Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

JEB
Journal of Environmental Biology

ISSN: 0254-8704
CODEN: JEBIDP

Effect of climate-ocean changes on the abundance of Pacific saury

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Abstract

Effects of ocean climate changes on the population structure and abundance of Pacific saury (*Cololabis sira*) were investigated on the basis of climate indices, sea surface temperature (SST) anomalies, catch and body size information from the Tsushima Warm Current (TWC) region (Yellow Sea, East China Sea and East/Japan Sea) during the period 1950-2010. It is suggested that oceanic regime shifts in the early 1970s, late 1980s and late 1990s occurred in the TWC region in winter, but the regime shifts in the mid-1970s and in the late 1980s were not evident in the spring SST anomaly series. The abundance and body size of Pacific saury fluctuated in association with the winter oceanic changes in the TWC region. The catch rates and abundance of large size saury were far bellow average during their northward migrations in the TWC region in the years with abnormally cool winters (e.g., 1963, 1970, 1977, 1981-1989 and 2006) and above average in the years with warm winters. These patterns demonstrate decadal-scale variations together with large inter-annual fluctuations in the structure and abundance of Pacific saury in association with the climatic-oceanic changes. These results, along with an alternation of dominant pelagic fish species, indicate the status of the saury population in the TWC region is in good condition, similar to that in the Kuroshio-Oyashio Current (KOC) region during the warm regime after the late 1980s climate regime shift.

Publication Info

Paper received:
29 June 2011

Revised received:
11 July 2012

Accepted:
28 August 2012

Key words

Abundance, Body size, Climate change, Pacific saury

Introduction

There is increasing evidence that variations in the abundance of pelagic fishes are forced by changes in ocean and climate conditions. The North Pacific atmosphere-ocean system and the abundance of pelagic fishes fluctuate in association with decadal climate changes. The mid-1970s climate regime shift in the North Pacific (Kuroshio-Oyshio Current: KOC region) and the late 1980s climate regime shift in the Tsushima Warm Current (TWC) region are well documented (Trenburth and Hurrell, 1994; Mantua *et al.*,1997; Beamish *et al.,* 1999; Chavez *et al*., 2003; Tian *et al*., 2008).

Pacific saury (*Cololabis saira*) makes extensive migrations from the subtropical to the subarctic regions in the North Pacific Ocean, and the spawning season continues from autumn through spring (Gong, 1996; Tian *et al*., 2004b; Watanabe *et al*., 1997). Since Pacific saury inhabit the warm and high salinity waters, no adult saury are found in the western East China Sea and northern Yellow Sea (Gong and Suh, 2004). Catches of saury in the TWC and KOC regions have fluctuated with an annual average of about 27,000 tons and 300,000 tons respectively over the last half century.

Climate regime shifts in 1976 and 1988 were detected in Korean waters and affected fisheries resources (Kang *et al*., 2000; Zhang *et al*., 2000). The size composition and abundance of Pacific saury in the TWC and KOC regions exhibit immense inter-annual variations (Takahashi, 1997; Kosaka, 2000; Gong and Suh, 2004). Although fishing has considerable impact on the trend in abundance, large interannual variations in abundance and size composition do not result from fishing, but are forced by environmental factors. It has been demonstrated that human factors drive the warming of regional seas in this area, impacting marine ecosystems and changing dominant fish species in commercial fishery catches of Korea (Jung, 2008). The abundance of Pacific saury is directly affected by sea surface temperature (SST) through large-scale atmosphere-ocean interactions, and the two size groups of saury (Large L and Medium M) are affected by different oceanic systems (Kuroshio and Transition region) in the northwestern Pacific (Tian *et al*., 2003). It is suggested that oceanographic conditions determine the recruitment success of Pacific saury, and that the fish could be used as a bio-indicator of regime shifts in the northwest subtropical Pacific (Tian *et al*., 2004b).

Despite an increasing trend in fishing effort and expanding fishing grounds, the catch of saury by gill net fishing and catch rates of the large size group in the waters off the Korean peninsula (western TWC region) experienced an abrupt decline in the early 1970s, indicating a strong influence of environmental factors. However, the cause and mechanisms of the large variations in abundance and body size composition of saury in the TWC region are not well explained. The objective of this study was to examine the effects of climatic-oceanic regime shifts on body size composition and abundance of Pacific saury in the TWC region.

Materials and Methods

The Pacific Decadal Oscillation (PDO), Southern Oscillation Index (SOI), Arctic Oscillation Index (AOI) and Monsoon Index (MOI) were chosen as climatic indices for the Far East region (Tian *et al*., 2006). These indices are associated with the interannual and decadal variability in atmospheric and oceanic conditions (Beamish *et al.,* 2000). Time series of annual, winter (January, February, March) and spring (April, May, June) sea surface temperature (SST) anomalies in the TWC region were used to examine the oceanic changes in relation to the climate regime shifts for the period of 1950-2010. SST anomalies were obtained from the Internet (http://www.data.knowledge.kishou.go.jp/kaiyou) (Fig. 2).

Year-to-year catch series and catch per unit fishing effort (CPUE) were compared to see if the catch series can be regarded as indices of the population abundance of Pacific saury. Since the CPUE data are limited to the active fishing period (1950s-1970s) in the TWC region, catch data were also used to examine the long-term trend of abundance. The catch data for the period 1950-2008 are based on the Yearbooks of Fishery Statistics of Korea and Japan, FAO Yearbooks of Fisheries Statistics, and previous reports including fishery data (Gong, 1996; NFRDI, 2010). Pacific saury has been successfully fished by synthetic fiber gillnets in the TWC region since the late 1950s and by stick-held dip nets in the KOC region since the early 1950s. Therefore, year-to-year catch series for the TWC region were constructed for the period of 1950-2008.

Body size composition data for the Pacific saury during their northward migration in the spring and summer were collected from the southwestern (off Korea), northwestern (off Russia), southeastern (off Honshu, Japan) and northeastern (off Hokkaido, Japan) areas of the TWC region for the period of 1952-2010. Time series anomalies of the hydro-climatic indices (PDO, SOI, AOI, MOI, and SST) were compared with the abundance indices (catch and catch per unit effort) and biological parameters (catch rates per body size group). The fluctuations of abundance of the saury population were then compared with oceanic conditions, the proportions of body size groups, and the alternation of dominant pelagic fish populations (saury, anchovy, sardine, mackerel, squid).

Results and Discussion

The anomalies of climate indices and their cumulative sums (CuSums) are shown in Fig.1. The winter PDO showed decadal scale variations with distinct changes in 1977 and 1989. The pattern of SOI changed from positive to negative anomalies in 1976 with the CuSum curve showing abrupt changes in 1976 and 1998. This pattern indicates that El Niño events tended to be intense after 1977, particularly during 1990 to 1995, whereas La Niña events were evident until 1976 and after 1998. There were distinct changes in 1971, 1977 and 1989 in the AOI. Winter MOI showed abrupt changes around 1987 from positive to negative anomalies indicating a weakening of the Asian Monsoon, whereas no distinct change occurred in the mid-1970s. The abrupt changes which occurred in 1976/1977 are common for PDO, SOI and AOI, while the changes at the end of the 1980s occurred in the PDO, AOI and MOI. Slight changes in the late 1990s were found in the PDO and SOI. In brief, four climatic indices showed that regime shifts occurred in the early or mid-1970s, in the late 1980s and mid or late 1990s.

Since the spawning of Pacific saury lasts from autumn through spring, the abnormal oceanic conditions in winter-spring would be detrimental to the successful growth and recruitment of the fish. The sea surface temperatures (SSTs) in the TWC region showed decadal variation patterns together with large inter-annual variations. The winter SSTs in 1962/63, 1970/71, 1976/77, 1980/81 and 1986/87 were far bellow normal in the TWC region. In the annual and winter SST anomaly series, oceanic regime shifts in the TWC region can be recognized in the early 1970s (1971/1972), late 1980s (1987/1988) and late 1990s (1997/1998) during the period from 1950-2010 (Fig. 2). In the spring SST anomaly series, oceanic regime shifts in the TWC region occurred in the early 1970s (1971/1972) and late 1990s (1997/1998) but not in the mid-1970s or late 1980s (Fig. 2).

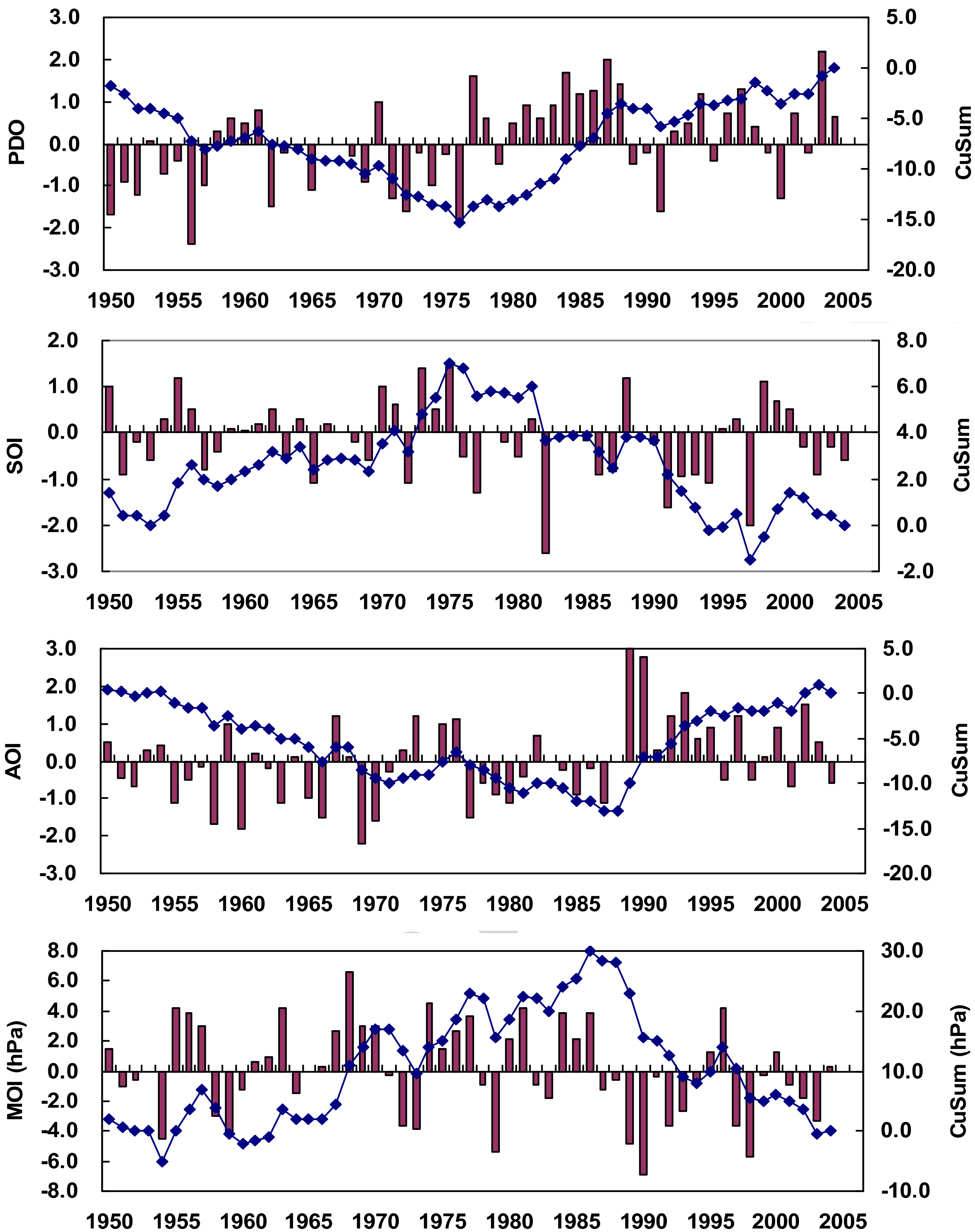

Fig. 1 : Anomaly values (vertical bar) and cumulative sums (CuSums, diamond) for the Winter Pacific Decadal Oscillation (PDO), Annual Southern Oscillation Index (SOI), Winter Arctic Oscillation Index (AOI) and Winter Monsoon Index (MOI) from 1950 to 2004 (Source Tian *et al*., 2006)

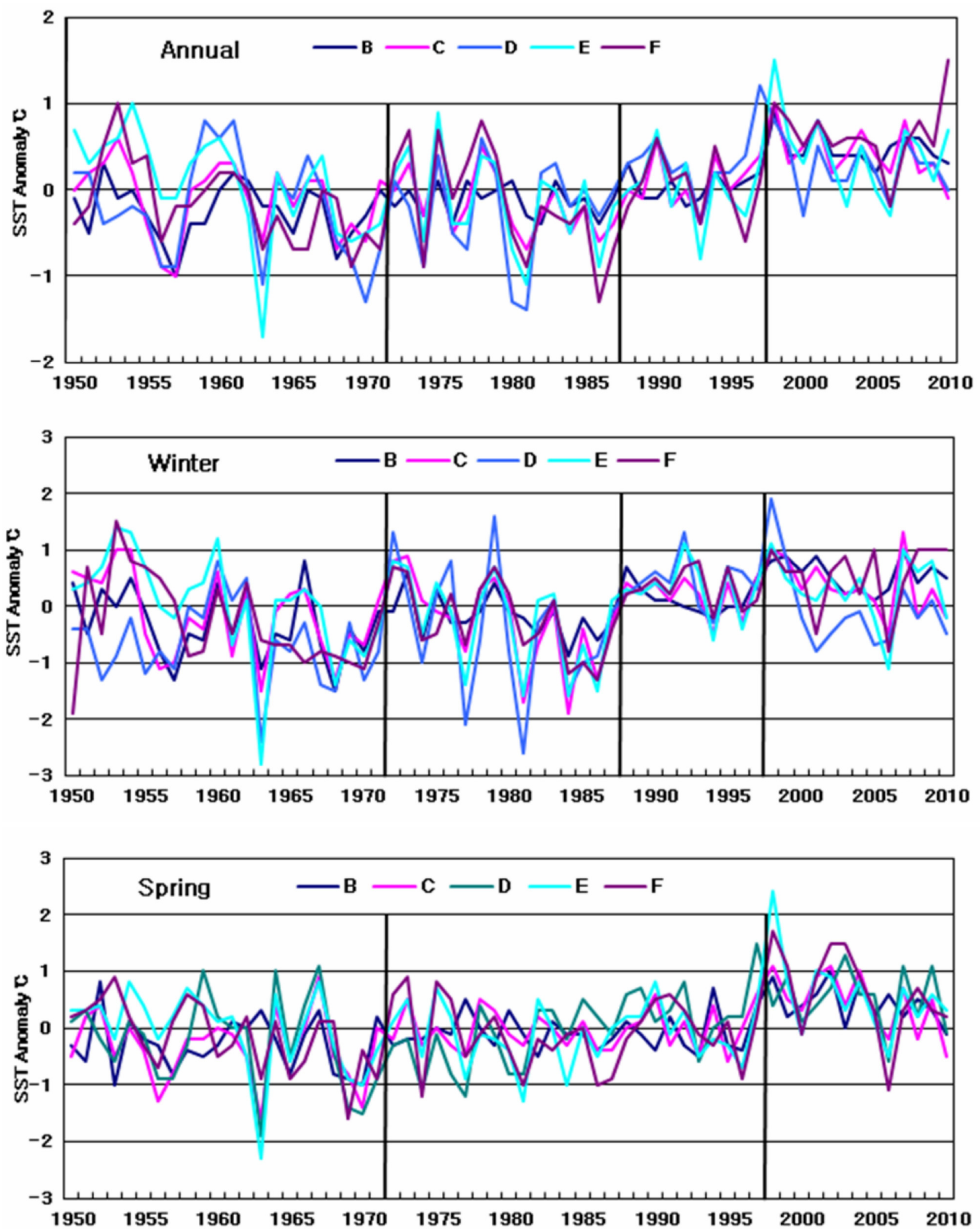

Fig. 2 : Annual (Jan.-Dec.), winter (Jan., Feb., Mar.) and spring (Apr., May, June) sea surface temperature (SST) anomalies in the TWC region, 1950-2010. The TWC region covers Area B (Southern East China Sea), C (northern East China Sea), D (Yellow Sea), E (southern East/Japan Sea), and F (middle East/Japan Sea). Vertical lines indicate regime shifts in sea surface temperature data

In brief, the time series of SST anomalies revealed that there are seasonal differences in the time when the oceanic regime shifts occurred in the TWC region. Winter oceanic regime shifts can be observed in the early 1970s, late 1980s and late 1990s, whereas spring regime shifts are recognized only in the early 1970s and late 1990s. In the TWC region the SST anomalies by area showed the same fluctuation patterns in winter but different patterns in spring, suggesting that strong and dominant factor (e.g., winter monsoon) controls all over the areas in the TWC region in winter, whereas many factors with different strength (e.g., precipitation, sunlight, oceanic currents etc.) control the thermal conditions in spring.

The negative Arctic Oscillation (-AOI) and strong winter monsoon (+MOI), which co-varied with the PDO, enhanced the cool regime in the TWC region in the 1980s and the positive Arctic Oscillation (+AOI) and weak monsoon (-MOI) enhanced the warm regime in the 1990s. The winter monsoon (MOI) seems to have the largest effect on the changes in winter thermal regime in the TWC region (Fig. 1 and 2).

The inter-decadal variability of integrated (0~150m layer) seasonal mean temperature and zooplankton biomass along the PM line (36°N, 136°E-44°N, 132°E) in the TWC region were positively correlated with a 3-year time lag during the period 1973-1995. Both variables were low during the 1980s but increased after the late 1980s regime shift and remained at high levels during the warm regime in the early 1990s (Minami *et al.,* 1999). The cool regime in the 1980s and warm regime in the 1990s are clearly shown in the year-to-year strength anomalies of the Tsushima Warm Current as defined by the area with temperature warmer than 10°C at the 100m layer in the East/Japan Sea during the period 1961-2007 (Gong *et al.,* 2010).

Abundance and body size of Pacific saury: Pacific saury has been fished mainly by gill-net (80%) and set net in the TWC region during their northward migrations in spring-summer and during their southward migrations in autumn-winter. The catch and CPUE series showed inter-annual and decadal scale fluctuations in the western TWC region (off Korea) (34° 30'N-38° 30'N, west of 133° 30'E) during the period 1950 to 2009. In the first half of the series, catch and CPUE were high with slight decreases in the late 1960s. The CPUE decreased from the early 1970s and catch decreased from the mid 1970s. The mean CPUE (4.3 kg net^{-1}) from the late 1970s to the early 1980s was far below the long-term mean (CPUE, 8.4 kg net^{-1}) (Fig. 3).

Catches remained high in the early 1970s even though the CPUE decreased which is attributed to sharp increases in fishing efforts (number of gill nets) and expansion of fishing grounds to the northeast (Gong, 1996). Annual total saury catches in the entire TWC region (off Korea and western Japan) sharply decreased in the late 1970s and remained low during the 1980s and then increased from the early 1990s. Thereafter, higher year-to-year fluctuations with sharply decreased catches in 1998 and 2006 are occurred in the recent two decades (Fig. 4).

The large size group (L, mode 28-32cm) of Pacific saury was taken in spring and summer during the abundant periods of the 1960s and 1990s, whereas the small (S, mode 21-24 cm) and medium size groups (M, mode 25-27.9cm) were taken in the TWC region during the adverse period of 1980-1990 (Fig. 4). The catch rate of large size saury (L) amounted to about 70 % in the TWC region during the spring fishing season from April to June in the years with normal or above normal oceanic conditions. However, most of the Pacific saury taken during the cool years (e.g., 1963, 1970, 1977) and the cool regime in the 1980s were of the medium size groups (M); the catch rates of the different size groups varied in association with the winter thermal conditions (Fig. 2 and 4).

Pacific saury in the western TWC region (off Korea) during their northward migration was dominated by two

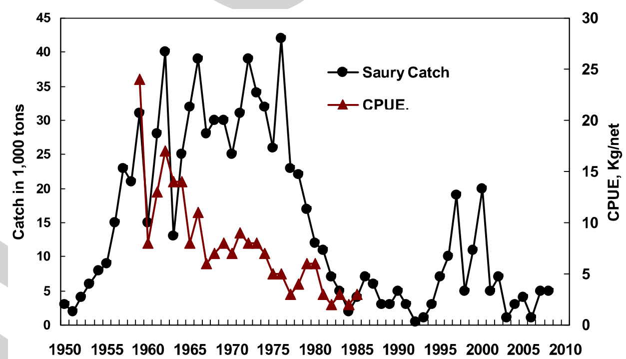

Fig. 3 : Catch and catch per unit effort (CPUE) of Pacific saury taken by gill net during northward and southward migrations in the western TWC region (34° 30'N-38° 30'N, west of 133° 30'E), 1950-2009

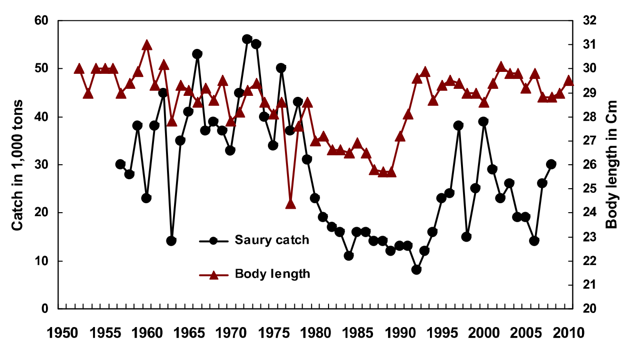

Fig. 4 : Year-to-year catch and body length of Pacific saury taken by gill-net in the Tsushima Warm Current (TWC) region (East/Japan Sea and East China Sea), 1952-2010

Table 1 : Correlation matrix of annual catch fluctuation of 7 pelagic fish populations in the TWC region for the period 1951-2008

TWC	1 Pacific herring (1963~08)	2 Pacific sardine (1963~08)	3 Japanese anchovy (1963~08)	4 Jack mackerel (1953~08)	5 Chub mackerel (1951~08)	6 Pacific saury (1954~08)	7 Common squid (1952~08)
1	1	-0.355	0.063	-0.299	0.297	0.514	0.315
2		1	-0.323	-0.373	0.096	-0.657	-0.268
3			1	0.207	0.353	-0.183	0.514
4				1	-0.529	0.107	-0.177
5					1	-0.115	0.674
6						1	0.208
7							1

Periods for each species are in the parenthesis

sized groups (L and M) in the year of normal oceanographic conditions, whereas saury in the eastern TWC region (off western Japan) was dominated by the large and small sized groups (S, 24-25cm). However, only the medium sized groups (M, 25-26cm) occurred in the eastern TWC region during the cold spring-summer of 1977. Usually, two groups (M and L) were taken in the northwestern TWC region (off Russia) in spring-summer. During the cool period from the mid-1970s to late 1980s mostly small (S, 21-24 cm) and medium sized (M, 25-27cm) groups were taken (Gong and Suh, 2004).

The large size group seems to have disappeared throughout the entire TWC region in spring and summer during the low abundance periods from the mid-1970s to the late 1980s. The large size group then reappeared during the abundant periods in the early 1990s and in the 2000s (Figs. 3 and 4). It is suggested that the abrupt changes in abundance and body size of Pacific saury occurred in association with the winter sea surface temperature changes in the TWC region, and that the decadal-scale variations in abundance responded to the regime shifts in the early 1970s, late 1980s and late 1990s (Fig. 2, 3 and 4).

It is possible to predict the status of the Pacific saury abundance by its body size composition. The saury population status must be in poor conditions when the large size group (L, mode 28-32 cm) does not appear in the TWC region during the northward migrations in spring and summer. After the climate regime shift in the late 1980s, the catch rates and abundance of large size saury increased sharply and remained at high levels during the warm regime in the 1990s and 2000s. These patterns strongly indicate decadal-scale variations together with large interannual fluctuations in the structure and abundance of Pacific saury in association with climatic and oceanic changes.

Pacific saury in the KOC region has been fished mainly by stick-held dip nets during their southward migration in autumn since the early 1950s (Kosaka, 2000). Pacific saury has a short life span of 1-2 years and age at maturity is one year (20cm fork length). Therefore, impacts of climate change on saury abundance should appear after a short time lag (Fukushima *et al*., 1990; Kosaka, 2000; Tian *et al.,* 2003). Note that the abundance of saury is affected by its reproductive success or failure in relation to climate changes, and drastic population declines do not result from overfishing. Although fishing can have considerable impact on the trends in abundance, large variations in both abundance and size composition do not result from fishing, but are forced by environmental factors (Tian *et al*., 2004a). The population of Pacific saury in the KOC region in autumn is dominated by the two size groups, large (L >29 cm) and medium (M, 24-28cm). It is demonstrated that long-term variability in the abundance of saury is largely affected by oceanic and climatic changes and that two size groups are affected by different oceanic systems in the northwest Pacific (Tian *et al*., 2003).

The catches in the TWC and KOC regions were not high even when the catch rates of large size saury and CPUEs increased in the 2000s. This seems to be attributable to decreased gill-net fishing efforts in the TWC region to influence prices (Gong *et al.,* 2010) and to the regulation of fishing and the selection of large size fish in the stick-held dip net fishing operations in the KOC region (Oozeki *et al*., 1998). The annual catch in the KOC region was far below the average when the proportion of the large size group was low during their southward migration in the period 1952-1993 (Takahashi, 1997; Isoda and Sakurai, 2000). Two groups of saury (L and M) were taken during the abundant period, whereas a single group (L or M) was taken during adverse years (Kosaka, 2000). However, the large size groups of saury have been landed selectively from the stick-held dip net fishery in the KOC region in recent years.

Sharply decreased abundances and catch rates of the large size group of Pacific saury in the TWC and KOC regions in the early to mid-1970s and 1980s indicated a strong link between ocean climate regime shifts and the population structure as well as abundance in the entire population area in the Far East. The body size of the fish in the two (TWC and KOC) regions showed normal compositions of population structure in the 1990s and 2000s. Therefore, the abundance of Pacific saury in the entire population area in the Far-East seems to be relatively high in the warm periods following the climate regime shift of the late 1980s.

It is suggested that the recruitment failure and disappearance of the large size group of Pacific saury in the TWC and KOC regions in the 1970s and 1980s were attributable to decreased zooplankton production during the cool regimes. The time series of diatom abundance in the eastern TWC region (off western Japan) showed decadal variability with large inter-annual variations (Tian *et al*., 2008). High spring diatom abundance in the TWC region must have been favorable for the recruitment of Pacific sardine (phytoplankton and zooplankton feeder) in the cool regime (1980s) and high spring zooplankton abundance must have been favorable for the recruitment of the other zooplankton feeders such as Pacific saury and anchovy (*Engraurlis japonicus*) in the warm regime (1990s).

Cyclical dominant periods of Pacific saury: In the TWC region, the catch of Pacific sardine was negatively correlated with the catches of 5 other species (Pacific herring, anchovy, jack mackerel, Pacific saury and common squid) during the last half century. In particular, the correlation between sardine and saury showed a significant negative value (n=46, r=-0.657) during the period 1963-2008 (Table 1). After the chub mackerel (*Scomber japonicus*) catch decreased, the Pacific sardine dominated during the cool regime in the 1980s and 4 other species such as Pacific saury, anchovy, jack mackerel (*Trachurus japonicus*) and common squid (*Todarodes pacificus*) dominated soon after the climate regime shift of the late 1980s. The abundances of these 4 species remained high during the warm regime in the 1990s (Gong *et al*., 2007).

The catch and CPUE from the Pacific saury gillnet fishery in the TWC region sharply decreased from the early to mid 1970s when Pacific sardine (*Sardinops melanostictus*) began to increase sharply (Gong *et al.,* 2010). Historical records of Pacific saury catch also show decadal scale variations with abundant periods around the early 1910s, mid-1920s and early 1950s after the decline of the Pacific sardine population (Takahashi, 1997; Tian *et al.,* 2003). Gillnet fishing for Pacific saury was introduced to coastal fishers in the western TWC region (off the eastern coast of Korea) soon after the notable decrease of sardine abundance in the late 1930s (Gong, 1996). Changes in the dominant species of small pelagic fishes occurred after successive recruitment failures of sardine in the KOC region (Sugimoto *et al*., 2001; Nishikawa and Yasuda, 2008). The catch per unit effort (CPUE) for Pacific saury from the stick-held dip net fishery in the KOC region sharply increased as the recruitment of Pacific sardine sharply decreased in association with the climate regime shift in the late 1980s, suggesting the replacement of sardine by saury (Watanabe, 2007). In fact, the abundance of the other 4 pelagic fish populations were at high levels in the 1990s even though the catches may not have been high due to changes in fishing such as reduced fishing effort and/or regulation of fishing activities.

It is postulated that the abundance of Pacific saury remained high in the 1990s and 2000s, even though catches were not high due to the limited fishing activities. It is possible to predict the status of the abundance of Pacific saury by their body size composition. When the large size group (L group) appears in the TWC region during the northward migration in spring and summer, it is predicted that their population will be in good conditions.

Acknowledgments

We are grateful to Dr. Ian Perry of the Pacific Biological Station, Fisheries & Oceans Canada, Nanaimo B.C., Canada for insightful comments in improving the manuscript, and also to Dr. Yongjun Tian of the Japan Sea National Fisheries Research Institute, Niigata, Japan for providing information about the climate indices. This work was funded by a research project of study on "the consequences and countermeasure of the effect of climate change on marine ecosystem and fisheries resources" of the National Fisheries Research and Development Institute (NFRDI) (RP-2012-ME-002).

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