JEJU NATIONAL UNIVERSITY

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Climate-change driven range shifts of chub mackerel (*Scomber japonicus*) projected by bio-physical coupling individual based model in the western North Pacific

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Climate change to change menus on table

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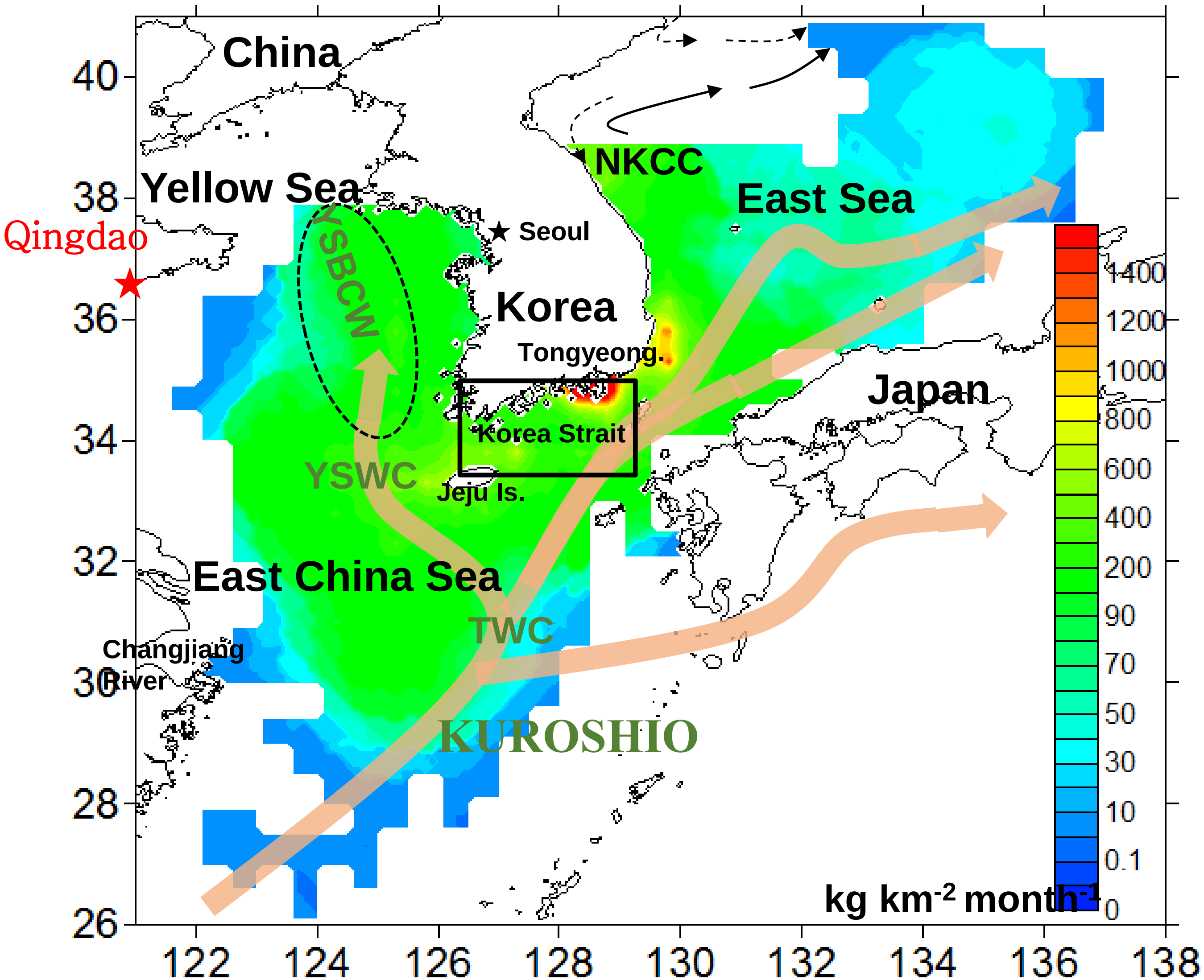
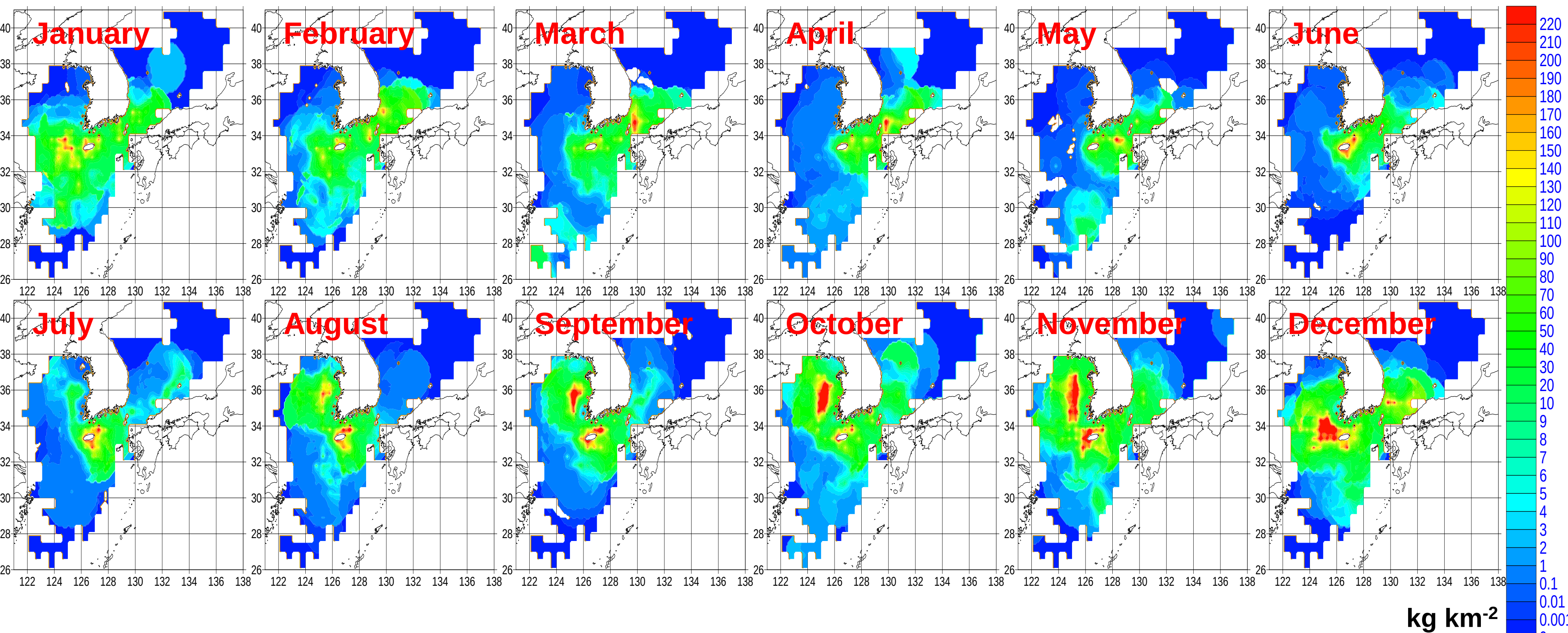
Study Area

Mean biomass of fishes captured (1984-2010)

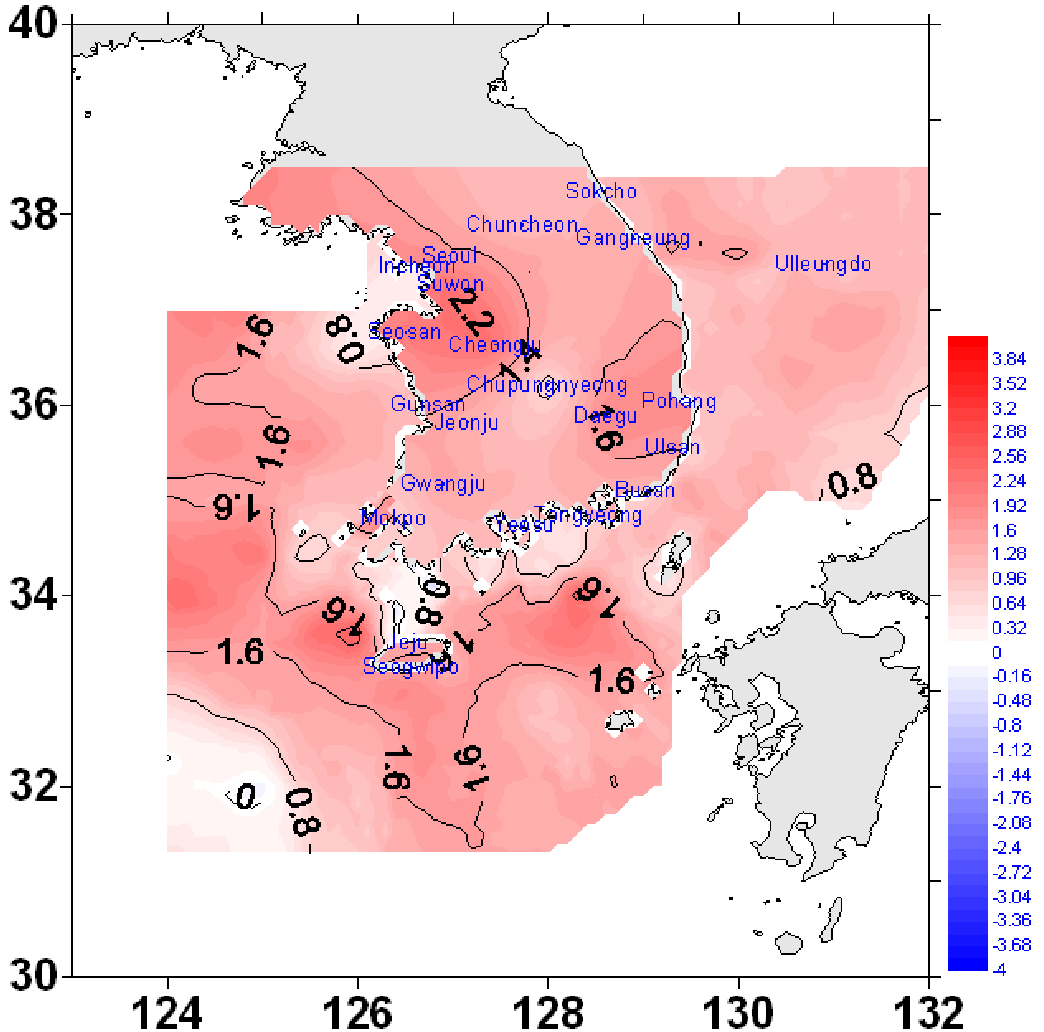


Scomber japonicus, monthly-averaged catch by Korean fishers (1983-2010)



Stations for Serial Oceanographic Data
NFRDI (Korea Oceanographic Data Center)
1961-2014, ca. 190 stations, 0-1,000 m depths)

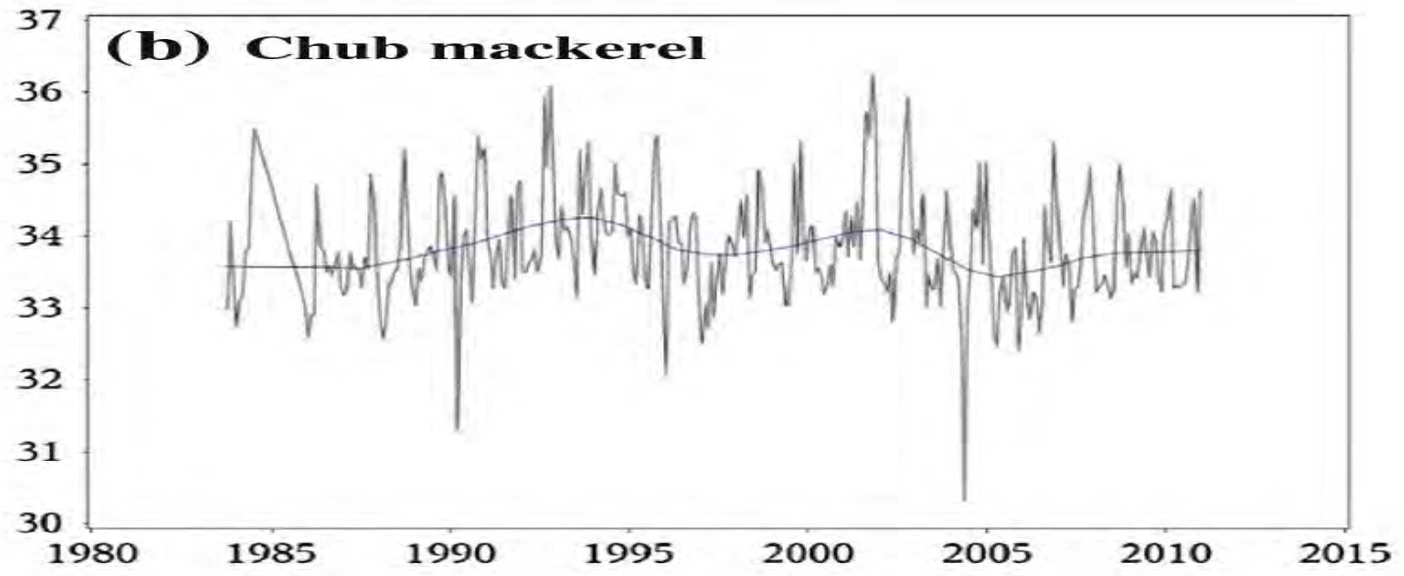
Linear trend of temperature change (ºC) in the land and sea surface (1968-2010)



c.f. Jung, S., 2008. Spatial variability in long-term changes of climate and oceanographic conditions in Korea. J. Environ. Biol. 29, 519-529.

ºC

Biomass-weighted, monthly mean latitudes of the catch distribution of mackerel (1984-2010)



From Jung, S., Pang, I.-C., Lee, J.-h., Choi, I., Cha, H.K., 2014. Latitudinal shifts in the distribution of exploited fishes in Korean waters during the last 30 years; a consequence of climate change. Rev. Fish Biol. Fish. 24, 443-462.

Also c.f.: Yasuda, T., Yukami, R., Ohshimo, S., 2014. Fishing ground hotspots reveal long-term variation in chub mackerel *Scomber japonicus* habitat in the East China Sea. Mar Ecol Prog Ser 501, 239-250.

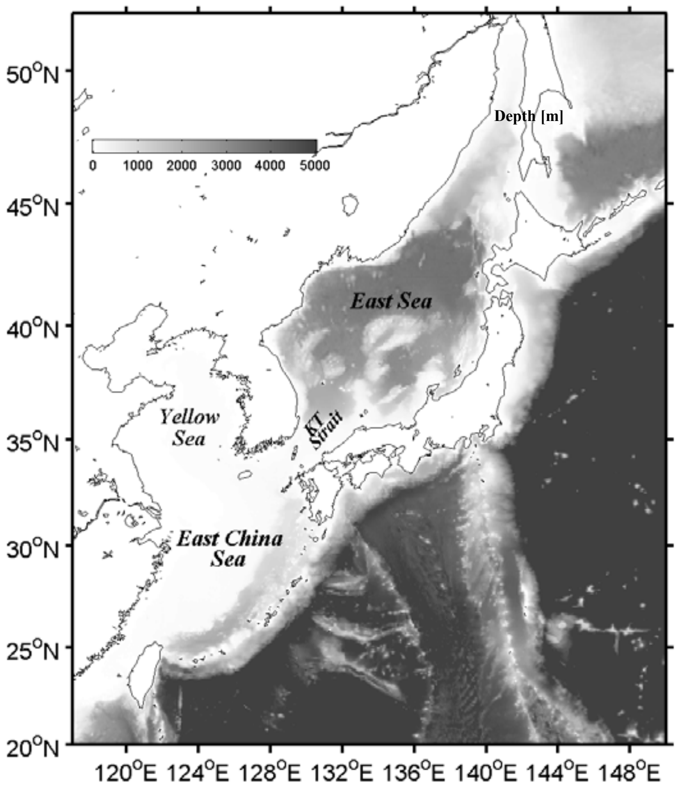
Question

- Will the major fishing grounds of chub mackerel shift north by global warming?

Outline

1. ROMS for projecting oceanic conditions in the 2050s
2. Bio-physical coupling, individual-based model for predicting spatial distributions of young-of-the-year chub mackerel

Western North Pacific model domain and description



✓**ROMS 3.4**

✓**North Western Pacific (117~150˚E, 20~52˚N)**

✓**Horizontal and vertical resolutions: ~8 km and 30 sigma layers**

✓**Initial & lateral boundary conditions:**

- Global MPI ECHAM5 RCP2.6 and RCP 8.5 Senario monthly mean values at boundaries (2006~2050)

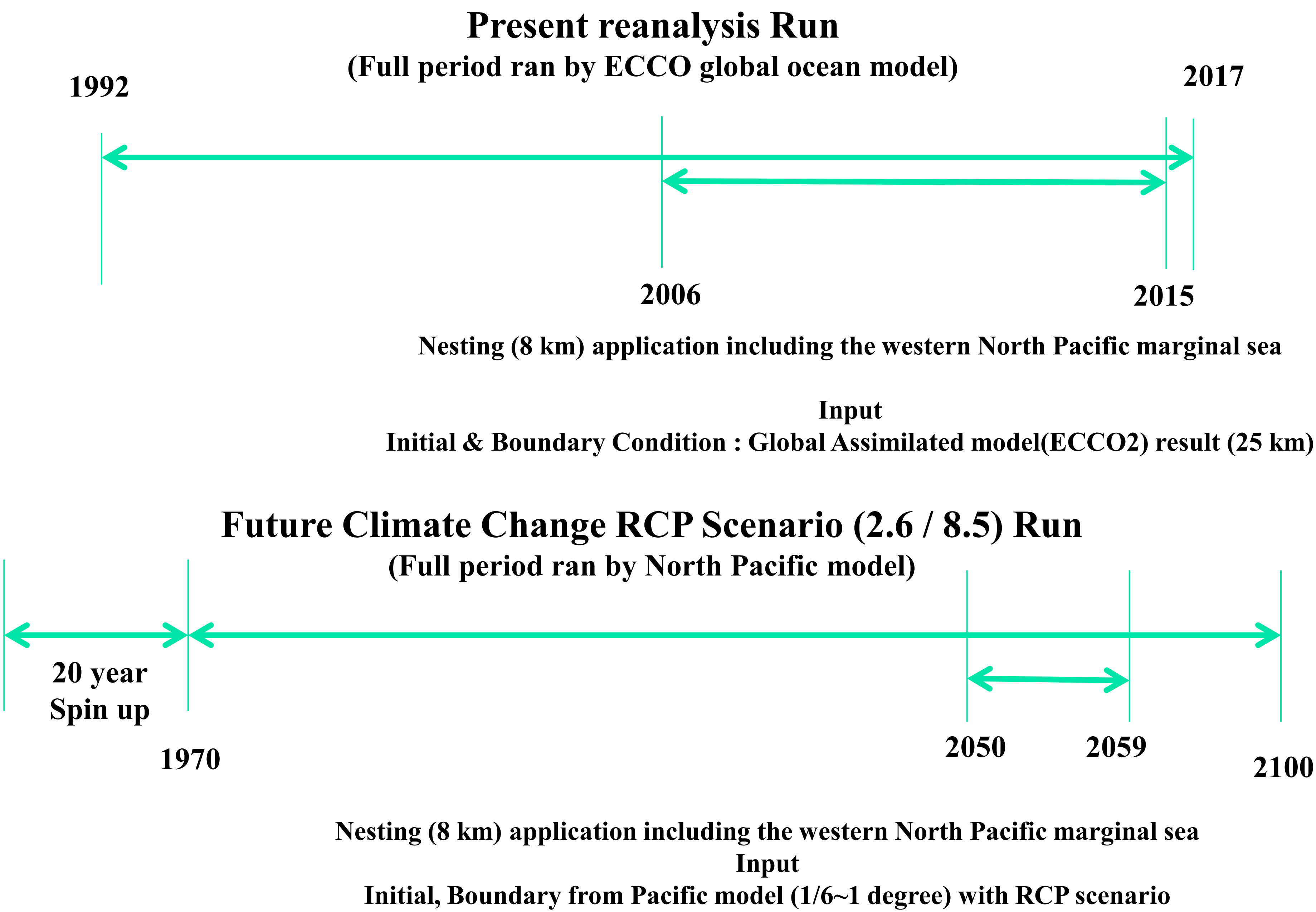
✓**Atmospheric forcing:**

-Wind➔Global MPI ECHAM5 RCP2.6 and RCP 8.5 Scenario daily mean values (2006~2050)

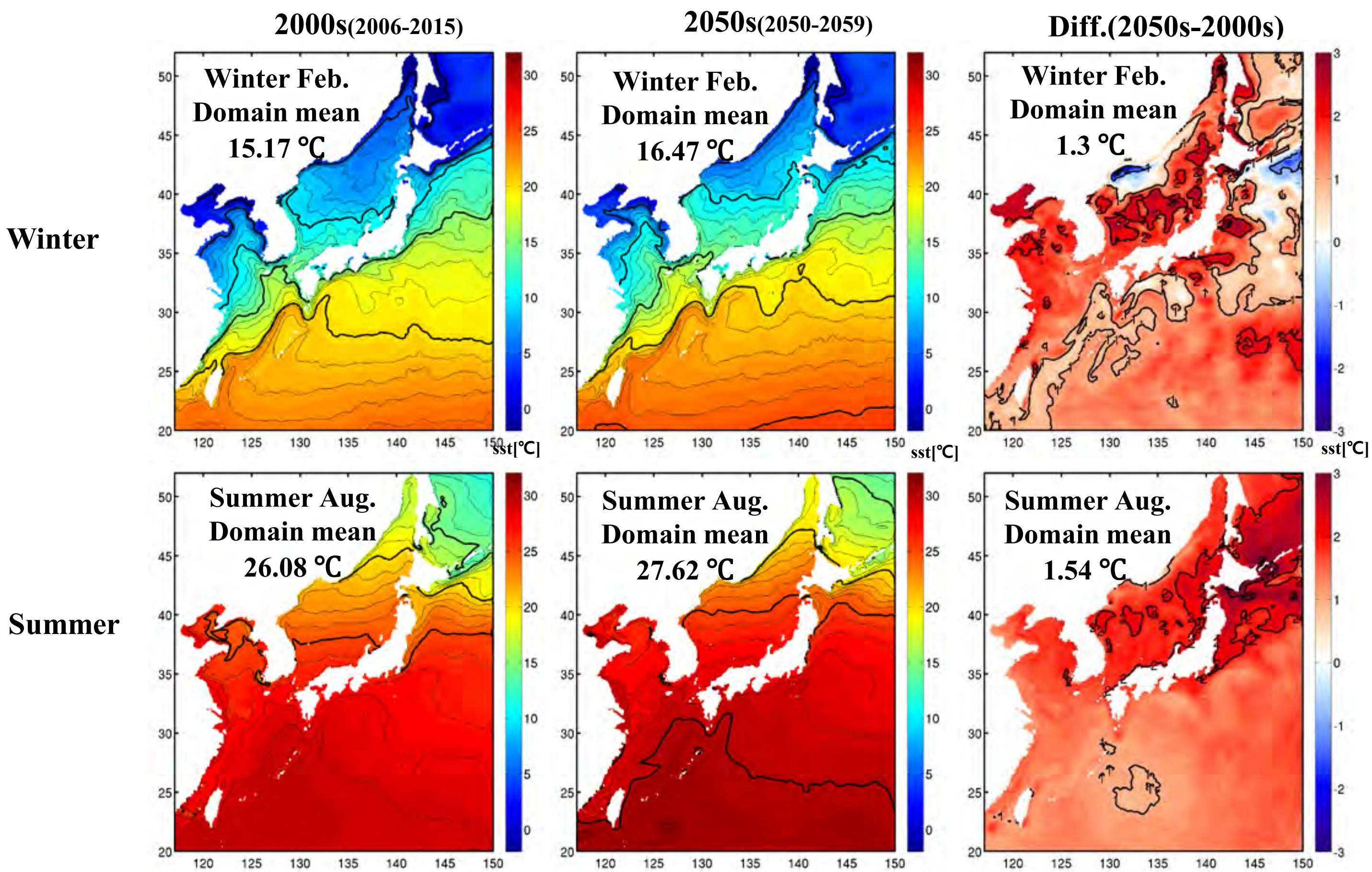
-Heat flux➔Global MPI ECHAM5 RCP2.6 and RCP 8.5 Scenario monthly mean values (2006~2050) using bulk formula

✓**Realistic Changjiang River discharge [Senjyu et al., 2006]**

✓**Tidal forcing: 10 constituents from Global tidal model (TPXO6)**


Present reanalysis Run
(Full period ran by ECCO global ocean model)
1992
2017
2006
2015
Nesting (8 km) application including the western North Pacific marginal sea
Input
Initial & Boundary Condition : Global Assimilated model(ECCO2) result (25 km)
Future Climate Change RCP Scenario (2.6 / 8.5) Run
(Full period ran by North Pacific model)
20 year
Spin up
1970
2050
2059
2100
Nesting (8 km) application including the western North Pacific marginal sea
Input
Initial, Boundary from Pacific model (1/6~1 degree) with RCP scenario

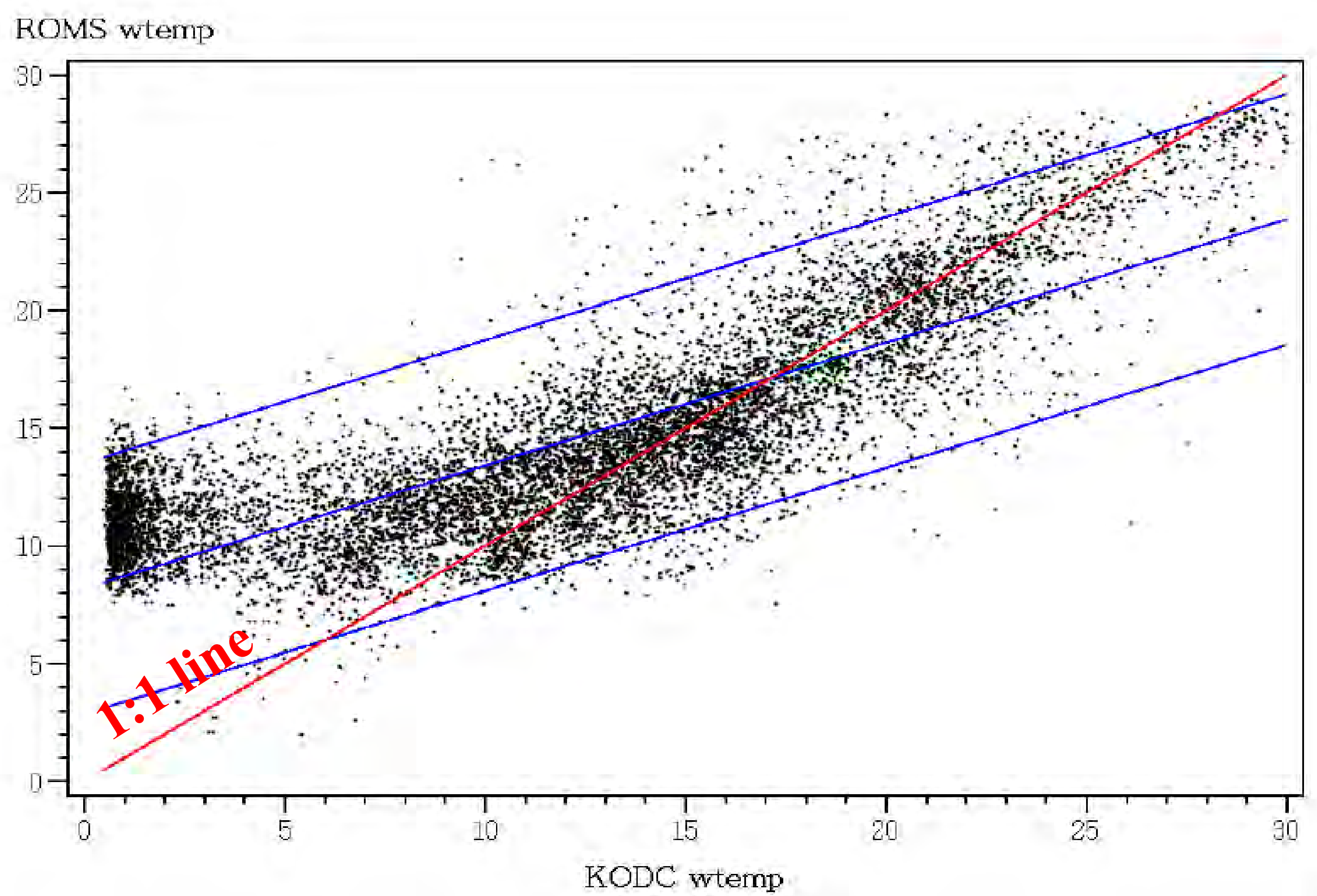
Sea surface temperatures hindcasted and projected by the ocean circulation model for the 2000s and 2050s by the RCP8.5 scenario.



Overall, temperature increases , especially in the Japan/East Sea

Validation with observed data

KODC water temperatures at 0-75 m depths
2006-2013



Biological model for young-of-the-year mackerel

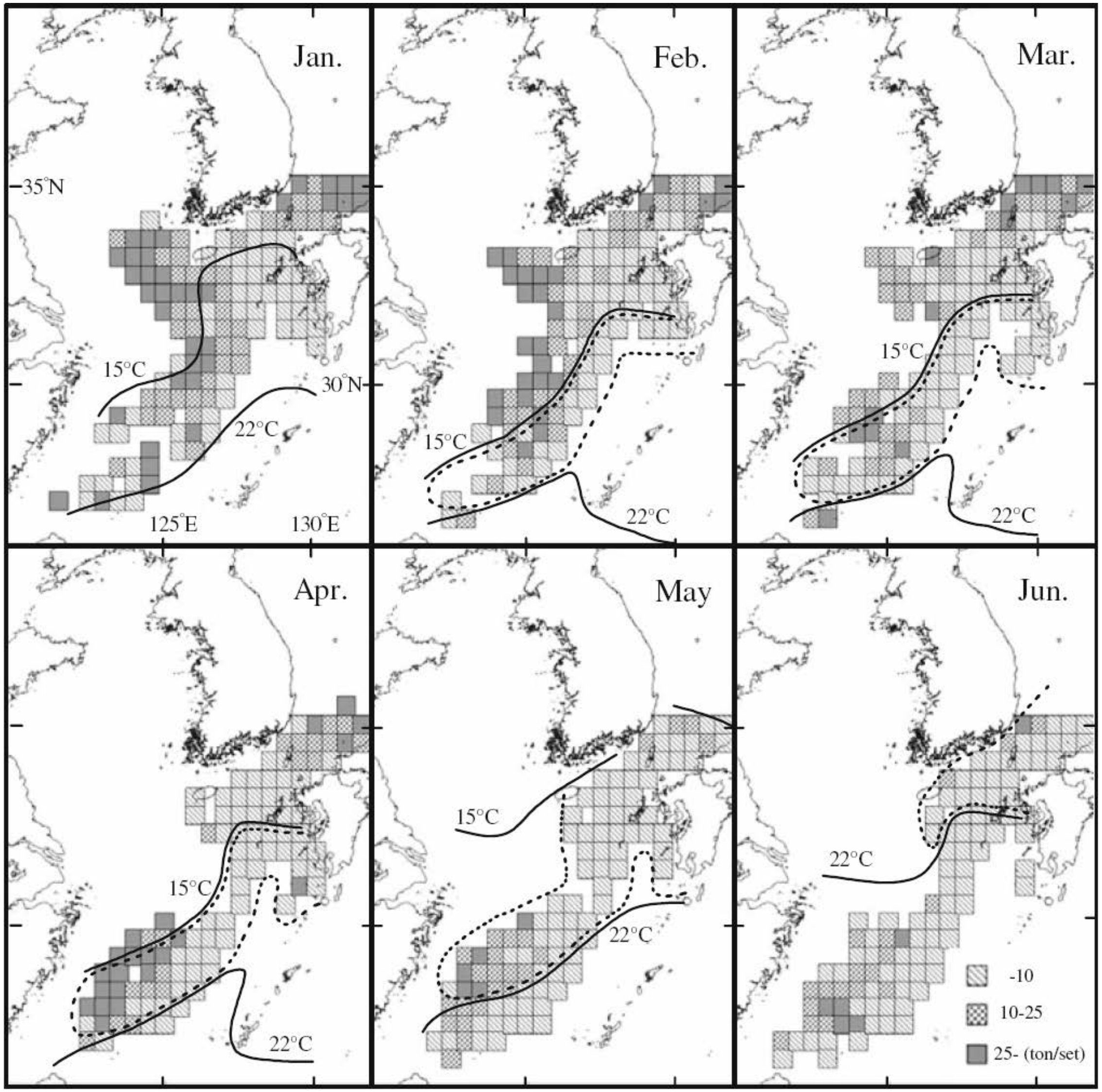
- Daily simulations for the same periods of ROMS

- Spawning
- Growth
- Horizontal and vertical passive movement
- Survival

Spawning

- Distribution of spawning activity
  - Yukami et al. (2009)
- Spawning occurs in the upper 10 m of the water column (Fritzsche, 1978)
- Spawning frequency
  - Yamada et al. (1998)
  - Normal distribution from Feb. 1 to Jun. 30, peaking on Apr. 16

Spawning grounds



From:
<u>Yukami, R., Ohshimo, S., Yoda, M., Hiyama, Y.</u>, 2009. Estimation of the spawning grounds of chub mackerel *Scomber japonicus and spotted mackerel Scomber australasicus in the East China Sea based on catch statistics and biometric data. Fish. Sci. 75, 167-174.*

Growth equations

- Larval stages: Laird-Gompertz growth function
  - Data from Hunter & Kimbrell (1980)
  - $\alpha = a \exp(b \cdot T^{o}C)$

    where a = 0.0028, b = 0.097
  - Daily growth rate:

$$\mathbf{dL/dt = \alpha \cdot L_t \cdot \ln(L_t/L_\infty) \cdot \ln(L_\infty/L_0) / \ln(L_0/L_\infty)}$$

where $L_\infty = 38.51$ cm, $L_0 = 0.31$ cm (length at hatching)

- Juvenile stage: von Bertalanffy growth function
  - Data from Hwang & Lee (2005)
  - Daily growth rate:

$$\mathbf{dL/dt = K (L_\infty - L_t)}$$ where $K = 1.023\ yr^{-1}$

Vertical movement

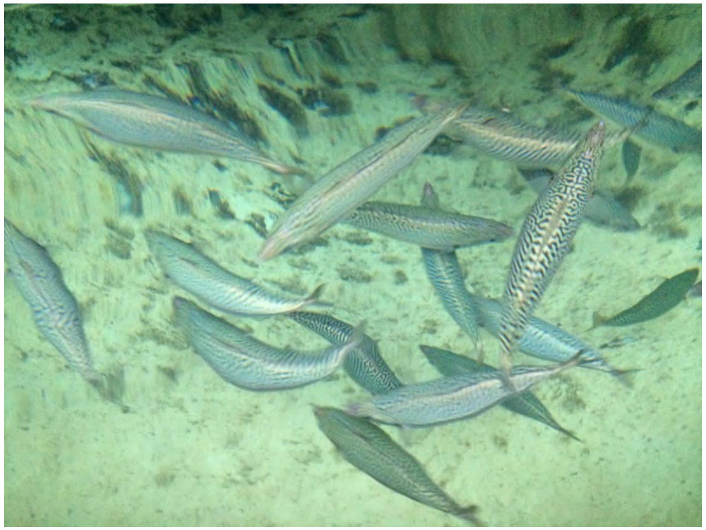
- Stokes' law
- **Terminal Velocity of Sphere Falling in a Fluid**

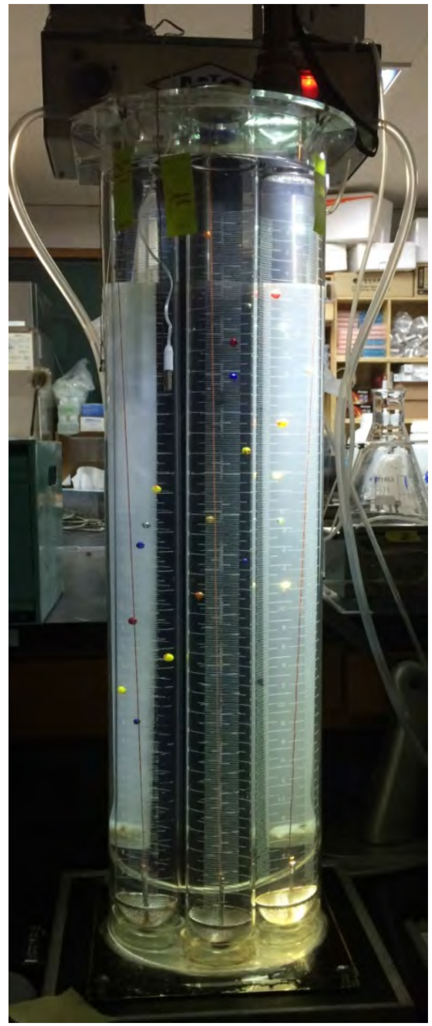
$$V = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} g\, R^2$$

where V is the flow settling velocity (m/s), g is the gravitational acceleration(m/s^2), ρ_p is the mass density of the particles (kg/m^3), ρ_f is the mass density of the fluid (kg/m^3) and μ is the dynamic viscosity(kg /m*s).

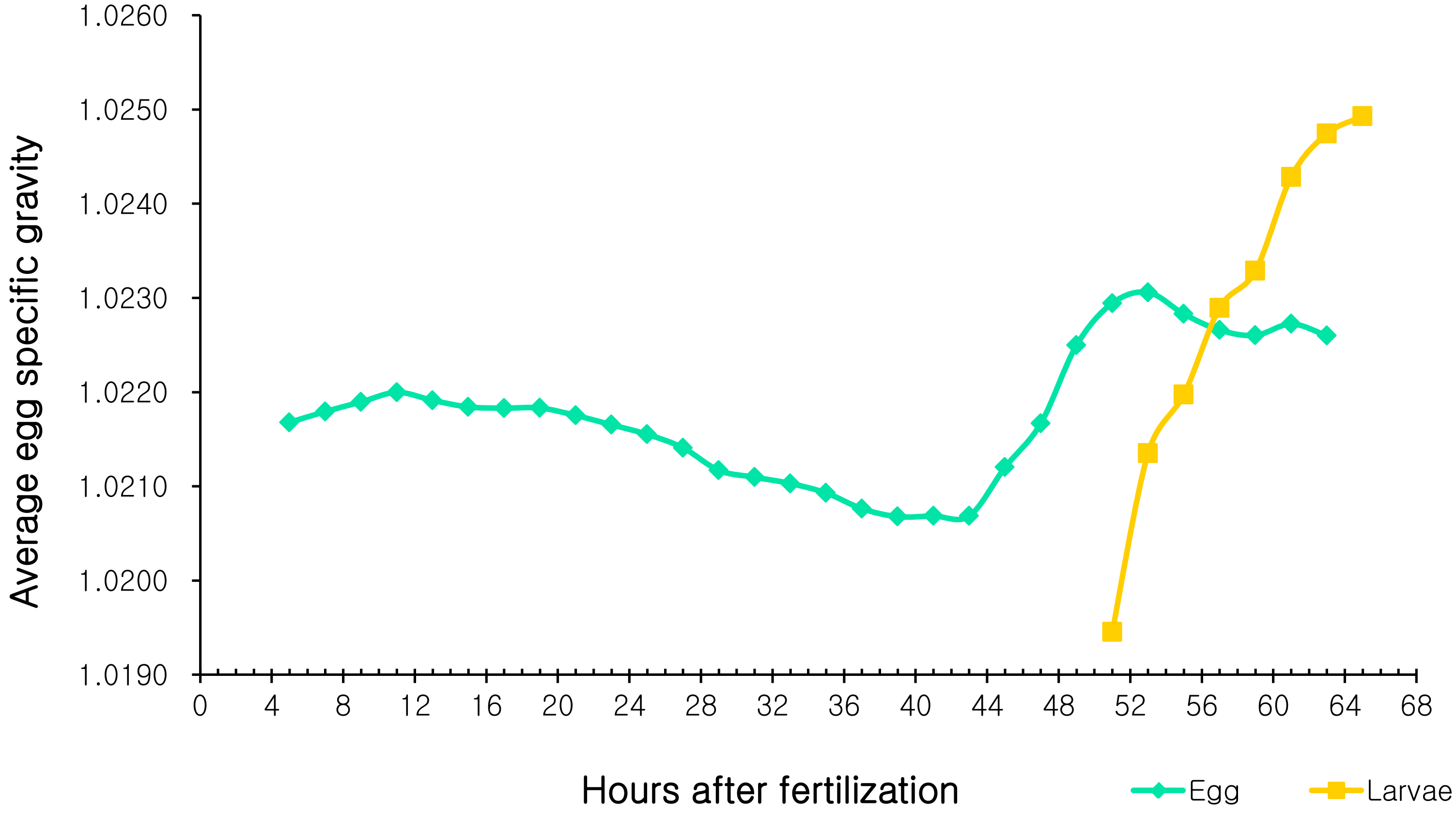
Measuring specific gravity (ρ_p) of mackerel egg and larva

BIO presentation by Hwa Hyun Lee (Tue)



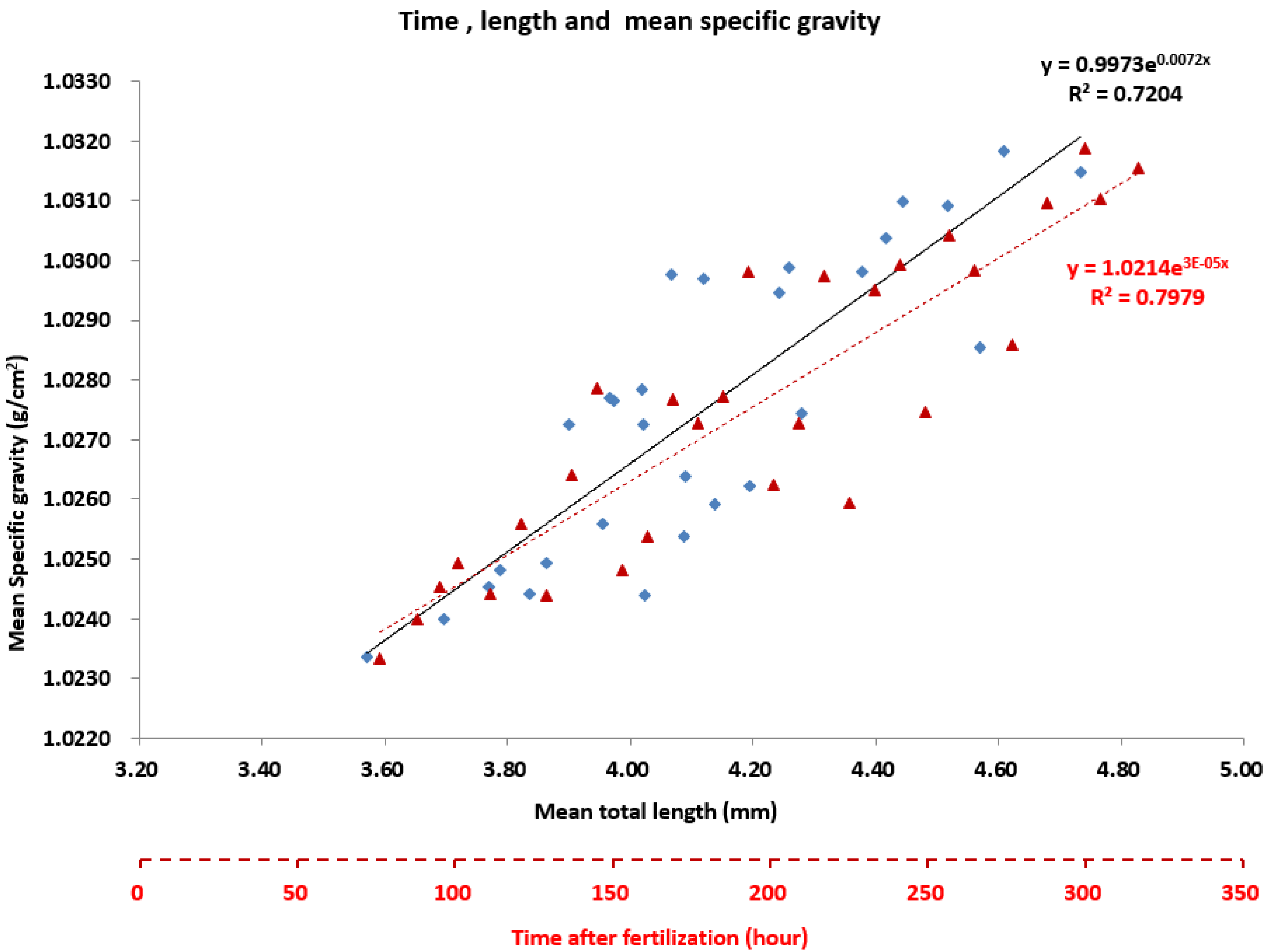


Specific gravity (ρ_p) of mackerel egg & larva



BIO presentation by Hwa Hyun Lee (Tue)

Specific gravity of mackerel larva (ρ_p)



Leslie matrix for deriving size-dependent survival rate

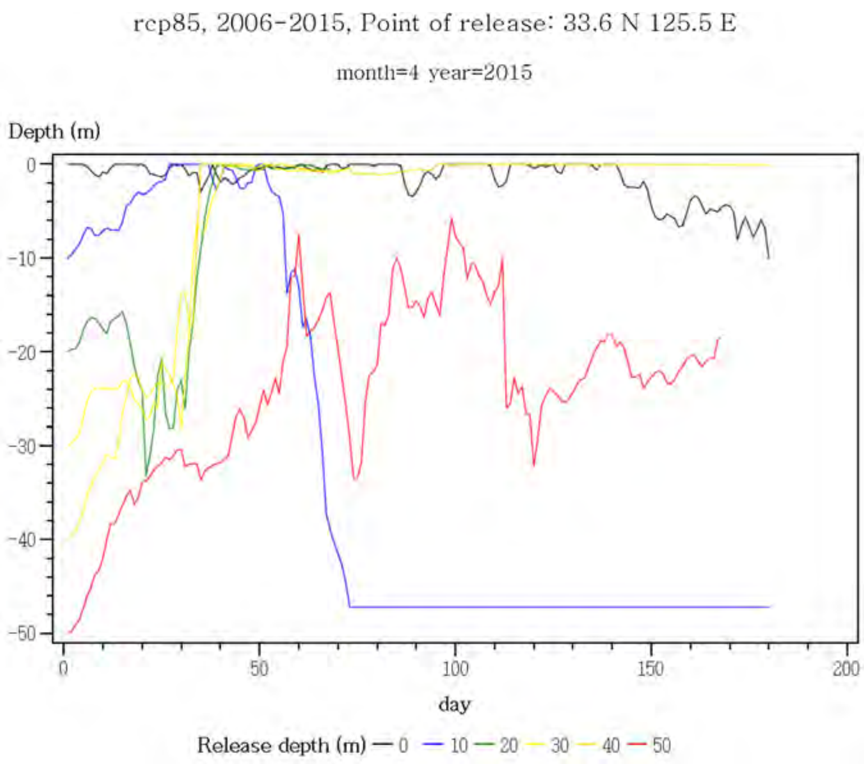
$$N(t+1)=\begin{bmatrix} n_0(t+1) \\ n_1(t+1) \\ n_2(t+1) \\ \vdots \\ n_5(t+1) \end{bmatrix}=\begin{bmatrix} f_1S_0 & f_2S_1 & \cdots & f_5S_4 & f_6S_5 \\ S_0 & 0 & \cdots & 0 & 0 \\ 0 & S_1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & S_4 & 0 \end{bmatrix}\begin{bmatrix} n_0(t) \\ n_1(t) \\ n_2(t) \\ \vdots \\ n_5(t) \end{bmatrix}=LN(t)$$

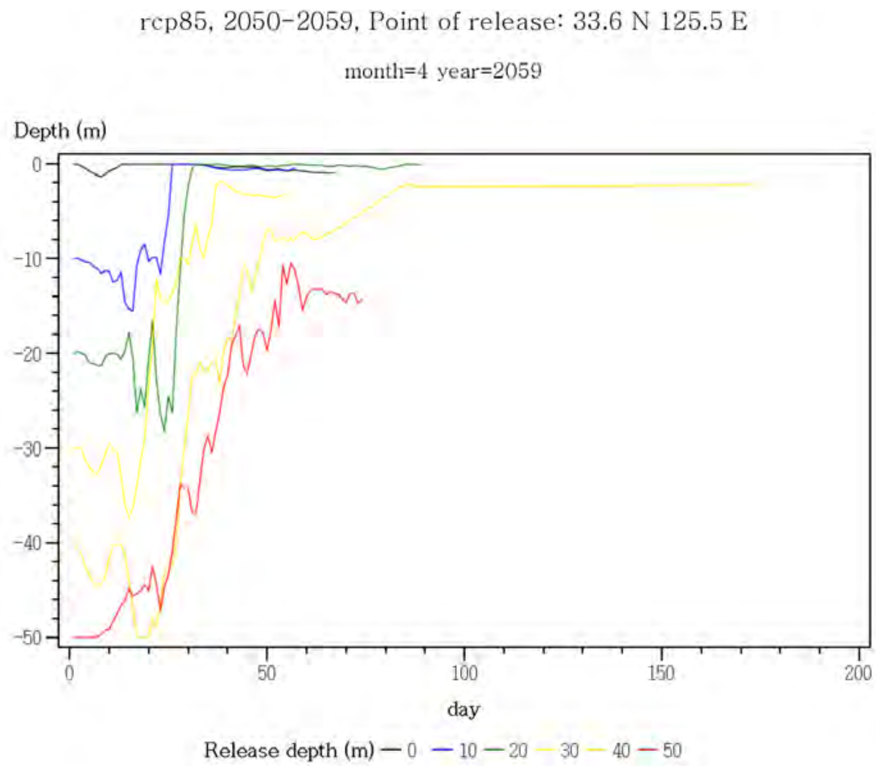
Parameter	Description
$n_k(t)$	Number of age k mackerel at time t (yr)
f_k	Average effective fecundity of female mackerel at age k
S_k	Survival rate from age k to $k+1$ of mackerel

Survival

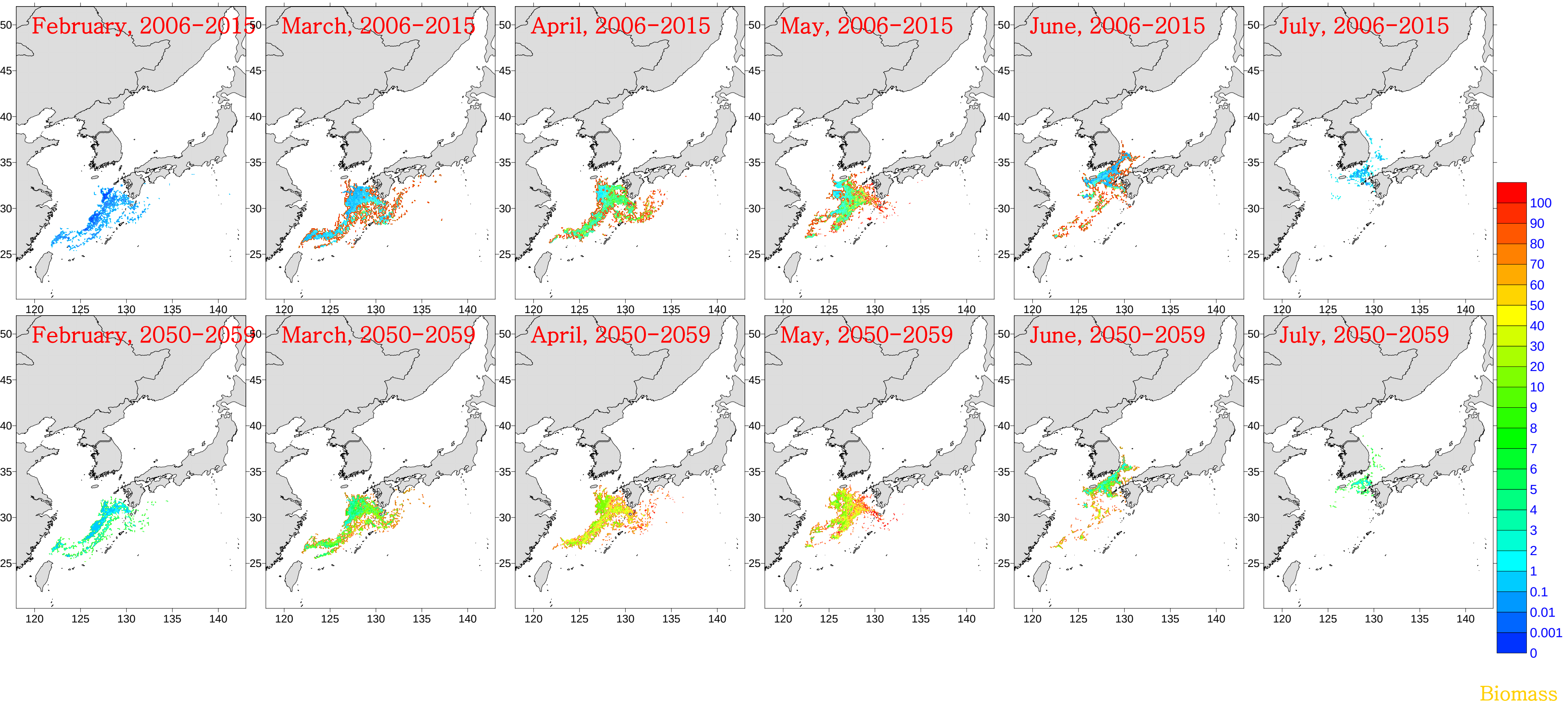
- Leslie matrix and a steady-state hypothesis (Jung et al., 2008 & 2009)
- Size-dependent natural mortality
  - $M_t = M_\infty L_{\infty/} L_t$
  - $M_\infty L_\infty = q = 0.10$ (cm/day)

Vertical movement of mackerel larvae by RCP8.5, April 2015 vs. 2059

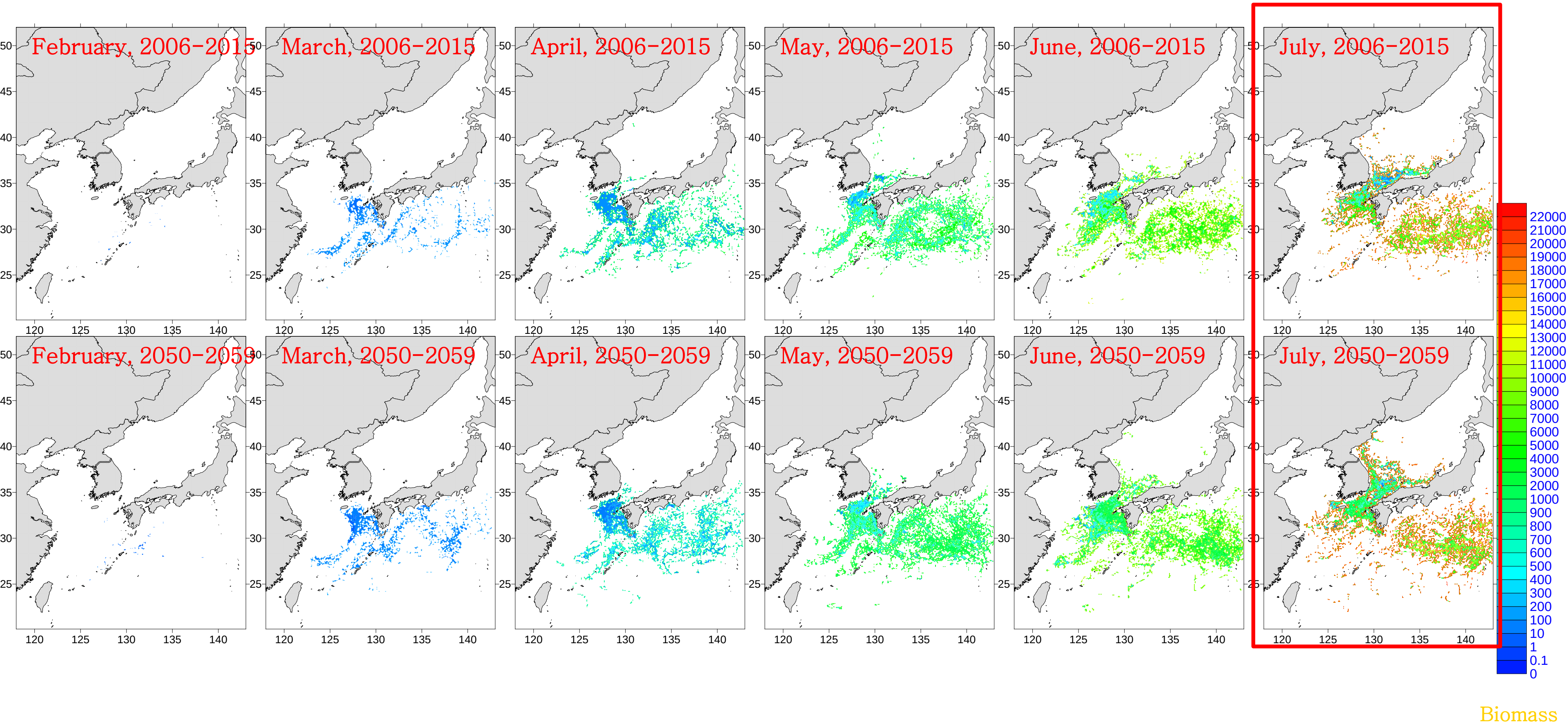




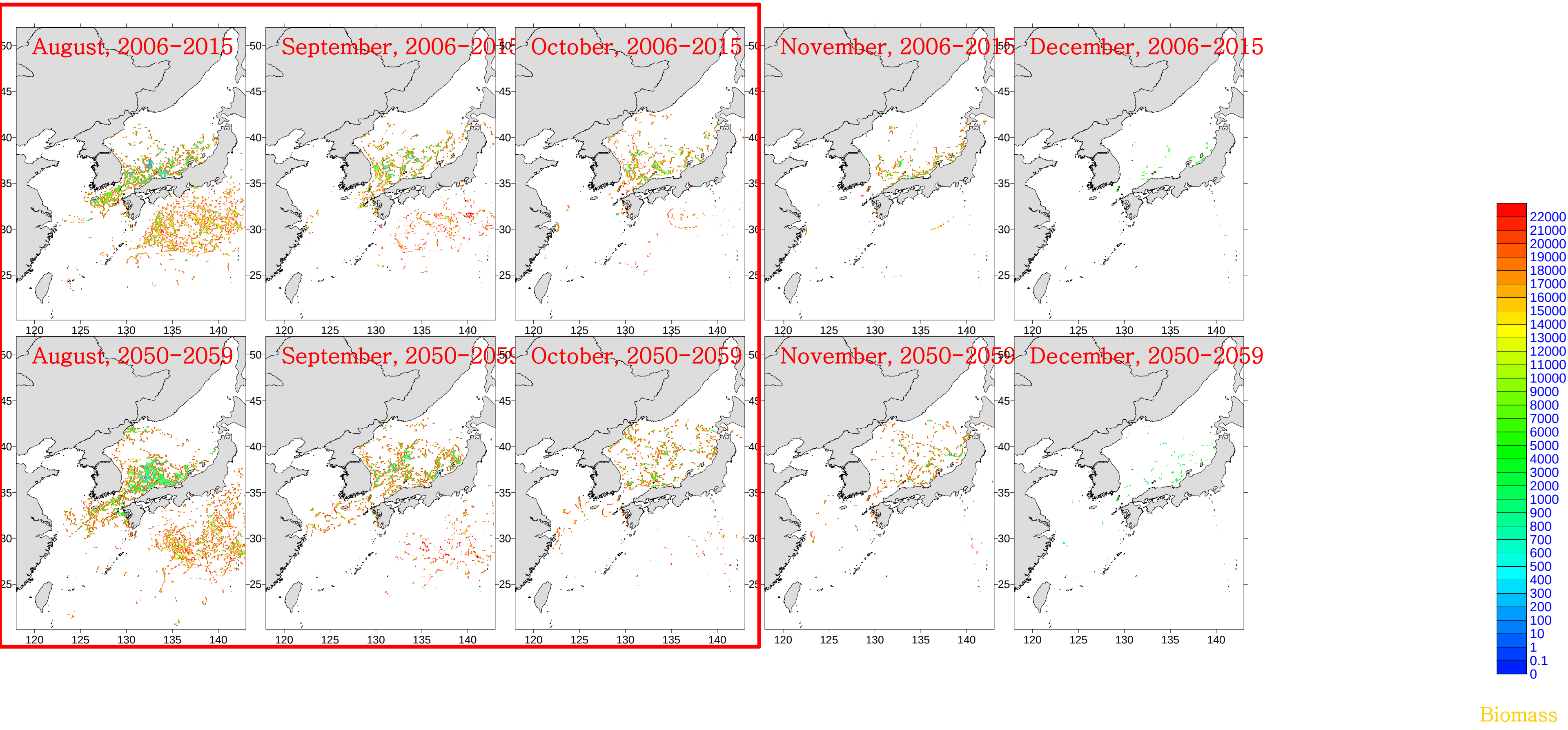
Change of biomass of larval mackerel by rcp8.5



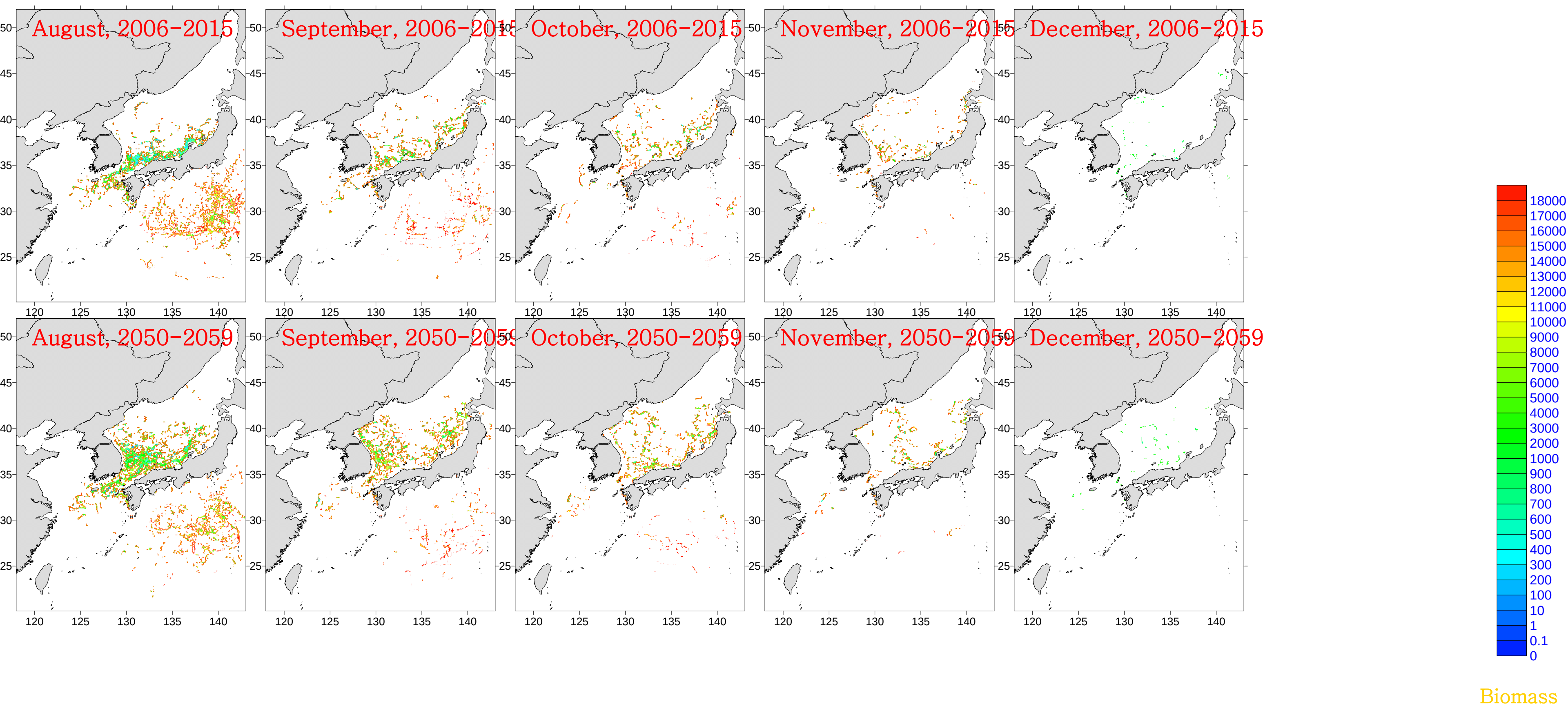
Change of biomass of juvenile mackerel by rcp8.5



Change of biomass of juvenile mackerel by rcp85



Change of biomass of juvenile mackerel by RCP 2.6



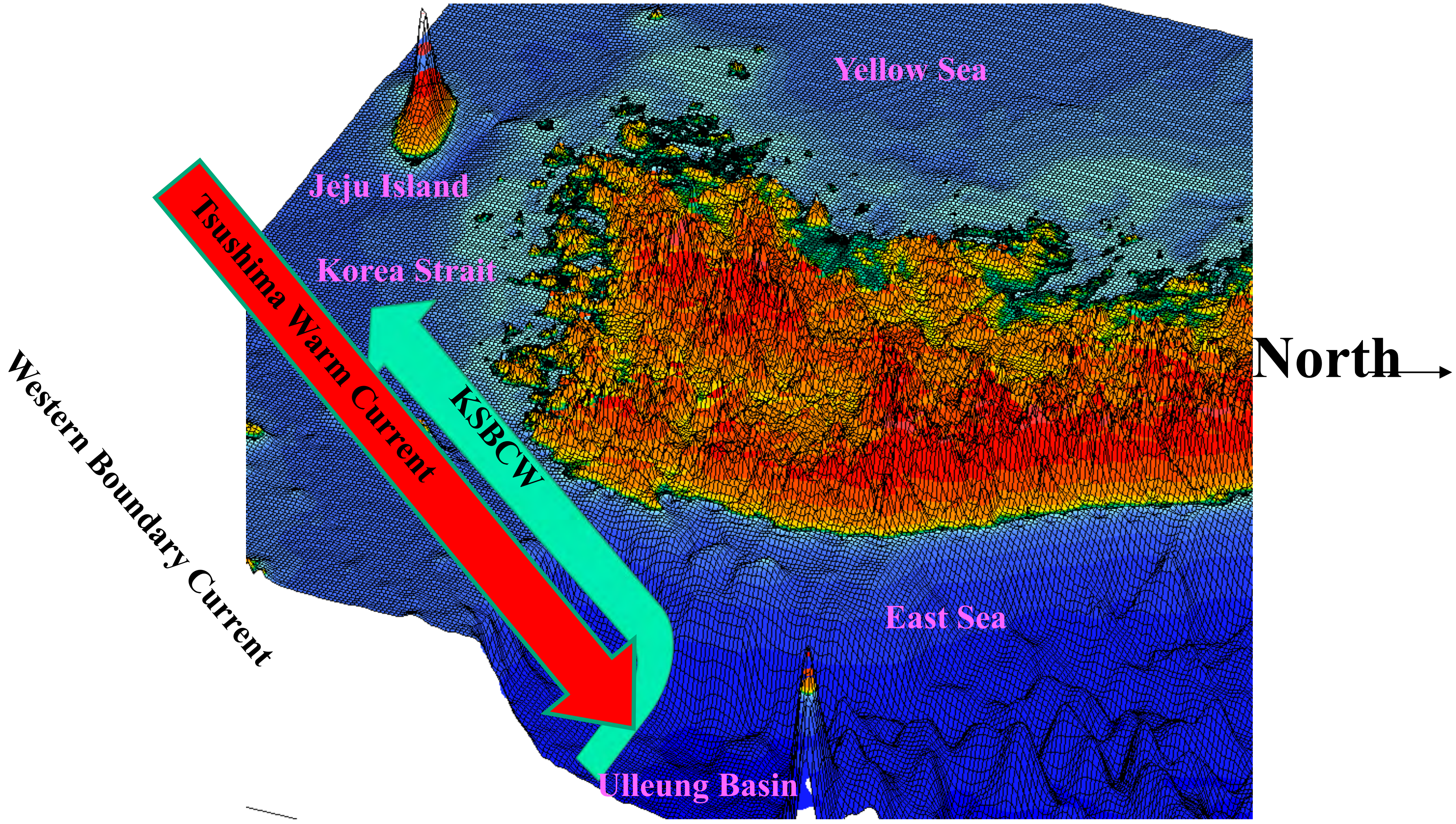
Summary

- Projection for the 2050s
  - Larva: Survival will be enhanced in overall
  - Juvenile: The distribution will be shifted northeast to the Japan/East Sea
- The results are preliminary, and the model is still at the early stage of development.

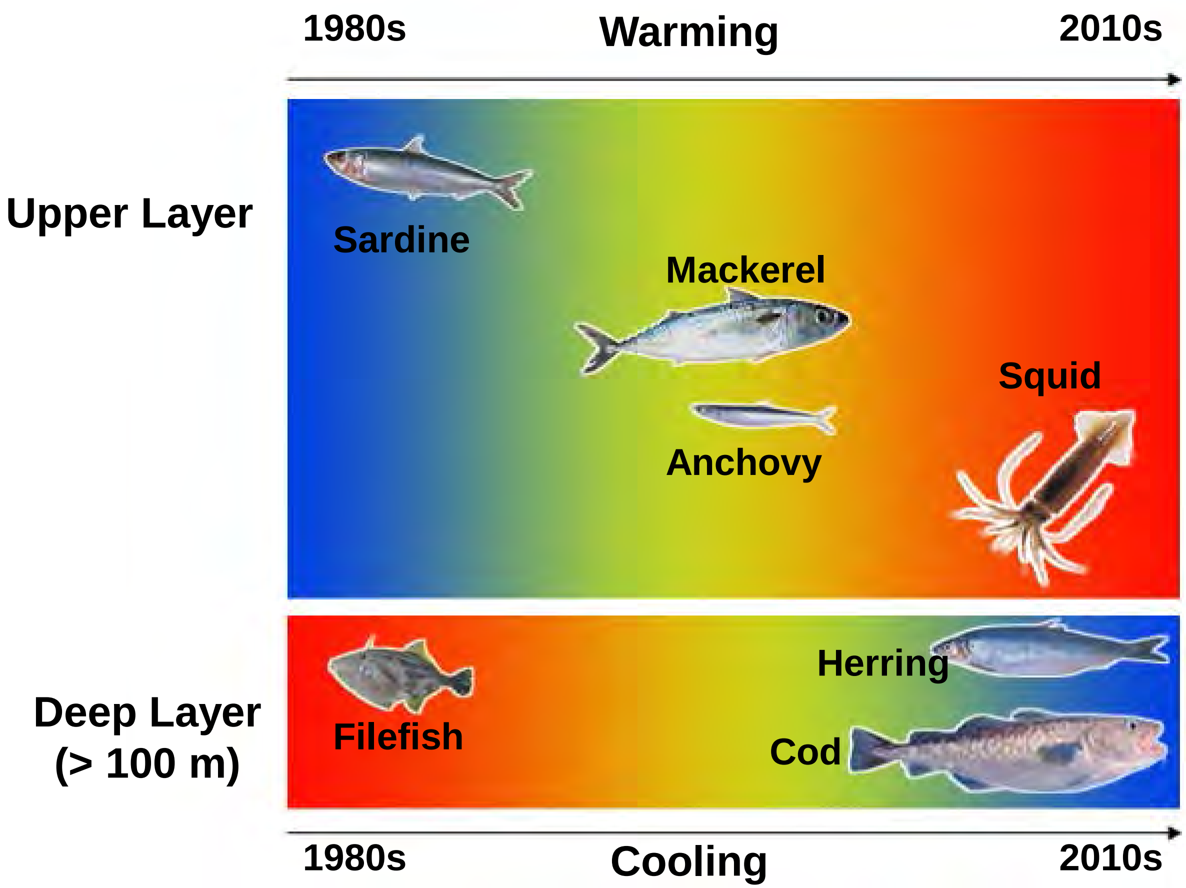
Problems and Future works

- Poor prediction of deep/bottom-layer temperatures by the ocean circulation model
  - Data assimilation
  - Better under standing of interactions between the mixed and deep layer, especially in the Japan/East Sea (western boundary current)
- Modeling active migration of juvenile/adult mackerel
  - Developing habitat models
  - Possible joint studying group of ISC and PICES
- Comprehensive ichthyoplankton surveys in the region through international cooperation
- Model validation and improvement

Hypothesized interaction between the Tsushima Warm Current (Surface) and the Korea Strait Bottom Cold Water (Deep)



Changes of major fisheries species along the Tsushima Warm Current (Western Boundary Current)



From: Jung, S., 2014. Asynchronous responses of fish assemblages to climate-driven ocean regime shifts between the upper and deep layer in the Ulleung Basin of the East Sea from 1986 to 2010. Ocean Science Journal 49, 1-10.

Acknowledgement

<u>The late Dr. Bernard A. Megrey</u>
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National Fisheries Research & Development Institute

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