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Fluctuations in return rates for hatchery-reared chum salmon (*Oncorhynchus keta*) in relation to coastal ocean environment in Japan

by

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Abstract

Return rates for 1976-93 brood-year stocks from seven regions of Japan, Okhotsk, Nemuro, East and West Hokkaido Pacific coast, Japan Sea, Honshu Japan Sea, and Honshu Pacific coast regions, were compared by correlation and cluster analyses to identify in which regions fluctuations in return rates showed synchronous trends. The analyses revealed that in two pair of regions, Okhotsk-Nemuro, and West Hokkaido-Honshu Pacific coast regions, the synchrony of changes in return rates were found. Since each pair of these regions is geographically close each other, coastal oceanographic conditions during early ocean life were thought to be possible factors causing the fluctuations. In Okhotsk-Nemuro regions, the return rates were positively correlated with November-July sea surface temperatures (SST), whereas in West Hokkaido-Honshu Pacific coast regions, a positive correlation between the return rates and cumulative areas of SST ranging from 5 to 13 ℃ during juveniles' migration period was detected. These findings suggest that brood-year strengths of chum salmon from some regions of Japan are probably regulated by oceanographic conditions during early ocean life, and that the factors affecting their survival may be different among regions.

Introduction

Abundance of Pacific salmon (*Oncorhynchus* spp.) generally exhibits year-to-year variation. One reason for this is a difference in abundance among brood-year stocks. Understanding mechanisms determining brood-year strengths is one of the most important challenges to know actual and future status of salmon stocks. Pacific salmon, however, migrate across a variety of habitats from fresh water to the ocean in their life histories, which makes it difficult to monitor when and/or where brood-year strengths are determined.

In Japan, most chum salmon are exclusively sustained by hatchery programs (Kobayashi 1980; Mayama 1985; Kaeriyama 1989, 1996, 1999). Annual number of released chum fry has been almost constant (1.8-2.1 billions) for the last two decades. In general, chum fry released in rivers migrate to coastal waters in a short time (Kobayashi et al. 1965; Mayama et al. 1982, 1983; Kaeriyama 1986), suggesting that mortality of fry in rivers is probably very low if healthy fry are released (Mayama et al. 1983). These special situations of Japanese chum salmon give me an opportunity to examine environmental effects of the ocean on survival of Japanese chum, because their brood-year strengths are thought to be entirely affected in their ocean life.

The objectives of the present study are (1) to compare return rates for brood-year stocks of chum salmon among different regions of Japan in order to detect in which regions fluctuations in return rates show synchronous patterns and (2) to explain detected covariations of return rates in relation to coastal environmental conditions.

Materials and Methods

The numbers of released chum fry and adult returns (catch in coastal waters + escapement), and the age composition of chum salmon captured in rivers were obtained by 1976-1996 annual reports of Hokkaido Salmon Hatchery (presently, National Salmon Resources Center; NASREC) and Salmon database of NASREC (NASREC 1997-1999). For stocks from Honshu (Fig. 1), some data such as the number of escapement and the age composition were occasionally supplemented by other report (Honshu Keison Zoushoku Shinkoukai 1989) and data collected in each prefecture. Using the mentioned above data, the number of released fry and return rates for 1976-93 brood-year stocks from seven regions of Japan, Japan Sea (JS), Okhotsk (OH), Nemuro (NE), East and West Hokkaido Pacific coast (EP and WP, respectively), Honshu Japan Sea (HJ), and Honshu Pacific coast (HP), were compiled. The Return rate of each brood-year stock is defined by dividing the number of adult returns at 2-6 years old by its release number (percentage). Since age at maturity of Japanese chum has increased gradually in the last 20 years (Ishida et al. 1993; Kaeriyama 1996, 1998, 1999), some fish occasionally return to Japan at 7-8 years old. But almost fish (about 97-99%) of a given brood-year stock return to Japan at up to 6 year old (Saito, unpublished data). Therefore, I excluded 7-8 years old fish from calculation of the return rates.

To examine synchrony of return rates among the regions, I applied correlation and cluster analyses. It is well known that time series such as recruitment and environmental data frequently show autocorrelation (e.g., Thompson and Page 1989; Peterman et al. 1998; Pyper and Peterman 1998; Pyper et al. 1999; Botsford and Paulsen 2000). In general, a normal correlation analysis between these autcorrelated data cause miss conclusion because autcorrelated time series do not satisfy the assumption of independence, which is a central premise for the significance test of a correlation coefficient (e.g., Pyper and Peterman 1998; Botsford and Paulsen 2000). But in case of the present study, I didn't find autocorrelation in the time series of return rates for all seven regions. This situation enabled me to use a normal correlation analysis to conduct significance test of a correlation coefficient. To carry out a cluster analysis, return rates for 1976-93 brood-year stocks were transformed to z-scores (a mean of 0 and a standard deviation of 1) for each region separately, because difference in scale of return rates among the regions affected the calculations of distance measures. The squared Euclidean distance and Ward's method were used as distance measures and linking clusters, respectively.

If synchronous fluctuations in return rates are detected in some groups of regions, there is a possibility that these fluctuations would stem from (a) common oceanographic factor(s) around the grouped regions. To examine the possibility, aggregated return rates were compiled for regions where similar changes in return rates were observed, and a correlation analysis was then carried out between the aggregated return rates and the following coastal oceanographic factors during early ocean life: (1) November-July sea surface temperature (SST) and (2) cumulative areas of SST ranging from 5 to 13 °C during juveniles' migration period. Oceanographic processes in the winter season affect ocean production in the subsequent spring and summer (Brodeur and Ware 1992). That is why I chose the SST during November and July as a possible factor affecting return rates. Firstly, every 10 days' mean SSTs from November 1976 to July 1994 were expressed as anomalies from 18 years' averages (1976-93 for every 10 days' SSTs during November and December, and 1977-94 for those during January and July), and then these anomalies were averaged from November in the year i to July in the year $i+1$ for the brood-year stock i (i = 1976-93) released in the spring of the year $i+1$. Juvenile chum salmon are generally distributed coastal waters when SST ranges from 5 to 13 °C (Kobayashi 1977; Irie 1990; Seki and Shimizu 1996). For that reason, areas of SST ranging from 5 to 13 °C during their coastal residence and migration periods were considered as an another possible factor affecting return rates. The areas were calculated at 10-day intervals, and then added up through the mentioned above periods. The original data of SST were provided by Japan Meteorological Agency as 10-day mean sea surface temperatures analyzed for 1 degree by 1 degree grid points (NEAR-GOOS Regional real time database). The two oceanographic factors were calculated with a software package for marine geographic information systems, "GIS Marine explorer version 3.1" (Environment simulation laboratory Co. Inc., Kawagoe, Japan) across coastal waters where juvenile chum are thought to be distributed (see below). When relationships between the aggregated return rates and the oceanographic factors were observed, the averaged factors for the best and worst three brood-year stocks about return rates were calculated and then compared between them, in order to identify difference in coastal oceanographic conditions between good and bad years for survival of juvenile chum salmon.

Results

The number of released chum fry and return rates for 1976-93 brood-year stocks among seven regions of Japan were shown in figure 2. In each region, annual number of released chum fry has been almost constant since the early 1980s: about 200 millions in each of five regions of Hokkaido, 200-300 millions in HJ, and 600-700 millions in HP. These results indicate that the number of released chum fry itself was not the major source for determining abundance of returning salmon for the brood-year stocks in the all regions.

The return rates for 1976-93 brood-year stocks were significantly correlated each other in three pairs of regions, OH-NE, NE-EP, and WP-HP regions (Table 1). A cluster analysis grouped two pairs of regions, OH-NE, and WP-HP regions, as showing synchronous trends in the return rates (Fig. 3). As results of these two analyses, I regarded OH-NE and WP-HP regions as each pair of regions where similar changes in the return rates were observed. Since each pair of regions is geographically close each other (see, Fig. 1), common coastal oceanographic factors possibly affected the return rates for stocks in each pair of regions.

For OH-NE and WP-HP regions, the following areas were set up to measure the coastal oceanographic factors (hereafter, measuring area): 43°N-46°N latitude and 142°E-147°E longitude for the former pair, and 35°N-43°N latitude and 140°E-146°E longitude excluding an area 35°N-41°N latitude and 143°E-146°E longitude for the latter pair. In general, chum juveniles are mainly distributed within 18-30 km from the shore, but occasionally they occur in 100 km offshore (Irie 1990). Therefore, each of the measuring areas was approximately determined so as to include areas about 100 km offshore. The measuring area for stocks from WP-HP regions included eastern

Hokkaido Pacific coast, because juveniles from these regions pass this area during their offshore migration (Irie 1990).

Aggregated return rates were positively correlated with November-July SSTs ($r = 0.54$, $n = 18$, $p < 0.05$), but not with cumulative areas of SST ranging from 5 to 13 °C ($r = 0.04$, $n = 18$, $p > 0.05$) for stocks from OH-NE regions (Fig. 4). A graphical comparison in averaged deviations of SST during November and July was conducted between the best and worst three brood-year stocks about return rates (Fig. 5). In good years, i.e., years when the best three brood-year stocks were released (in contrary sense, bad years), SST was relatively warmer than the 18 years' average, particularly during January and April. Another emphasized point was that SST was cooler than the average during June and July in bad years.

On the other hand, aggregated return rates for stocks from WP-HP regions were positively correlated with cumulative areas of SST ranging from 5 to 13 °C ($r = 0.74$, $n = 18$, $p < 0.01$), but not with November-July SSTs ($r = -0.39$, $n = 18$, $p > 0.05$; Fig. 6). Averaged contour maps of SST for the best and worst three brood-year stocks revealed that in good years SST ranging from 5 to 13 °C remained in the West Hokkaido Pacific coast at the beginning of July, whereas in bad years it moved back to the Cape Erimo at the same period (Fig. 7).

Discussion

In the present study, fluctuations in return rates for 1976-93 brood-year stocks showed synchronous trends in each pair of regions, OH-NE and WP-HP regions. Since each pair of regions is geographically close each other, I believe that the return rates were influenced by regional-scale events, probably coastal oceanographic conditions. There are two stages that Japanese chum stay in the coastal waters in their life history: one is when released chum enter to the sea, the other is when maturing adults return to Japan from the ocean. In this study, however, the former was only taken into consider as possible stage where brood-year strengths are determined. In general, mortality of fish is much higher in the young stages such as eggs and larvae and is lower as they grow up, which is well known to be described as a Type ? survivorship curve (e.g., Wooton 1998). That is why, in case of Japanese chum also, it is hardly to image that higher rate of mortality occurs in the maturing adult stage, which determines finally the brood-year strengths.

In OH-NE regions, a positive relationship between aggregated return rates and November-July SSTs was detected. Comparison in averaged November-July SST between the best and worst three brood-year stocks demonstrated that brood-year stocks released in years when SST was warmer in the preceding winter and early spring seasons tended to mark higher return rates. A key point to link the warm SST conditions and the improved survival of juvenile chum salmon may be a relationship between oceanographic conditions and biological production. Unfortunately, information on biological production in the Sea of Okhotsk was not available for this study, which didn't enable me to explain the biological production in relation to SST. However, there has been evidence that long-term changes in oceanographic conditions and zooplankton biomass are closely related in various regions of North Pacific and adjacent seas (McFarlane and Beamish 1992; Brodeur and Ware 1992; Beamish 1993; Beamish and Bouillon 1993; Nagasawa 2000). In addition, Brodeur and Ware (1992) reported that oceanographic processes during the winter season influence the biological production in the subsequent spring and summer. Taking these findings into accounts, a possible explanation is that warm ocean conditions during winter and early spring seasons increase zooplankton biomass, which in turn leads to improve survival of juvenile chum salmon in OH-NE regions. Another explanation is also possible in case of these regions. When brood-year stocks that marked bad return rates were released, there was a tendency that SST was much cooler than the average during June and July. Since this period is coincident with juveniles' residence and migration periods in these regions, low SST conditions may suppress their survival in early ocean life. Temperature has an obvious effect on the rates of both food consumption and metabolism for fishes, which consequently controls fish growth (e.g., Wootton 1998). From this viewpoint, juveniles at low temperature conditions during early ocean life would grow slowly before leaving coastal waters. Some studies concerning survival of juvenile chum salmon reported that their mortality during early ocean life is probably size dependent (Healay 1982; Hargreaves and LeBrasseur 1986; Fukuwaka and Suzuki 2000). If this is true, size dependent mortality is thought to be high in years when ocean temperature is low, which may lead to week brood-year strengths.

In case of WP-HP regions, the aggregated return rates were positively correlated with cumulative areas of SST ranging from 5 to 13 °C during juveniles' migration period, but not with November-July SSTs. Comparisons in the contour maps of SST between good and bad brood-year stocks revealed that the SST distribution ranging from 5 to 13 °C differed at the beginning of July between them. These findings suggest that timing of seasonal changes in SST vary from one year to another in the Pacific coast of Japan, possibly affecting survival of stocks from these regions. In the Pacific coast of Japan, the peak of zooplankton biomass shifts from the West to East Hokkaido Pacific coast during May and July as water temperature and salinity rise seasonally, and these seasonal and spatial changes in zooplankton biomass coincide with distribution of juvenile chum salmon (Irie 1990). From this observation, Irie (1990) hypothesized that larger juveniles migrate northward along the Pacific coast so as to chase waters in which zooplankton biomass is abundant, whereas smaller juveniles did as if they were driven away by severe water conditions (e.g., high temperature and high salinity). If the hypothesis were accepted, the latter case would be more likely in years when seasonal changes in oceanographic conditions occur faster, reducing consequently brood-year strengths.

Recently, there has been increasing evidence that long-term trends in salmon production in the North Pacific links to trends in climate/ocean environment (Beamish 1993; Beamish and Bouillon 1993; Beamish et al. 1997, 1999a, 1999b; Downton and Miller 1998, Nagasawa 2000; Azumaya et al. 2001). The climatic impacts on salmon production are observed over a vast range of stocks not necessarily at each stock level, because climate changes cause large-scale oscillations in regional ocean environment (Beamish 1999b; Nagasawa 2000). The present study also indicated that oceanographic conditions affecting brood-year strengths of Japanese chum salmon are probably different among regions. Although those oceanographic conditions may be merely driven from the global climate fluctuations, I stress that individual stocks are greatly influenced by regional-ocean impacts during early ocean life, which in turn determines the general trends in salmon production. Therefore, monitoring regional-scale response of stocks to ocean environment as well as global-scale one is necessary to understand details of relationships between climate/ocean environments and salmon production.

Japanese chum salmon are exclusively sustained by hatchery programs and these techniques have greatly contributed to increase salmon production in Japan (Kobayashi 1980; Mayama 1985; Kaeriyama 1989, 1996, 1999). But the present study demonstrated that their survival was not independent of oceanographic conditions during early ocean life at all, even though body size at release and timing of release for the hatchery-reared chum fry were controlled by artificial ways. This finding indicates that hatchery-reared salmon may be also regulated by long-term production trends in the whole North Pacific. For that reason, it is important to recognize that impacts of artificially reared fry on wild fish may change when the production trends shift from one state to another, as Beamish and Bouillon (1993) pointed out. In future study, therefore, understanding responses of hatchery-reared and wild salmon to changes in climate/ocean environments is necessary to make both salmon coexist under variable ecosystems.

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Table. 1. Correlation coefficients among return rates of 1976-93 chum brood-year stcks from seven regions of Japan. Significant correlations at 0.01 and 0.05 levels are shown by solid and shad cells, respectively. The abbreviations in the Table represent the seven regions of Japan (see, Fig. 1).

	OH	NE	EP	WP	JS	JS	HP
OH	**-**						
NE	**0.66**	**-**					
EP	**0.23**	**0.49**	**-**				
WP	**0.19**	**0.13**	**0.11**	**-**			
JS	**0.26**	**0.47**	**0.31**	**0.17**	**-**		
JS	**-0.08**	**-0.26**	**0.21**	**-0.16**	**0.22**	**-**	
HP	**-0.06**	**-0.37**	**-0.43**	**0.51**	**-0.20**	**-0.28**	**-**

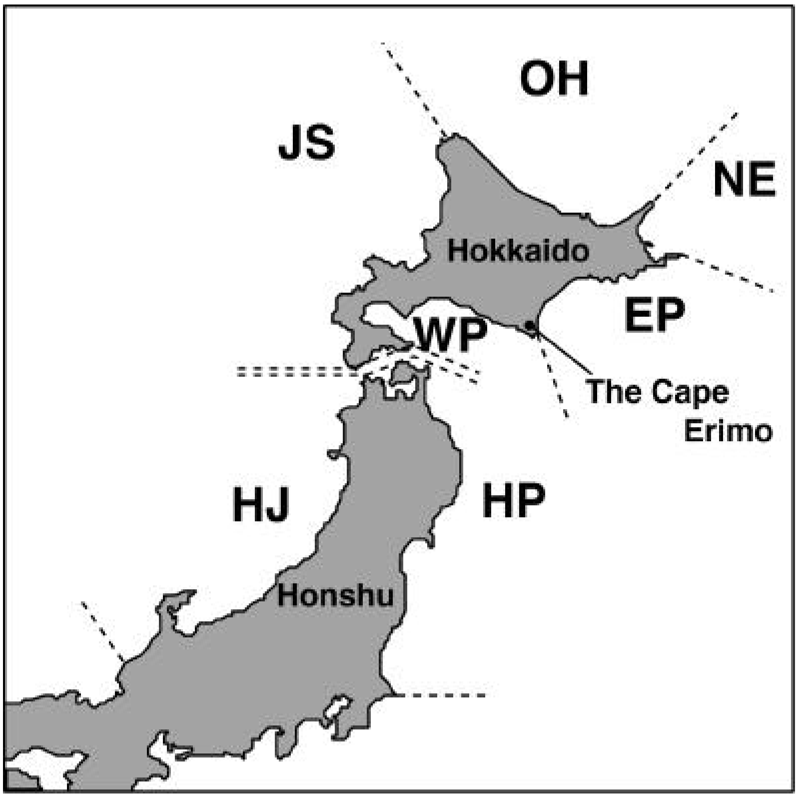

Fig. 1. Defined seven regions of Japan. For each of the regions, return rates for 1976-93 chum brood-year stocks were calculated.

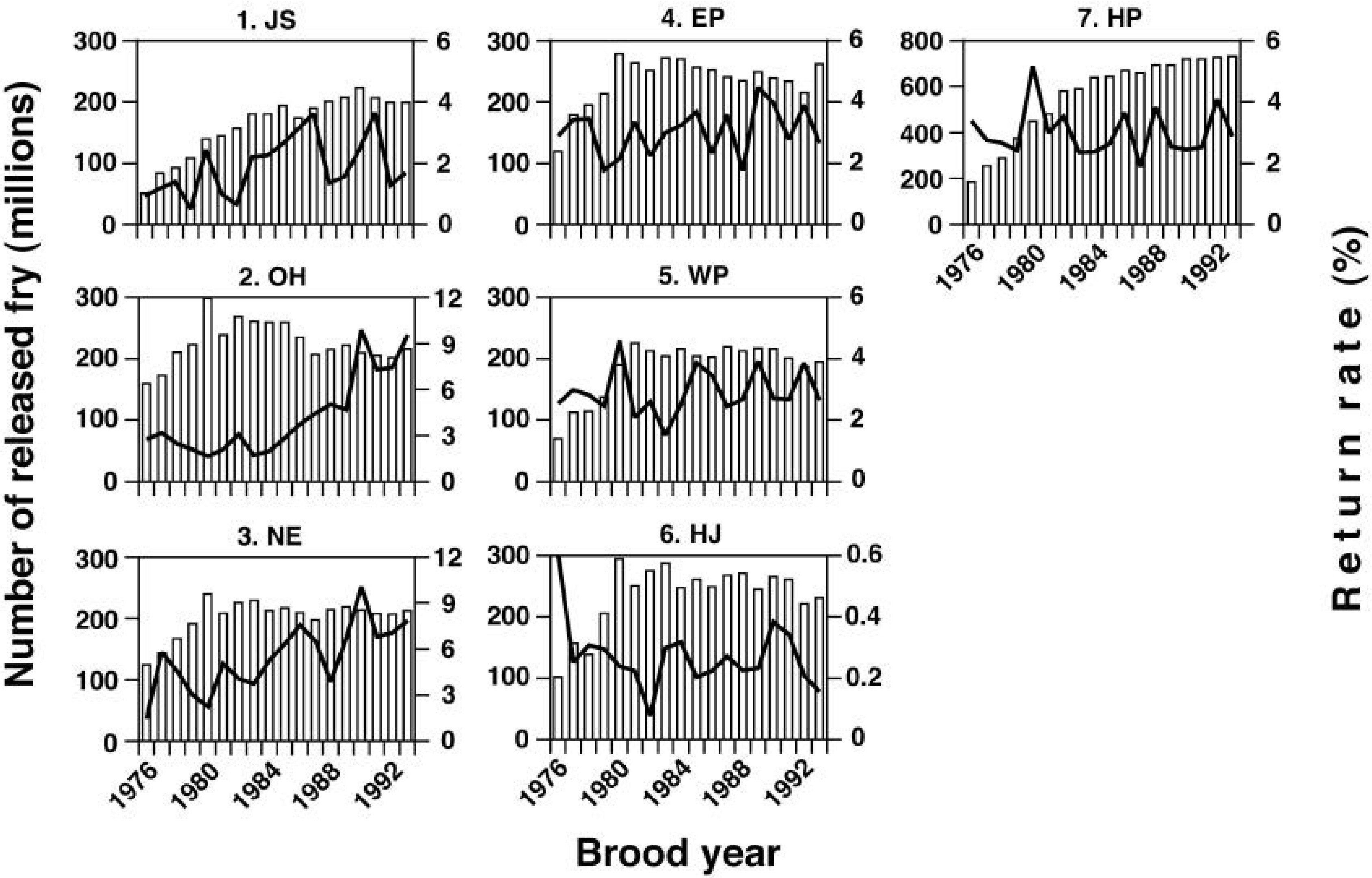

Fig. 2. The number of released fry (open bars) and return rates (slide lines) for 1976-93 chum brood-year stocks from seven regions of Japan. The abbreviations above each graph indicate the seven regions of Japan (see, Fig. 1).

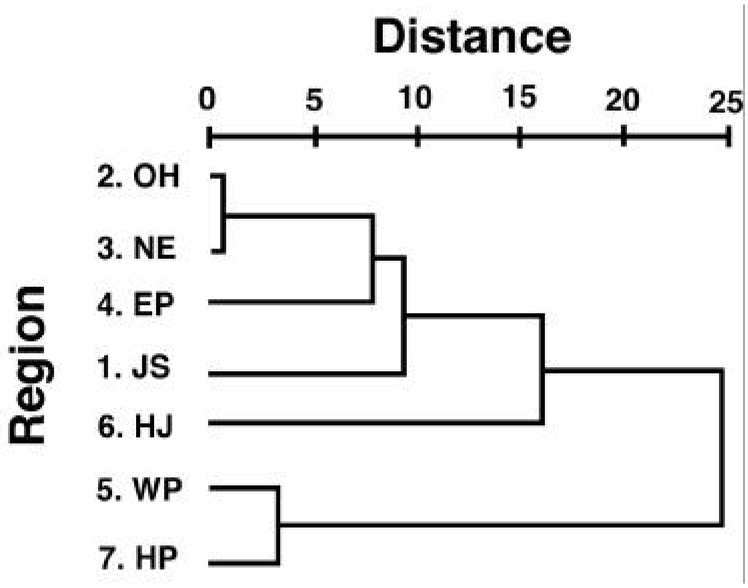

Fig. 3. Result of cluster analysis based on return rates for 1976-93 brood-year stocks from seven regions of Japan. See Fig. 1 for locations and names of the regions.

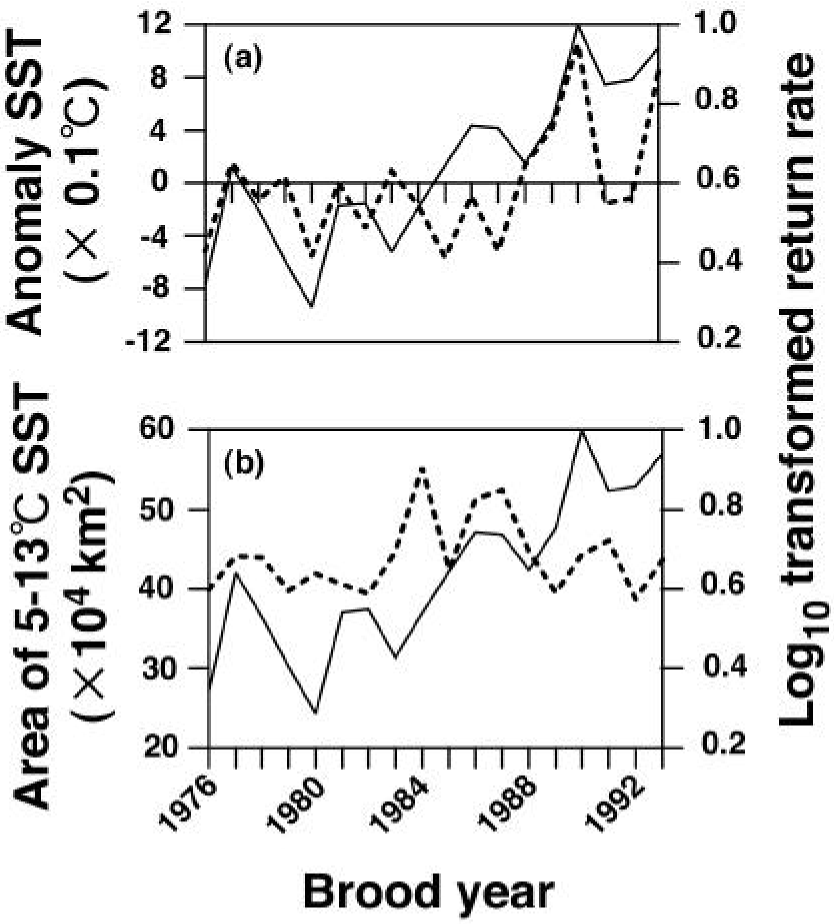

Fig. 4. Relationships between return rates for 1976-93 brood-year stocks from Okhotsk and Nemuro regions (slid lines) and coastal oceanographic conditions (dash lines). Examined coastal oceanographic conditions are (a) November-July anomalies of sea surface temperatures and (b) cumulative areas of sea surface temperature ranging from 5 to 13 °C during juveniles' coastal residence and migration periods.

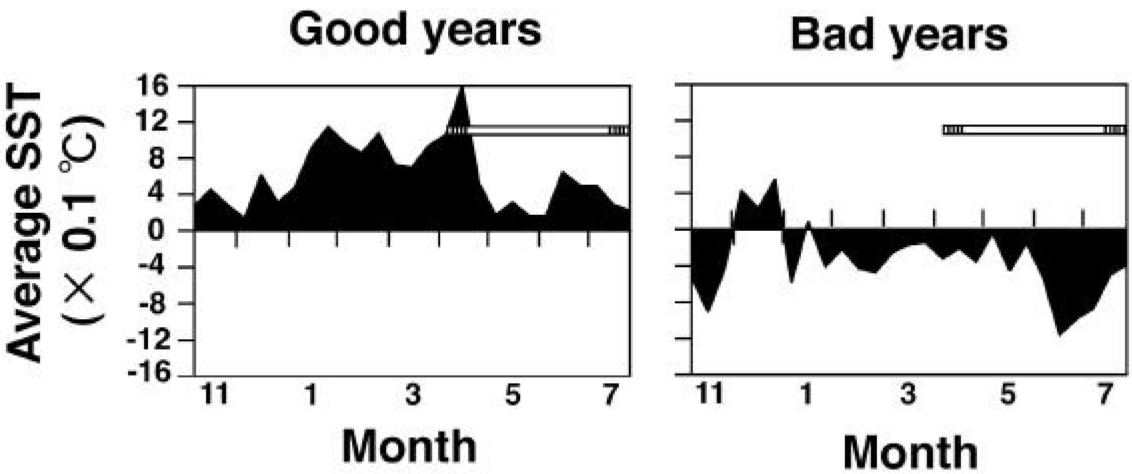

Fig. 5. Average sea surface temperatures during November and July in coastal waters of Okhotsk and Nemuro regions for the best and worst three brood-year stocks about return rates, good and bad years respectively. SST was shown as deviation from 18 years' mean (mean for 1976-93 brood-year stocks). Bars indicate juveniles' coastal residence and migration periods in the regions.

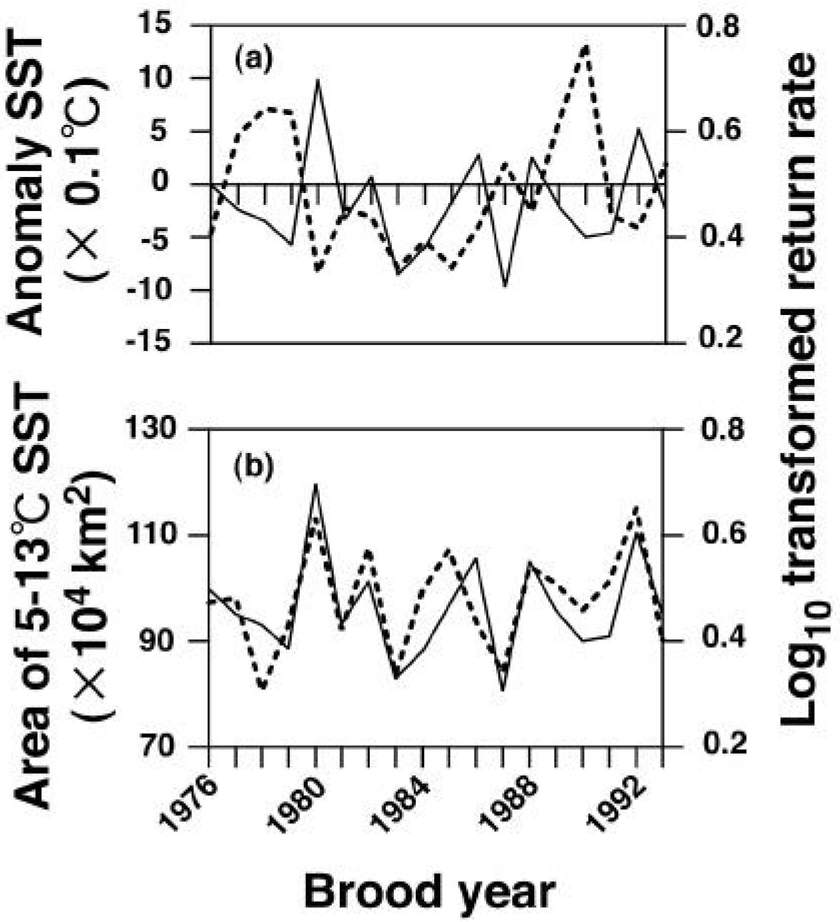

Fig. 6. Relationships between return rates for 1976-93 brood-year stocks from West Hokkaido and Honshu Pacific coast regions (slid lines) and coastal oceanographic conditions (dash lines). Examined coastal oceanographic conditions are (a) November-July anomalies of sea surface temperatures and (b) cumulative areas of sea surface temperature ranging from 5 to 13 °C during juveniles' coastal residence and migration periods.

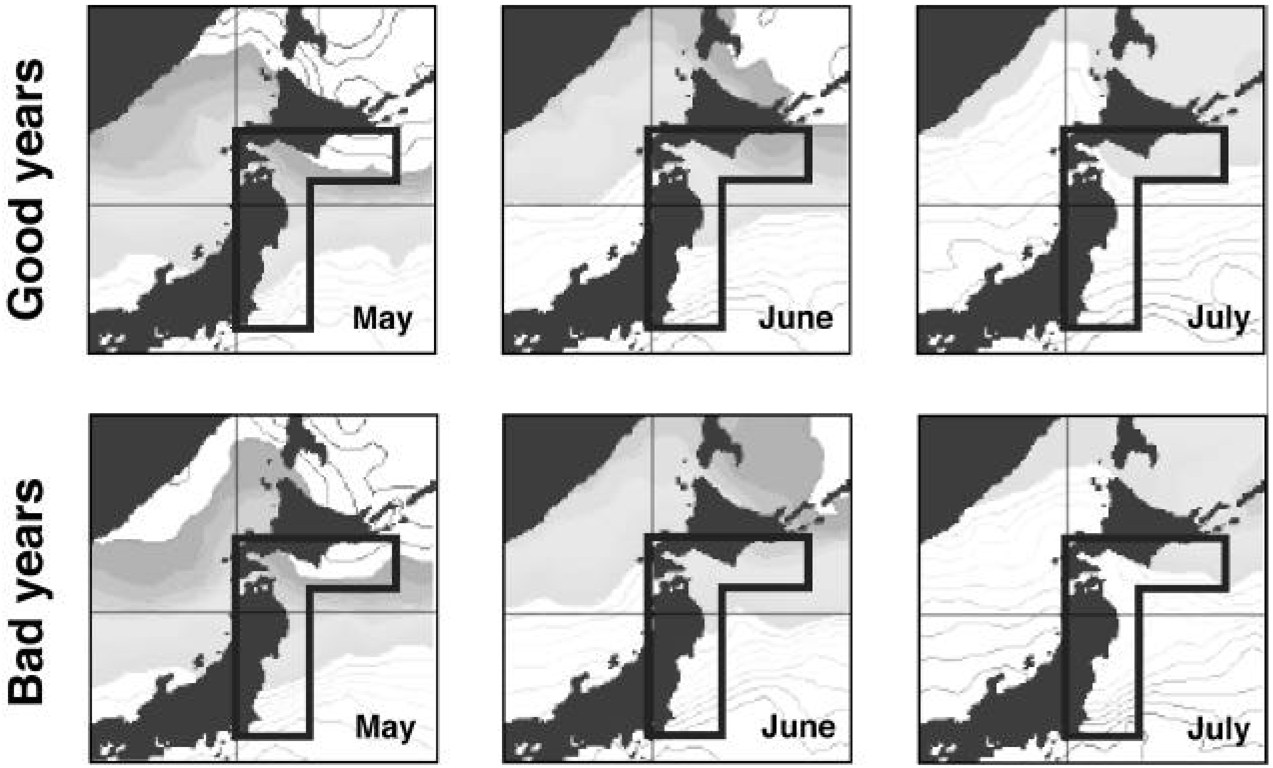

Fig. 7. Average contour maps of sea surface temperatures ranging from 5 to 13 °C (colored areas) in the Pacific coast waters for the best and worst three brood-year stocks about return rates (expressed as good and bad years respectively). Those brood-year stocks were released from West Hokkaido and Honshu Pacific coast regions. Enclosed areas indicate measuring areas for coastal oceanographic conditions.