Influence of climate warming for migration, growth and survival of Japanese chum salmon in the North Pacific Ocean and the Okhotsk Sea

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Temporal changes in return of Japanese chum salmon and PDO (1965-2017)
**Annual change in catch of chum salmon in the North Pacific**

- Southern populations: Decreasing
- Northern populations: Increasing or high stable

Data Source: NPAFC
It was predicted .......

- "Population size of Japanese chum salmon became a half of the maximum by around 2010 because of the new climate regime shift." (Kaeriyama 2004)
- "The global warming will affect the distribution of chum salmon in the North Pacific in this century" based on the IPCC SRES-A1B scenario. (Kaeriyama 2008)

Prediction of areas of optimum temperature for chum salmon based on the IPCC SRES-A1B scenario (Kaeriyama 2008)

Hokkaido chum salmon
Max: 60 millions in 2004
Half period: 30 millions in 2016
R=-0.0656
Objects and Methods

Objects
- To verify my prediction on the global warming
- To address potential progress of the global warming effect on Japanese chum salmon

Material & Method
- Sea surface temperature (SST) in the North Pacific:
  1) COBE-SST in Japan Meteorological Agency (1º × 1º, 1975-2017)
  2) NOAA-ESRL-PSC (1948-2017)
- Growth back-calculation using the scale analysis of adult chum salmon returning to the Tsugaruishi River in the Sanriku Coast (1996-2017)

Definition
- Adaptable temperature (AT): 5-12 ºC
- Optimum temperature (OT): 8-12 ºC
- Using the data on growth rate, feeding behavior, and CPUE for chum salmon

\[ L_i = FL - \frac{(TS-S_i)}{(TS-114)} \times (FL-4) \]
FL: fork length, TS: ΣS_i (Seo et al. 2011)
Migration pattern of juvenile chum salmon released from Hokkaido

Migration pattern of juvenile chum salmon

- Foraging & precedent migration in the coast
- Juvenile stay in coastal seas around Japan as the post-fingerling stage (mean 10 cm, range 8-12 cm in FL) by the end of June

The development stage of chum salmon in the early life period (Kaeriyama 1986) (Mayama & Ishida 2003)
Juvenile migrate to the Okhotsk Sea in **July**, and stay during summer and autumn.

- Their survival rate is considered to be decided at the first oceanic life and wintering, based on the size-selective mortality (Healey 1982) and the size-related mortality (Beamish et al. 2004) respectively.
Temporal change in resident duration for juvenile chum salmon in coastal seas around Japan

<table>
<thead>
<tr>
<th>Area</th>
<th>Difference</th>
<th>$R^2$</th>
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</thead>
<tbody>
<tr>
<td>OK</td>
<td>3</td>
<td>0.018$^{\text{NS}}$</td>
</tr>
<tr>
<td>EP</td>
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<td>0.082$^{\text{NS}}$</td>
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<tr>
<td>NJS</td>
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<tr>
<td>SC</td>
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<tr>
<td>SJS</td>
<td>7</td>
<td>0.037$^{\text{NS}}$</td>
</tr>
</tbody>
</table>

- The resident duration (RD) is decreasing year by year.
- Since the 1990s, the RD decreased more than one week in most of coastal seas, except for the Okhotsk coast.
- In Northern Japan Sea and Sanriku coasts, chum salmon reduced the survival rate with decreasing the RD since the 1990s.
Temporal changes in areas of adaptable and optimal temperatures in August for chum salmon in the North Pacific Ocean.

- Area of optimum temperature (8~12 °C)
- Area of adaptable temperature (5~12 °C)

Since the 2000s, the area has drastically declined in the North Pacific Ocean.
Change in area of adaptable temperature (AT) for chum salmon in August of 2005 (■) and 2017 (■) in the North Pacific Ocean

- The area of adaptable temperature in 2017 markedly decreased in the Okhotsk Sea and the Gulf of Alaska
- The global warming will progress to affect the distribution area of chum salmon
Temporal change in areas of adaptable and optimum temperatures in July in the Okhotsk Sea

- Since the 2010s, the area of optimal temperature quietly departed from Hokkaido Island.
- This indicates that Japanese juvenile chum salmon will be difficult to migrate to the Okhotsk Sea in July, with the progress of global warming.
**Temporal changes in areas of adaptable (■ AA) and optimum (■ AO) temperatures of juvenile chum salmon in the Okhotsk Sea from May to October**

- Russian juvenile chum salmon migrate to the sea from May to June
- Since the 2000s, the June AA: increase  
  → **Survival rate of Russian juvenile is rising**  
- In August, the AO became less than half since the 2010s.  
  → **Carrying capacity is declining**  
  → **Biological interaction between wild and hatchery salmon will occur**
Temporal changes in survival rate and growth anomaly at age-1 (L1) of Japanese chum salmon since the 1993 brood year

- The causal linkage between survival rate and the growth at age-1 is observed
- A decline of survival for Japanese chum salmon will be affected by the decrease of growth at the age-1 in the coastal seas around Japan and the Okhotsk Sea

Growth at age-1 was back-calculated by scales of chum salmon returning to the Tsugaruishi River.
The relationship indicates the significant positive correlation within the optimum temperature.

The survival rate sharply declined over the optimum temperature.
Wild salmon have higher trophic level than hatchery population in case of the Yurappu River chum salmon

- Wild salmon had higher $\delta^{15}$N than hatchery fish.
- Hatchery salmon had more significant variation of $\delta^{13}$C than wild fish.

Wild salmon had higher trophic level than hatchery fish.
Wild salmon will distribute and forage at higher-productive area (e.g., coast).
Hatchery salmon will travel further offshore than wild fish.

Population-specific differences in migration
- Steelhead (Quinn et al. 2012)
- Baltic (Atlantic) salmon (Kallio-Nyberg et al. 1999)
- Chinook salmon (Quinn et al. 2011)

Wild salmon has higher adaptability than hatchery salmon.
Conservation of the wild salmon is very important.

*Wild: $12.546 \pm 0.185$
Hatchery: $11.265 \pm 0.210$
(F=21.069, P<0.001)

Fig. 2 Relationship between carbon and nitrogen stable isotopes of presumably wild (●) and hatchery (○) chum salmon returning to the Yurappu River.
(Qin et al. 2013)
SUMMARY & CONCLUSION

○ Japanese chum salmon:
  - has decreased the survival rate since the 2000s.
  - will be difficult to migrate to the Okhotsk Sea since the 2010s with progress of the global warming.

○ Near future, all Russian and Japanese juvenile chum salmon will have following issues during summer in the Okhotsk Sea, depending on progress of the global warming and decrease of the carrying capacity:
  - a intraspecific interaction between wild and hatchery salmon,
  - a population density-dependent effect.

○ In Japan, the conservation of wild chum salmon is of primary importance, because the wild salmon has higher adaptability than hatchery salmon under the changing climate.
Sustainable conservation management for chum salmon

Goals

1. Conservation & use
   - Conservation and recovery of wild salmon
   - Innovation of salmon fisheries & hatchery stocking

2. Interaction between aquatic ecosystem & salmon
   - Climate change (e.g., Global warming, Regime-shift): sea & freshwater ecosystems
   - Change in aquatic ecosystem affecting the life history & population dynamics of salmon

3. Restoration & resilience for wild salmon and river ecosystem
   - Restoration for impoverished river ecosystem
   - Resilience of wild salmon

Science Council of Japan (2017)