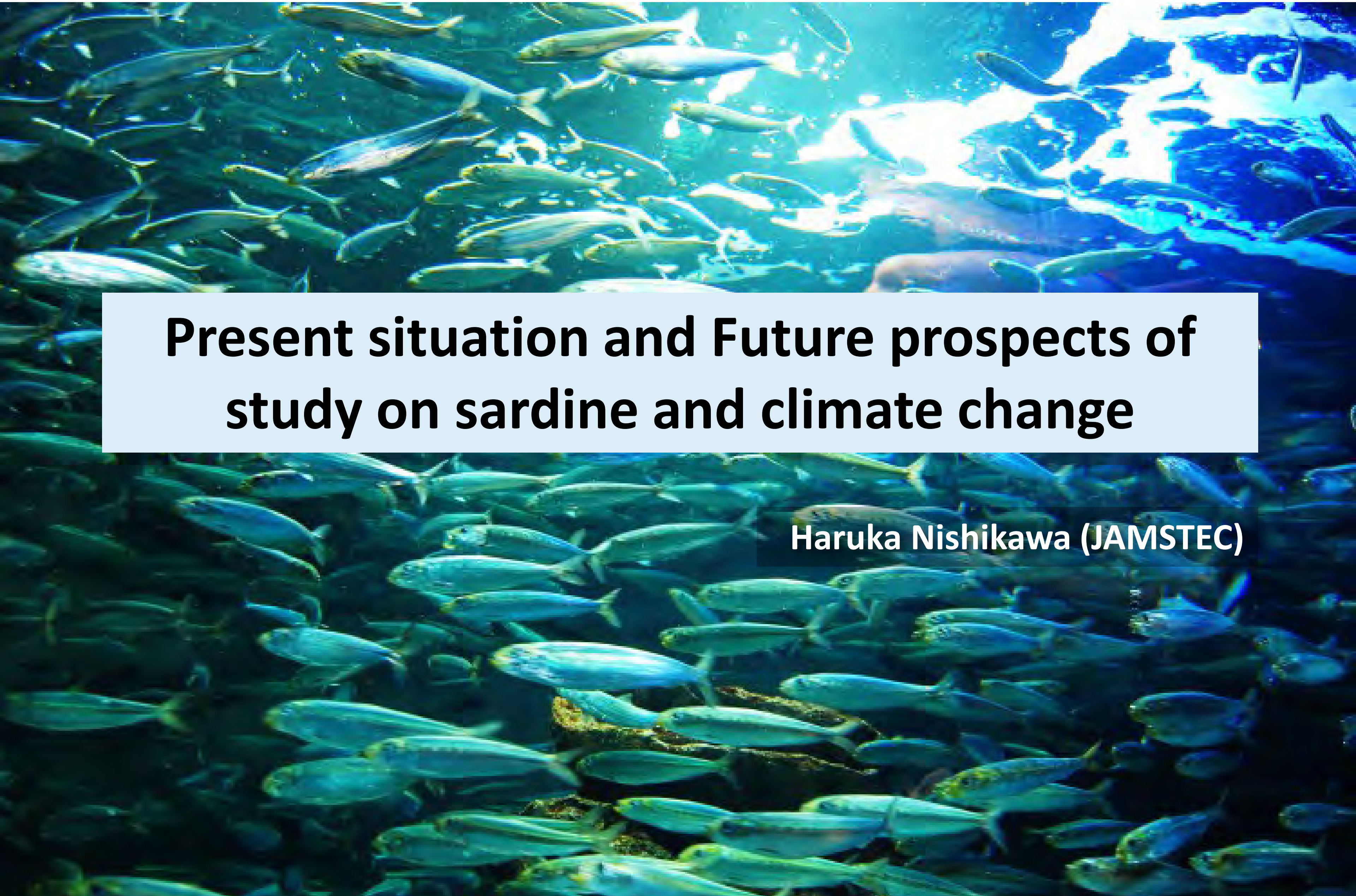
Nov. 1, 2018 11:00–11:30, Yokohama

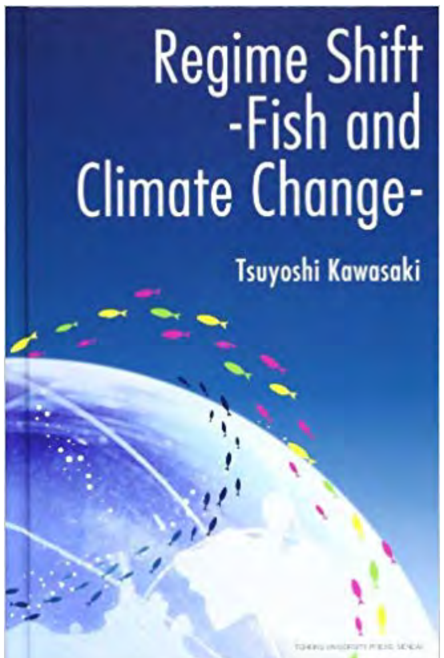


Present situation and Future prospects of study on sardine and climate change

Haruka Nishikawa (JAMSTEC)

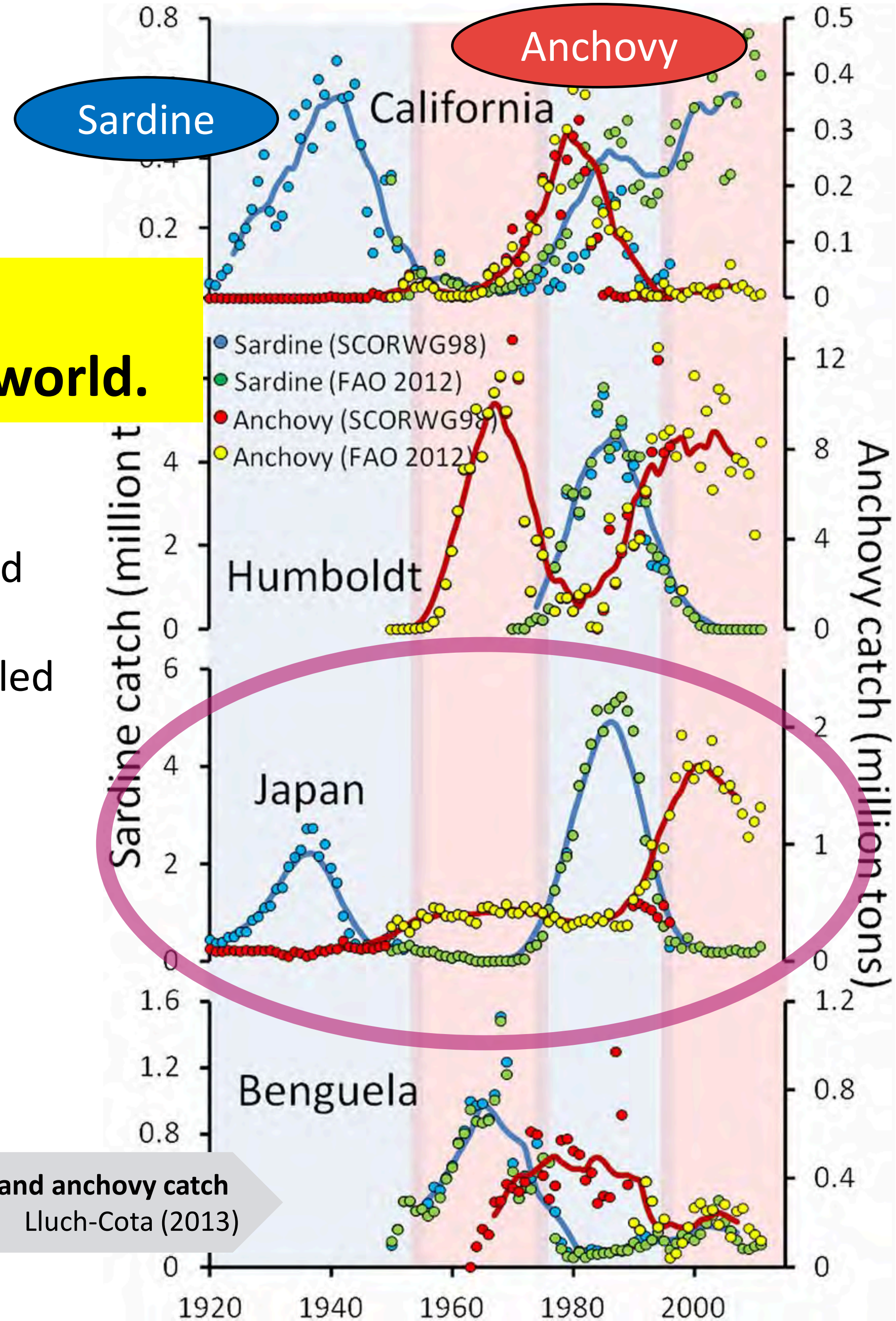
Sardine characteristics

Sardine stocks show multi-decadal fluctuations in four regions of the world.



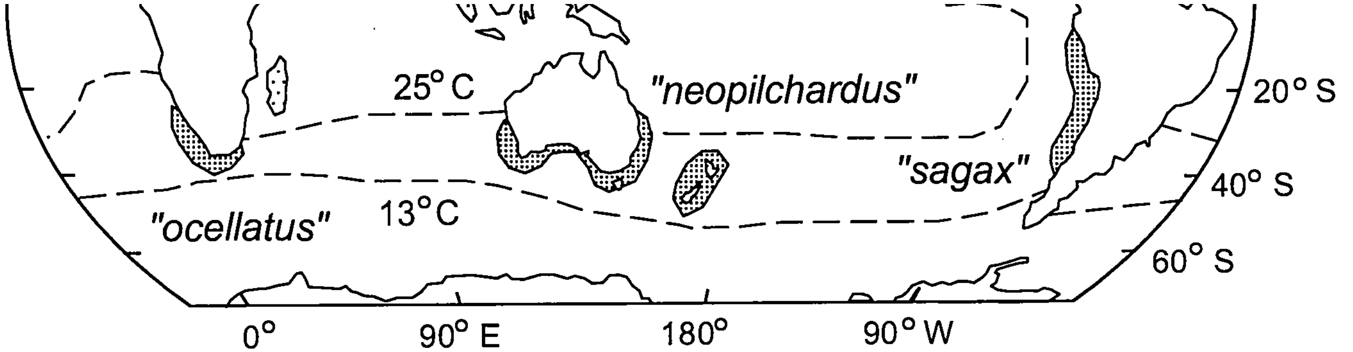
Kawasaki (2013)

Kawasaki (1983) inferred that the sardine stock fluctuations are controlled by climate and environmental change.



Time series of sardine and anchovy catch
Lluch-Cota (2013)

Japanese sardine *(Sardinops malanostictus)*



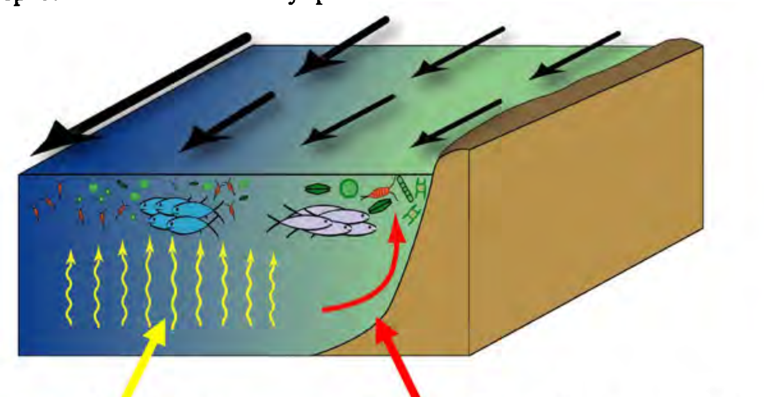
IG. 1. Distribution of *Sardinops*. The boundaries of temperate sardine habitat (13° and 25°C isotherms) are indicated by dashed lines.

such that the most recent contact between regional forms would be mediated by coastal movement across the equator, presumably facilitated by cooler conditions in the past (see Greenland Ice-Core Project Members 1993; Guilderson et al. 1994; Kotilainen and Shackleton 1995). In this interpretation, the closest phylogenetic affinities would be between California and Chile in the East Pacific and possibly between Japan and Australia in the West Pacific.

derstanding of evolutionary history would emerge from the consideration of both nuclear and mitochondrial lineages (Karl et al. 1992; Palumbi and Baker 1994; Bernatchez and Osinov 1995). Nuclear gene genealogies are not currently available, but a recently completed survey of alleles at 34 protein electrophoretic loci ($n = 224$; Grant and Leslie 1996) can provide additional perspectives on evolutionary processes in *Sardinops*.

Bowen and Grant (1997)

Most of Sardinops species are distributed in the upwelling region.



Rykaczewski and Checkley (2008)

Japanese sardine *(Sardinops malanostictus)*

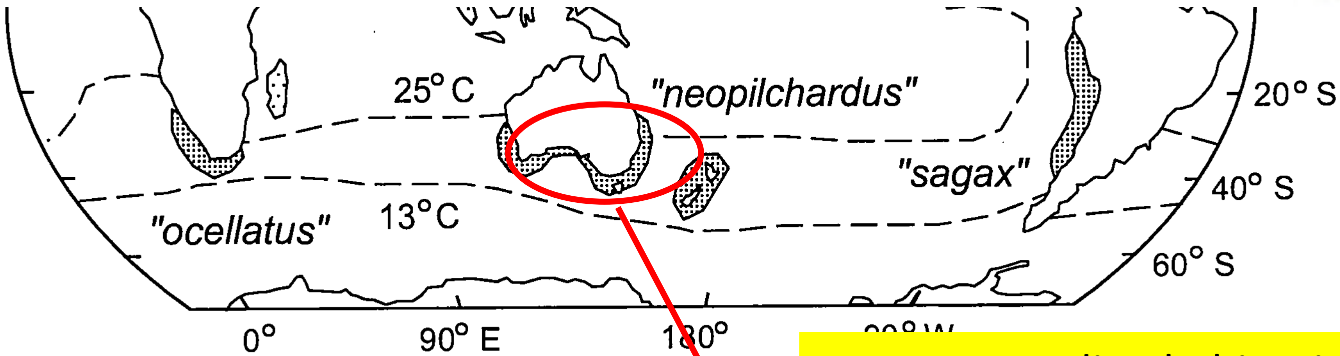
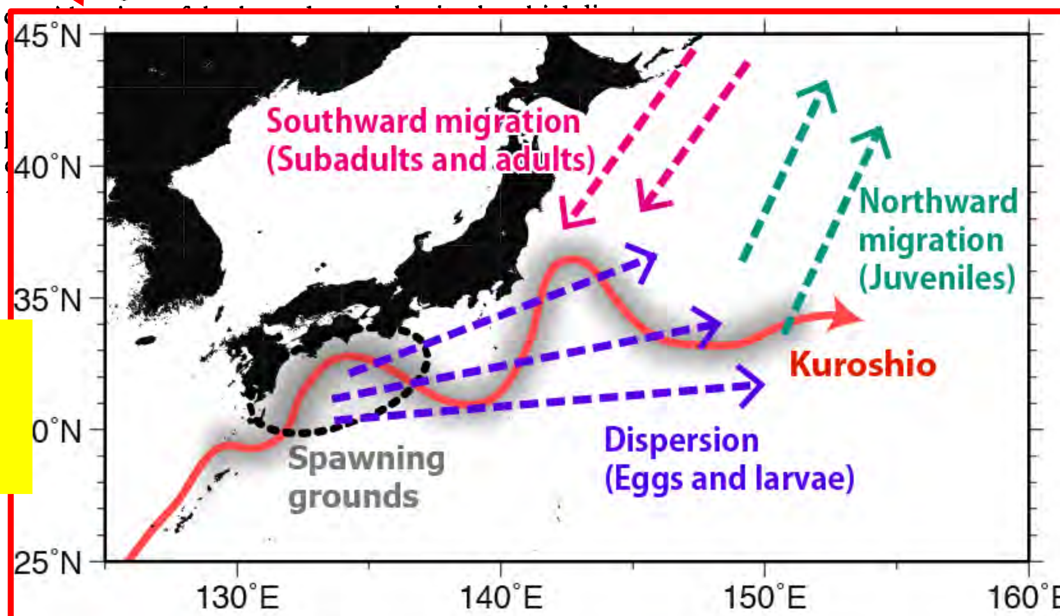


FIG. 1. Distribution of *Sardinops*. The boundaries of temperate sardine habitat

such that the most recent contact between regional forms would be mediated by coastal movement across the equator, presumably facilitated by cooler conditions in the past (see Greenland Ice-Core Project Members 1993; Guilderson et al. 1994; Kotilainen and Shackleton 1995). In this interpretation, the closest phylogenetic affinities would be between California and Chile in the East Pacific and possibly between

derstanding of evolutionary history would emerge from the

Japanese sardine habitat is strongly influenced by a western boundary current, the Kuroshio.



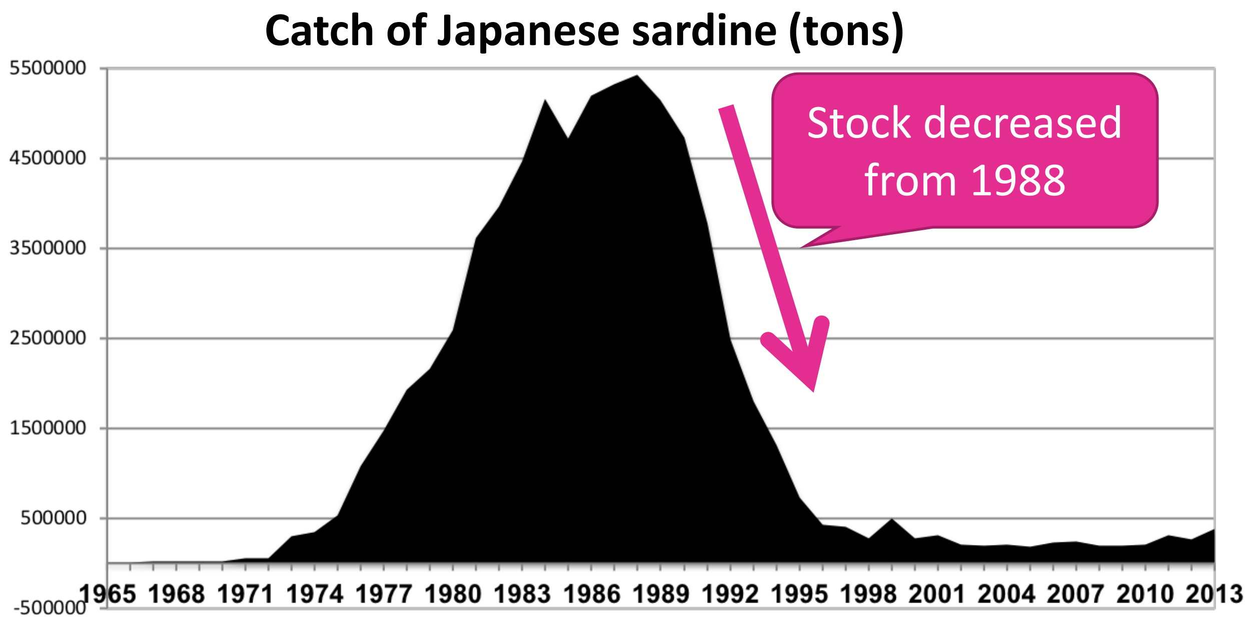
Life history of Japanese sardine

For the stock fluctuation, **the Kuroshio is important.**

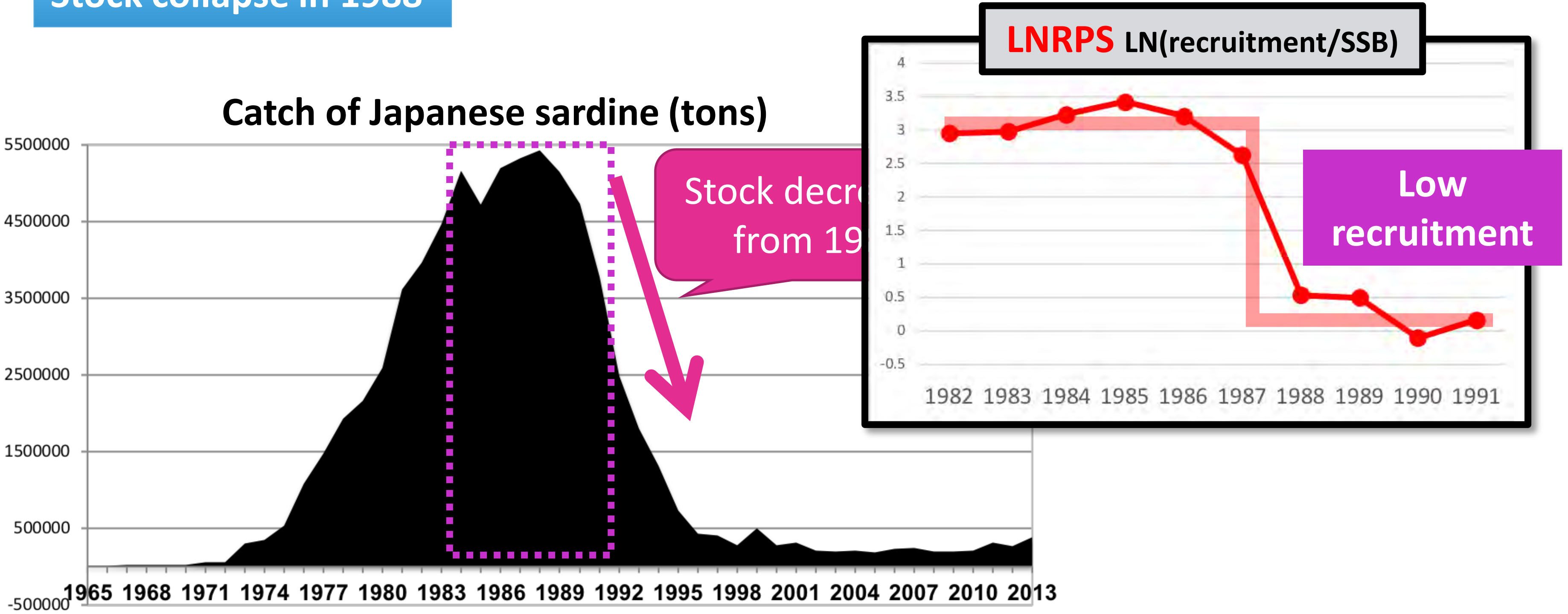
- **What we know about the environmental change influence on the Japanese sardine stock fluctuation**
  - The same environmental change can explain a whole cycle (increase and decrease) of stock fluctuation?
  - The environmental change can explain the stock fluctuation sufficiently?

- **Future topics**

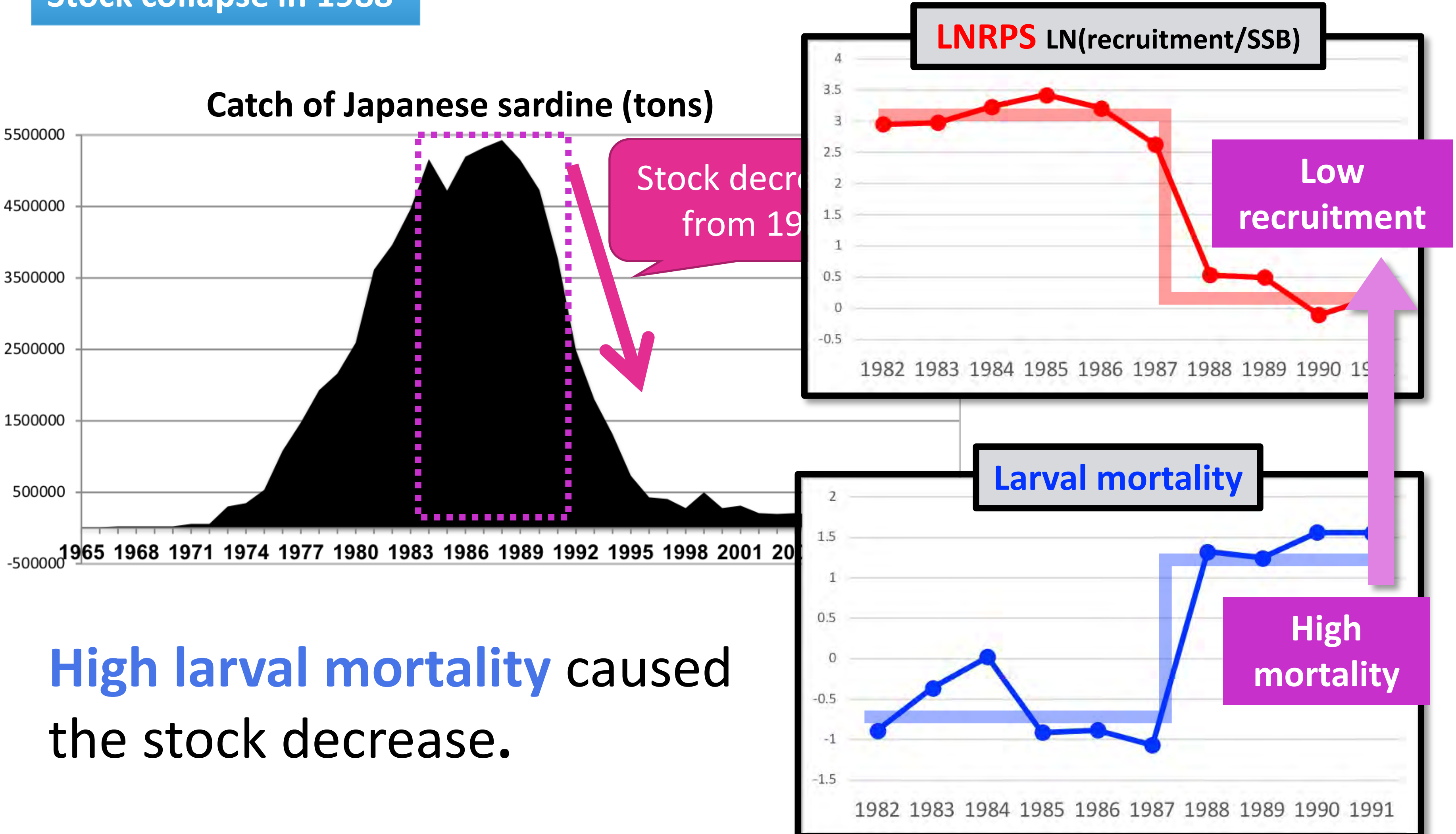
Stock collapse in 1988



Stock collapse in 1988



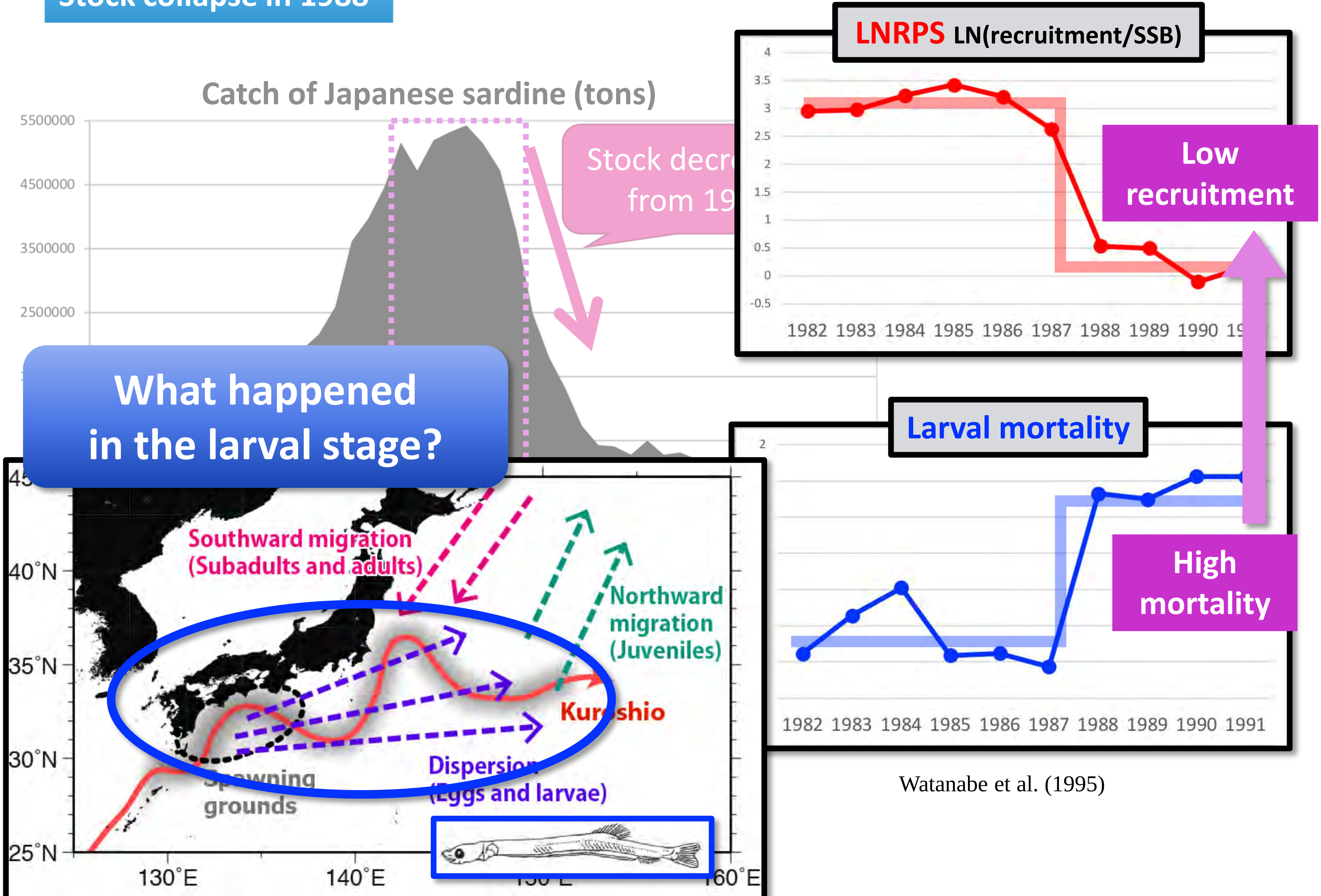
Stock collapse in 1988



High larval mortality caused the stock decrease.

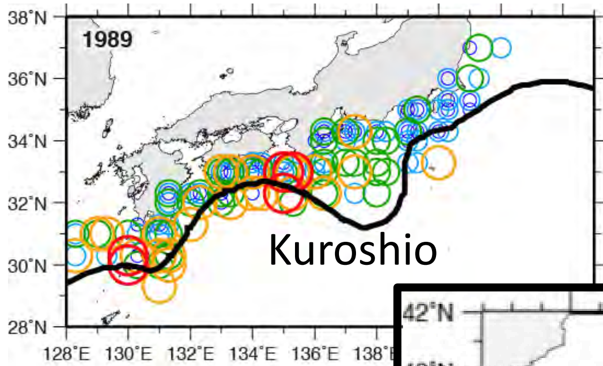
Watanabe et al. (1995)

Stock collapse in 1988



Watanabe et al. (1995)

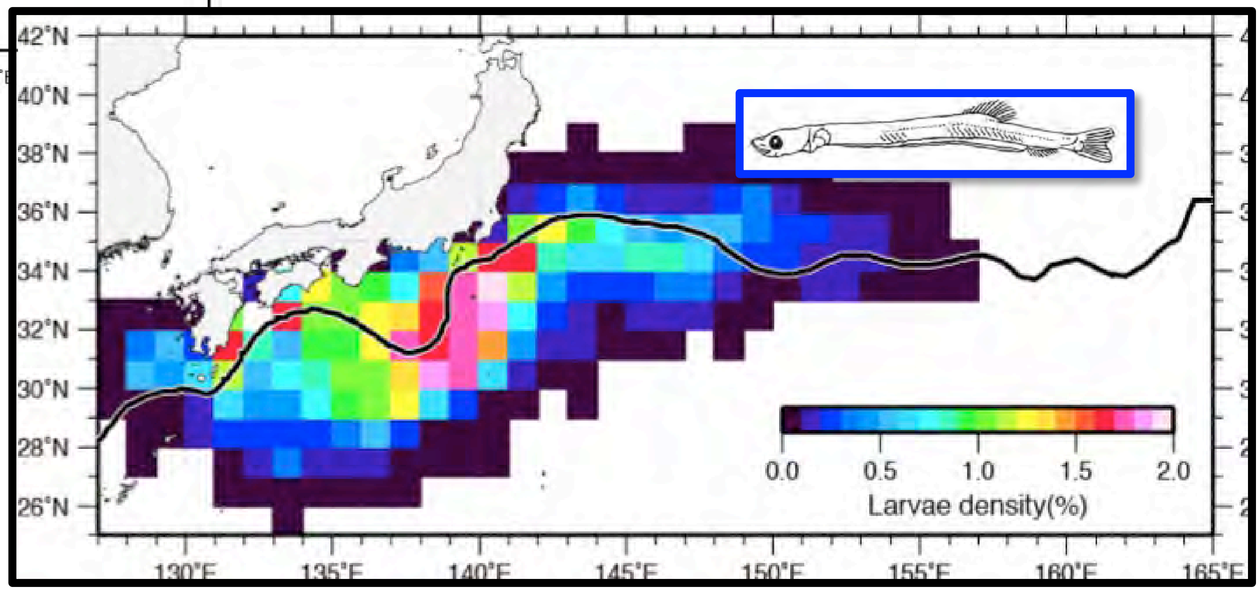
Distribution of the sardine larvae



Observed egg distribution
(Oozeki et al., 2007; Takasuka et al., 2008)

Larval distribution area

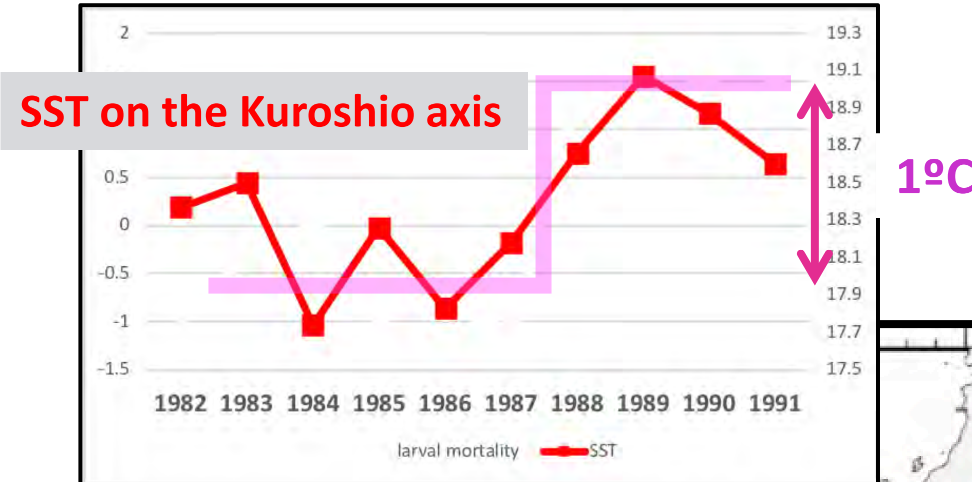
Results of the particle tracking experiments from the spawning grounds.



Nishikawa et al. (2013)

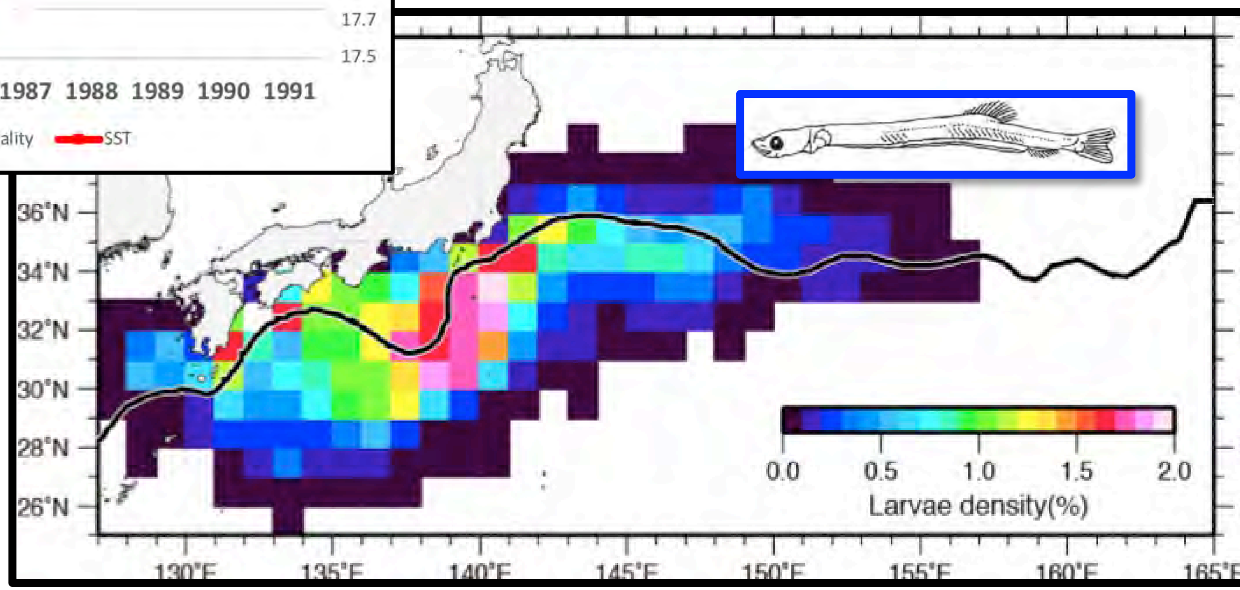
Main larval distribution area is
the vicinity of the Kuroshio axis from winter to spring.

Environment of the Kuroshio axis and larval survival



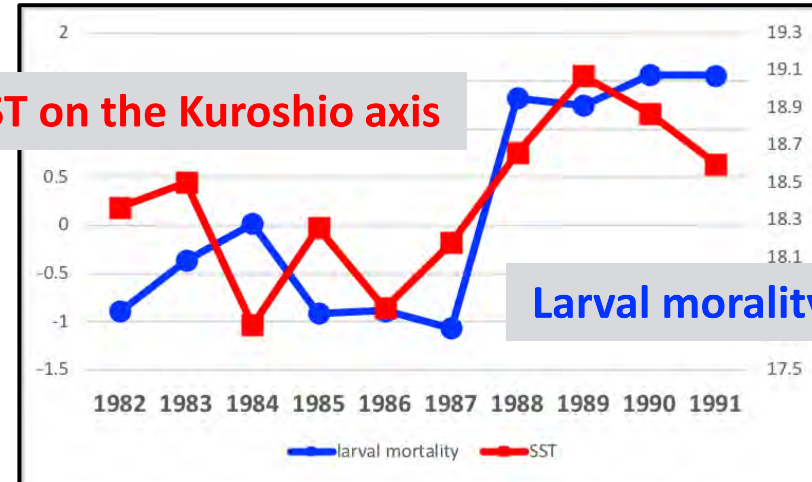
Nishikawa et al. (2011)

From 1988, the SST suddenly rose.



Nishikawa et al. (2013)

Environment of the Kuroshio axis and larval survival

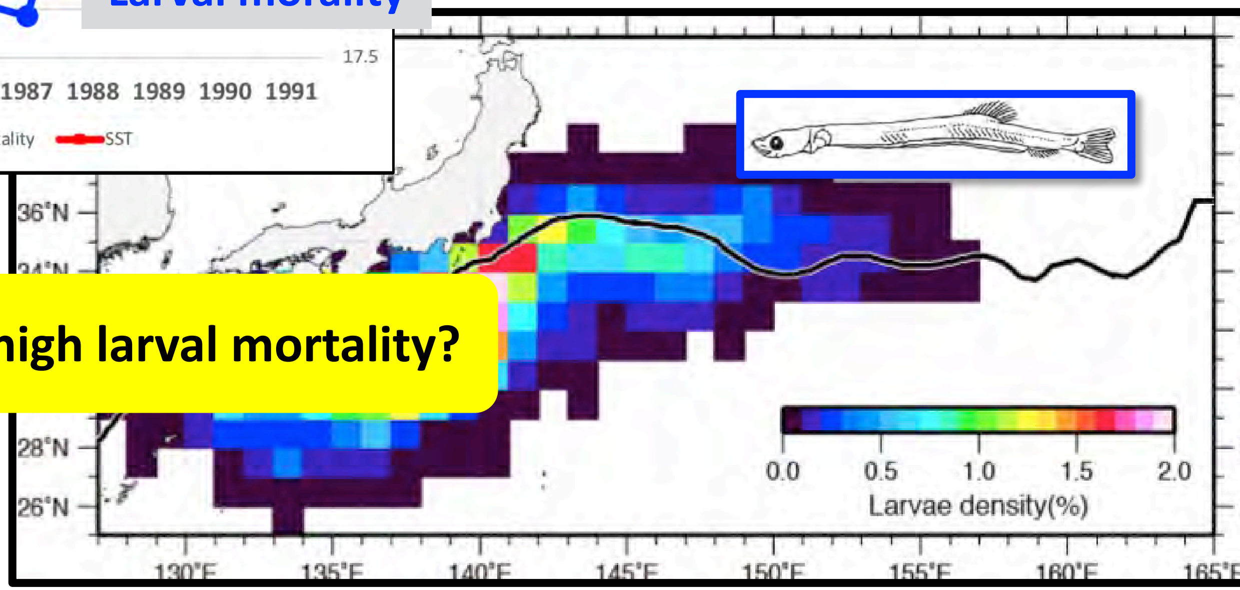


Nishikawa et al. (2011)

From 1988, the SST suddenly rose.

Then, the larval mortality increased.

High SST caused high larval mortality?



Nishikawa et al. (2013)

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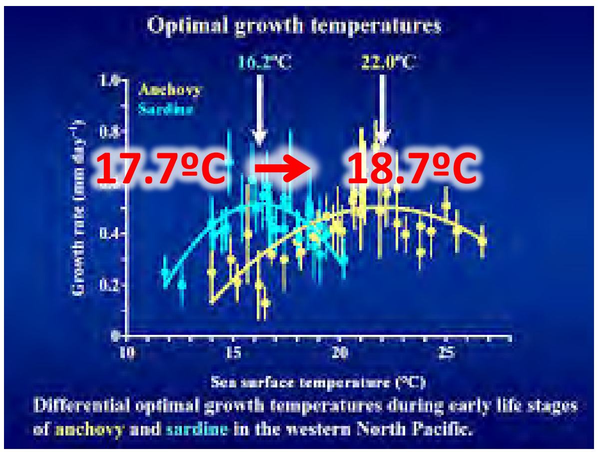


Takasuka et al. (2007)

High SST slows the larval growth

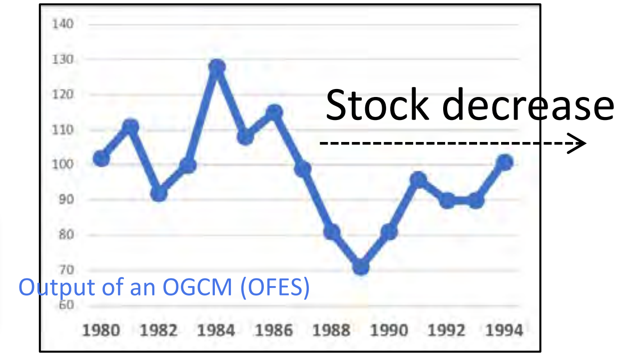
High SST

Weak mixing

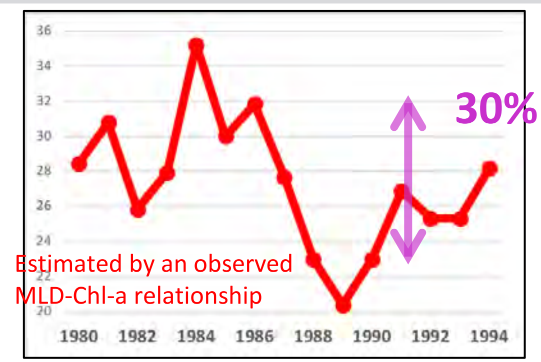
Food shortage

High mortality

Winter MLD (m)

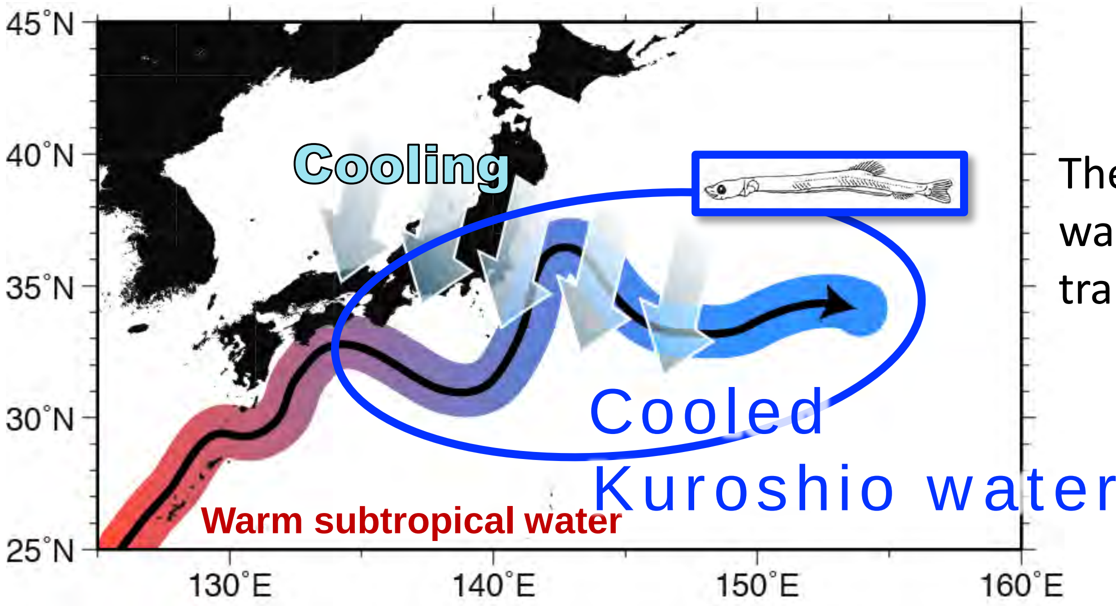


Spring Phytoplankton (mgC/m³)



High SST related to the low food availability via the vertical mixing

Backgrounds of the SST rise

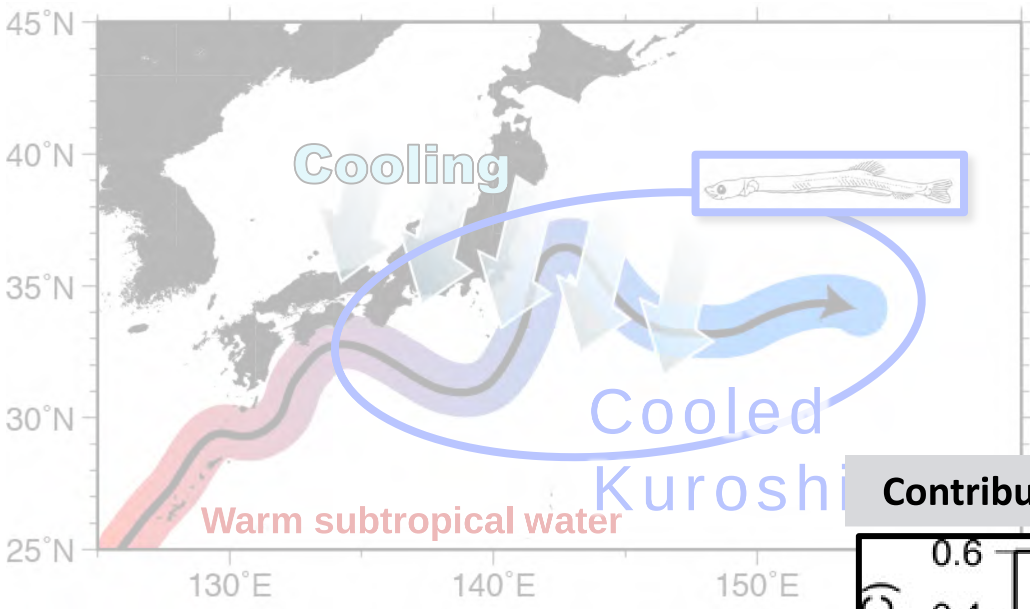


The original Kuroshio water is warm, and it cooled during transportation near Japan.

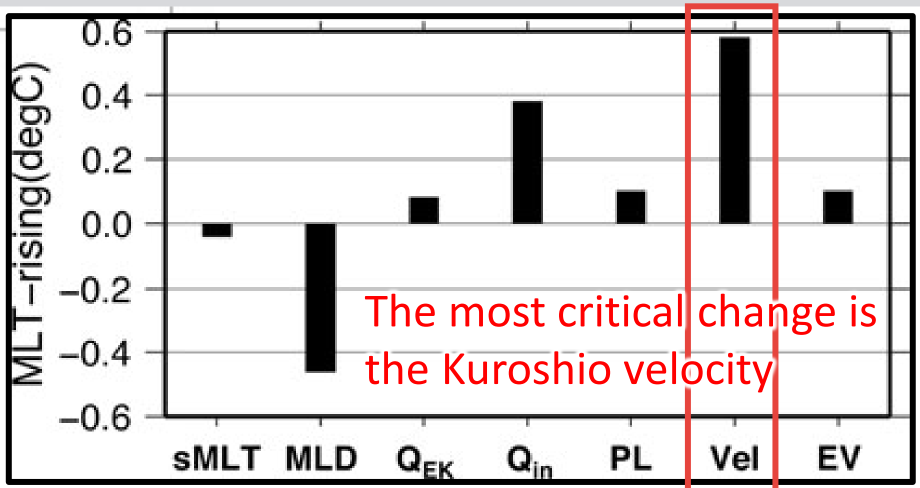
Major cooling process

- **Length of cooling period**
  - **Kuroshio path length**
  - **Kuroshio velocity**
- **Cooling intensity (net heat flux)**
- **Cold water entrainment**
  - **Ekman pumping**
  - **Mixed layer development**

Backgrounds of the SST rise



Contributions of each component to the SST rise



Nishikawa and Yasuda (2011)

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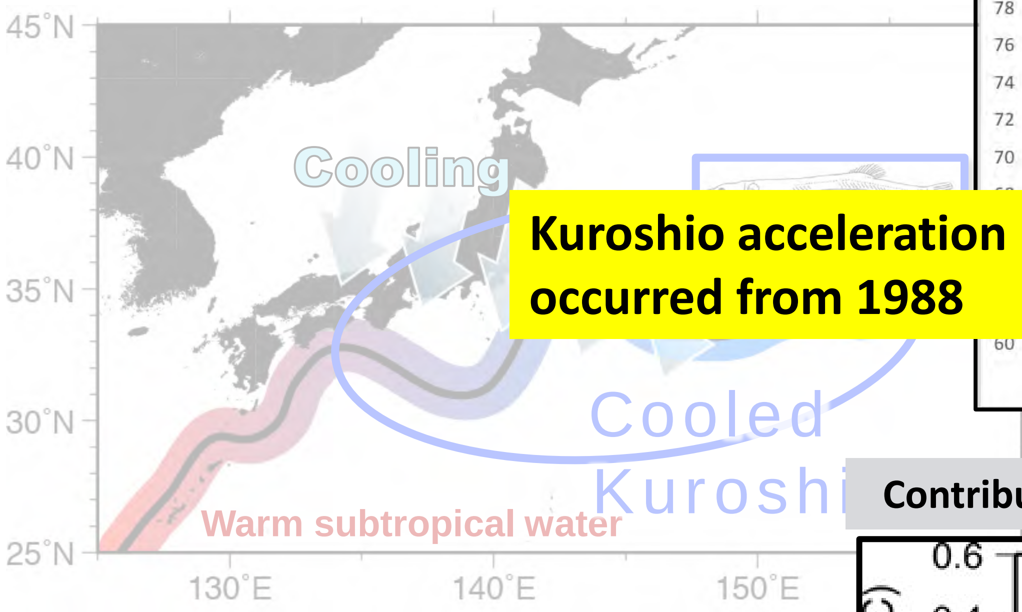
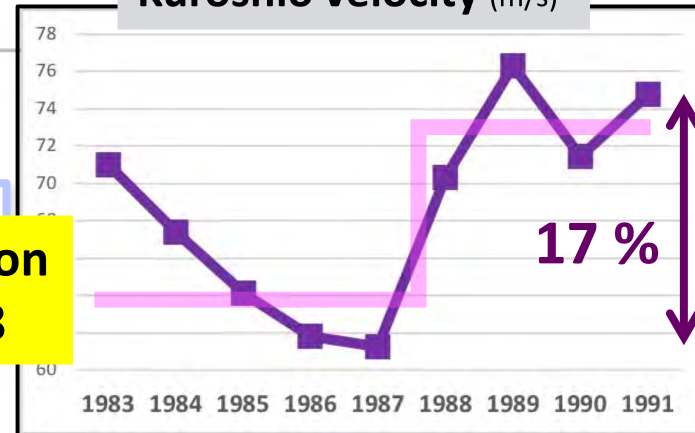
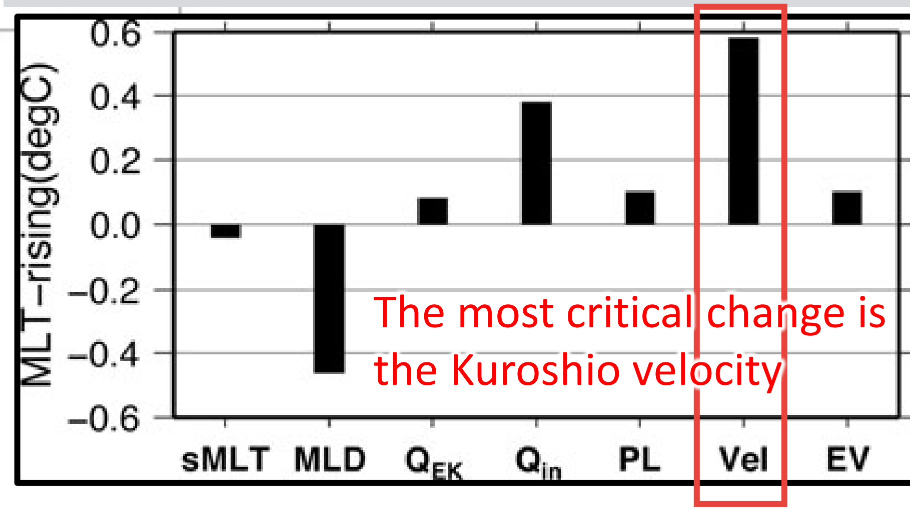


Kuroshio acceleration occurred from 1988

Kuroshio velocity (m/s)



Contributions of each component to the SST rise



Nishikawa and Yasuda (2011)

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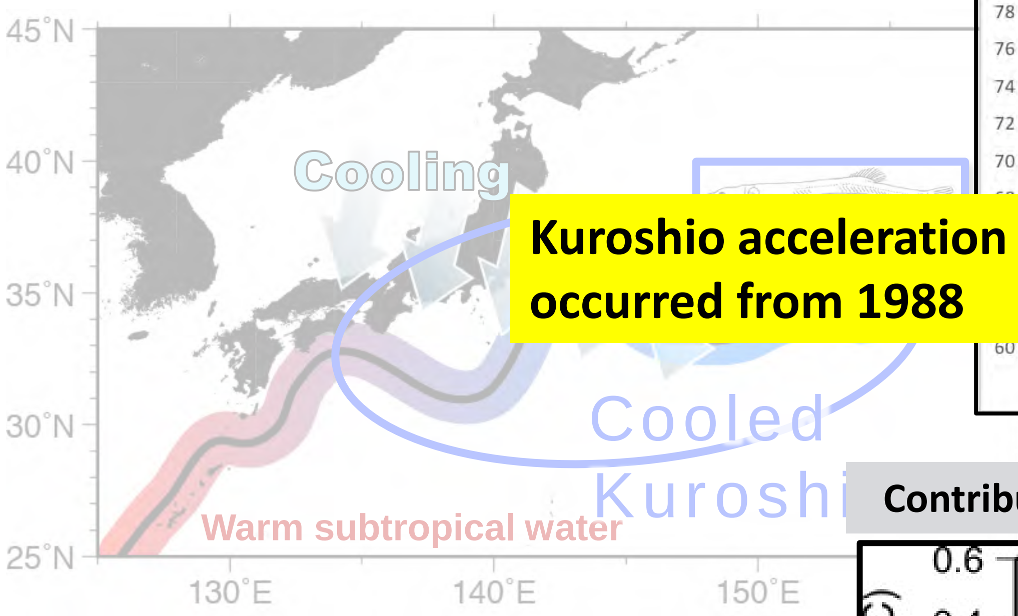

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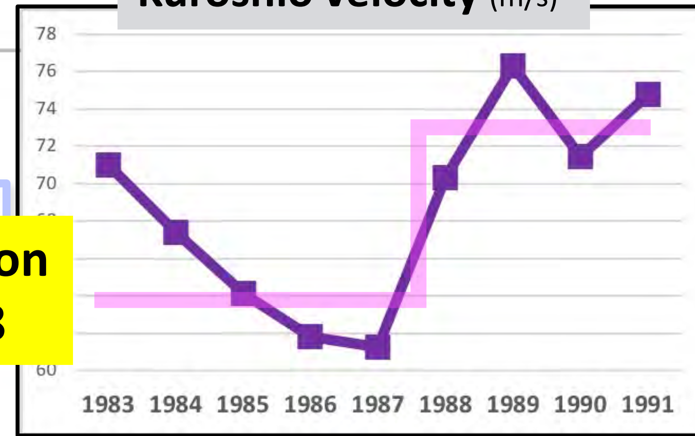
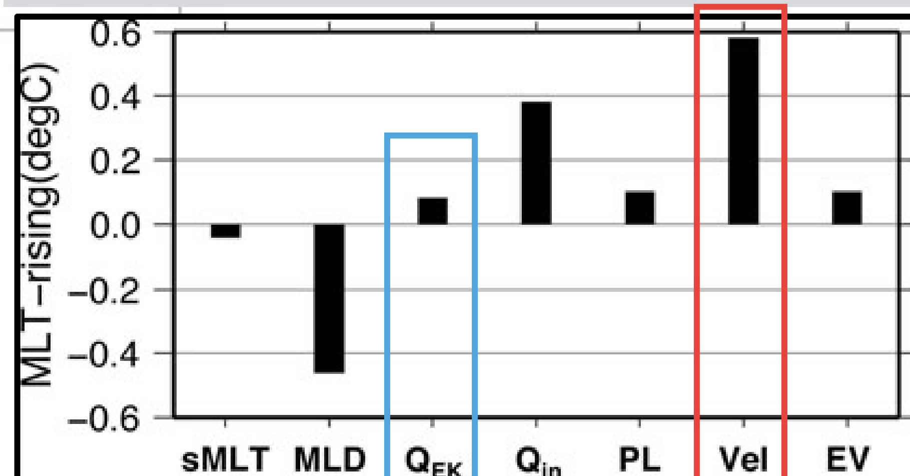


Contributions of each component to the SST rise

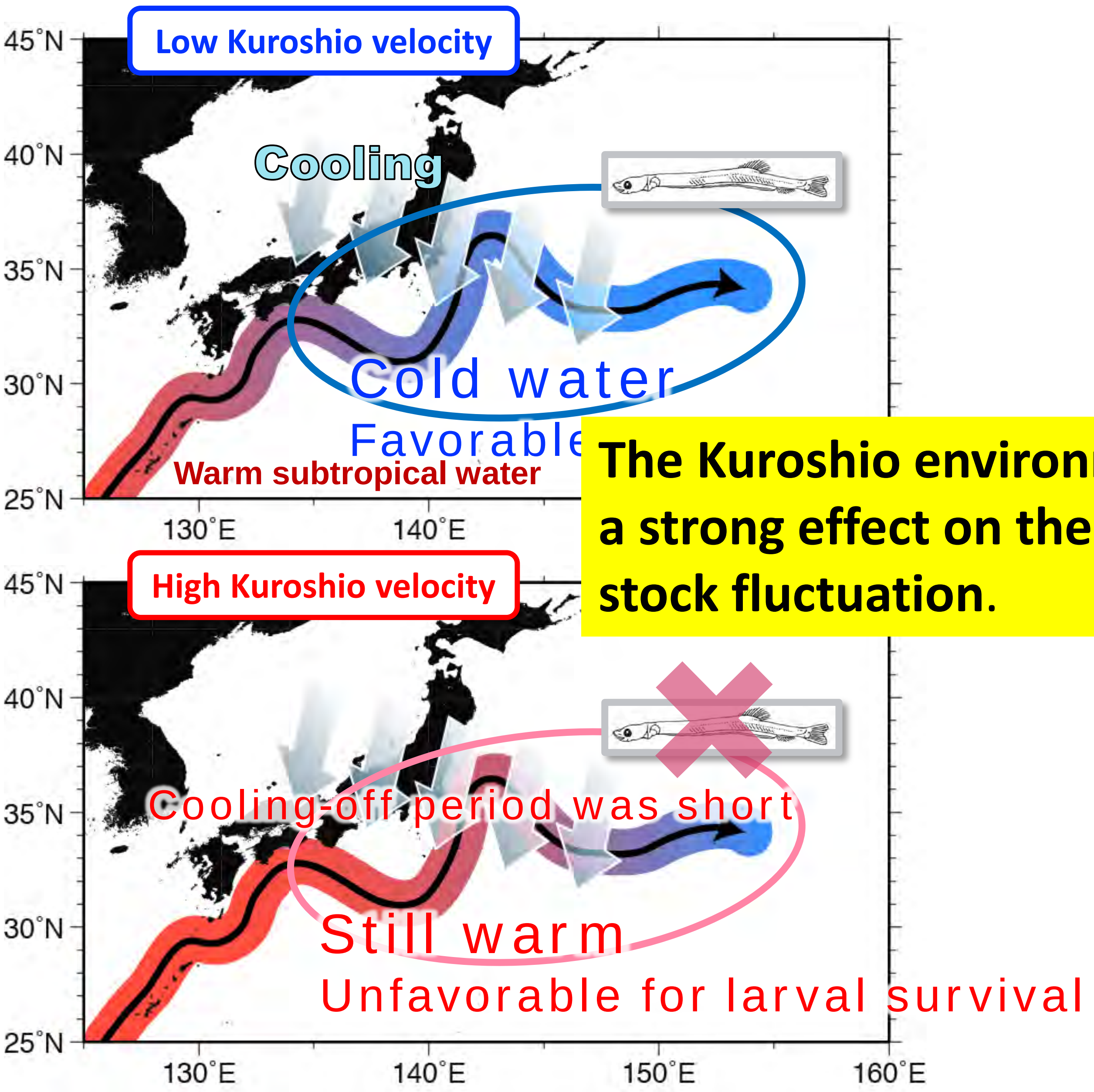


Ekman pumping did not change during sardine decrease period.

Major cooling process

- **Length of cooling period**
  - **Kuroshio path length**
  - **Kuroshio velocity**
- **Cooling intensity (net heat flux)**
- **Cold water entrainment**
  - **Ekman pumping**
  - **Mixed layer development development**

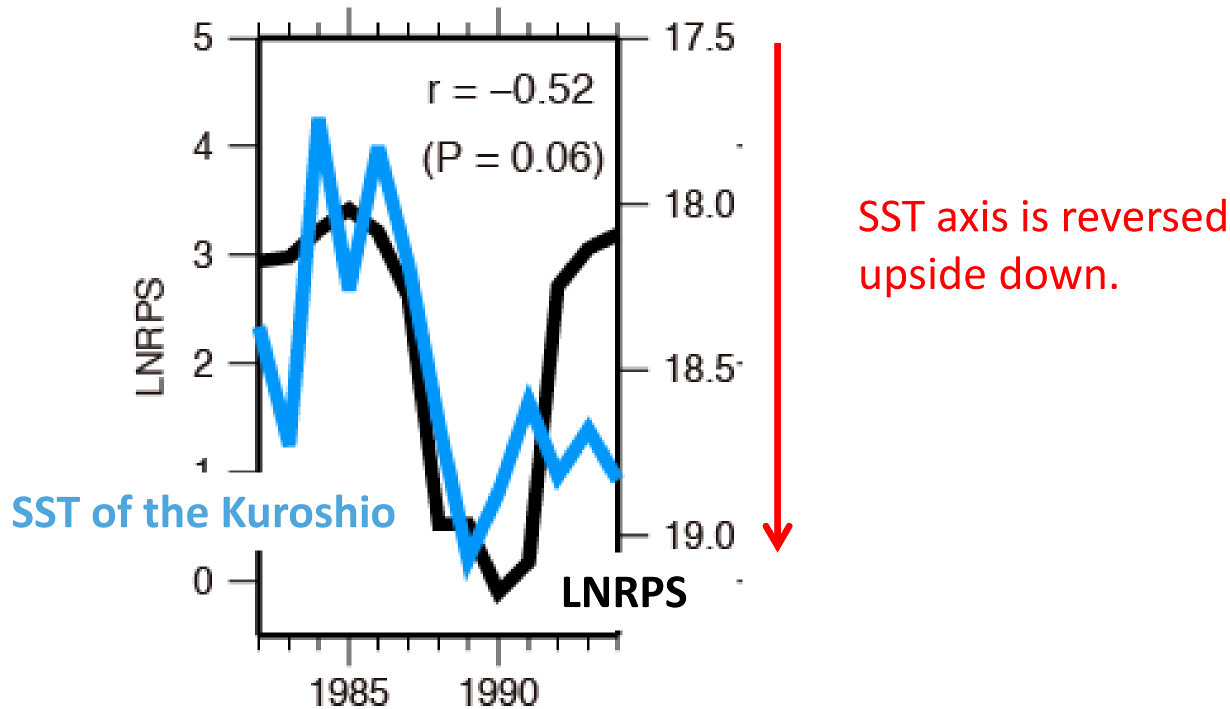
Sardine stock fluctuation and environmental change



The Kuroshio environmental change has a strong effect on the Japanese sardine stock fluctuation.

How about the increasing period?

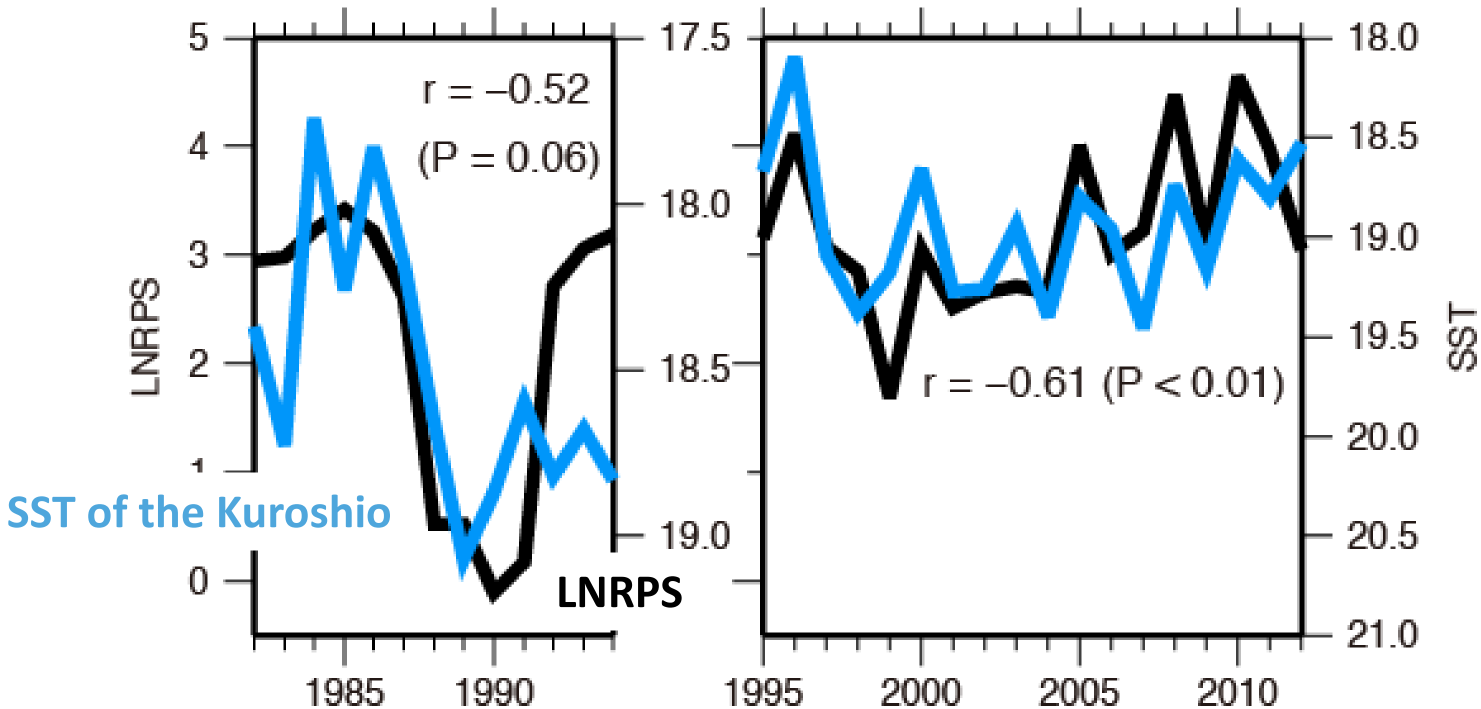
SST variation in the stock decreasing period (1982–1994) was corresponding to the LNRPS variation.



LNRPS: LN(recruitment/SSB), an index of the recruitment success.

How about the increasing period?

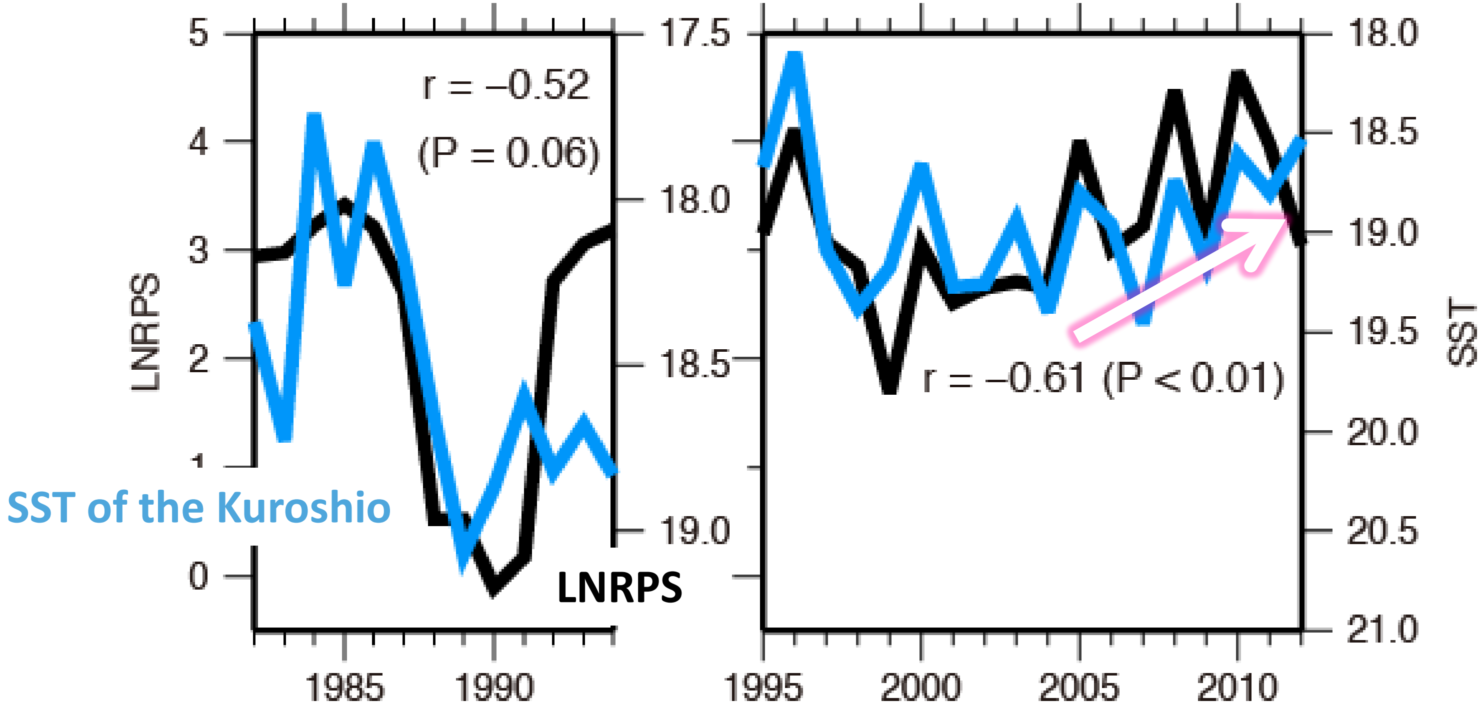
SST variation in the stock decreasing period (1982–1994) was corresponding to the LNRPS variation.



SST–LNRPS relationship seems to exist in the stock increasing period from 1995.

How about the increasing period?

SST variation in the stock decreasing period (1982–1994) was corresponding to the LNRPS variation.



SST–LNRPS relationship seems to exist in the stock increasing period from 1995.
The recent stock recovery was a result of low SST?

How about the increasing period?

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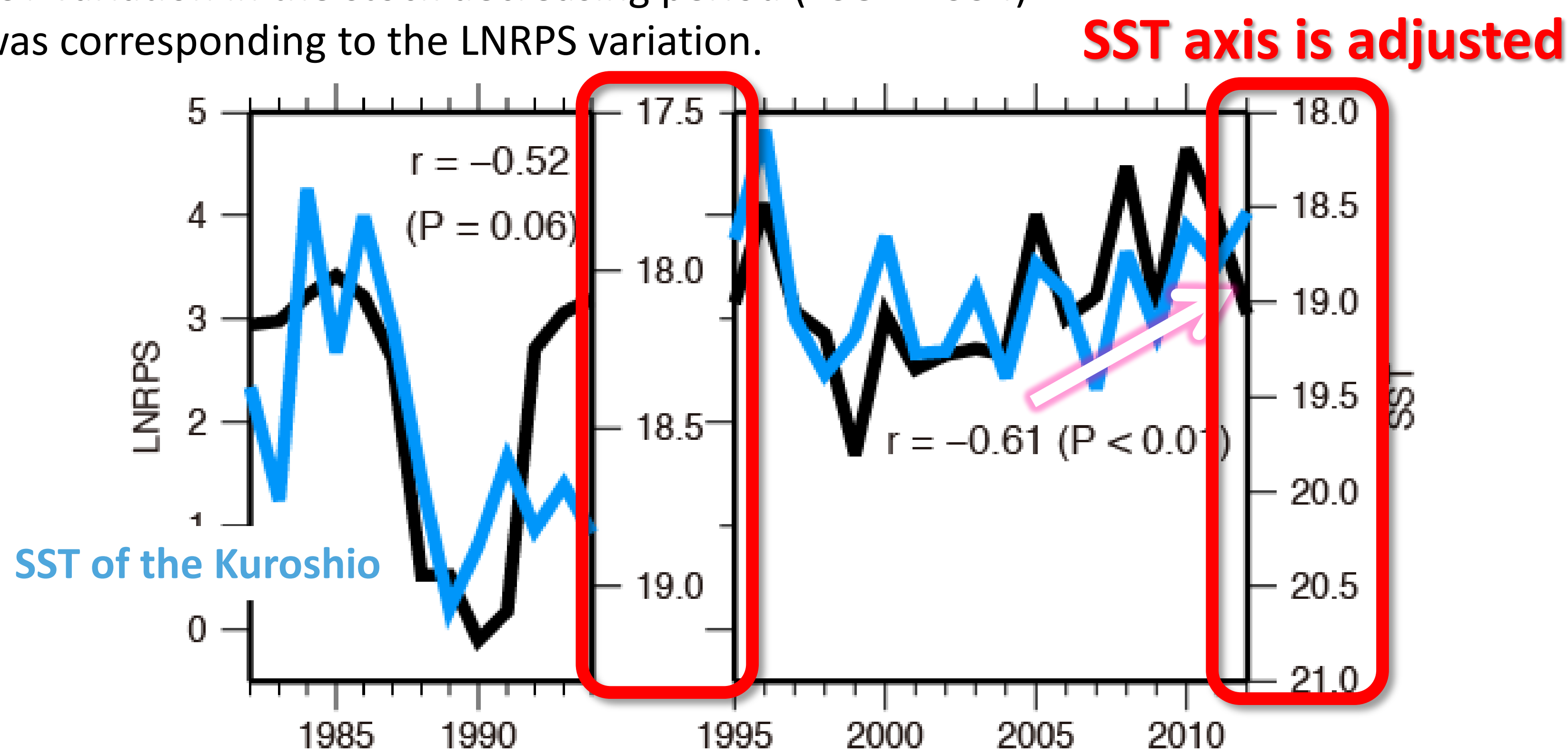

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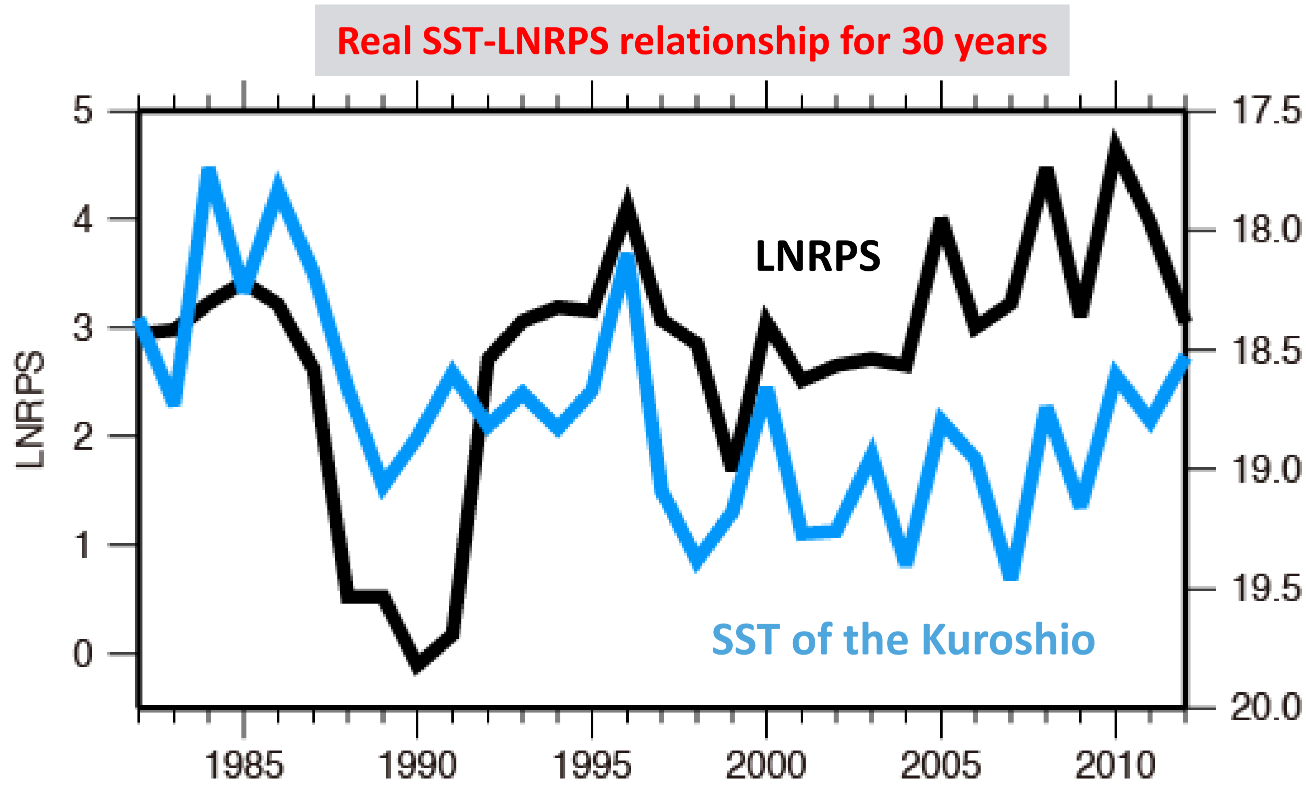
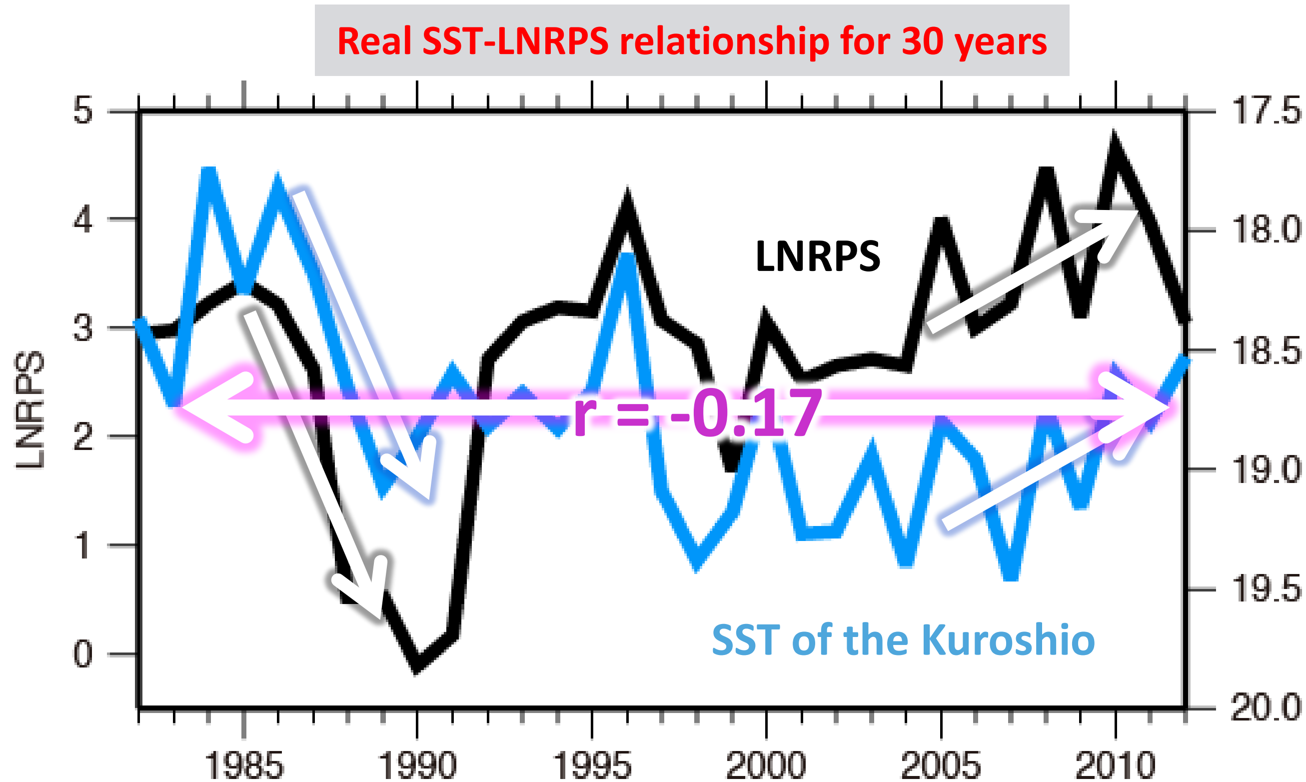


How about the increasing period?



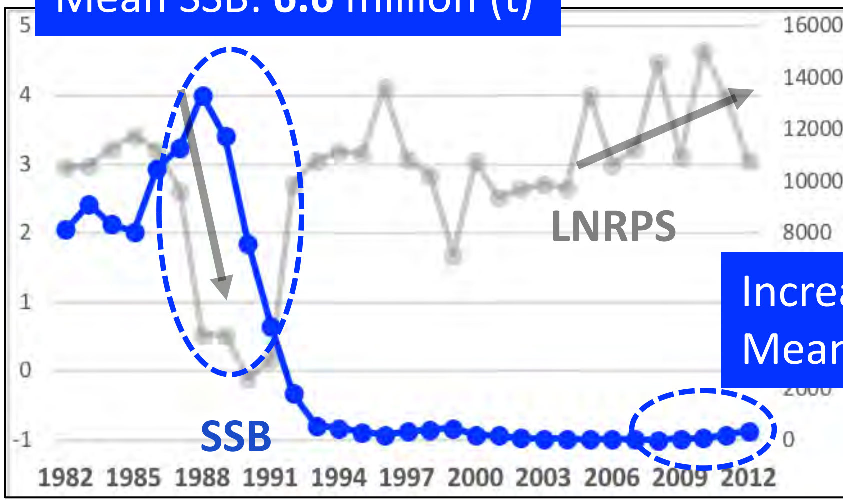
Decreasing and increasing tendencies occurred at the same time.

But the correlation coefficient for 30 years, including decrease and increase period is not significant.

Kuroshio environment was not an only explanatory variable for the stock variation.

The other explanatory variable

Decreasing period
Mean SSB: **6.6** million (t)



Increasing period
Mean SSB: **121** (t)

A big difference between the stock decreasing period and increasing period is SSB (Spawning Stock Biomass).

SSB-recruitment relationship should be considered to explain the LNRPS variation.

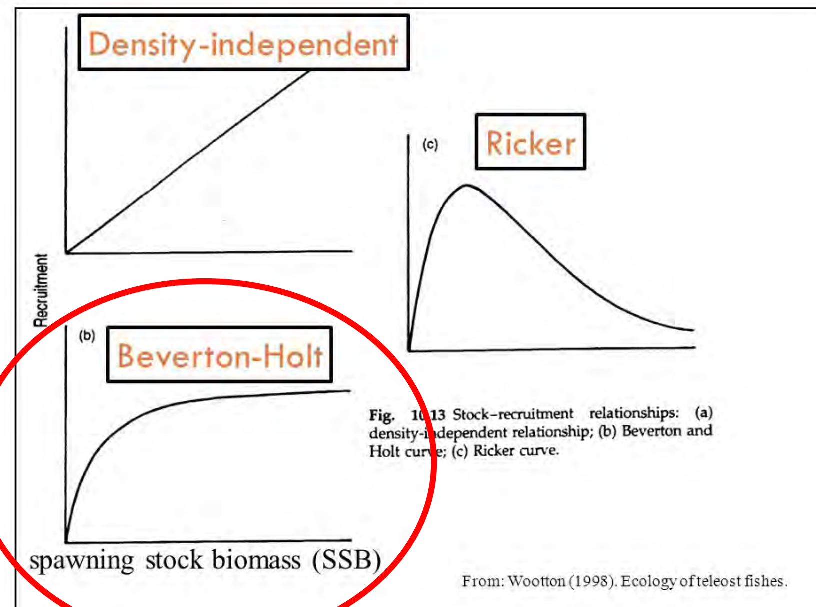


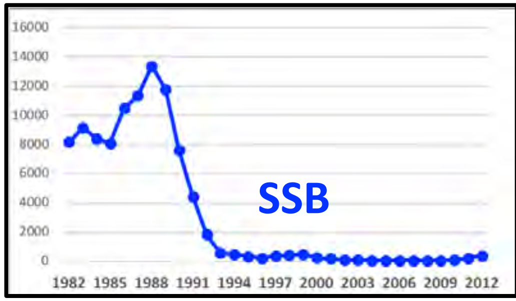
Fig. 10.13 Stock–recruitment relationships: (a) density-independent relationship; (b) Beverton and Holt curve; (c) Ricker curve.

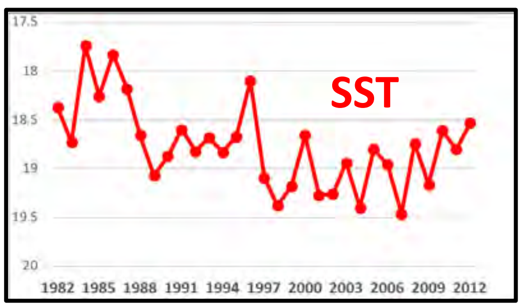
From: Wootton (1998). Ecology of teleost fishes.

LNRPS estimation model

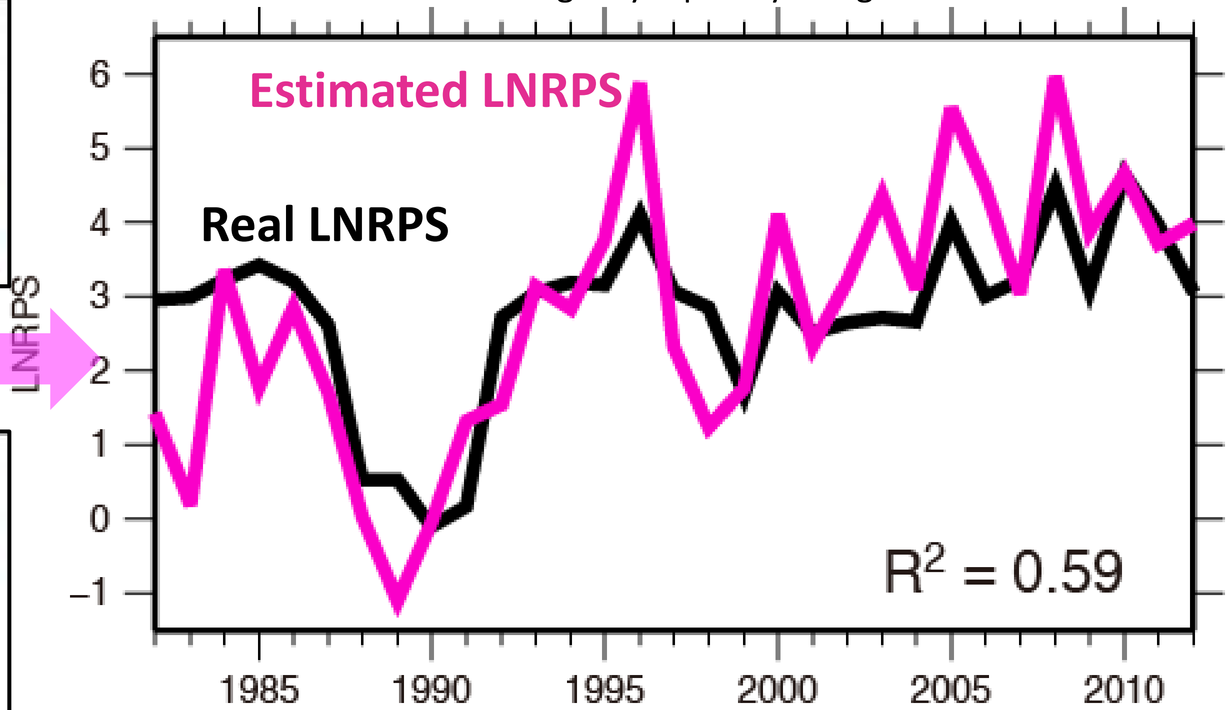
$$\mathrm{LNRPS} = -\ln(1 + aSSB) + bSST + c$$

a = -0.0002, b = -1.50886, c = 31.9789





Real LNRPS is estimated by the Fisheries Agency Japan by using observation data



The decreasing and increasing tendencies of LNRPS are controlled by the environmental change.

SSB determines the baseline of LNRPS.

LNRPS estimation model

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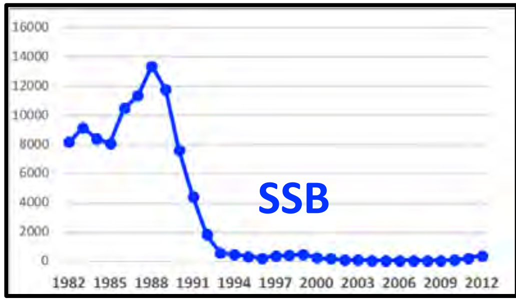

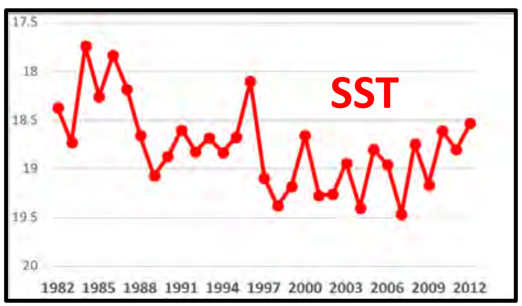

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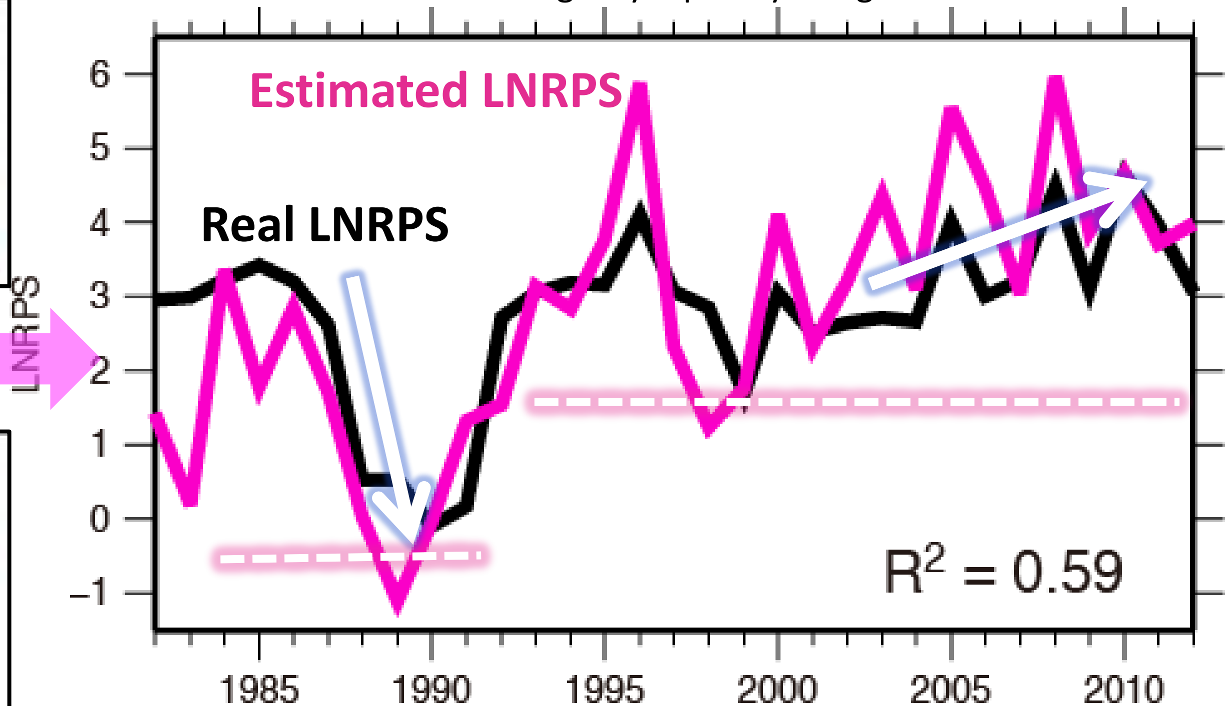


The decreasing and increasing tendencies of LNRPS are controlled by the environmental change.

SSB determines the baseline of LNRPS.

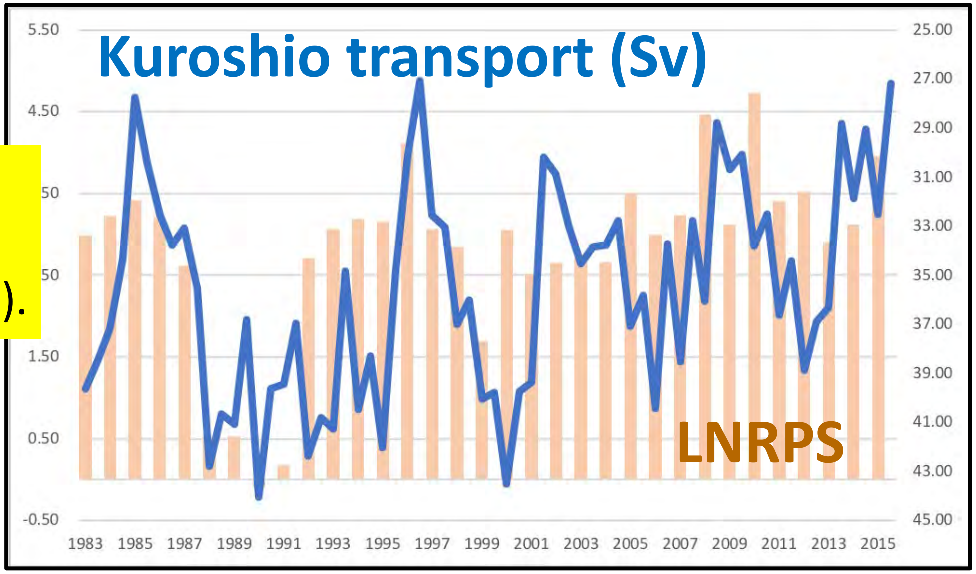
What we know about the environmental change influence on the Japanese sardine stock fluctuation

The Kuroshio condition (warm or cold), which is under the influence of the Kuroshio velocity is the principal factor of the stock interannual variation.

But, the density effect also affected the recruitment absolute value.

Kuroshio intensification (weakening) **linked to the recruitment failure** (success).

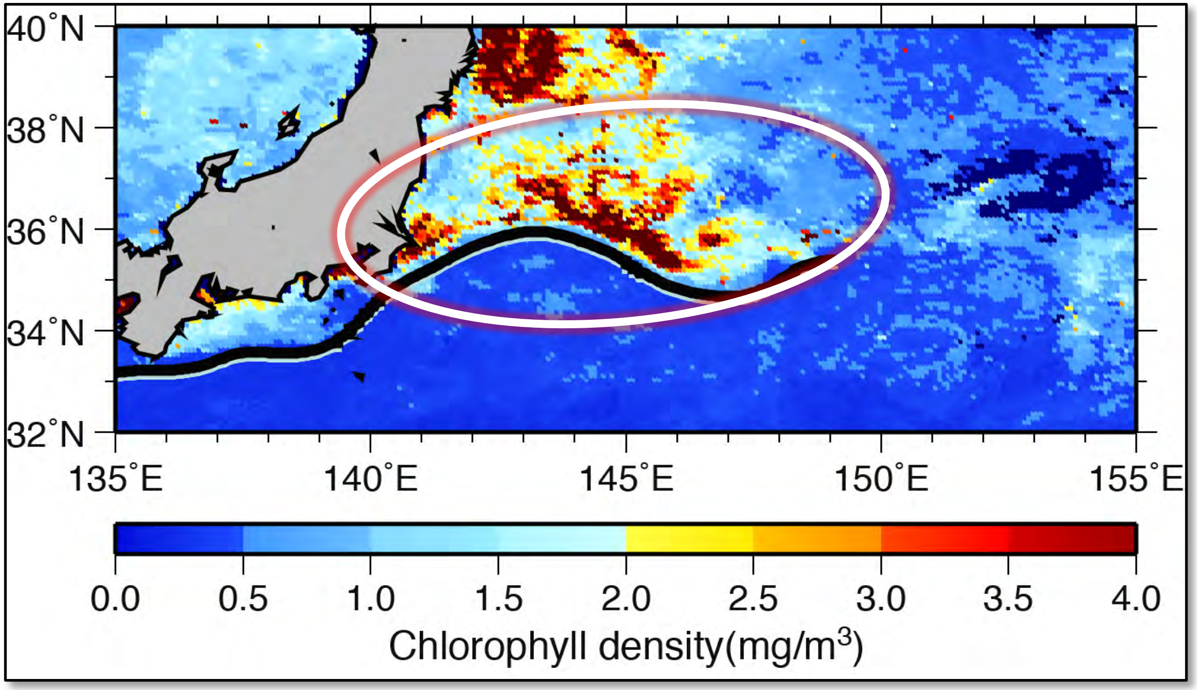
Observed Kuroshio transport and LNRPS



Kuroshio transport axis is reversed upside down

Kuroshio productivity

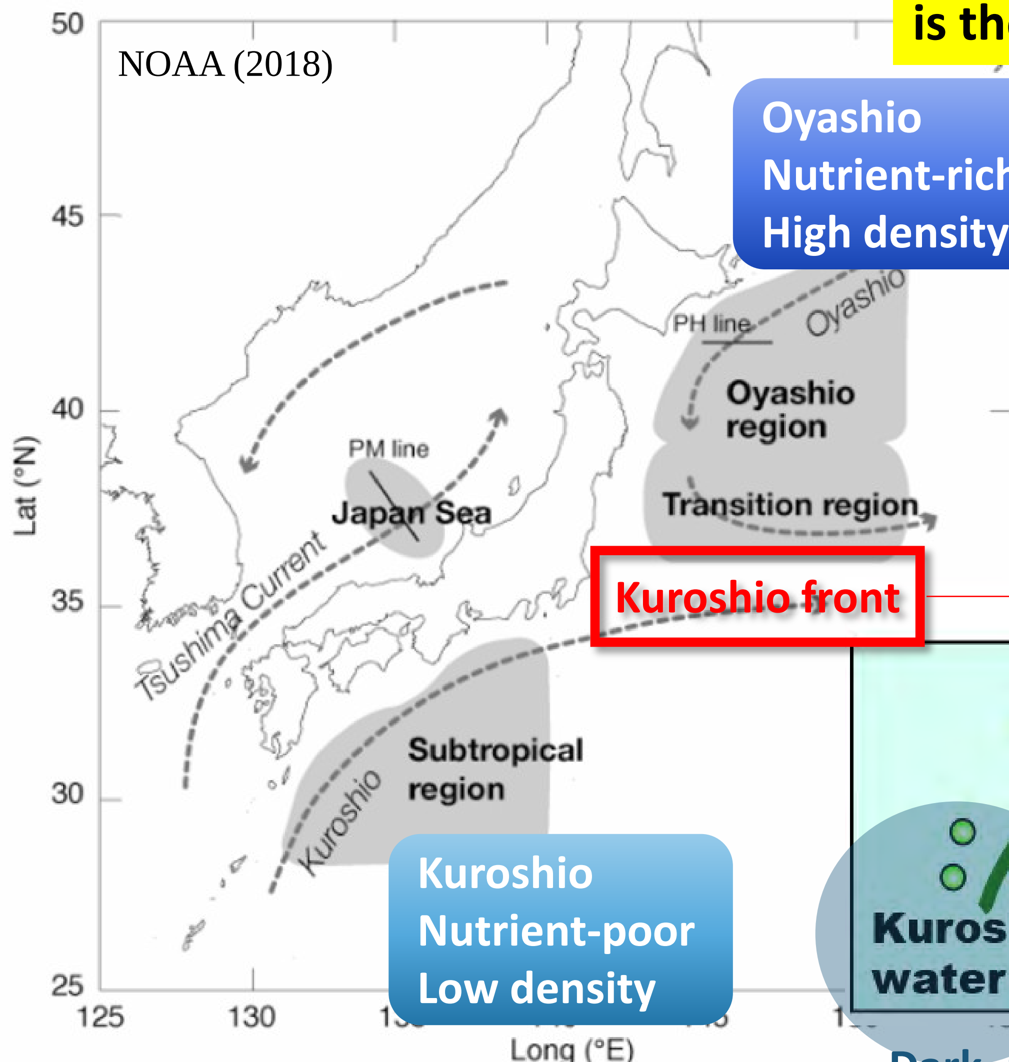
The Kuroshio is nutrient-poor water? Actually, not.
The Kuroshio front is productive (Nakata et al., 1995).
The productivity is comparable to other upwelling regions.



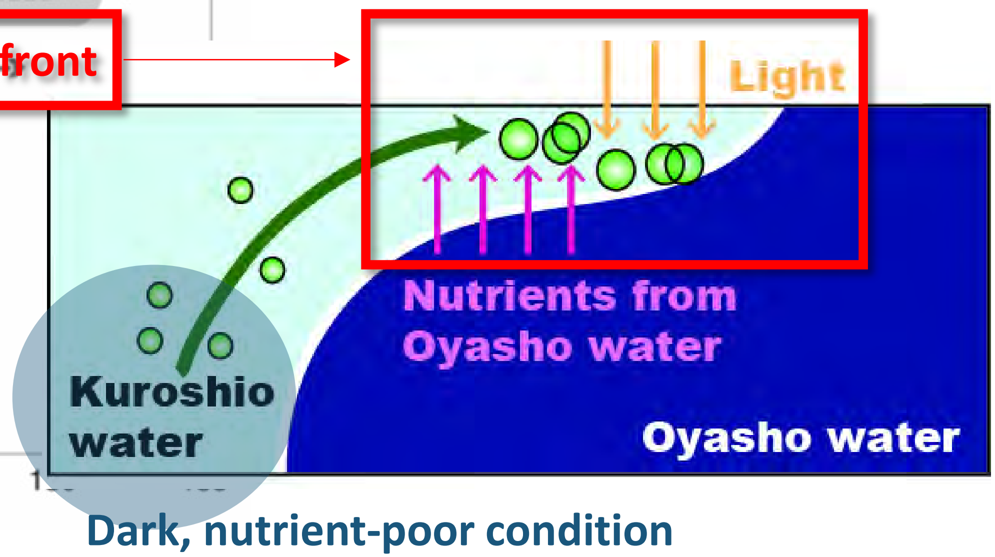
Chlorophyll a density off the coast of Japan in April 2004 (SeaWiFS data).

Kuroshio productivity

One of the possible nutrient source is the Oyashio.



Kuroshio-Oyashio layered structure
Light Kuroshio water runs on the dense Oyashio water. The surface Kuroshio plankton can use nutrient from Oyashio water for photosynthesis.



Nishikawa et al. (2016)

LNRPS estimation model

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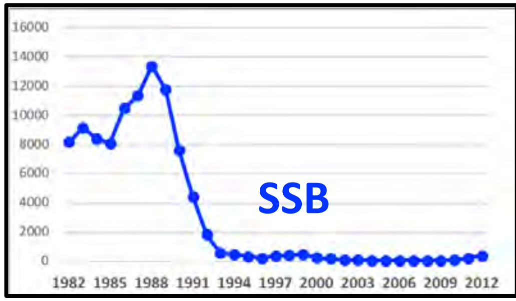
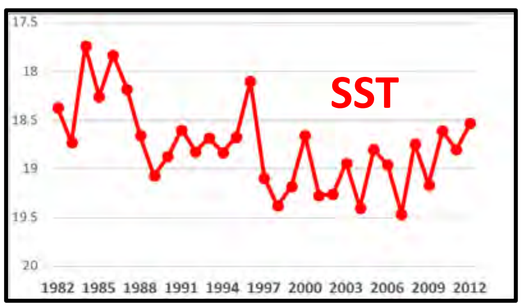
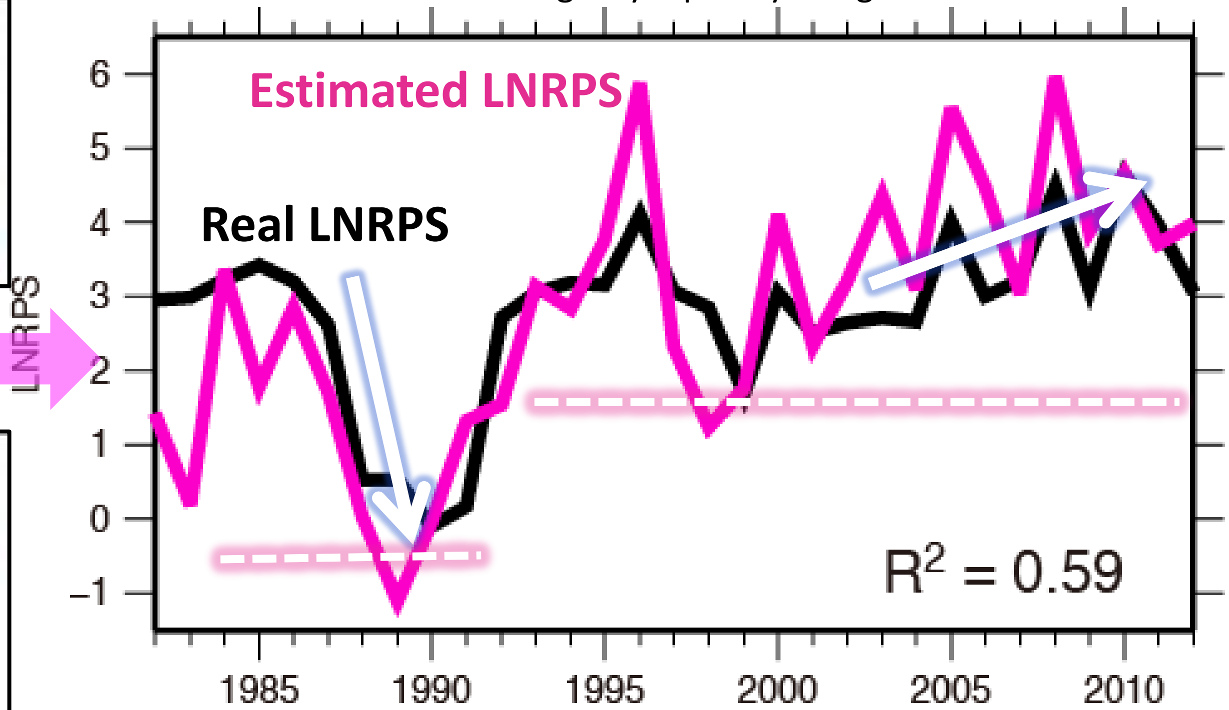
a = -0.0002, b = -1.50886, c = 31.9789





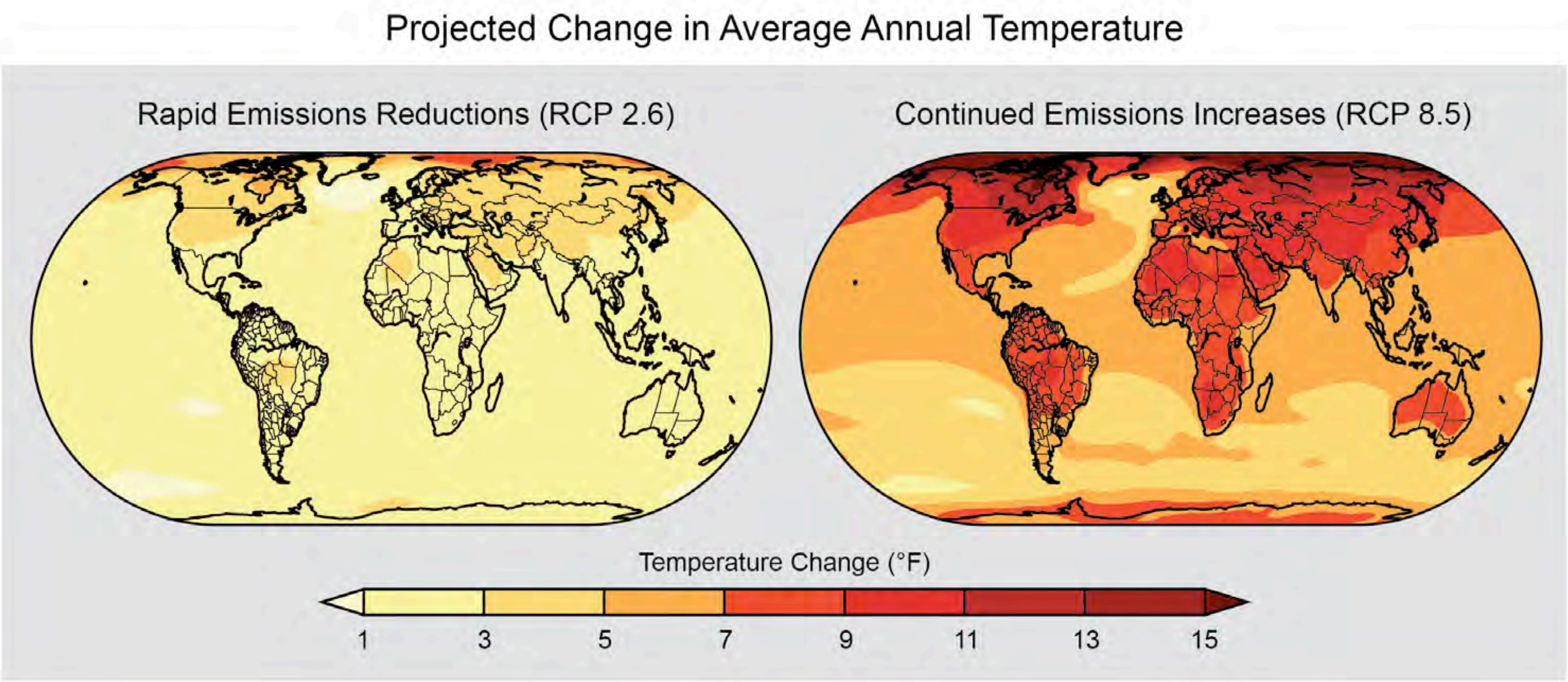
Real LNRPS is estimated by the Fisheries Agency Japan by using observation data



The decreasing and increasing tendencies of LNRPS are controlled by the environmental change.

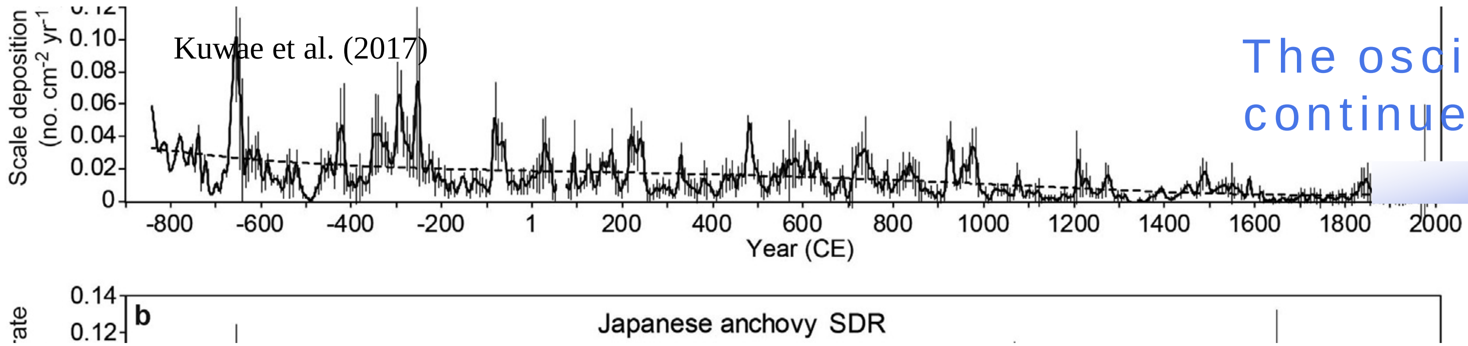
SSB determines the baseline of LNRPS.

Japanese sardine stock in future under the global warming condition



Future estimation

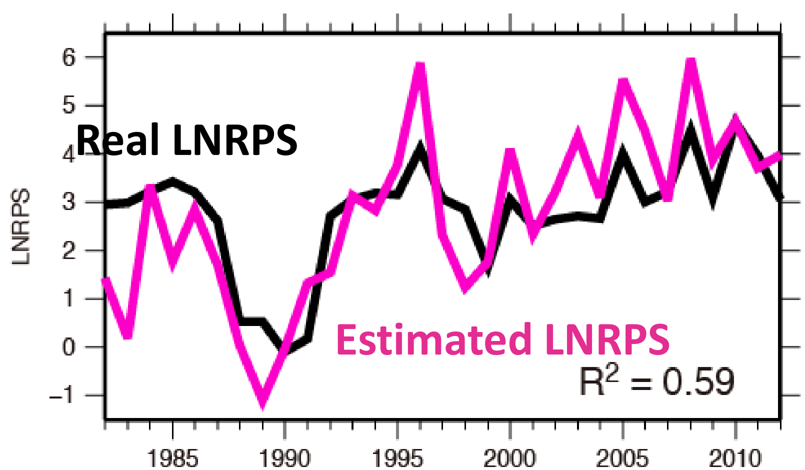
The multi-decadal scale stock fluctuation has been occured at least 2850 years ago. (confirmed by scale deposition rate analysis, Kuwae et al. 2017)



The oscillation will continue in future?

$$\mathrm{LNRPS} = -\,ln(1 + a\,SSB) + b\,SST + c$$

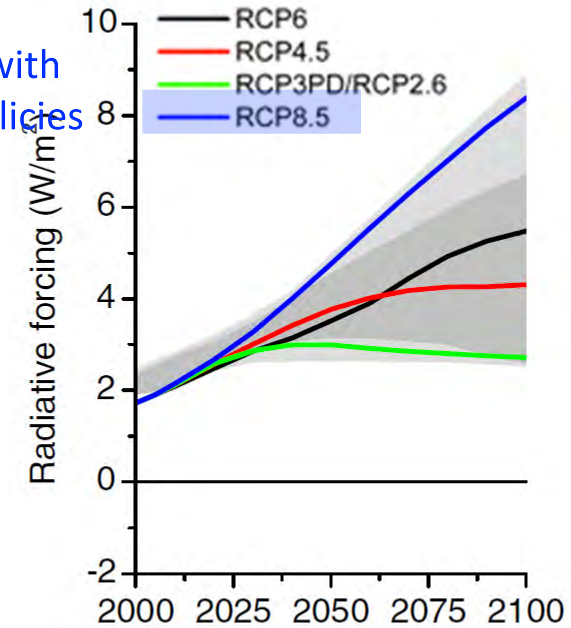
a = -0.0002, b = -1.50886, c = 31.9789



The LNRPS estimation model is applied to the future climate change.

Future estimation

High emission scenario with no climate mitigation policies



Environmental condition

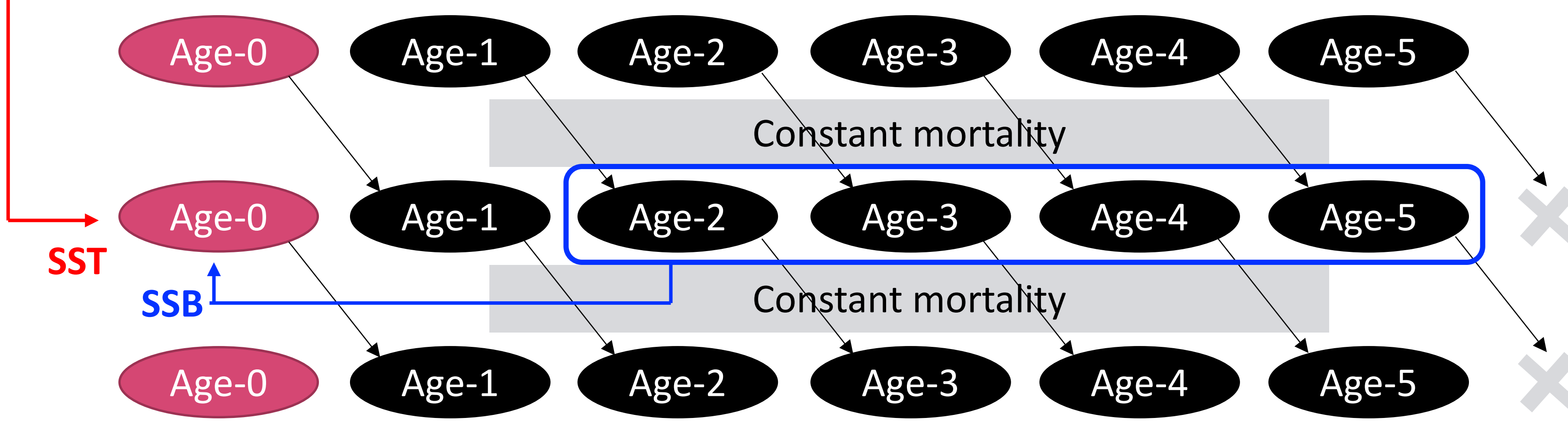
Winter Kuroshio SST (averaged from 130–160ºE, Kuroshio axis from 0.5º south to 0.5º north)

1982–2005: Reanalysis data of FORA-WNP (Usui et al., 2017)

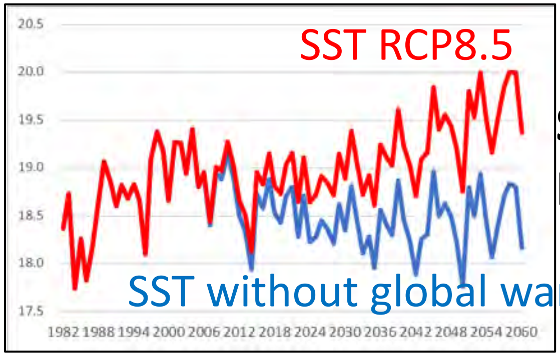
2006–2060: Output from down scaled MRICGCM3 **with RCP8.5 condition** and **without global warming**

Stock estimation

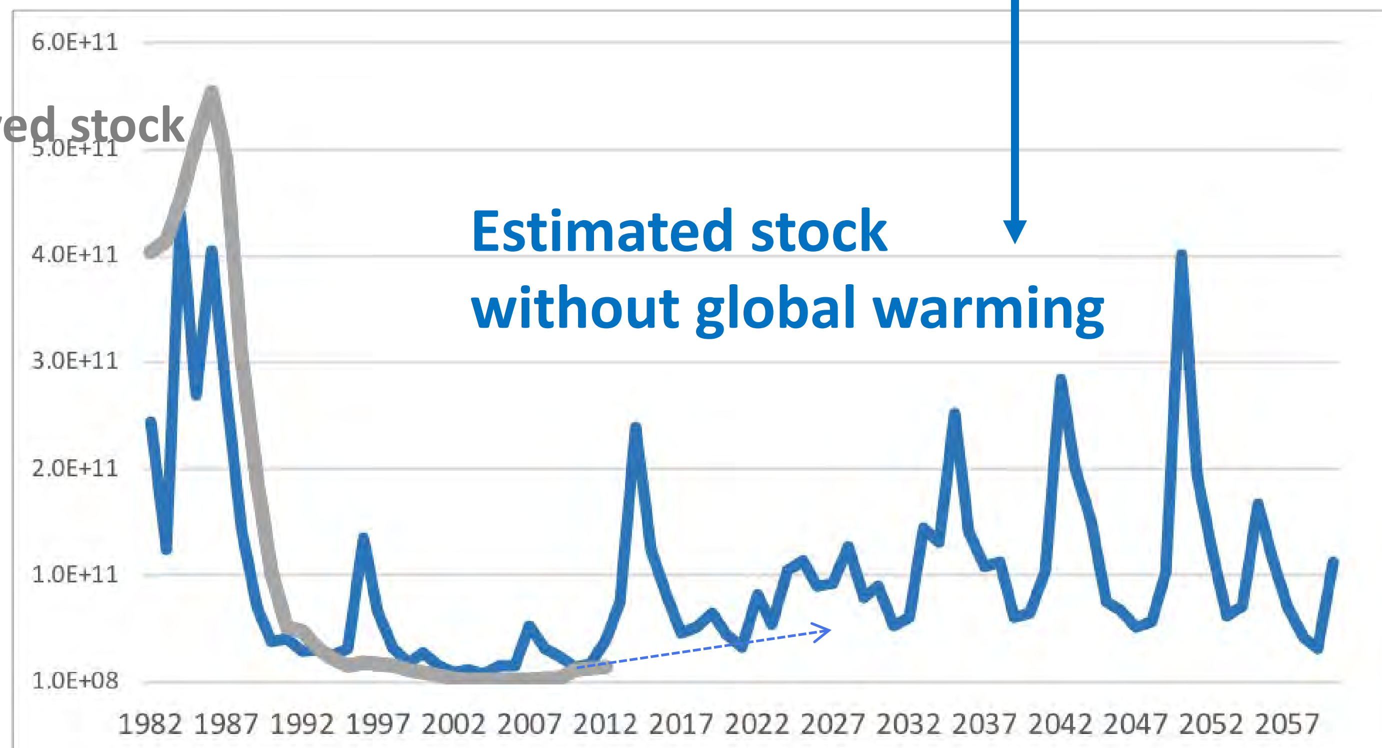
Start with the stocks of each year class in 1982.



Future estimation

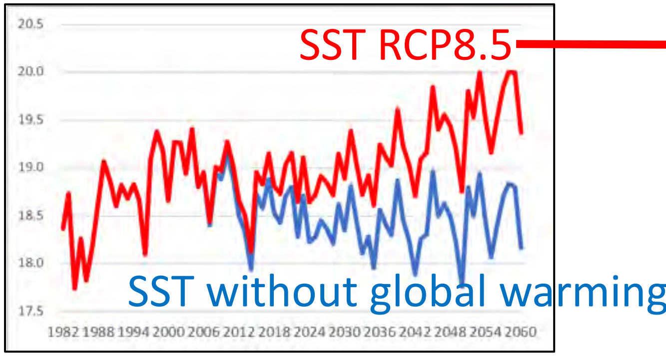


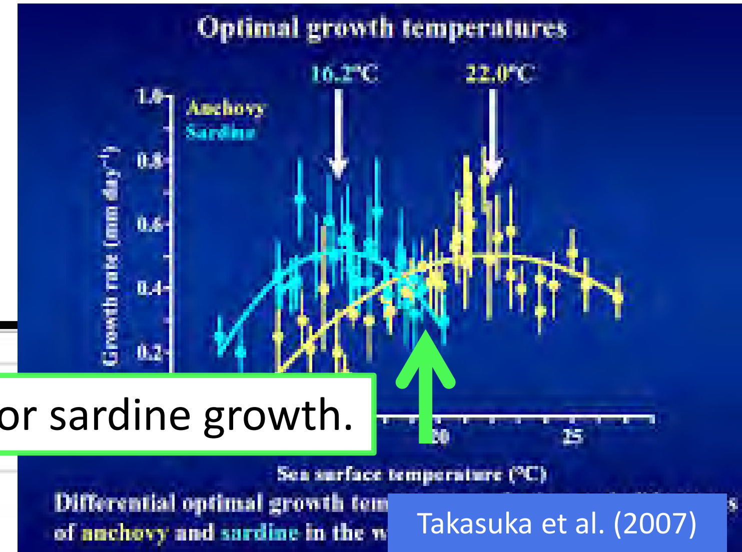
Sardine stock continues to recover.
Next high stock period will occur within several decades ?



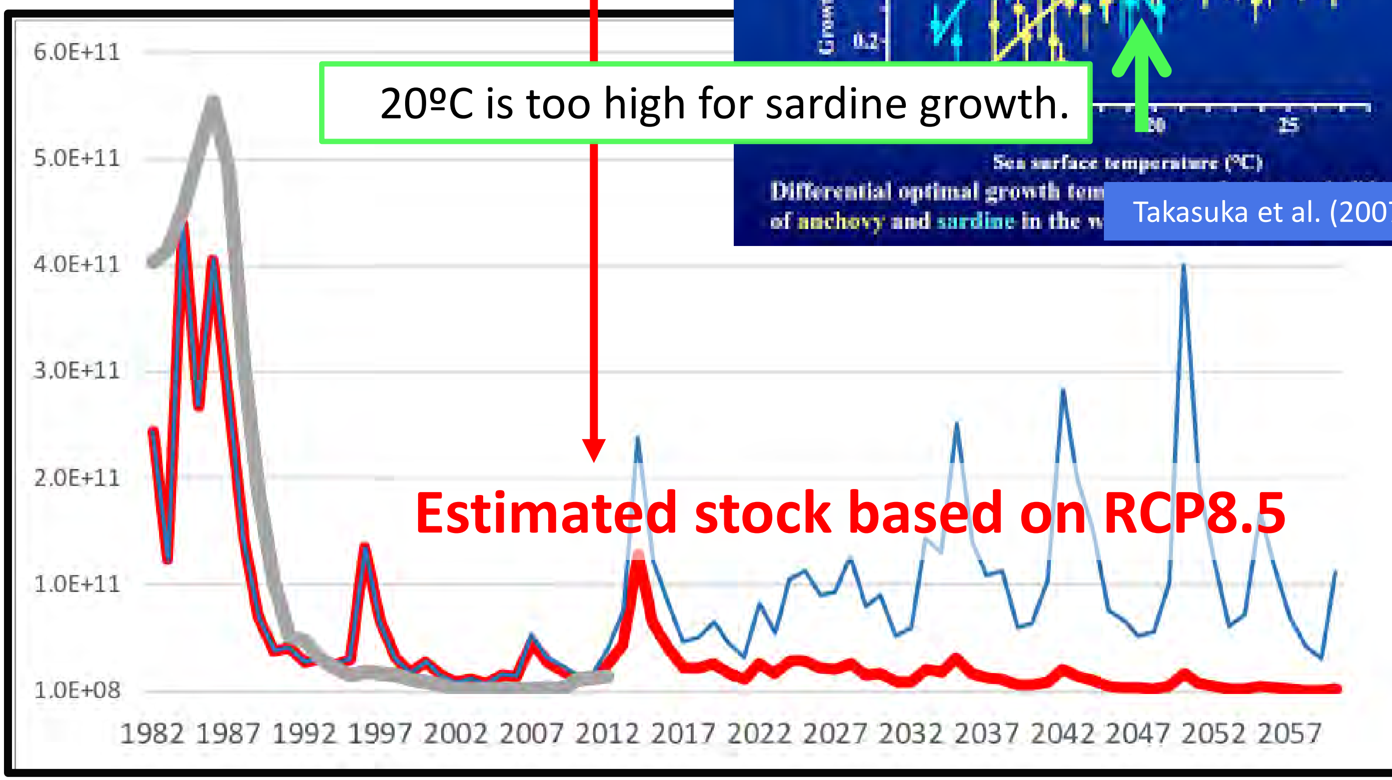
Future estimation

Due to the Kuroshio intensification, the SST rise steadily.



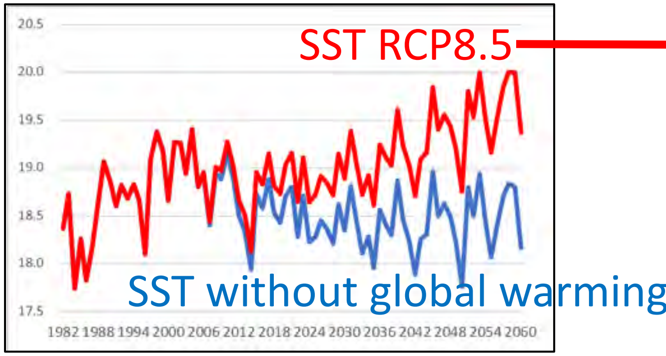


20ºC is too high for sardine growth.

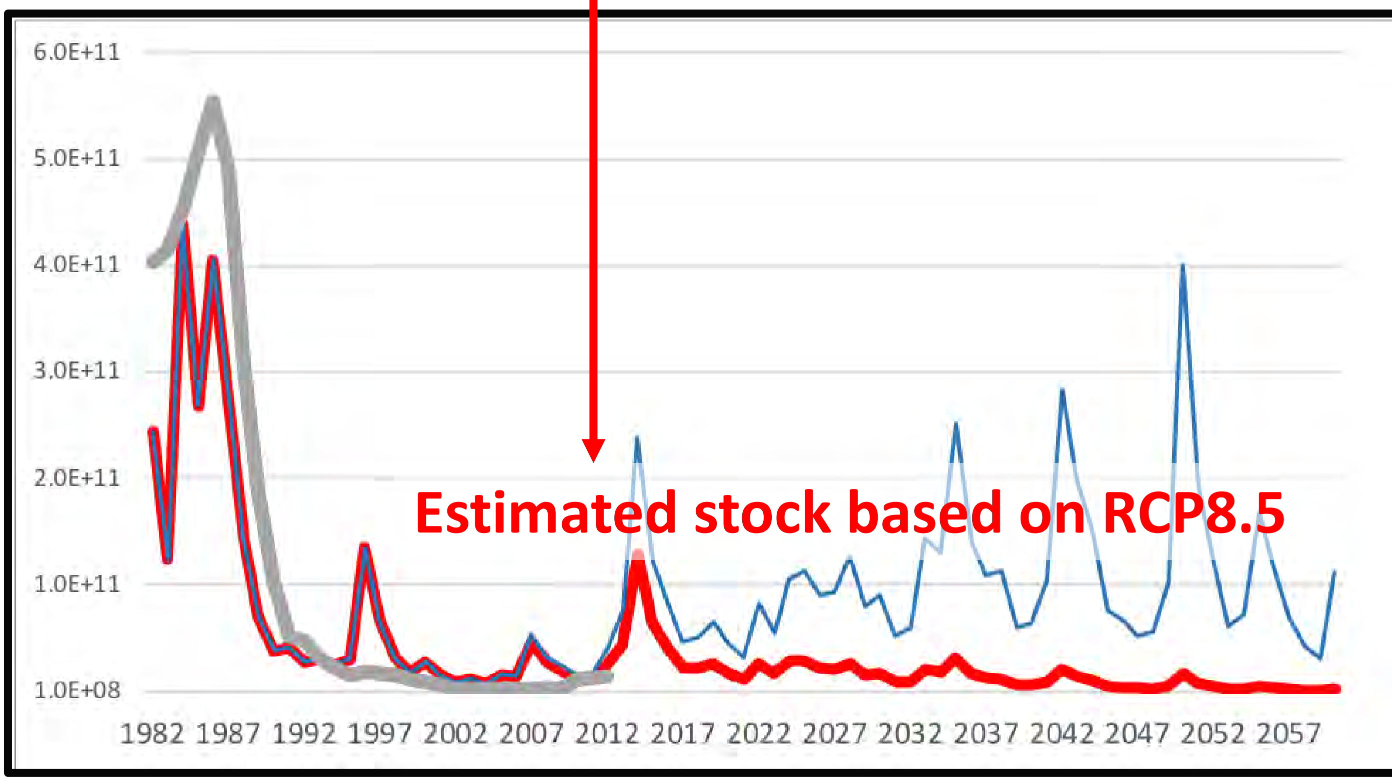


Future estimation

Due to the Kuroshio intensification, the SST rise steadily.



If the Global warming progress, sardine will never prosper again.



SUMMARY

Japanese sardine stock and environmental change

- **Japanese sardine stock level strongly depends on the Kuroshio condition.**

  When the Kuroshio acceleration occurs, the larval distribution area becomes warm. Warm condition is bad for both larval growth itself and forage plankton growth (food availability).

- **Density effect is also important for sardine stock fluctuation.**
- **Global warming might be bad for sardine stock.**

  But more realistic estimation needs to include impact of the global warming on the migration, food and so on.