The recent decline of pink salmon (*Oncorhynchus gorbuscha*) abundance in Japan

Toshihiko Saito*[1], Yukihiro Hirabayashi[1], Kengo Suzuki[1], Kyuji Watanabe[1], and Hiromi Saito[2]
[1] Hokkaido National Fisheries Research Institute, 2-2 Nakanoshima, Toyohira-ku, Sapporo, Hokkaido 062-0922, Japan
[2] Tokai University, 1-1 1-Chome 5-Jo Minami-sawa, Minami-ku, Sapporo, Hokkaido 005-8601, Japan
*brochet@affrc.go.jp

Objectives

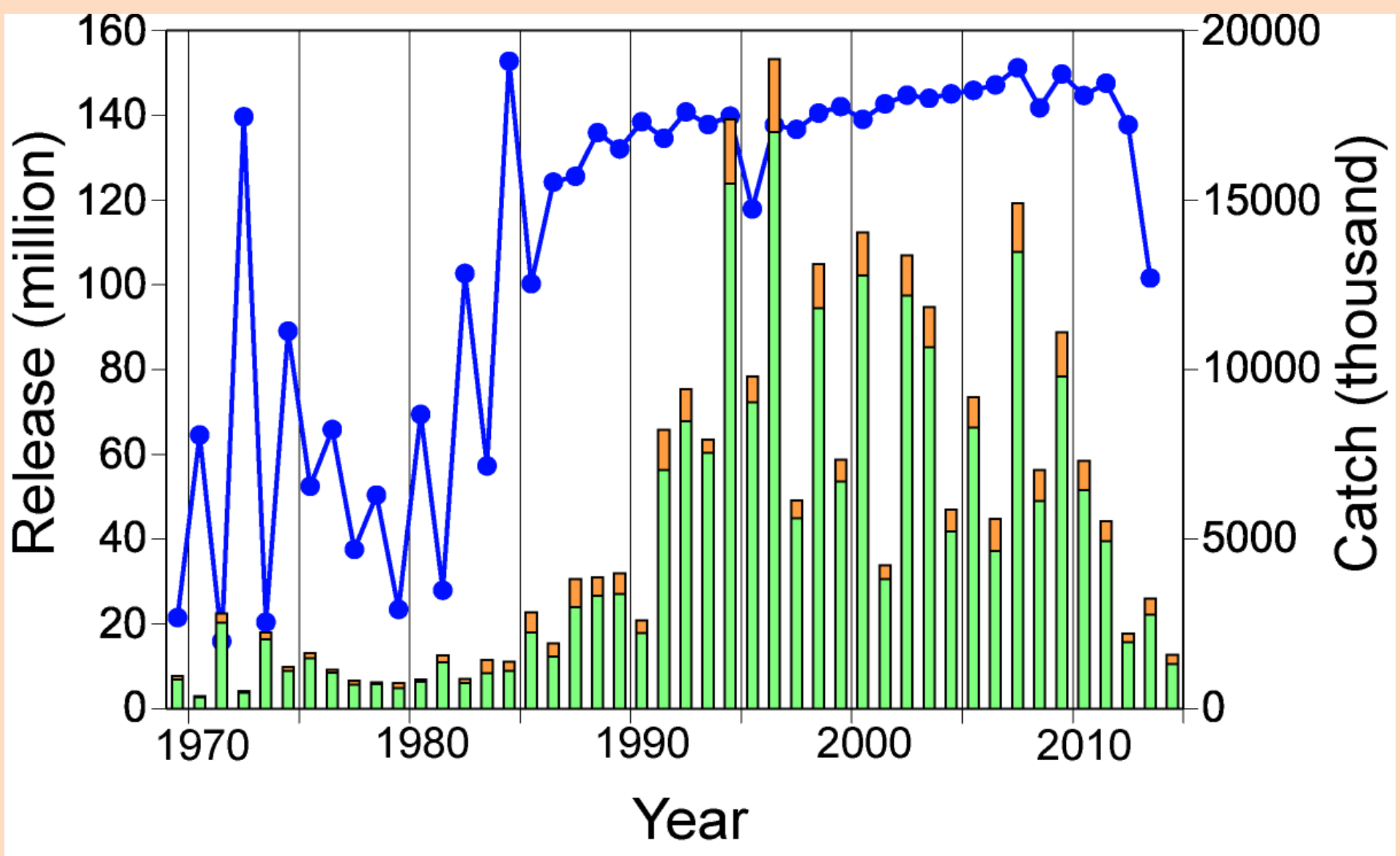

Fig.1 Number of released juveniles and coastal and in-river catch of pink salmon in Japan during 1969-2014.

- The decline in catch of pink salmon is evident in 2011 thereafter (Fig.1).

  The objectives of this study are to

- clarify the geogaraphical variability in abundance of Japanese pink salmon,
- understand possible causes of the recent decline of pink catch.

Methods

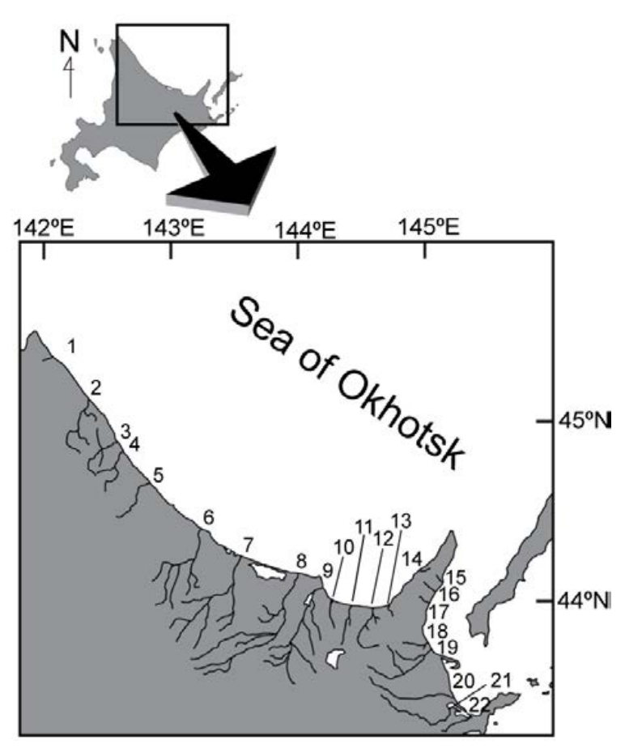

Fig.2. Locations of river stocks (#1-22) analyzed in this study.
#1 Chiraibetsu River, #2 Tonbetsu R.,
#3 Kitamihorobetsu R., #4 Tokushibetsu R.
#5, Horonai R., #6 Shokotsu R., #7 Yubetsu R.,
#8 Tokoro R., #9Abashiri R., #10 Mokoto R.,
#11 Yanbetsu R., #12 Sahri R., #13 Okushibetsu R.,
#14 Iwaobetsu R., #15 Sashirui R., #16 Rausu R.,
#17 Shunkarikotan R., #18 Ichani R., #19 Shibetsu R.,
#20 Nishibetsu R., #21 Furen R., #22 BettogaR..

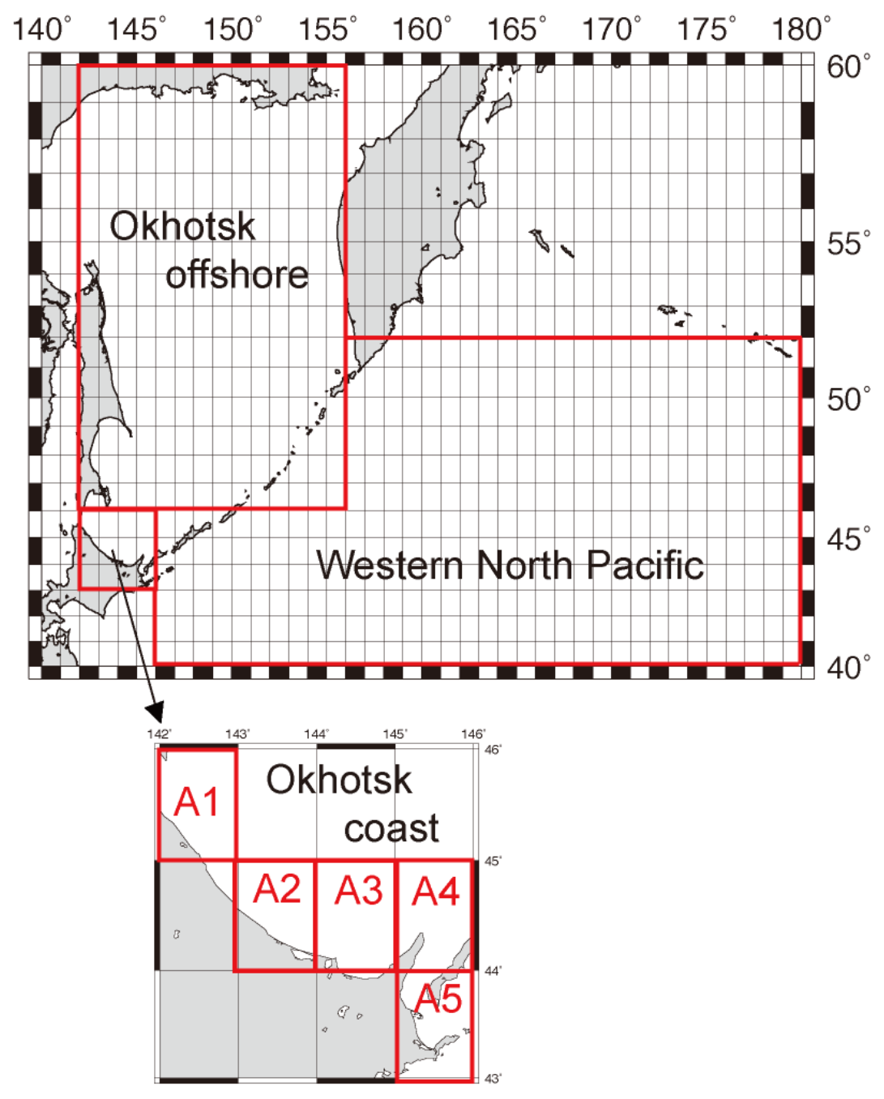

Fig.3. Ocean areas where correlation analysis between PC scores and SSTs were conducted. The proportion of grid mesh in which statisitically significant correlations were found to total grid mesh numbers was summarized for the following areas: Okhotsk coast, Okhotsk offshore, and Western North Pacifc. SSTs during April to September were also analyzed for anomalies from 1976-2014 in coastal area A1 -A5.

Hatchery-produced juvenile pink salmon are released every year in Japan (Fig. 1), but the contribution of hatchery fish to commercial catch is estimated about 20% (1). Thus, naturally-spawning of pink salmon is thought to play a important role to determine annual abundance of pink salmon.

We obtained data of in-river catch of pink salmon during 1976-2014 from 22 stocks in Hokkaido (Fig. 2). To quantify the effect of natural spawning on abundance of each stock, regression analyses were conducted between in-river catch in year *t* and that in year *t+2*, (*t* = 1976-2012) by separating odd- and even-year lines, because pink salmon have typically a two-year life cycle.

Residuals from each regression of stock indicate the variability independent of the parent-offspring relationships. Using the residual data of 22 stocks, a principal component analysis (PCA) was carried out to identify patterns of the residual variability. Based on extracted PCs, PC scores were obtained, and then correlation analysis was conducted between each of PC scores and 10-day averaged sea surface temperatures (SSTs), which were analyzed for 1º×1º grid meshes, through the entire ocean life period (i.e., from April in the first year of ocean life to September in the second year of ocean life) over the expected ocean distribution of pink salmon (Fig.3). The percentage of grid meshes where statistically significant correlations were found as compared to total grid meshes where correlation analysis was conducted were summarized as the following three areas: Okhotsk coast, Okhotsk offshore, and Western North Pacific (Fig. 3). Since SSTs in Okhotsk coast were associated with PC scores in most cases (see, Results), SSTs along shoreline (A1-A5, in Fig 3) were used for further analyses. SST anomalies from April through September in 1976-2014 were calculated at a 10-day interval for A1-5, and these anomalies were annually averaged to examine annual trends in SSTs.

During 1980s and mid-1990s, run timing of Japanese pink salmon was altered to be earlier by artificial selection in hatcheries. To alter the run timing, early migrants were used for producing hatchery releases, but late migrants were sold for making hatcheries' working capital. Such artificial selection was carried out at the entire hatcheries in Hokkaido. To demonstrate the alternation of run timing, we summarized in-river catches at a 10-day interval by stock groups determined with PCA. Furthermore, using proportion of in-river catch at given 10-day periods to annual total catch, Shannon's diversity index were calculated:

$$H'_{t,pc} = -\sum_{i=1}^{z} p_{t,pc,i} \ln p_{t,pc,i}$$

where $H'_{t,pc}$ is Shannon's diversity index in year *t* for stocks related to *pc*, *i* is the *i* thnumberd 10-day period of in-river catch (total number of 10-day periods = *z*), $p_{t,pc,i}$ is the proportion of in-river catch in the *i* th numbered 10-day period of year *t* for stocks related to *pc* ($\sum p_{t,pc,i}$=1), respectively. Calculated Shannon's diversity index were correlated with the annually averaged SST anomalies (A1-5) , to examine whether coastal SSTs affected run timing of pink salmon.

Results

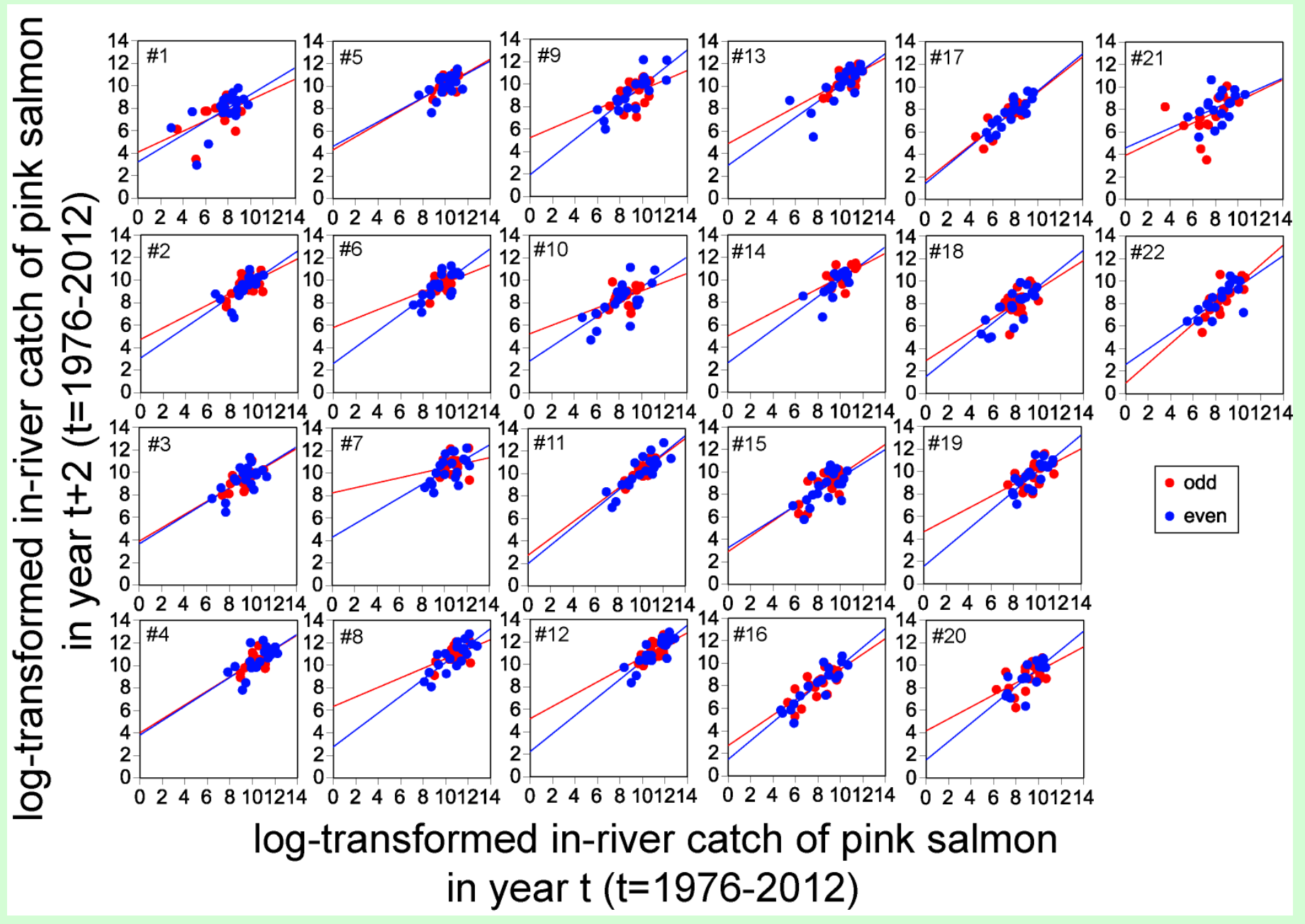

Fig.4.Regression analysis between in-river catch in year *t* and that in year *t+2* for 22 stocks of pink salmon (i.e., parent-offspring relationships). The number # indicates river stocks shown in Fig. 2

- Statistically significant regressions were obtained between in-river catch in year *t* and that in year *t+2* for all stocks of pink salmon examined (Fig. 4).
- Assuming that observed in-river catch reflect the abundance of naturally spawning fish, this result implies that natural spawning is important to determine abundance of Japanese pink salmon as previous studies suggested.

Table 1. Component matrix obtained with varimax-rotated principal component analysis based on residuals from parent-offspring relationships shown in Fig. 4.

River	PC1	PC2	PC3	PC4	PC5
1.Chiraibetsu R.	.039	.793	.239	.028	.272
2.Tonbetsu R.	.071	.785	.047	-.183	.286
3.Kitamihorobetsu R.	.158	.830	-.109	.100	-.058
4.Tokushibetsu R.	.112	.930	.136	.083	.031
5.Horonai R.	.017	.774	.523	.024	-.120
6.Shokotsu R.	.171	.488	.691	.006	-.051
7.Yubetsu R.	.298	.233	.822	.207	.008
8.Tokoro R.	.342	.285	.700	.122	.169
9.Abashiri R.	.219	-.257	.716	.222	.218
10.Mokoto R.	.608	.150	.540	.025	.194
11.Yanbetsu R.	.798	.134	.141	.223	.319
12.Shari R.	.789	.199	.285	.367	.094
13.Okushibetsu R.	.858	-.062	.273	.289	.066
14.Iwaobetsu R.	.891	.213	.170	.008	.043
15.Sashirui R.	.565	-.072	.140	.053	.557
16.Rausu R.	.097	.259	.118	.074	.775
17.Shunkarikotan R.	.419	.124	.061	.204	.622
18.Ichani R.	.318	-.026	.262	.652	.373
19.Shibetsu R.	.322	-.080	.029	.791	.175
20.Nishibetsu R.	.199	.242	.075	.802	-.019
21.Furen R.	.005	-.011	.292	.645	-.108
22.Bettoga River	-.009	-.100	-.122	.643	.478
Eigenvalues	4.235	4.130	3.228	3.001	2.117
% of variance	19.252	18.775	14.673	13.642	9.621
Cumulative %	19.252	38.027	52.700	66.342	75.963

🟥 :values > 0.5

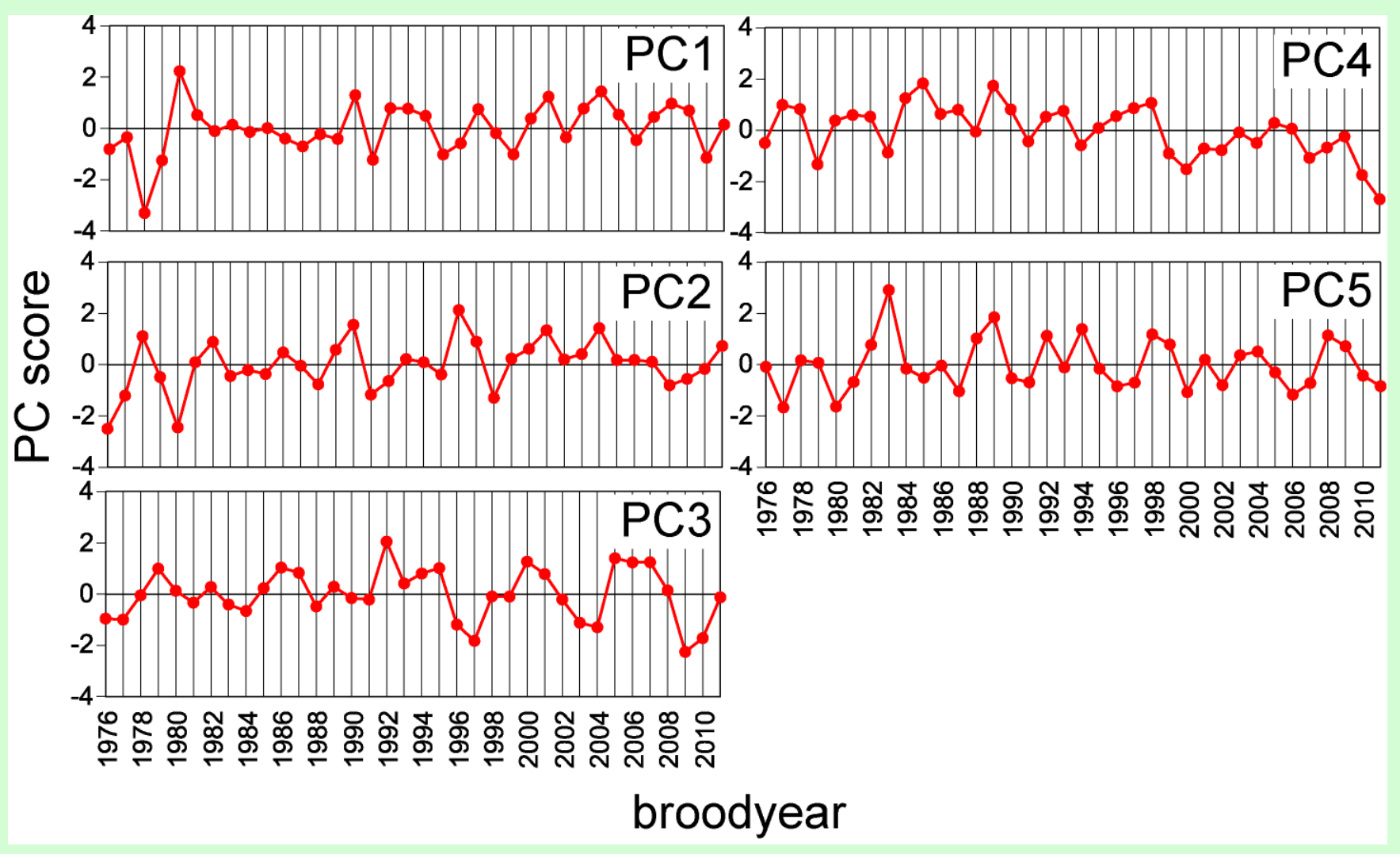

Fig.5. PC scores obtained from a principal component analysis (PCA) shown in Table 1. Since no data was available for in-river catch in #20-22 in 2014 (due to low returns), PCA was performed using residuals of the 1976-2011broodyears (return year:1978-2013).

- PCA reduced 22 residual data into five principal components (PC1-5) (Table 1).
- From values of component matrix, each of PCs reflect residual variability of pink-shade stocks shown in Table 1.
- Broodyear 2009-2010 showed nagative PC scores in PC1-5 with some exceptions, suggesting that these broodyears showed low survival rates.
- PC scores of PC4, related to stocks #18-22, indicate almost negative values during the 1999-2011 broodyears, which suggests that survival of these stocks reduced over a decade.

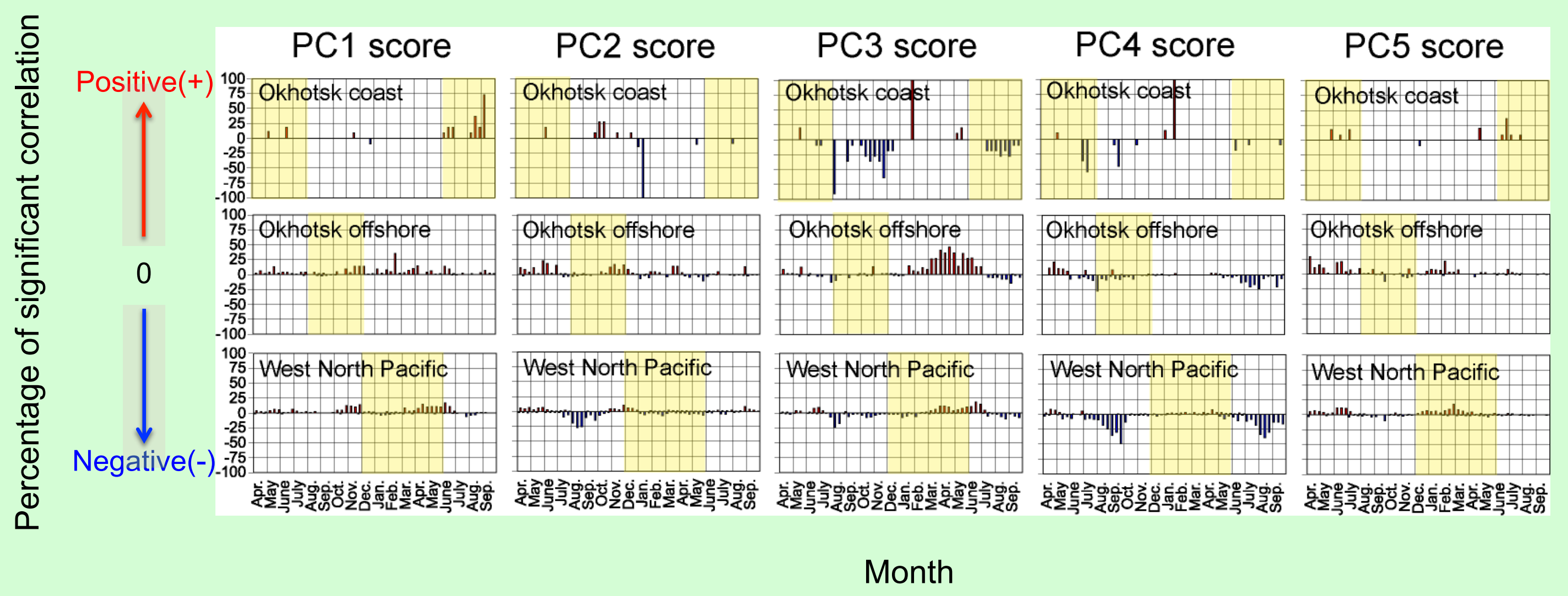

Fig.6. Percentage of grid meshes (see, Fig. 3) showing statistically significant correlations between average sea surface temperatures at an interval of 10 days for 1º by 1º grid meshes and PC scores from April in the first ocean life to September in the second ocean life for the 1976 -2011 broodyear pink salmon. Yellow-shade duration indicates expected periods of Japanese pink salmon distribution.

- Almost all PC scores showed statistically significant positive or negative correlations with SSTs in Okhotsk coast (Fig.6) During May and June in the first year of ocean life, which corresponds to coastal residency of juveniles, positive correlations were dominant, indicating that warm SST conditions were good for their survival. However, in late June to July, stocks related to PC3 and 4 showed negative correlations in their first ocean life. Furthermore, SSTs during June and September in the second ocean life (i.e., period of spawning migration as adults) positive or negative correlations were again dominant in some PC scores.

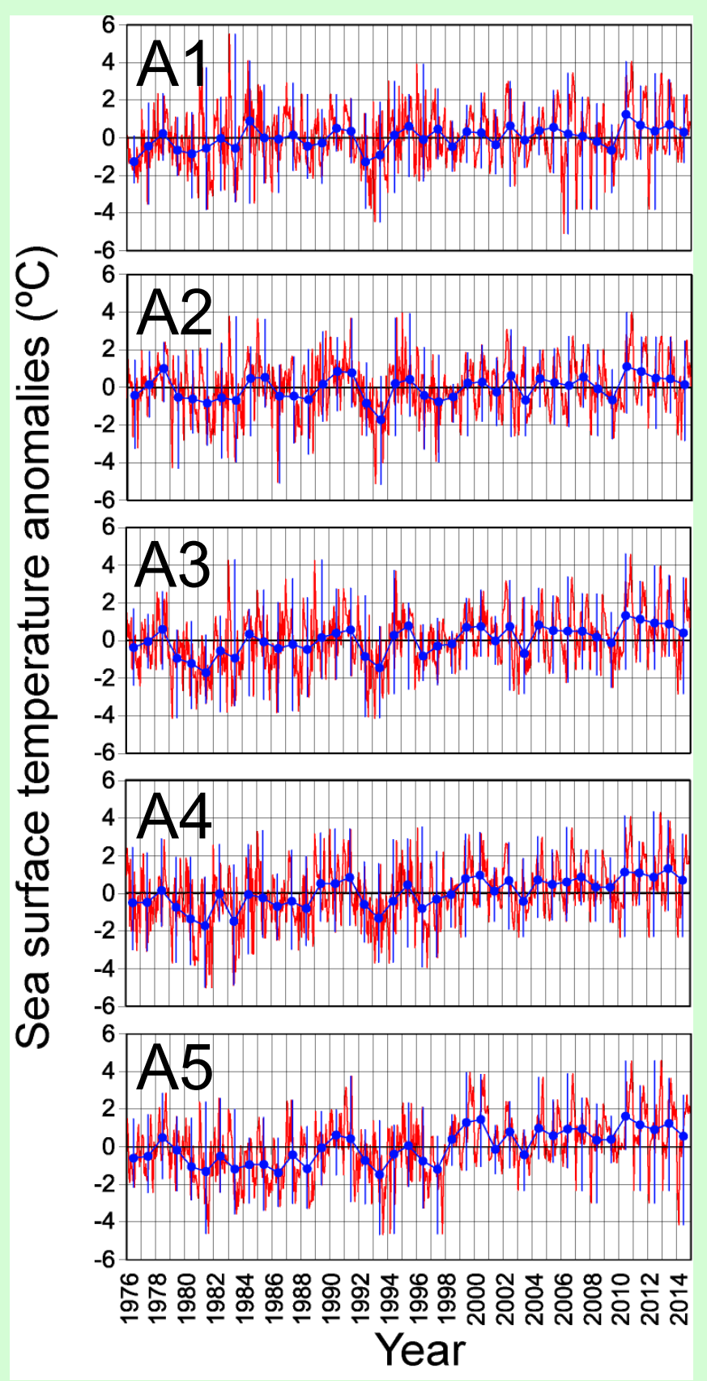

Fig.7.SST anomalies (red line) during April and September in 1976-2014 in area A1-5 (Fig.3). Annual averages of anomalies are also shown with blue lines.

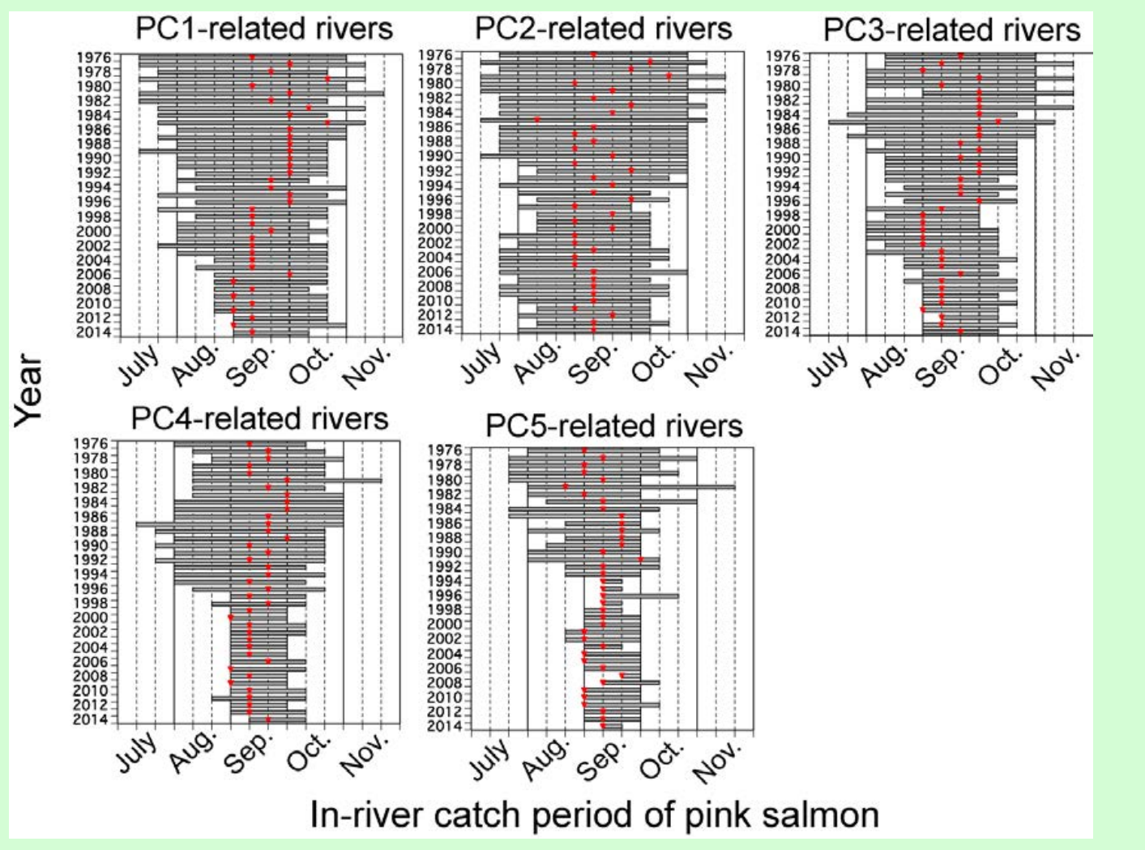

Fig.8. Periods of in-river catch summarized at an interval of 10 days for PC1-5 related rivers duirng 1976-2014. Red triangles indicate peak of the catch.

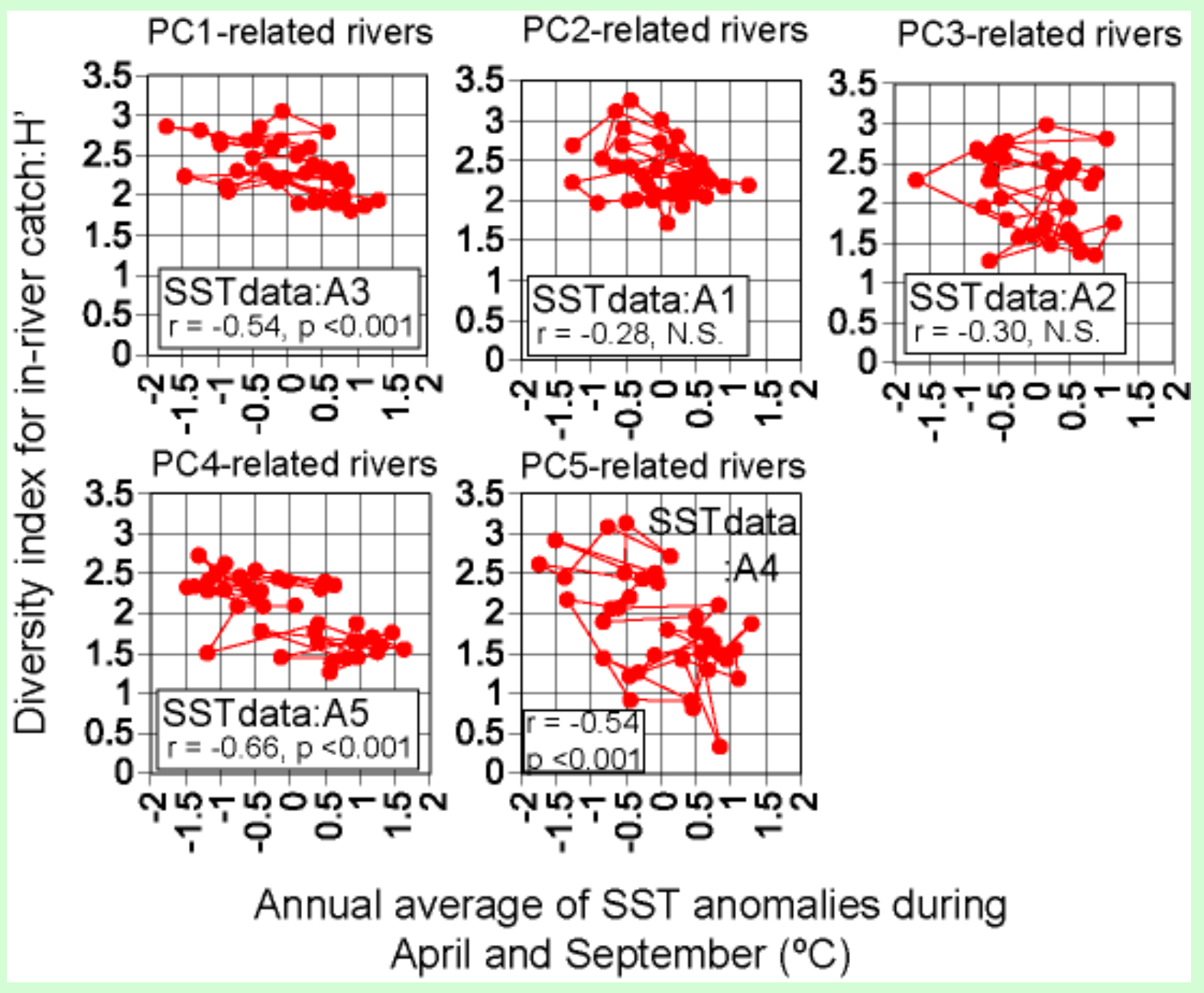

Fig.9. Correlation between Shannon's diversity index for in-river catch and annual average of SSTs during April and September.

- Coastal SSTs tended to show negative anomalies up to about May after late 1990s, and it reached to positive anomalies in summer (June-August). Positive anomalies in summer became remarkable after mid-2000s. In A5 annual average SST anomalies showed positive values after 1999 (Fig. 7). Except of A4, the annual average SST was the highest in 2010.
- Period of in-river catch was drastically changed during 1976 and 2014 (Fig.8). In particular, PC4- and PC5-related river stocks (#15-22) demonstrate decreased catch period after mid 1990s. Except for PC2-related rivers, peaks of in-river catch occurred at nearly beginning of catch period after mid-1990s or mid-2000s.
- There was a tendency that higher SST anomalies were negatively correlated with diversity index of in-river catch (Fig.9). However, such tendency was not observed in PC2- and PC3-related rivers (#1-10), located in more northern area as compared with other rivers of #11-22.

Conclusion

- Natural spawning of Japanese pink salmon affects their abundance strongly, but residual from parent-offspring relationships are associated with coastal SST during at the beginning of ocean life (up to May) and/or summer (June-August) in the first and second year of ocean life.
- In 2010, coastal SSTs were the highest with some exception: this probably led to reduce survival of the 2009 broodyear. The higher SST conditions continued after 2010, which might have had a negative effect on survival of the 2010 broodyear.
- Higher SST conditions possibly reduced diversity of run timing in southern river stocks, which is concerned to degrade resilience against an environmental severity like recent years.

(1) Morita et al. 2006. Population dynamics of Japanese pink salmon (*Oncorhynchus gorbuscha*) : are recent increases explained by hatchery programs or climate variations? Can. J. Fish. Aquat. Sci., 63:55-62.