NEMURO & NEMURO.FISH

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NEMURO Mafia

Today's contents

1. **Brief history of ecosystem model**
   (go through Prof. Fei Chai's lecture in the 1st PSS)
2. **NEMURO (a lower trophic level EM)**
3. **NEMURO.FISH (a higher trophic level EM)**
4. **hands on**

Ecosystem

Ecosystem is one component of the earth system.
It is not static but dynamic.

Difficulties of Earth System Science

Harte (2002)

1. **The global scale of human activities and the historically unprecedented magnitude of human disturbance of the planet mean that past experience is often not a reliable guide to predicting the consequences of our actions.**
2. **The Earth system is rife with feedback, nonlinear synergies, thresholds, and irreversibilities, that confound our intuition.**
3. **Ecosystem is dynamically changing.**
4. **Conducting large scale experiments on this system is impossible.**

Ecosystem modeling

Therefore, we need models to test the ecosystem functions and responses and to understand its structure and functioning.

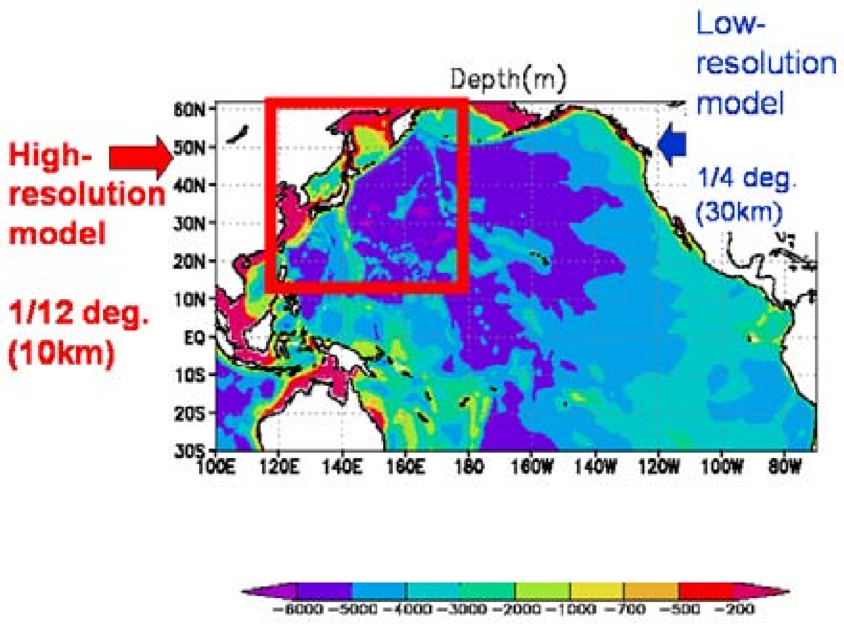
Problems

- **Always we meet with tradeoff between "resolution or coverage in biological components" & "spatial resolution or coverage".**
- **Computational power is still limited.**

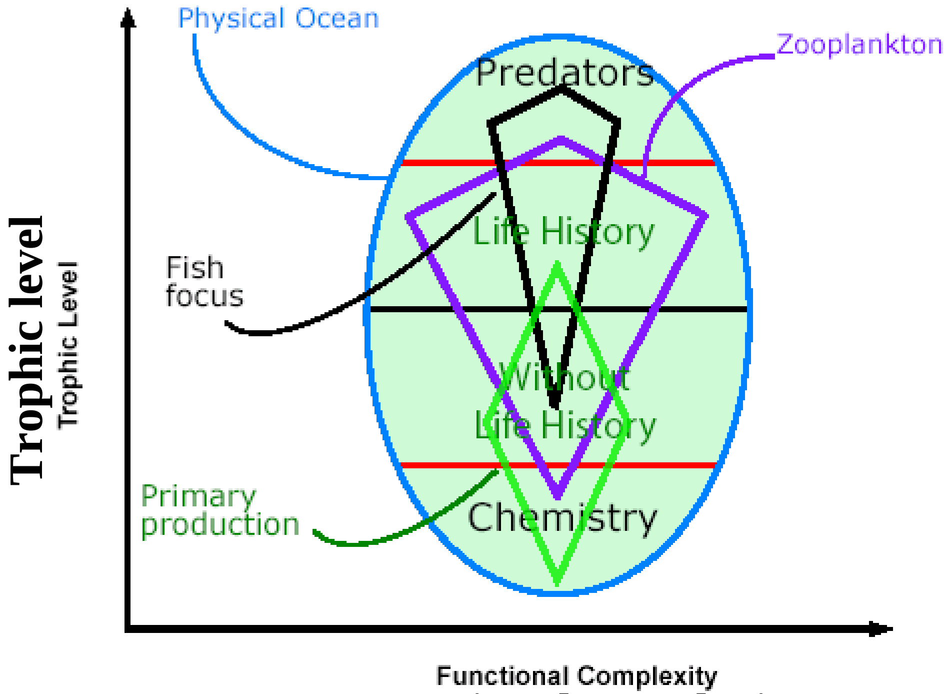
Strategy for Ecosystem Modeling

1. **Nesting in spatial resolution**
2. **Rhomboidal approach (deYoung et al., 2004)**

increase resolution of target species.



From JCOPE home page



deYoung et al. (2004)

Another or similar solution

Fermi approach (simple models)

1. Complex models, which look as inscrutable as nature itself, have numerous adjustable parameters and are generally unfalsifiable. However, it is impossible to validate the models.
2. Simple models that capture the essence of the problem, but not all the details, might get us farther (Fermi approach).
3. This "Fermi approach" to ESS will only be effective, of course, if decision makers can be weaned from their awe of computer-simulated complexity.

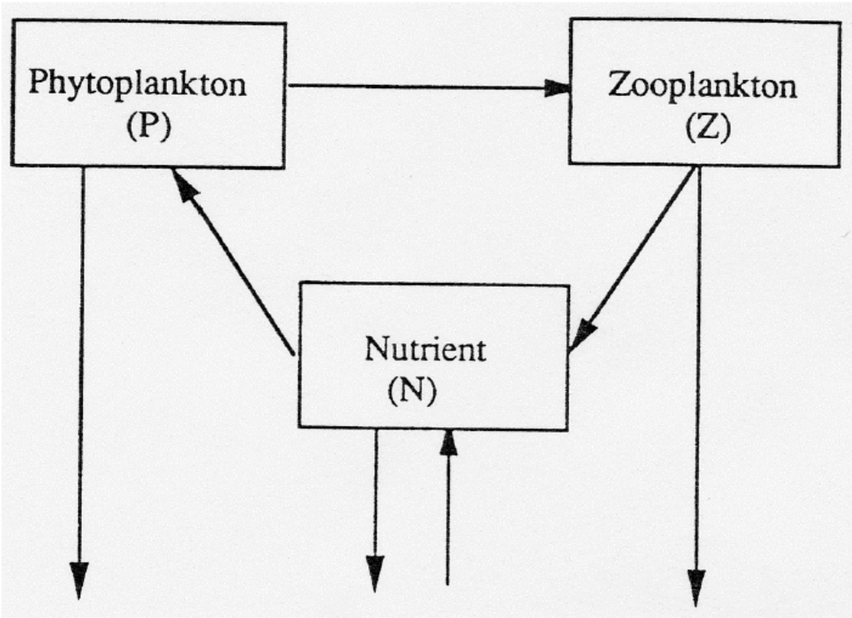
Harte (2002)

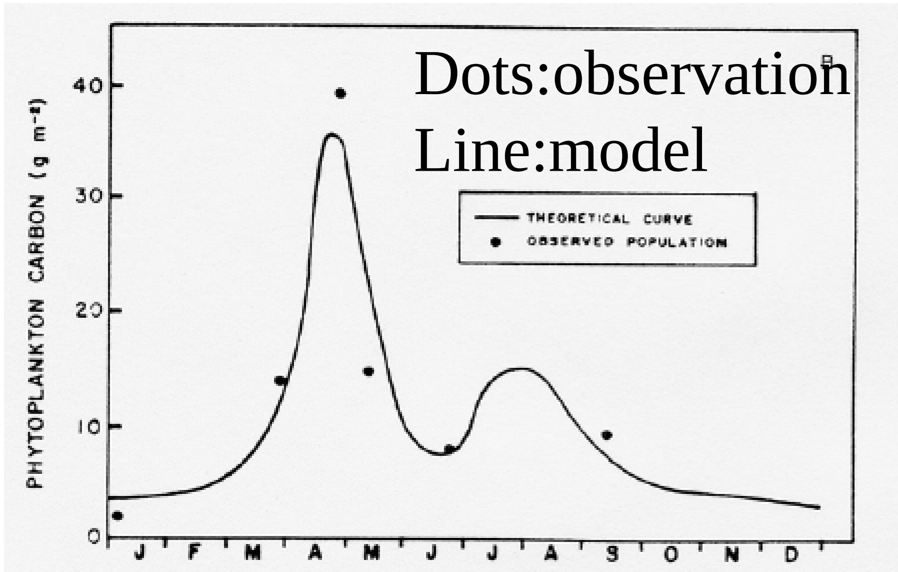
Everything should be as simple as possible, but no simpler.

By Albert Einstein

history of marine ecosystem model

**Riley G. A. (1946) "Factors controlling phytoplankton population on Georges Bank.", J. Mar. Res., 6, 54-73.
This is the first paper introduced differential equation to marine ecosystem modeling.**





Memoirs (G. A. Riley, 1984)

H. Bigelow said "Anybody who thinks he can predict more than 10% of plankton variability is a damn fool, but good luck".

To be sure, I have never pretended that [models] are truly realistic. My only defense has been that they help us to think….

They frequently yield results that are not intuitively obvious, and they teach us caution about drawing conclusions that seem to violate mathematical logic.

That is the way physics and astronomy have grown.

Biological oceanography, messy though it may be, needs the same kind of disciplined thinking.

milestones of NPZD models

<u>Gorden Riley (1946)</u>

Factors controlling phytoplankton population on Georges Bank.

J. Mar. Res. 6, 54-73

<u>John Steele (1974)</u>

The structure of marine ecosystems

<u>Evans and Parslow (1985)</u>

A model of annual plankton cycles, Biol. Oceanogr., 24, 483-494

<u>Fasham, Ducklow, McKelvie (1990)</u>

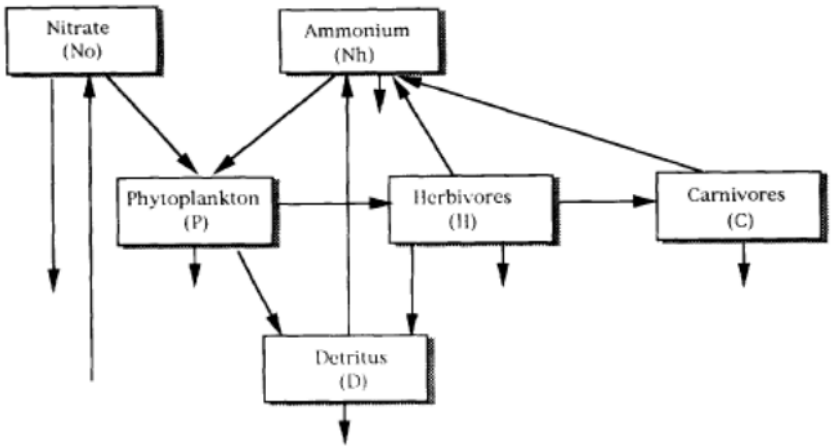
A Nitrogen-based model of plankton dynamics in the ocean mixed layer

J. Mar. Res., 48 (3): 591-639

<u>Fasham (1995)</u>

Variations in the seasonal cycle of biological production in sub-arctic oceans - a model sensitivity analysis.

Deep-Sea Res. Part I: 42 (7): 1111-1149



courtesy of Fei Chai

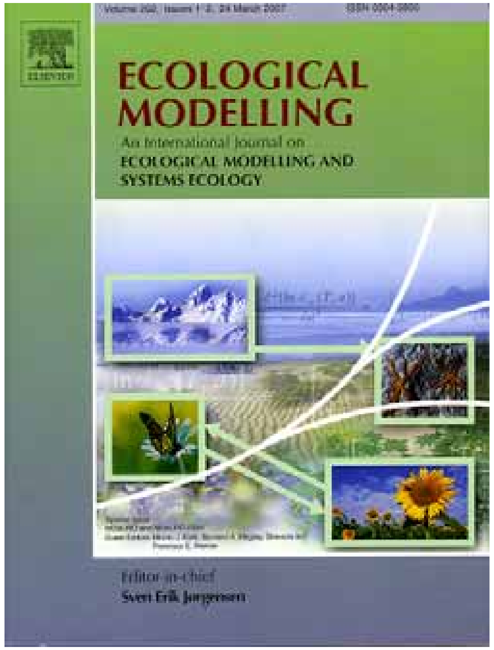
NEMURO

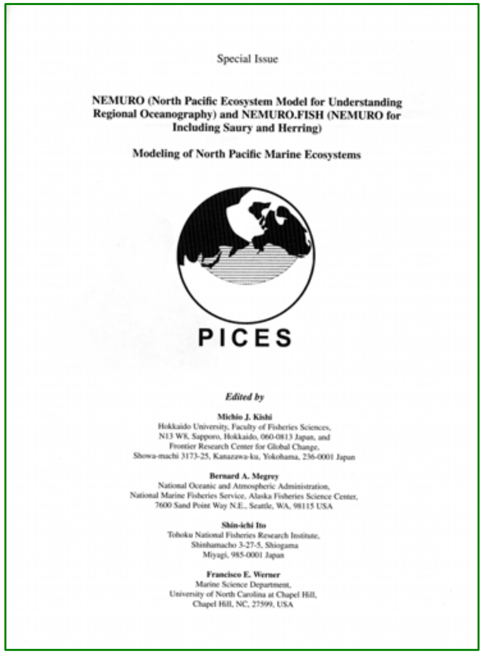
As a science project of PICES, CCCC (Climate Change and Carrying Capacity) was started in 1993.
Under CCCC, "Conceptual theoretical modeling studies Task Team" was formed. =>MODEL Task Team

To develop a lower trophic ecosystem model which can be applied commonly to the North Pacific, PICES LTL model workshop was held in Nemuro in 2000.
The developed model was names as NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography).

NEMURO


2000 PICES 低次生産モデリング
根室ワークショップ
2000 PICES Lower Trophic Level Modeling Nemuro Workshop
PICES
ネップ





Special Issue

NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) and NEMURO.FISH (NEMURO for Including Saury and Herring)

Modeling of North Pacific Marine Ecosystems

PICES

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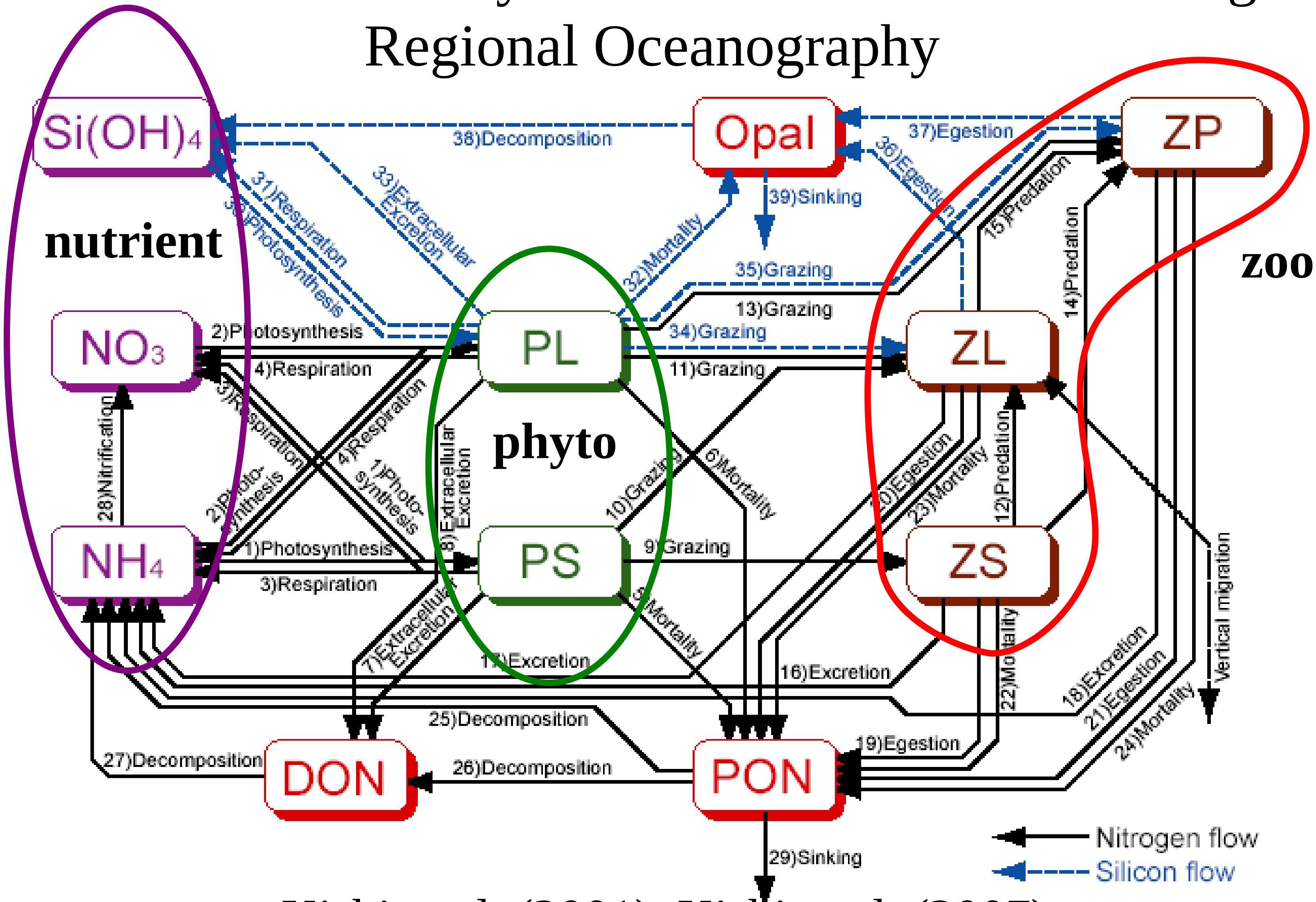
NEMURO

(North Pacific Ecosystem Model for Understanding Regional Oceanography)

1. Nutrient-Phytoplankton-Zooplankton model
2. Developed under PICES Model Task Team since 2000
3. Coupled with fish bioenergetics models
4. Published special issue on Ecological Modelling in 2007
5. Published 37 papers on peer reviewed journals
6. Used in more than 8 countries (Canada, Russia, South Korea, China, USA, Japan, Mexico, Greek, etc.)

NEMURO

North Pacific Ecosystem Model for Understanding Regional Oceanography



Kishi et al. (2001), Kishi et al. (2007)

Nitrogen equations

$$\frac{dPSn}{dt} = GppPSn - ResPSn - MorPSn - ExcPSn - GraPS2ZSn - GraPS2ZLn$$

$$\frac{dPLn}{dt} = GppPLn - ResPLn - MorPLn - ExcPLn - GraPL2ZLn - GraPL2ZPn$$

$$\frac{dZSn}{dt} = GraPS2ZSn - GraZS2ZLn - GraZS2ZPn - MorZSn - ExcZSn - EgeZSn$$

$$\frac{dZLn}{dt} = GraPS2ZLn + GraPL2ZLn + GraZS2ZLn - GraZL2ZPn - MorZLn - ExcZLn - EgeZLn$$

$$\frac{dZPn}{dt} = GraPL2ZPn + GraZS2ZPn + GraZL2ZPn - MorZPn - ExcZPn - EgeZPn$$

$$\frac{dNO3}{dt} = -(GppPSn - ResPSn)RnewS - (GppPLn - ResPLn)RnewL + Nit + UPWn$$

$$\begin{aligned}\frac{dNH4}{dt} = &-(GppPSn - ResPSn)(1 - RnewS) - (GppPLn - ResPLn)(1 - RnewL) \\ &- Nit + DecP2N + DecD2N + ExcZSn + ExcZLn + ExcZPn\end{aligned}$$

$$\begin{aligned}\frac{dPON}{dt} = &MorPSn + MorPLn + MorZSn + MorZLn + MorZPn + EgeZSn + EgeZLn \\ &+ EgeZPn - DecP2N - DecP2D - SEDn\end{aligned}$$

$$\frac{dDON}{dt} = ExcPSn + ExcPLn + DecP2D - DecD2N$$

Silicon equations

$$\frac{dPLsi}{dt} = GppPLsi - ResPLsi - MorPLsi - ExcPLi - GraPL2ZLsi - GraPL2ZPsi$$

$$\frac{dZLsi}{dt} = GraPL2ZLsi - EgeZLsi$$

$$\frac{dZPsi}{dt} = GraPL2ZPsi - EgeZPsi$$

$$\frac{dSi(OH)4}{dt} = -GppPL\,si + ResPL\,si + ExcPLsi + UPWsi + DecP2Si$$

$$\frac{dOpal}{dt} = MorPLsi + EgeZLsi + EgeZPsi - SEDsi - DecP2Si$$

e.g. small phytoplankton equation

$$\frac{dPSn}{dt} = GppPSn - ResPSn - MorPSn - ExcPSn - GraPS2ZSn - GraPS2ZLn$$

photosynthesis

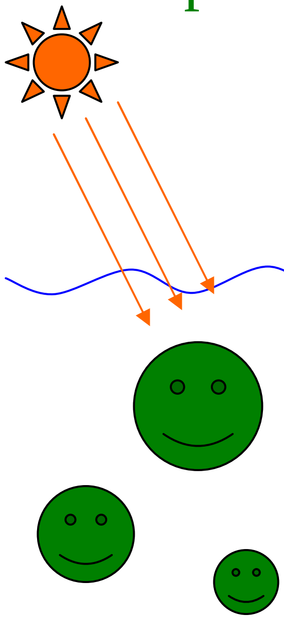
respiration

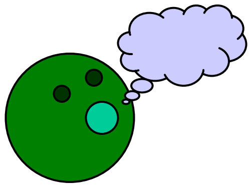
mortality

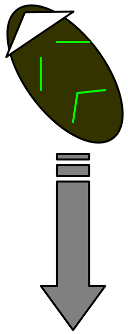
Extracellular excretion

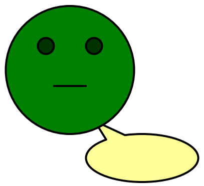
Grazing from small zooplankton

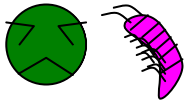
Grazing from large zooplankton

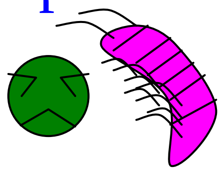












small phytoplankton equations

$$GppPSn = V_{\max S} * \left(\frac{NO3}{NO3 + K_{NO3S}} \exp(-\Psi_S * NH4) + \frac{NH4}{NH4 + K_{NH4S}} \right)$$

$$* \exp(k_{GppS} * TMP) * \int_{-H}^{0} \frac{I}{I_{optS}} \exp\left(1 - \frac{I}{I_{optS}}\right) dz * PSn$$

$$I = I_0 \exp(-\kappa |Z|)$$

$$\kappa = \alpha_1 + \alpha_2 (PSn + PLn)$$

$$RnewS = \frac{\frac{NO3}{NO3 + K_{NO3S}} \exp(-\Psi_S * NH4)}{\frac{NO3}{NO3 + K_{NO3S}} \exp(-\Psi_S * NH4) + \frac{NH4}{NH4 + K_{NH4S}}}$$

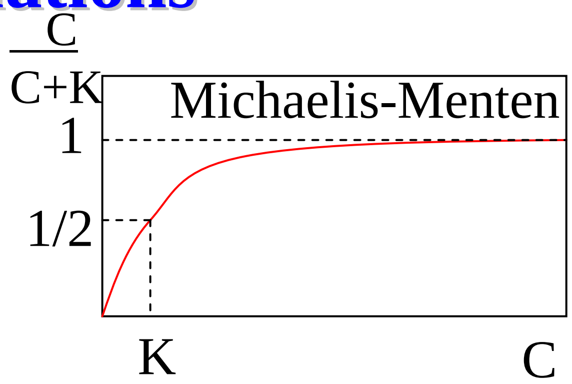
$$ResPSn = ResPS0 * \exp(kResPS * TMP) * PSn$$

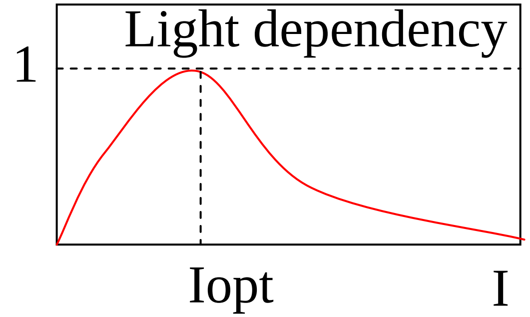
$$MorPSn = MorPS0 * \exp(kMorPS * TMP) * PSn^2$$

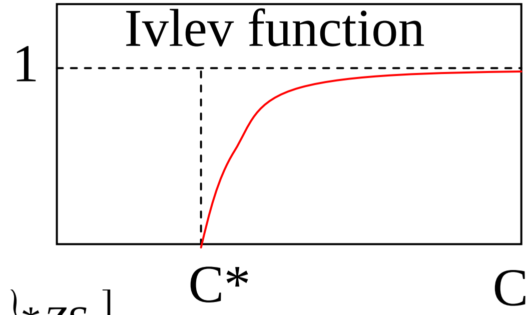
$$ExcPSn = \gamma PS * GppPSn$$

$$GraPS2ZSn = \mathrm{Max}\left[0, GR_{\max}Sps * \exp(k_{GraS} * TMP) * \left\{1 - \exp(\lambda_S * (PS2ZS^* - PSn))\right\} * ZSn\right]$$

$$GraPS2ZLn = \mathrm{Max}\left[0, GR_{\max}L_{ps} * \exp(k_{GraL} * TMP) * \left\{1 - \exp(\lambda_L * (PS2ZL^* - PSn))\right\} * ZLn\right]$$







problems

1. **Limiting factor for Photosynthesis**

   Multiplier of nutrient concentration, temp. and light.

   Another possibility is f(T)*min(f(N), f(L))

2. **Natural mortality**

   Proportional to square of plankton density

   Due to stabilize the system (no theoretical reason)

   Insensitive to high frequency variability

   (Wainwright et al. 2007)

   Since predation pressure from higher trophic already acts on planktons, it is possible to modify such as D**1.5.

3. **Predation pressure**

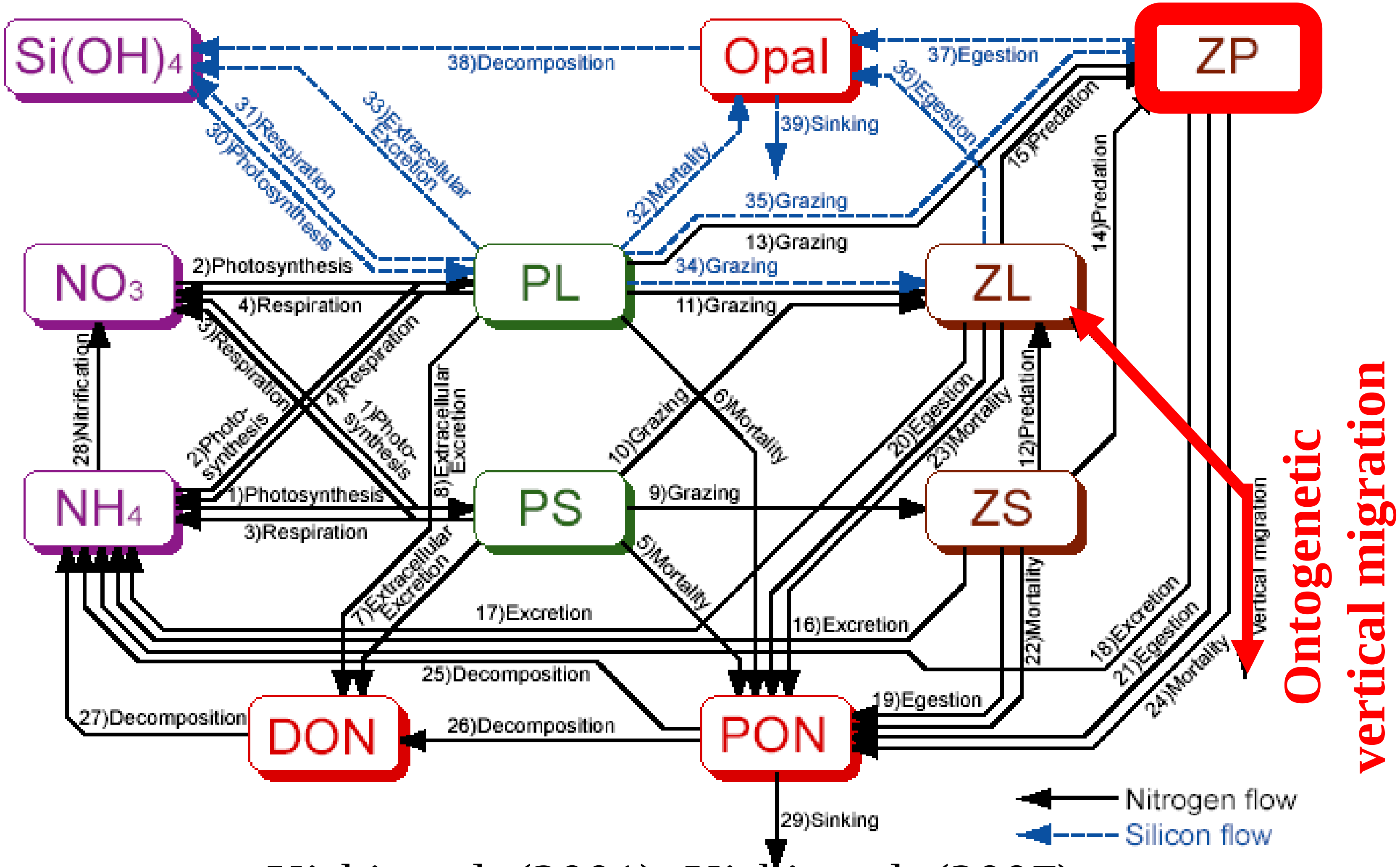
   Critical value is defined to avoid extinction

4. **Many of parameters were borrowed from other models.**

   PL photosynthesis parameters must be revised.

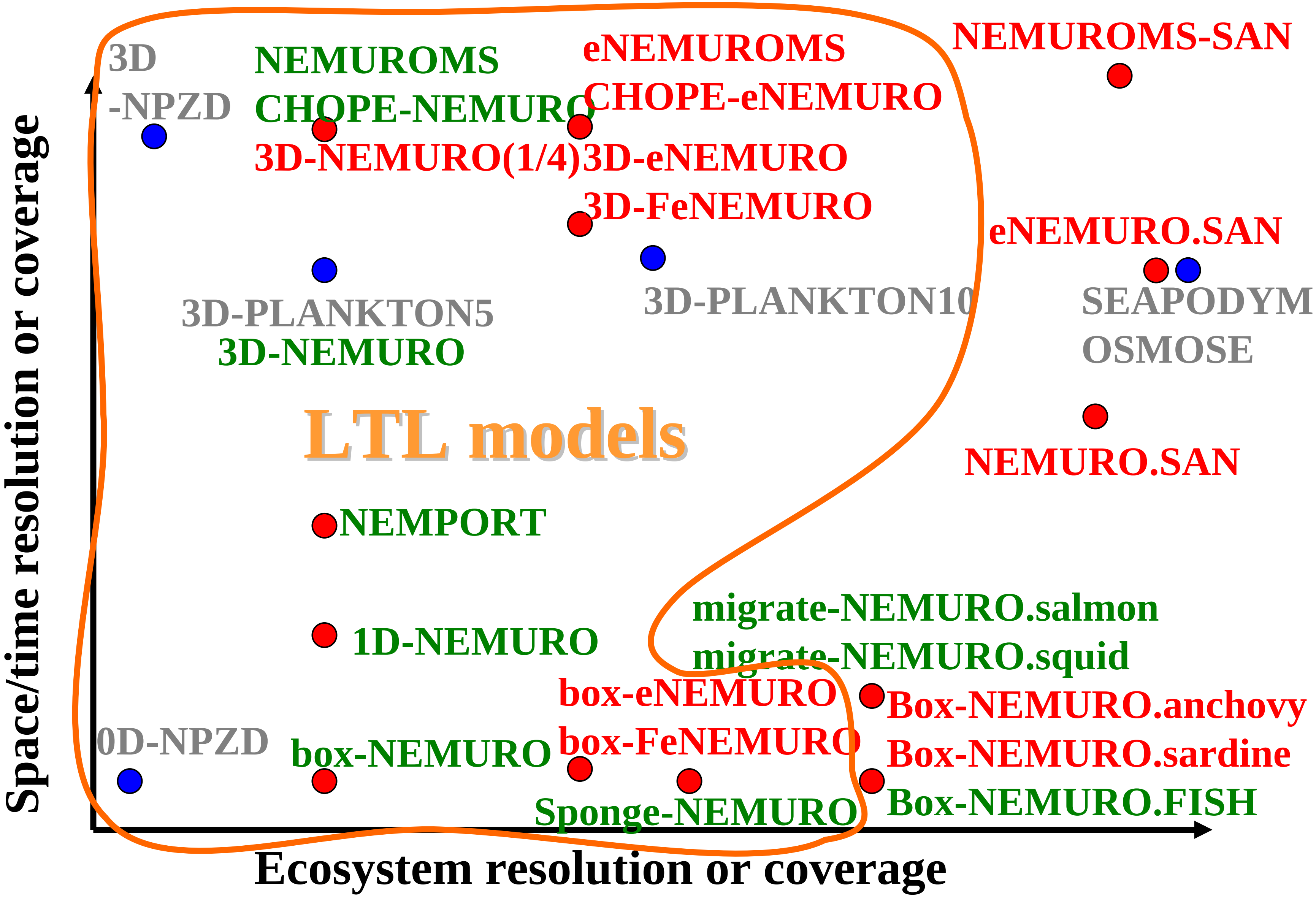
NEMURO

North Pacific Ecosystem Model for Understanding Regional Oceanography



Kishi et al. (2001), Kishi et al. (2007)

NEMURO family (GR: published, RD:developing)



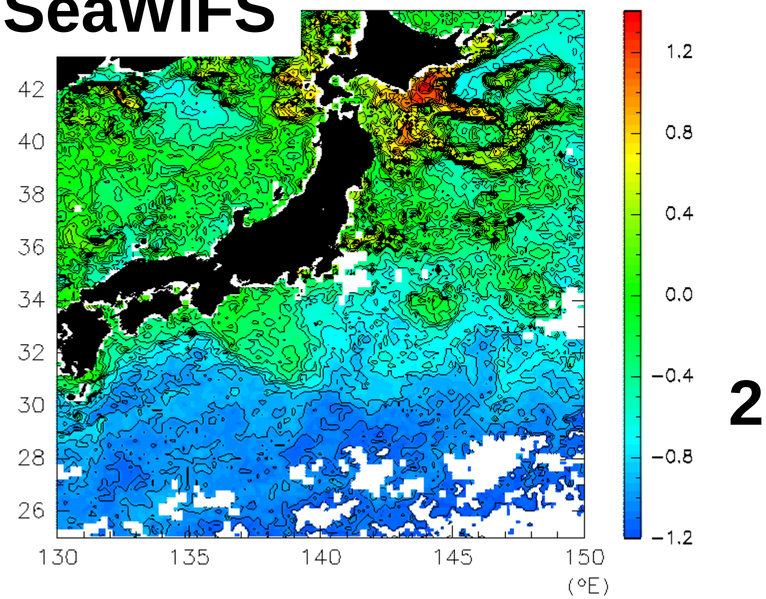
tradeoff between (finer individual species) & (basin scale model)

CHOPE + eNEMURO

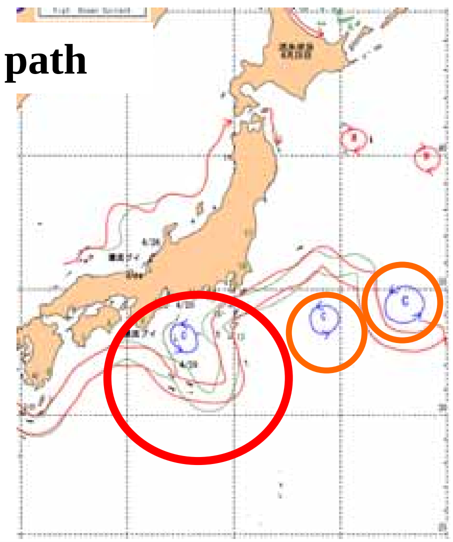
Komatsu et al. (in prep.)

SeaWiFS

Log10(Chl) [mg/m-3]

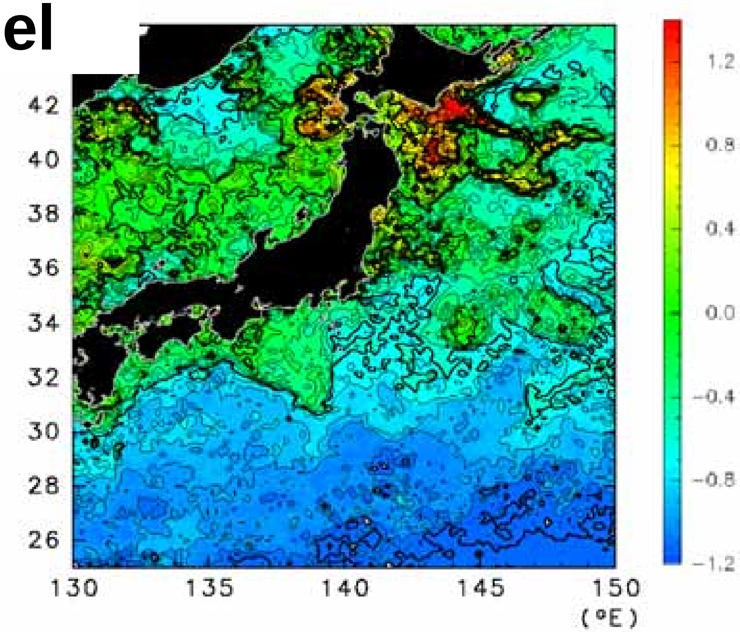


Kuroshio path

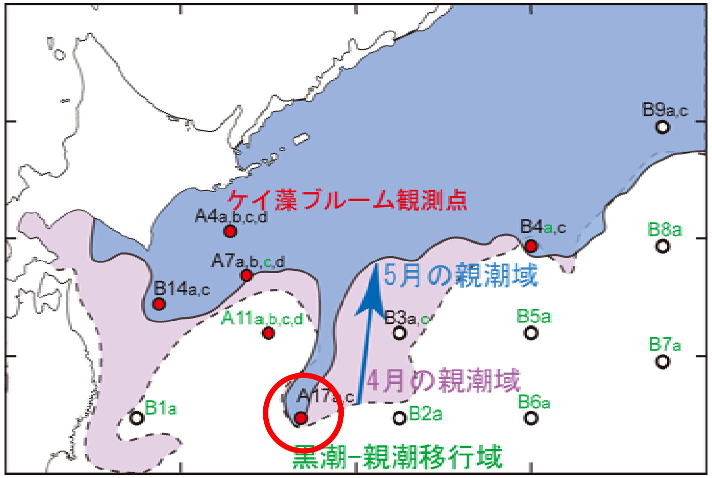


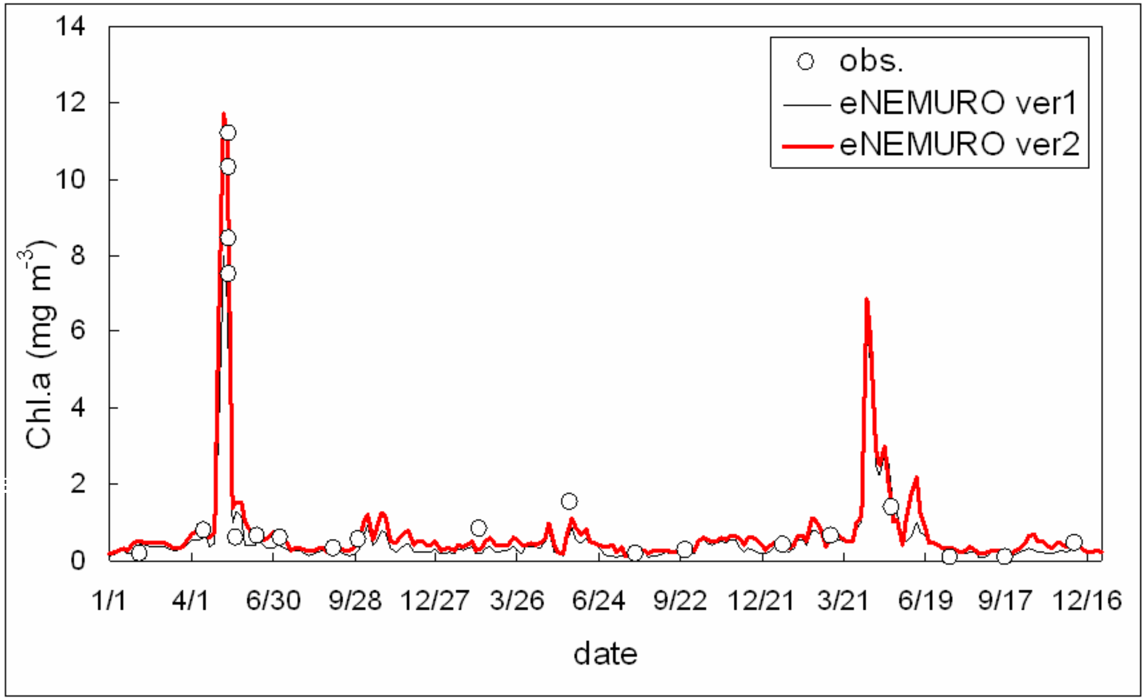
2005/4/22

model



CHOPE + eNEMURO



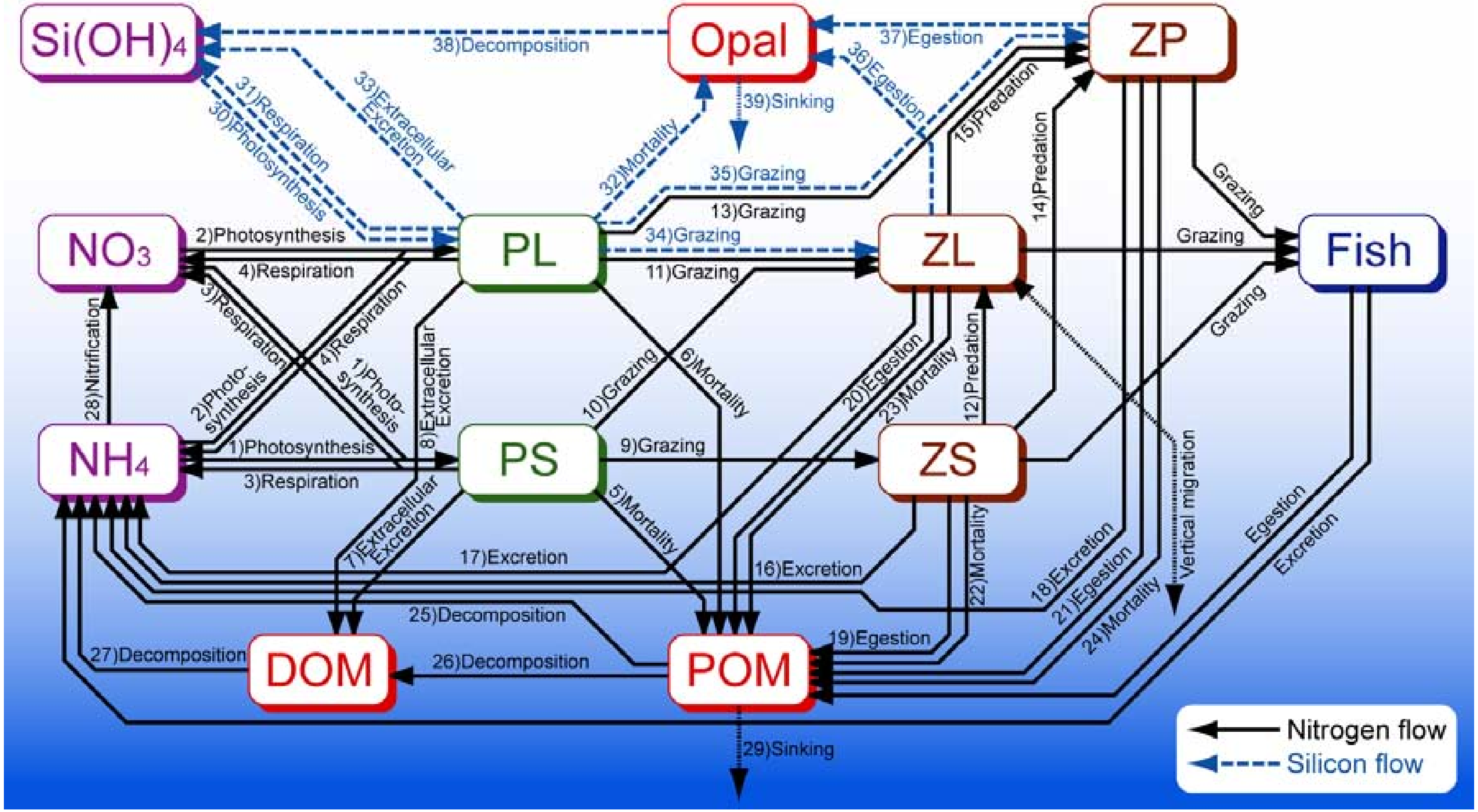


(Yoshie *et al.*, *in prep.*)

High resolution ocean circulation model was assimilated to satellite altimetry data.
Therefore, physical part is close to the true.
LTL model can capture the variability of phytoplankton well in this case.

NEMURO.FISH

NEMURO for Including Saury and Herring



Megrey et al. (2007a), Ito et al. (2004) etc.

Bioenergetics Model for herring and saury

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

change of weight

C: consumption

R: respiration (loses through metabolism)

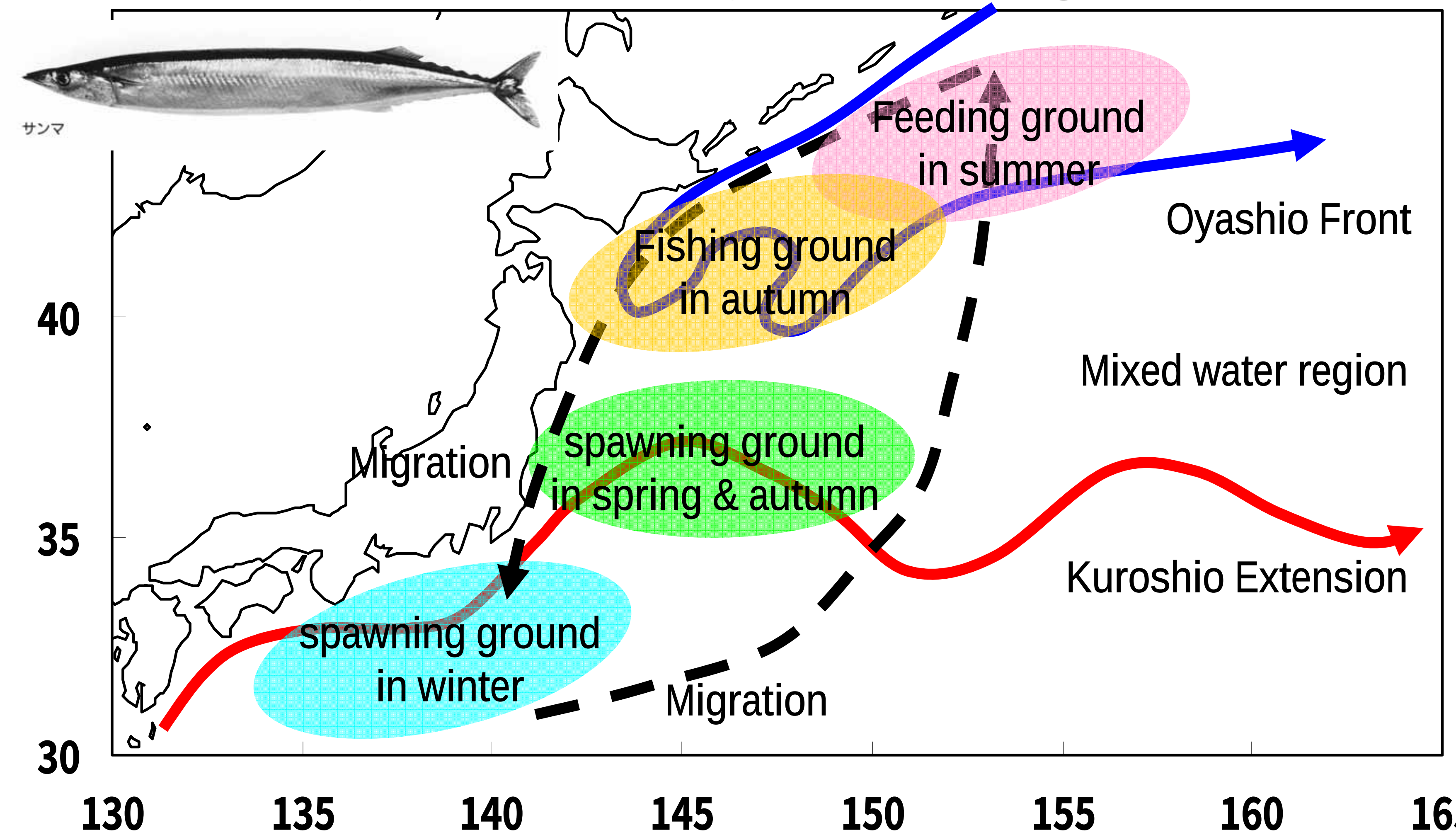
S: specific dynamic action (digesting food)

F: egestion

E: excretion

P: egg production

Life History of Pacific Saury with Oceanographic Features



Ito et al. (2004a)

3-box version

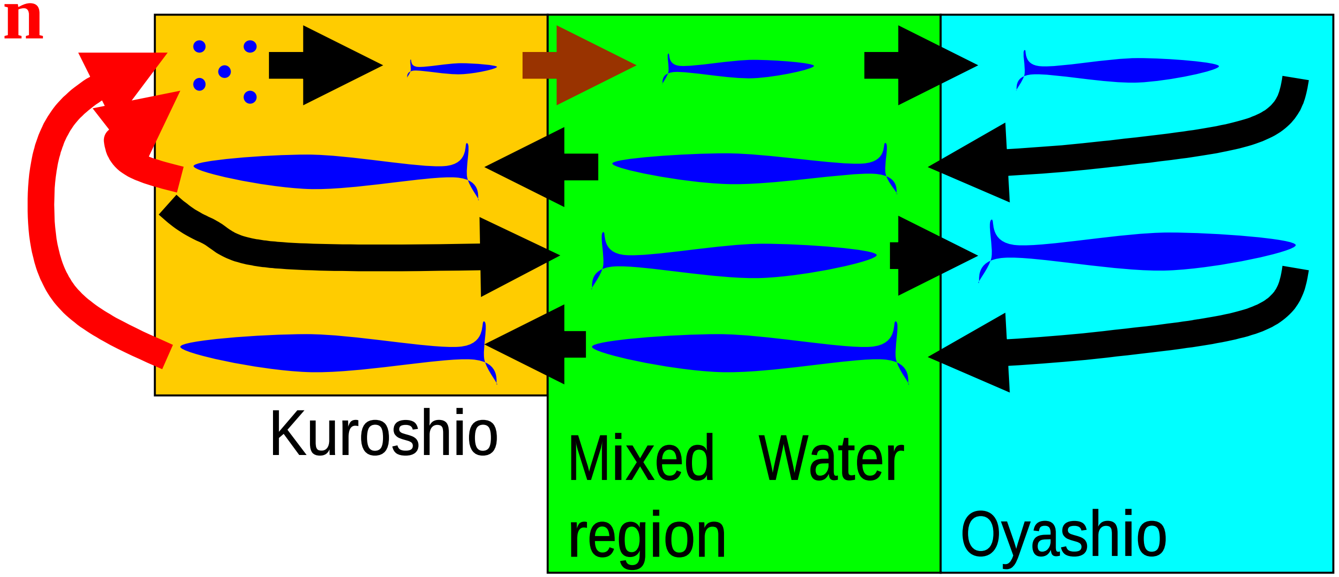
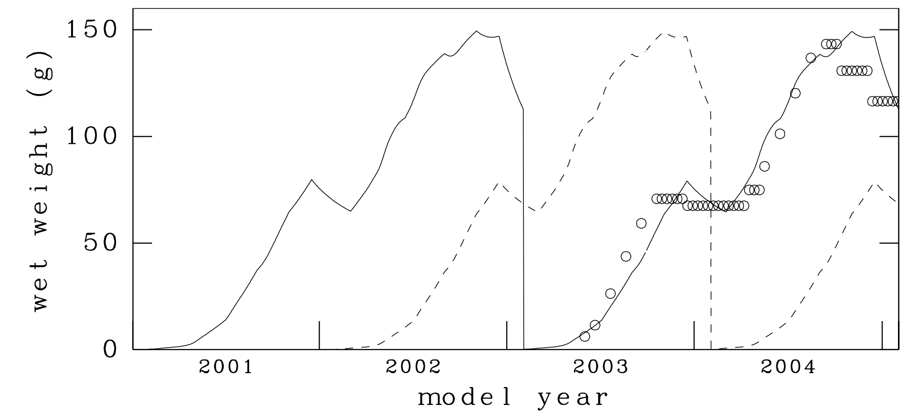


Table 2. Life stages of Pacific saury in the saruy bioenergetics model

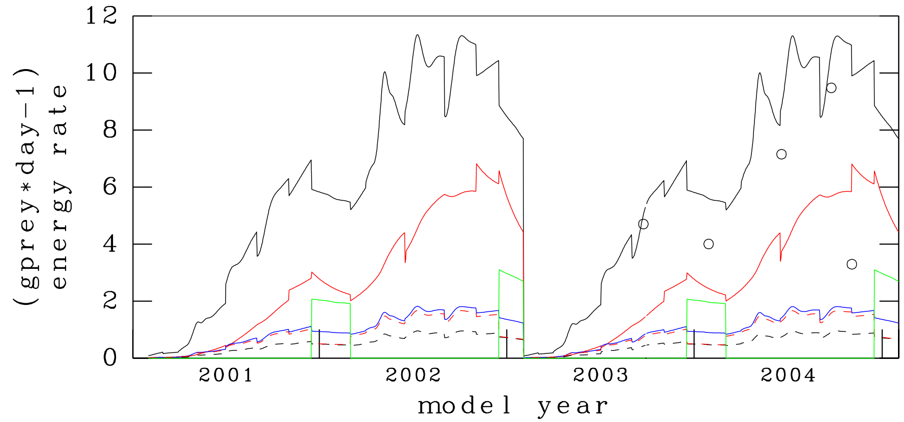
Stage	region
larvae	Kuroshio
juvenile & young	mixed region
small	Oyashio
adult	mixed region
adult matured	Kuroshio
adult	mixed region
adult	Oyashio
adult	mixed region
adult matured	Kuroshio

9 life stages

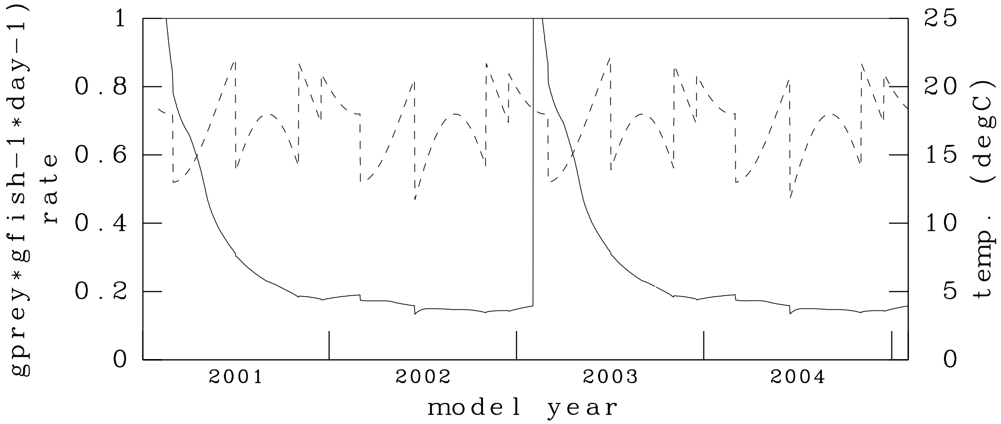
Ito et al. (2004b)
Ito et al . (2007)
Mukai et al. (2007)



Simulated wet weight & observed growth (Kurita et al.)



Terms of the bioenergetics equation
black solid: consumption
red solid: respiration
blue solid: egestion
black dotted: excretion
red dotted: specific dynamic action
green: egg production
open circle: observed consumption by Kurita (2002)



maximum consumption rate multiplied by temperature function (solid line) & water temperature (dotted line).

Ito et al. (2004b)

Dynamic linkage between LTL & HTL

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

NH4

PON

$dN/dt = -(F+M)\,N$

Population dynamics model

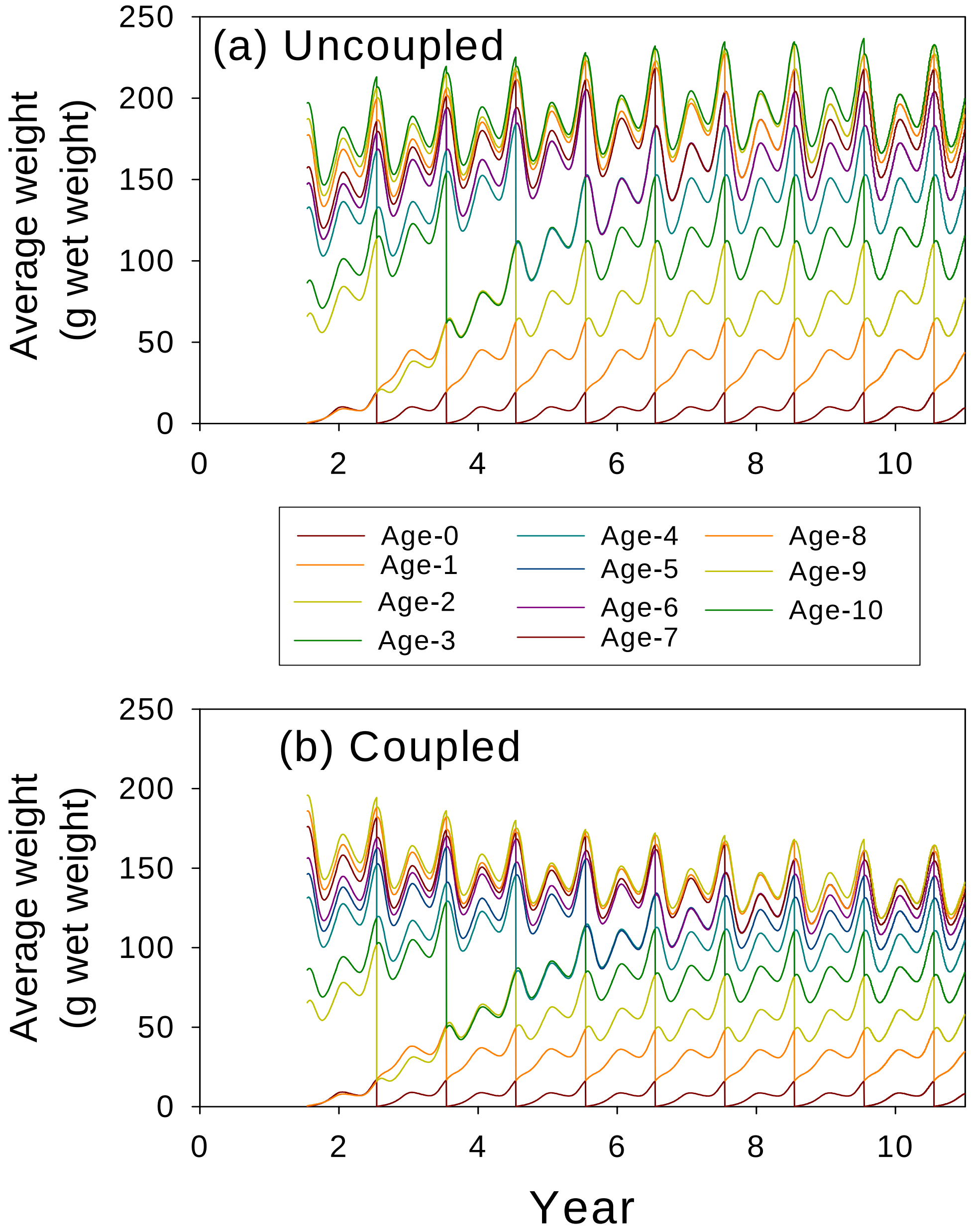
Decrease ZS, ZL, ZP

Effect of Dynamic Linkage and Predation Pressure

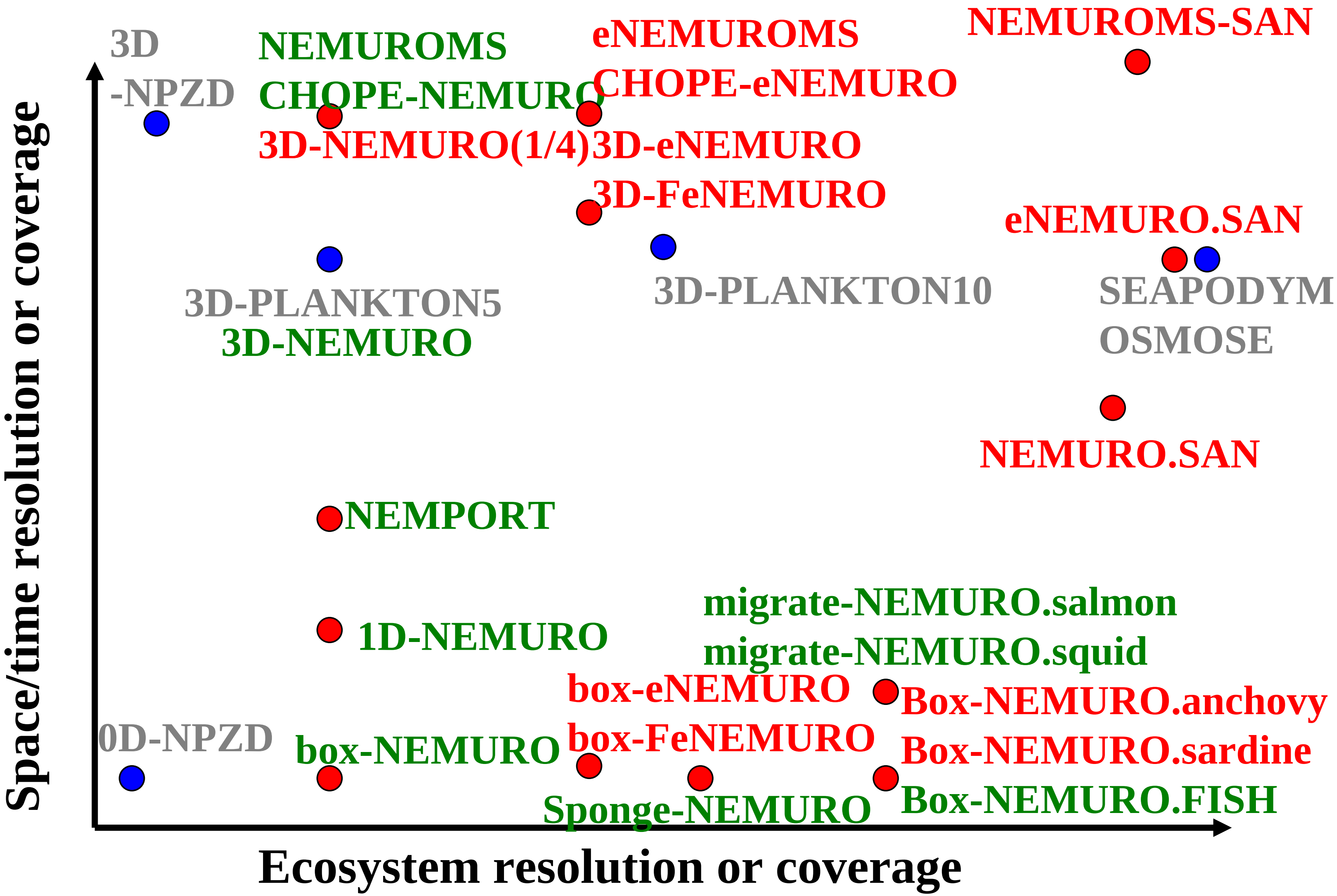
Reduction in large zooplankton

Slower herring growth

(Megrey et al. 2007a)

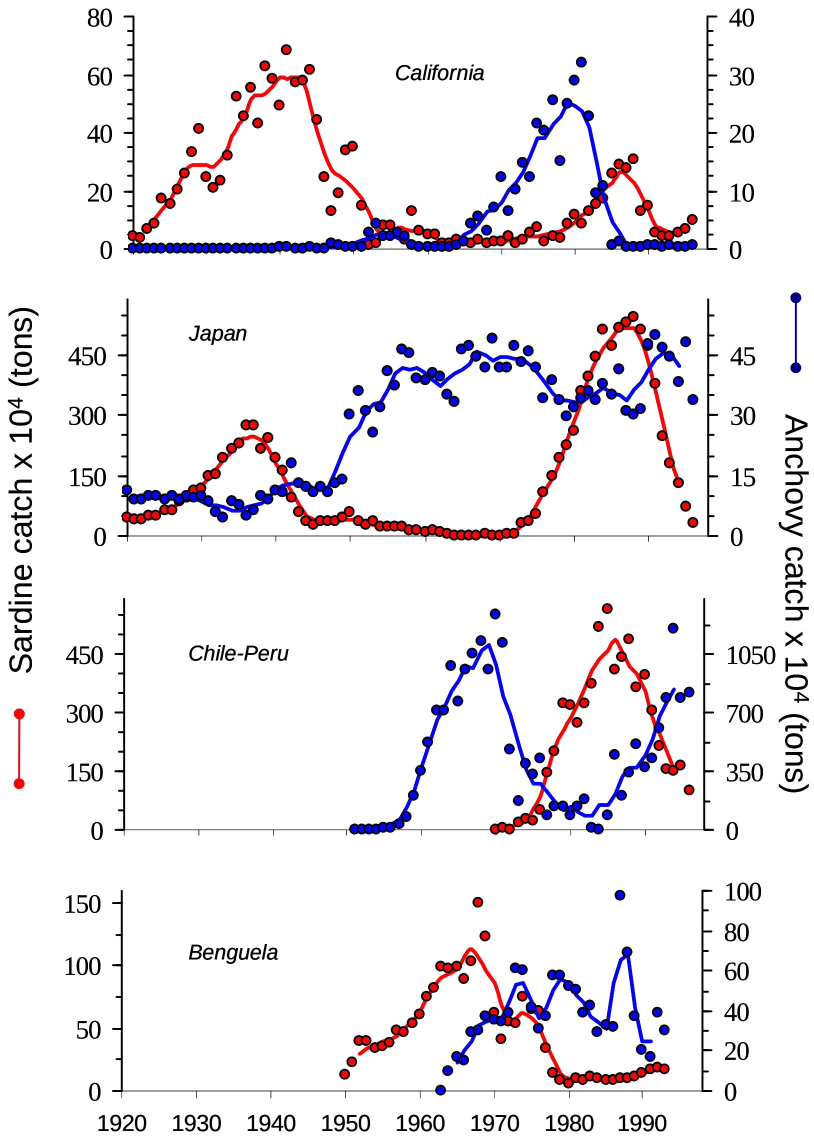


NEMURO family (GR: published, RD:developing)



tradeoff between (finer individual species) & (basin scale model)

NEMURO.SAN



Provided by: Salvador E. Lluch-Cota
Source: Schwartzlose et al., 1999

Held a workshop in Tokyo in 2005 to compare sardine & anchovy in California, Benguera, Funbolt, Oyashio/Kuroshio Current systems.

Common features:

◆**asynchronicity between sardine & anchovy**

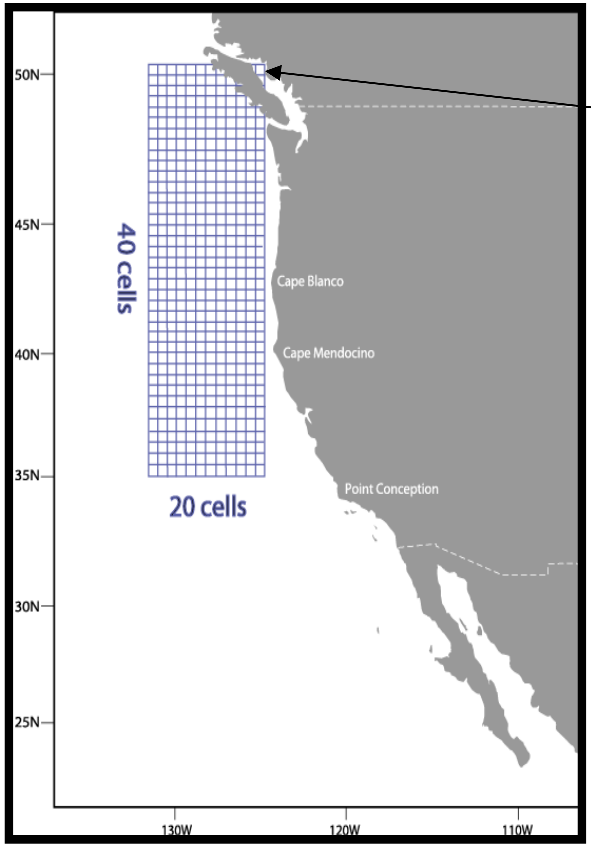
◆**geographical expansion and reduction of distribution**

We decided model extensions:

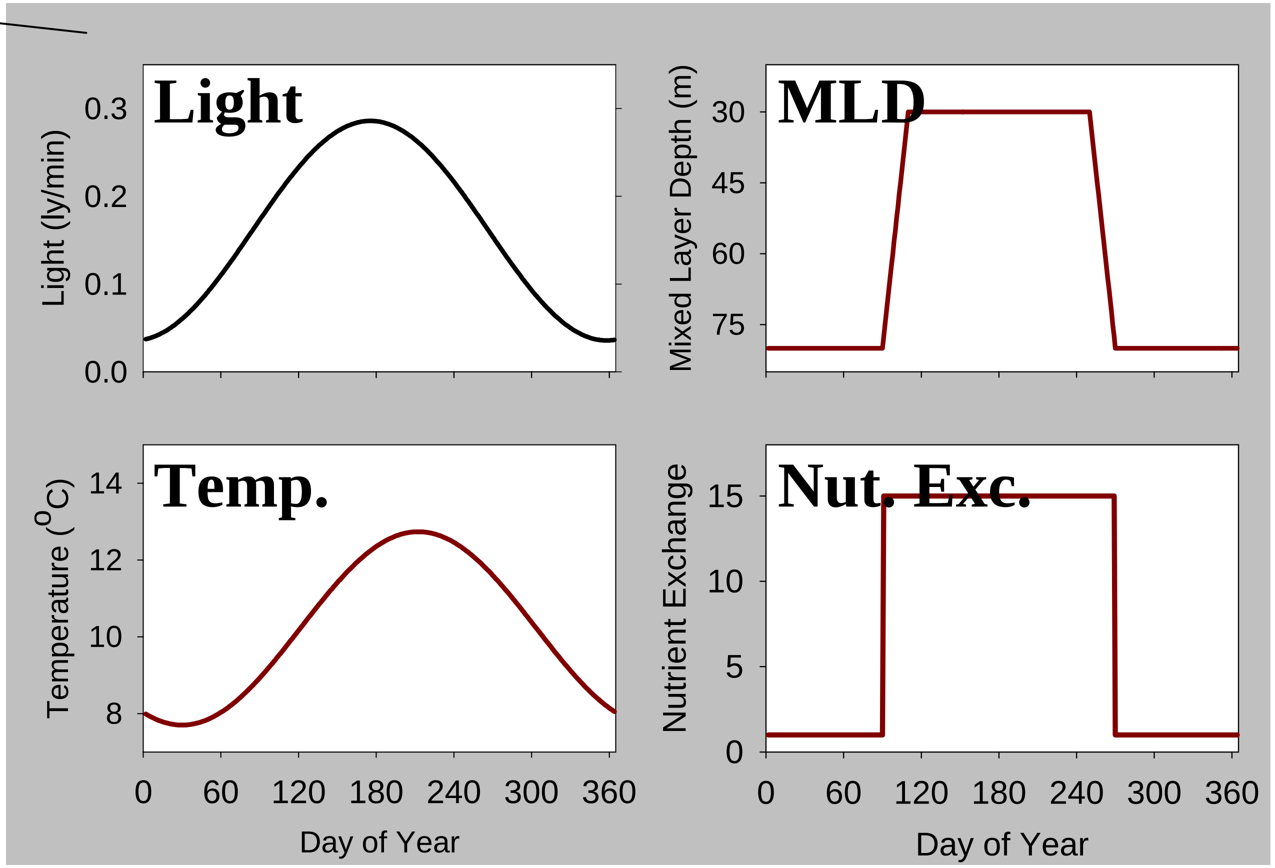
◆**Two species (sardine & anchovy)**

◆**Dynamic predator on sardine & anchovy**

California Current System



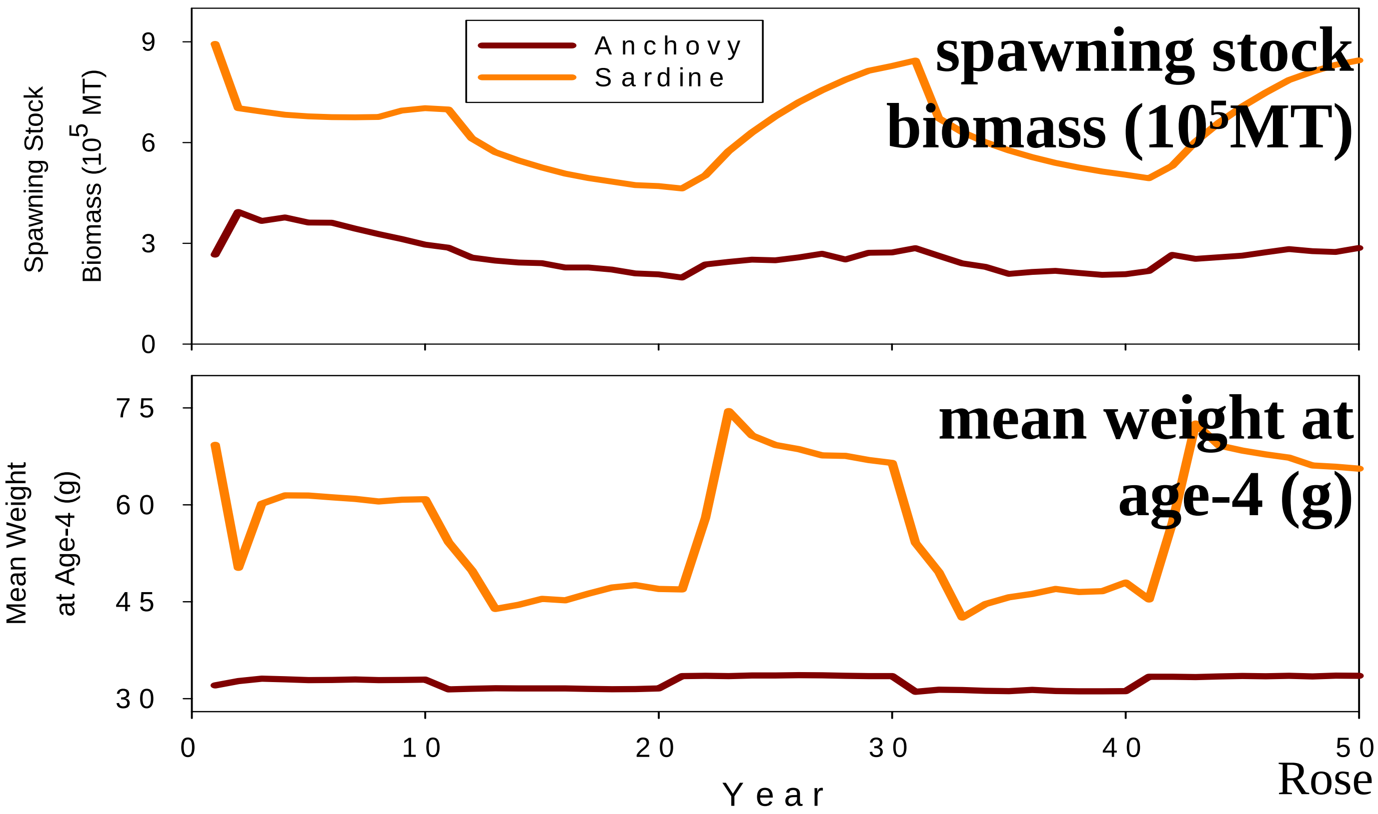
Environmental Variables
At West Vancouver Island



Rose et al.(in prep.)

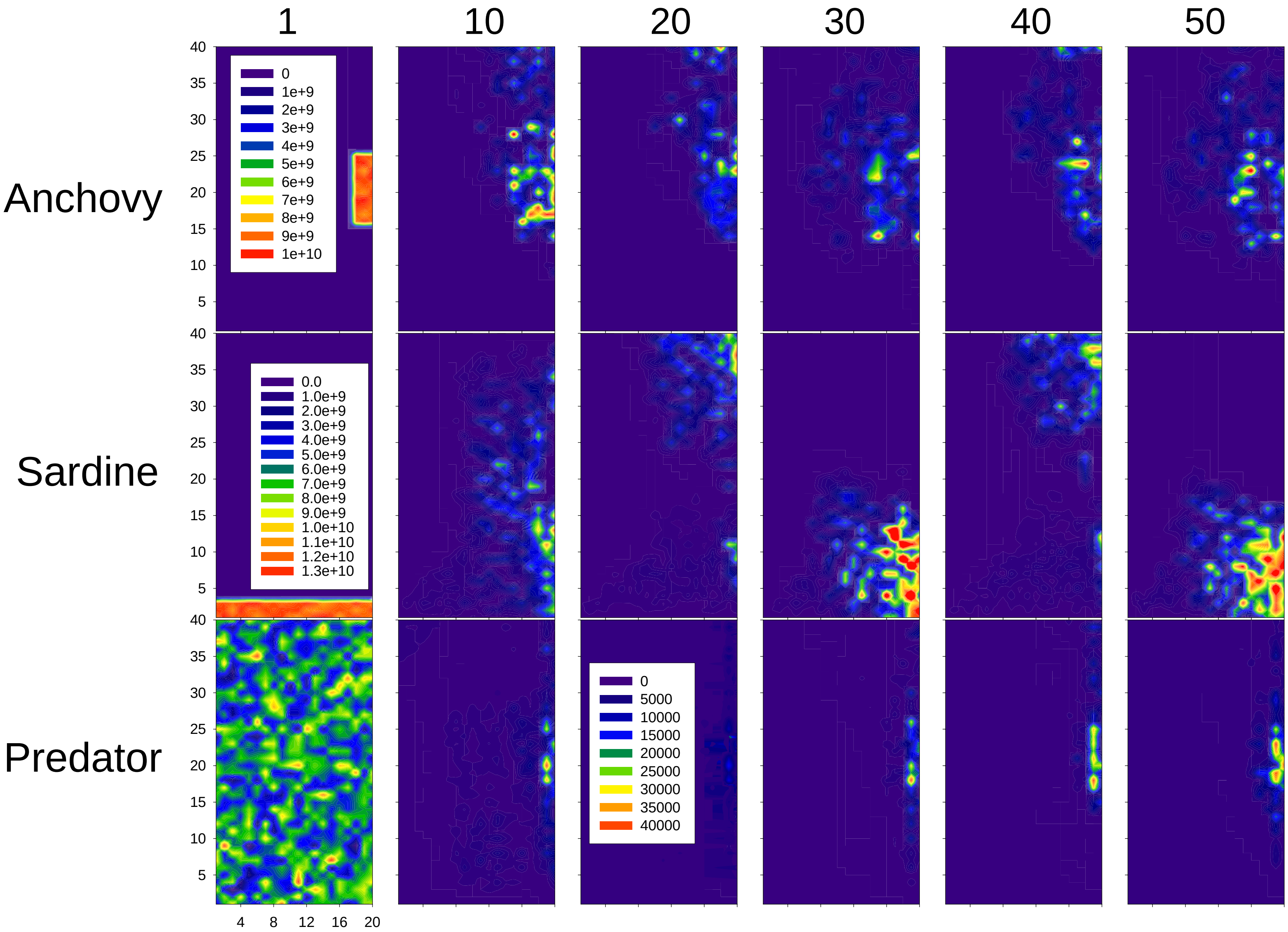
Experiment 1

Year 1-10: Spin-up
Year 11-20: warm (+2 degC)
Year 21-30: cold (-2 degC)
Year 31-40: warm (+2 degC)
Year 41-50: cold (-2 degC)



Rose et al.(in prep.)

Experiment 1



Rose et al.(in prep.)

NEMURO & NEMURO.FISH

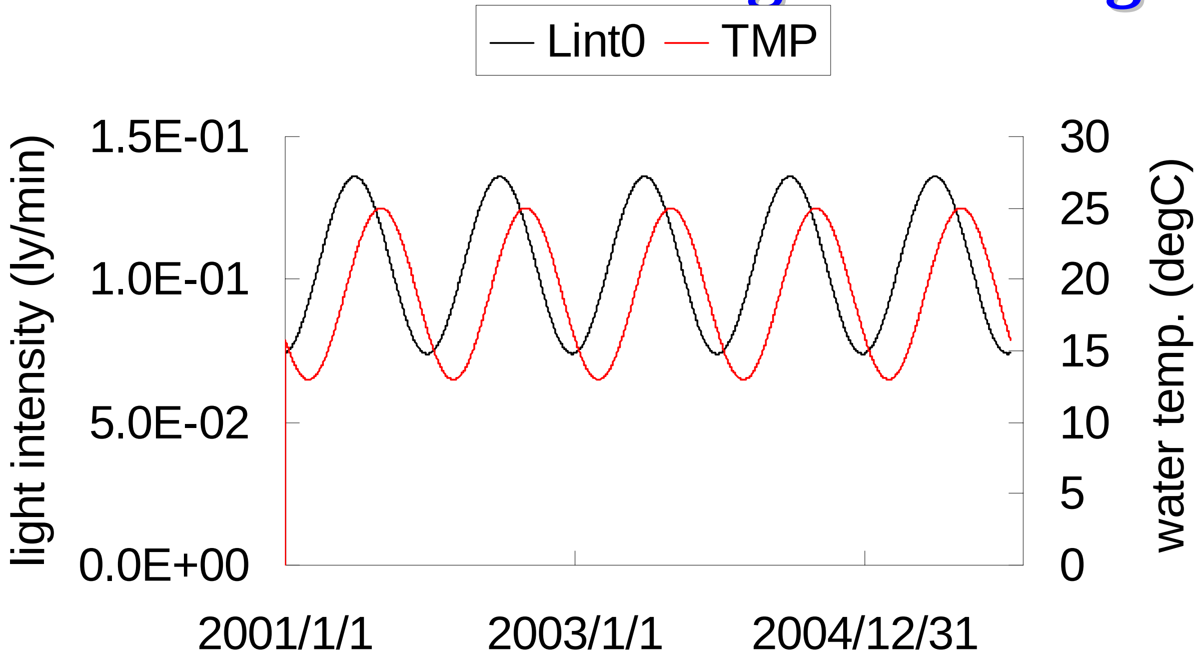
- **LTL-HTL coupled model.**
- **Now interspecies interaction is included.**
- **Therefore, it is possible to apply NEMURO.FISH to ecosystem based management**

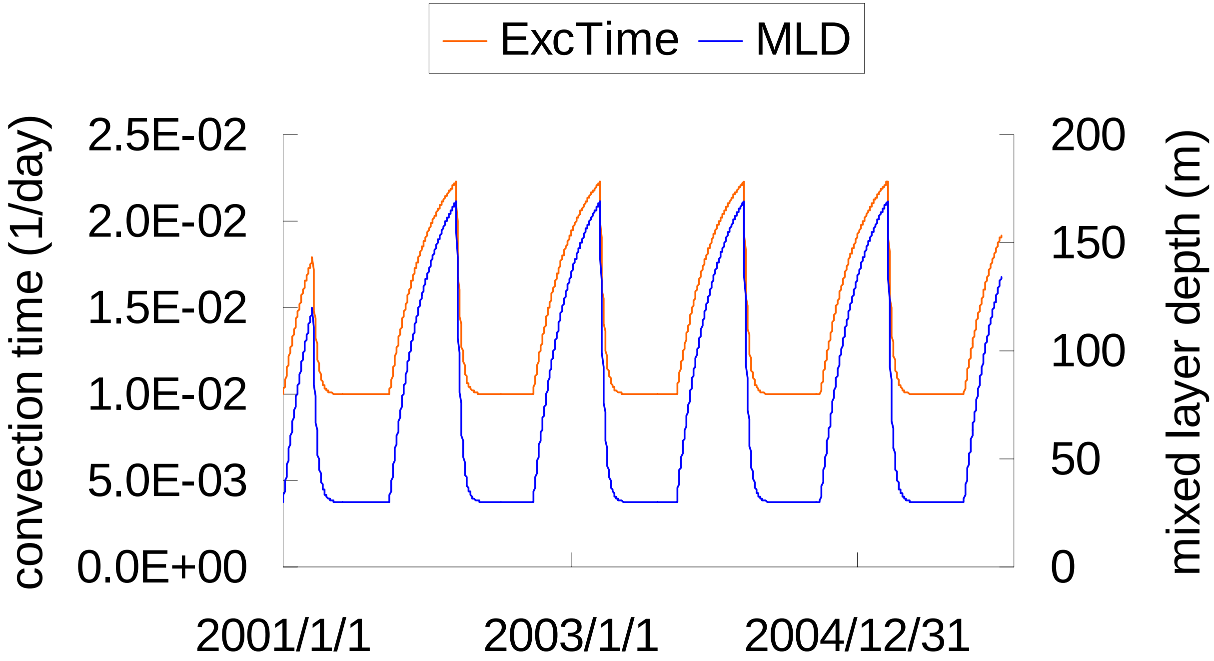
- **However, we must keep the fact in memories that the model parameters are not enough validated and other factors such as adaptability may change the parameters.**
- **Models include errors (uncertainty) because of**
  - **lack of dynamics,**
  - **insufficient determination of parameters,**
  - **inapposite forcings, etc.**
- **Make model simple as possible as we can.**

NEMURO.FISH
Very simple exercises

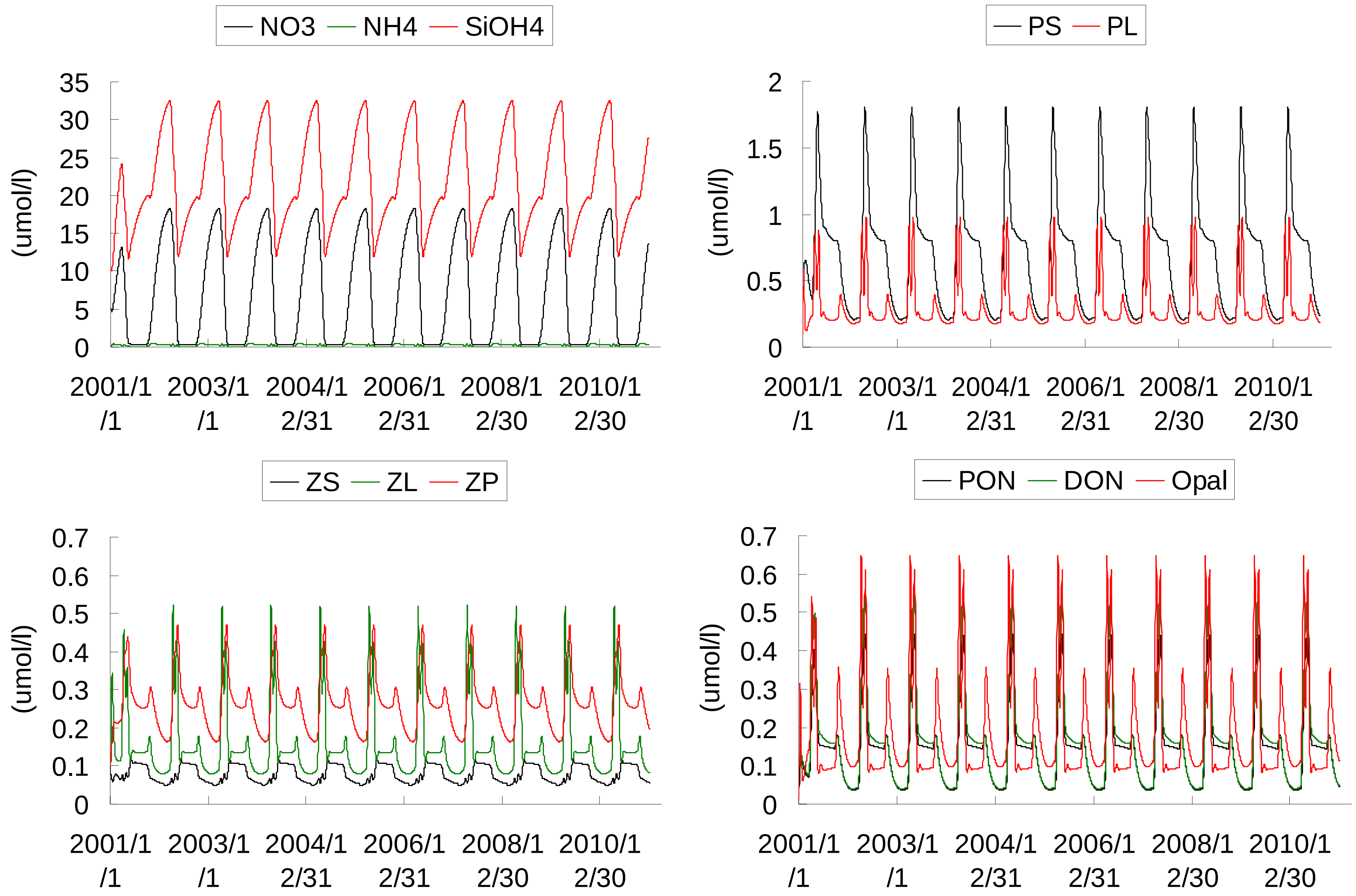
1. One box model and one fish.
2. Physical forcing only includes SST.
3. Deeper layer temperature is fixed.
4. If the SST becomes cooler than DL temp, vertical mixing ratio is increased by unstable stratification and nutrient is transported to the surface layer.
5. Idealized seasonal light intensity is assumed.
6. Fish has two year life history and the parameters are similar to Pacific saury.
7. Fish natural mortality depends on body length.
8. Annual fishery mortality is assumed to 30%.
9. Reproduction depends on the size and food availability of spawning stock.

Ex. 1. Climatological forcing

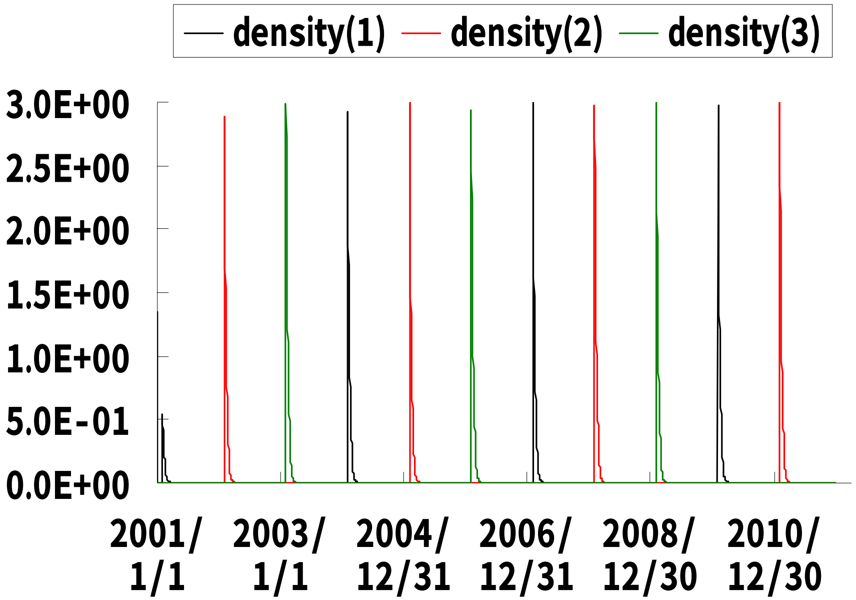


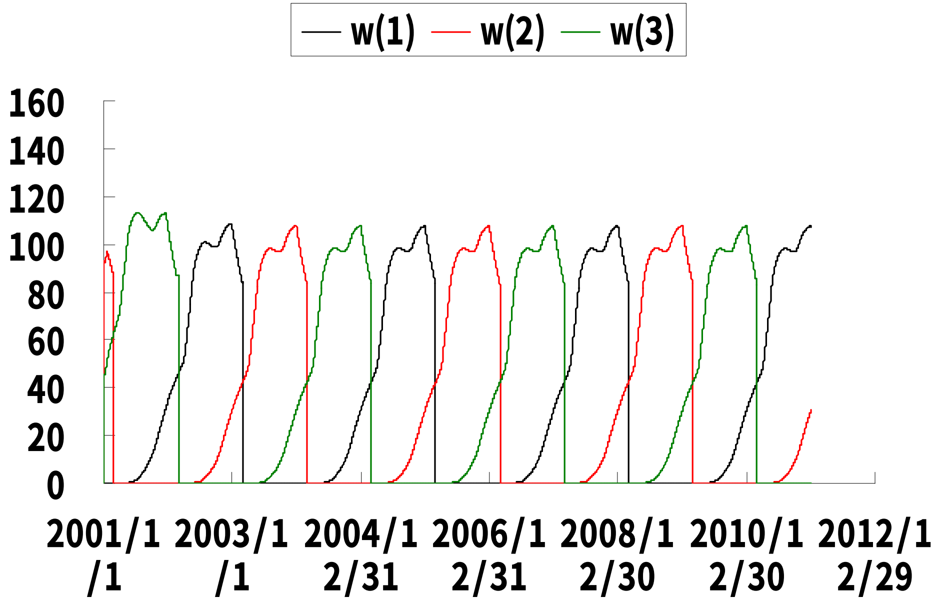


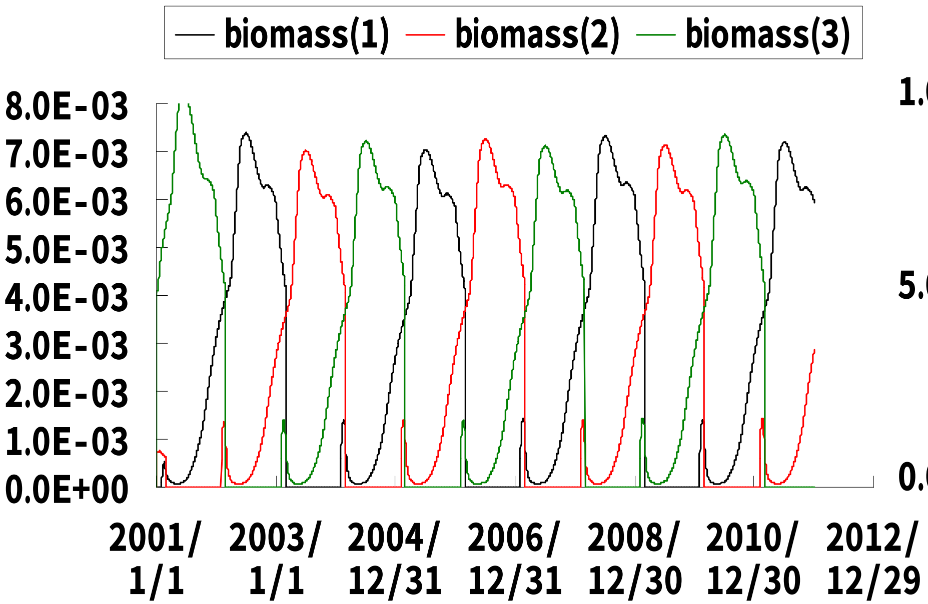
Climatological forcing

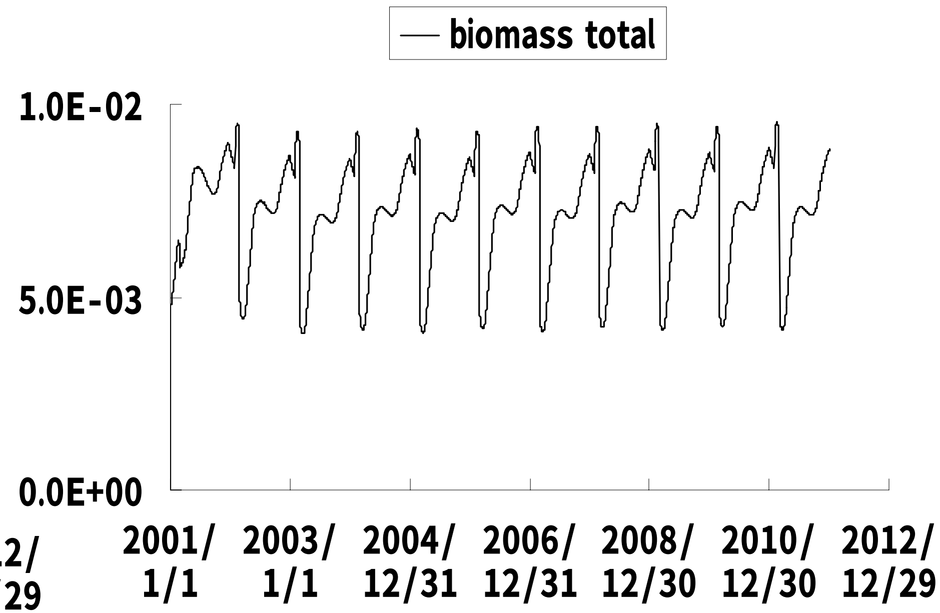


Climatological forcing



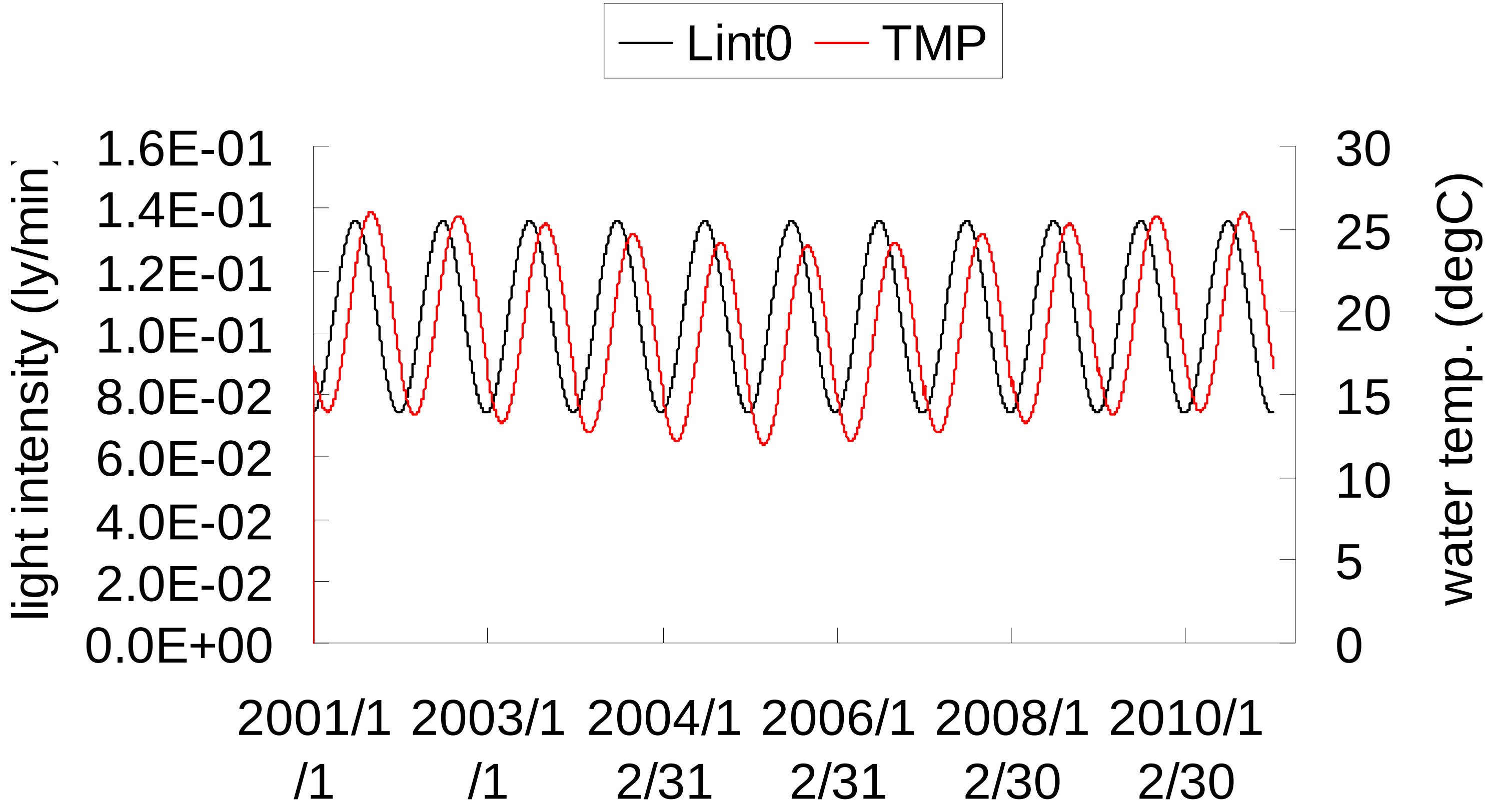




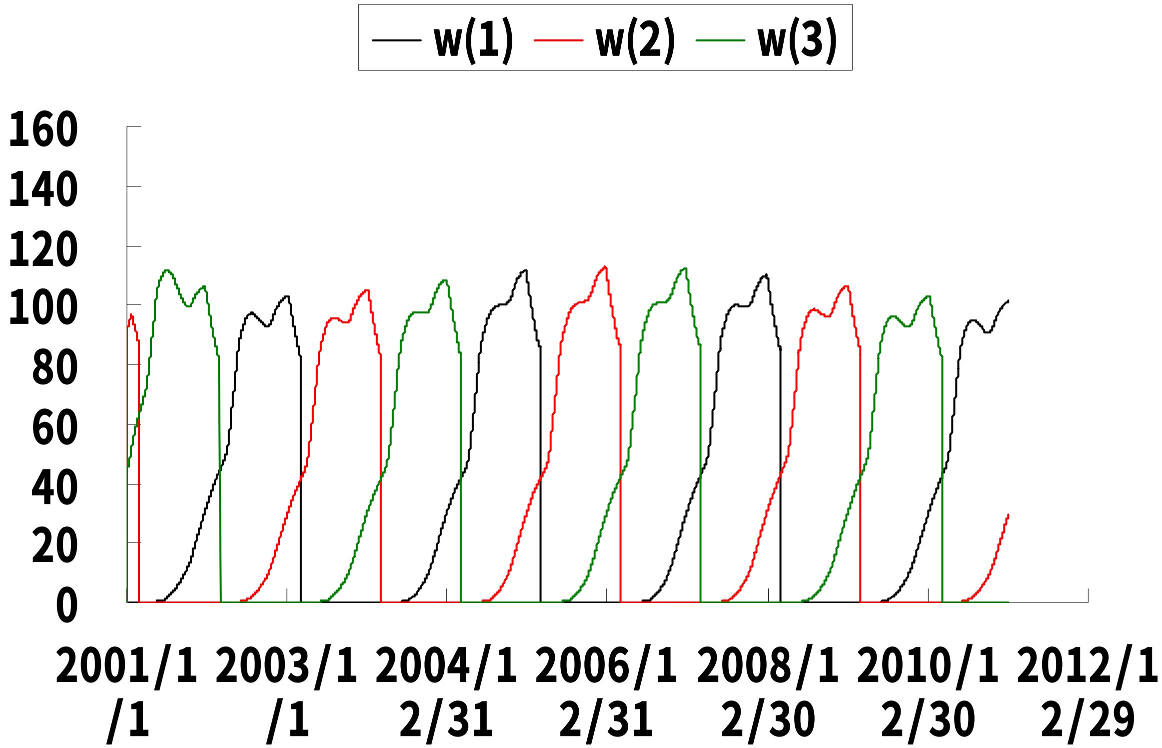


Ex. 2. decadal forcing

1 degC decadal fluctuation is added to idealized seasonal forcing.

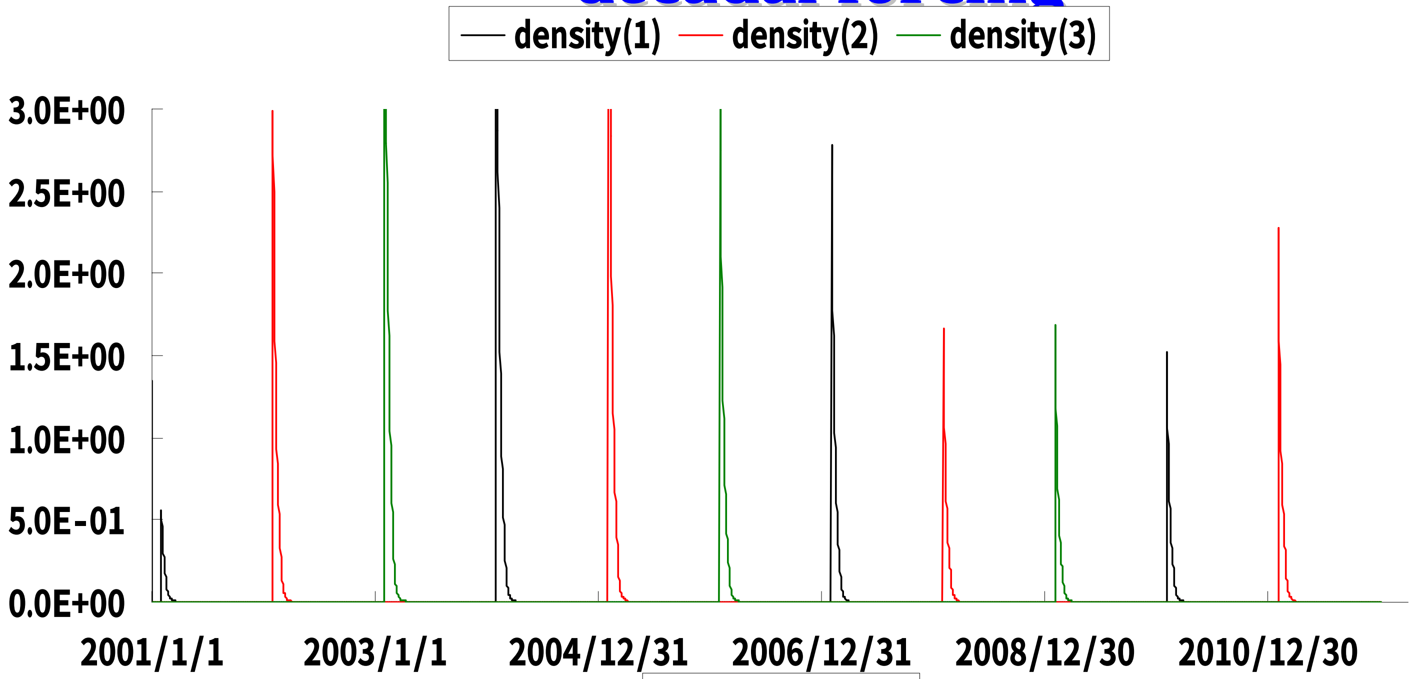


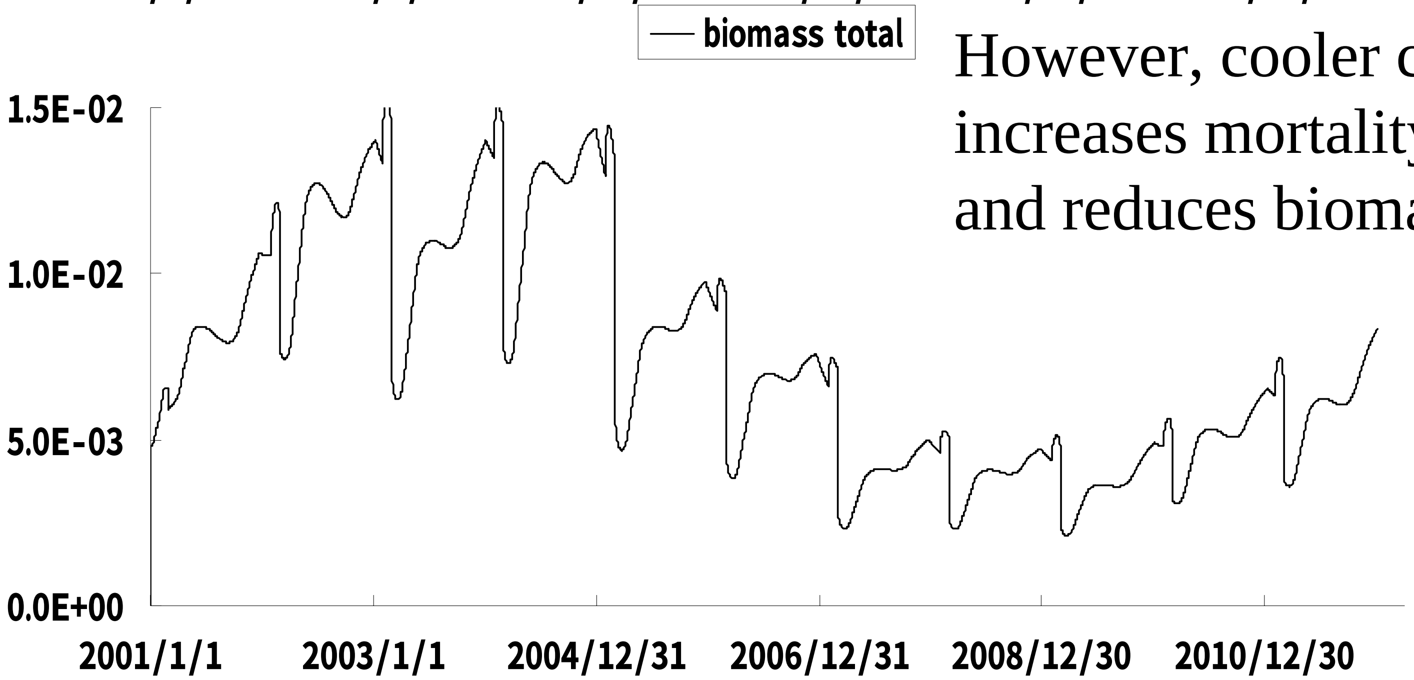
decadal forcing



Cooler condition increases wet weight of adult fish because of rich food.

decadal forcing





However, cooler condition increases mortality of larvae and reduces biomass.

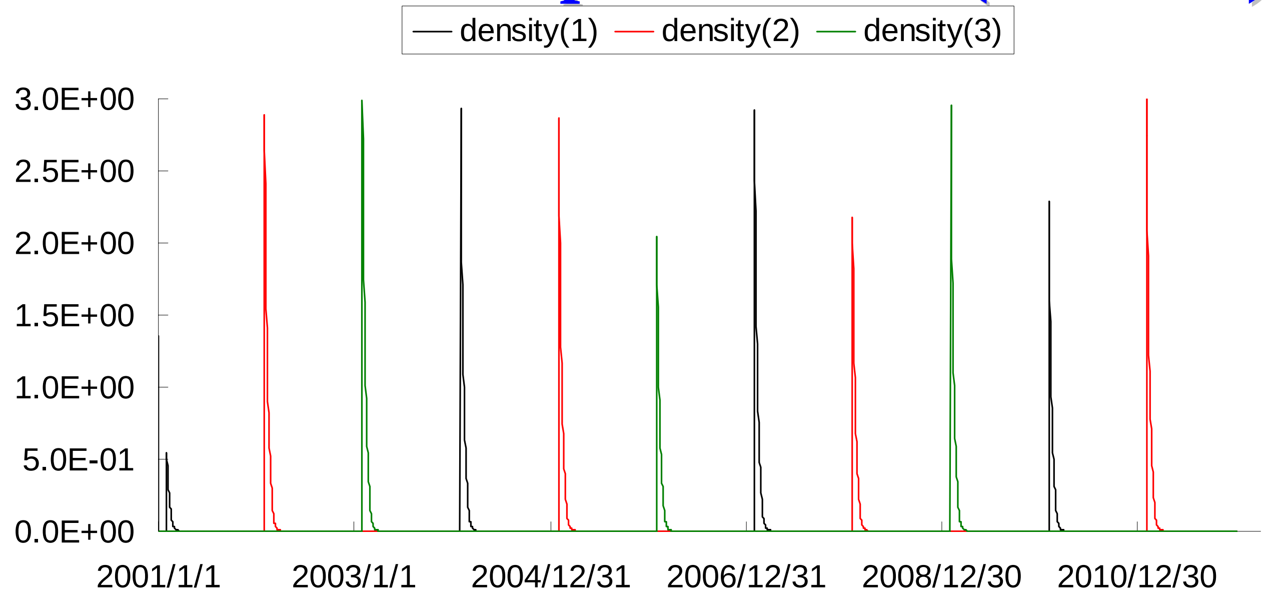
Ex. 3. Fisheries impact

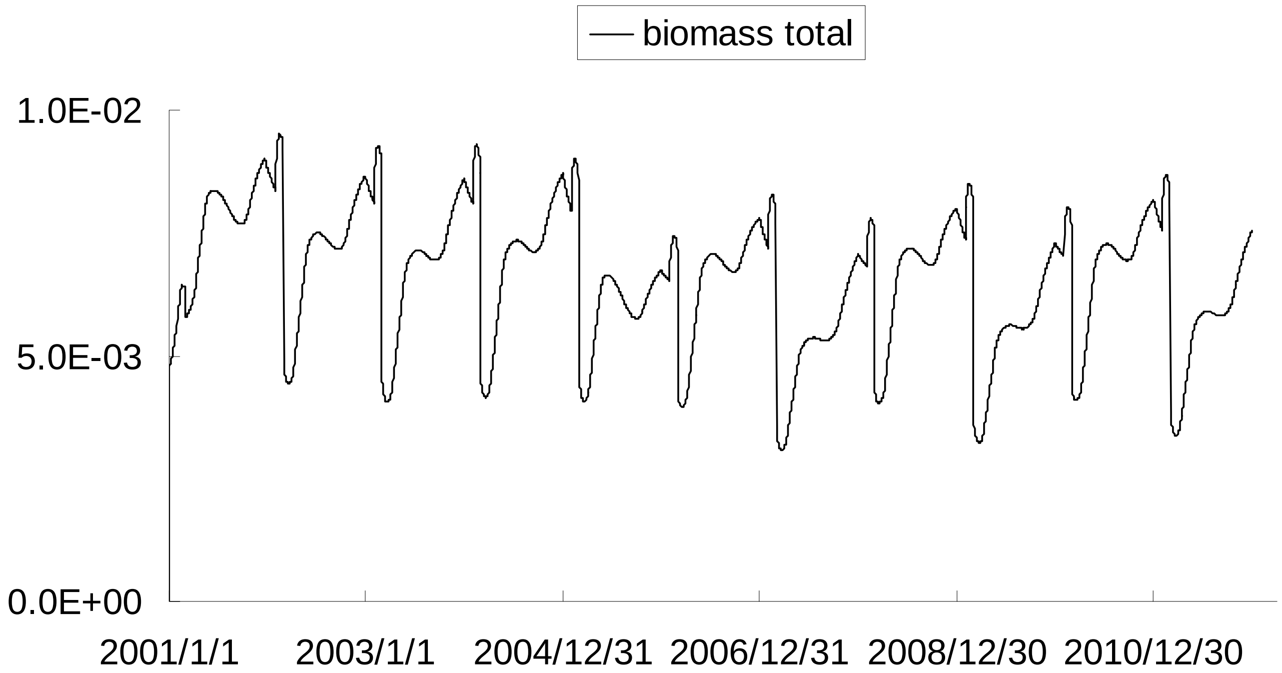
Fisheries pressure is doubled in 2005 only.

In normal year, the annual fisheries catch is 30% of adult biomass.

In 2005, the annual fisheries catch is increased to 60%.

Fisheries impact in 2005 (doubled)





Memoirs (G. A. Riley, 1984)

H. Bigelow said "Anybody who thinks he can predict more than 10% of plankton variability is a damn fool, but good luck".

To be sure, I have never pretended that [models] are truly realistic. My only defense has been that they help us to think….

They frequently yield results that are not intuitively obvious, and they teach us caution about drawing conclusions that seem to violate mathematical logic.
That is the way physics and astronomy have grown.
Biological oceanography, messy though it may be, needs the same kind of disciplined thinking.