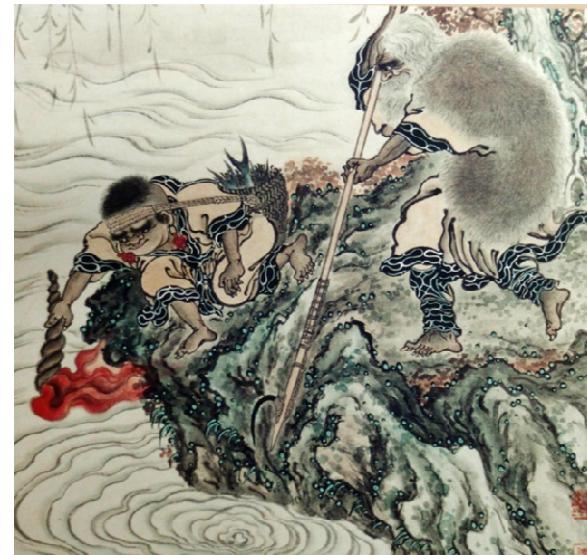


Ecological interactions across habitats and life histories of Pacific salmon in the North Pacific

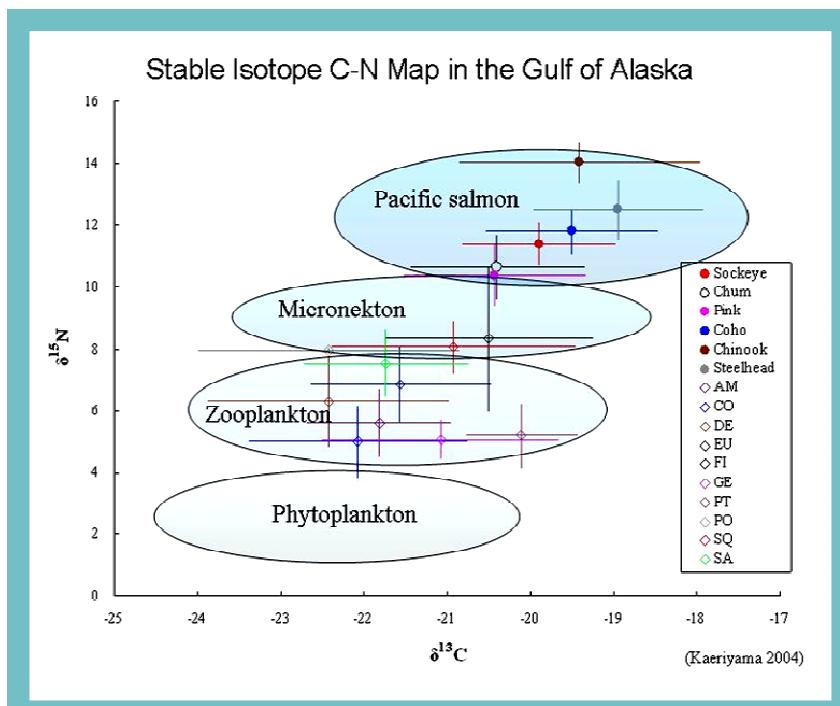


Masahide Kaeriyama

Faculty of Fisheries Science, Hokkaido University
salmon@fish.hokudai.ac.jp



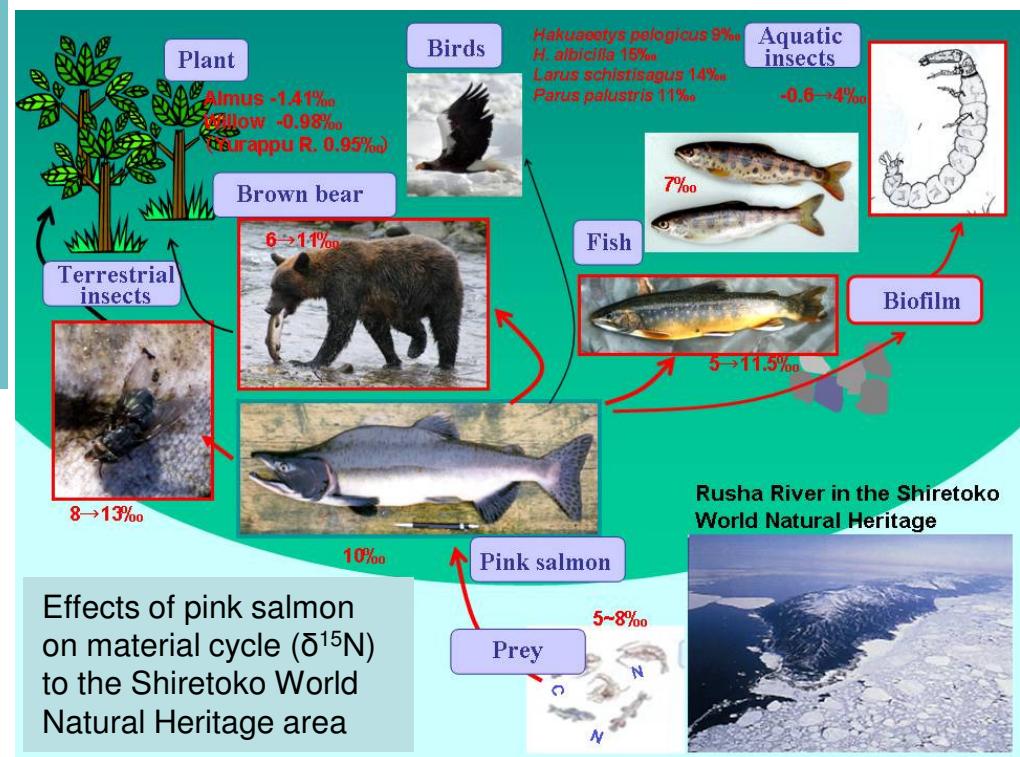
Pacific salmon play an important role as keystone species and ecological service in the North Pacific ecosystem



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

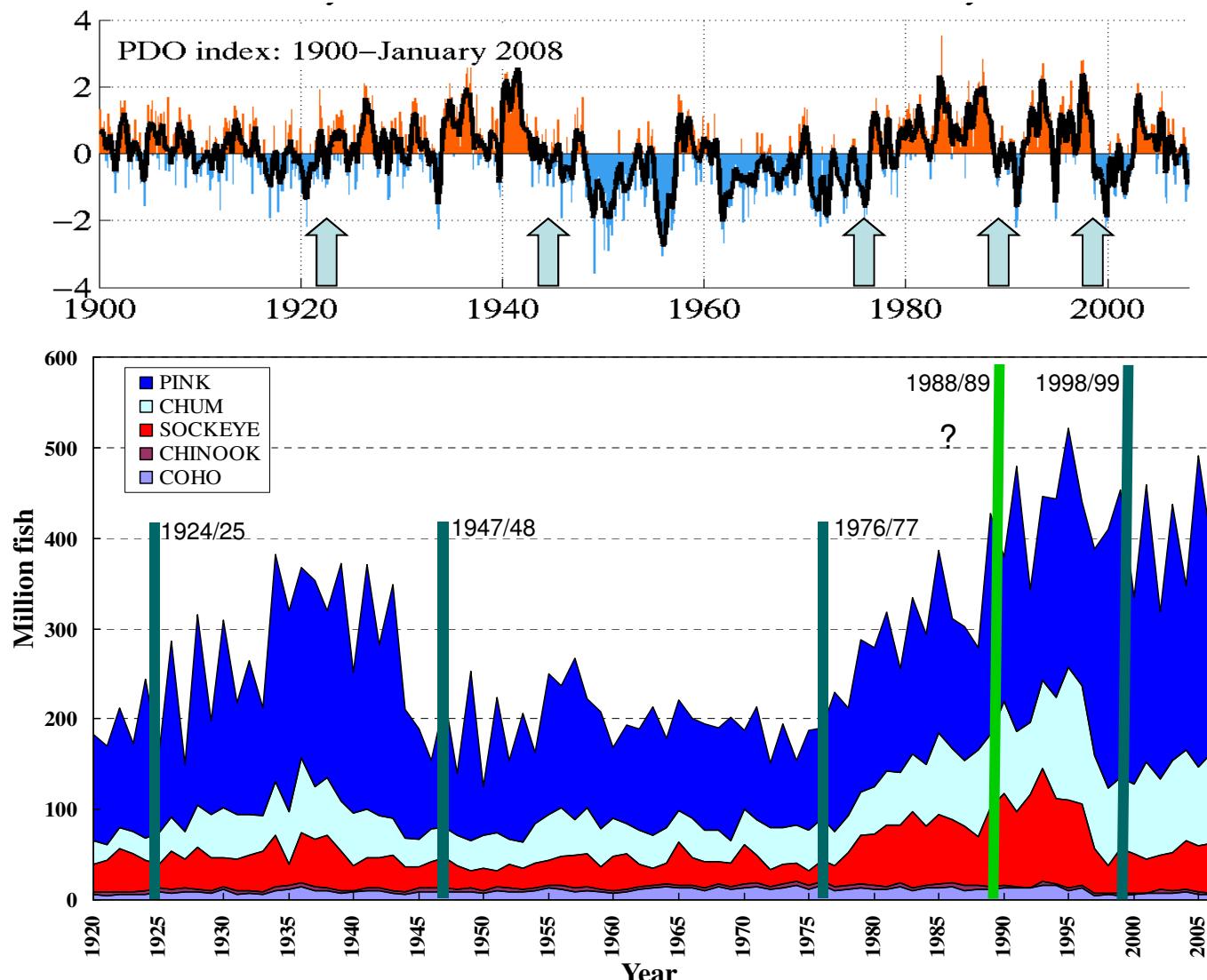


Topics

- Current situation on Pacific salmon biomass dynamics
- Intra-specific interaction of chum salmon
- Global warming effect on chum salmon
- Sustainability of Pacific salmon and aquatic ecosystem

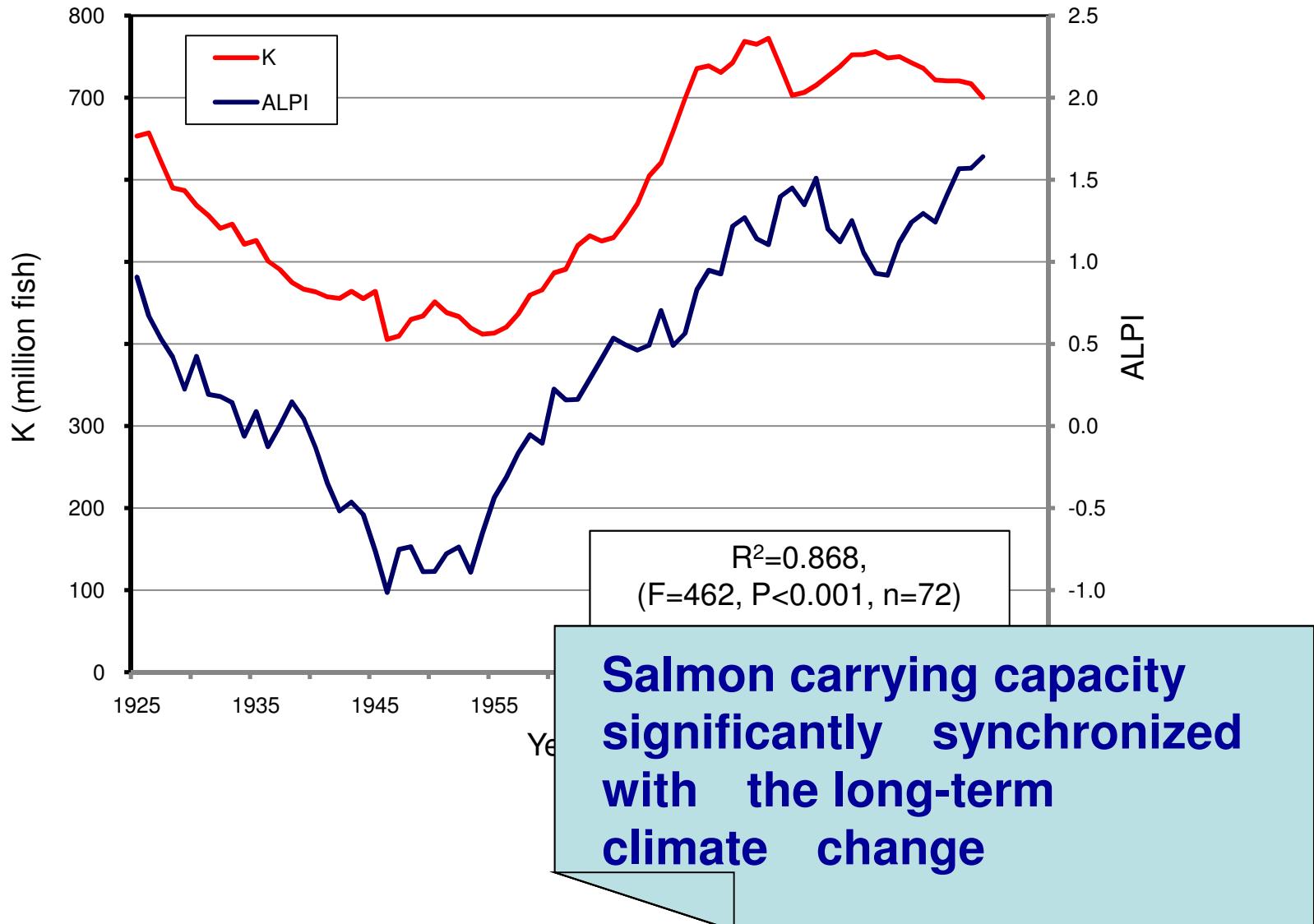


Production trend of Pacific salmon: Corresponding the long-term climate change



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

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



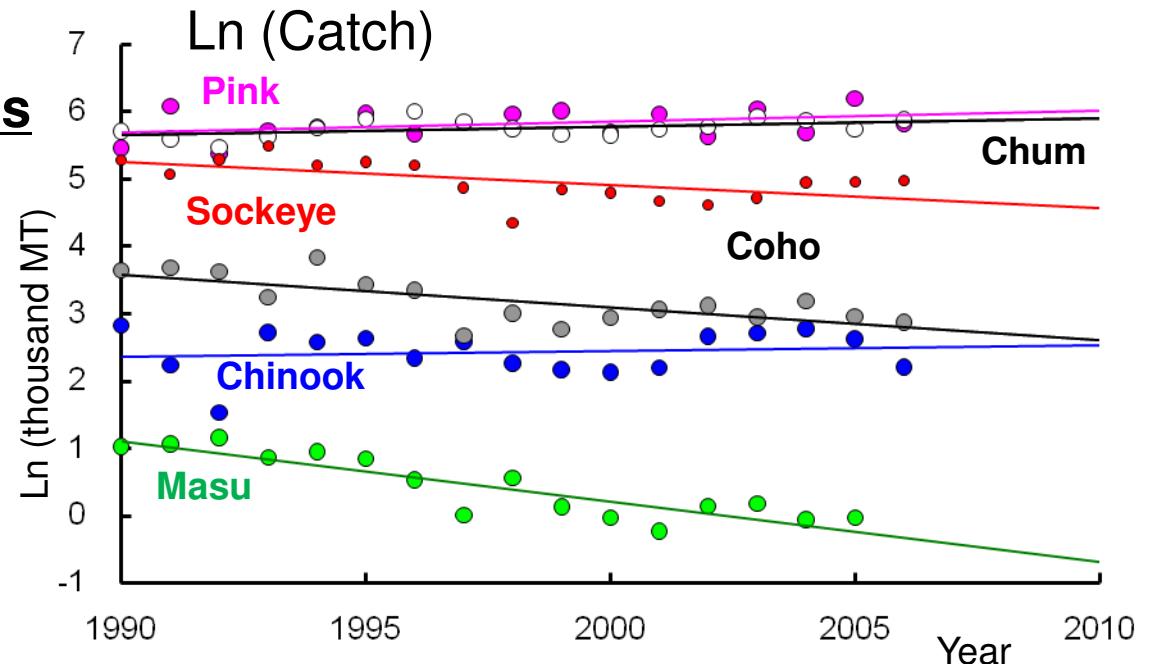
Recent trends

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)

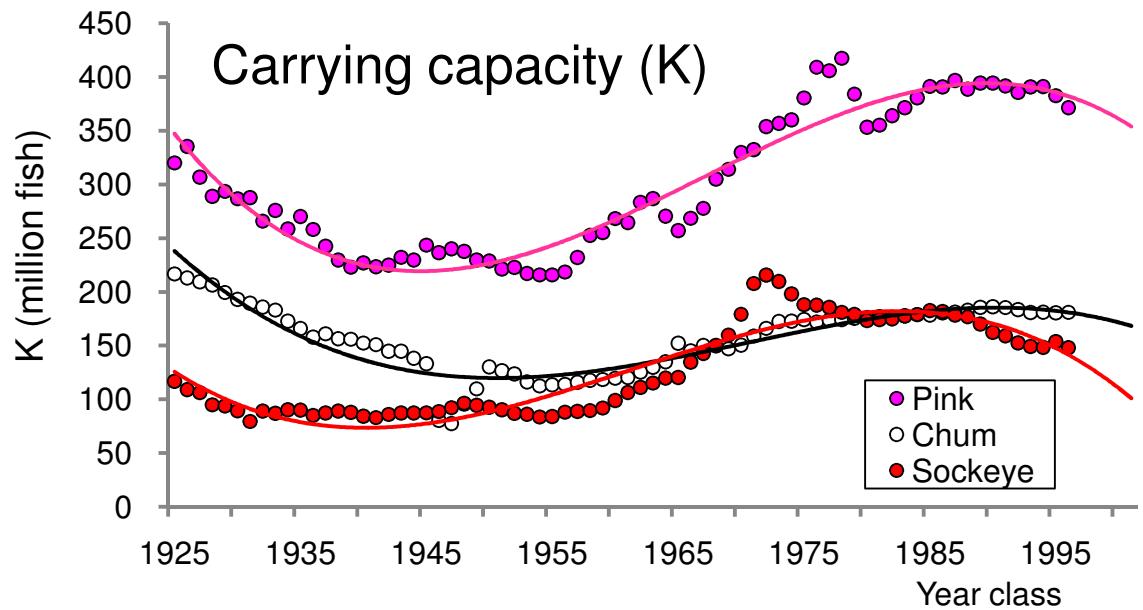
(): Slope in regression lines

* Homogeneity ($P < 0.01$)



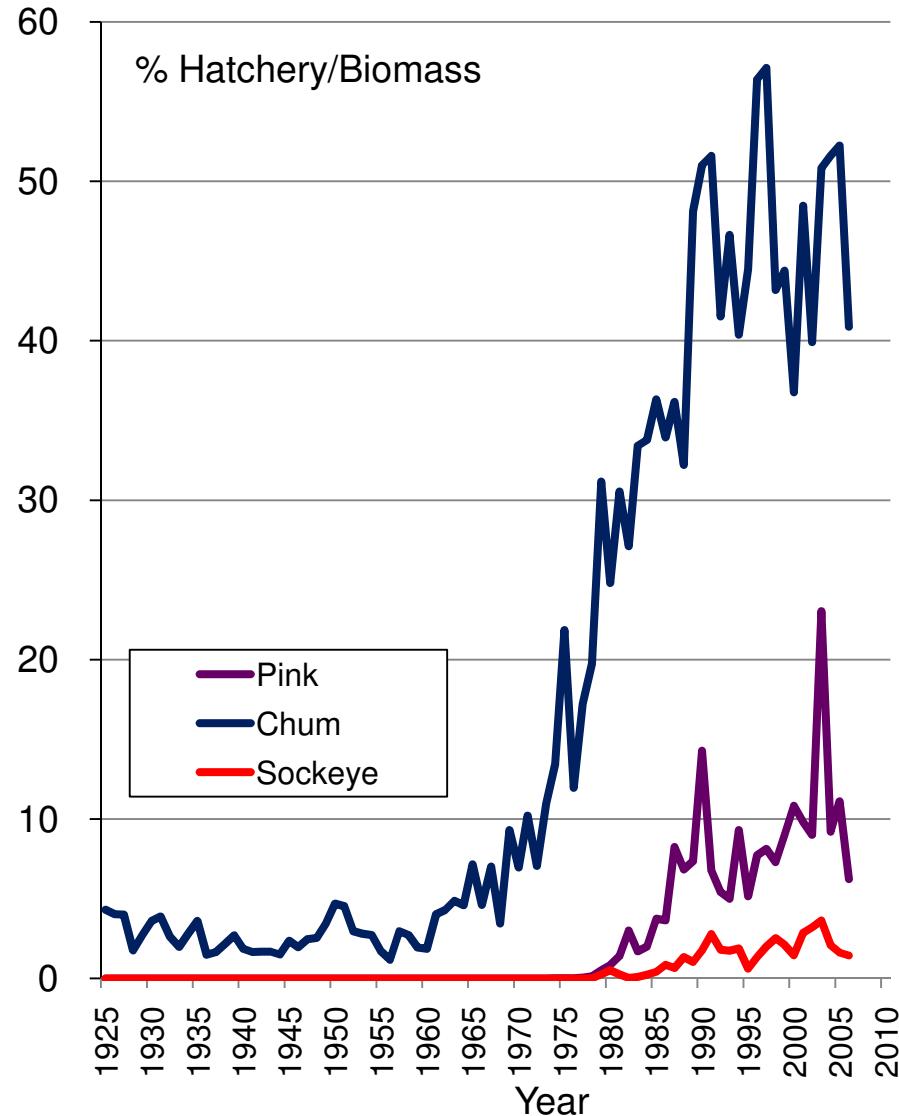
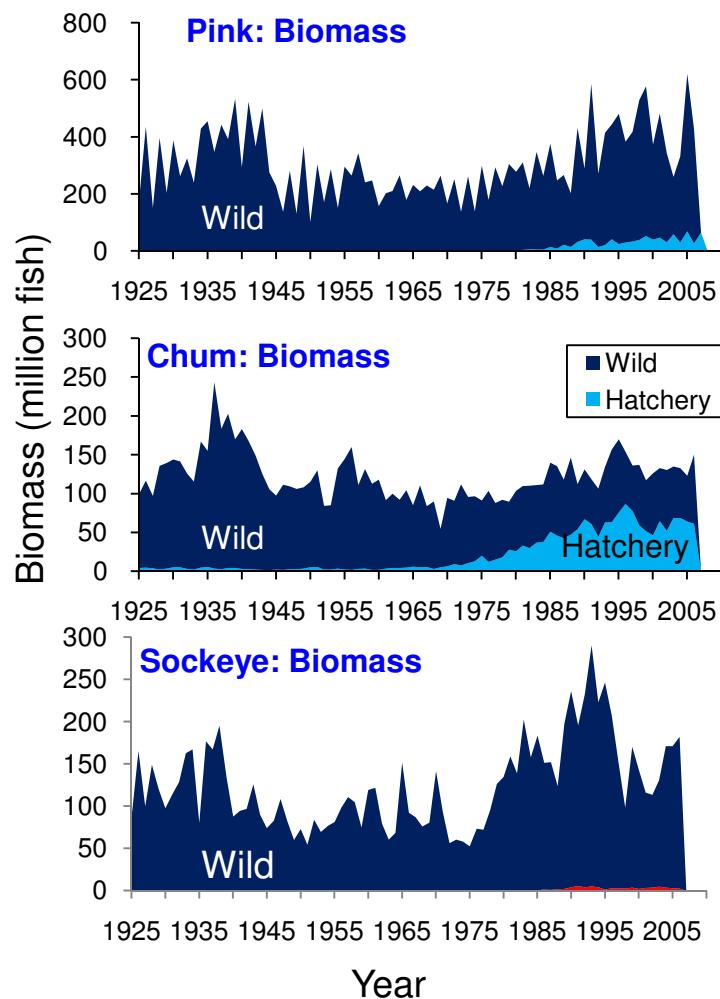
Carrying capacity trend

- Pink: stable?
- Chum: stable?
- Sockeye: decrease

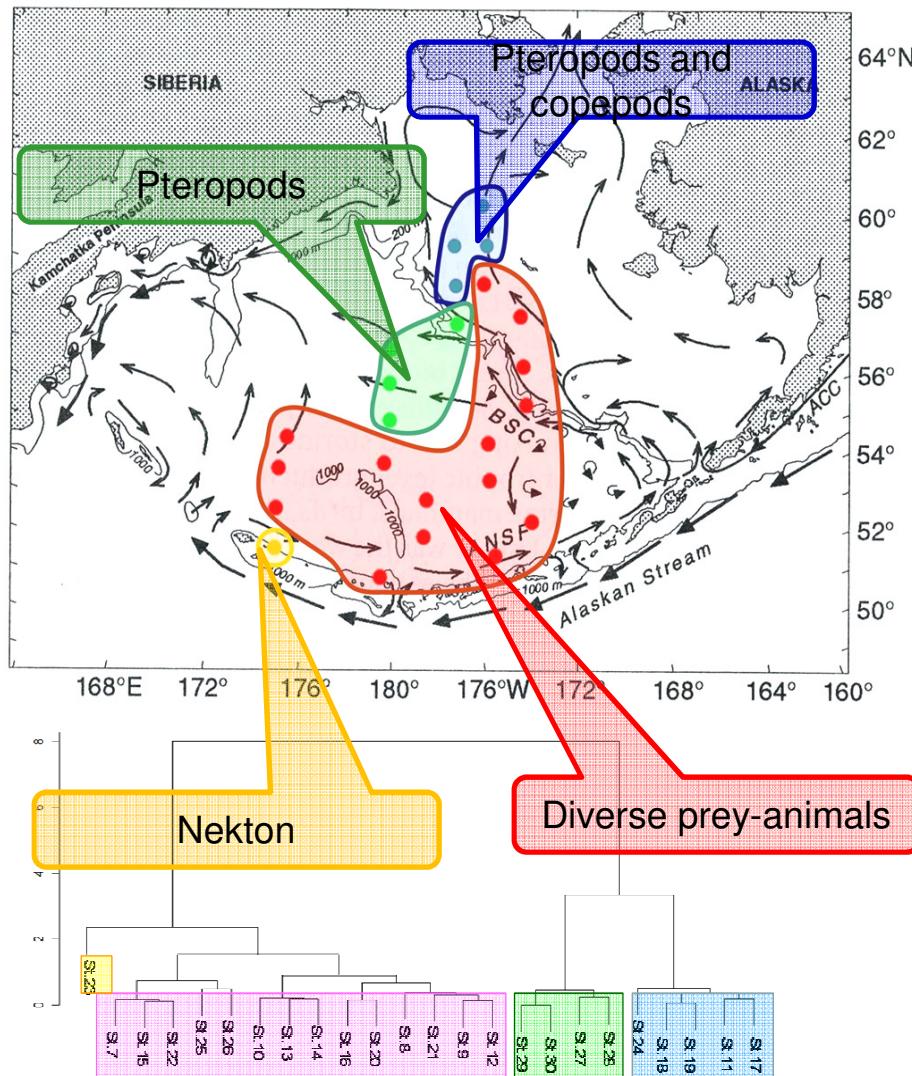


Annual changes in biomass of wild/hatchery salmon

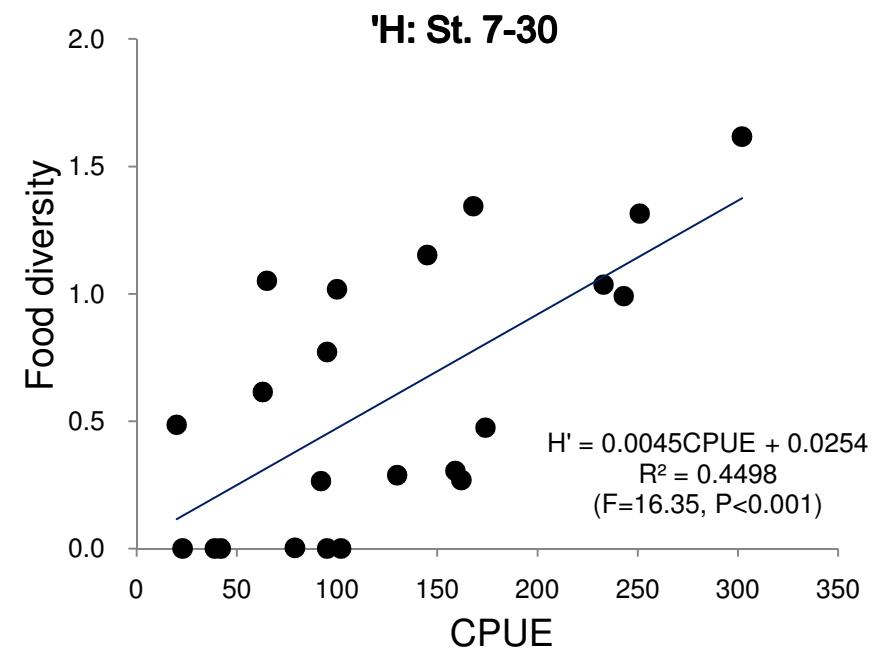
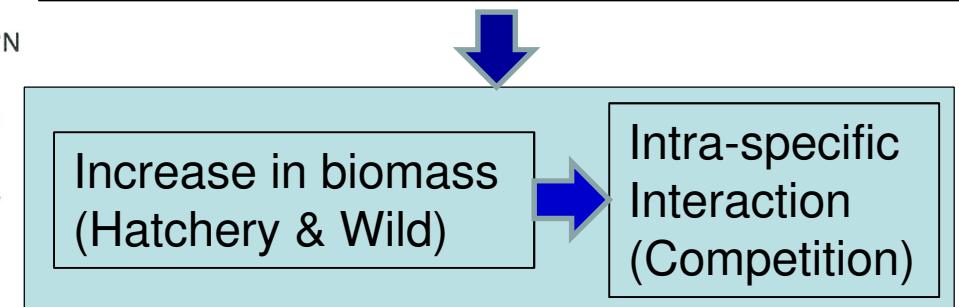
Hatchery salmon
Pink >10%
Chum > 50%
Sockeye <10%



Feeding habit of chum salmon in the Bering Sea in 2009



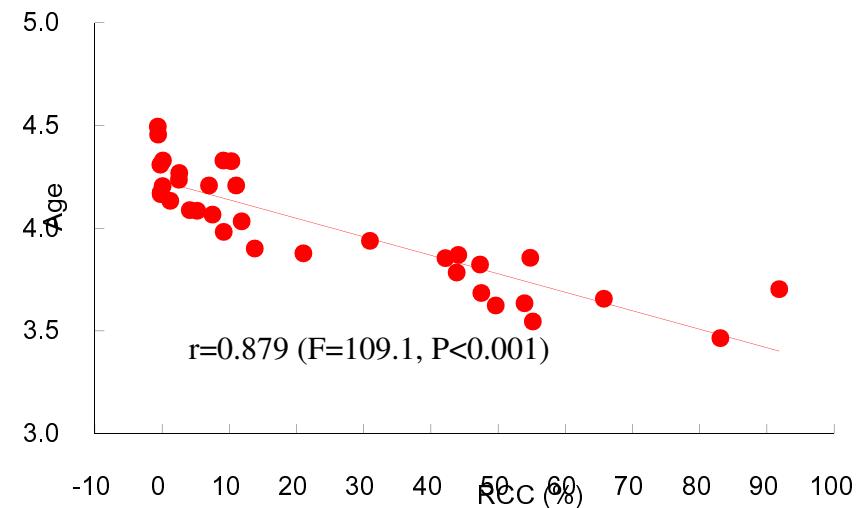
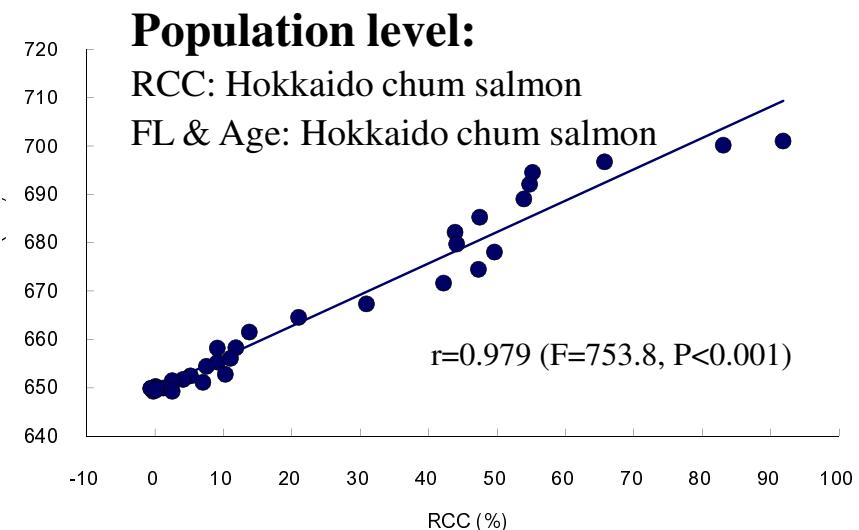
- Plasticity in feeding strategy
- Density-dependent effect on the diet shift (Prey: dominat→diversed)

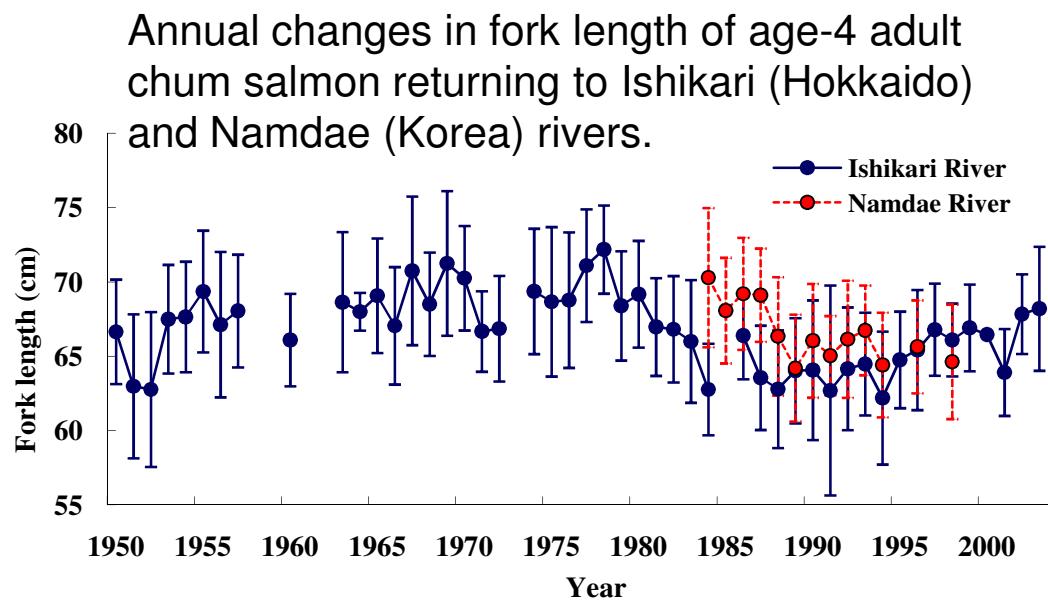


Carrying capacity and density-dependent effect of chum salmon

This suggests that a population density-dependent effect causes the individual growth reduction in Hokkaido chum salmon population with decrease in the residual carrying capacity.

Does the density-depend effect really occur at meta-population or species levels?





Regression coefficients for the slope of the linear relation of fork length to biomass on ANCOVA (Seo et al. 2009).

Level of Catch	River	R^2	b	a	N	Slope	
						t	P
Population	Namdae	0.577**	-0.016	4.26	13	2.11	0.04
	Ishikari	0.304**	-0.038	4.58	34		
Meta-population	Namdae	0.367*	-0.087	5.17	13	0.22	0.83
	Ishikari	0.313*	-0.066	4.91	32		
Species	Namdae	0.307*	-0.088	5.19	13	0.16	0.87
	Ishikari	0.304*	-0.068	4.59	32		

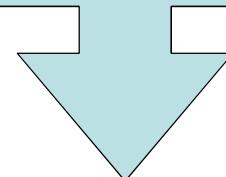
Population level: each Hokkaido and Korea populations of chum salmon

Meta-population level: Catch of Asian chum salmon (Japan, Korea, and Russia)

Species level: Total catch of chum salmon in the all North Pacific (Japan, Korea, Russia, Canada and USA)

ANCOVS results:

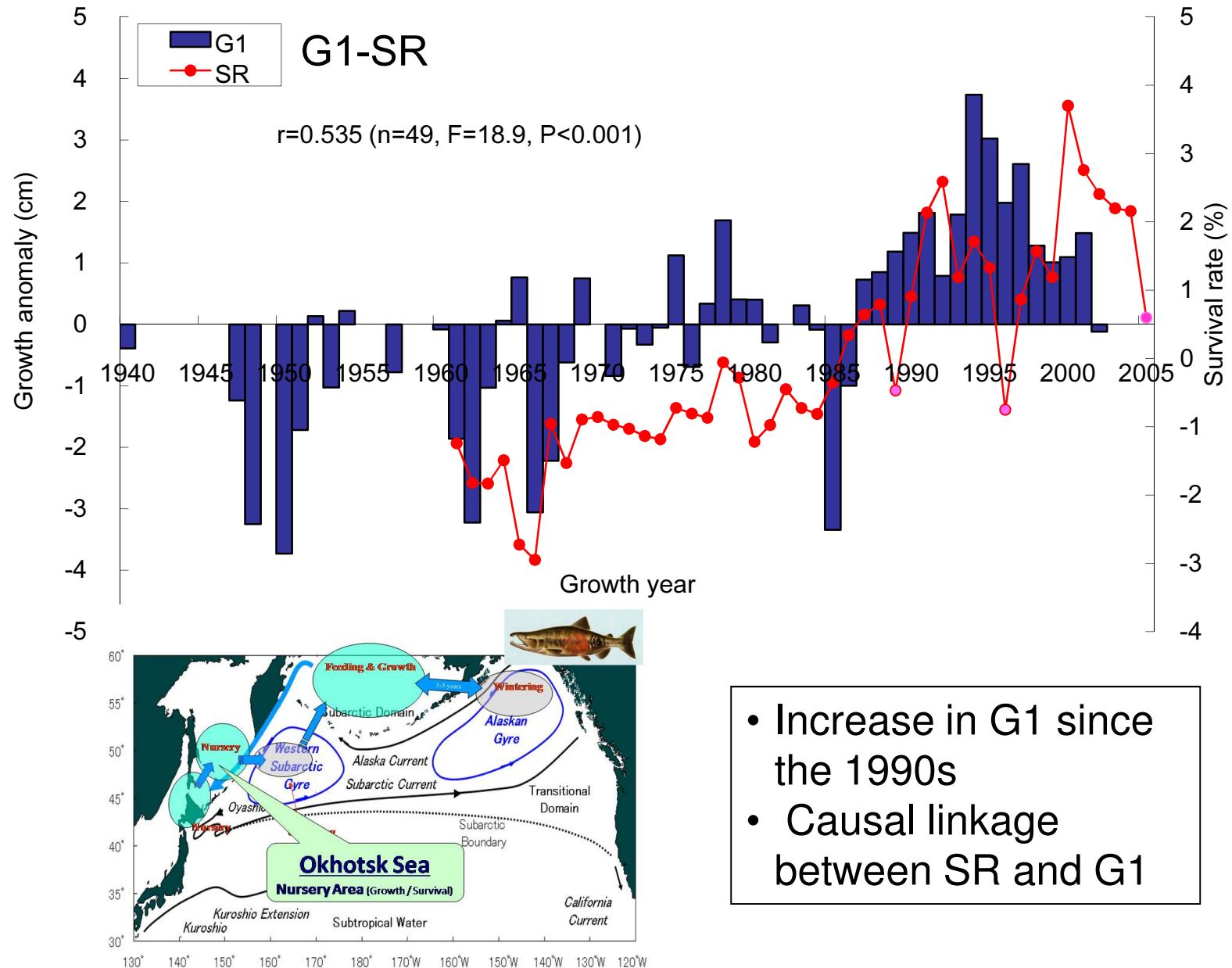
- (1) Negative linear relation between FL and Catch.
- (2) Non-homogenous slopes at the population level.
- (3) Homogeneous slopes of those relations at meta-population and species levels.



Density-dependent effect:

- significant at a population level
- no-significant at meta-population and species levels.

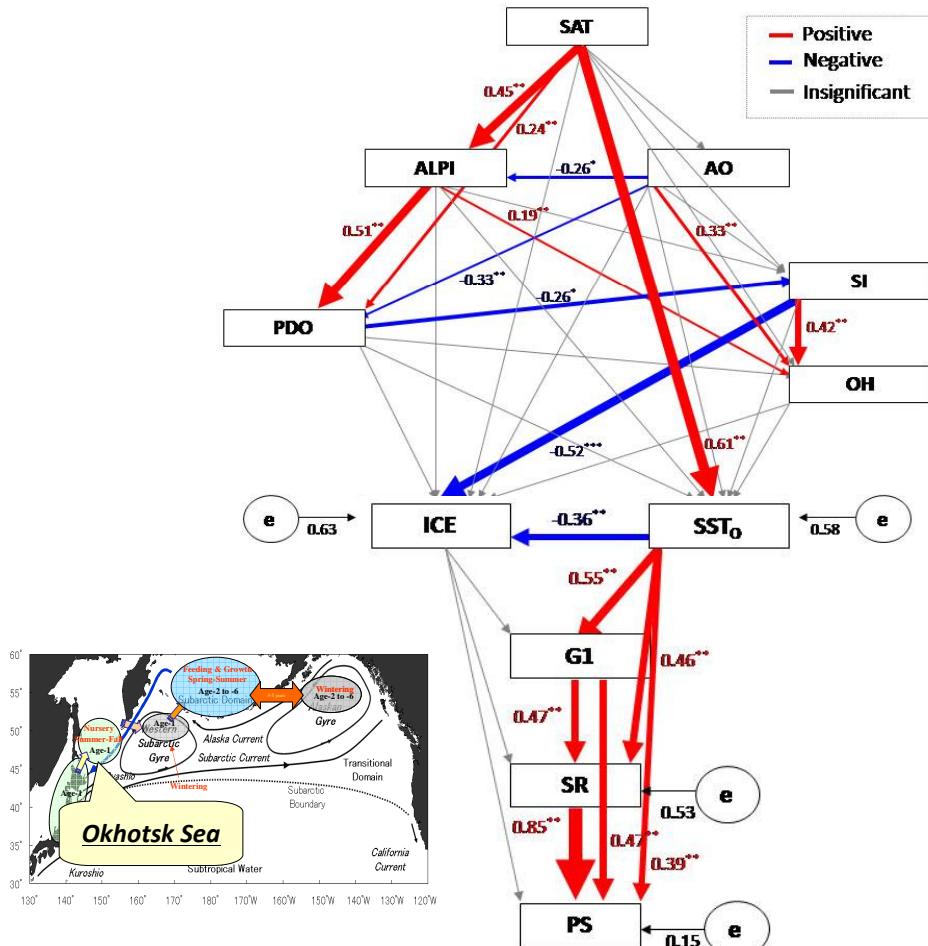
Temporal changes in growth at age-1 (G1) and survival rate (SR) of Hokkaido chum salmon population



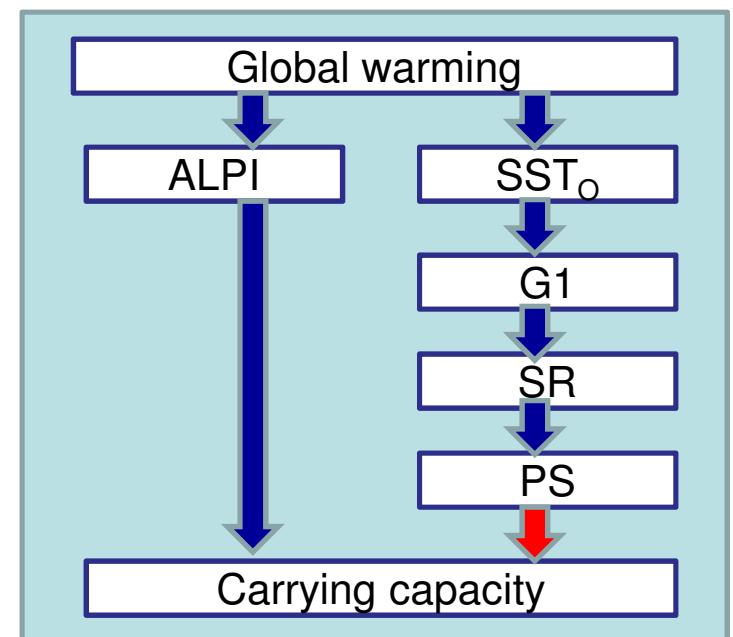
Path model analysis

relationships among global surface temperature (SAT), ALPI, PDO, AO, Siberian high (SI), Okhotsk High (OH), Ice cover area (ICE), Summer-Fall SST in the Okhotsk Sea (SST_O), Growth at age-1 (G1), Survival rate (SR), and Population size (PS) of Hokkaido chum salmon

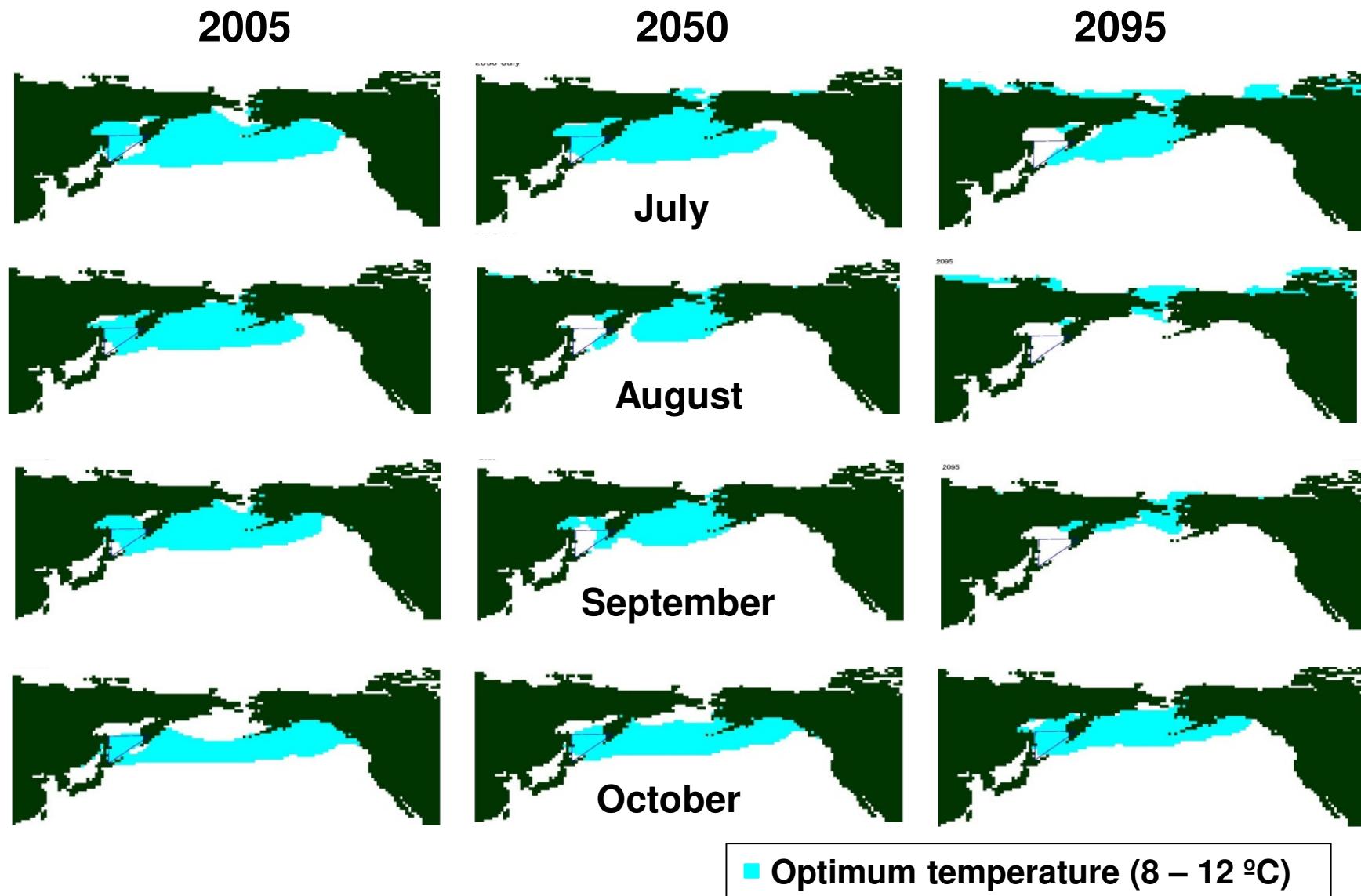
For estimating climate/oceanic effects on the growth and survival of Hokkaido chum salmon



Global warming is directly and indirectly affecting growth in the Okhotsk Sea and survival of Hokkaido chum salmon



Prediction about the Global Warming Effect on Chum Salmon in the North Pacific Ocean based on the SRES-A1B scenario

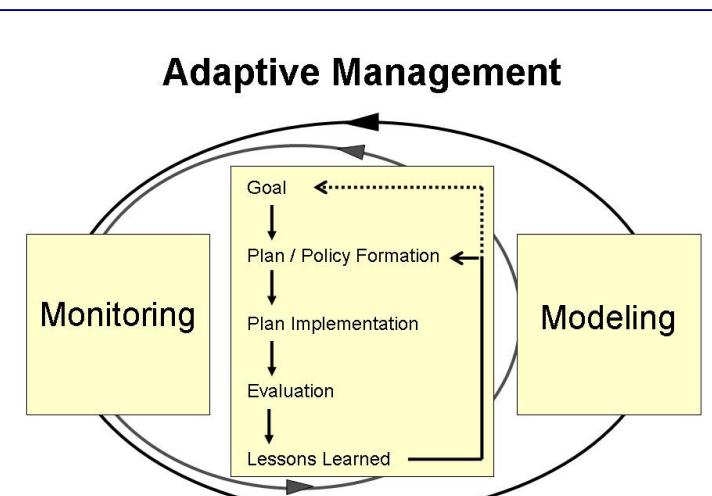


Global Warming Effect for Chum salmon

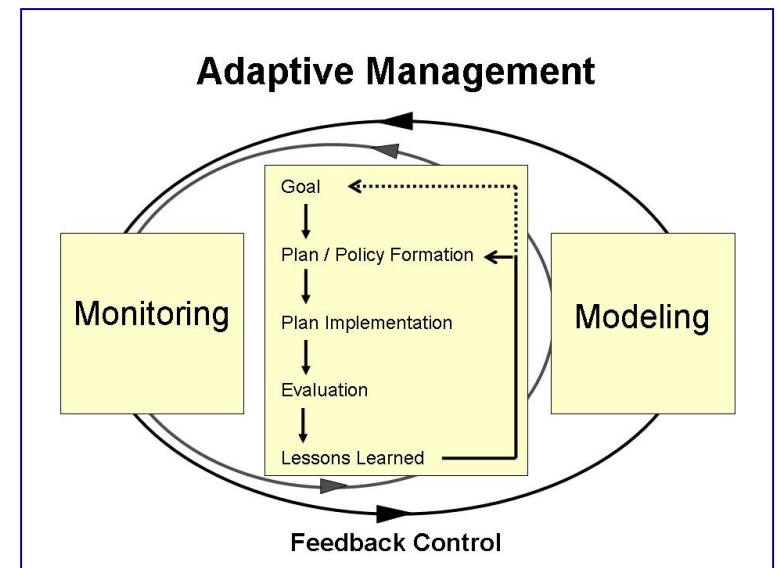
- **At present**, the global warming is affecting:
 - **Positively**, increase in growth and survival of Hokkaido chum salmon in the Okhotsk Sea since the 1990s
 - **Positively**, increase in carrying capacity in the Bering Sea since the late 1990s
- **In the Future**, the global warming will **negatively** affect:
 - Decrease in their carrying capacity for reducing distribution area in the North Pacific Ocean
 - Strong density-dependent effect will occur
 - Hokkaido chum salmon population will lose migration route to the Okhotsk Sea by 2050 and will be crushed by 2100



Sustainability of Pacific salmon and aquatic ecosystem

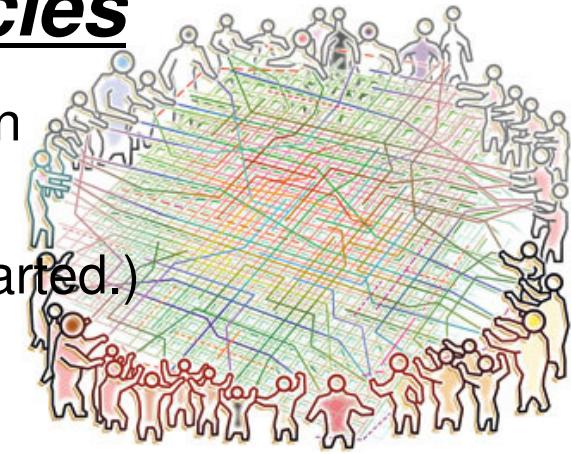
1. **How** to protect Pacific salmon and aquatic ecosystem under increase in human impacts (e.g., global warming, fisheries, hatcheries, river construction, urbanization)
 2. **Monitoring** the structure and function in the aquatic ecosystem and the dynamics of Pacific salmon
 - Spatial and temporal changes: Carrying capacity, Food web & trophic level
 - Climatic-oceanic conditions: Global warning, Regime shift
 - Biological interaction: Wild vs Hatchery, Density-dependent effect, Invasive alien species
 - Human impacts: Change in aquatic ecosystem, Urbanization, Fisheries
 3. **Adaptive management** and **Precautionary principle** for Pacific salmon in aquatic ecosystem
 - Adaptive learning
 - Feedback control
 - Monitoring
 - Modeling

The diagram illustrates the Adaptive Management cycle. It features three main components: Monitoring, Modeling, and a central vertical flow of processes. The central flow starts with 'Goal' at the top, followed by 'Plan / Policy Formation', 'Plan Implementation', 'Evaluation', and finally 'Lessons Learned' at the bottom. A curved arrow at the top connects 'Lessons Learned' back to 'Goal'. To the left of this central flow is a box labeled 'Monitoring'. To the right is a box labeled 'Modeling'. Bidirectional arrows connect 'Monitoring' to the central flow and 'Modeling' to the central flow, indicating their integration into the adaptive process.



Brief History of Fisheries Management, Regulations and Policies

- ✓ 2K years ago: Blue-fin tuna fisheries in the Sicilian was drawn on the Fresco Wall Painting. (Fisheries already started.)
- ✓ Roman period : Blue-fin tuna was commanded a high price.
- ✓ The Colonial Period: Marine liberum (Hugo Grotius 1609)
→ “*Fish are bona vacantia*”
- ✓ Law of the Sea Convention in Geneva (1958): Territory was 12 sea miles
- ✓ Garrett Hardin (1968): The Tragedy of the Commons
→ “*First come will lead over-fishing*”
- ✓ UNCLOS (1982): Exclusive Economic Zone (EEZ)
- ✓ Earth Summit (UNCED) 1992: Precautionary principle
- ✓ FAO (1995): Code of Conduct for Responsible Fisheries



**“Overfishing” has long been the cause
of fisheries decline!!**



Fisheries management calls for:

✓ Global governance ---

Eco-label



Fish Traceability

Food mileage

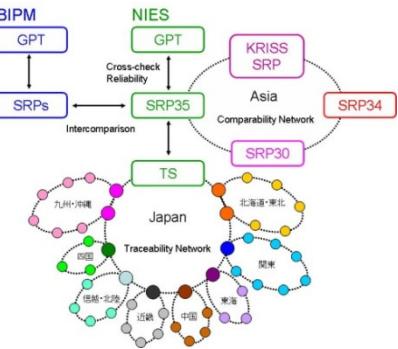


✓ Risk Management ---

Precautionary principle &
Adaptive management

✓ Sustainability based on the ecosystem
approach ---

Marine protected area, ABC, etc.



Food mileage of salmon

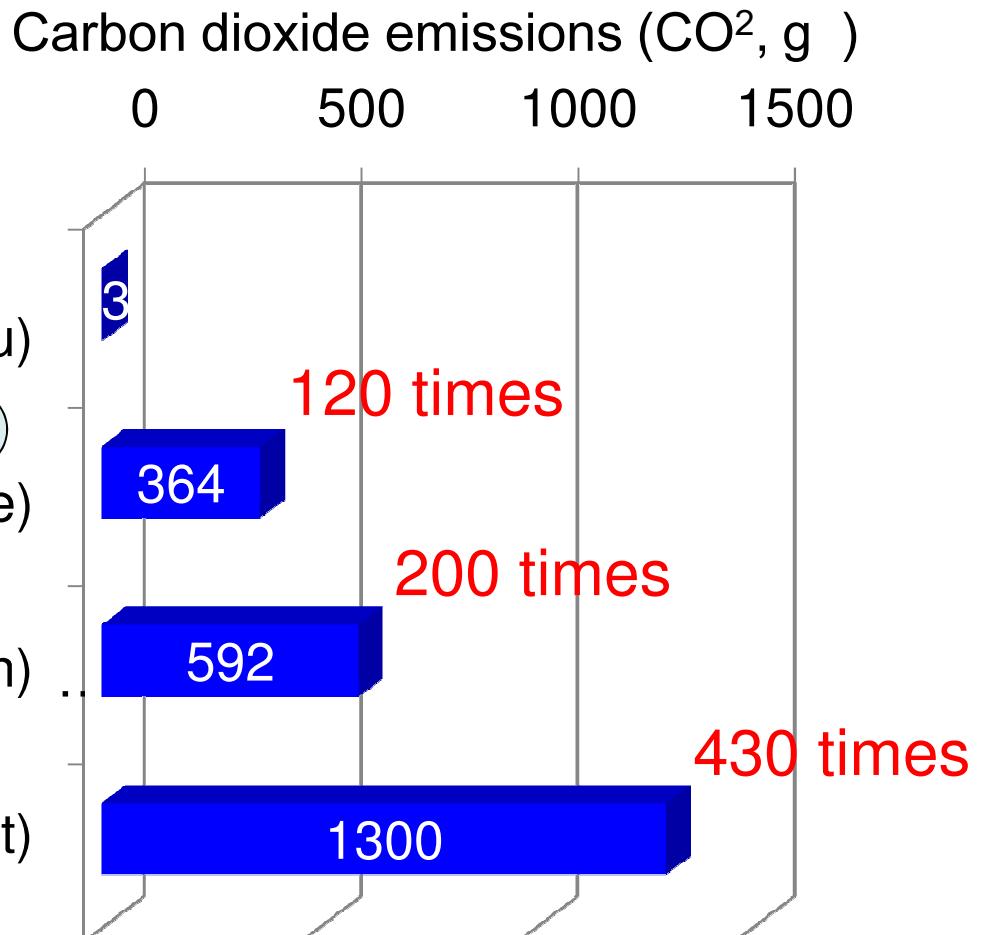
A piece of salmon (50g) in Sapporo



Chum salmon (Shibetsu)



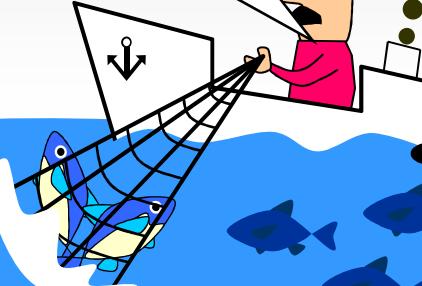
The “local production
for local consumption”
is a most important
issue for the prevention
of global warming



Traditional Fisheries Science

For only Fisheries

大漁だ！



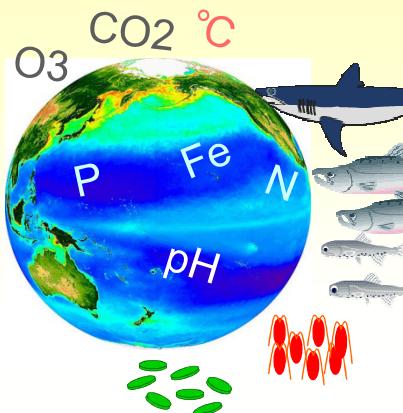
- Change in Marine Ecosystem
“Fishing down marine food webs” (Pauly et al. 2003)
- Sea Food Gourmet → Tuna Laundering / Overfishing
- “Tragedy of Commons”
First come → Overfishing
- Ecosystem Crash & Food Pollution
Vanishing Mangrove forest ecosystem, Cutoff food chain, Food security
- Food Import
→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

Paradigm Shift

New Ecological Fisheries Science

For Marine Ecosystem & Human Seafood

おさかなは
残すところないな



- 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)



Sustainability on seafood security and ocean ecosystem conservation

■ Will we be able to use the ocean organisms as seafood in the future?

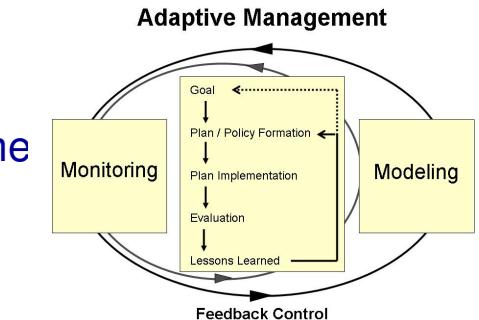
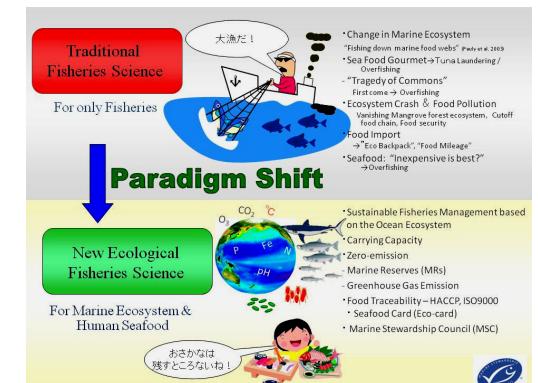
- Carrying capacity in the marine ecosystem → 吾唯足知 “More than enough is too much”
- Fisheries Industry : Economic efficiency → Ecosystem Approach

■ 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
 - Dietary education 食育
 - e.g. “local production for local consumption” 地産地消

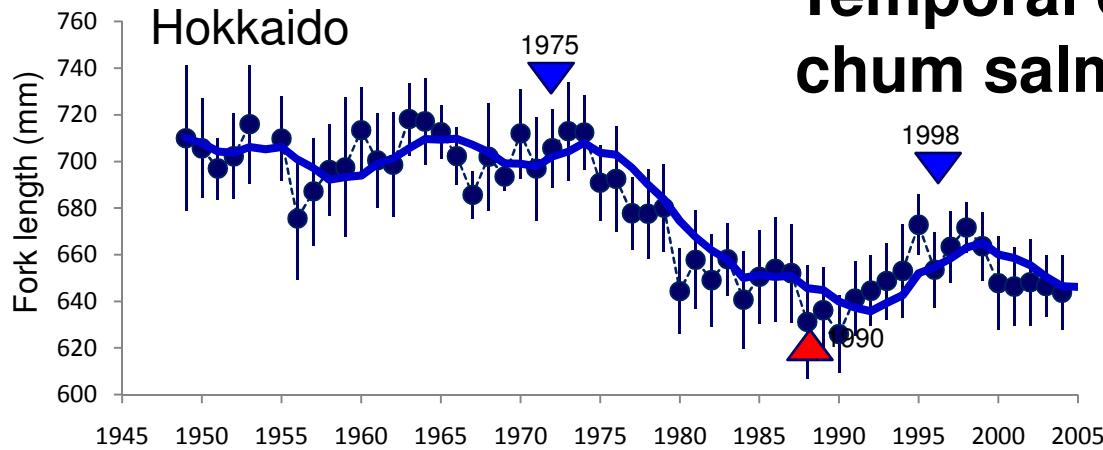
■ How do we establish the sustainable fisheries and aquaculture management based on the ecosystem approach?

- 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



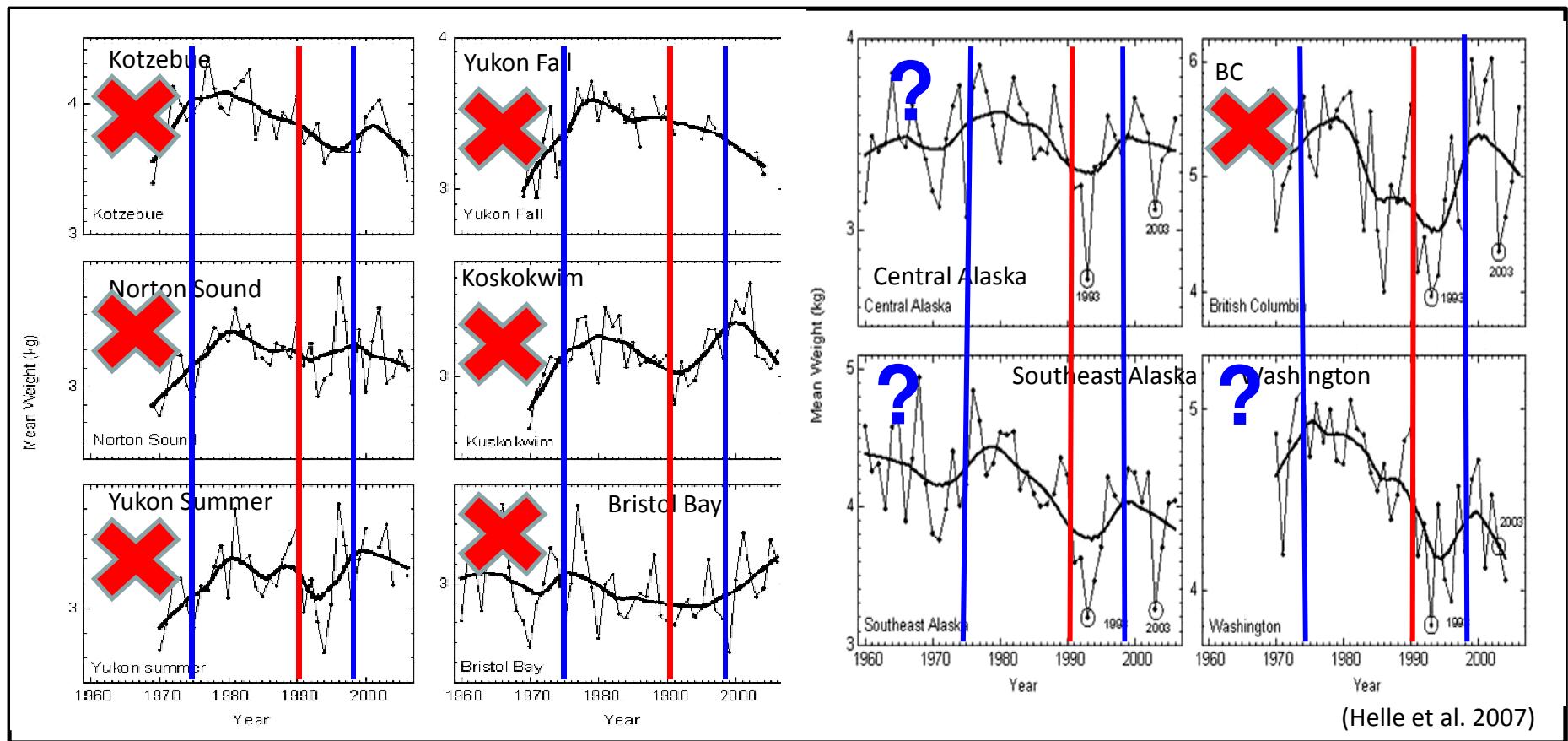
Database

Index	Definition	Period	Season	Data source
Climate indices and ocean environment variables				
SAT	Global anomalies of Surface Air Temperature	1940-2005	Annual	NOAA Satellite and Information Service, http://www.ncdc.noaa.gov/oa/climate/research/anomalies/index.php#means
PDO	Pacific Decadal Oscillation	1940-2005	Annual	Mantua et al. 1997 (http://jisao.washington.edu/pdo/)
ALPI	Aleutian Low Pressure Index	1940-2005	Annual	Beamish et al. 1997, http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_idx_alpi.htm
SI	Siberian high	1948-2005	Winter (December to March)	Gong et al. 2001; Wu and Wang 2002, http://www.beringclimate.noaa.gov/data/BCresult.php
OH	Okhotsk High	1948-2005	Annual	Ogi et al. 2004 (NCEP/NCAR Re-analysis dataset, http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl
AO	Arctic Oscillation	1950-2005	Annual	Thompson and Wallace 1998, http://www.cpc.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml
ICE	sea ICE cover rate (Okhotsk Sea)	1957-2004	Annual	Kaeriyama et al. 2007 (National Snow and Ice Data Center)
SST_o	Sea Surface Temperature (Okhotsk Sea)	1948-2005	Summer and fall (June to October)	NCEP/NCAR Re-analysis dataset, http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl
Biological characteristics				
SR	Survival Rate of Hokkaido chum salmon	1963-2005	Annual	Updated & modified from Kaeriyama et al. 2007
PS	Population Size of Hokkaido chum salmon	1943-2005	Annual	Updated & modified from Kaeriyama et al. 2007

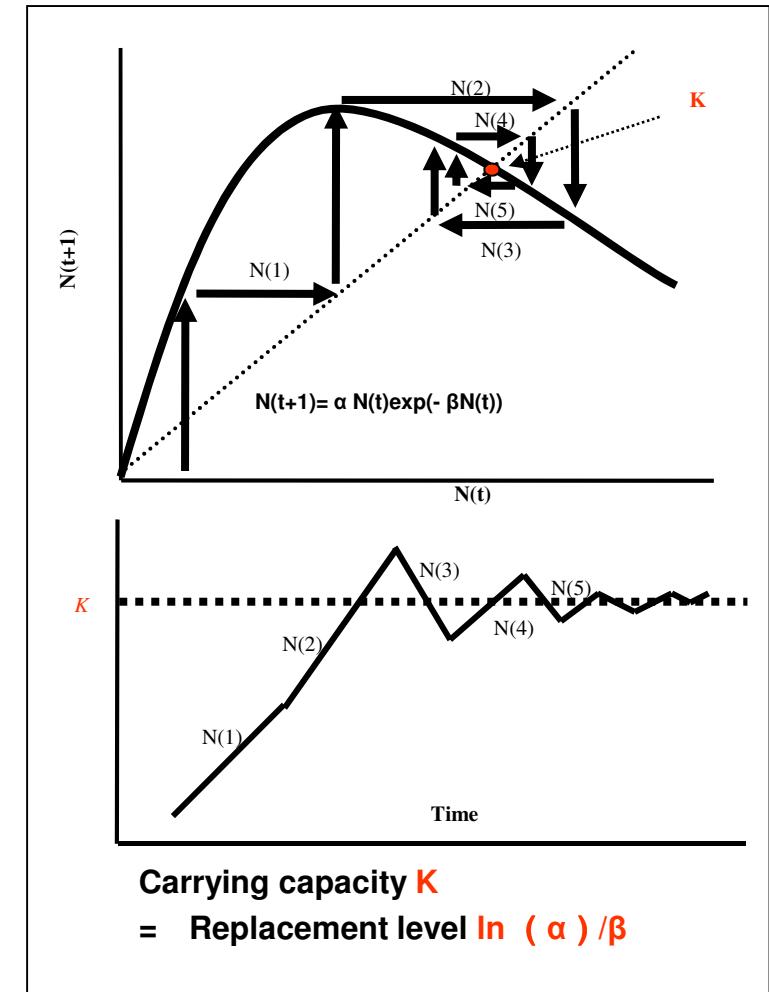
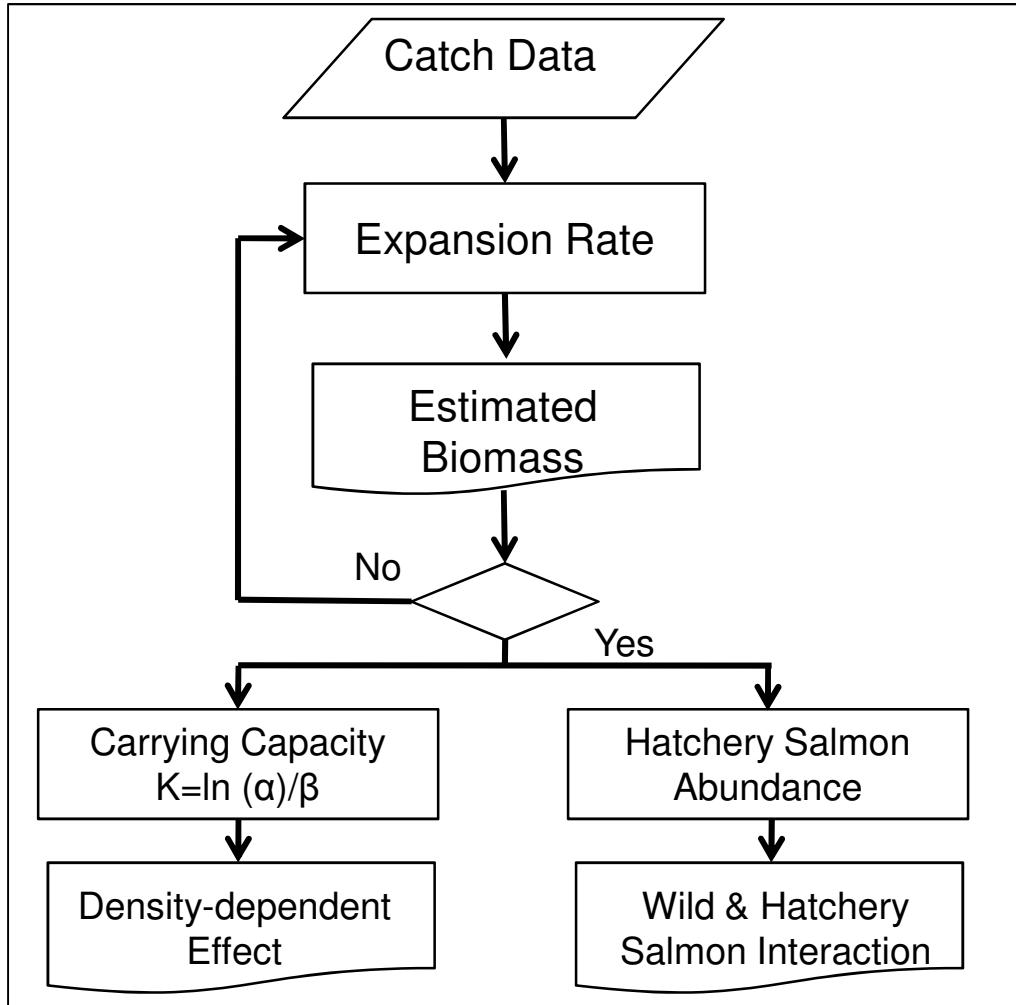


Temporal change in body size of chum salmon in the North Pacific

	Pattern	Period
O	Yes	Yes
?	Yes	No
X	No	No



Main Database, Flowchart, and Carrying Capacity



Catch & Hatchery Data

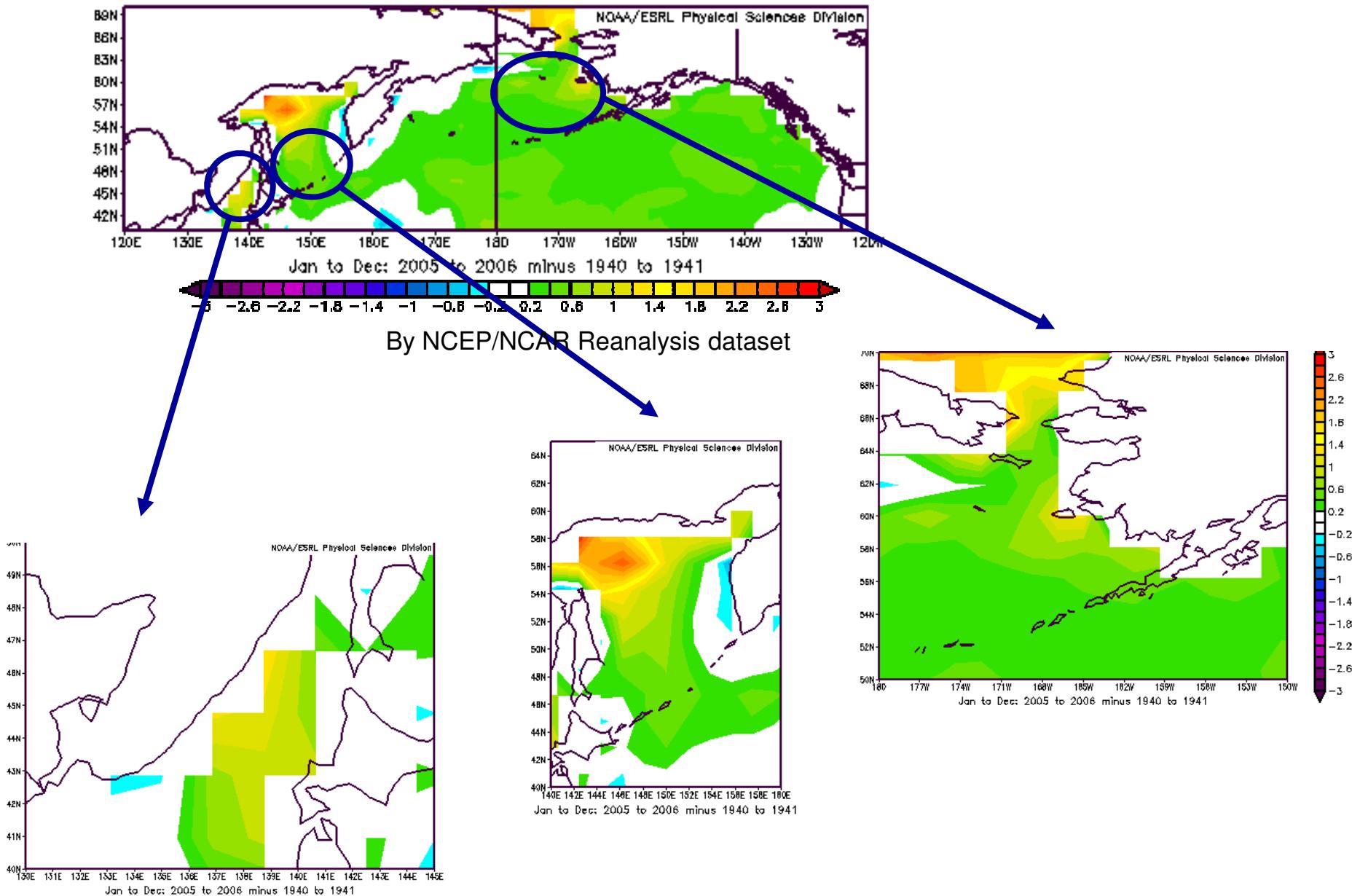
FAO (1950-1996), NPAFC (1993-2006), INPFC (1979), Fredin (1980)
 Kaeriyama & Edpalina (2004), White (2008), Eggers (2004)
www.cf.adfg.state.ak.us, <http://salmon.fra.affrc.go.jp>

Time span: t (bi-decadal cycle span)

Pink salmon: 10 generations by odd and even year classes

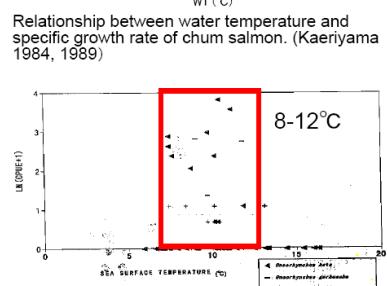
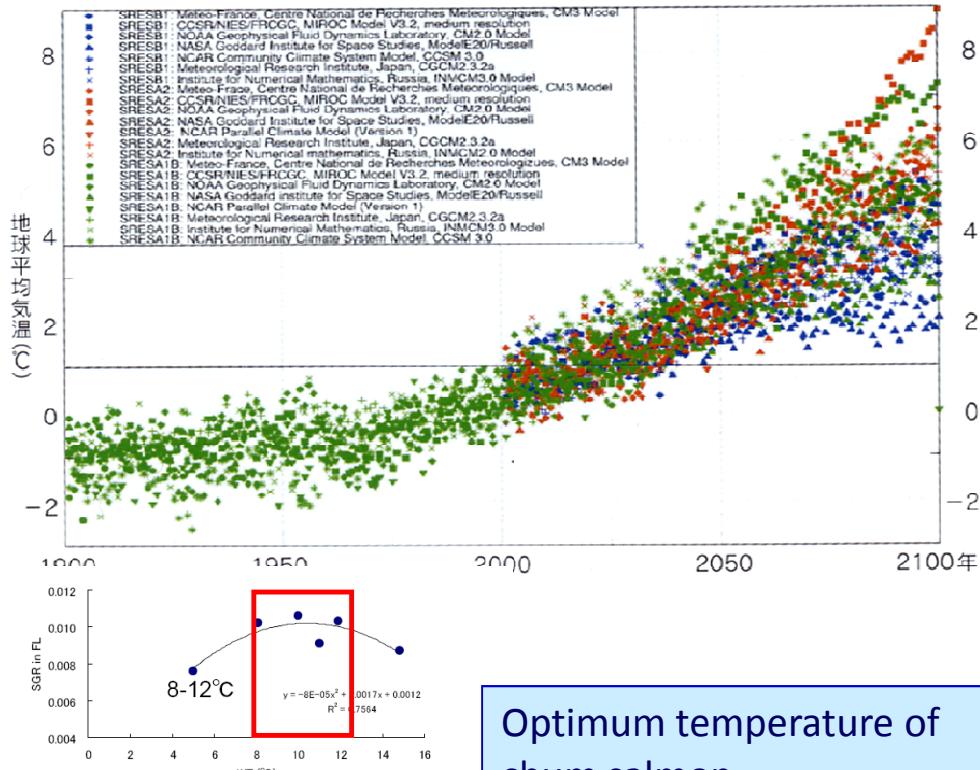
Chum & Sockeye salmon: 20 brood years

Difference in average SST between 1940-1941 and 2005-2006 in the North Pacific



Prediction about the Global Warming Effect on Chum Salmon in the North Pacific Ocean based on the SRES-A1B scenario

SRES-A1B scenario : 4 ~ 7°C



Optimum temperature of chum salmon

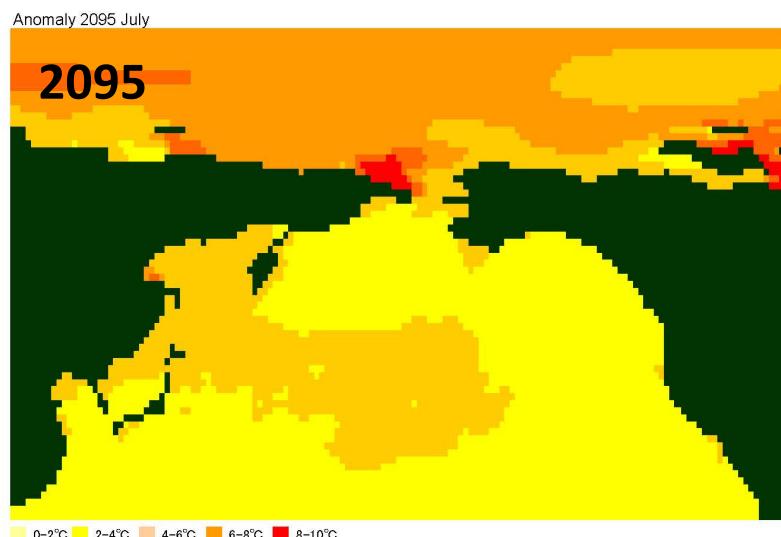
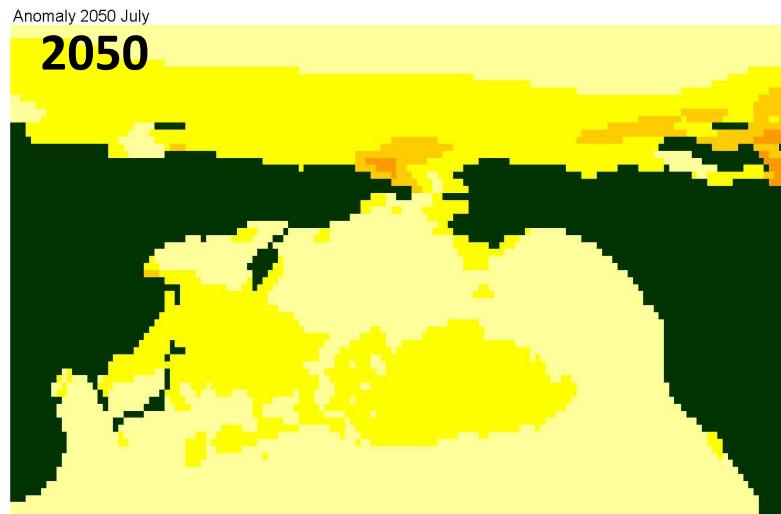
Feeding migration period :

8-12°C

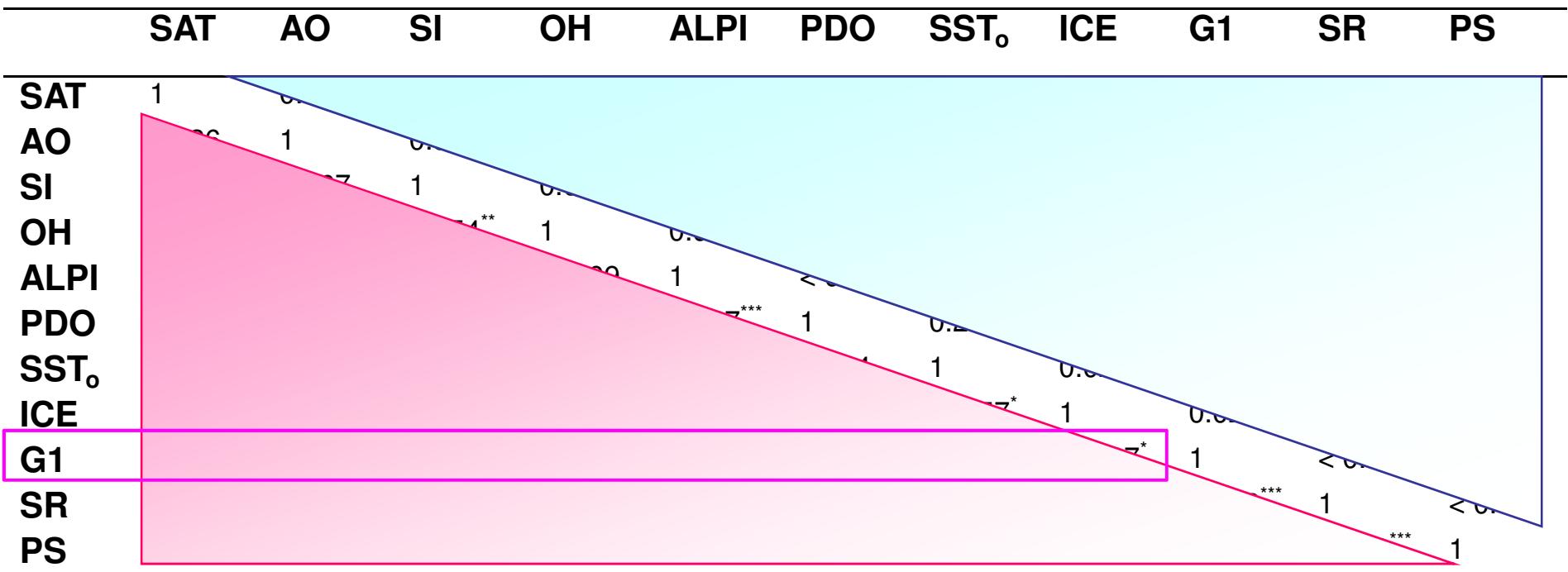
Wintering period :

4-6°C

SST Anomaly in July



Correlation matrix among climate/oceanic indices and variables, growth at age-1, survival rate, and population size of chum salmon



Climate indices

SAT: global Surface Air Temperature
 ALPI: Aleutian Low Pressure Index
 PDO: Pacific Decadal Oscillation
 AO: Arctic Oscillation
 SI: Siberian high
 OH: Okhotsk High

Environmental variables

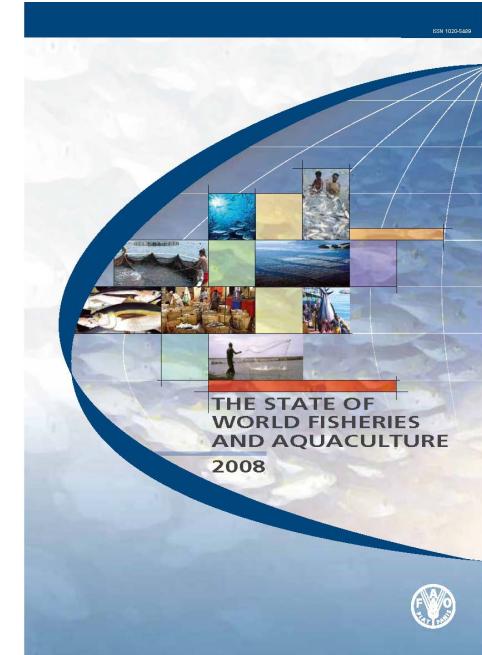
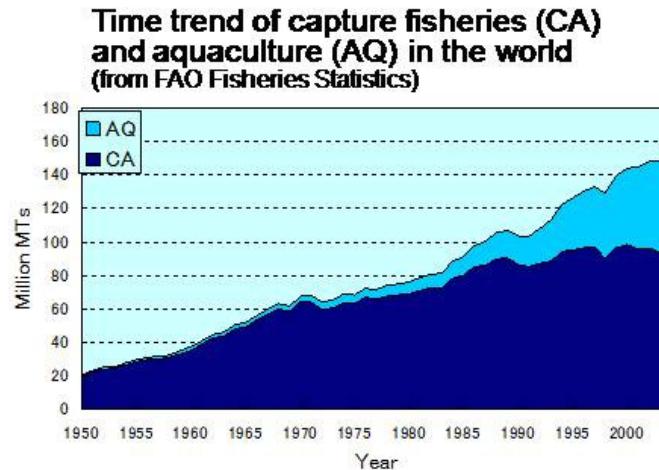
ICE: extent of ICE cover area
 SST_o: summer and fall SST in the Okhotsk Sea

Biological characteristics

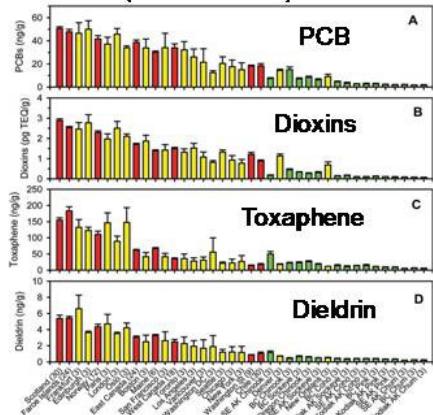
G1: Growth at age-1
 SR: Survival Rate
 PS: Population Size

Recent situation of seafood and fisheries in the world

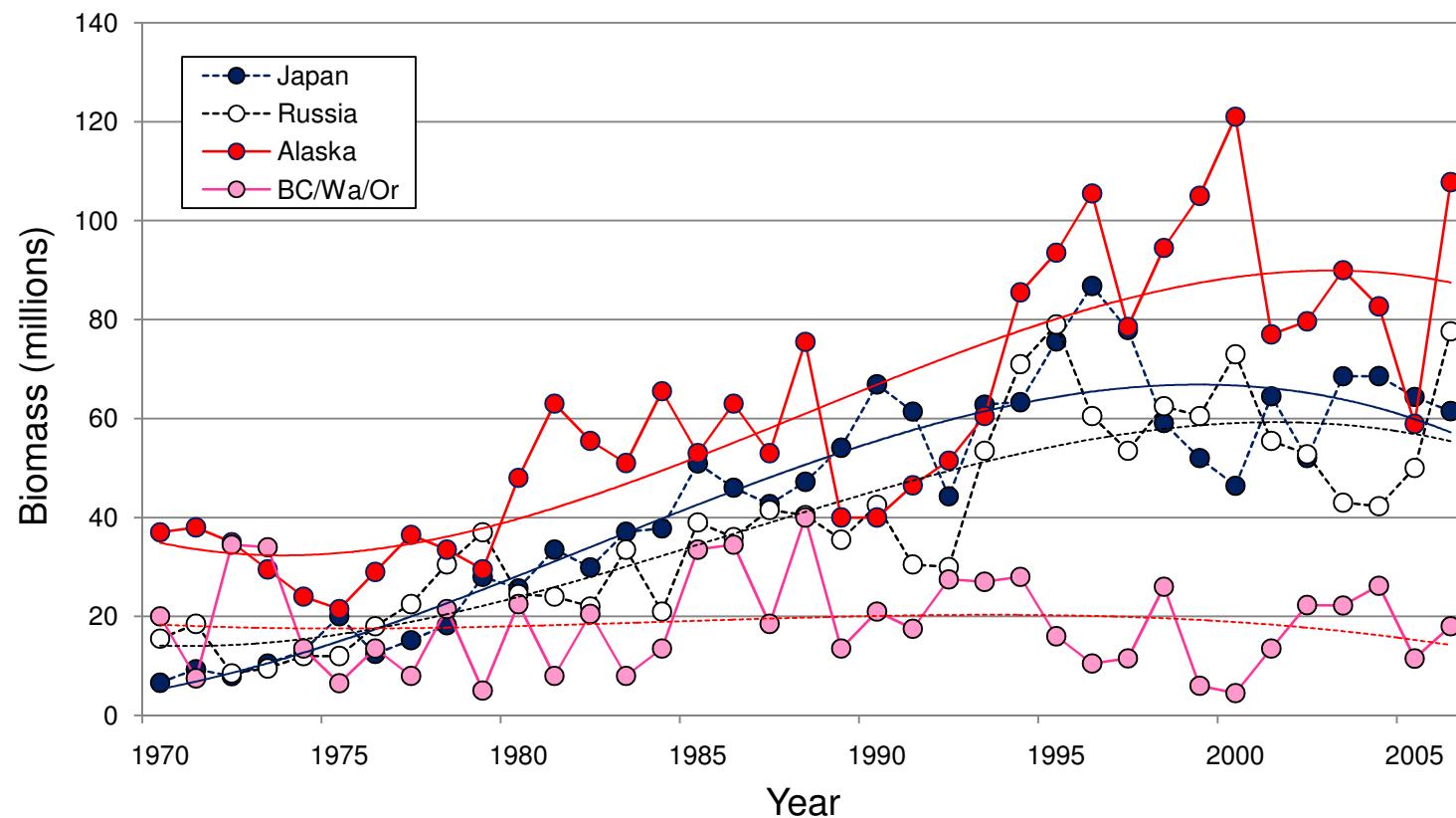
- More than **2.9 billion people** are provided by seafood in the world. Capture fishes and aquaculture supplied the world with about **110 million tons** of food fish in 2006. Of this total, aquaculture accounted for **47 percent**. Share of fish proteins in total world animal protein supplies is about **15-16 percent**.
- Although production of aquacultures are increasing in the world, many aquacultures cause destruction of aquatic ecosystems, marine pollution, and threats to marine food security.



Food security of farmed Atlantic salmon (Hites et al. 2004)

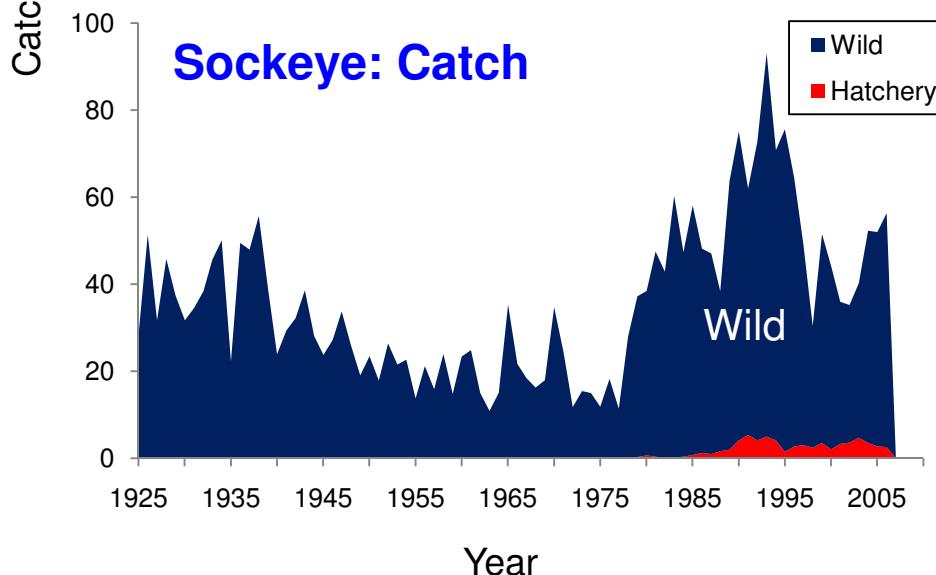
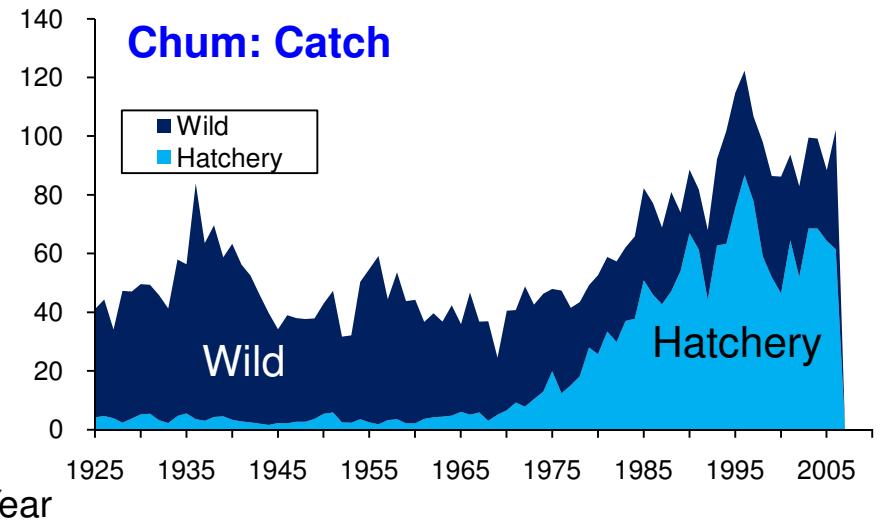
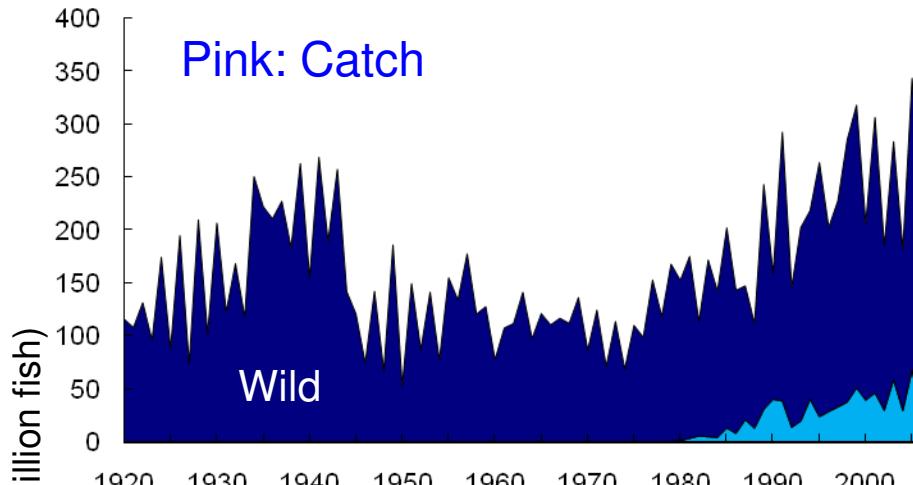


Annual change in biomass of chum salmon by meta-population since the 1970s



Alaska: Increase
Russia & Japan: Stable
BC/Wa/Or: Decrease

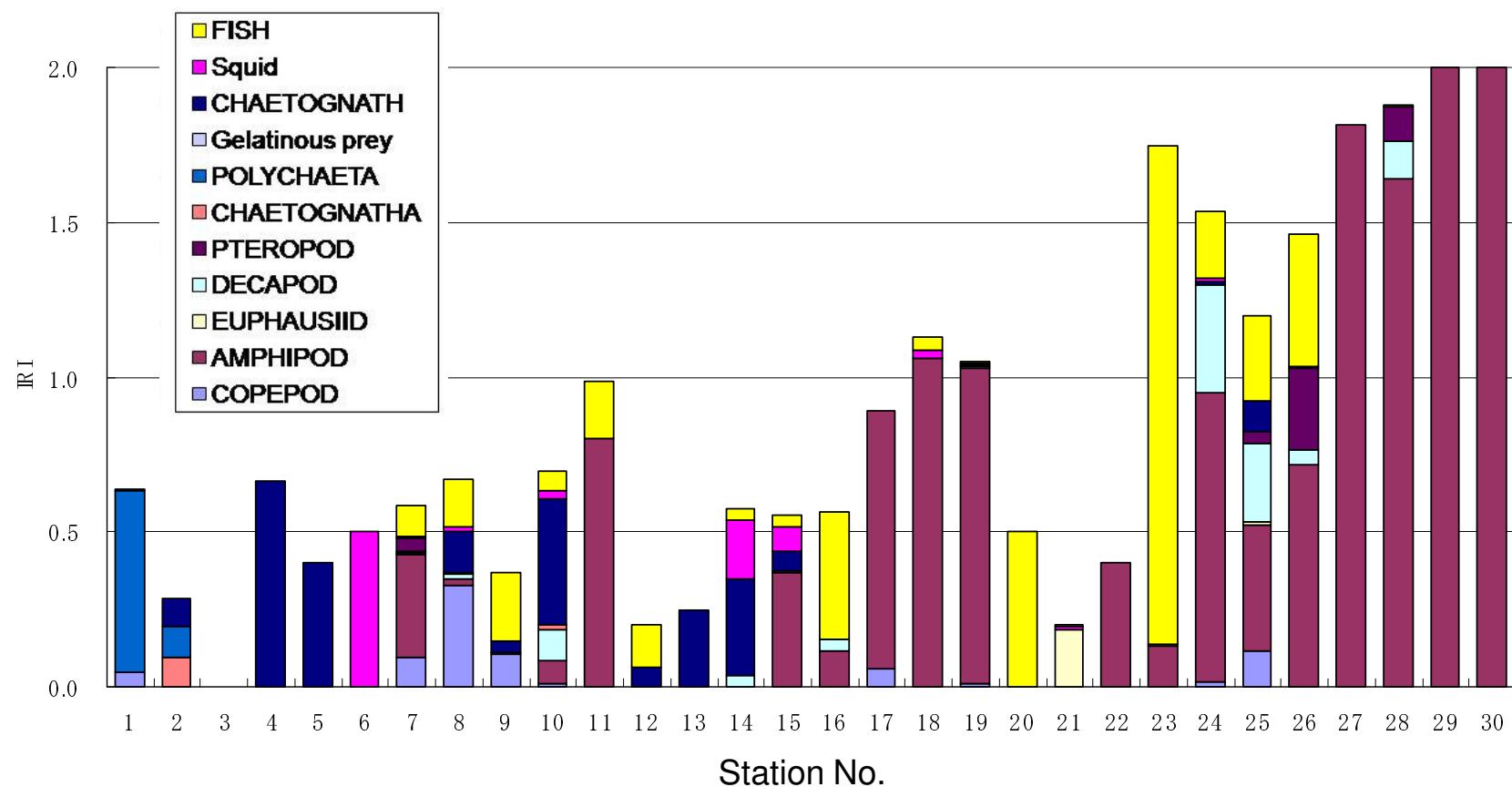
Annual changes in catch of wild/hatchery salmon



Hatchery salmon

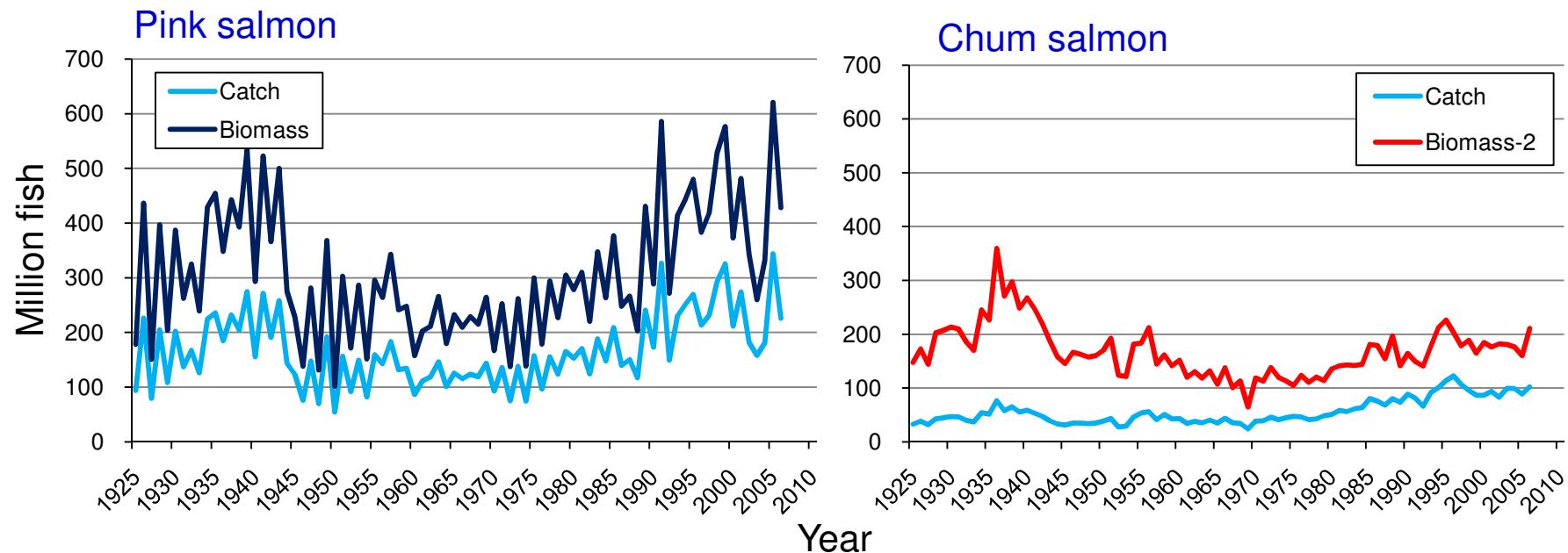
Pink	<20%
Chum	>80%
Sockeye	<15%

Stomach contents (IRI) of chum salmon collected in the Bering Sea in the summer 2009



Expansion of Terminal Run to Total Biomass

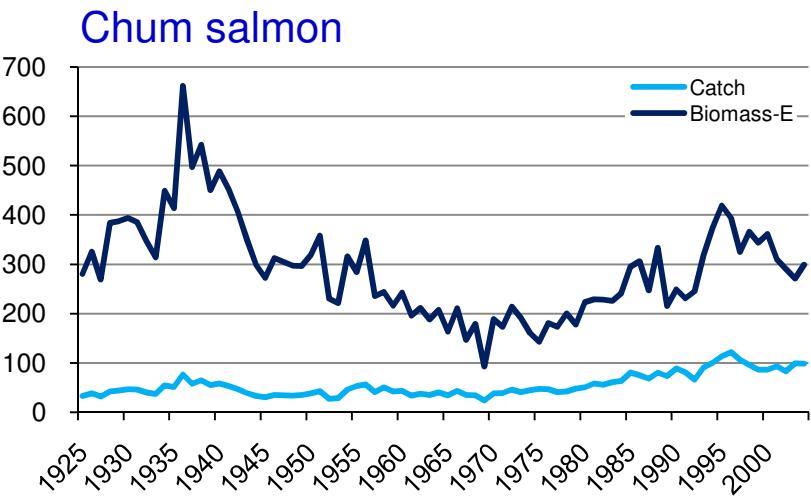
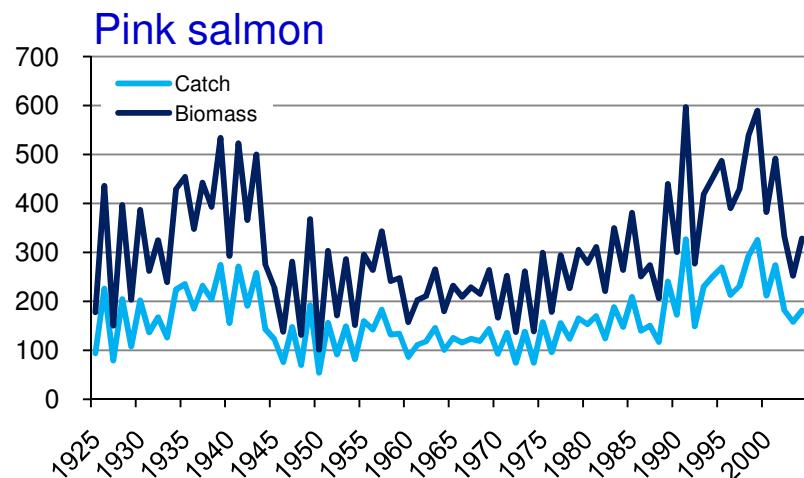
(Eggers, unpublished; White 2007)



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%	22%
Russian: Coastal	50%	30%	20%
Western Alaska	None	30%	20%
Central Alaska	62%	30%	20%
PWS Hatchery	White (2007)	None	None
Southeast Alaska	55%	40%	20%
Southeast Alaska Hatchery	White (2007)	None	White (2007)
B.C./Washington/Oregon	55%	40%	20%

Method of Expansion of Terminal Run to Total Biomass

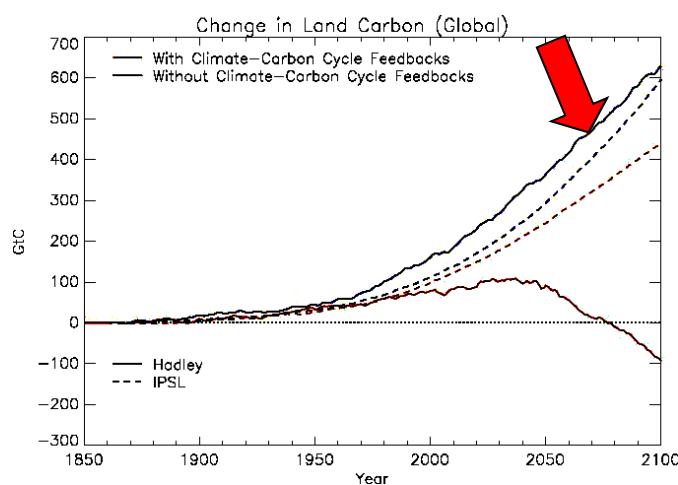
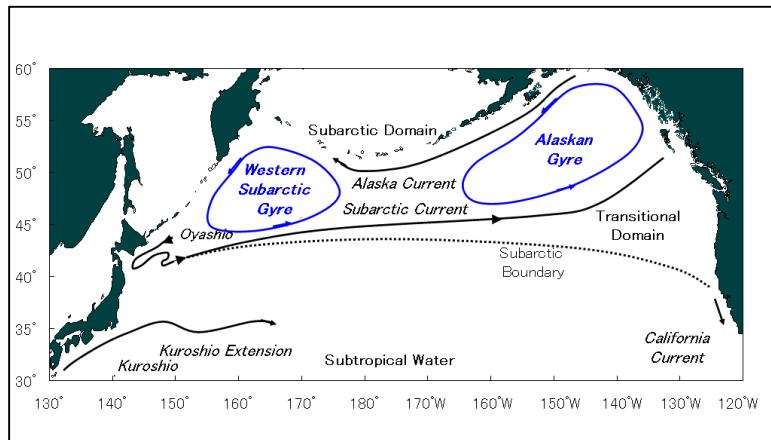
(Eggers, unpublished; White 2007)



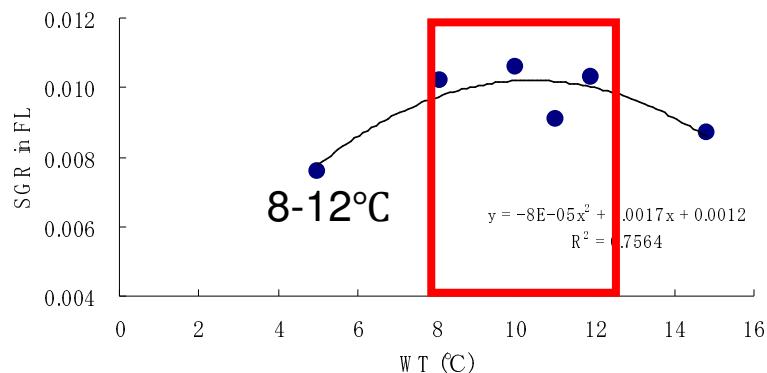
Biomass: Chum>Pink?

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%

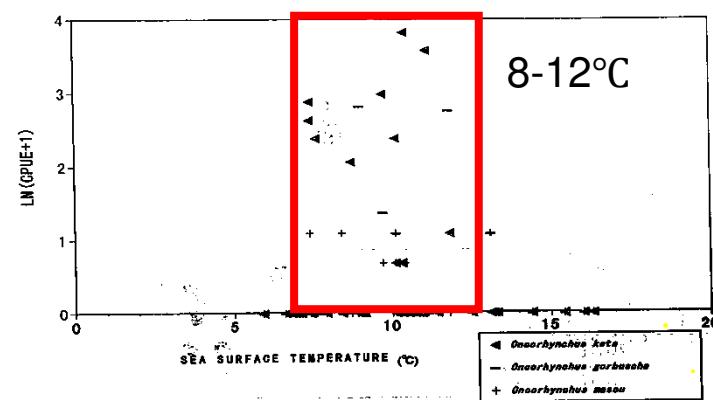
Prediction on the Global Warming effect on chum salmon in the North Pacific Ocean based on the SRES-A1B scenario



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

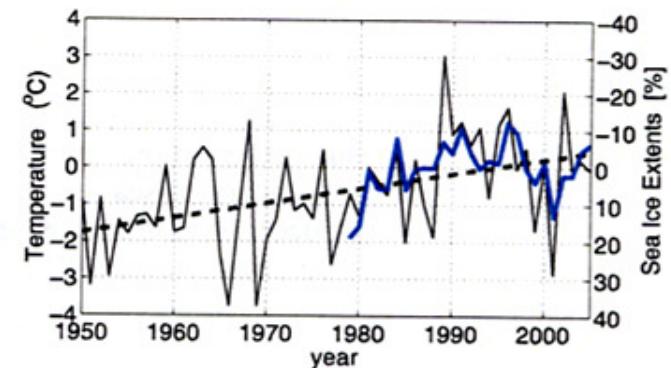
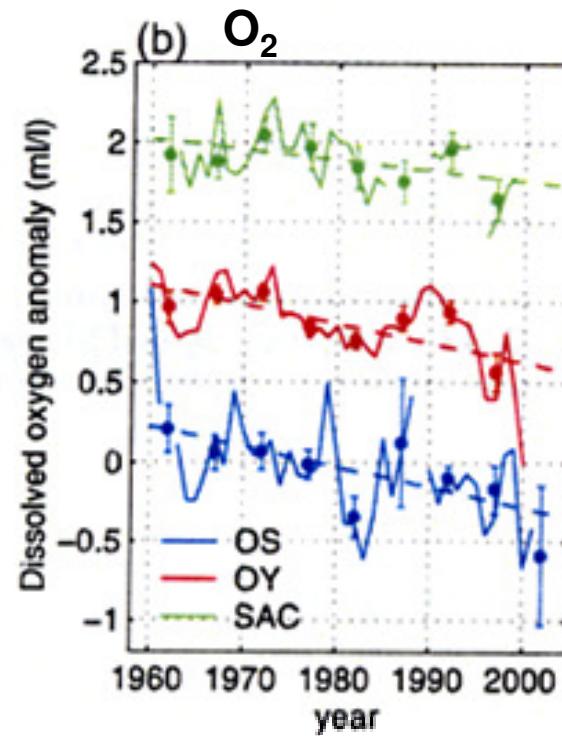
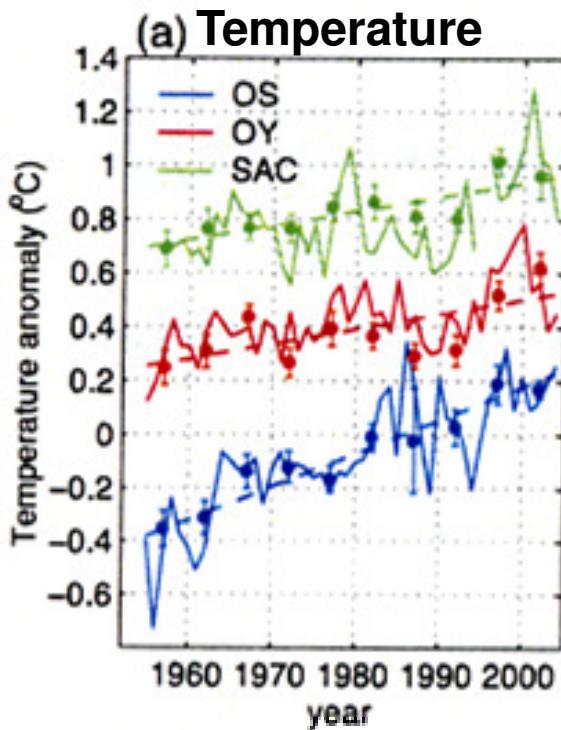


Relationship between water temperature and specific growth rate of chum salmon. (Kaeriyama 1984, 1989)



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

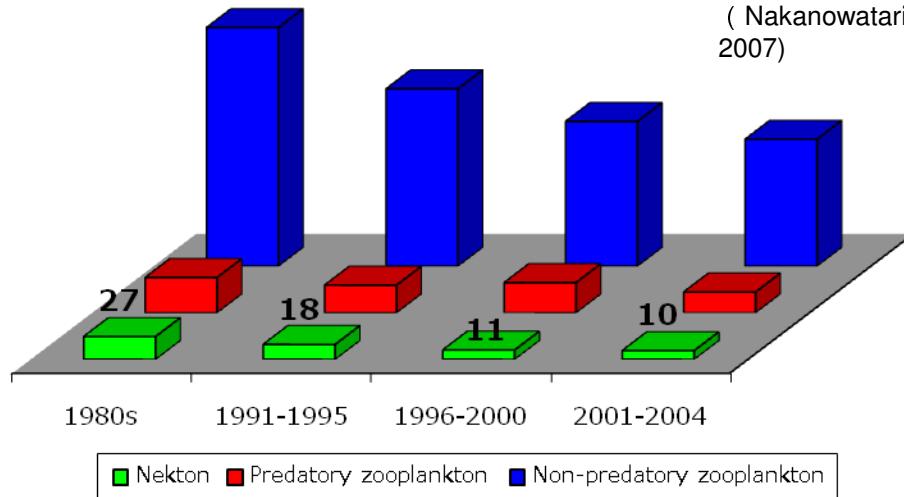
Optimal temperature for chum salmon
Growth and feeding migration period: 8-12°C



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

Time series of potential temperature (a) and dissolved oxygen (b) at $27.0 \sigma_0$ in the Okhotsk Sea (OS), Oyashio (OY), and SAC region (SAC).

(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 & Impacts on material cycle

Growth of chum salmon



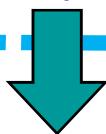
SST

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.

Traditional Fisheries Science

For only Fisheries

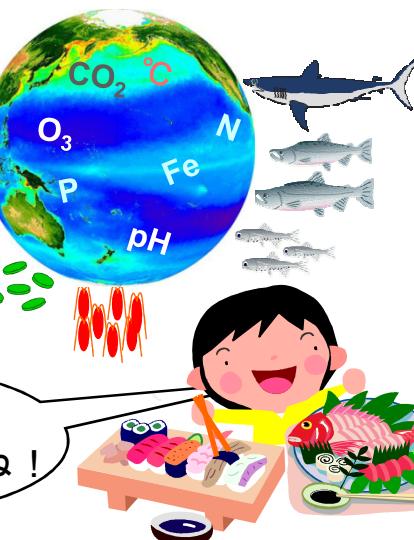


Paradigm Shift

New Ecological Fisheries Science

For Marine Ecosystem & Human Food

おさかなは
残すところないね！

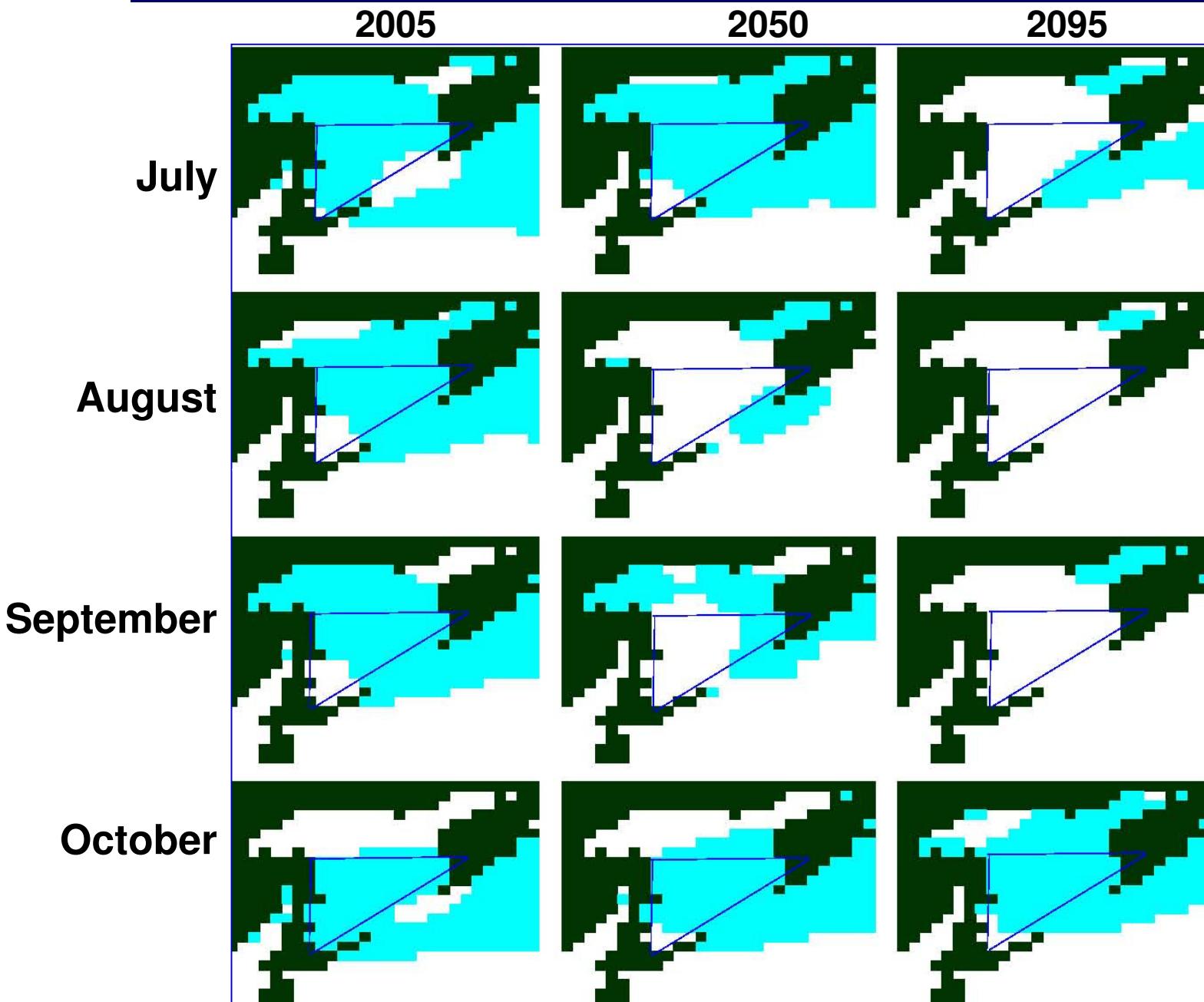


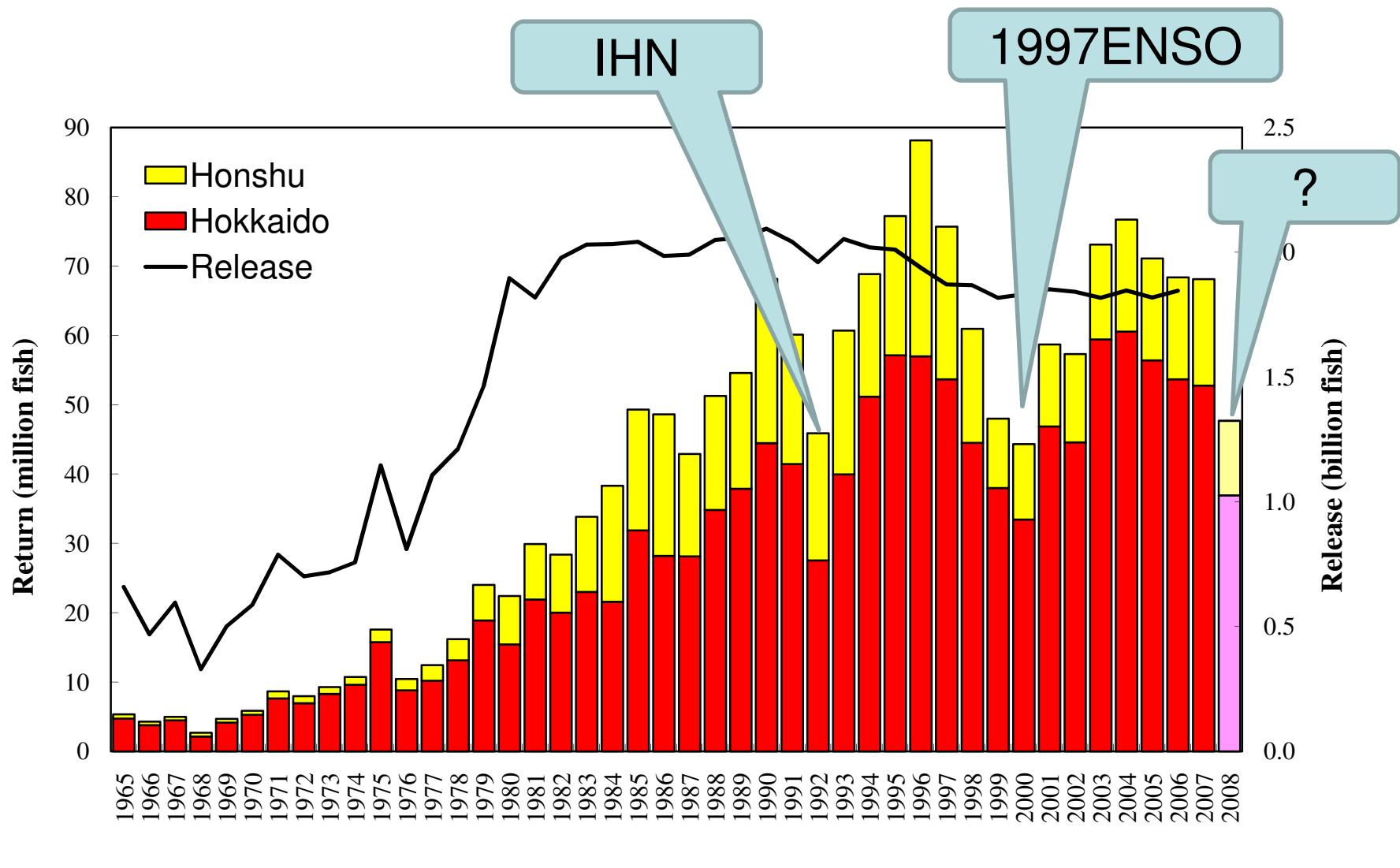
- Change in Marine Ecosystem**
“Fishing down marine food webs” (Pauly et al. 2003)
- Sea Food Gourmet → Tuna Laundering / Overfishing**
- “Tragedy of Commons”**
First come → Overfishing
- Ecosystem Crash & Food Pollution**
Vanishing Mangrove forest ecosystem, Cutoff food chain, Food security
- Food Import**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

- 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**

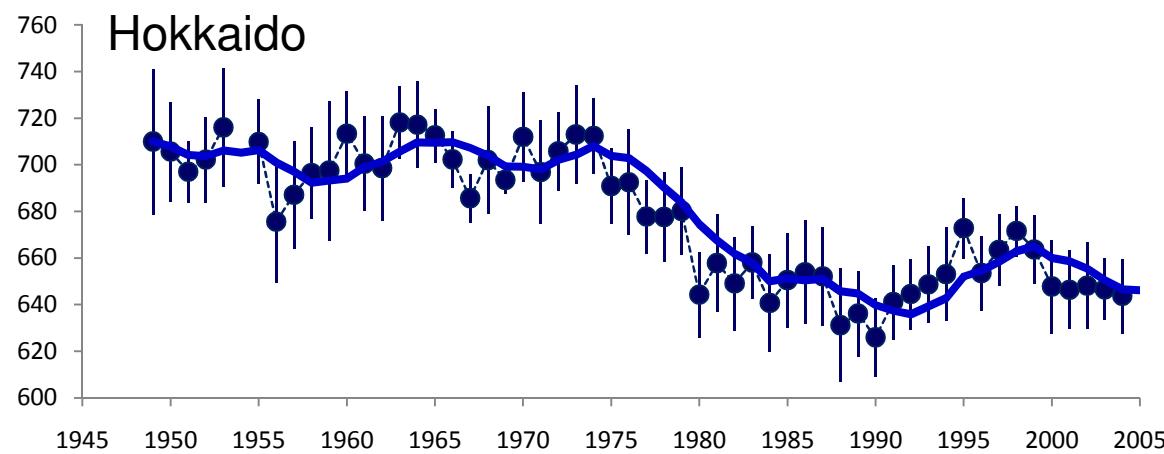
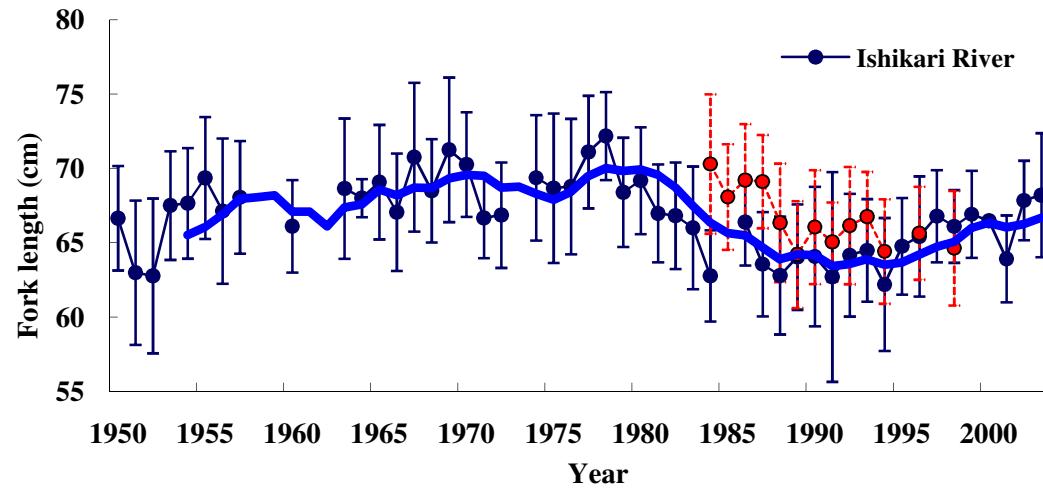


Hokkaido chum salmon in the Okhotsk Sea

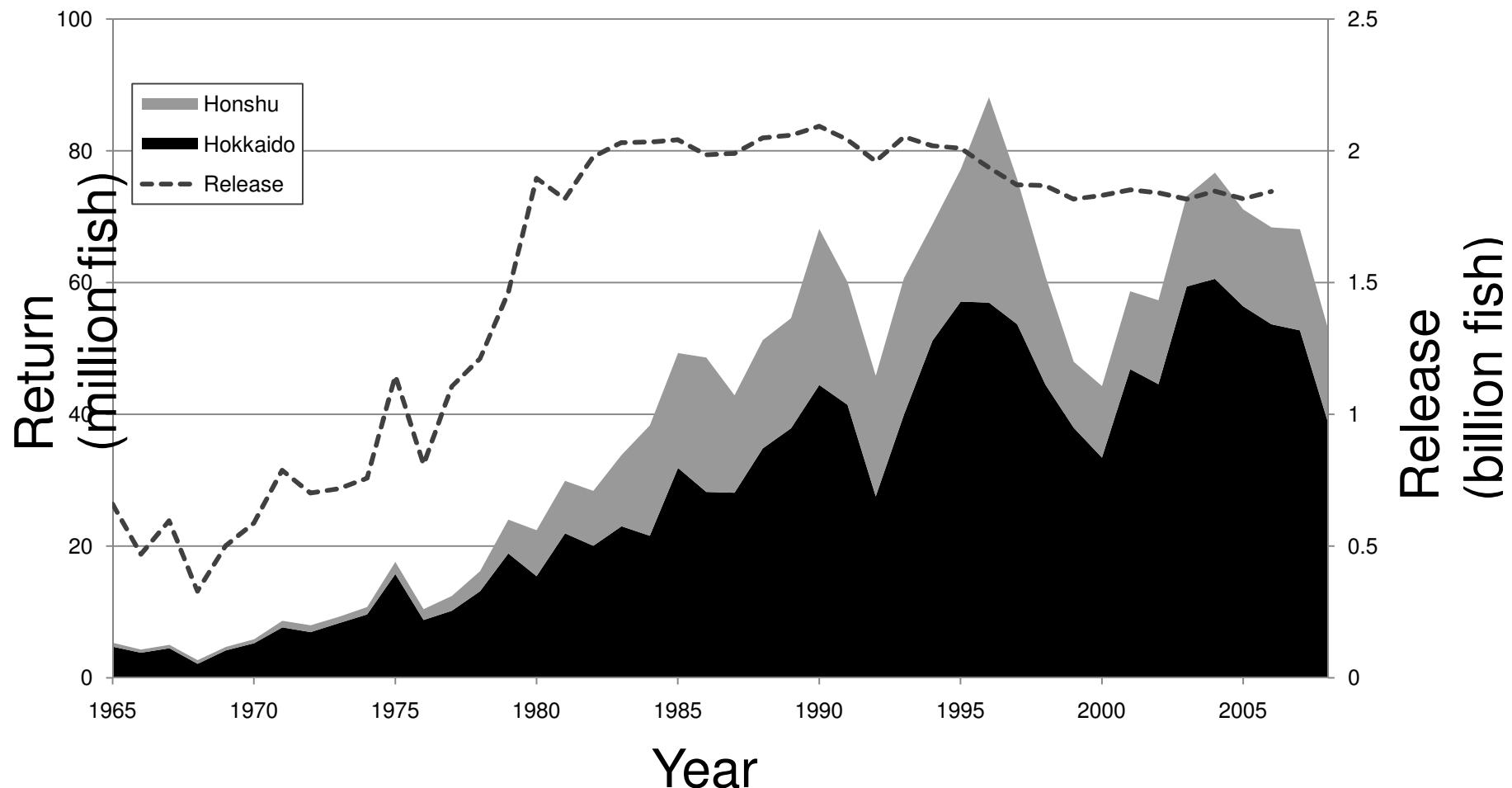




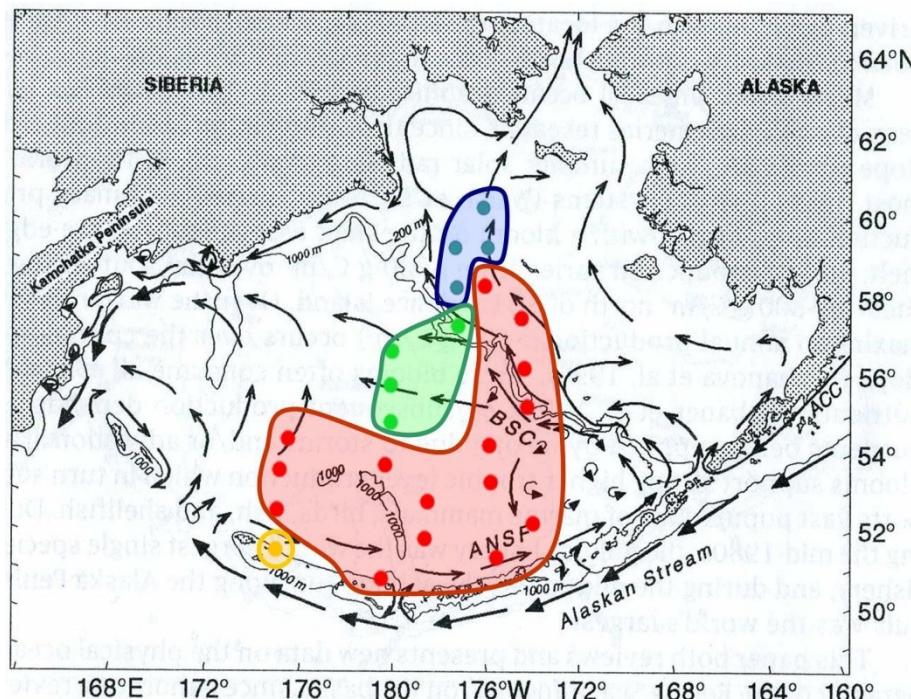
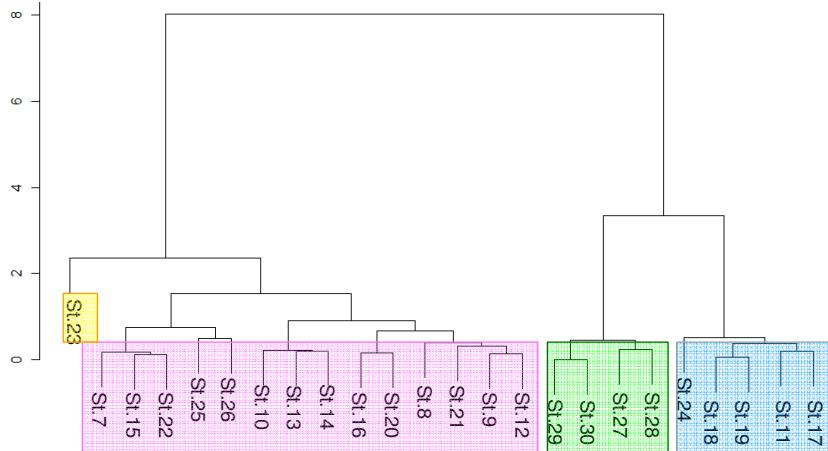
Annual change in return of chum salmon in Japan



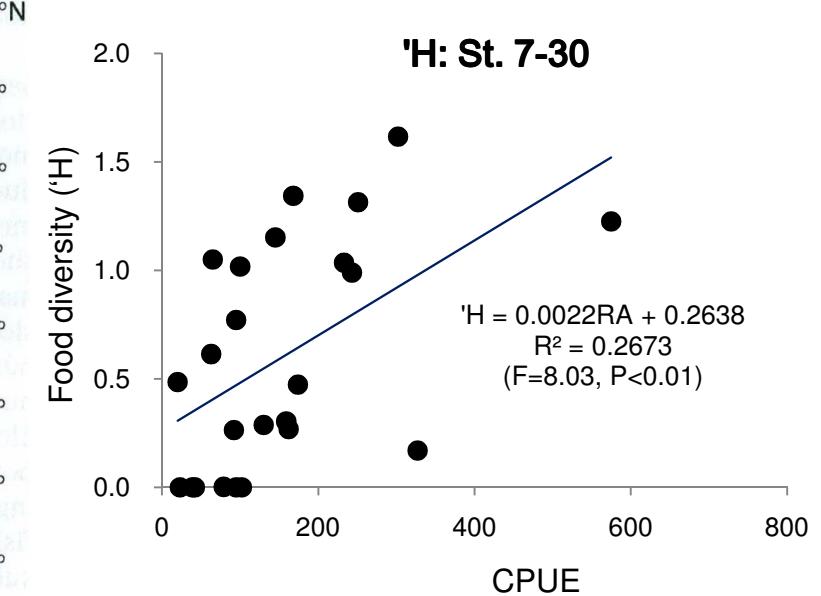
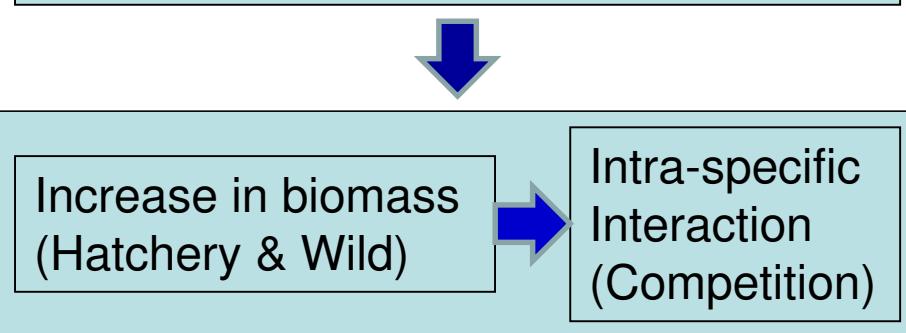
Annual change in return of chum salmon in Japan



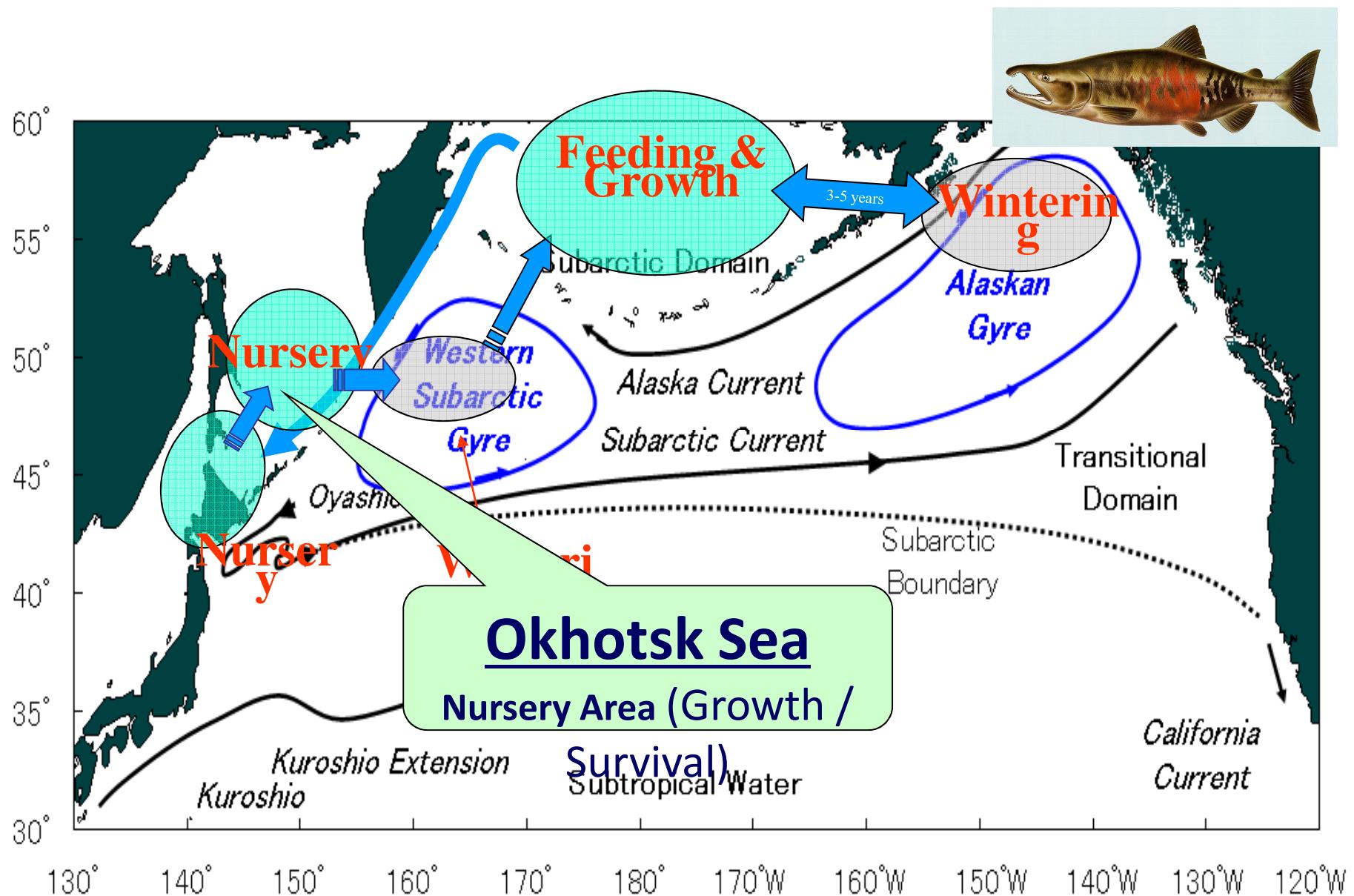
Feeding habit of chum salmon in the Bering Sea in 2009

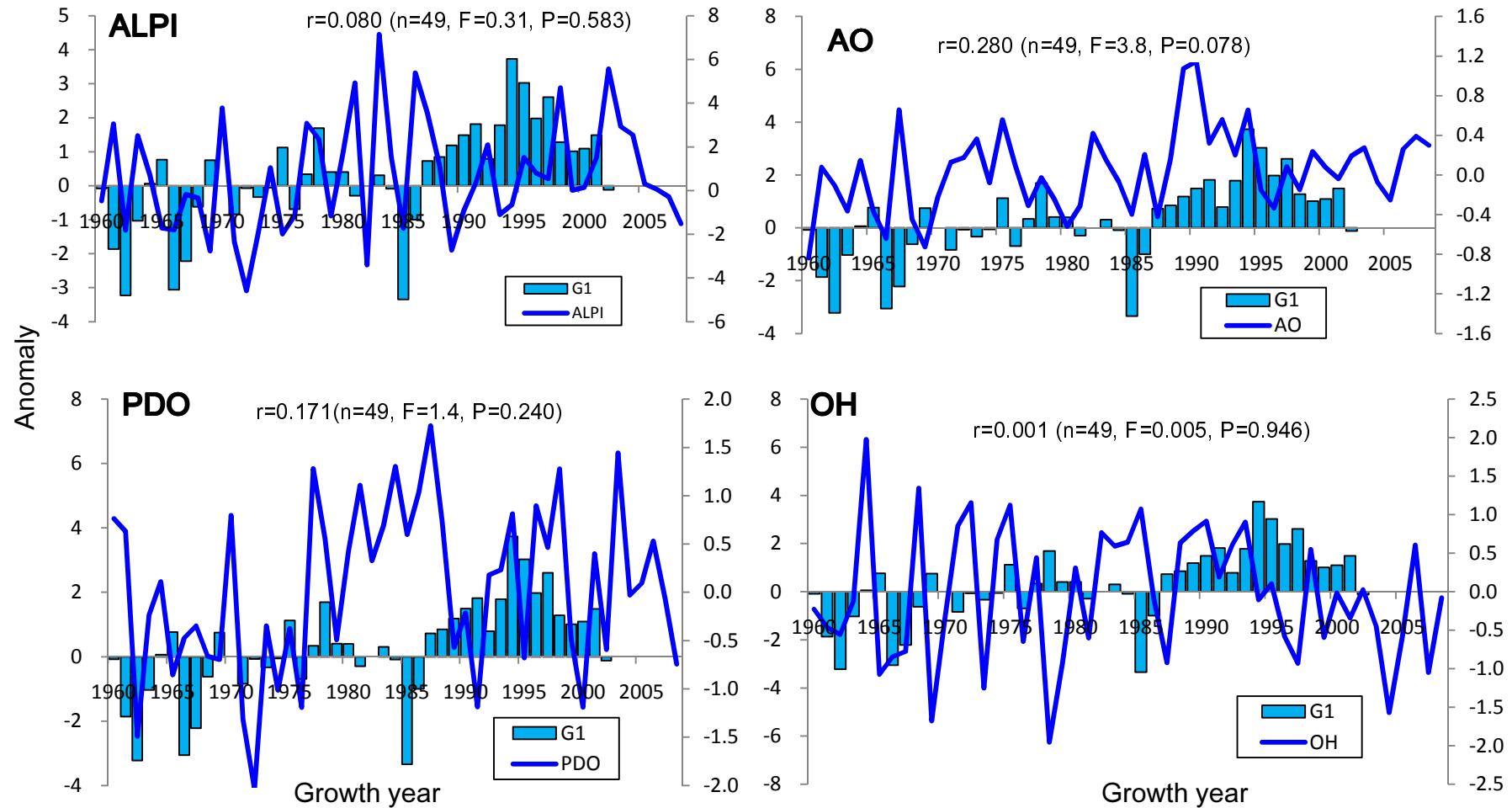


● Plasticity
● Density-dependent

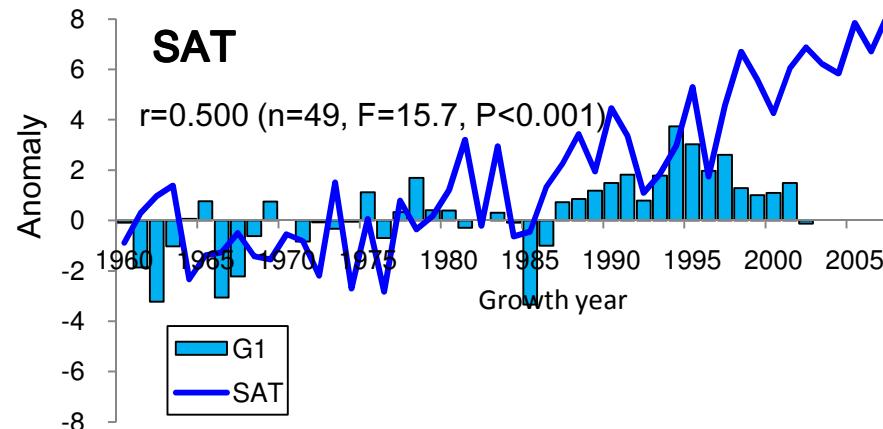


Migration route of Japanese chum salmon

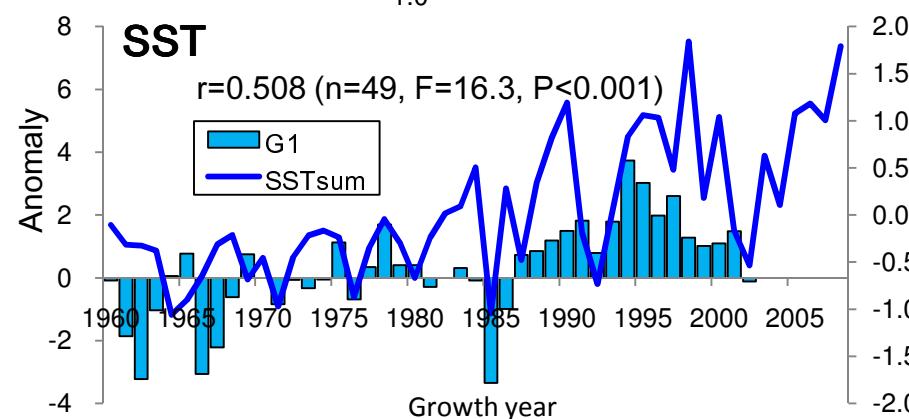




No linkage with climate change indexes such as the Aleutian Low Pressure Index (ALPI), the Pacific Decadal Oscillation (PDO), the Arctic Oscillation (AO), and the Okhotsk High (OH). 成長量→
長期気候変動指数とリンクせず



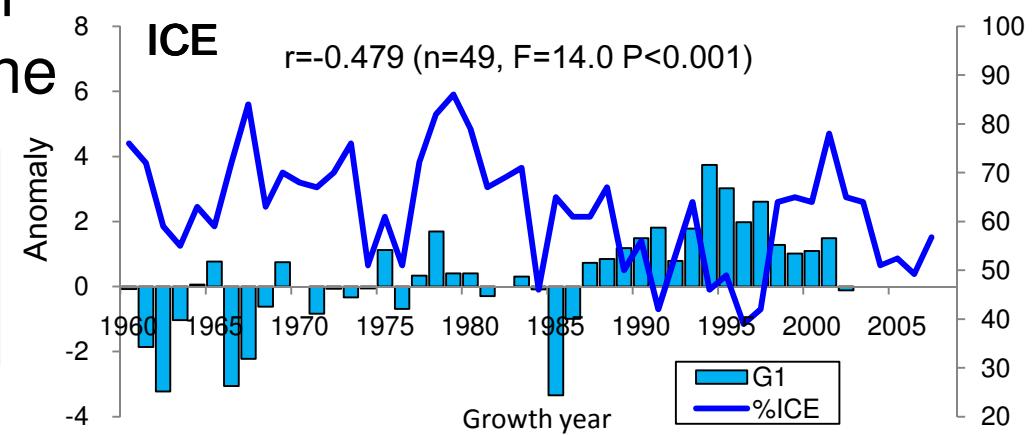
Global Surface Air Temperature (SAT)

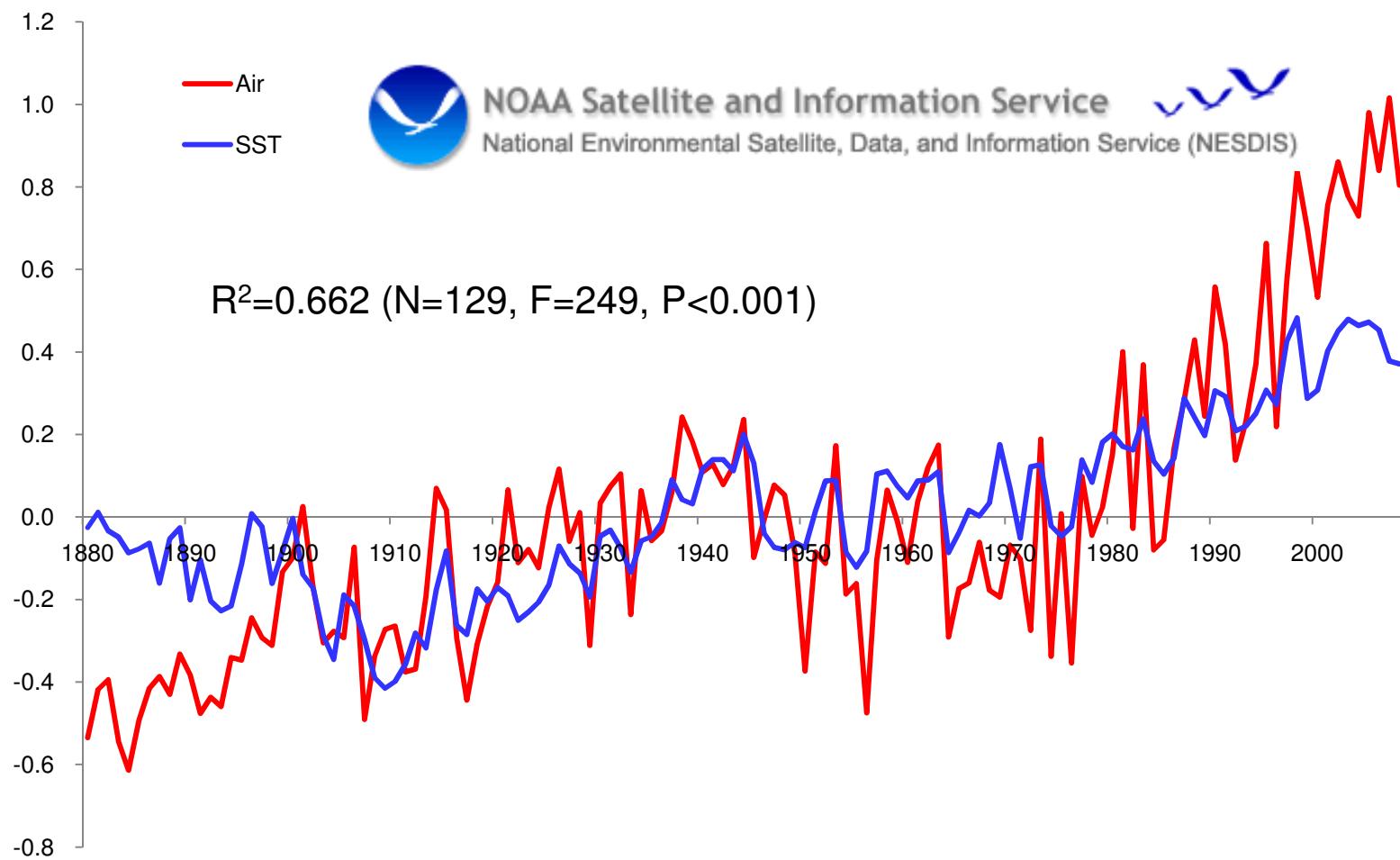


Sea Surface Temperature in Summer and Autumn in the Okhotsk Sea (SST)

Ice Cover Rate in the Okhotsk Sea

The **Growth** at age-1 correlates positively with the **SAT** and the **SST**, and negatively with the **ICE**.





NOAA Satellite and Information Service

National Environmental Satellite, Data, and Information Service (NESDIS)