Perspective on Production Trends and Carrying Capacity of Pacific Salmon in the North Pacific

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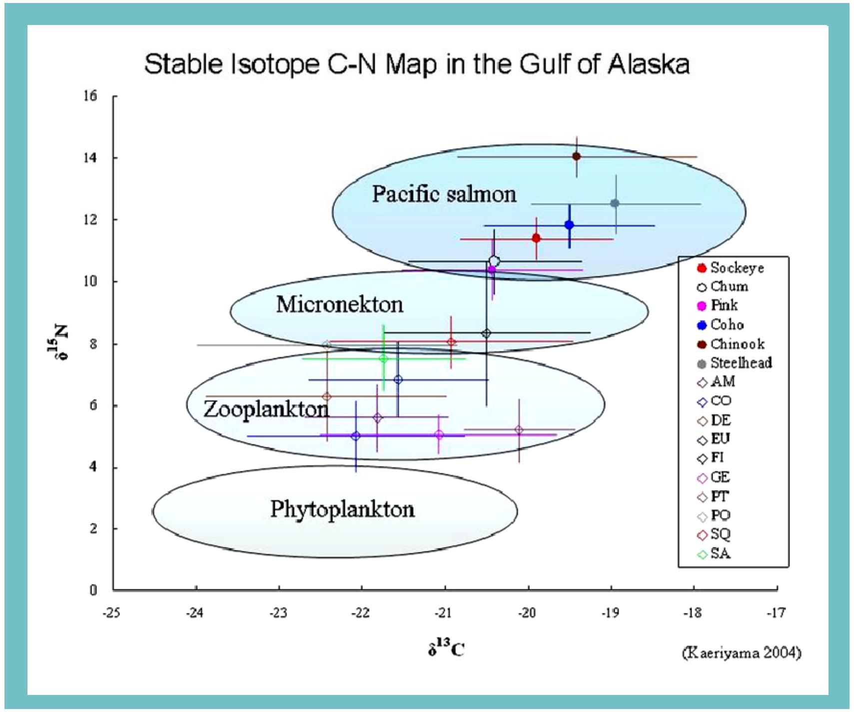
Pacific salmon play an important role as keystone species and ecological service in the North Pacific ecosystem

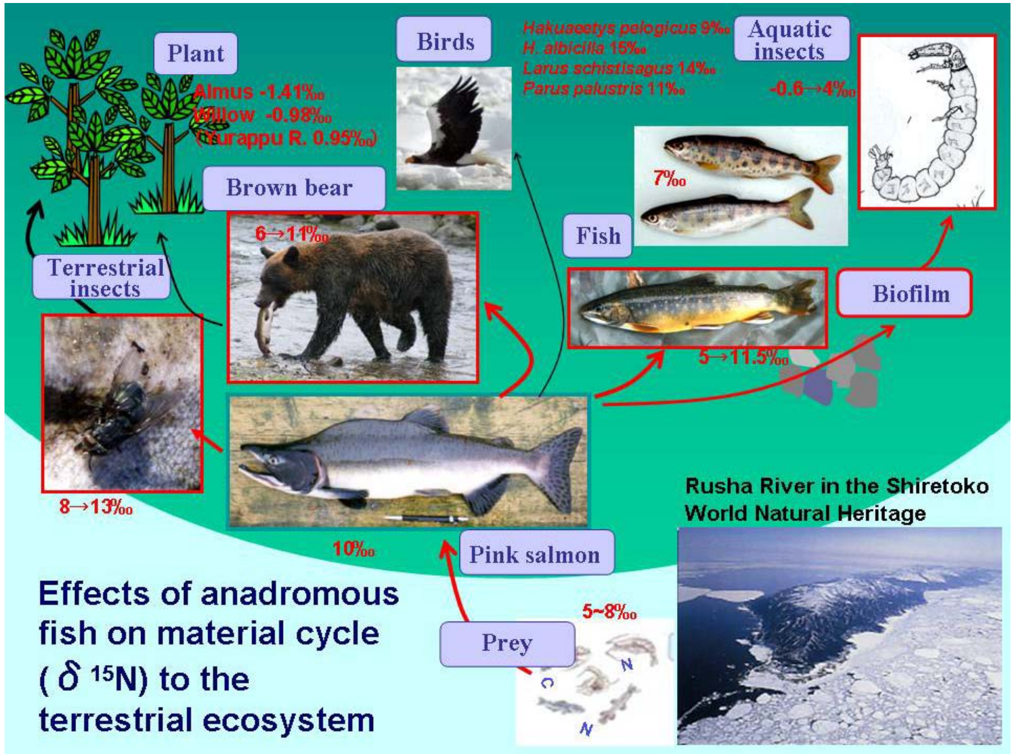


Pacific salmon:

Higher trophic level in the North Pacific

Pacific salmon:

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



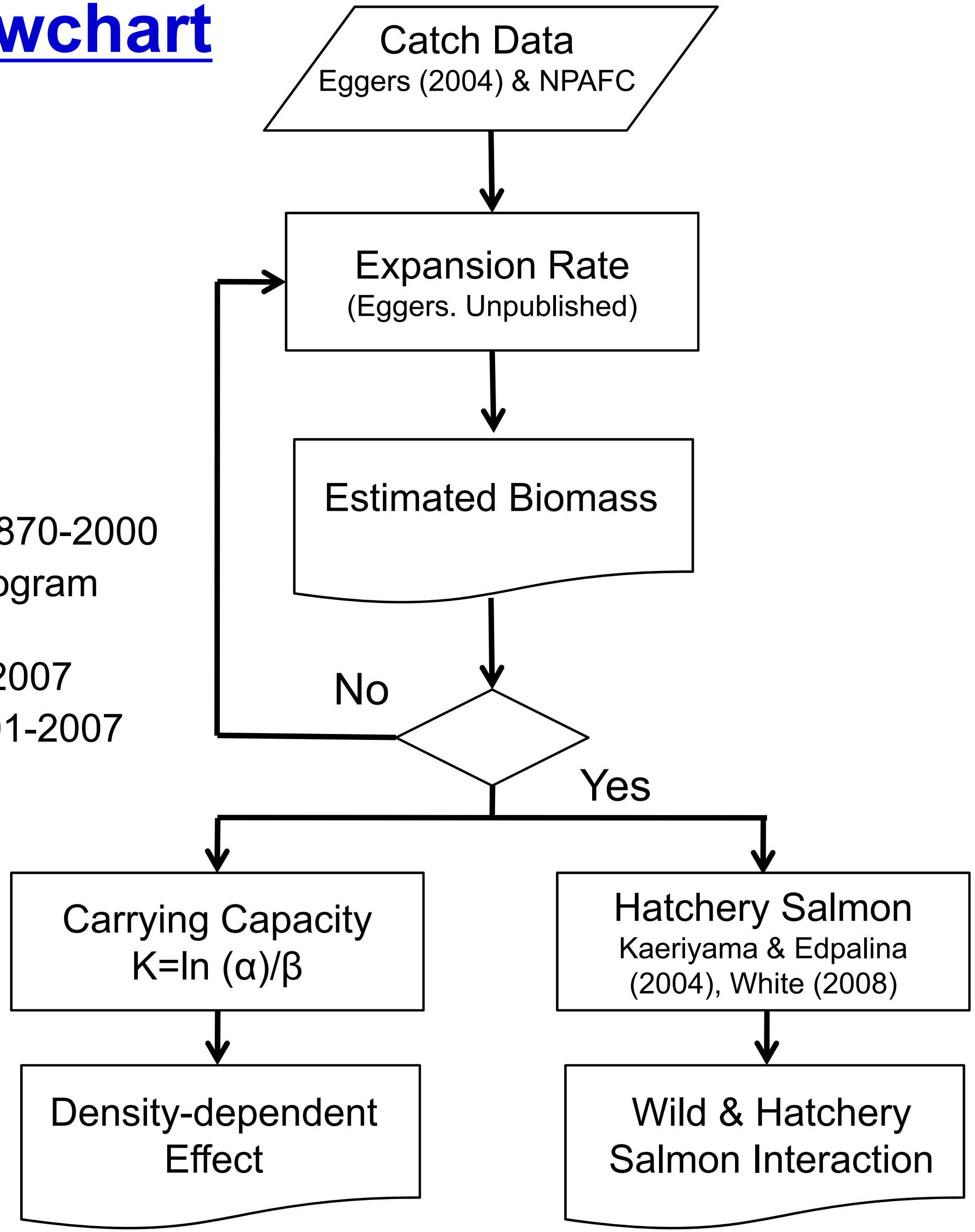
Main Database & Flowchart

Catch Data

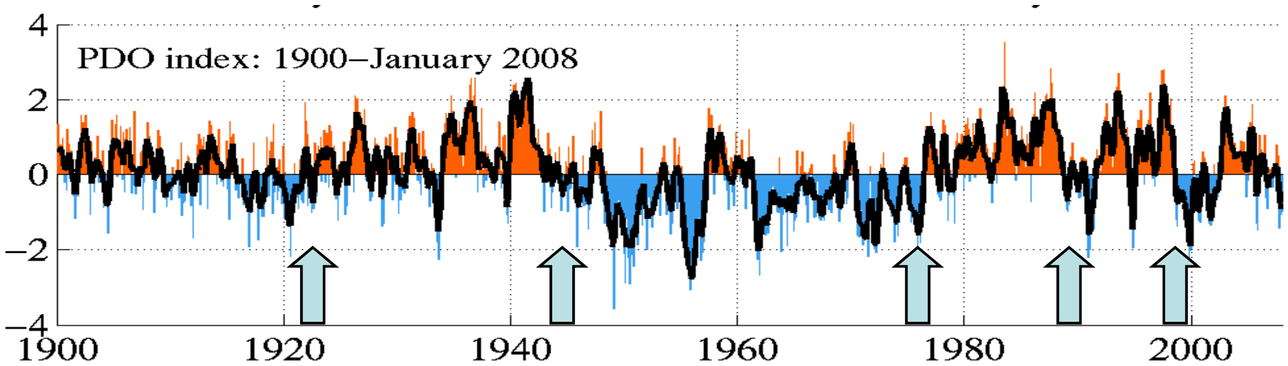
- FAO: 1950-1996
- NPAFC: 1993-2006
- INPFC (1979): 1893-1976
- Eggers (2004): 1925-2001
- Fredin (1980): 1920-1977
- Kaeriyama & Edpalina (2004): Japan 1870-2000
- White (2008): Alaska Enhancement Program 1966-2007
- www.cf.adfg.state.ak.us: Alaska 1970-2007
- http://salmon.fra.affrc.go.jp/: Japan 2001-2007

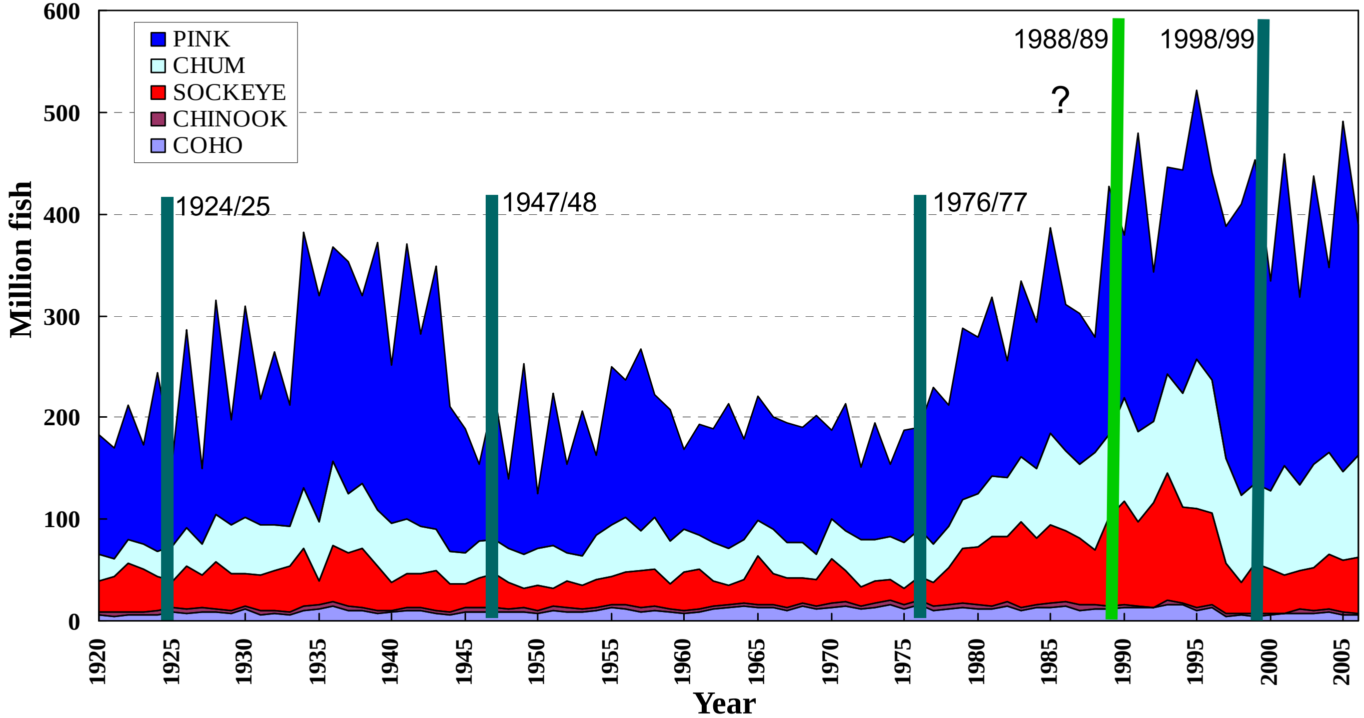
Climate Data

- Beamish & Bouillion (1993): ALPI
- Mantua et al. (1997): PDO
- http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx_alpi.htm: ALPI
- http://jisao.washington.edu/pdo/: PDO



Production trend of Pacific salmon:
synchronizing with the climate regime shift?

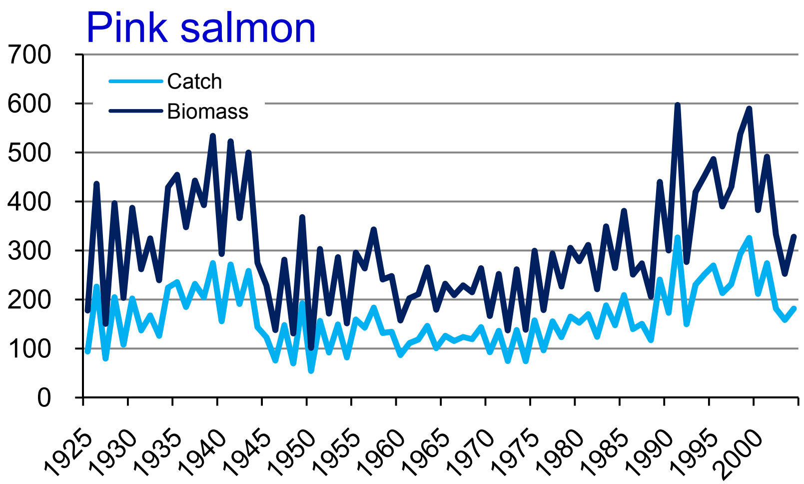


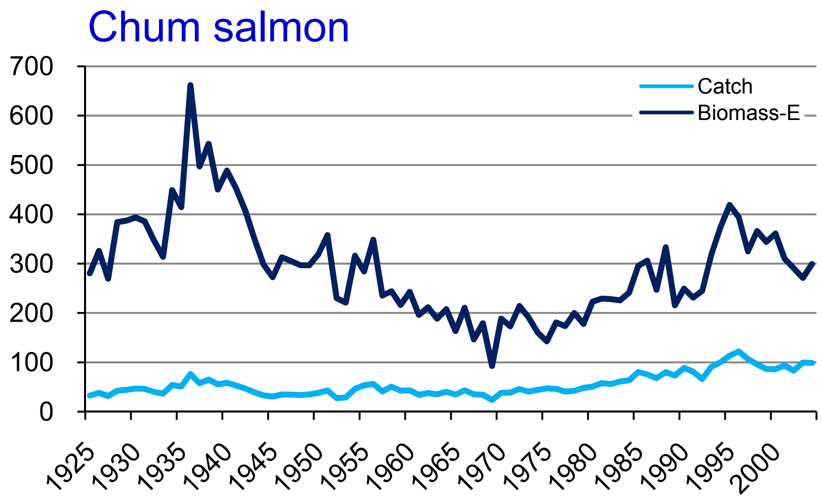


Annual change in catch of Pacific salmon in the North Pacific in 1920-2006

Method of Expansion of Terminal Run to Total Biomass

(Eggers, unpublished; White 2007)

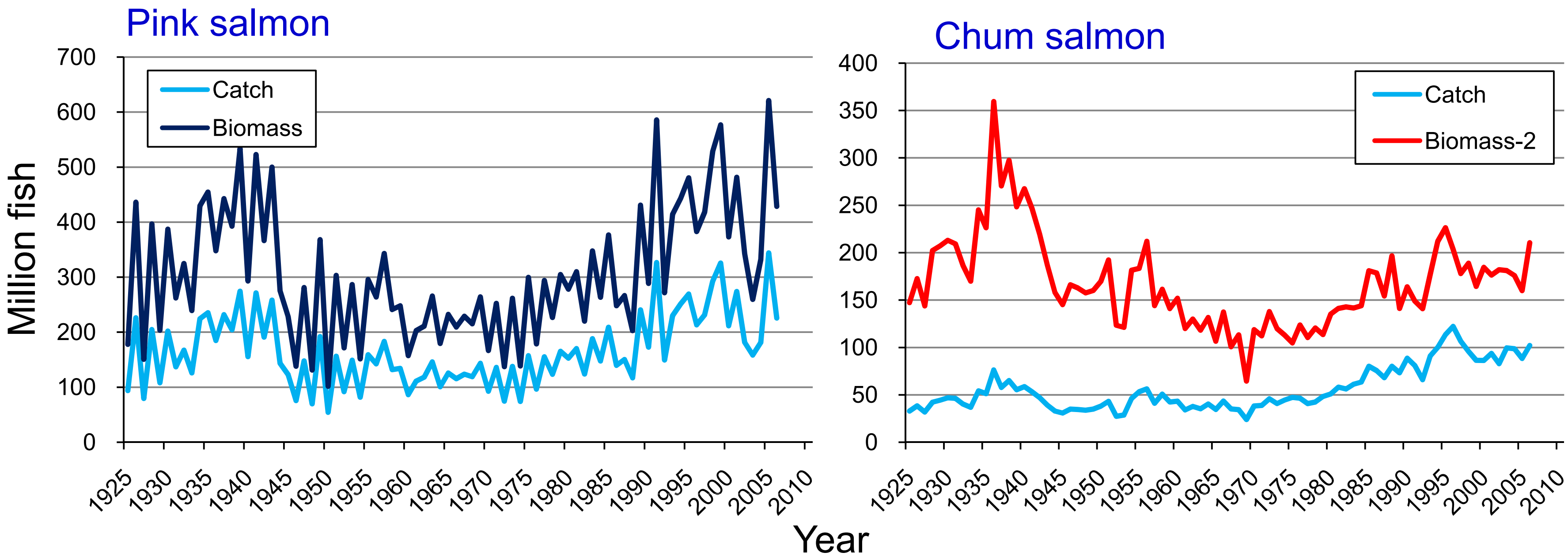




Biomass: Chum>Pink?

Area	Pink salmon	Sockeye salmon	Chum salmon
Japan; Coastal	49%	None	0%
Japanese: Japan Sea	57%	None	None
Japanese: High Seas Immature	None	46%	43%
Japanese: High Seas Maturing	56%	32%	13%
Russian: Coastal	50%	30%	11%
Western Alaska	None	30%	10%
Central Alaska	62%	30%	10%
PWS Hatchery	White (2007)	None	None
Southeast Alaska	55%	40%	10%
Southeast Alaska Hatchery	White (2007)	None	White (2007)
B.C./Washington/Oregon	55%	40%	10%

Changing the Expansion of Chum salmon



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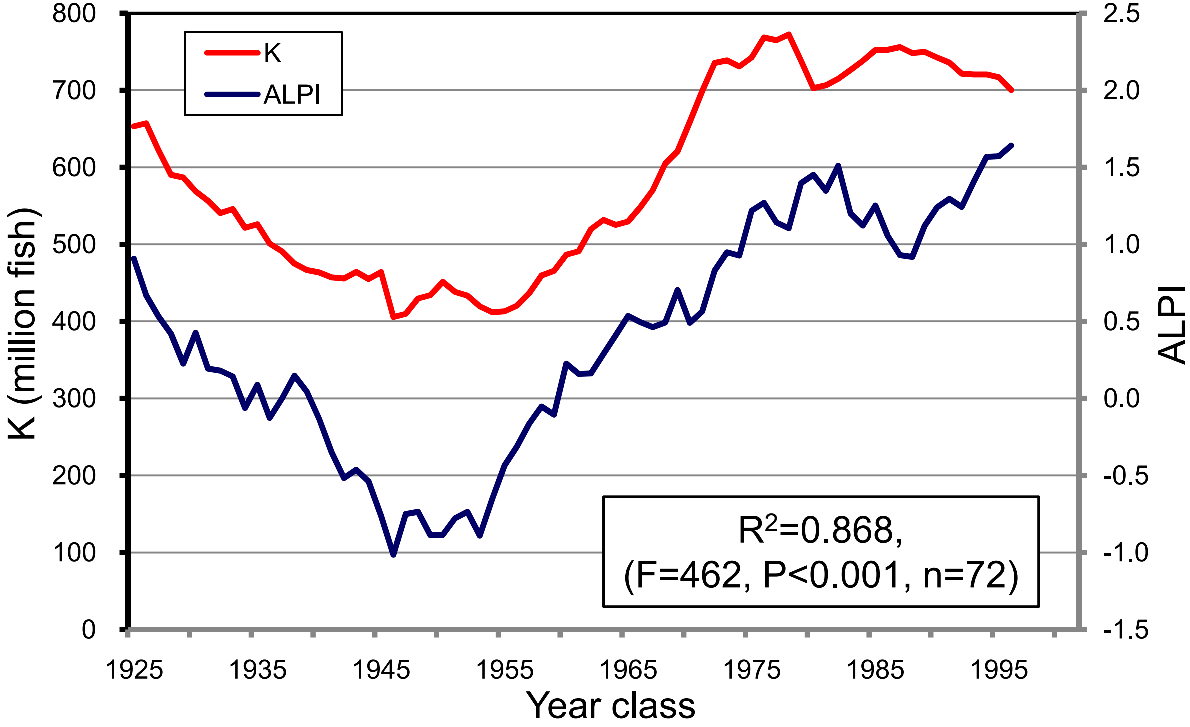
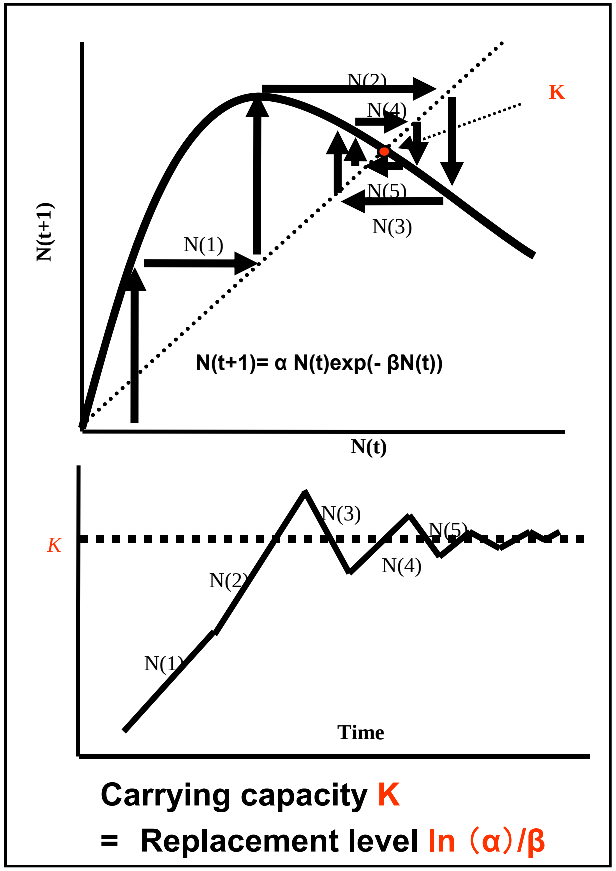
Temporal changes in ALPI and carrying capacity (K) of three species (sockeye, chum, and pink salmon)





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

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

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

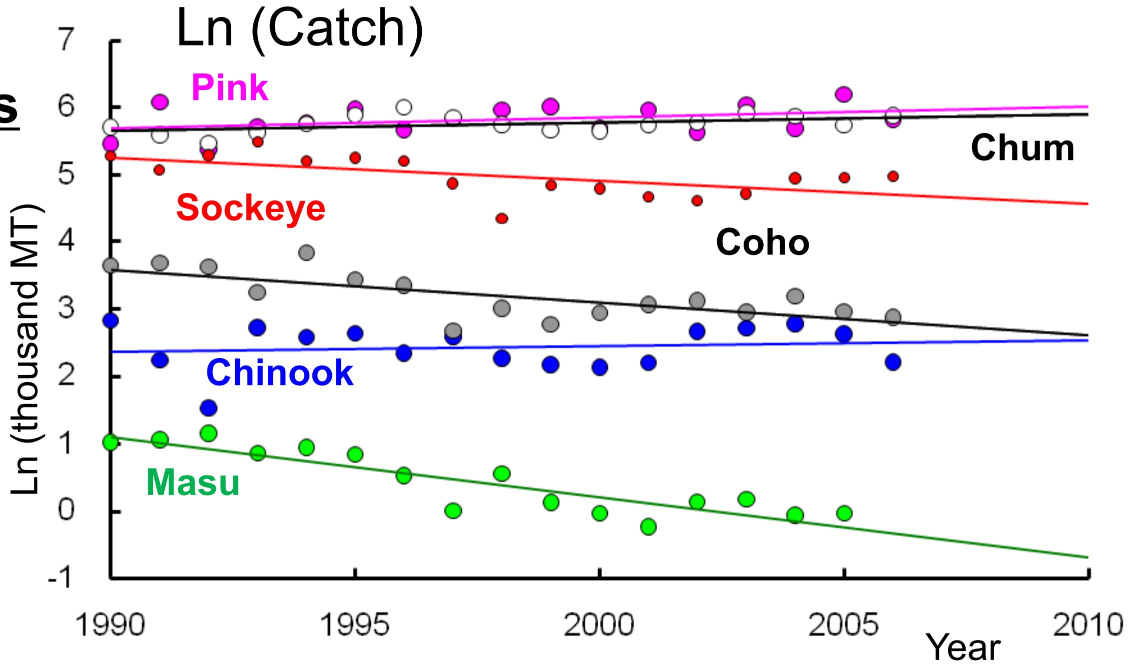
Chum & Sockeye salmon: 20 brood years

Recent trends

Catch trend since the 1990s

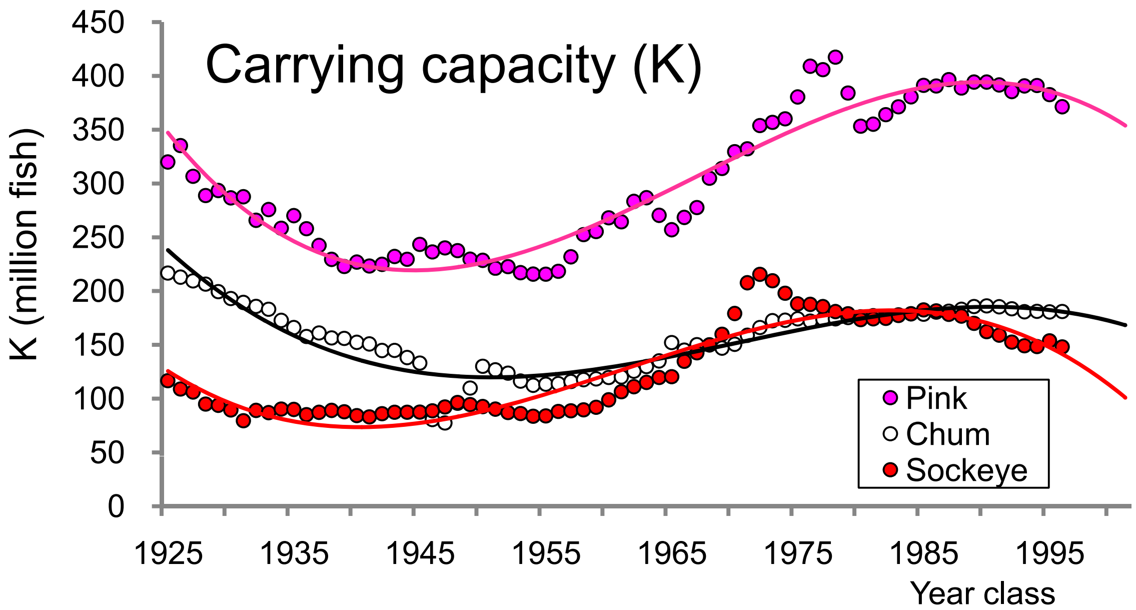
- ■Pink: increase (0.016)
- ■Chum: increase (0.012)
- ■Sockeye: decrease (-0.035)
- ■Chinook: stable (0.008)
- ■Coho: decrease (-0.049)
- ■Masu: decrease (-0.090)

( ): Slope in regression lines
* Homogeneity (P<0.01)

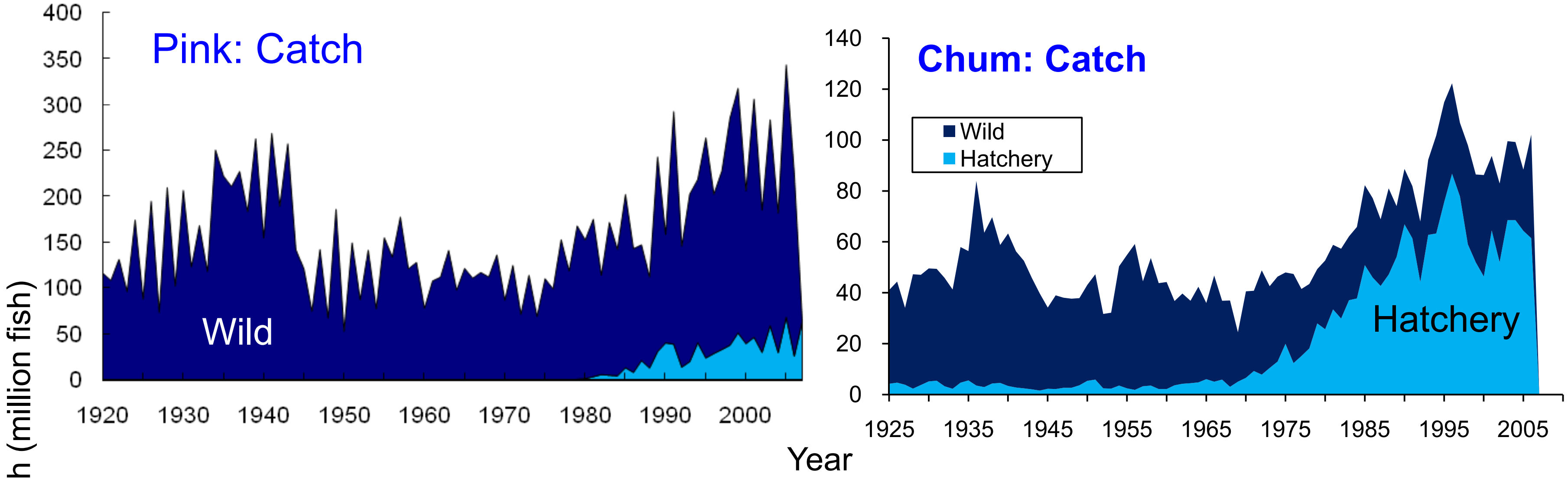


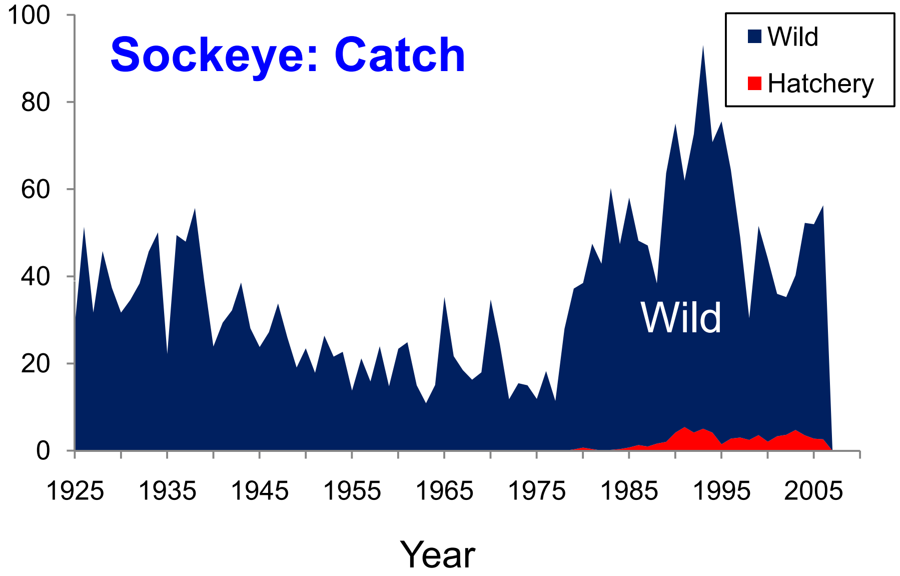
Carrying capacity trend

- ■Pink: decrease
- ■Chum: decrease
- ■Sockeye: decrease



Annual changes in catch of wild/hatchery salmon





Catch

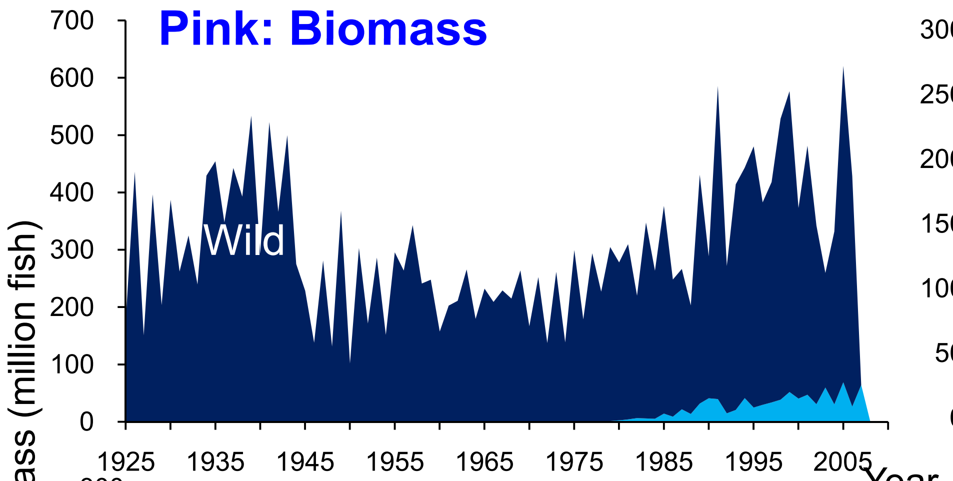
<u>Hatchery salmon</u>

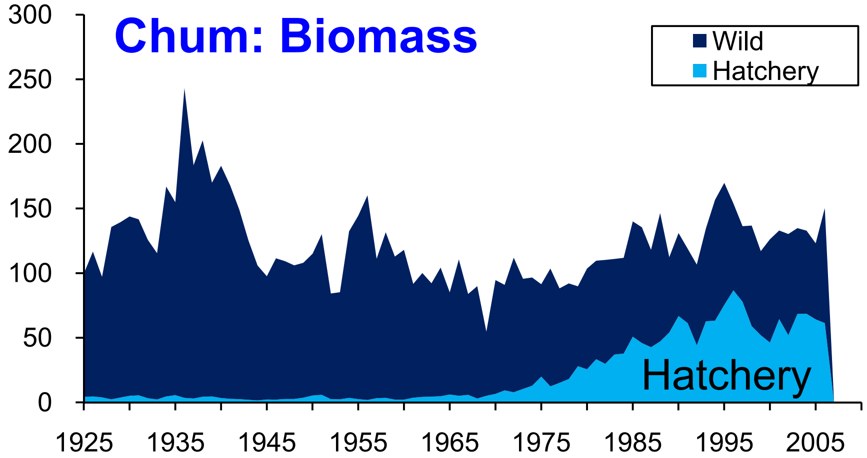
Pink <20%

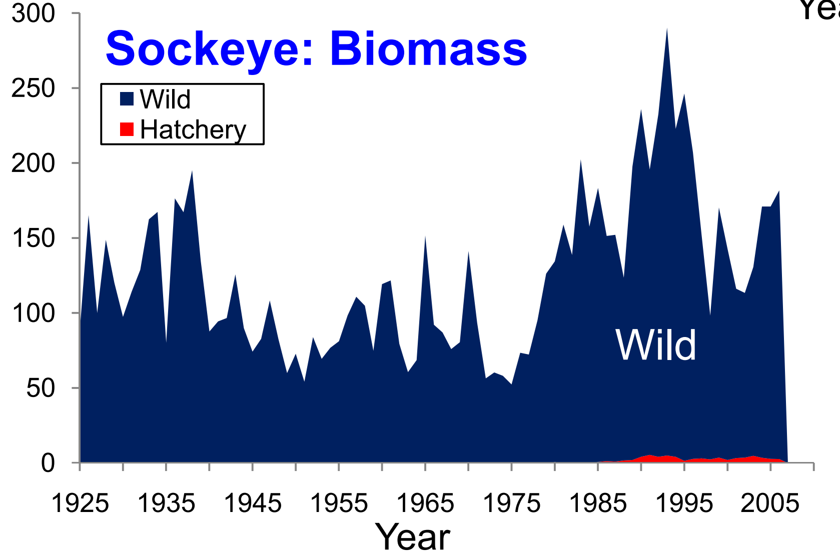
Chum >80%

Sockeye <15%

Annual changes in biomass of wild/hatchery salmon





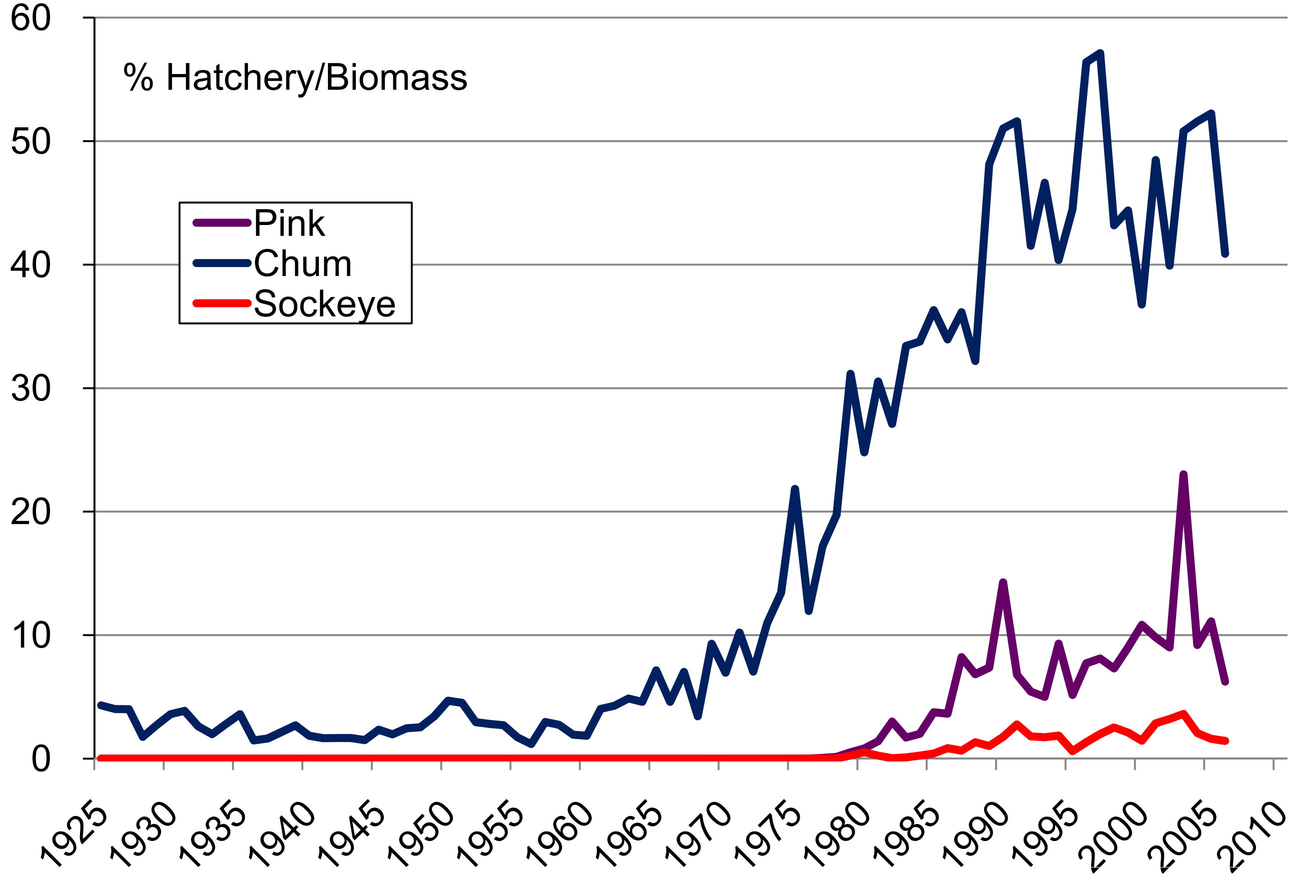


Biomass

<u>Hatchery salmon</u>

Pink	<10%
Chum	< 60%
Sockeye	<10%

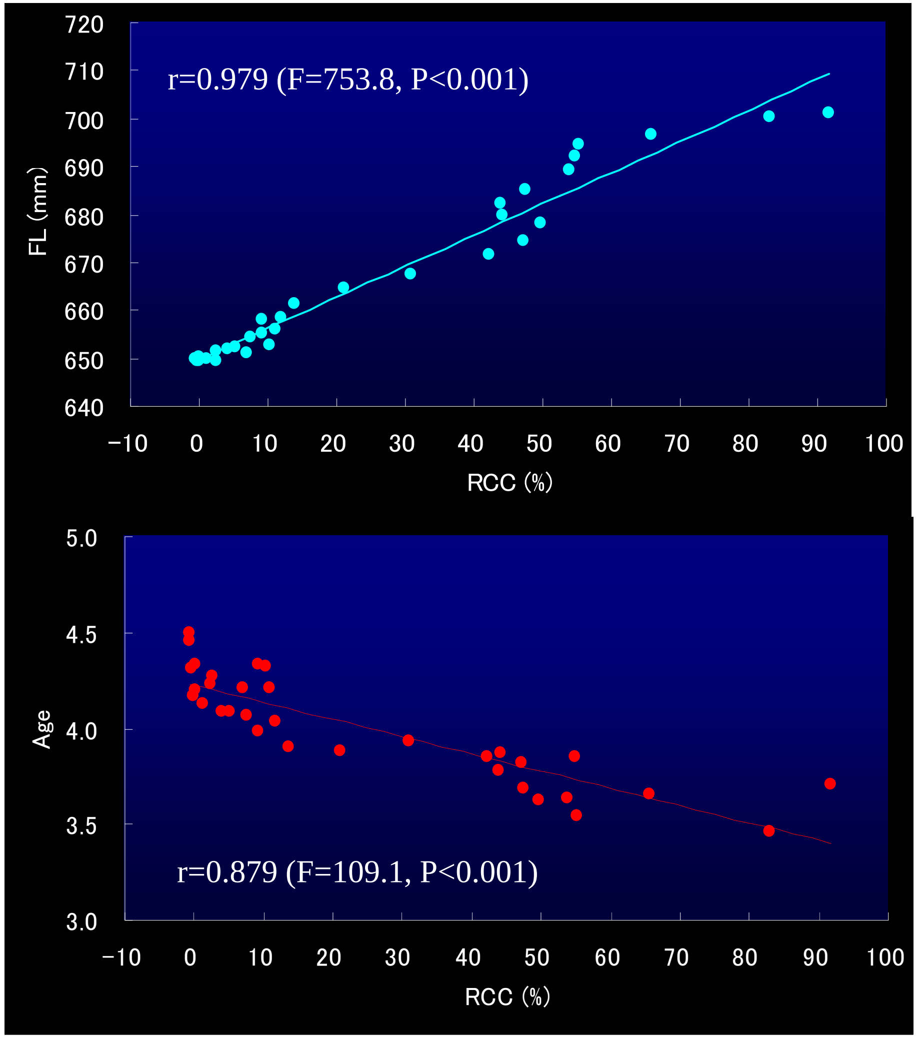
Rate of hatchery salmon in Pacific salmon biomass



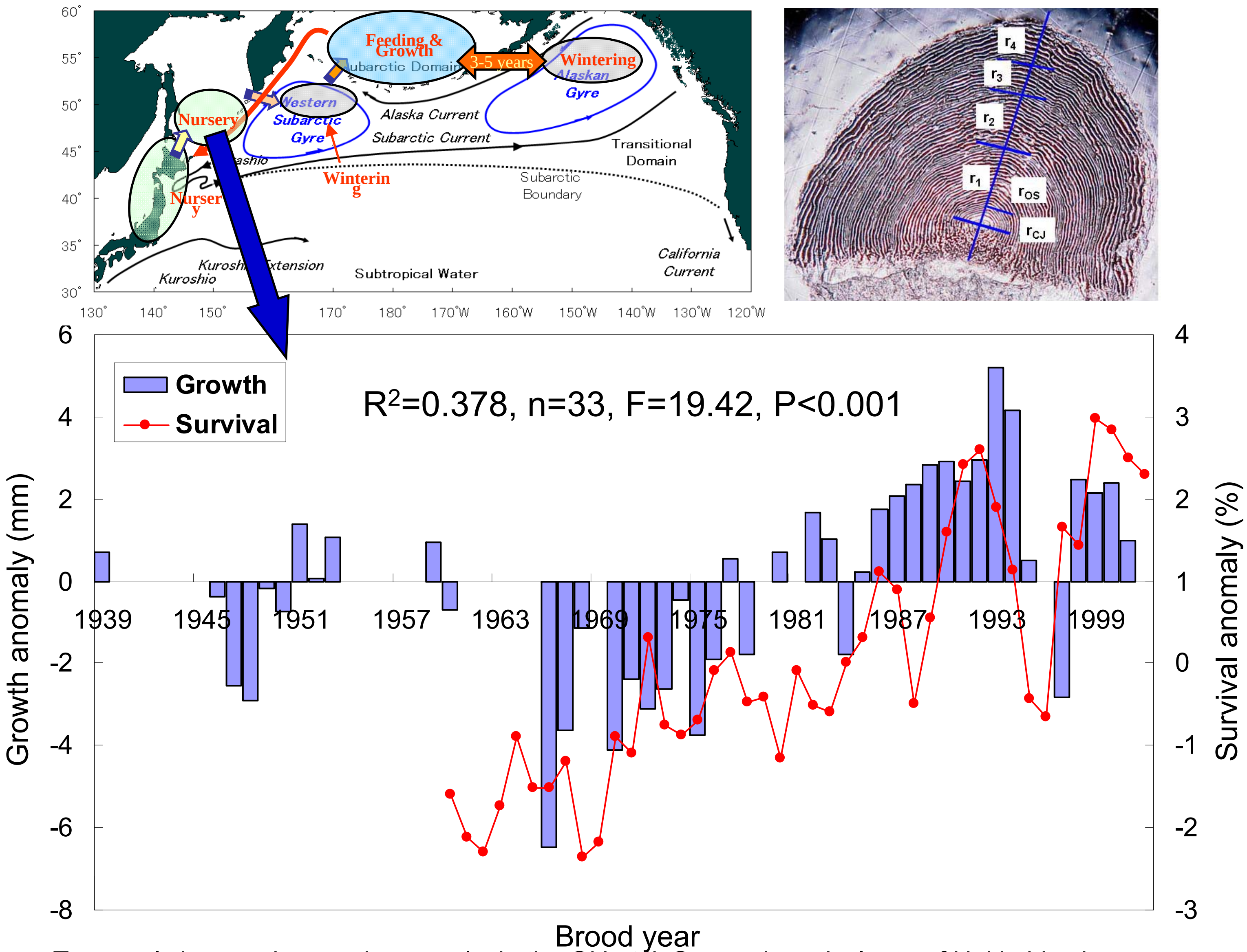
Carrying capacity and density-dependent effect of chum salmon in the Bering Sea

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.

Population level

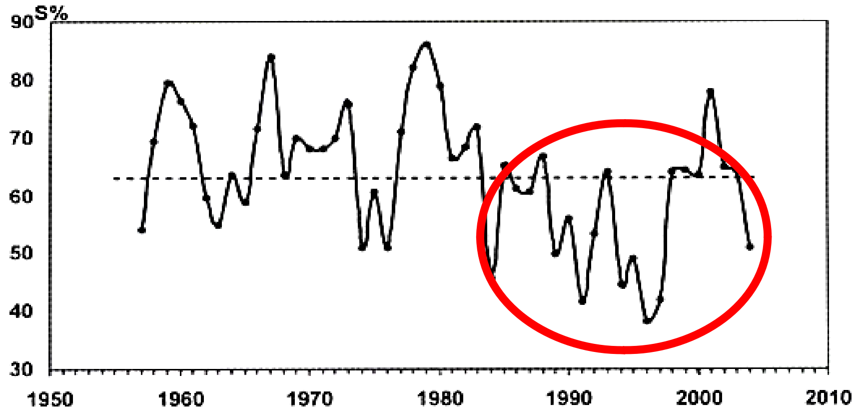


Temporal changes growth in the Okhotsk Sea and survival rate of Hokkaido chum salmon



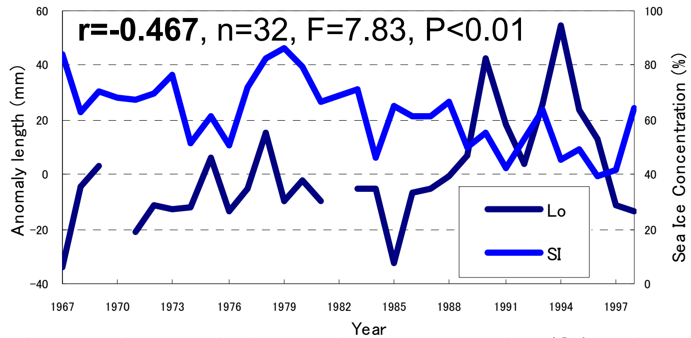
Temporal changes in growth anomaly in the Okhotsk Sea and survival rate of Hokkaido chum salmon. The growth based on a back calculation of the fork lenth using the scale analysis.

Growth in the Okhotsk Sea of Hokkaido chum salmon

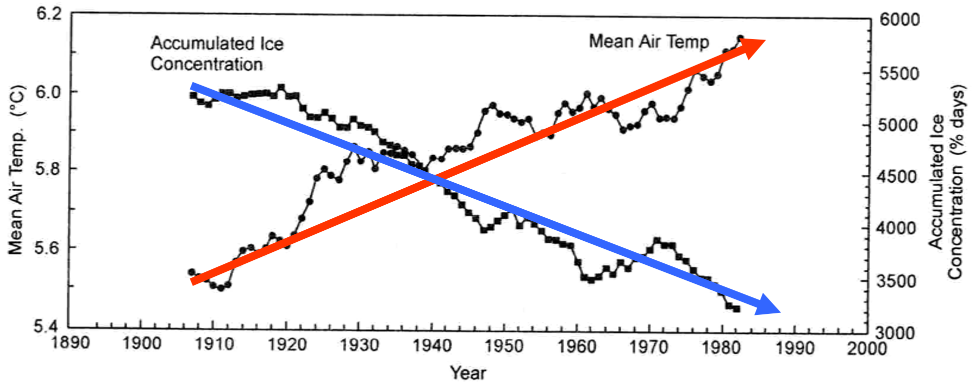


Temporal change in the rate of ice cover area in the Okhotsk Sea (Ustinova et al. 2002)

Sea Ice - Growth

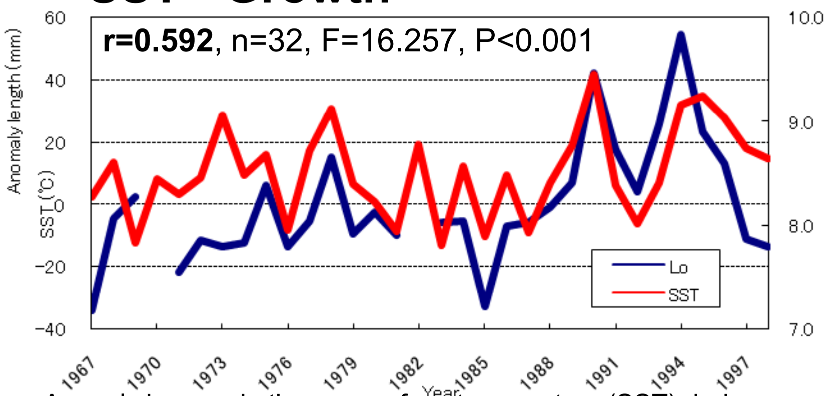


Annual changes in the sea ice concentration (SI) and anomaly of growth at the Okhotsk Sea (Lo) of the age-4 chum salmon returning to the Ishikari River.



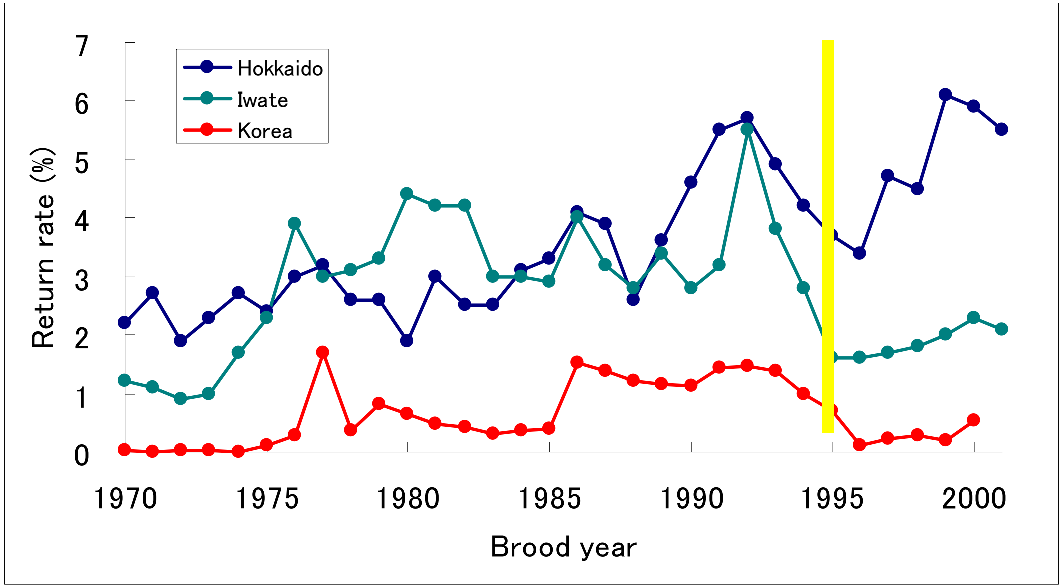
Thirty-year running averages of the yearly mean air temperature (●) and accumulated ice concentration (■) at Abashiri, Hokkaido. (Aota 1999)

SST - Growth

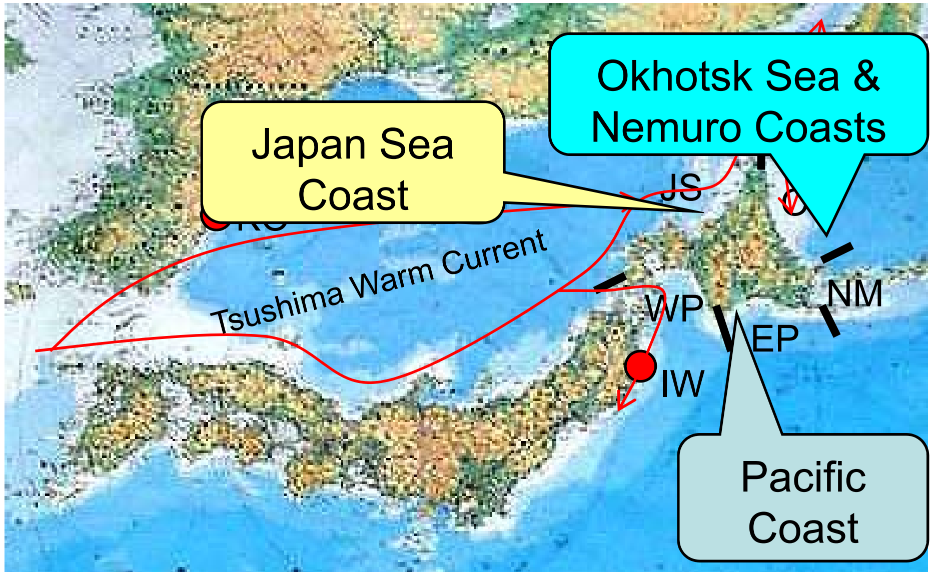


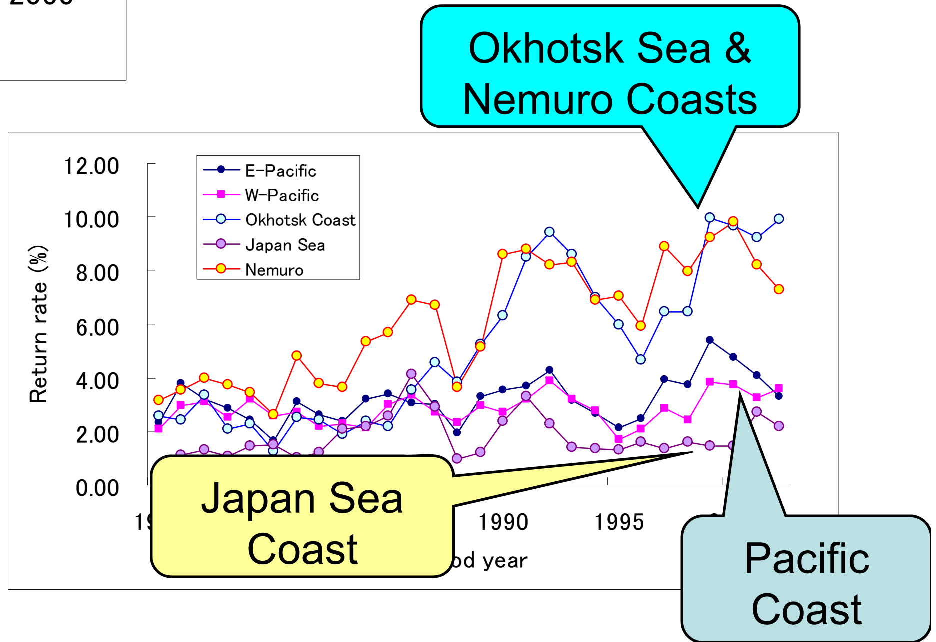
Annual changes in the sea surface temperature (SST) during summer and fall, and anomaly of growth at the Okhotsk Sea (Lo) of the age-4 chum salmon returning to the Ishikari River.

Global warming effect on the growth of chum salmon in the Okhotsk Sea!



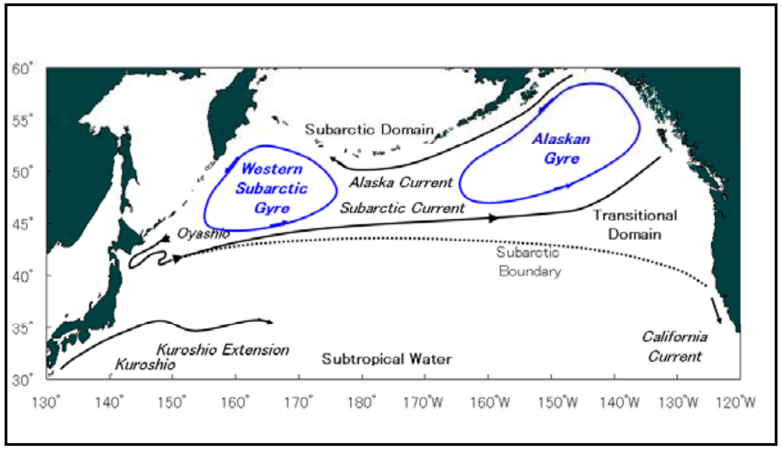
Temporal change in return rates of chum salmon released from Japan and Korea

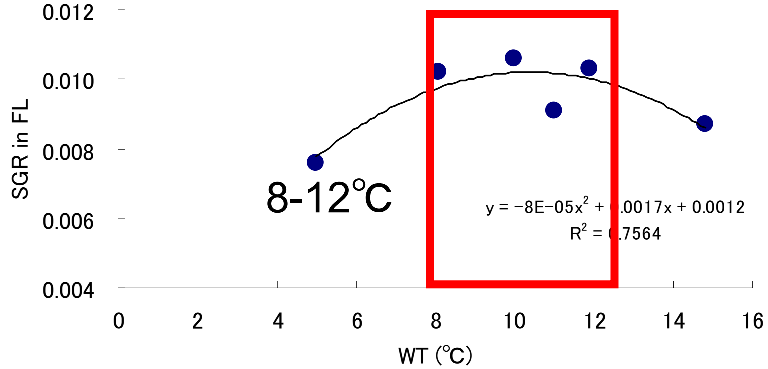




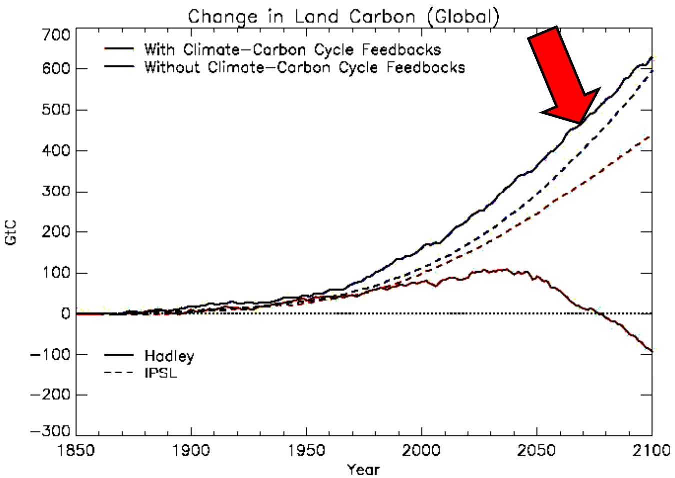
OS: Okhotsk Sea Coast, NM: Nemuro Coast, EP: Eastern Pacific, WP: Western Pacific, JS: Japan Sea, IW: Iwate Pref., KO: Korean H.

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

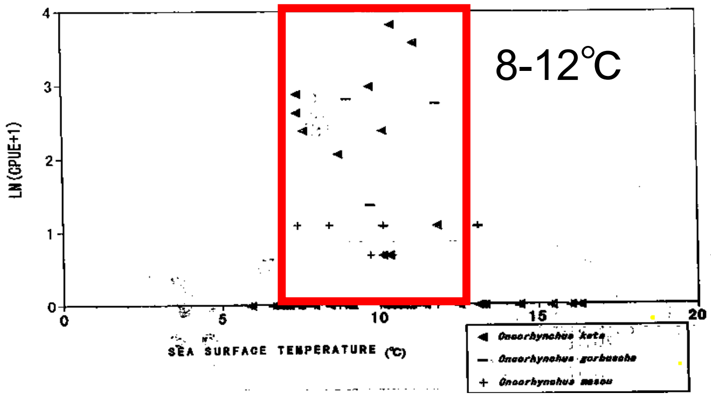




Relationship between water temperature and specific growth rate of chum salmon. (Kaeriyama 1984, 1989)



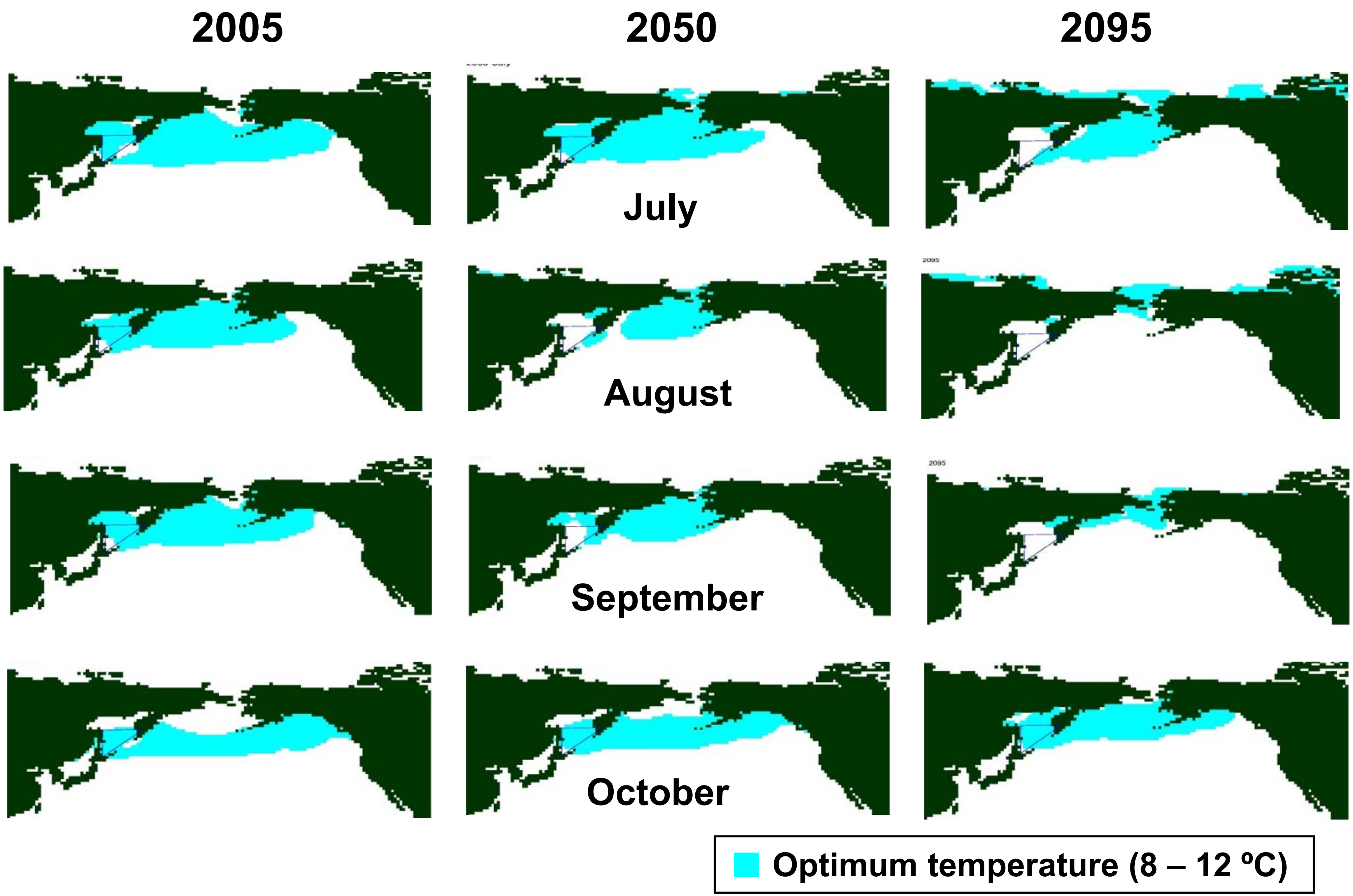
Estimation on SST in the North Pacific Ocean in 2050 and 2095 (Kawamiya 2004)



Relationship between SST and CPUE of chum salmon in the Okhotsk Sea. (Ueno et al. 1998)

Optimal temperature for chum salmon
Growth and feeding migration period: **8-12℃**

Global Warming effect on chum salmon in the North Pacific Ocean



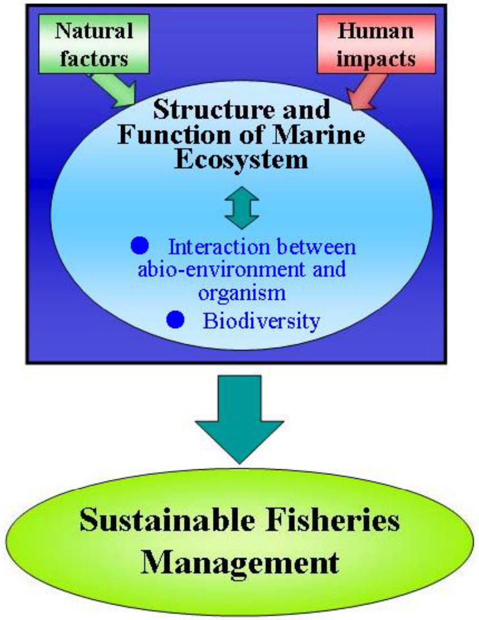
Global Warming Effect for Chum salmon

- **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 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