Egg size variability in Japanese anchovy under the species alternations between anchovy and sardine in the Kuroshio Current system

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Background

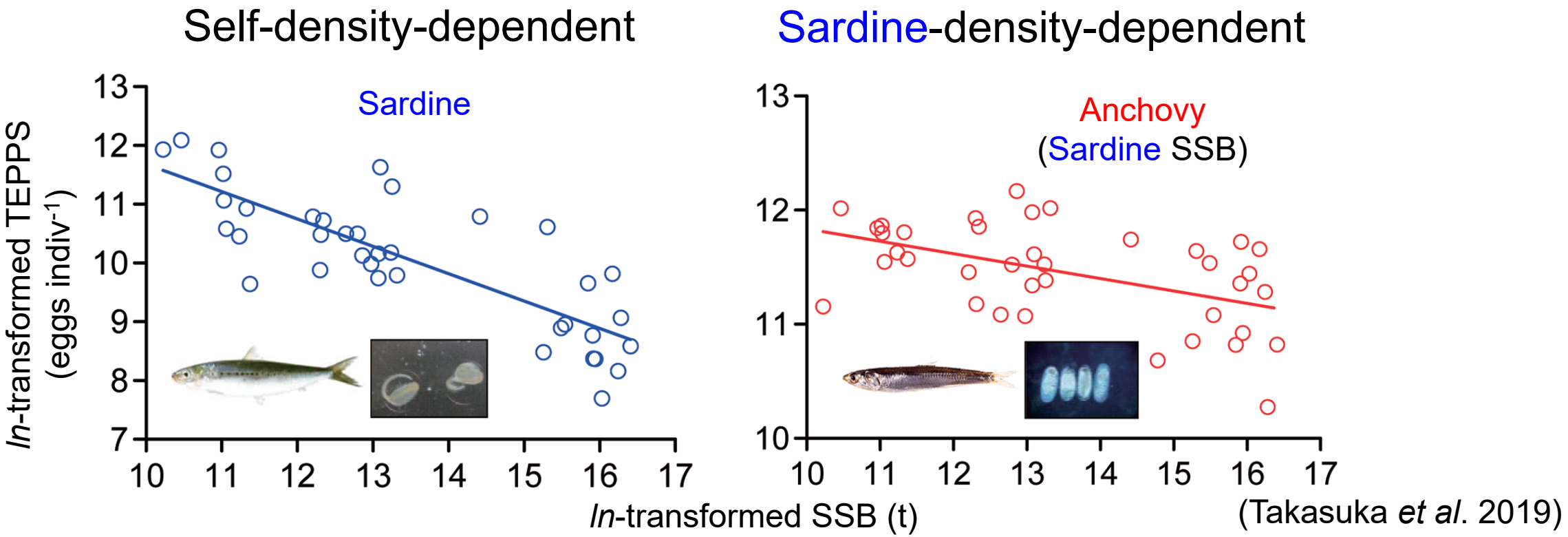
- Paradigm of fisheries science

  "Spawning stock biomass (SSB) and total egg production (TEP) are proportional"

  ⟶ A basic premise underlying spawner recruitment model
  for fisheries management and studies on recruit mechanisms of fish

- Density-dependent effects on egg production
  - ➢ The more fish, the fewer eggs per fish. (Takasuka *et al*. 2019)

Density-dependent egg production



(Takasuka *et al*. 2019)

How about "egg quality (size)"?

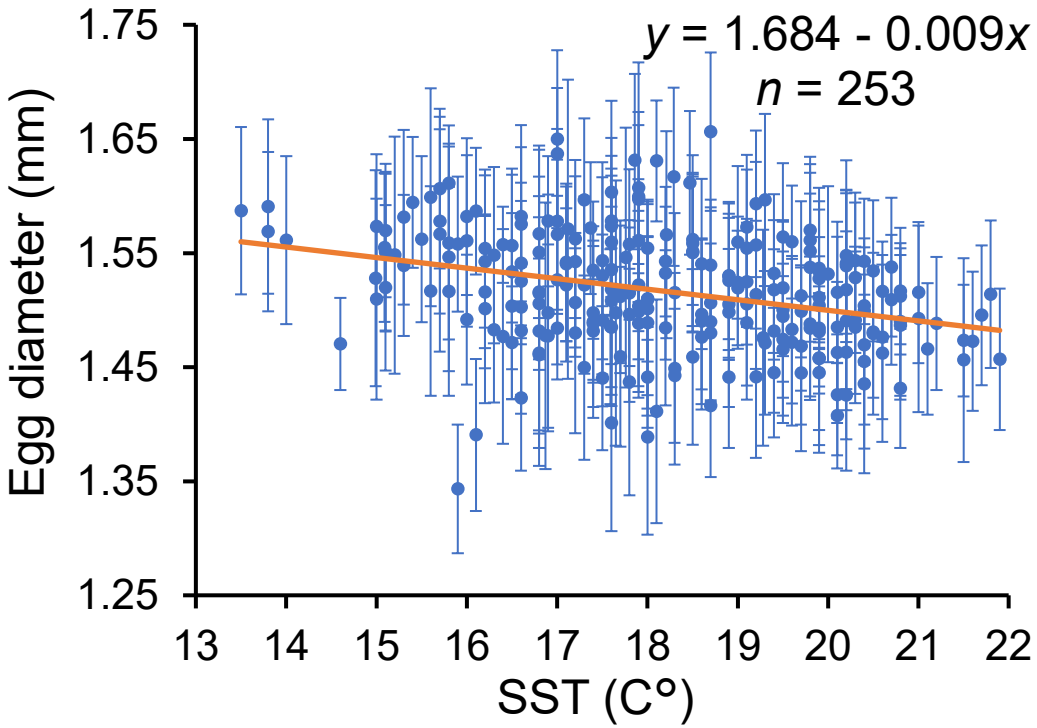
Egg size is related to length at hatching and growth, which potentially affect survival.

Recent studies

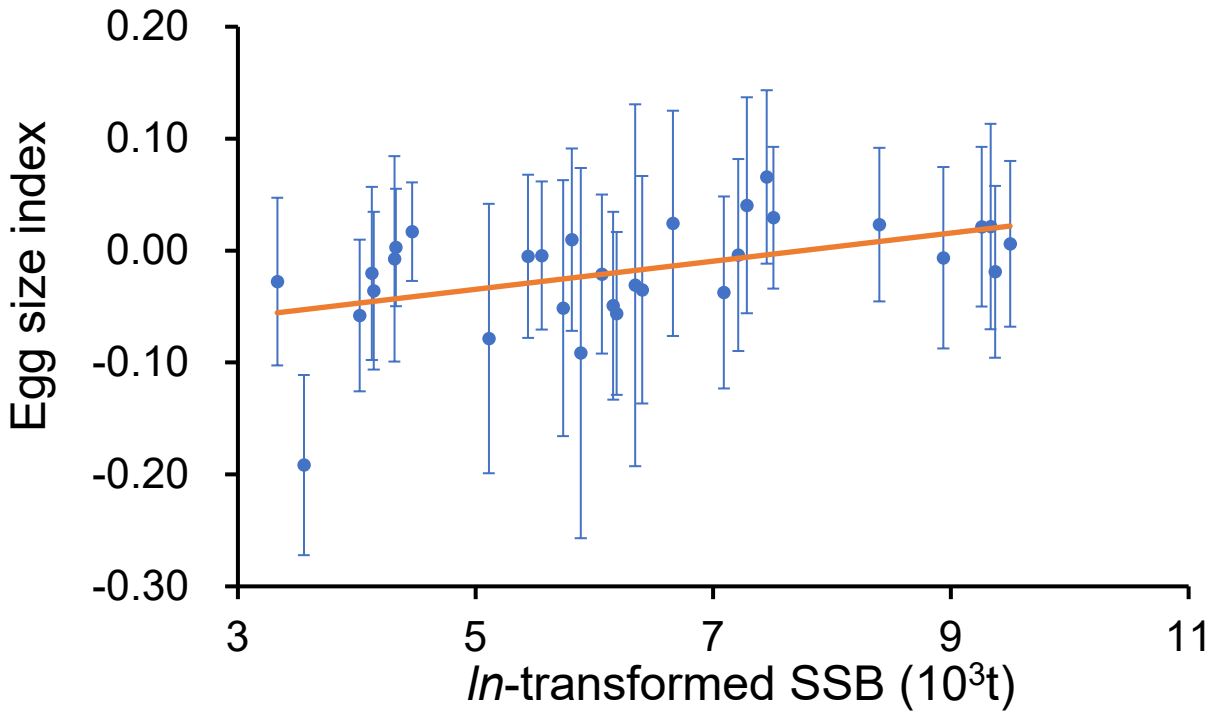
A positive relationship between spawning stock biomass (SSB) and egg size

Japanese sardine

Effect of sea surface temperature (SST) on egg diameter



SSB and egg size index



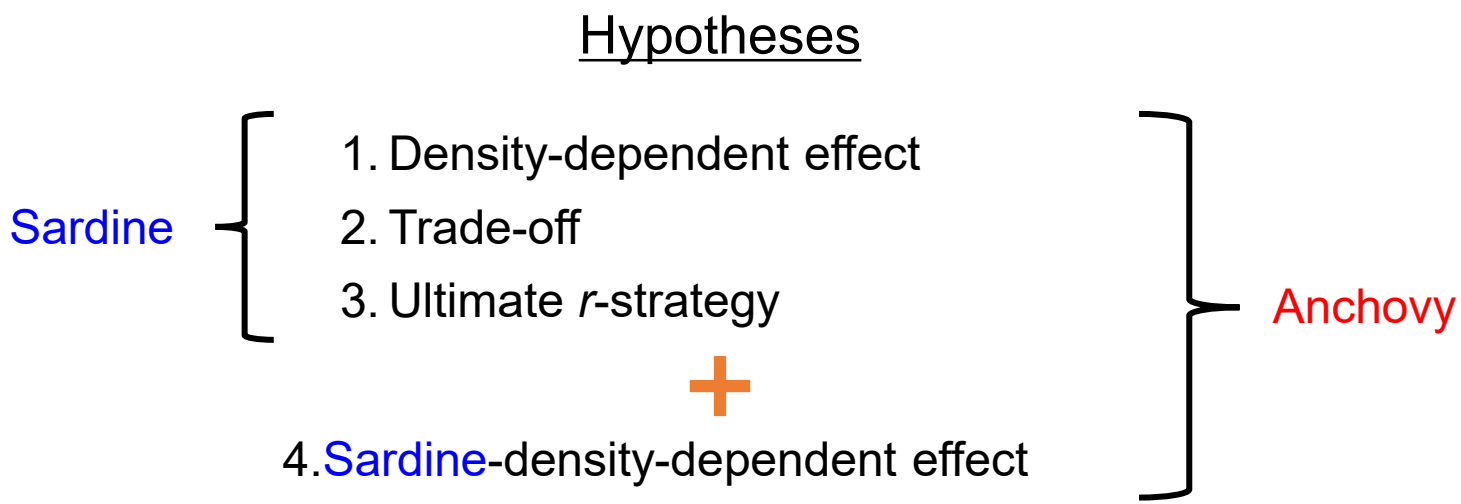
(Utsugi the 2022 SPF Symposium)

Objective

Egg size variability in Japanese anchovy
at large spatial and temporal scales in the field

① Seasonal and regional variability in anchovy egg size and environmental factors

② Annual variability in anchovy egg size and population dynamics to test intraspecific and interspecific density-dependent effects



Egg surveys

【Survey】
Japan Fisheries Research and Education Agency
Fisheries Resources Institute

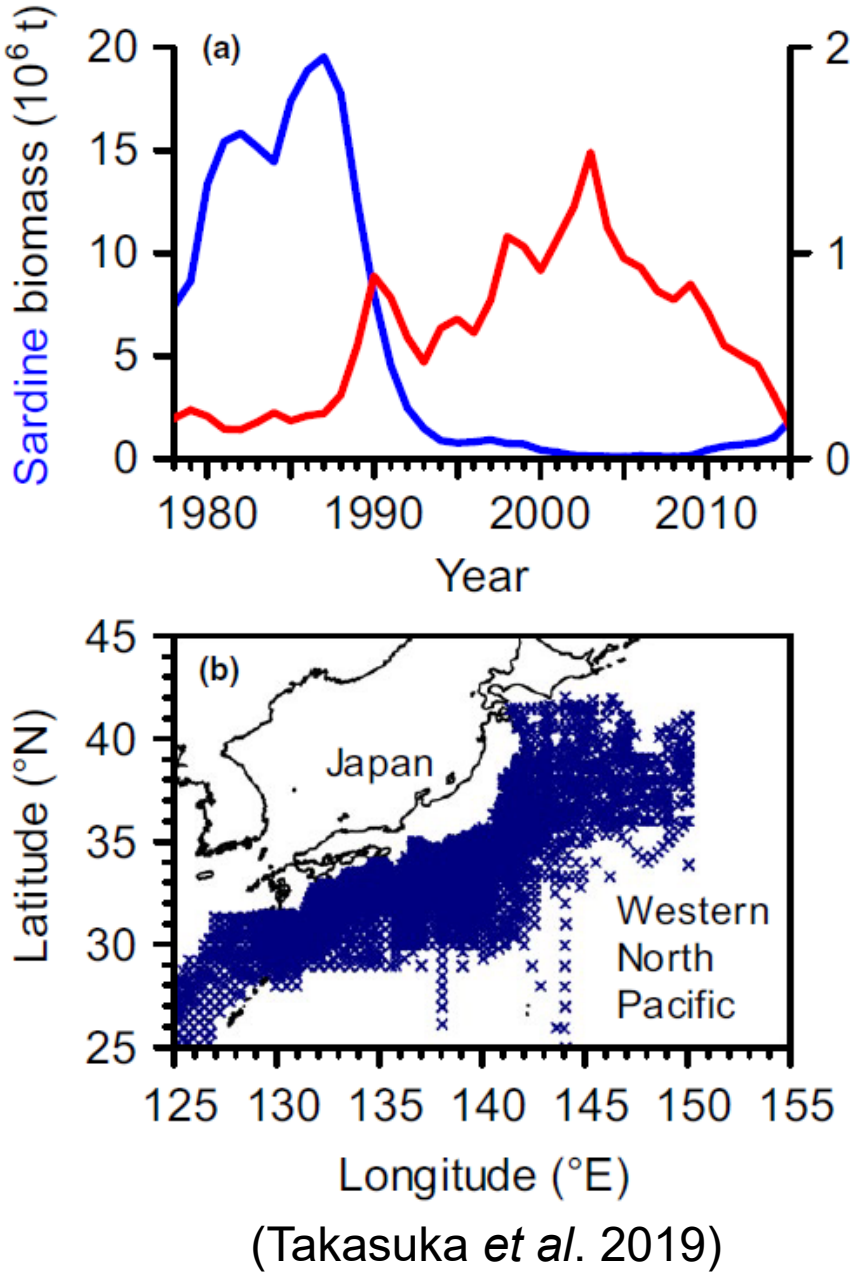
18 prefectural experimental stations or fisheries research institutes

【Period】
Monthly basis since 1978

【Area】
Pacific coast of Japan in the Kuroshio Currents system

【Gear】
Vertical tows of plankton nets (0.330/0.335 mm)

Based on historical sample collections of egg surveys



(Takasuka *et al*. 2019)

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① Seasonal and regional variability in anchovy egg size
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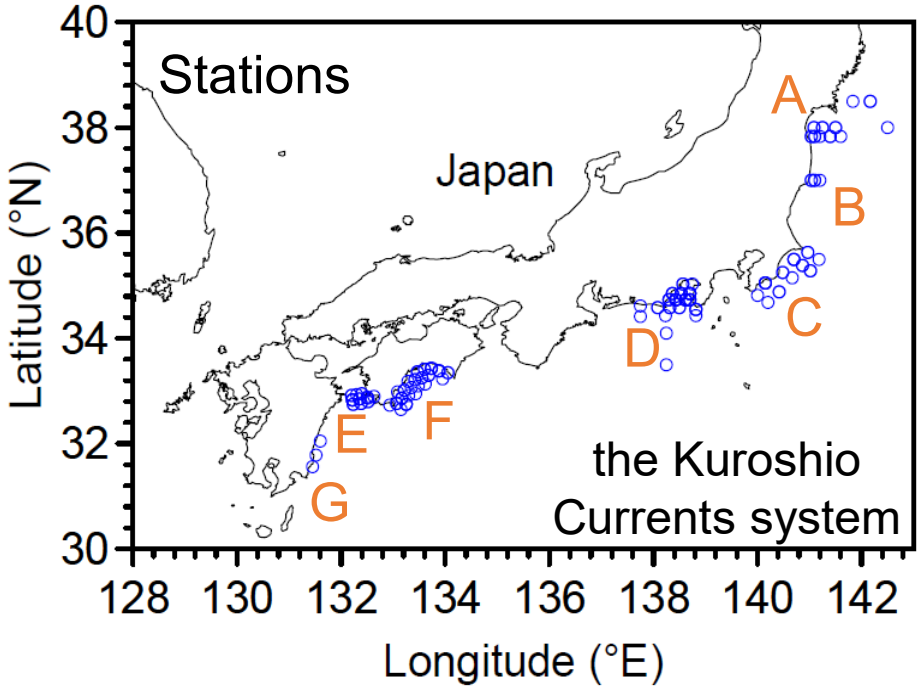
to test intraspecific and interspecific density-dependent effects

Samples

- We used anchovy egg samples (preserved in 5–10% formalin) collected from the Pacific coast of Japan in 2012.

- Imai & Tanaka (1987)
  A negative relationship between SST and egg size during the low-biomass period

→ Medium-biomass period and extended seasons and regions in present study



	Prefecture	Month	Sample	Individual
A	Miyagi	6–8	10	632
B	Fukushima	6–7	13	754
C	Chiba	4–8	21	1,161
D	Shizuoka	3–10	45	2,256
E	Ehime	5–10	19	925
F	Kochi	4–8,11	40	1,788
G	Miyazaki	4,5,7	3	131
	Total	–	151	7,647

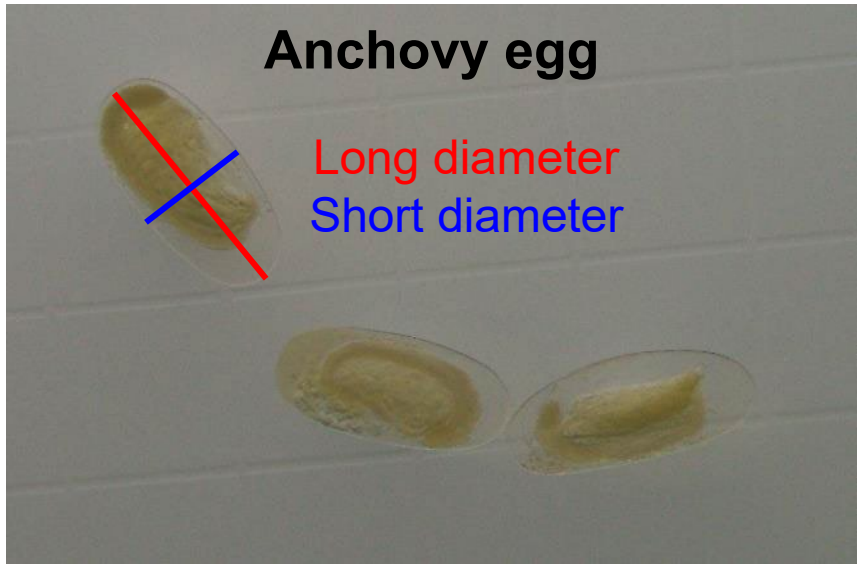
Method

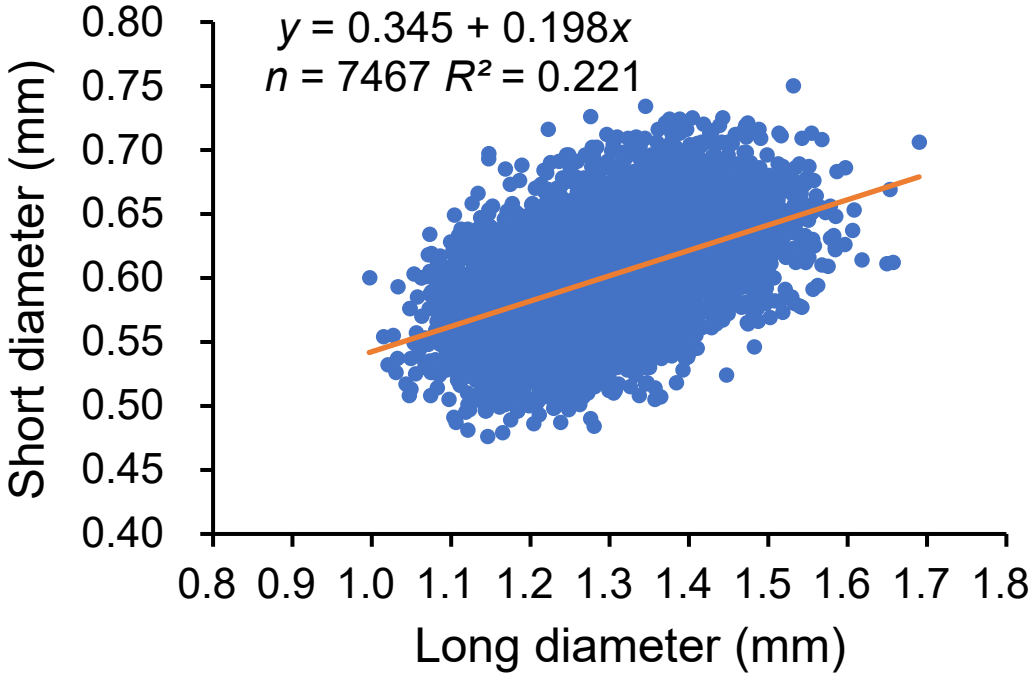
- Anchovy eggs were ellipsoid in shape and filled with yolk.

  → Egg size was determined as ellipsoidal volume.

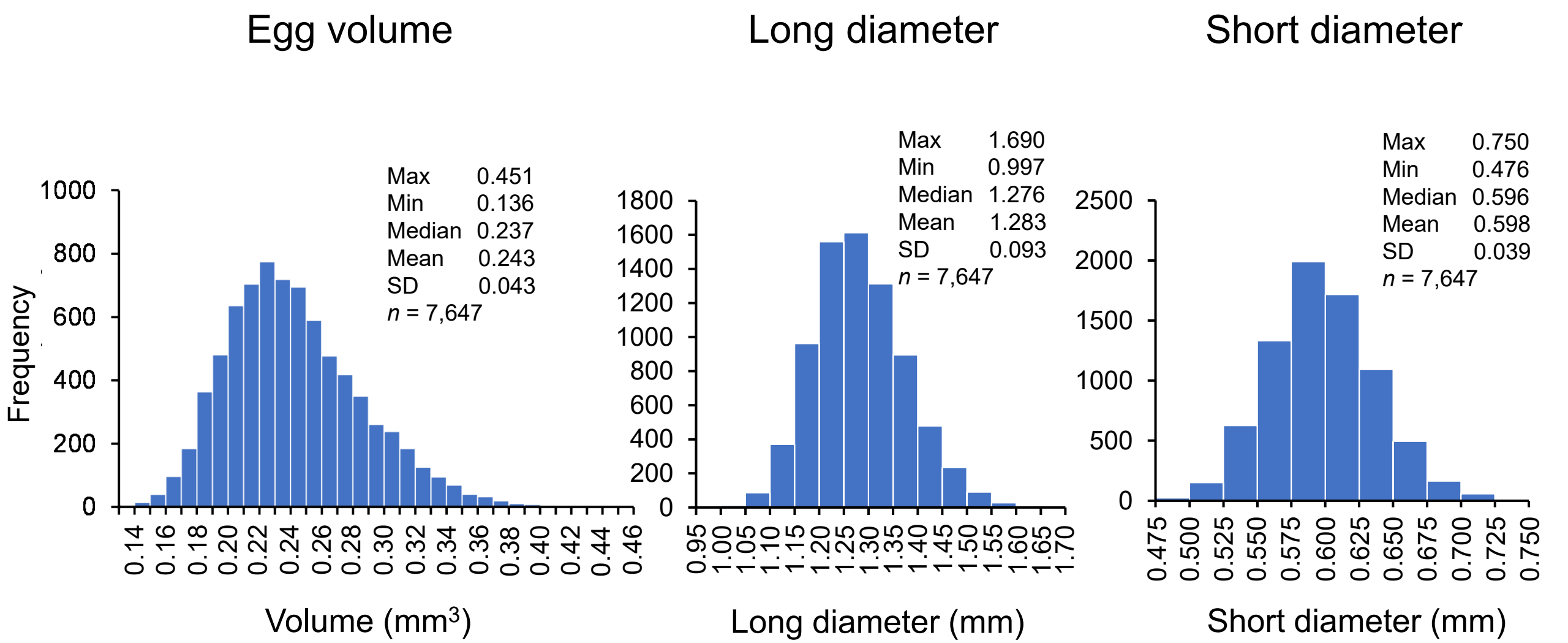
- Photos of anchovy eggs were taken by a camera connected to a microscope.

  → Ellipsoidal volume was calculated from long and short diameters measured with ImageJ.



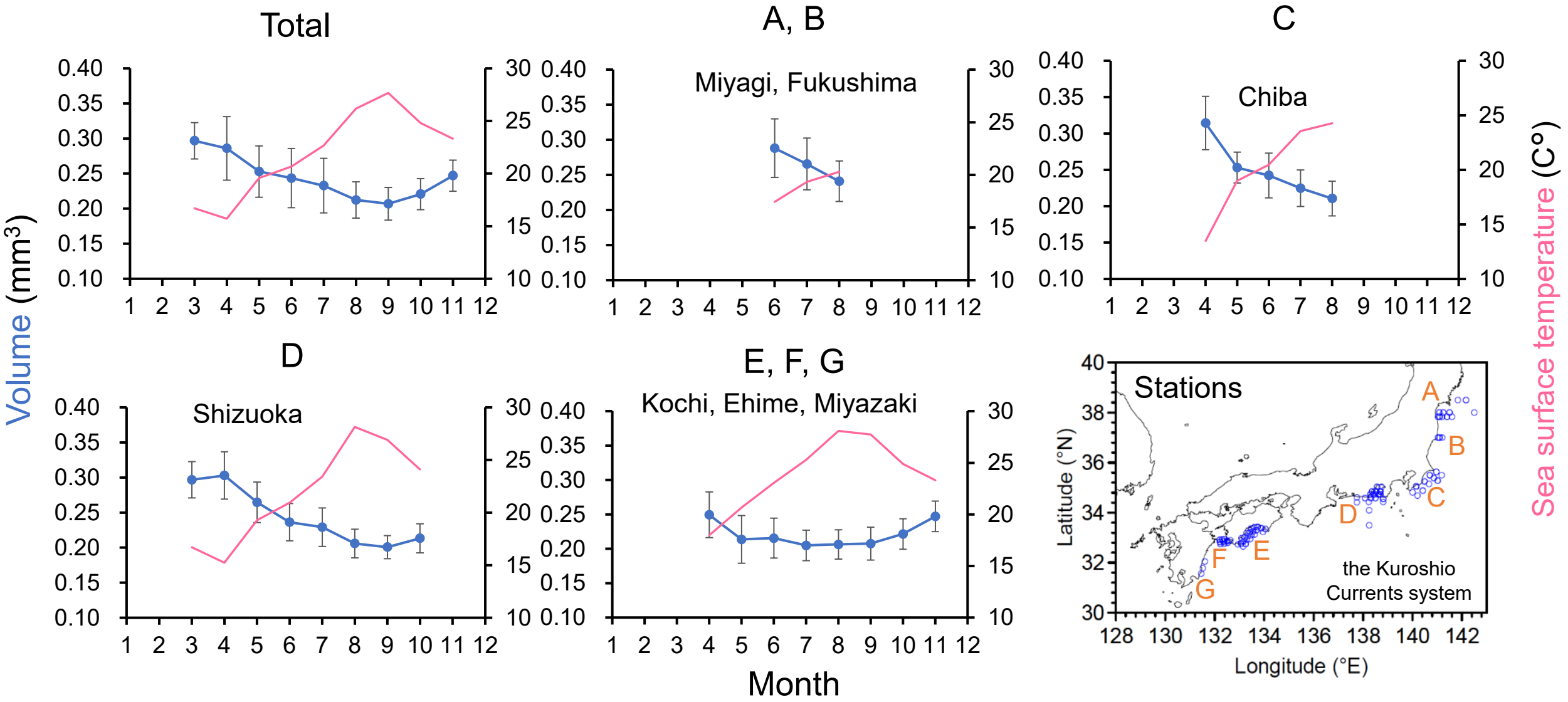


Distribution



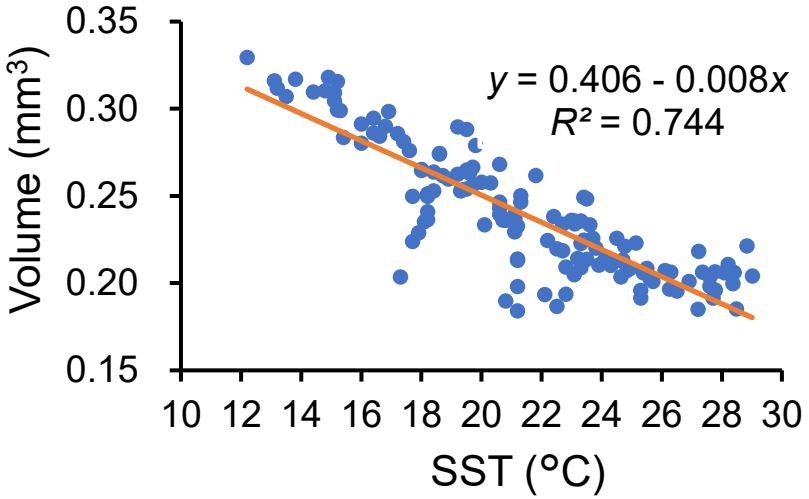
Monthly variability in egg volume by regions (mean±SD)

Egg volume was smaller at lower latitudes and in summer.

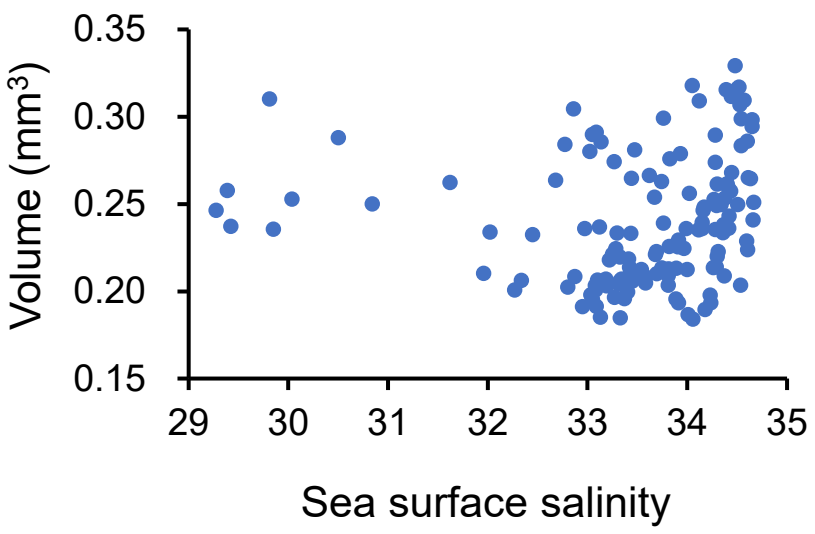


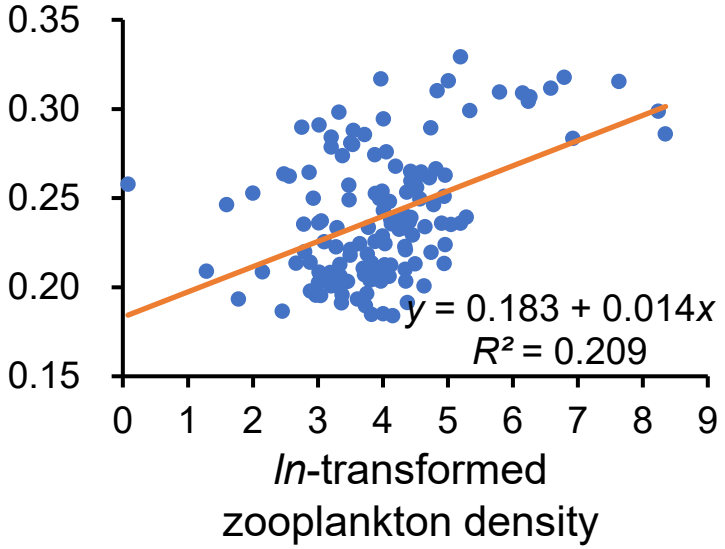
Stepwise multiple regression analysis

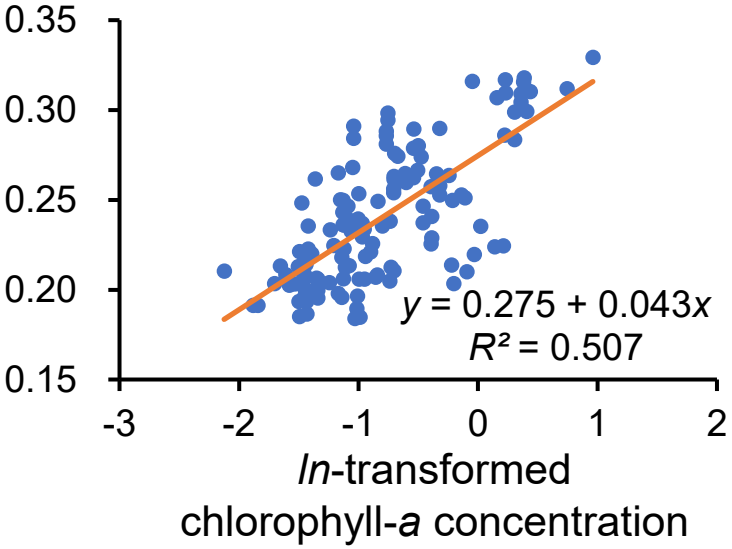
Strongly negative relationship to sea surface temperature (SST)



	P-value
SST	< 0.001
Sea surface salinity	0.005
Zooplankton density (ml/m²)	0.007
Chlorophyll-*a* concentration (mg/m³)	0.278

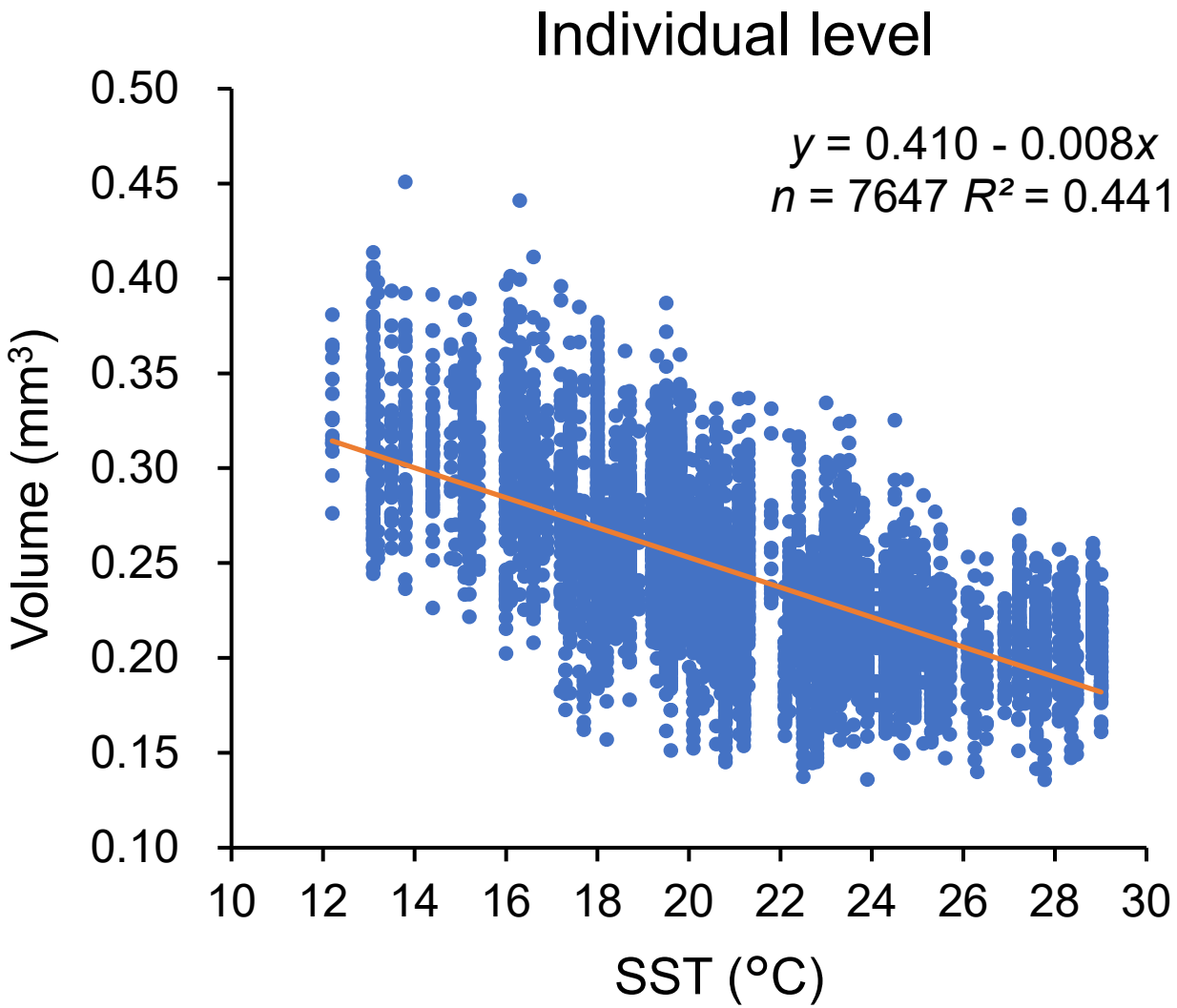


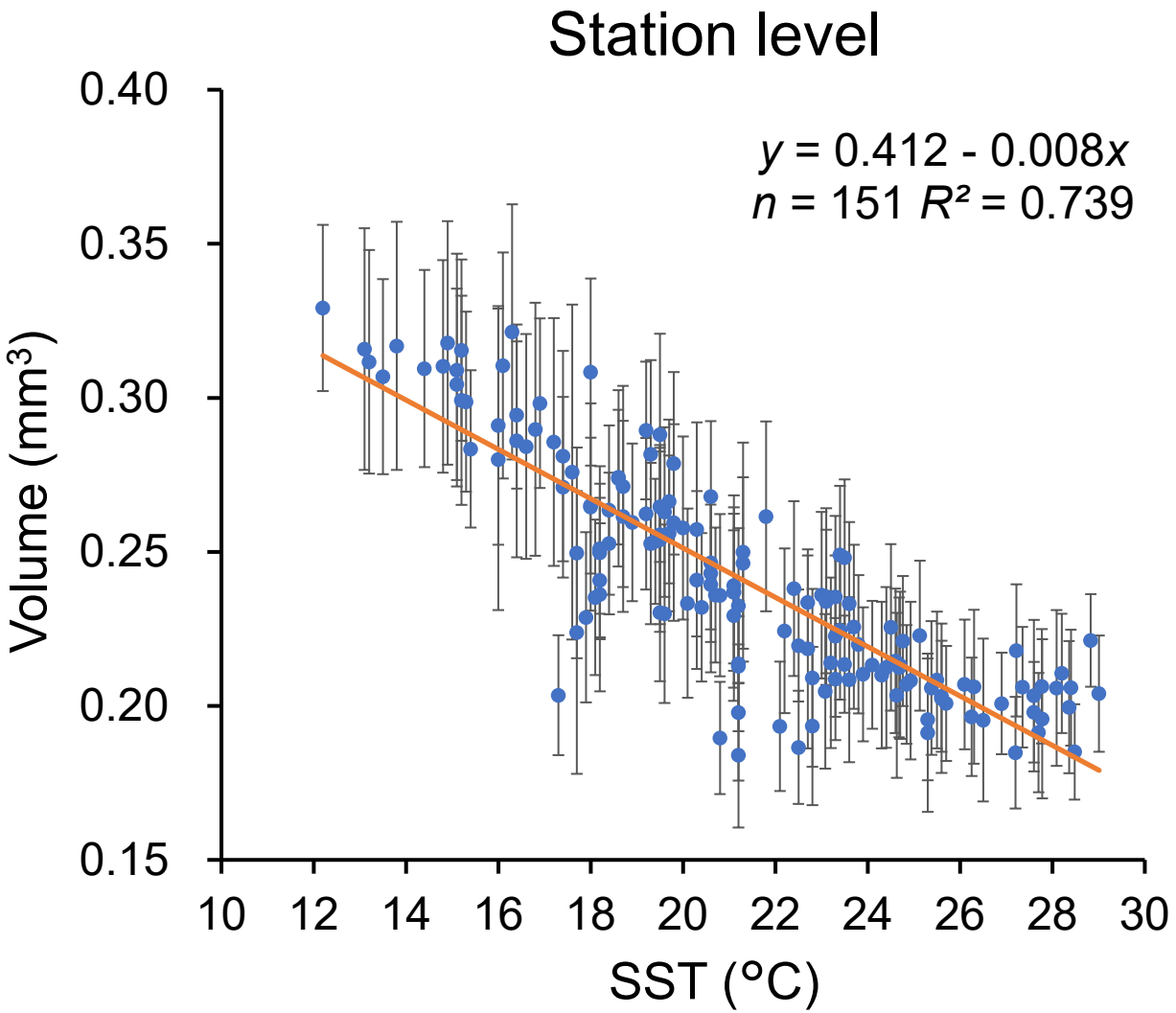




Effect of SST on egg volume

A strong negative relationship between SST and egg volume





Seasonal and regional variability in anchovy egg

- Substantial seasonal and regional variability in egg size in 2012
  Egg size was smaller at lower latitudes and in summer.
- Egg size was significantly related to all the environmental factors.
  The effect of SST was considered to be the strongest.
- A strong negative relationship between SST and egg size

Understanding the effects of environmental factors would enable test of density-dependent effects on anchovy egg "quality (size)".

Why is egg size smaller at higher water temperature?

Higher water temperature

Smaller egg

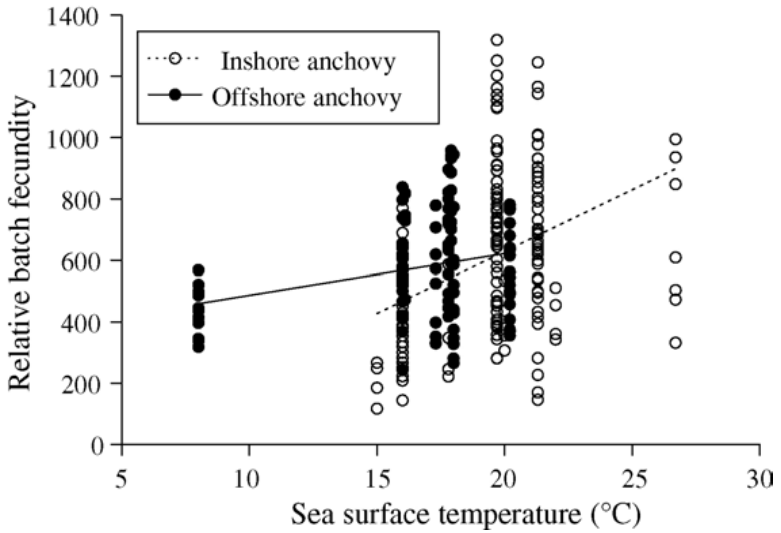
Early spawning due to
accelerated maturation and development

Higher frequency

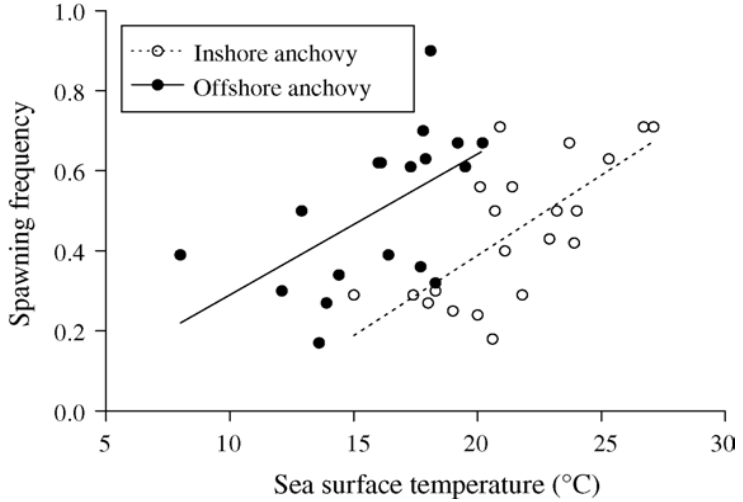
Higher fecundity

Trade-off between
"quality (size)" and "quantity (fecundity) "

Batch fecundity



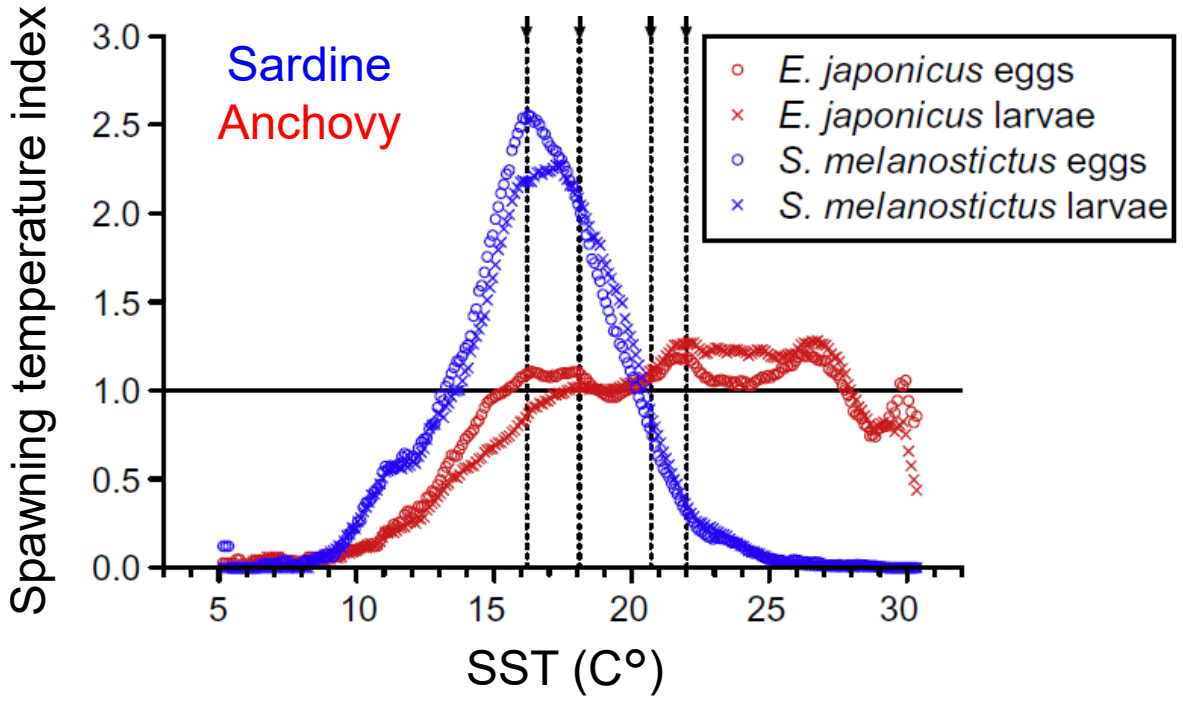
Spawning frequency



(Takasuka *et al*. 2005)

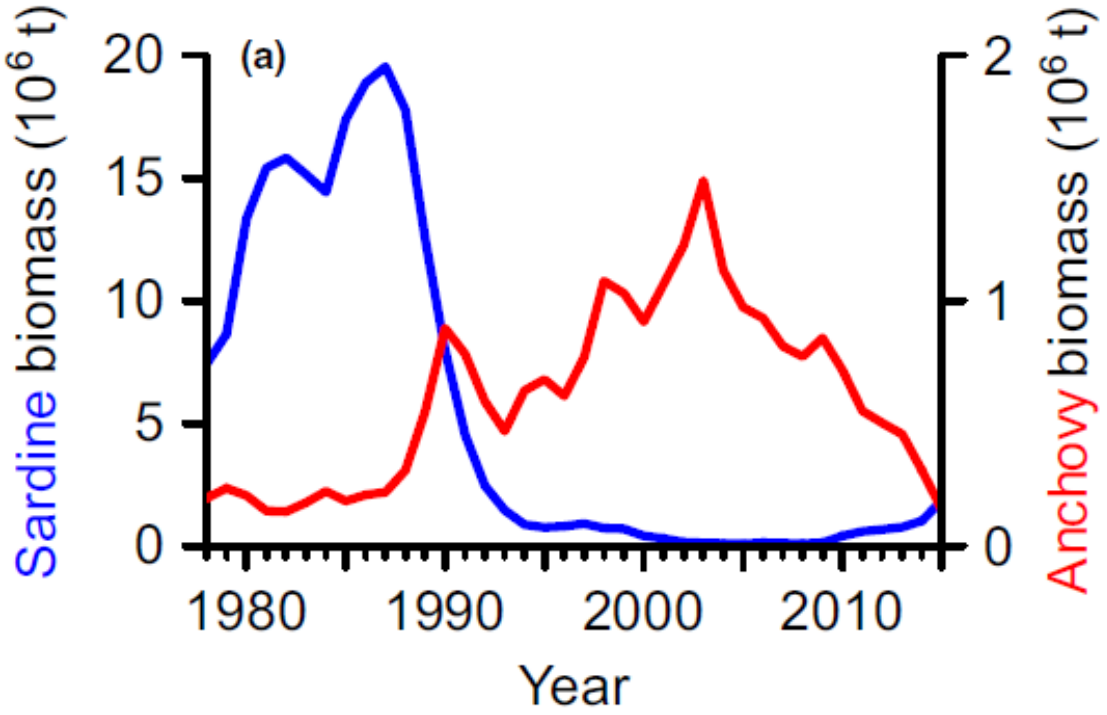
Differences between sardine and anchovy

Spawning temperature



(Takasuka *et al*. 2008)

Biomass fluctuations



(Takasuka *et al*. 2019)

Sardine

Winter spawning (peak: Feb.)

High biomass & High fluctuation

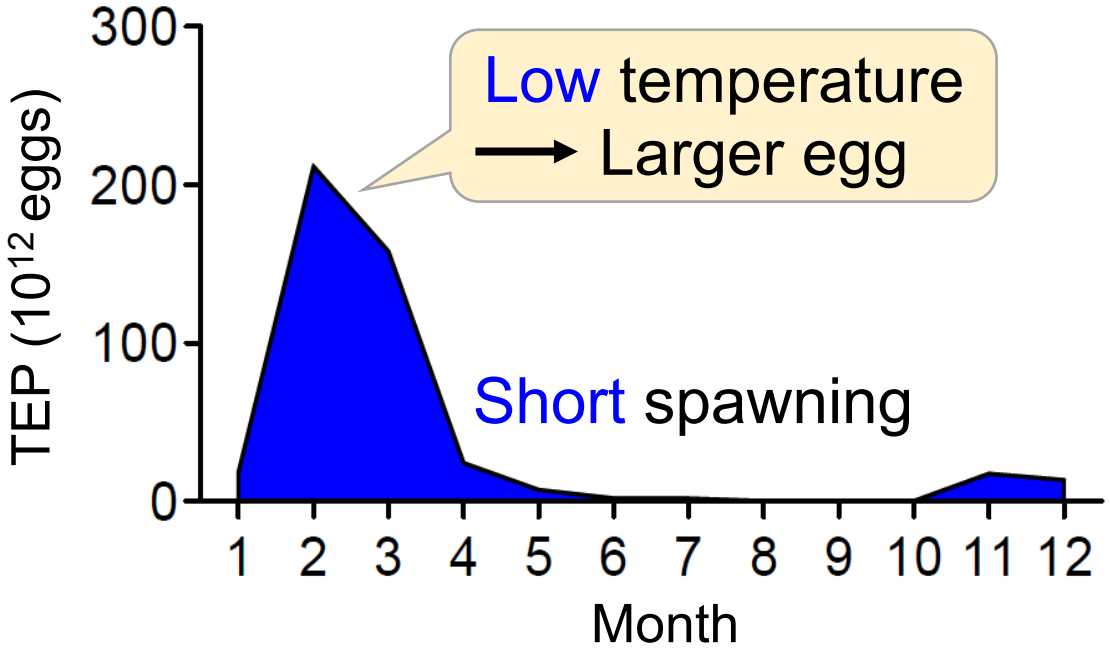
Anchovy

Year-round spawning (peak: June–July)

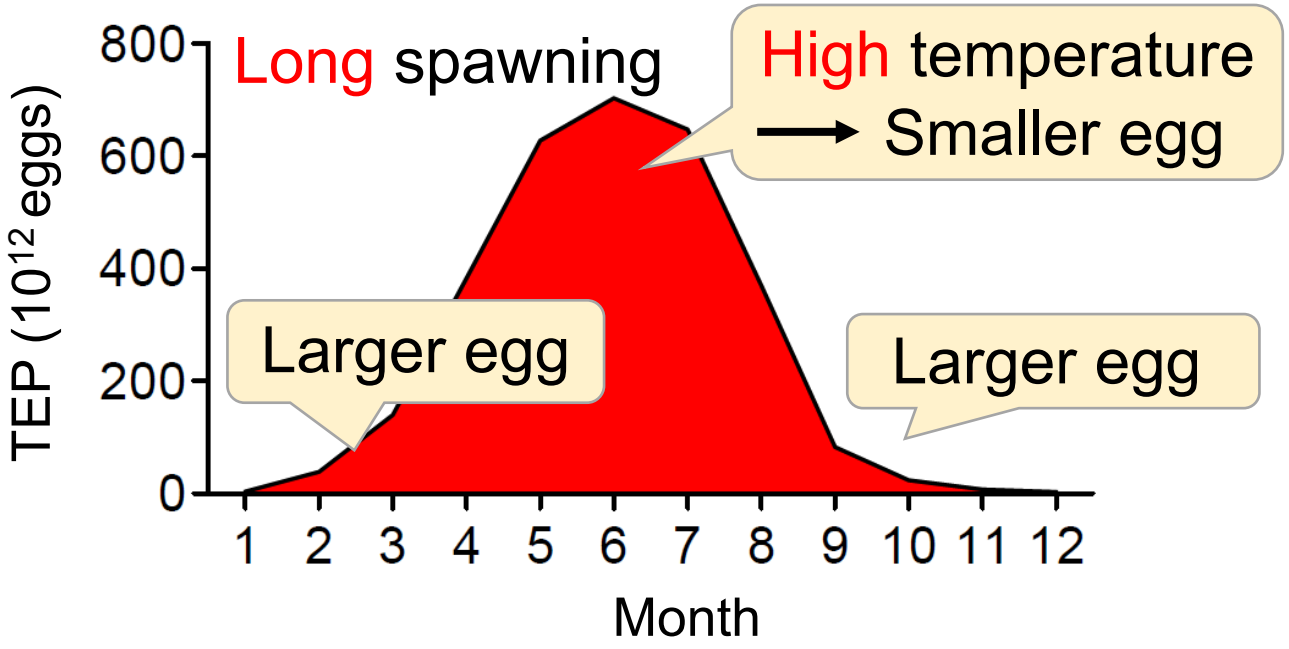
Low biomass & Low fluctuation

Differences between sardine and anchovy

Sardine



Anchovy



“Single pointed”

High fluctuation depending on availability of suitable environment

“Balanced”

Moderate fluctuation due to availability of suitable environment

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① Seasonal and regional variability in anchovy egg size
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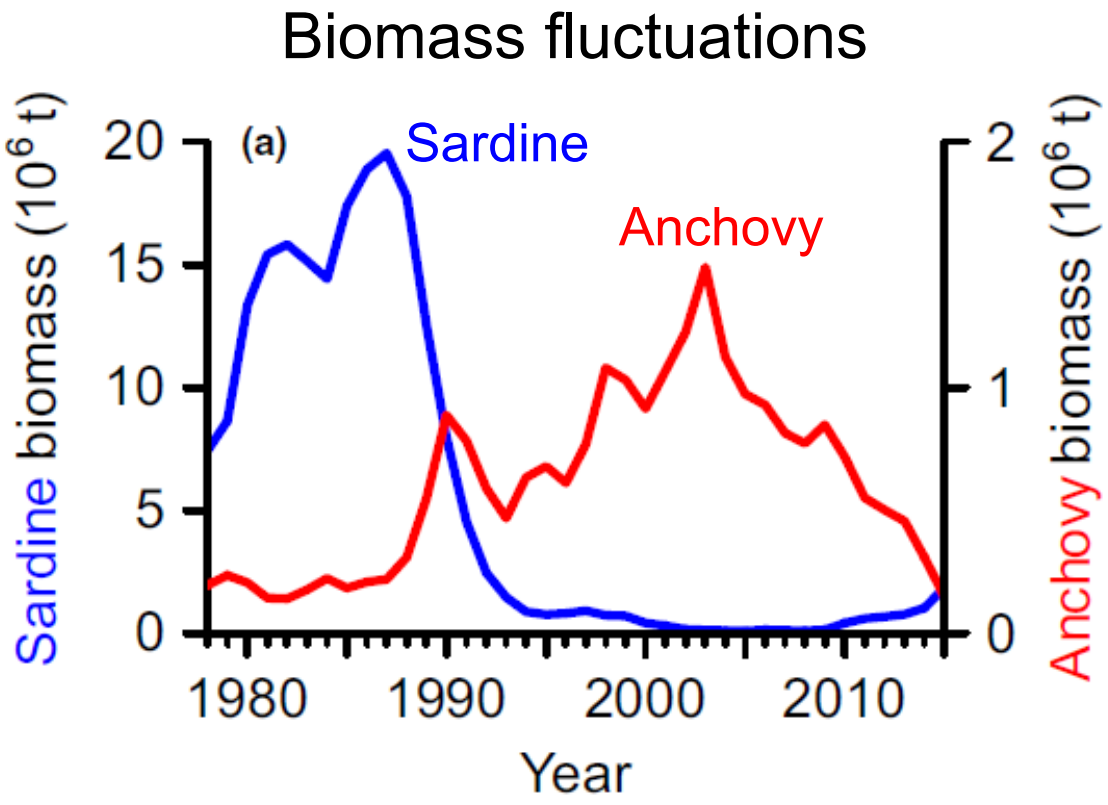
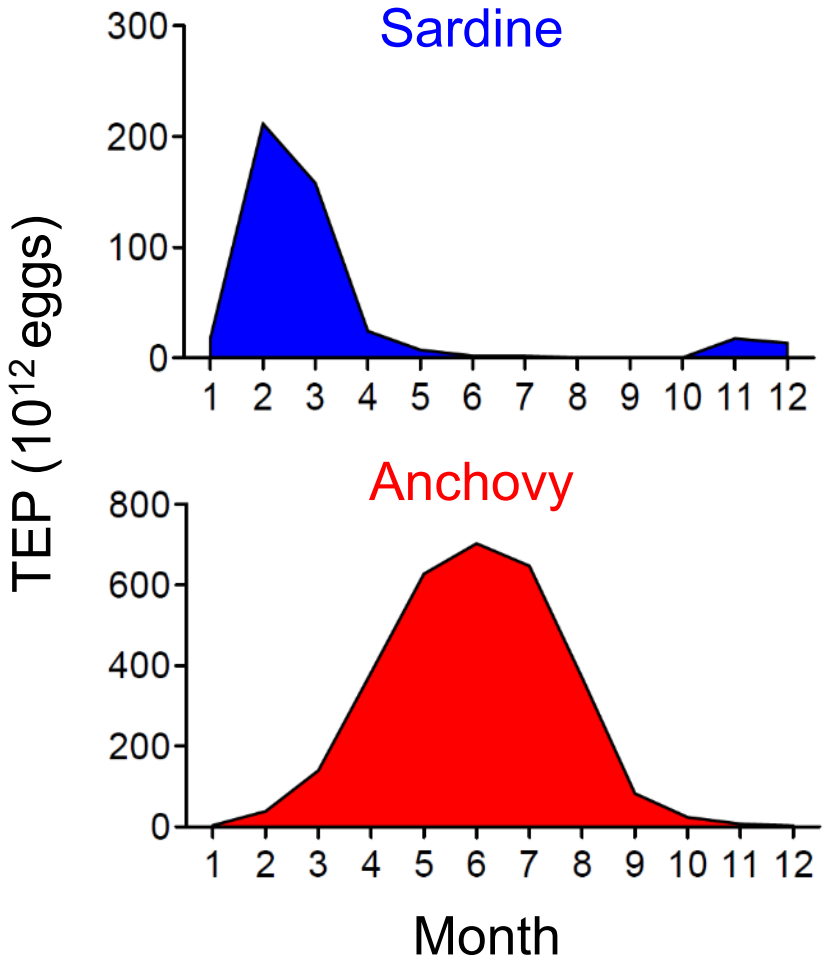
② Annual variability in anchovy egg size and population dynamics
to test intraspecific and interspecific density-dependent effects

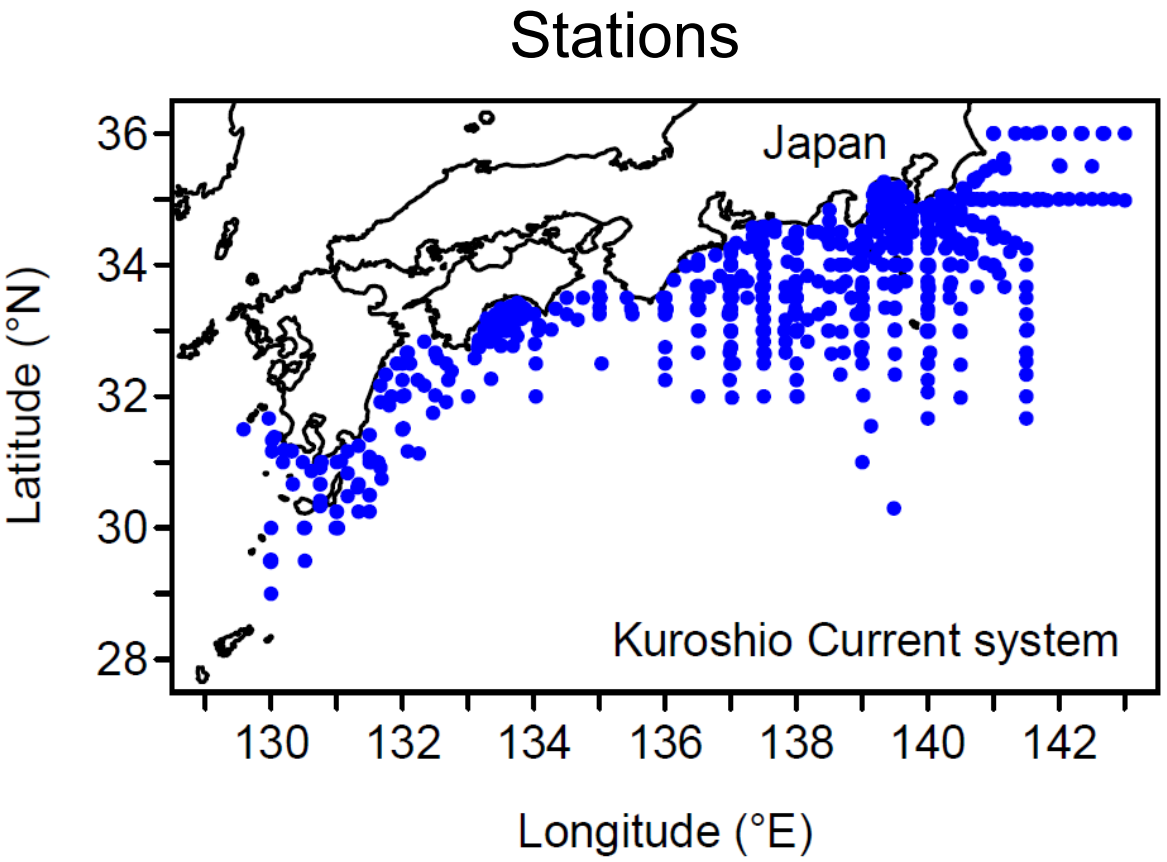
Samples

Anchovy egg size was measured for samples off the Pacific coast of Japan January to May (the main spawning season of sardine) from 1986 to 2021.





Samples

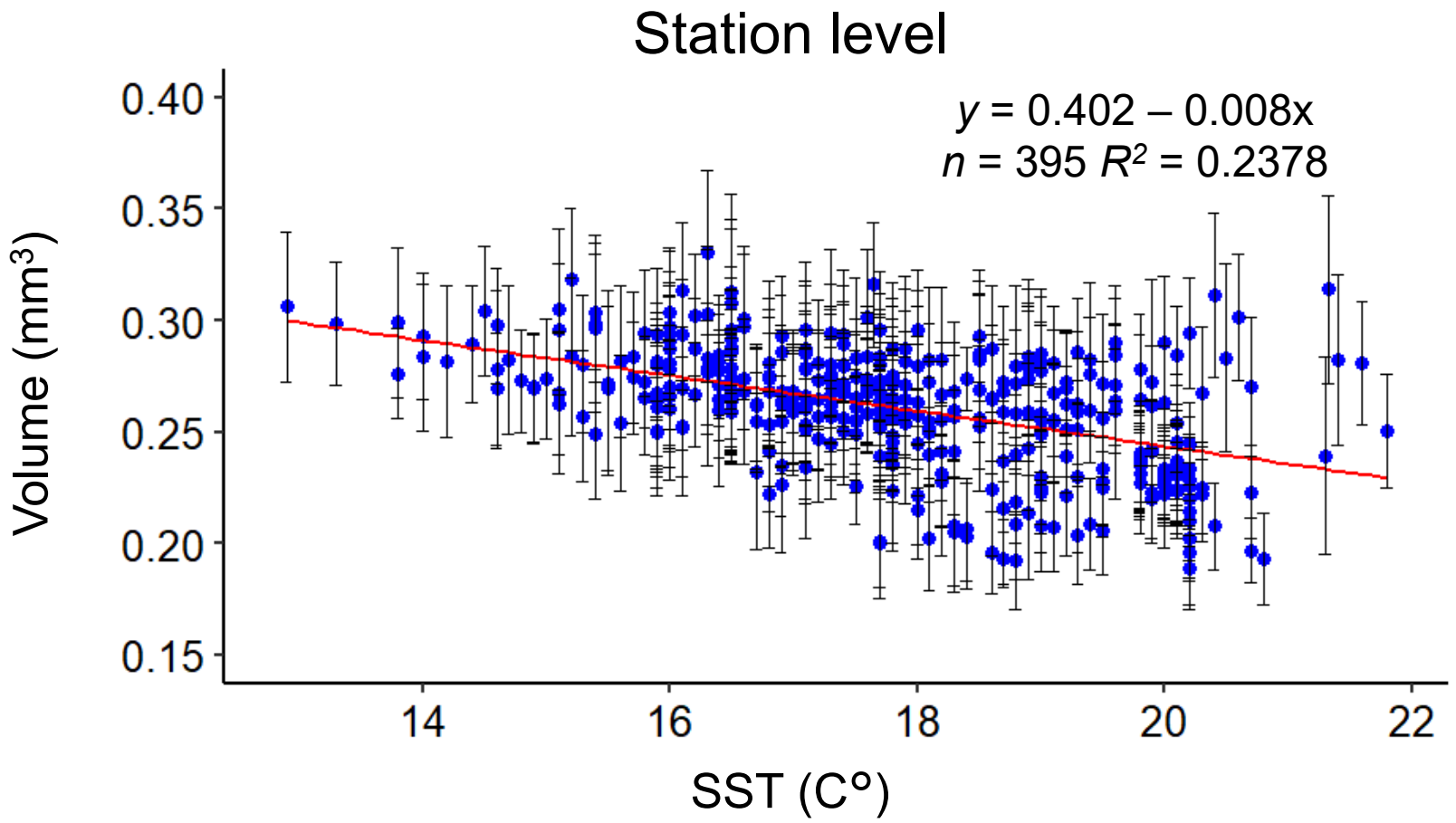


Year	Sample	Individual	Year	Sample	Individual
1986	13	273	2003	32	1,103
1987	9	121	2004	13	299
1988	28	249	2005	7	82
1989	5	9	2006	2	3
1990	27	346	2007	11	135
1991	68	2,317	2008	3	55
1992	60	2,409	2009	11	269
1993	38	1,316	2012	3	65
1994	43	449	2013	17	109
1995	39	756	2014	11	47
1996	13	82	2015	2	2
1997	8	195	2016	9	35
1998	14	230	2017	2	3
1999	124	5,316	2019	2	2
2000	84	3,531	2020	5	25
2001	16	835	2021	3	24
2002	42	3,530	Total	764	24,222

Effect of SST on anchovy egg volume

A strong negative relationship between SST and egg volume

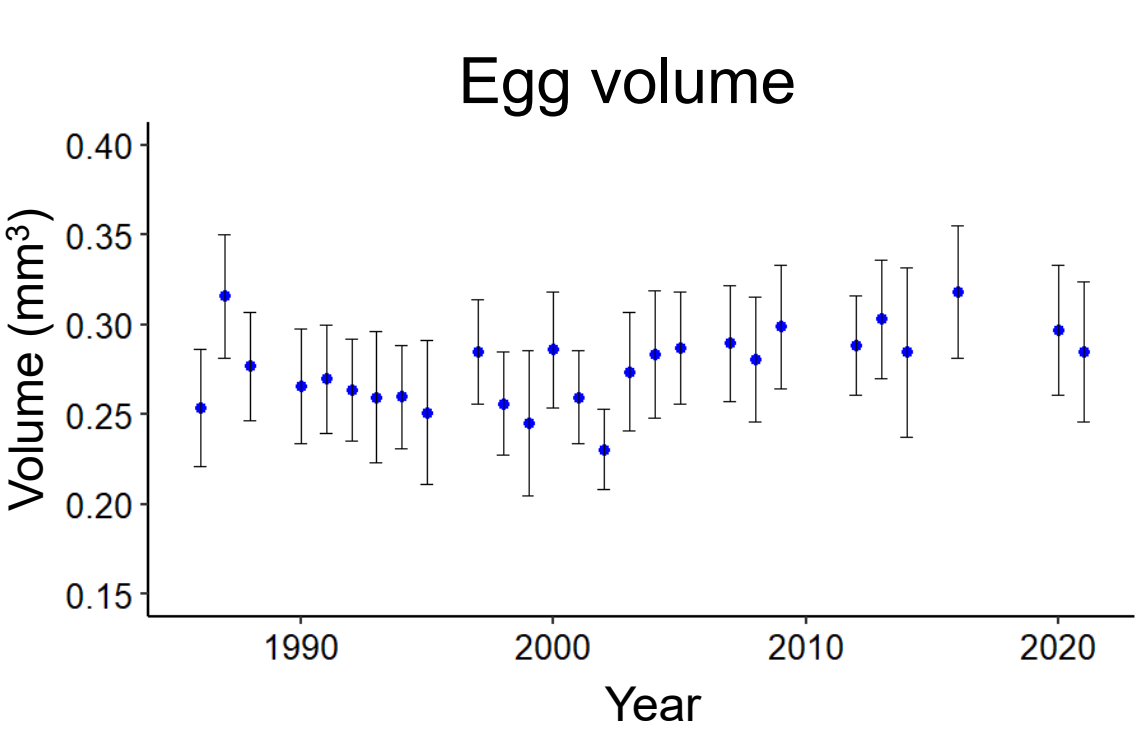
→ Residual from the regression line was used as an egg size index by removing the effect of SST.

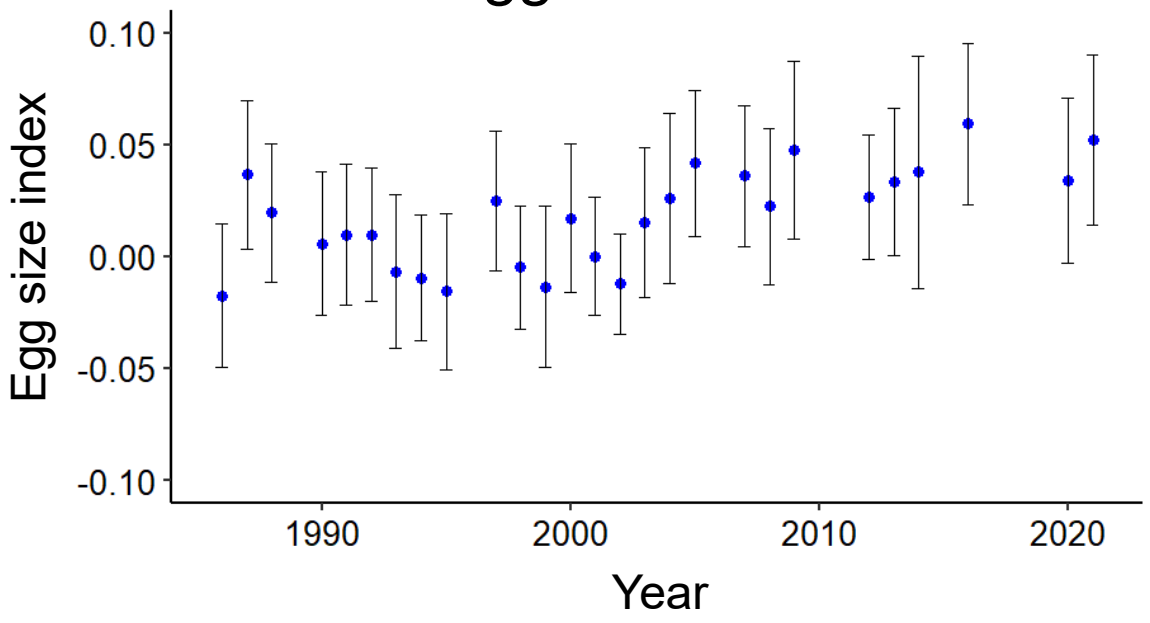


Annual variability in anchovy egg size

Substantial variability in egg size index
even after standardization by SST

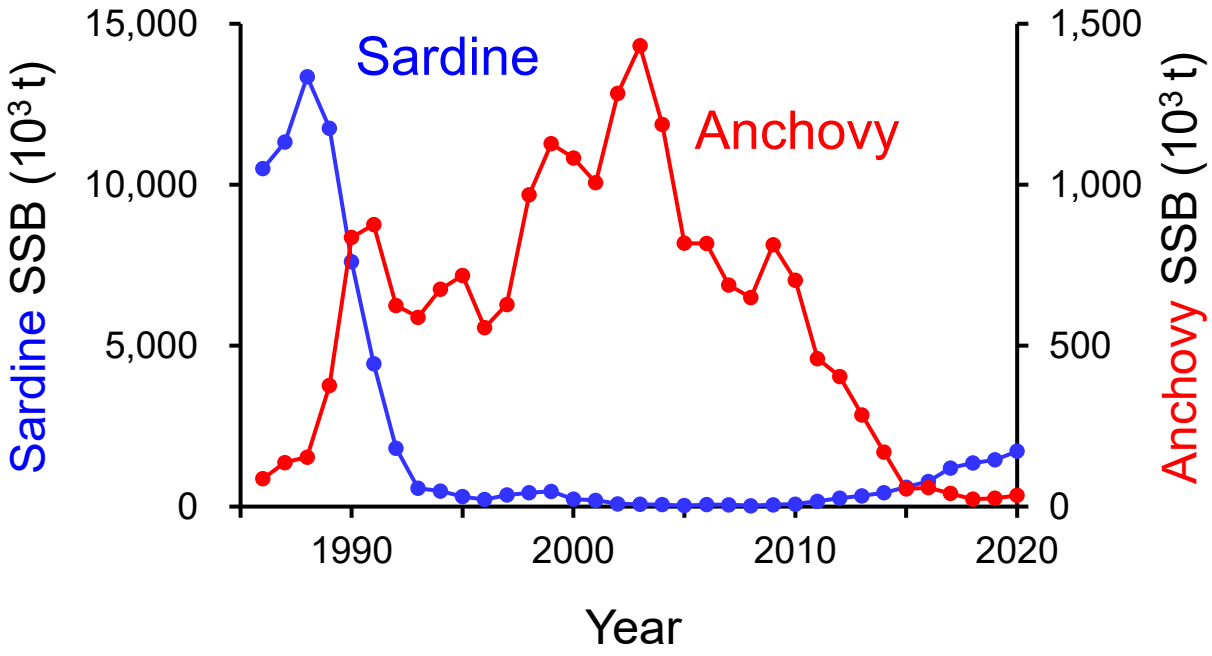
Standardization





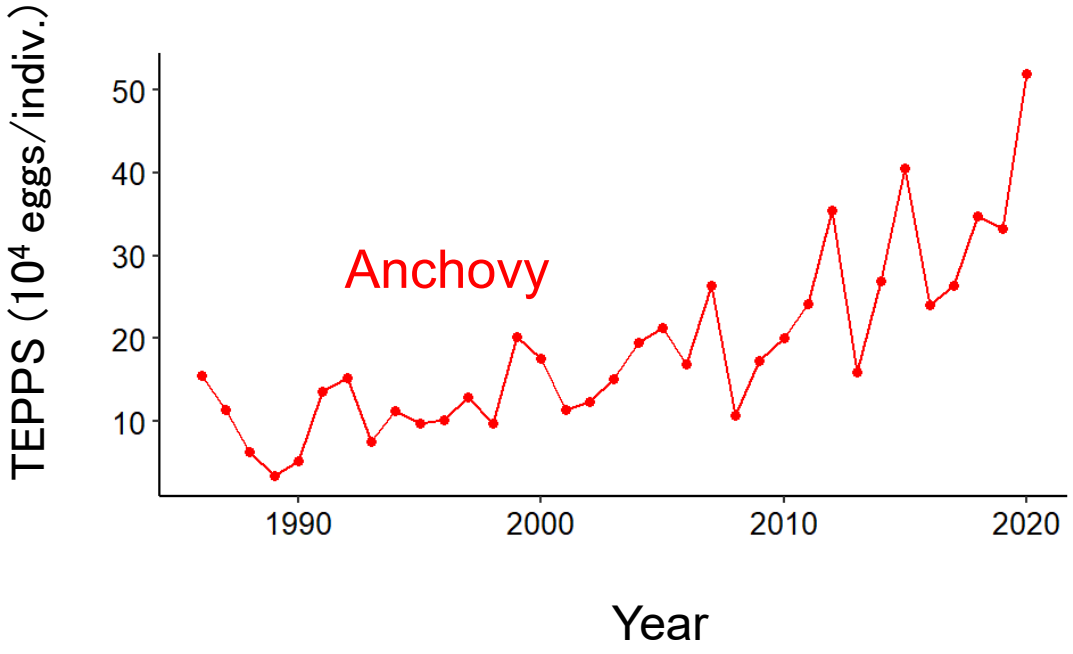
Population dynamics

Spawning stock biomass (SSB)



Density-dependent effects

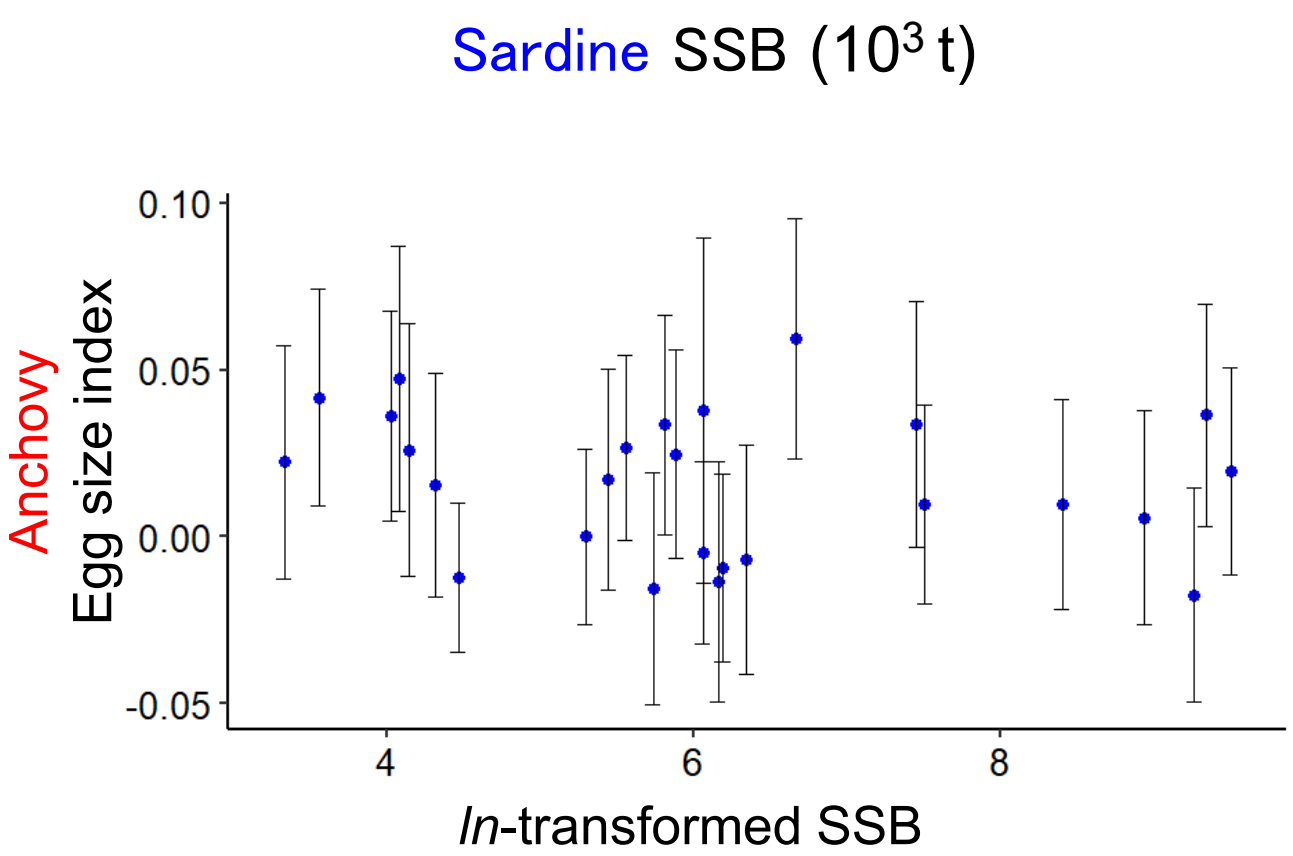
Total egg production per spawner individual (TEPPS)

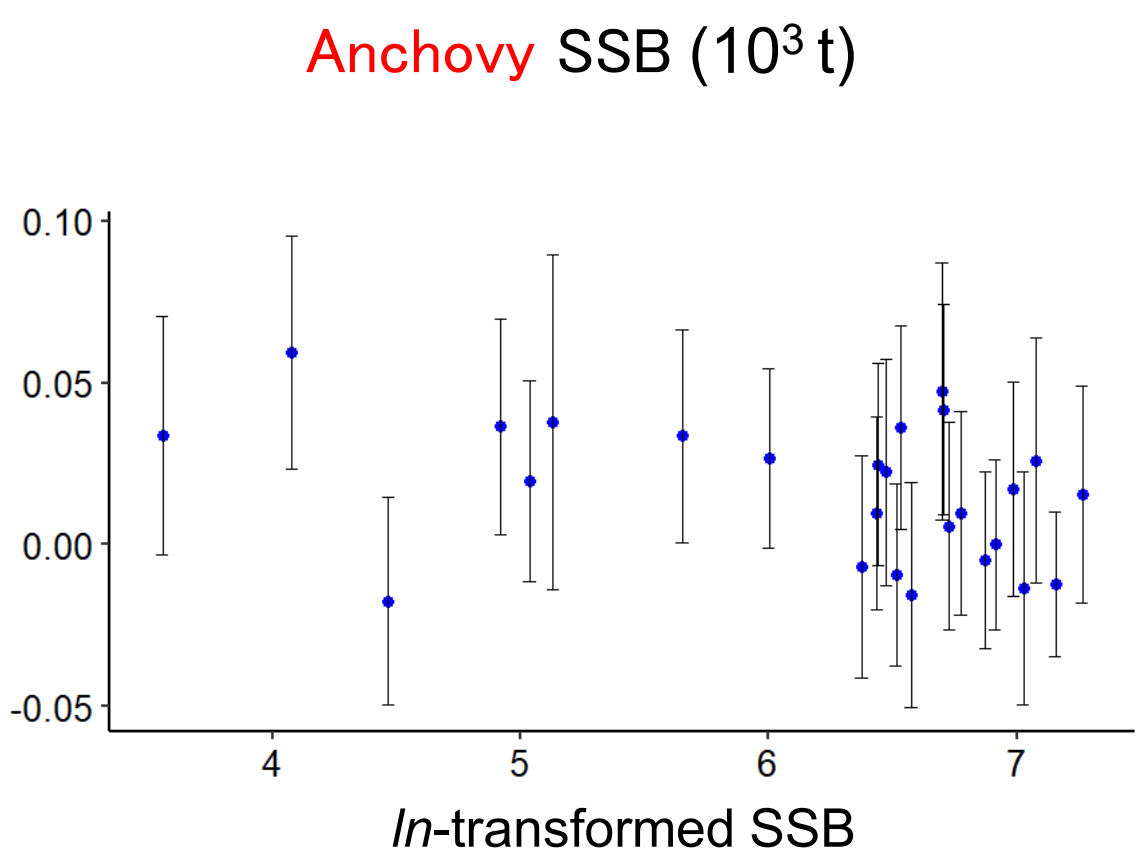


Trade-off between fecundity and egg size

The relationship with SSB of sardine and anchovy

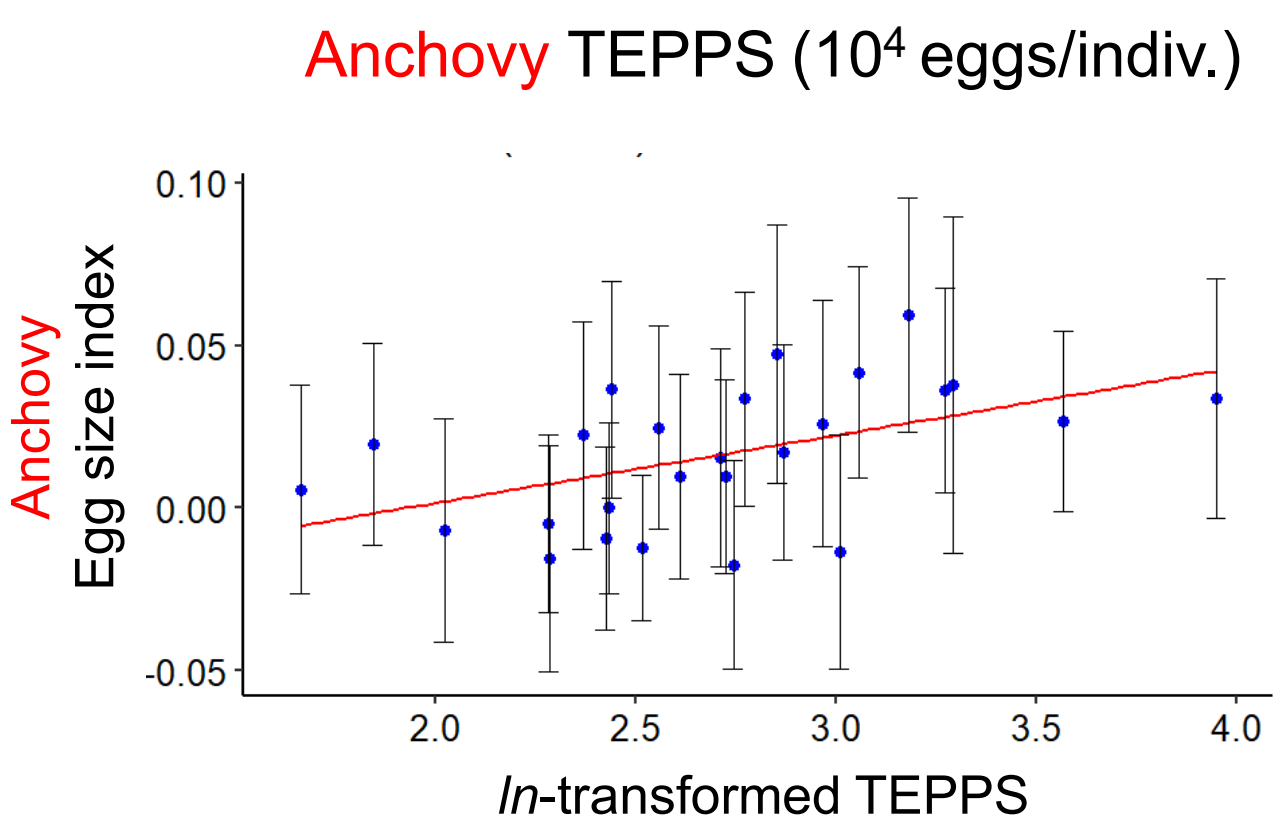
No significant relationship between SSB and anchovy egg size index





The relationship with anchovy TEPPS

A positive relationship between anchovy TEPPS and anchovy egg size index



Sardine SSB

High

Negative relationship
(Takasuka *et al*. 2019)

Anchovy TEPPS

Low

Positive relationship

Anchovy egg size

Small

Density-dependent effect on anchovy egg size

A positive relationship between anchovy TEPPS and anchovy egg size

- This positive relationship cannot be explained by trade-off between fecundity and egg size.
- No significant relationship between anchovy SSB and anchovy egg size

→ No intraspecific density-dependent effect

Anchovy TEPPS was sardine-density-dependent. (Takasuka *et al*. 2019)

⇩

Anchovy egg size may also be affected by sardine-density dependent effect.

Summary

Seasonal and regional variability

A negative relationship between SST and anchovy egg size

Annual variability

A positive relationship between anchovy TEPPS and anchovy egg size

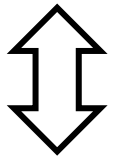
⇩

Possible sardine-density-dependent effect on anchovy egg size

Differences from Previous Studies

Imai & Tanaka (1987)

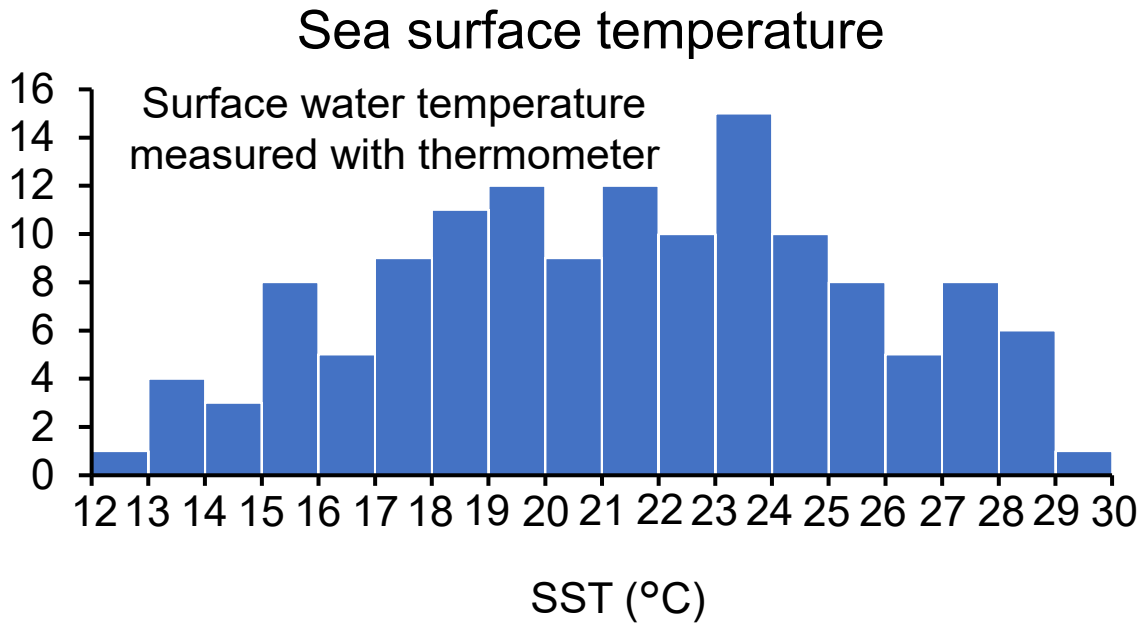
A negative relationship between water temperature and anchovy egg size during the low-biomass period of anchovy

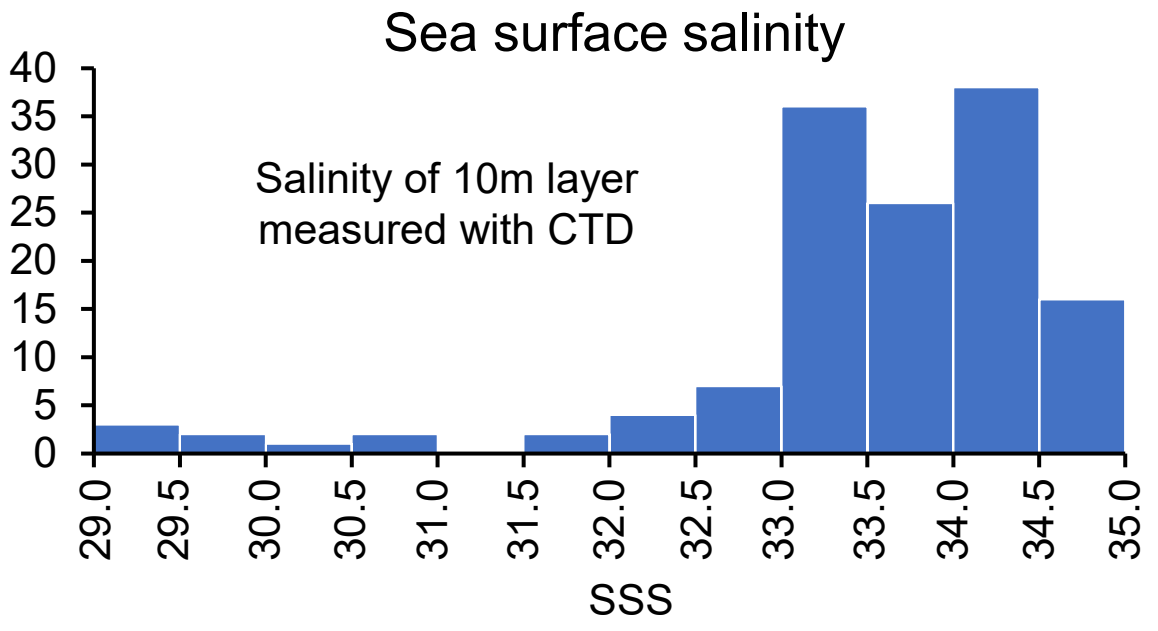


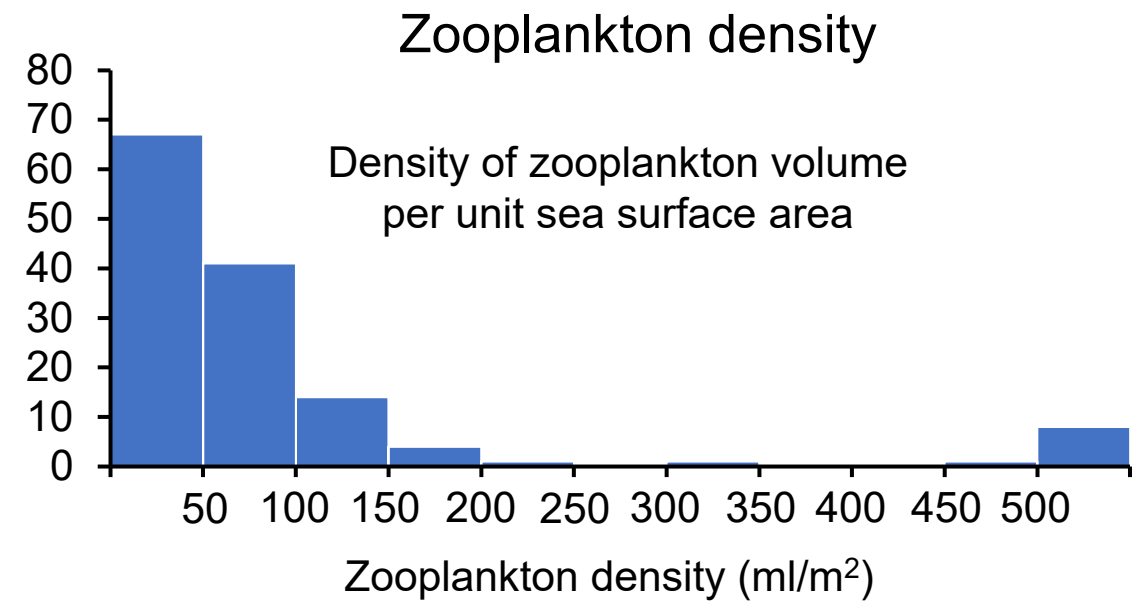
Present study

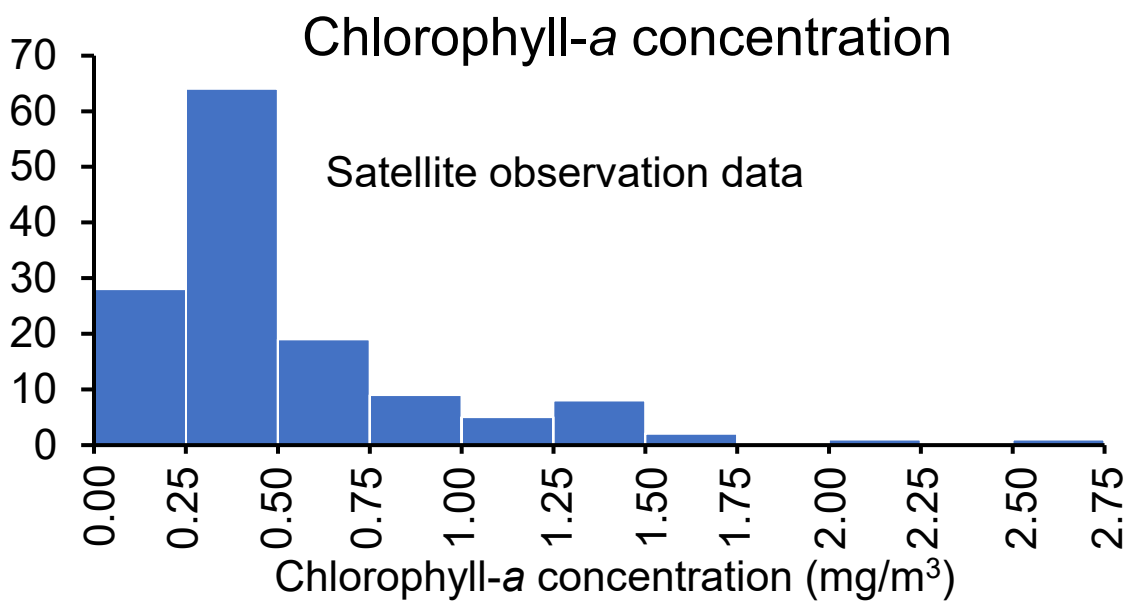
- The samples from medium-biomass period of anchovy
- Extending the seasons and the regions
- Including multiple environmental factors
- The ultimate goal was to test density-dependent effects.

Distribution of environmental factors



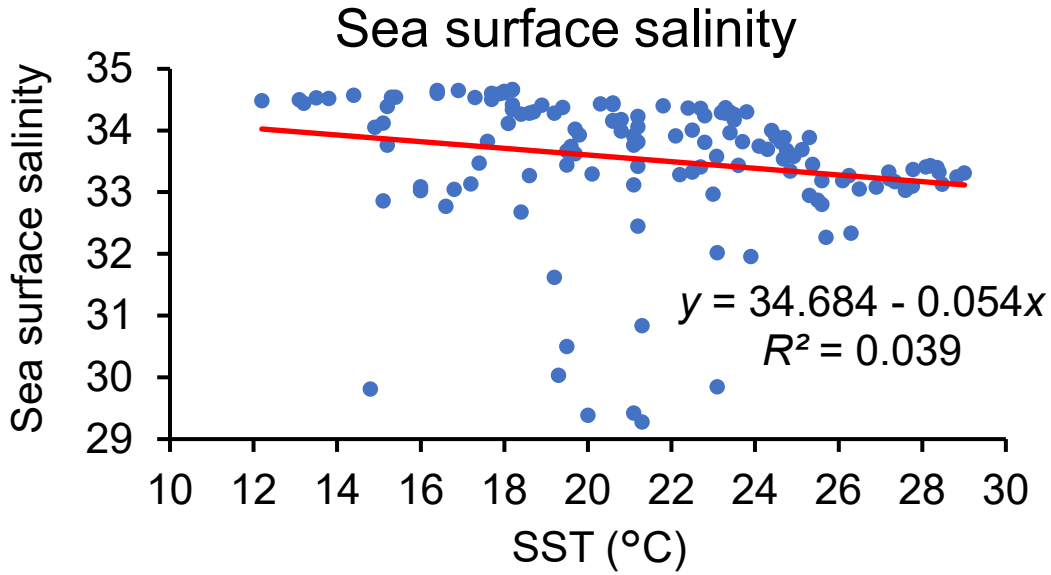


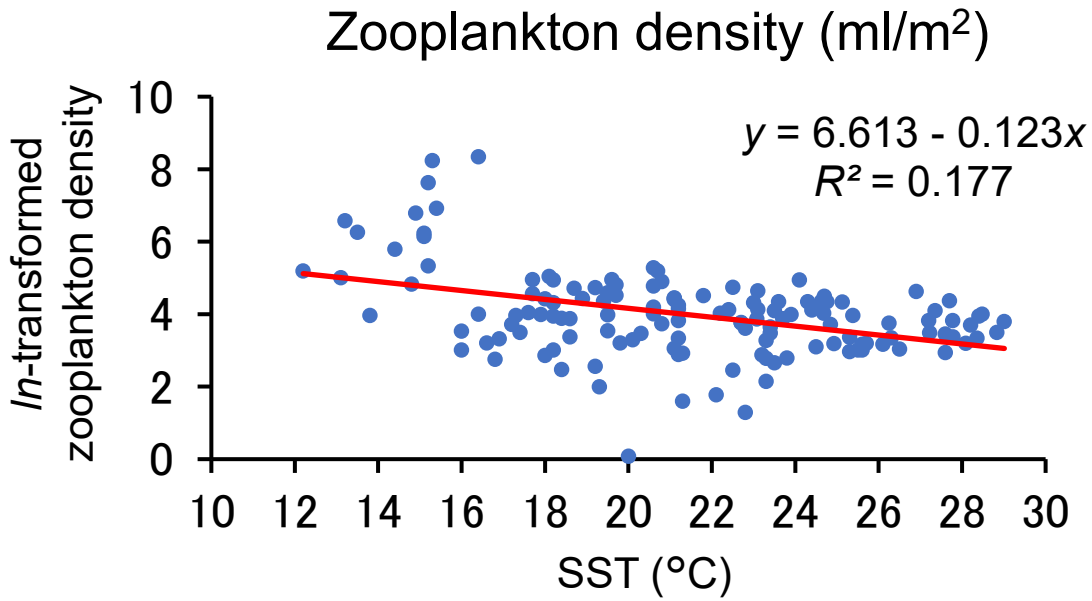


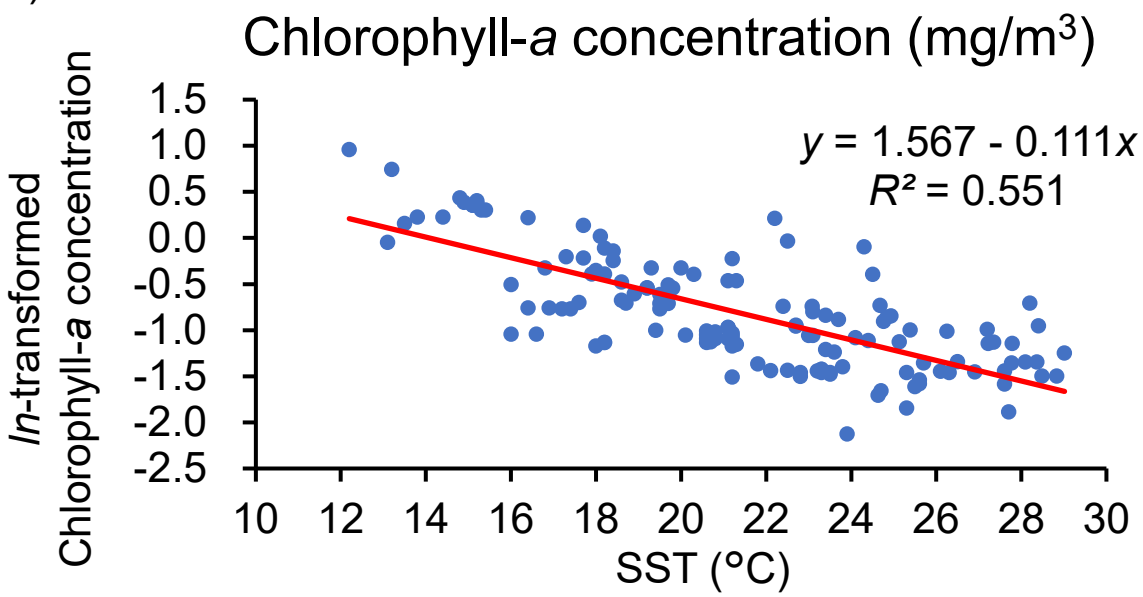


Relationships between SST and the other environmental factors

Significant relationships between SST and the other environmental factors

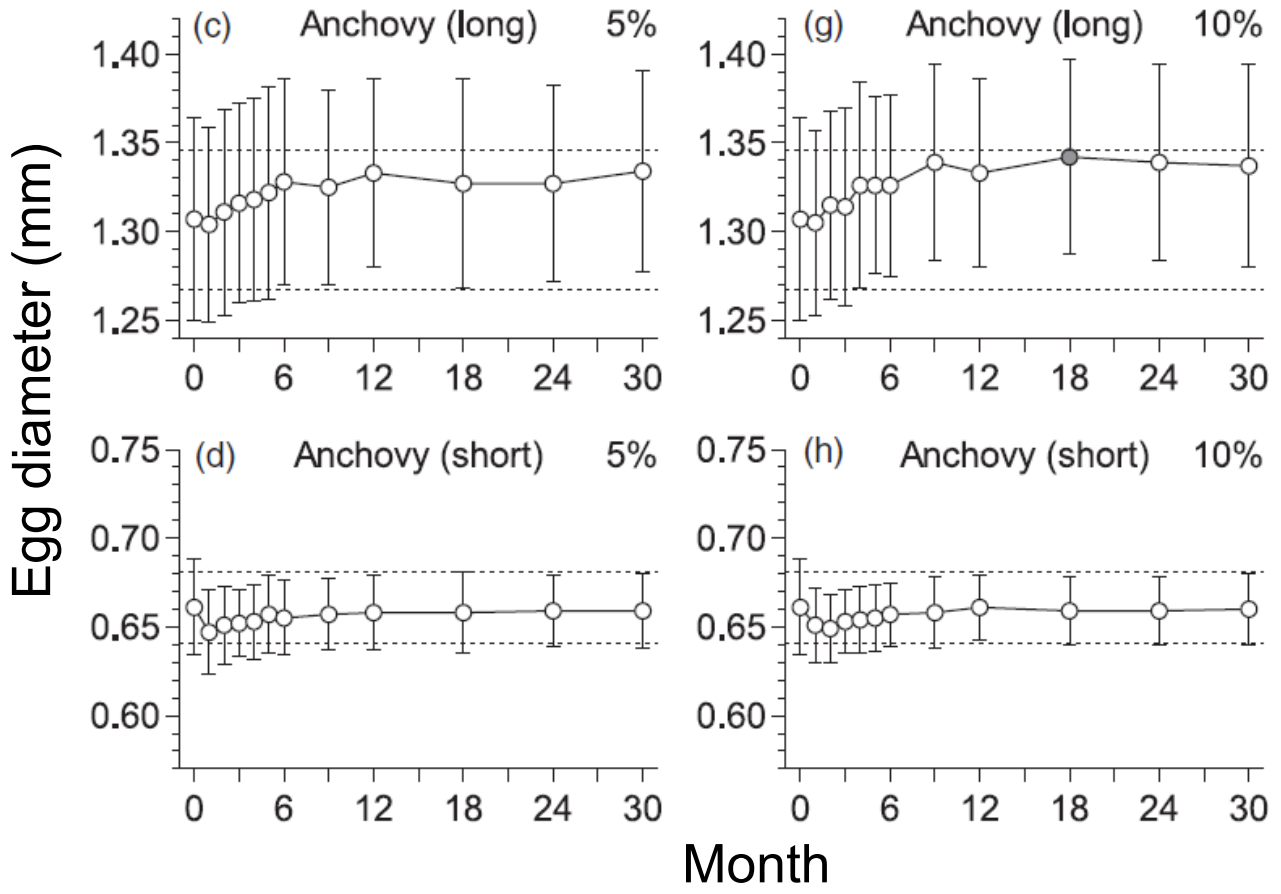






Effects of formalin preservation on egg size

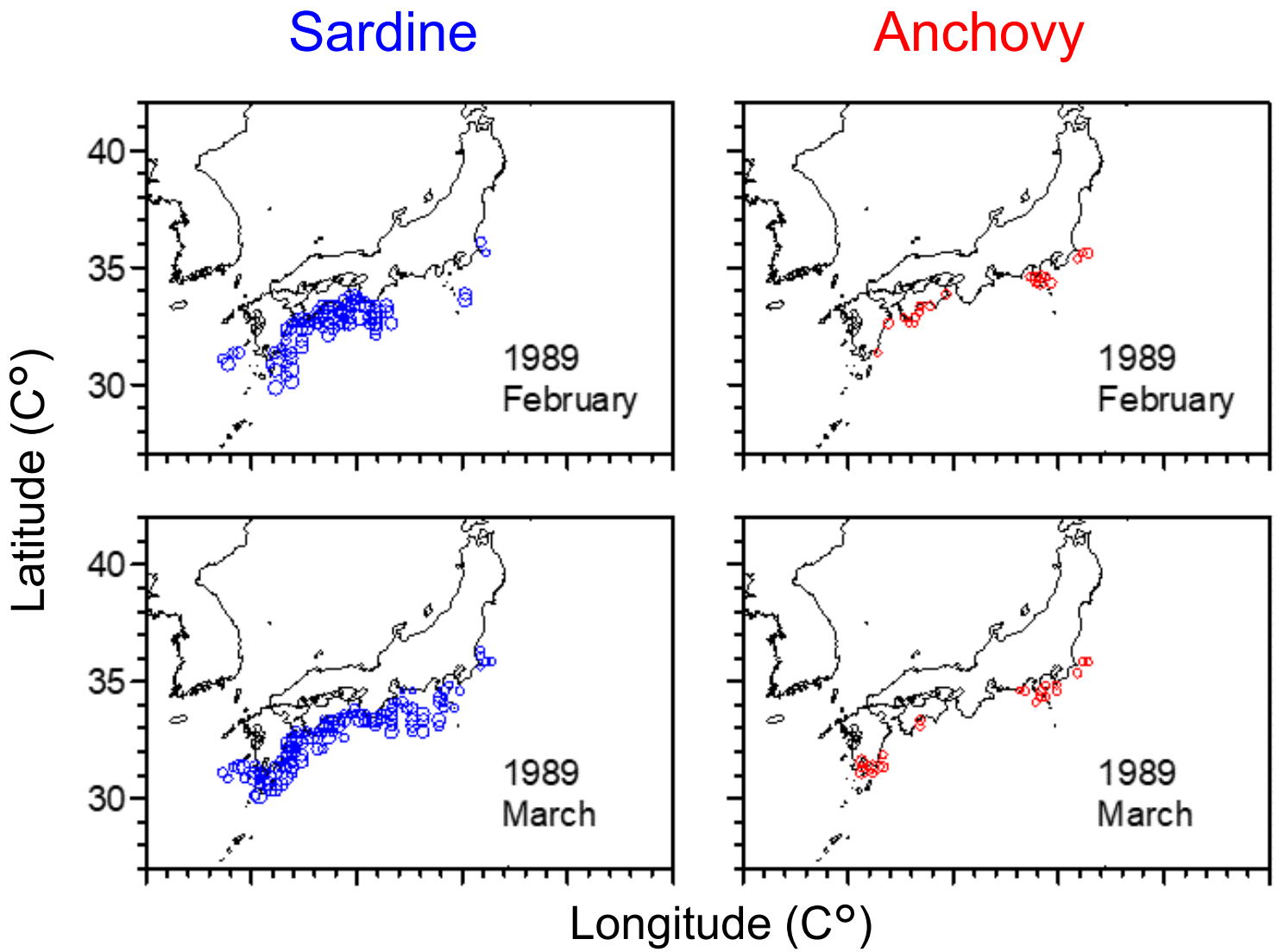
- Anchovy eggs were preserved in 5% and 10% formalin.
- Egg diameters were measured over 30 months.
  →Small variability in both long and short diameters



(Nyuji *et al*. 2022)

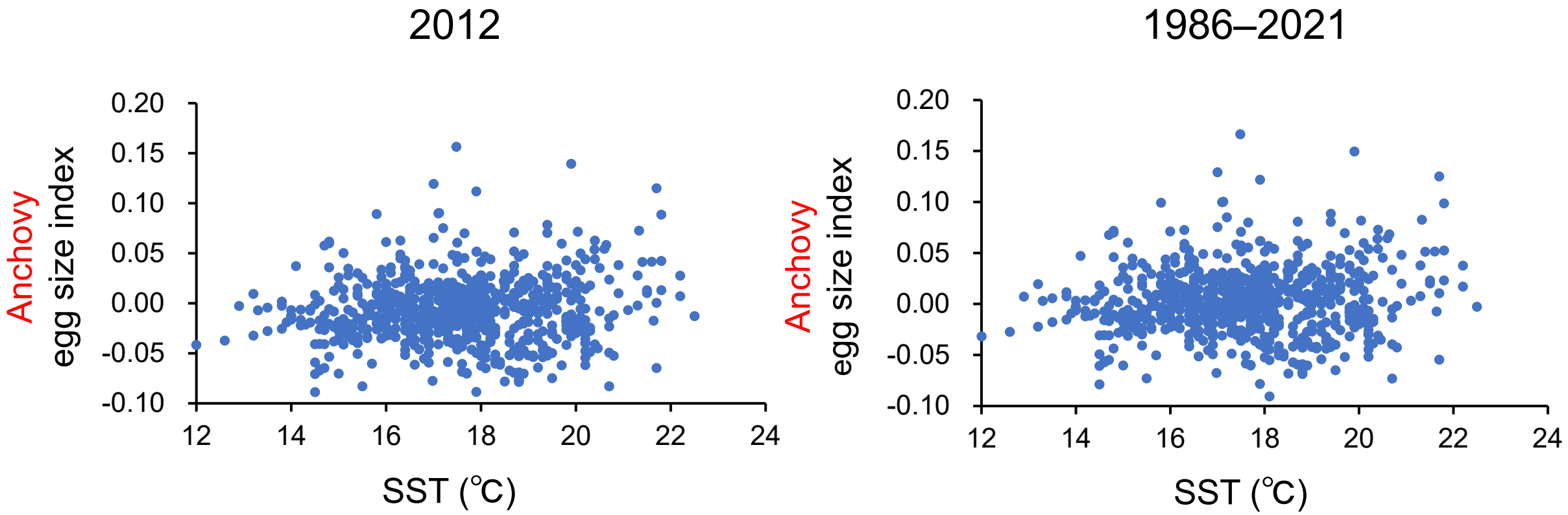
Spawning overlap

There is spawning overlap between sardine and anchovy.



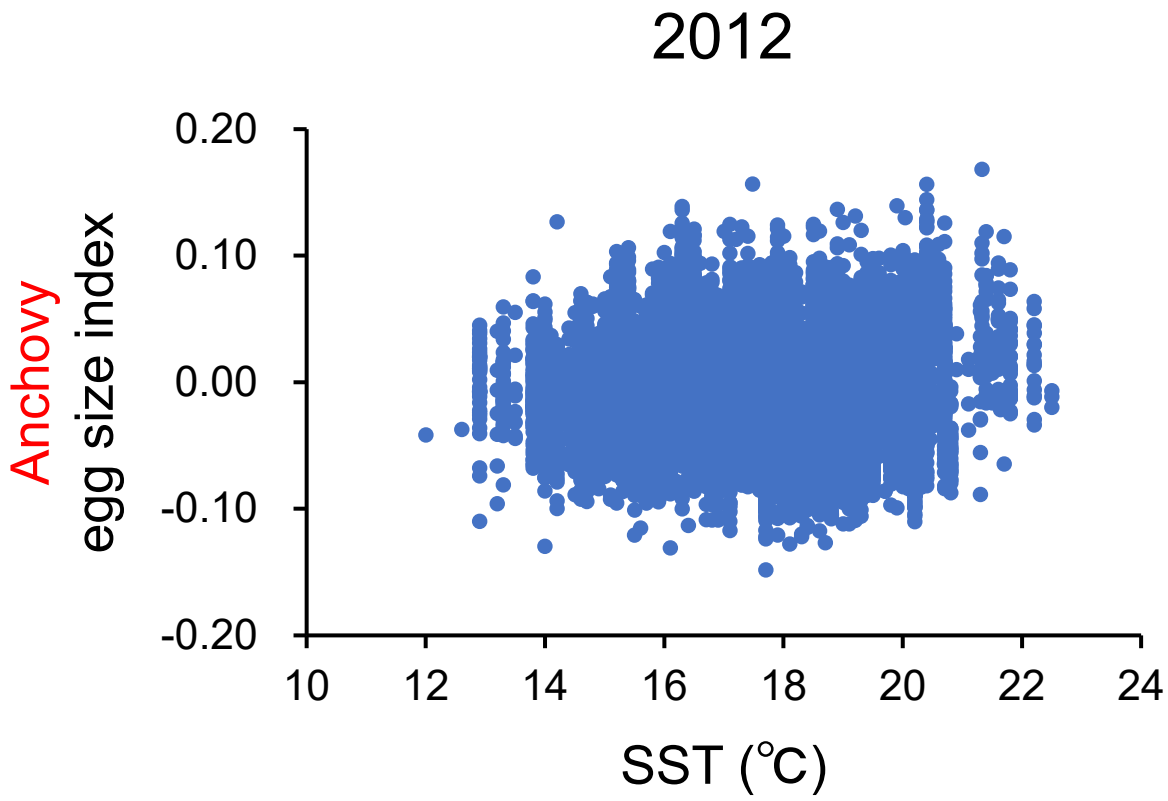
Standardization by SST

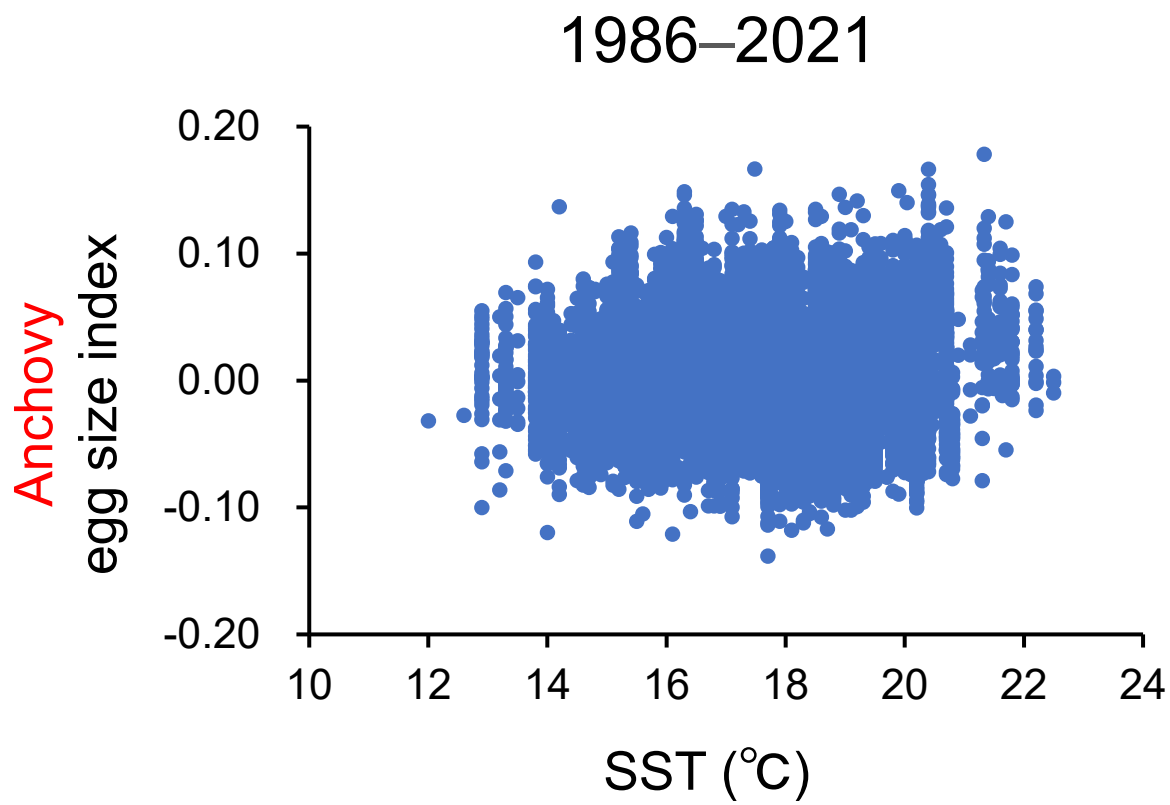
No significant relationship at the station level



Standardization by SST

A significant relationship at the individual level

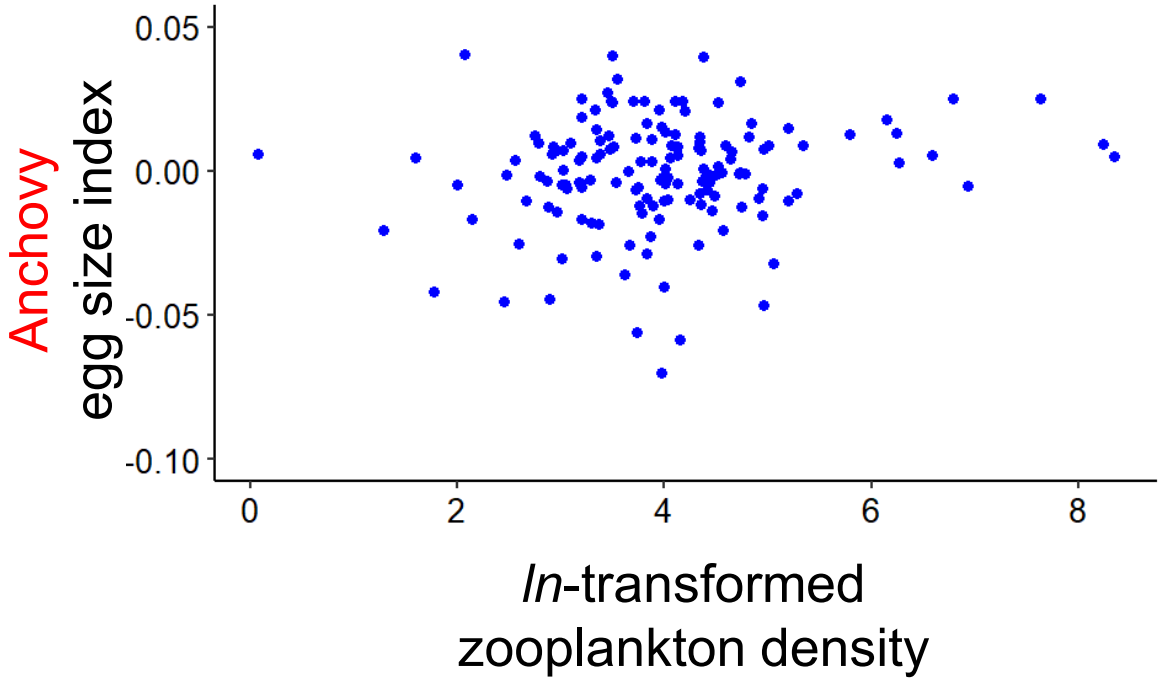




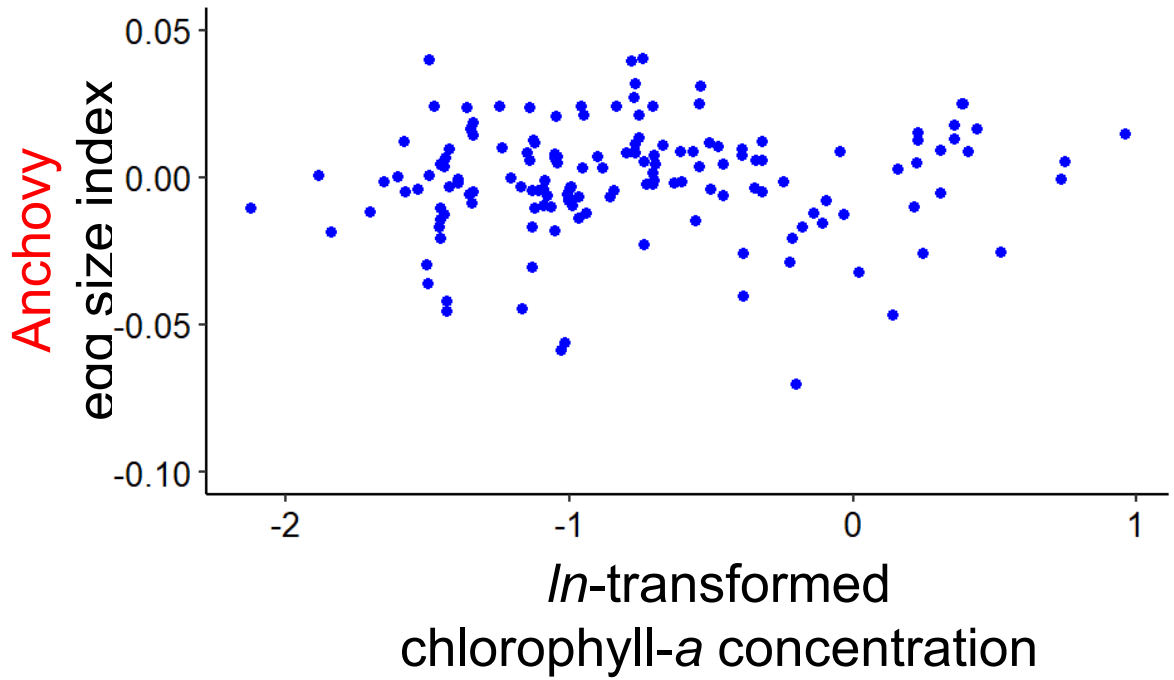
Effect of other environmental factors

No significant relationships between other environmental factors and egg size index

Zooplankton density (ml/m^2)

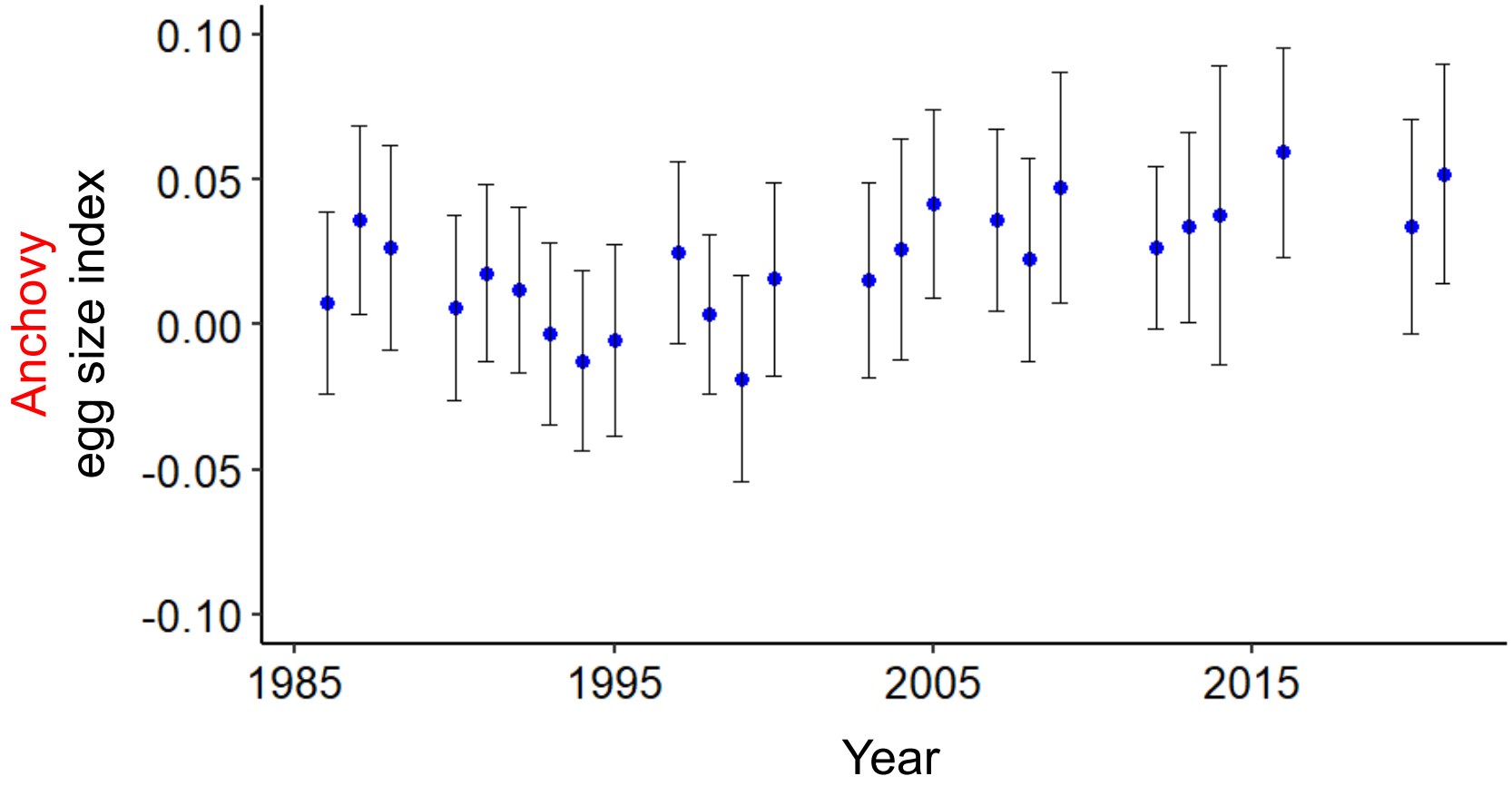


Chlorophyll-*a* concentration (mg/m^3)



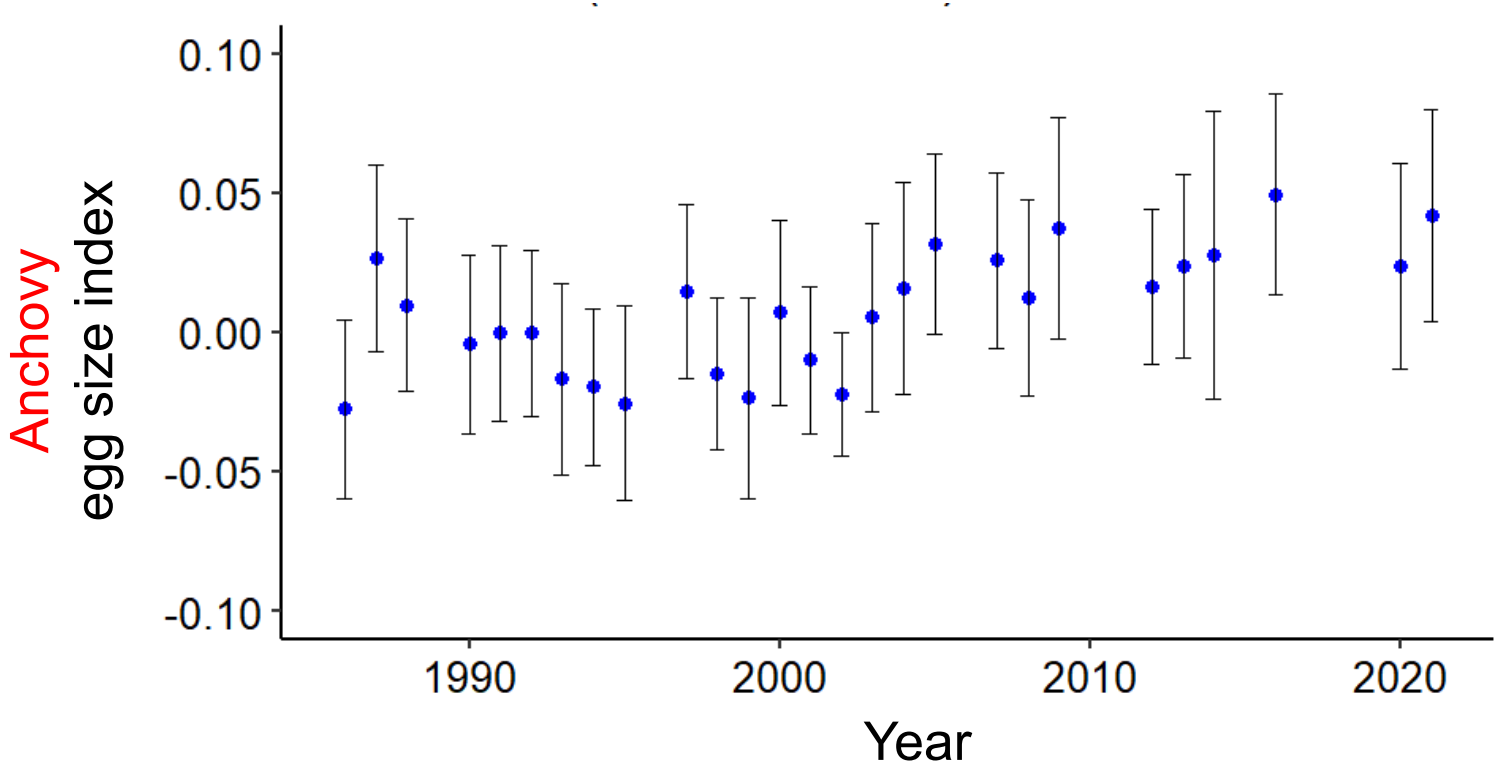
Annual variability in anchovy egg size (Feb. & Mar.)

Considerable variability in egg size index
in February and March



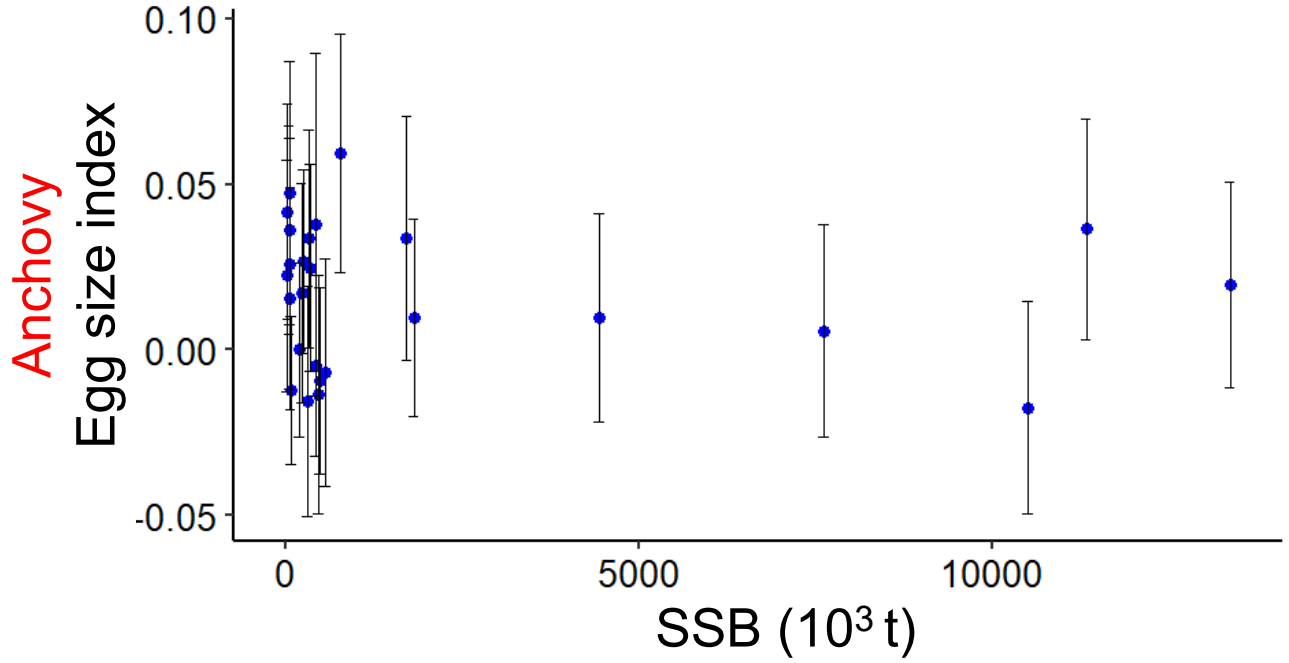
Standardization based on the relationship in 2012

Considerable variability in egg size index
even after standardization based on the relationship in 2012

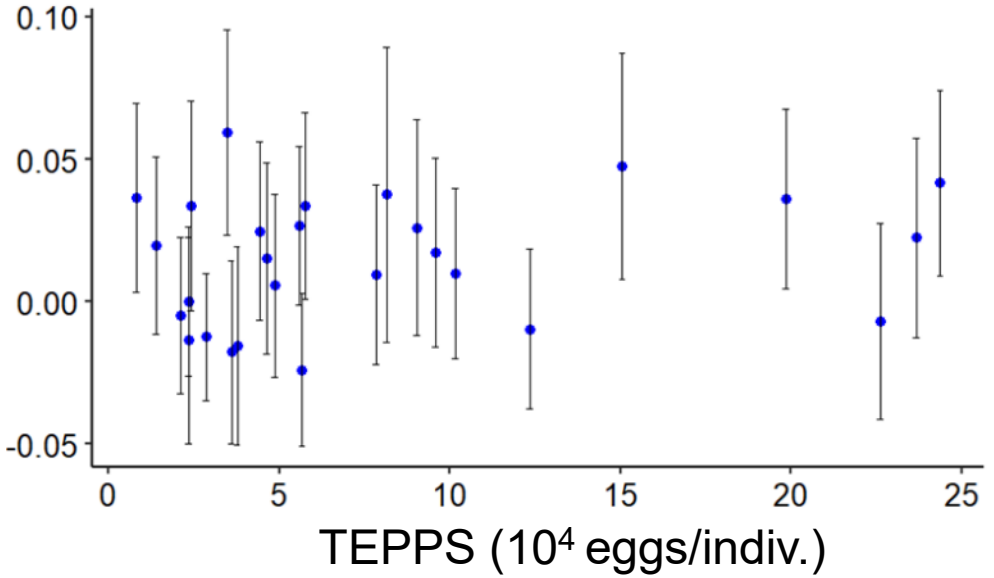


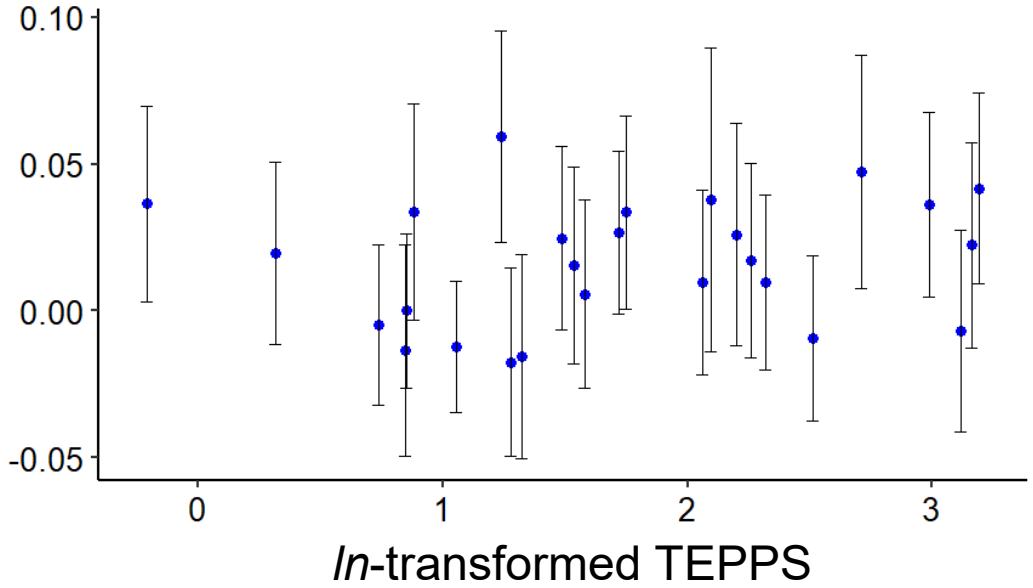
The relationship with sardine biomass

Sardine SSB



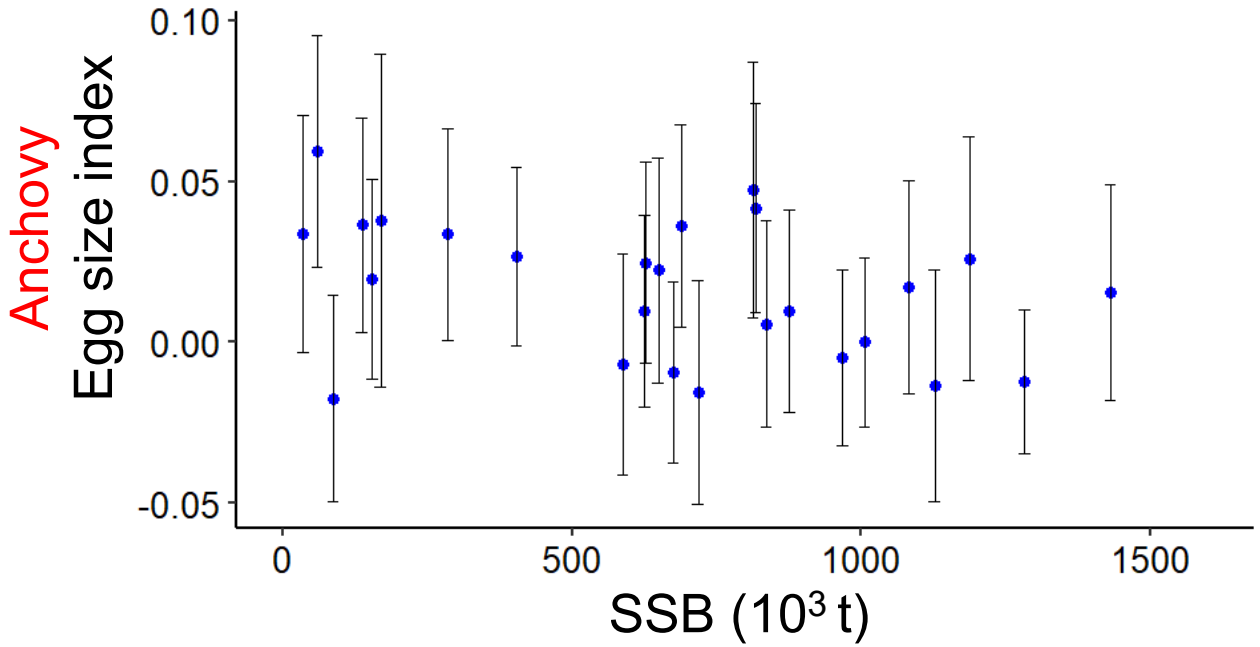
Sardine TEPPS (10^4 eggs/indiv.)



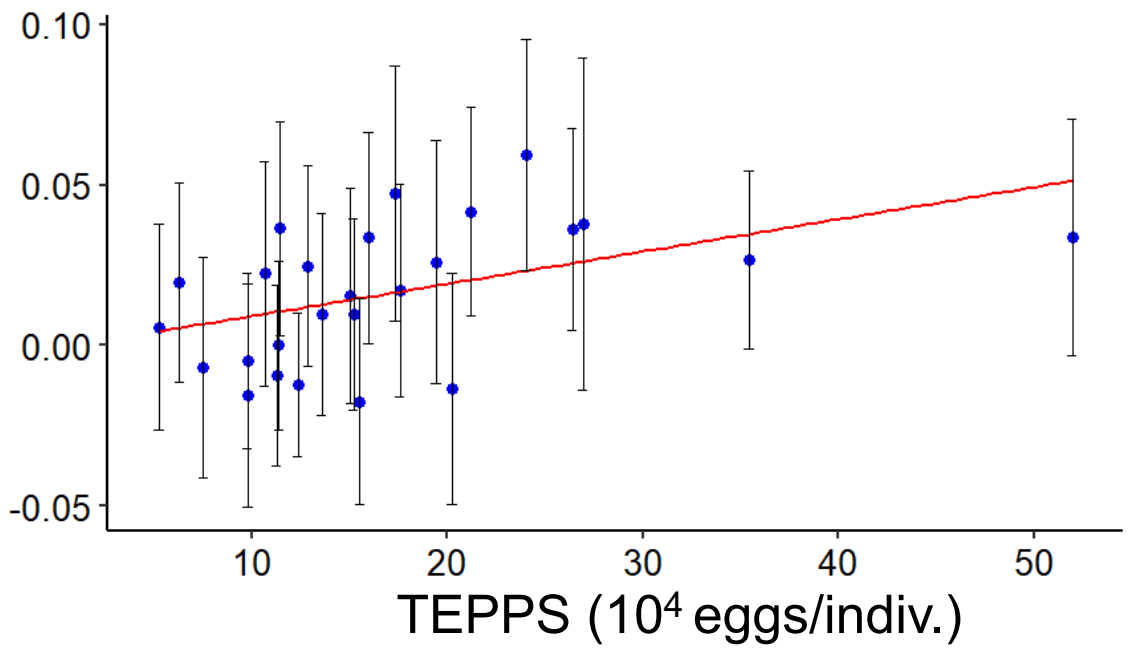


The relationship with anchovy biomass

Anchovy SSB

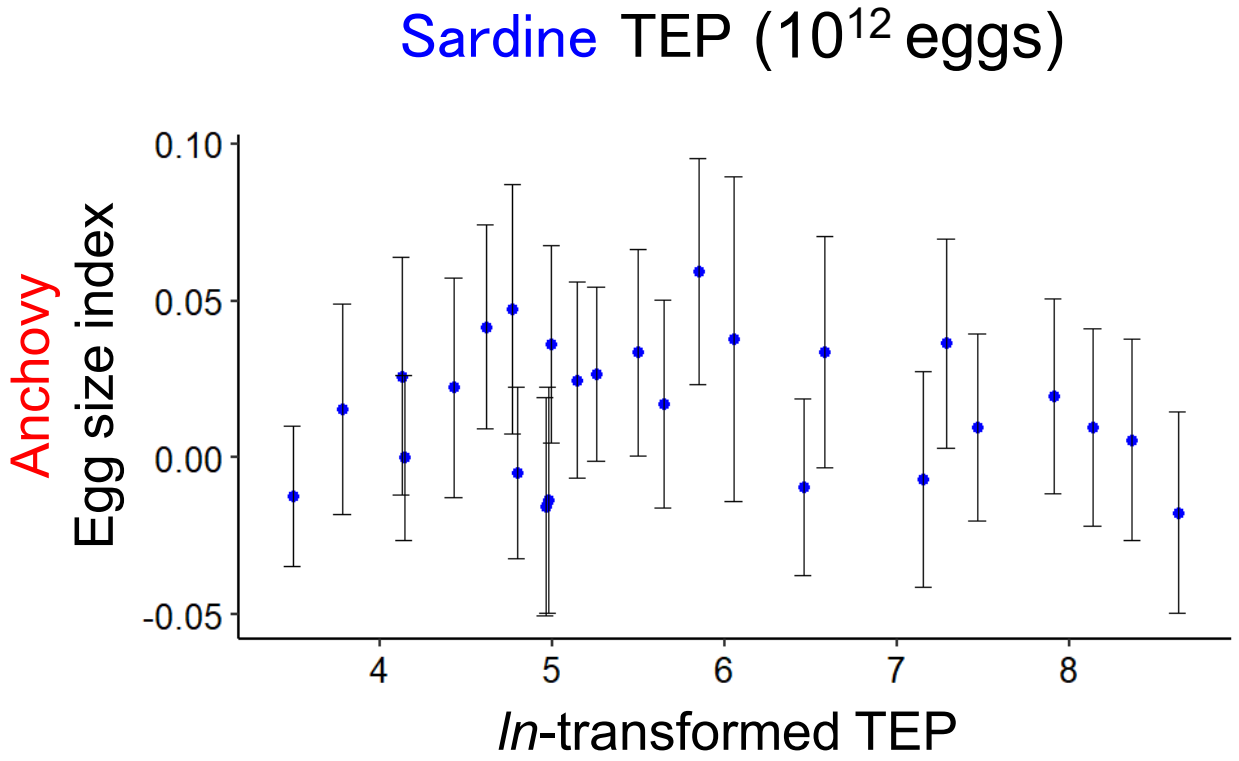


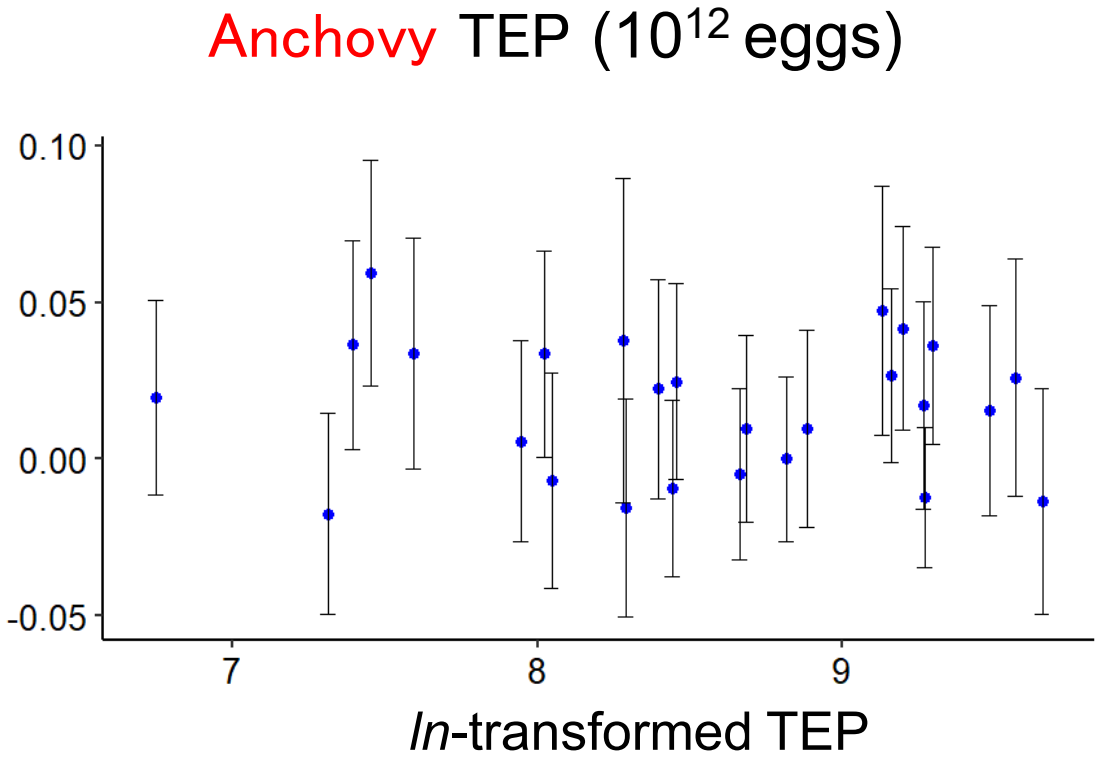
Anchovy TEPPS



Total egg production (TEP) of sardine and anchovy

No significant relationship between TEP and Anchovy egg size





Total egg production (TEP) of sardine and anchovy

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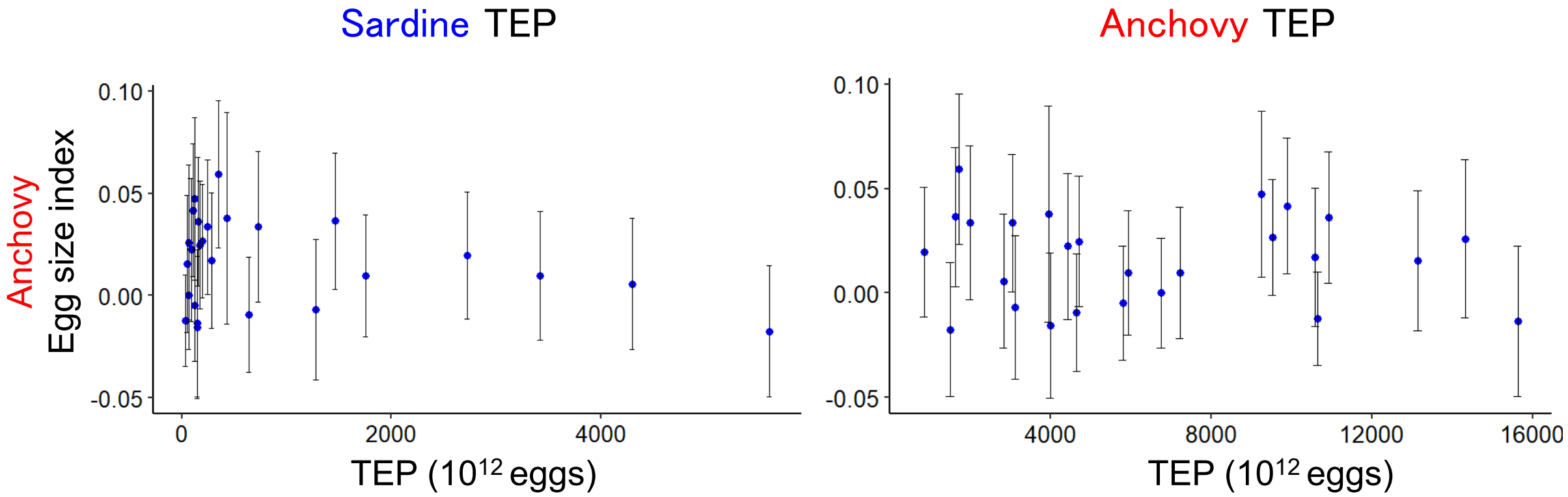
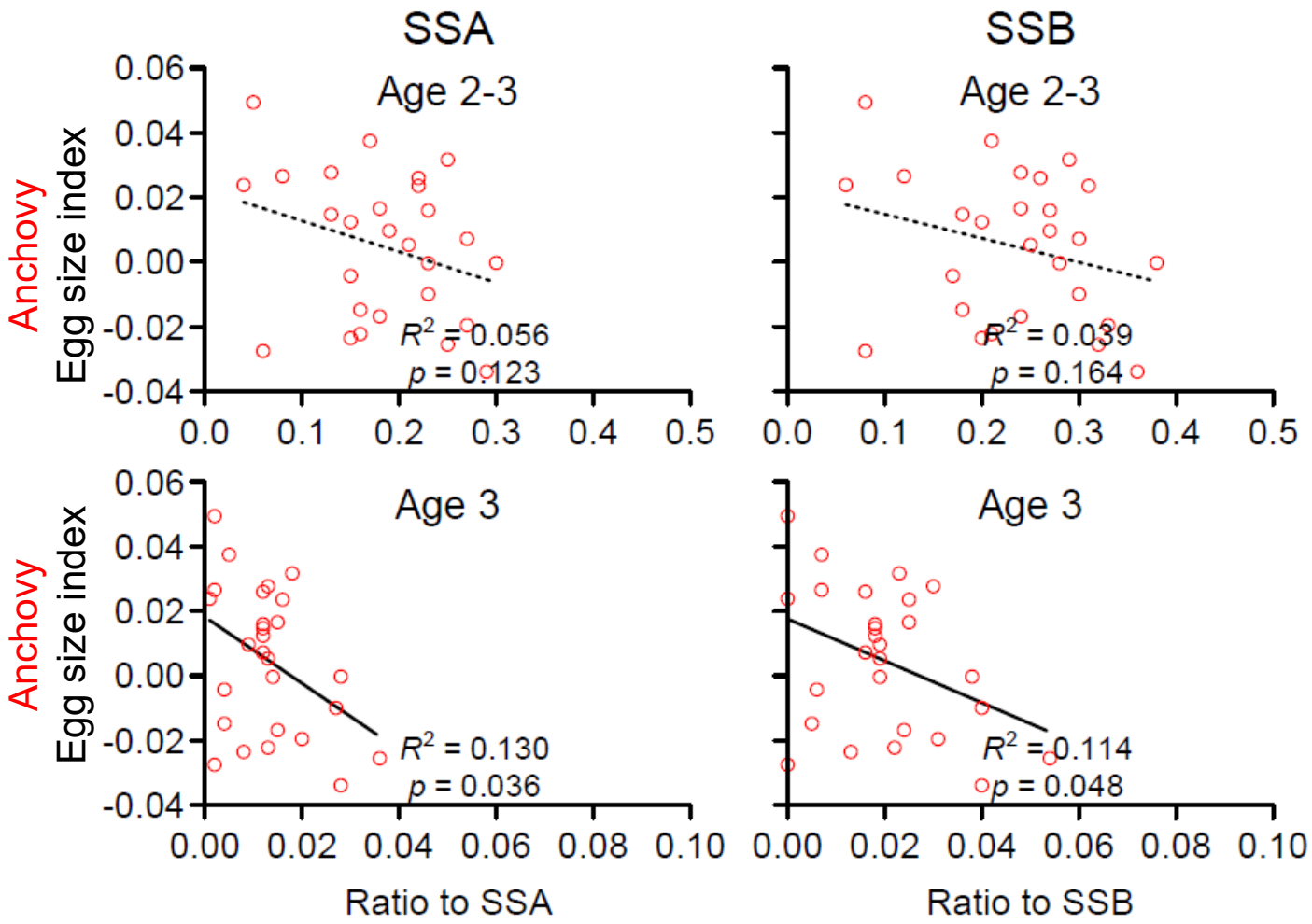


Age structures

A negative relationship between the ratio of older fish and egg size index

→ Anchovy egg size may be affected by sardine-density dependent effect.



Sardine-density dependent effect

Sardine and anchovy compete for food resources.

→ The fluctuation of sardine biomass would be critically effective, whereas that of anchovy biomass is negligible.

Biomass fluctuations