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Latitudinal shifts in catch distribution of fisheries species in Korean waters during the past 30 years in relation to climate change

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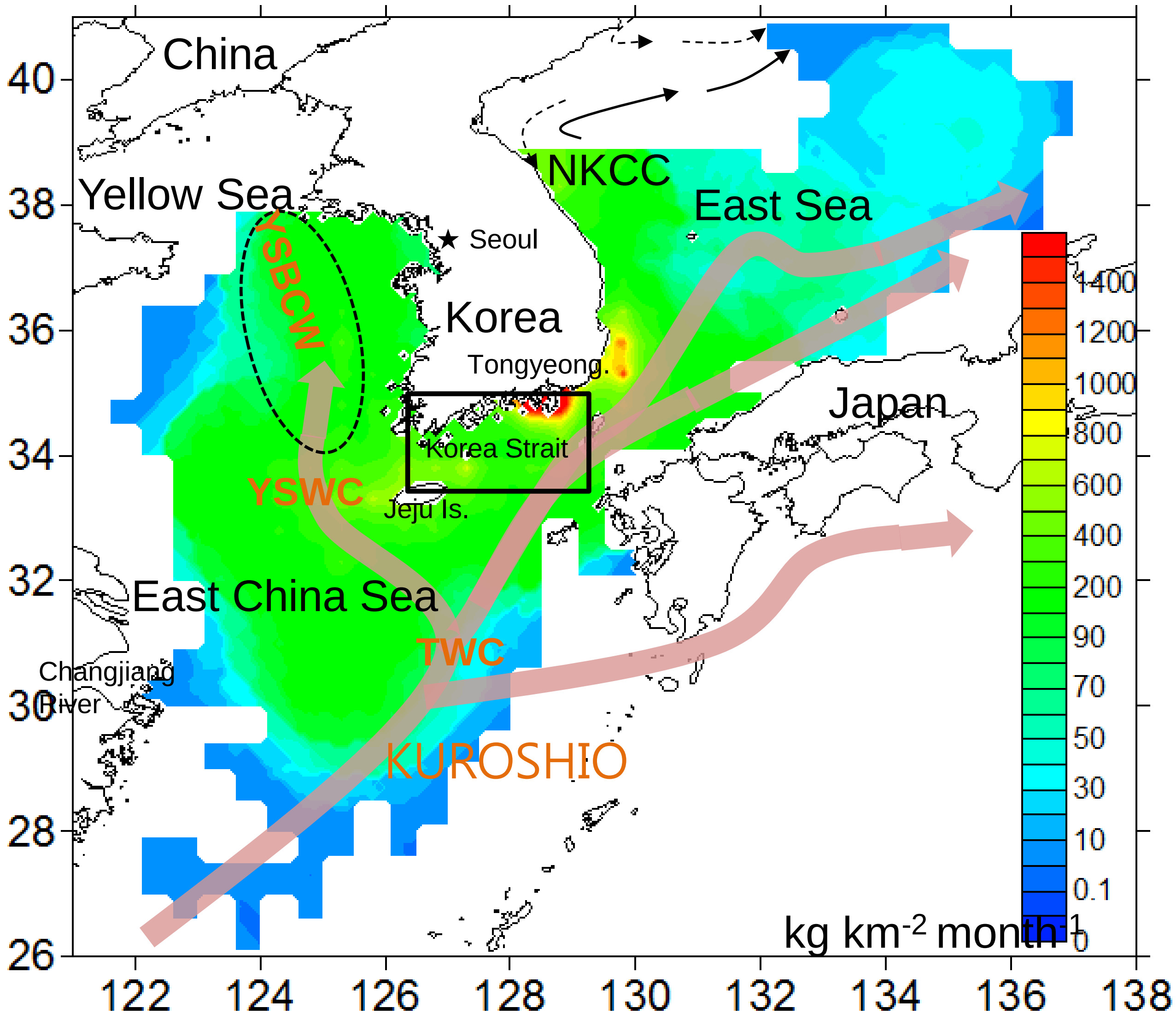
- Major currents (arrows)
- Mean biomass of fishes captured (1984-2010)



Problem and Objective

- Lack of studies on latitudinal shifts of fish species in the Pacific (IPCC AR5)
  - Mostly confined to the North Atlantic
- Document range shifts of fish species in Korean waters based on fisheries statistics despite uncertainty
- Implications for fisheries management in adapting to climate change in Korea

Outline

- Long-term oceanographic changes in Korean waters
- Range shifts of major commercial fish species
  - Small pelagic species
  - Large pelagic species
  - Demersal/Bentho-pelagic species
- Implications to fisheries management in adapting to climate change

Long-term Data in Korea

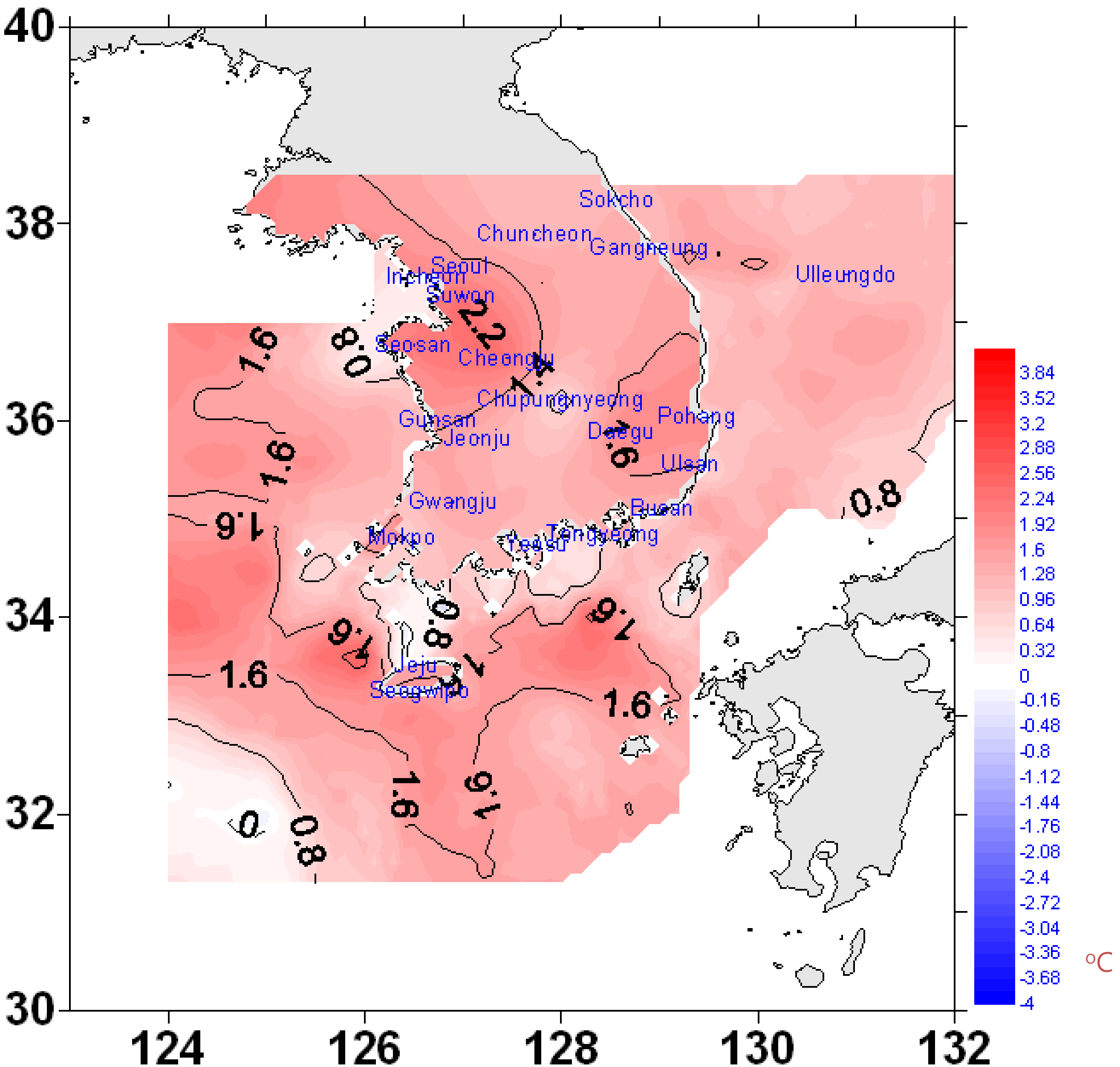
- NFRDI, Korea
  - Depth-specific water temperature, salinity and dissolved oxygen (1968-2010)
  - Bimonthly
- MIFAFF, Korea
  - Spatially-explicit daily catch data of marine capture fisheries in South Korea (1983-2010)
- Korea Meteorological Administration
  - Air temperature and precipitation at 22 cities (1968-2010)

Statistical Methods

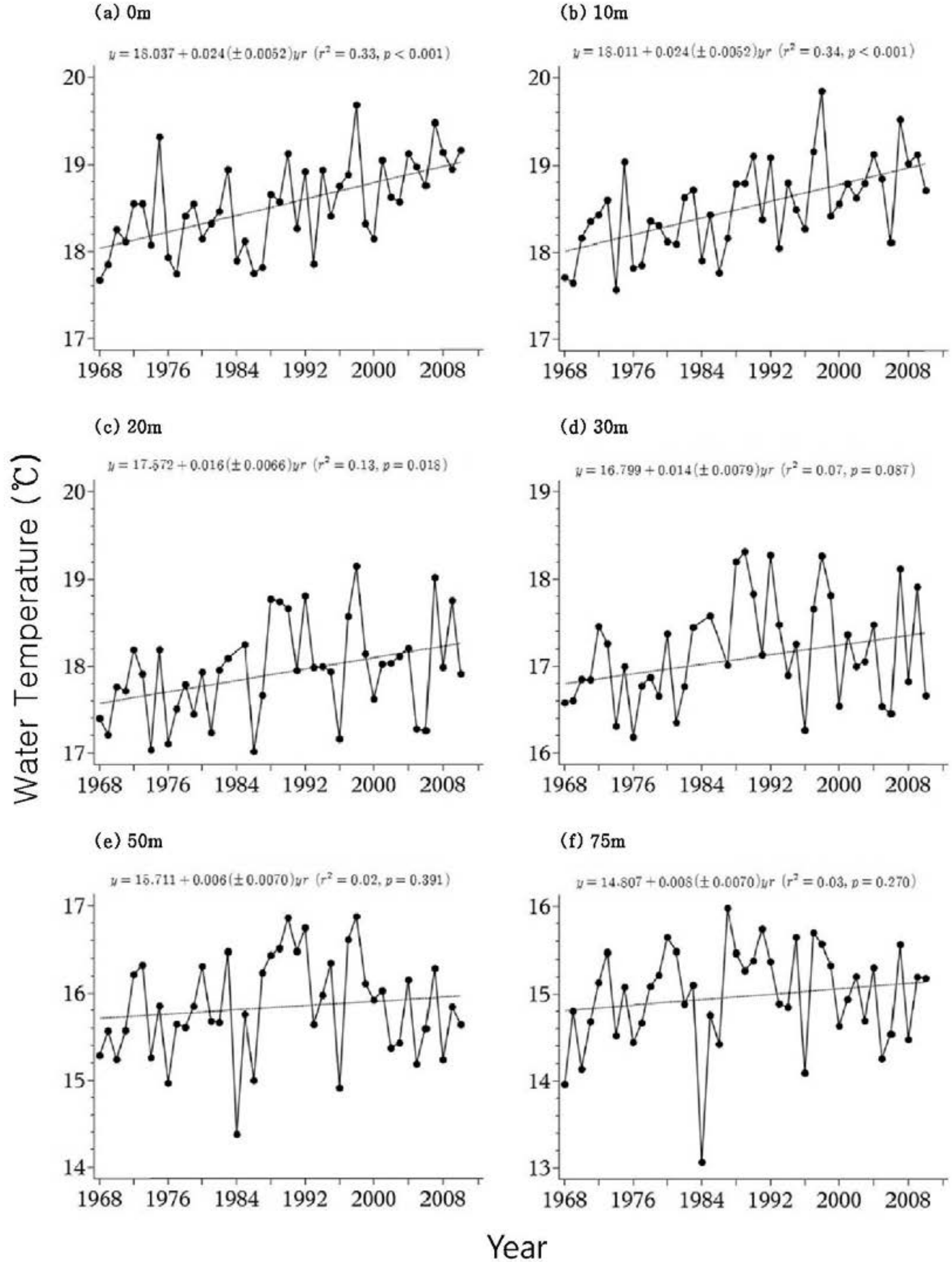
Range shifts of major commercial fish species

- Monthly catch-weighted mean latitude
- Monthly-averaged region- and depth-specific water temperature
- Removing socio-economic effects
  - Fuel price of fishing vessels
  - Catch of the species
  - Changes in fishing gear/method
- Linear regression between monthly mean latitude and mean value of environmental variable
- Removing seasonality
  - Monthly anomaly of mean latitude vs. Monthly anomaly of environmental factors

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



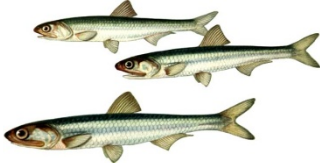
Annually averaged, depth-specific water temperatures in the Korea Strait from 1968 to 2010

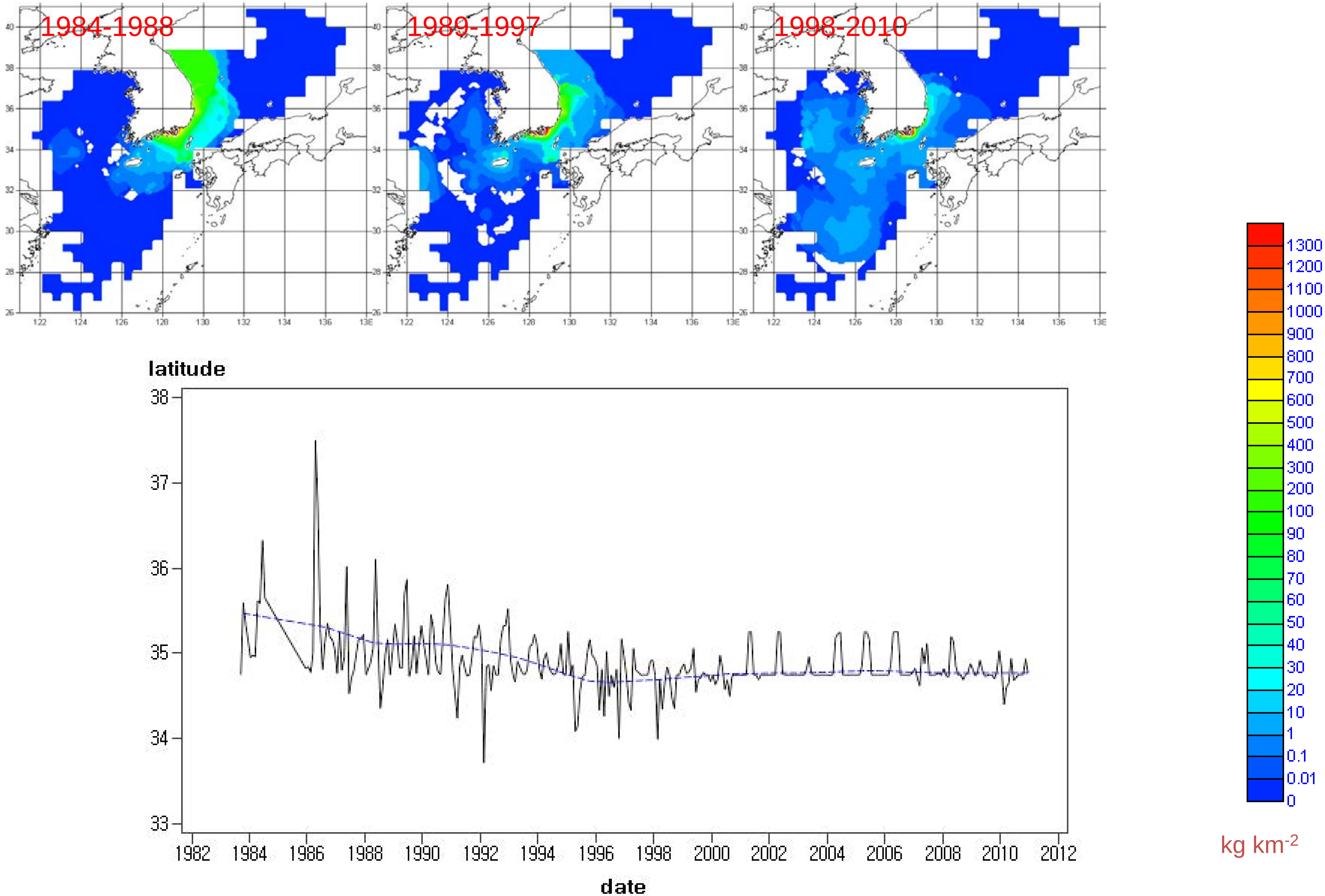


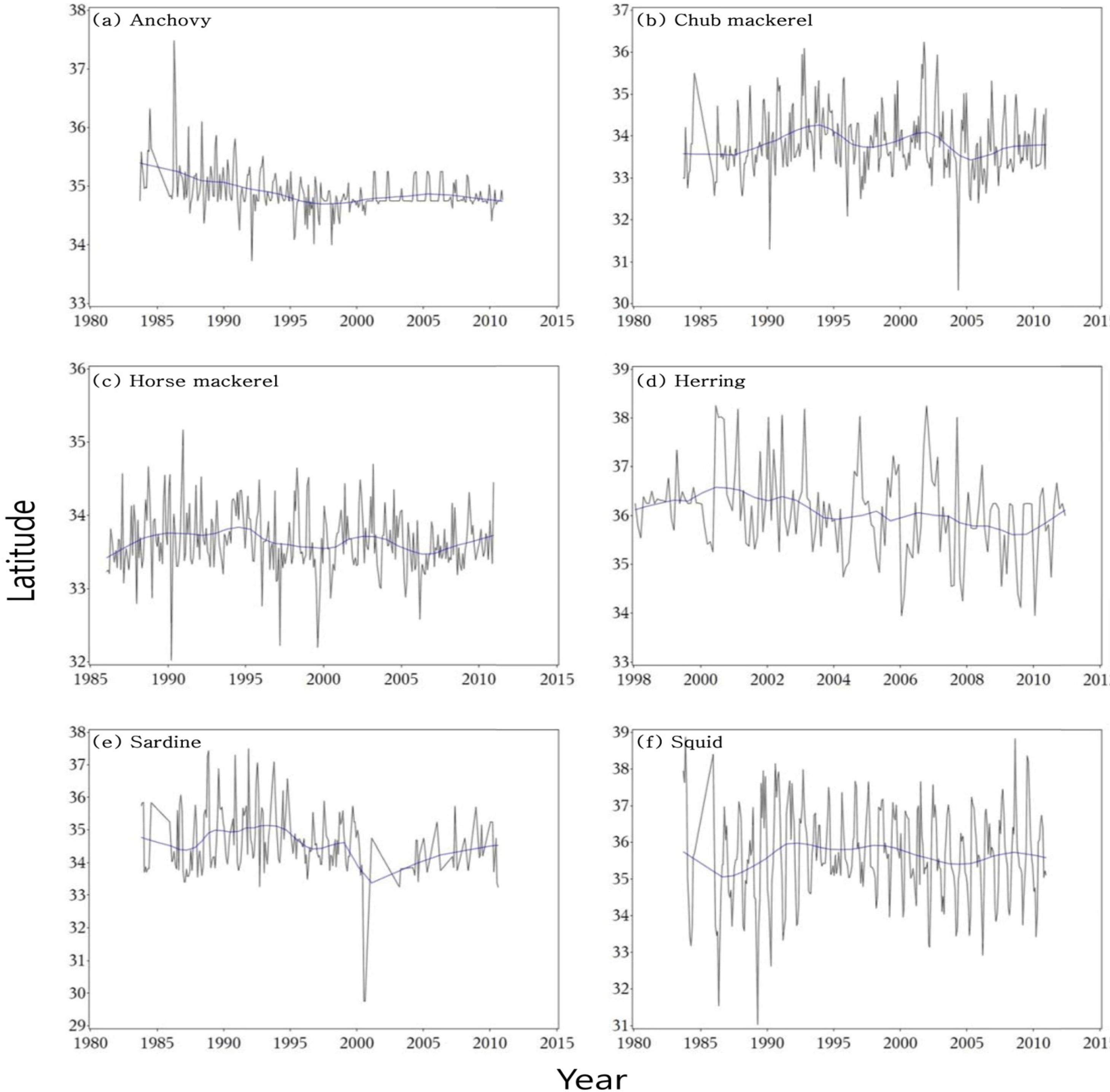
Small pelagic species

- Pacific Anchovy
- Chub mackerel
- Horse mackerel
- Pacific herring
- Pacific sardine
- Common squid

Pacific Anchovy






(a) Anchovy
(b) Chub mackerel
(c) Horse mackerel
(d) Herring
(e) Sardine
(f) Squid
Latitude
Year

Large pelagic species

- Bluefin tuna
- King mackerel
- Yellowtail

Bentho-pelagic species

- Hairtail
- Small yellow croaker
- Filefish

Demersal Fish

- Red horsehead

Grouping of years based on the depth-specific, annually-averaged water temperature in the Korea Strait from 1984 to 2010

Year/ Depth(m)	0	10	20	30	50	75	100
1984							
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
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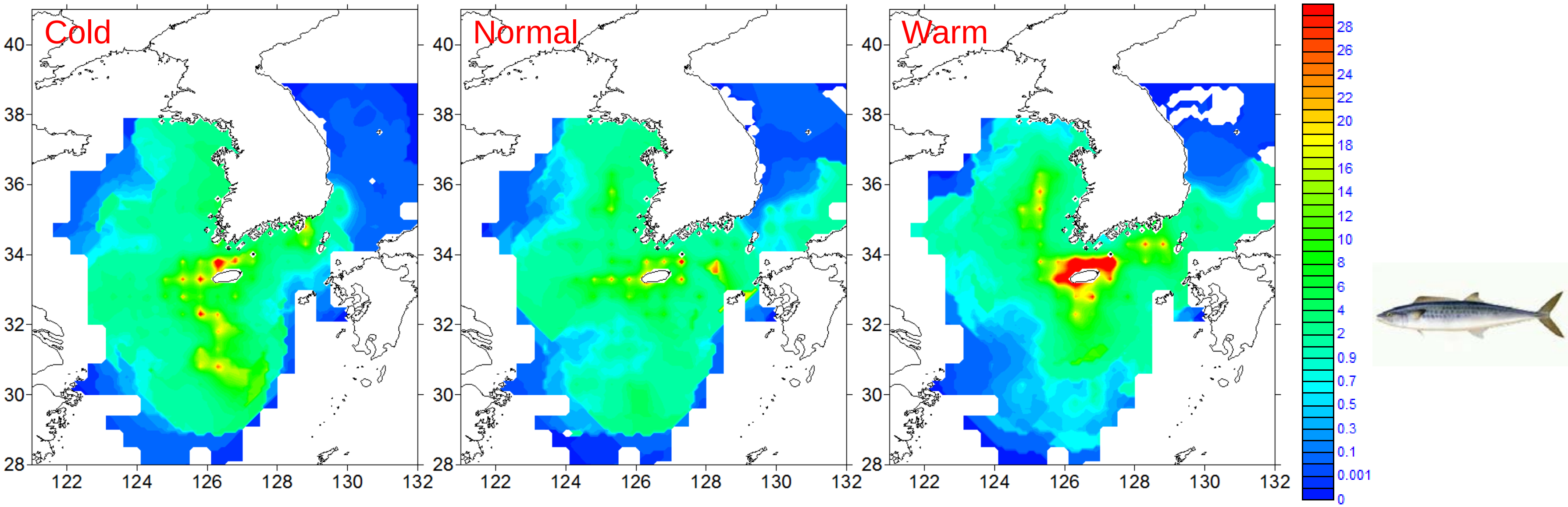
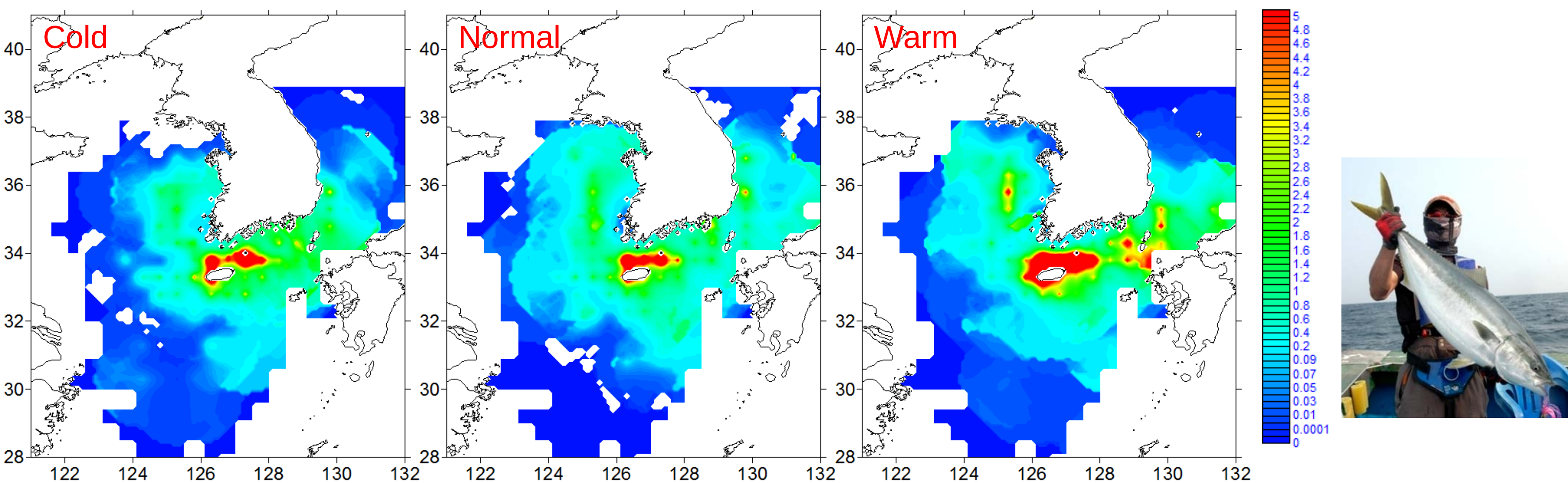
2005							
2006							
2007							
2008							
2009							
2010							

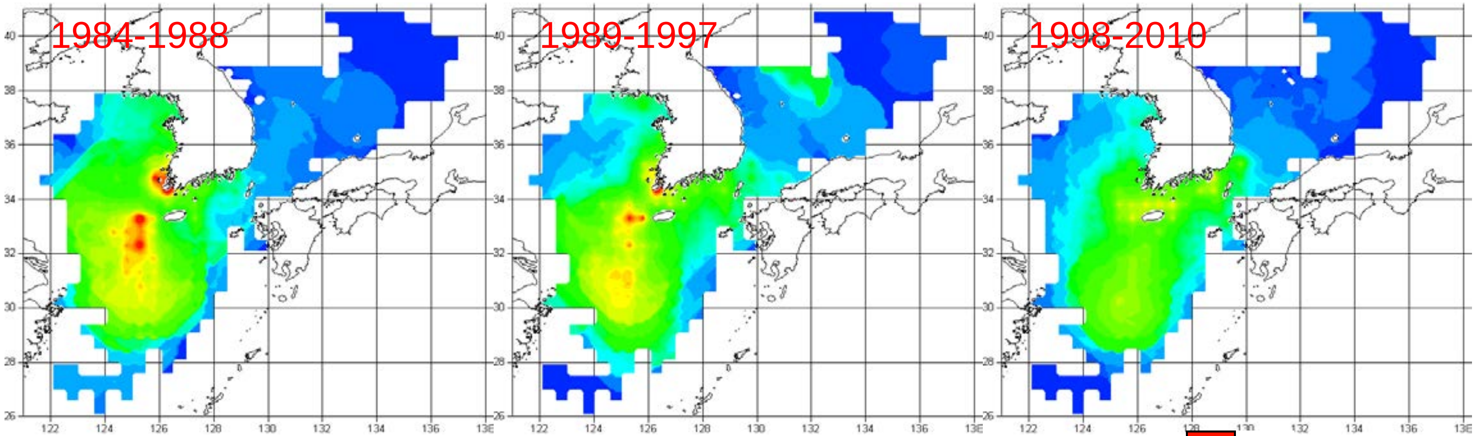
(a) Spanish mackerel (0 m)

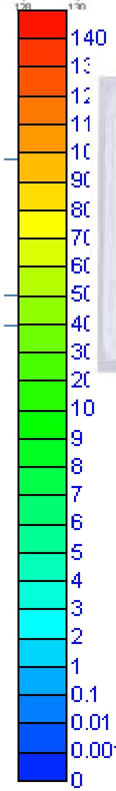


(b) Yellowtail (0 m)

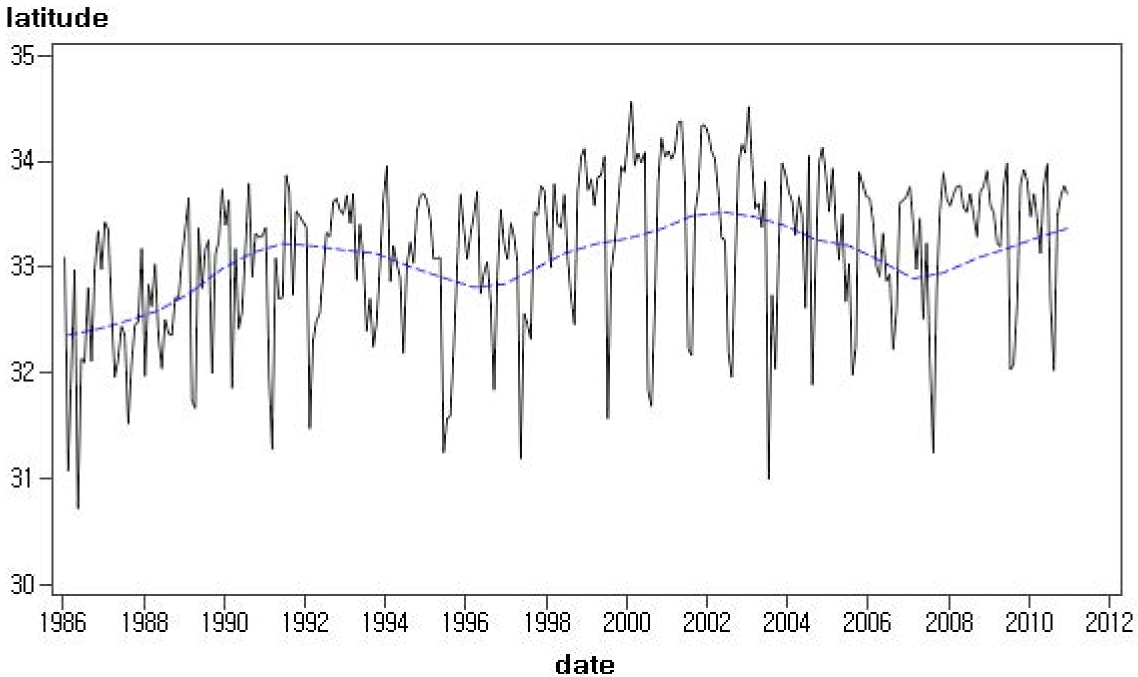


Hairtail

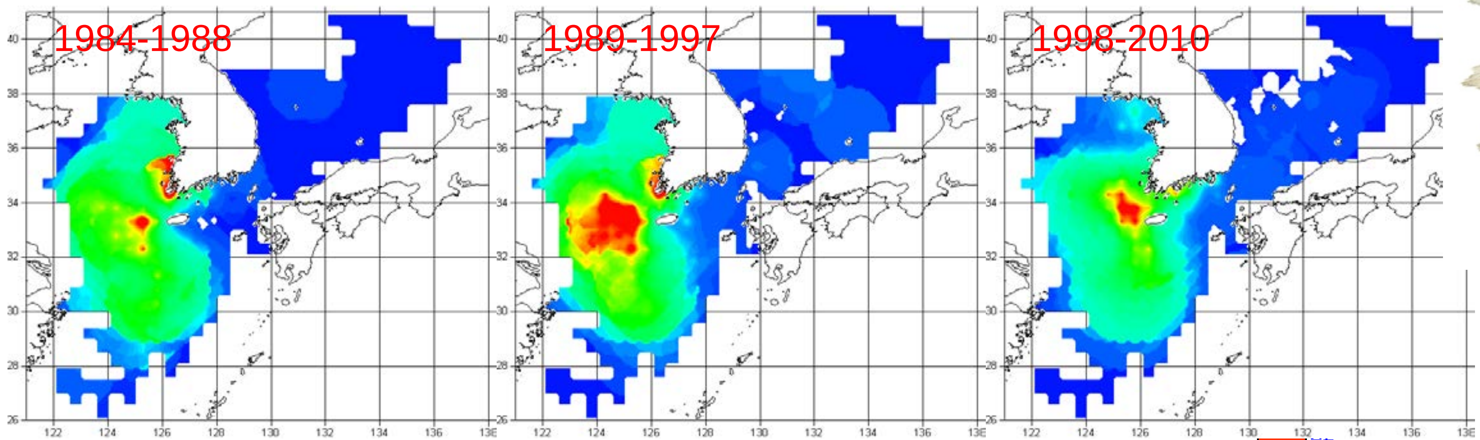


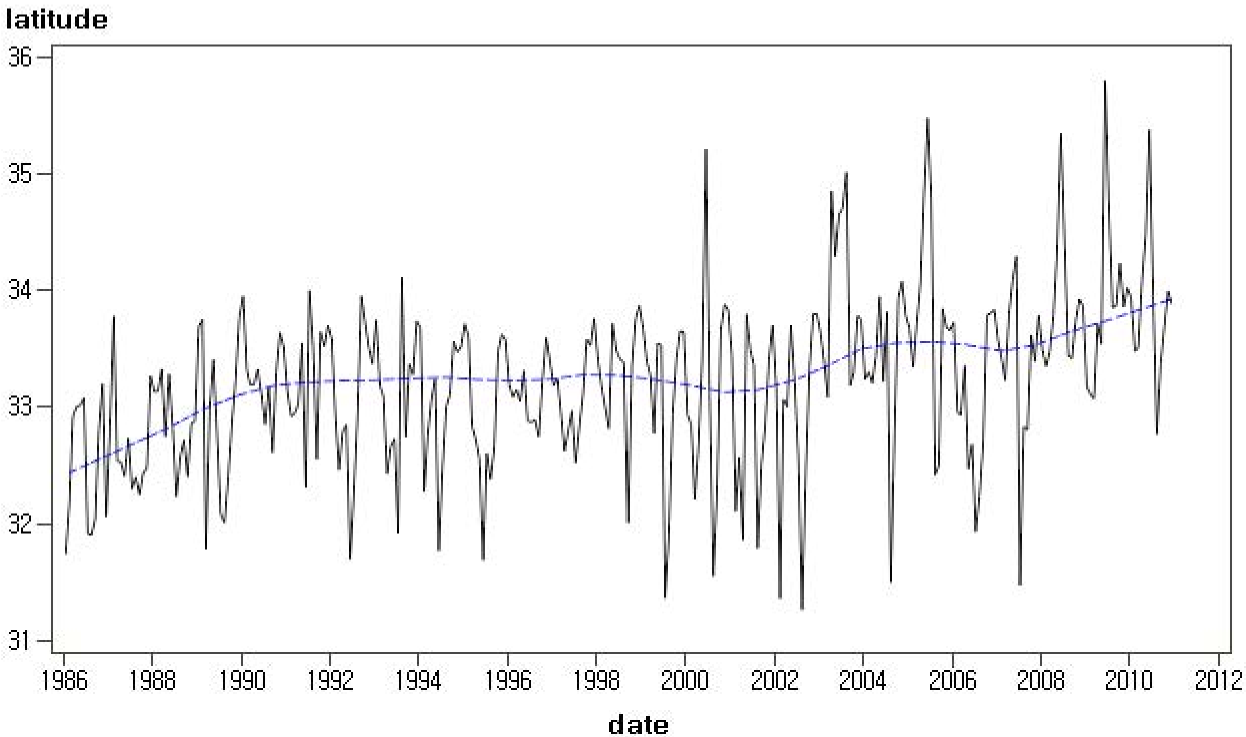


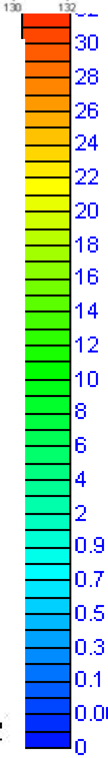
kg km^{-2}



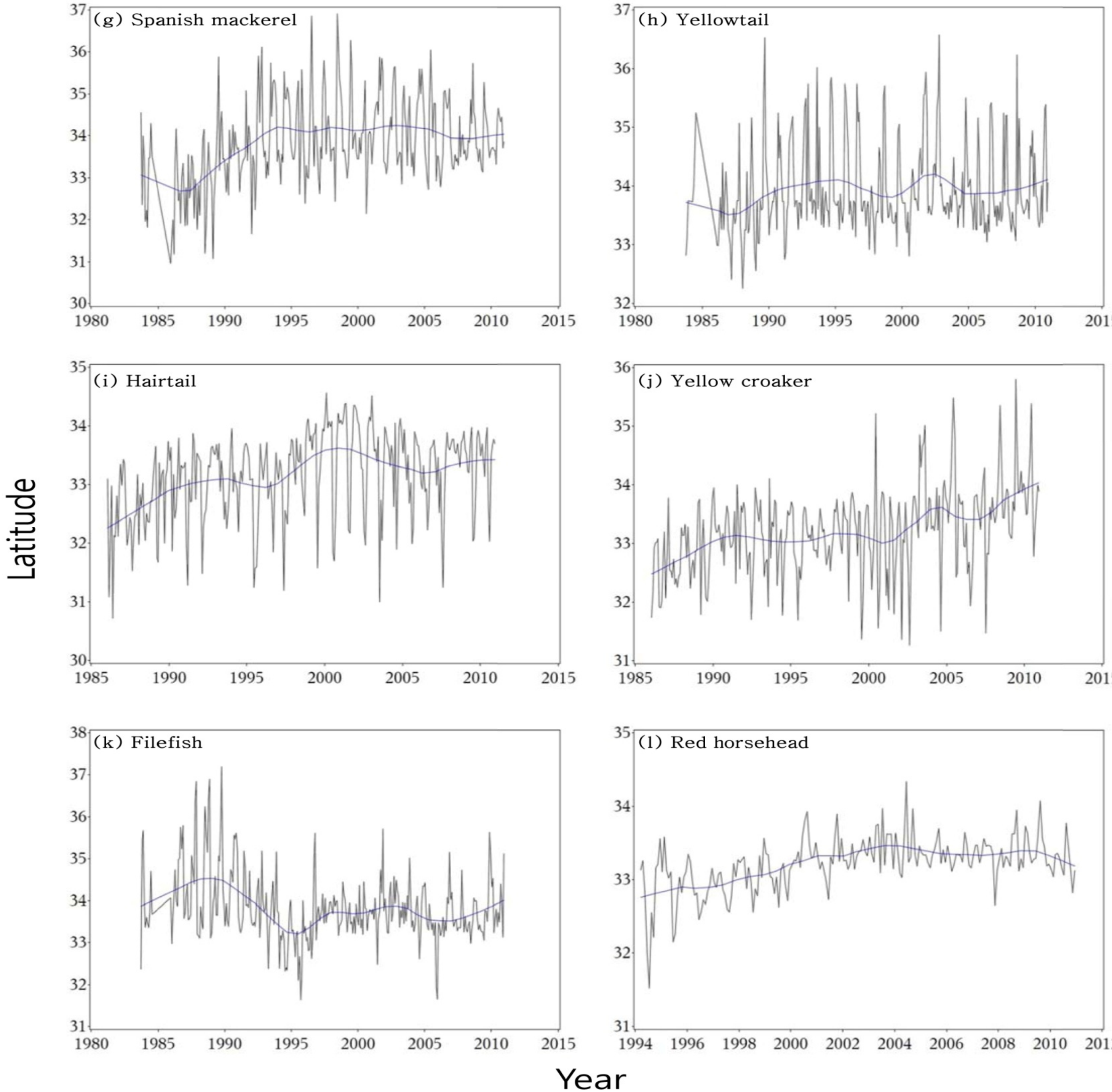
Small yellow croaker







κg km^{-2}


(g) Spanish mackerel
(h) Yellowtail
(i) Hairtail
(j) Yellow croaker
(k) Filefish
(l) Red horsehead
Latitude
Year

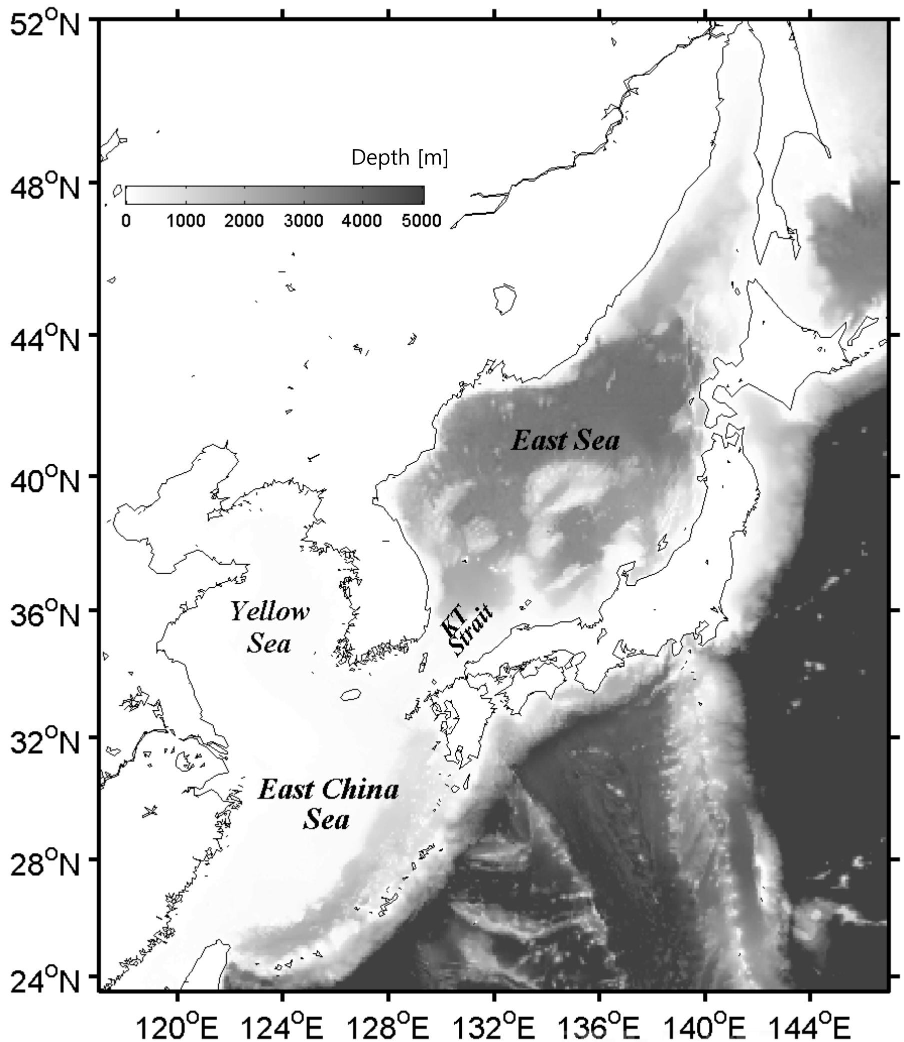
Statistically significant regression coefficients between depth-specific, water temperatures in the Korea Strait and the mean latitudes of 12 fish species 1984 to 2010

Fish/Depth (m)	0	10	20	30	50	75	100
Anchovy	-0.11	-0.13	-0.11	-0.09	-0.09		
Chub mackerel							
Horse mackerel	0.11	0.14	0.12	0.08	0.11	0.13	
Pacific herring							
Pacific sardine				0.09		0.23	0.23
Common squid	0.24	0.29	0.23	0.17	0.21		
Spanish mackerel	0.41						
Yellowtail	0.22						
Hairtail							
Yellow croaker							
Filefish							
Red horsehead							

Projections for the 2030s

- Emission Scenario
  - IPCC AR4 SRES A1B
- Oceanographic model
  - ROMS (Regional Ocean Modeling Systems)
- Fish model
  - Empirical relationships (regression analysis)
  - Individual-based model

✓North Western Pacific Model domain and description



✓ROMS 3.4 (Regional Ocean Modeling Systems)

✓North Western Pacific (117~147°E, 23.5~52°N)

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

✓Initial & lateral boundary conditions:
-Global ECCO2(Estimating the Circulation & Climate of the Ocean Version 2) model (~25km)
- Monthly mean values at boundaries (2000~2009)

✓Atmospheric forcing: QuikSCAT 0.5° daily 10m-wind
NCEP daily data (2000~2009)

✓Surface flux: Bulk formulation

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

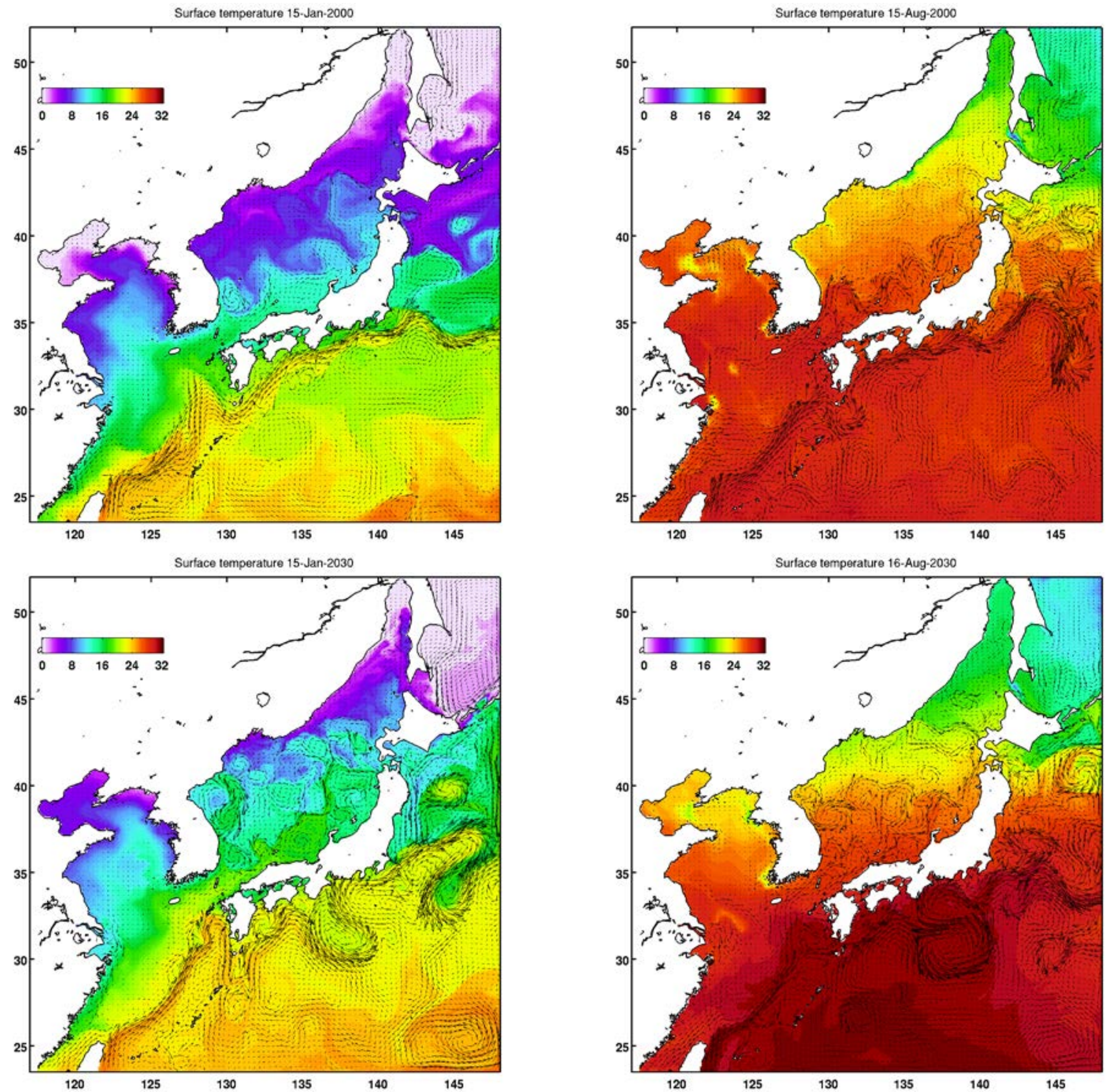
✓Tidal forcing : 10 constituents from Global tidal model (TPXO6)

Sea surface temperatures hindcasted and projected by ROMS for 2000 and 2030.

Winter | Summer

2000

2030



Depth-specific mean temperature (°C) of the Korea Strait predicted for 2000s and projected for 2030s based on IPCC A1B scenario by the general circulation model and observed for 1968-2010.

Depth (m)	2000-2009 (A)	2030-2039 (B)	(B – A)	Rate (°C yr^{-1}) (C)	Observed rate (1968-2010) (°C yr^{-1}) (D)	Factor (C ÷ D)
1	19.18	20.75	1.57	0.052	0.024	2.2
10	18.20	19.75	1.55	0.052	0.024	2.2
20	17.17	19.50	2.33	0.078	0.016	4.9
30	16.51	19.52	3.01	0.100	0.014	7.2
50	16.13	19.59	3.46	0.115	0.006	19.2
75	16.12	19.72	3.60	0.120	0.008	15.0

Projected poleward latitudinal shift of fish species from the 2000s to the 2030s based on the IPCC A1B scenario

Fish	Predictor depth	Regression coefficient (degree $^{o}C^{-1}$)	Projected temperature change (^{o}C)	Projected poleward shift (km)
Anchovy	10 m	-0.13	1.55	-23
Horse mackerel	30 m	0.08	3.01	26
Pacific sardine	75 m	0.05	3.60	19
Common squid	10 m	0.29	1.55	50
Spanish mackerel	1 m	0.41	1.57	71
Yellowtail	1 m	0.22	1.57	39

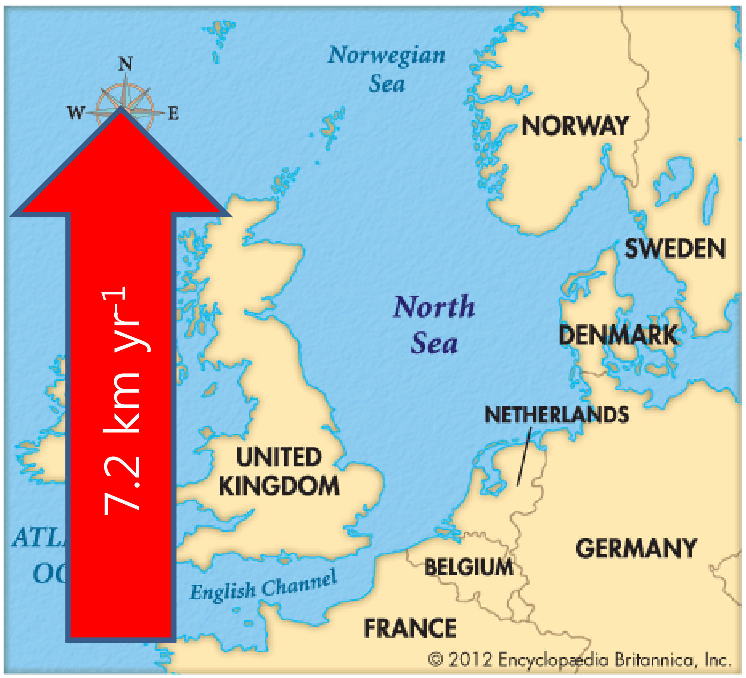
Summary of latitudinal shifts of fishes (1983-2010)

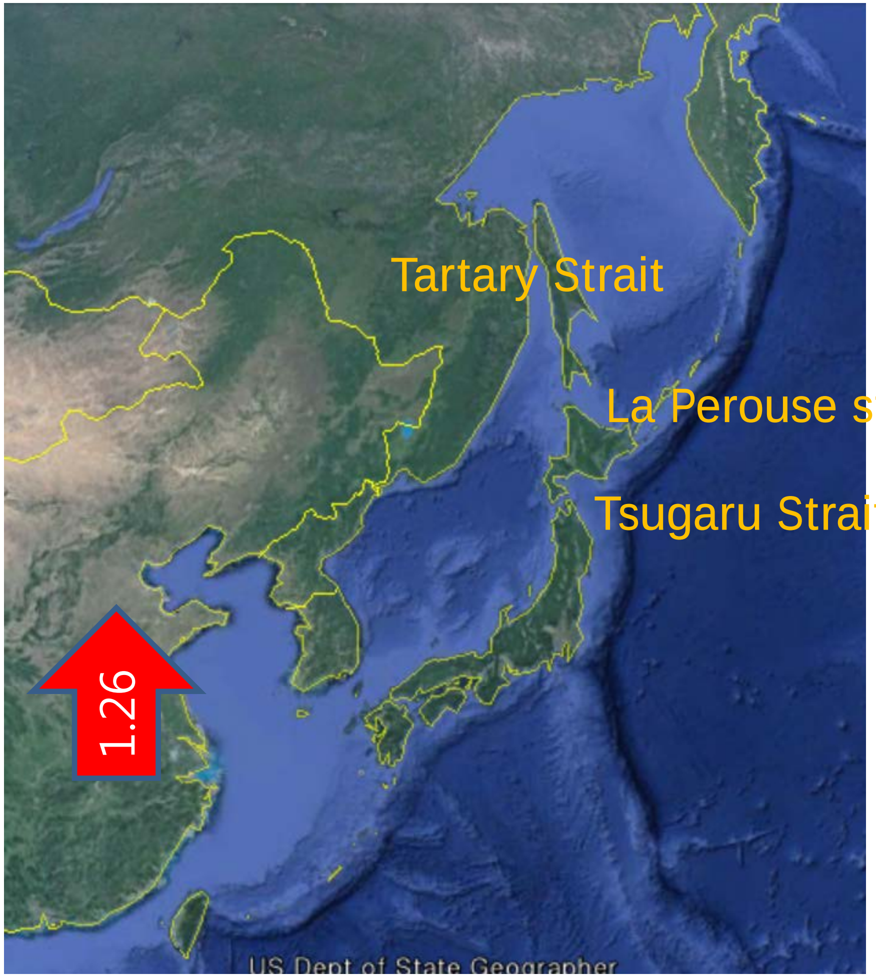
- Large pelagic species are the most sensitive to water temperature
  - Tuna, Yellowtail, Spanish mackerel
  - Northward shift

Comparisons with other regions

Region	Poleward moving speed (km yr-1)	
	Range	Average or Median
Global (Cheung et al. 2009)	4.5-5.9	5.2
North Sea (Perry et al. 2005)	2.0-16.8	**7.2**
Northeast U.S.A (Nye et al. 2009)	1-8	2.94
North Sea (Jones et al. 2013)		2.7
Korea (Present study)	0.63-2.37	**1.26**

Geomorphology
(North Sea vs. western N. Pacific)





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RESEARCH PAPER

Latitudinal shifts in the distribution of exploited fishes in Korean waters during the last 30 years: a consequence of climate change

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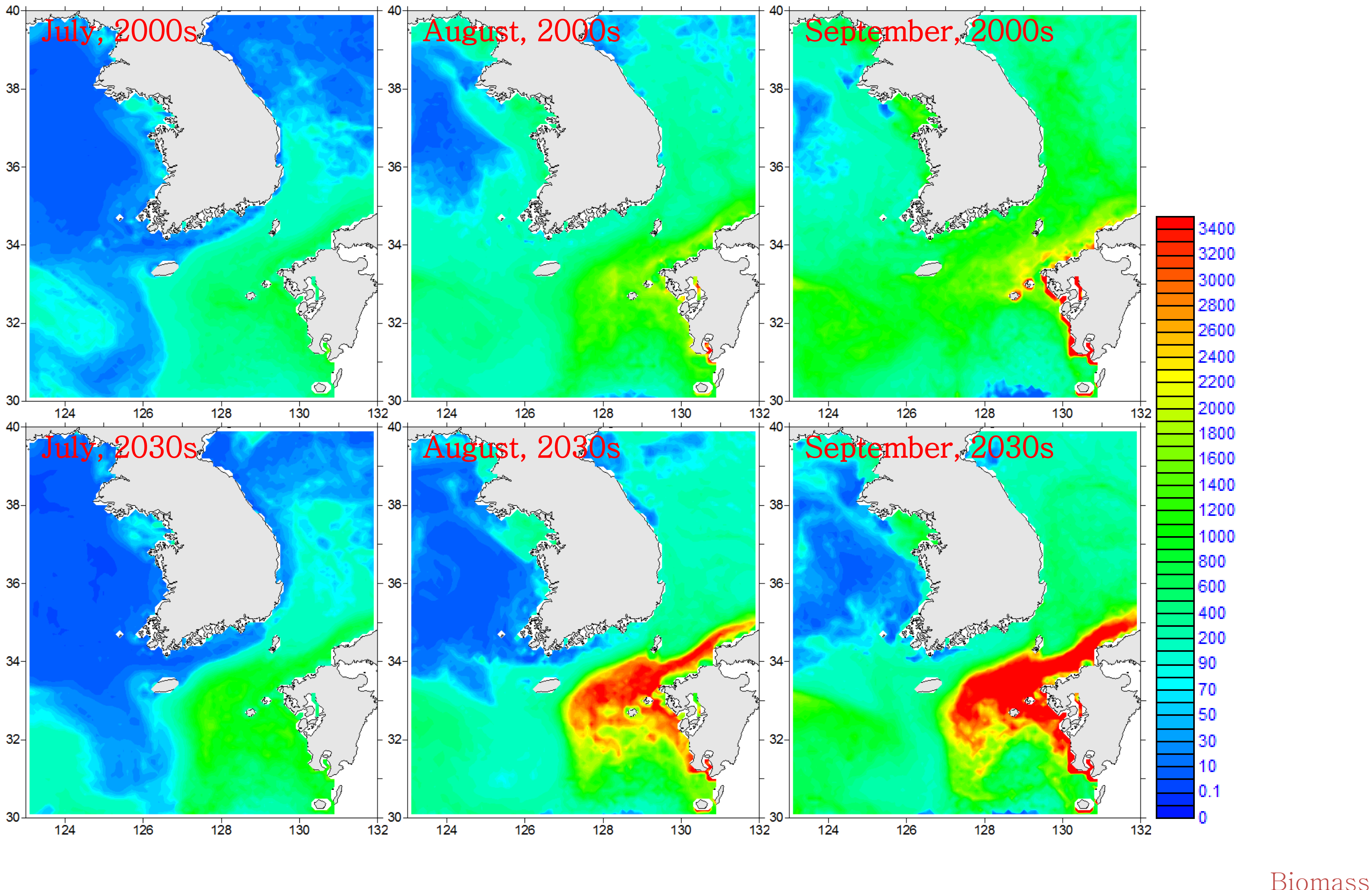
Abstract Sea surface temperatures in Korean waters have increased by approximately 1 °C during the past 40 years, implying possible range shifts of marine fishes and invertebrates. We analyzed spatially explicit, commercial catch data for 12 major fish our empirical relationships predicted that the ranges of five of the fish species examined will shift poleward by 19–71 km from the 2000s to the 2030s. Compared with studies of demersal fishes in the western North Atlantic and the North Sea, our estimated speeds of

Future work

- Reliable estimates of volume transports by the Tsushima Warm Current and the Korea Strait Cold Bottom Water
- IPCC AR5 Scenarios (RCP 2.7 vs. 8.5)
- Bio-physical coupling individual-based model

Modeled Biomass of anchovy larva < 180 day old
2000s vs. 2030s (Individual-based model and IPCC SRES A1B)



Implications to fisheries management adapting to climate change (tentative)

- **Small pelagic species**
  - Despite greater decadal variability in recruitment, they seem to be resilient to climate change.
  - Significant changes in habitat range are unlikely.
  - Minimize fisheries regulations (e.g., sardine)
- **Large pelagic species**
  - Ranges are sensitive to climate change
  - Long-term plans need to be developed to adapt fisheries to climate change and global warming (e.g., vessels equipped with freezers)

Implications 2

Artisanal vs. Industrial fisheries

- **Demersal/bentho-pelagic species**
  - Trends of shift are inconsistent among species.
  - Both artisanal and industrialized fisheries exploit these species.
    - Artisanal fisheries are the major provider of hairtail (ca. 300 million USD in 2010)
    - Industrialized fisheries are the major provider of yellow croaker (ca. 250 million USD in 2011)
  - Artisanal fisheries will be less competitive in adapting to range shifts of their target species

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