Status and trend of production of Japanese chum salmon under the warming climate

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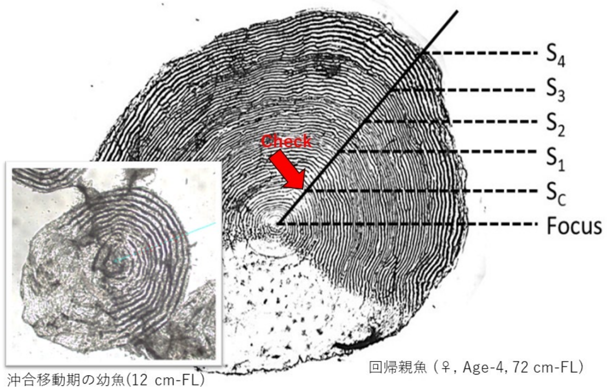
● Objects

- This presentation reviews the evidence for warming climate impacts on Pacific salmon:
  - (1) Temporal changes in productivity of Pacific salmon and SST in the North Pacific Ocean,
  - (2) Population dynamics of Japanese chum salmon under the warming climate,
  - (3) Archaeological records of historical chum salmon distribution in Japan during the Jomon Period (2.8-16 ky BP).

● Material & Method

- **COBE-SST database** of Japan Meteorological Agency for evaluating the global SST (1º × 1º, **1900-2021**).
- **NPAFC Salmonid Catch Statistics** for catch data of Pacific salmon in 1925-2021.
- **Scale back-calculation** for analyzing growth of chum salmon at each developmental stage: $L_i = L - (S-S_i)/(S-114) \times (L-4)$, $L_o = L_1 - L_c$ (Campana 1990; Ricker 1992).
- **Mann-Kendall test** as the non-stationary analysis, and **Sen's slope** for detecting the trend of temporal change in SST and growth of salmon.
- Japanese chum salmon was divided into two groups:
  - (1) Warm-Current Populations (**WCPs**) affected by the Tsushima warm current: OC, NSJ, SSJ.
  - (2) Cold-Current Populations (**CCPs**) affected by the Oyashio cold current: NC, PC, SC.
- Definition of temperature for chum salmon: (1) Allowable growth temperature (**AGT**, 5-7 ºC) and (2) Optimum growth temperature (**OGT**, 8-12 ºC).
- Evaluation for **salmon relicts in the Jomon Period (**16-2.8 kyr BP) using more than 130 thousand reports of the Jomon archaeological site. (*https://sitereports.nabunken.go.jp/ja*)



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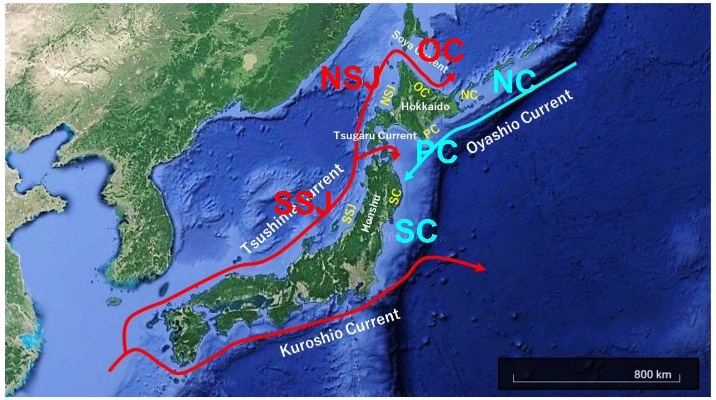
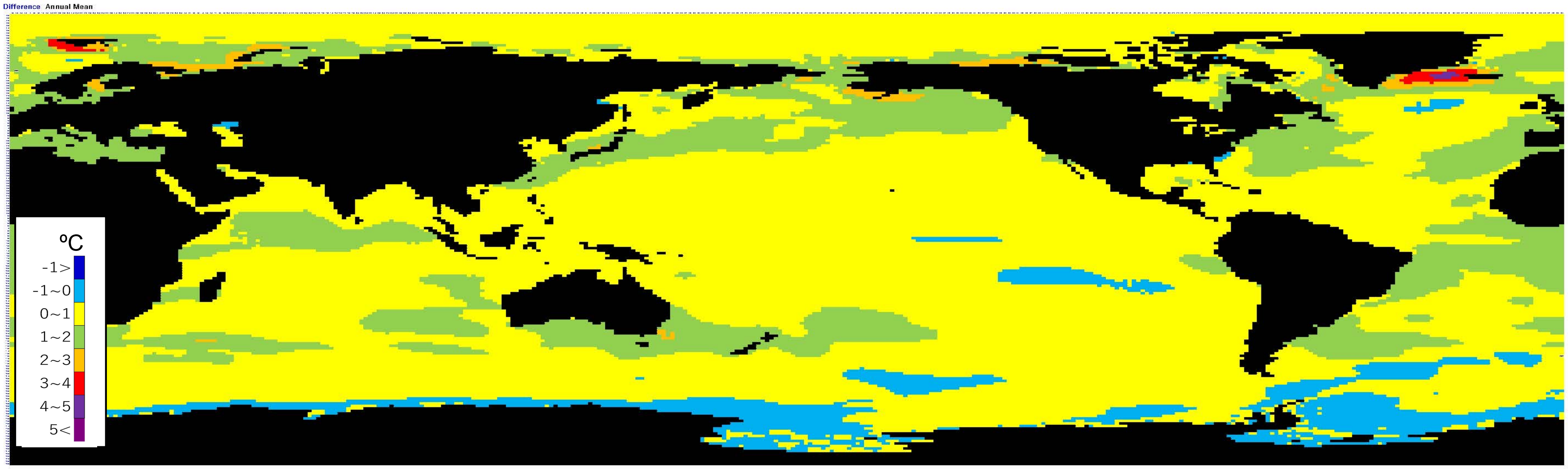
Warming climate impacts on production dynamics of southern populations of Pacific salmon in the North Pacific Ocean

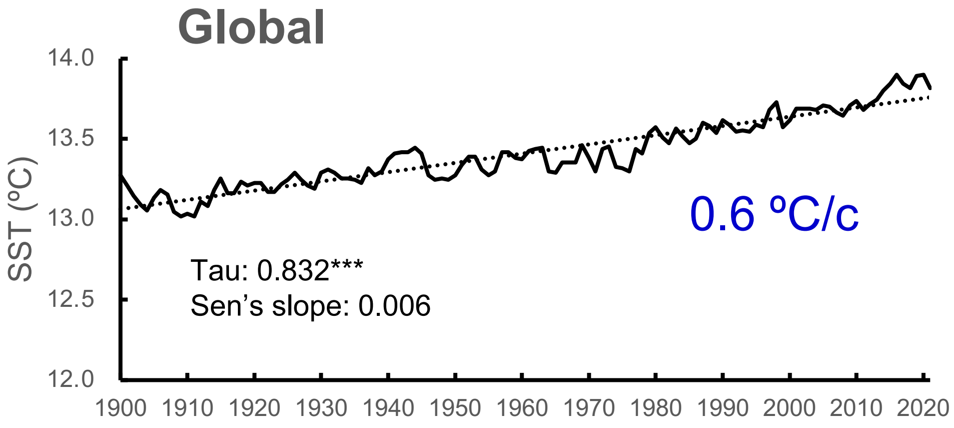
Masahide Kaeriyama

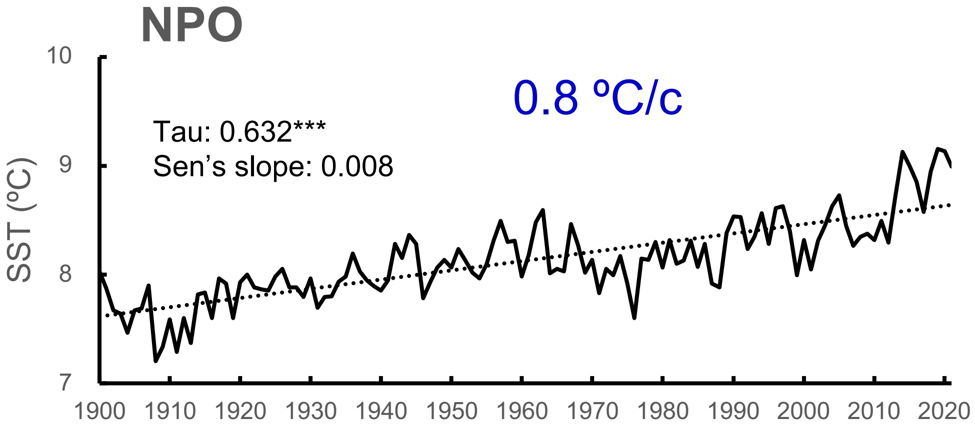


● **SST difference between 1900s and 2010s in global mean**



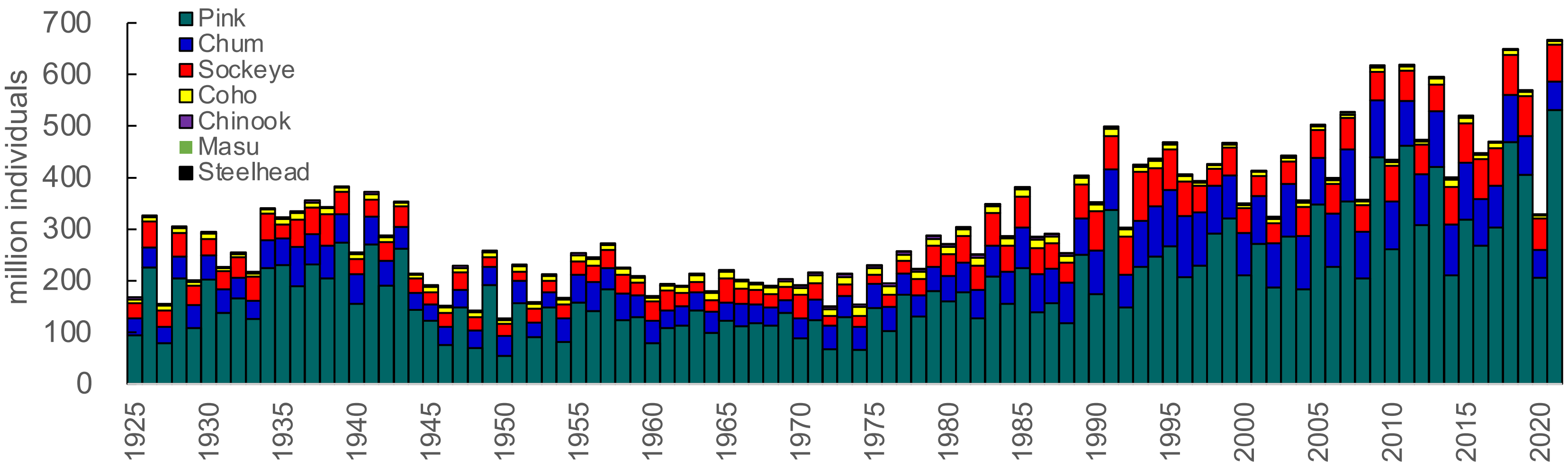
● **Temporal change in annual mean of SST in the Global and North Pacific Ocean in 1900-2021**

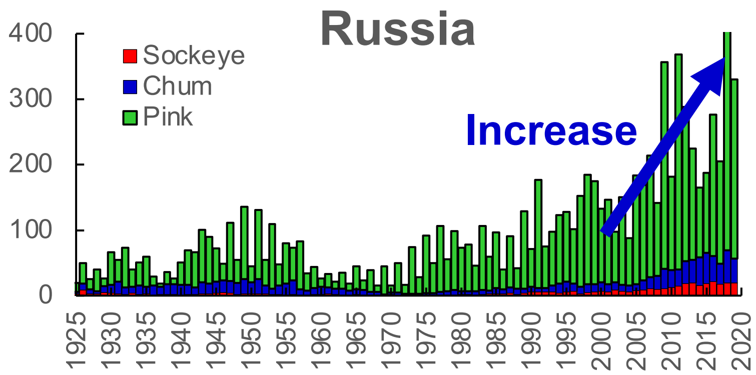


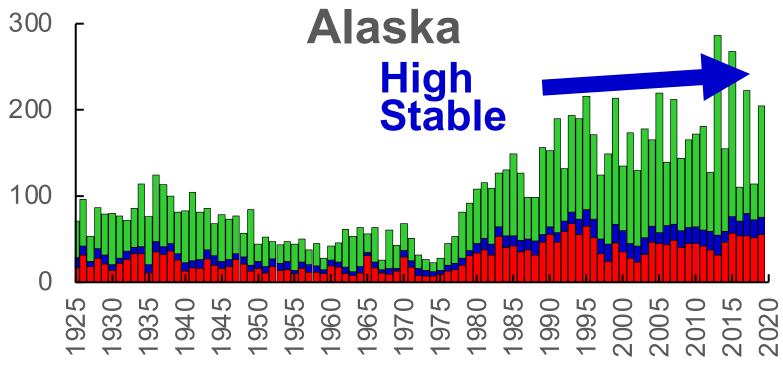


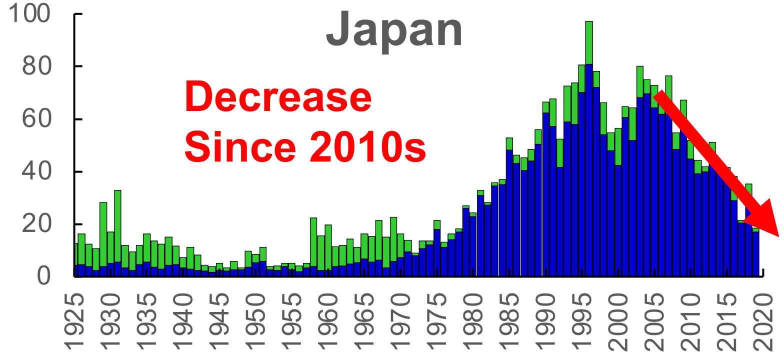
● Annual change in catch of Pacific salmon in the North Pacific Ocean (Database: NPAFC 1925-2021)

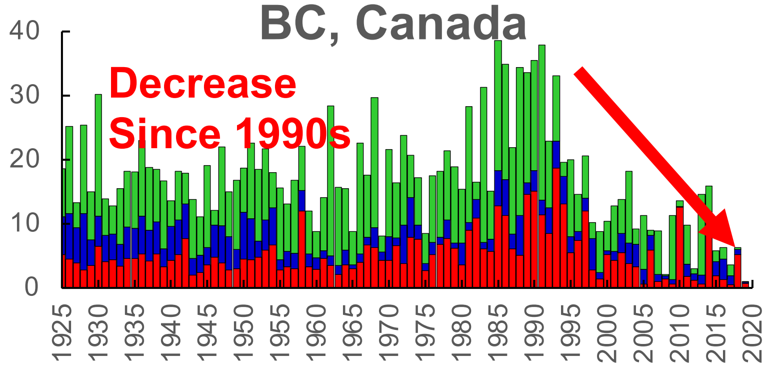
- Salmon catch indicates an increasing trend since 1975.
- Salmon catch for 2021 was the highest ever
- Southern populations: Decreasing trends
- Northern populations: Increasing / high stable





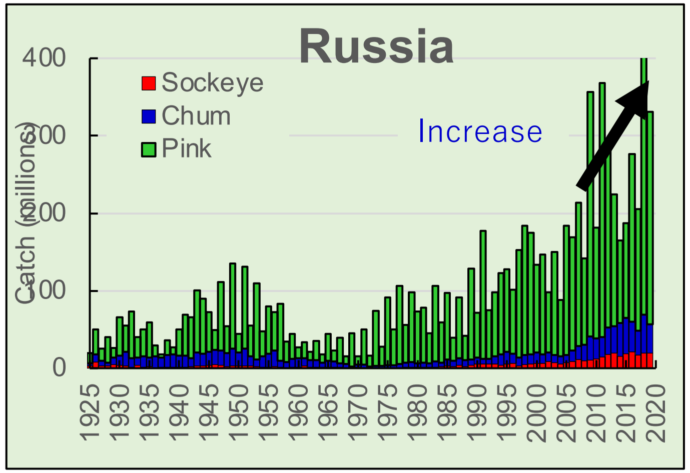


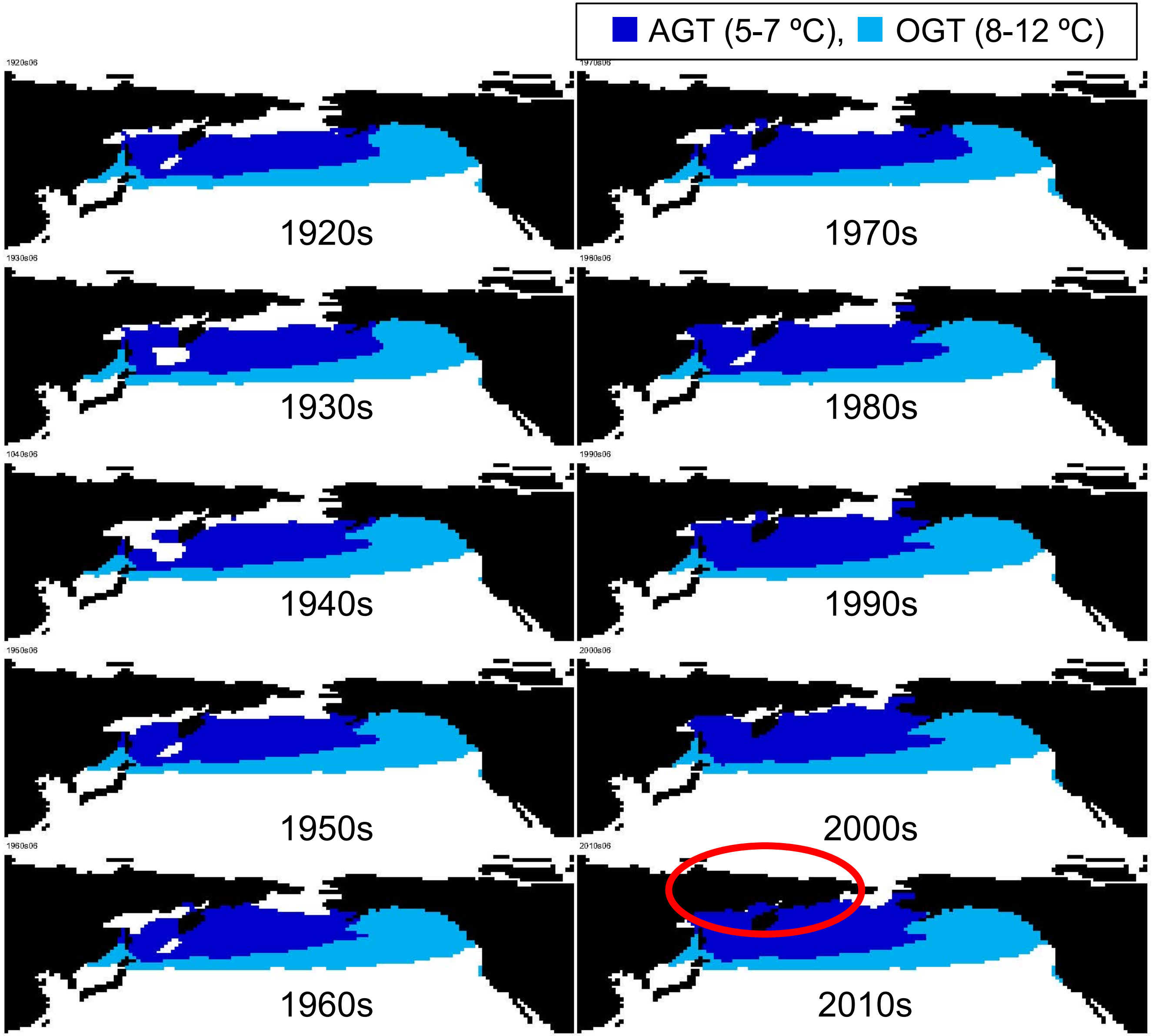




- Temporal change in areas of allowable growth (AGT) and optimum growth (OGT) temperatures of chum salmon in **June** during 1920s-2010s in the North Pacific Ocean

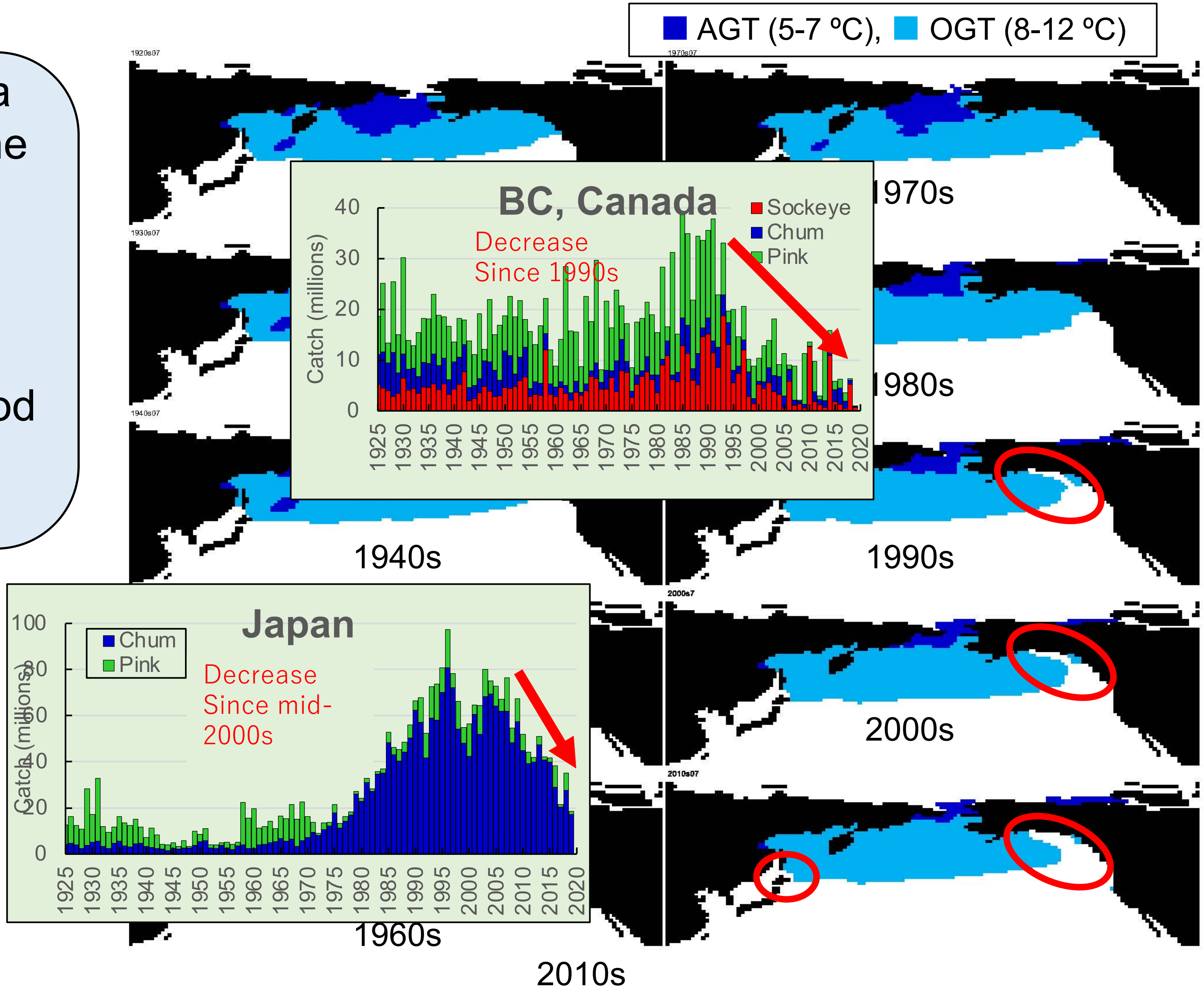
- Area of AGT showed the increasing trend.
- In the 2010s, the AGT approached all coasts of Russia
- This period will correspond to increase abundance for Russian salmon



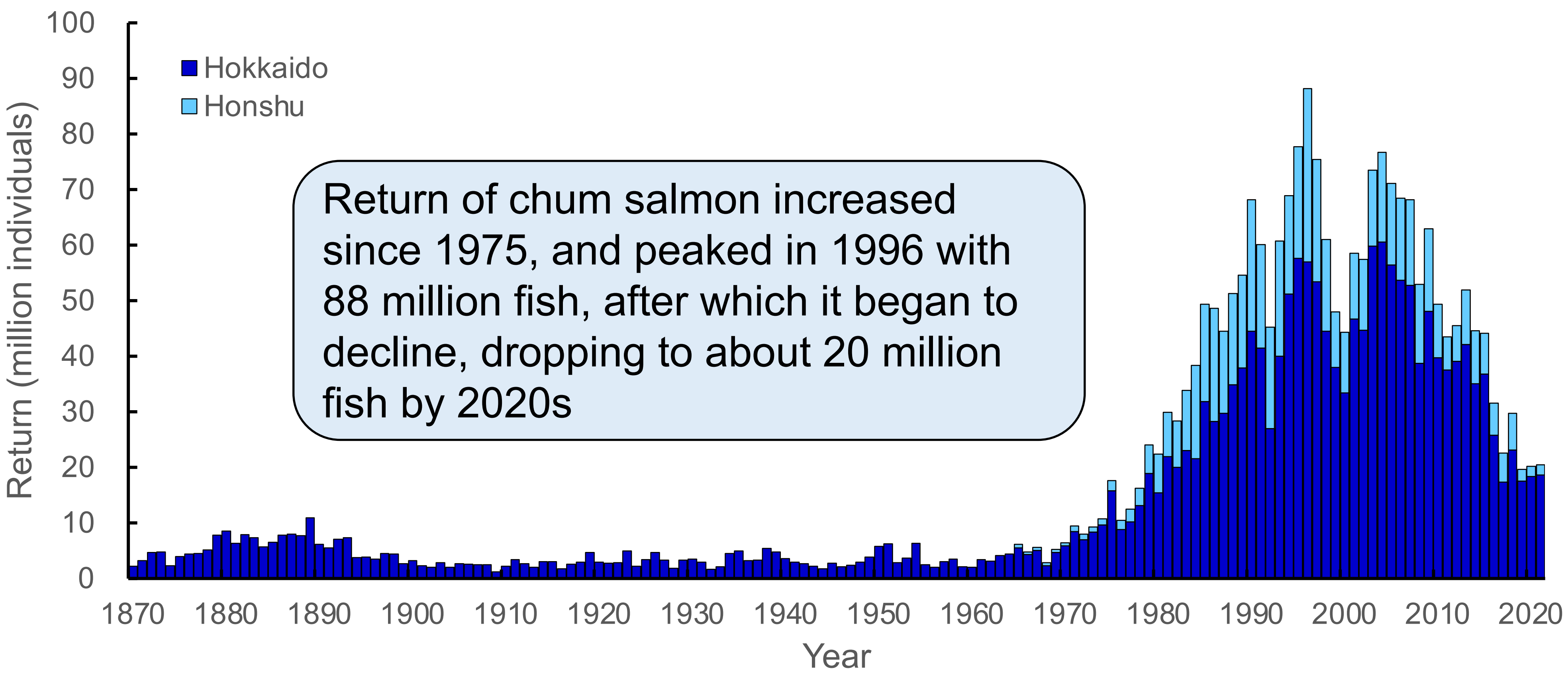


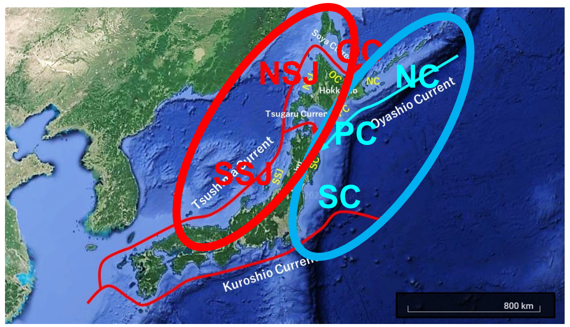
- Temporal change in areas of allowable growth (AGT) and optimum growth (OGT) temperatures of chum salmon in **July** during 1920s-2010s in the North Pacific Ocean

- In July, the area of OGT shows a tendency to leave the coast in the Gulf of Alaska since the 1990s and from the waters near Japan in the 2010s
- Each of these periods will coincide with the beginning period when salmon abundance declined



● Annual changes in return of chum salmon in Japan during 1870-2021





●Warm-Current Population (WCP):

Tsushima warm current

- **SSJ**: Southern Sea of Japan
- **NSJ**: Northern Sea of Japan
- **OC**: Okhotsk Coast

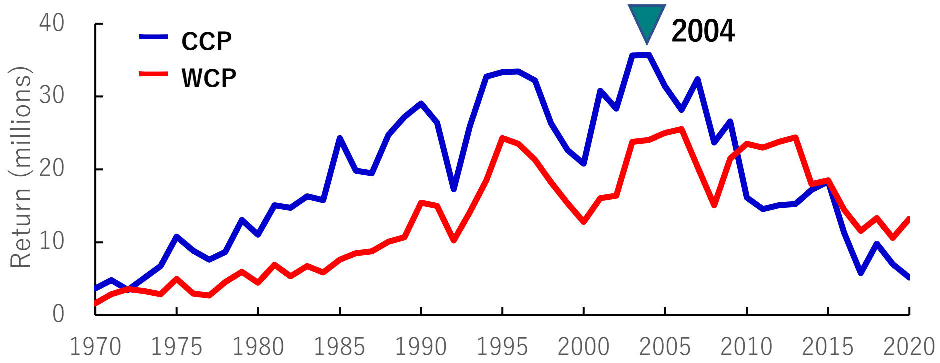
●Cold-Current Population (CCP):

Oyashio cold current

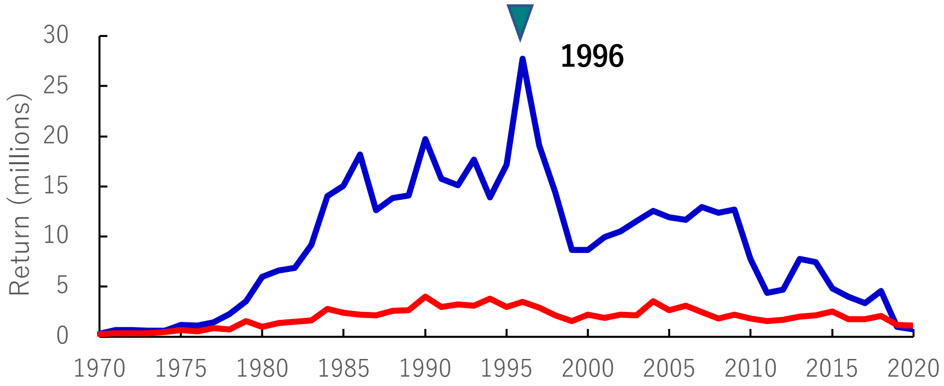
- **NC**: Nemuro Coast
- **PC**: Pacific Ocean in Hokkaido
- **SC**: Pacific Ocean in Honshu

● Annual changes in return and decline rate for WCPs and CCPs of chum salmon in Hokkaido and Honshu islands of Japan

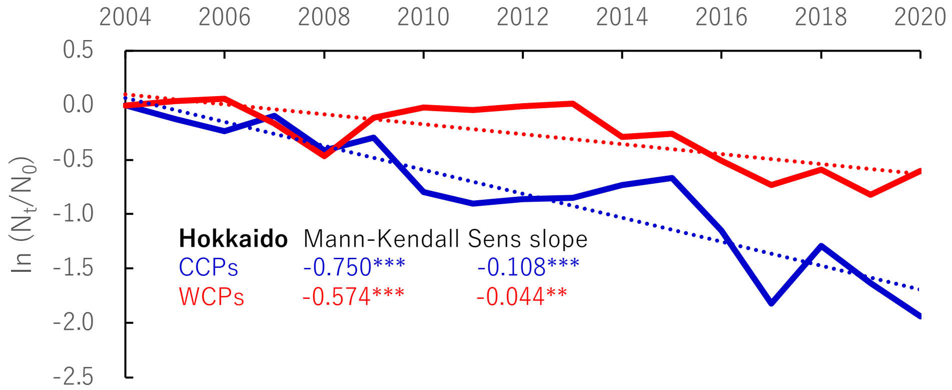
Return: Hokkaido



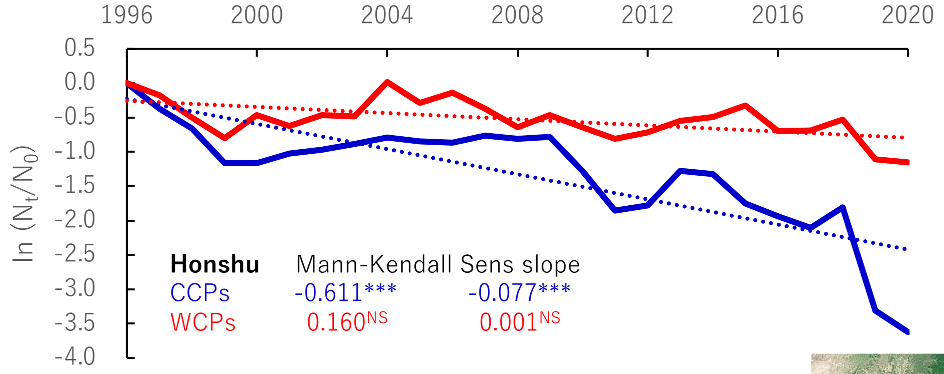
Return: Honshu



Decline rate: Hokkaido



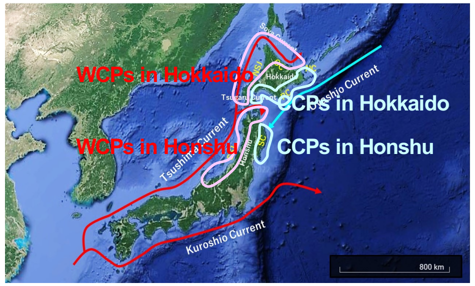
Decline rate: Honshu



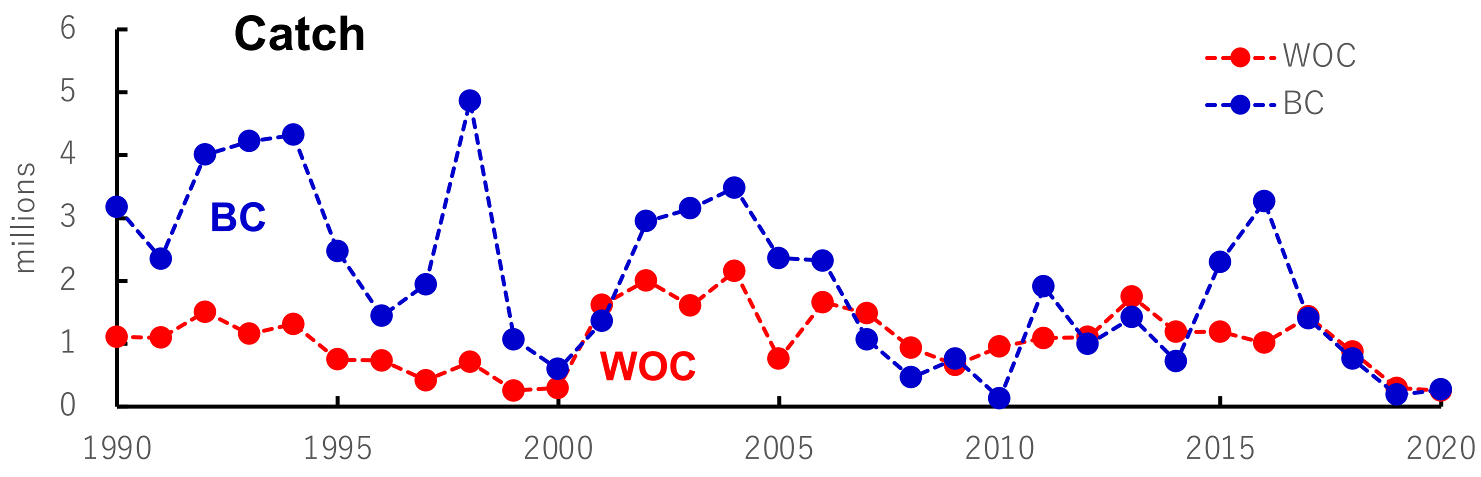
WCPs may be relatively more adaptable to global warming than CCPs for chum salmon

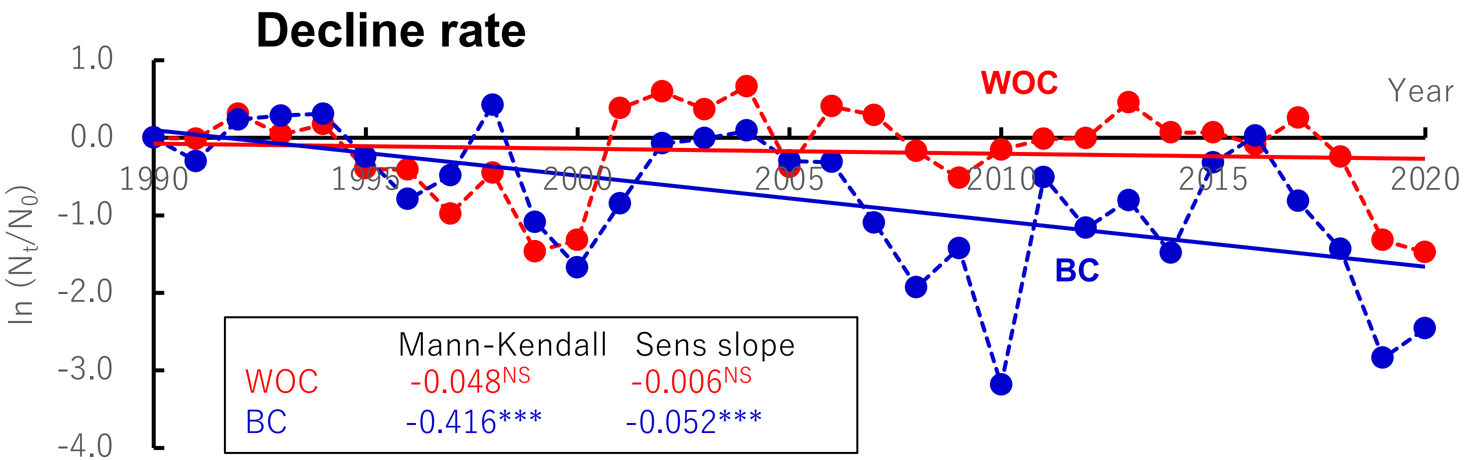
Non-stationary analysis: The Mann-Kendall test and Sen's slope

Decline rate: ln (N_t/N_0)



●Annual changes in Catch and decline rate of chum salmon in BC and WOC





A slope of decline rate for BC populations was lower than that for the WOC populations

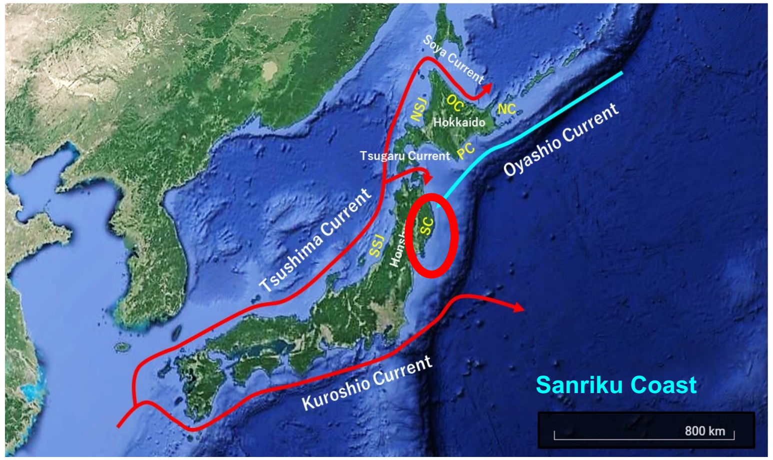
Warm-water-population may be relatively more adaptable to global warming than Cold-water-population for the southern chum salmon.

● **Temporal changes in the spring SST and stay duration of juvenile chum salmon on the Sanriku Coast during 1995-2021**

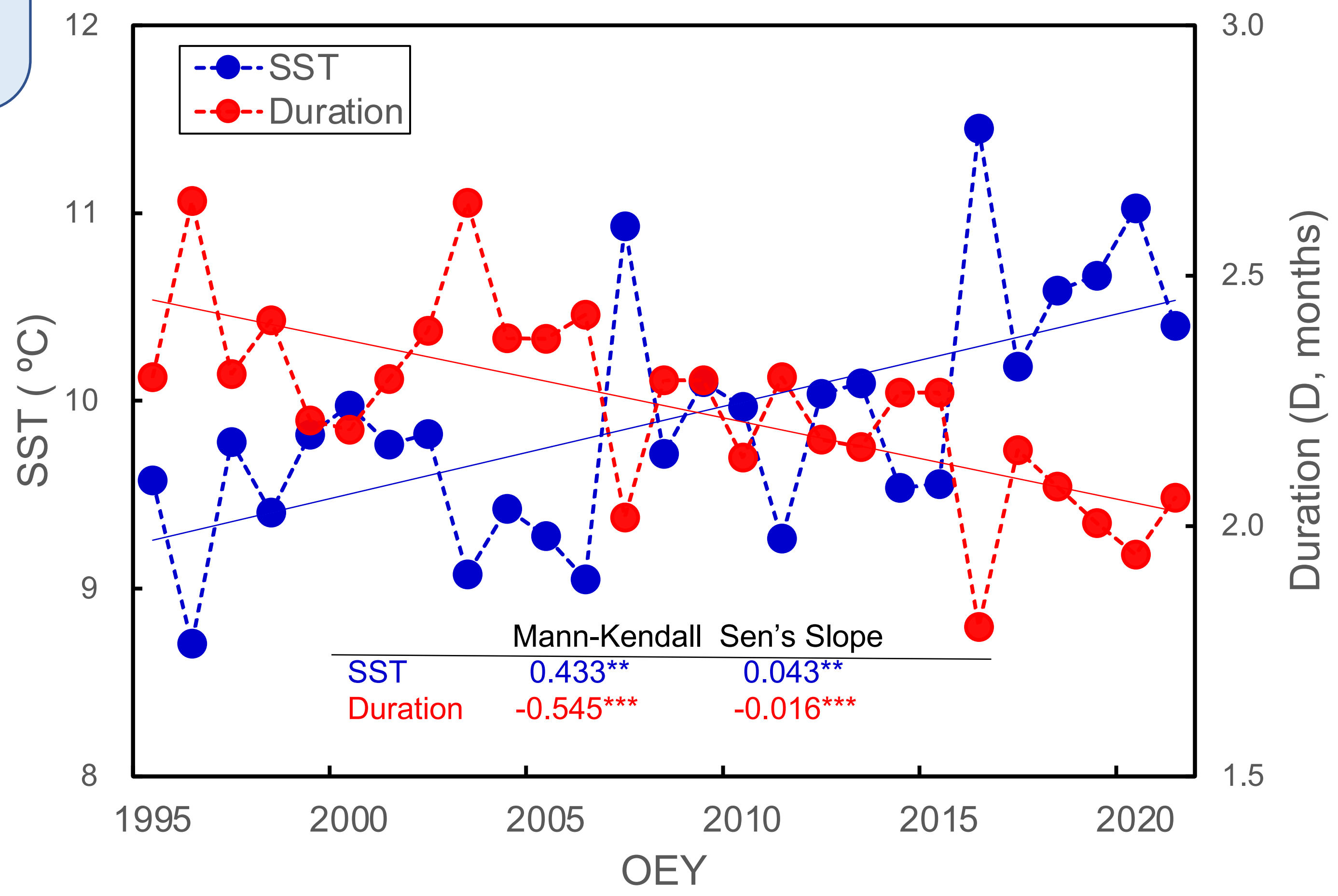
Temporal trend

- **Spring SST: positive (+1.1 ºC)**
- **Stay duration: negative (-0.41 months)**

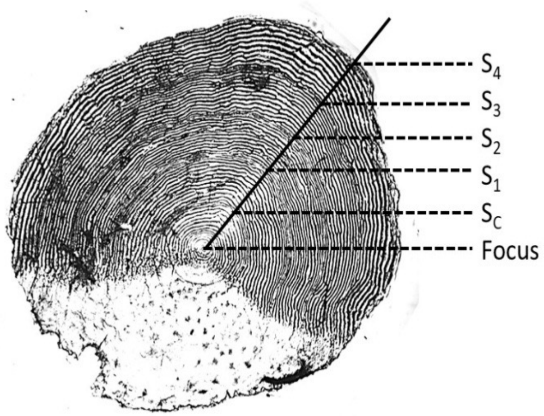
Sanriku Coast: 39-41N 142-143E

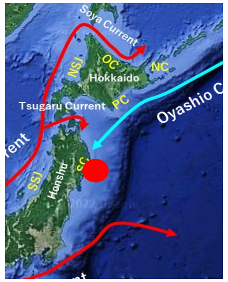


SST: Mean in March – June.
Stay duration: the number of months from March to the date at 12.5 ºC in SST.

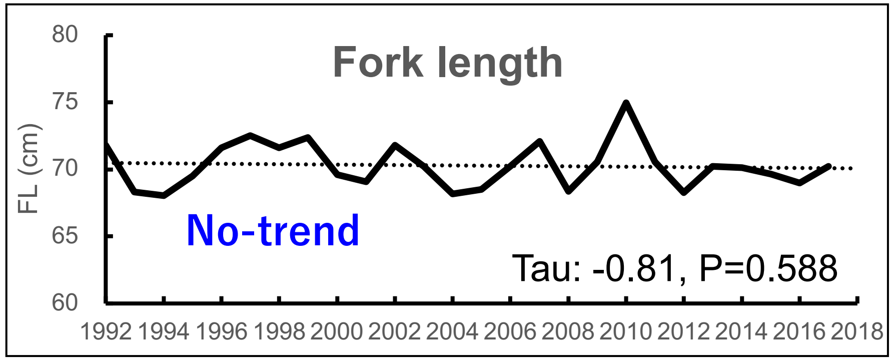


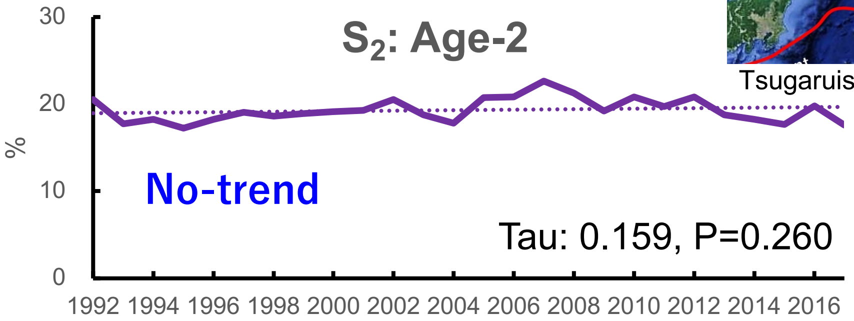
- **Temporal changes in ratios of scale length at each development of Tsugaruishi River chum salmon in Sanriku Coast**

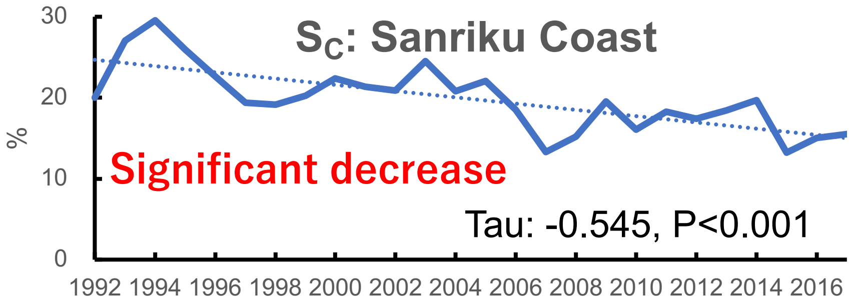


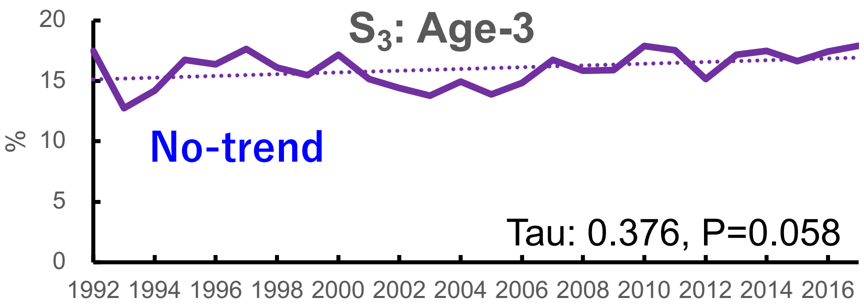


Tsugaruishi River

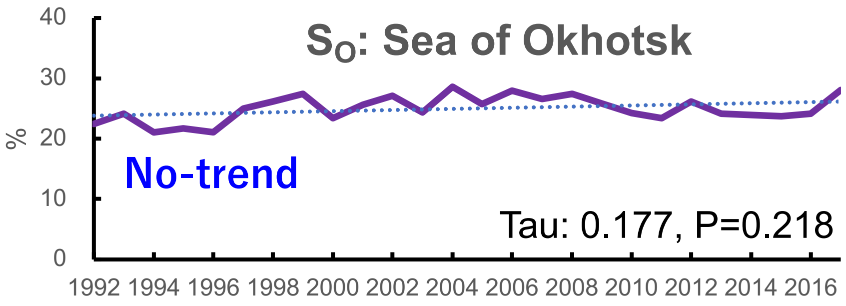


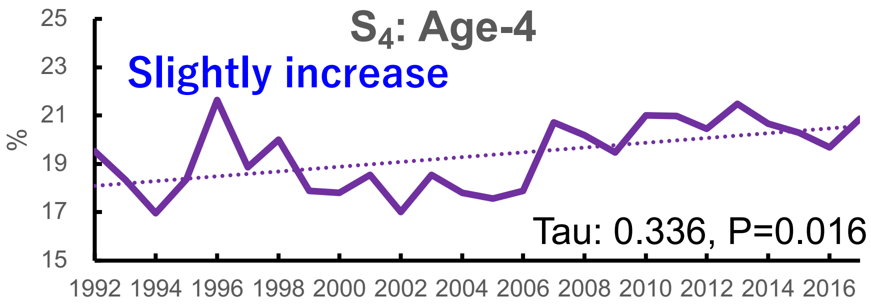






Tsugaruishi River chum salmon indicates a declining trend of their growth in only coastal life period





Brood year

Non-stationary analysis: The Mann-Kendall test

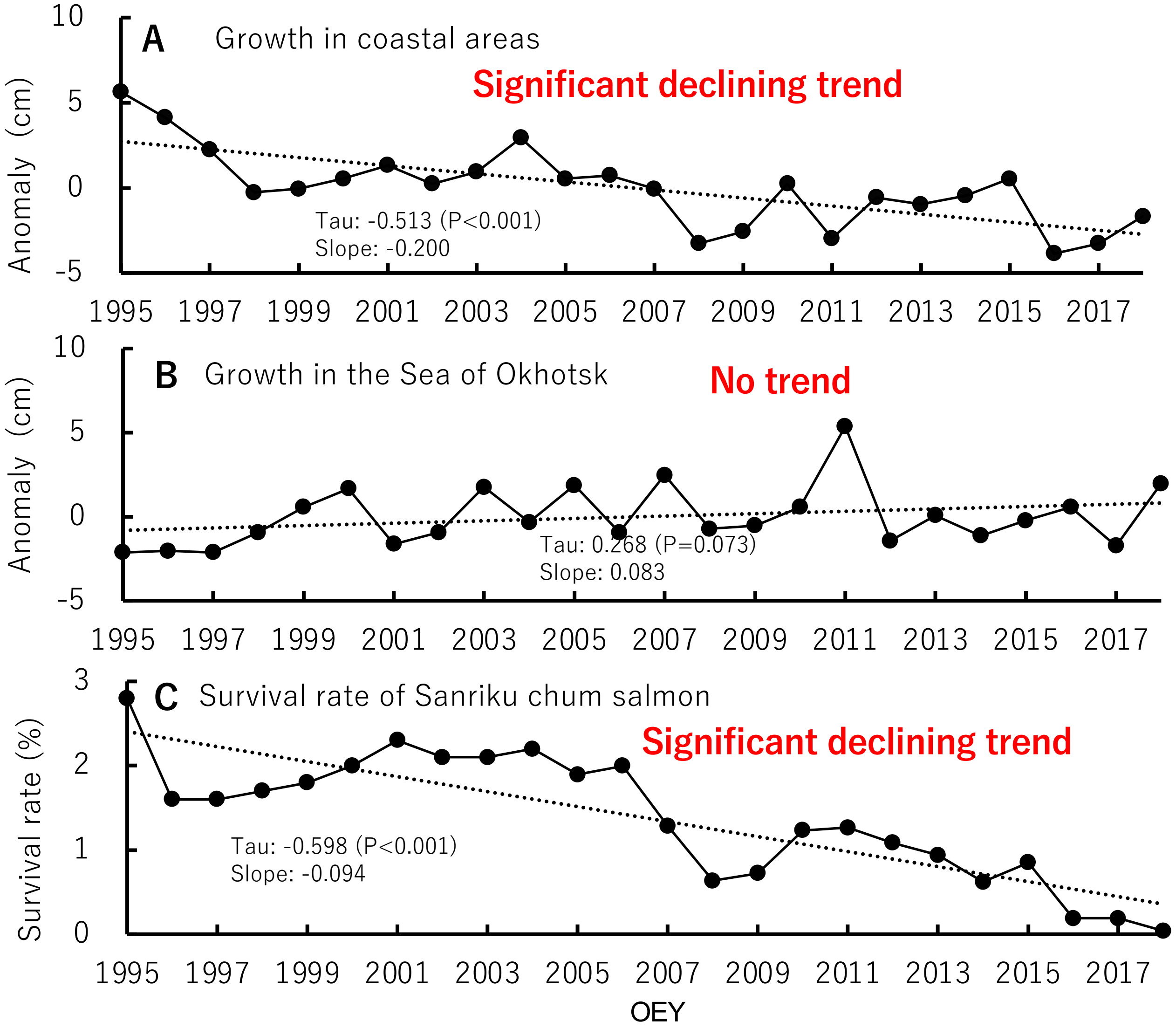
● Temporal changes in growth at the Sanriku Coast and in the Sea of Okhotsk, and survival rate of Sanriku chum salmon

Non-stationary analysis: The Mann-Kendall test

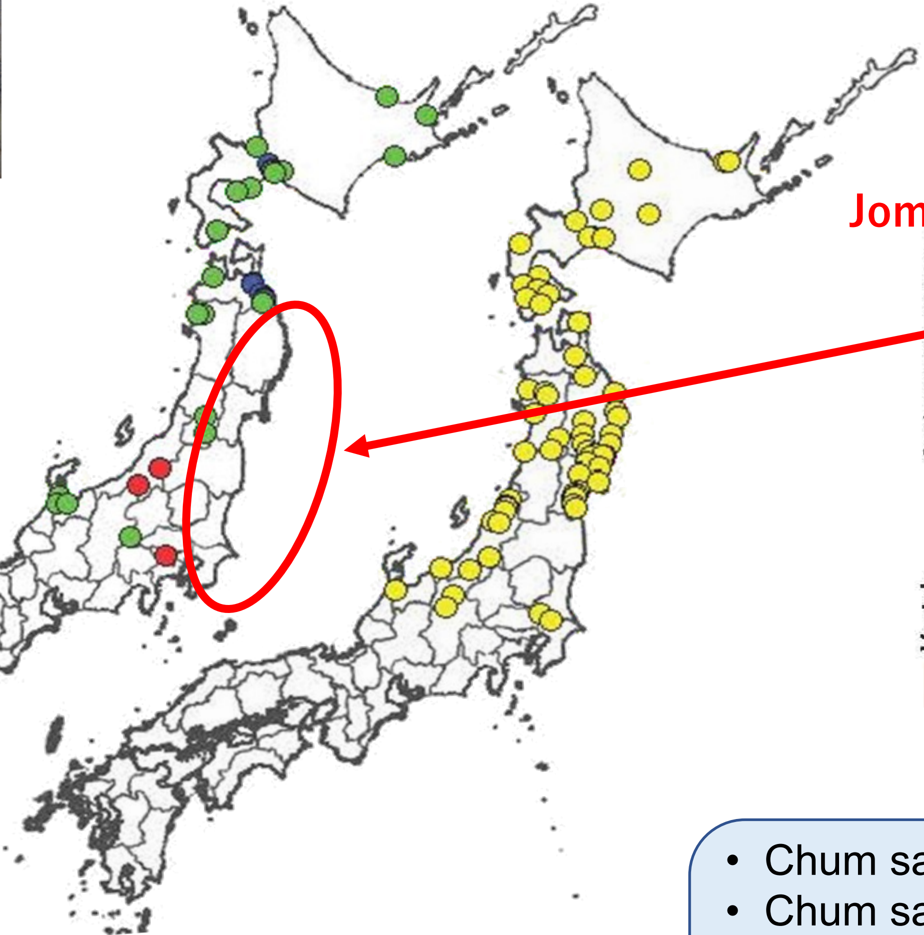
- For Sanriku chum salmon, growth in coast waters and survival rate show the decreasing trend, despite no temporal-trend of growth in the Sea of Okhotsk
- There are significant positive correlations among stay duration, growth (L_c) of juvenile in coastal area and survival rate (S).
- **Juvenile chum salmon could not grow sufficiently in the coastal areas owing to the shortened stay duration, resulting in a reduced survival rate**

Results of simple regression analysis on relationships among stay duration, Lc, Lo and survival rate of Juvenile Sanriku chum salmon during 1995-2018 OEY.

Relationship	r	P	Slope	Intercept
Duration-L_c	0.612	0.001	6.176	−13.983
Duration-L_o	−0.145	0.499	−1.713	3.903
Duration-S	0.677	<0.001	2.509	−4.288
L_c-S	0.802	<0.001	0.251	1.388
L_o-S	−0.145	0.499	−0.046	1.382
L_c-L_o	−0.316	0.133	−0.297	0.023

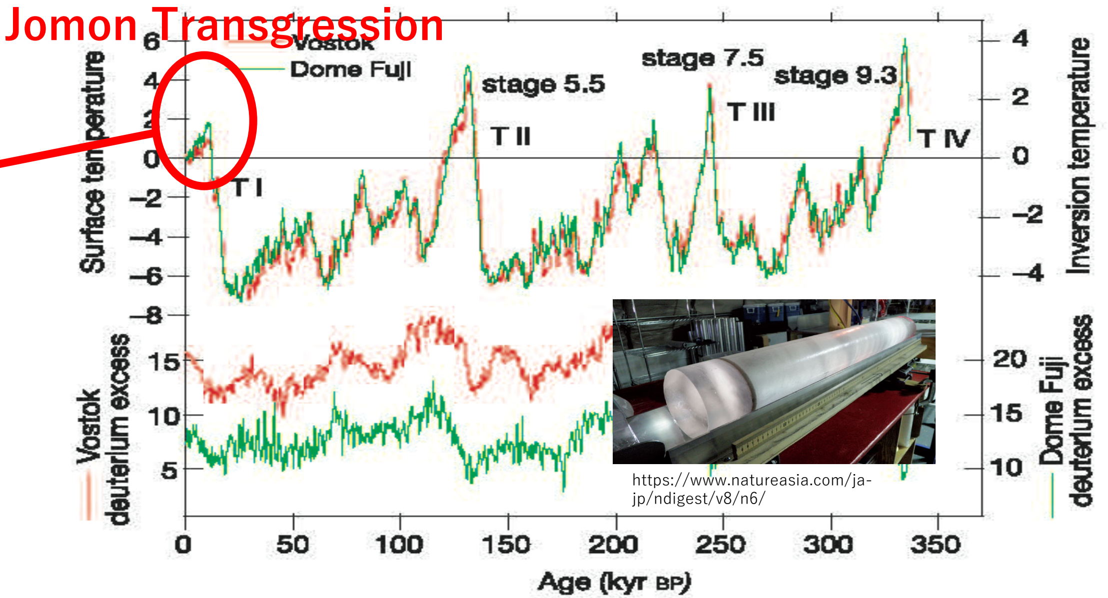


● Distribution of relicts of chum salmon in the Jomon Era (16 – 2.8 kyr BP)



- 🔴 Incipient Jomon Period (16 - 12 kyr BP)
- 🔵 Initial Jomon Period (12 - 7 kyr BP)
- 🟢 **Early Jomon Period (7 - 5.5 kyr BP)**
- 🟡 Middle to Last Jomon Periods (5.5 - 2.8 kyr BP)

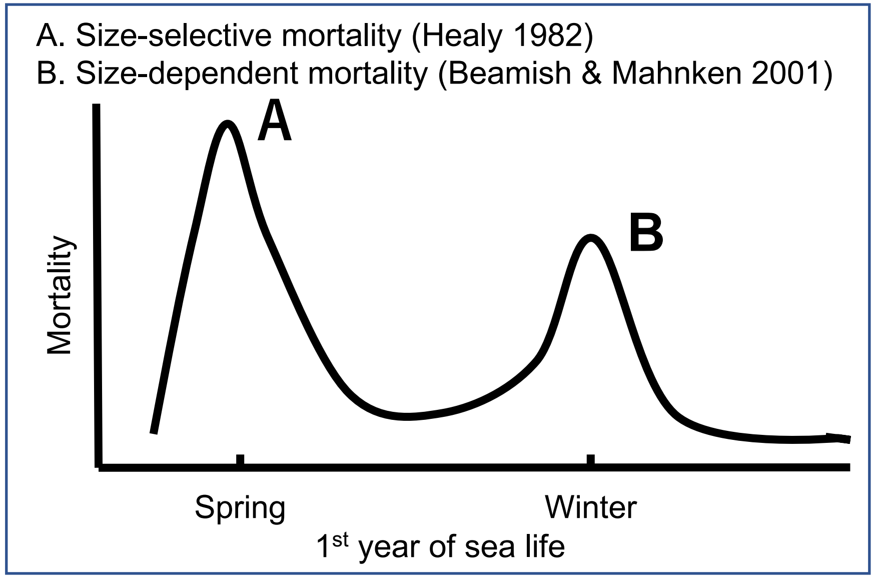
Historical change in the isotopic temperature of the ice core at the Dome Fuji of the East Antarctica in 0-350 kyr BP (Watanabe et al. 2003. Nature)



- Chum salmon were widely distributed throughout northern Japan.
- Chum salmon disappeared in the Pacific coast of Honshu in Early Jomon Period **(Jomon Transgression Period)**, because the temperature was about 2 ºC higher than at present.
- The current situation of chum salmon would be approaching the aspect of Jomon Transgression Period as much as possible.

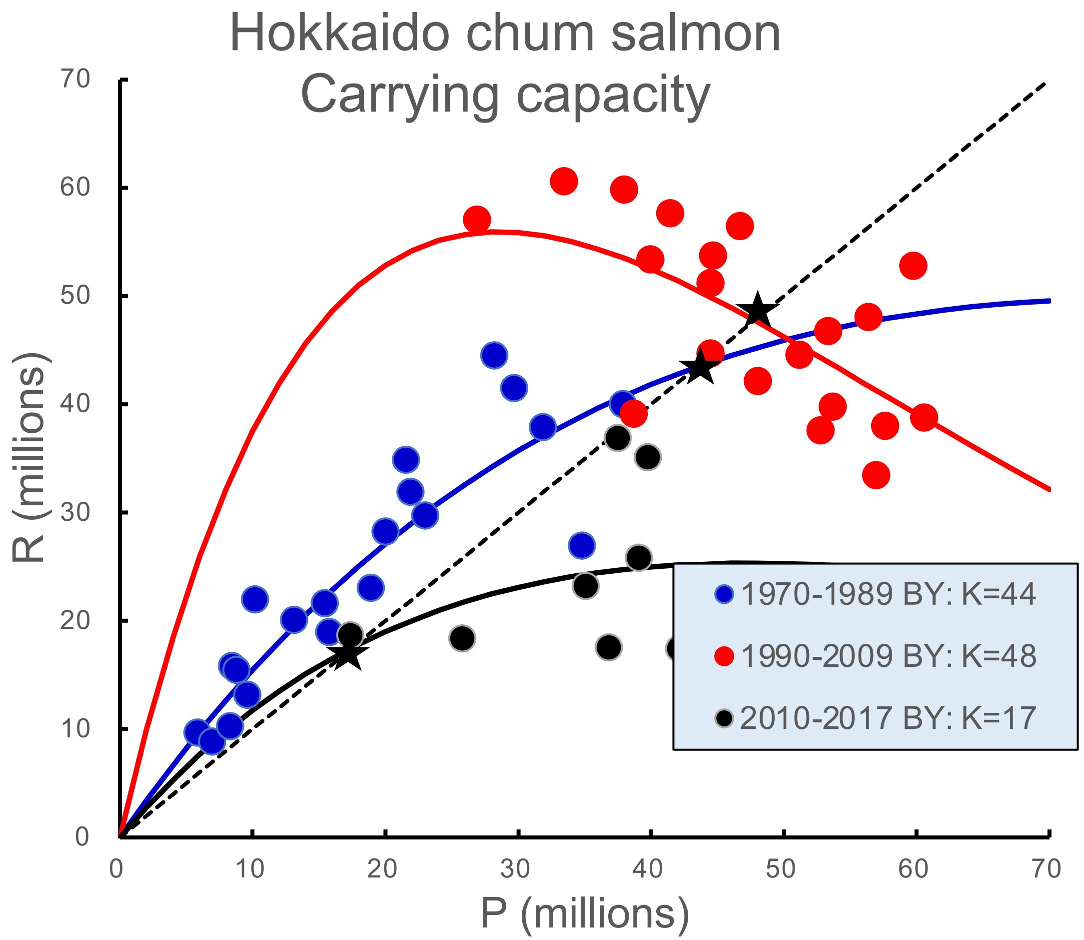
● Conclusion

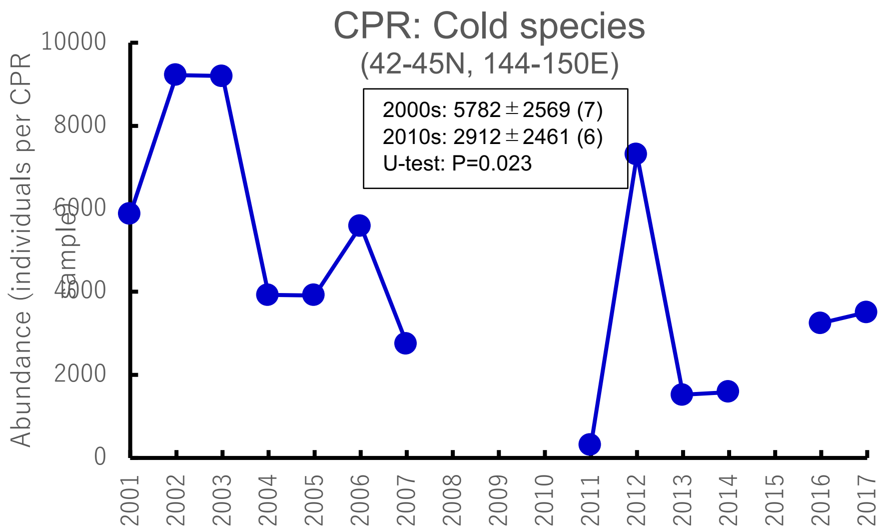
- Pacific salmon productivity has increased in northern areas, but decreased in southern areas in the North Pacific with global warming. For southern chum salmon, WCPs may be relatively more adaptable to global warming than CCPs.
- Since this century, Japanese juvenile chum salmon has been a declining-trend of survival rate, because they could not grow sufficiently in the coastal areas owing to the shortened stay duration, despite no declining-trend of their growth in the Sea of Okhotsk. This result supports the size-selective mortality hypothesis (Healy 1982).
- Salmon remains from the Pacific side in Honshu disappeared during the “Jomon transgression period”. The current situation of Japanese chum salmon is approaching that of the Jomon transgression period. Southern chum salmon, including Japanese salmon, seems to be difficult to adapt well for the extreme warming climate in the near future.
- Therefore, we should establish the sustainable salmon conservation management under a warming climate regime as following final goals:
  (1) conservation and recovery of wild salmon, and zoning between wild and hatchery-produced salmon,
  (2) long-term research and monitoring of interactions between aquatic ecosystems and salmon, and
  (3) restoration and resilience of wild salmon and river ecosystems.



Spare Slides

- Carrying capacity of Hokkaido chum salmon and temporal change in biomass of cold species of Zooplankton in the Western Subarctic North Pacific (42-45N, 144-10E).





CPR: Continuous Plankton Recorder
Data from Dr. Atsushi Yamaguchi

● Offshore migration pattern of juvenile chum salmon in the Sanriku Coast

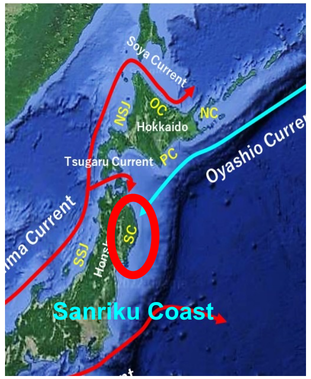
Larger juvenile precede at the offshore migration period

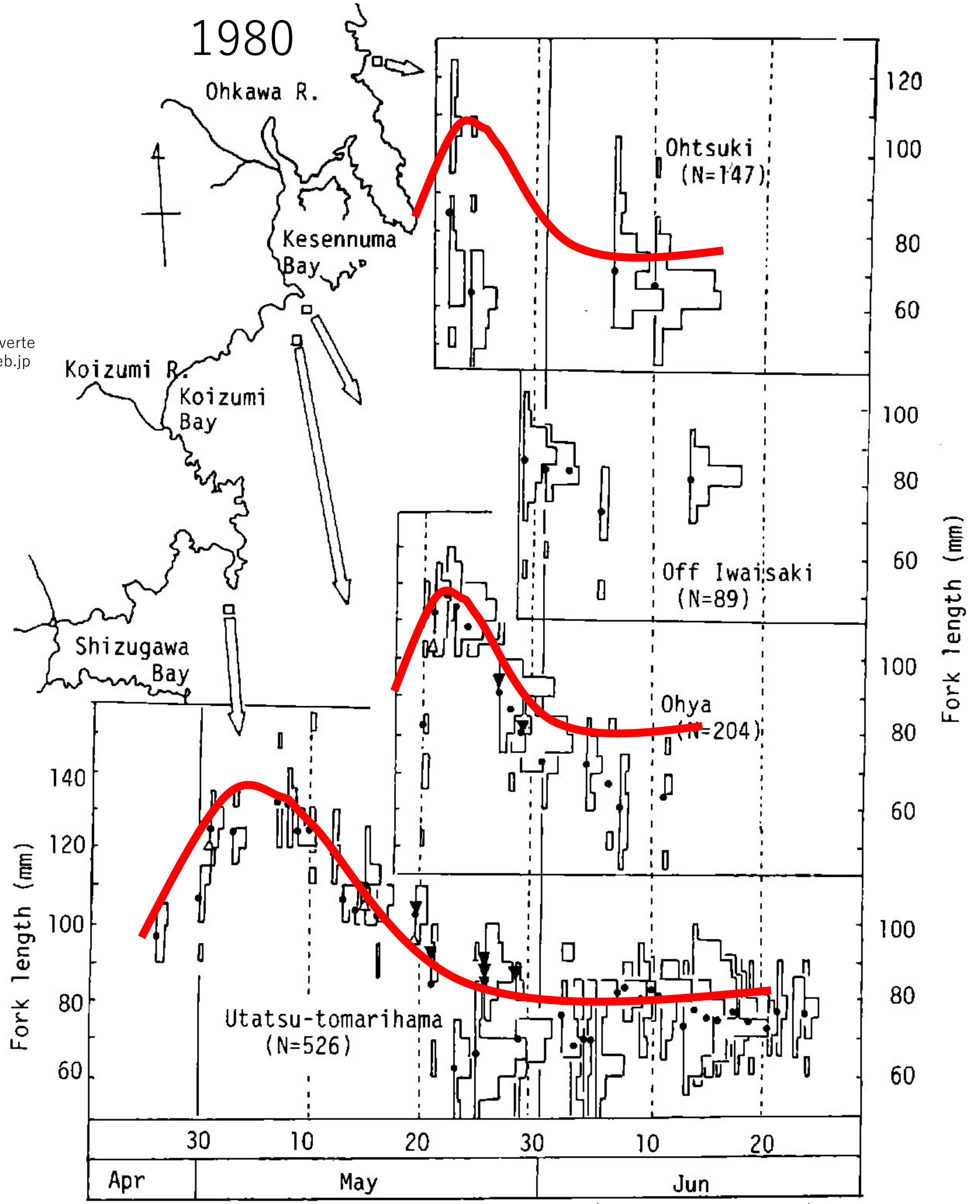
■ Active migration: **AM** (May, 10-14 cm in FL)
- Optimal foraging strategy
  (e.g., Dominant prey: *Themisto japonica*)
- Patchy distribution
  (Offshore migration during the period approaching the Oyashio Cold Current)

■ Passive migration: **PM** (June, 8 cm in FL)
- Escaping from higher SST (>13ºC)
  (Offshore migration after leaving the Oyashio Current)
- Non-selective feeding strategy
  (empty or lower index of stomach content)

http://www.invertebase.org/imglib/invertebase/misc/201512/2_1449380111_web.jpg

Sanriku Coast
39-41N 142-





(Kaeriyama 1986)

● Temporal changes in offshore migration period of juvenile chum salmon on the Sanriku Coast

● **Larger juvenile precede at the offshore migration period**

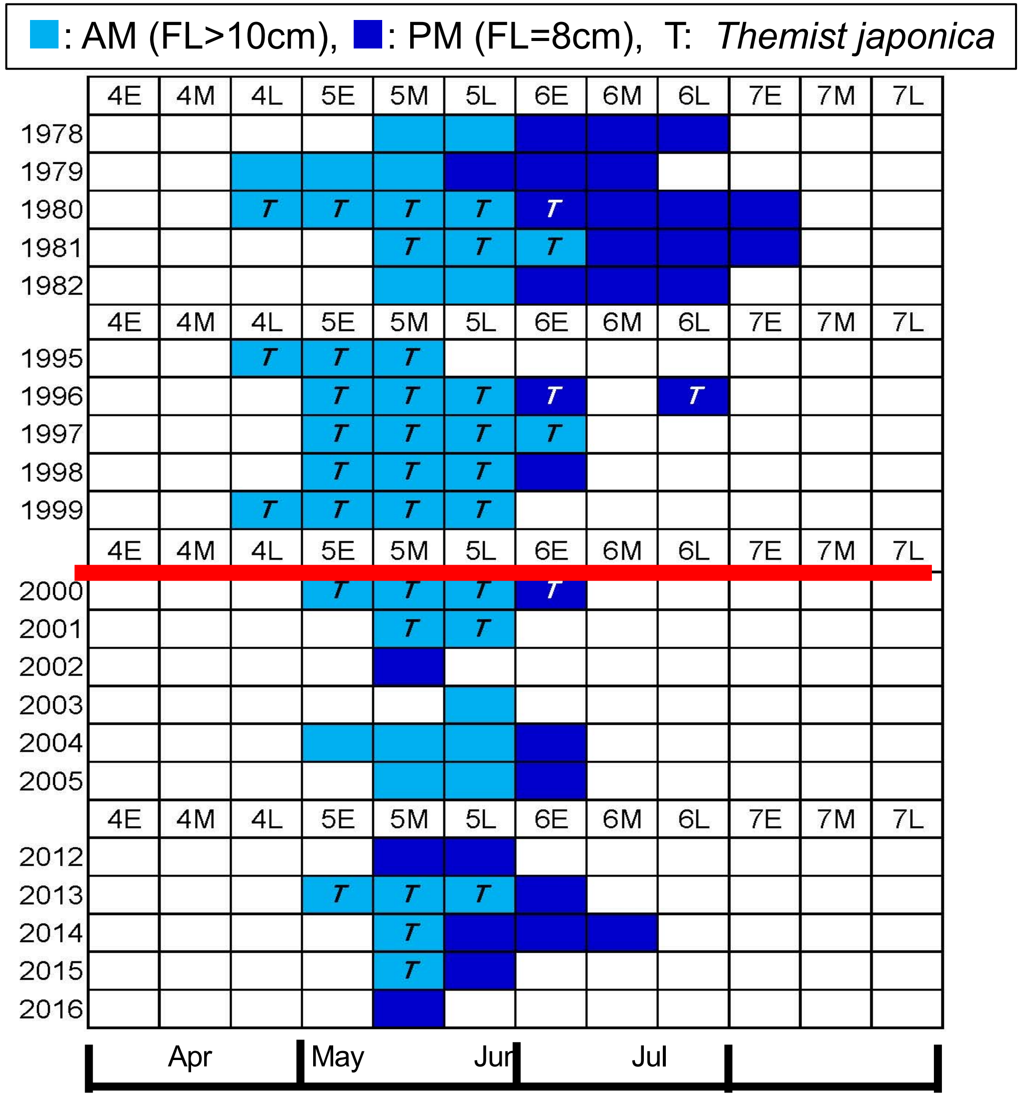
- <u>Active migration: **AM**</u> (■, 10-14 cm in FL)
- <u>Passive migration: **PM** </u>(■, 8 cm in FL)
- Dominant prey: *Themisto japonica*

■ 2000年代以降

- 幼魚の沖合移動期間の短縮（10-20日）
- 能動的回遊魚AM：6月以降減少/消失
- 受動的回遊魚PM：移動期が早まる
- 卓越餌種*T. japonica* ：6月以降胃内容物から減少/消失

＊T: 1978-79, 1982, 2002-12→No data

http://www.invertebase.org/imglib/invertebase/misc/201512/2_1449380111_web.jpg



1978-1982: Kaeriyama (1986), 1995-2005: Hokkaido Salmon Hatchery (1996-1997), National Salmon Resources Center (1998-2006), 2012-2016: Iwate Prefecture (unpublished data)

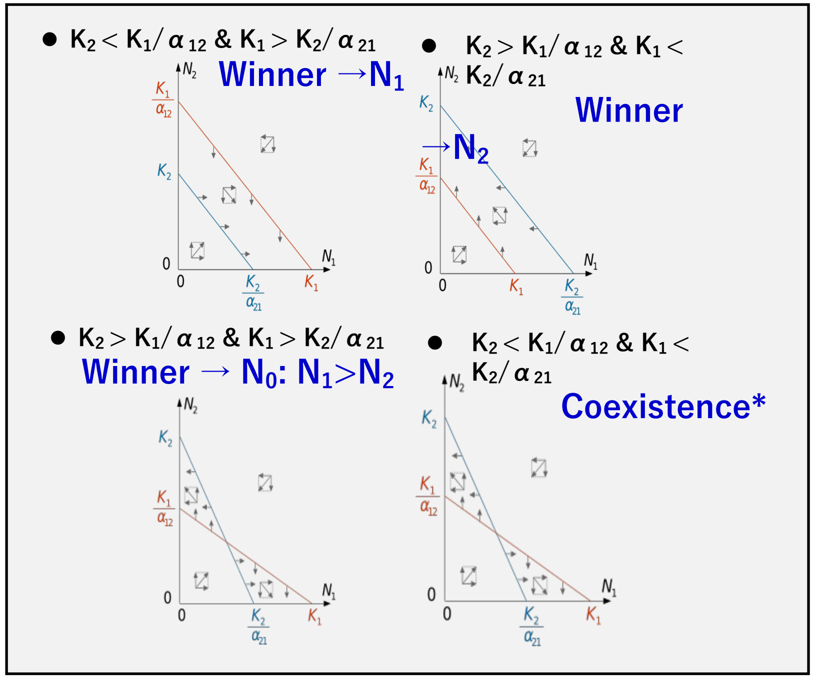
● Results of inter- and intra-specific interactions of Japanese chum salmon with Russian chum and pink salmon based on the Loka-Volterra competition model

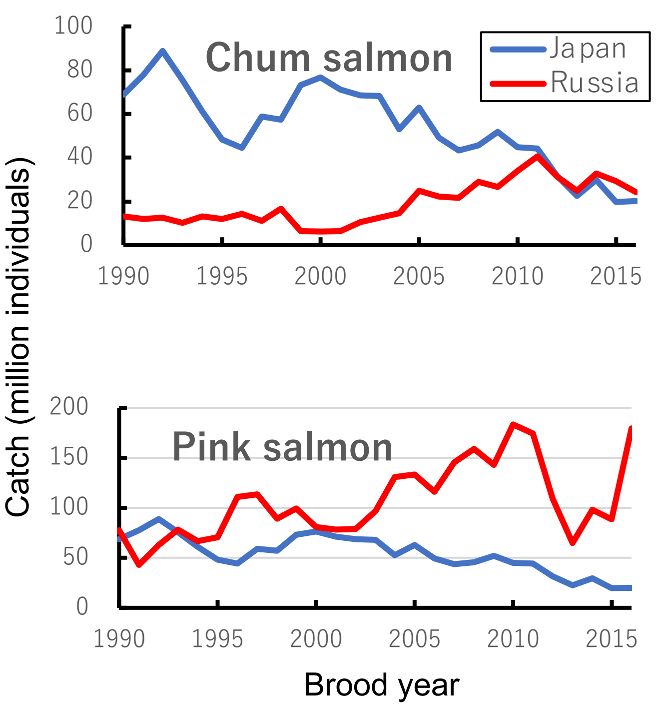
K: Carrying capacity, N: Population size,
α: Competition coefficient

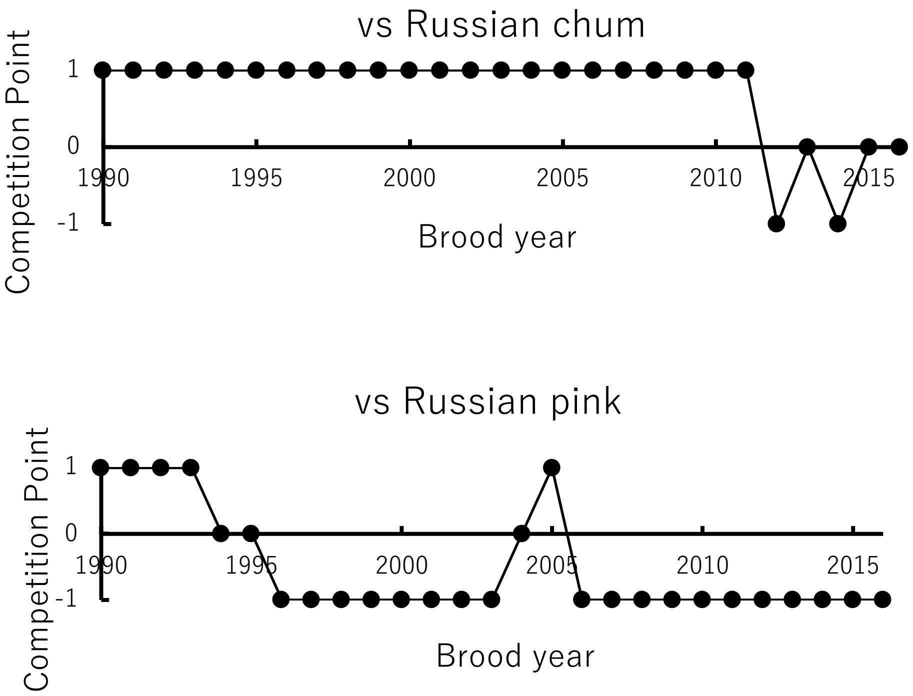
1. $\frac{dN_1}{dt} = r_1 N_1 \left[1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right]$ $\quad \frac{dN_2}{dt} = r_2 N_2 \left[1 - \frac{N_2 + \alpha_{21} N_1}{K_2}\right]$

2. $N_1 = K_1 - \alpha_{12} N_2 \quad N_2 = K_2 - \alpha_{21} N_1$

3. $\alpha_{12} = \frac{K_1 - N_1}{N_2} \quad \alpha_{21} = \frac{K_2 - N_2}{N_1}$

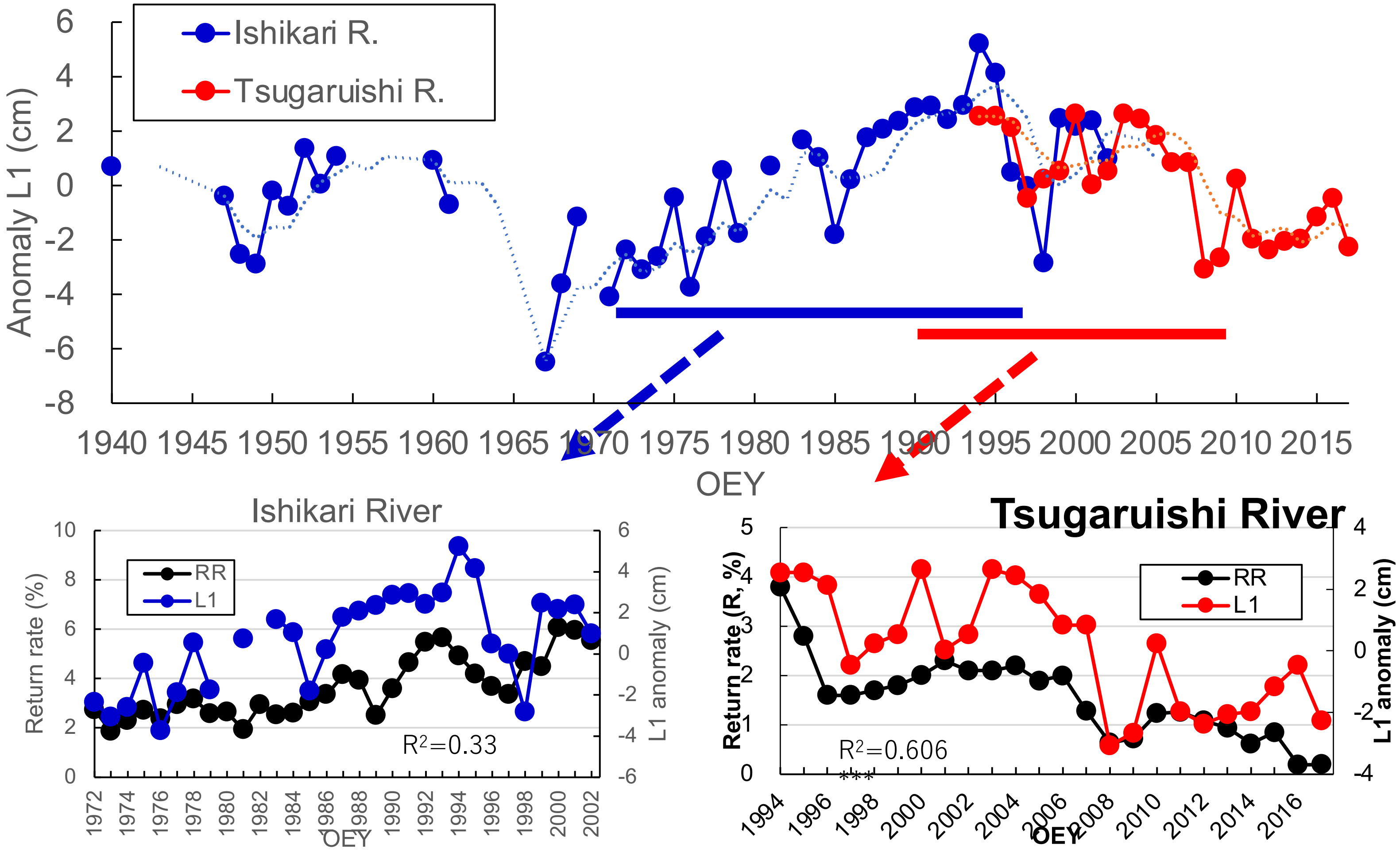






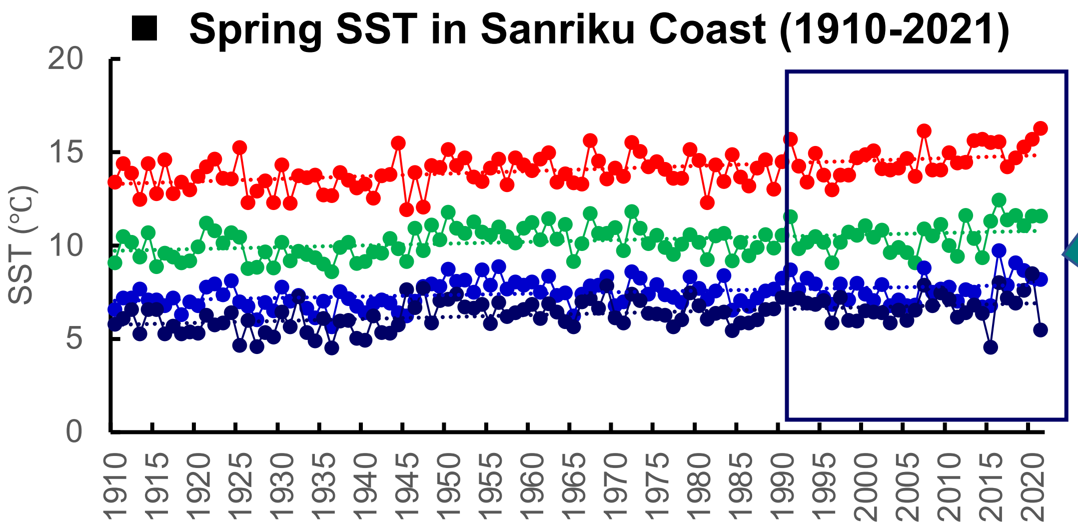
- Against Russian chum salmon, Japanese chum salmon was the winner until the 2011 BY and became coesistent or a loser after that.
- Japanese chum salmon were almost a loser against Russian pink salmon after the 1995 BY.

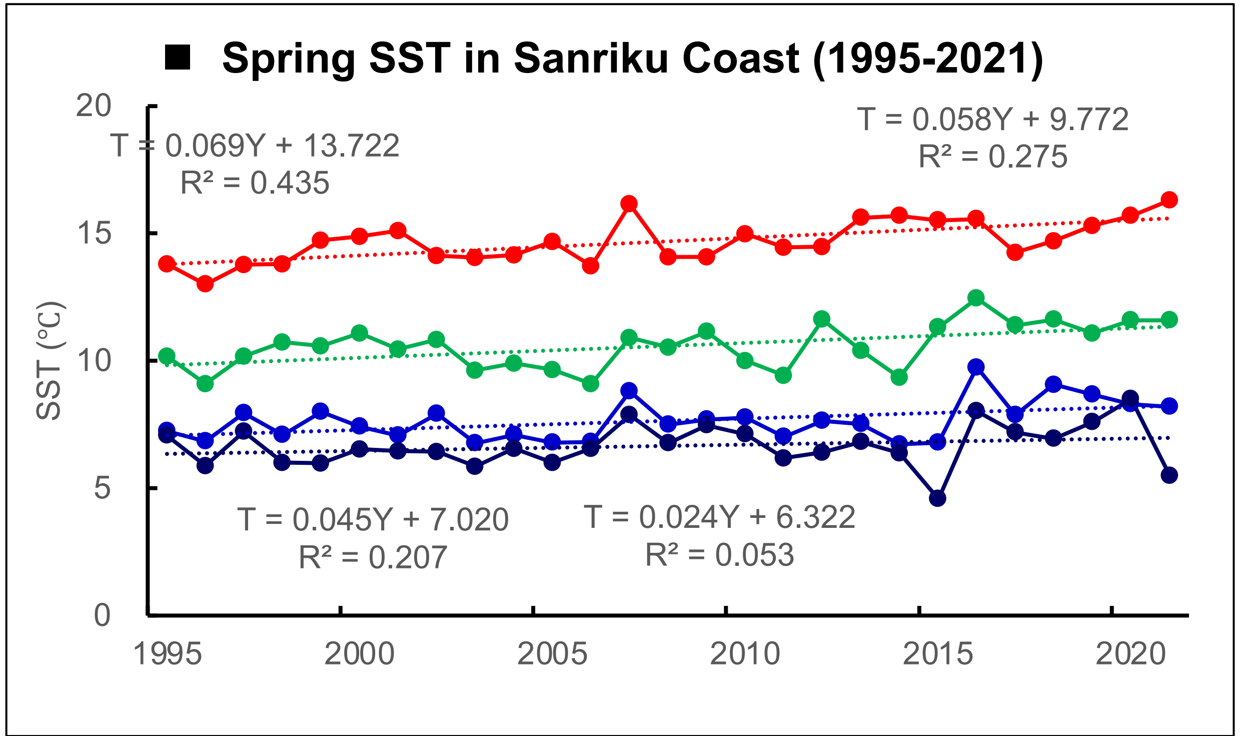
● **Temporal changes in growtn at age-one and survival rate of Ishikari and Tsugaruishi chum salmon**



● Annual change in Spring SST in Sanriku Coast

COBE-SST, March-June, 1920-2020, 39-41N 142-143E





● Biological properties of chum salmon

■サケのクリティカルな減耗期
- 沿岸生活期：沖合移動可能な体力（遊泳力）と体サイズ
- 海洋生活1年目の越冬期：十分なエネルギー蓄積

■サケの最適水温：8-12 °C
　　適水温：5-7 °C

Size-selective mortality: Early marine life period (Healy 1982)
Size-dependent mortality: First marine fall and winter (Beamish & Mahnken 2001)

A. Size-selective mortality (Healy 1982)
B. Size-dependent mortality (Beamish & Mahnken 2001)