J. of the Environmental Sciences
Vol. 13, No. 5, 449~467, 2004

Effect of environmental conditions on the stock structure and abundance of the Pacific saury, *Cololabis saira* in the Tsushima Warm Current region

Yeong Gong and Young-Sang Suh*

Korea Fisheries Association, Seoul 120-012, Korea
**National Fisheries Research and Development Institute, Busan 619-902, Korea*

(Manuscript received 24 March, 2004 ; accepted 22 May, 2004)

Interannual and decadal scale changes in body size of Pacific saury, catch and catch per unit effort were examined to investigate the environmental effects on the stock structure and abundance in the Tsushima Warm Current region. Interannual changes in thermal conditions are responsible for the different occurrence (catch) rates of sized group of the fish. Changes in body size due to environmental variables lead the stock to be homogeneous during the period of high abundance, while one of the reminder cohorts supports the stock during the period of low level of abundance.

Migration circuits of two cohorts of saury stock are hypothesized on the basis of short life span and spatio-temporal changes of the stock structure in normal environmental conditions. Changes in upper ocean structure and production cycles by the decadal scale climate changes lead changes in stock structure and recruitment, resulting in the fluctuation of saury abundance. Hypothesized mechanism of the effects of climate changes on stock structure and abundance is illustrated on the basis of changes in thermal regime and production cycle.

Key Words : Pacific saury, Sized group, Catch, Occurrence rate, Abundance, Ocean climate, Migration circuit

1. Introduction

A Part of the Kuroshio water penetrates onto the outer continental shelf of the East China Sea (near 29°30'N, 127°30'E) and continues to the north. The saline Kuroshio branch overlaid with fresh shelf water enters to the East/Japan Sea through the Korea Strait as the Tsushima Warm Current. The Tsushima Warm Current advects into the surface layer (above 300m) of the southern East/Japan Sea and flows out to the Pacific Ocean through the Tsugaru and Soya Straits. The northward flows of the Tsushima Warm Current in the East/Japan Sea vary from a single meandering path to the current splitting to separate, identifiable streams. The most westward stream, known as the East Korea Warm Current, flows northward along the east coast of Korea up to about 37°N-38°N, where it meets the southward flowing North Korea Cold Current (extension of the Liman Cold Current). At the confluence, the currents separate from the coast and flow eastward towards the Tsugaru Strait along the subarctic (polar) front.

There are regular variations in the positions and contours of the polar front not only from season to season, but also in the course of one or more months, and for the same month in different year. These year-to-year changes in positions of the front, which are on a particularly large scale in the western region, may considerably exceed the seasonal fluctuations[1]. The large scale meridional changes in positions of the front are easily checked in the satellite images (Fig. 4-b). The circulation in the East/Japan Sea is driven by the net pressure difference between the straits, wind stress and thermohaline

Corresponding Author : Yeong Gong, Korea Fisheries Association, Seoul 120-012, Korea
Phone : +82-51-701-3974
E-mail : hjgong@nfrdi.re.kr

forcing[2]. Land and open-ocean based materials tend to converge at the frontal zones. Hence, the oceanographic conditions of the peripheral zones of the Tsushima Warm Current make it favourable spawning and nursery grounds for pelagic fishes. It is suggested that the shallow mixed layer depth along the polar frontal zone and higher light intensity in the western central East/Japan Sea are favourable conditions for primary production in winter and spring[3,4].

Pacific saury, *Cololabis saira* (Brevoort) inhabiting the Tsushima Warm Current region undertake large-scale migrations between summer feeding grounds in the northern East/Japan Sea and their over-wintering grounds in the East China Sea (Fig. 1). The spawning season of Pacific saury continues from late autumn through early summer in the Tsushima Warm Current region[5~8]. Annual catches of saury in the Tsushima Warm Current region by Korea and Japan have fluctuated greatly from 55,600 tonnes in 1972 to 7,900 tonnes in 1992 with an annual average of about 28,770 tonnes over the past 43 years (Fig. 2). Catch and catch per unit fishing effort by Korean gillnet fishing in the southwestern East/Japan Sea (34°N-40°N, 128°E-137°E) showed the sharp decline in the late 1970s and the early 1980s (Fig. 3). Previous studies have shown that the timing and pattern of the distribution and migrations by sized groups of saury have varied widely in relation to the changes in oceanic conditions, resulting in changes of availability to the fishing fleets[9]. It was suggested that the changes

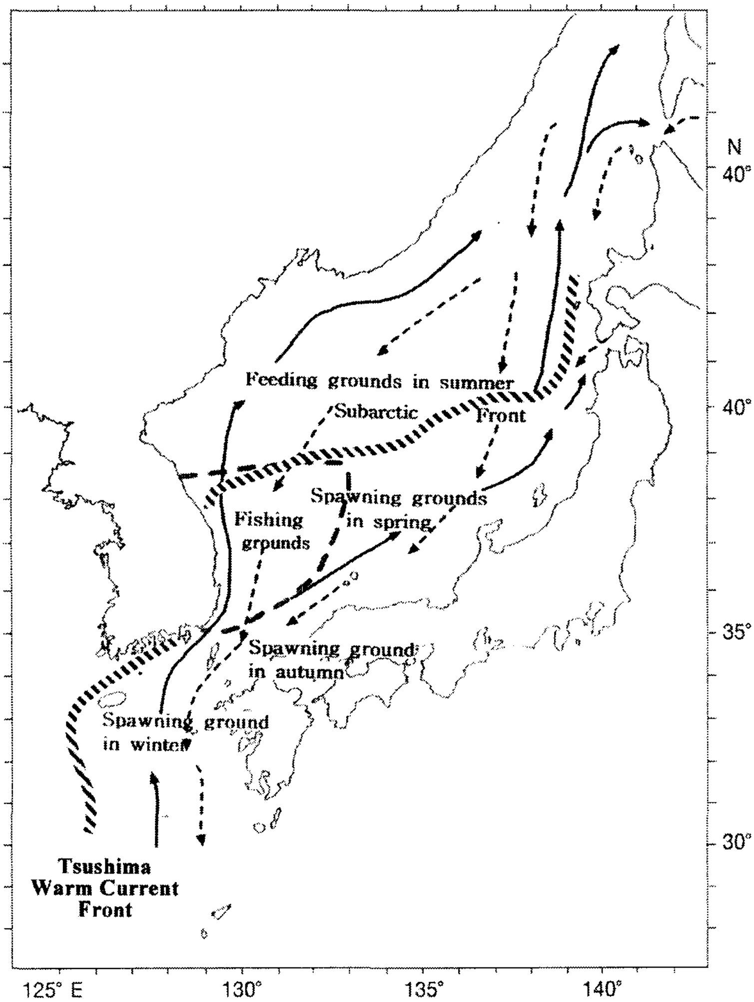

Fig. 1. Migration circuit of Pacific saury and fishing grounds in the eastern East China Sea and the East/Japan Sea.

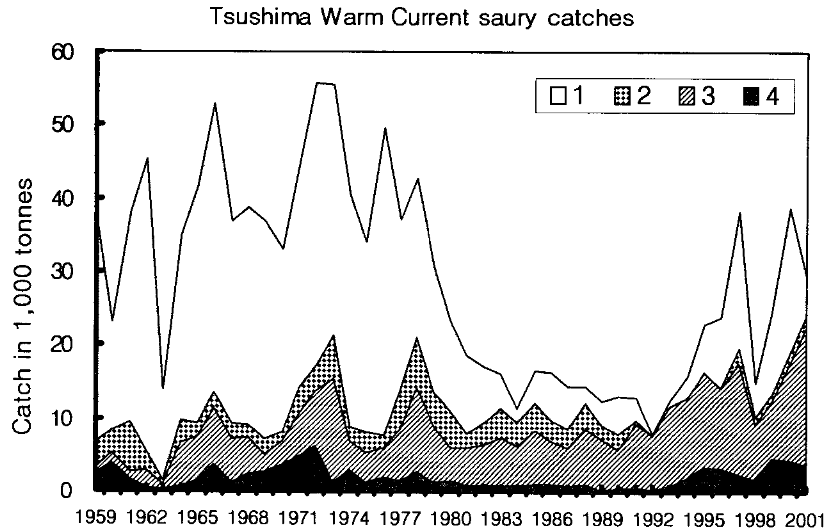

Fig. 2. Annual variation in catches of Pacific saury in the Tsushima Warm Current region, 1959- 2001; (1) in the waters off Korea, (2) off Hokkaido, (3) off Honshu in the East/Japan Sea, and (4) off Kyushu in the East China Sea.

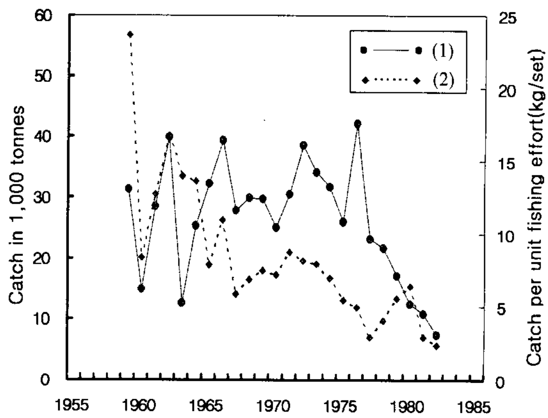

Fig. 3. Annual catch(1) and catch per unit effort(kg/set)(2) of the Pacific saury by Korean gillnet fishing in the southwestern East/Japan (34°N-40°N, 128°E-137°E), 1959-1982.

in environmental conditions affect the distribution and the structure of the stock manifested by occurrence rates in the Tsushima Warm Current region[10].

Although interannual changes in occurrence (catch) rates of sized groups were noticed in the Tsushima Warm Current region from the 1950s to the 1990s, it was not made clear whether the changes in the rates are due to variable availability or due to recruitment failure in relation to environmental conditions. While the decadal changes in the stock structure (occurrence rates of sized group) and changes in abundance of saury have been considered to be related to the ecosystem disturbance by the ocean climate regime shift, systematic mechanism has not been explored yet mainly because of limited data on productivity and stock structure.

Recent studies have revealed that the atmosphere-ocean system fluctuates with a decadal scale, and major changes in the North Pacific climate occurred in 1925, 1947, 1977, and 1989[11~16]. There is increasing evidence that variations in abundance of small pelagics are forced by changes in climate driven oceanic environments[17~19]. The response of ocean ecosystems to oceanic regime shifts and long- term climate changes has caused great concern[20~23].

It is suggested that the abundance of saury in the northwest Pacific Ocean is directly affected by the sea surface temperature (SST) fields through the large-scale atmosphere-ocean interactions such as *El Niño* events[24]. Regime shifts are detectable in a variety of biological and physiological time series and there is growing recognition that shift year such as 1977 are an important reference point in environmental series. The dependence of the marine ecosystem, in particular fish stocks, on climate changes has not been fully understood. Recognition of the 1976/77 and 1988/89 regime shift has opened question of whether that event affects the generation of recruitment and changes in abundance of fish stocks in the Tsushima Warm Current region.

The Pacific saury stock of Tsushima Warm Current system is known to be composed of two spawning cohorts; one autumn-winter-cohort spawning in the East China Sea and the other spring-summer-cohort spawning in the East/Japan Sea[25,26]. It was suggested that spring-spawned saury is major component of the stock on the basis of body size composition and life span of 2.5years[25]. However, Pacific saury has a short life-span of 1-2 years, therefore impacts of climate changes on the abundance of saury should operate after a short time lag[24,27~29].

The objective of this study is to examine the interannual and decadal scale changes in occurrence (catch) rates of different sized groups and abundance of Pacific saury and to provide evidence that the decadal scale climate-driven oceanic changes lead the disturbance production system, resulting in changes of recruitment of main spawning cohort, and hence changes in abundance of the fish in the Tsushima Warm Current region.

2. Data and Methods

Fluctuation indices of sea surface temperature(SST) anomalies were used to examine year-to-year and decadal ocean climate changes based on monthly mean SSTs from 5 coastal and 67 offshore stations in the southern East/Japan Sea from 1957 to 2000[10]. Zooplankton biomass and the anomalies in the southern East/Japan Sea (35°N-38°30'N, 18°30'E-133°E) from 1965 to 1999[30], and integrated mean temperature (0-150m) along PM line (36°N, 136°E- 41°N, 132°E)[31] were adopted to explore the trend of food environments in the Pacific saury stock area.

Annual catches of Pacific saury in the waters off Korea (34°N-40°N, 128°E-137°E) and off Japan (from western Kyushu to western Hokkaido) were collected from the annual reports of fisheries statistics from Korea and Japan for the period of 1959 through 2001. Abundance indices of the fish were estimated as following ;

$$P = \sum (Yi/fi) \cdot Ai$$

where, Yi/fi represents catch per unit effort (set ; pok in Korea and tan in Japanese) and Ai; the numbers of sea blocks (0.5°×0.5°) in the Korean gillnet fishing grounds (34°N-40°N, 128°E-137°E).

Year-to-year occurrence (catch) rates and mean body size of saury in the East/Japan Sea were obtained on the basis of monthly body length compositions by Korean commercial gillnet fishing (1957-2003)[32], Japanese experimental gillnet fishing (1951-1977)[25,33~36] and Russian trawl fishing (1960-1999)[37]. Migration circuits of two cohorts of the saury stock in the Tsushima Warm Current region will be hypothesized on the basis of spatio-temporal changes in sized groups[10] in consideration for their short life-span of 1-2 years[27,28].

The possible changes of the fish stock structure will be shown on the basis of the hypothesized growth rates under different environmental conditions. We discuss the possible disturbance of production system in the upper water column and recruitment failure of major spawning cohort of the Pacific saury in relation to the ocean climate changes. We compare the year-to-year and decadal changes in temperature anomalies and zooplankton biomass with the occurrence rates of the different sized group and abundance of the fish. The processes of climate effect on the stock structure and abundance of the Pacific saury will be illustrated in a simple diagram.

3. Results

3.1. Changes in environmental conditions

Time series of SST anomaly showed that the observed temperatures were higher than normal in the late 1950s, 1970s and early 1990s, while those were lower than normal in the early 1960s and 1980s in the Tsushima Warm Current region from the Korea Strait to the southern East/Japan Sea. In particular, SSTs in the winter of 1962/63, 1980/81, 1986/87 and 1995/96 were far below-normal in the east coast of Korea(Fig. 4-a). The thermal regime in the upper layer showed oscillation with high amplitude in the mid 1970s and thereafter decadal quasi-steady state of low temperatures in the central and southern East/ Japan Sea. The SSTs were far above average in the late 1980s and the early 1990s. Year-to-year changes in SSTs in the late 1990s were detectable in the satellite images (Fig. 4-b). Zooplankton biomass in the southwestern East/Japan Sea decreased in the 1980s and increased in 1990s. The anomalies of zooplankton biomass were far below average with 3-year lag in association with the integrated mean temperature (0-150m) in the central East/Japan Sea(PM

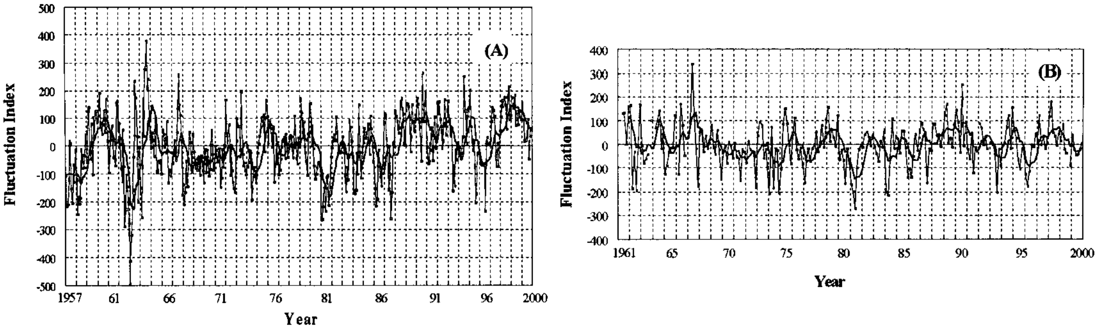

Fig. 4-a. SSTs anomalies in the East Korea Warm Current region from 5 coastal stations, 1957-2000 (A) and 67 offshore stations, 1961-2000 (B). Fluctuation Index=100(x-xbar)/σ (x : SST, σ : standard deviation). Monthly SST anomalies (—⊟—), Annual SST anomalies (▬▬).

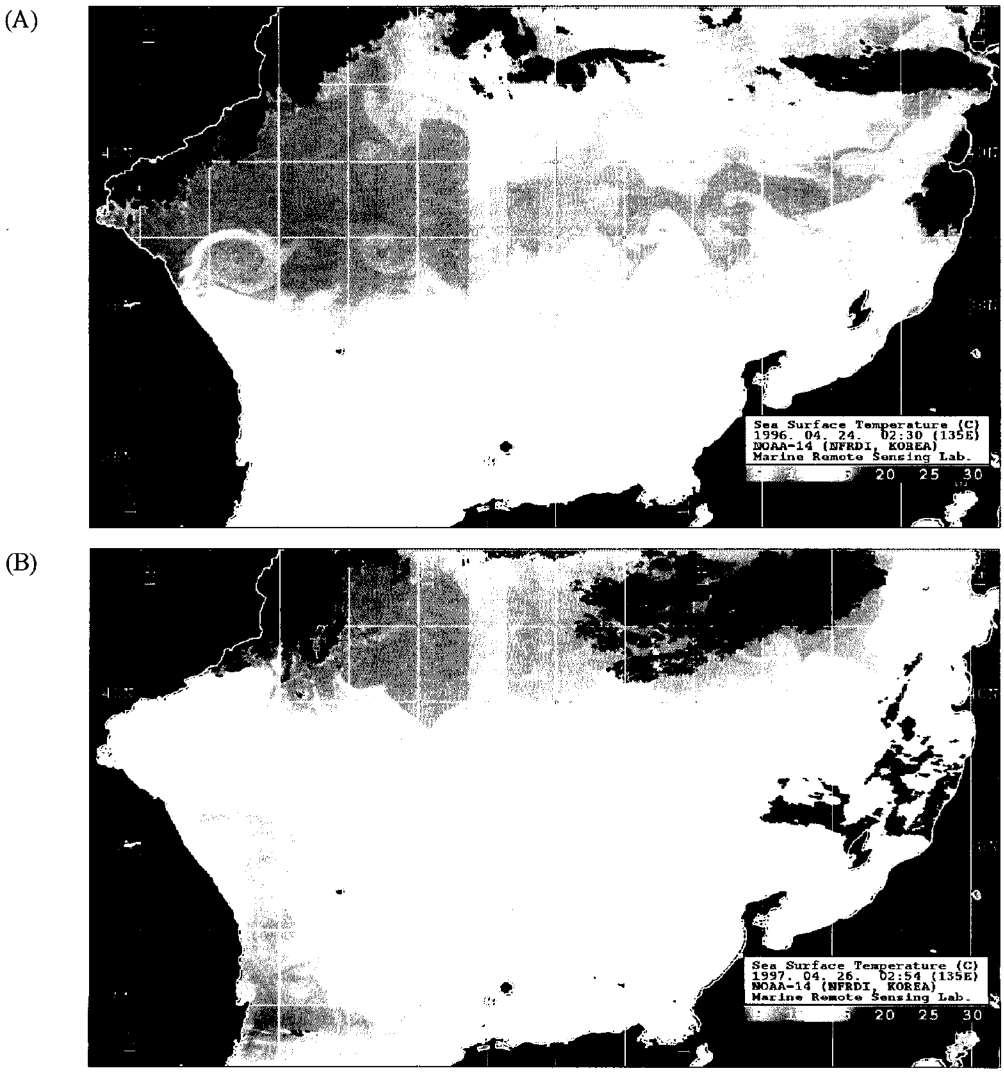

Fig. 4-b. Satellite images showing the positions of the sub-polar thermal fronts in the East/Japan Sea in April 24, 1996 (A) and April 26, 1997 (B).

line) in the 1980s, however, both varibles were above average in the early 1990s (Fig. 5).

3.2. Monthly shifting of gillnet fishing center

The distribution of monthly mean catches by statistical sea blocks (0.5°×0.5°) from Korean gillnet fishing over the 24years (1959-1982) (Fig. 6) revealed apparently the northward migration of Pacific saury in spring-summer and the southward migration in autumn-winter in the East/Japan Sea. The highest catches from April to June with a peak in May were noticed and fish shoals continuously recruited to the fishing grounds from the south until May, and then the main groups moved to the north of the 38°30'N (northern limit restricted from fishing by military reason) in June. The faster shifting of monthly fishing center in autumn-winter suggests the faster migration of the fish in the season than in spring-summer.

3.3. Interannual changes of the body length compositions

The large sized group(L, 28.0-31.9cm in mode) and small sized group(S<24.9cm) of Pacific saury are dominant, while medium sized group(M, 25.0-27.9cm) often appears during northward migrating season (Mar. or Apr.-July) in the southwestern East/Japan Sea (East Korea Warm Current region). However, M group occur scarcely in the eastern side (toward the coast of Japan) of the East/Japan Sea. In the early southward migrating season (Oct.-Dec.) medium (M) and large (L) or extra-large sized group (LL> 32.0cm) appear in the central and southern East/Japan Sea. In the late southward migrating season (Jan.-Feb.) most of the L and LL groups disappear, then only M group remain in the southern East/Japan Sea and northeastern East China Sea off Kyushu. However, L groups were found in these regions during warm winter(e.g. 1954/55, 1975/76)[10]. The seasonal occurrence types of different sized groups of the fish in relation to oceanic conditions are summarized on the basis of above analysis (Table 1). During northward migrating season body size of same sized group is larger(smaller) when surface water is warmer(cooler) than normal. The L group scarcely occur if the oceanic conditions are cold enough. The colder the surface water, the earlier disappear the larger sized groups during southward migrating season in the southern East/Japan Sea and northeastern East China Sea (off Kyushu).

3.4. Year-to-year changes in occurrence rates and mean body size

In the year-to-year variations in occurrence(catch) rates by sized group of the Pacific saury in the southwestern region (off Korea) during main fishing season (Apr.-June) from 1957 to 2003 and in the northwestern region(off Russia) during spring-summer months (May-Oct.) from 1960 to 1999, it was clear that the occurrence rates of larger sized groups (L and LL) were higher than those of smaller groups (S and M) in early 1960s and 1990s, while the rates of larger groups were extremely low in the late 1970s and 1980s(Fig. 7). In both regions the rates of small and medium sized groups were relatively high in winter-spring of 1963, 1977 and 1981-88. The higher rates of larger groups in the warm winter (e.g. 1954/

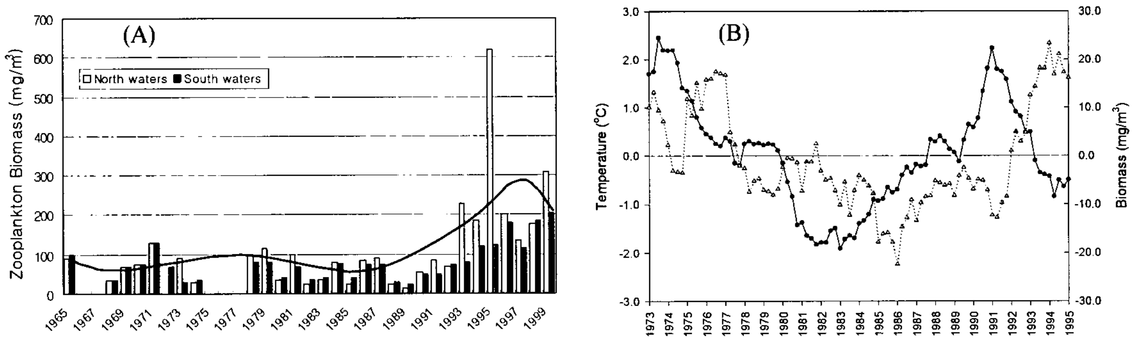

Fig. 5. Zooplankton biomass in the southwestern East /Japan Sea off Korea (35°N-38°30′N, 128°30′-133°E)[30] (Kang *et al.* 2000) (A), Anomalies of zooplankton biomass (wet weight) (circle) and integrated mean temperatures (0-150m) (triangle) along PM line (36°N, 136°E-41°N, 132°E) (B)[31] (Minami *et al.* 1999).

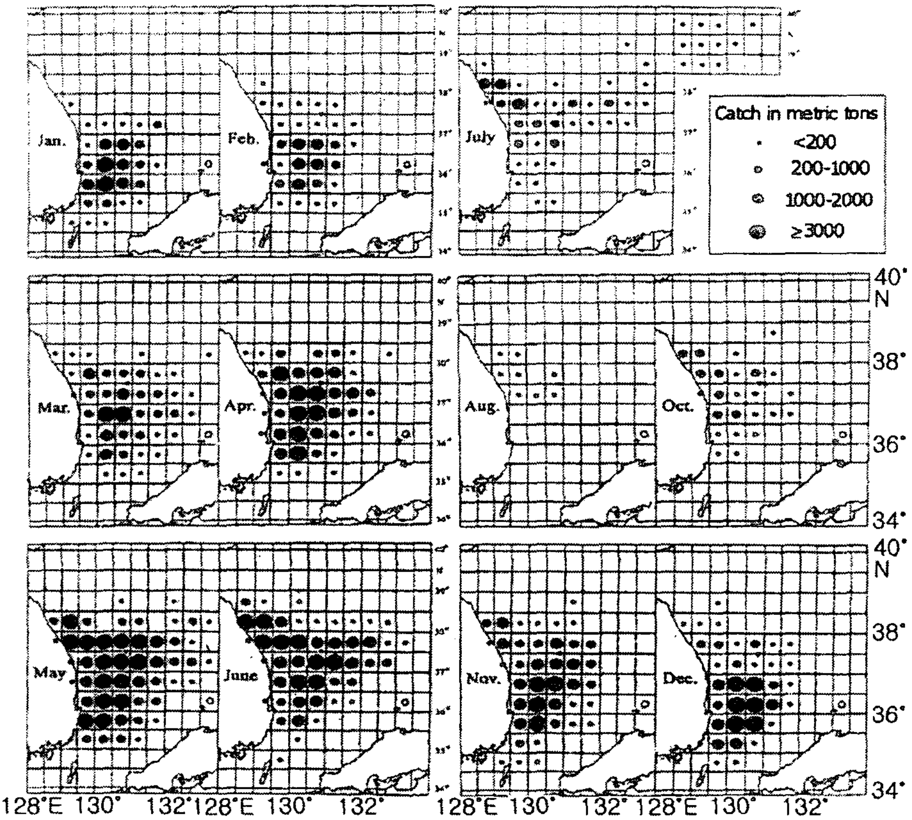

Fig. 6. Monthly catches of Pacific saury by sea block($0.5^{\circ}\times0.5^{\circ}$) for the Korean gillnet fishery in the southern East/Japan Sea.

Table 1. Occurrence of sized groups of the Pacific saury in relation to oceanic conditions in the southern East/Japan Sea during northward and southward migration. Sized groups are classified as Small(S<24.9cm), Medium(M, 25.0-27.9cm), Large(L, 28.0-31.9cm) and Extra large(LL>32.0cm)[10]

Season	Thermal conditions	Year	Sized group	Seasonal mean size	Occurring pattern
Northward migration, Mar. or Apr.-July	Warm	1976, 79, 88, 89, 90, 98	S, (M), L	Large	○ Larger than normal size in the same group
	Normal	1969, 72, 78, 85, 87, 97	S, (M), L		○ M group scarcely occur in the eastern EJS
	Cold	1963, 77, 81, 84, 86	S, M, (L)	Smaller	○ L scarcely occur depending on thermal conditions
Southward migration ; Oct.-Feb. or Mar.	Warm	1954/55 1975/76 1978/79 1989/90 1988/99	(A) M, L, LL (B) M, L	Larger	○ The color the surface water, the calier disappear the larger sized group in A and B
	Normal	1952/53, 1961/62 1968/69, 1971/72 1977/78, 1990/91	(A) M, L, LL (B) M (L)		○ Most of the L group disappear in B
	Cold	1956/57, 1962/63 1969/70, 1981/82 1983/84, 1985/86 1995/96	(A) M, L, LL (B) M	Smaller	○ Only smaller M group occur in B

A; Early southward migrating season (Oct.-Dec.)

B; Late southward migrating season (Jan.-Feb. or Mar. in relation to ocean conditions).

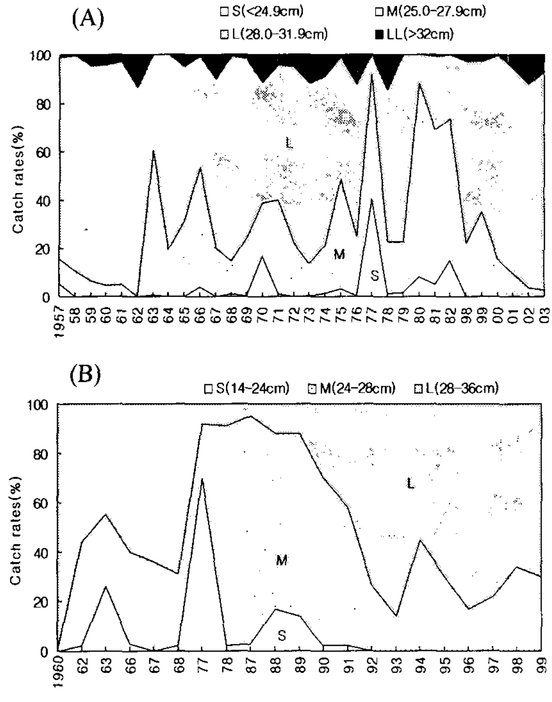

Fig. 7. Year-to-year variations in catch rates by size group of Pacific saury in the southwestern East/Japan Sea during northward migration season (Apr.-June) 1957-2003 (data in App. Table[32]) 10 of Gong, 1984 and NFRDI) (A) and in the northwestern East/Japan Sea during spring-summer months(May-Oct.) 1960-1999[37]) (After Baytalyuk, 2000) (B).

55) and low rates in the cold winter (e.g. 1962/63) indicate the short-term(year-to-year) changes in stock structure manifested by the body size compositions.

Time series of seasonal mean body size of the Pacific saury in the southwestern region (off Korea) and northwestern region (off Russia), and mean body size of large sized groups in the eastern region (off Honshu, Japan) and in the northeastern region (off Hokkaido, Japan) during spring and summer from 1950 to 2003 revealed that the body size were large in the 1950s, 1960s and 1990s ranging from 28 to 31cm, while they were abnormally small in 1963, 1977 and 1980-1988 ranging from 24-27cm when SSTs were below average (Fig. 8).

It is clear that the decadal disappearance of large sized groups and hence low average body size of the Pacific saury was the phenomenon occurred in the whole stock area in spring and summer from the late 1970s to the late 1980s.

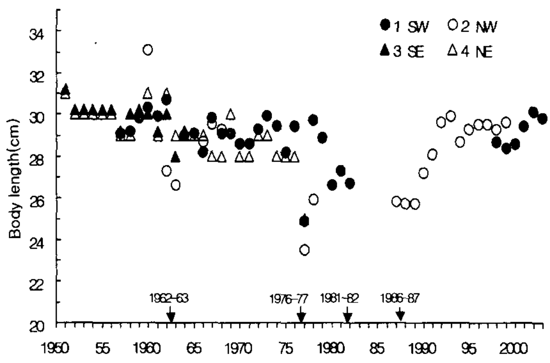

Fig. 8. Year-to-year variations in body size of Pacific saury in the waters off Korea (1; mean, Apr.-June), off Russia (2; mean, May-Oct.), off Honshu (3; mode of large size group; L, Apr.-July) and off Hokkaido (4; L, Apr.-July) in the East/Japan Sea from 1951 to 2003. Arrows indicate the year of far below normal sea surface temperature.

3.5. Saury catch in the Tsushima Warm Current region

Fig. 2 shows the year-to-year variations in the catch of Pacific saury by Korea in the southwestern region (off Korea ; 34°N-40°N, 128°E-137°E) and by Japan in the region from Kyushu to Hokkaido from 1959 through 2001. Annual total catch in both regions were high during the period of the mid 1960s to mid 1970s with same pattern of fluctuation, decreased sharply from 1977 to 1981, sustained a relatively low level from 1982 to 1993, and increased rapidly during 1995 to 2001. The catch trend revealed high year-to-year fluctuations during higher level of catch in both regions. Comparing catches of Pacific saury by Korea and Japan, the catch in the East/Japan Sea of Korea was highly significantly correlated with that in the East China Sea off Japan ($P<0.001$). During the pre-1976 and post-1976 periods, the variation in catch of Pacific saury was statistically significant in the East/Japan Sea of the Korean side ($P<0.001$), in the East China Sea off Kyushu ($P<0.01$), and in the waters off Honshu ($P<0.01$), while that in the waters off Hokkaido was not statistically significant.

3.6. Year-to-year changes in seasonal mean catch and abundance indices of the Pacific saury from gillnet fishing

Mesh size of unit gillnet for saury ranged from 9 knots (37.9mm) to 11 knots (30.3mm) with 10 knots (33.6mm) in average in the period of 1960s and 1970s[32]. Size of unit gillnet was 45-50m in length and 2.5m in depth[32]. Annual total numbers of unit fishing nets(poks=sets) used by Korean gillnetters ranged from 1 to 2 million nets in the early 1960s and from 3.5 to 4.8 million nets during the period of 1965 to 1975 and increased again in 1976 and 1977.

The seasonal mean catch and abundance indices sustained a relatively stable period from 1965 to 1975, and decreased rapidly from 1977(Fig. 9 and Fig. 10). Mean catch and abundance indices were higher in spring (Apr.-June) than in autumn-winter (Nov.-Jan.) during the pre-1976/77, while there were no seasonal differences during the post-1976/77. In the 1980s most of the Korean saury gillnetters changed their target species from saury to other species. Therefore, annual saury catch by Korea in the 1980s were lower than that by Japan in the Tsushima Warm Current region. The fishing efforts and abundance indices of Pacific saury during the most stable gillnet fishing period (1965-1975) in the southwestern East/Japan Sea are presented in Table 2.

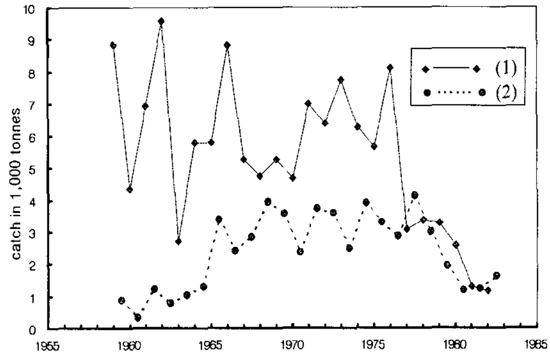

Fig. 9. Year-to-year variations in mean catch of Pacific saury by Korean gillnet fishing in the southwestern East/Japan Sea in spring (Apr.-June)(1) and autumn (Nov.-Jan.)(2), 1959-1982.

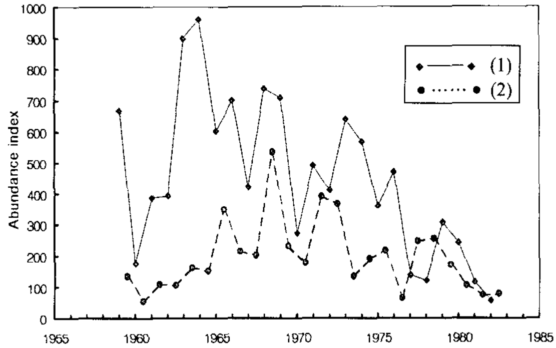

Fig. 10. Year-to-year variations in mean abundance indices of the Pacific saury by Korean gillnet fishing in the southwestern East/Japan Sea in spring (Apr.-June)(1) and autumn(Nov.-Jan.) (2), 1959-1982.

Table 2. Fishing effort and abundance of the Pacific saury during the most stable gillnet fishing period in the southern East/Japan Sea

Item	contents
Period	11years (1965-1975)
Fishing area	34°30'N-38°30'N, 128°30'E-133°30'E
Fishing power	15-30Ts of gillnetter
Fishing day per cruise	1-2days (one night fishing)
Fishing efforts	120-200poks(sets per boat. day)
Annual total efforts	3.5-4.8 × 10^{6}poks (sets)
Annual catch	26,000-39,000 tonnes (273-410 × 10^6(individuals)
Overall CPUE	5.5-11.0 kg/set (58-116individuals/set)
Abundance index	1,700-3,900

Note; Length of one unit gillnet (pok or set) ≒ one half of original net of 151m before shortning ; 45-50m depended upon the rate of shortening. Depth of the unit net ≒ 2.5meters.
Mesh size of the net ranged from 9 knots(37.9mm) to 11 knots(30.3mm) with average 10 knots(33.6mm) during the period of 1965-1975.

3.7. Regional difference in abundance of the Pacific saury

The annual average catch per unit effort by Korean commercial gillnet fishing in the west(off Korea) and by Japanese experimental fishing in the east (off Japan) of the East/Japan Sea in the early 1960s revealed that the abundance of Pacific saury in the west was higher than that in the east ($P<0.05$)(Table 3-a). The catch per unit effort by Japanese gillnet fishing in the Kuroshio and Oyashio Current region of the northwestern Pacific during southward migrating season(Sep.-Dec.) from 1935 through 1943 ranged 217-678 animals per net, suggesting that the density of the Pacific saury in the northwest Pacific Ocean was higher than that in the Tsushima Warm Current region (Table 3-b). The trend of year-to-year catch of Pacific saury in the Tsushima Warm Current and Kuroshio and Oyashio Current regions showed roughly the same pattern during the period of 1960s to 1980s (Fig 11).

3.8. Relationships of environmental variables to occurrence rates, body size and abundance of the Pacific saury

To address the questions of climate impacts on the stock structure and abundance of Pacific saury, we examined the environmental variables such as temperature and zooplankton biomass, year-to-year mean body size and saury catch and abundance index in the Tsushima Warm Current region from 1950 to 2003. The SST anomalies and zooplankton boimass anomalies were below average, and the mean body size of the Pacific saury in the four regions of the Japan/East Sea were significantly small in the late 1970s and 1980s. The abundance of Pacific saury decreased sharply in the gillnet fishing grounds in the period from 1977 to 1982, and hence less catch. However, most of the physical and biological variables

Table 3-a. Annual average catch per unit effort for saury gillnet fishing in the East/Japan Sea in the early 1960s

	1959	1960	1961	1962	1963	1964	Mean
West(1) kg/set	23.7	8.4	12.7	16.7	14.0	13.6	14.9
(2) fish/set	215	76	115	139	140	126	135.2
East (3) fish/set	~	~	76	66	53	135	82.5

Note; (1) Korean gillnet fishing data[32].
(2) No. of fish per set converted by body length-weight relationship.
(3) Japanese experimental gillnet fishing data[33].
(4) Unit net (Set ; Pok in Korea = Tan in Japan)
(5) Length of 1 unit gillnet = One half of original net of 151m before shortening for Korean commercial gillnet fishing and for Japanese experimental fishing in the Japan/East Sea
(6) Korean gillnet mesh size ranged from 9 knots(37.9mm) to 11knots(30.3mm) with average 10 knots(33.6mm) in the late 1950s through early 1980s.

Table 3-b. Catch in numbers of Pacific saury per unit gill-net in the northwestern Pacific Ocean, 1935-1943[33,44]

	1936	1937	1938	1939	1940	1941	1942	1943
Late Sep.	610	460	474	258	205	-	-	-
Early Oct.	1,210	403	562	640	360	404	346	338
Mid Oct.	605(170)	235	294	130	159	255	270	413
Late Oct.	795	-	535	-	266	336	308	155
Early Nov.	-	-	510	-	264	239	180	183
Mid Nov.	-	-	-	-	115	145	117	103
Late Nov.	-	-	-	-	91	102	85	321
Early Dec.	-	-	-	-	-	52	-	232
Mean	678	366	475	343	208	219	217	256

Note; Length of unit gillnet before shortening = One third of original net of 151m in the northwest Pacific Ocean during 1930s and 1940s.

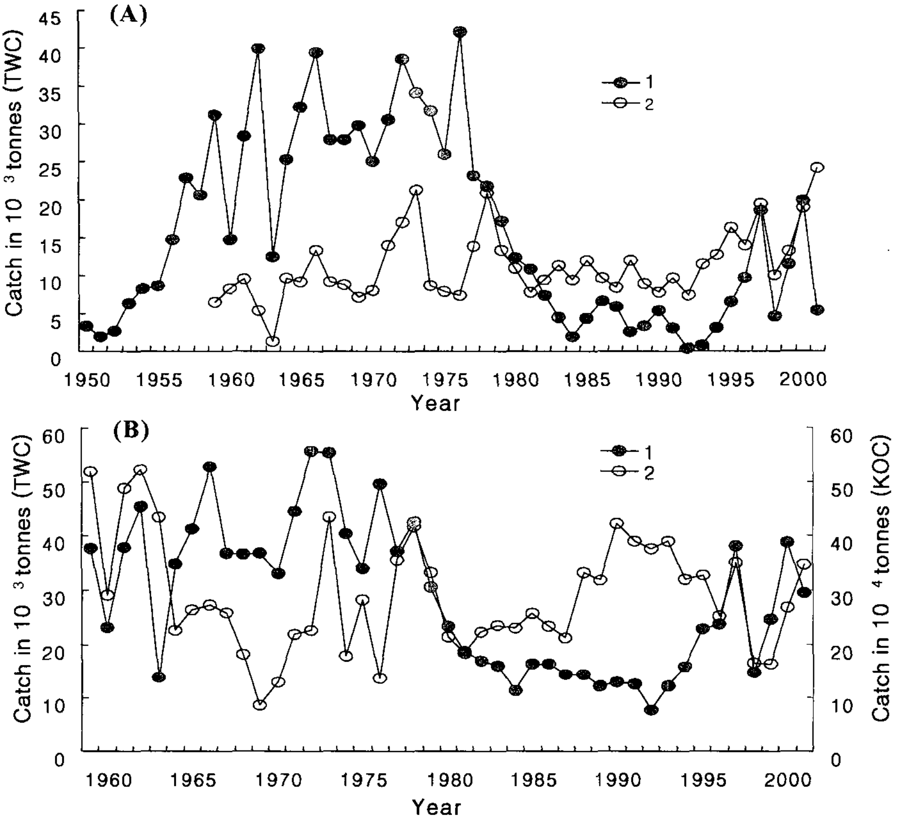

Fig. 11. Pacific saury catch in tonnes by Korea(1) and Japan(2) in the Tsushima Warm Current region, 1950-2000(A), and by Korea and Japan in the Tsushima Warm Current region (1), and by Korea, Japan, Russia and Taiwan in the Kuroshio-Oyashio Current region Kuroshio-Oyashio Current (2) 1959-2000(B).

returned to normal and higher than normal in the early 1990s as in the 1950s and 1960s, suggesting that the climate regime shift occurred in 1976/77 and 1988/89 in association with a deepening Aleutian Low and enhanced East Asian Monsoon had strong impacts on the production system and on the growth and recruitment of pelagic fish such as the Pacific saury in the Tsushima Warm Current region.

4. Discussion

4.1. The distribution and migrations of the Pacific saury in relation to oceanic conditions

Pacific saury in winter and early spring inhabit the warm and haline Tsushima Warm Current system. Thereafter they undertake a northward migration. No adult saury were found in the low haline surface water in the western East China Sea and the Yellow Sea[10,32]. Pacific saury are sensitive to water temperature and salinity gradients throughout their life cycle. Saury larger than 6 cm occur at the temperature of 7 to 23℃. However, high concentrations of saury usually occur at temperatures of 13 to 18℃, with a peak in 15℃ and at salinities of 33.6-34.4 psu, and averaging 34.1 psu in the central and southern East/Japan Sea[7,32,37~41,47].

Adult saury consume large species of zooplankton (copepoda, amphipoda, pteropoda) and juveniles consume early stages of zooplankton[7,8]. One of typical migratory animals, Pacific saury (*Cololabis saira*) show a dispersed pattern of northward migration over an extensive area of the East/Japan Sea and again a more or less dispersed southward migration but mainly confined in the western half of the sea[42]. Therefore, no commercial saury fishing activities were conducted in the eastern East/Japan Sea in autumn.

It is suggested that the larger fish is always taking the lead on the smaller fish notwithstanding the migratory direction in the East/Japan Sea[43]. It is hypothesized that large saury lead the southward migration and are influenced by the shifting of the Oyashio front[45]. However, the large size saury do not always lead the smaller size groups during their migration. On the point in guestion, a size specific getting-ahead model was presented on the movements of each sized group of Pacific saury in the normal, abnormally cold and warm oceanographic year[9]. In the northward migration period(Mar. or April-July) or in the southward migration period (Oct.-Feb.) the larger fish migrate to get ahead of the smaller fish[9]. In the monthly compositions of sized(age) groups by area taken by stick-held dip-net in the northwestern Pacific Ocean during southward migrations(Aug.-Dec.) from 1952 to 1986 the catch rates of larger sized(older) groups increased in the earlier months(Aug.-Sep.) and decreased in the later months(Oct.-Dec.)[46], suggesting that the larger sized group get ahead of the smaller sized groups during their migrations. Therefore, the wintering and getting-ahead grounds of different sized groups are shifted to the north(south) in warm(cold) oceanographic conditions, resulting in changes in availability to the fishing fleets[32,47,48] in the stock area of the Tsushima Warm Current region and the Kuroshio and Oyashio Current region as well. It is suggested that this pattern of movements and migration in relation to oceanic conditions would be applicable to the most of pelagic fishes.

The main fishing grounds with high aggregation of different sized groups of the fish around the frontal zone in the East/Japan Sea can be easily detected by SST and ocean color derived from remote sensing satellite during the northward migrating season (Apr.-June), before advection of the low haline-warm superficial water originating from the East China Sea[10].

4.2. Regional difference of abundance of the Pacific saury

Abundance of Pacific saury in the western (toward Korean coast) side was higher than the eastern (toward Japanese coast) side of the East/Japan Sea ($P < 0.05$) even though it is lower than that in the northewest Pacific. The number of sized groups of saury is higher in the west than in the east in the East/Japan Sea[10,49]. It is postulated that the difference in hydrographic structure and production system favourable for aggregation (around frontal zone) and growth (continuous production in the western region even in winter in the normal conditions) of the pelagic fish are responsible for the regional difference in numbers of body size groups (3 in the west, 2 in the east), resulting in regional difference of abundance (higher in the west than in the east of the East/Japan Sea). The catch by Korea in the East/Japan Sea was highly significantly correlated with that by Japan in the East China Sea off Kyushu ($P < 0.001$). The East China Sea is the source area for many animals such as sardine, Pacific saury and common squid occurring in the East/Japan Sea during warm seasons[42].

The Pacific saury catch by Korea and Japan amounted to about 53,000 tonnes in 1966 and decreased to about 8,000 tonnes in 1992 with an annual average of about 28,770 tonnes over the past 43 years (1959-2001) in the Tsushima Warm Current region(Fig 11). The Pacific saury catch in the north of 38°30'N off Korea were the same as that in the south from 1921 to 1945[32,50,51]. Therefore, the annual average catch from the Tsushima Warm Current region will amount to about 100,000 tonnes(1/5 of the Kuroshio-Oyashio Current region) during the period of high catch level. However it was under-estimated for the comparison of fishing conditions between the two regions[52]. The annual saury catch in the Kuroshio-Oyashio Current region fluctuated greatly from about 596,000 tonnes in 1958 to 124,000 tonnes in 1969 over the past 43years (1958-2001). Recently, Pacific saury in the Kuroshio-Oyashio Current region have been exploited by Japan, Russia, Korea and Taiwan (Fig. 11). The Japanese landings have been regulated since 1988[53]. The year-to-year catch in the Kuroshio-Oyashio Current and Tsushima Warm Current regions showed roughly the same trend of fluctuation from the 1960s to the 1980s[32,54]. Taking the advanced fishing methods and changed efforts into accout, it is postulated that the trend of abundance of saury in the two regions would have the same pattern. In spite of zonal and regional difference in abundance of the fish, the same pattern of long-term catch trend suggests that the Pacific saury stocks are controlled by common environmental impacts in the entire stock area from the Tsushima Warm Current and Kuroshio-Oyashio Current regions.

4.3. Environment specific growth model

Taking the variations of body size into account, an environment specific growth model for Pacific saury under various environmental conditions such as thermal regime and zooplankton biomass is hypothesized to describe the changes in stock structure of the fish occurring in a certain region during migration in the stock area(Fig. 12). In the model the fish grow to medium size(M, 28cm in mode) in 1.0-1.5 years under fairly good environmental conditions, while the fish grow to the same size(28cm in mode) in 1.5-2.0 years under very bad conditions(e.g. abnormal cold and/or very poor foods). However, the former (28cm in mode) belongs to the medium size (M), while the later (28cm in mode) belongs to the large sized group(L) of the cohort in the body size category[32] (table 1). In brief, year to year changes in body size of the Tsushima Warm Current stock of Pacific saury due to the environmental conditions lead the stock to be homogeneous even in a sized groups from different cohort during the period of high stock level.

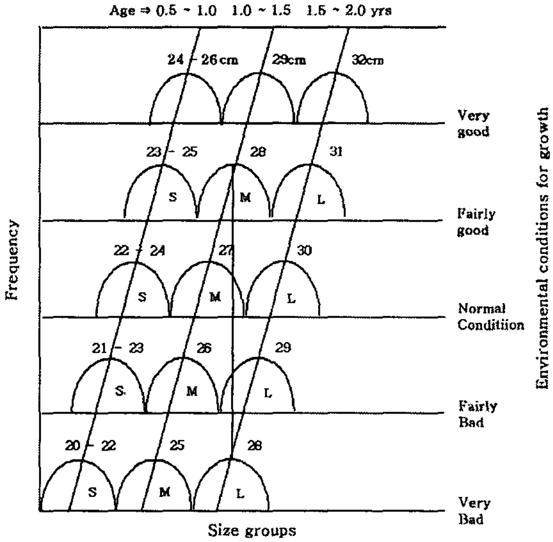

Fig. 12. Hypothesized stock structure of the Pacific saury (*Coloabis saira*) under various environmental conditions in the Tsushima Warm Current region. Numbers on the apex of each sized group indicate the mode of the body(fork) length compositions.

4.4. Model for migration circuits of two cohorts of the Pacific saury in the Tsushima Warm Current region

It is suggested that saury stock in the East/Japan Sea are composed of two spawning lines: spring-spawning and autumn-spawning lines, of which the former with 2.5 years of life span is major component[25]. A hypothetical migration routes of the spring-spawned saury was presented on the basis of 2.5 years of life span in the East/Japan Sea[26]. However, Pacific saury in the North Pacific is known to have a short life-span of 1-2years in recent studies[8,27,28,55].

Migration circuits of autumn-winter-spawned and spring-summer-spawned cohorts are modelled on the basis of spatio-temporal occurrence of different sized groups of saury taking into consideration of short life span (1.5-2.0 years) under normal environmental conditions (Fig. 13-a and Fig. 13-b). The positions of center of distribution and migration of sized groups of a cohort are presumed on the basis of geographical distance and size of the fish. In nature, combining the two circuits of Fig. 13-a and 13-b, different sized groups of different cohort such as autumn-winter-born (S and L) and spring-summer-born(M) will appear in a certain site in the central East/Japan Sea during their northward migration season (April through June). In the model the large sized group (L, 1.5-year old) and small sized group (S, 0.5-year old) occurring in the spring and early summer are originated from autumn-winter-born cohort (Fig. 13-a). However, they may be believed to be originated from spring-born line of the saury with life span of 2.5 years[25,26,56].

The general features of Pacific saury migration in the East/Japan Sea are the same as in the northwest Pacific Ocean and two main routes of the northward migrating saury are well-known in the East/Japan Sea[7,8,32]. It is suggested that the summer (July-September)-born cohort is the strongest in the East/Japan Sea and this generation forms the base of saury fishery for Korean peninsular in spring and summer of following years[8]. In this case the life-span of the fish appears to be very short (1 year) as suggested by Watanabe[28].

In any case the spatio-temporal occurrence rates of sized groups originated from both cohorts will be changed depending upon growth rate, availability and recruitment success in relation to year-to-year or long-term ocean environmental changes. Taking into consideration of the environment-specific groweh model (Fig. 12) to the migration circuits of the sized groups from two different cohorts (Fig. 13-a and Fig. 13-b),

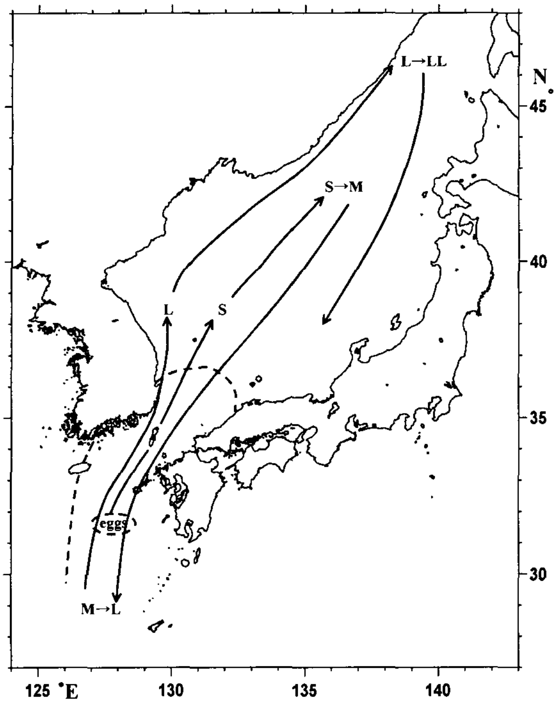

Fig. 13-a. Migration circuit of autumn-winter-spawned cohort of the Pacific saury in the Tsushima Warm Current region.

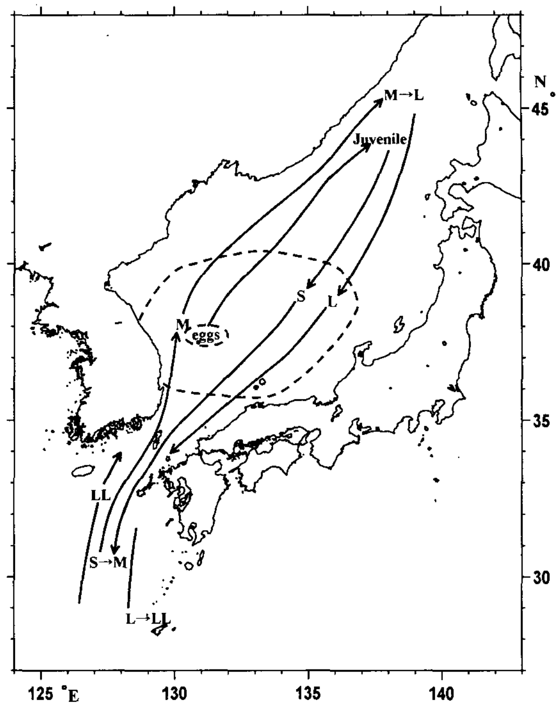

Fig. 13-b. Migration circuit of spring-summer-spawned cohort of the Pacific saury in the Tsushima Warm Current region.

it is postulated that a certain sized group (e.g. L, autumn-winter-spawned cohort) can be identified as the other sized group (e.g. M, spring-summer-spawned cohort) in the same site of fishing ground during a certain migration season in their earlier life stages and vice versa.

As seen in the year-to-year variations in occurrence(catch) rates (Fig. 7) and in mean body size (Fig. 8) in the East/Japan Sea, ocean climate changes in the period of the late 1970s and 1980s must have been associated with changes in the stock structure by recruitment failure of a certain cohort of the saury. The long-term disappearance of large sized group(L) during spring-summer months of the late 1970s and 1980s suggests the recruitment failure of the autumn-winter-spawned cohort according to our proposed model of migration circuits (Fig. 13-a and Fig. 13-b).

4.5. Hypothesized mechanisms of decadal scale changes in stock structure and abundance of the Pacific saury

A traditional period in climate variability during the late 1970s attracted much attention, when a deeper Aleutian Low, warmer SSTs in the eastern North Pacific, and cooler SSTs in the central and western middle latitudes replaced a persistent period of opposite conditions[11,57]. Aleutian Low covaried with the Pacific North America pattern but also with the Arctic Oscillation and Asian Monsoon[14,15].

① Intensification of Aleutian Low pressure system strengthened the wintertime East Asian Monsoon over the Siberia and the East/Japan Sea. The cooled surface water by strong westerlies over the northern East/Japan Sea subducted below the Tsushima Warm Current[58]. ② SST and integrated (0-150m) mean temperature anomalies were far below normal in the region south of the subarctic (polar) front in the East/Japan Sea in the late 1970s and 1980s[31](Fig. 4 and 5). ③ In addition, springtime solar radiation increased in the 1980s and the superficial warm water dispersed over the northern region of the sea[59]. These conditions led to enhanced stratification between subsurface and surface waters in spring, resulting in limiting the nutrients supply to the surface[58]. ④ These conditions enhanced the earlier switch of production cycles from diatom based food chain to longer microbial food loop in the euphotic zone[62,63]. In spring mixed layer nutrients, abundance of both phytoplankton and zooplankton decreased in the southern East/Japan Sea during 1966-1990, suggesting the duration of spring bloom might have shortened[58,60,61]. Baumann and LeBlond[64] discussed how decreases in fish production can arise from structural changes in energy transfer, and hence a shift from shorter to longer food chains. ⑤ The zooplankton biomass in the southwestern and central East/Japan Sea were below average in the 1980s but increased in the early 1990s in association with temperature anomalies (Fig. 4 and 5). Zooplankton biomass decreased in the south (main spawning ground of saury) in spring and in the north (main feeding ground of the fish) in summer in the East/Japan Sea in the late 1970s and the 1980s[60]. ⑥ Decadal scale low thermal regime, disturbed production cycle and decreased zooplankton biomass were responsible for the recruitment failure of important cohort of Pacific saury, resulting in the disappearance of major sized groups in the central East/Japan Sea in spring-summer during the period of the late 1970s to the 1980s. ⑦ The recruitment failure of the cohort led the changes in stock structure manifested by decadal scale disappearance of large sized group. The mean body size were extremely small in the entire stock area in spring-summer during the period of the late 1970s and the 1980s(Fig. 8), resulting in decreased abundance and catch(Fig. 2, 10 and 11). ⑧ The oceanic environmental conditions such as thermal regime and production cycles must have returned to normal and higher than normal conditions in the early 1990s, resulting in the normal stock structure and high abundance of the fish. However, the saury fishing was not active in the Tsushima warm Current region in the late 1990s because most of the fishing fleets engaged in other fishery(Fig. 14).

Decadal scale Aleutian Low — Asian monsoon strengthened

↓

Stratifiction limited nutrient supply

↓

Earlier switch of production cycle of microbial loop

↓

Changes in zooplankton in spawning and feeding grounds

↓

Unfavourable growth by low temperature and limited foods for saury

↓

Recruitment failure of main cohort which will be large sized groups

↓

Change in stock structure by collapse of main cohort

↓

Decreased abundance

↓

Low catch per fishing effort resulted in the suspension of fishing

Fig. 14. Diagram illustrating processes of climate effects on stock structure and abundance of the Pacific saury (*Cololabis saira*) in the Tsushima Warm Current region.

Concluding remark

Changes in interannaul thermal conditions are responsible for the changes in spatio-temporal occurrence (catch) rates of different sized groups of Pacific saury during their migrating seasons in the Tsushima Warm Current region. Changes in body size of the Tsushima Warm Current stock of Pacific saury due to the environmental conditions lead the stock to be homogeneous during the period of high abundance level, while one of the cohorts remains during the period of low level of the stock abundance. Migration circuits of two cohorts of the Pacific saury are modelled on the basis of short life span and spatio-temporal changes in occurrence rates of different sized groups.

The high amplitude oscilation of thermal regime in the mid 1970s and thereafter decadal quasi-steady state of cool regime with intensified stratification of the euphotic zone are responsible for the changes in production cycle and zooplankton biomass in the spawning and feeding grounds. Under these conditions the changed stock structure due to collapse of main cohort of the fish led the abundance to be changed in the Tsushima Warm Current region. The hypothesized mechanisms explaining the effects of climate changes on the structure and abundance of the Tsushima Warm Current stock of Pacific saury are summarized as following;

① The strong westerlies in association with the East Asian Monsoon and Aleutian Low cooled surface water of the northern East/Japan Sea and facilitated subduction of cold water below the Tsushima Warm Current in the mid 1970s and the 1980s. ② Enhanced stratification by the strong spring radiation and dispersed superficial warm water limited supply of nutrients to the euphotic zone. ③ Earlier switch of production cycle of diatom-based short food chain to longer microbial food loop led the production system to be ineffective and the changes in dominant species of phytoplankton. ④ Zooplankton biomass decreased in spring saury spawning grounds in the south and in summer feeding grounds in the north of the East/Japan Sea in the late 1970s and the 1980s. ⑤ Unfavourable growth by low temperature and limited foods for saury led recruitment failure, resulting in the changes of stock structure. ⑥ No large sized group of saury migrated in spring-summer, resulting in decreased abundance in the Sea. The ocean climate shifts (1976/77 and 1988/89) appear to be associated with change in the trends of stock structure due to the collapse of major cohort and in the abundance and catches of Pacific saury in the Tsushima Warm Current region. ⑦ Saury gillnet fishing were suspended in the East Korea Warm Current region in the 1980s(Fig. 14).

In spite of zonal and regional difference in abundance of the fish, the same pattern of long-term catch trend suggests that the Pacific saury stocks are controlled by the common environmental impacts in the entire stock area from Tsushima Warm Current and Kuroshio-Oyasio Current regions. Further systematic sampling on the early life stage and the adult fish in the source areas of the fish in relation to production and ocean climate will give full answer to the problem of common impacts on the stock, then the long-term predition of changes in abundance will be possible.

Acknowledgements

We express our gratitude to Miss Young Hee Huh, East Sea Fisheries Research Institute of the National Fisheries Research and Development Institute (NFRDI) for the recent information on the Pacific saury. Our gratitude is extended to Ms. Hea Ja Gong of the NFRDI for the development of data bases and the production of the figures.

This study was funded by the research project "the application of satellite data for fisheries oceanography" of the Korea Aerospace Research Institute.

References

1) Gong, Y. and H. J. Lie, 1984, Distribution of thermal fronts in the South-East Sea of Korea (Southern Japan Sea), Min. Sci. and Tech. Korea, BSPE 00055-86-7B, 215pp.

2) Ohshima, K., 1994, The flow system in the Japan Sea caused by a sea level difference through shallow straits, J. Geophys. Res., 99, 9925-9940.

3) Kim, S. W. and Y. Isoda 1998, Interannual variations of the surface mixed layer in the Tsushima Current Region, Umi to Sora, 74, 11-22 (in Japanese).

4) Zhang, C. I. and Y. Gong, 2002, Effect of ocean climate changes on the Korean stock of Pacific saury, *Cololabis saira*(BREVOORT). In Long-term variations in the Northwestern Pacific Eco-system, To sugimto, S. Kim, C.I. Zhang, H. nakata and S.H. Huh (eds.), Proceedings of Korea-Japan GLOBEC Symposium, 2000, Busan, 239pp.

5) Hatanaka, M. and K. Sekino, 1956, Spawning ground of the saury, *Cololabis saira* (Brevoort) in the Japan Sea, Tohoku Jour. Agr. Res., 7(1), 59-64.

6) Fukataki, H, 1959, Occurrence and distribution of eggs and larvae of the saury in the Tsushima Current region, Bull. Jap. Sea Reg. Fish. Res. Lab., 7, 17-42 (in Japanese).

7) Shuntov, V. P., 1967, Saury of the Sea of Japan. Izvestiya, TINRO, 56, 51-66 (in Russian).

8) Baytalyuk, A., 2002, Contemporary stock status, distribution, place and role of Pacific saury in the Japan/East Sea. Extended abstract, Science Board Symposium, 11th PICES annual meeting, Qingdao, China, 45pp.

9) Gong, Y., T. Hirano and C. I. Zhang, 1983, On the migration of Pacific saury in relation to oceanographic conditions off Korea, Bull. Jap. Soc. Fish. Oceanogr., 44, 51-75.

10) Gong, Y. and Y. S. Suh, 2003, Effect of envi-ronmental conditions on the structure and distri-

bution of Pacific saury in the Tsushima Warm Current region, J. Environmental Sciences, 2, 1137-1144.

11) Trenberth, K. E. and J. W. Hurrell, 1994, Decadal atmosphere-ocean variations in the Pacific, Clim. Dyn., 9, 303-319.

12) Minobe, S., 1997, A 50-70year climatic oscillation over the North Pacific and North America, Geophys. Res. Lett., 24, 683-686.

13) Zhang, Y., J. M. Wallace and D. S. Battisti, 1997, ENSO-like interdecadal variability : 1900-1993, J. Climate, 10, 1004-1020.

14) Hare, S. R. and N. J. Mantua, 2000, Empirical evidence for North Pacific regime shifts in 1977 and 1989, Progress in Oceanography, 47, 103-145.

15) Overland, J. E., J. M. Adams and H. O. Mofjeld, 2000, Chaos in the North Pacific : spatial modes and temporal irregularity, Progress in Oceanography, 47, 337-354.

16) Polovina, J. J., G. T. Mitchum, N. E. Graham, M. P. Crag, E. E. Demartini and E. N. Flint, 1994, Physical and biological consequences of a climate event in the central North Pacific, Fish. Oceanogr., 3, 15-21.

17) Sinclair, M., M. J. Tremblay and P. Bernal 1985, El Niño events and variability in a Pacific mackerel (*Scomber japonicus*) survival index : support for Hjort's second hypothesis, Can. J. Fish. Aquat. Sci., 42, 602-608.

18) Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace and R. C. Francis, 1997, A Pacific interdecadal climate oscillation with impacts on salmon production, Bull. Am. Met. Soc., 76, 1069-1079.

19) Beamish, R. J., D. Noakes, G. McFarlane, L. Klyashtorin, V. V. Ivanov and V. Kurashov, 1999, The regime concept and natural trends in the production of Pacific salmon, Can. J. Fish. Aquat. Sci., 56, 516-526.

20) Polovina, J. J., G. T. Mitchum and G. T. Evans 1995, Decadal and basin-scale variation in mixed layer depth and the impact on biological production in the Central and North Pacific, 1960-88, Deep Sea Res., 42, 1701-1716.

21) Miller, A. J. and N. Schneider, 2000, Interdecadal climate regime dynamics in the North Pacific Ocean : theories, observations and ecosystem impacts. Progress in Oceanography, 47, 355-379.

22) Kang, S., S. Kim and S. W. Bae, 2000, Changes in ecosystem components induced by climate variability off the eastern coast of the Korean Peninsula during 1960～1990, Progress in Oceanography, 47, 205-222.

23) Zhang, C. I., J. B. Lee, S. Kim and J. H. Oh, 2000, Climate regime shifts and their impacts on marine ecosystem and fisheries resources in Korean waters. Progress in Oceanography, 47, 171-190.

24) Tian, Y., T. Akamine and M. Suda, 2003, Variations in the abundance of Pacific saury (*Cololabis saira*) from the northwestern Pacific in relation to oceanic-climate changes, Fisheries Research, 60, 439-454.

25) Fukataki, H., 1963, The growth stage and racial problem of the saury occuring in the Japan Sea, 117-132. Reports of the Cooperative Investigations on the Saury in the Japan Sea for 1962, Japan Sea Fish. Res. Lab.(ed), 138pp (in Japanese).

26) Kobayashi, T., M. Wako and M. Naito, 1970, Studies on the life of the Pacific saury, *Cololabis saira* (Brevoort), Ⅲ. Aggregative characteristics of the spring-spawning population in the spawning season in the Japan Sea, Sci. Rep. Hokkaido Fish. Exp. St., 12, 13-24.

27) Suyama, S., Y. Sakurai and K. Shimazaki, 1996, Age and growth of Pacific saury *Cololabis saira* (Brevoort) in the western North Pacific estimated from daily otolith growth increments, Fisheries Science, 62, 1-7.

28) Watanabe, Y., J. L. Butler and T. Mori, 1988, Growth of Pacific saury, *Cololabis saira* in the northeastern and northwestern Pacific Ocean, Fish. Bull. US, 86, 489-498.

29) Watanabe, Y., O. Yoshioki and D. Kitagawa, 1997, Larval parameters determining preschooling juvenile production of Pacific saury(*Cololabis saira*) in the northwestern Pacific, Can. J. Fish. Aquat. Sci., 54, 1067-1076.

30) Kang, Y. S., J. Y. Kim, H. K. Kim and J. H. Park, 2000, Long-term trend in zooplankton and its relationship with squid, *Todarodes pacificus*, in the East Sea of Korea, In T. Sugimoto, S. Kim and T. Terazaki, Proceedings of Korea-Japan GLOBEC Symposium "Long-term variations in the northwestern Pacific ecosystems", Pusan,

Korea, 103-111pp.
31) Minami, H., S. Kawae, N. Nagai and J. Jifuka, 1999, Long-term variability of oceanic conditions along the PM Line in the Japan Sea, Sokko Jiho, 66, 63-80 (in Japanese).
32) Gong, Y., 1984, Distribution and movements of Pacific saury, *Cololabis saira* (Brevoot), in relation to oceanographic conditions in waters off Korea, Bull. Fish Res, Dev. Agency, 33, 59-172.
33) Fukataki, H., 1966, Distribution, migration and population density of the saury occurring in the Japan Sea, 123-134. Reports of the Cooperative Investigations on the Saury in the Japan Sea for 1963 and 1964, Japan Sea Fish. Res. Lab. (ed), 134pp (in Japanese).
34) Kuroiwa, M., 1963, The body length and weight composition of northward migrating saury in the Japan Sea, 93-97. Reports of the Cooperative Investigations on the Saury in the Japan Sea for 1962, 138pp (in Japanese).
35) Kuroiwa, M., 1966, The body length and weight composition of the northward migrating saury in the Japan Sea for 1963 and 1964, 107-113. Reports of the Cooperative Investigations on the Saury in the Japan Sea for 1963 and 1964, 134pp (in Japanese).
36) Wakoh, M., 1978, Studies on the characteristics of the northward migrating saury (*Cololabis saira*) in-the Japan Sea, 1977, Jour Hokkaido Fish. Exp. St. (Hokusuishi Geppo), 35(6), 1-12.
37) Baytalyuk, A., 2000, Distribution and stock of saury(*Cololabis saira*) in the north-western part of the Japan Sea. Extended abstract, Science Board Symposium, 9th PICES annual meeting, Hakodate, Japan, 29-30pp.
38) Han, H. S. and Y. Gong, 1965, On the fishing conditions of saury in the adjacent waters of Korea. Rep. Fish. Res., Nat'l Fish. Res. Dev. Agency, 6, 13-35 (in Korean).
39) Han, H. S. and Y. Gong, 1970, Relation between oceanographical conditions and catch of saury in the eastern sea of Korea. In The Kuroshio, A Symposium on the Japan Current (J. C. Marr ed.), 585-592, East-West Center Press, Honolulu, 614pp.
40) Sano, Y., 1966, Relation between hydrography and catch of the saury in the Japan Sea, 43-54. Reports of the Cooperative Investigations on the Saury in the Japan Sea for 1963 and 1964, Japan Sea Reg. Fish. Res. Lab. (ed.), 134pp (in Japanese).
41) Nishimura, S., 1969, The zoogeographical aspects of the Japan Sea, Part V, Publ. Seto. Mar. Biol. Lab., 17(2), 67-142.
42) Nishimura, S., 1965, The zoogeographical aspects of the Japan Sea, Part Ⅱ, Publ. Seto Mar. Biol. Lab., 13(2), 81-101.
43) Hatanaka, M., 1956, Biological studies on the population of the saury, *Cololabis saira* (Brevoort), PartⅡ, Habits and migrations, Tohoku Jour. Agr. Res., 6, 313-340.
44) Kimura, K., 1956a, Drift-net fishery of Pacific saury of Japan in 1936-1943, Bull. Tohoku Reg. Fish. Res. Lab., 7, 146-183 (in Japanese).
45) Yasuda, I. and D. Kitakawa, 1996, Locations of early fishing grounds of saury in the north-western Pacific, Fish. Oceanogr., 5, 63-69.
46) Kosaka, S. 2000, Life history of the Pacific saury *Cololabis saira* in the northwestern Pacific and considerations on resource fluctuations based on it, Bull. Tohoku Natl. Fish. Res. Inst., 63, 1-96 (in Japanese).
47) Gong, Y., T. Hirano and C. I. Zhang, 1985, A study on enviromnental conditions for Pacific saury in Korean waters, Bull. Jap. Soc. Fish. Oceanogr., 47-48, 36-58.
48) Gong, Y. and T. Hirano, 1987, Distribution and migration of Pacific saury and oceanic environments, 81-90, Fisheries Oceanographic Environments (Sugimoto, K., M. Ishino, K. Sugiura and H. Nakata, ed.) Koseisha Koseikaku, Tokyo, 325pp (in Japanese).
49) Gong, Y. and J. B. Lee, 2001, Regional difference in production mechanism and abundance in the Pacific saury stock area. In Korea Fishery Science and National Fisheries Research Institute (NFRI), Report of Fisheries Oceanography Symposium for 80~year Anniversaly of NFRI "Ocean~environmental impact on mass~productive marine organisms", 21-30pp (in Korean).
50) Kimura, K., 1956b, On the Pacific saury caught by the set-net. Bull. Tohoku Reg. Fish. Res. Lab., 7, 184-238 (in Japanese).
51) Gong, Y., 1996, Oceanic environments and Pacific saury resources in the northwestern Pacific and its adjacent seas, Pacific Saury Ocenography,

Natl. Fish. Res. Dev. Ag., 198pp (in Korean).
52) Kawai, H., 1995, Macroscopic fishing conditions of major pelagic fish on the Pacific and Japan Sea coasts related to the hydrography of main spawning grounds, Bull. Jap. Soc. Fish. Oceanogr., 59(3), 265-272 (in Japanese).
53) Oozaki, Y., D. Kitagawa and T. Kawai, 1998, Assessment method of the stock size of immigrated Pacific saury (*Cololabis saira*) including the information on the distribution outside the fishing grounds, Bull. Natl. Res. Inst. Fish. Sci., 12, 53-70 (in Japanese).
54) Novikov, Yu. V., 1979, Fisheries biology of Pacific sardine, mackerel and Pacific saury, TINRO, (Japanese version by Translation Program of Science and Technology Cooperation of Japan and USSR), 69pp.
55) Isoda, Y. and Y. Sakurai, 2000, Verification of age and spawning hypothesis of Pacific saury based on an offspring parent model, Bull. Jpn. Soc. Fish. Oceanogr., 64, 77-84 (in Japanese).
56) Hotta, H., 1960, On the analysis of the population of the saury(*Cololabis saira*) based on the scale and the otolith characters, and their growth, Bull. Tohoku Reg. Fish. Res. Lab., 16, 41-64 (in Japanese).
57) Nitta, T. and S. Yamata, 1989, Recent warming of tropical sea surface temperature and its relationship to Northern Hemisphere circulation, J. Meteor. Soc. Japan, 67, 375-383.
58) Chiba, S. and T. Saino, 2002, Interdecadal change in the upper water column environment and spring diatom community structure in the Japan Sea : an early summer hypothesis, Mar. Ecol. Prog. Ser., 231, 23-25.
59) Maizuru Marine Observatory, 1999, Oceanographic and marine meteorological observations in the Japan Sea. Oceanographic Prompt Report 411, 1-45pp.
60) Chiba, S., T. Saino, Y. Hirota and S. Hasegawa, 2003, North-south contrast of multi-decadal scale variation of lower trophic level ecosystem in the Japan/East Sea : light-limited versus nutrients-limited. Extended abstract, Science Board Symposium, 12th PICES annual meeting, Seoul, Korea, 72pp.
61) Kubo, N. and S. Ebara, 1992, Longterm change of diatoms distribution and oceanographic conditions in the sea south of Hokkaido and the Japan Sea, J. Meteor. Res. (Kenkyu Jiho), 44, 107-117 (in Japanese).
62) Sorokin, Yu. I., 1974, Vertical structure and production of a microplankton community in the Sea of Japan in summer, Oceanology, 14, 266-271.
63) Cushing, D. H., 1989, A difference in structure between ecosystems in strongly stratified waters and in those that are only weakly stratified, J. Plank. Res., 11, 1-13.
64) Baumann, M. and P. H. LeBlond, 1996, Climate change and fish production in the northeast Pacific : the missing link, World Resource Review, 8, 139-157.