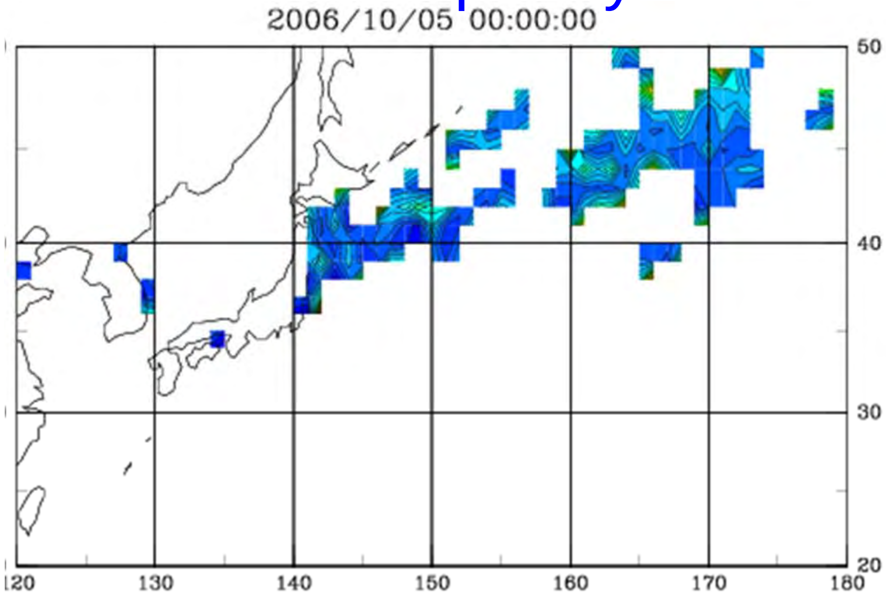
Standard deviation of adult saury weight became small.

This result shows reduction of high price large fish.

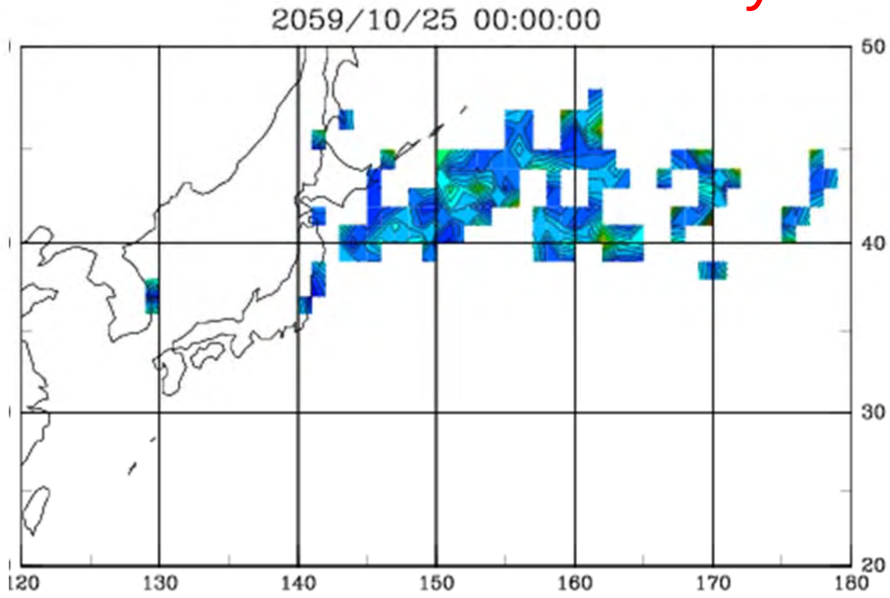
Projection of distribution of Pacific saury

example for saury distribution on Oct. 5th which spawned on Feb. 2nd

contemporary



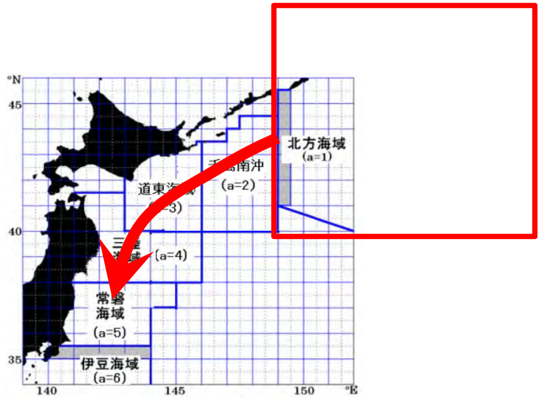
middle of 21st century

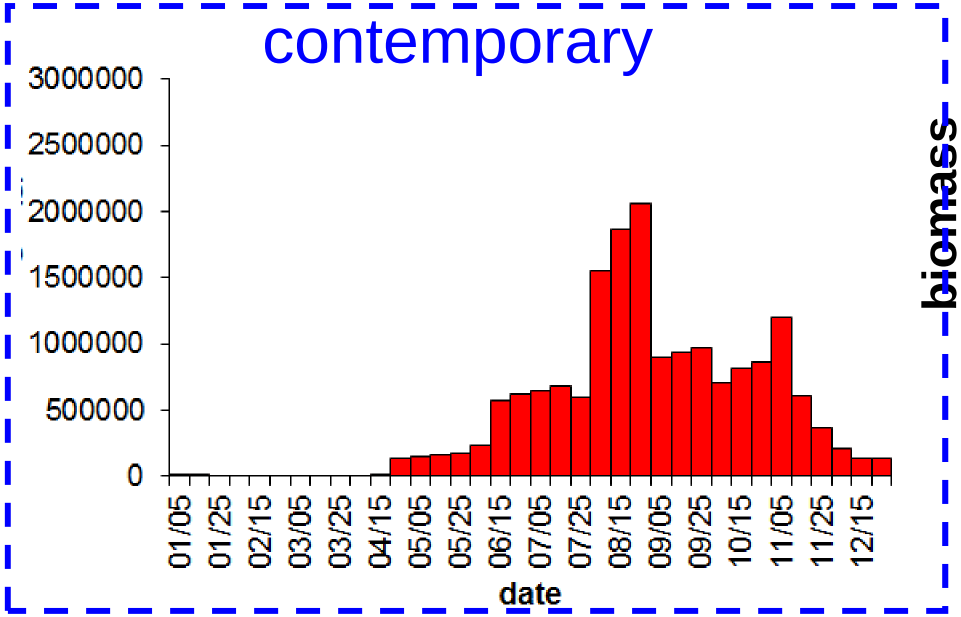


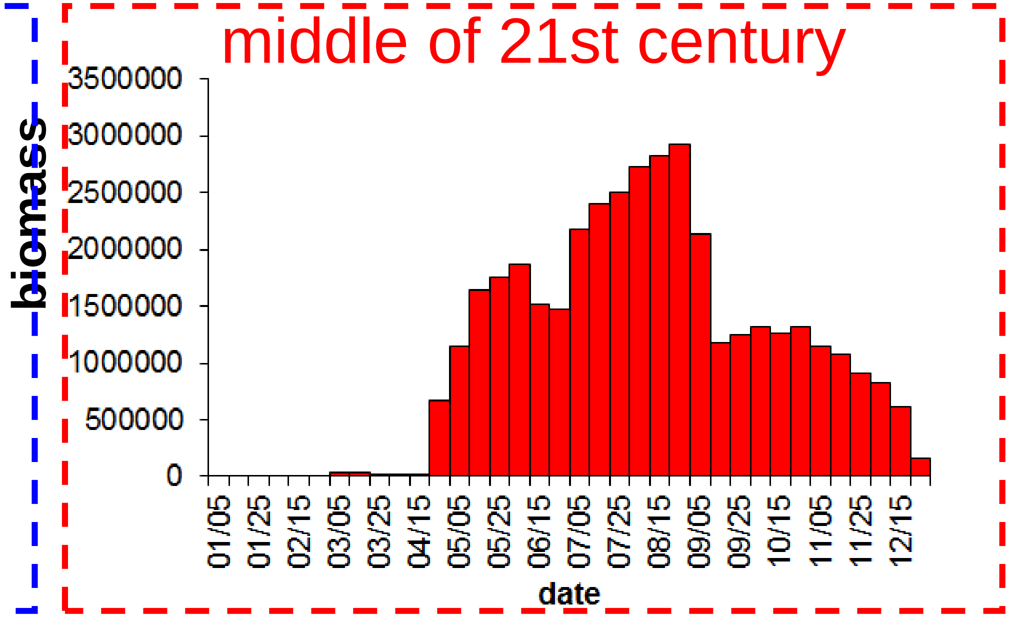
- **Spawning migration timing was delayed and all saury stayed in the prey rich field (subarctic region).**
- **Therefore, the s.d. of saury weight was reduced.**

Projection of migration biomass of Pacific saury

example for saury migration biomass to 40-50N, 149-160E area which spawned on Feb. 2nd







Projection

The biomass increased since the number increased.
The timing of maximum biomass was not changed.

Possible responses to the future climate

Japanese sardine

- Main spawning region may move to northeastward.
- The size of sardine may not change since they compensate food by northern migration.

Pacific saury

- Main spawning region may move to northeastward.
- The high price large saury may disappear but the migration biomass to coastal fishing ground may increase since the migration number increase.

What is the difference between two species.

Pacific saury have already used the subarctic region for feeding ground, but Japanese sardine uses only a part of subarctic region.

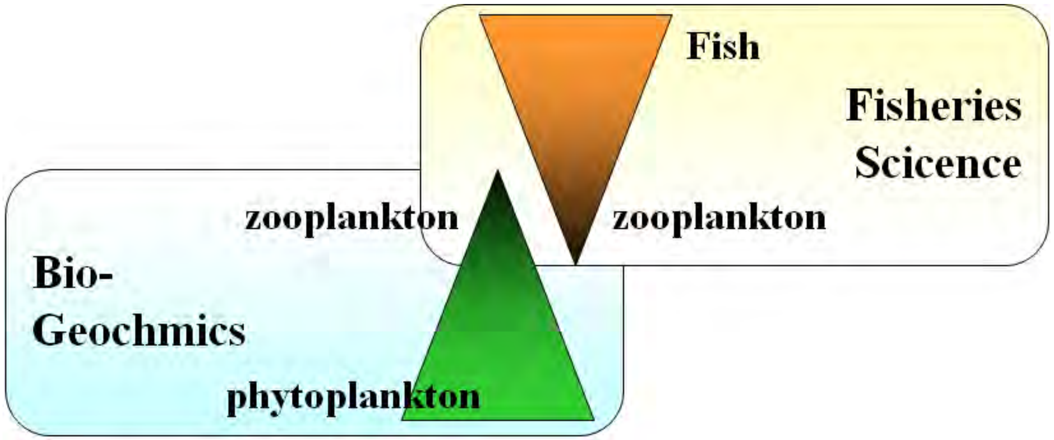
There is more buffer for Japanese sardine.

Caveats & Challenges

Growth model

- It is usually very difficult to estimate all the parameters even for one target species under natural condition.
- Parameters estimated under laboratory experiments were sometimes far from values speculated under natural conditions (e.g. because of different prey).
- **Additionally, accuracy of prey plankton is usually immature to predict fish growth (Ito et al., 2010).**

This is because bottom-up focusing scientists start from phytoplankton and top-down focusing scientists start from fish. Therefore, zooplankton resolution or accuracy often becomes an weakness of marine ecosystem models.



Caveats & Challenges

Reproduction model

1. Income-breeder, who immediately utilize energy inputs from prey to egg production, is simple to be modeled (e.g. Pacific saury: Ito et al., 2004; European anchovy: Politikos et al., 2011).
2. Capital-breeder, who reserve energy inputs from prey for specific duration, is difficult to be modeled (e.g. Japanese sardine: Okunishi et al., 2010).
3. **Additionally, many species have spawning grounds in narrow coastal regions where needs high resolution ocean circulation model (Ito et al., 2010).**

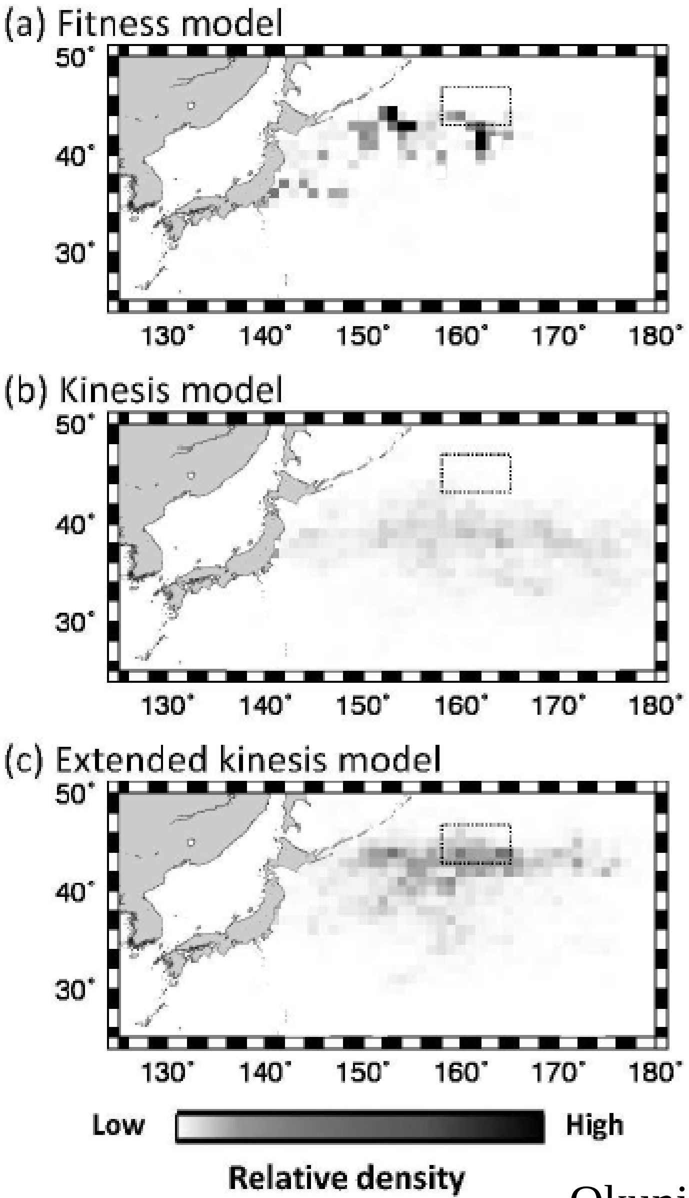
Migration model

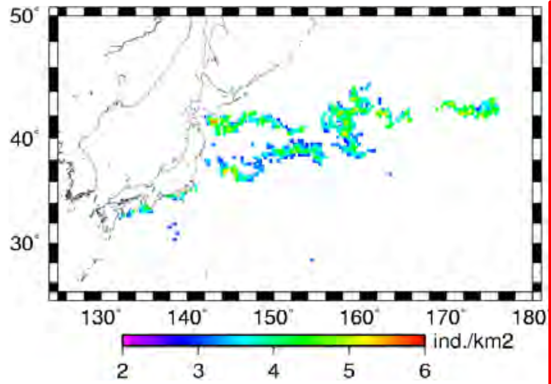
Although fish behavior determines their migration, fish behavior is not usually well elucidated (Hamston et al., 2004).

1. We don't know how clever fish is (information storage, searching, etc.)?
2. What is fish's motivation?
3. What is the response of fish for bad/good conditions?

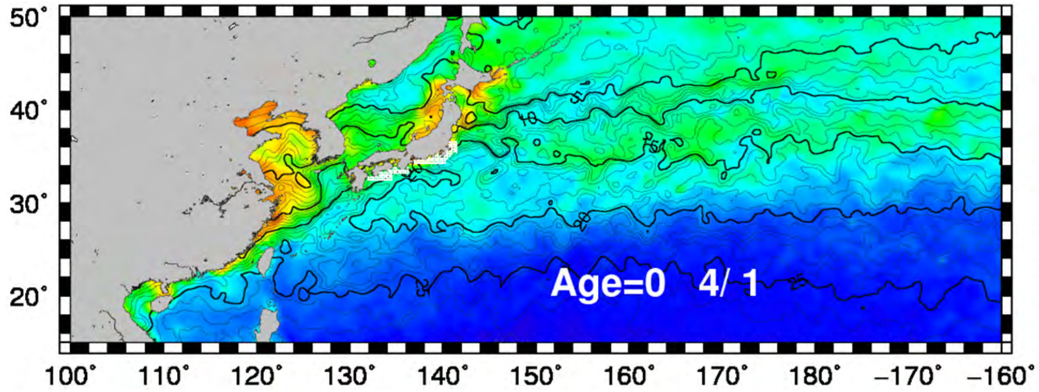
Uncertainty caused by forcing is also important (e.g. Ito et al, 2013).
Species interaction is also important.

Migration across the Subarctic Boundary





When the escaping behavior from predator is included, sardine migrates to the north of the Subarctic Boundary with fitness algorithm.



Examined 3 types of migration algorithms and found only extended kinesis model can reproduce northern migration of sardine.

Okunishi et al. (2012, Fish.Oceanogr.）

Conclusion

To project small pelagic fish responses under future climate, improvements of growth, production and migration models coupled to regional models are essential.

Big Challenges

- Improvement of biological growth information
- Improvement of zooplankton prediction
- Modeling of reproduction process of capital breeders
- Long integration of biological oriented high resolution models
- Modeling of fish behavior
- Modeling density dependent effect (today not shown)
- Modeling species interaction
- Modeling spawning migration (today not shown)
- Ensemble experiments
- Skill assessment of models

Model inter-comparison seems key process to improve the model skills.
High technical observation methods (compact tags, contacting buoys, etc.) to observe fish behaviour are essential.
Laboratory experiments are also needed to improve the model skills.

Thank you for attention.

References

Takasuka, A., H. Kuroda, T. Okunishi, Y. Shimizu, Y. Hirota, H. Kubota, R. Kimura, S. Ito and Y. Oozeki, 2014, Occurrence and density of Pacific saury *Cololabis saira* larvae and juveniles in relation to environmental factors during the winter spawning season in the Kuroshio Current system, Fish. Oceanogr., 23, 304-321, doi:10.1111/fog.12065.

Ito S., T. Okunishi, M. J. Kishi and M. Wang, 2013, Modelling ecological responses of Pacific saury (*Cololabis saira*) to future climate change and its uncertainty, ICES J. Mar. Sci., 70, 980-990, doi: 10.1093/icesjms/fst089.

Okunishi T., S. Ito, T. Hashioka, T. T. Sakamoto, N. Yoshie, H. Sumata, Y. Yara, N. Okada, Y. Yamanaka, 2012, Impacts of climate change on growth, migration and recruitment success of Japanese sardine (*Sardinops melanostictus*) in the western North Pacific, Climatic Change, 3-4, 485-503, DOI 10.1007/s10584-012-0484-7.

Okunishi T., S. Ito, D. Ambe, A. Takasuka, T. Kameda, K. Tadokoro, T. Setou, K. Komatsu, A. Kawabata, H. Kubota, T. Ichikawa, H. Sugisaki, T. Hashioka, Y. Yamanaka, N. Yoshie and T. Watanabe, 2012, A modeling approach to evaluate growth and movement for recruitment success of Japanese sardine (*Sardinops melanostictus*) in the western Pacific, Fish. Oceanogr., 21, 44–57, 2012, doi:10.1111/j.1365-2419.2011.00608.x

Politikos D. V., G. Triantafyllou, G. Petihakis, K. Tsiaras, S. Somarakis, S. Ito, B. A. Megrey, 2011, Application of a bioenergetics growth model for European anchovy (*Engraulis encrasicolus*) linked with a lower trophic level ecosystem model, Hydrobiologia, 670, 141-163, doi 10.1007/s10750-011-0674-8.

Ito S., K. A. Rose, A. J. Miller, K. Drinkwater, K. M. Brander, J. E. Overland, S. Sundby, E. Curchitser, J. W. Hurrell and Y. Yamanaka, 2010, Ocean ecosystem responses to future global change scenarios: A way forward, In: M. Barange, J.G. Field, R.H. Harris, E. Hofmann, R. I. Perry, F. Werner (Eds) Global Change and Marine Ecosystems. Oxford University Press., 287-322, pp440.

Okunishi T., Y. Yamanaka and S. Ito, 2009, A simulation model for Japanese sardine *(Sardinops melanostictus*) migrations in the western North Pacific. Ecol. Model., 220, 462-479, doi:10.1016/j.ecolmodel.2008.10.020.

Iwahashi M., Y. Isoda, S. Ito, Y. Oozeki and S. Suyama, 2006, Estimation of seasonal spawning ground locations and ambient sea surface temperatures for eggs and larvae of Pacific saury (*Cololabis saira*) in the western North Pacific, Fish. Oceanogr., 15, 125-138.

Ito S., B. A. Megrey, M. J. Kishi, D. Mukai, Y. Kurita, Y. Ueno and Y. Yamanaka, 2007, On the interannual variability of the growth of Pacific saury (*Cololabis saira*): a simple 3-box model using NEMURO.FISH. Ecol. Modelling, 202, 174-183, doi:10.1016/j.ecolmodel. 2006.07.046.

Ito S., M. J. Kishi, Y. Kurita, Y. Oozeki, Y. Yamanaka, B. A. Megrey and F. E. Werner, 2004, Initial design for a fish bioenergetics model of Pacific saury coupled to a lower trophic ecosystem model, Fish. Oceanogr., 13, Suppl. 1, 111-124

Ito S., H. Sugisaki, A. Tsuda, O. Yamamura and K. Okuda, 2004, Contributions of the VENFISH program: meso-zooplankton, Pacific saury (*Cololabis saira*) and walleye pollock (*Theragra chalcogramma*) in the northwestern Pacific, Fish. Oceanogr., 13. Suppl. 1, 1-9.