Sustainability and risk management of Pacific salmon under the changing climate and catastrophic earthquake and tsunami in coastal ecosystems around Japan

Masahide Kaeriyama, Yuxue Qin, Yosuke Koshino, and Hideaki Kudo
Faculty and Graduate School of Fisheries Sciences
Hokkaido University
salmon@fish.hokudai.ac.jp
Topics

- Climate change and production trend of Pacific salmon
- Human impacts for Pacific salmon:
  - Hatchery salmon
  - Global warming
- Conclusion
Climate change and production trend of Pacific salmon
Production trend of Pacific salmon

Synchronizing with the climate regime shift

Monthly values for the PDO index: 1900 - August 2011

Annual change in catches of Pacific salmon in the North Pacific Ocean 1920-2009
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

Carrying capacity trend
- Pink: stable?
- Chum: stable?
- Sockeye: decrease

R² = 0.868, (F = 462, P < 0.001, n = 72)
Annual change in catch of chum and pink salmon in the North Pacific in 1990-2010 (by NPAFC Database)

### Chum salmon
- **Canada**: Decrease
- **Japan**: Decrease
- **Russia**: Increase
- **USA**: Stable?

### Pink salmon
- **Canada**: Decrease
- **Japan**: Decrease
- **Russia**: Increase
- **USA**: Stable?

**Southern populations:** Decrease
**Russian populations:** Increase
Human impacts for Pacific salmon: Hatchery salmon
Hatchery Salmon Effects

Annual changes in abundance of wild/hatchery salmon

Hatchery salmon
- Pink <20%
- Chum <60%
- Sockeye <10%

% Hatchery/Biomass

Abundance (million fish)

Year

Wild

Hatchery

Pink

Chum

Sockeye

Wild

Hatchery Salmon Effects
**Carrying capacity and density-dependent effect of chum salmon**

\[ \text{RCC} = \frac{\text{CC-B}}{\text{CC}} \times 100 \]

RCC: Residual Carrying Capacity  
CC: Carrying Capacity  
B: Biomass  
FL: Fork length (mm)  
AGE: Mean age at maturity

This result suggests that
- carrying capacity of chum salmon is closely related not only with the long-term climate change, but also the density-dependent effect,
- the density-dependent growth will also affect breeding characters (e.g., body size and fecundity) of the **wild salmon**
**Genetic Influence of Hatchery Salmon**

**Genetic differentiation of Yurappu River chum salmon**
Variable nucleotide sites in the 481 bp 5’ portion of mtDNA control region

Pairwise population $F_{st}$ estimated between chum salmon populations

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*P<0.05  **P<0.01

Yurappu River chum salmon remains a native stock in the late-run, but is intermingled with populations introduced from other rivers by the artificial hatchery program.
**Genetic Influence of Hatchery Salmon (2) Tedori R.**

Unrooted tree based on genetic distance between haplotypes.

- **Tedori River** received a massive seed-transplantation of chum salmon from the Chitose Salmon Hatchery during 1980s and 1990s.
- Tedori River chum salmon were closely related with Chitose and Tokachi River populations, and did not show the genetic differentiation with Tokoro River population, despite no-seed-transplantation from this river in Hokkaido.
- This result shows that a part of Tedori River chum salmon receive gene flow and disturbance following the seed transplantation from not only Chitose River, but also other river populations in Hokkaido.
• Chitose Salmon Hatchery (CSH) play a role of a center of salmon hatchery program and main base of salmon seed transplantation in Japan.
• Chitose River chum salmon population extremely decreased and could not reproduce by 1960s because of the overfishing.
• The CSH released a lot of juvenile transported from almost all populations around Hokkaido during 1960s and 1980s.
• So, the massive seed transplantation from the CSH caused that almost all early-run populations were genetically disturbed in Japan since the 1980s.

A. Total number of both native and non-native juvenile chum salmon released into the Chitose River. B. Total number of juveniles transplanted from each region and released into the Chitose River.
Human impacts for Pacific salmon: *Global warming*
Mean SST isothermal diagrams around Japan in September

Tsushima Warm Current
→ **S**: Strong, **W**: Weak

Annual change in the run size of early-population chum salmon returning to the Japan Sea coast in Hokkaido.

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Weak: 2,407±1,028 thousands (N=14)
Strong: 1,478±785 thousands (N=10)

(ANOVA: F=4.314, P<0.05)
Long-term change in escapement pattern of Hokkaido chum salmon

- **1970-80s**: Bimodality (Early & Late runs)
- **1990s-early 2000s**: Late run disappeared by hatchery selection for salmon fisheries industry
- **Since 2006**: Faint sigh on decline in early run and increase in late run in order to the global warming
- **Early run**: Mixed (& artificial disturbed) population
- **Late run**: Wild population

Trophic level: Wild>Hatchery salmon in the Yurappu River

Please see a poster of FIS-P-4.

**Wild population:** Important Genetic Resources
Prediction about the Global Warming effect on chum salmon in the North Pacific Ocean based on the SRES-A1B scenario

(Kaeriyama 2012)
Global Warming Effect on Chum Salmon in the North Pacific

- **At present,** the global warming is affecting:
  - Positively & directly for increases in growth at age-1 and survival of Hokkaido chum salmon through the SST (sea surface temperature) during summer and autumn in the Okhotsk Sea since the late 1980s
  - Negatively for the spawning migration of early-run populations returning to Japan since the late 1990s

- **In the Future,** the global warming will affect:
  - Decrease in their carrying capacity for reducing distribution area in the Bering Sea
  - Moving to the northern area (e.g., the Chukchi Sea)
  - Strong density-dependent effect will occur
  - Wintering area change from the Gulf of Alaska to the Northwestern Subarctic Gyre
  - Hokkaido chum salmon population will lose migration route to the Okhotsk Sea by 2050 and will be crushed by 2100
Conclusion
Conceptual Diagram on the Sustainable Adaptive-Management of Pacific Salmon in Japan

Feedback control

Monitoring
- Climate change
- Biological information (body size, age composition, breeding & genetic characters)
- Condition of river ecosystem, etc.

Action plan (& Modeling)
- Conservation: Natural freshwater ecosystems
- Protection: wild salmon
- Sustainable hatchery program
Sustainability for ocean ecosystem conservation and seafood security

- Will we be able to use the ocean organisms as seafood in the future?
  - We should recognize to live in the earth ex dono ecosystem service, and know natural threats
  - Carrying capacity in the marine ecosystem → “More than enough is too much”
  - Fisheries Industry: Economic efficiency → Ecosystem Approach

- What do we need for seafood security and marine ecosystem sustainability in present and future?
  - Education
    - Paradigm shift from the traditional fisheries science to the new ecological fisheries science in the advanced education
    - Dietary education for kids
      → e.g. “local production for local consumption”

- How do we establish the sustainable fisheries and aquaculture management based on the ecosystem approach?
  - Risk Management: Adaptive management & Precautionary principle
    1) Adaptive learning: Learning by doing, Responsibility of risk exposition
    2) Feedback control: Monitoring, Modeling
      - Fisheries: Long-term climate change (e.g., Global warming, Regime shift), Carrying capacity
      - Aquaculture: Food security, Conservation of marine ecosystem, Water pollution

- Carrying capacity in the marine ecosystem → “More than enough is too much”
- Fisheries Industry: Economic efficiency → Ecosystem Approach