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Fish weight reduction in response to intra- and interspecies competition under climate change

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Lin and Ito (2024, Fish and Fisheries)

ORIGINAL ARTICLE | Open Access

Fish weight reduction in response to intra- and interspecies competition under climate change

Zhen Lin, Shin-ichi Ito

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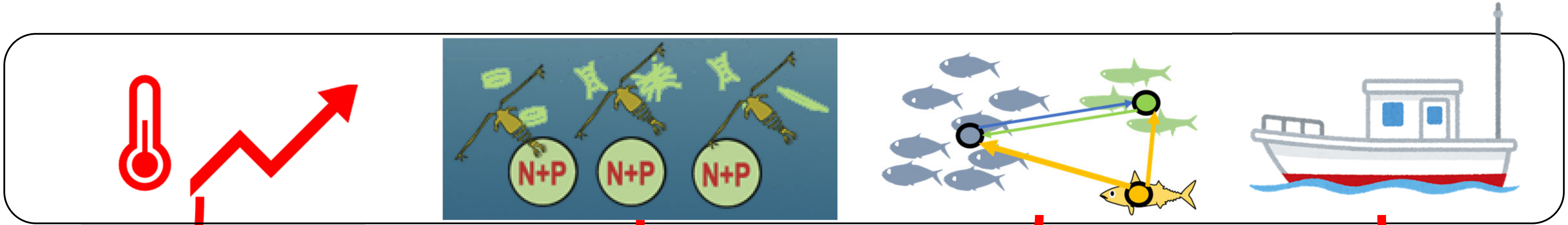
1. Possible mechanisms for fish size change



Temperature-size rule (Atkinson, 1996)

Prey production (Frederiksen et al., 2006)

Density effect Minto et al. (2008)

Fishing effect Bianchi et al. (2000)

Smaller

North Sea (Baudron et al., 2014)

West of Scotland (Ikpewe et al., 2021)

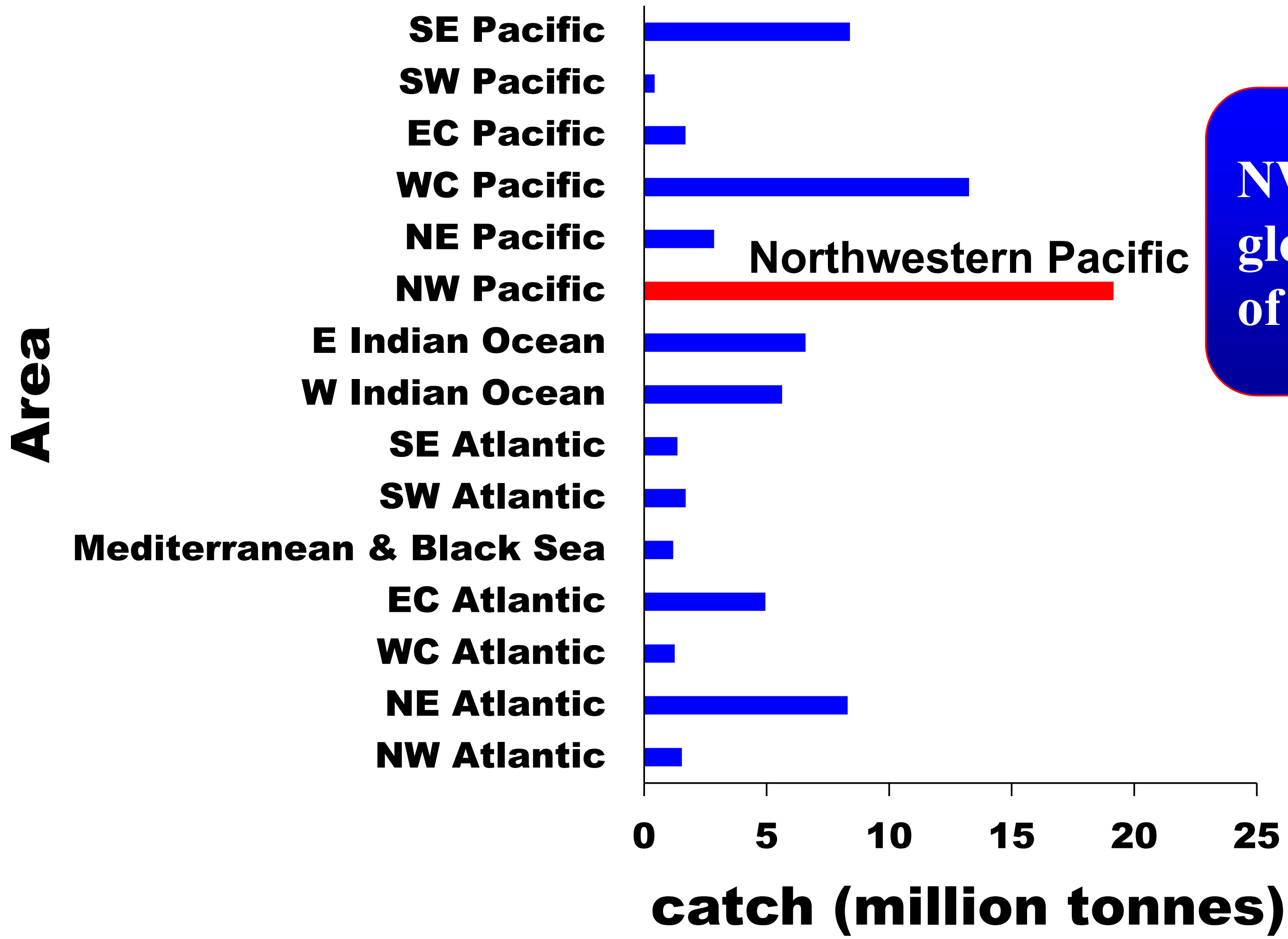
1/2 are bigger

Australian continents

(Audzijonyte et al., 2020)

We do not know which mechanism is dominant. Must analyze size change in unstudied area.

Northwestern Pacific

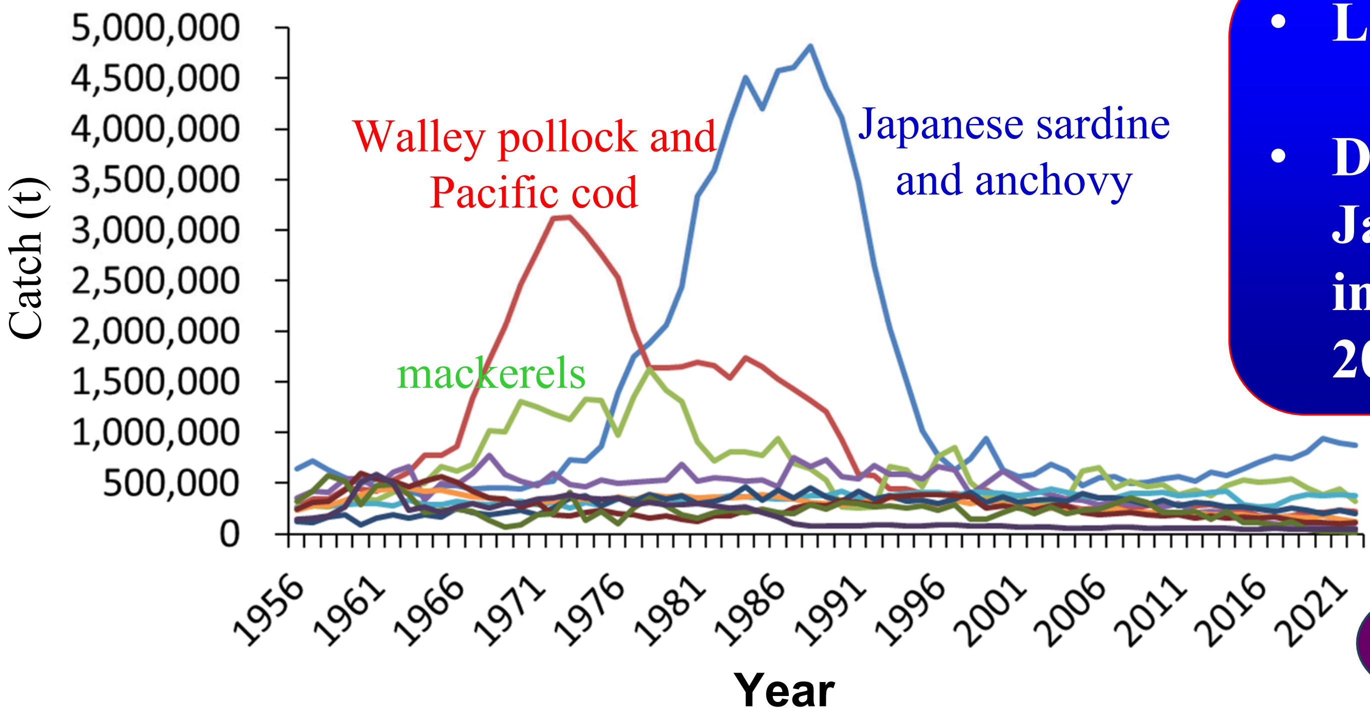


NW Pacific occupies 6% of the global ocean, but products 24% of catch in the world.

Very productive ocean

Data from FAO (2022)

Catch in Japan



Data: Ministry of Agriculture, Forestry, and Fisheries

- **Large fluctuation of stocks**
- **Density effects generated by Japanese sardine outbreak in 1980s (Tadokoro et al., 2005; Ito et al., 2007)**

Good testbed to compare drivers

Motivations

1. Temperature increase is higher in Northwestern Pacific.
   ⇒Whether temperature-size rule dominates or not?

2. Intra- and inter-species competition induced by Japanese sardine was reported (Tadokoro et al., 2005; Ito et al., 2007)
   ⇒Which is more important: density effect or temperature-size rule?

Objectives

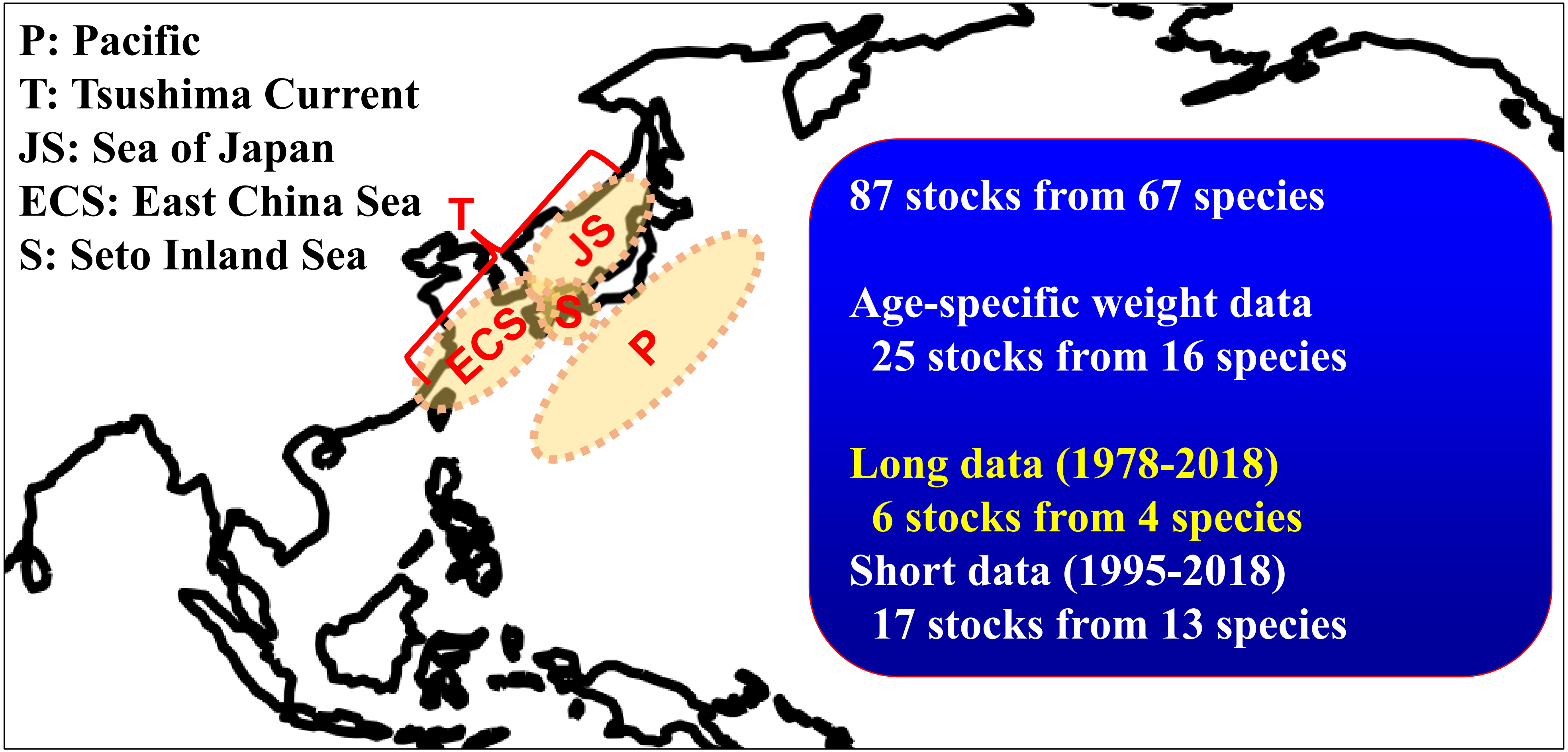
1. Describe the fish size change around Japan

2. Determine the main drivers of fish size change

2. Data mining

Fish stock assessment reports

(Fisheries Agency, Fisheries Research and Education Agency, 2021)



P: Pacific
T: Tsushima Current
JS: Sea of Japan
ECS: East China Sea
S: Seto Inland Sea

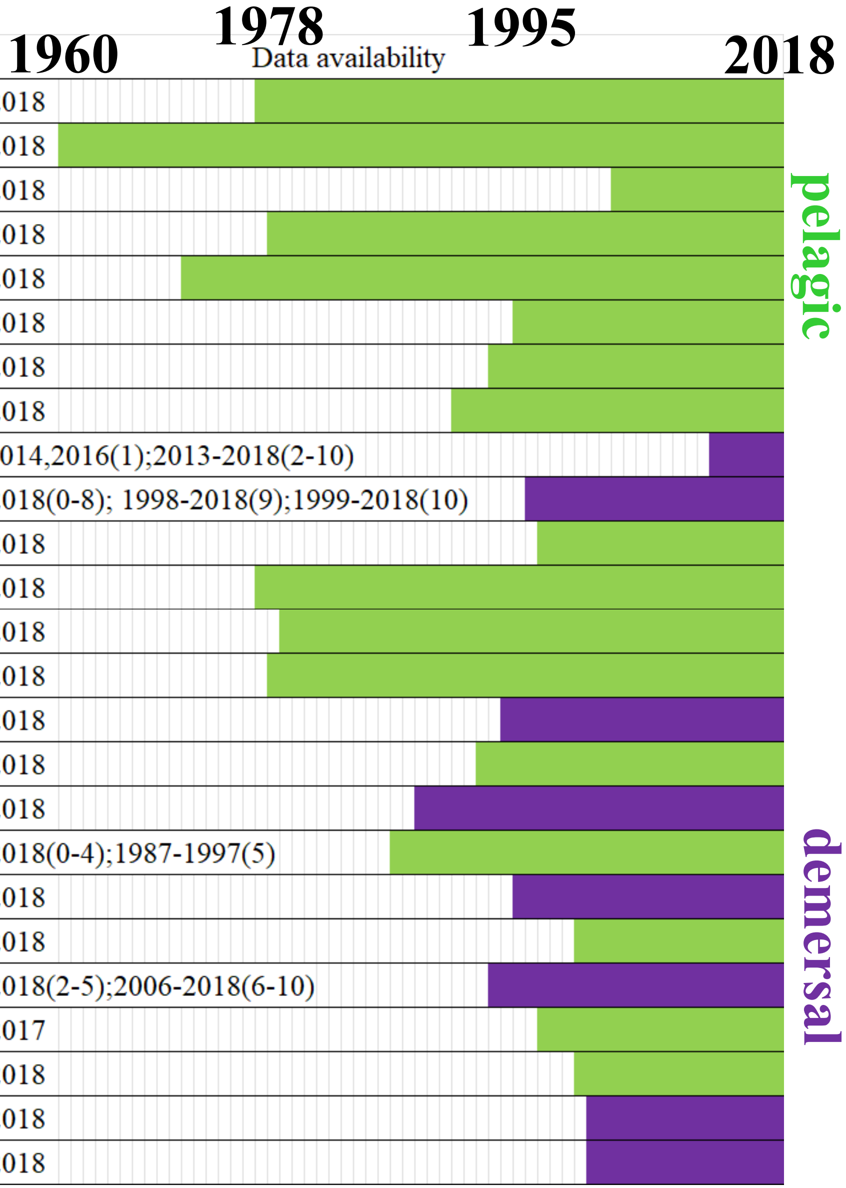
87 stocks from 67 species

Age-specific weight data
25 stocks from 16 species

Long data (1978-2018)
6 stocks from 4 species
Short data (1995-2018)
17 stocks from 13 species

Data availability

ID	Name	Species	Population	Age	Data availability
1	**sardine** Japanese sardine	*Sardinops melanostictus*	Pacific	0-5	1976-2018
2			Tsushima	0-5	1960-2018
3	Japanese jack mackerel	*Trachurus japonicus*	Pacific	0-3	2005-2018
4			Tsushima	0-3	1997-2018
5	**mackerel** chub mackerel	*Scomber japonicus*	Pacific	0-6	1970-2018
6			Tsushima	0-3	1997-2018
7	blue mackerel	*Scomber australasicus*	Pacific	0-4	1995-2018
8			East China Sea	0-3	1992-2018
9	walleye pollock	*Theragra chalcogramma*	Sea of Japan	1-10	2013,2014,2016(1);2013-2018(2-10)
10			Pacific	0-10	1998-2018(0-8); 1998-2018(9);1999-2018(10)
11	**round herring** round herring	*Etrumeus micropus*	Pacific	0-1	1999-2018
12			Tsushima	0-2	1976-2018
13	**anchovy** Japanese anchovy	*Engraulis japonicus*	Pacific	0-3	1978-2018
14			Tsushima	0-2	1977-2018
15	Pacific cod	*Gadus macrocephalus*	Pacific North	1-6	1996-2018
16	Japanese yellowtail	*Seriola quinqueradiata*	Japan	0-3	1994-2018
17	western sand lance	*Ammodytes japonicus*	Seto Inland Sea East	0	1989-2018
18	Japanese Spanish mackerel	*Scomberomorus niphonius*	Seto Inland Sea	0-5	1987-2018(0-4);1987-1997(5)
19	pointhead flounder	*Hippoglossoides pinetorum*	Sea of Japan	1-4	1997-2018
20	Japanese pufferfish	*Takifugu rubripes*	Tsushima	0-4	2002-2018
21	Kichiji rockfish	*Sebastolobus macrochir*	Pacific North	2-10	1995-2018(2-5);2006-2018(6-10)
22	red seabream	*Pagrus major*	Pacific Central	0-6	1999-2017
23			Pacific South	0-5	2002-2018
24	olive flounder	*Paralichthys olivaceus*	Pacific South	0-6	2001-2018
25			Pacific Central	0-6	2001-2018



Data preparation

- Body weight was standardized.
- Standardized weight was averaged to three life stages based on proportion of maturation (M) because responses to "temperature-size-rule" possibly depends on life stages.

Standardized age-specific body weight data (z-score)

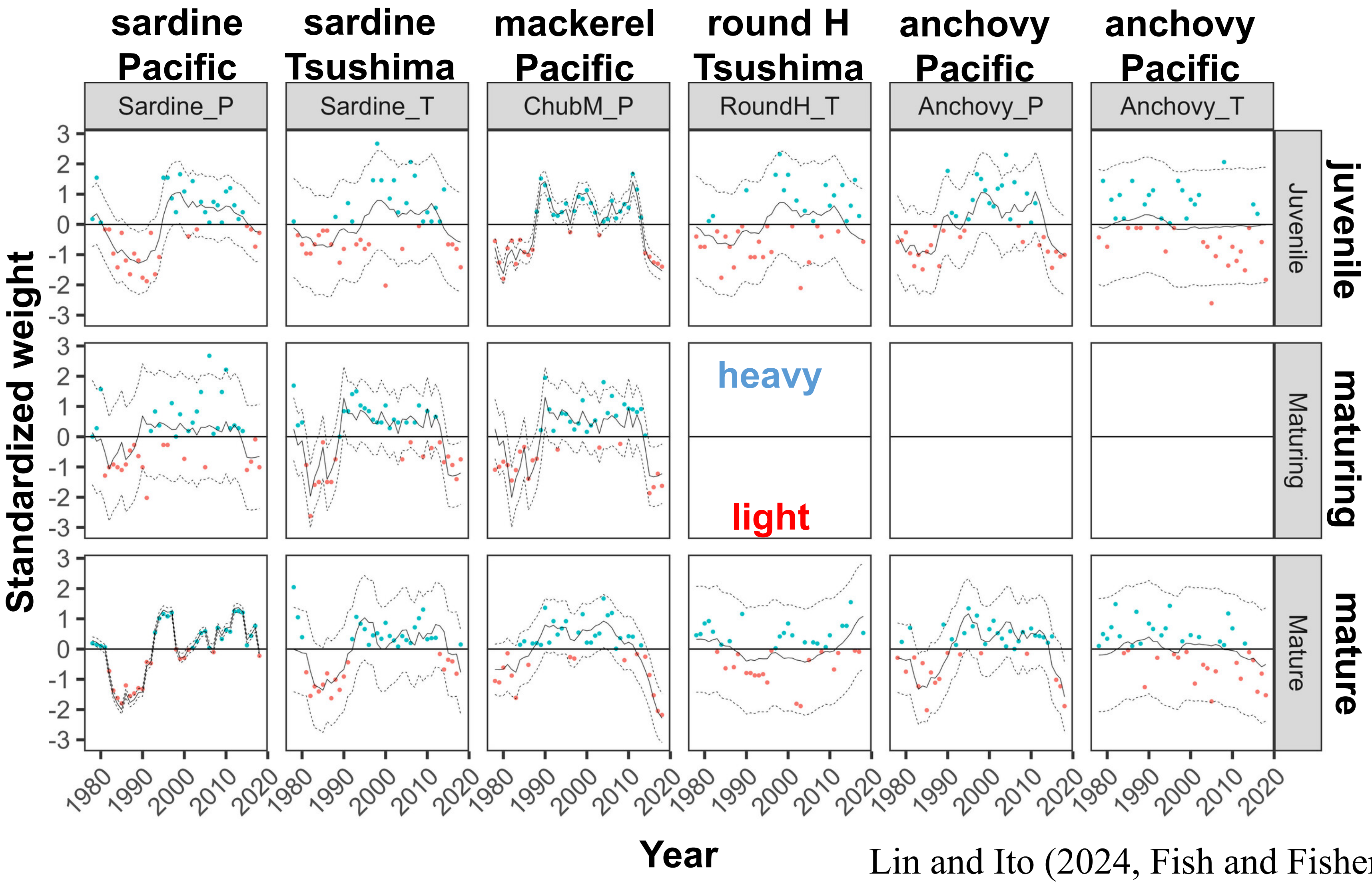
Definition of life stages

- juvenile: $0 \leq M < 20\%$
- maturing: $20 \leq M < 80\%$
- mature: $80 \leq M \leq 100\%$

M: proportion of maturation

Average standardized age-specific body weight for each life stage.

Long-term variability of standardized body weight



Lin and Ito (2024, Fish and Fisheries)

Many stocks showed weight reduction in 1980s and 2010s.

All juvenile, maturing and mature showed the reduction.

3. Common trend
Dynamic Factor Analysis (DFA)

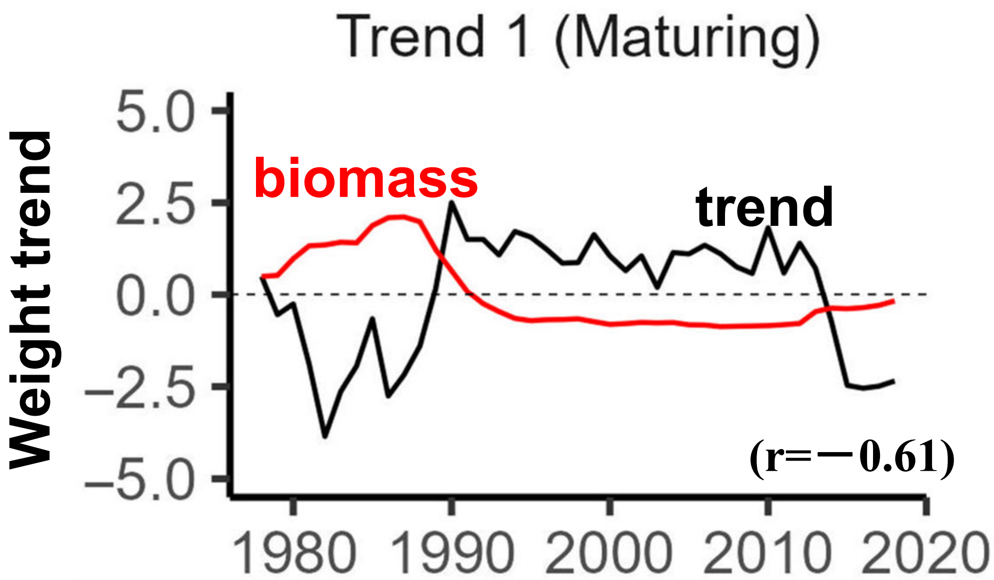
Data series = **Factor loadings** * **Trends** + **offset** + **Noise**

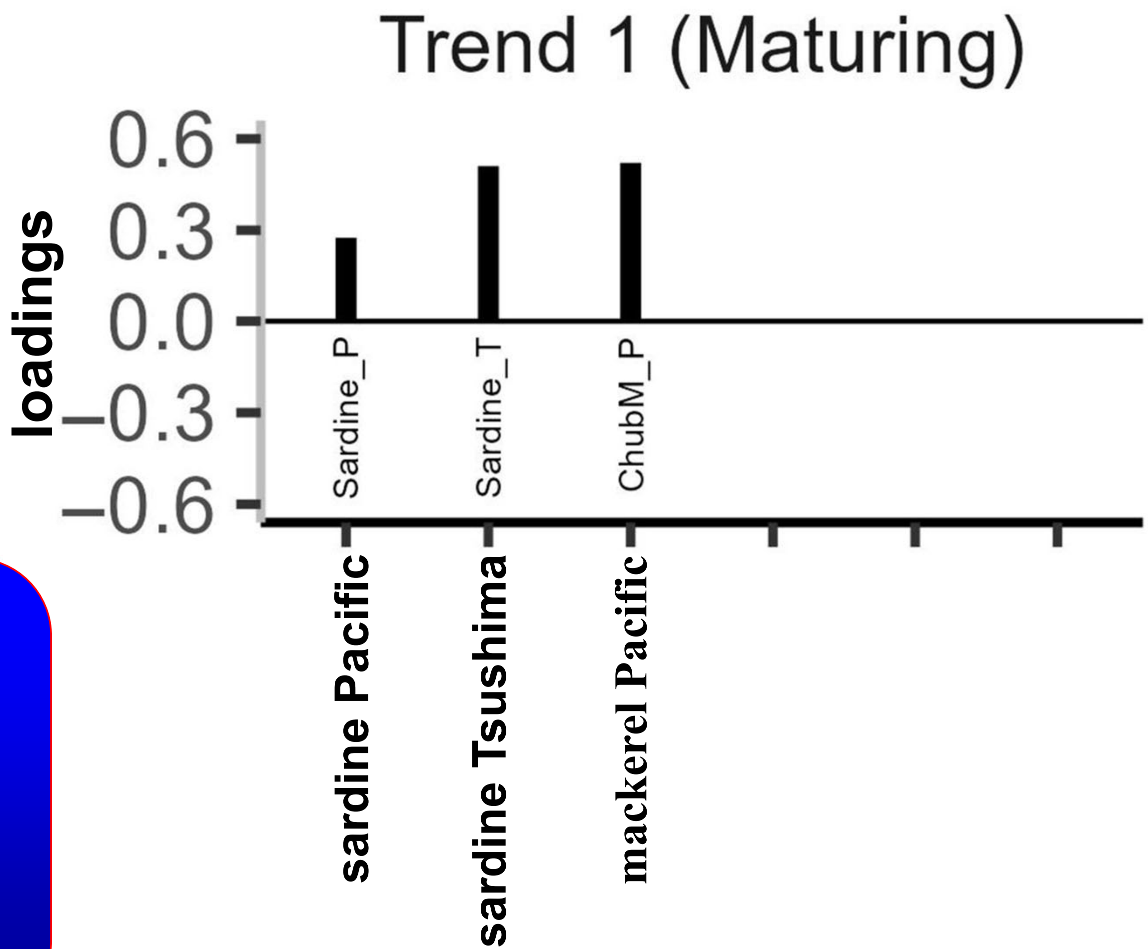
$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \cdots \\ y_{i-1} \\ y_i \end{bmatrix}_t = \boldsymbol{Z}_{i*j} * \begin{bmatrix} x_{trend1} \\ x_{trend2} \\ \cdots \\ x_{trend\,j} \end{bmatrix}_t + \alpha_i + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \cdots \\ \varepsilon_{i-1} \\ \varepsilon_i \end{bmatrix}_t$$

- i: Stock, t: Year
- $\varepsilon_{i,t}$: Noise $\sim \mathrm{MVN}(0, R)$ with R being the error covariance matrix

Detect common trend
(represent longer timescale and wider spatial-scale)

Weight trend of maturing



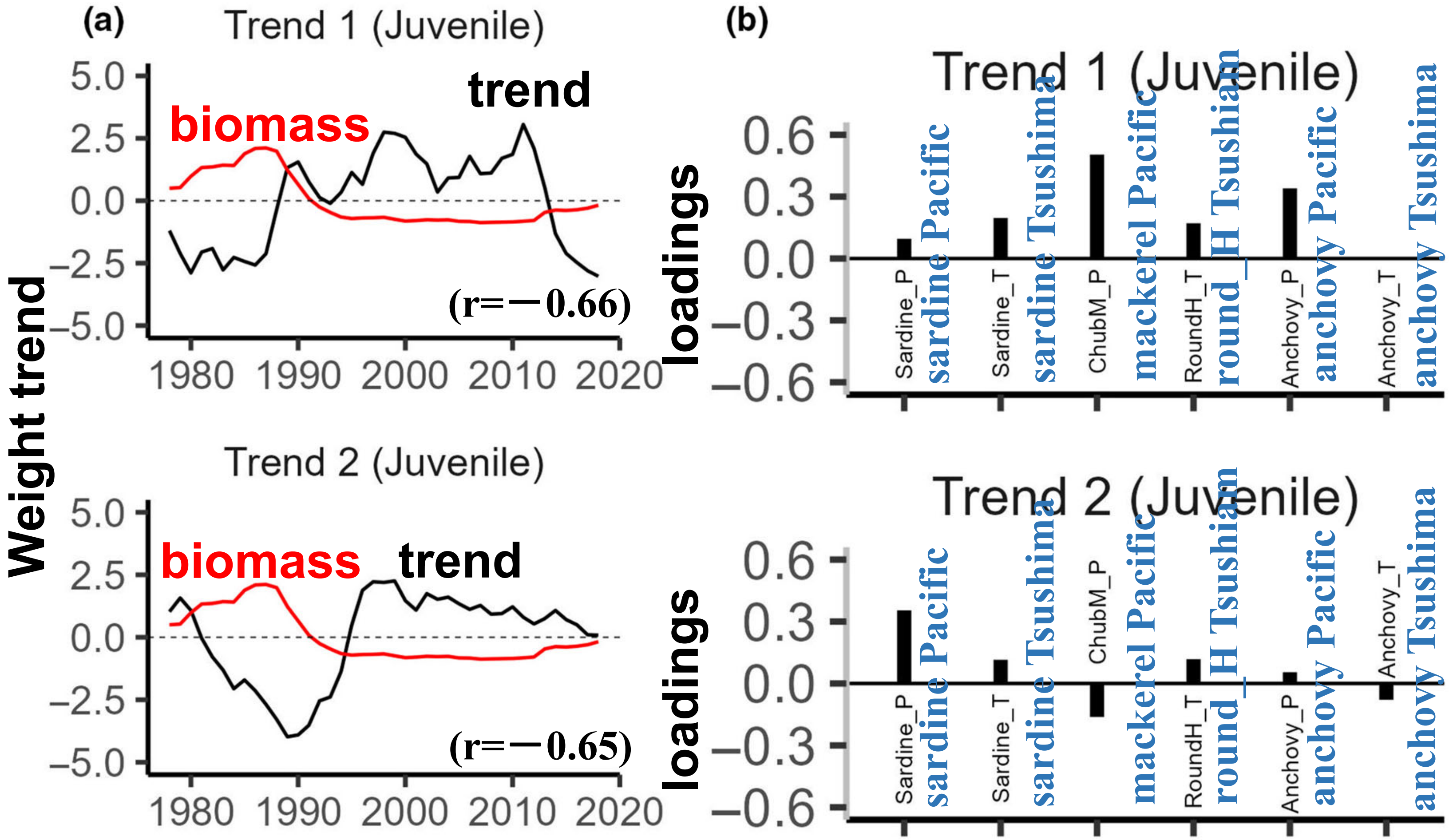


- weight reduction in 1980s and 2010s.
- 1980s corresponds to the outbreak of sardine in 1980s. =>density effect

biomass: summed biomass of sardine, mackerel and anchovy

Lin and Ito (2024, Fish and Fisheries)

Weight trend of juvenile

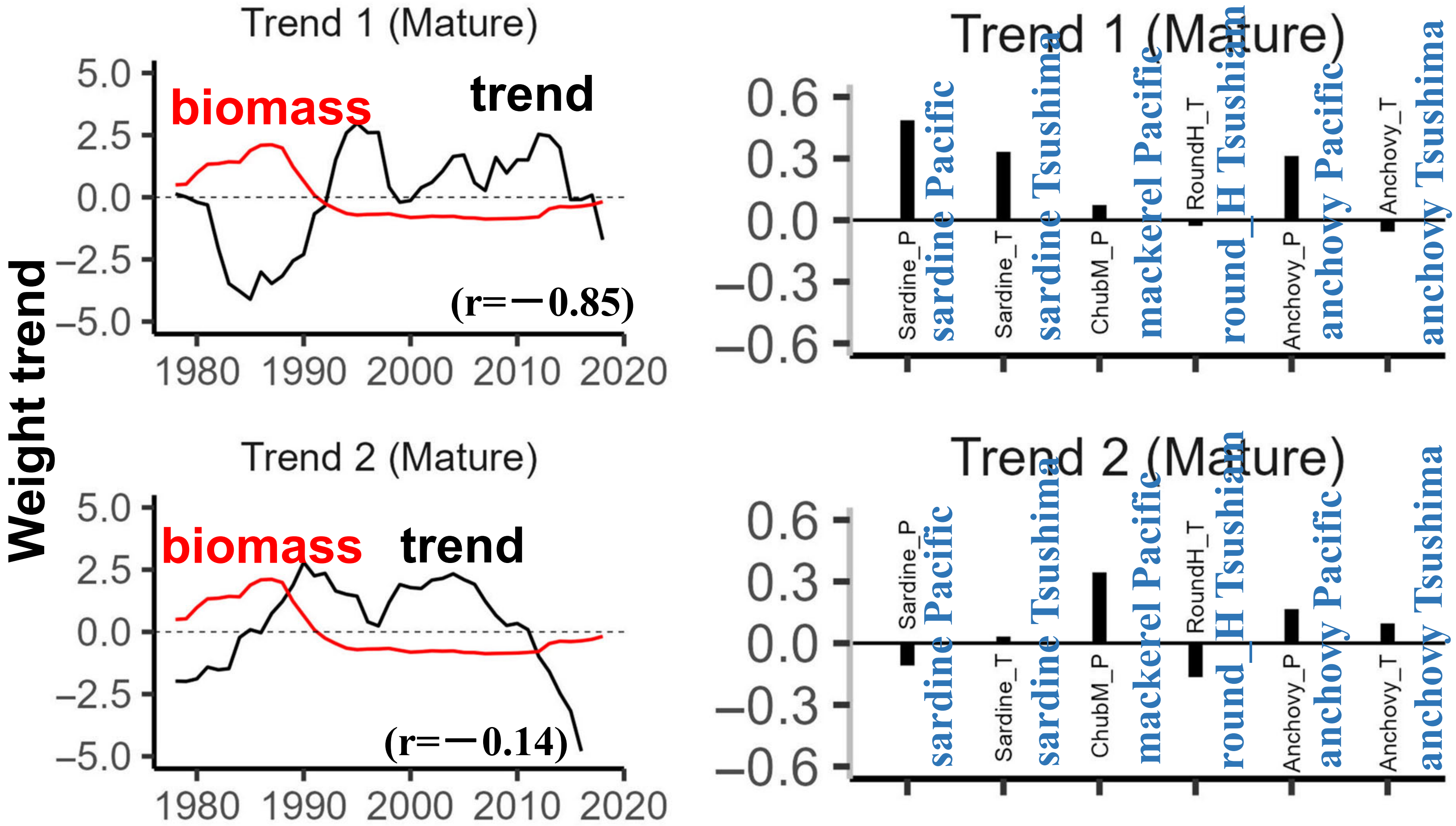


Lin and Ito (2024, Fish and Fisheries)

Trend showed weight reduction in 1980s and 2010s.

1980s corresponds to the outbreak of sardine in 1980s. (weight decrease in sardine continued until 1990s)

Weight trend of Mature



Lin and Ito (2024, Fish and Fisheries)

Trend showed weight reduction in 1980s and 2010s.

1980s corresponds to the outbreak of sardine in 1980s. (weight decrease in sardine continued until 1990s)

The biomass in 2010s was not extremely high.

The outbreak of sardine seems to influence the long-term weight tends

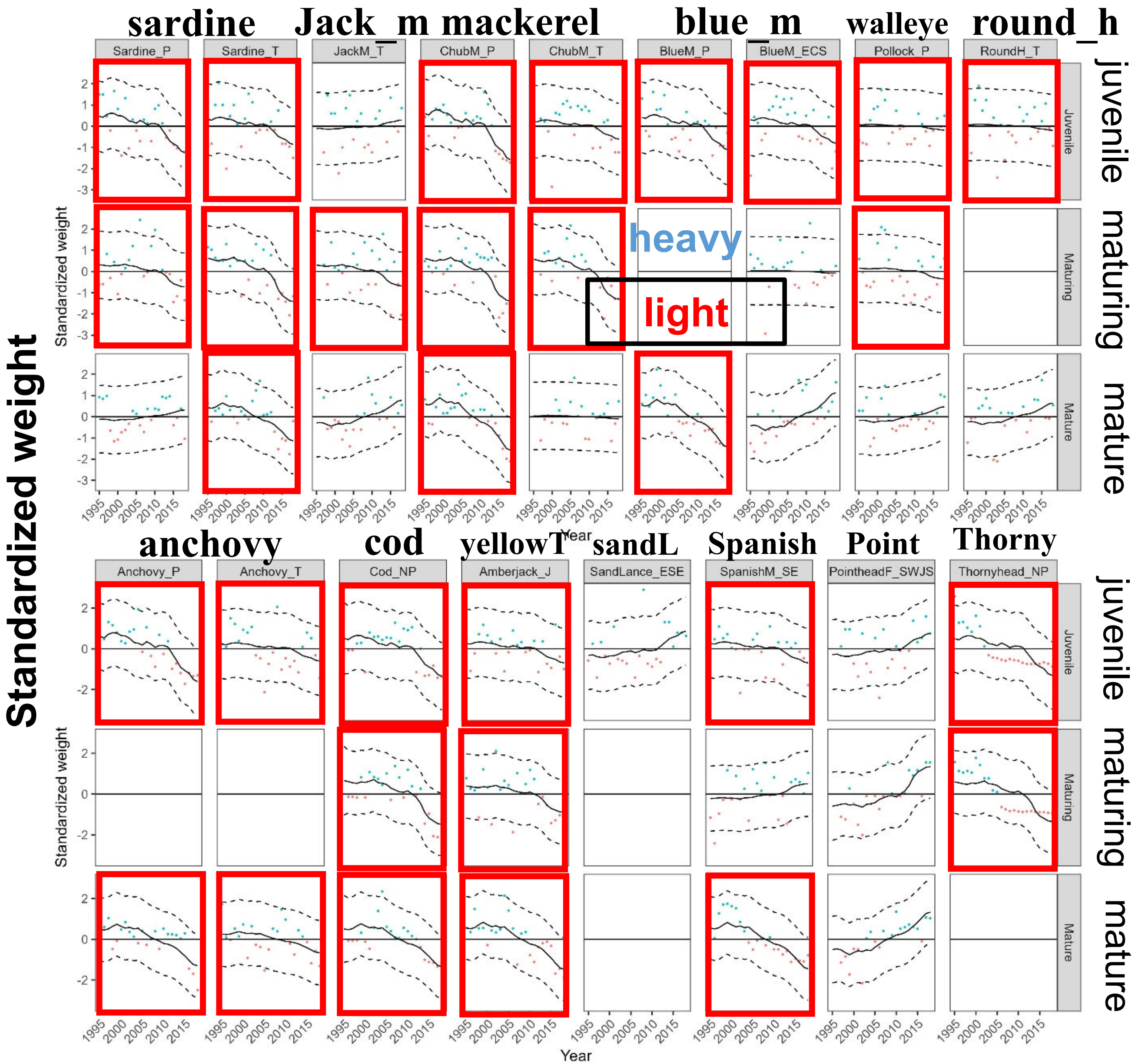
[density effect]

obvious in 1980s

questionable in 2010s

↓

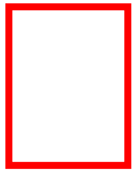
Check the weight change in 2010s with more stocks (shorter time-series)



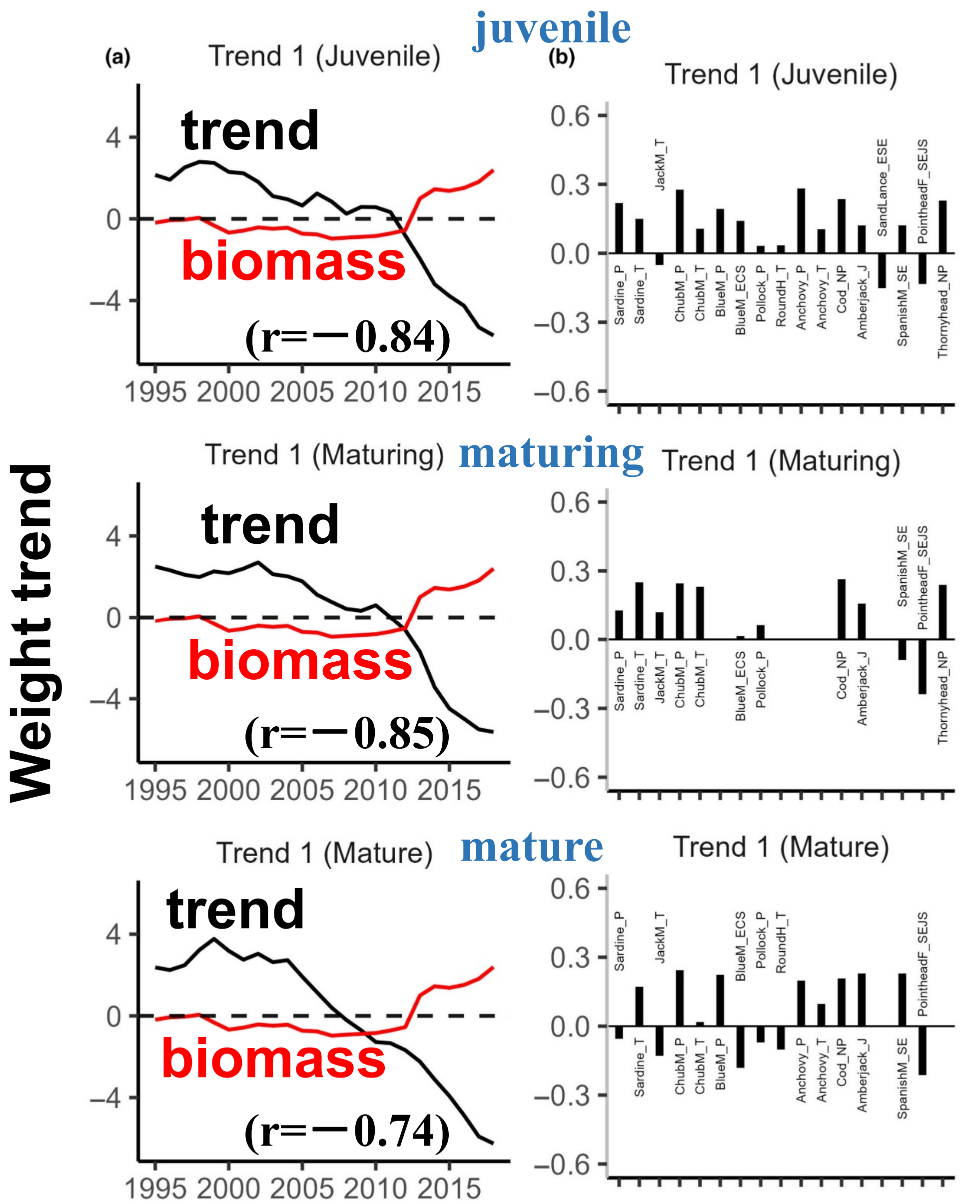
Shorter time-series

Many stocks showed weight reduction in 2010s.

All juvenile, maturing and mature showed the reduction.



Lin and Ito (2024, Fish and Fisheries)



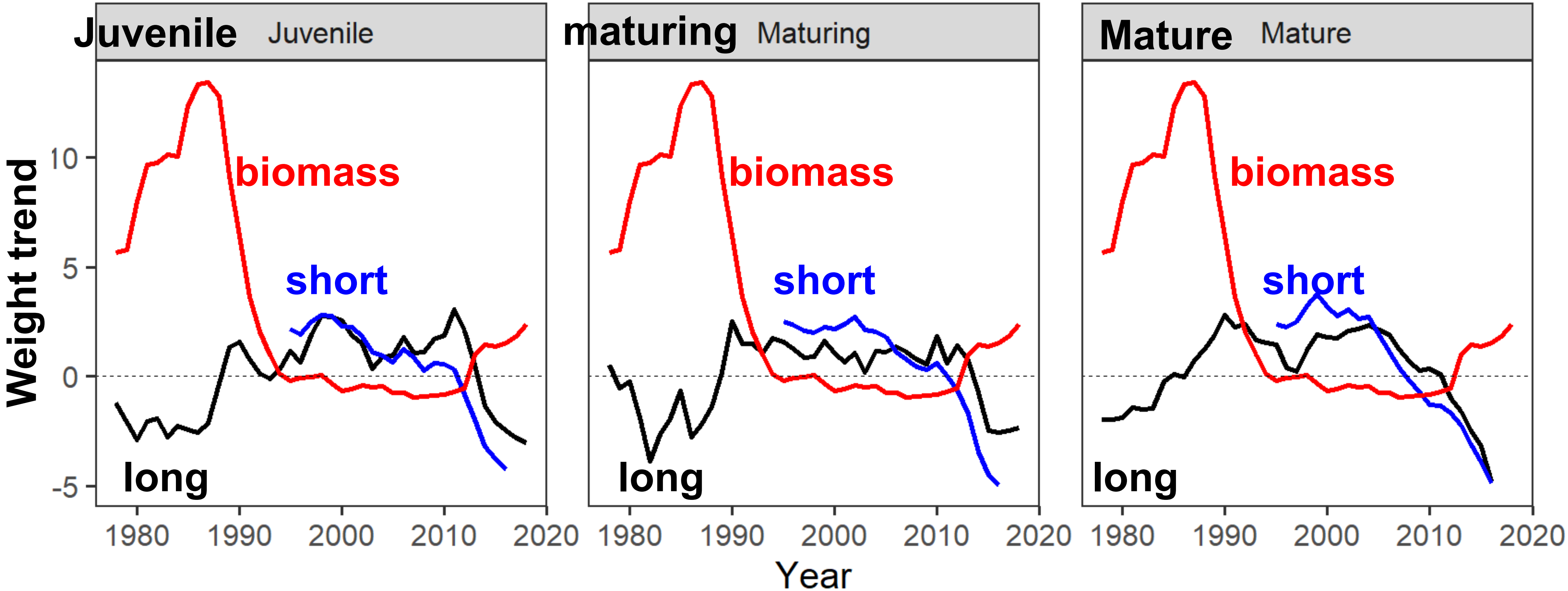
Trends in shorter time-series

Even for 17 stocks in 13 species, the common trend showed weight reduction in 2010s.

Significant negative correlation with biomass was detected.
=> density effect?

Lin and Ito (2024, Fish and Fisheries)

Longer vs Shorter time-series



The decrease trend is common between longer and shorter time-series.
Weight trend 1980s < 2010s
biomass 1980s>2010s :contradiction

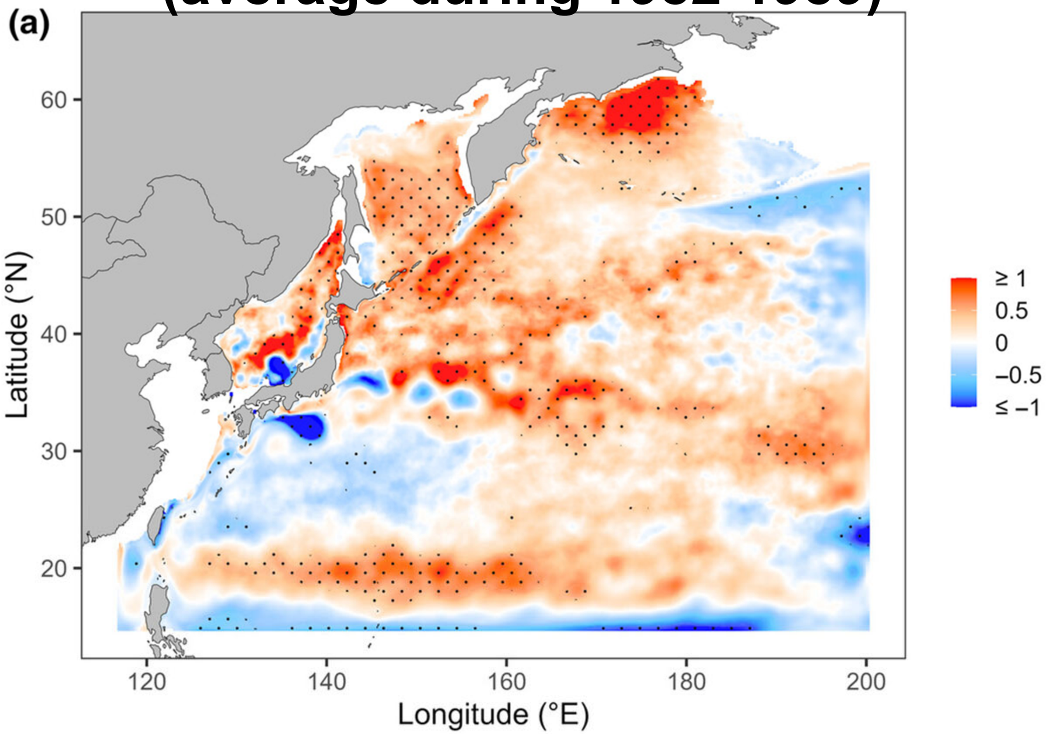
Lin and Ito (2024, Fish and Fisheries)

Investigated possible reason

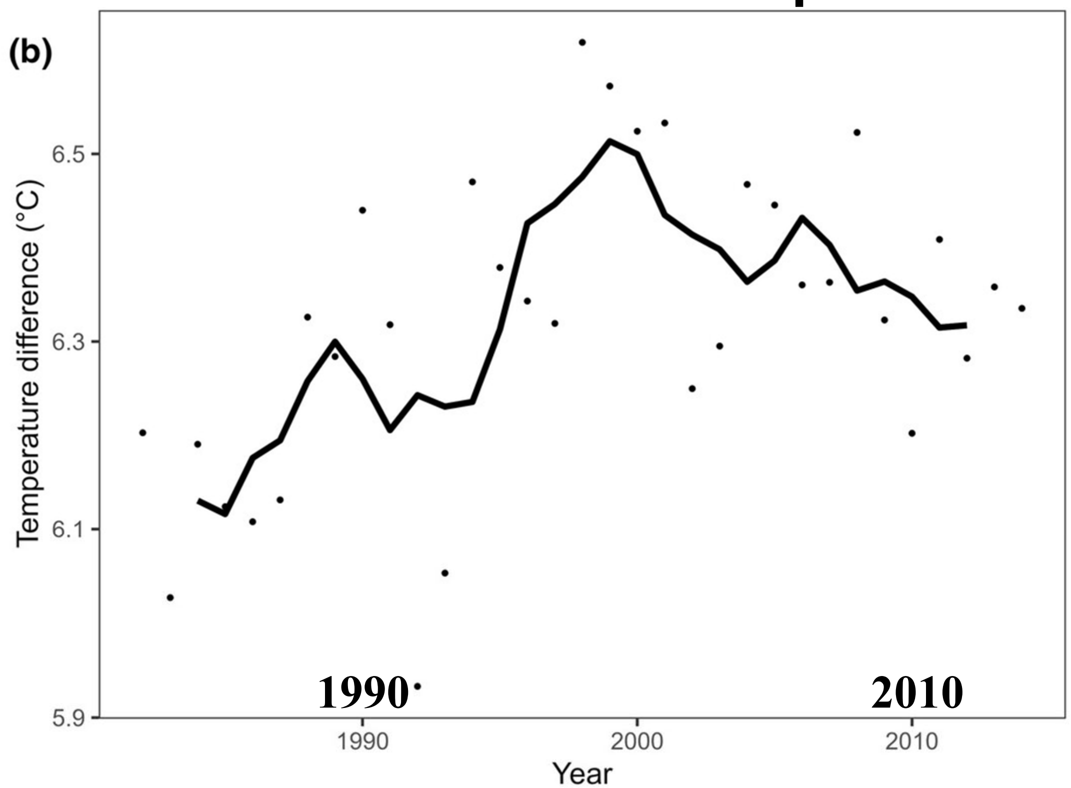
Mixed layer depth
Wind stress
Kinetic eddy activity
Chl-a
Fishing
Etc.
Vertical temperature difference

Vertical temperature difference between surface and 200m

(average during 2007-2014)
− (average during 1982-1989)



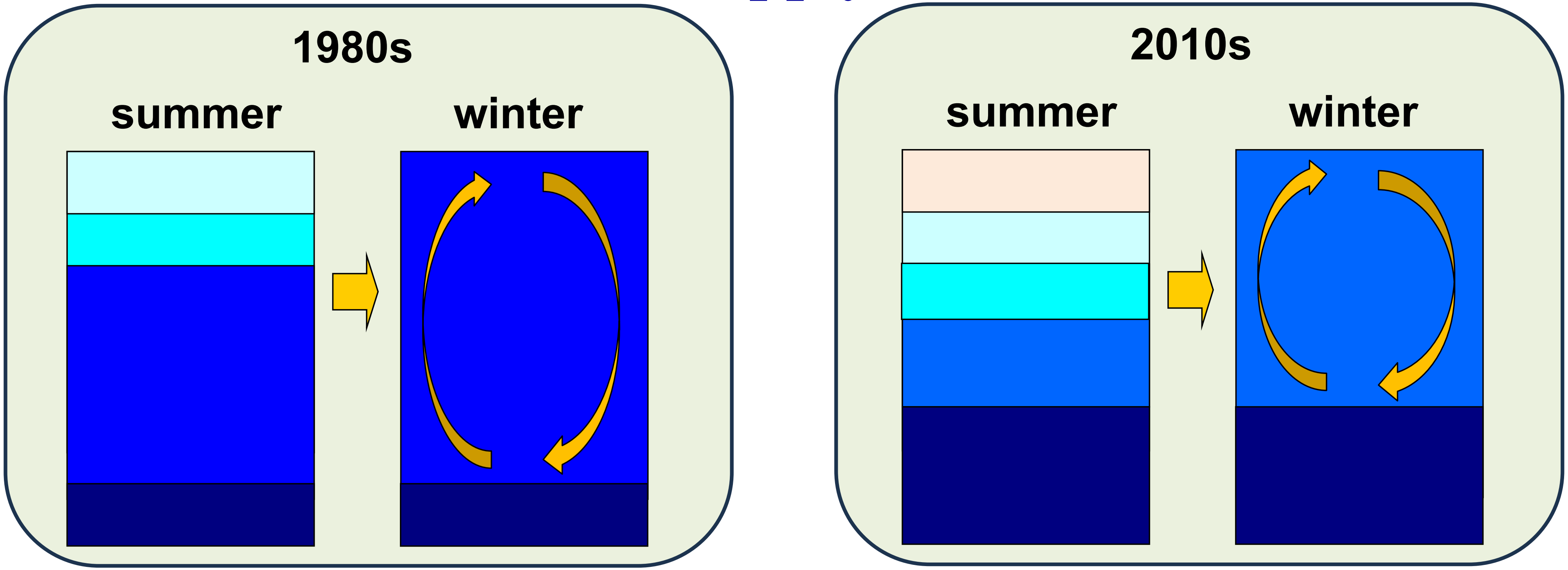
SST - 200m temp.



Vertical stratification was enhanced in 2000s

Lin and Ito (2024, Fish and Fisheries)

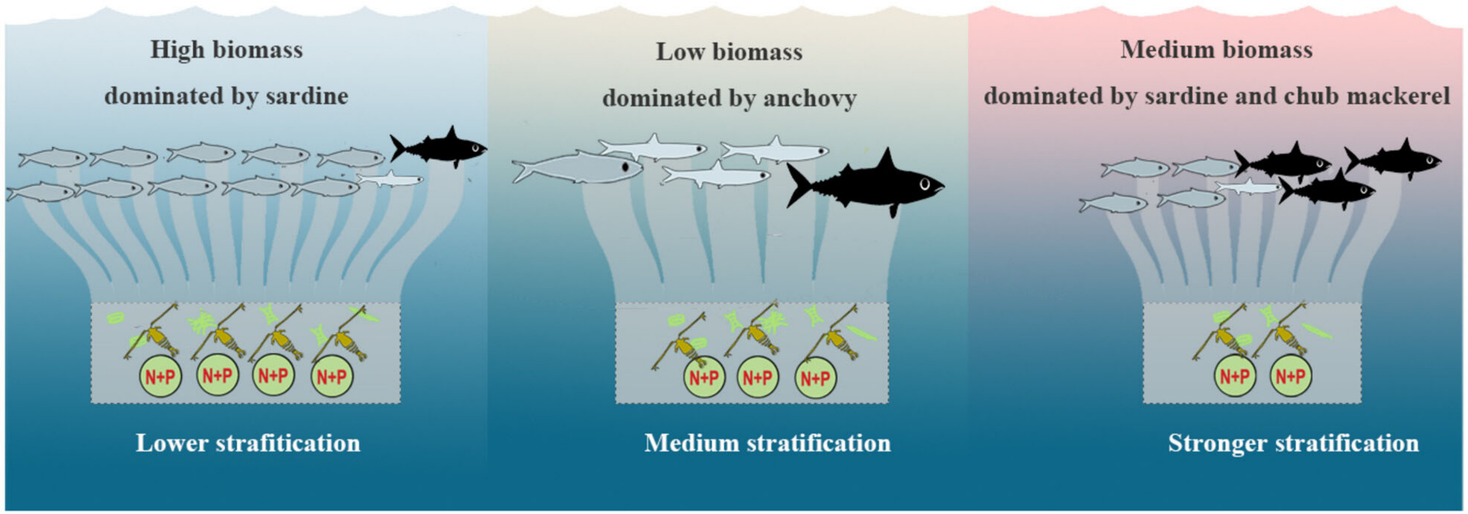
Nutrient supply reduction



Enhancement of surface and subsurface temperature difference (Li et al., 2020)
=>Reduction in nutrient supply from subsurface to surface
=> Reduction in prey plankton production

Fish weight fluctuation in NW Pacific

1. Many fishes showed common weight reduction in 1980s and 2010s around Japan
2. Density effect, induced by sardine increase, reduced fish weights in 1980s (Tadokoro et al., 2005; Ito et al., 2007)
3. Stronger stratification reduced prey production in 2010s. Then, density effect might emerge with moderate biomass increase and resulted in common fish weight reduction in 2010s.



Caveats and future perspectives

1. **Length data**
   Other studies used length data. But, only weight data was available in this study. It may overestimate the prey influence.
   We did weight data analyses in the North Sea (next time).

2. **Common trend analysis**
   Common trend analysis might mask the individual response.
   We conducted state-space modeling approach to each stock (next time).

3. **Life stages**
   We used fixed life stages. But, it could change interacting with weight fluctuation.
   We used a cohort type model in the state-space modelling approaches (next time)

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