Sustainability on seafood security and ocean ecosystem conservation

食と海を守るためのサステナイビリティ科学

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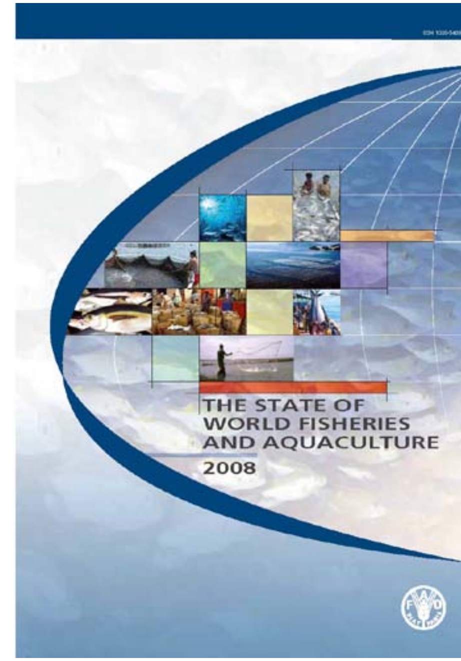
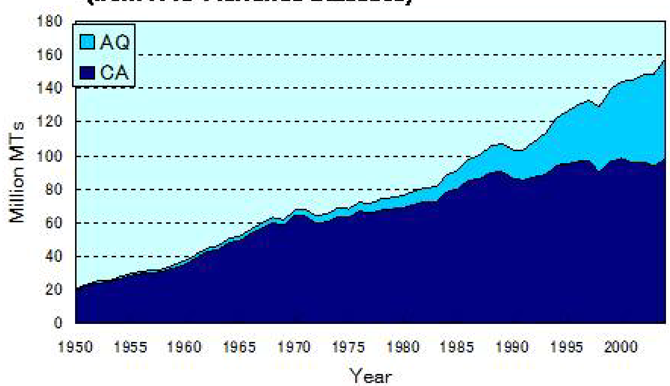
Recent situation of seafood and fisheries in the world

- 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.

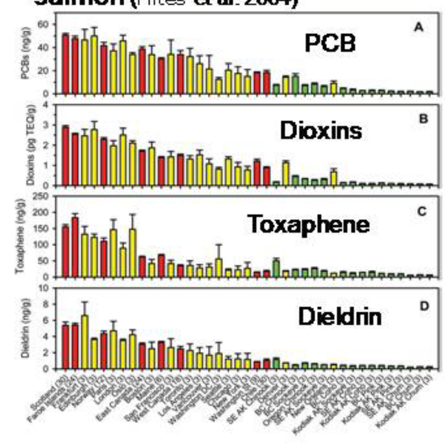


Time trend of capture fisheries (CA) and aquaculture (AQ) in the world (from FAO Fisheries Statistics)



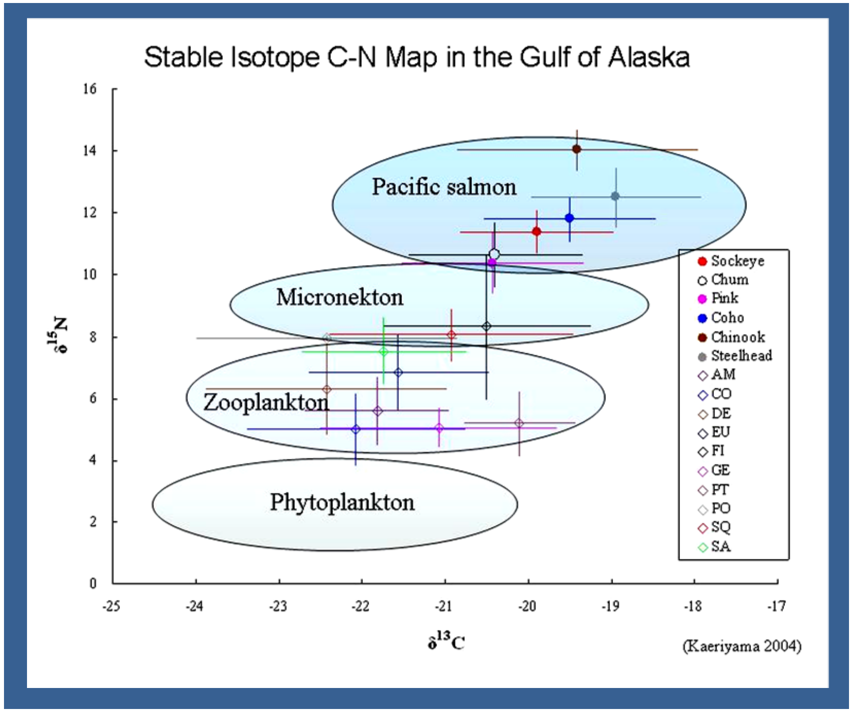
Vanishing 35% mangrove forests by the shrimp aquaculture over the last 20 years (Primavera 2005)

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



A case study in the climate change and sustainable fisheries:

Pacific salmon play an important role as the ecosystem service and the keystone in   the North Pacific ecosystems サケ：生態系サービス，キーストン種

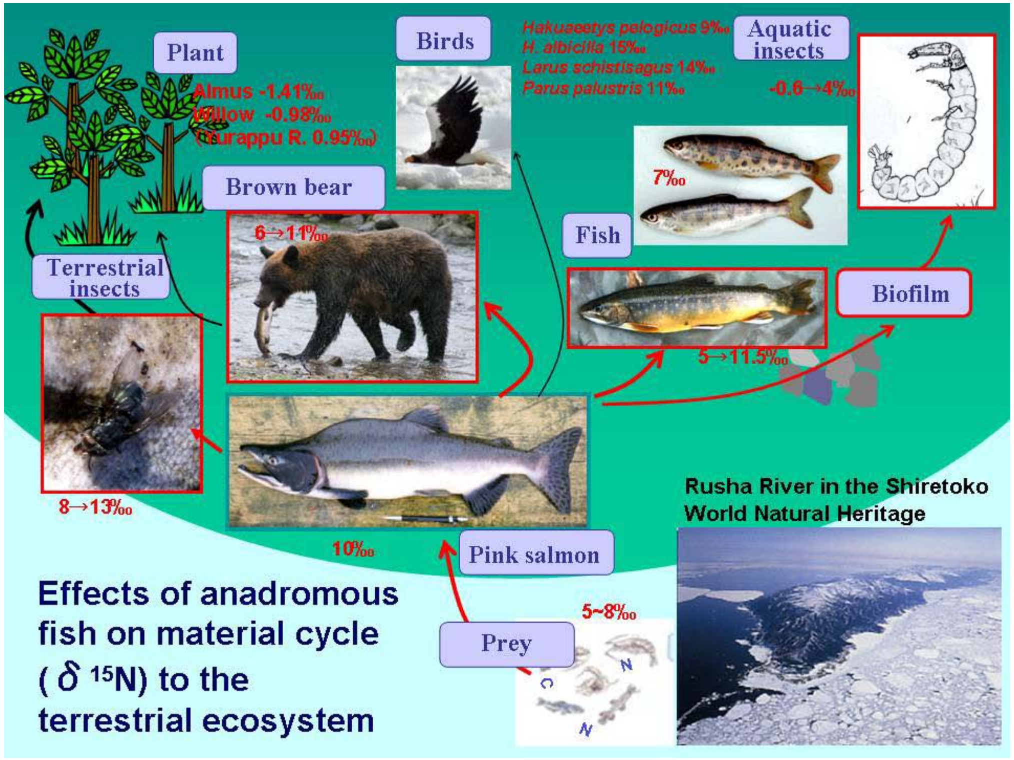


Pacific salmon:

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 material to the terrestrial ecosystem

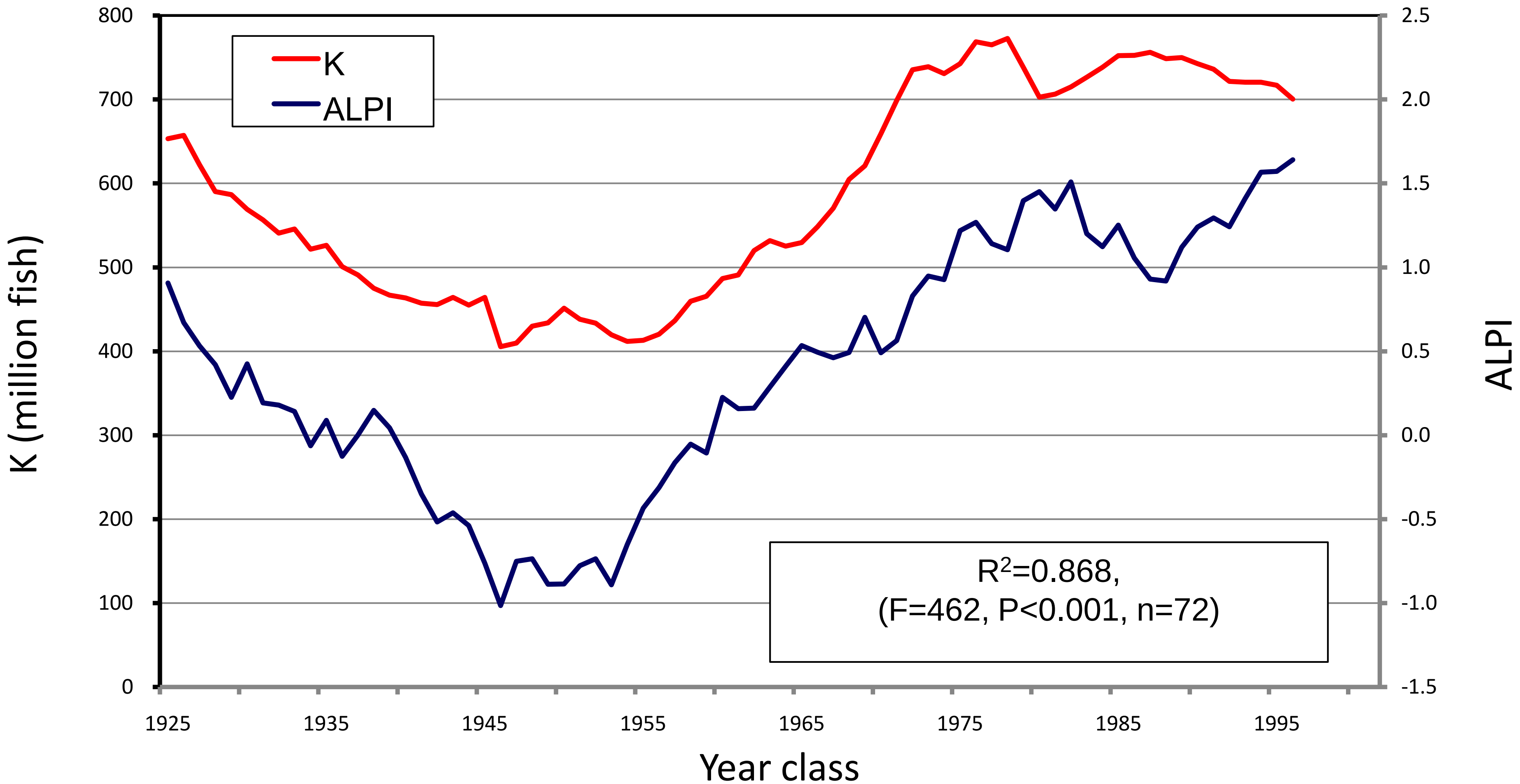


Topics

- Relationship between climate change and growth and survival of Hokkaido chum salmon
- Global warming effect on chum salmon: Path model & Prediction
- Salmon food mileage
- Issues on the sustainability on seafood security and ocean ecosystem conservation

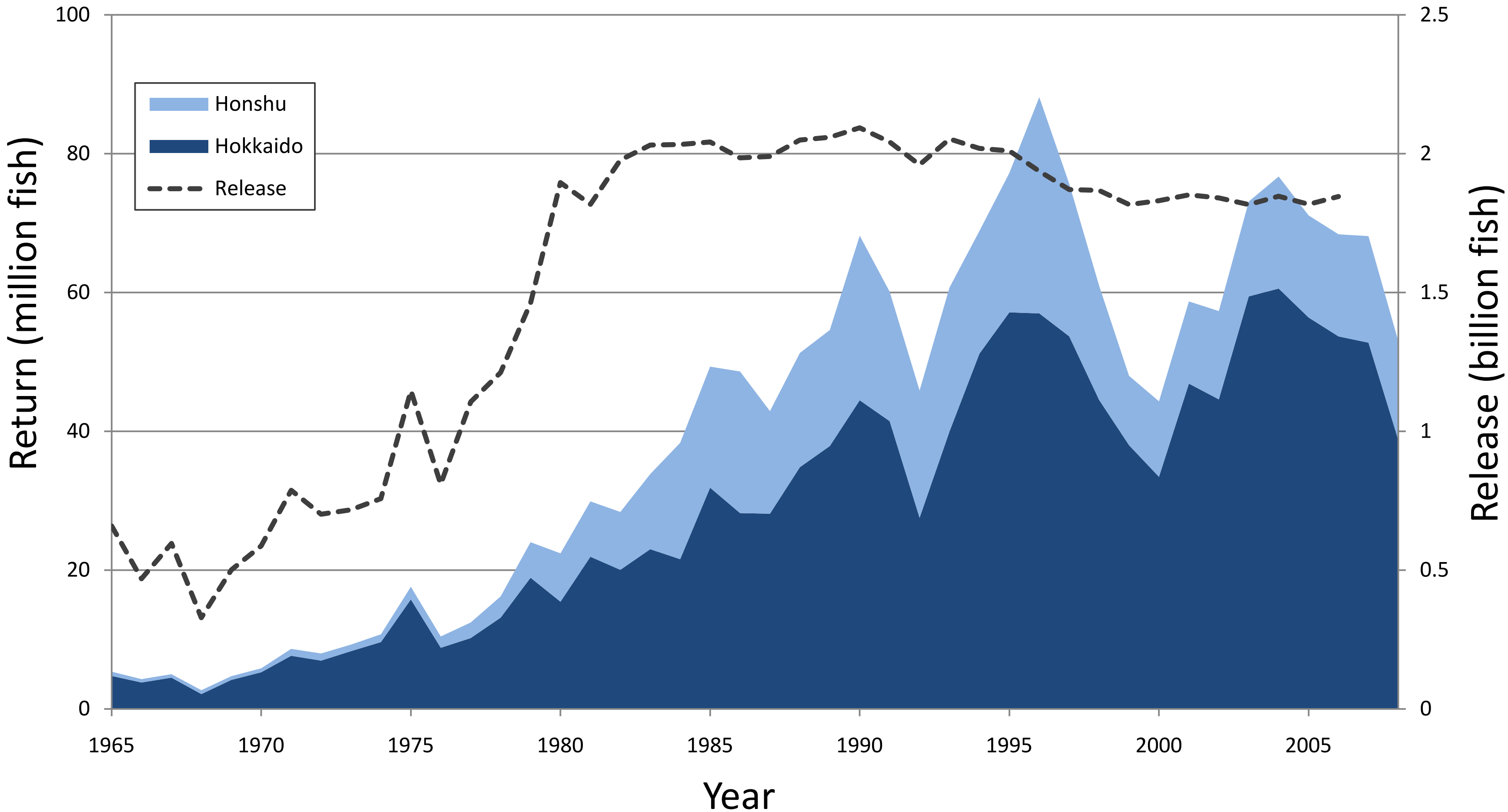
Temporal changes in ALPI and carrying capacity (K) of three species (sockeye, chum, and pink salmon)

アリューシャン低気圧とサケ環境収容力の時系列変化

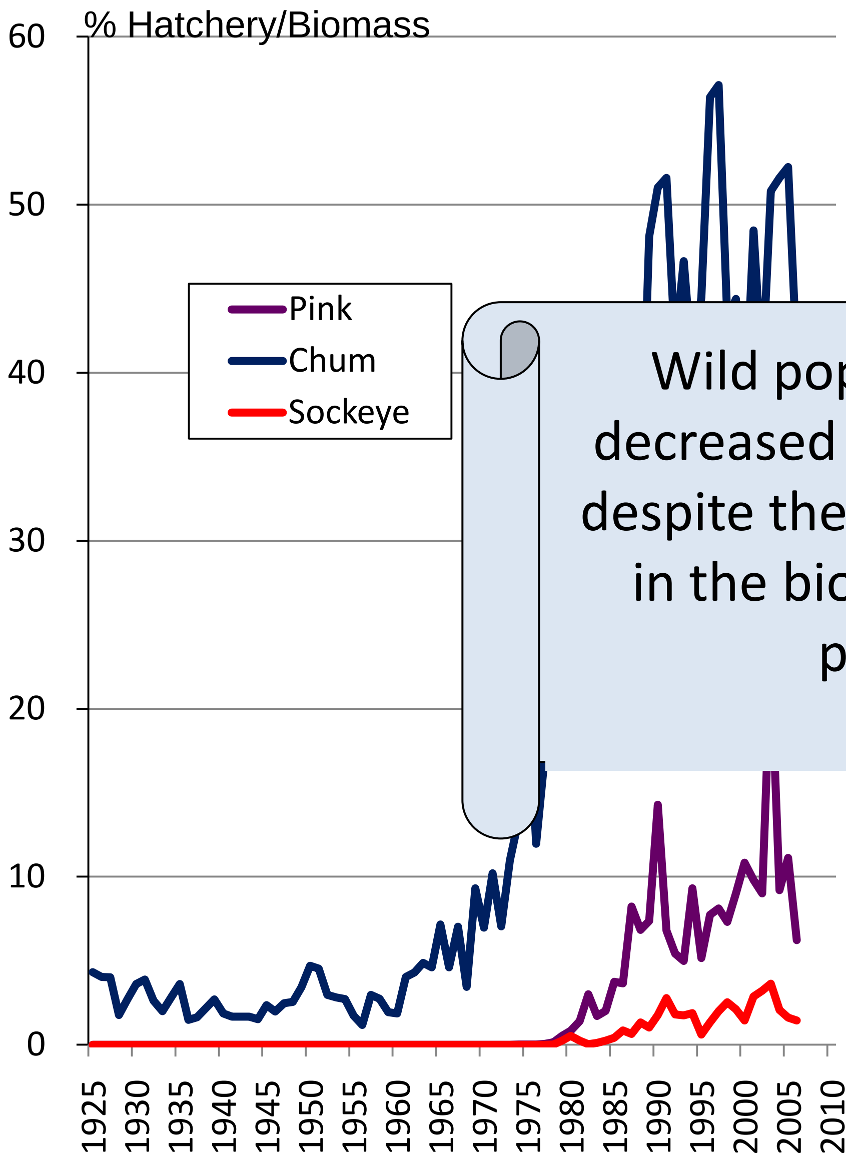


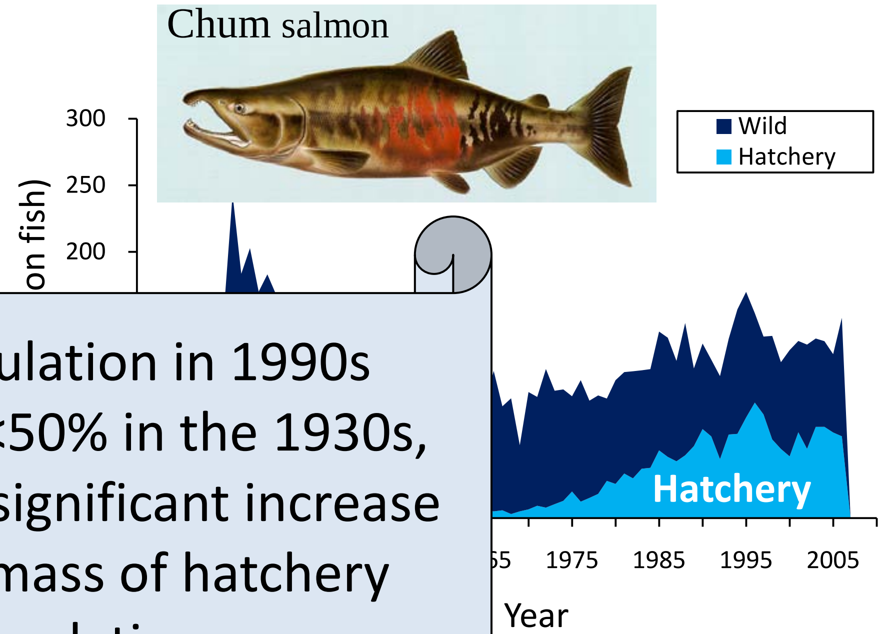
Salmon carrying capacity significantly synchronized with the long-term climate change

Annual change in return of chum salmon in Japan



Annual changes in biomass of wild/hatchery salmon
孵化場魚の増加





Wild population in 1990s decreased <50% in the 1930s, despite the significant increase in the biomass of hatchery population

Hatchery salmon

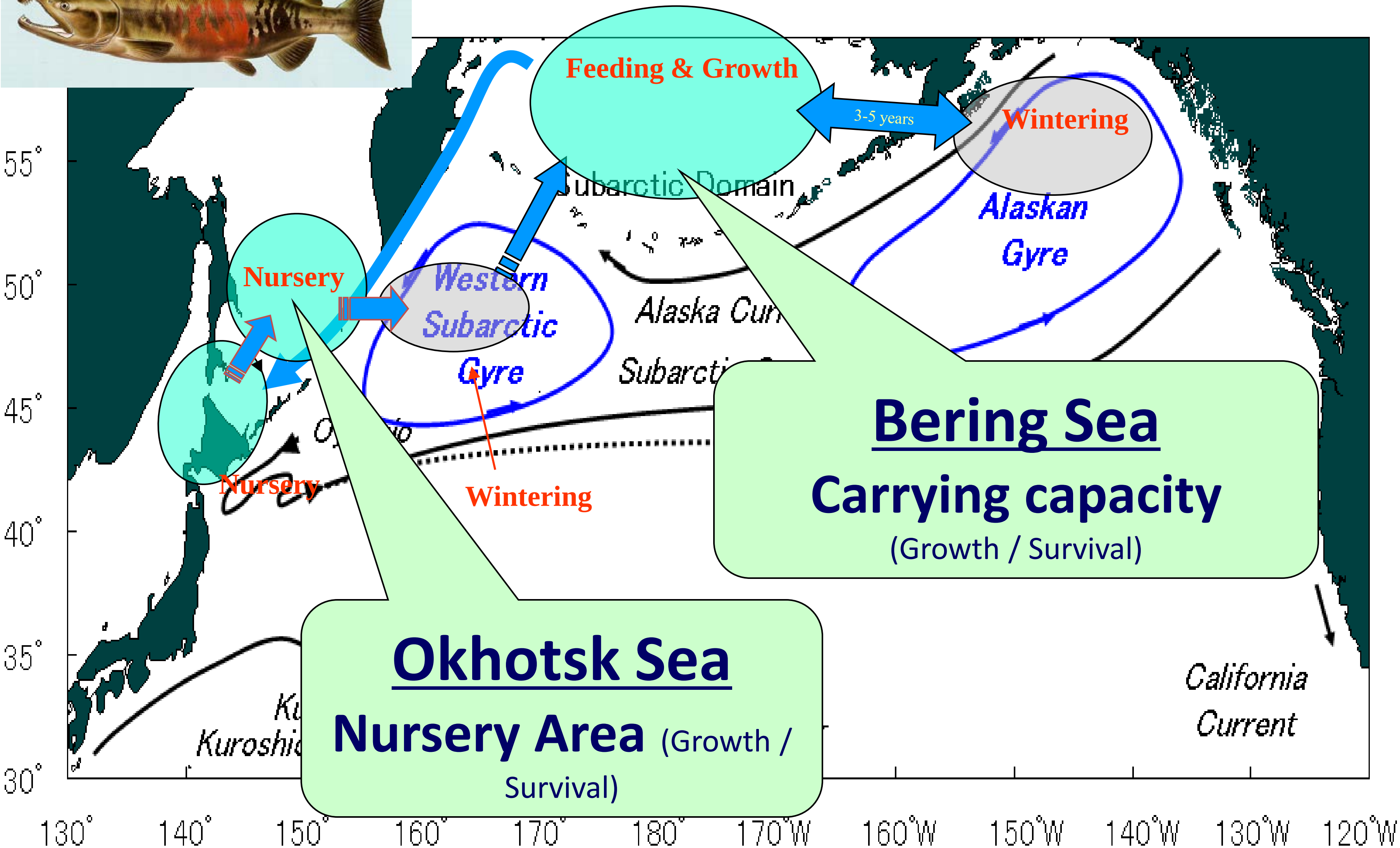
Pink <20%

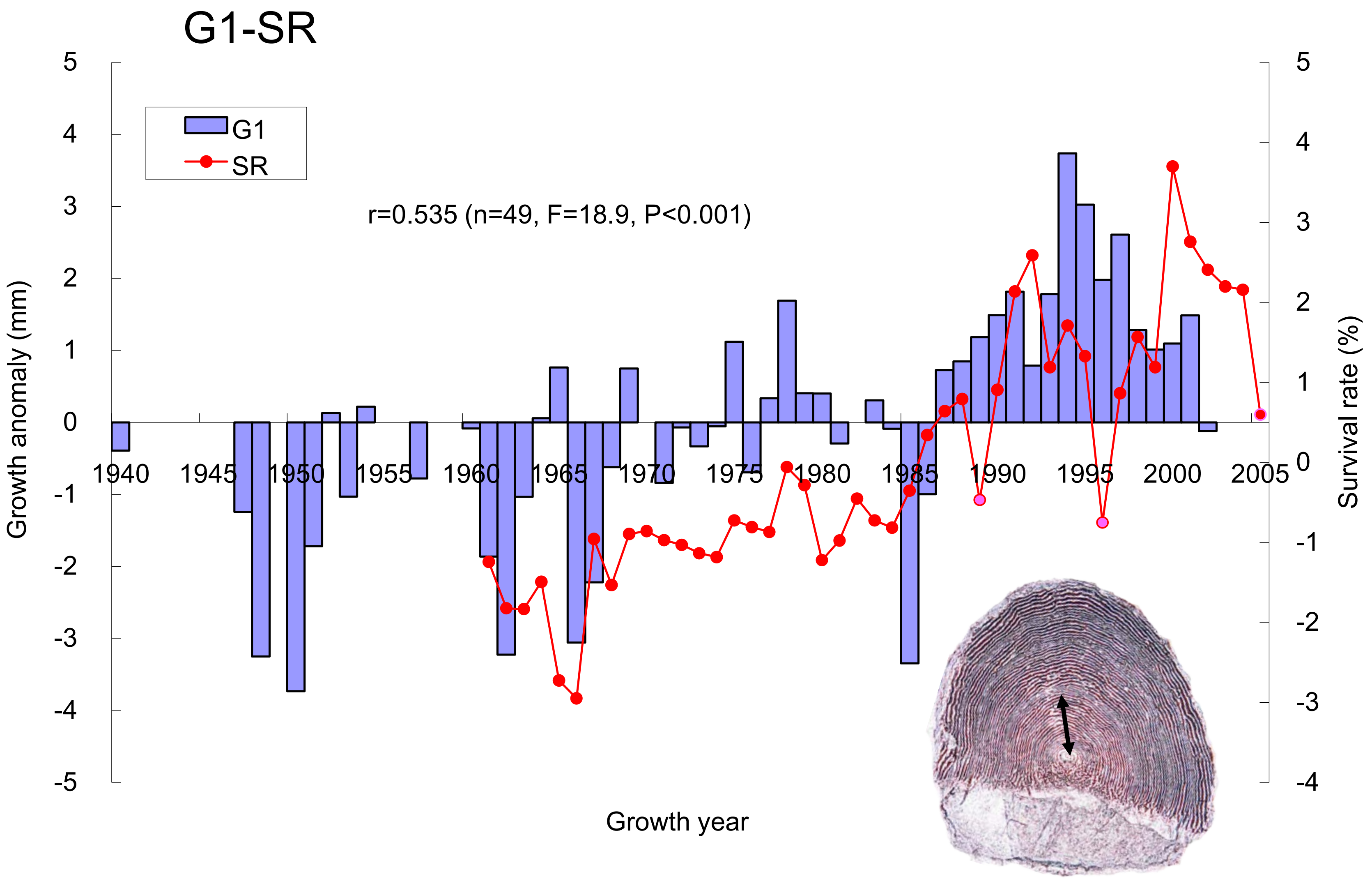
Chum >50%

Sockeye <5%

Migration route of Japanese chum salmon

北海道シロザケの回遊ルート:オホーツク海は成長と生残にとって大切





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

Database

使用したデータベース

Climate Change

SAT (annual changes in global anomalies of surface air temperature) : NOAA Satellite and Information Service

SST (sea surface temperature in summer and autumn in the Okhotsk Sea): NOAA Earth System Research Laboratory (NCEP/NCAR Reanalysis Project)

ALPI (Aleutian low pressure index):Fisheries and Oceans Canada, Pacific Biological Station

PDO (Pacific decadal oscillation): University of Washington, PDO

AO (arctic oscillation): NOAA Climate Prediction Center

OH (Okhotsk High): NOAA Earth System Research Laboratory (NCEP/NCAR Reanalysis Project)

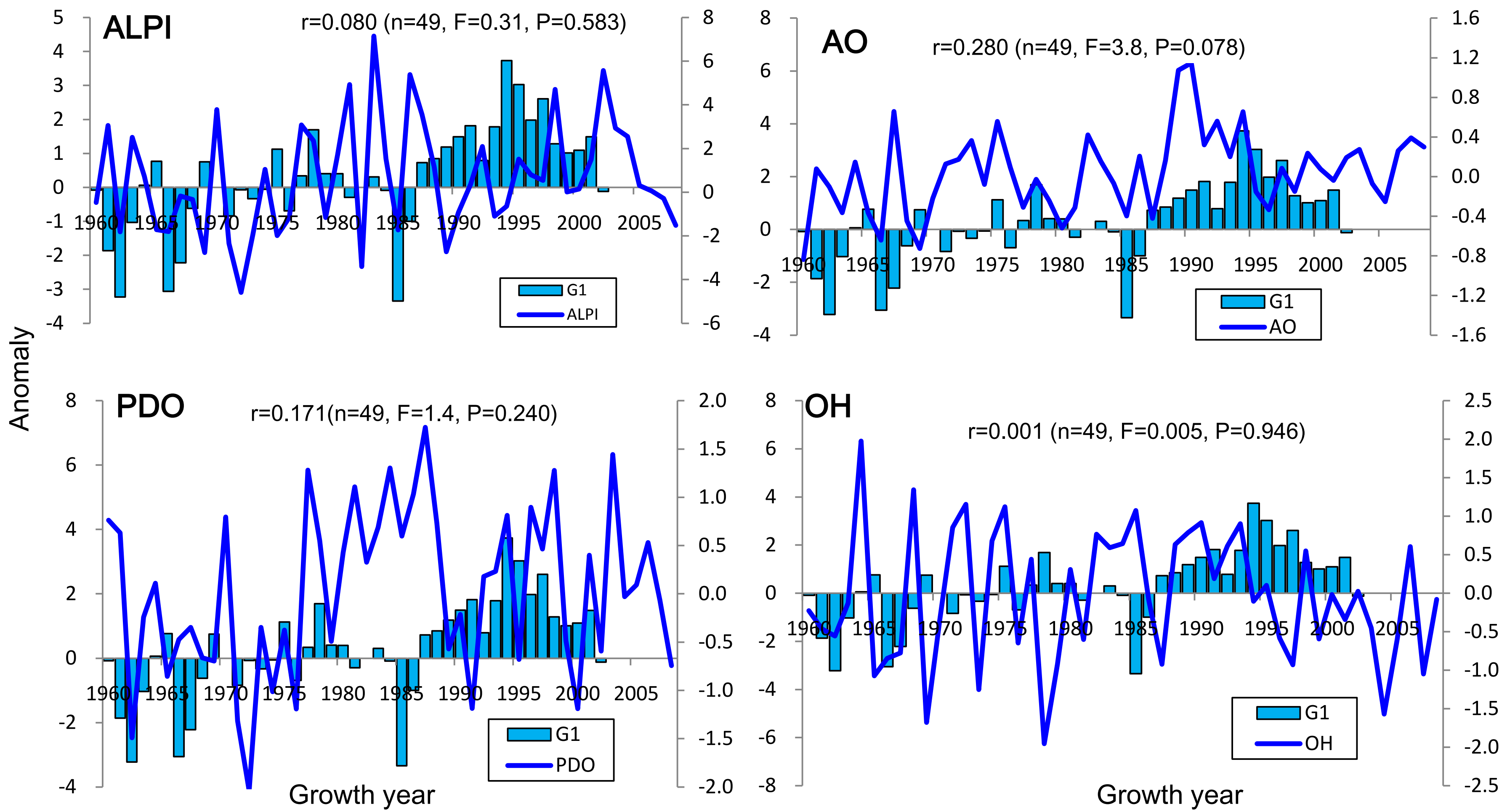
ICE (sea ice cover rate in the Okhotsk Sea): National Snow and Ice Data Center and Kaeriyama et al. (2007)

Growth and Survival Rate of Hokkaido chum salmon

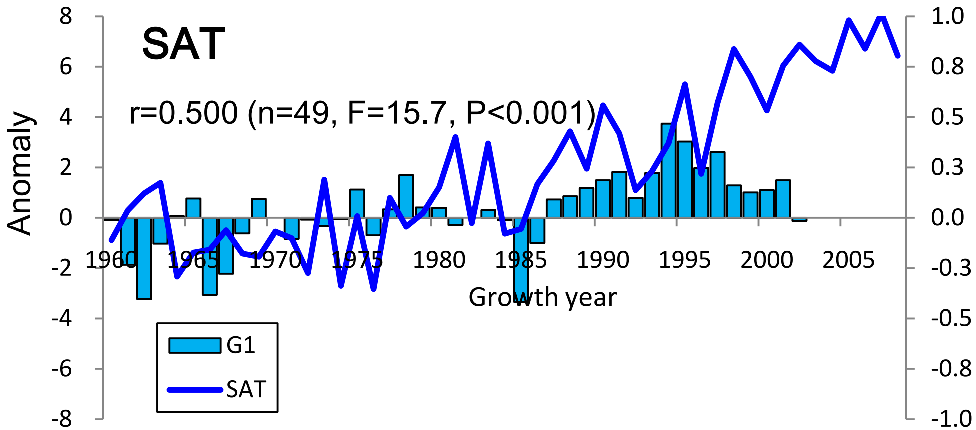
G1 (growth at age-1): modified Kaeriyama et al. (2007)

SR (survival rate): modified Kaeriyama and Edpalina (2004)

BW (mean body weight of juvenile released from hatchery in Hokkaido): modified Kaeriyama (1999)

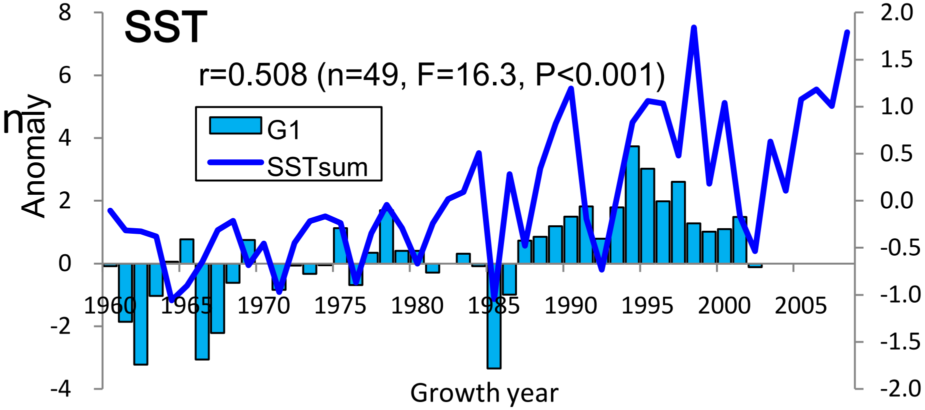


No linkage with climate change indexes such as the Aleutian Low Pressure Index (ALPI), the Pacific Decadal Oscillation (PDO), the Arctic Oscillation (AO), and the Okhotsk High (OH).

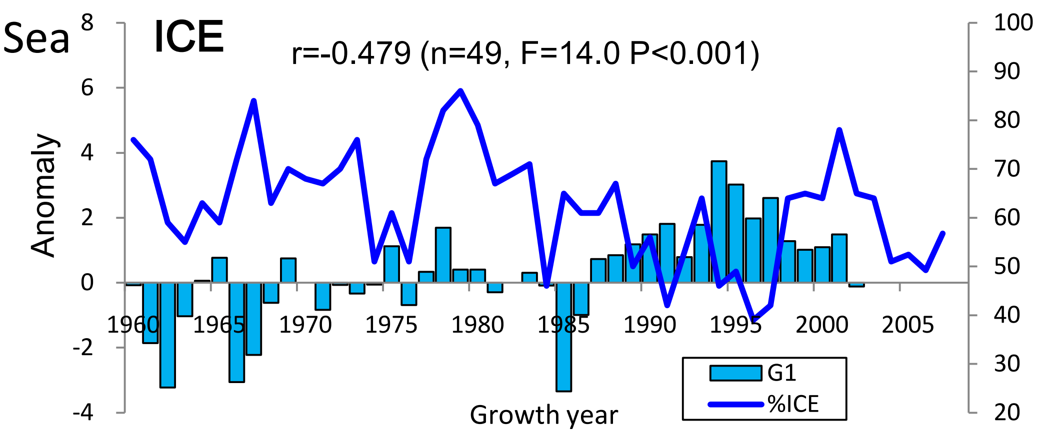


Global Surface Air Temperature (SAT)

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

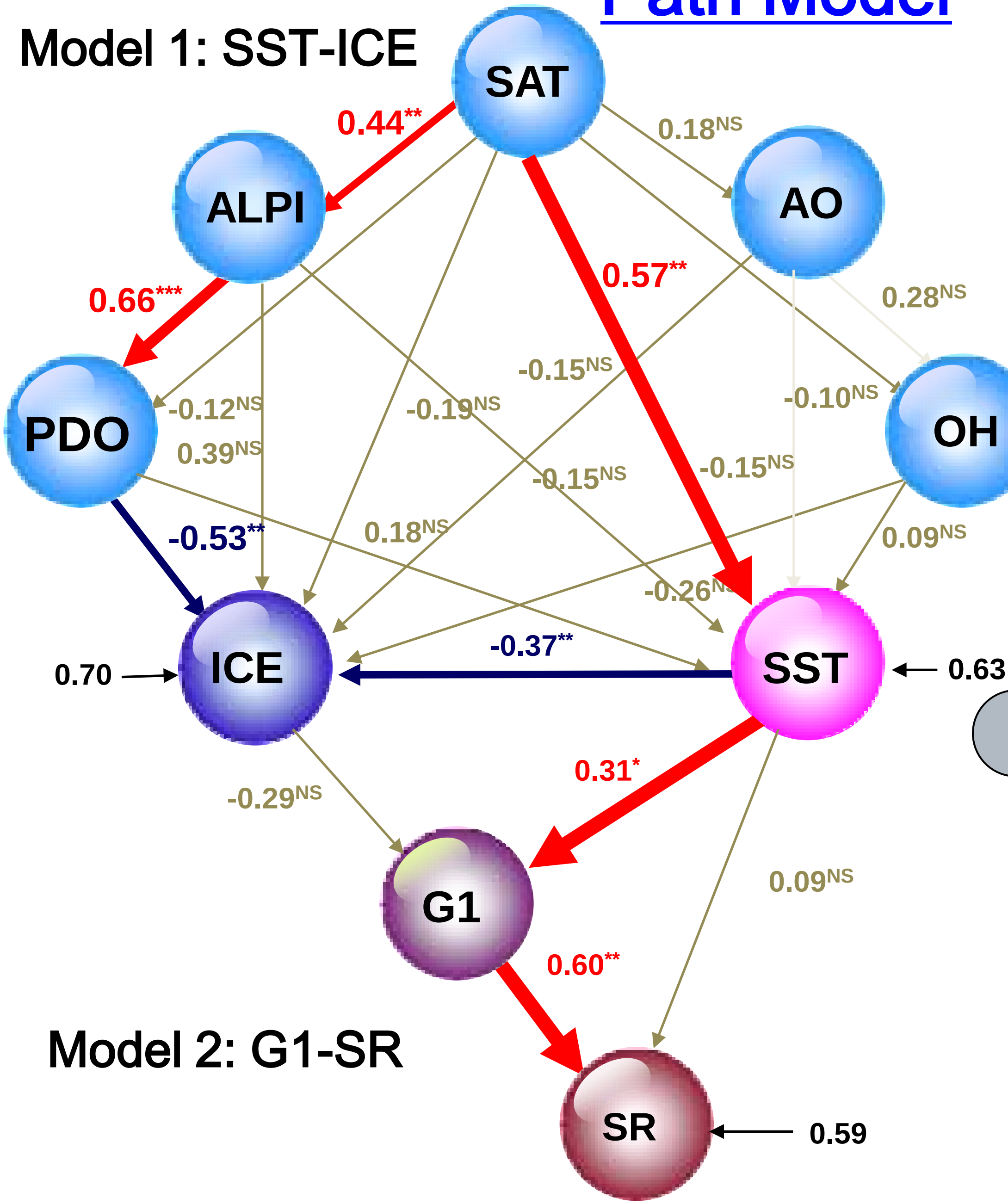


Ice Cover Rate in the Okhotsk Sea (ICE)



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

Path Model



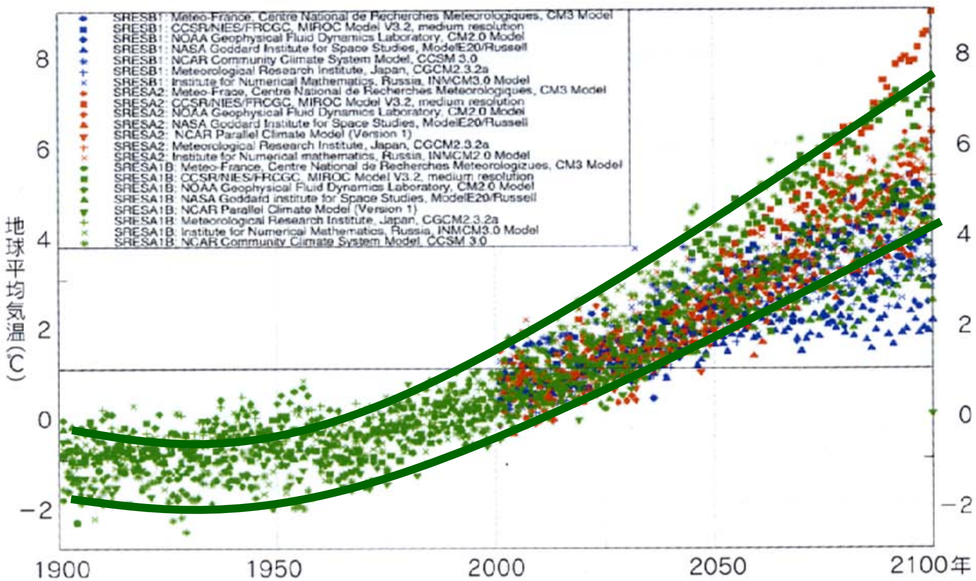
Global warming is directly and indirectly affecting growth in the Okhotsk Sea and survival of Hokkaido chum salmon

<u>地球温暖化の影響</u>
直接：SAT, SST
間接：ALPI, PDO, ICE

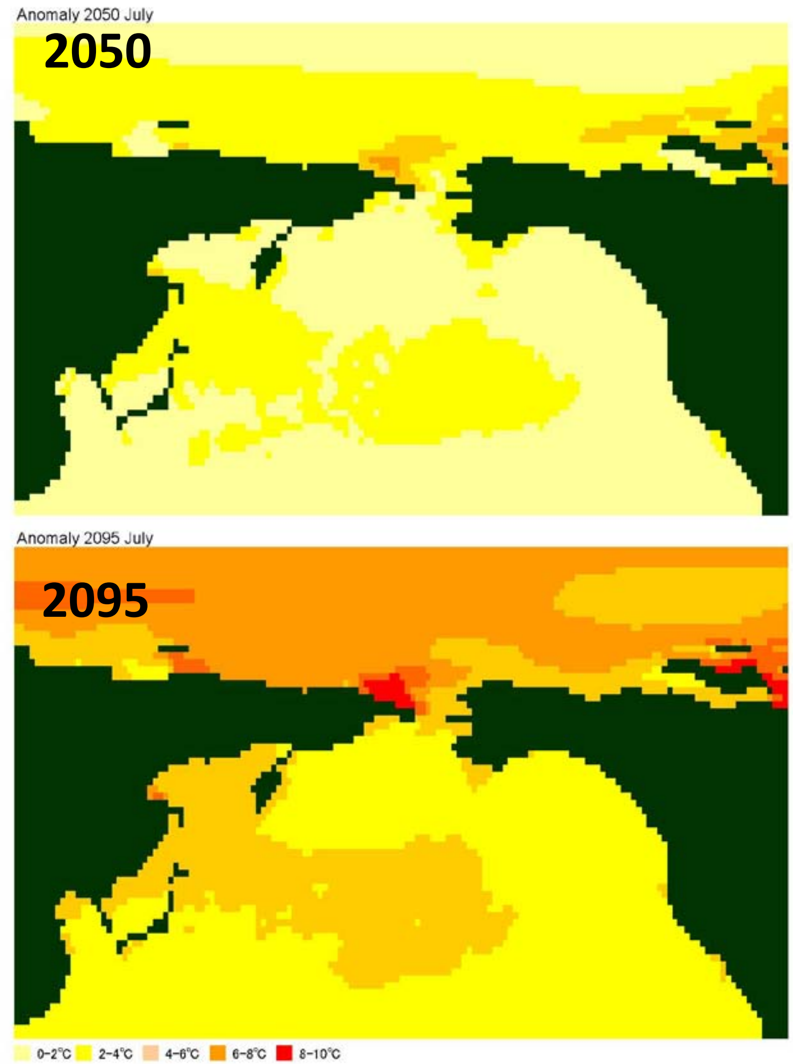
Prediction about the Global Warming Effect on Chum Salmon in the North Pacific Ocean based on the SRES-A1B scenario

サケへの地球温暖化による今後の影響

SRES-A1B scenario：4～7℃



SST Anomaly in July



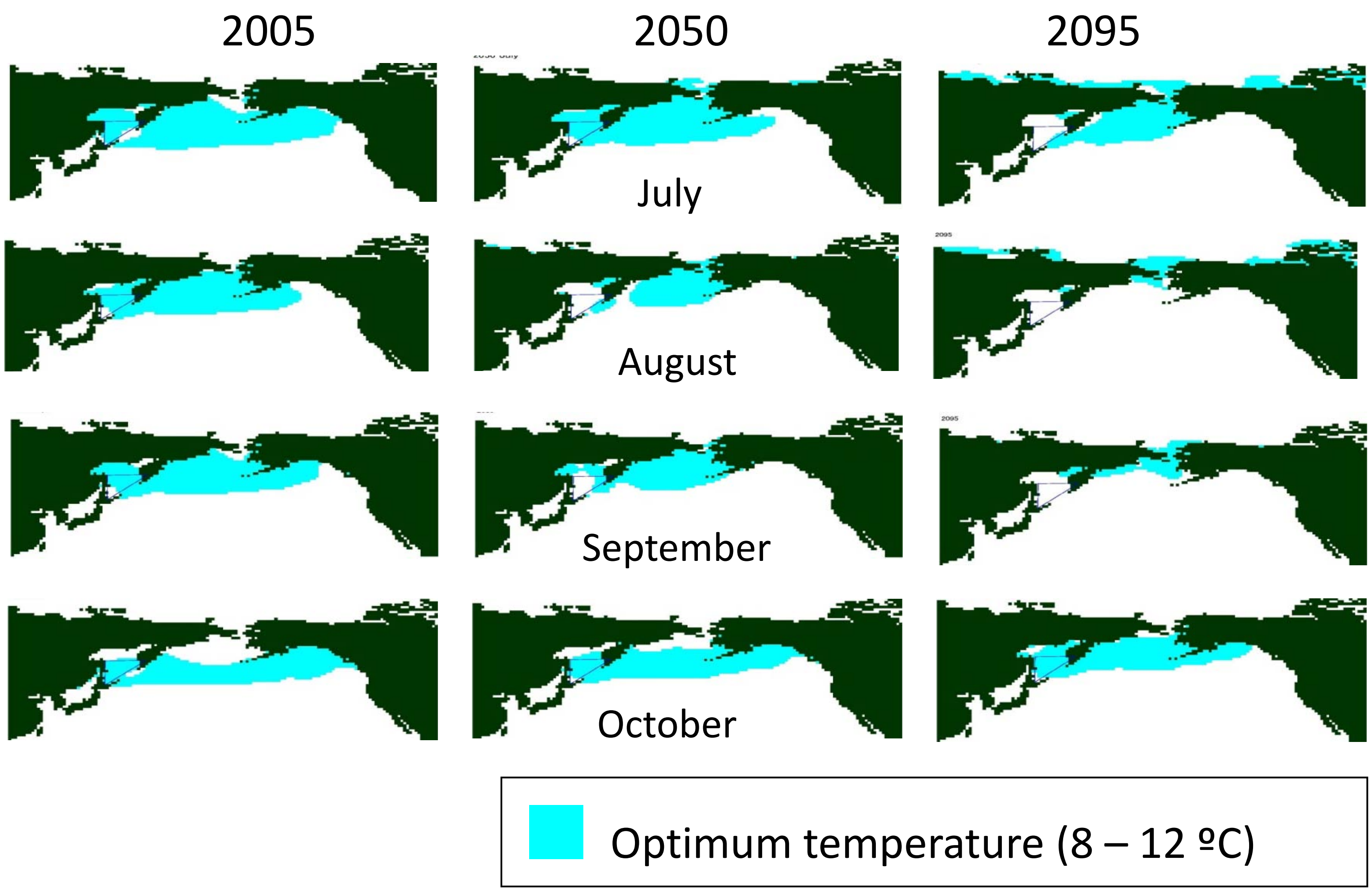
Optimum temperature of chum salmon

Feeding migration：8-12℃

Wintering：4-6℃

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

シロザケ分布域の将来予測



Global Warming Effect on Chum Salmon and the Okhotsk Sea

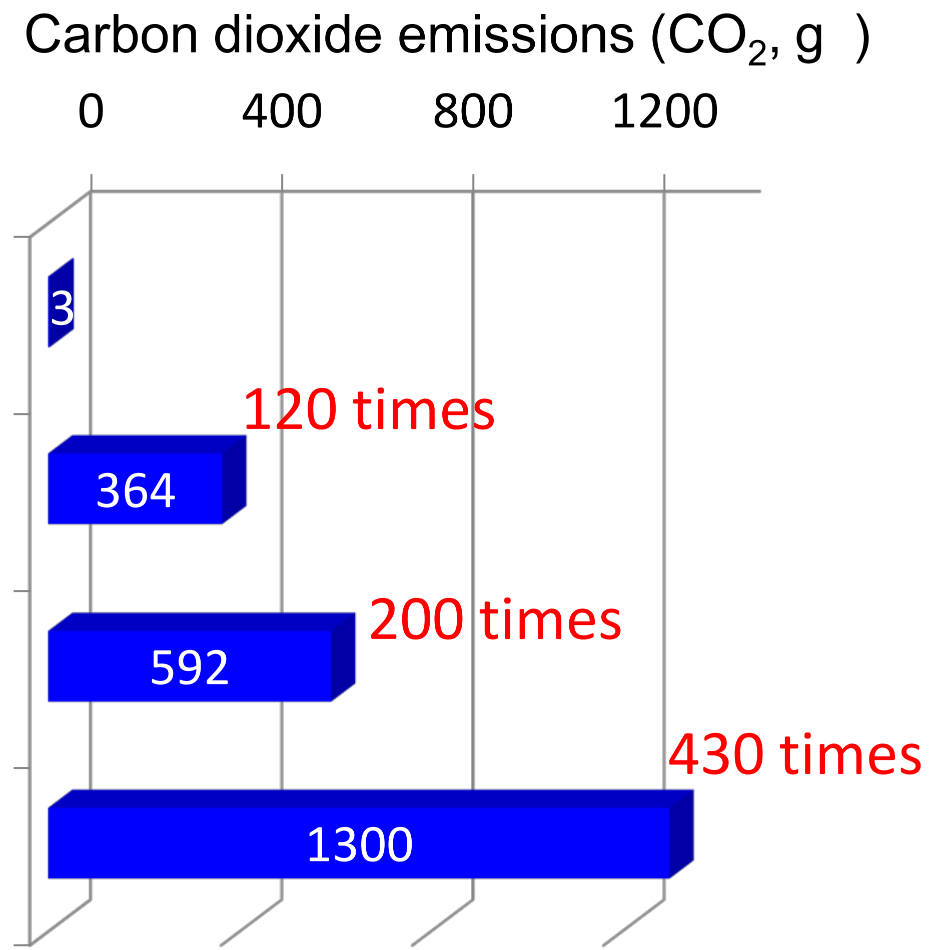
- **At present,** the global warming is affecting:
  - Positively & directly for increases in growth at age-1 and survival of Hokkaido chum salmon through the SST (sea surface temperature during summer and autumn) in the Okhotsk Sea since the late 1980s
  - Indirectly for the rate of sea ice area through the ALPI and the PDO in the Okhotsk Sea

- **In the Future,** the global warming will affect:
  - Decrease in their carrying capacity for reducing distribution area in the North Pacific Ocean
  - Strongly the density-dependent effect
  - Hokkaido chum salmon population will lose migration route to the Okhotsk Sea by 2050 and will be crushed by 2100

Food mileage of salmon

サケ・フードマイレージ

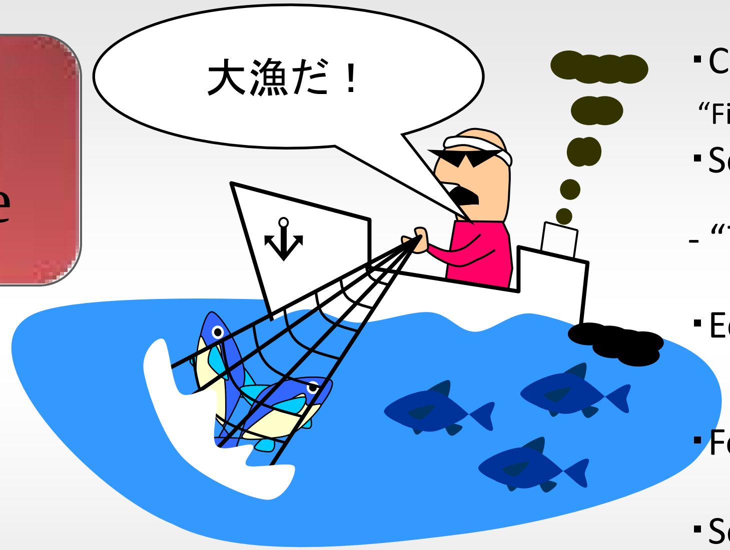
A piece of salmon (50g) in Sapporo



The "local production for local consumption (地産地消)" is a most important issue for the prevention of global warming

Traditional Fisheries Science

For only Fisheries

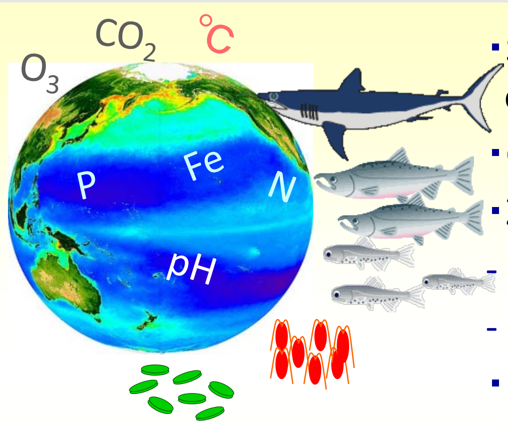


- Change in Marine Ecosystem
  "Fishing down marine food webs" (Pauly et al. 2003)
- Sea Food Gourmet→Tuna Laundering / Overfishing
- "Tragedy of Commons"
  First come→Overfishing
- Ecosystem Crash & Food Polution
  Vanishing Mangrove forest ecosystem, Cutoff food chain, Food security
- Food Import
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

Paradigm Shift

New Ecological Fisheries Science

For Marine Ecosystem & Human Seafood



- 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)

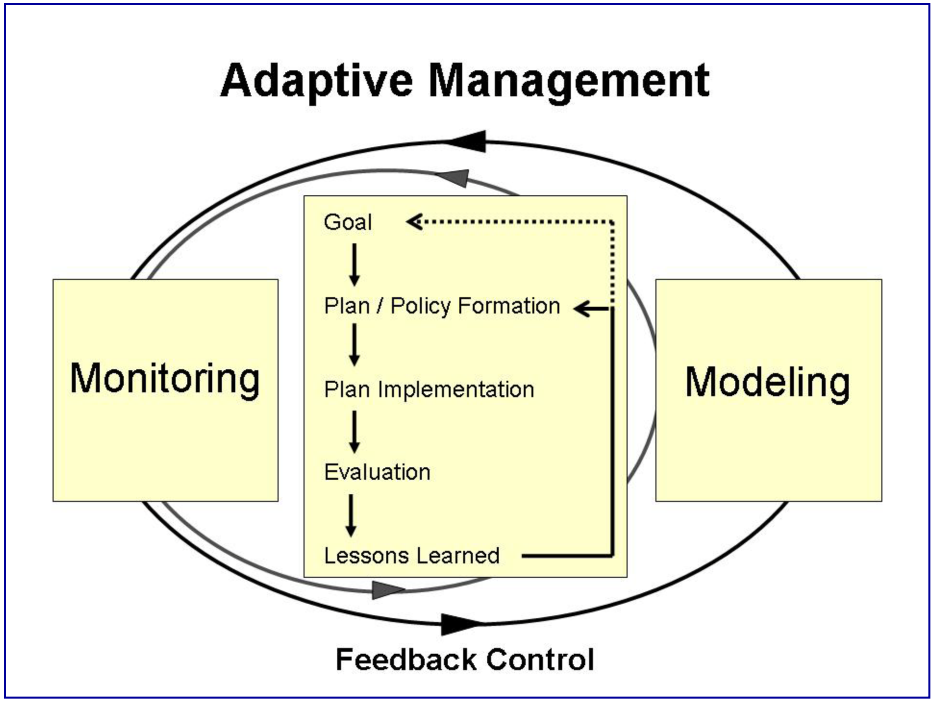
Risk Management for Sustainable Fisheries Management Based on the Ecosystem Approach (RSMEA)
In case of Pacific salmon

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

2. Monitoring the structure and function 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. Adaptive management and precautionary principle for Pacific salmon in ocean ecosystem
   - Adaptive learning
   - Feedback control
     - Monitoring
     - Modeling

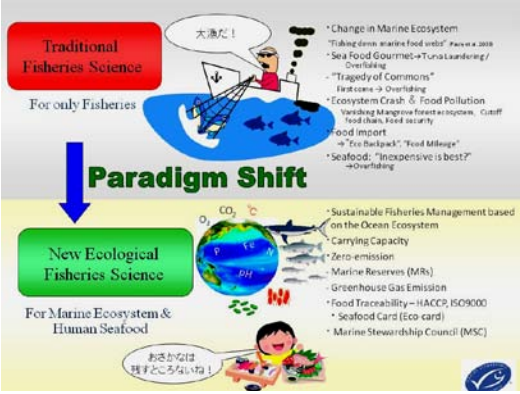
順応的管理と予防原則(リスク管理)



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

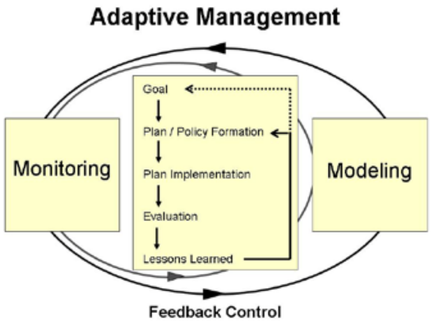
- **What do we need for seafood security and marine ecosystem sustainability in present and future?**
  - Education
    - Paradigm shift from the traditional fisheries science to the new ecological fisheries science
    - Dietary education 食育
      → e.g. “local production for local consumption” 地産地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



- **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



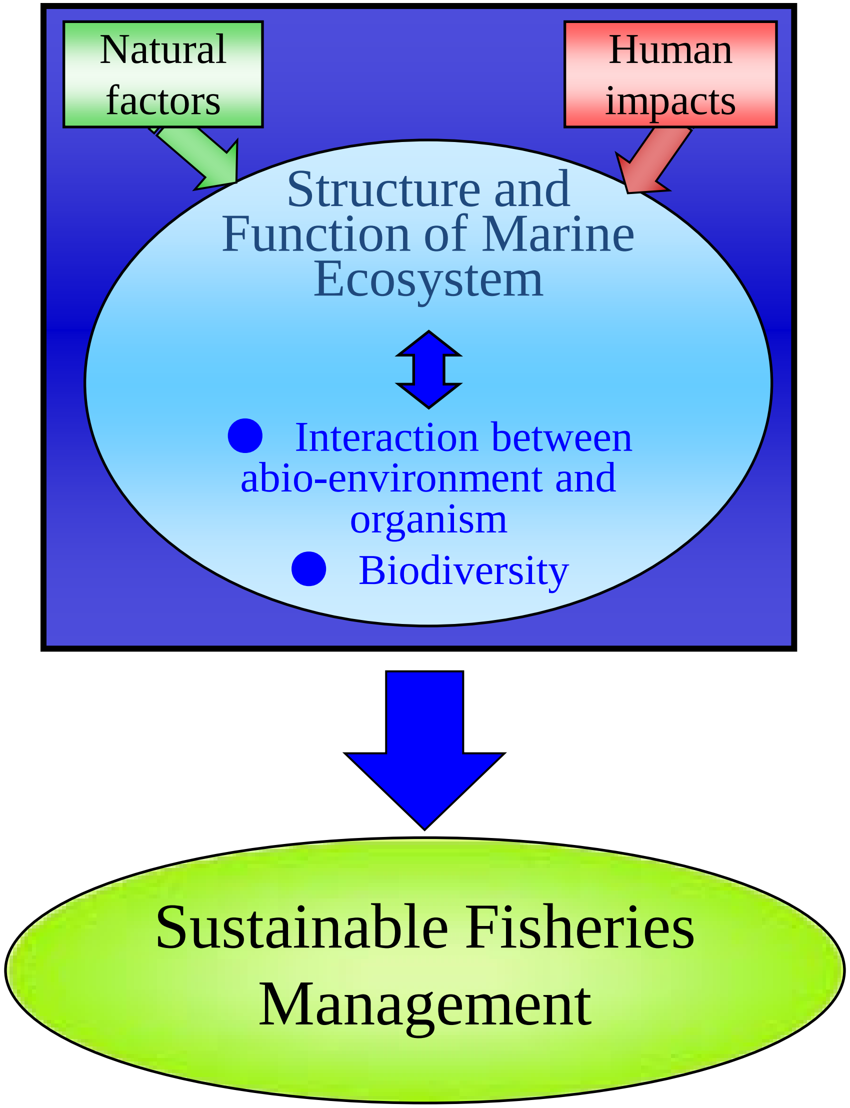
Fisheries Management

- We should understand the limitations of the fisheries management at a single species level.

- Carrying capacity & Density-dependent effect
- Biological interaction between wild & hatchery salmon
- Global warming effect

- We should establish the sustainable fisheries management based on marine ecosystem.

持続可能性とは・・・・・



Relationship between residual carrying capacity (RCC) and population density dependent effect

環境収容力と密度依存効果

Species level

Population level

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.

The density-dependent effect leads decline in growth rate and fecundity of wild salmon.

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

Eco Label - MSC

Marine Stewardship Council

PRINCIPLE 1: A fishery must be conducted in a manner that does not lead to over-fishing or depletion of the exploited populations and, for those populations that are depleted, the fishery must be conducted in a manner that demonstrably leads to their recovery

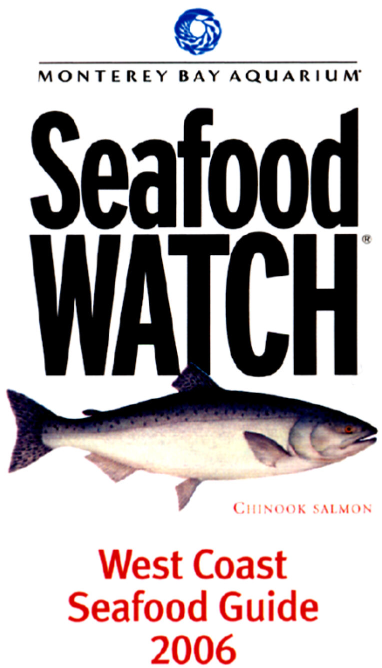
PRINCIPLE 2: Fishing operations should allow for the maintenance of the structure, productivity, function and diversity of the ecosystem (including habitat and associated dependent and ecologically related species) on which the fishery depends.

PRINCIPLE 3: The fishery is subject to an effective management system that respects local, national and international laws and standards and incorporates institutional and operational frameworks that require use of the resource to be responsible and sustainable.

(MSC 2002)

Eco label エコラベル

Seafood Watch (Santa Barbara, 07/03/03)



BEST CHOICES

- Abalone (farmed)
- Catfish (US farmed)
- Clams, Mussels, Oysters (farmed)
- Cod: Pacific (longline-caught from AK)*
- Crab: Dungeness, Snow (Canada)
- Halibut: Pacific
- Lobster: Spiny (US)
- Pollock (wild-caught from AK)*
- Rockfish: Black (CA, OR)
- Sablefish/Black Cod (AK, BC)
- Salmon (wild-caught from AK)*
- Sardines
- Shrimp: Pink (OR)
- Spot Prawn (BC)
- Striped Bass (farmed)
- Sturgeon, Caviar (farmed)
- Tilapia (US farmed)
- Trout: Rainbow (farmed)
- Tuna: Albacore, Bigeye, Yellowfin (troll/pole-caught)
- White Seabass

GOOD ALTERNATIVES

- Basa/Tra (farmed)
- Clams, Oysters* (wild-caught)
- Cod: Pacific (trawl-caught)
- Crab: King (AK), Snow (US), imitation
- Dogfish (BC)*
- Flounders, Soles (Pacific)
- Lingcod
- Lobster: American/Maine
- Mahi mahi/Dolphinfish/Dorado
- Rockfish (hook & line caught from AK, BC)*
- Sablefish/Black Cod (CA, OR, WA)
- Salmon (wild-caught from CA, OR, WA)
- Sanddabs: Pacific
- Scallops: Bay, Sea
- Shrimp (US farmed or wild-caught)
- Spot Prawn (US)
- Squid
- Sturgeon (wild-caught from OR, WA)
- Swordfish (US)*
- Tuna: Albacore, Bigeye, Yellowfin, (longline-caught)*
- Tuna: canned light
- Tuna: canned white/Albacore*

AVOID

- Chilean Seabass/Toothfish*
- Cod: Atlantic
- Crab: King (imported)
- Dogfish (US)*
- Grenadier/Pacific Roughy
- Lobster: Spiny (Caribbean imported)
- Monkfish
- Orange Roughy*
- Rockfish (trawl-caught)*
- Salmon (farmed, including Atlantic)*
- Sharks*
- Shrimp (imported farmed or wild-caught)
- Sturgeon*, Caviar (imported wild-caught)
- Swordfish (imported)*
- Tuna: Bluefin*

AK = Alaska BC = British Columbia
CA = California OR = Oregon
WA = Washington US = United States

* Limit consumption due to concerns about mercury or other contaminants. Visit www.oceansalive.org/eat.cfm
* Certified as sustainable to the Marine Stewardship Council standard. Visit www.msc.org

BEST CHOICES

These fish are abundant, well managed & caught or farmed in environmentally friendly ways.

Cod: Pacific (longline-caught from AK),
Crab: Dungeness, Snow (Canada),
Salmon (wild-caught from AK)*,
Shrimp: Pink (OR),
Tuna: Albacore, Bigeye, Yellowfin

AVOID

These fish are overfished and/or caught or farmed in ways that harm other marine life or the environment.

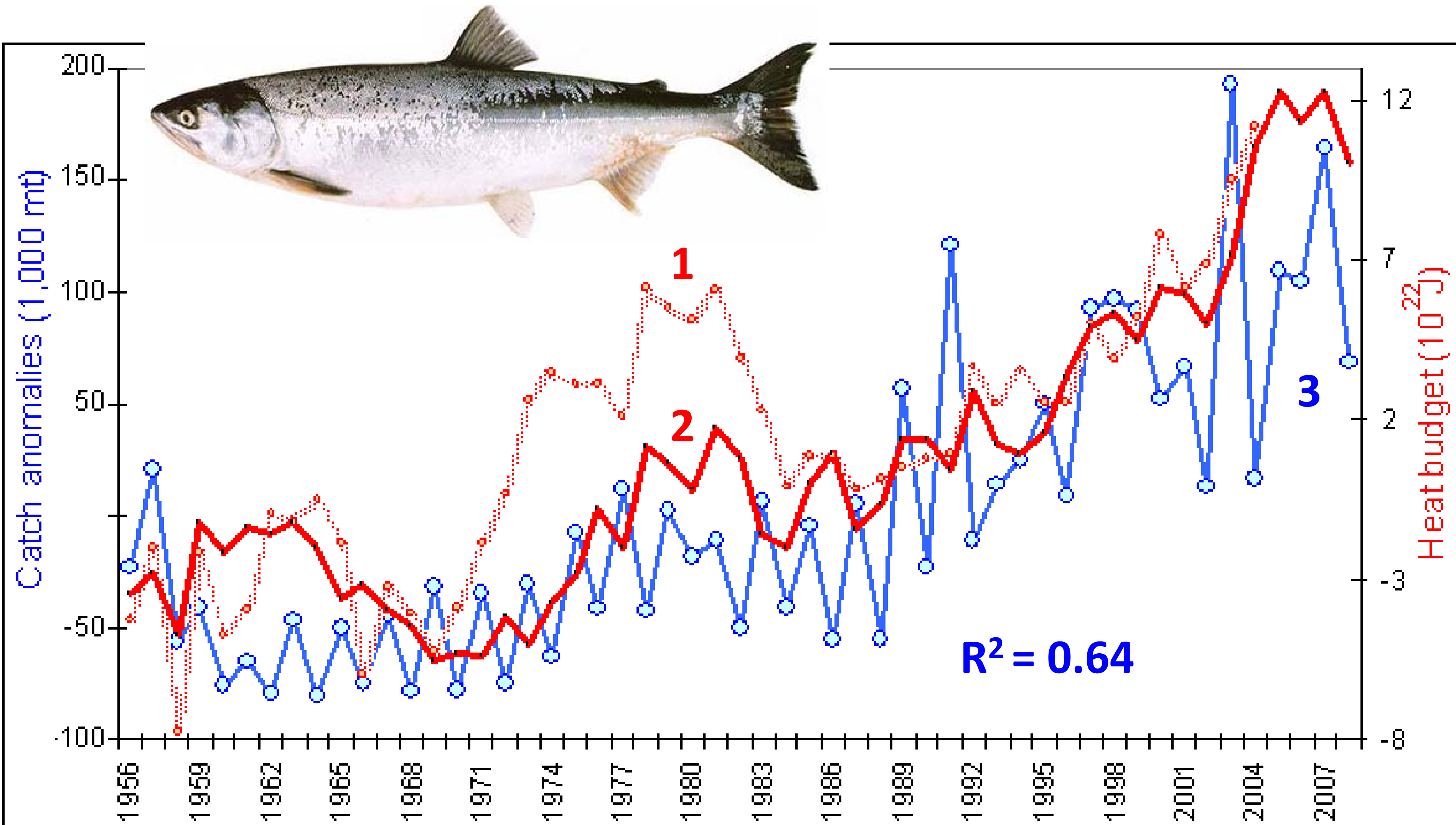
Cod: Atlantic,
Crab: King (imported)
Salmon (farmed, including Atlantic)*
Shrimp (imported farmed or wild-caught)
Tuna: Bluefin*

*Certified as sustainable to the Marine Stewardship Council standard 海洋管理協議会(MSC).

*Limit consumption due to concerns about *mercury of other contaminants.*

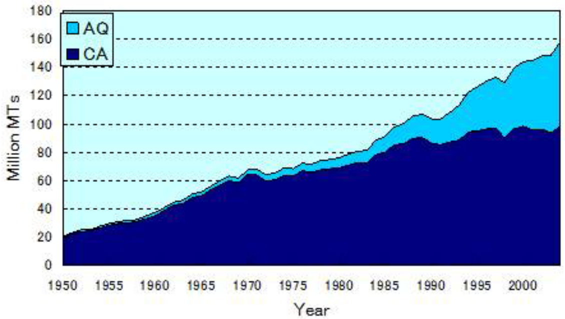
Time series of yearly ocean heat content for the 0-700 m layer and pink salmon catch on the Russian East coast during 1956-2008 (Radchenko 2009)

1: Livitus et al. (2005), 2: Lindsey (2008)

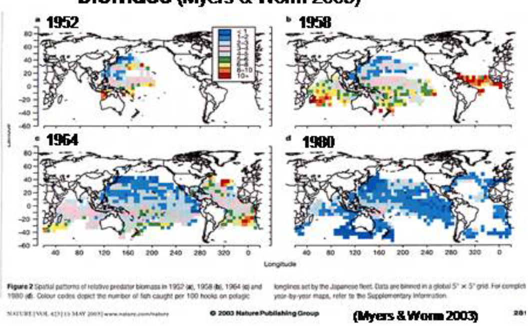


Are seafood reproducible resources for human!?

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



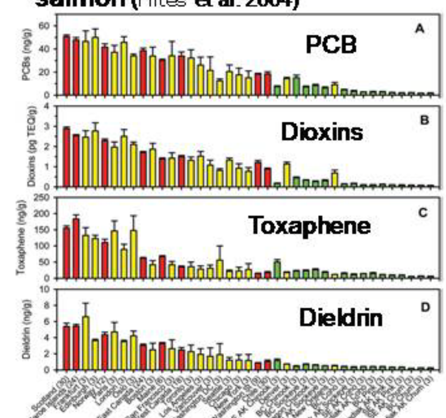
Spatiotemporal change in relative tuna biomass (Myers & Worm 2003)



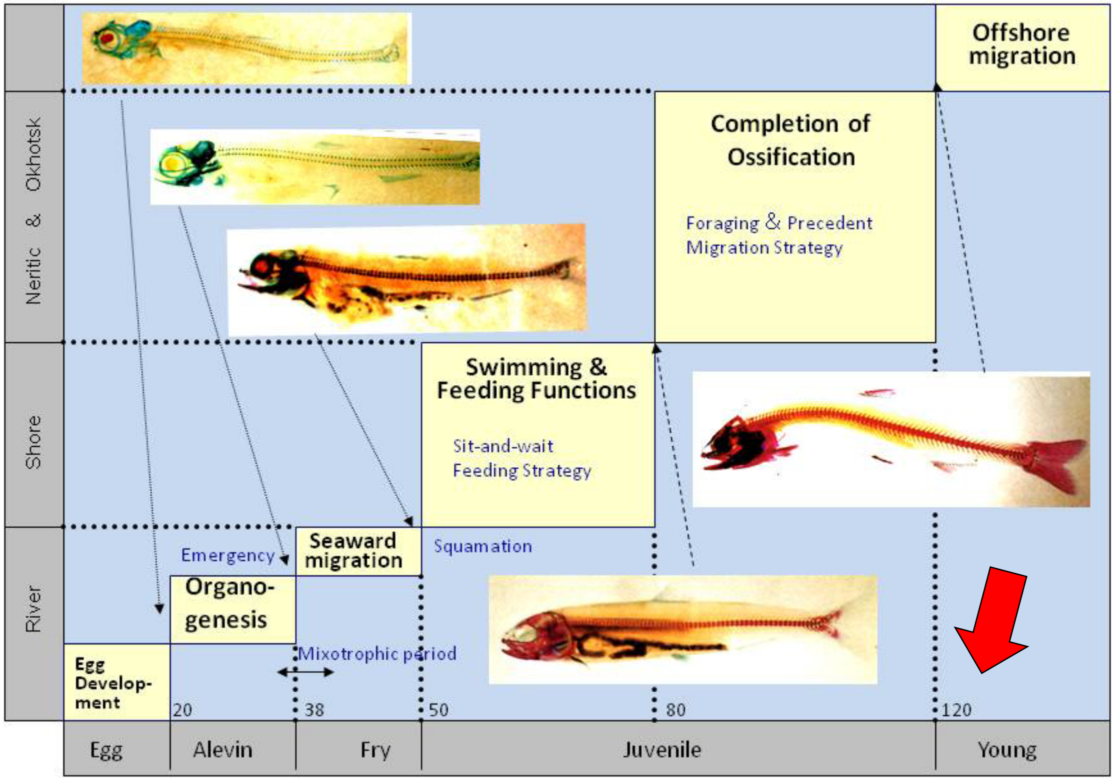
- World fish catches have peaked since the 1990s despite increase in aquaculture production.
- "Large predatory fish biomass today is only about 10% of pre-industrial levels" (Myers & Worm 2003). Bluefin tuna populations are already "Critically Endangered" species in IUCN
- Although production of aquacultures are increasing in the world, many aquacultures cause destruction of aquatic ecosystems, marine pollution, and threats to marine food security.
- 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.

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

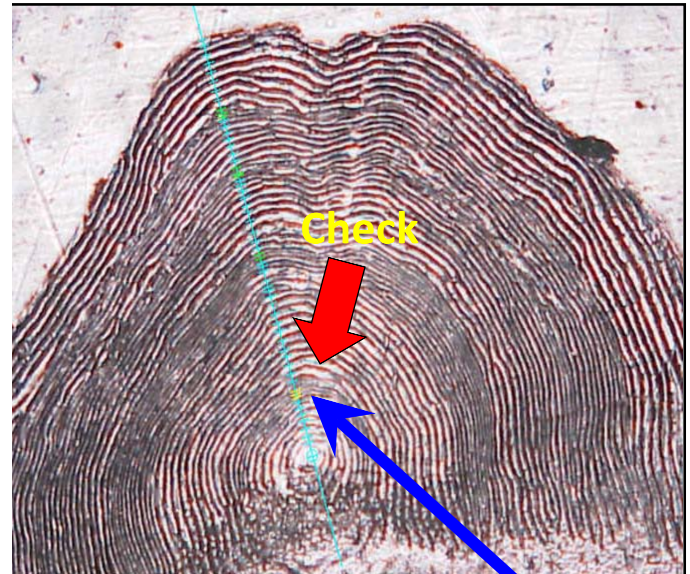
Food security of farmed Atlantic salmon (Hites et al. 2004)

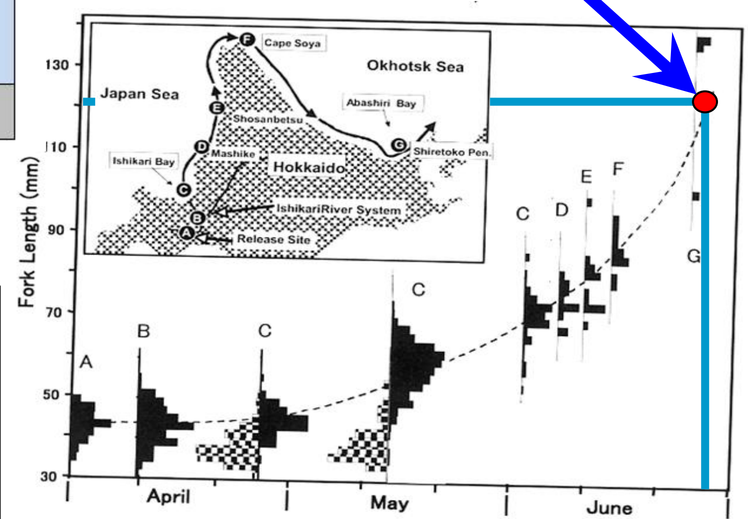


Migration pattern of juvenile chum salmon released from Hokkaido



The development stage and ossification of chum salmon in the early life period (Kaeriyama 1986)





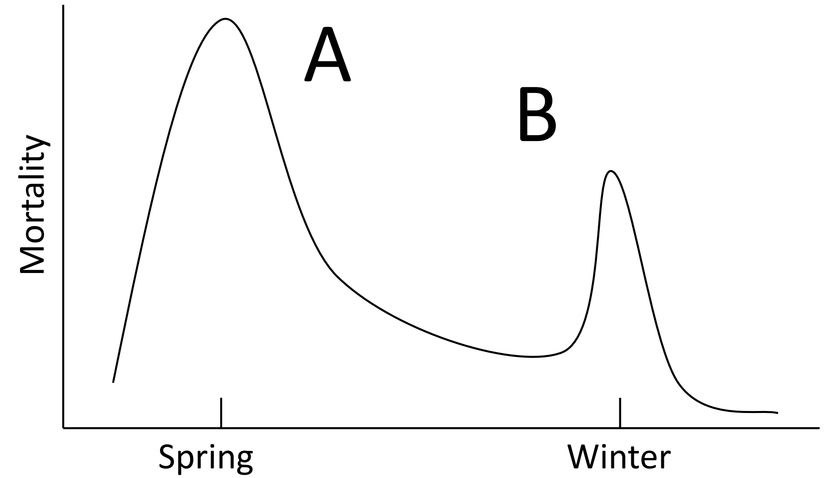
Growth pattern of chum salmon in the coast sea (Mayama & Ishida 2003)

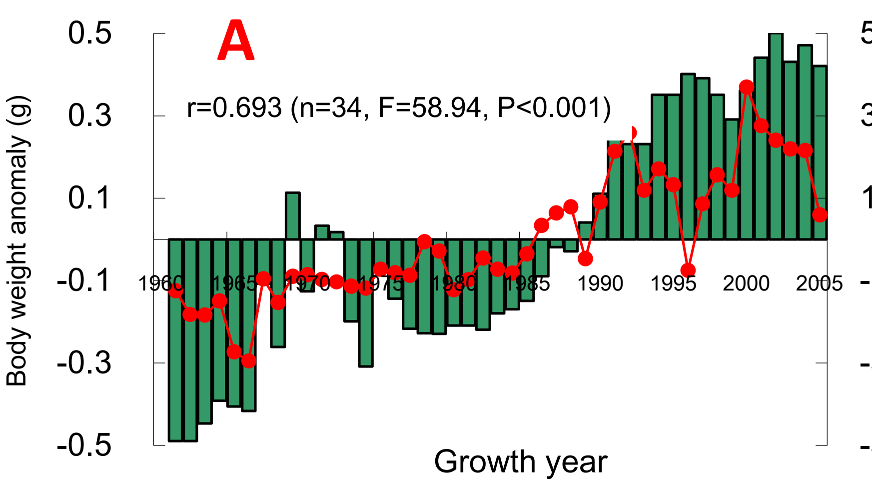
Migration pattern of juvenile chum salmon

- Foraging & precedent migration in the coast
- Offshore migration at 12 cm in FL by the end of June
- Distribution in the Okhotsk Sea during the first summer and autumn period of the ocean life

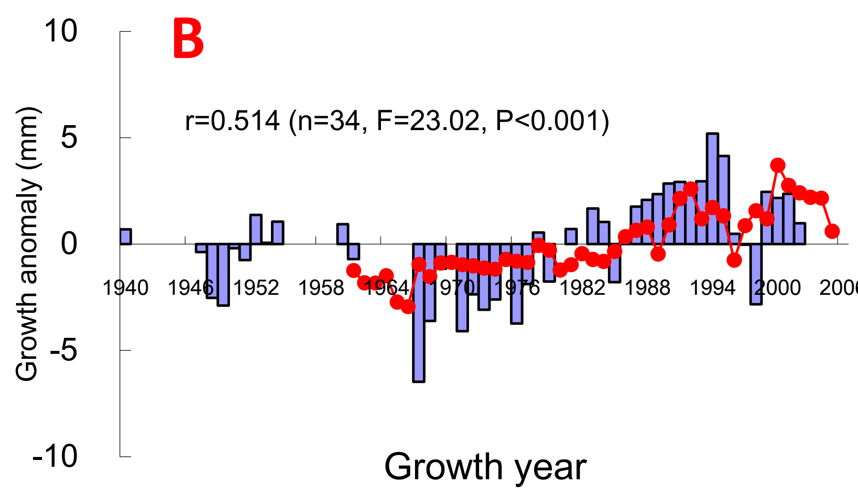
Period of Critical Mortality in chum salmon

1. **Healey (1982):** Size-selective mortality immediately after the seaward migration
   → Spring (A)
2. **Beamish et al. (2004):** Size-related mortality over the first marine wintering
   → Winter (B)

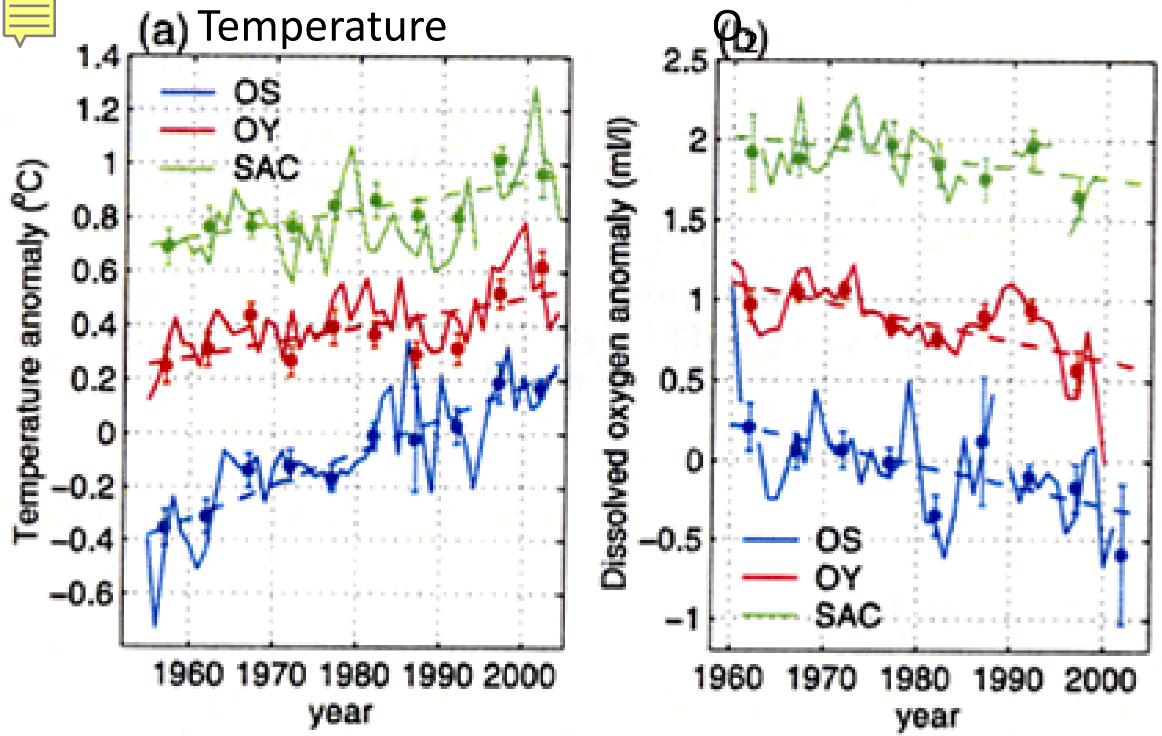




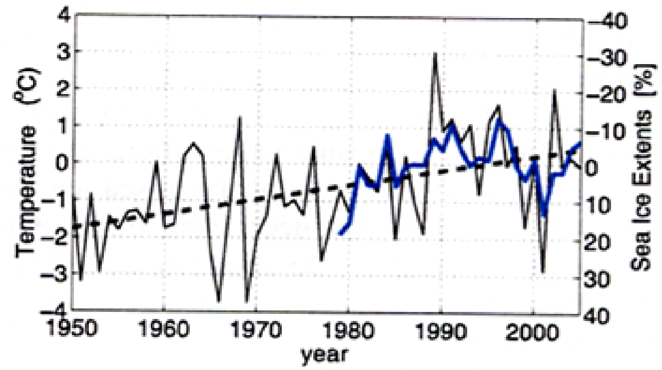
Changes in body weight (BW) of juvenile released and survival rate (RR) of chum salmon in Hokkaido.



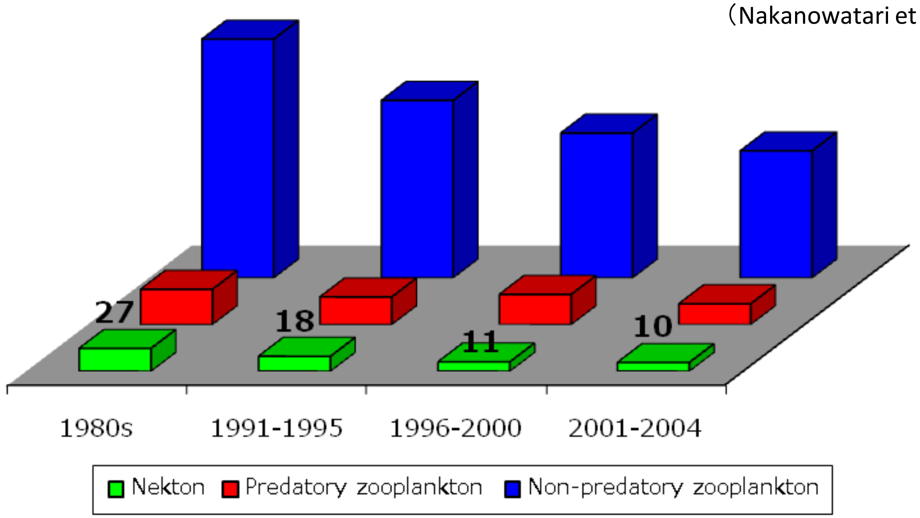
Changes in anomaly of growth at age-1 (Length) and return rate (RR) of chum salmon in Hokkaido.



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 & Impacts on material cycle

Growth of chum salmon

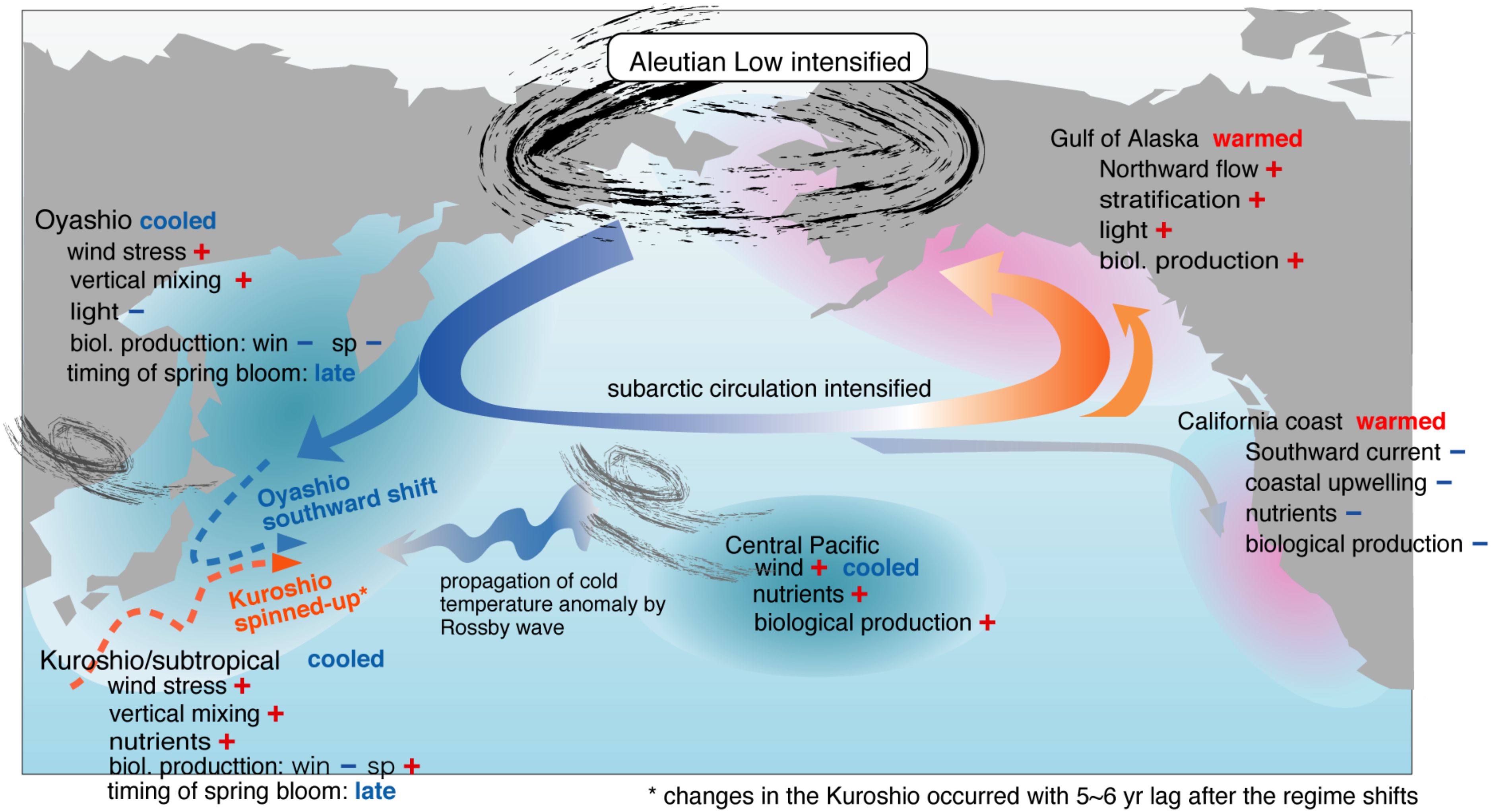
↓

SST

Wintertime climate and winter-spring production: 1976/77RS

After 1976/77 Regime shift

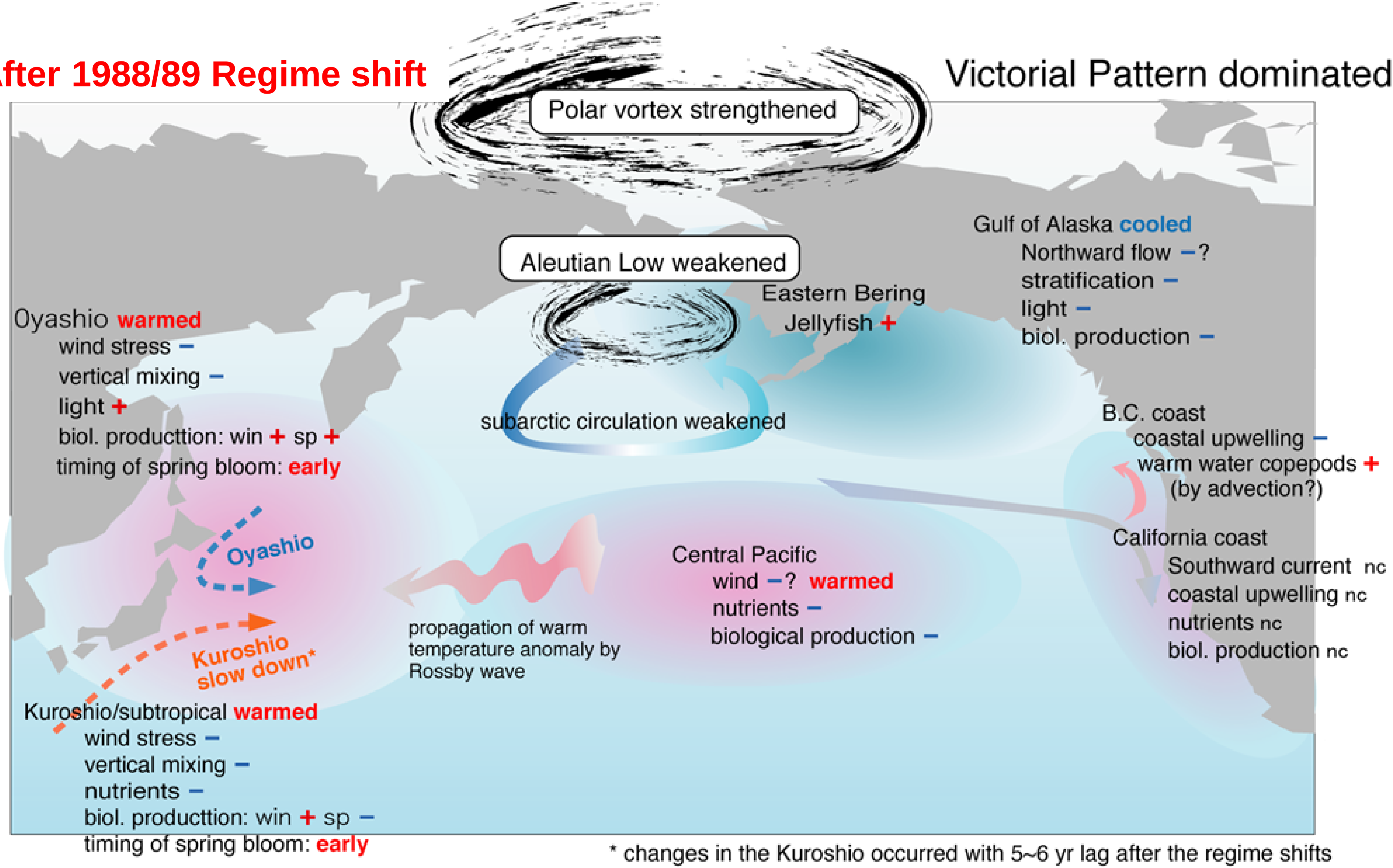
PDO pattern dominated



* changes in the Kuroshio occurred with 5~6 yr lag after the regime shifts

Presented by Akihiko Yatsu in CCCC, 2006 (modified from Chavez et al 2003 * information of the western North Pacific added by Chiba)

Wintertime climate and winter-spring production: 1988/89RS

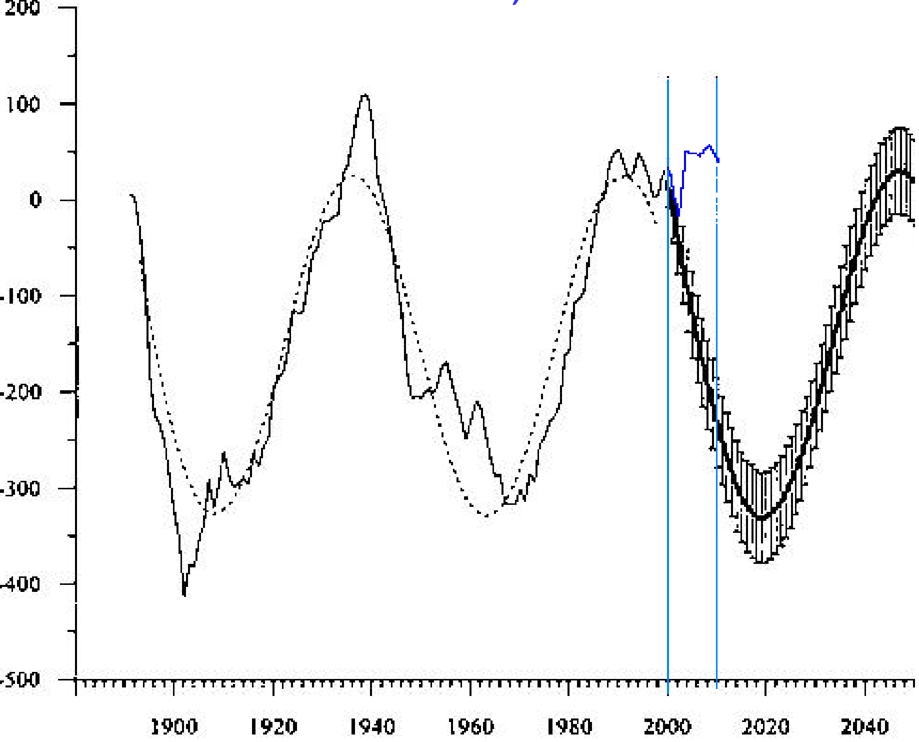


Presented by Akihiko Yatsu in CCCC, 2006 (Fig by Chiba based on various sources)

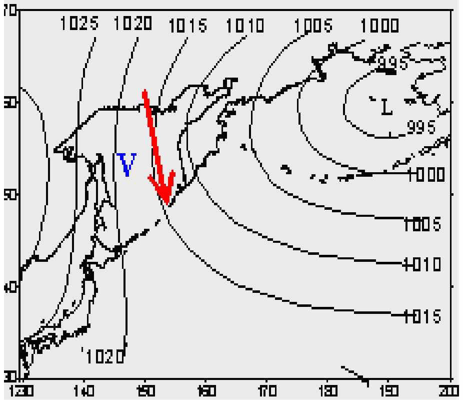
Global and regional atmospheric circulation patterns

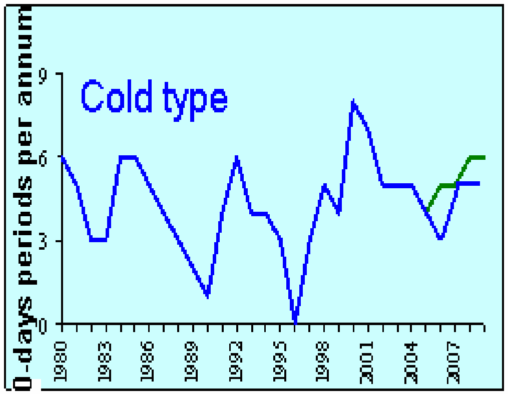
Thin solid line – ACI_WE atmospheric circulation index (zonal), 1891-1999, dashed line – its model (harmonic oscillation). Thick solid line with standard deviation error bars – its forecast for 2000-2050, after Klyashtorin & Lyubushin, 2005.

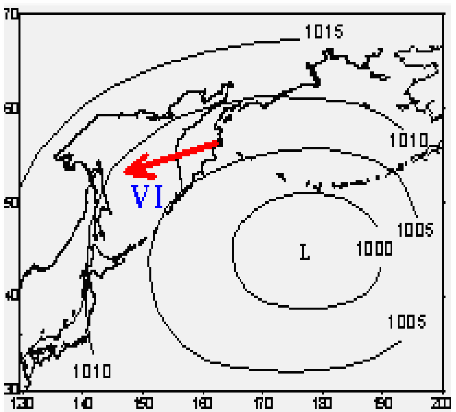
Blue fragment – additional observed data from Dumanskaya & Fedorenko, 2008

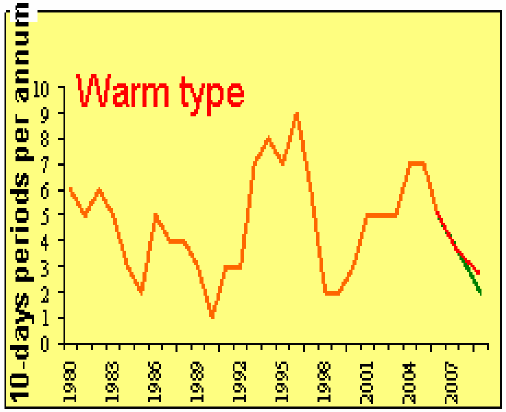


Repetition of the "cold" and "warm" types of atmospheric circulation above the Sea of Okhotsk, in accordance to Glebova (2006) classification. Green line – previous forecasts

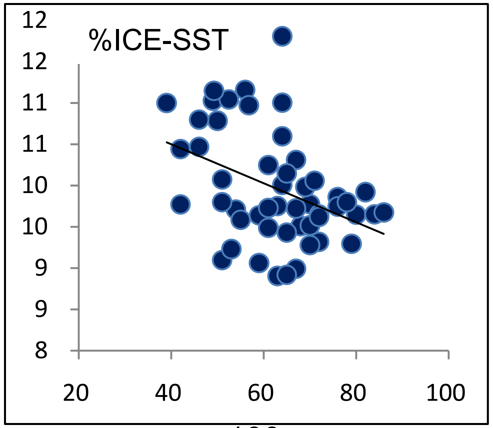


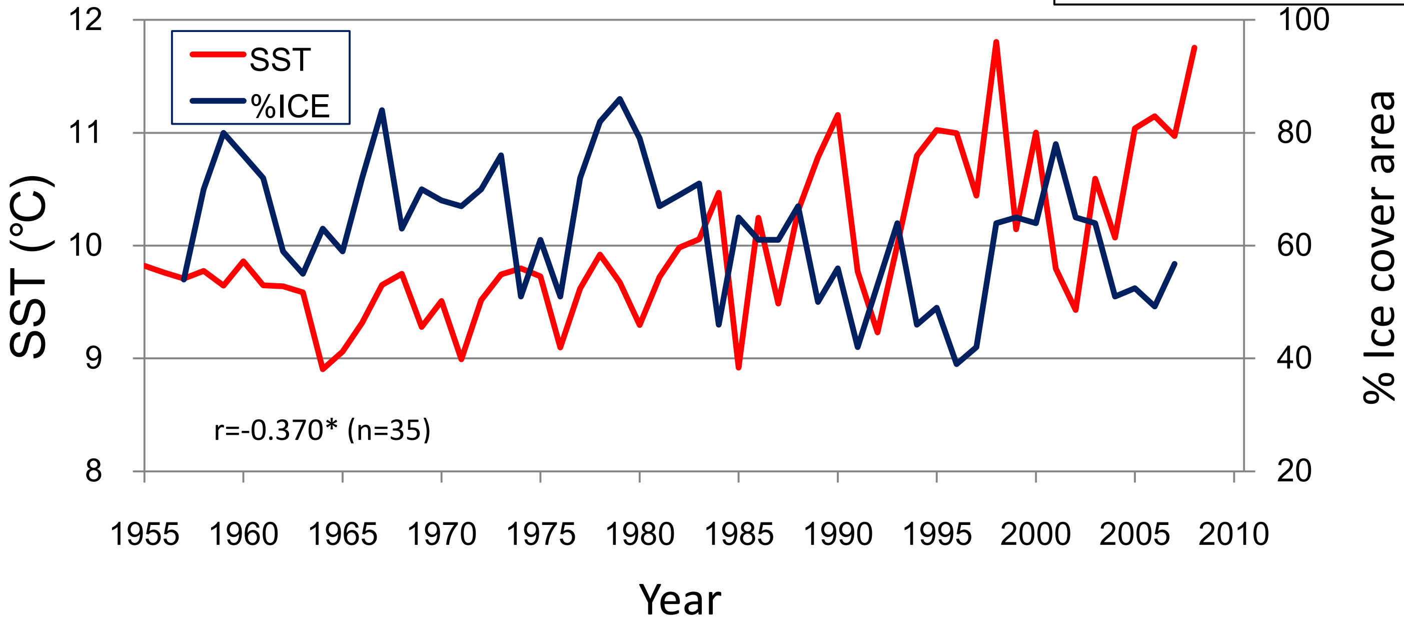


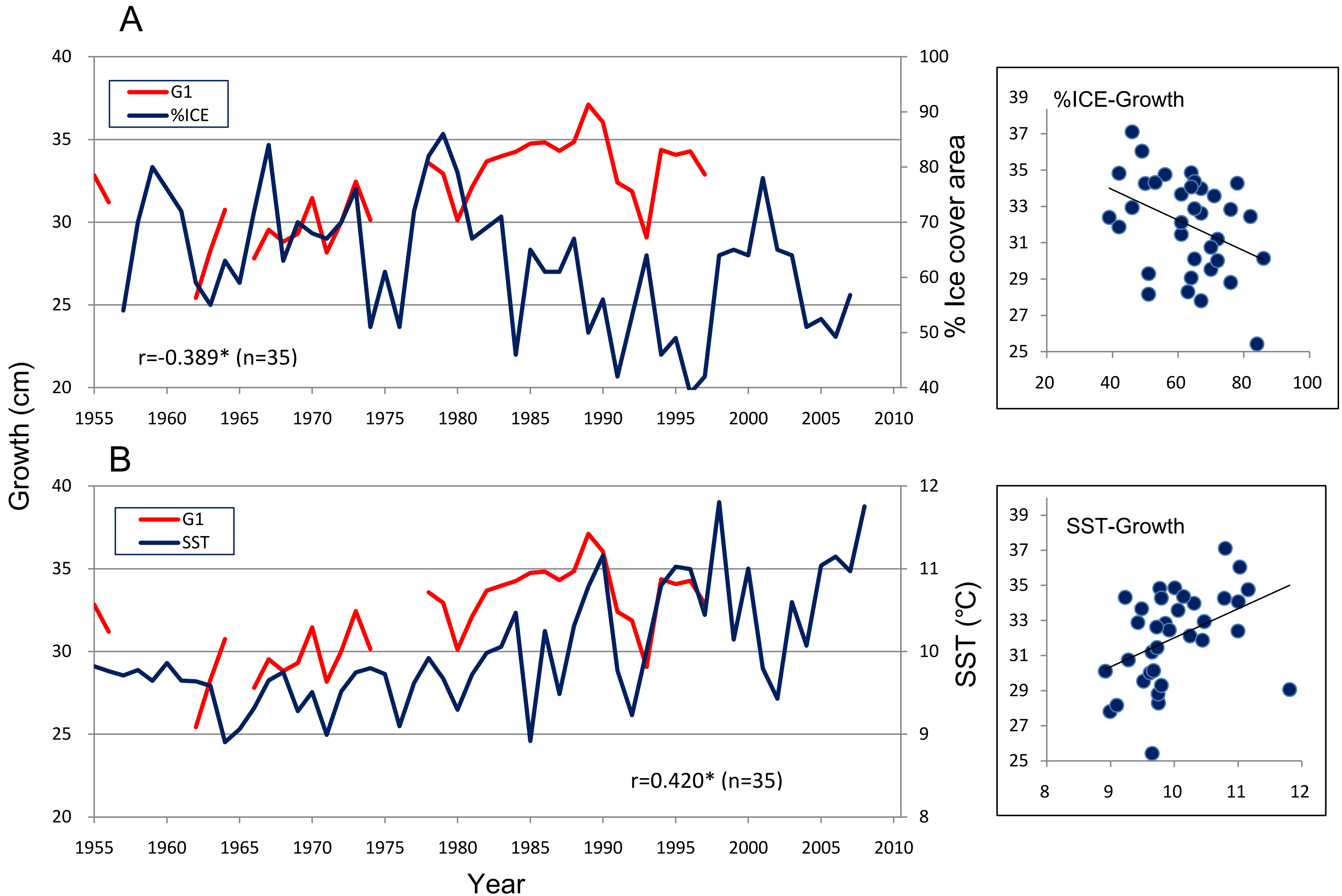




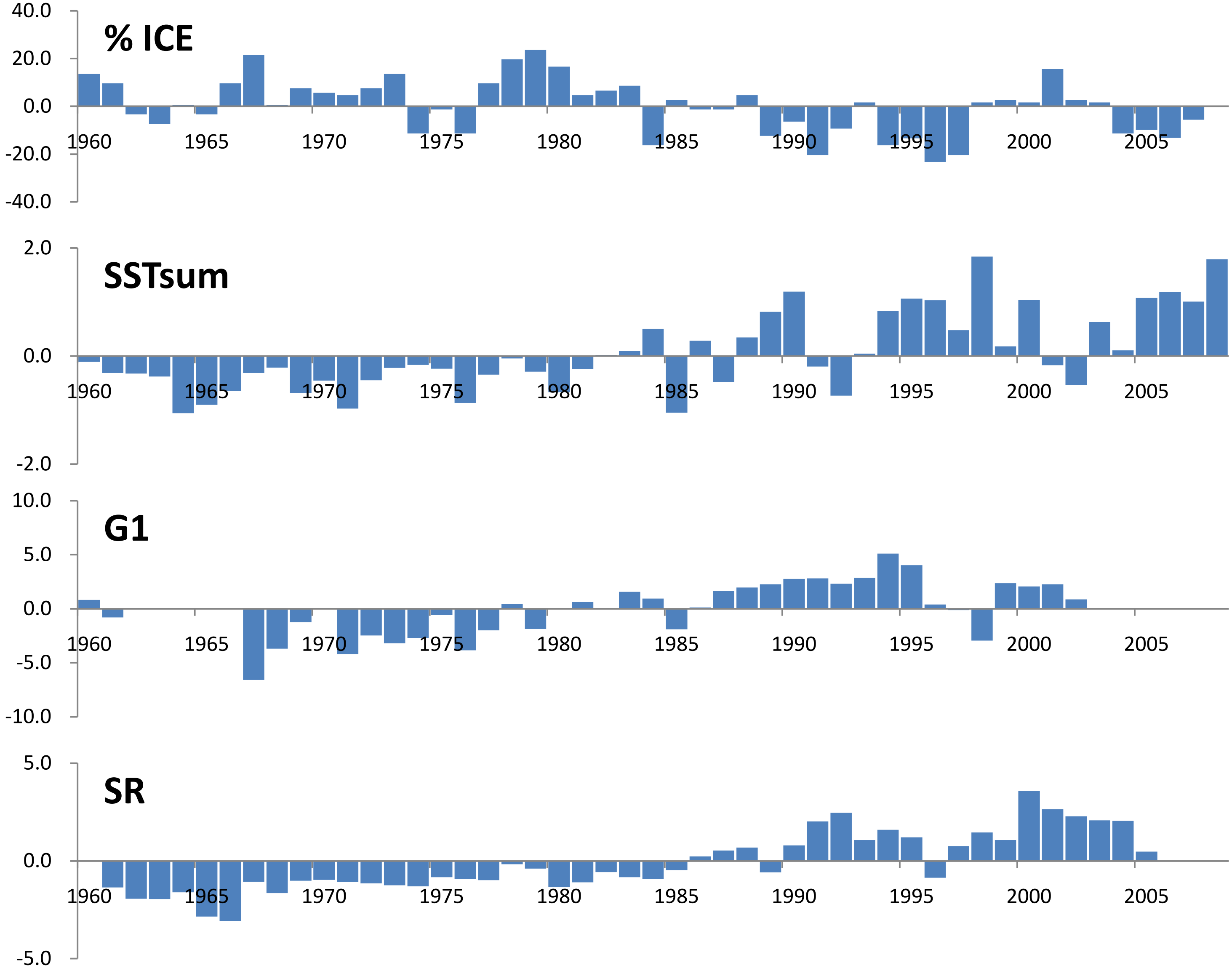
Temporal changes in the sea ice cover rate and the sea surface temperature (SST) during summer and autumn seasons in the Sea of Okhotsk.







Temporal changes in the growth at age-1 of Hokkaido chum salmon population, the sea ice cover rate (%ICE) and the sea surface temperature (SST) during summer and autumn seasons in the Sea of Okhotsk.

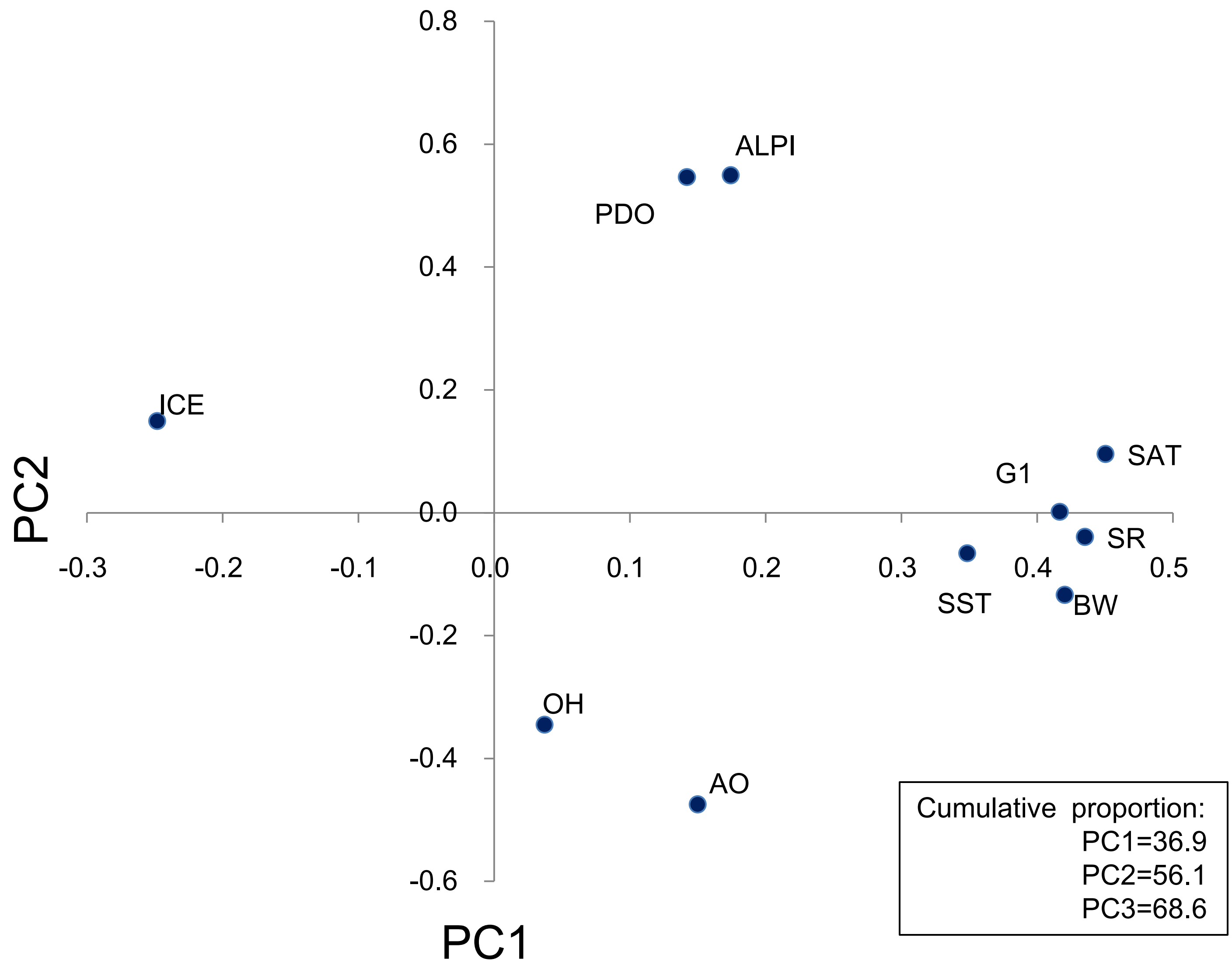

% ICE
40.0
20.0
0.0
-20.0
-40.0
SSTsum
2.0
0.0
-2.0
G1
10.0
5.0
0.0
-5.0
-10.0
SR
5.0
0.0
-5.0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

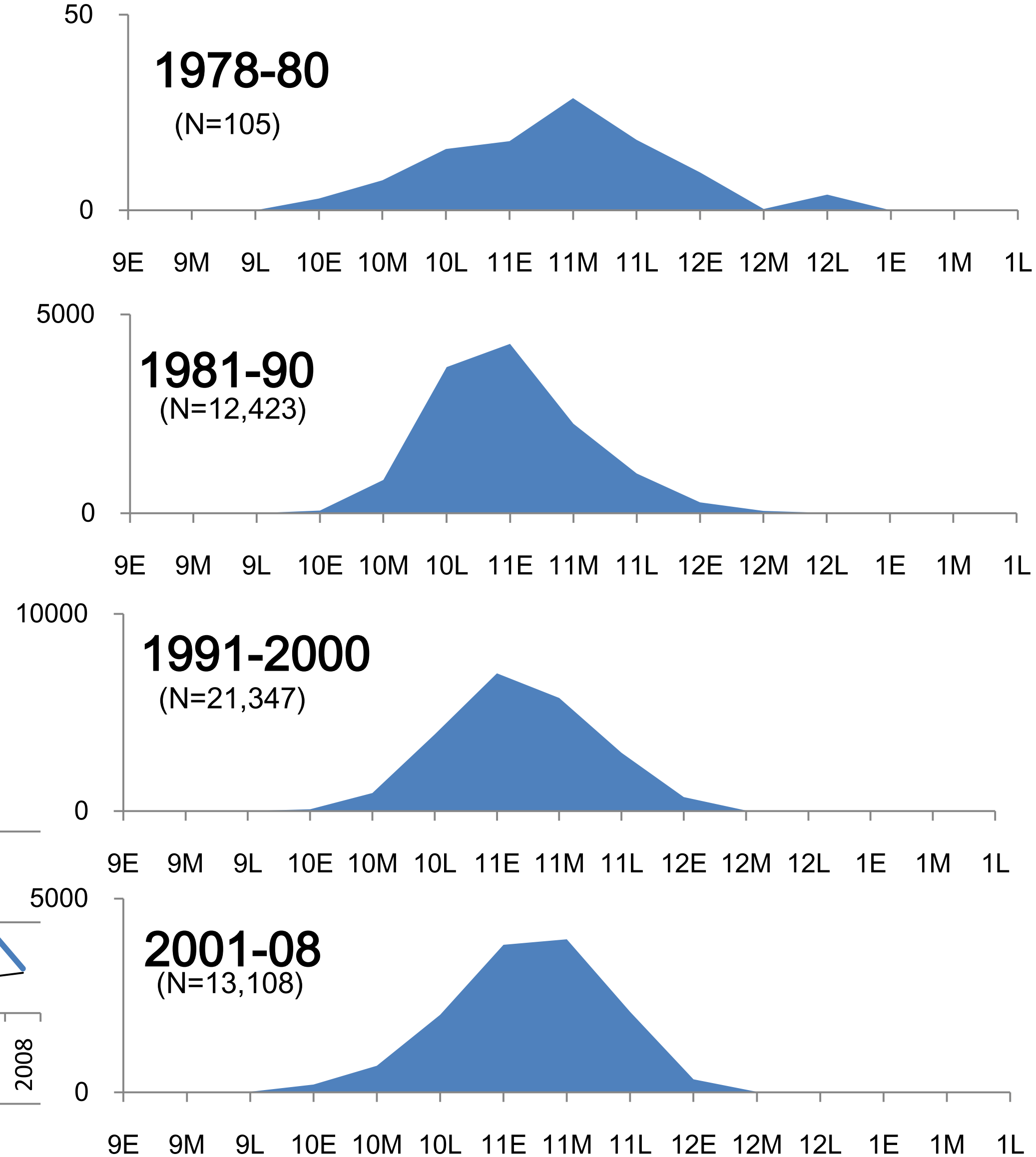
Correlations

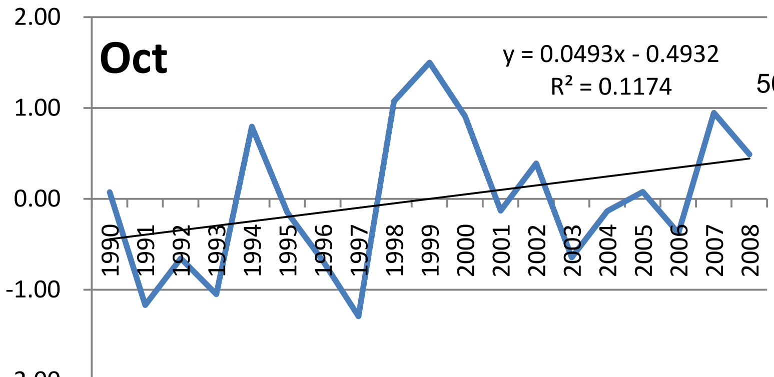
		ICE	SSTSUM	G1	SR
ICE	Pearson Correlation	1.000	-.370*	-.407*	-.190
	Sig. (2-tailed)	.	.031	.017	.282
	N	34	34	34	34
SSTSUM	Pearson Correlation	-.370*	1.000	.423*	.341*
	Sig. (2-tailed)	.031	.	.013	.048
	N	34	34	34	34
G1	Pearson Correlation	-.407*	.423*	1.000	.639**
	Sig. (2-tailed)	.017	.013	.	.000
	N	34	34	34	34
SR	Pearson Correlation	-.190	.341*	.639**	1.000
	Sig. (2-tailed)	.282	.048	.000	.
	N	34	34	34	34

*. Correlation is significant at the 0.05 level (2-tailed).

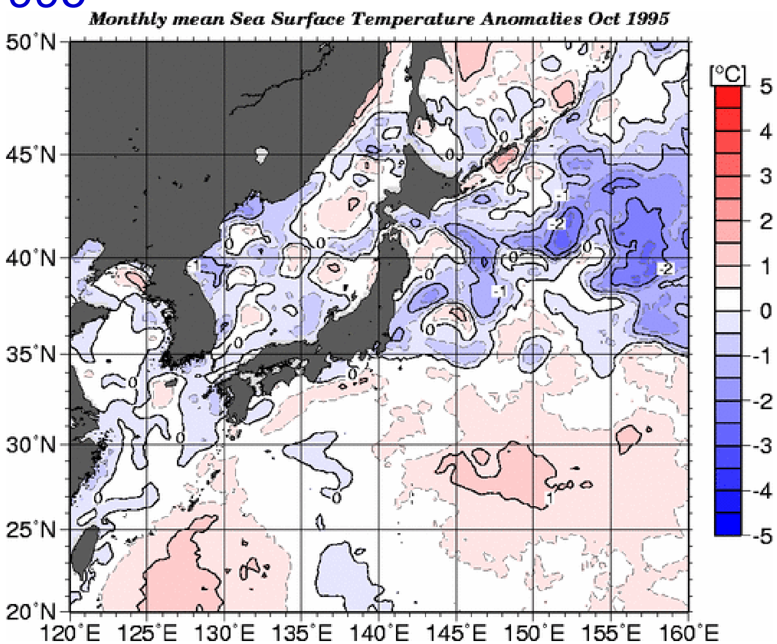
**. Correlation is significant at the 0.01 level (2-tailed).


0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
PC2
PC1
ALPI
PDO
ICE
SAT
G1
SR
SST
BW
OH
AO
Cumulative proportion:
PC1=36.9
PC2=56.1
PC3=68.6

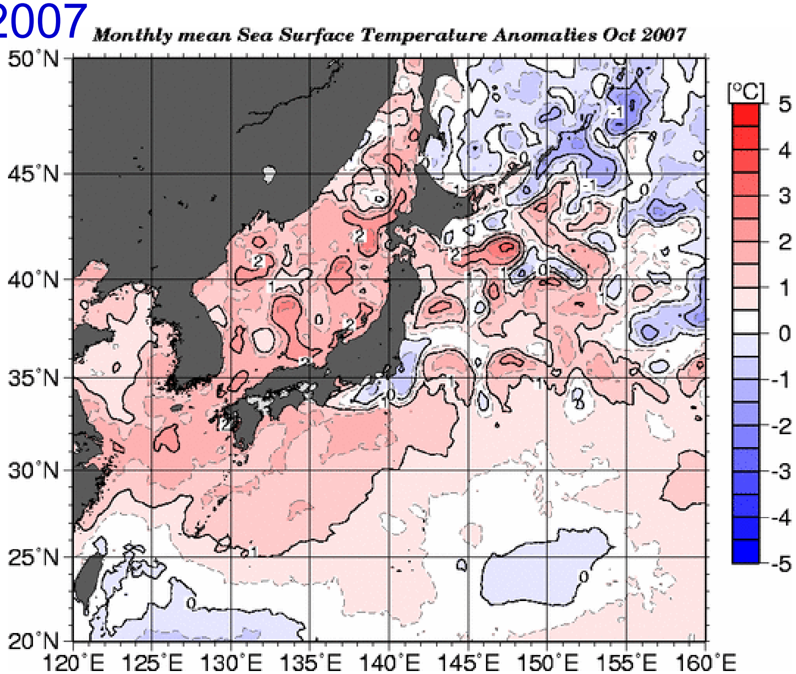

1978-80
(N=105)
1981-90
(N=12,423)
1991-2000
(N=21,347)
2001-08
(N=13,108)
50
5000
10000
0
9E 9M 9L 10E 10M 10L 11E 11M 11L 12E 12M 12L 1E 1M 1L

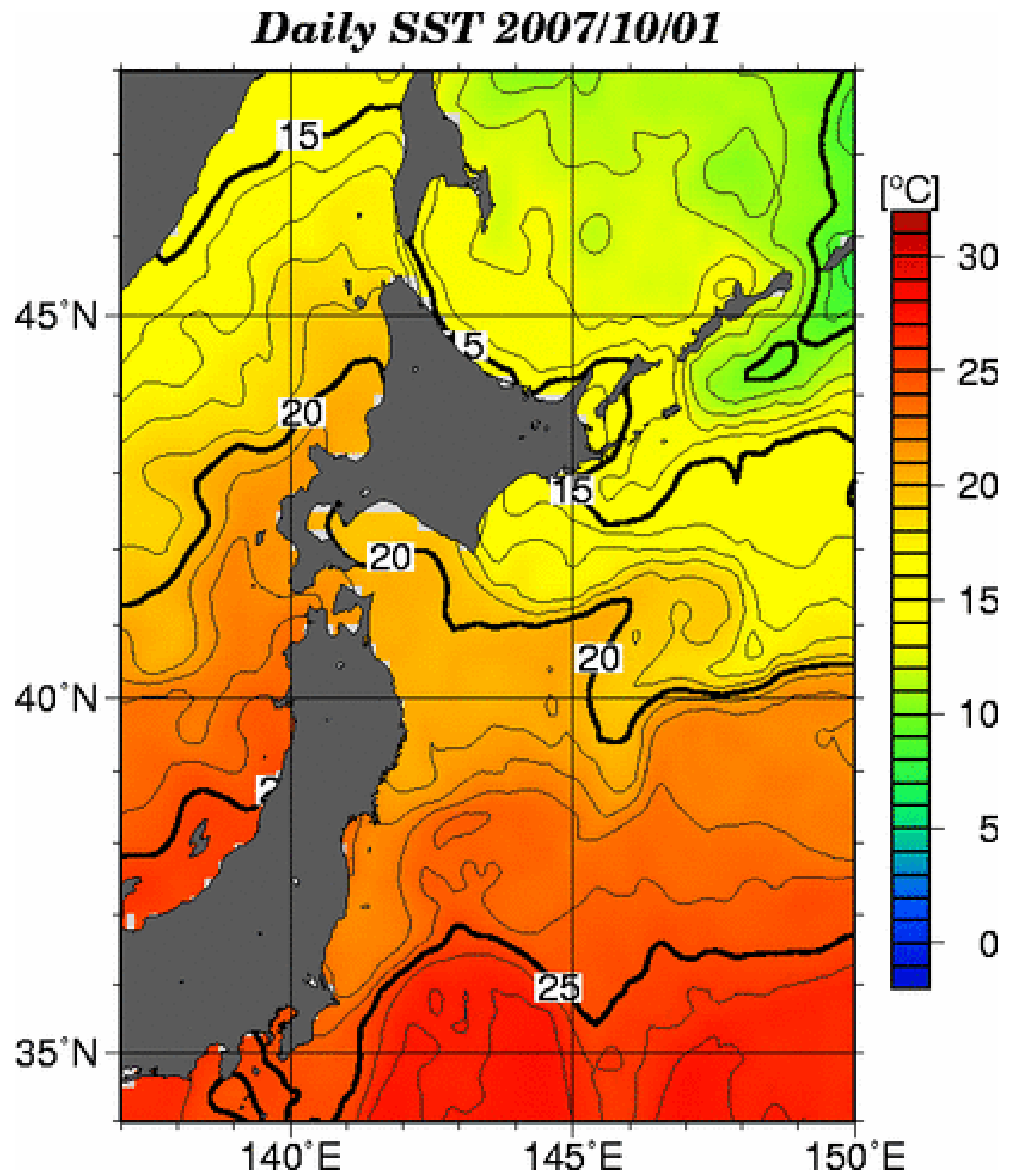

Oct
y = 0.0493x - 0.4932
R² = 0.1174
2.00
1.00
0.00
-1.00
-2.00
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008

1995


Monthly mean Sea Surface Temperature Anomalies Oct 1995
50°N
45°N
40°N
35°N
30°N
25°N
20°N
120°E 125°E 130°E 135°E 140°E 145°E 150°E 155°E 160°E
[°C]
5 4 3 2 1 0 -1 -2 -3 -4 -5

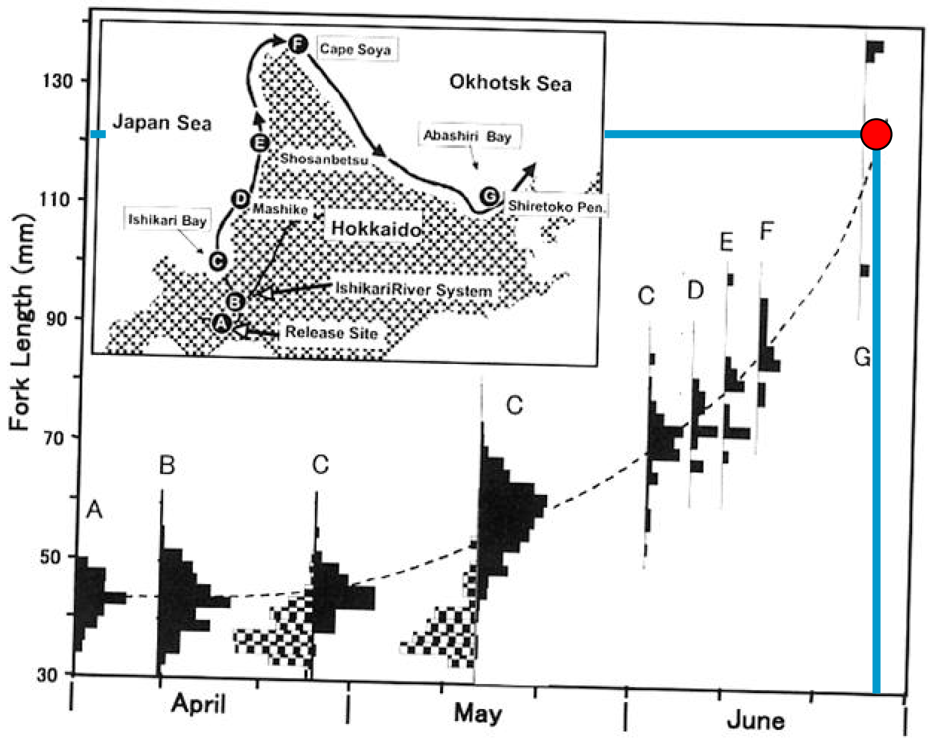
2007


Monthly mean Sea Surface Temperature Anomalies Oct 2007
50°N
45°N
40°N
35°N
30°N
25°N
20°N
120°E 125°E 130°E 135°E 140°E 145°E 150°E 155°E 160°E
[°C]
5 4 3 2 1 0 -1 -2 -3 -4 -5

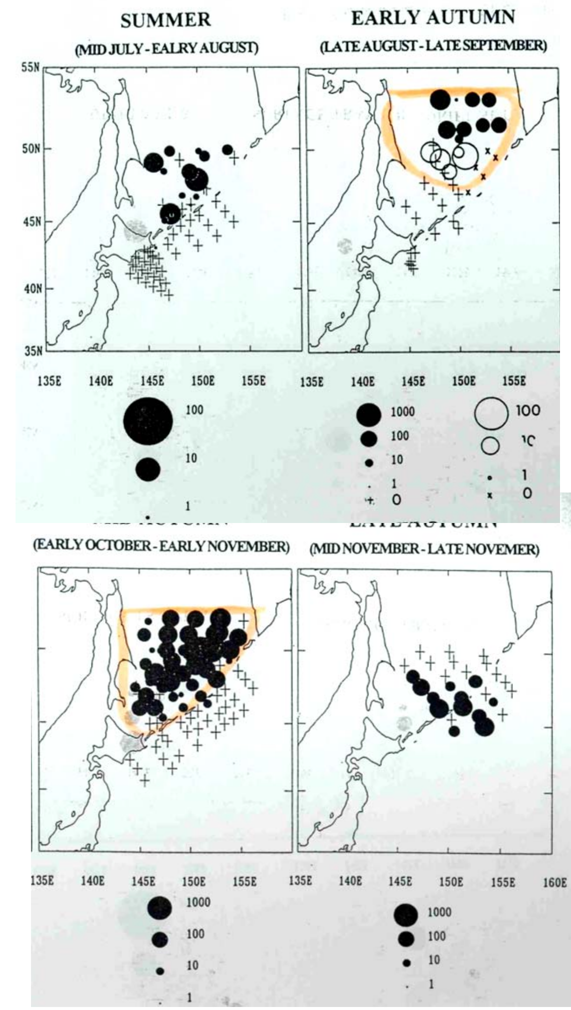

Daily SST 2007/10/01
45°N
40°N
35°N
140°E 145°E 150°E
[°C]
30 25 20 15 10 5 0
15
20
25

Migration pattern of juvenile chum salmon

- Prior residence near the spawning area
- Growth inversion in the river
- Foraging & precedent migration in the coast
- Offshore migration at 12 cm in FL by the end of June
- Distribution in the Okhotsk Sea during the first summer and autumn period of ocean life



(Mayama & Ishida 2003)



Distribution of juvenile chum salmon in the Okhotsk Sea (Ueno et al. 1998)