Situation and Perspective on Production Trends of Pacific Salmon in the North Pacific

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Pacific salmon play an important role as keystone species and ecological service in the North Pacific ecosystem.

Pacific salmon:
Keystone species for sustaining the biodiversity and productivity in riparian ecosystem, and for supplying marine-derived nutrients (MDN) to the terrestrial ecosystem.

Pacific salmon:
Higher trophic level in the North Pacific.

Effects of anadromous fish on material cycle ($\delta^{15}N$) to the terrestrial ecosystem.
Main Database

Catch Data
- FAO: 1950-1996
- NPAFC: 1993-2006
- INPFC (1979): 1893-1976

Climate Data
- Beamish & Bouillion (1993): ALPI
- Mantua et al. (1997): PDO
Production trend of Pacific salmon: synchronizing with the climate regime shift?

Annual change in catch of Pacific salmon in the North Pacific
Temporal changes in ALPI and carrying capacity ($K$) of three species (sockeye, chum, and pink salmon)

Salmon carrying capacity significantly synchronized with the long-term climate change

$\text{Carrying capacity } K = \text{Replacement level} \ln\left(\frac{\alpha}{\beta}\right)$

Time span: $t$ (bi-decadal cycle span)

Pink salmon: 10 generations by odd- and even year classes

Chum & Sockeye salmon: 20 brood years
Production trends of Pacific salmon since the 1990s

Since the 1990s

- Pink: increase (0.016) [*]
- Chum: increase (0.012)
- Sockeye: decrease (-0.035)
- Chinook: stable (0.008)
- Coho: decrease (-0.049)
- Masu: decrease (-0.090)

(): Slope in regression lines
* Homogeneity (P<0.01)
Annual changes in catch of wild/hatchery salmon in the North Pacific

Hatchery salmon
Pink <20%
Chum >80%
These results suggest that the carrying capacity of chum salmon is closely related not only with the long-term climate change, but also the density-dependent effect. Biological interaction between wild and hatchery populations should be an important consideration in the sustainable fisheries management based on the ecosystem level.
Temporal changes in growth anomaly in the Okhotsk Sea and survival rate of Hokkaido chum salmon. The growth based on a back calculation of the fork length using the scale analysis.
Growth in the Okhotsk Sea of Hokkaido chum salmon

Temporal change in the rate of ice cover area in the Okhotsk Sea (Ustinova et al. 2002)

Sea Ice - Growth

Annual changes in the sea ice concentration (SI) and anomaly of growth at the Okhotsk Sea (Lo) of the age-4 chum salmon returning to the Ishikari River.

SST - Growth

Annual changes in the sea surface temperature (SST) during summer and fall, and anomaly of growth at the Okhotsk Sea (Lo) of the age-4 chum salmon returning to the Ishikari River.

Global warming effect on the growth of chum salmon in the Okhotsk Sea!
Temporal change in return rates of chum salmon released from Japan and Korea

- **Japan Sea Coast**
- **Okhotsk Sea & Nemuro Coasts**
- **Pacific Coast**

Prediction on the Global Warming effect on chum salmon in the North Pacific Ocean based on the SRES-A1B scenario

Relationship between water temperature and specific growth rate of chum salmon. (Kaeriyama 1984, 1989)

Estimation on SST in the North Pacific Ocean in 2050 and 2095 (Kawamiya 2004)

Optimal temperature for chum salmon
Growth and feeding migration period: 8-12°C
Global Warming effect on chum salmon in the North Pacific Ocean

2005

2050

2095

July

August

September

October

Optimum temperature (8 – 12 °C)
Global Warming Effect for Chum salmon

- **At present**, the global warming is affecting:
  - Positively, increase in growth and survival of Hokkaido chum salmon in the Okhotsk Sea since the 1990s
  - Negatively, reduction in growth and survival of the southern chum salmon (e.g., Korean and Iwate populations) since the late 1990s

- **In the Future**, the global warming will affect:
  - Decrease in their carrying capacity for reducing distribution area in the North Pacific Ocean
  - Strong density-dependent effect
  - Hokkaido chum salmon population will lose migration route to the Okhotsk Sea by 2050 and will be crushed by 2100
Sustainable Fisheries Management Based on the Ecosystem Approach of Pacific Salmon

1. Marine ecosystem conservation and stable marine-food product should be carried in order to address the increase in human population and impacts on the earth ecosystem

2. Sustainable fisheries management based on the Ecosystem Approach: Risk Management (Adaptive management & Precautionary principle)

- Spatial and temporal changes: Carrying capacity, Food web & trophic level
- Climatic-oceanic conditions: Global warning, Regime shift
- Biological interaction: Wild vs Hatchery population, Density-dependent effect
- Feedback control: Monitoring and Modeling
- Adaptive learning & Risk accountability