The effect of global warming and density-dependence on Hokkaido chum salmon from the 1940s to the early-2000s

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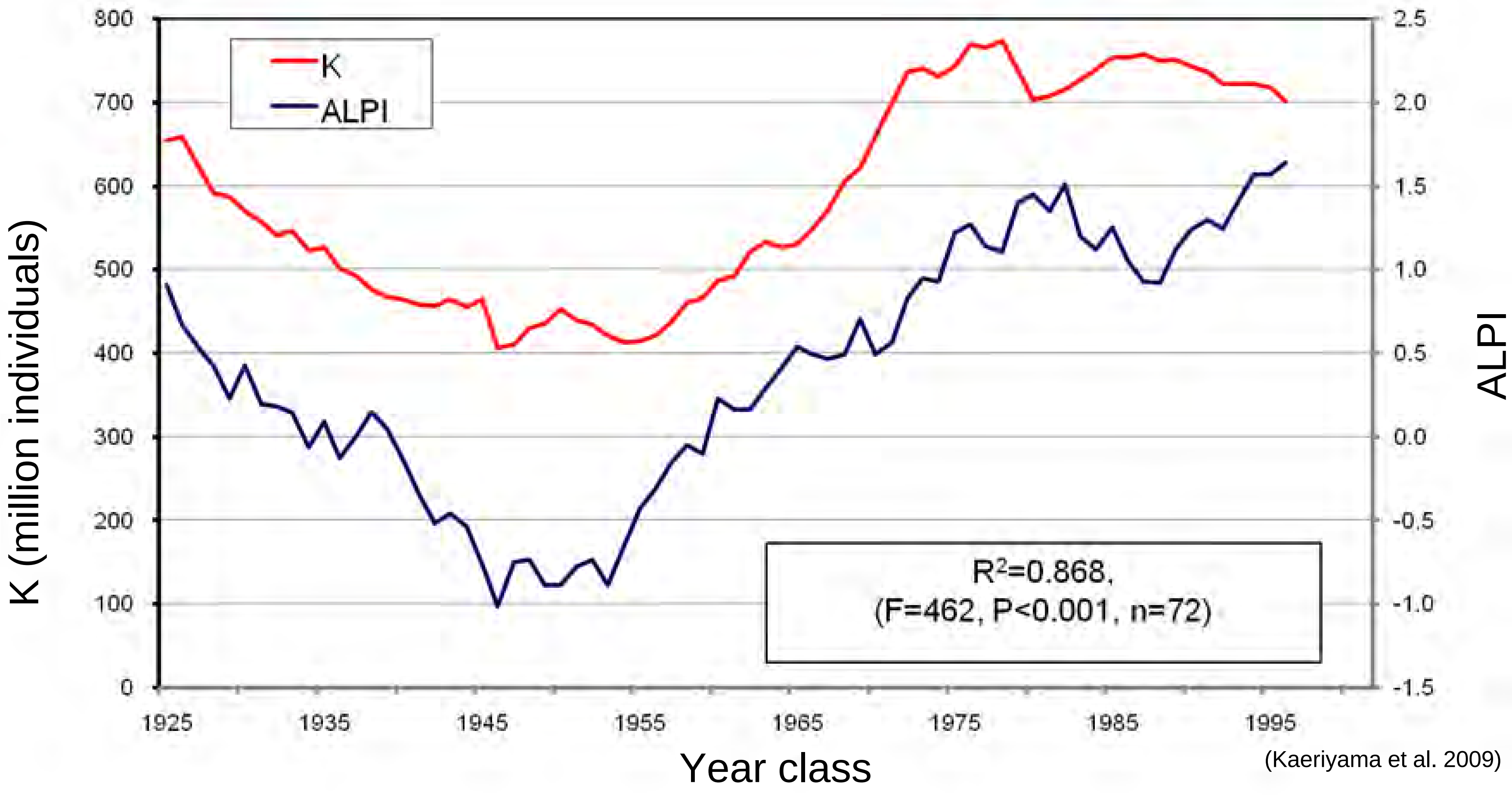
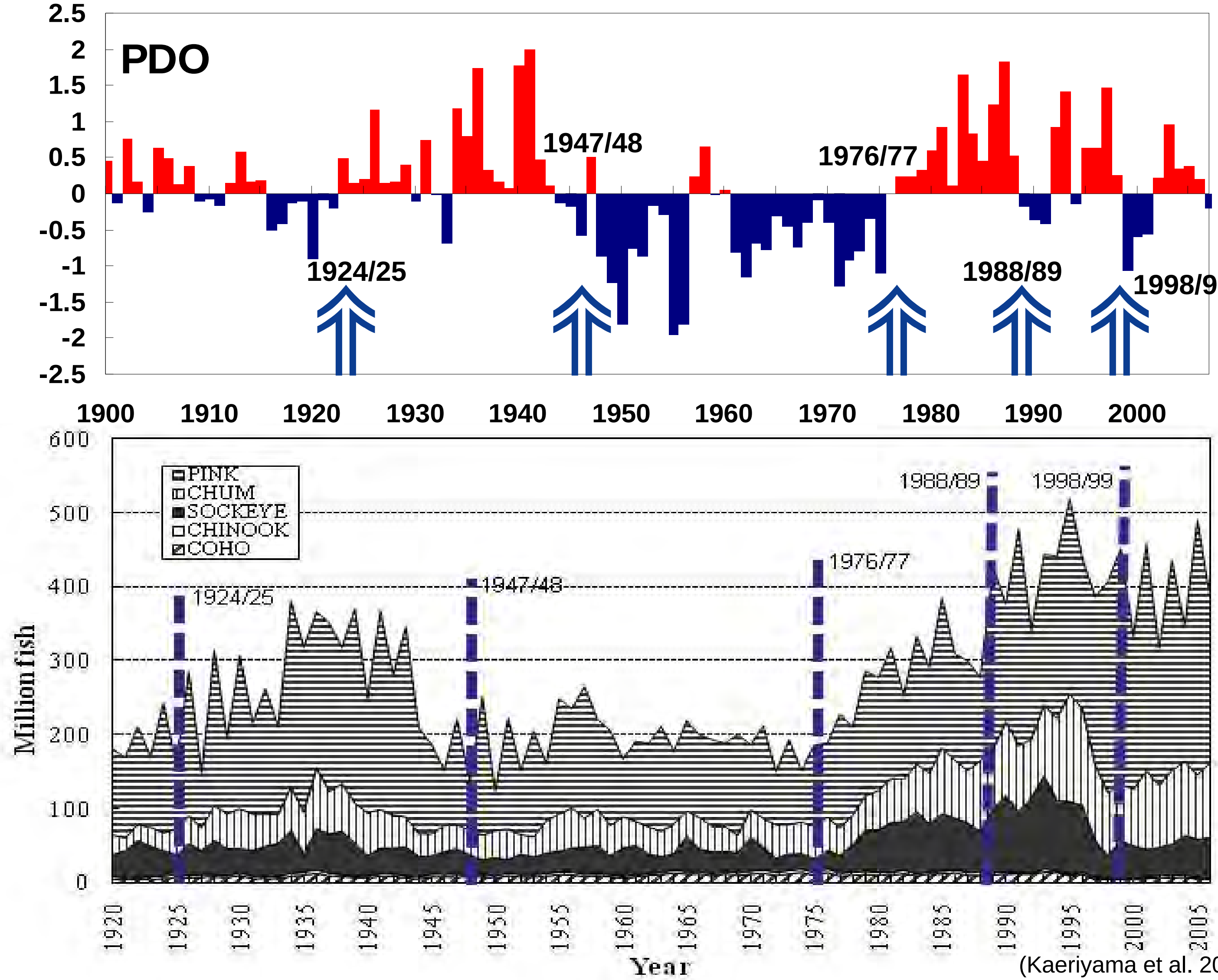
Temporal changes in ALPI and carrying capacity (K) of three species (sockeye, chum, and pink salmon)



(Kaeriyama et al. 2009)

- ✓**Pacific salmon: Keystone species in North Pacific ecosystems** (Kaeriyama 2008)
- ✓**Salmon carrying capacity: Synchronization with the long-term climate change** (Kaeriyama et al. 2009)

Annual changes in catches of Pacific salmon and climate Regime Shift in Pacific Decadal Oscillation (PDO)



(Kaeriyama et al. 2009)

✓ **The catch of Pacific salmon seems to link with climate Regime Shifts in 20th century**

How exactly do climatic/oceanic conditions affect the salmon life history (growth, survival, and population dynamics)?

Purpose

Clarify the mechanism of relationship between climatic/oceanic conditions and long-term fluctuations in life history of chum salmon in the North Pacific Oceans

Topics

Global warming effect on chum salmon

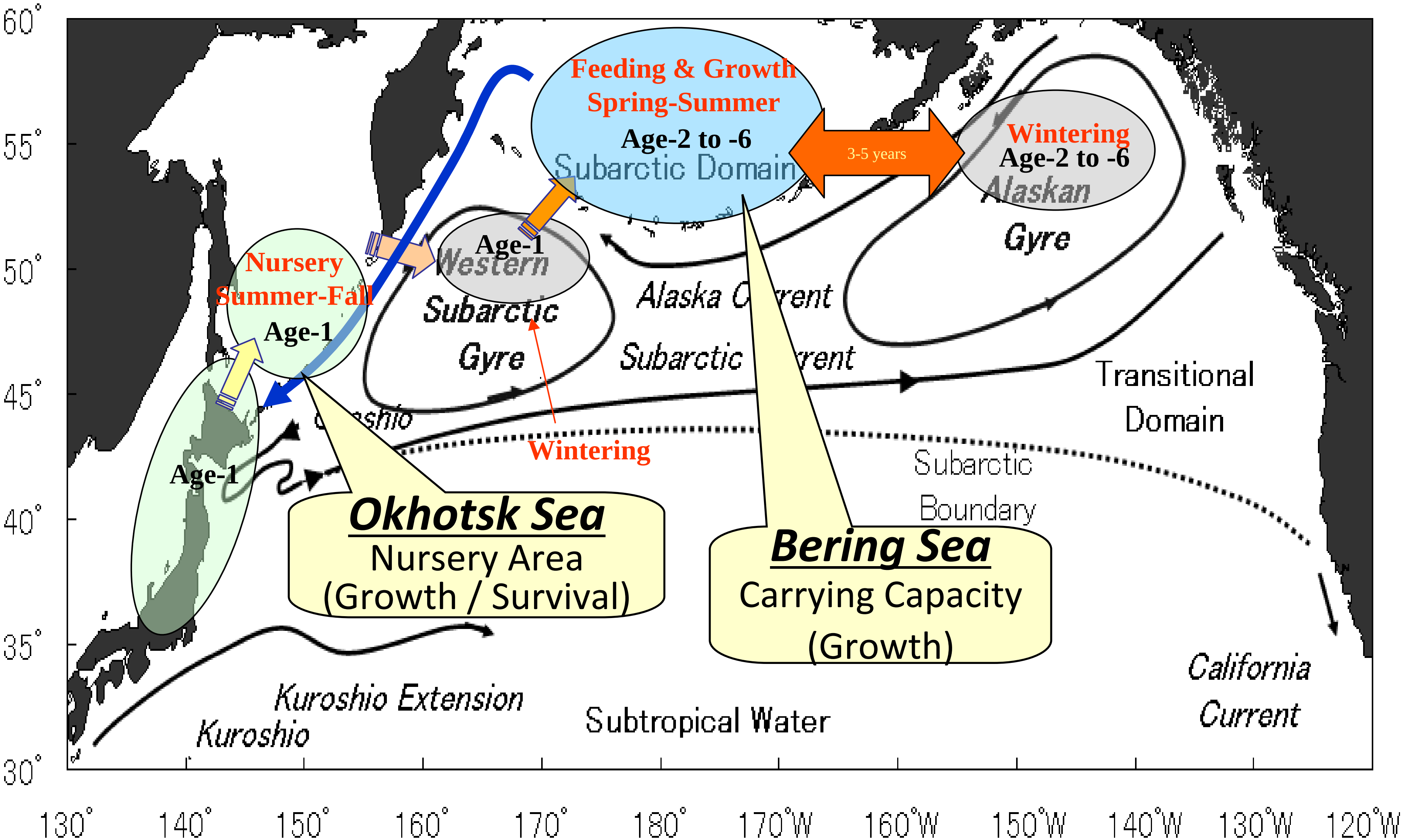
1. **Past: Path model analysis**

   Mechanism on relationship between climatic/oceanic conditions and salmon life history

2. **Future: Prediction**

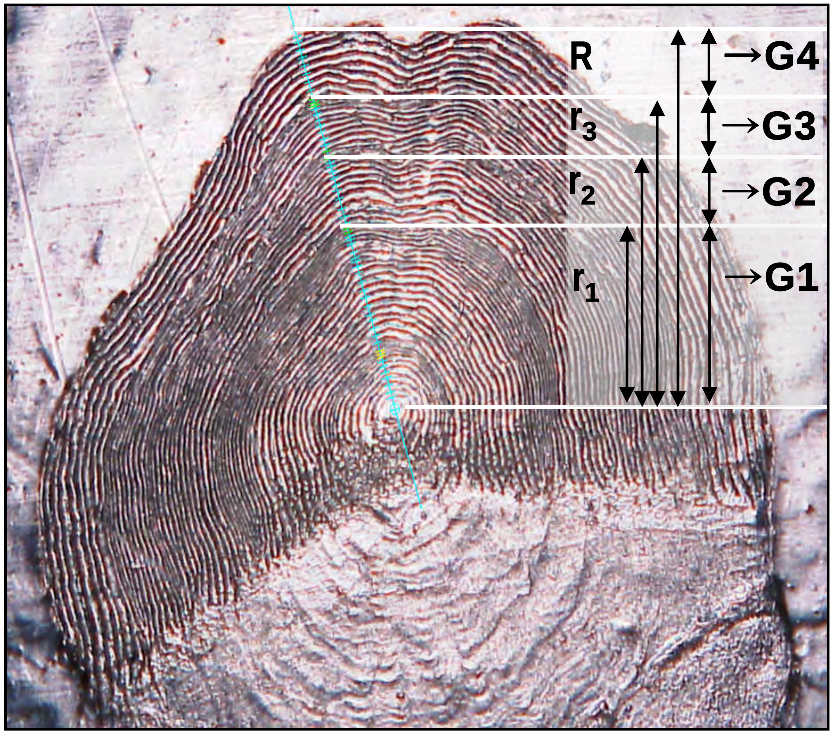
   IPCC SRES-A1B scenario and optimum temperature for chum salmon during their growth and feeding migration

Migration route of Japanese chum salmon



(Urawa 2000; Yatsu & Kaeriyama 2005)

Growth back calculation using scale analysis



1. Scale sample (n=2,936)

Age-4 female chum salmon

Ishikari River (Japan), 1943-2005

2. Scale analysis

Scale measurement from focus to annual rings (i.e., $\mathbf{r_1, r_2, r_3, R}$)

Estimated growth at age-1 to -4 (i.e., **G1, G2, G3, G4**)

R = total scale radius,

r_i = scale radius at age i

3. Back calculation (Smale and Taylor 1987; Campana 1990; Morita et al. 2005)

$$Gi = G_t - (R - r_i) / (R - r_0) \times (G_t - G_0)$$

Where Gi = back calculated FL at age i,

G_t = FL of adult at the capture,

G_0 and r_0 = FL (4 cm) and scale length (0.0114 cm) at the squamation (Fukuwaka and Kaeriyama 1994)

Database

Index	Definition	Period	Season	Data source
Climatic/oceanic indices and conditions				
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_indx_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)

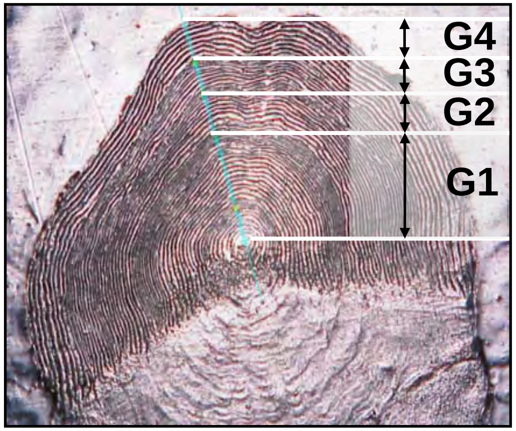
(Seo et al. 2011)

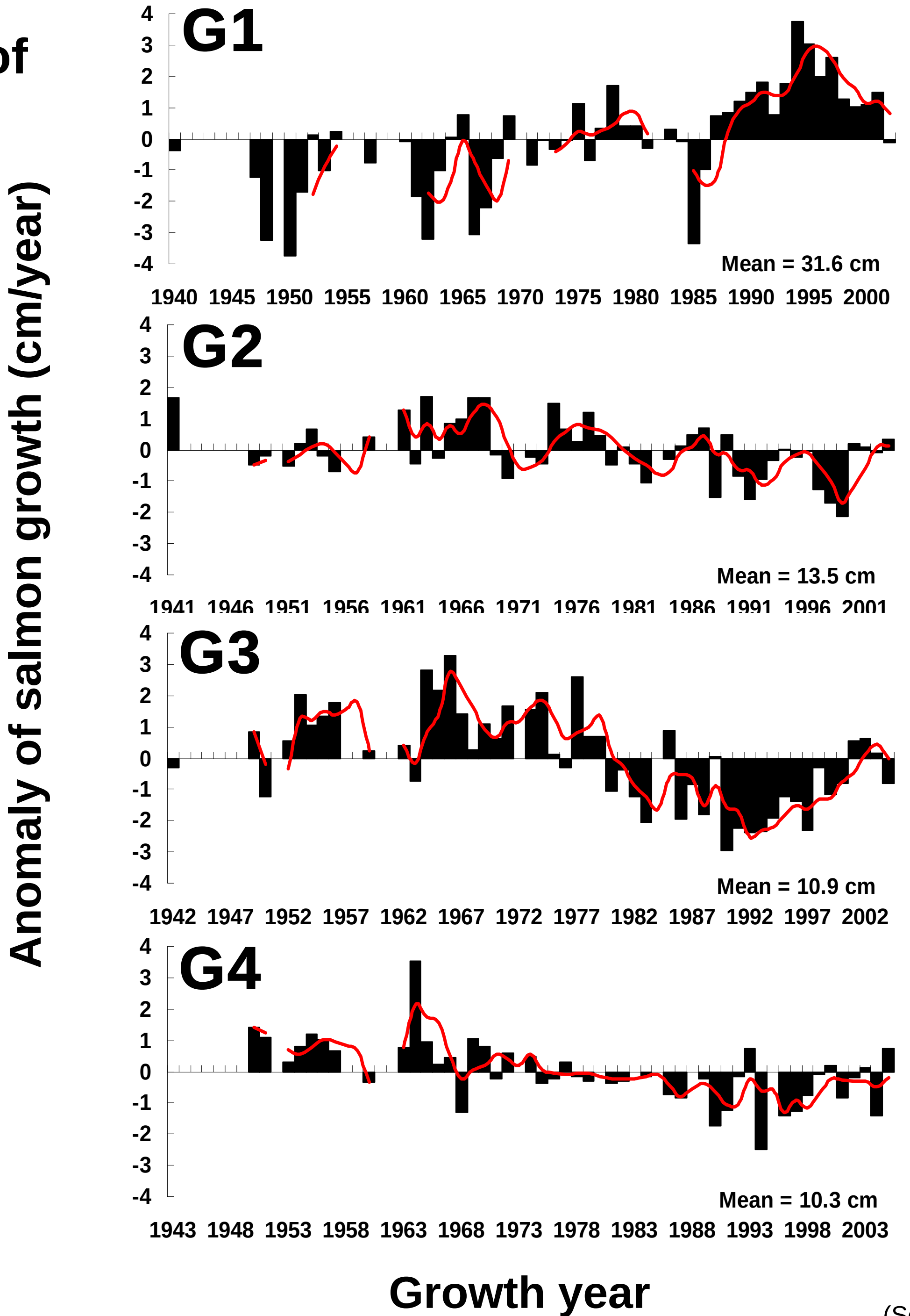
Database (continued)

Index	Definition	Period	Season	Data source
Climatic/oceanic indices and conditions (continued)				
SST_B	Sea Surface Temperature (Bering Sea)	1948-2005	Summer (June to July)	NCEP/NCAR Re-analysis dataset, http://www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl
ZP	ZooPlankton biomass (Bering Sea)	1955-1994	Summer (June to July)	Sugimoto and Tadokoro (1997)
Biological characteristics of salmon				
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

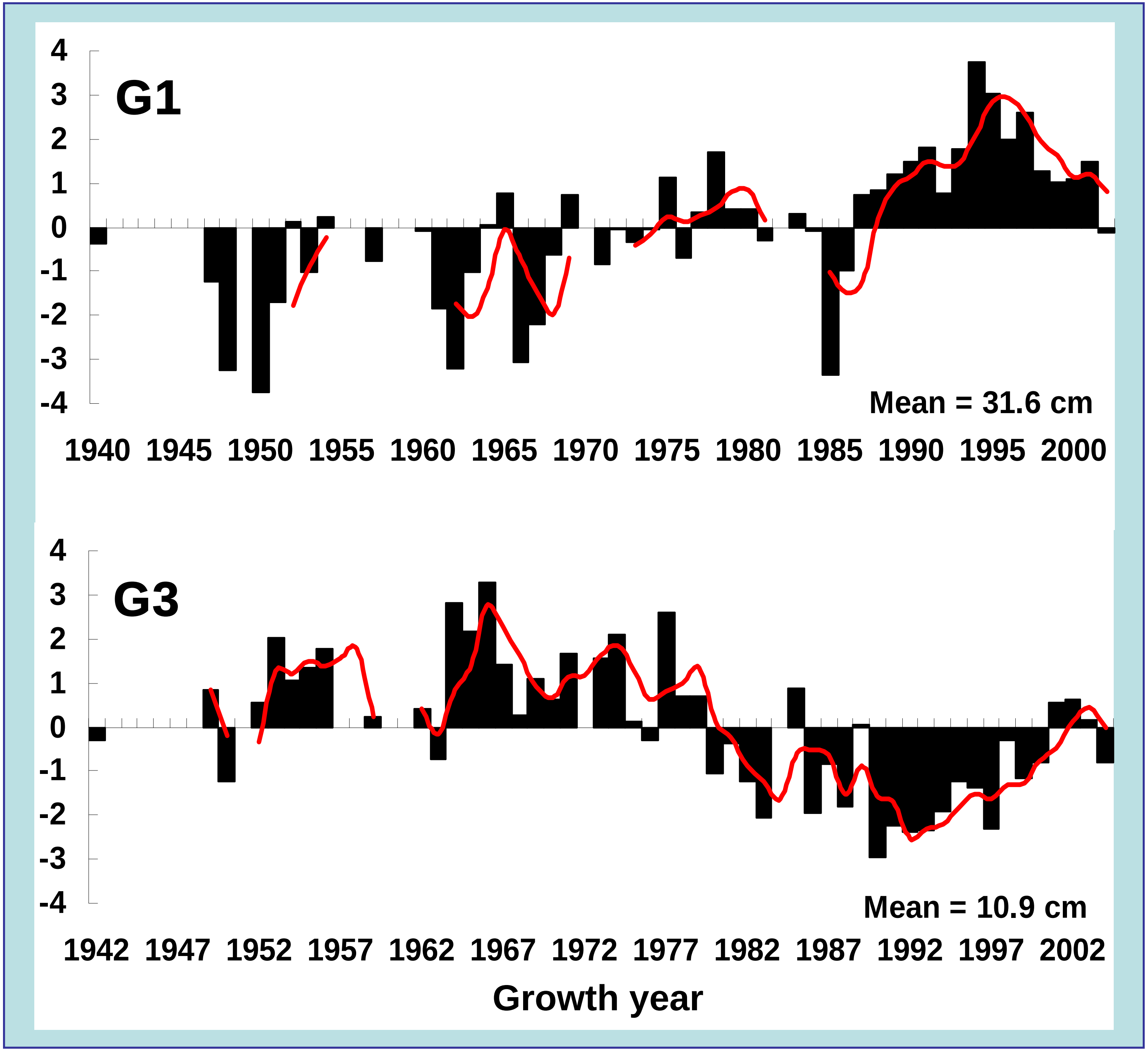
(Seo et al. 2011)

Temporal change in growth of the Ishikari River chum salmon from 1940 to 2005





(Seo et al. 2011)


G1
4
3
2
1
0
-1
-2
-3
-4
Mean = 31.6 cm
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
G3
4
3
2
1
0
-1
-2
-3
-4
Mean = 10.9 cm
1942 1947 1952 1957 1962 1967 1972 1977 1982 1987 1992 1997 2002
Growth year

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

	SAT	AO	SI	OH	ALPI	PDO	SST_o	ICE	G1	SR	PS
SAT	1	0.143	0.979	0.869	0.003	0.141	< 0.001	0.459	0.002	< 0.001	< 0.001
AO	0.236	1	0.302	0.053	0.405	0.25	0.039	0.22	0.093	0.019	0.07
SI	-0.004	0.167	1	0.003	0.253	0.346	0.515	0.015	0.834	0.782	0.529
OH	-0.027	0.309	0.454**	1	0.955	0.828	0.602	0.175	0.987	0.551	0.233
ALPI	0.451**	-0.135	0.185	-0.009	1	< 0.001	0.230	0.813	0.638	0.104	0.052
PDO	0.237	-0.186	-0.153	-0.035	0.547***	1	0.23	0.288	0.071	0.139	0.001
SST_o	0.609***	0.328*	0.106	0.085	0.194	0.194	1	0.024	< 0.001	0.003	0.001
ICE	-0.121	-0.198	-0.383*	-0.219	0.039	-0.172	-0.357*	1	0.02	0.267	0.105
G1	0.475**	0.27	-0.034	-0.003	0.077	0.288	0.552***	-0.367*	1	< 0.001	< 0.001
SR	0.731***	0.368*	-0.045	0.097	0.261	0.238	0.458**	-0.18	0.566***	1	< 0.001
PS	0.675***	0.289	-0.103	0.193	0.31	0.521	0.522**	-0.26	0.566***	0.852***	1

<u>Climatic/oceanic indices</u>

SAT: global Surface Air Temperature

ALPI: Aleutian Low Pressure Index

PDO: Pacific Decadal Oscillation

AO: Arctic Oscillation

SI: Siberian high

OH: Okhotsk High

<u>Oceanic variables</u>

ICE: extent of ICE cover area

SST_o: summer and fall SST in the Okhotsk Sea

<u>Biological characteristics of salmon</u>

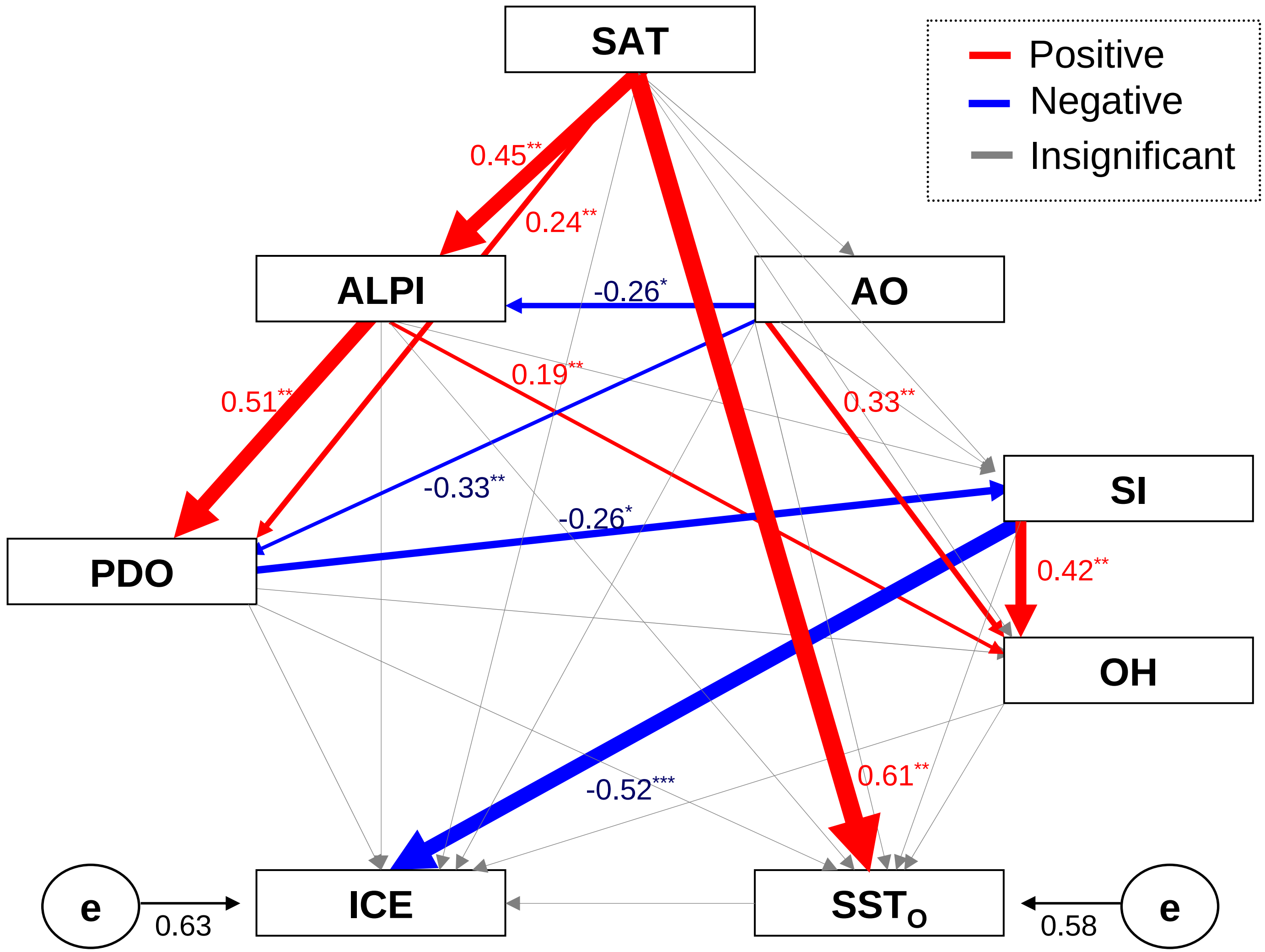
G1: Growth at age-1

SR: Survival Rate

PS: Population Size

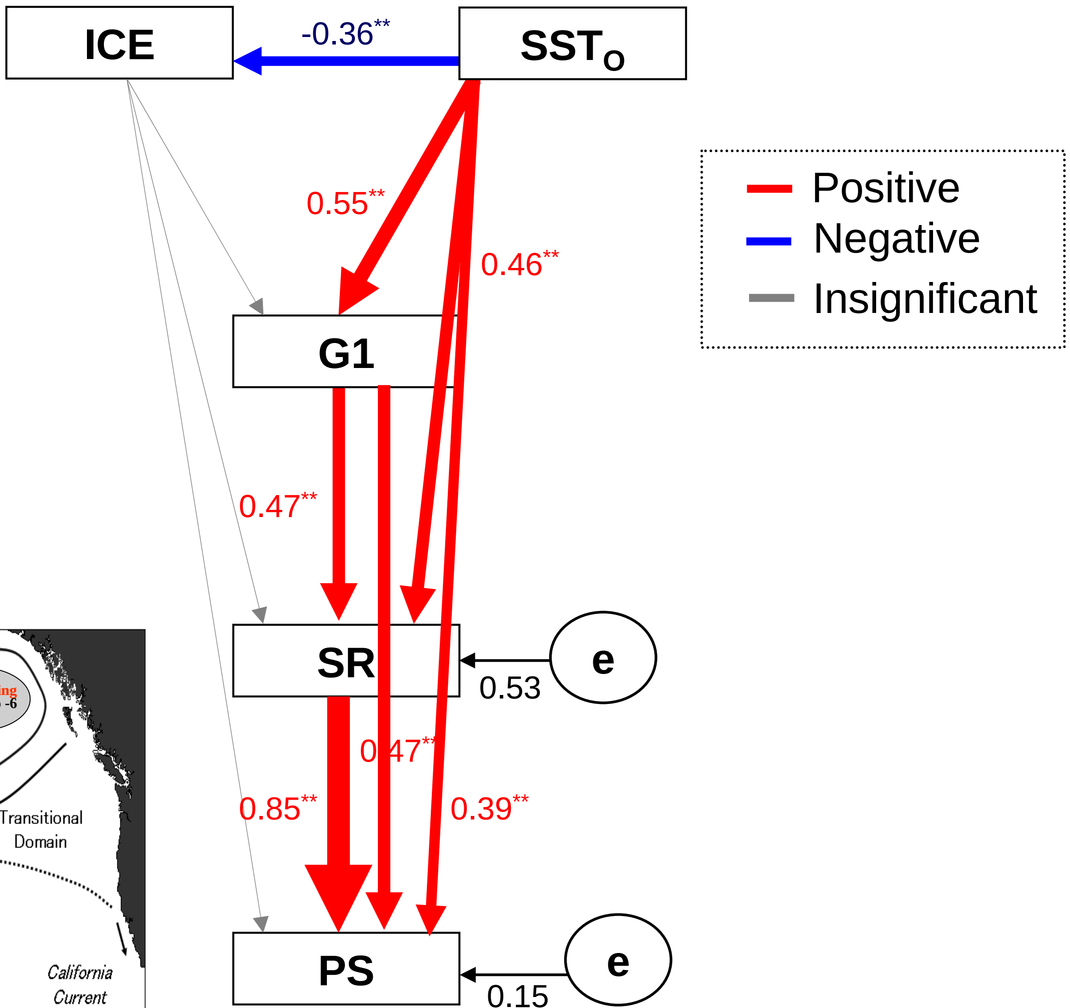
(Seo et al. 2011)

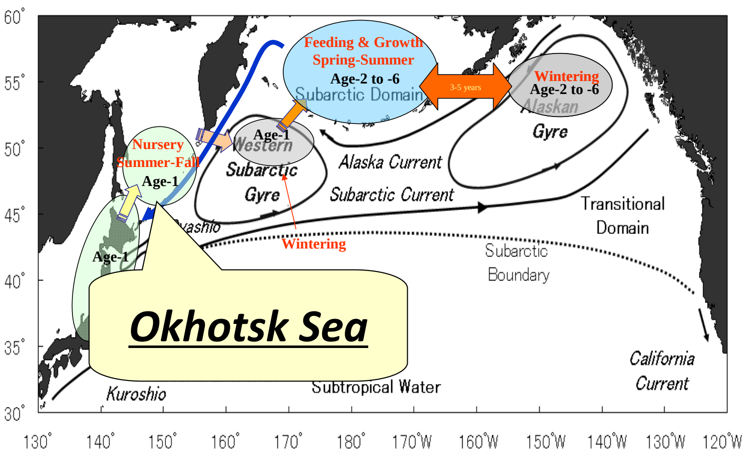
Path model analysis relationships among global surface temperature (SAT), ALPI, PDO, AO, Siberian high (SI), Okhotsk High (OH), ice cover area (ICE) and summer SST in the Okhotsk Sea (SST_O)



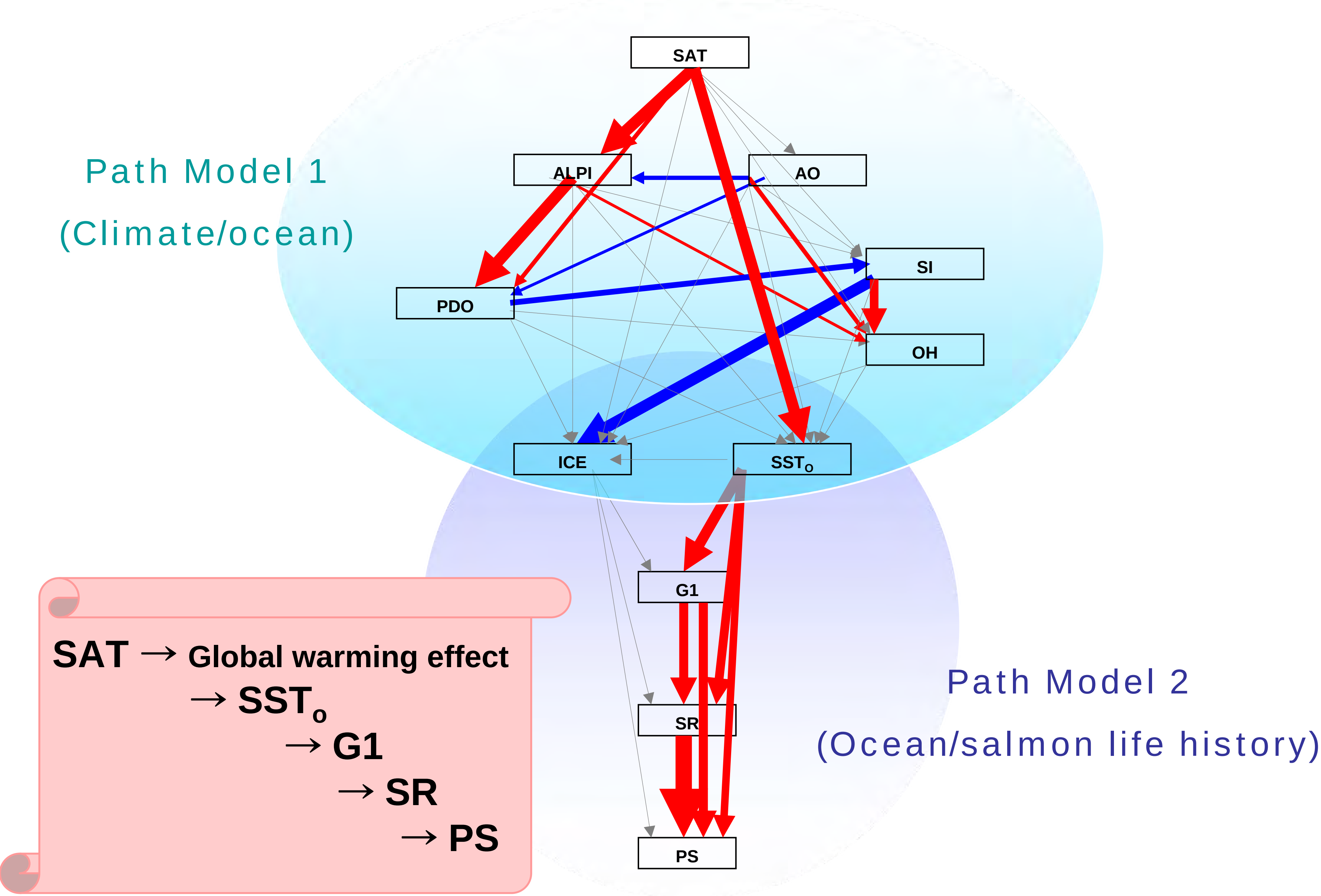
(Seo et al. 2011)

Path model analysis relationships among ice cover area (ICE), summer SST in the Okhotsk Sea (SST_O), growth at age-1 (G1), survival rate (SR), and population size (PS)

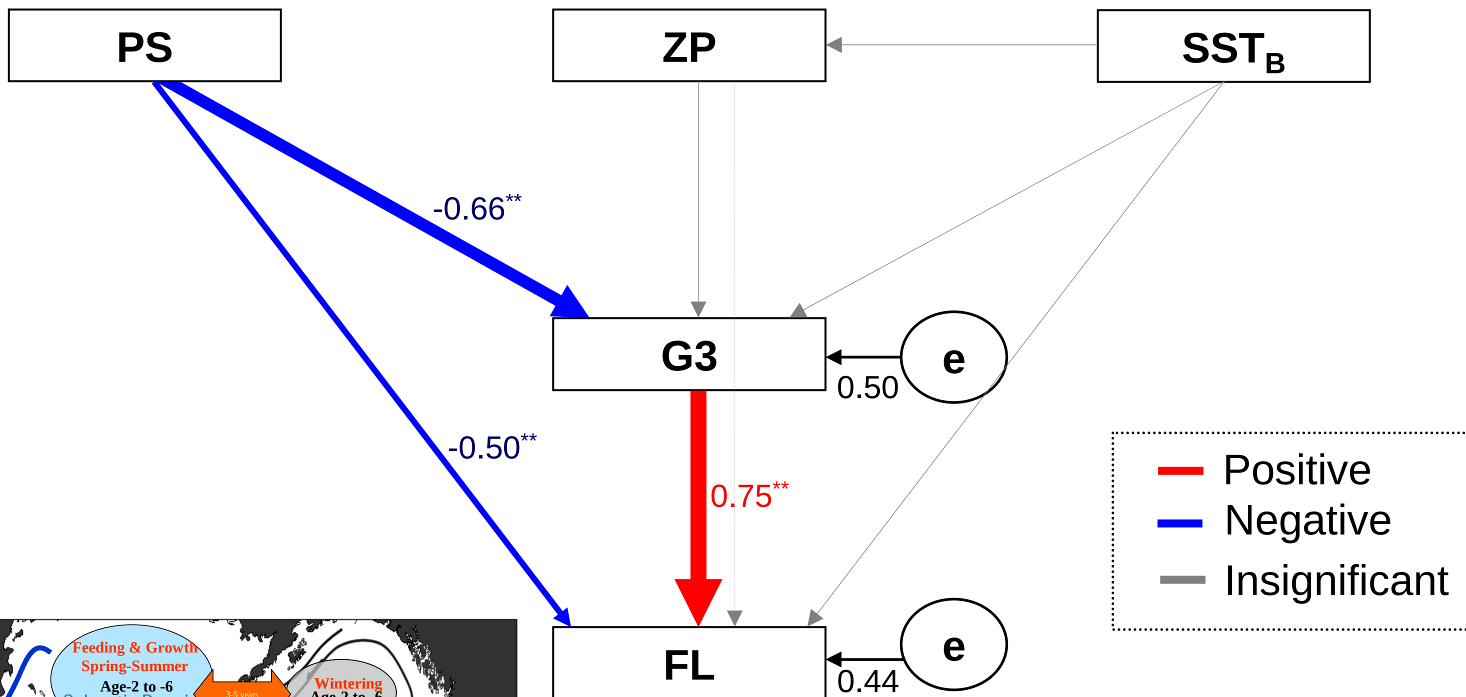


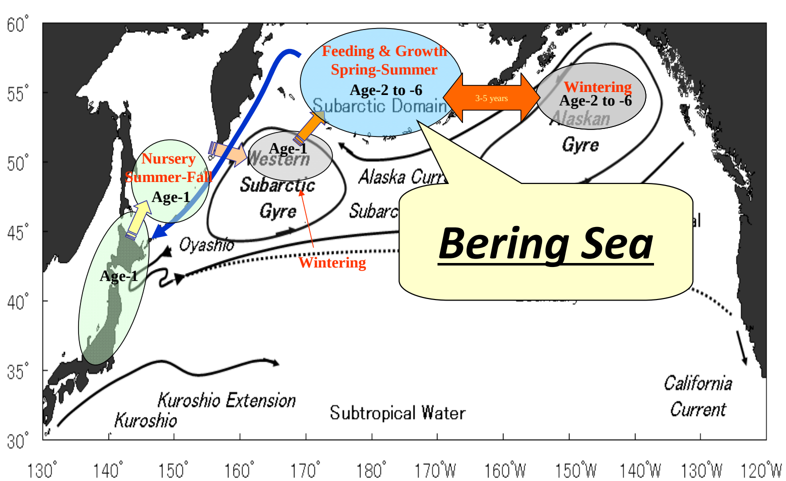


(Seo et al. 2011)


Path Model 1
(Climate/ocean)
SAT
ALPI
AO
SI
PDO
OH
ICE
SST$_O$
G1
SR
PS
Path Model 2
(Ocean/salmon life history)
SAT → Global warming effect
→ SST$_o$
→ G1
→ SR
→ PS

Path model analysis relationships among zooplankton biomass (ZP), summer SST in the Bering Sea (SST_B), population size (PS), growth at age-3 (G3), and FL of adult





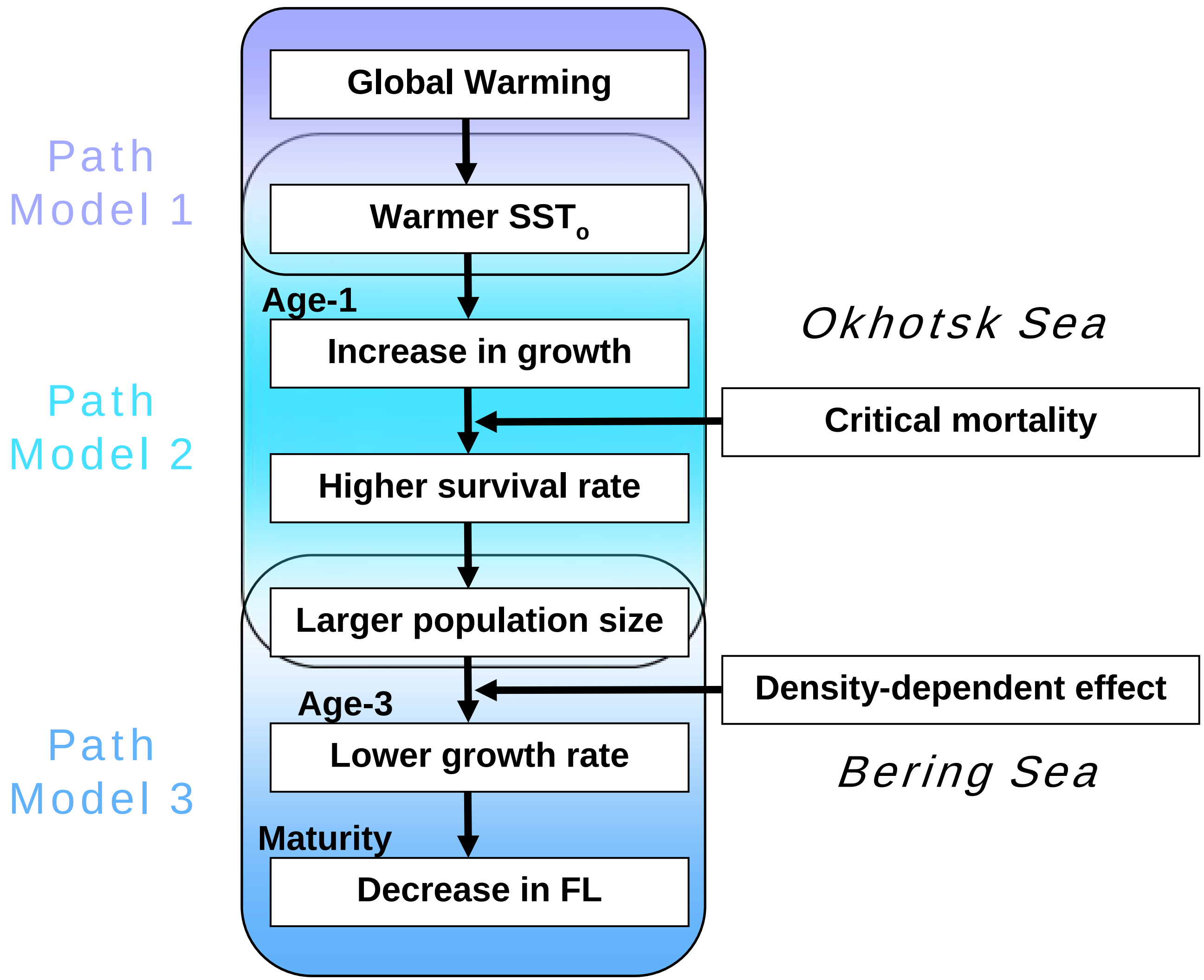
PS→ Population density-dependent effect

→ G3

→ FL

(Seo et al. 2011)

Summary (topic 1)



(Seo et al. 2011)

Topics

Global warming effect on chum salmon

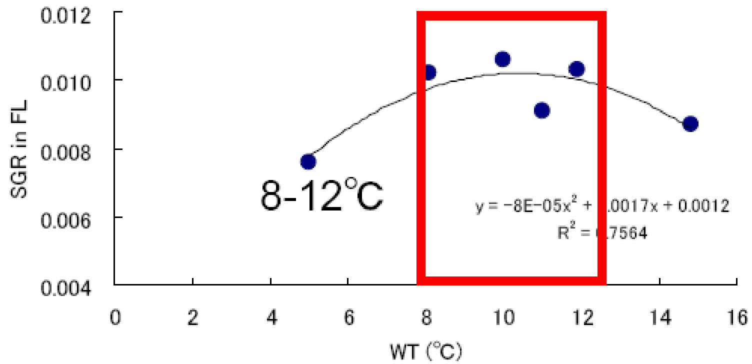
1. **Past: Path model**

   Mechanism on relationship between climatic/oceanic conditions and salmon life history

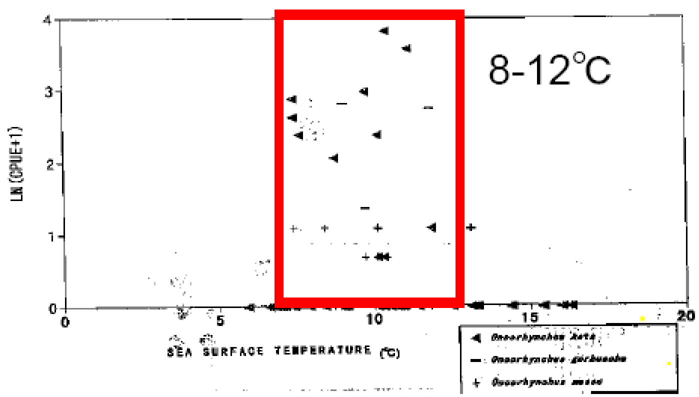
2. **Future: Prediction**

   IPCC SRES-A1B scenario and optimum temperature

Prediction on the global warming effect on chum salmon in the North Pacific Ocean using SRES-A1B scenario of the IPCC and optimum temperature of salmon (Kaeriyama 2008)



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

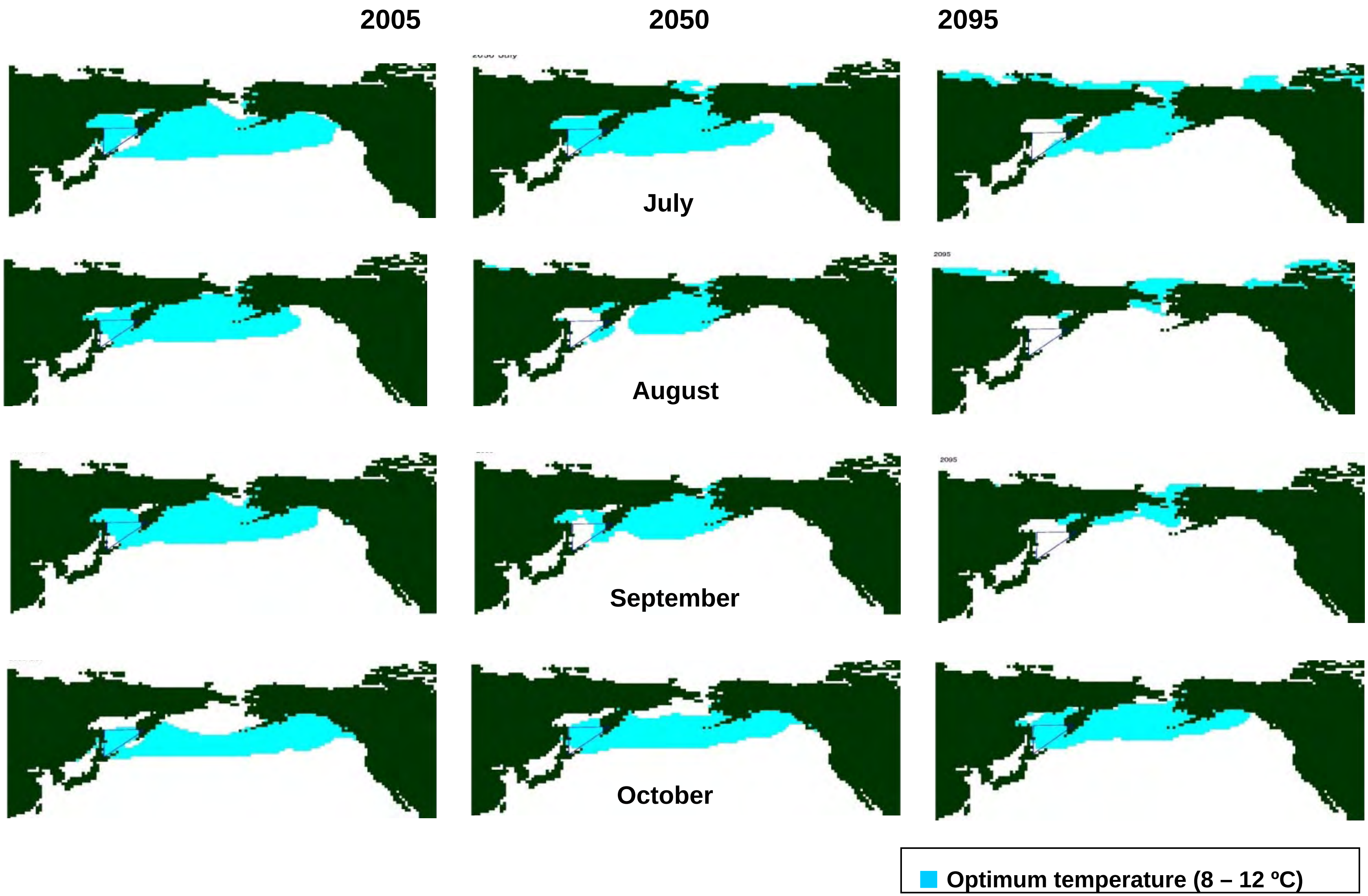


Relationship between SST and CPUE of chum salmon in the Okhotsk Sea. (Ueno et al. 1998)

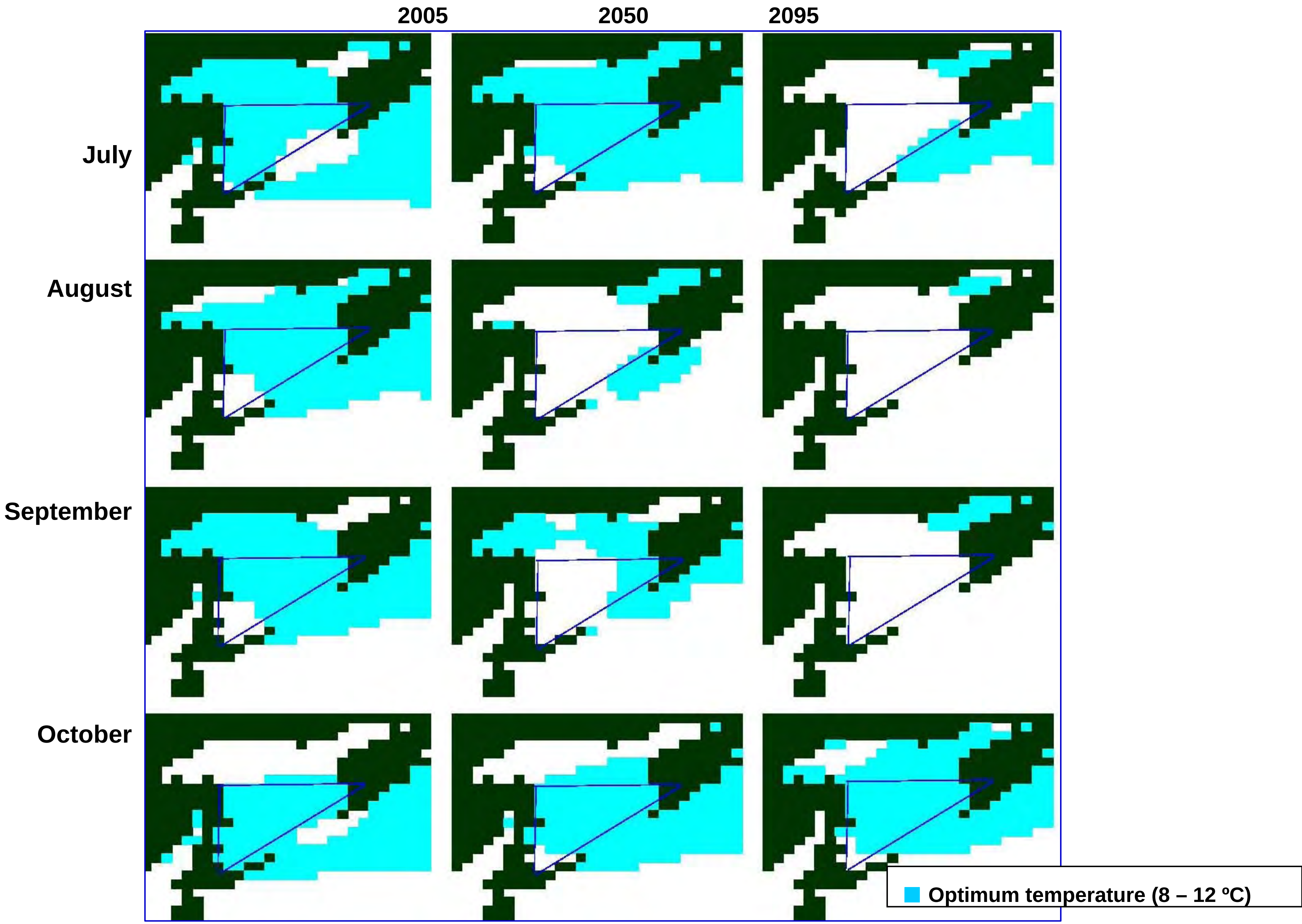
Optimal temperature for chum salmon

Growth and feeding migration period: **8-12℃**

Prediction on the global warming effect on chum salmon in the North Pacific Ocean using SRES-A1B scenario of the IPCC and optimum temperature of salmon (Kaeriyama 2008)



Prediction about the Global Warming effect on chum salmon in the Okhotsk Sea based on the SRES-A1B scenario (Kishi et al. in press)



Conclusion

✓ **At present, the global warming is affecting:**

- **Positively** for increases in growth at age-1 and survival of Hokkaido chum salmon through the warmer sea surface temperature during summer and fall in the Okhotsk Sea

- However, this appears to be leading to a population density-dependent effect on the growth at age-3 and maturing in the Bering Sea because of limited carrying capacity

✓ **In the future, the global warming will affect:**

- **Negatively** for decreases in their carrying capacity because of possible reduction in habitat area in the North Pacific Ocean

- Hokkaido chum salmon population will lose migration route to the Okhotsk Sea by 2050 and will be crushed by 2100