Sustainable fisheries management based on an ecosystem approach: Pacific salmon

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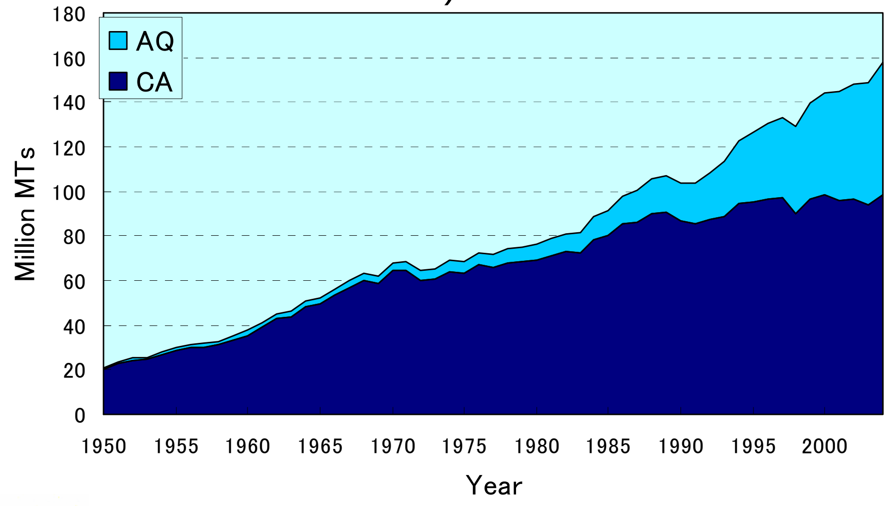
Are marine foods reproducible resources for human!?

- World fish catches have peaked since the 1990s despite increase in aquaculture production.
- “Large predatory fish biomass today is only about 10% of pre-industrial levels” (Myers & Worm 2003). Bluefin tuna populations are already “Critically Endangered” species in IUCN.

Time trend of capture fisheries (CA) and aquaculture (AQ) in the world (from FAO Fisheries Statistics)



Spatiotemporal change in relative predator biomass (Myers & Worm 2003)

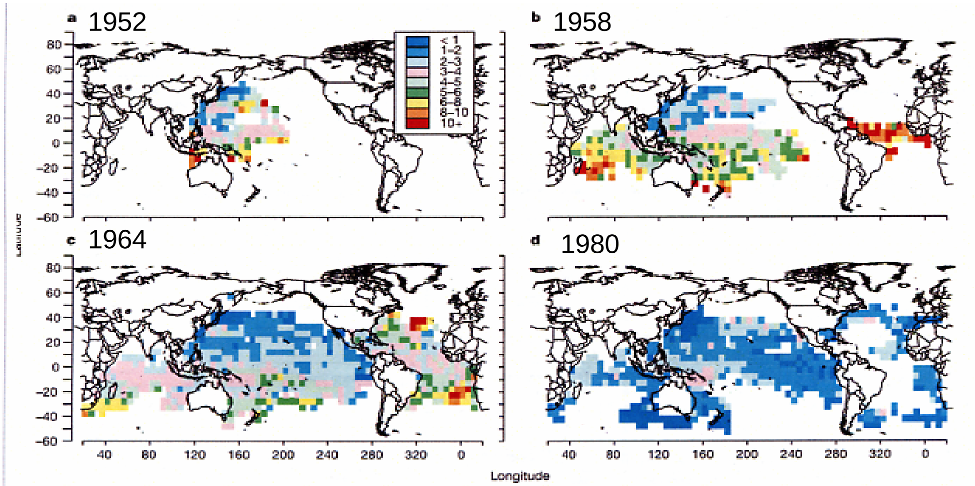


Figure 2 Spatial patterns of relative predator biomass in 1952 (a), 1958 (b), 1964 (c) and 1980 (d). Colour codes depict the number of fish caught per 100 hooks on pelagic longlines set by the Japanese fleet. Data are binned in a global 5° × 5° grid. For complete year-by-year maps, refer to the Supplementary Information.

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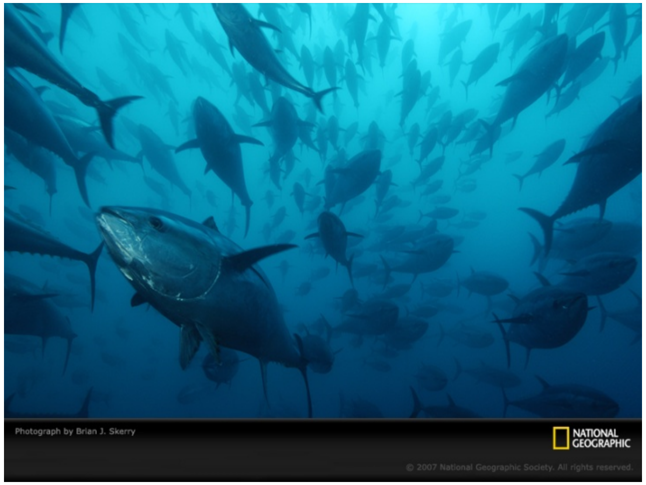


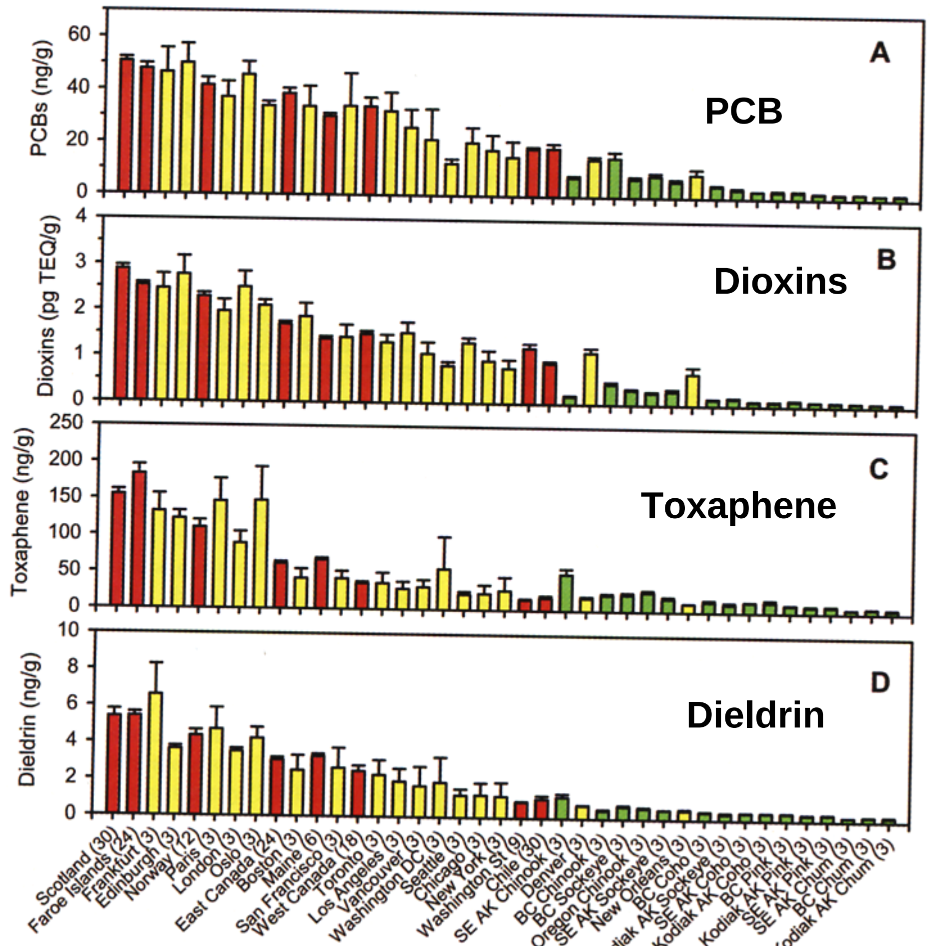
Are marine foods reproducible resources for human!?

- Although production of aquacultures are increasing in the world, many aquacultures cause destruction of aquatic ecosystems, marine pollution, and threats to marine food security.

Vanishing mangroves at Dagupan in Philippine

Vanishing 35% mangrove forests by the shrimp aquaculture over the last 20 years (Primavera 2005)

Food Security of Farmed Atlantic Salmon

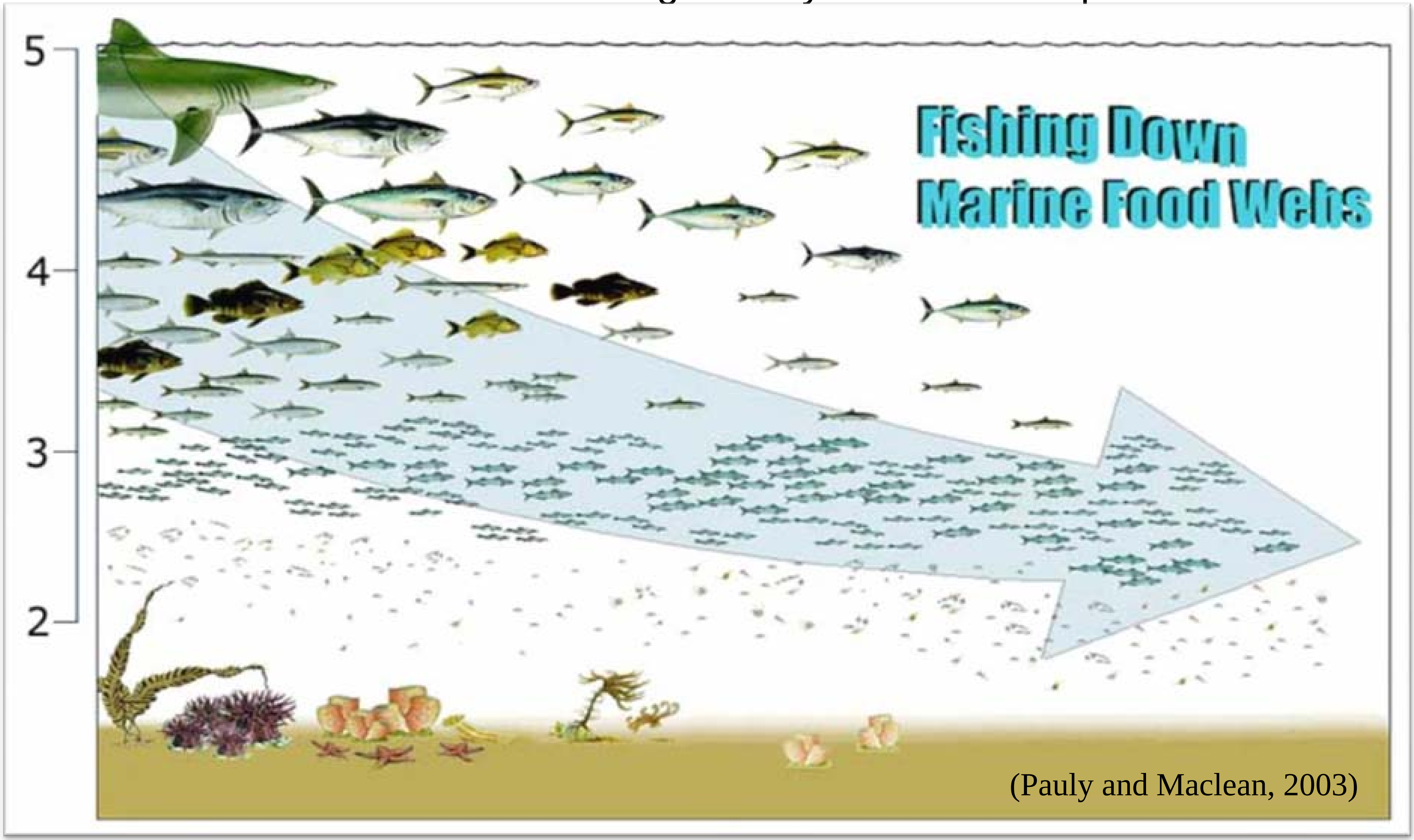


Green: Wild, Red: Farmed, Yellow: at Supermarkets

(Hites et al. 2004)

Are marine foods reproducible resources for human!?

- **Fishing down:** After the large fish at the top of the food web are fished out, fisheries go after smaller fish and invertebrates at lower levels in the food web while their trawling destroys animals and plants on the sea



Are marine foods reproducible resources for human!?

- In this century, we need to paradigm shift from traditional fisheries sciences for only fisheries to the **new ecological fisheries** sciences for protecting marine ecosystem and human food resources.

- **Change in Marine Ecosystem**
  "Fishing down marine food webs" (Pauly et al. 2003)
- **Sea Food Gourmet**→Tuna Laundering / Overfishing
- **"Tragedy of Commons"**
  First come→Overfishing
- **Ecosystem Crash & Food Polution**
  Vanishing Mangrove forest ecosystem, Cutoff food chain, Food security
- **Food Import**
  →"Eco Backpack", "Food Mileage"
- **Seafood: "Inexpensive is best?"**
  →Overfishing

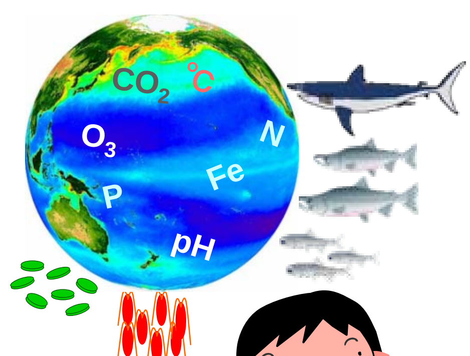
Traditional Fisheries Science

For only Fisheries

Paradigm Shift

New Ecological Fisheries Science

For Marine Ecosystem & Human Food Sciences



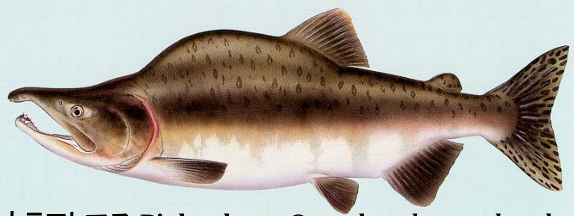
- **Sustainable Fisheries Management based on the Ocean Ecosystem**
- **Carrying Capacity**
- **Zero-emission**
- **Marine Reserves (MRs)**
- **Greenhouse Gas Emission**
- **Food Traceability** – HACCP, ISO9000
- **Seafood Card (Eco-card)**
- **Marine Stewardship Council (MSC)**

Topics: Pacific salmon (*Oncorhynchus* spp.)

- Carrying Capacity and population density-dependent effect of Pacific salmon
- Relationship between wild and hatchery salmon
- Global warming effect on chum salmon
- Sustainable fisheries management based on the ecosystem approach

シロザケ Chum salmon *Oncorhynchus keta*

ギンザケ Coho salmon *Oncorhynchus kisutch*



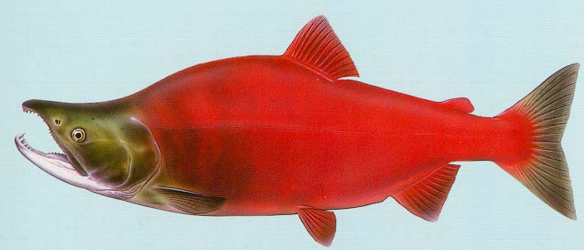
カラフトマス Pink salmon *Oncorhynchus gorbuscha*

マスノスケ Chinook salmon *Oncorhynchus tshawytscha*

サクラマス Masu salmon *Oncorhynchus masou*

ニジマス Rainbow trout *Oncorhynchus mykiss*

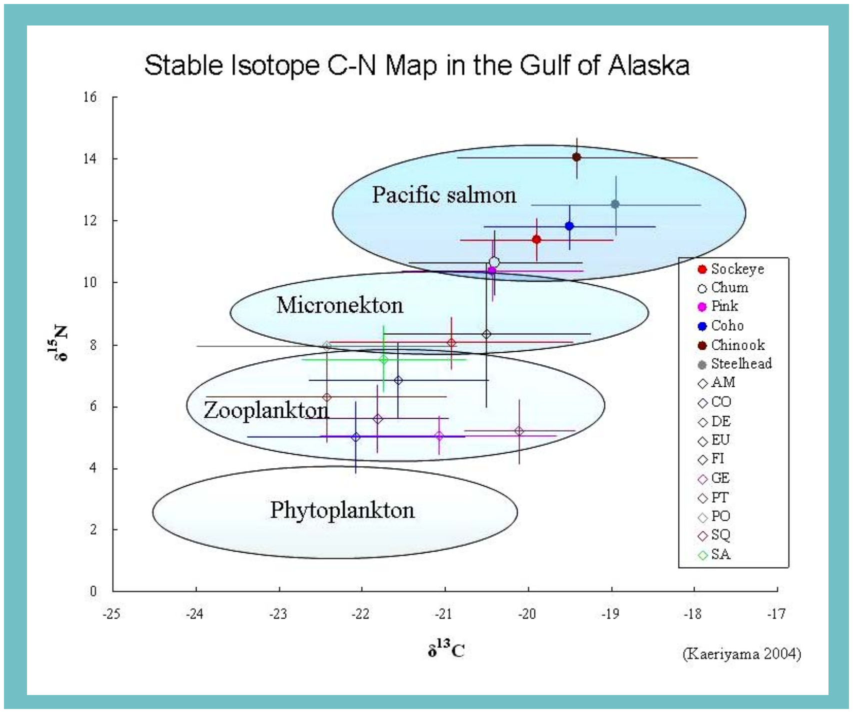
In the case of Pacific salmon



ベニザケ Sockeye salmon *Oncorhynchus nerka*

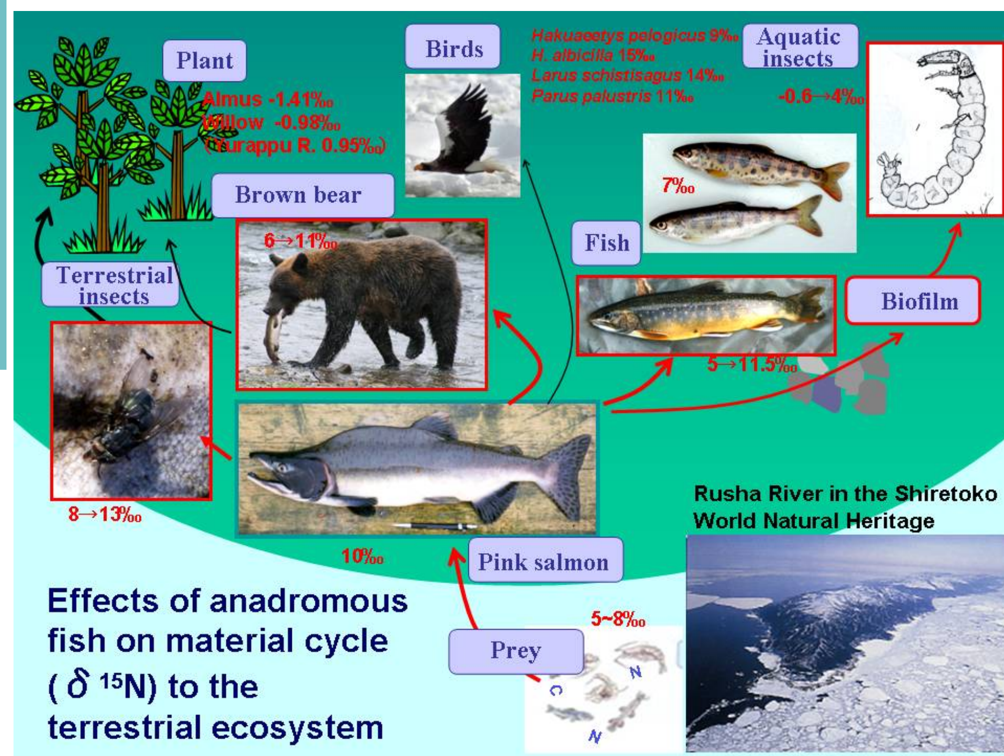
Seven species of Pacific salmon (*Oncorhynchus* spp.)

Pacific salmon are keystone species in the North Pacific ecosystem



Pacific salmon:

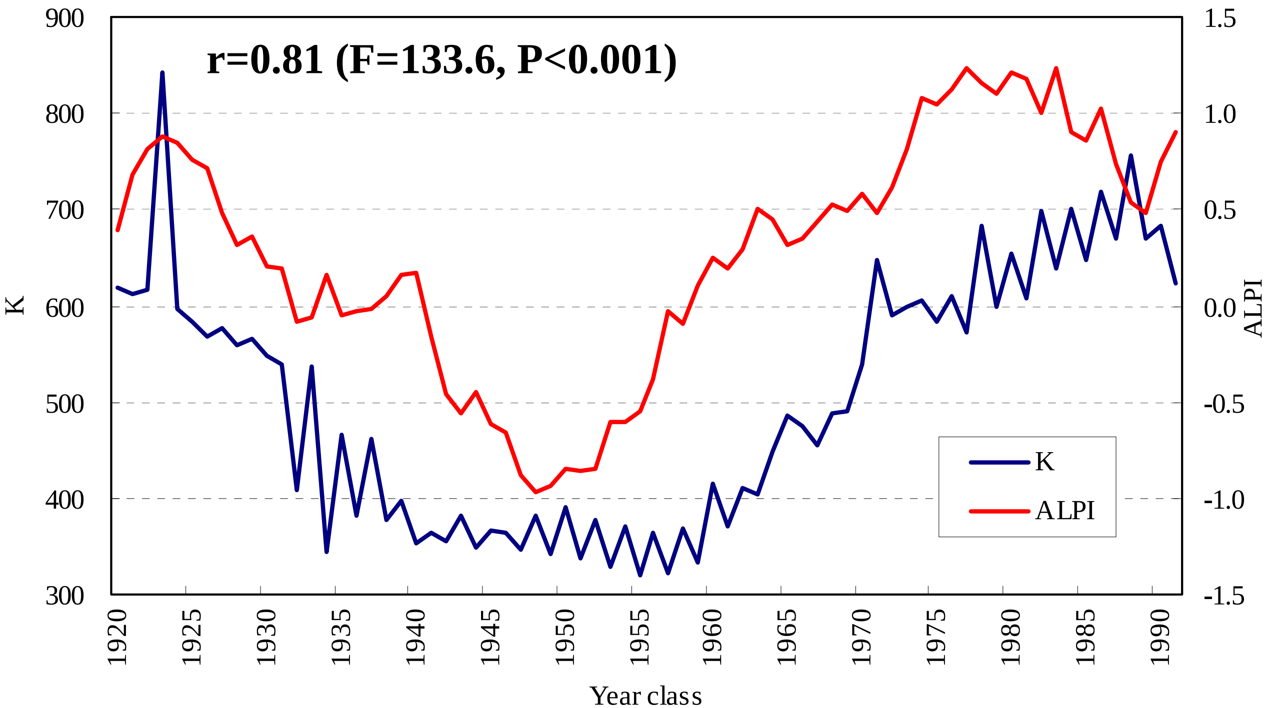
Keystone species for sustaining the biodiversity and productivity in riparian ecosystem, and for supplying marine-derived material to the terrestrial ecosystem

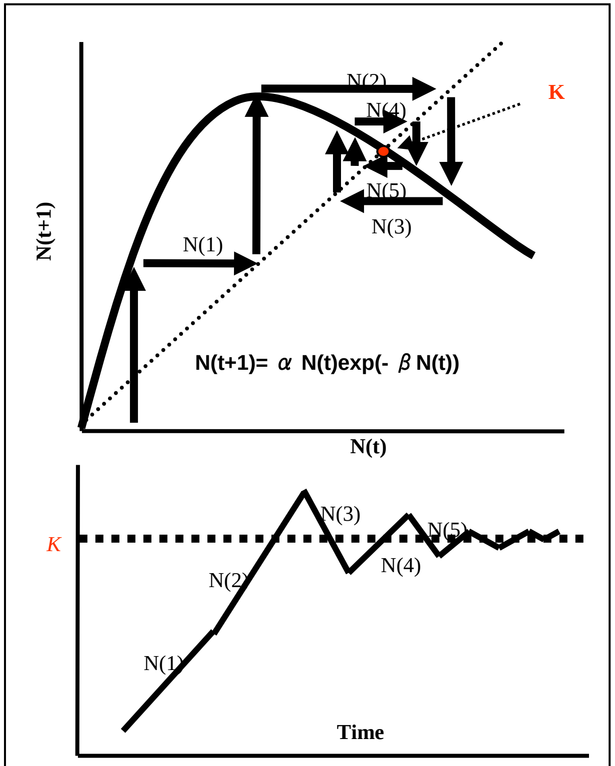


Pacific salmon:

Higher trophic level in the North Pacific

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





Carrying capacity K

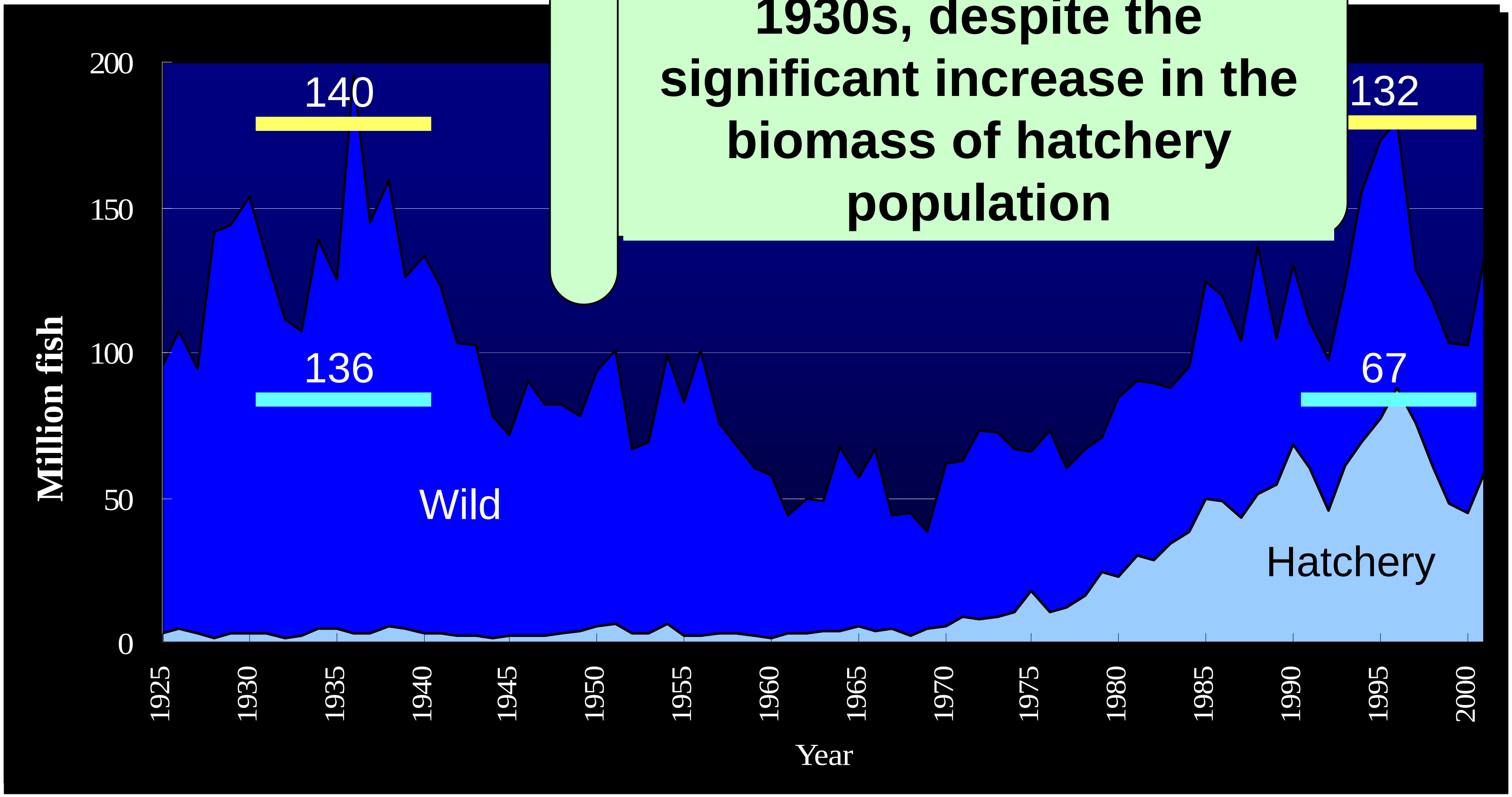
= Replacement level ln（α）/ β

Salmon carrying capacity will be 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



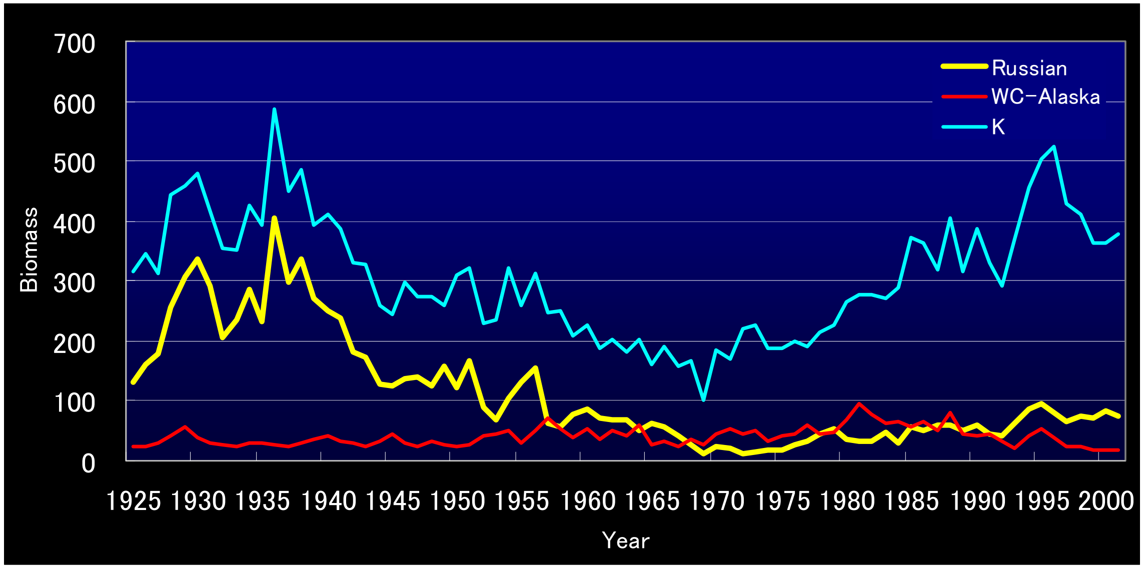
Temporal change in biomass of wild and hatchery populations of chum salmon in the North Pacific during 1925-2001

Biological interaction between wild and hatchery populations in chum salmon

(1) Empty ecological niche

1. **Wild salmon: Failure in Reproduction & Poaching (Korolev 2001)**
2. **High carrying capacity & Empty ecological niche**
3. **Increase in Hatchery salmon**

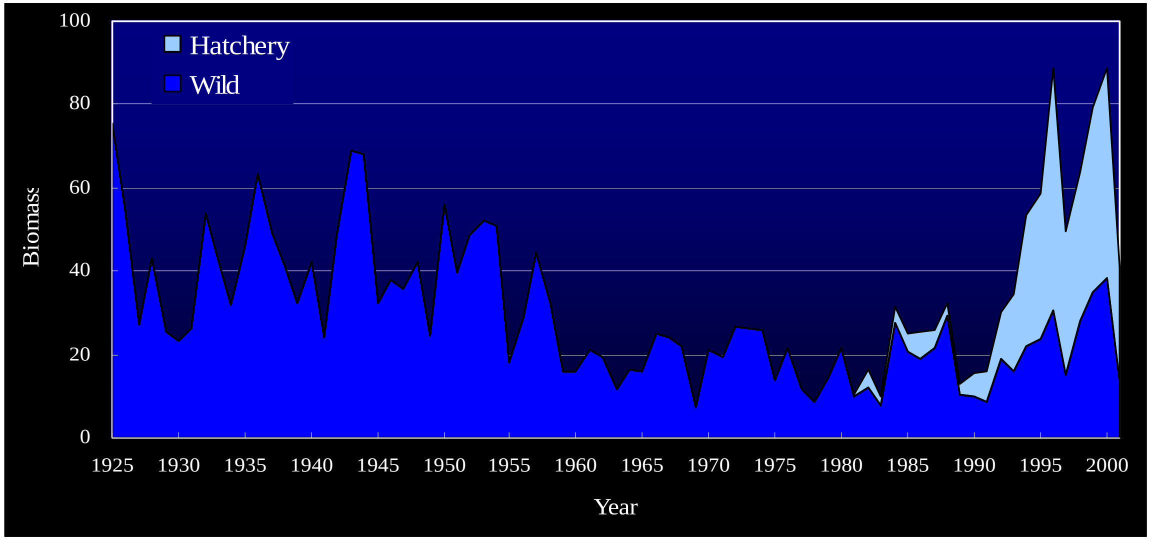
e.g. Russian, Western and Central Alaska populations



(2) Replacement

- **Replacement of Wild by Hatchery Salmon**

e.g. Southeast Alaska population, Pink salmon in the Prince William Sound (Hilborn and Eggers 2000)



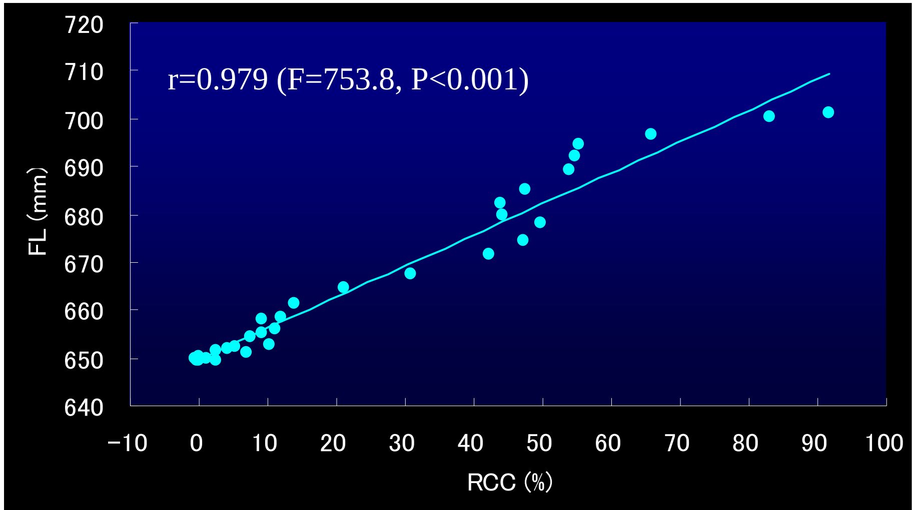
Annual change in biomass of chum salmon in southeast Alaska

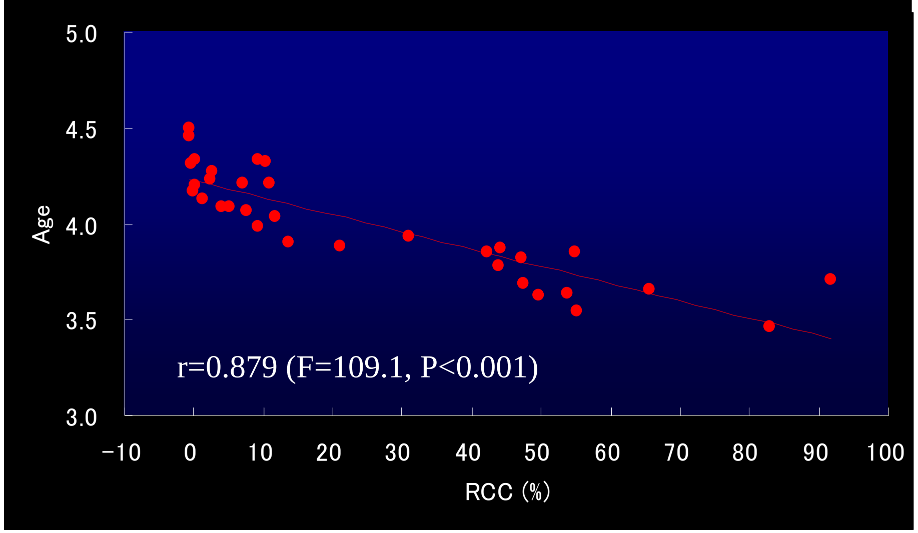
Carrying capacity and density-dependent effect of chum salmon in the Bering Sea

These results suggest that the carrying capacity of chum salmon would be closely related with not only the long-term climate change, but also the density-dependent effect.

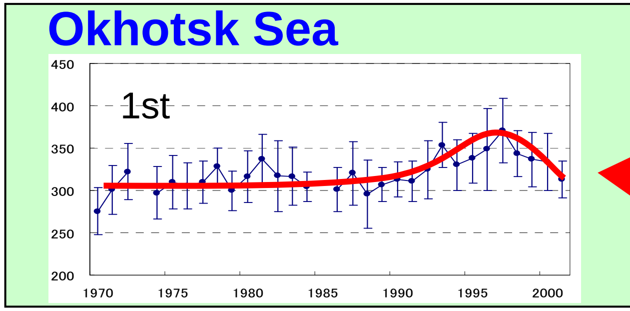
Biological interaction between wild and hatchery populations should be an important consideration in the sustainable fisheries management based on the ecosystem level.

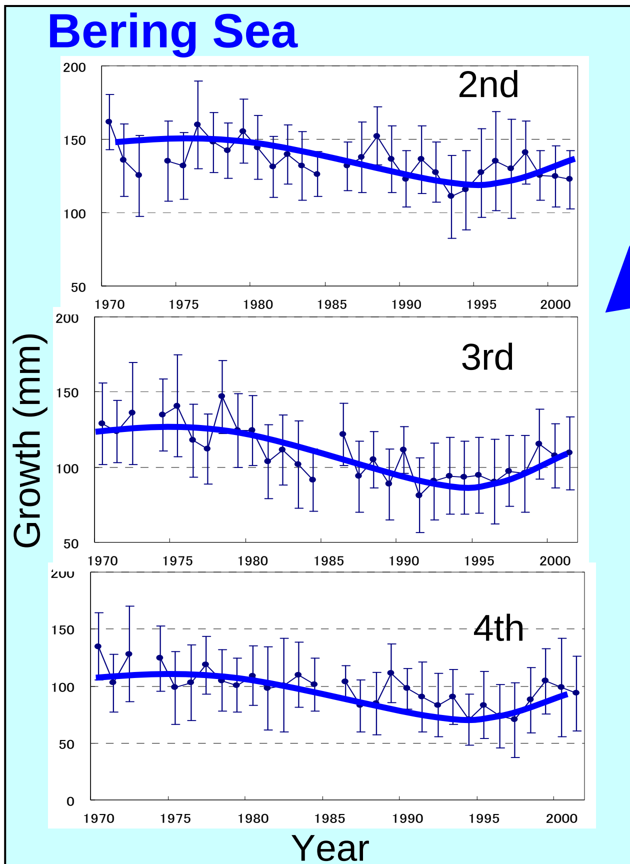
Population level





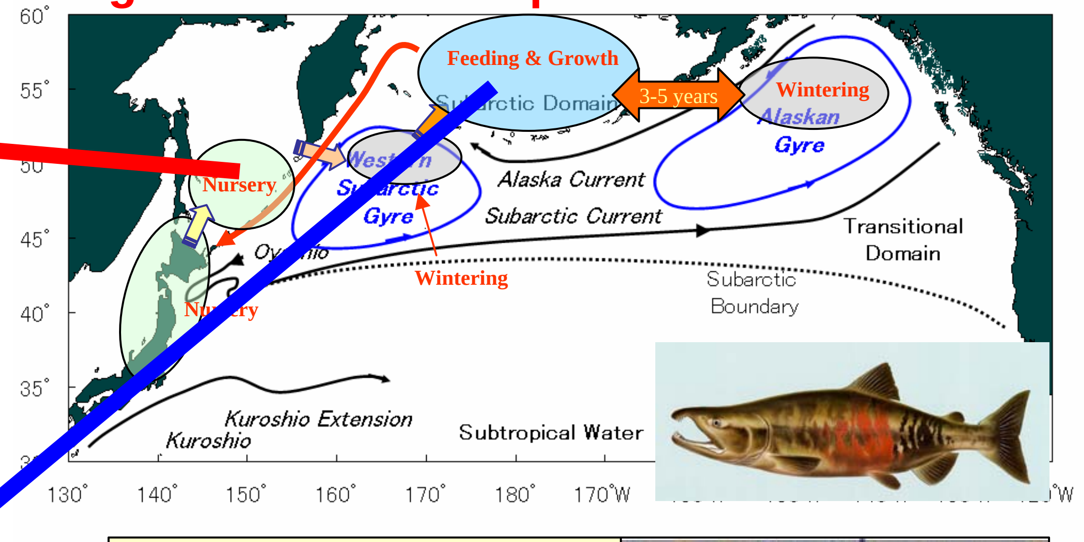
Temporal change in growth pattern of Hokkaido chum salmon



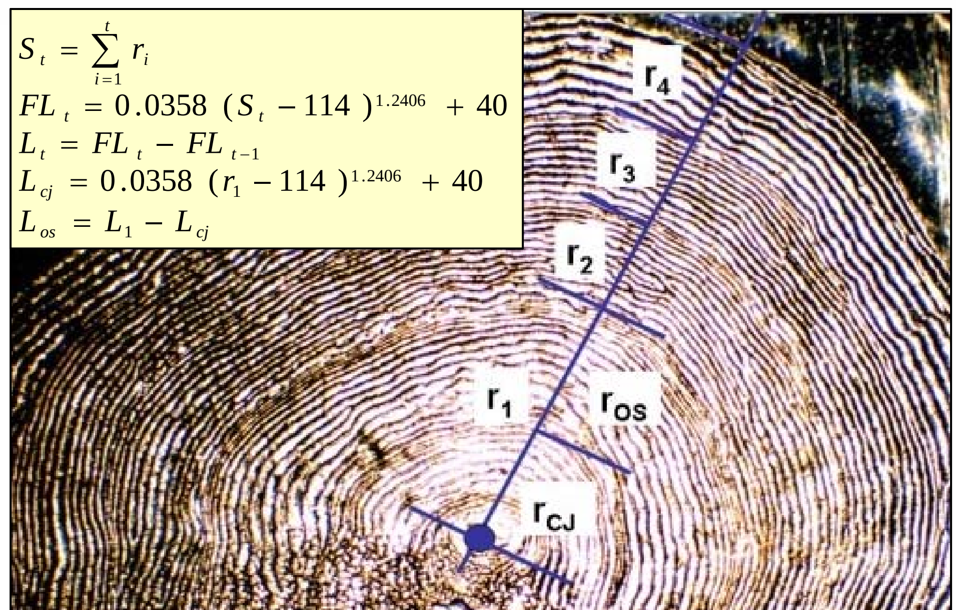


Temporal changes in growth of chum salmon returning to the Ishikari River by age

Migration route of Japanese chum salmon



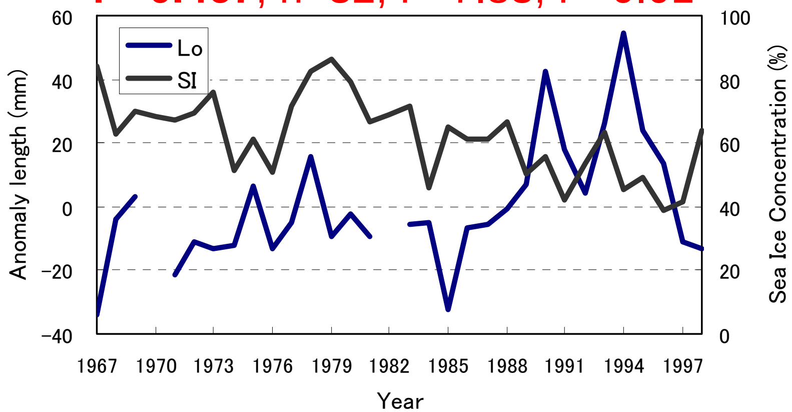
$$S_t = \sum_{i=1}^{t} r_i$$
$$FL_t = 0.0358\ (S_t - 114)^{1.2406} + 40$$
$$L_t = FL_t - FL_{t-1}$$
$$L_{cj} = 0.0358\ (r_1 - 114)^{1.2406} + 40$$
$$L_{os} = L_1 - L_{cj}$$



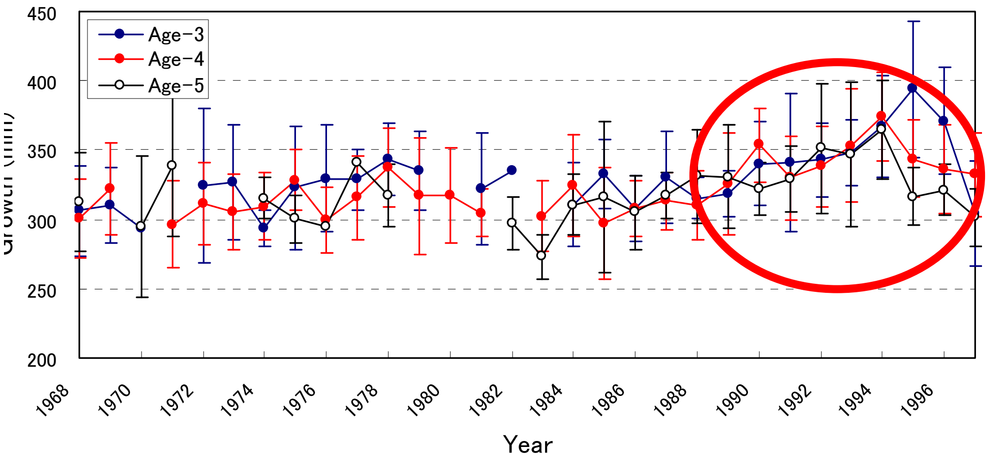
Scales of age-4 adult chum salmon returning to the Ishikari River, Hokkaido.

Growth of Hokkaido chum salmon in the Okhotsk Sea

r=-0.467, n=32, F=7.83, P<0.01

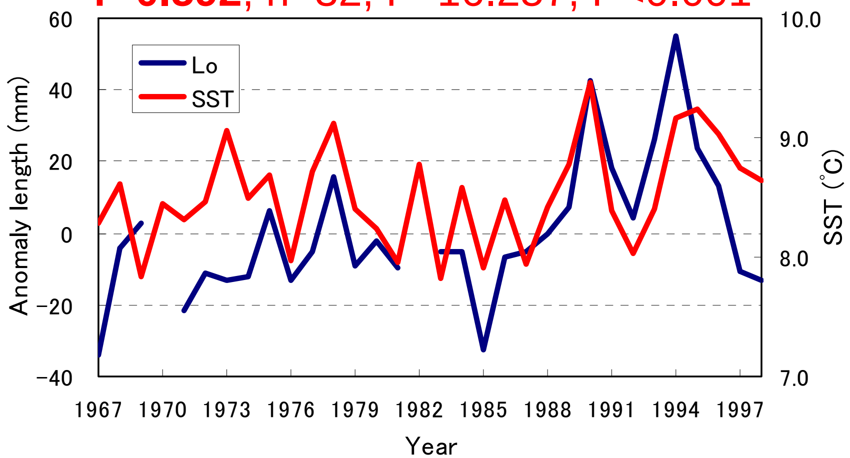


Annual changes in the sea ice concentration (SI) and anomaly of growth at the Okhotsk Sea (Lo) of the age-4 chum salmon returning to the Ishikari River.

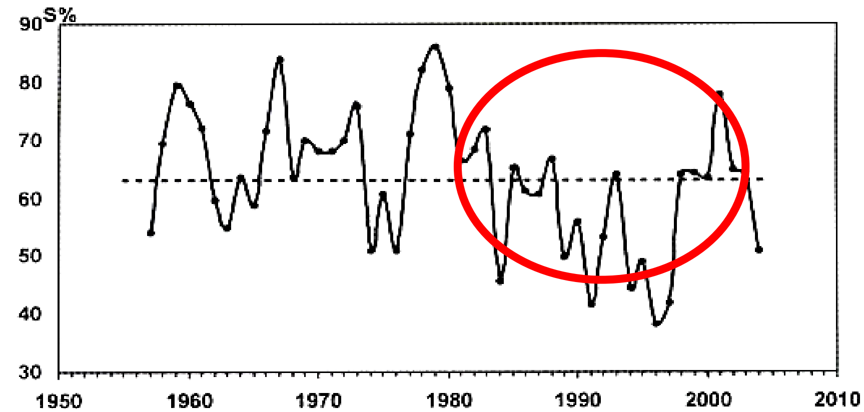


Annual change in growth at the first year of Ishikari River chum salmon in the Okhotsk Sea.

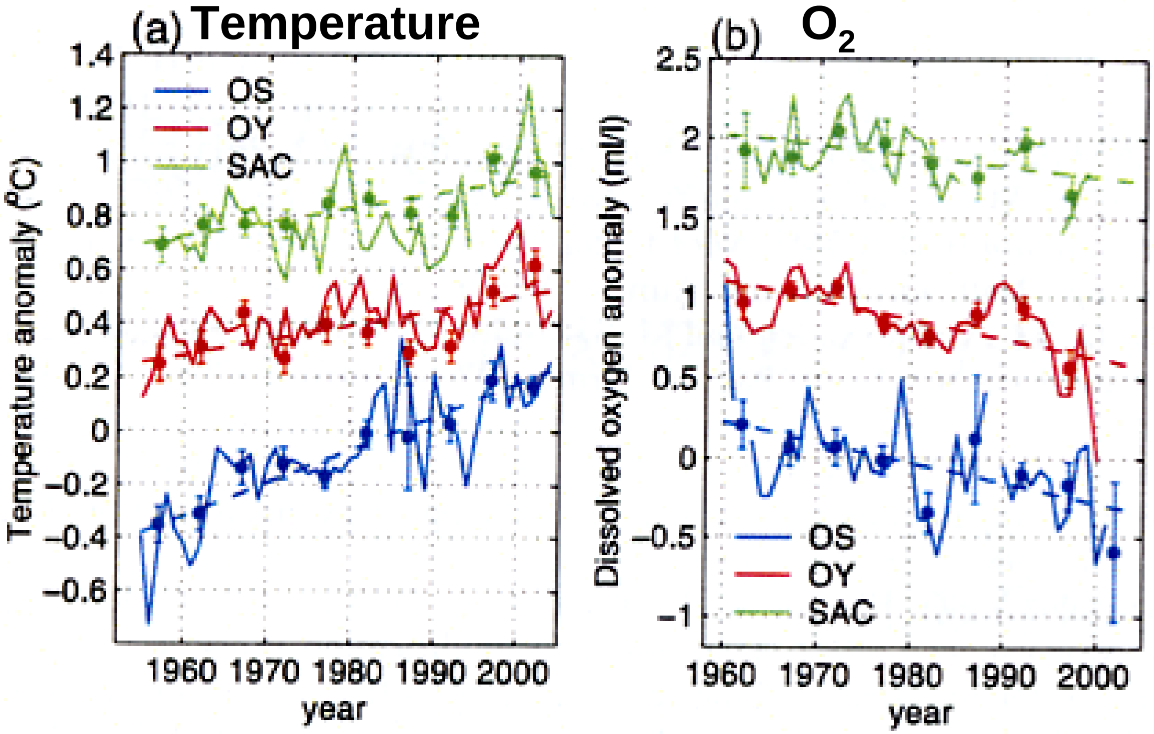
r=0.592, n=32, F=16.257, P<0.001



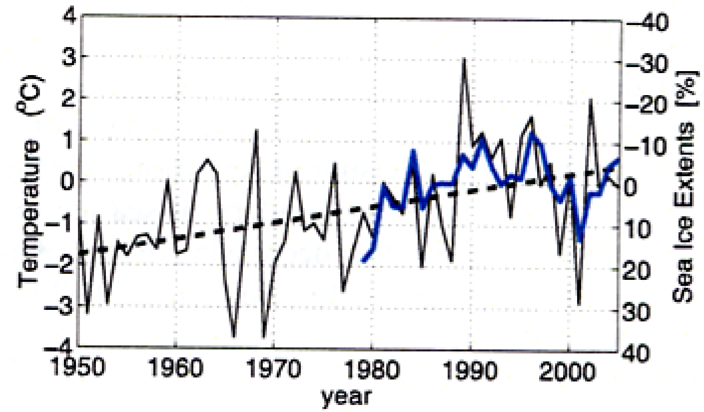
Annual changes in the sea surface temperature (SST) during summer and fall, and anomaly of growth at the Okhotsk Sea (Lo) of the age-4 chum salmon returning to the Ishikari River.



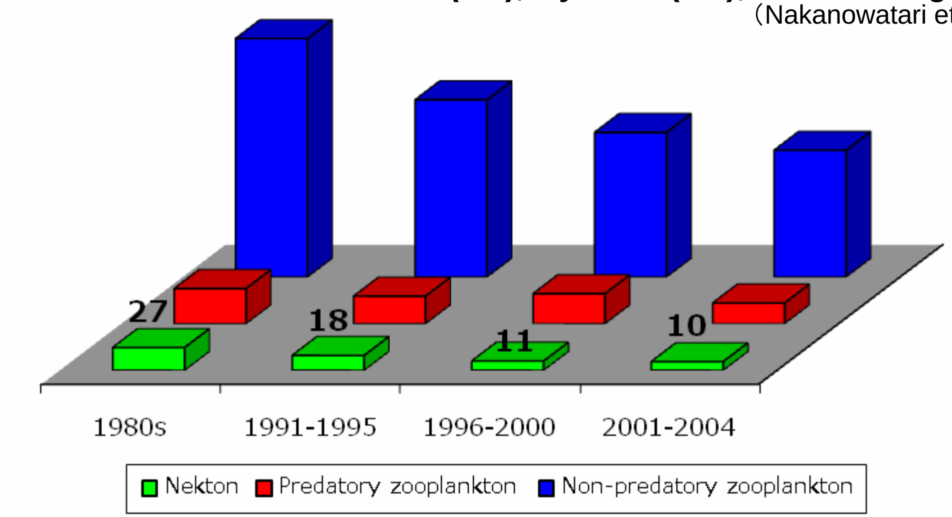
Temporal change in the rate of ice cover area in the Okhotsk Sea (Ustinova et al. 2002)



Time series of potential temperature (a) and dissoloved oxygen (b) at 27.0 σ_θ in the Okhotsk Sea (OS), Oyashio (OY), and SAC region (SAC). (Nakanowatari et al. 2007)



Time series of surface air temperature (black) and the sea ice extent anomaly in the Okhotsk. (Nakanowatari et al. 2007)



Temporal changes in zooplankton and nekton biomass in the Okhotsk Sea (Dulepova 2005).

- **Warming trend of water temperature**
- **Decline in dissolved oxygen and biological production**

⇓

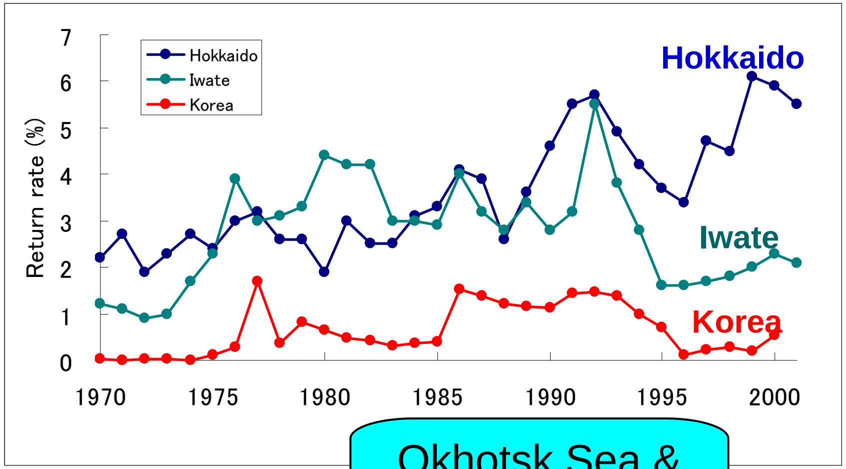
Global warming effect

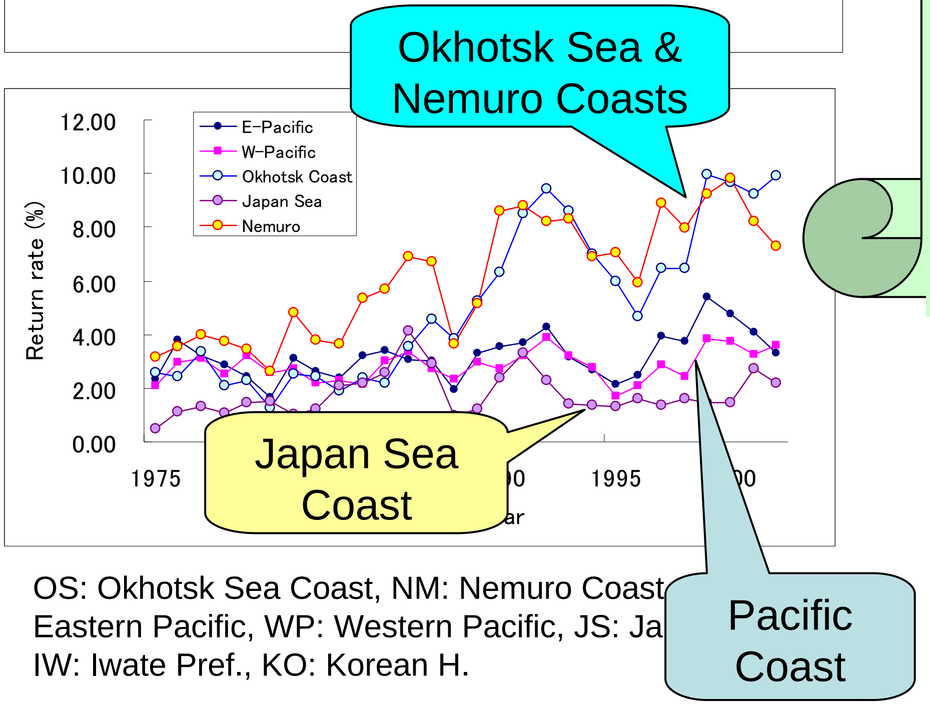
Growth of chum salmon

⇓

SST

Change in return rates of chum salmon released from Japan and Korea



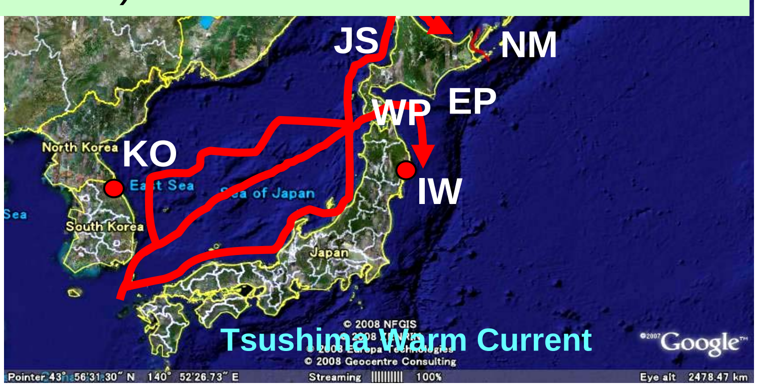


OS: Okhotsk Sea Coast, NM: Nemuro Coast, Eastern Pacific, WP: Western Pacific, JS: Ja IW: Iwate Pref., KO: Korean H.

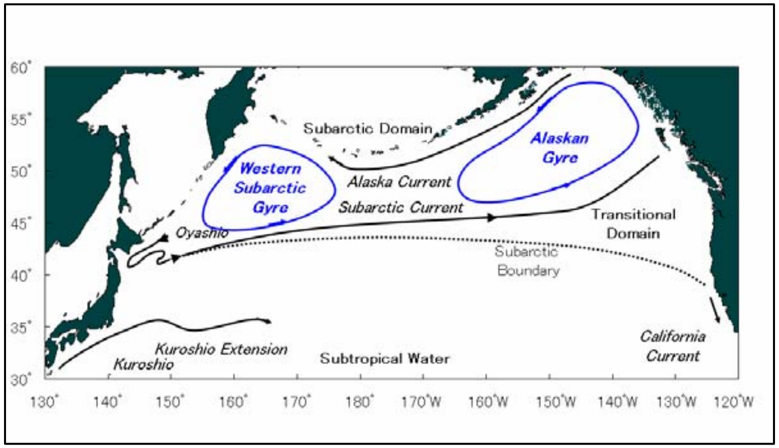
These results indicate that the growth and survival of juvenile Hokkaido chum salmon will be affected by the SST and not by the productivity trends, relating to the rate of ice cover area in the Okhotsk Sea.

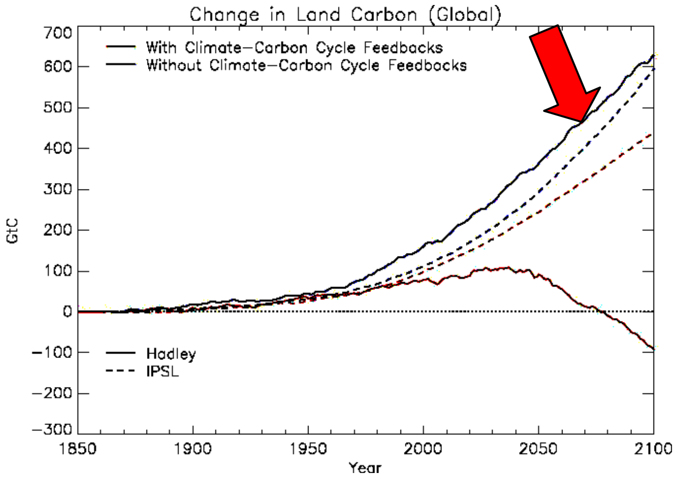
Survival of both Korean and Iwate populations will be strongly affected by the Tsushima Warm Current in the spring offshore-migration period.

Sea ice concentration is decreasing during the last 100 years in the Okhotsk Sea Coast of Hokkaido by the global warming effect (Aota 1999).

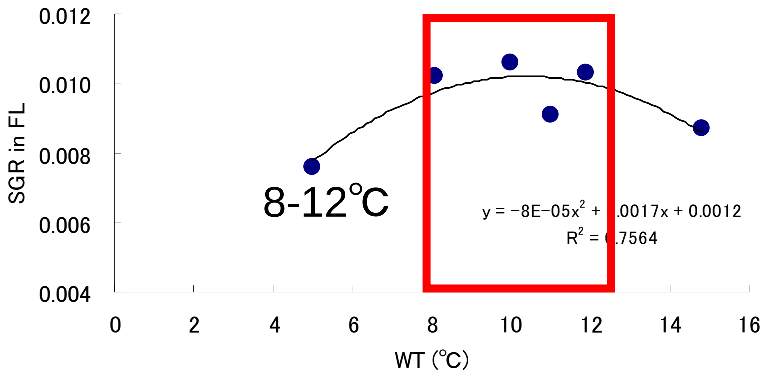


Prediction about the Global Warming effect on chum salmon in the North Pacific Ocean based on the SRES-A1B scenario

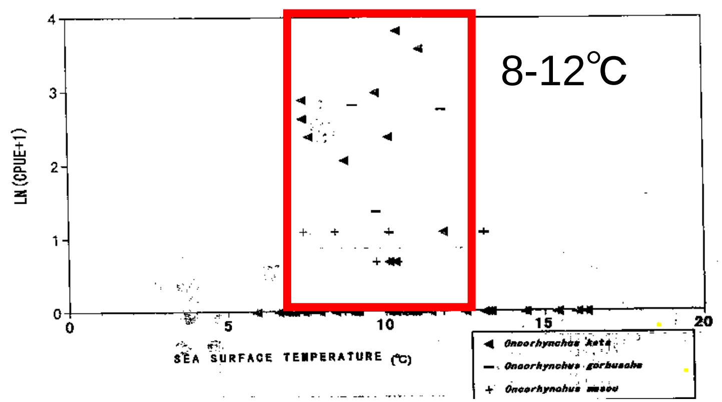




Estimation on SST in the North Pacific Ocean in 2050 and 2099 (Kawamiya 2004)



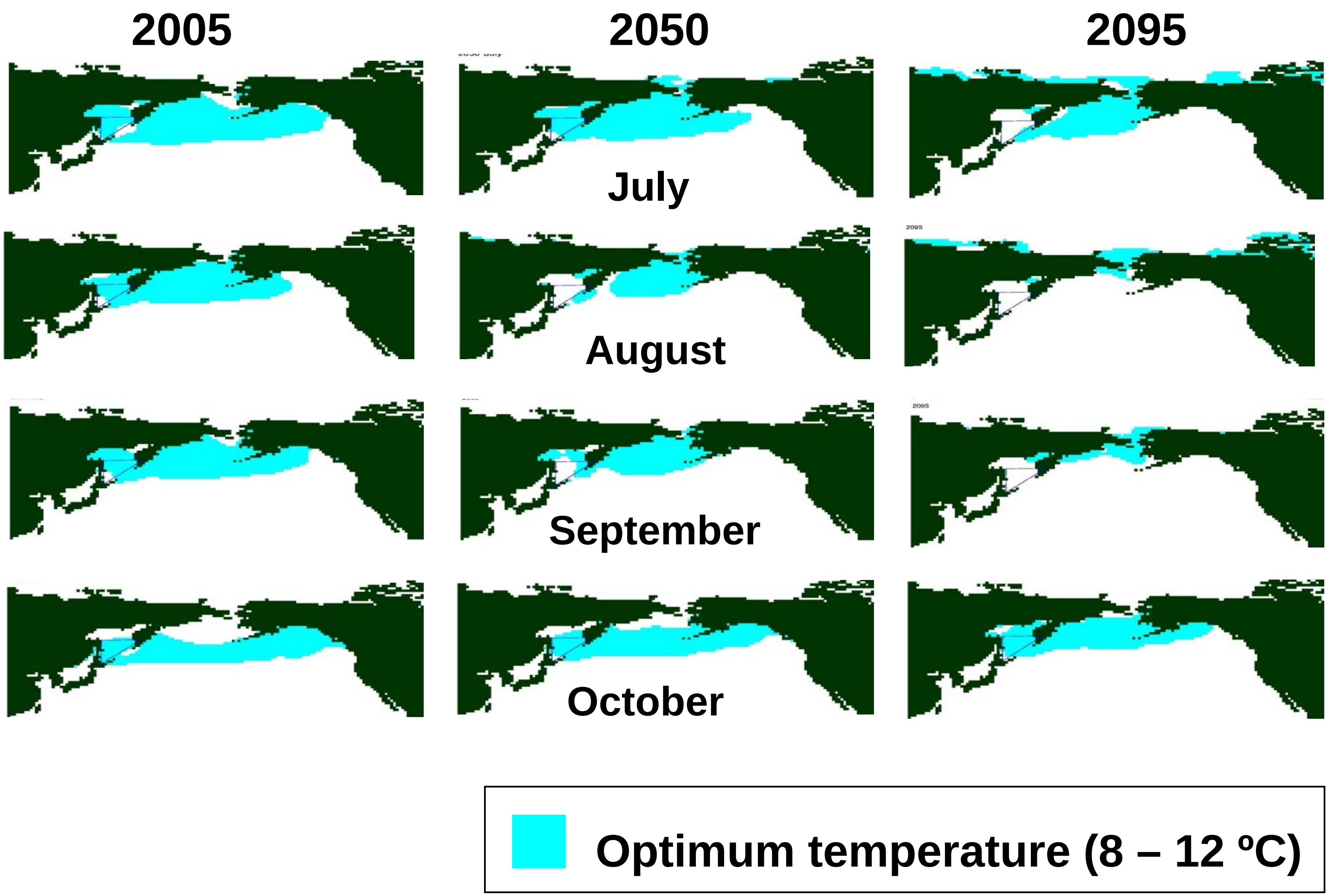
Relationship between water temperature and specific growth rate of chum salmon. (Kaeriyama 1984, 1989）



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℃**

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



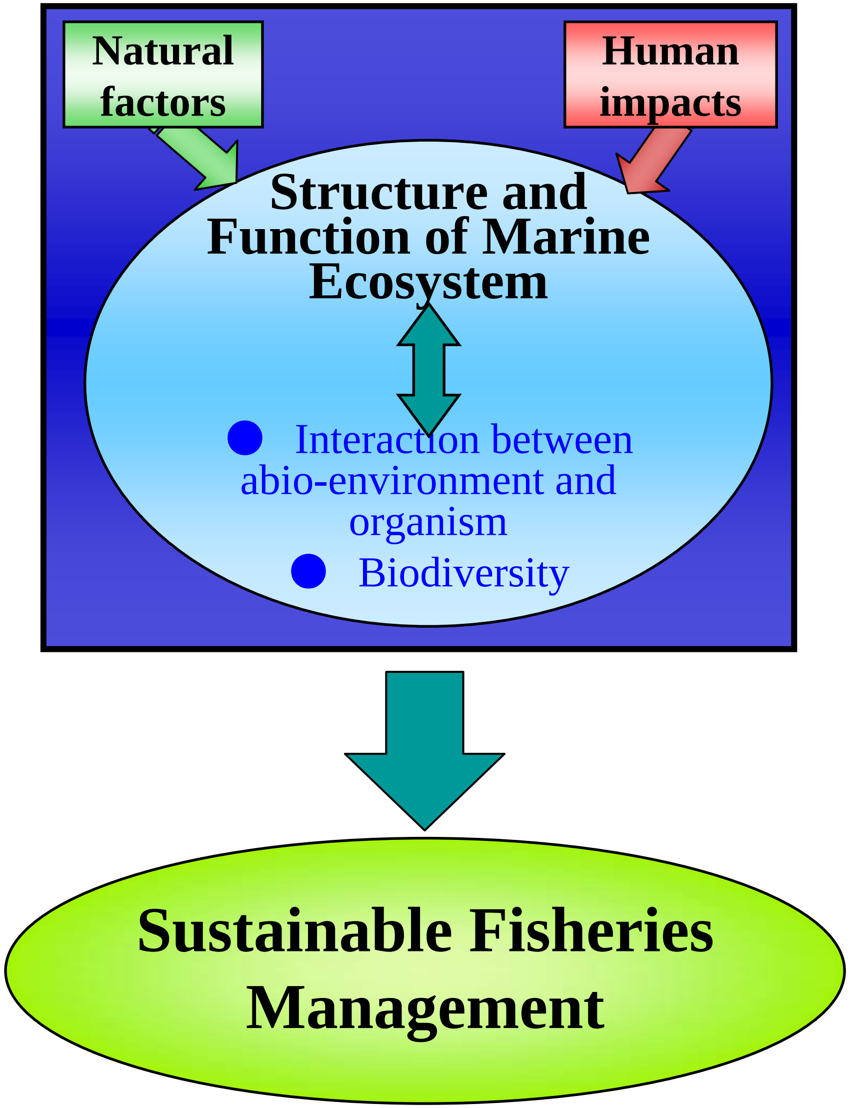
<u>Global Warming Effect for Chum salmon</u>

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

- **<u>In the Future</u>,** the global warming will affect:
  - Decrease in their carrying capacity for reducing distribution area in the Gulf of Alaska and the Bering Sea
  - Strongly the density-dependent effect
  - Hokkaido chum salmon population which will lose migration route to the Okhotsk Sea by 2050 and will be crushed by 2100

Fisheries Management

- We should understand the limitations of the fisheries management at a population level.
  - Carrying capacity & Density-dependent effect
  - Biological interaction between wild & hatchery salmon
  - Global warming effect
  - Loss of Genetic Diversity
- We should establish the sustainable fisheries management based on marine ecosystem.

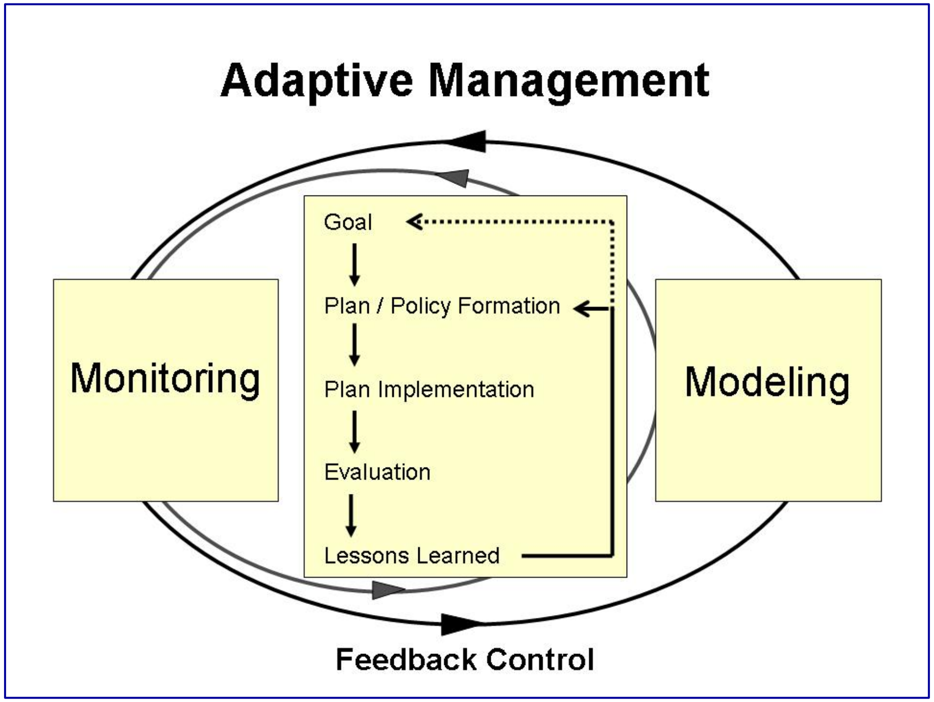


Risk Management for Sustainable Fisheries Management Based on the Ecosystem Approach of Pacific Salmon (RSMEAP)

1. Marine ecosystem conservation and stable marine-food product with increase in human impacts on the earth ecosystem

2. Monitoring the <u>structure and function</u> in the ocean ecosystem
   - Spatial and temporal changes: Carrying capacity, Food web & trophic level
   - Climatic-oceanic conditions: Global warning, Regime shift
   - Biological interaction: Wild vs Hatchery, Density-dependent effect

3. <u>Adaptive management</u> and <u>precautionary principle</u> for Pacific salmon in ocean ecosystem
   - Adaptive learning
     - Learning by doing
     - Responsibility of
     - Risk exposition
   - **Feedback control**
     - Monitoring
     - Modeling



Action Plan Framework: Ecosystem-based Sustainable Conservation Management of Pacific Salmon

- **Climatic and oceanic monitoring**
  - Climate events (e.g., El Niño, La Niña)
  - Long-term climate change (e.g., Regime Shift, Global warming)
  - Ecosystem structure (e.g., Trophic level, Food web)

- **Biological monitoring**
  - Carrying capacity in the ocean
  - Body size & age composition of a population
  - Genetic & reproductive characteristics (e.g., fecundity, egg size)
  - Stock identification in the ocean

- **Restoration of natural river system and rehabilitation of wild salmon**
  - Rehabilitations and conservation of wild salmon population (Especially, chum and masu salmon)
  - Exclusion and non-introduction of exotic fishes
  - Biological interaction between hatchery and wild salmon