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

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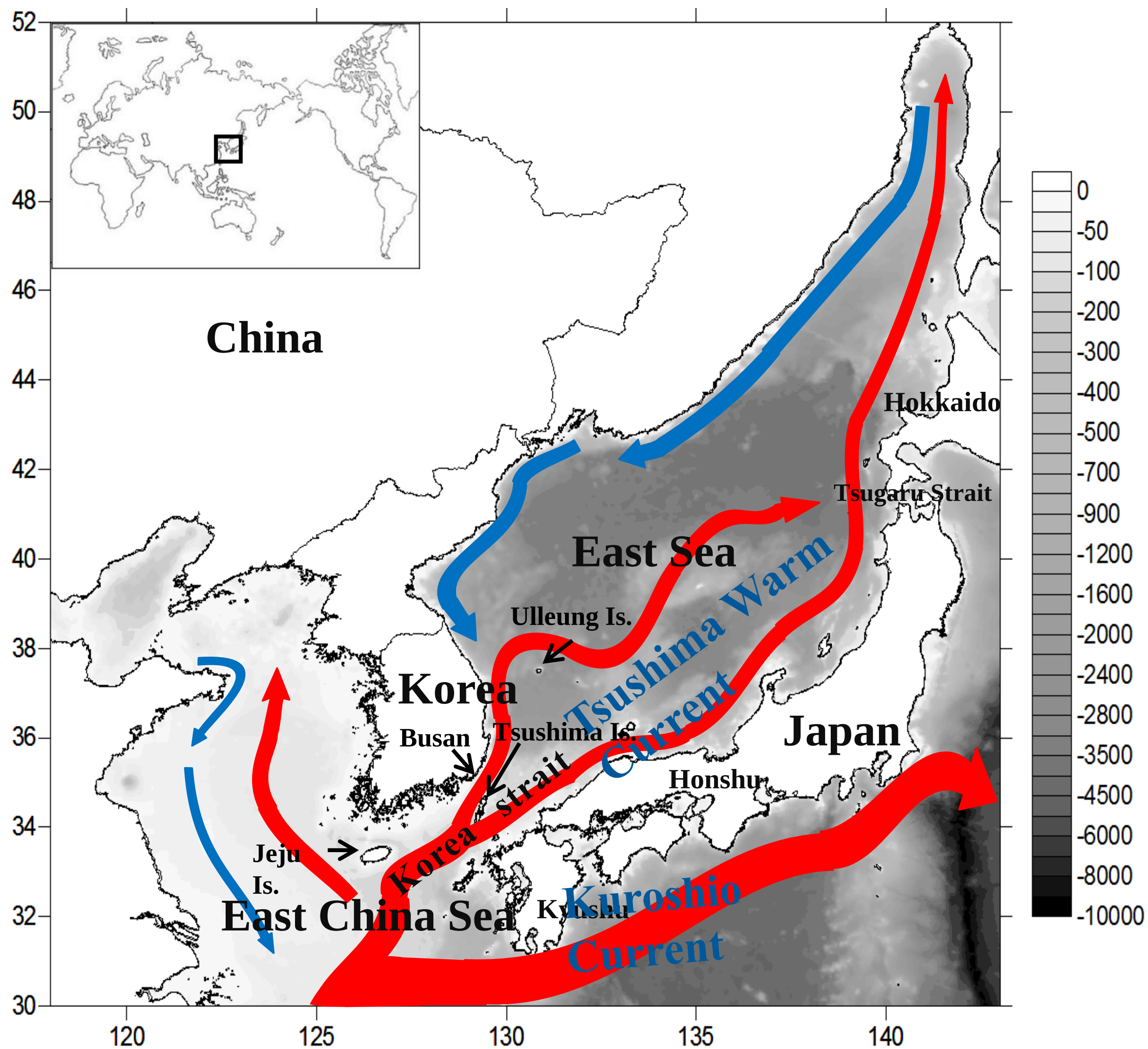
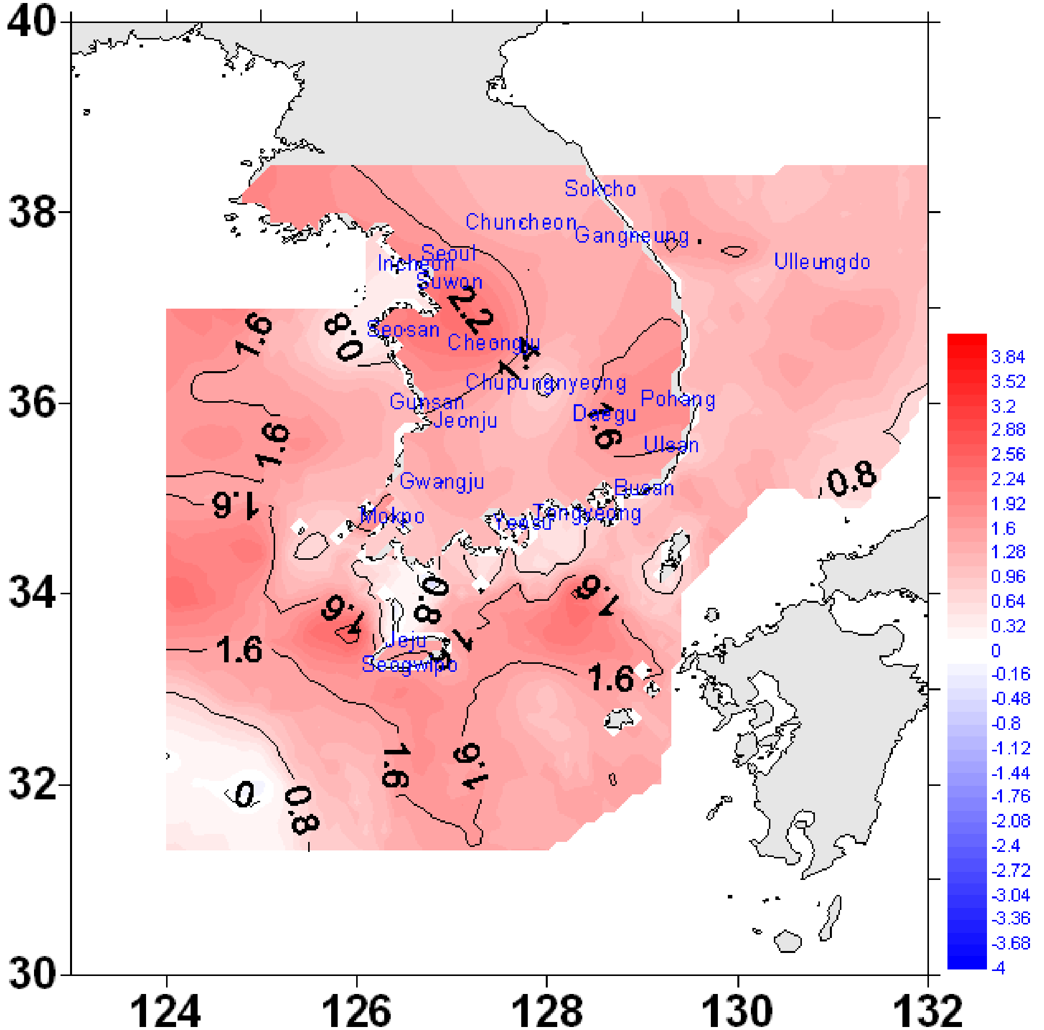
The study area and its topography.

The scale bar denotes water depth (m).



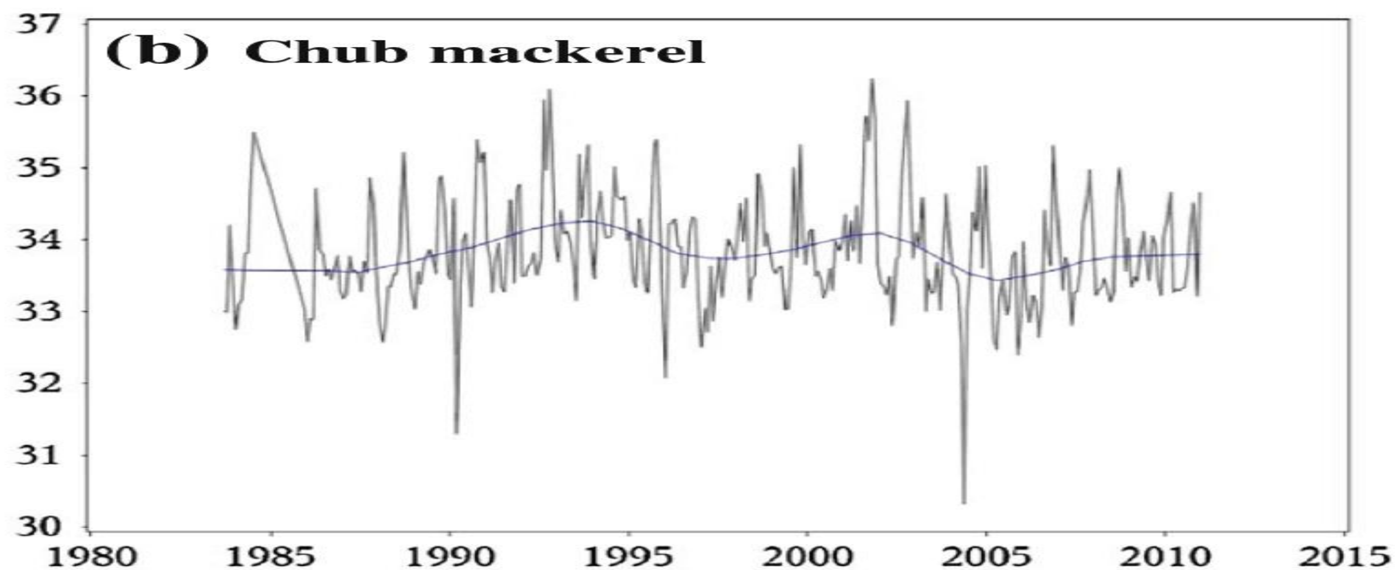
Linear trend of temperature change (°C) in the land and sea surface (1968-2010)



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

°C

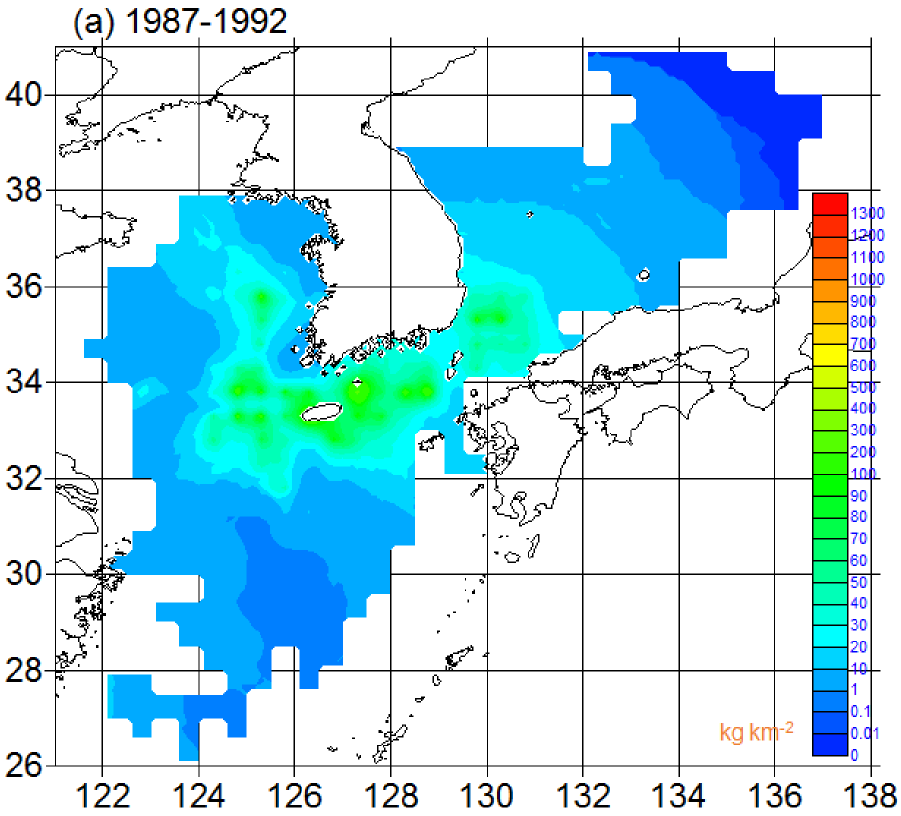
Biomass-weighted, monthly mean latitudes of the catch distribution of mackerel (1984-2010)

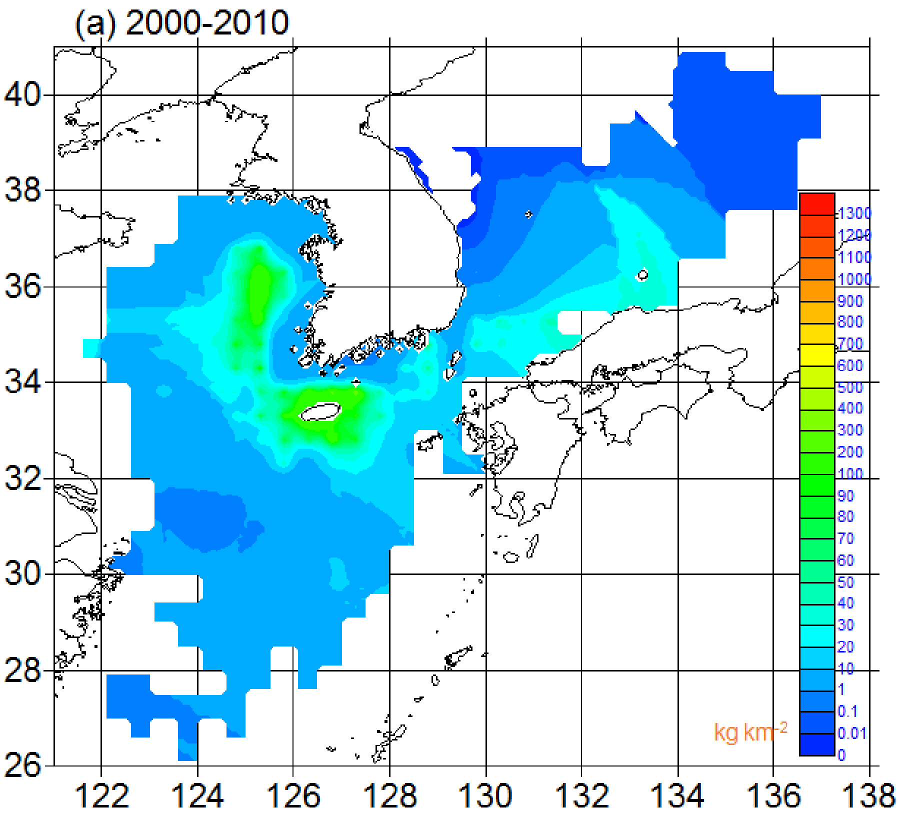


From Jung, S., Pang, I.-C., Lee, J.-h., Choi, I., Cha, H.K., 2014. Latitudinal shifts in the distribution of exploited fishes in Korean waters during the last 30 years; a consequence of climate change. Rev. Fish Biol. Fish. 24, 443-462.

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.

Average catch of chub mackerel by Korean fishers





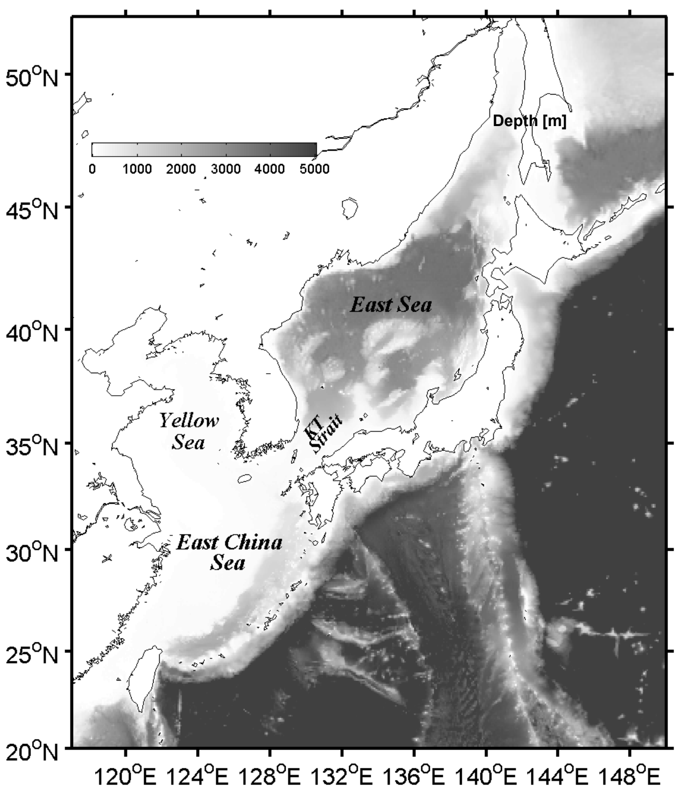
Question

- 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 and exploitable 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)

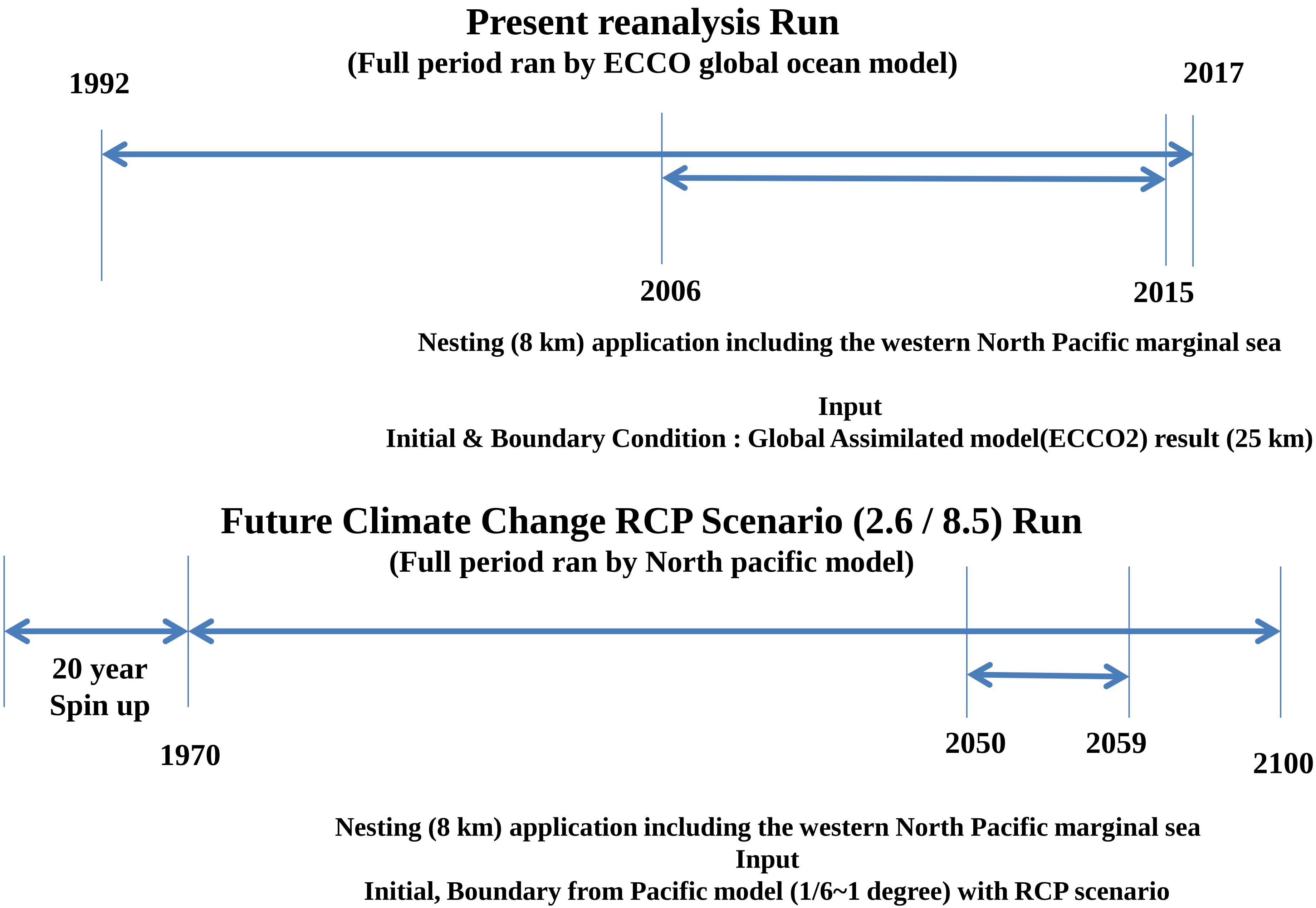
✓**Atmospheric forcing:**

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

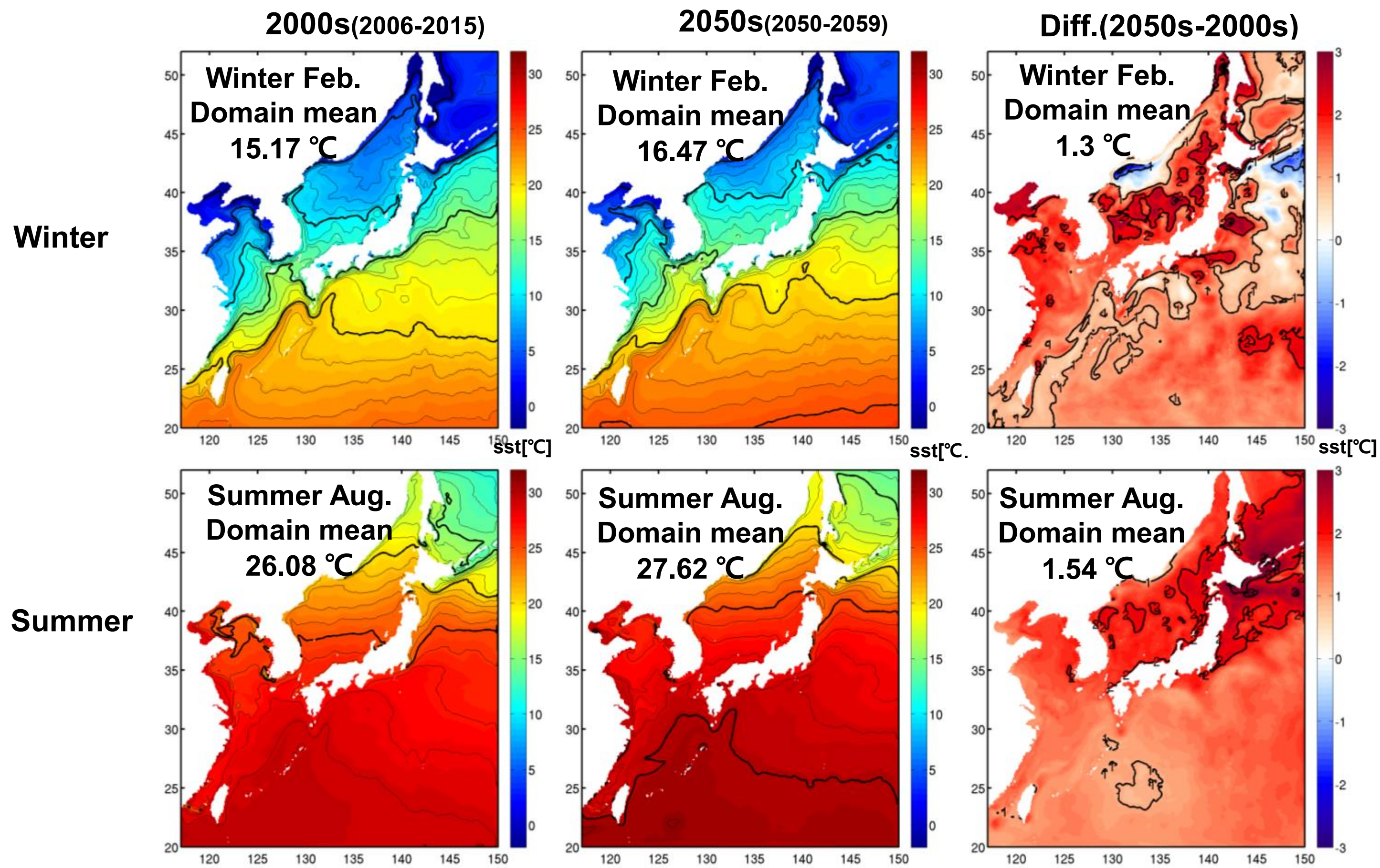
-Heat flux➔Global MPI ECHAM5 RCP2.6 and RCP 8.5 Scenario monthly mean values (2006~2050) using bulk formula

✓**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

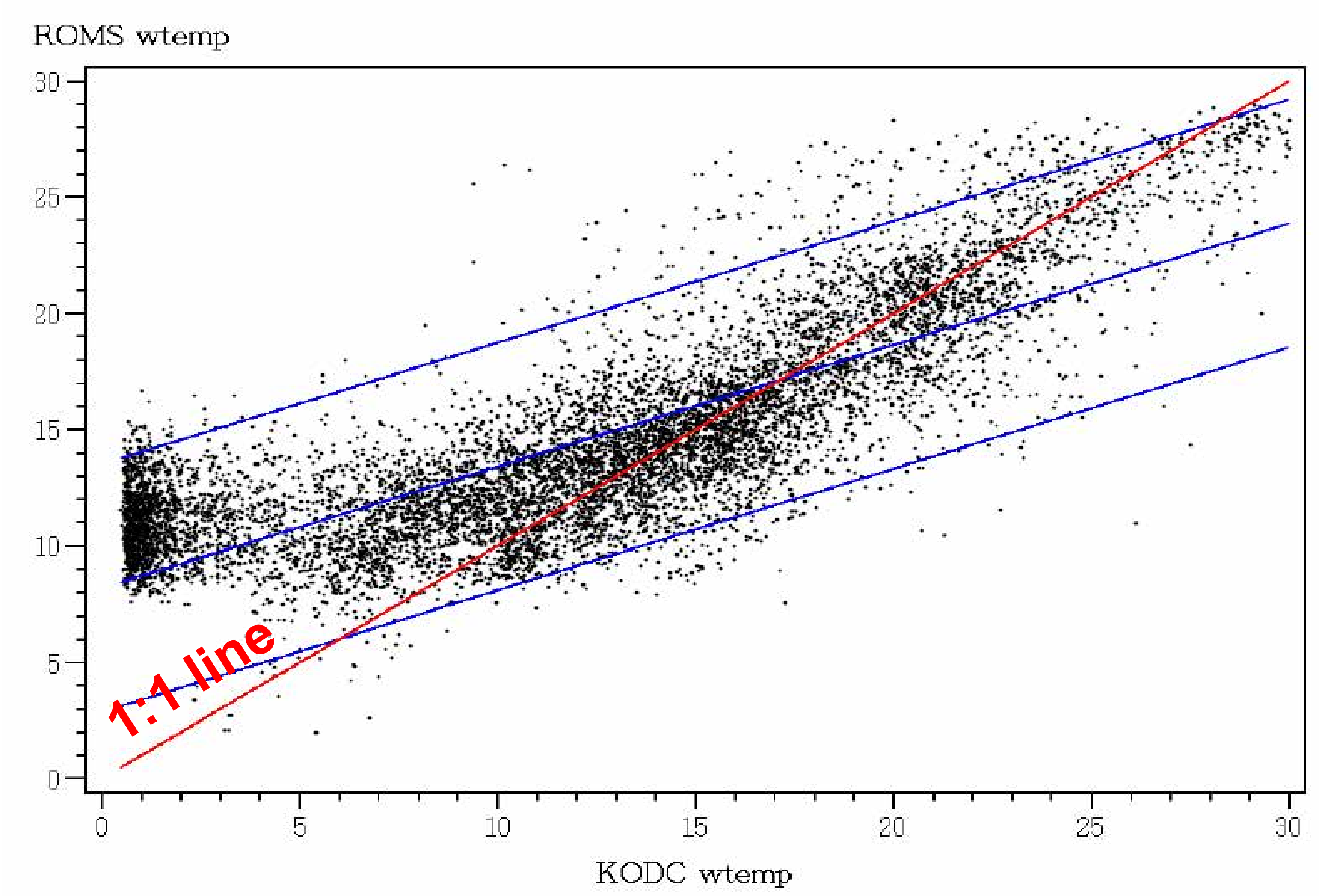
Sea surface temperatures hindcasted and projected by the ocean circulation model for the 2000s and 2050s by the RCP8.5 scenario.



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

Validation with observed data

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

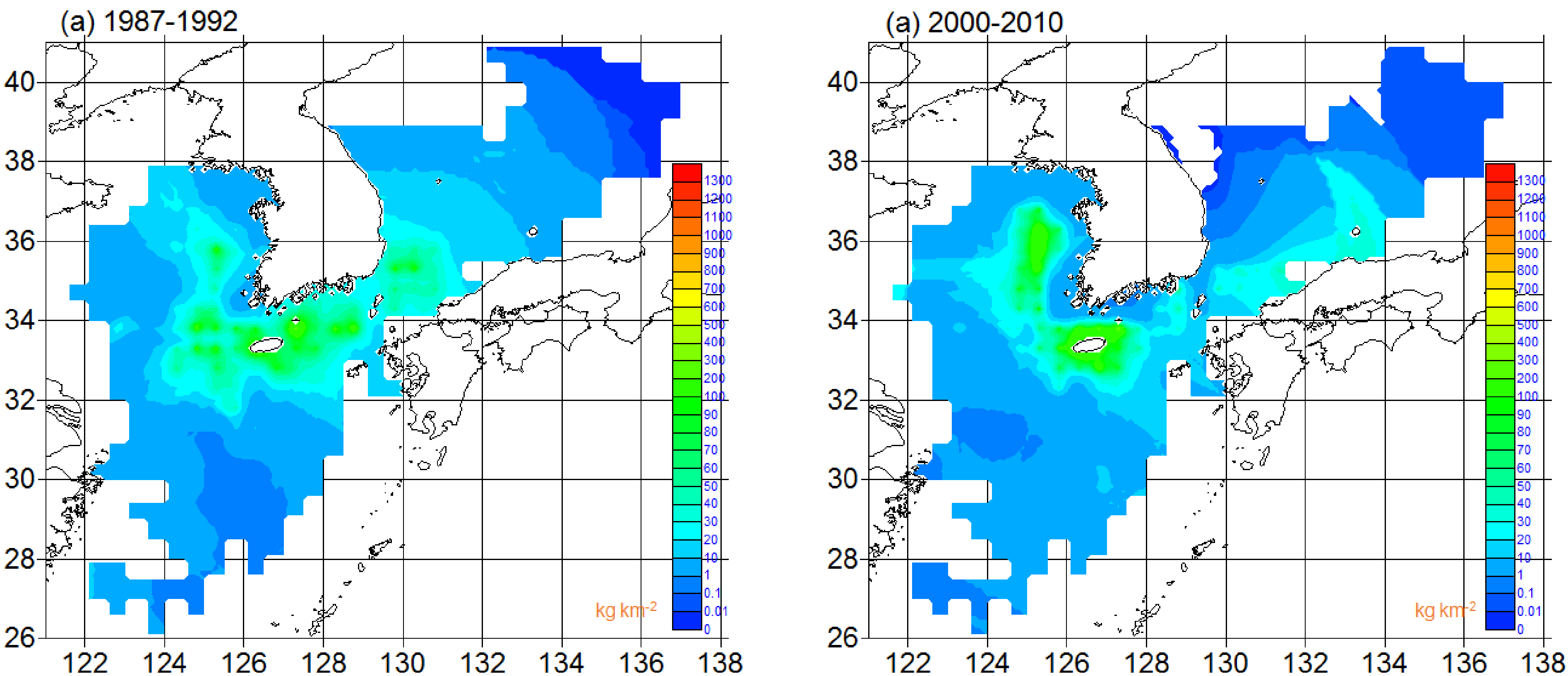


Individual-based model: Chub mackerel

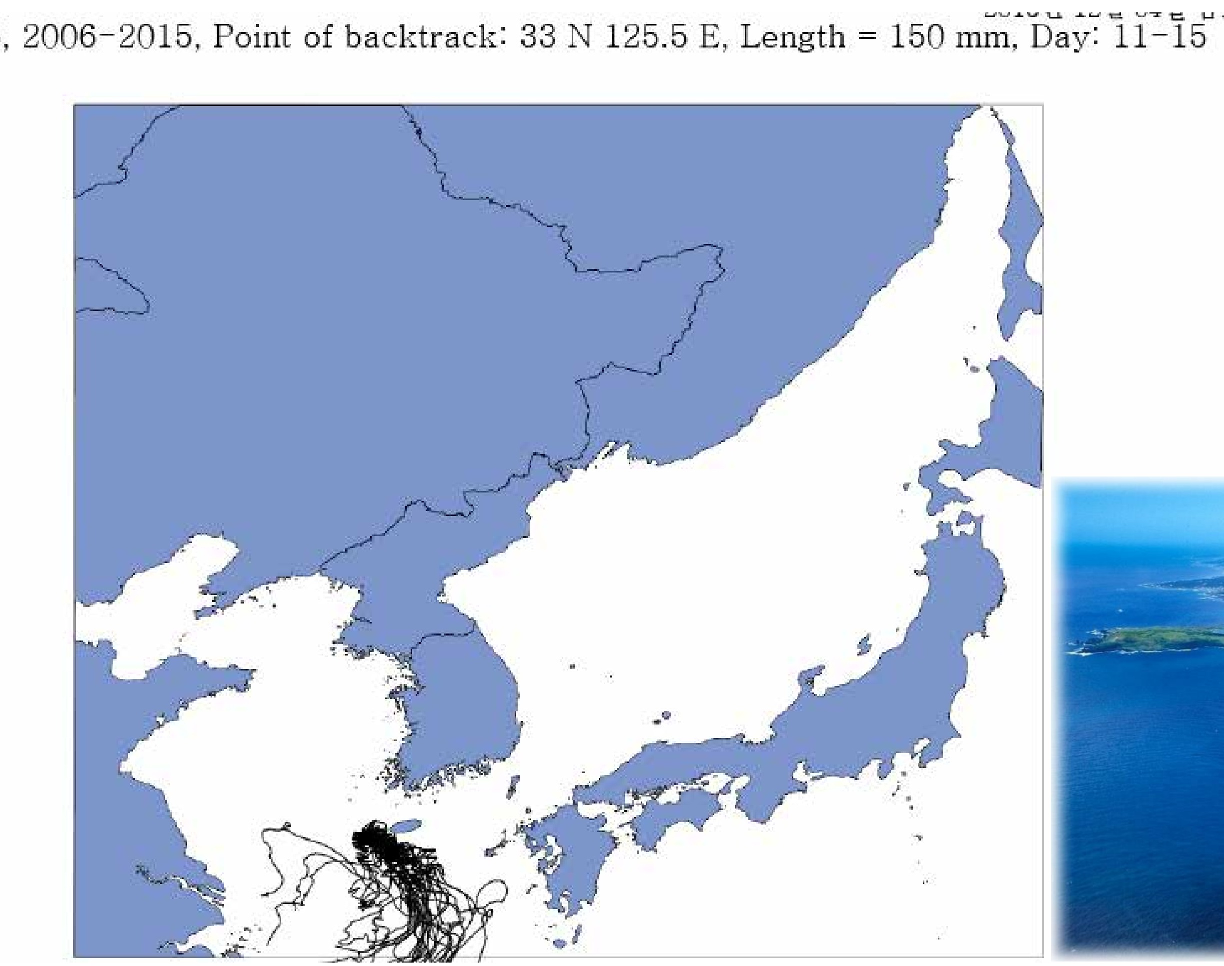
Biological model for young-of-the-year mackerel

- Spawning
- Growth
- Horizontal and vertical movement
- Survival

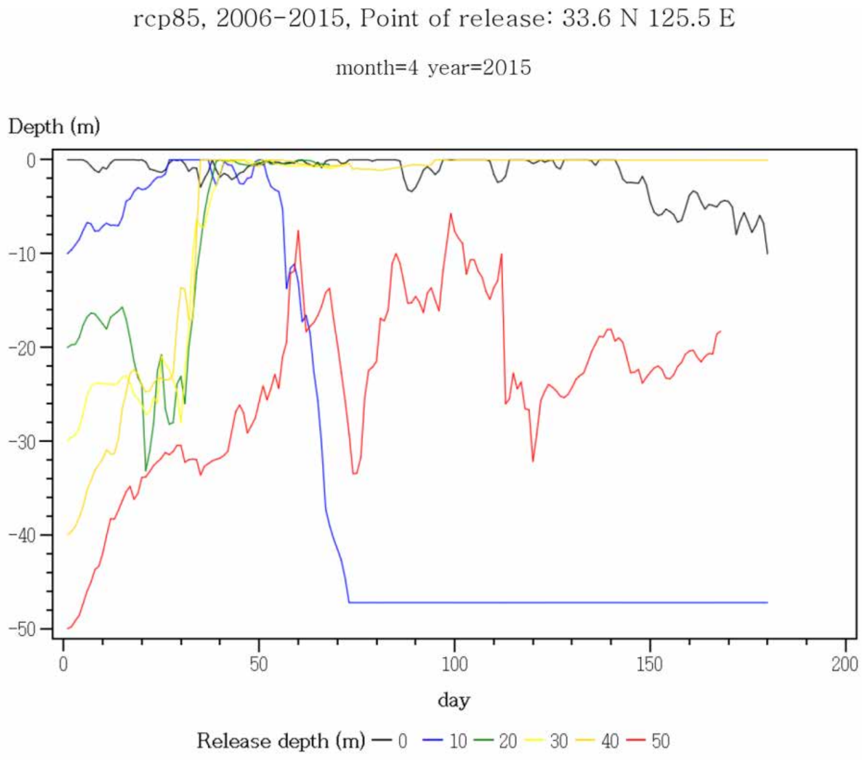
Average catch of chub mackerel by Korean fishers

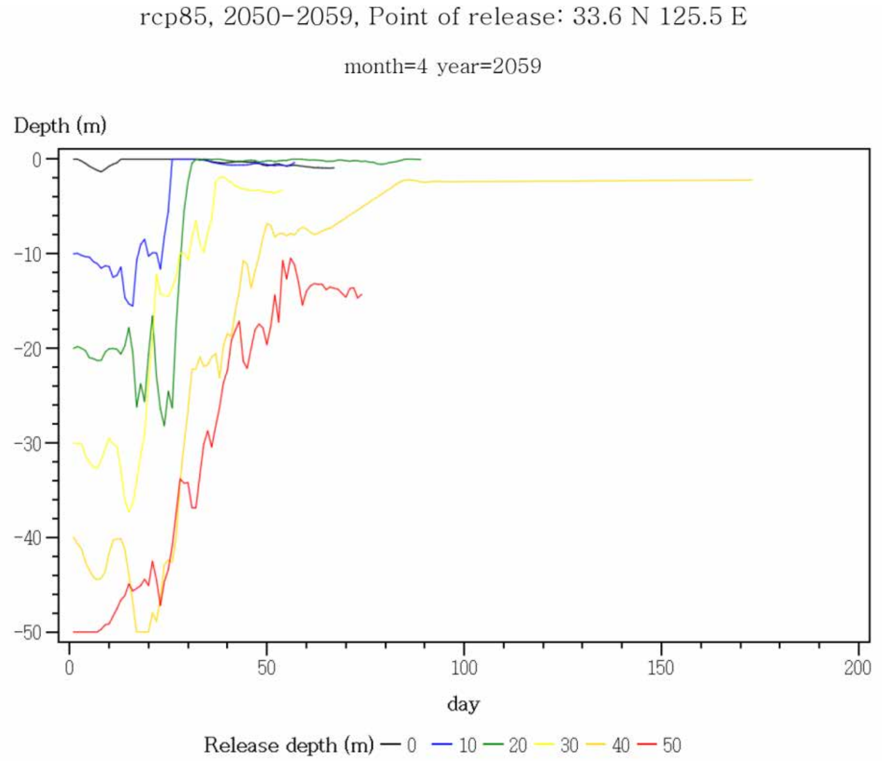


Backtracking of the spawning site of a larval mackerel individual collected near Jeju island

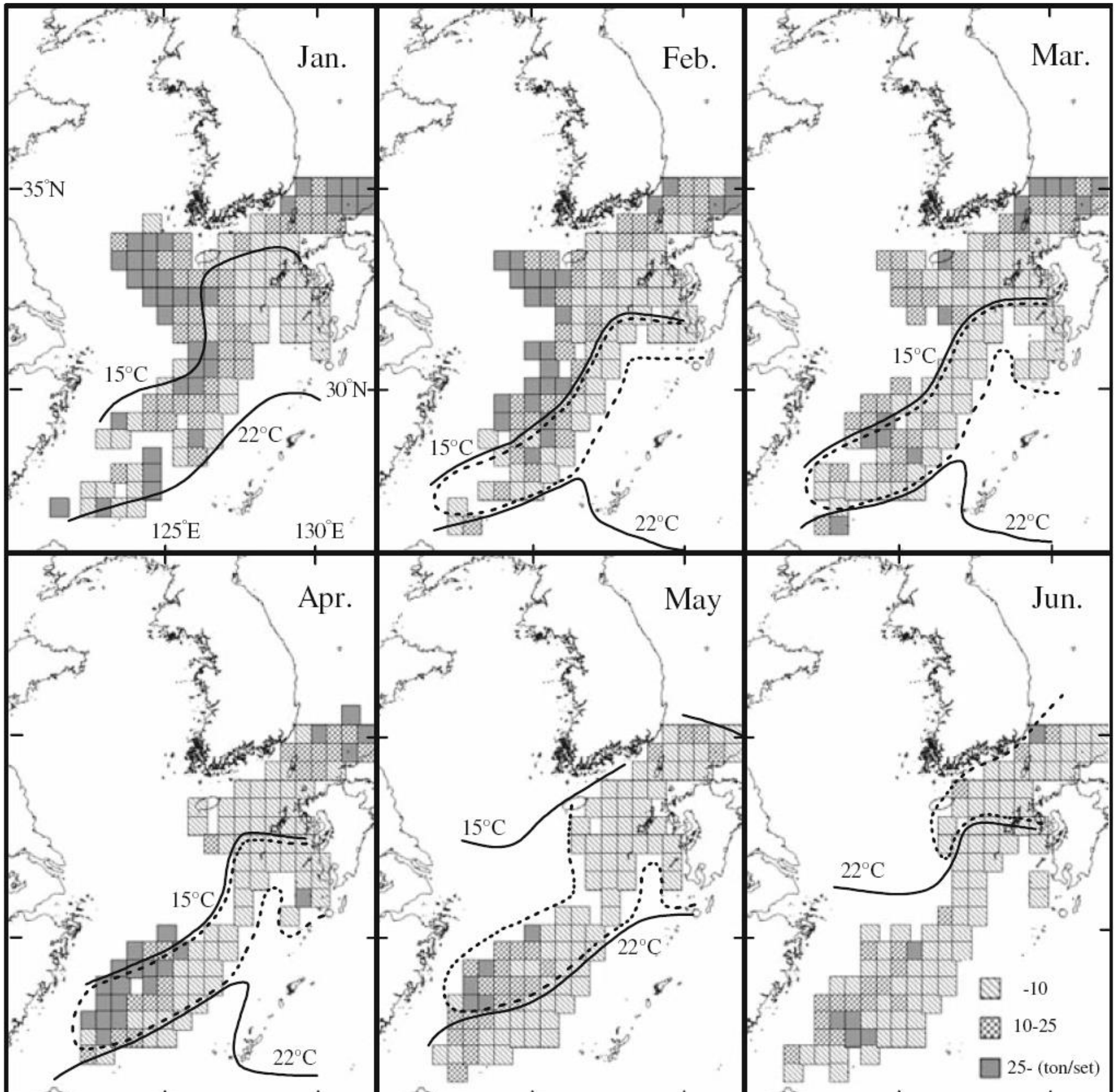


Vertical movement of mackerel larvae by RCP8.5, April 2015 vs. 2059





Spawning grounds



From:
Yukami, R., Ohshimo, S., Yoda, M., Hiyama, Y., 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)
  - $\alpha = a \exp(b \cdot \text{wtemp})$

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

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

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

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

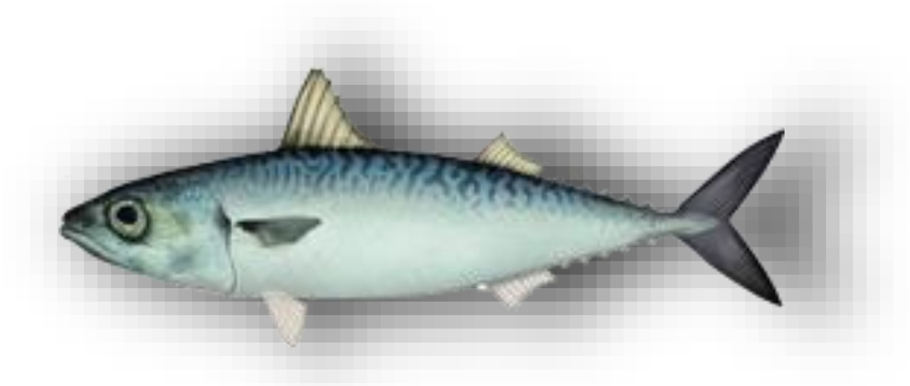
$dL/dt = K(L_\infty - L_t)$ where $K = 1.023\ yr^{-1}$

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).



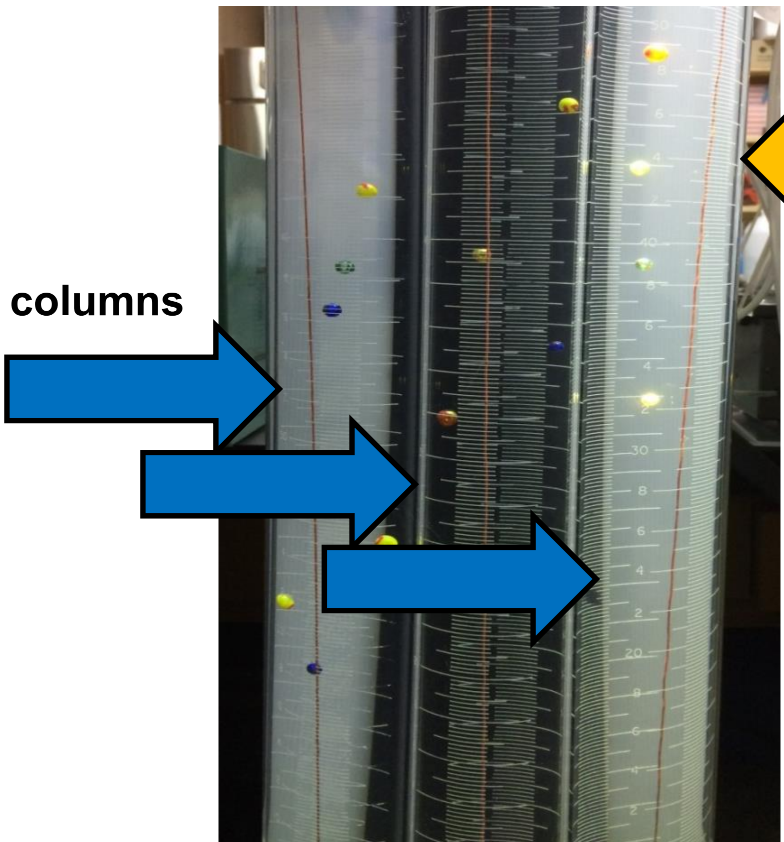
- Pacific mackerel eggs
  - were released by hormone injection for spawning and,
  - were fertilized after spawning in the tank

- Experimental duration
  - May 27 – June 12
- Embryonic period
  - 48 hours at 20℃, 33.5
  - **50 hours at 18℃, 33.5**

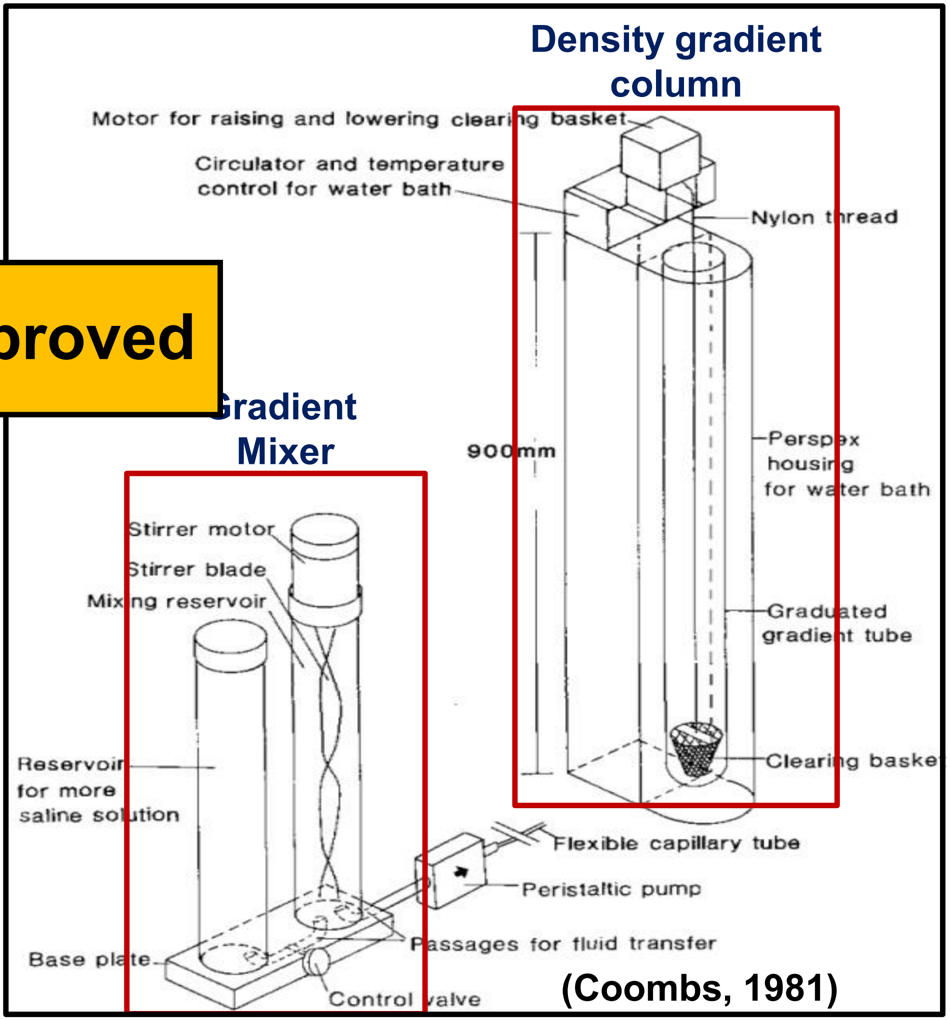
Methods for specific gravity measurement

– **A Density-gradient column for determining the specific gravity of fish eggs.**

3 columns



Improved



(Coombs, 1981)

Leslie matrix for deriving size-dependent survival rate

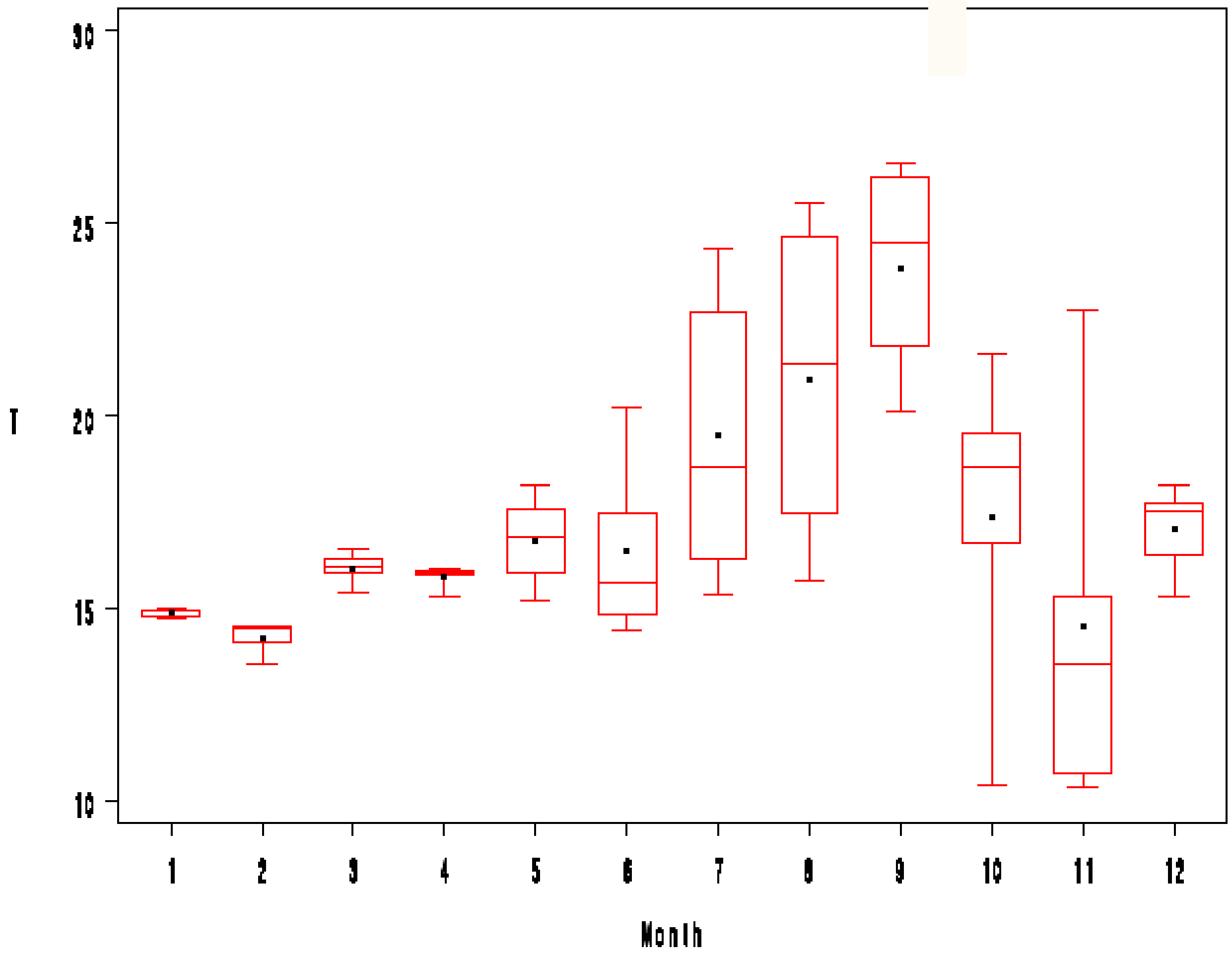
$$N(t+1) = \begin{bmatrix} n_0(t+1) \\ n_1(t+1) \\ n_2(t+1) \\ \vdots \\ n_5(t+1) \end{bmatrix} = \begin{bmatrix} f_1 S_0 & f_2 S_1 & \cdots & f_5 S_4 & f_6 S_5 \\ S_0 & 0 & \cdots & 0 & 0 \\ 0 & S_1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & S_4 & 0 \end{bmatrix} \begin{bmatrix} n_0(t) \\ n_1(t) \\ n_2(t) \\ \vdots \\ n_5(t) \end{bmatrix} = LN(t)$$

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

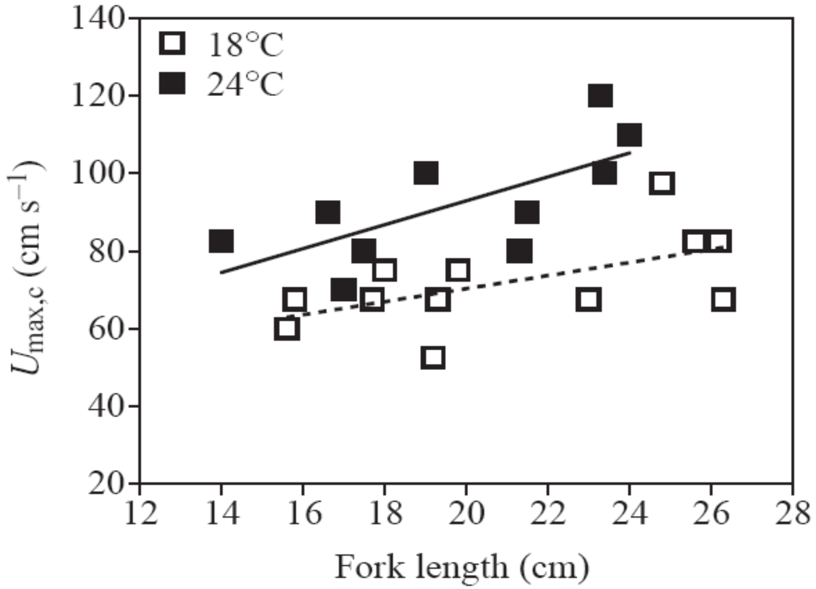
Survival

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

Estimated optimal temperature ranges of adult chub mackerel by month



Swimming speed



$a = 36.6 + (T - 18) \times (31.4 – 36.6)/(24-18)$
$b = 0.168 + (T - 18) \times (0.308-0.168)/(24-18)$

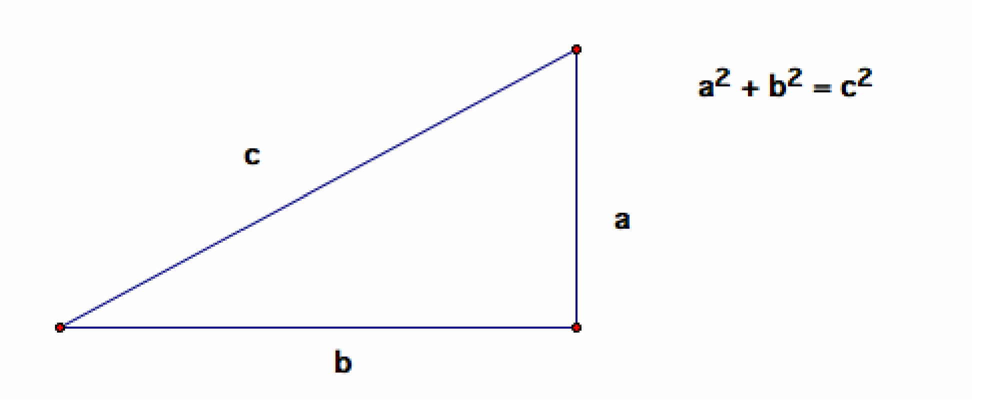
$U = a + b \ L_t$ (단위: cm/s)

Fig. 1. Maximum continuous swimming speed ($U_{max,c}$) *versus* fork length (*FL*) in chub mackerel (*Scomber japonicus*) acclimated to 18 °C (open squares) or 24 °C (filled squares) measured at the respective acclimation temperature. The lines are the best-fitting linear regressions (with coefficients ± S.E.M.): $U_{max,c}$=(0.168±0.075)*FL*+(36.6±16.0), r^2=0.33, *N*=12, *P*=0.049, at 18 °C (dashed line); $U_{max,c}$=(0.308±0.114)*FL*+(31.4±22.9), r^2=0.48, *N*=10, *P*=0.027, at 24 °C (solid line). At a given *FL*, $U_{max,c}$ was significantly greater at 24 °C (ANCOVA; *P*=0.001), but $U_{max,c}$ increased with *FL* at the same rate at the two temperatures.

Dickson, K.A., Donley, J.M., Sepulveda, C., Bhoopat, L., 2002. Effects of temperature on sustained swimming performance and swimming kinematics of the chub mackerel *Scomber japonicus. J. Exp. Biol. 205, 969-980.*

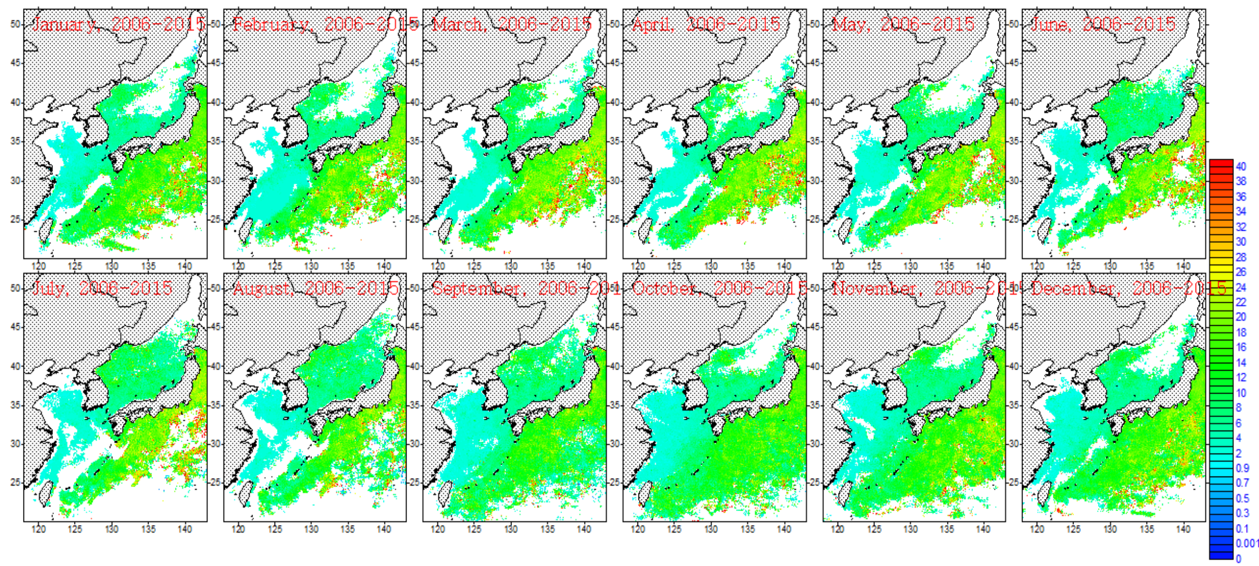
Horizontal migration

- $\Delta Tx = T_{x+0.1} - T_x$
  $\Delta Ty = T_{y+0.1} - T_y$
  $Ux = U \sqrt{\Delta Tx^2/(\Delta Tx^2 + \Delta Ty^2)}$
  $Uy = U \sqrt{\Delta Ty^2/(\Delta Tx^2 + \Delta Ty^2)}$

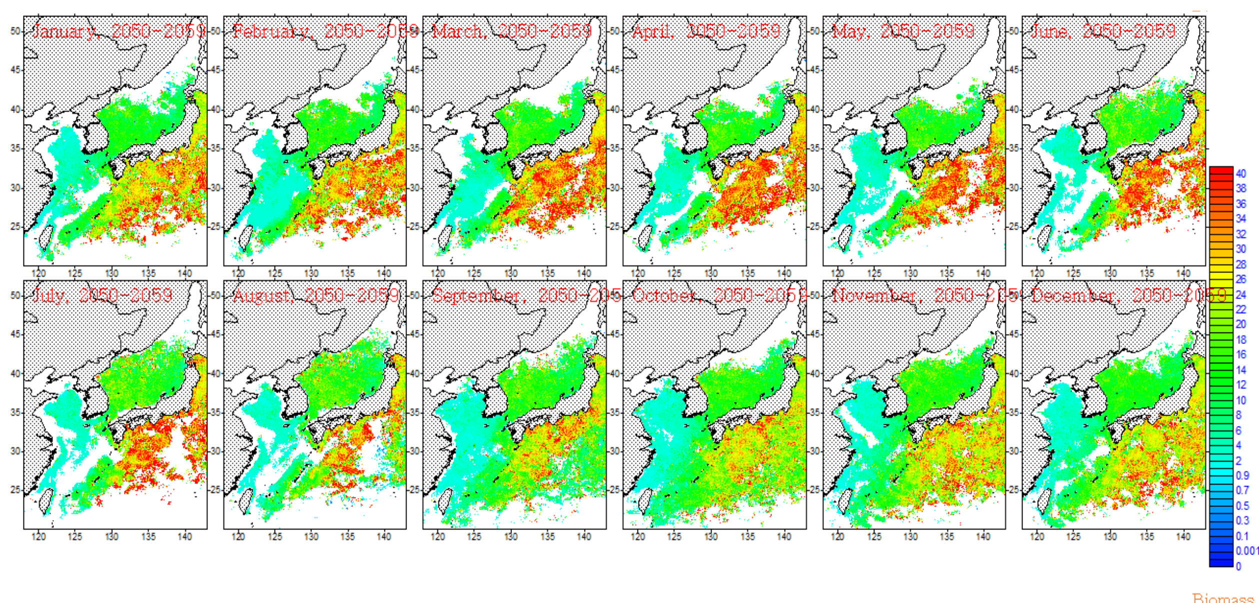


Predicted the young-of-the-year mackerel biomass based on RCP 8.5

2006-2015

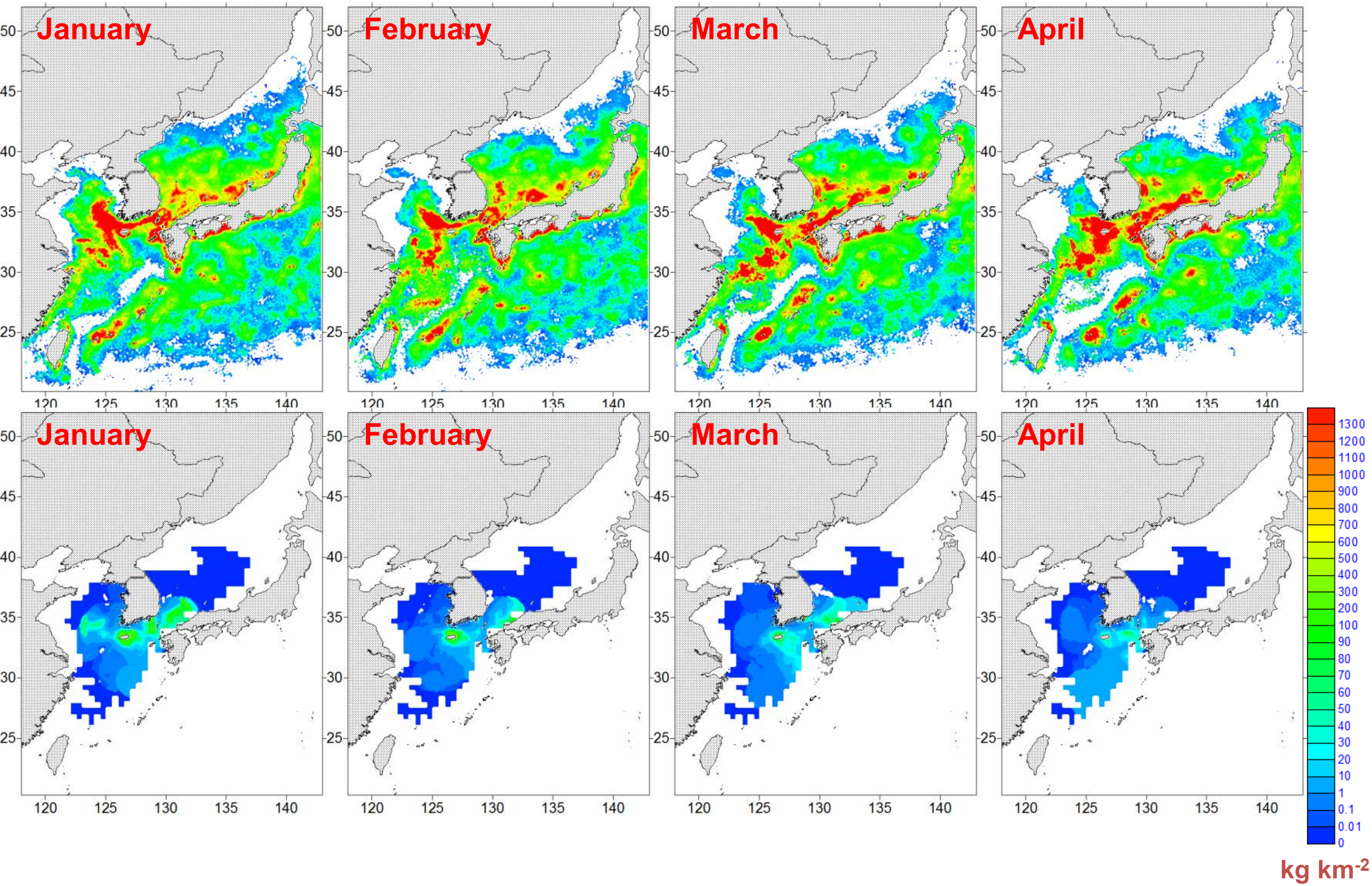


2050-2059

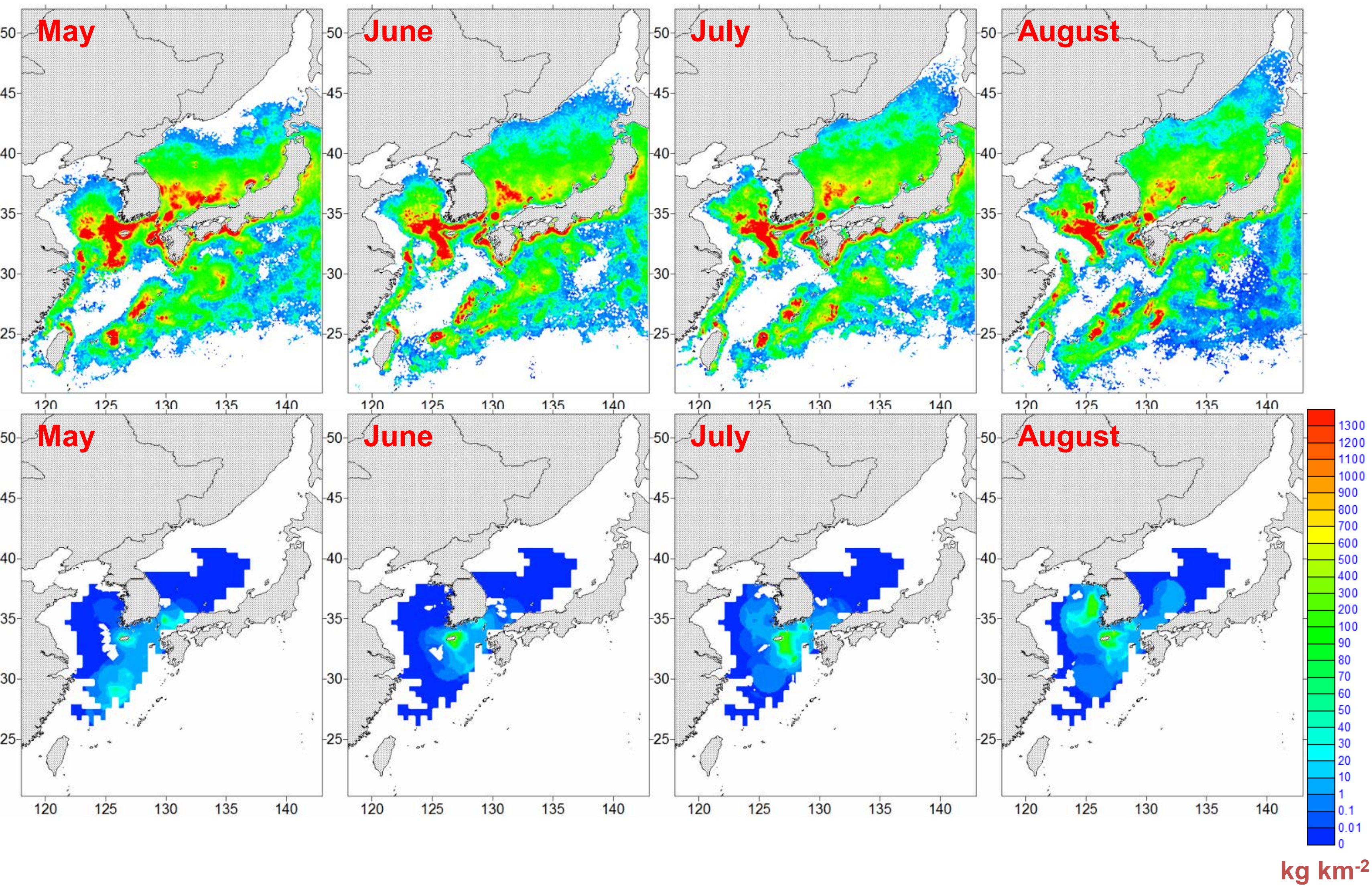


Model validation with commercial catch by Korean fishers

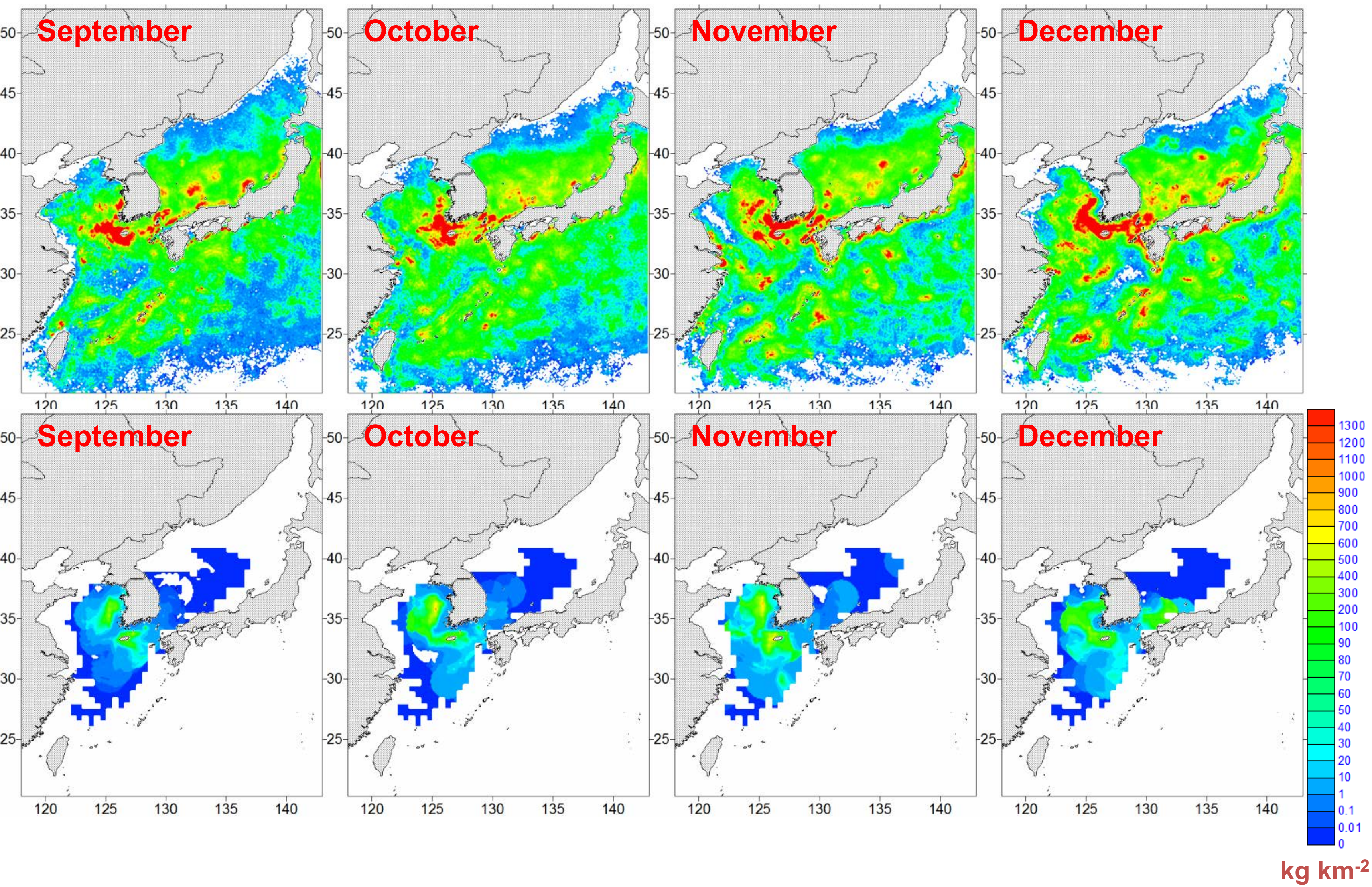
Predicted vs. Observed Catch of Mackerel



Predicted vs. Observed Catch of Mackerel



Predicted vs. Observed Catch of Mackerel

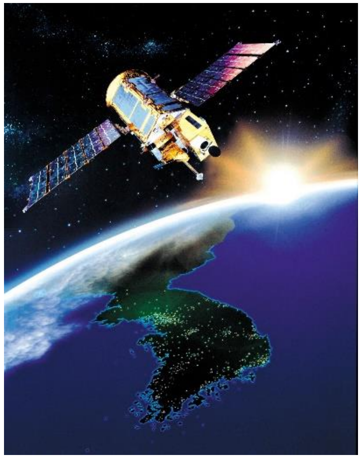


Summary

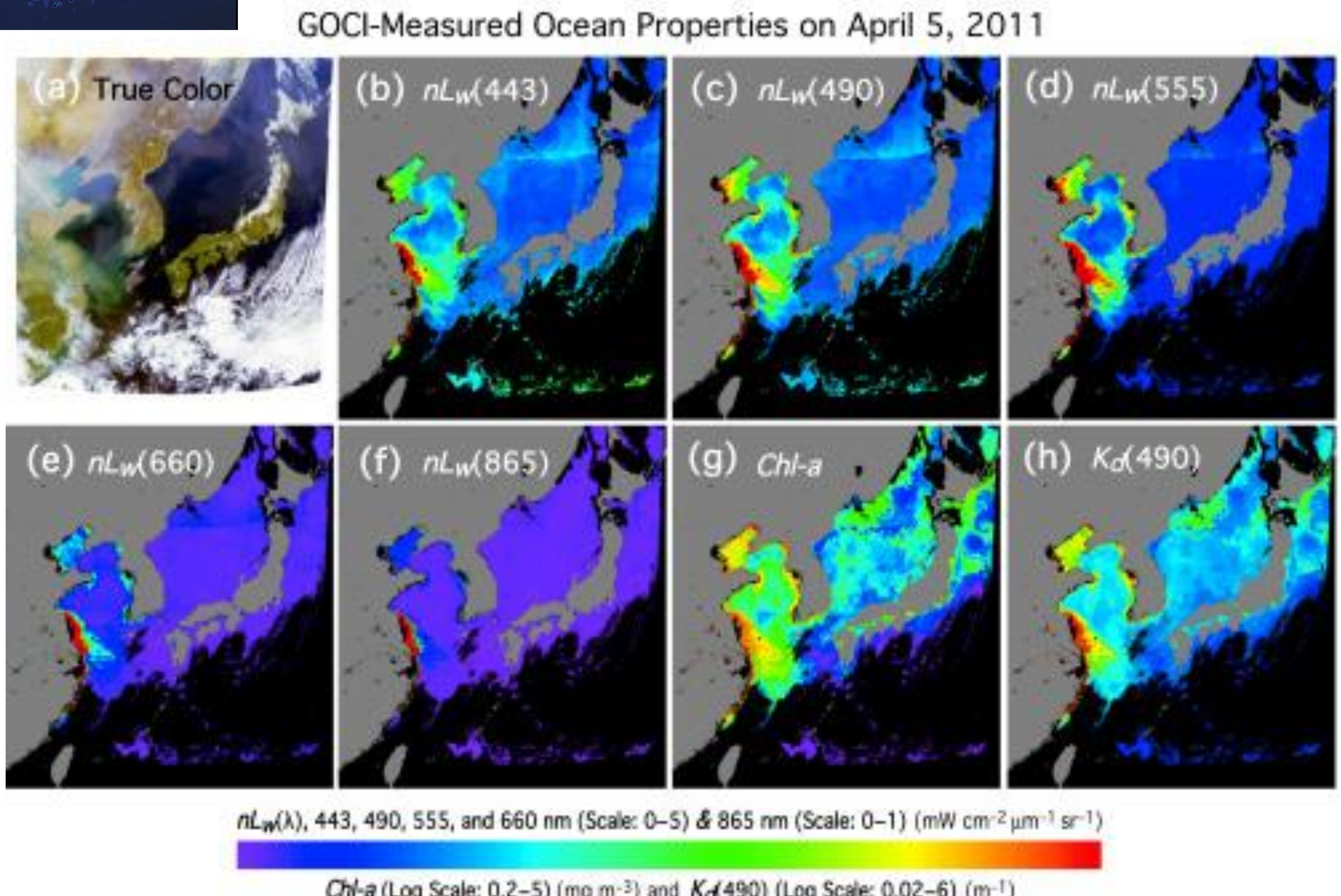
- Projection for the 2050s
  - Larva: Survival will be enhanced in overall
  - Juvenile: The distribution will be shifted northeast to the Japan/East Sea
- The results are preliminary, and the model is still at the early stage of development.

Problems and Future works

- Poor prediction of deep-layer or bottom water 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
- Comprehensive ichthyoplankton surveys in the region
- Model validation and improvement
- International cooperation and feedback



The Korean Geostationary Ocean Color Imager (GOCI)



Acknowledgements

KEI
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