Long-term fluctuations in somatic growth, survival, and population dynamics of Hokkaido chum salmon, *Oncorhynchus keta*, linking to climate changes

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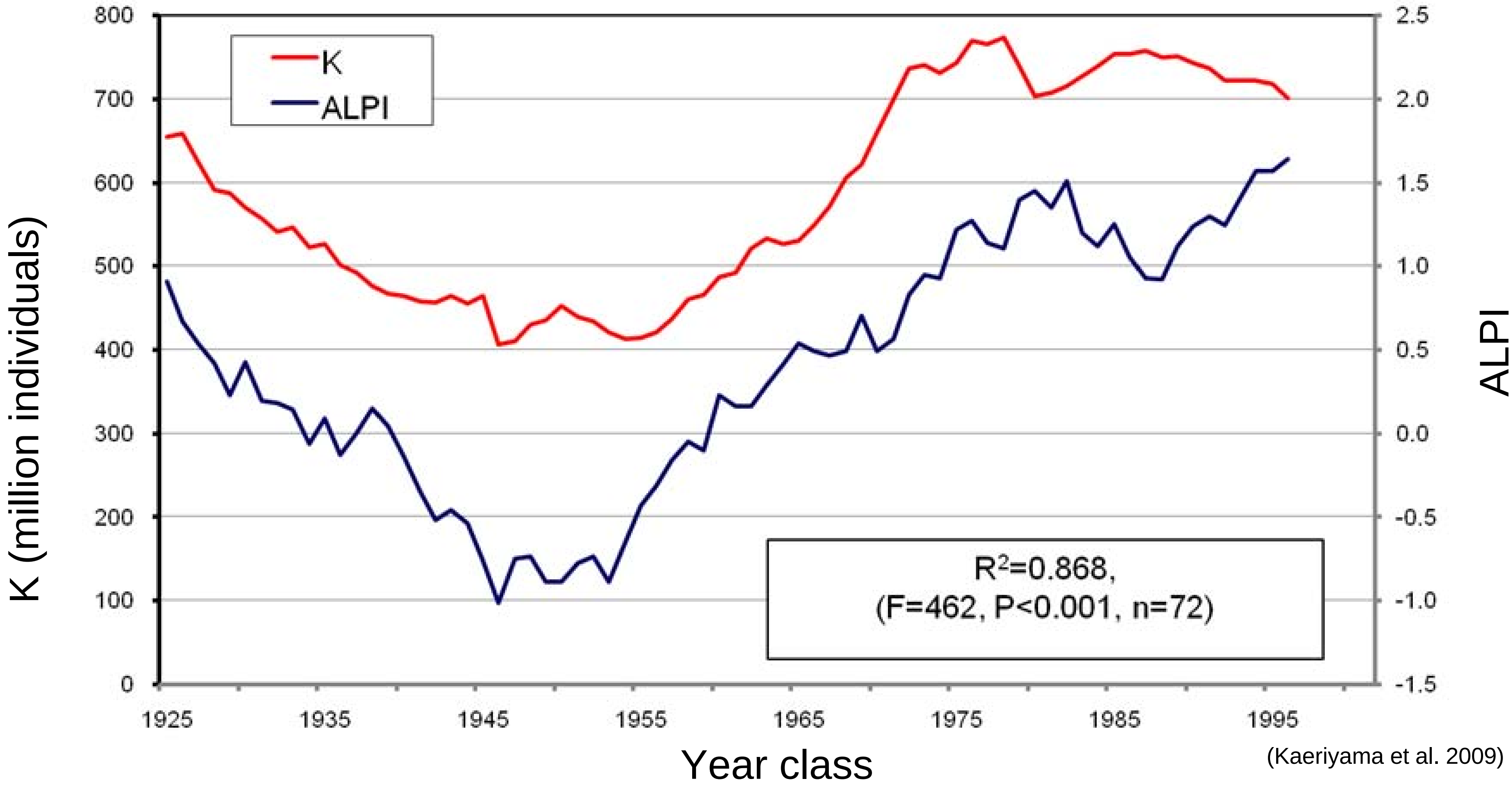
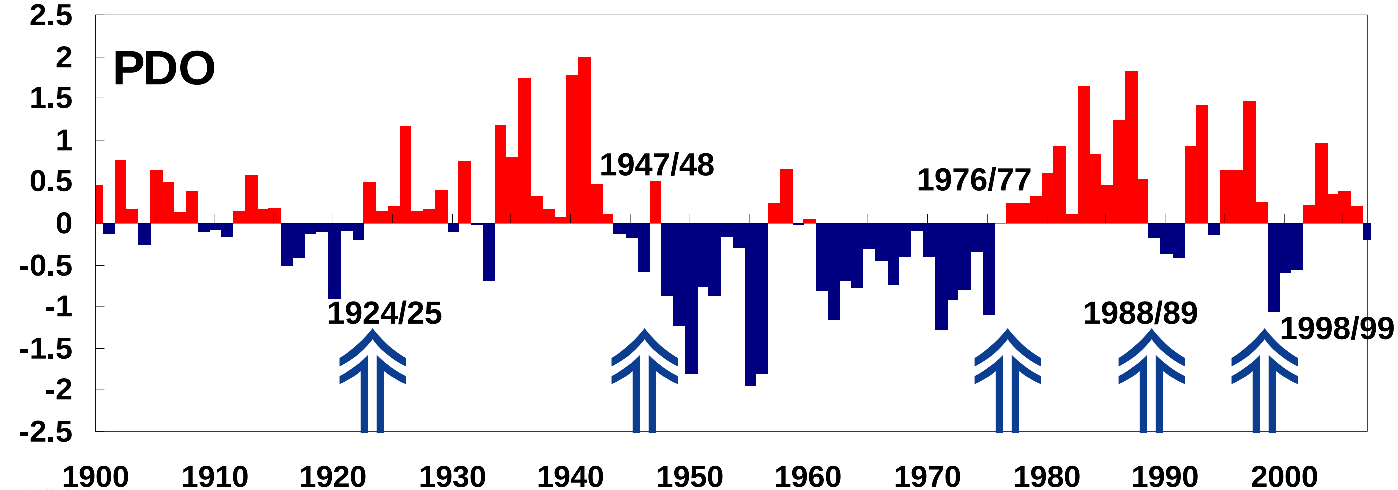
Temporal changes in ALPI and carrying capacity (K) of three species (sockeye, chum, and pink salmon)

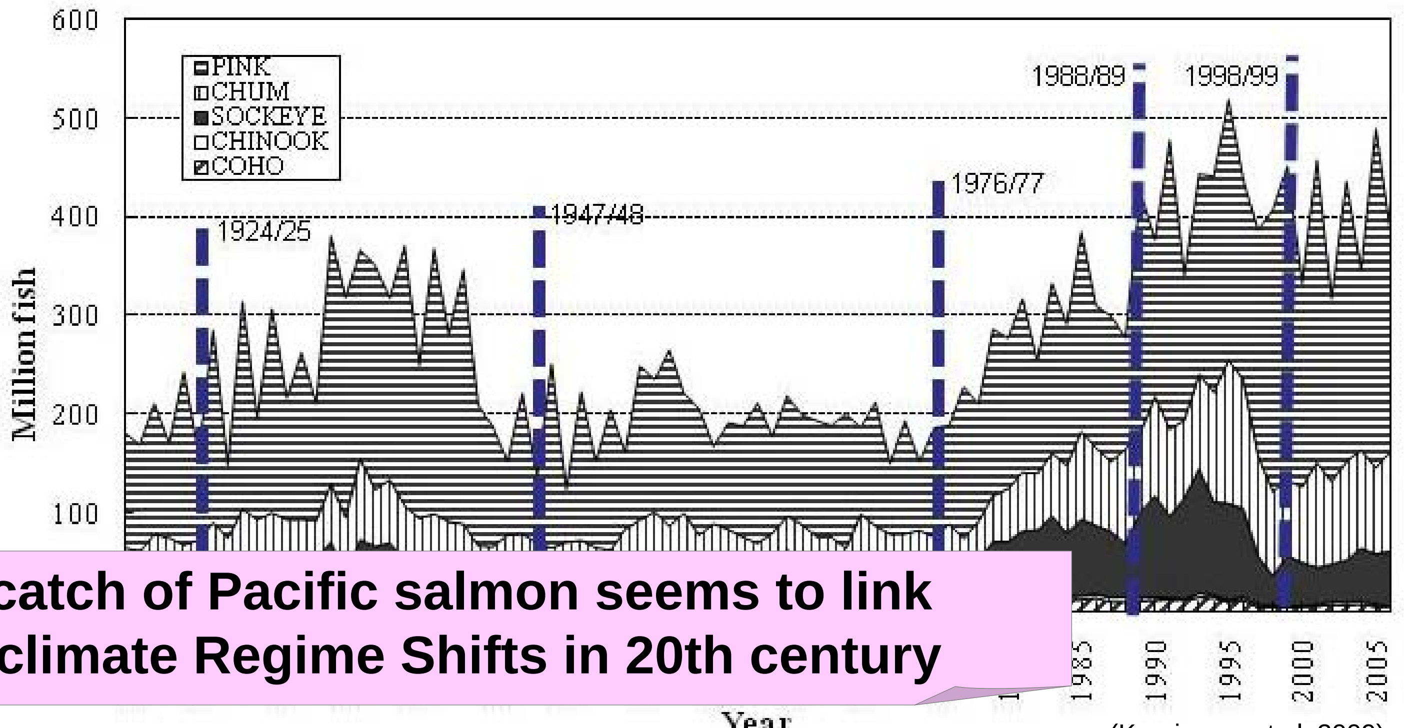


(Kaeriyama et al. 2009)

- ✓**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)





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

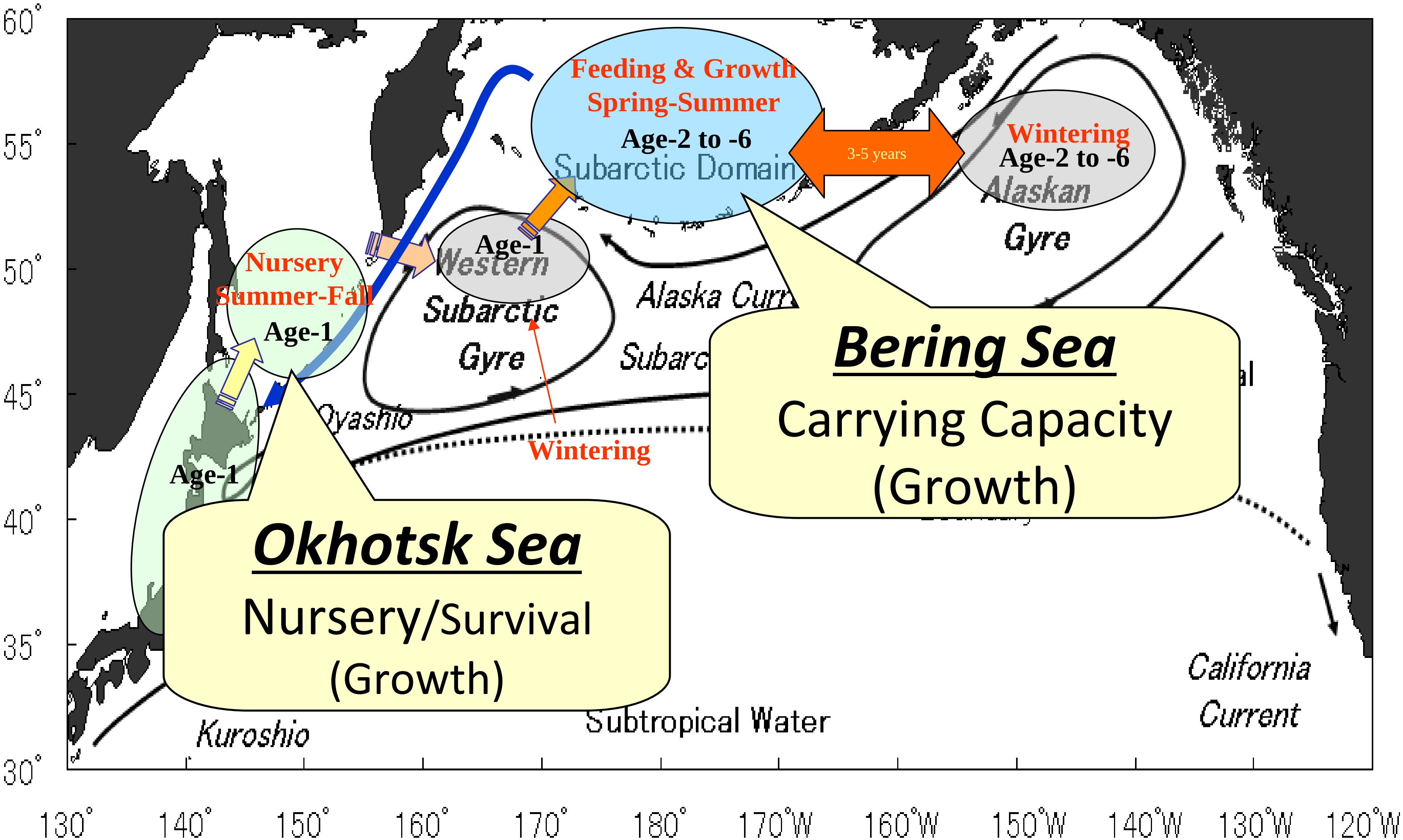
(Kaeriyama et al. 2009)

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

Purpose

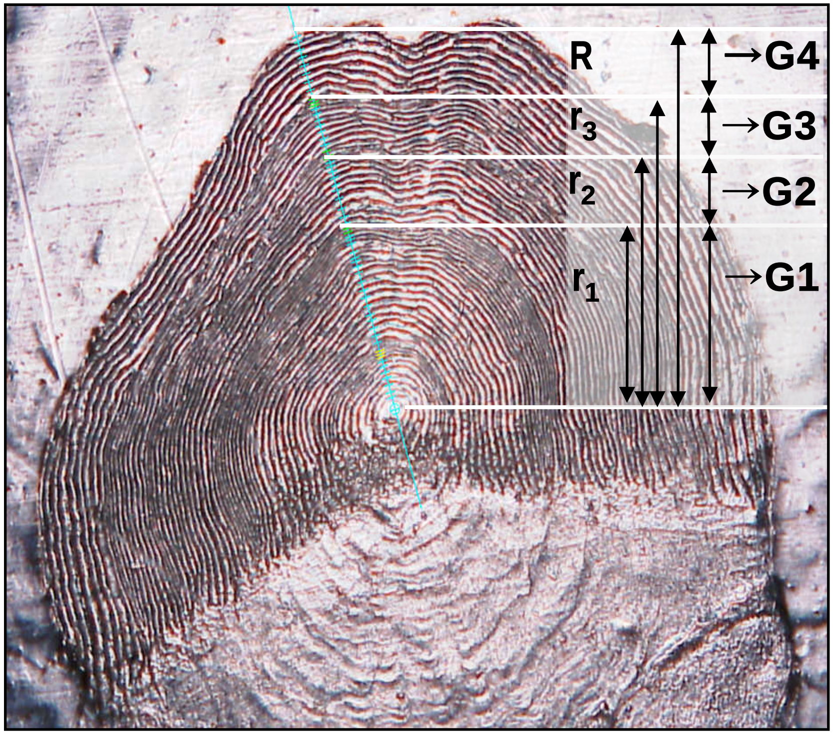
Clarify the mechanism of relationship between climatic/oceanic conditions and long-term fluctuations in life history of chum salmon in the North Pacific Oceans

Migration route of Japanese chum salmon



(Urawa 2000; Yatsu & Kaeriyama 2005)

Growth back calculation using scale analysis



1. Scale sample

Age-4 female chum salmon

Ishikari River (Japan), 1943-2005

2. Scale analysis

Scale measurement from focus to annual rings (i.e., 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	Thomposon 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)

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

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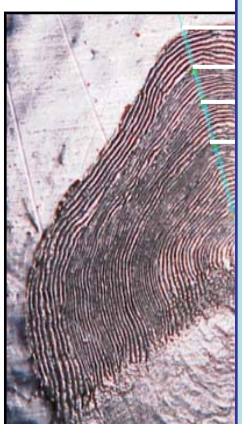
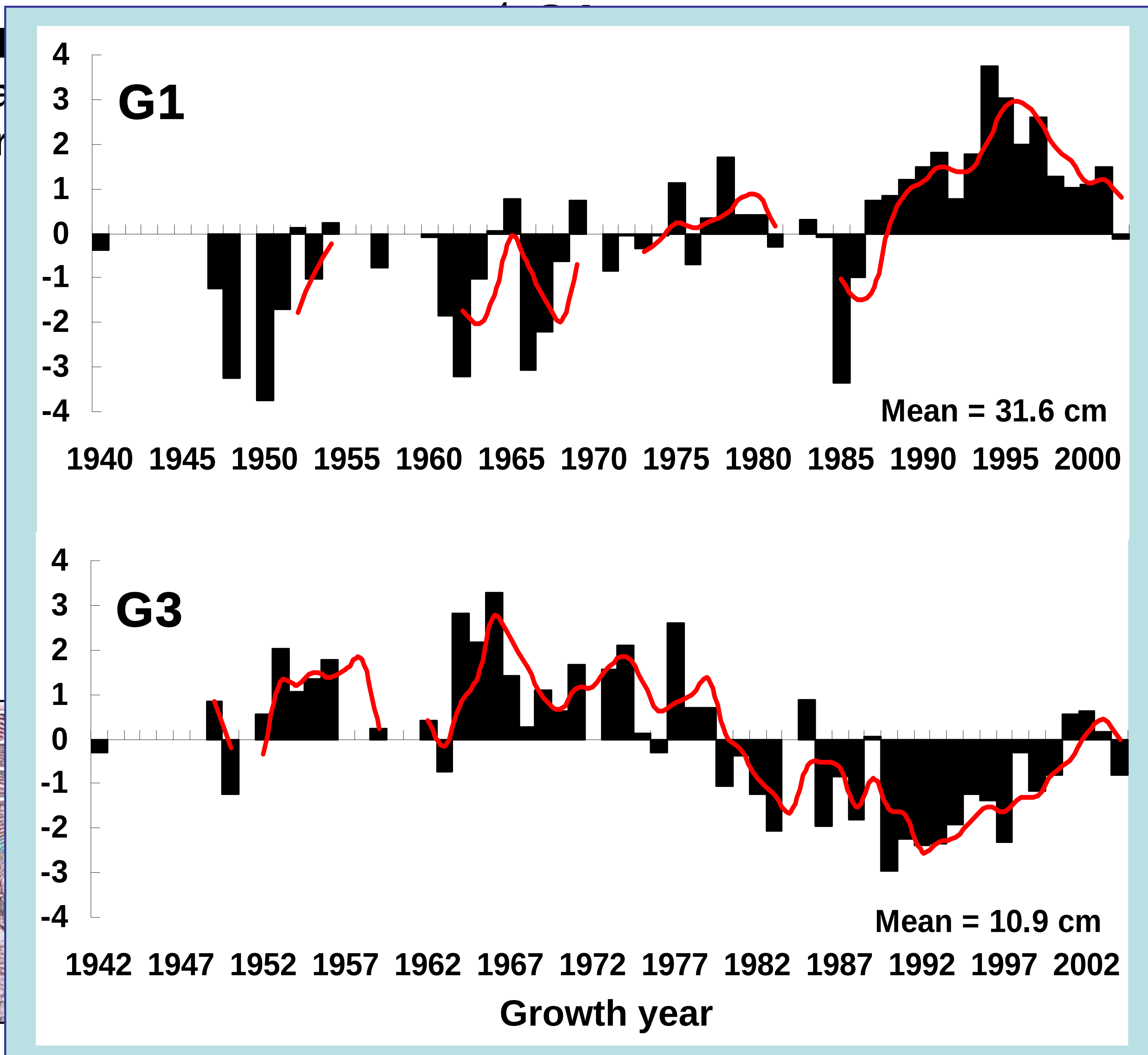




Correlation matrix among climatic/oceanic indices and variables, growth at age-1, survival rate, and population size of chum salmon

	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

Climatic/oceanic indices

SAT: global Surface Air Temperature

ALPI: Aleutian Low Pressure Index

PDO: Pacific Decadal Oscillation

AO: Arctic Oscillation

SI: Siberian high

OH: Okhotsk High

Oceanic variables

ICE: extent of ICE cover area

SST_o: summer and fall SST in the Okhotsk Sea

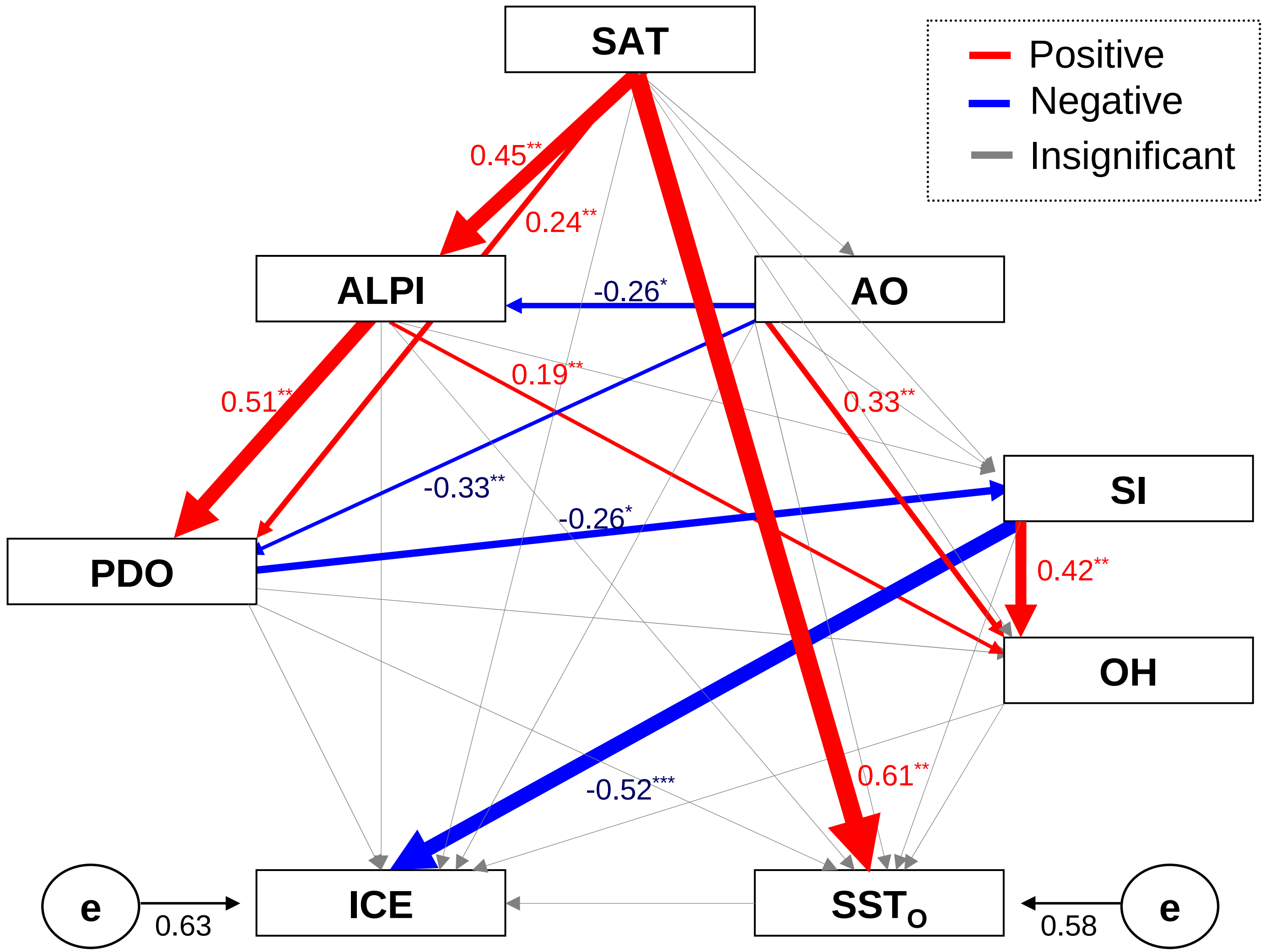
Biological characteristics of salmon

G1: Growth at age-1

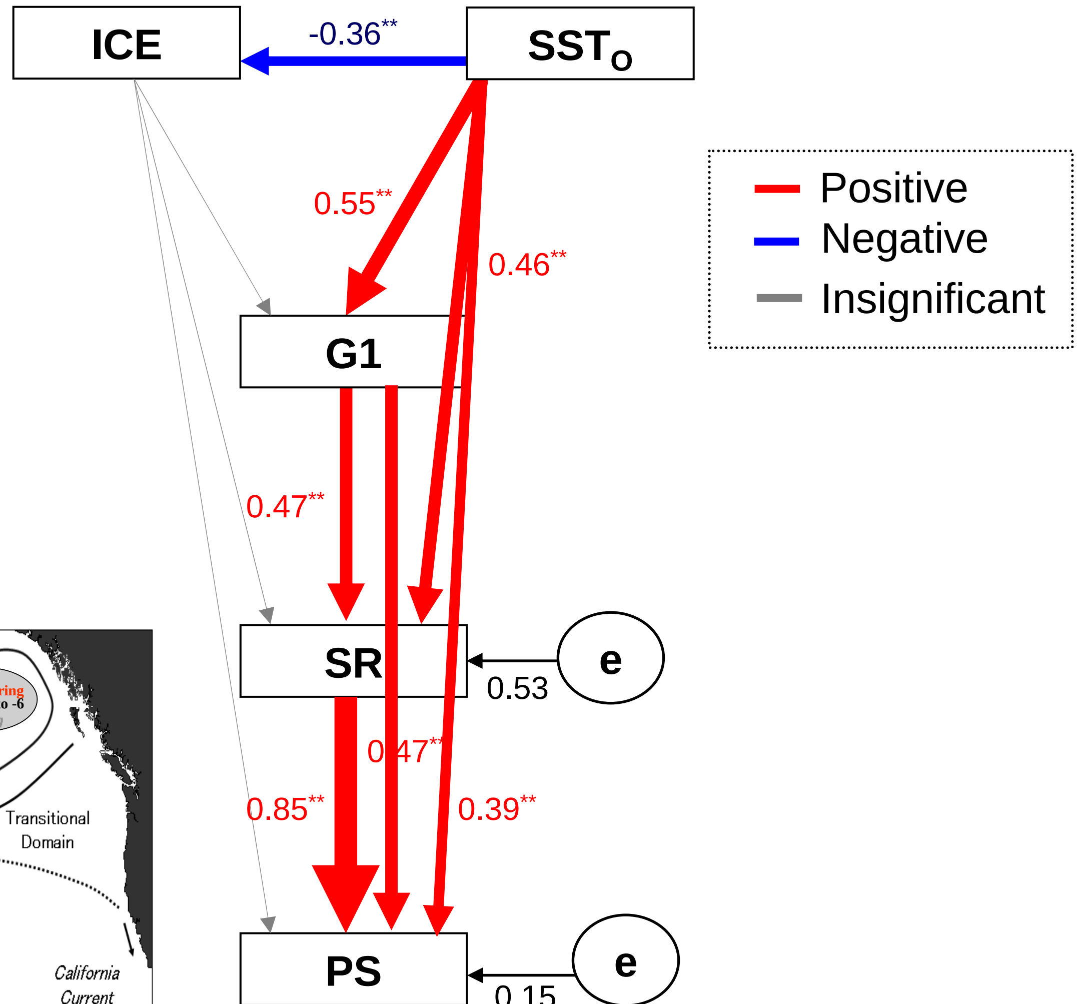
SR: Survival Rate

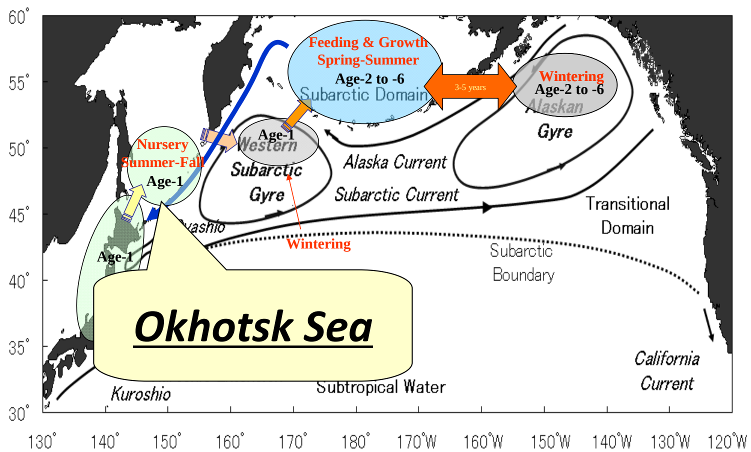
PS: Population Size

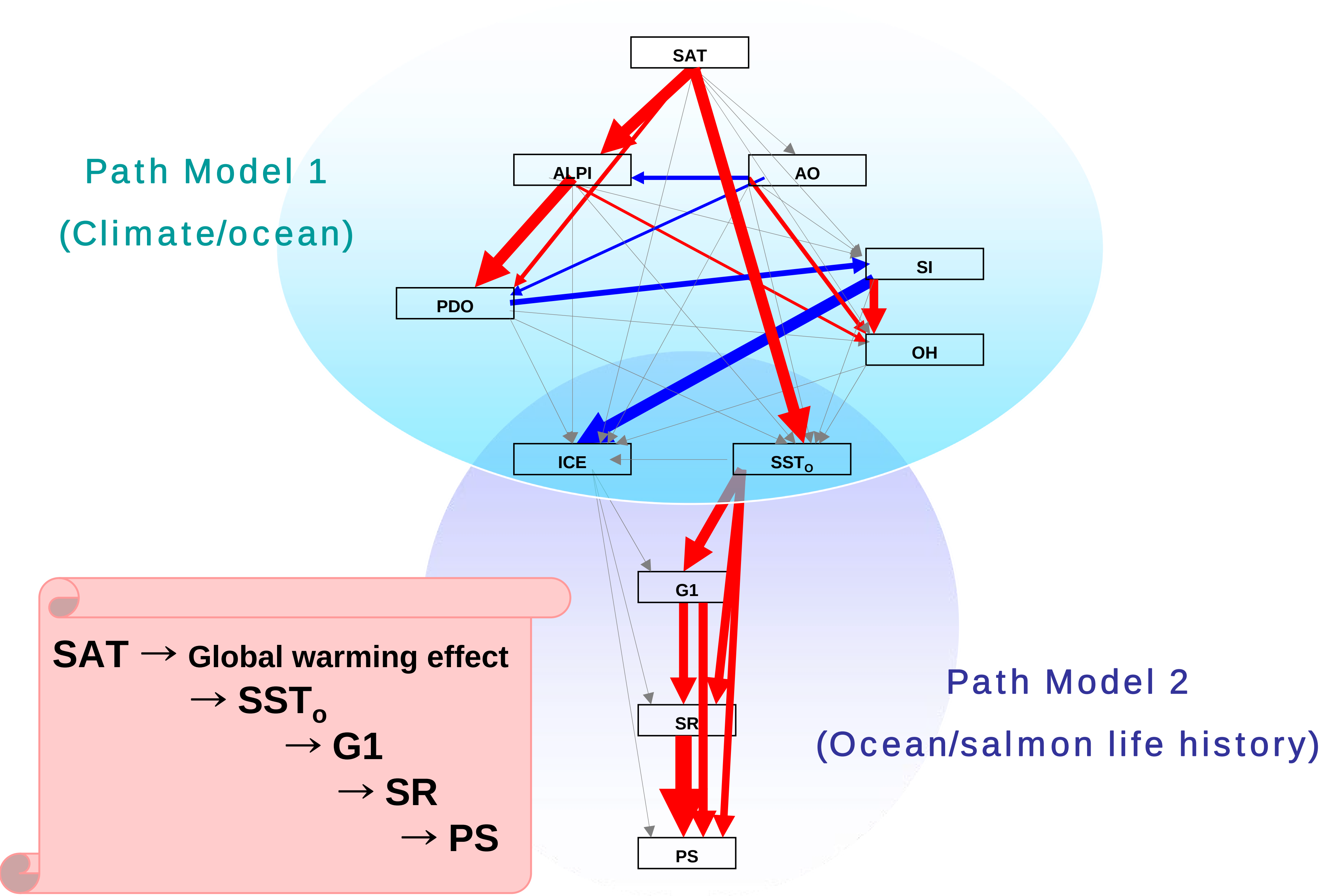
Path model analysis relationships among global surface temperature (SAT), ALPI, PDO, AO, Siberian high (SI), Okhotsk High (OH), ice cover area (ICE) and summer SST in the Okhotsk Sea (SST_O)



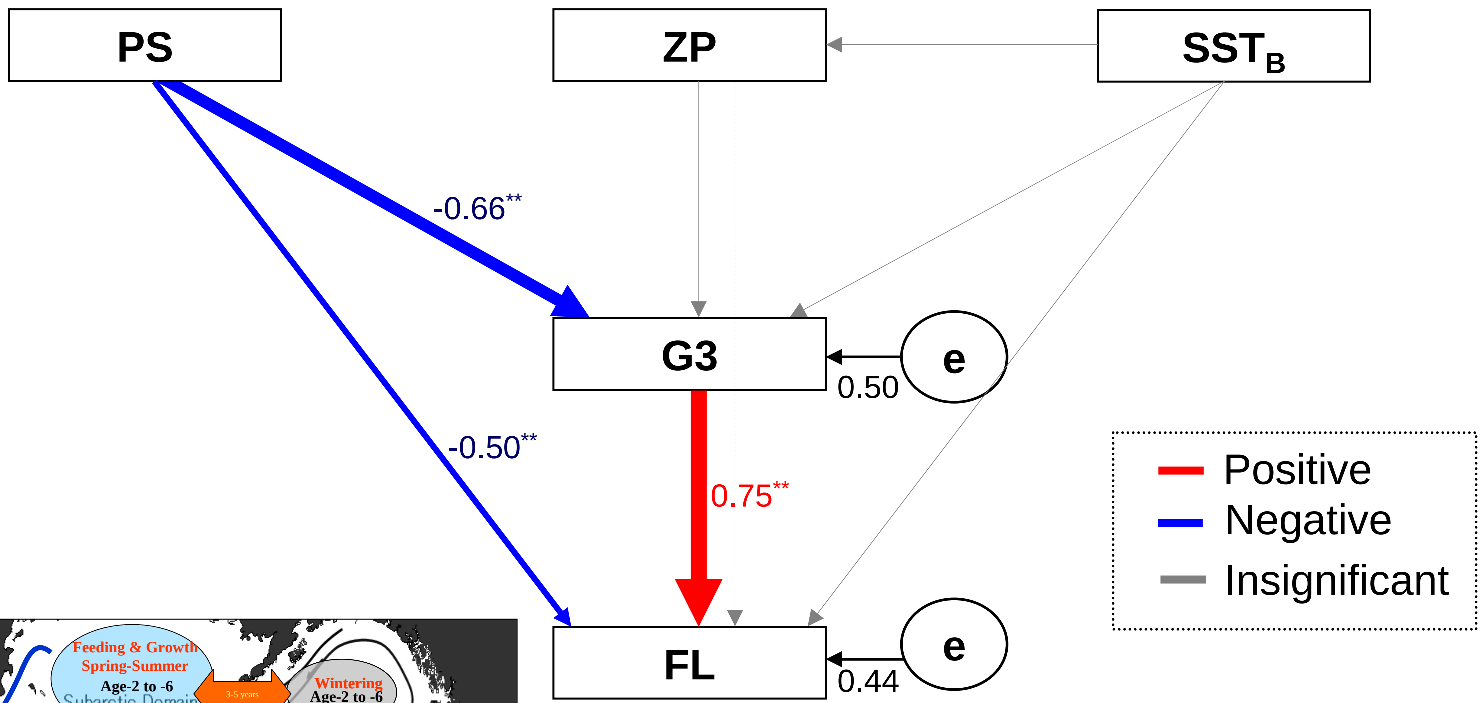
Path model analysis relationships among ice cover area (ICE), summer SST in the Okhotsk Sea (SST_O), growth at age-1 (G1), survival rate (SR), and population size (PS)

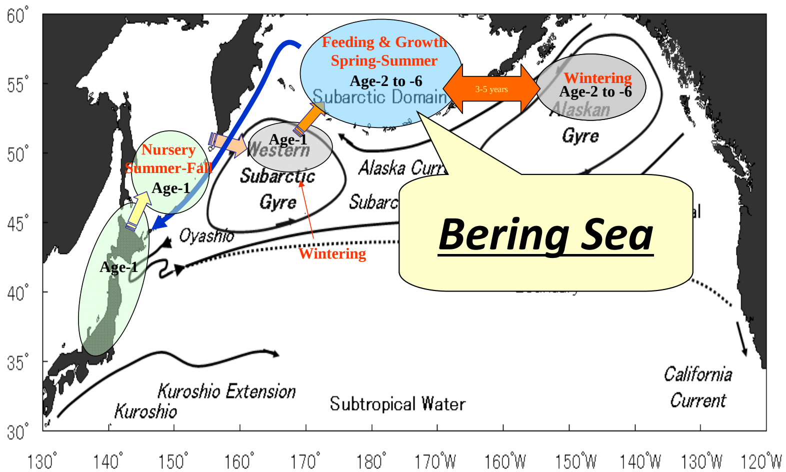





Path Model 1
(Climate/ocean)
SAT
ALPI
AO
SI
PDO
OH
ICE
SST$_O$
G1
SR
PS
Path Model 2
(Ocean/salmon life history)
SAT → Global warming effect
→ SST$_o$
→ G1
→ SR
→ PS

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



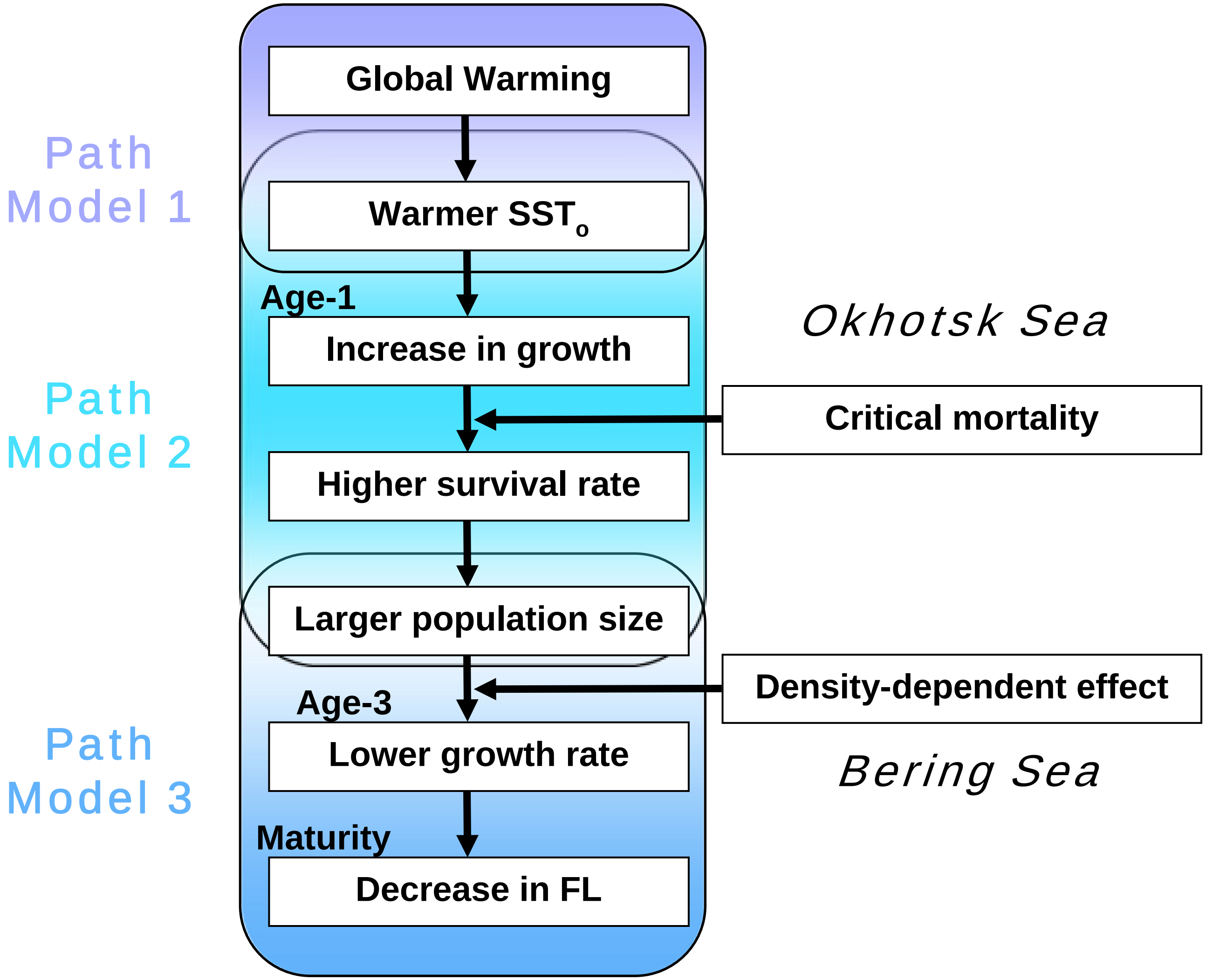


PS→ Population density-dependent effect

→ G3

→ FL

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 SST (sea surface temperature during summer and fall) in the Okhotsk Sea

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