東京大学大気海洋研究所共同利用研究集会
海洋生態系モデリングの最前線：成果、連携、次世代への展開

Current status of fish growth and migration models coupled to a lower trophic marine ecosystem model and its perspectives.

低次栄養段階生態系ー魚類成長・回遊結合モデルの現状と今後

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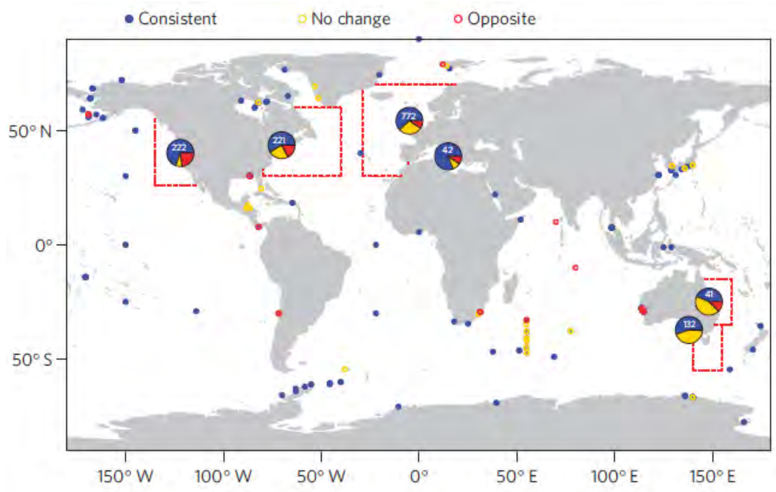
Today's Contents

1. Introduction
2. growth model
3. production model (closure of the life cycle)
4. migration model
5. skill assessment
6. conclusion

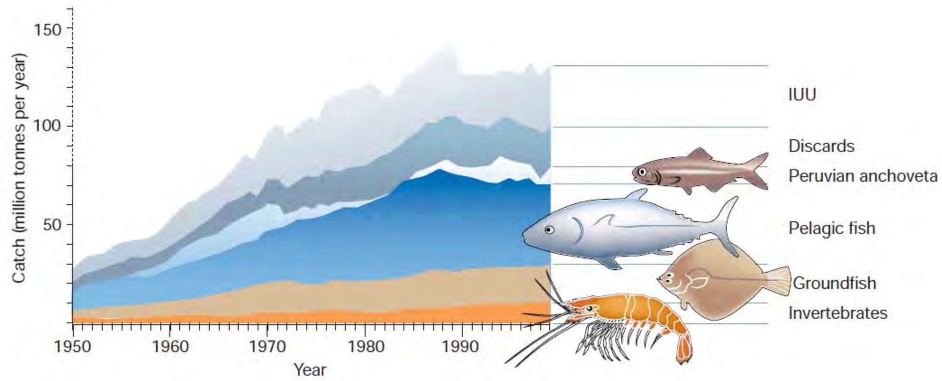
Why we think about fish?

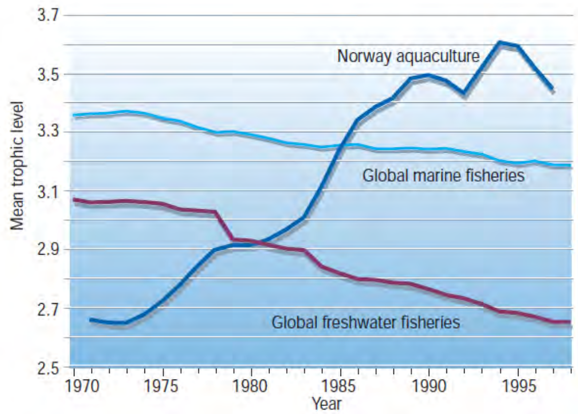
- Marine ecosystem responses to climate variability and change.
- One of the key services of the global oceans is the provision of food, currently yielding 18.5 kg of high quality protein per capita and year (FAO 2014).
- Climate pressure combined with overfishing decreases mean trophic level of marine ecosystems.



Poloczanska et al. (2013)

More than 80% observations showed consistent responses of marine biota to climate change.





Mean trophic level decreased with increasing fishing pressure.

Pauly et al. (1998, 2002)

Why we adapt modeling approaches to investigate fish responses to climate variability and change?

- The availability of observations is generally limited.
- Information on life history and ontogenetic migration is often limited.

- Implementation of a higher trophic model coupled to a general lower trophic model to estimate variability in fish growth and population dynamics is a feasible alternative to field data analyses.

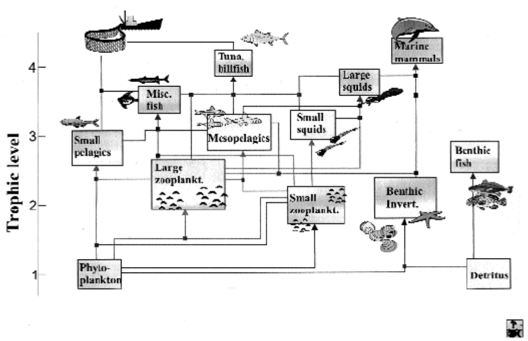
- Of course, use of model output has the caveat that analysis of "model data" is completely dependent on the skill of the underlying models (Ito et al., submitted).
- However, they help us to think (Riley G.A., 1984).

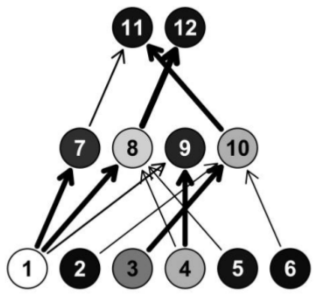
How to imitate marine ecosystems?

There are many different types of food web and multispecies models.

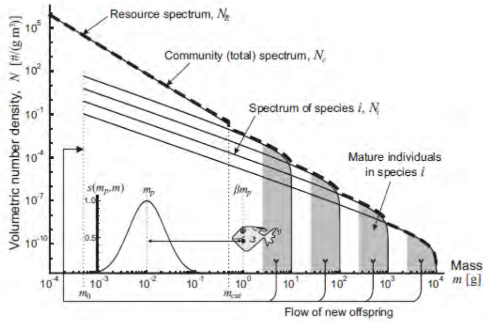
Species-based ⟷ **Size-based**

ECOPATH

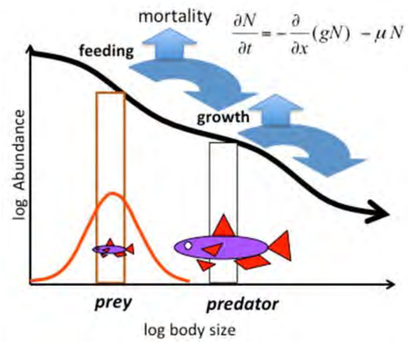




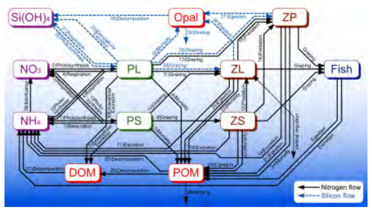
Yodzis & Innes, 1992



Hartvig et al. 2010



NEMURO



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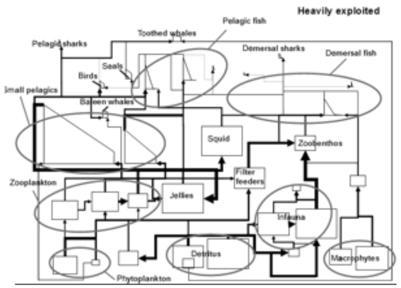
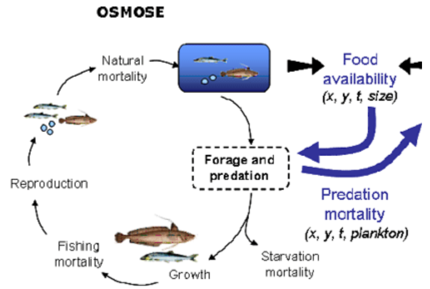
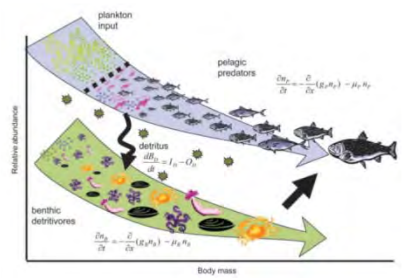


OSMOSE





Blanchard et al., 2009

"Purely size-based or species-based models are the extremes of a continuum of approaches that contain both dimensions". Ito et al. (2013)

Species-based

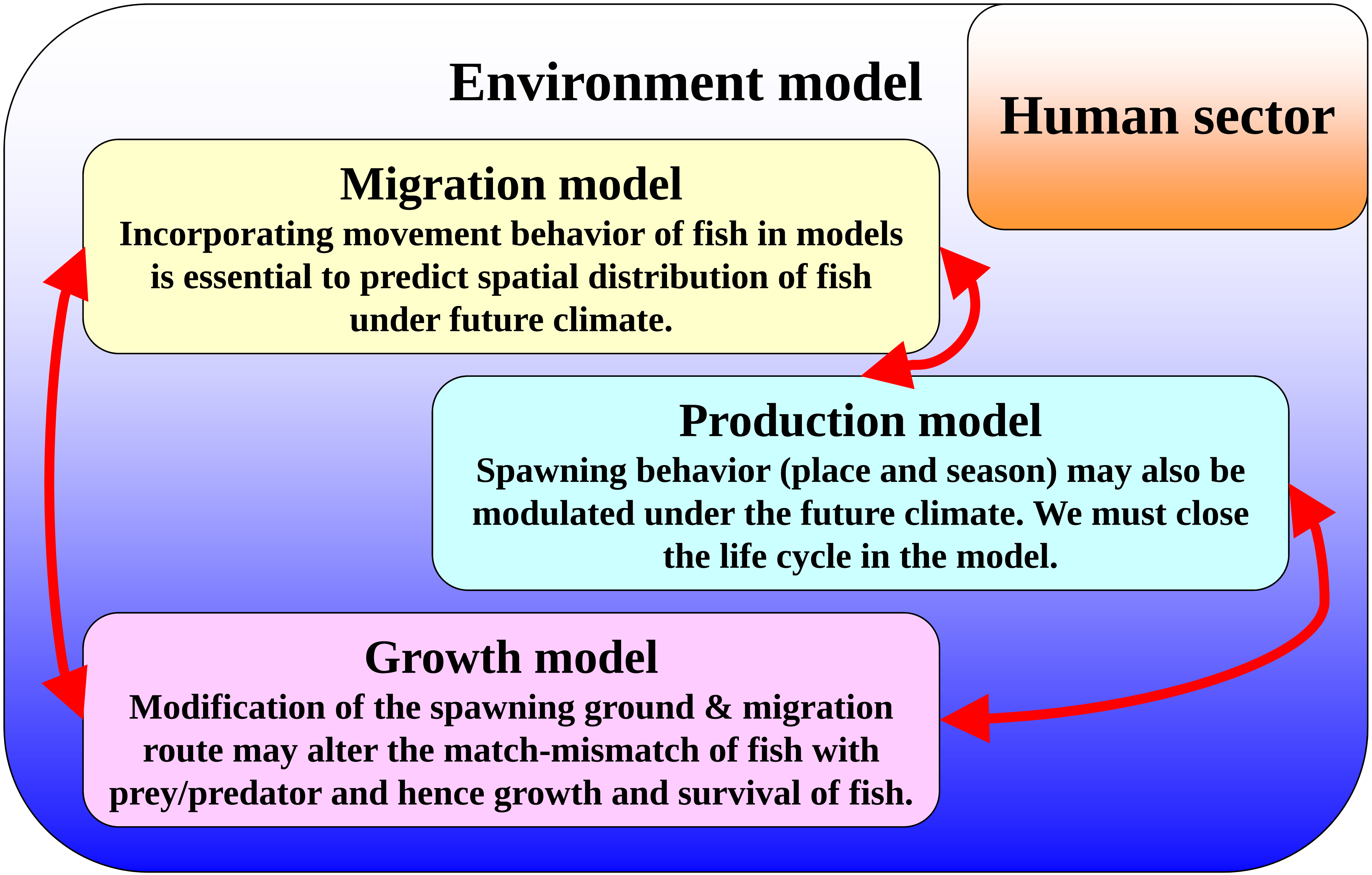
advantages	limitation
Suited to focused interests in certain species.	Species interactions pre-defined by species/model group pairs and species that do not interact will not interact in a model.
Species interactions determined by functional response settings.	Cannot resolve size-based processes (large predate on small) except where sub-species groups are included
Climate impacts are possible to be incorporated. Adaptation effects may be possible to be incorporated with high computational cost.	Changing in primary production are represented by changes in functional phytoplankton groups. Size and space are implicit in species-based models with diet information.
Useful for global assessment of **specific species regarding spatial distribution and biomass change.**	Representation of global ecosystems may be impossible.

Size-based

Advantages	limitation
Coverage of ecosystem is greater since size-based models can represent continuous distribution of biota from small phytoplankton to large top predator fish.	Core of many size-based models is metabolic theory (allometric scaling) and cannot resolve detailed biological processes.
Species interactions are emergent (large species prey upon small ones).	Interactions are defined by differences and overlap in body size and specific, strong interactions between species may not be included.
Climate impacts are possible to be incorporated.	Climate impacts on primary productivity is imitated by changing the intercept and/or slope of the size spectrum line.
Useful for global assessment of **climate change impacts on marine ecosystems since size-based models are generic and able to be applied without local species composition.**	Representation of regional ecosystems may be limited. Adaptation of species may be difficult to reveal.

Ito et al. (2013)

Essential components of models to investigate fish responses to climate forcing.



1. 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

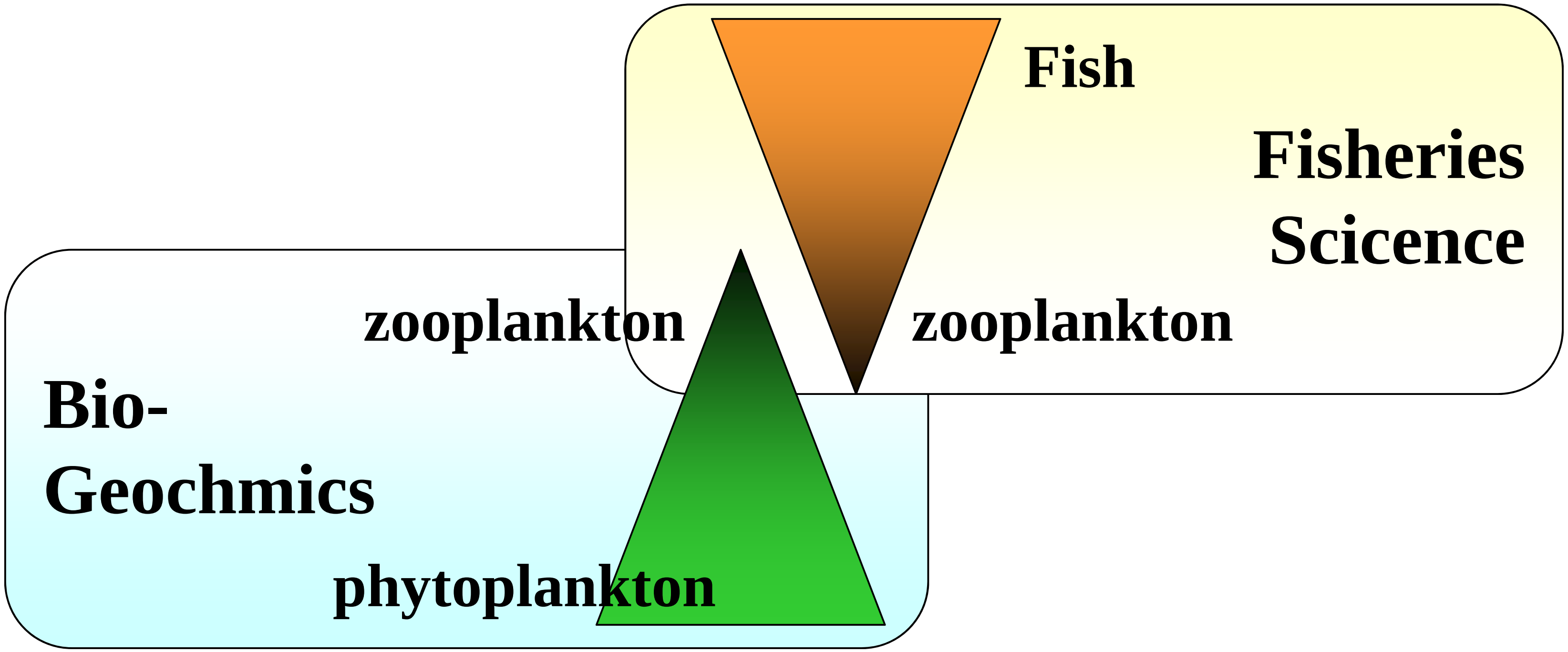
P: egg production

1. Each term is a function of weight, temperature, prey density, etc.
2. It is usually impossible to know all the parameters even for one target species under natural condition.
3. It is not unusual that parameters estimated under laboratory experiments are far from those speculated under natural conditions (e.g. because of different prey).

1. growth model

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.



2. production model

Bioenergetics model (Wisconsin model) sometime includes production term.

Hanson et al. (1997)

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

P: egg production

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; Japanese anchovy).
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. Sometime a simple spawner-recruitment model is applied for the closure of the life cycle (e.g. herring: Megrey et al., 2007).

2. production model

Additionally, many species have spawning grounds in narrow coastal regions where needs high resolution ocean circulation model.

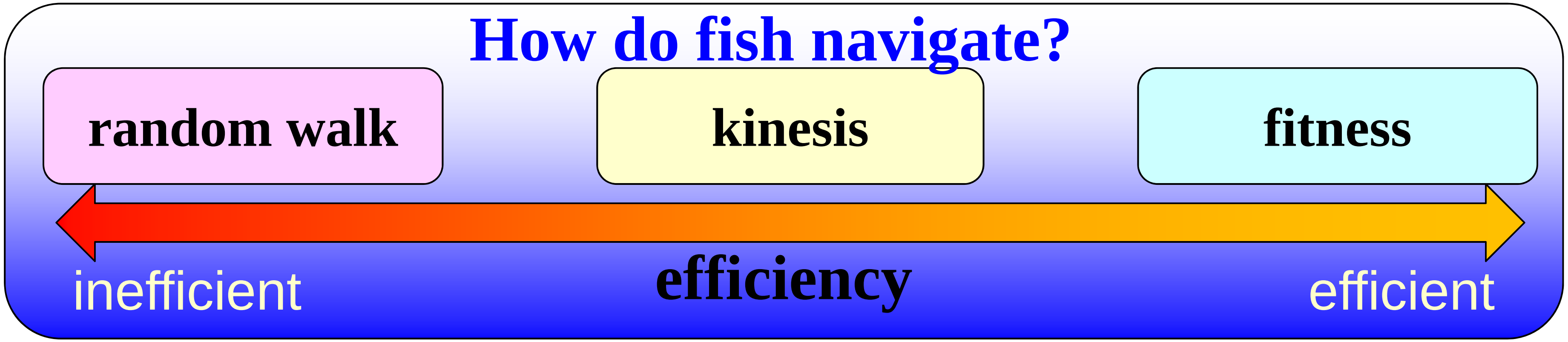
1. For physical models to provide useful information for the estimation of near-shore fish production, the physical model needs to resolve the shelf and coastal morphology (bathymetry and coastline) on relatively fine temporal and spatial scales.
2. Decadal to centurial simulations are necessary in order to make projections of fish distribution under future climate.
3. Such kind of simulations needs tremendous computer power and are big challenges of the physical-chemical models.

Ito et al. (2010)

3. migration model

Although fish behavior determines their migration, fish behavior is not usually well elucidated.

Hamston et al. (2004)



We don't know how clever fish is?

How long fish can storage the information?

How far fish can search? How often fish is searching?

What is fish's motivation? What is the cue of fish?

temp., salinity, oxygen, color, light, prey, magnetic, tide, conversation, etc.

Can fish estimate the gradient of the cue?

What is the response of fish?

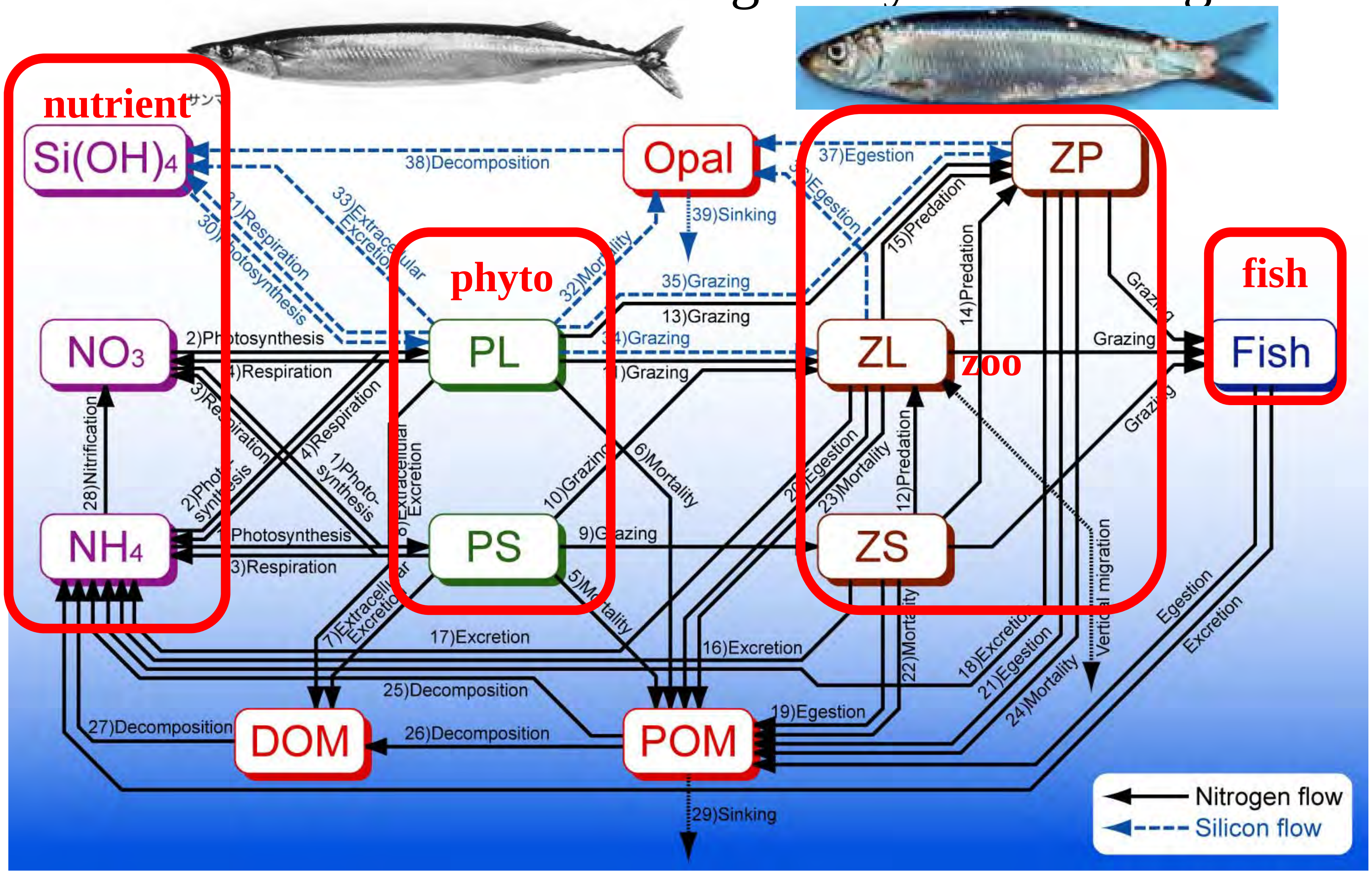
bad condition: random search/gradient search,

good condition: keep going/slow down

Examples

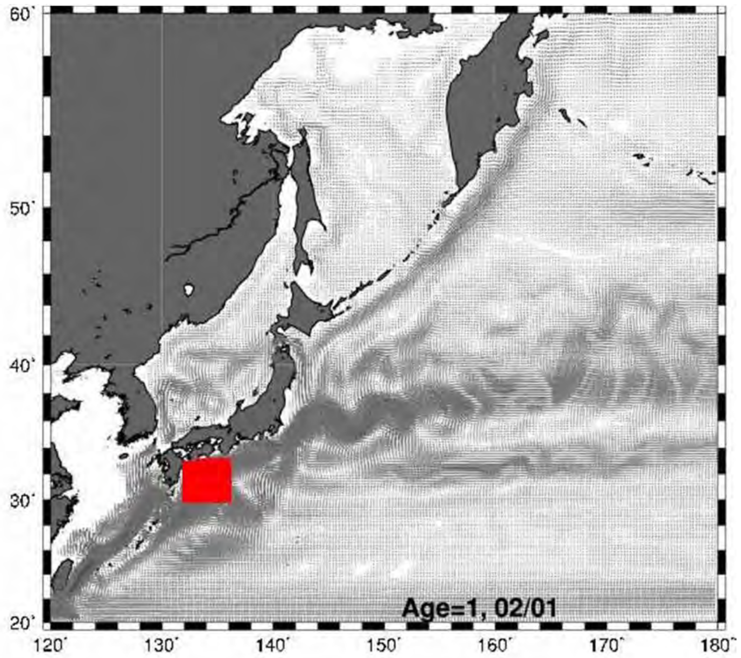
NEMURO.FISH

NEMURO for Including Saury and Herring



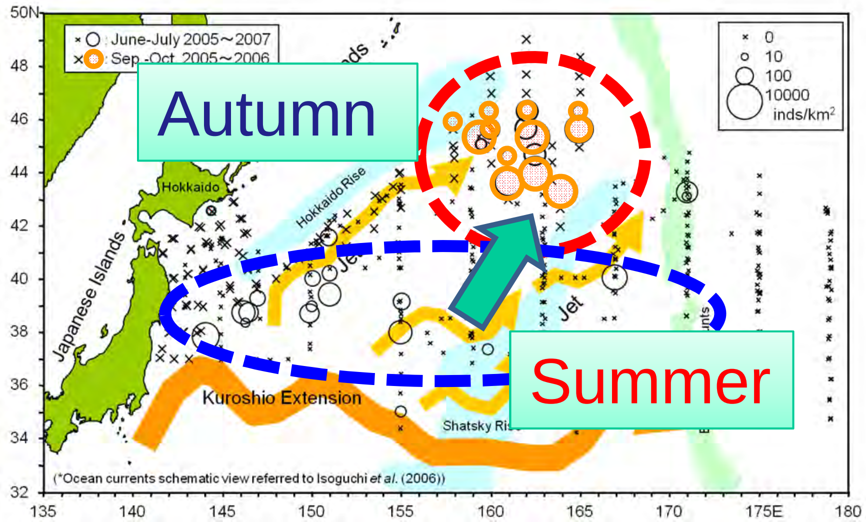
Megrey et al. (2007a, Ecol. Model.), Ito et al. (2004b Fish. Oceanogr.) etc.

EX.1: Migration across the Subarctic Boundary



Okunishi et al. (2009, Ecol. Model) reasonably reproduced migration of Japanese sardine.

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



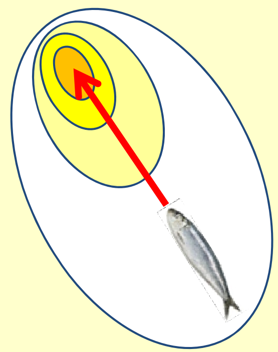
Kawabata et al. (2008)

Question: Which migration model can reproduce the migration of Japanese sardine across the Subarctic Boundary?

Comparison of feeding migration algorisms

Fitness algorism (Okunishi et al, 2009)

toward the most preferable place
growth index estimated by the bioenergetics model was used for measure



Kinesis algorism (Humston et al, 2000)

swimming velocity

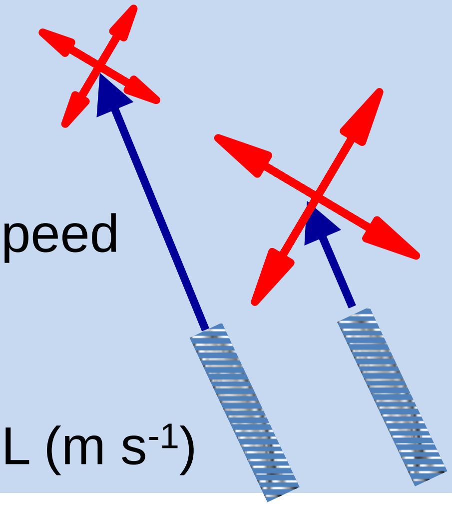
$$St = f(S_{t-1}) + g(\theta)$$

$f(S_{t-1})=S_{t-1} \times H_1 \times HI$ 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 BL ($m\ s^{-1}$)



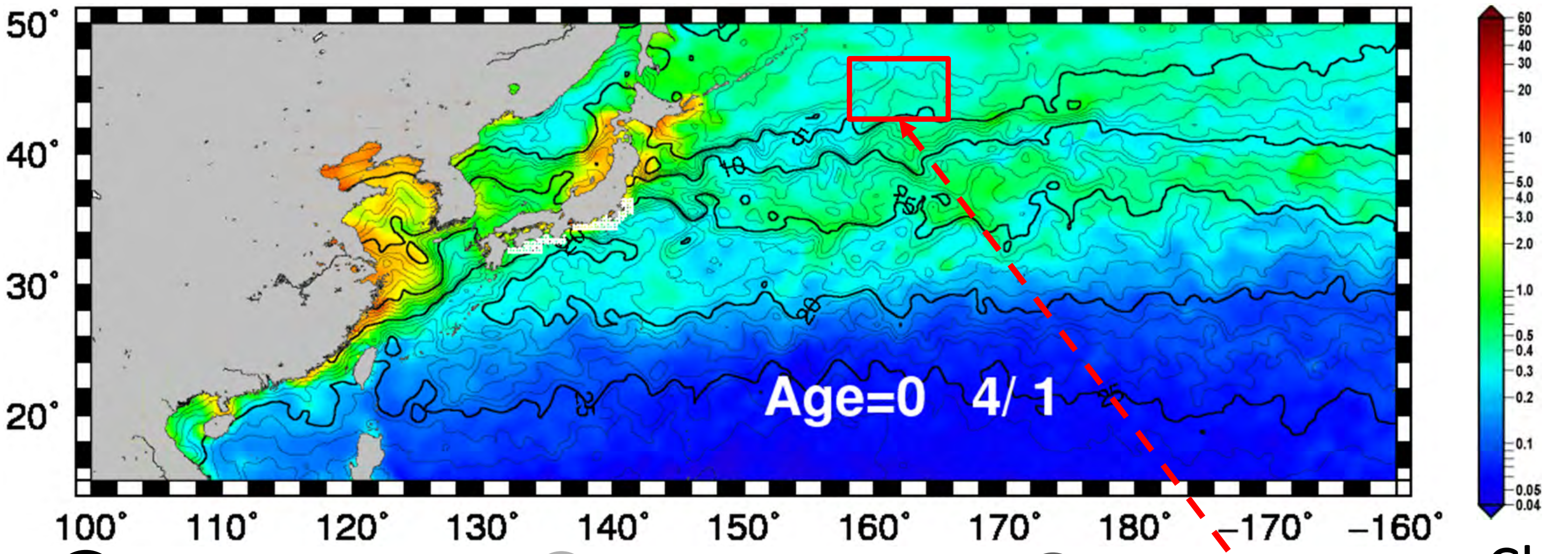
extended Kinesis algorism (Okunishi et al, 2012 Fish. Oceanogr.)

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

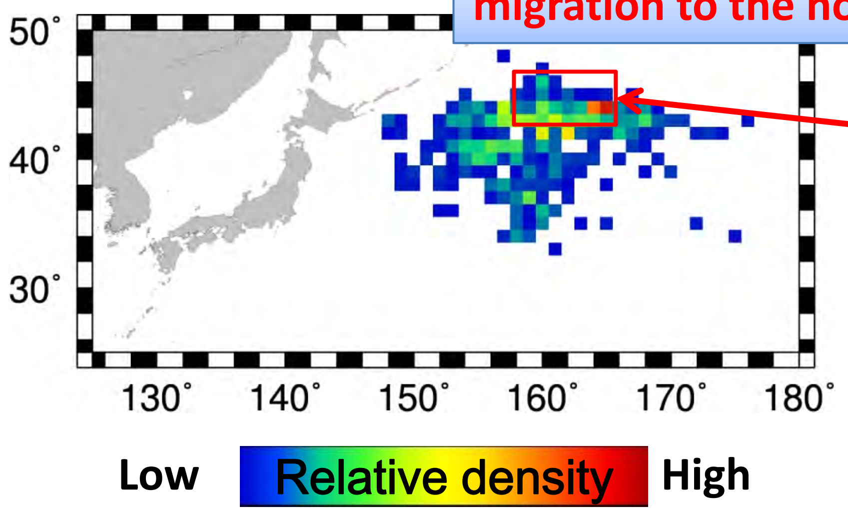
e.g. 2006 April spawned cohort (extended kinesis)



Chl-a (mg m-3)

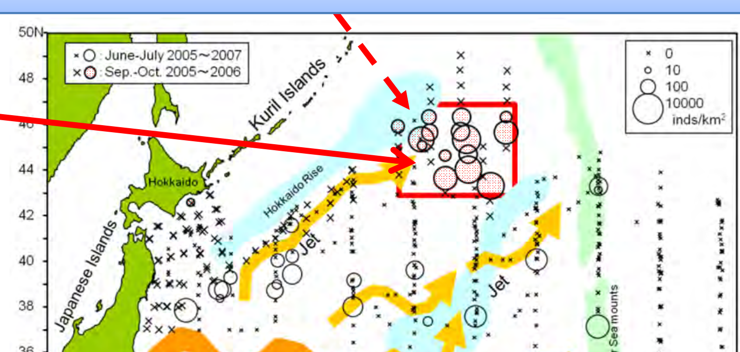
BL < 1 cm　BL 1-3 cm　BL 3-5 cm　BL > 9 cm

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



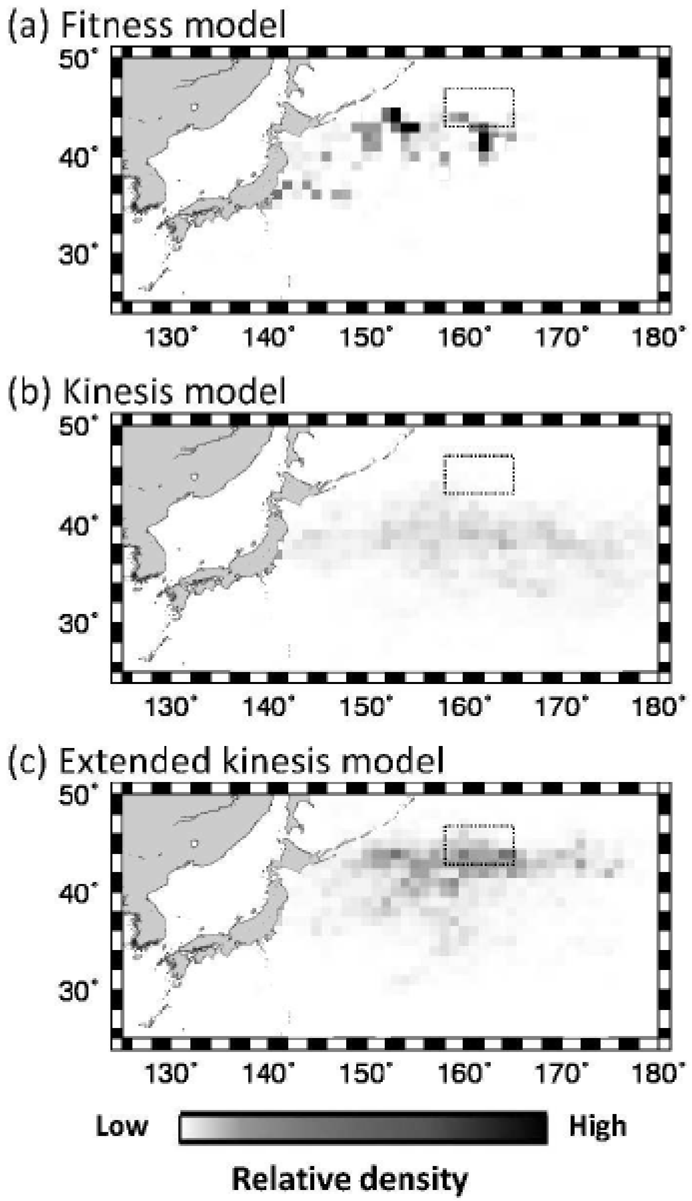
migration to the north of the Subarctic Boundary was reproduced.

ng to



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

Comparison of three algorisms



Only extended kinesis model can reproduce northern migration of sardine.

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

4. skill assessment

How to assess the skill of the models?

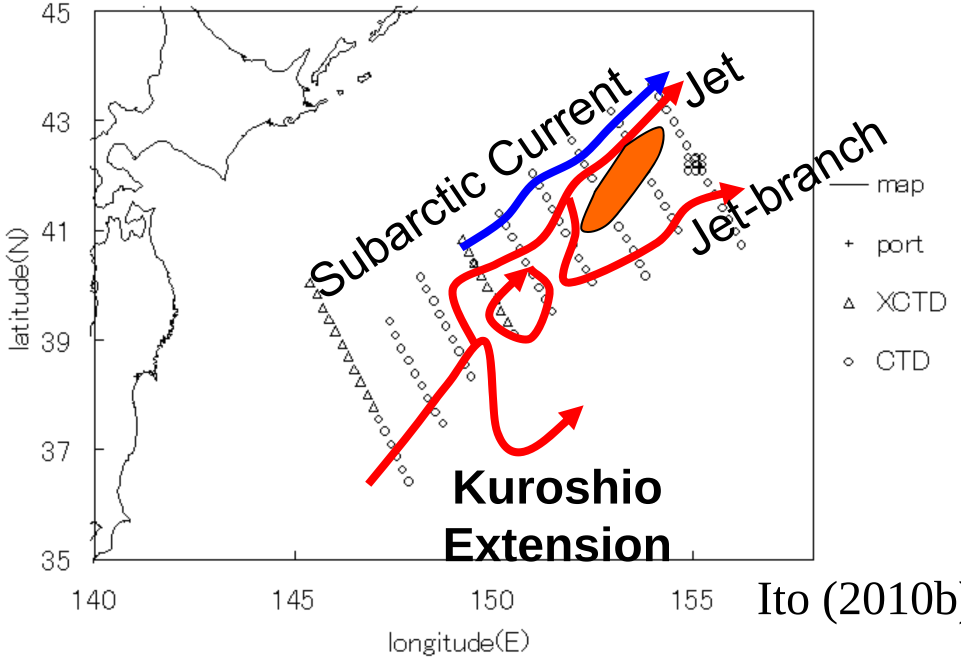
Compared three types of migration algorithms and only the extended kinesis was able to reproduce northward migration of sardine across the Subarctic Boundary.

Is this mean that "the slow down behavior with better condition is crucial mechanism of sardine migration"?

Pattern matching is enough skill assessment?

EX.2: species interaction

2009 Sep.

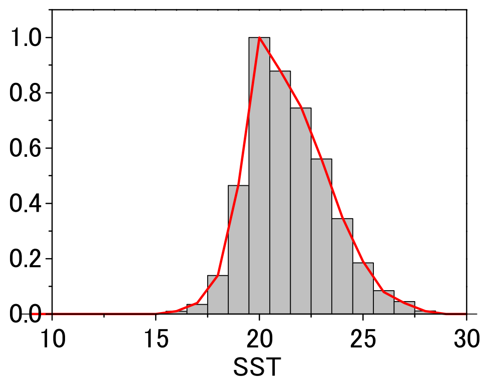


Ito (2010b)

There is a quasi-steady warm water jet from the KE (Isoguchi et al. 2006).

Many predators migrate along the jet (my experience).

➡ including top predator

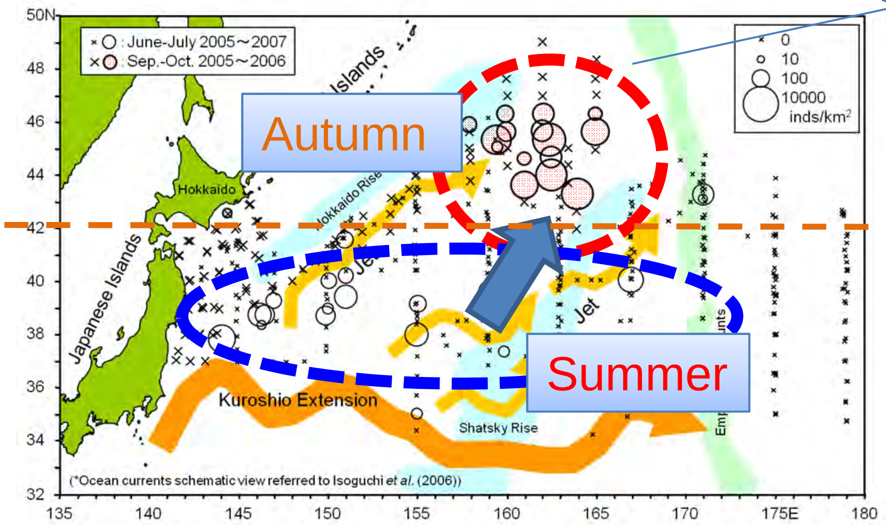


Feeding migration : toward high fitness regions

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

Case B : **fitness =Growth Rate**

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

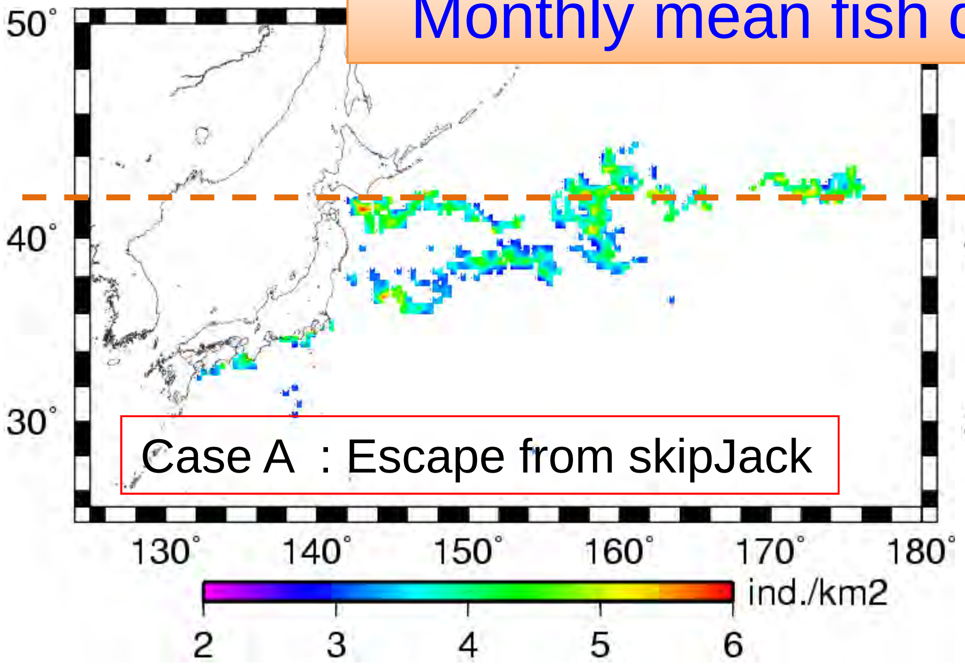


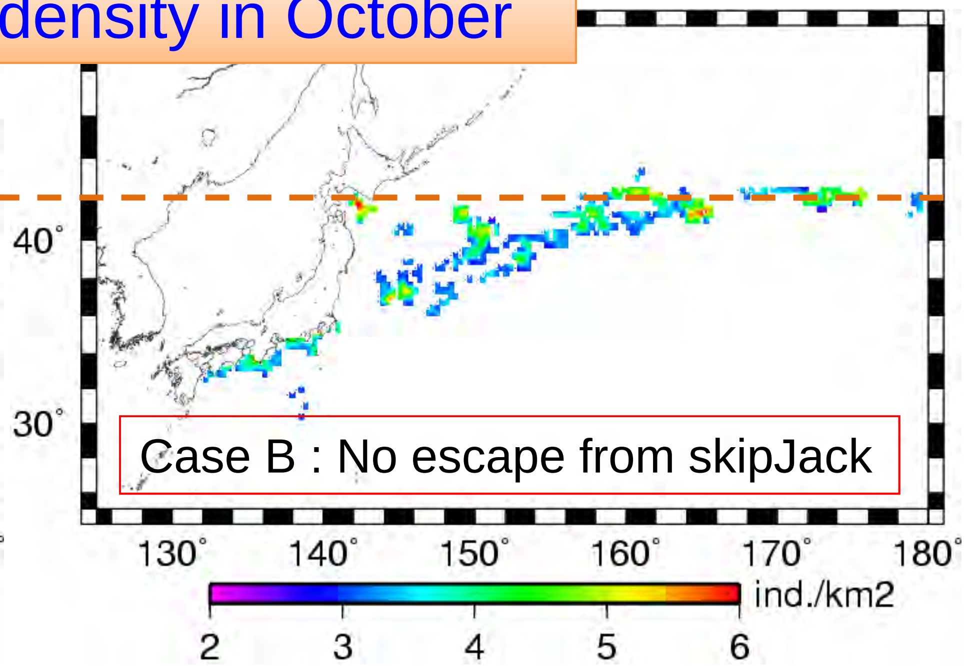
Observation data shows fish (Age 0) distributes in the area which SST is12-14 degC in autumn.

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

Okunishi et al. (in prep.）

Monthly mean fish density in October





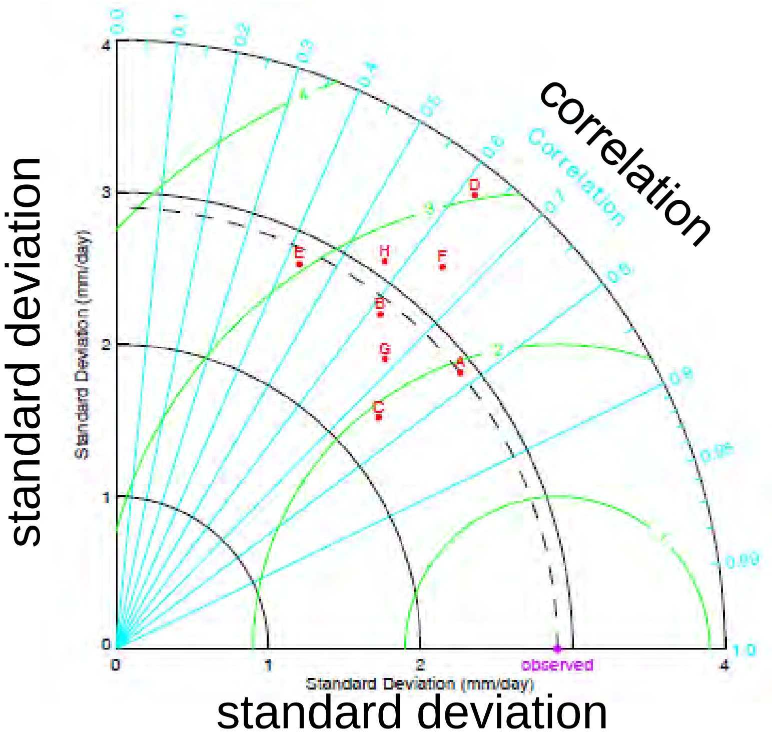
Case A : **HI= Growth Rate * (1-Predation Risk)**

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

4. skill assessment

Pattern matching does not seem enough skill assessment.
Different mechanisms can reproduce a similar pattern.

In meteorology, Taylor diagram is often used.
However, to draw the diagram, fish distribution data is too sparse in space and time.



Taylor (2005)

For large species, fish behavior (e.g. archival tag data) seems feasible for the skill assessment.

For small species, synoptic survey (e.g. acoustic survey) or otolith analysis seems feasible for the skill assessment.

Since data is insufficient, model comparison seems good strategy to improve models. Model portability may be a good index.

Summary

To investigate/project fish responses to climate forcing, improvements of growth, production and migration models are essential.

Big Challenges

- Improvement of biological growth information
- Improvement of zooplankton production
- 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)
- 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.
High technics to reconstruct fish experienced environments are essential (otolith stable isotope analysis, etc.)
Laboratory experiments are also needed to improve the model skills.

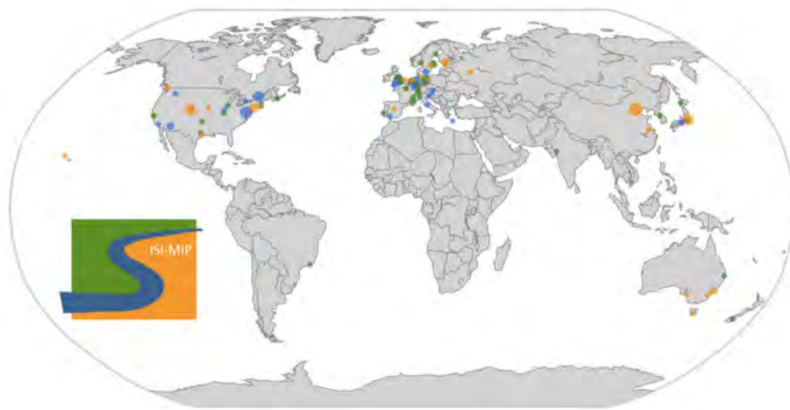
S-CCME &FISH-MIP (ISI-MIP *Marine Ecosystems and Fisheries Sector)*

FISH-MIP

Use a standard selection of GCMs and RCPs (related to the overall ISI-MIP effor
t www.isi-mip.org) to
(A) compare output of a range of global fisheries and ecosystem models,
(B) compare output of a range of regional fisheries and ecosystem models within A
ND across regions,
(C) compare output of global AND regional models in selected focus regions, and
(D) engage in inter-sectoral comparison activities within the ISI-MIP framework (l
onger term goal).

There are many overlaps between FISH-MIP and S-CCME.
Both chairs discussed and agreed to seek the potential to work together from Brazil Symposium.

The Inter-Sectoral Impact Model Intercomparison Project is a community-driven modelling effort bringing together impact models across sectors and scales to create consistent and comprehensive projections of the impacts of different levels of global warming. Find out more about the project.

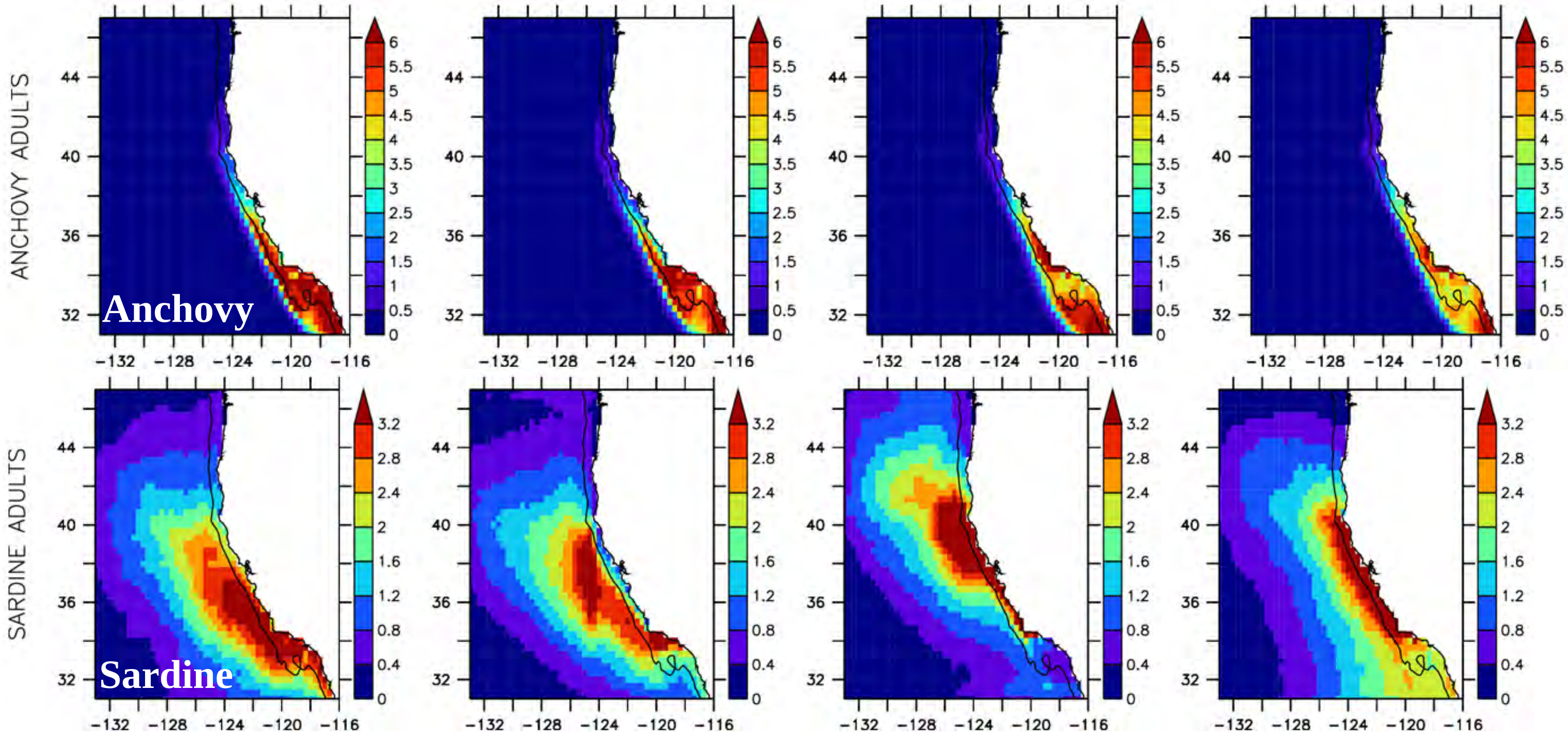


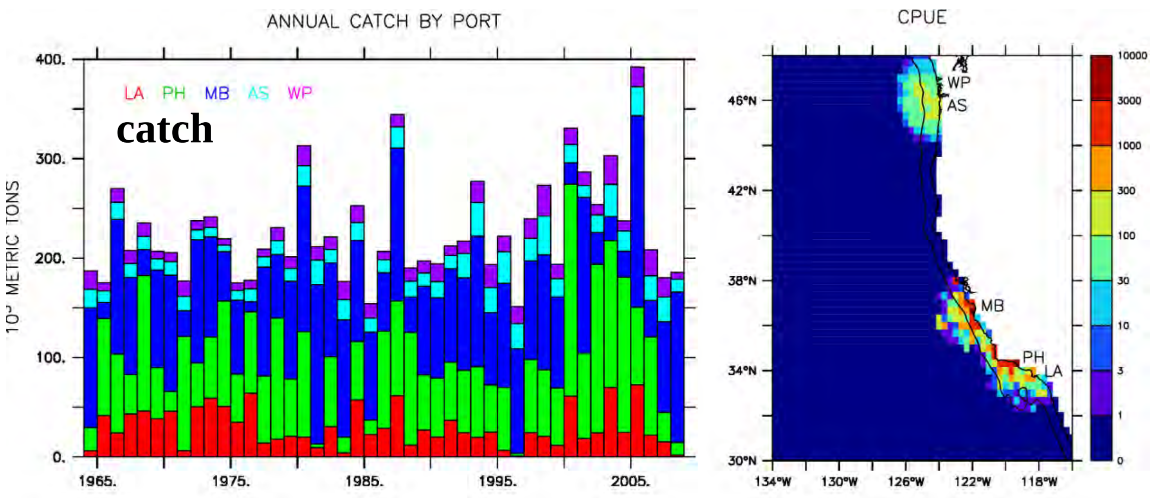
Time schedules in 2015

S-CCME &FISH-MIP

Date	Place	Title
Mar.23-27	Santos, Brazil	3rd Int. Symposium "Effects of Climate Change on the World's Oceans"
Jun.08	Paris, France	World Oceans Day
Jul.07-10	Paris, France	POC21 Science Conference "Our Common Future Under Climate Change"
Aug.10-12	Princeton, USA	NOAA international workshop "Ecosystem projection model inter- comparison and assessment of climate change impacts on global fish and fisheries"
Sep.21-25	Copenhagen, Denmark	ICES Annual Science Conference "Managing Marine Ecosystem Services in a Changing Climate" session
Oct.15-25	Qingdao, China	PICES Annual Meeting "Past, present, and future climate in the North Pacific Ocean: updates of our understanding since IPCC AR5" session

NEMURO.SAN





ROMS+NEMURO
+ 8 species fish
+ predator
+ fishing boat

Rose et al. (in press)

Future directions