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On the Migration of Pacific Saury in Relation to Oceanographic Conditions off Korea*

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Abstract

The migration of Pacific saury (*Cololabis saira*, BREVOORT) was analysed, using the data of monthly length (fork) frequency distribution, catch and effort data, and oceanographic observations. In the study of the migration pattern of Pacific saury which are considered as one of the epipelagic fish, it was recognized that the oceanographic environmental conditions should be fully taken into consideration. With respect to this, we suggest a schematic migration model of Pacific saury with relation to oceanographic conditions. This model represents the movements of each size group of Pacific saury in the normal, abnormally cold and warm oceanographic year. In the normal type, Pacific saury which are spending winter in the southern part of the Japan Sea off Korea and the East China Sea are distributed separately by size group, that is, the smaller in the northern part, the larger in the southern part. In the northward migration period in spring or in the southward migration period in autumn, the larger fish migrate to get ahead of the smaller fish. In the warm type, as the winter ground is shifted to the northern part compared to the normal condition, even the larger fish remain in the south of the Japan Sea off Korea to spend winter. When they migrate northward, the center of the distribution of larger fish would be shifted around Lat. 44°N. In the cold type, the center of the winter ground is shifted to the south of Kyushu, and in the northward migration period the large size group doesn't move to the middle part of the Japan Sea due to the barrier of the thermal front which is formed in the southern part of the Japan Sea, and then it moves northward rapidly in early summer. Results of this study can be used to predict the Pacific saury stock structure qualitatively and quantitatively, understanding the conditions of temporal recruitment of Pacific saury by size group to the fishing grounds, based on the information of variations of oceanographic environmental characteristics.

1. Introduction

Pacific saury, *Cololabis saira* (BREVOORT), in Korean waters are mostly captured by means of gill-nets. The Korean Pacific saury gill-net fishery is carried out in the southwestern area of the Japan Sea, south of Lat. 38°30′N. The fishery is conducted over a period of a year except August and September. Catches of Pacific saury for the last 25 years (1958-1982) ranged from 7,500 to 42,000 metric tons (mt) with the average of 25,936 mt, and their variations were very large (C. V. = 0.37). On the other hand, oceanographic conditions off Korea have shown big variations seasonally and annually. In relation to this, UDA (1938, 1958), HAN and GONG (1965), NAGANUMA (1966), GONG (1972), GONG and SON (1982), HUH (1974, 1982a) and KOLPACK (1982) reported oceanic fronts in the Japan Sea off Korea and adjacent seas. NAGANUMA (1969, 1979, 1981) recognized that oceanographic characteristics had a periodicity in the Tsushima Warm Current area off Japan. Variations of water temperatures in the western Japan Sea area including the Japan Sea off Korea have been reported several times (Fisheries Research & Development Agency 1979; GONG 1968; MIITA 1967; INOUE 1981, TOMOSADA 1982).

Concerning the quantitative variations of Pacific saury in Korean waters, MARR and ROTHSCHILD (1970), KIM *et al.* (1972), KIM

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(1973b, 1975) and GONG and LEE (1977) reported. HAN and GONG (1965) and GONG and OH (1977) reported annual and monthly geographical distributions of catches of Pacific saury. NISHIMURA (1969) and OGAWA (1981) indicated that oceanographic conditions in the Japan Sea had a great effect on distributions of marine organisms. On the distribution and migration of Pacific saury in the Japan Sea, RUMJANTSEV (1947), KOTOVA (1958), APANOVICH (1962), SHUNTOV (1967), NISHIMURA (1965, 1969), HAN and GONG (1965), FUKATAKI (1966), HARA (1966), SUH and KIM (1970), KOBAYASHI *et al.* (1970), KIM (1973a), NOVIKOV (1972, 1979), and GONG (1975) reported. FUKATAKI (1966) reported that Pacific saury had different winter grounds by size group and thus bigger fish spent winter in the southern area and smaller fish in the northern area. SHUNTOV (1967) remarked that the northward migration of Pacific saury in the Japan Sea began in March or April and at first the large proceeded and a little later the small followed along the warm water. On the contrary to SHUNTOV (1967), KIM (1973a) reported that the medium size group of the northward migrating Pacific saury in spring in the Japan Sea off Korea proceeded and the large size group followed, but in the southward migration period the large size group moved to the south first. KUROIWA (1963) stated that in the northward migrating Pacific saury along the coast of Japan in spring the large size group appeared first in the north and thus this group was thought to move to the north first. In Fisheries Agency of Japan (1972) Pacific saury which are caught by drift gill nets in the northward migration period in the Japan Sea off Japan consist of mainly large fish of 30–31 cm mode each year and the fishing rate of the small size group (25–26 cm) becomes higher near the closing period of fishing. Up to now, most of past studies on variations of water temperature in the Japan Sea off Korea were analysed, based on the data of monthly unit. However, it would be necessary that the data of at least a ten-day period unit should be used for more accurate variations of them. Moreover, most studies till now on the variations of length compositions of Pacific saury in Korean waters were made based on short-term data (RUMJANTSEV 1947; Central Fisheries Experimental Station 1958; KOTOVA 1958; HUE and KIM 1959; BAE 1962; SHUNTOV 1967; SUH and KIM 1970; KIM 1973b; SHON and PARK 1977; KIM and PARK 1981). On the other hand, even though those for the Japan Sea off Japan were done based on relatively long-term data (KASAHARA and OTSURU 1952; HATANAKA 1956; KUROIWA 1963, 1966; FUKATAKI 1963, 1966; WAKOH 1978), those for the Japan Sea off Korea were not mentioned there. Reports on the distribution and movement of Pacific saury in the East China Sea and the Japan Sea didn't have detailed information on the distribution time and migration routes of Pacific saury in the Japan Sea off Korea, and they didn't agree to the views of distribution and movement by size group. The reason why the migration mechanism of Pacific saury is not made out clearly seems to be two factors; first, despite the wide range of the distribution and movement of Pacific saury, the study area and time for catch statistics and biological data were limited, second, the pattern of distribution and movement can be varied depending upon the variations of oceanographic conditions, but this factor has not been considered for the study.

It is quite necessary to study the forecast of fishing conditions, as the fishing conditions of Pacific saury are severely variable. The conclusive aim of this study would be to establish a basis for forecasting fishing conditions with high precision, understanding the migration mechanism of Pacific saury by considering the effect of oceanographic environmental factors on the fishing grounds and the distribution of Pacific saury by size group. Accordingly, in this study, considering that Pacific saury are one of the epipelagic fish, first, annual and seasonal variations of oceanographic structure at the upper layer of fishing grounds were analysed by means of the distribution and anomalies at water temperatures. Second, based on catch and effort data of the Korean Pacific saury drift gill net fishery, the shift of centers of fishing grounds in terms of abundance index was analysed. Third, based on the data of length compositions of Pacific saury, the distribution and recruitment rate of Pacific saury by size group were analysed. With the results above, a migration mechanism of Pacific saury in the East China Sea and the Japan Sea was attempted to be made clear.

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2. Materials and methods

Monthly water temperature anomalies for 1957–1981 were estimated based on coastal and sectional oceanographic observations (Central Fisheries Experimental Station 1954–1963; Fisheries Research and Development Agency 1964–1982a), Pacific Saury Fishing Grounds Survey (Fisheries Research and Development Agency 1964–1982b) and Oceanographic Prompt Report in Japan Sea Fishing Grounds (Japan Sea Regional Fisheries Research Laboratory 1957–1982), in order to examine annual and seasonal variations of surface temperatures in fishing grounds of Pacific saury.

It was possible for us to use the whole month surface temperature data from coastal oceanographic observations, however, only one or two of the three 10-day data of each month was available from sectional oceanographic observations. Thus, for the calculation of monthly water temperature anomalies, average 10-day surface water temperature anomalies of each month for 1957–1981 were obtained from the data of coastal and sectional oceanographic observations, and they were used as the representative monthly water temperature anomalies for each month.

In order to see annual and seasonal shifts of Pacific saury drift gill net fishing grounds, abundance indices were estimated, using catch and effort data by sea block (0.5° Lat. × 0.5° Long.) (Central Fisheries Experimental Station 1959–1963, Fisheries Research and Development Agency 1964–1982b), and centroids of fishing grounds in terms of abundance index and their variances were obtained from the map of distribution of fishing grounds by sea block for showing the center of fishing grounds. During the periods of 1959 to 1981, mesh sizes and raw materials of Korean Pacific saury drift gill nets were not changed, therefore the standardization of fishing efforts for calculating abundance indices was not necessary in this analysis. Abundance indices (P) were calculated as follows; $P=\sum(Y_i/f_i)\cdot A_i$, where Y_i and f_i are catch (kg) and effort (set), respectively in i-th rectangle, and A_i is the area of $30'\times30'$ rectangles and is actually assumed to be same for all rectangles. Centers of fishing grounds $(\bar{x}, \bar{y})$ and their variances $(\bar{X}, \bar{Y})$ were calculated as following formulae;

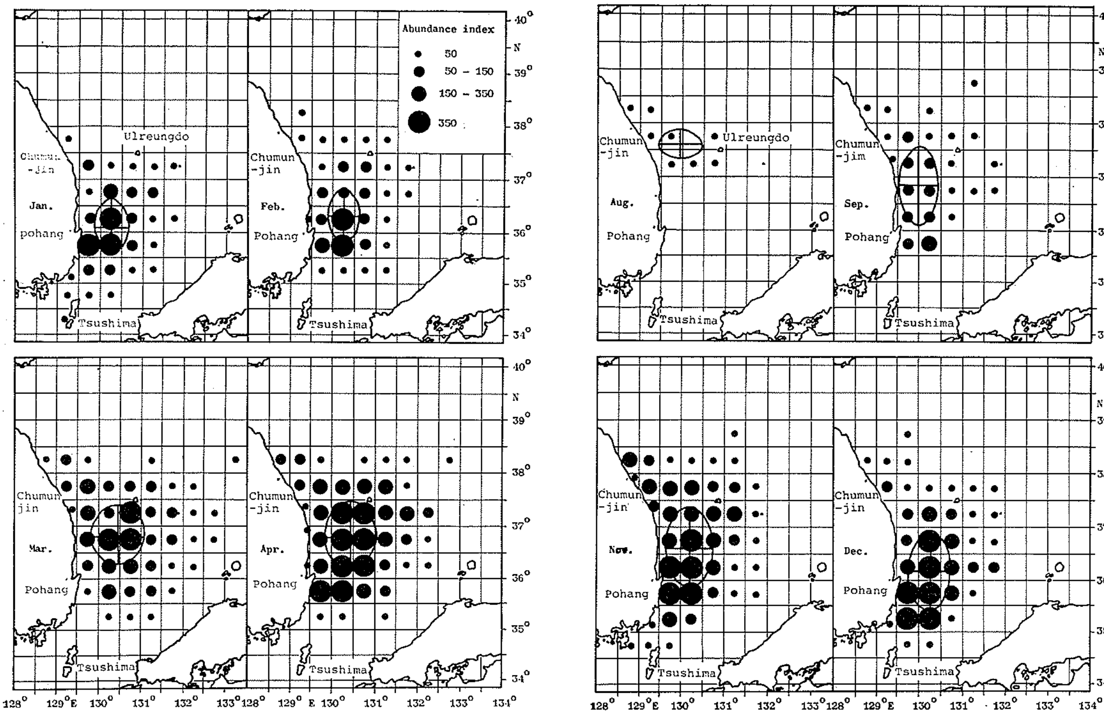
$$\bar{x}=\sum_{i=1}^{n} Cs_i\cdot x_i \Big/ \sum_{i=1}^{n} Cs_i,$$

$$\bar{y}=\sum_{i=1}^{n} Cs_i\cdot y_i \Big/ \sum_{i=1}^{n} Cs_i,$$

$$\bar{X}=\Big(\sum_{i=1}^{n} Cs_i\cdot x_i^2 \Big/ \sum_{i=1}^{n} Cs_i\Big)-\bar{x}^2,$$

$$\bar{Y}=\Big(\sum_{i=1}^{n} Cs_i\cdot y_i^2 \Big/ \sum_{i=1}^{n} Cs_i\Big)-\bar{y}^2,$$

where, x_i and y_i represent coordinates of representative points of each sea block (x-axis for east-west direction and y-axis for south-north direction), and Cs_i represents the corresponding catch for x_i and y_i. The longitudinal distances from the positions of centers $(\bar{x}, \bar{y})$ in terms of abundance index which were the southernmost one in spring (March, April or May) of each year to Lat. 36°30′N were estimated from annual and monthly centers of fishing grounds. The distance becomes positive when the center is in the north of Lat. 36°30′N, but it becomes negative when the center is in the south of the latitude.



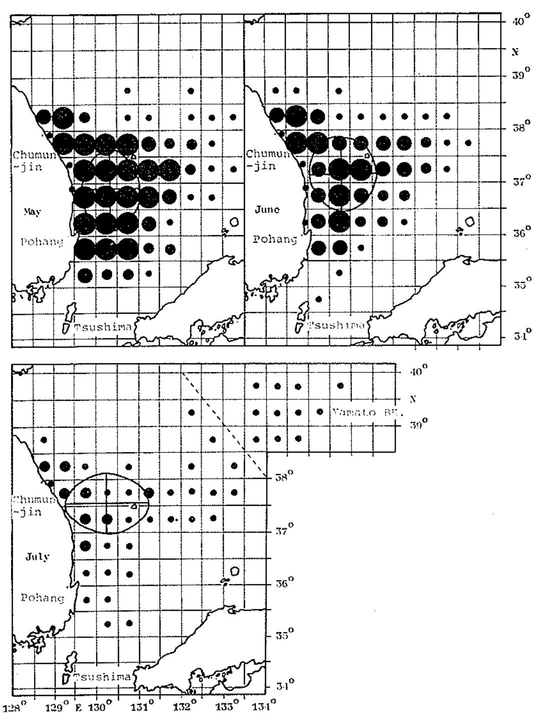


Fig. 1. Monthly abundance indices and their dispersions and centers of Pacific saury by sea block for the Korean Pacific saury gill net fishery in the Japan Sea off Korea, 1959-1982. Black dots represent abundance indices, ellipsoids denote their dispersions, and intersection points of crossed lines in ellipsoids indicate their centers.

Monthly length frequency distributions of of Pacific saury were drawn by fish measurement data which were made at the Pohang and Chumunjin Branches of the National Fisheries Research and Development Agency in 1957-1982. Based on the mode distribution of length compositions, size groups of Pacific saury were divided into small, medium, large and extra large groups, The proportions by year and month of small and medium size groups to the total were estimated.

In order to compare monthly sea surface temperature anomalies with distances from centers of fishing grounds to Lat. 36°30′ N and composition rates of small and medium size groups, a standardization of each value was carried out and fluctuation indices (FI) were estimated by the formula;

$$FI = \frac{x - \bar{x}}{\sigma} \times 100$$

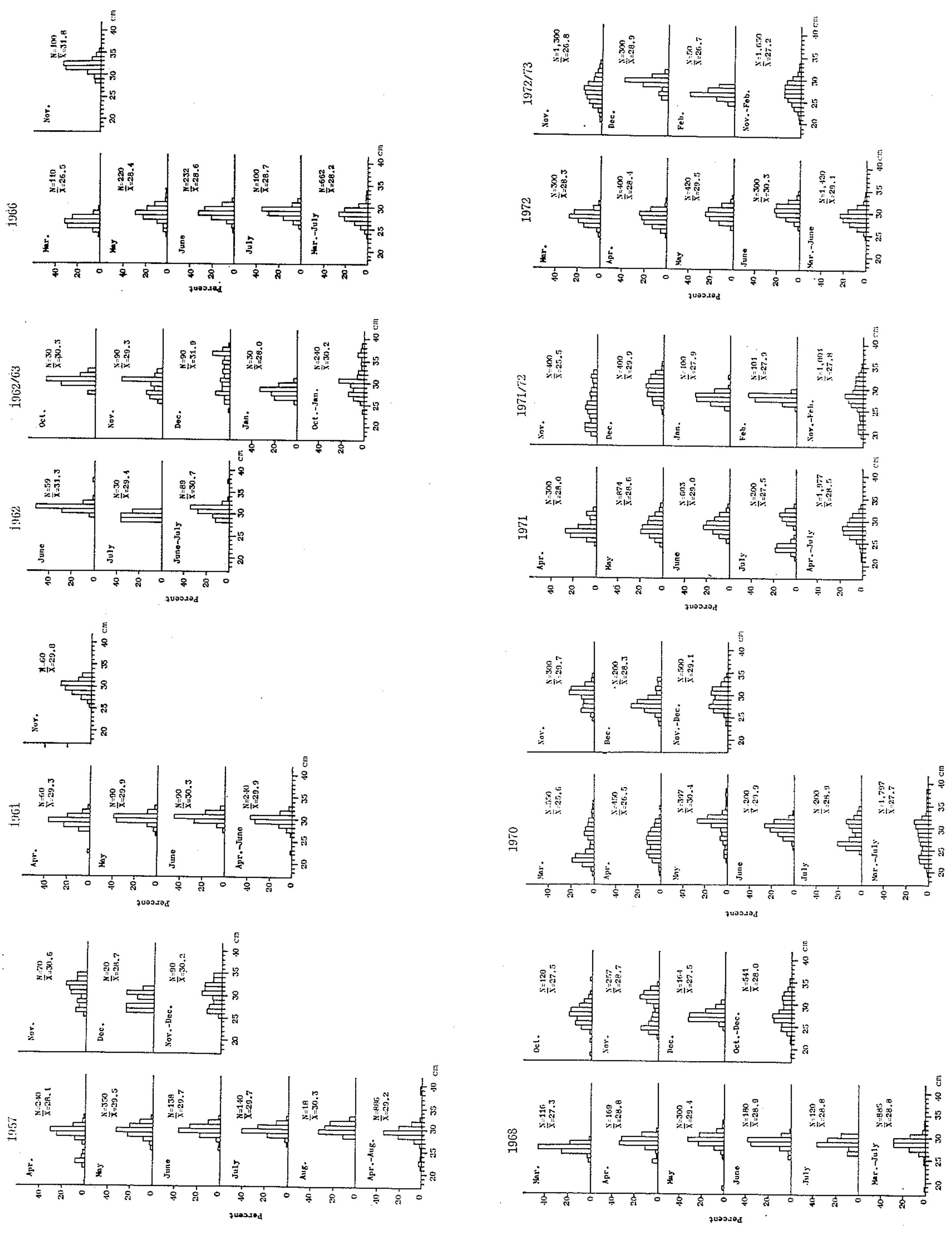
that is, FI represents the percentage of deviations from mean ($\bar{x}$) to standard deviation (σ). And multiple correlationships among the three data series were estimated to show the correlated level one another. In addition to this, the relationship of monthly sea surface temperature anomalies to the variations of catch and composition rates of small and medium size groups of Pacific saury was also estimated.

3. Variations of Pacific saury gill net fishing grounds

The distributions of monthly mean abundance index by sea block for 1959–1982 obtained from sampling data of the Pacific saury drift gill net fishery were drawn and their centers of fishing grounds and their dispersions from the centers were expressed to show seasonal shifts of fishing grounds (Fig. 1). As shown in Fig. 1, in January and February fishing grounds were formed in the southern area of the Japan Sea off Korea, and the area where the abundance index was higher than 150 were located off Pohang and the center of the fishing ground was around 30 miles east of Pohang. The abundance index in February was lower than that in January. In March the range of fishing grounds extended to the northeastern side and the center moved to the north, and the range of the fishing ground covered most part of the southeast of the Korean Peninsula from Lat. 35°00′ to Lat. 38°30′ N and west of Long. 135°30′ E, and the center of the fishing ground was located around Lat. 36°45′ N and Long. 130°25′ E. In April the range and center of the fishing ground were almost the same as in March, but the abundance index in May was the highest of all and it still kept high in the western part as in April. The dispersion from the center (Lat. 36°50′ N and Long. 130°23′ E) in May was a little higher than that in April. In June the range extended to the northeast of Ulreungdo and the center also moved northward compared to May. The dispersion of the fishing ground was circle-shaped in June, while it was a longitudinal elongate ellipsoid-shape in May. In July the fishing ground extended to the south of the Yamato Bank, but the actual fishing operation near the Yamato Bank was only conducted in July of 1977. Even though the fishing ground near the Yamato Bank which was expressed as a dotted line in Fig. 1 was excluded, the center of the fishing ground in July moved northward remarkably and the dispersion of the fishing ground showed rather latitudinal ellipsoid than longitudinal one in July. In August and September the Korean Pacific saury drift gill net fishing operation has been occasionally conducted. In October the abundance index was relatively lower than in the spring season and the high abundance index was on the coastal area from Lat. 35° to Lat. 38° N and the west of Long. 130°30′ E, and the center of the fishing ground was around Lat. 36°22′ N and Long. 130° E. In November the range extended to the southeast and the center moved southward. In December the center moved southward up to the spot of 40 miles east from Pohang, but the northern part of the fishing ground was still stretched to the line of Lat. 38° N.

4. Pacific saury length compositions

Based on the monthly mode distribution of length compositions for 1957–1982, Pacific saury were divided into four size groups, that is, small size group (smaller than 24.9 cm), medium size group (25.0–27.9 cm), large size group (28.0–31.9 cm) and extra large size group (larger than 32.0 cm). The 28 cm fish were considered as the large size group which was in the process of transition from the medium size group to the large size group. It is well-known that Pacific saury spend summer (August to September) in the northern part of the Japan Sea and winter (February) in the southern part of the Japan Sea and the East China Sea. Considering monthly catch and shifts of centroids of fishing grounds of Pacific saury, it was assumed that the northward migration period was from March till August and the southward migration period from October till February. Monthly length frequency distributions of Pacific saury were presented in Fig. 2, and their size groups which


1957
1961
1962
1962/63
1966
1968
1970
1971
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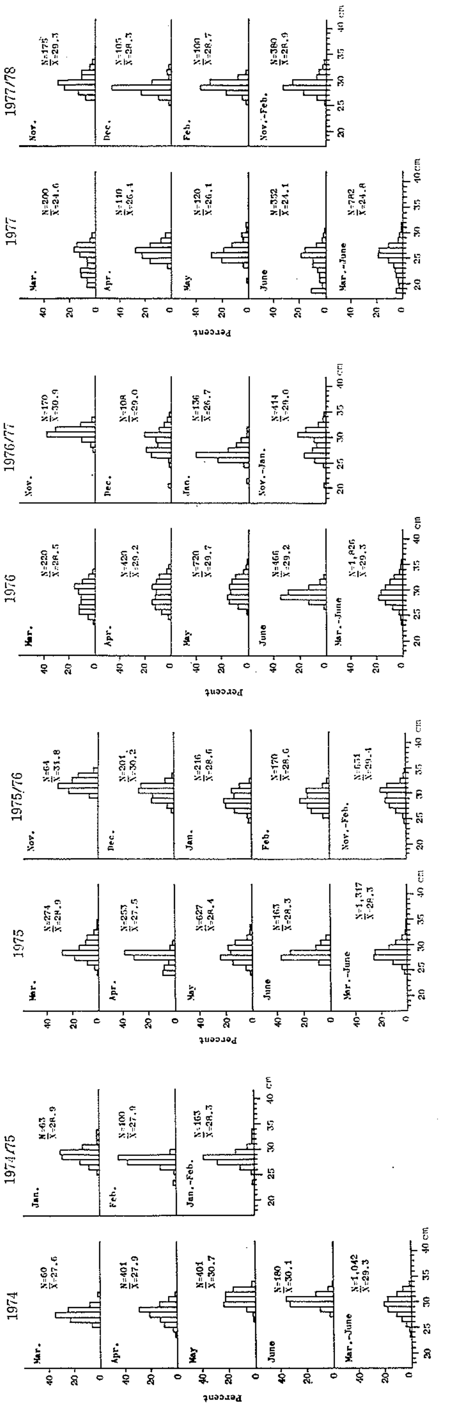
1972
1972/73
Percent



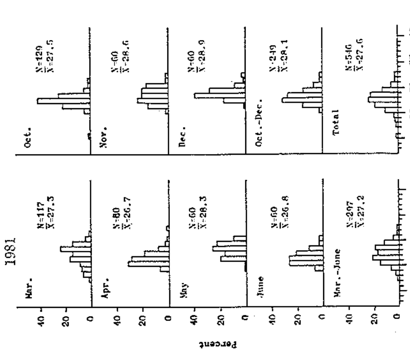


Fig. 2. Monthly length frequency distributions of Pacific saury captured by Korean Pacific saury drift gill nets in the Japan Sea off Korea in 1957-1981. N denotes numbers of individuals measured, $\overline{X}$ denotes mean length of the sample. The left is for the northward migration period, and the right, the southward migration period.

composed of monthly modes were presented in Table 1.

As shown in Table 1, in the northward migration period of 1957, 1961 and 1962, the large size groups were dominant. In the northward migration period of 1970 the length composition in March had three modes in the small size group (22 cm), the large size group (28 cm) and the extra-large size group (33 cm), and that in April had two modes in the small size group (23–24 cm) and the medium size group (27 cm) and the proportion of the large size group de-

Table 1. Size groups which composed of monthly modes in length compositions of Pacific saury by migration period in the Japan Sea off Korea, 1957–1981. S represents the small size group, M, the medium, L, the large, LL, the extra-large, respectively

Year	Northward migration period	Year	Southward migration period
1957	L (Apr.-Jul.) S, L (Apr.)		M, LL (Nov.) M, L (Dec.)
1961	L (Apr.-Jun.)		
1962	L (Jun.-Jul.)	1962/63	M, L (Oct.-Nov.) M, L, LL (Dec.) L (Jan.)
1966	M (Mar.) L (May-Jul.)		
1968	M, L (Mar.) L (May-Jul)		M (Oct.) S, L (Nov.) M (Dec.)
1970	S, L, LL (Mar.) S, M (Apr.) S, M, L, LL (May) L (Jun.) M, L (Jul.)		M, L (Nov.) M, L (Dec.)
1971	M, L (Apr.) M (May) L (Jun.) S, L (Jul.)	1971/72	S, M, L, LL (Nov.) L (Dec.-Feb.)
1972	L (Mar.-Jun.)	1972/73	M (Nov.) M, L (Dec.) M (Feb.)
1974	M (Mar.) L (Apr.-Jun.)	1975	L (Jan.-Feb.)
1975	L (Mar.) S, L (Apr.-May) M (Jun.)	1975/76	L (Nov.-Feb.)
1976	M, L (Mar.-May) L (Jun.)	1976/77	L (Nov.) M, L (Dec.) M (Jan.)
1977	S, M (Mar.) M (Apr.) S, M, L (May) S, M (Jun.)	1977/78	L (Nov.-Feb.)
1981	M, L (Mar.) M (Apr.) M, L (May) M (Jun.)		M (Oct.-Nov.) L (Dec.)

clined remarkably, and that in May had four modes in the small size group (23–24 cm), the medium size group (27 cm), the large size group (31 cm) and the extra-large size group (37 cm), and that in June had only one mode in the large size group (30 cm) and in July there were two modes in the medium size group (26 cm) and the large size group (31 cm).

In the southward migration period of 1971/72 the length composition in November had four modes in the all size groups (20–21 cm, 25 cm, 28 cm and 32 cm, respectively), and that in December had two modes of 28 cm and 30 cm and consisted of the large size group, and in January and February there was only one mode in the large size group which was in the process of transition from the medium size group to the large size group. In the northward migration period of 1972 the length composition in March had one mode in the large size group (28 cm), and those in April and May had one in the large size group (29 cm), and that in June had one in the large size group (30 cm). It was recognized that the modes became larger while the months proceeded between March and June. In the southward migration period of 1972/73 the length composition in November had one mode in the medium size group (27 cm), and that in December had two modes in the medium (26 cm) and large (29 cm) size groups, and the large size group was dominant, and in February there was only one mode in the medium size group (26 cm). This composition indicated that the small size group appeared in earlier southward migration period (October to November) and then the large size group followed and this large size group disappeared in winter (December to February). In the southward migration period of 1975/76 the length composition in November had a mode in the large size group (31 cm), and from December to the next February there were constantly two modes of 28 cm and 30 cm. It was an abnormal phenomenon that the mode in the large size group (30 cm) was still present in the wintering season (around February). In the northward migration period of 1976 the length composition in March had two modes in the medium size group (25–26 cm) and the large size group (30 cm), and that in April had two modes in the medium (27 cm) and large (30 cm) size groups, and that in May had two modes in the medium or large size group (27–28 cm) and the large size group (30 cm) and had one more subsidiary mode in the extra-large size group (32 cm), and in June there was a mode of 28 cm and the large size group which was present until May was remarkably rare.

The occurrence of the large size group in the Japan Sea off Korea from winter through spring of 1975/76 when this year was considered as a warmer-than-normal year in the previous chapter was exceptional (Fig. 2), and the disappearance of the large size group from June was the result of getting out of the fishing ground earlier than other size groups.

In the northward migration period of 1977 the length composition in March had two modes in the small (22 cm) and medium (26 cm) size groups, and that in April had one mode in the medium size group (26 cm), and that in May had one main mode (25 cm) and a subsidiary mode (29 cm), and in June there appeared one main mode (25 cm) and a subsidiary mode (18 cm), too. In the northward migration period of 1981 the length compositions in March and May had two modes of 26 cm and 28 cm. Those in April and June had a main mode in the medium size group (25–26 cm) and two subsidiary modes in the large and extra-large size groups The length compositions in the northward migration period of 1981 consisted of the medium size groups (25–26 cm) and the large size groups which were in the process of transition from the medium to the large size group.

Remarkably, in lower-than-normal years (1963, 1977, 1981) the small size group was dominant in the length freuqency distributions.

5. Relationships of oceanographic conditions to length compositions and fishing conditions

(1) Variations of thermal structures at the upper layer of fishing grounds

The charts of horizontal distributions of the water temperature in April for 1961–1978 and in April or May for warmer-than-normal and colder-than-normal years were drawn to show annual variations of surface water temperature of spring in the Japan Sea off Korea (area from Lat. 34° to 38°30′ N and from Long. 129° to 132° E) (Fig. 3). The surface water temperature in April of normal years for 1961–1978 ranged from 10°C to 14°C, and isotherms were usually distributed in parallel with latitudinal lines. It was recognized that the East Korean Warm Current moved northward along the coastal line and then tended to turn northeast at the north of Ulreungdo. The water temperature in April of 1960, in May of 1966, in April of 1972 and in April of 1976 were higher than normal years in the East Korean Warm Current Area. Especially in April of 1976 it was extraordinary warm. But, in April of 1972 the thermal front which was formed by contacting the North Korean Cold Current with the East Korean Warm Current apparently occurred in the coastal area on the line of Lat. 38° N, and it was abnormally cold in the Cold Current Area, north of the thermal front. The water temperatures in May of 1963, in April of 1970, in April of 1977 and in April of 1981 were lower than those in normal years, especially in May of 1963 and in April of 1981 it was abnormally cold except the area of the Korea Strait. Accordingly, in May of 1963 two thermal fronts occurred not only between the East Korean Warm Current and mixed zone but also between mixed zone and the Cold Current Area. In April of 1970 the water temperature represented that it was low near Ulreungdo but it was rather high near mid-coastal area, abnormally. In April of 1977 it showed the similar pattern with in April of 1970, and the East Korean Warm Current was located contacting almost with the coastal line. And the thermal front which was formed between the East Korean Warm Current and mixed zone moved southeastward from the coast. In April of 1981 the strength of the East Korean Warm Current remained south of the line of Lat. 36° N and the thermal front extended eastward along the line of Lat. 35°30′ N from the southeastern part of the Korean Peninsula. It was 2–4°C colder than normal years in the northern part of the thermal front.

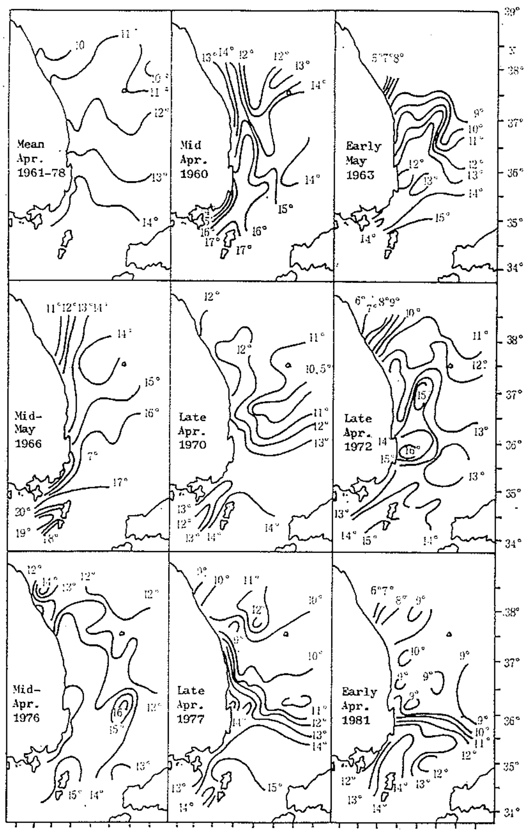


Fig. 3. Horizontal distributions of sea surface temperature (°C) in spring (April or May) of colder-than-normal oceanographic years (1963, 1970, 1977 and 1981) and warmer-than-normal years (1960, 1966, 1972 and 1976) and mean sea surface temperatures in April for 1961–1978 in the Japan Sea off Korea.

(2) Annual and monthly variations of sea surface temperatures

In order to figure out annual and seasonal variations of sea surface temperatures in the Pacific saury drift gill net fishing ground, monthly temperature anomalies were estimated and their fluctuation indices by standardization were plotted in Fig. 4, based on the 10-day mean water temperatures of 17 coastal and offshore stations for 1957–1981. As shown in Fig. 4, the fluctuation indices for summer of 1959, 1960, 1961, 1964, 1967, 1973 and 1975 were higher than 200, and thus their surface temperatures were abnormally high, and those for winter and

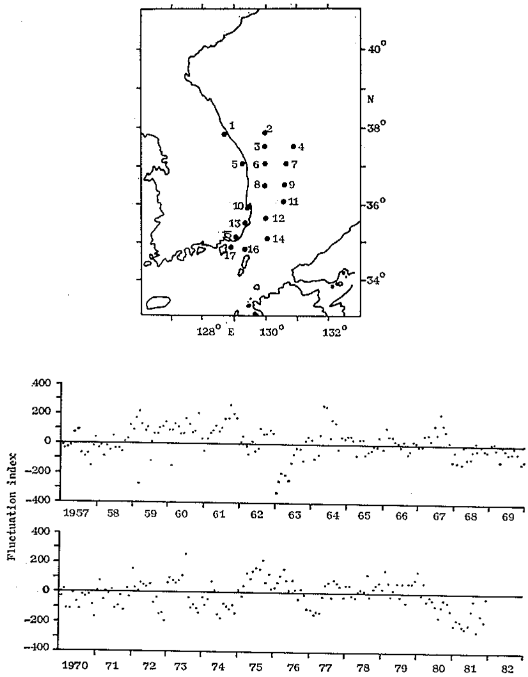


Fig. 4. Selected 17 coastal and offshore stations of sea surface temperature observations used for calculating 10-day mean water temperatures in this study (above). Monthly changes of fluctuation indices (FI) of sea surface temperatures for 1959–1981 periods combined with the 17 selected stations in the Japan Sea off Korea. FI represents the percentage of deviations from mean ($\bar{x}$) to standard deviation (σ) ($FI = x - \bar{x}/\sigma \times 100$) (below).

spring of 1971, 1976, 1979 and 1980 were higher than 130 and thus their surface temperatures were pretty high. On the other hand, the fluctuation indices for 1963 and 1981 were lower than −200 and thus their surface temperatures were abnormally low, and those for autumn of 1957, spring of 1968, winter of 1969/70, autumn of 1972, summer and autumn of 1974, winter of 1976/77 and spring of 1977 were lower than −130 and thus their surface temperatures were pretty low.

(3) Relationships of variations of water temperatures to composition rates of size groups, shifts of fishing grounds and variations of catch

Annual mean temperature anomalies for winter and spring (December to April) were estimated from monthly temperature anomalies obtained above, and their fluctuation indices were estimated by standardization (Fig 5). The fluctuation indices for winter and spring of 1958/59 and 1959/60 were pretty high, and those of 1971/72, 1975/76 and 1978/79 were fairly high. On the other hand, the fluctuation indices for winter and spring of 1962/63 and 1980/81 were abnormally low, and that of 1976/77 was pretty low. And those of 1967/68 and 1969/70 were fairly low.

Annual composition rates of small (smaller than 23.9 cm) and medium (24.0–27.9 cm) size

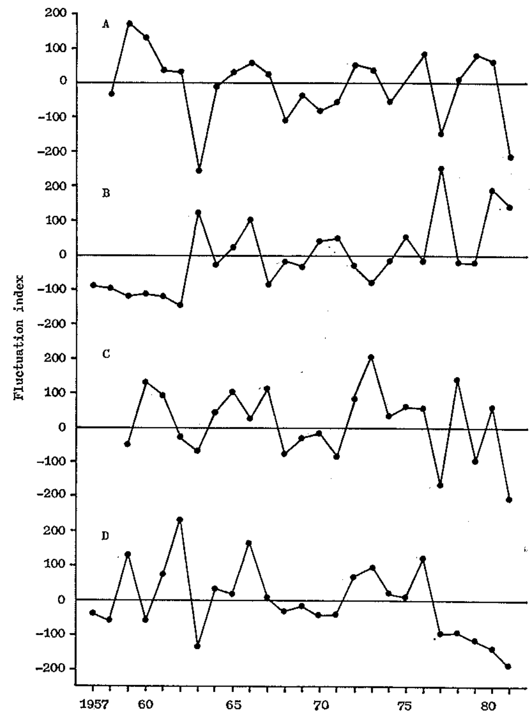


Fig. 5. Annual changes of fluctuation indices of sea surface temperatures calculated from annual mean temperature anomalies for winter and spring (December to April) (A), composition rates of small and medium size groups of Pacific saury for spring and summer (March to July) (B), distances from the positions of centers which were the southernmost one in spring (March, April or May) of each year to Lat. 36°30′N (C), and catch of Pacific saury for spring and summer (March to July) (D), in the Japan Sea off Korea, 1957–1982.

Table 2. Multiple correlationships of sea surface temperature anomalies for winter and spring to composition rates of small and medium size groups of Pacific saury for spring and centers of fishing grounds, and to composition rates of small and medium size groups for spring and catch in the Japan Sea off Korea, 1957-1982

Relationships	Multiple correlation coefficients	Results of F-test
1. Composition rates of small and medium size groups (Mar.-Jul.) and distances from centers of fishing grounds in terms of abundance index to Lat. 36°30′N (Mar. Apr. or May) on sea surface temperature anomalies (Dec.-Apr.)	0.7601	Very highly significant $F=13.68>F_{20}^{2}(0.01)=5.85$
2. Composition rates of small and medium size groups (Mar.-Jul.) and catch (Mar.-Jul.) on sea surface temperature anomalies (Dec.-Apr.)	0.6584	Very highly significant $F=7.65>F_{20}^{2}(0.01)=5.85$

groups to the total for spring and summer (March to July) were estimated from monthly composition rates, and their fluctuation indices were estimated by standardization (Fig. 5). Also, annual fluctuation indices for centers of fishing grounds in terms of abundance index were estimated from the longitudinal distances from the positions of centers which were the southernmost one in spring (March, April or May) of each year to Lat. 36°30′N (Fig. 5). On the other hand, annual catch for spring and summer (March to July) were estimated by combining monthly catch data and their fluctuation indices were estimated by standardization (Fig. 5). As shown in Fig. 5, when sea surface temperatures were lower than normal in winter and spring (December to April), the composition rates of small and medium size groups of Pacific saury were high, and the centers of the fishing ground were in the south, and catches of Pacific saury were low (example, 1963, 1977, 1981). The multiple correlationship of sea surface temperature anomalies for winter and spring to composition rates of small and medium size groups of Pacific saury for spring and centers of fishing grounds, and the multiple correlationship of sea surface temperature anomalies for winter and spring to composition rates of small and medium size groups of Pacific saury for spring and catch were highly significant (Table 2).

6. Discussion and conclusion

As shown in the previous chapter, Pacific saury in Korean waters begin to move northward in March and the main shoals of Pacific saury recruit to the fishing ground till May. From October they begin to move southward, and in November they move rapidly to the south of the Japan Sea off Korea. The southward migration in autumn seems to be faster in speed than the northward migration in spring. The abundance index was high from April to June with a peak in May in the northward migration period and more or less high in November and December in the southward migration period.

Oceanographic conditions of the Japan Sea are usually dominated by the strength of the Tsushima Warm Current Water and the Japan Sea Proper Cold Water and by the air-sea interaction (SUDA *et al.* 1932; UDA 1934; LEONOV 1948, 1958; RADZIKHOVSKAYA 1961; MIYAZAKI 1952; NISHIMURA 1969; ASAI and KATO 1981; MORIYASU 1972; NAGANUMA 1972; SHUTO 1982). As the Tsushima Warm Current which enters the Japan Sea after passing the Korea Strait extends to the north covering the upper layer of the Japan Sea Proper Cold Water, and moves northward and forms the permanent thermocline, the warm current water becomes narrower gradually, and it contacts with the cold water in the middle of the Japan Sea and the Polar Front. The Polar Front extends from the southeast of the Korean Peninsula up to the west coast of Hokkaido, passing Ulreungdo and crossing the middle part of the Japan Sea (UDA 1938, 1958; NAGANUMA 1966, 1967; GONG and SON 1982; HUH 1974, 1982a, 1982b; KOLPACK 1982). In the south of the Polar Front in the Japan Sea in winter, the depth of the upper mixed layer is large owing to cooling and convection (Maizuru Marine Observatory, Maritime Meteorology Division 1972). However, from around June the surface warm water is developed, and from July the high temperature and low salinity superficial water which enters the Japan Sea after passing the Korea Strait from the East China Sea extends to the north covering the upper layer of the high temperature and high salinity Tsushima Warm Current Core Water. Accordingly, the depth of the upper mixed layer in summer (June to September) is remarkably small (GONG and OH 1977). Many studies were reported on the stratification and the movement of water masses in the East Korean Warm Water area in the Japan Sea off Korea (KAJIURA *et al.* 1958; MIYATA 1958; GONG 1962; TANIOKA 1968; LEE and BONG 1968; GONG and PARK 1969; MORIYASU 1972; FUJII *et al.* 1976; YOON 1982a, 1982b, 1982c). Considering the distributions of normal surface water temperatures and salinities in the south of Lat. 38°30′ N of the Japan Sea off Korea and around Tsushima in the southwest of the Japan Sea by the Marine Environmental Atlas (Japan, Oceanographic Data Center 1978), the temperature and salinity in winter (January to March) were 5-15°C and 34.1-34.7‰, and those in spring (April to June) were 10-20°C and 34.1-34.6‰, respectively. Especially, the mean surface water temperature in April was 10-15°C. Those in summer (July to September) were 20-28°C and 32.0-33.9‰ and those in autumn (October to December) were 10-23°C and 33.0-34.2‰, respectively. Thus, in autumn it is more or less higher in water temperature and lower in salinity than in spring. On the oceanic structure and variation in the Japan Sea many studies were done, but in the southern part of the Japan Sea recent detailed studies on the surface thermal fronts and annual and seasonal variations of surface temperatures were not carried out yet.

Pacific saury in the Japan Sea are one of the epipelagic fish and they inhabit mainly within the depth of 1 m (NISHIMURA 1965; NIWA 1963; SHUNTOV 1967). When Pacific saury drift gill nets are set, the sinker of the net can be usually extended to 2.5 m. Accordingly, catches by Pacific saury drift gill nets will be able to reflect the distribution density of the population and body length frequency distributions of catches also will be able to reflect that of the population. Therefore, the oceanic structure at the upper layer and its variation were analysed to understand the influence of environments on the shifts of fishing grounds, composition rates of Pacific saury by size group, and catch. In winter and spring (January to June) the low salinity surface water which was originated from the East China Sea is not strong in the East Korean Warm Current area and adjacent regions. And the gradient of horizontal and vertical salinity in these seasons is small. Thus the thermal structure at the surface layer can be identified easily in the surface water temperature distribution. Moreover, the water mass boundary at the surface layer is represented by the thermal front which has a big horizontal temperature gradient, and the thermal front corresponds to the oceanic front, Shiome, which can be expressed by the gradient of density (GONG and SON 1982). When the standardized value of the variation of water temperature, that is, the percentage of deviations from mean to standard deviation, is greater than +200, it is classified into abnormally high, +130 to +199, pretty high, +60 to +129, fairly high and smaller than +59, more or less high, and so did for the negative values (NAGANUMA 1979). As shown in Fig. 3, it was well-known that the abnormal cold water temperatures and the southward sihfts of fronts occurred in winter of 1962/63 and spring of 1963 in the western part of the Japan Sea including the East Korean Warm Current area (HAN and GONG 1965; NAGANUMA 1966; HAN and GONG 1970; GONG and OH 1977; KITANI and UDA 1969). The fact that the oceanographic condition at the upper layer in the East Korean Warm Current area in winter of 1976 was pretty high was reported by GONG and SON (1982), and the positions of thermal fronts at surface in 1972 and 1981 could be identified in the satellite thermal infrared imagery (HUH 1974, 1982a, 1982b; KAWAMOTO and OGAWA 1981). As explained in the previous chapter, the pattern of the annual variation of surface water temperature anomalies in the East Korean Warm Current area tends to be similar to that at the station (Lat. 34°04′N and Long. 129°32′E) in the eastern channel of the Korea Strait and the coastal oceanographic station (Mitsushima). However, in 1970 the temperature of the eastern channel was lower than that of the East Korean Warm Current area (MIITA 1967; NAGANUMA 1969; INOUE 1981; TOMOSADA 1982; Japan Sea Regional Fisheries Research Laboratory 1970). In the East Korean Warm Current area no periodicity of variations of surface water temperatures was recognized, though the periodicity of variations of oceanographic characteristics appeared in the east Japan Sea (NAGANUMA 1981). This seems to be interpreted by the seasonal and regional differences of air-sea interaction, as indicated by ASAI and KATO (1981).

On the optimum water temperatures for inhabiting of and fishing Pacific saury in the Japan Sea there are many reports but they don't correspond one another (RUMJANTSEV 1947; KOTOVA 1958; TABATA 1963; HAN and GONG 1965; SANO 1963, 1966; SHUNTOV 1967; NISHIMURA 1969; HAN and GONG 1970; GONG *et al.* 1974; KIM and GONG 1978). FUKATAKI (1966) estimated that in the declining periods of water temperatures the habitat of Pacific saury was warmer area than the area with about 10°C, analysing the data of KOTOVA (1958) and HOTTA (1964). The range of the optimum water temperature for Pacific saury fishing was obtained, corresponding catch distributions to surface water temperature distributions for 1959–1981 by sea block which had both oceanographic observations and fishing records at the same time (GONG *et al.* 1983). According to the results of the study, the range of the water temperature for inhabiting Pacific saury in the East China Sea and the Japan Sea is 7–24°C, and the optimum water temperature ranges between 13°C and 18°C centering around 15°C. As explained in the previous chapter, in the Japan Sea off Korea the northern part of the thermal front in the abnormal cold years (example, 1963, 1981) is covered with cold water mass whose surface water temperature is below 10°C even in April and May. Accordingly, it can be seen that the northern side of the thermal front can play a role of a cold barrier to prevent the commercially valuable high density Pacific saury in the winter ground from the northward migration toward the middle of the Japan Sea. It is well known that oceanographic conditions in the North Pacific influence the distribution and movement of Pacific saury and the formation of the fishing ground (FUKUSHIMA 1979). Especially, the Oyashio front acts as a thermal barrier to the movement of fish species and accumulates fish shoals. It is known that the main fishing ground is formed in the current rip (or Shiome) between the Kuroshio and Oyashio (UDA 1936; NOVIKOV 1982; MATSUMIYA and TANAKA 1976; PAVLYCHEV 1977; SABLIN and PAVLYCHEV 1982). It seems that the variation of oceanographic conditions which represents the lower limit of the water temperature for inhabiting Pacific saury affects the distribution and movement and thus the formation of the fishing ground (KUNDIUS 1966; NOVIKOV 1966).

In general, the size frequency distribution of a population is the result of the interaction of growth and survivorship functions together with variation introduced by periodic phenomena, such as seasonal recruitment and by the strength of the year class. Because size distributions contain a record of past recruitment, growth and survival, as well as oceanographic conditions as basic causes for other population parameters it is reasonable to search for ways in which they might reveal population information, especially for epipelagic fish like Pacific saury to understand the migration pattern. If distributions and movements of fish populations are dependent upon variations of oceanographic conditions, fish populations would be indicators of variations of oceanographic conditions and thus the pattern of distributions and movements would be available to indicate variations of oceanographic conditions.

Pacific saury have a specific body shape, in that large size fish are caught in the net by the anterior (head) part of the body while small size fish are caught by the posterior (tail) part of the body for the net with the same mesh size. Therefore, it can be considered that the meshes of gill nets for Pacific saury would not have the selectivity for Pacific saury fishing in analysing the qualitative structure from catches. Other studies also hold the same view (KASAHARA and OTSURU 1952; HOTTA 1964). The mesh sizes of Pacific saury drift gill nets which have been used in the Japan Sea off Korea range from 9 to 11 knots constantly and especially 10.5 knots mesh size is the most common. Accordingly, annual Pacific saury length frequency distribution data used in this study have the consistency in sampling and can be considered as random samples which represent the population.

Considering the abnormally cold phenomenon in spring of 1963 in the Japan Sea, it could be assumed that the major component of the catch in the Japan Sea off Korea would be also the medium size group of 27-28 cm mode. Accordingly, KUROIWA (1966)'s data on the proportions of size groups of Pacific saury in spring of 1963 in the Japan Sea off Japan were used in this study. SHAW (1962) stated that even in schools as many as million fish all members are of a similar shape, and speed increases with size and the fish of a species therefore tend to sort themselves by size and by generation in the sea. Accordingly, Pacific saury in the East China Sea and the Japan Sea would tend to make schools and to sort themselves by size and also have different speeds by size. Fish cruise at 3 to 10 fish lengths per sec (CUSHING 1981) and thus it is extremely natural that larger fish cruise faster than smaller fish. On the other hand, HARDEN JONES (1977) stated that there was no obvious relation between fish length and speed. However, THOMPSON (1975) wrote that the larger it grows the greater is its speed in the case of the aquatic animal. And it is known that there is an exponential relationship between them (SENTA 1983). As noted in the previous chapter, there were very significant multiple correlationships of annual surface water temperature anomalies to composition rates of Pacific saury by size group and distances from centers of the fishing ground to Lat. 38°30′ N, and to composition rates of Pacific saury by size group and catch. This result represents that oceanographic conditions in winter and spring, especially the water temperature distribution at the upper layer in the fishing ground affect the composition of Pacific saury by size group which enter the fishing ground. In other words, the lower is the water temperature in the fishing ground compared to normal years, the later recruits the large size group which is the main target for fishing. Accordingly, the position of center of the fishing ground would be partial to the south and the density of fish shoals would be low and the catch would be also low, compared to normal years. And the water temperature is high, the reversed phenomena occur.

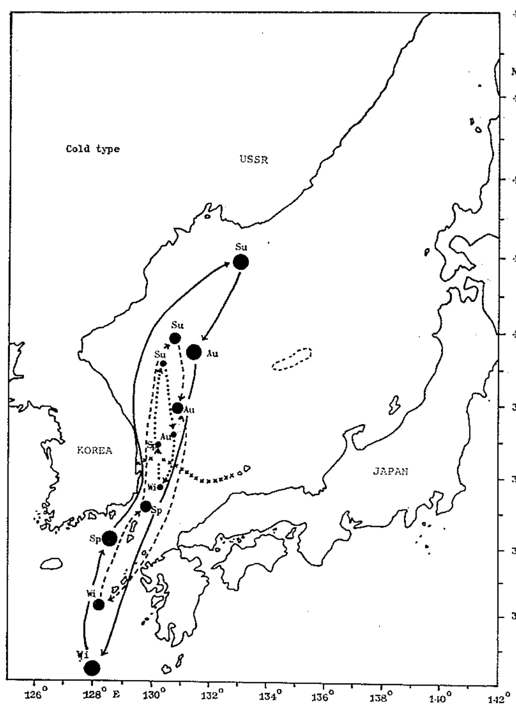
On the distribution and migration of Pacific saury in the East China Sea and the Japan Sea, RUMJANTSEV (1947) and APANOVICH (1962) reported the summer distribution in the north Japan Sea off Korea and monthly distribution in spring-summer season, respectively. KOTOVA (1958) reported monthly distributions and movements of spawning groups of Pacific saury, based on the data of RUMJANTSEV (1947). NOVIKOV (1979) reported northward and southward migration routes of spawning groups of Pacific saury in the Pacific Ocean and the Japan Sea. And TSUJITA (1979) reported the migration routes of Pacific saury in the northwestern Pacific Ocean. KOBAYASHI *et al.* (1970) presumed migration routes of spring developed Pacific saury, considering growth stages and annual life periodicity. Many supposed migration routes of Pacific saury in the Japan Sea off Korea were reported by HUE and KIM (1959), HAN and GONG (1965), HARA (1966), SUH and KIM (1970), GONG (1975) and GONG and LEE (1977), but they didn't mention the migration of Pacific saury by size group. NISHIMURA (1965) stated that Pacific saury in the Japan Sea were a typical epipelagic species and they moved to the north extensively in the northward migration period and they moved to the south extensively but partially to the Korean side in the southward migration period. NISHIMURA (1969) reported that the winter grounds were from Tsushima to the west of Kyushu and that the motive of the northward movements of saury in early spring was not in the strength of the

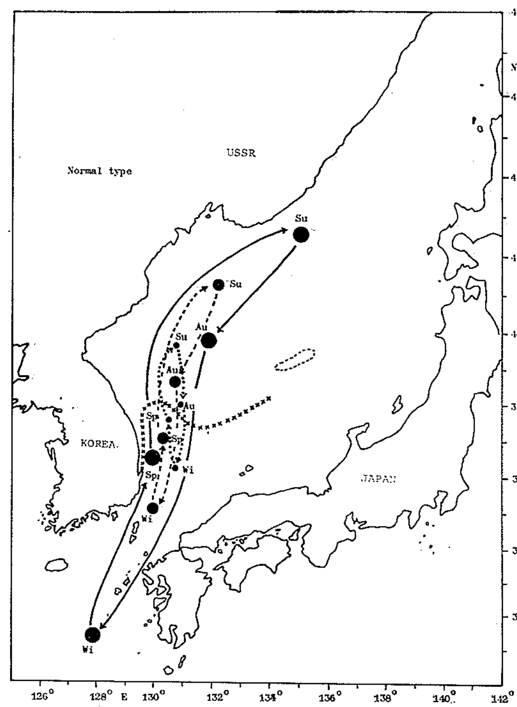
Tsushima Warm Current but in the northward spreading of upper water mass which was released from the northwest wind stress. Concerning the winter grounds of Pacific saury, NISHIMURA (1965), HAN and GONG (1965), FUKATAKI (1966) and SUH and KIM (1970) reported and most of them thought that the winter grounds were in the Korea Strait and its southern area. Especially, FUKATAKI (1966) reported that Pacific saury had different winter grounds by size group and thus bigger fish spent winter in the southern area and smaller fish in the northern area, especially the large and extra-large size groups moved to the south to spend winter in the south of Tsushima, not in the south Japan Sea off Korea. SUH and KIM (1970) also reported that Pacific saury in the lower latitude were larger than those in the higher latitude in the south of the Japan Sea off Korea. Prevailing oceanographic conditions that affect migration patterns of Pacific saury are believed primarily responsible for the large fluctuations in catch rate (HATANAKA, 1956). MATSUDAIRA *et al.* (1956) recognized that migrations of juvenile and adult Pacific saury which migrate south-north direction in the areas whose water temperature ranges from 13 to 18°C in each season were correspondent to geographical distributions of the high productive zone in the northwest Pacific Ocean including the East China Sea and the Japan Sea. SHUNTOV (1967) remarked that the northward migration of Pacific saury in the Japan Sea began in March or April and at first the large proceeded and a little later the small followed along the warm water. On the contrary to SHUNTOV (1967), KIM (1973a) reported that the medium size group of the northward migrating Pacific saury in spring in the Japan Sea off Korea proceeded and the large size group followed, but in the southward migration period the large size group moved to the south first. KUROIWA (1963) stated that in the northward migrating Pacific saury along the coast of Japan in spring the large size group appeared first in the north and thus the large size group was thought to move to the north first. In Fisheries Agency of Japan (1972) Pacific saury which are caught by drift gill nets in the northward migration period in the Japan Sea off Japan consist of mainly large fish of 30–31 cm mode each year and as the fishing period proceeds, that is, in the north, the size of Pacific saury is large, and the size increases about 1 cm by month during the period of April to July, and the fishing rate of small Pacific saury smaller than 26 cm becomes higher near the closing period of fishing.

Reports on the distribution and movement of Pacific saury in the East China Sea and the Japan Sea didn't have detailed information on the distribution time and migration routes of Pacific saury in the Japan Sea off Korea, and they didn't agree to the views of the distribution and movement by size group. The phenomenon that the large size group (mode, 30 cm) appeared in the south Japan Sea in the wintering periods (example, in winter of 1975/76) could deny the theory that only 28 to 29 cm Pacific saury appeared in the period (FUKATAKI 1966). KIM (1973a) and FUKATAKI (1966) stated that in the southward migration period the large size group first moved to the south in the Japan Sea off Korea and the southeast of the Japan Sea off Japan, but there exists an exception in this statement (example, in autumn-winter season of 1972/73). This exception means that small Pacific saury first immigrate to the north fishing ground in the early southward migration period (October to November) and then the large size group follows, and near December this large size group gets ahead of the small size group and in the closing season of fishing (February) the large size group already gets out of the Japan Sea to the East China Sea. On the other hand, as shown in annual and monthly length compositions from winter of 1970/71 to spring of 1971 and from winter of 1976/77 to spring of 1977, proportions of smaller than medium size Pacific saury accounted for considerable amounts compared to the large size group. Also, in length compositions of Pacific saury in the western coast of Hokkaido in spring of 1977, only the exceptional medium size group (mode, 25–26 cm) appeared (WAKOH 1978). As noted in the horizontal distribution chart of surface water temperatures and the variation of annual water temperature anomalies in the previous chapter, oceanographic conditions of the fishing ground in the Japan Sea off Korea were very variable in winter and spring. The water temperatures in winter and spring of 1958/59 and 1959/60 were pretty high, those of 1970/71, 1975/76 and 1978/79 were more or less high. In these years, the thermal front which was formed between the East Korean Warm Current and the North Korean Cold Water was formed northward and was extended longitudinally. On the other hand, the water temperature in winter and spring of 1962/63 and 1980/81 were abnormally low, and those of 1967/68, 1969/70, and 1976/77 were pretty or more or less low. In these years, the thermal front was formed in the southern area and was extended latitudinally. In spring of 1970 and 1977 the water temperature was very low near Ulreungdo, but it was normal near mid-coastal area and the southern part of the thermal front. Therefore, the surface water temperature anomalies in winter and spring for 17 stations were represented pretty or more or less high for these years. Especially, when water temperatures are high in winter-spring season, the large size group (mode, 29 cm) cosists of the major component in length compositions. On the other hand, from the southward migration period in autumn-winter season (October to February) of 1975/76 to spring of 1976 the large size group (mode, 30 cm) occurred continuously in the Japan Sea off Korea, and from late spring to early summer (June to July) the large size group didn't occur. The occurrence of the large size group in the Japan Sea off Korea from the southward migration period (example, autumn-winter season of 1975/76) to the north migration period (spring of 1976) would be explained by the fact that as water temperatures during the periods were high the large size group spent winter here and then moved to the north with the medium size group from the early northward migration period and from around June the large size group got ahead of the medium and small size groups and got out of fishing grounds and then moved to the north of the line of Lat. 38°30′N earlier than other size groups.

From winter of 1969/70 to spring of 1970 water temperatures were low, and only the medium size group and the small size group occurred, but from May the large size group began to occur. In winter-spring season of abnormally low water temperature years which were mentioned above the large size group didn't occur entirely. In this case it seems that the large size group moved to the north rapidly according to the rapid spreading of the warm water since July when the fishing operations had already ended. In length compositions of Pacific saury the 27–28 cm group was the main component in the early northward migration period of spring and a little later from around April or May the large size group (30–31 cm) consists of the main component of the catch. And as the second case, from the wintering periods (around February) through spring only the medium and small size groups consist of the main component of the catch, and at this time as the water temperatures were abnormally low in the south Japan Sea off Korea, the large size group doesn't appear in the fishing grounds. As the third case, from the southward migration period (October to February) to spring (March to June) the large size group is continuously distributed in the Japan Sea off Korea, and at this time the water temperature was pretty or abnormally high in winter-spring season. In this case the large size group first moves to the north and after June this group doesn't appear and instead the medium size group consists of the main component of the catch. Accordingly, in the fishing grounds of the Korean Pacific saury drift gill net fishery, when water temperatures are pretty or abnormally high, both the large and medium size groups spend winter together and they can be the target of fishing from winter to spring (example, 1975/76). And when water temperatures are abnormally low, the medium and small size groups are dominant and the large size group doesn't seem to be the target of fishing from the wintering period to spring, because the large size group passes through the fishing ground rapidly after the main fishing season.

Accordingly, the distributions and movements by size group would be explained in relation to variations of oceanographic conditions. Fig. 6 shows a model of seasonal migrations of Pacific saury by size group for normal, abnormally cold,





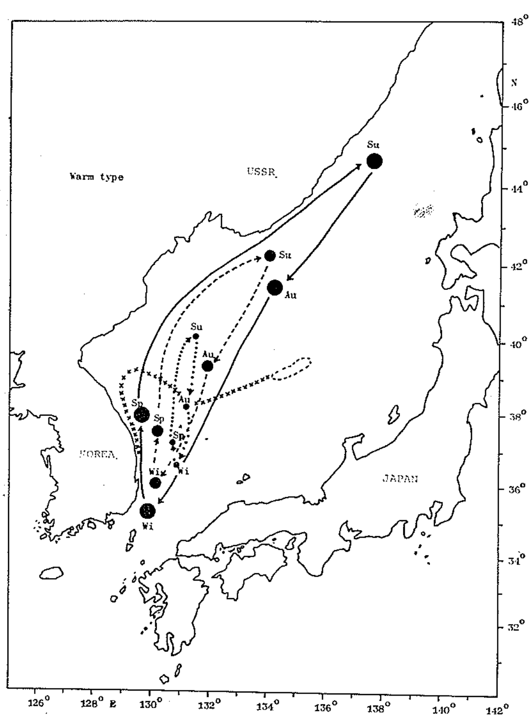


Fig. 6. Possible schematic migration routes of different size groups of Pacific saury under the normal, cold and warm oceanographic conditions in the Japan Sea off Korea. The largest dots represent the large size group, the medium dots, the medium size group, and the smallest dots, the small size group. The crossed line represents the oceanic thermal front in spring. Sp, denotes spring (Apr. — June), Su, summer (July — Sep.), Au, autumn (Oct. — Dec.), and Wi, winter (Jan. — Mar.).

and abnormally warm oceanographic conditions in the Japan Sea off Korea. When the oceanographic conditions are normal, the center of the distributions of the large size group is in the west of Kyushu, that of the medium size group is in the Korea Strait and the west of Kyushu, and that of the small size group is in the southern waters of Korea in the wintering period. Together with the spreading of the East Korean Warm Current water which was free from the stress of the northwesterly seasonal winds in early spring (around late March), Pacific saury move northward through the middle of the Japan Sea. Around April and May the small and medium size groups occur first and next the large size group occurs late near the Polar Front. Pacific saury immigrate continuously to the Korean Pacific saury drift gill net fishing grounds of the south of Lat. 38°30′ N untill May. From around June the position of the Polar Front does not move at the subsurface layer deeper than 50 m, but the water temperature at the surface layer becomes higher than 15°C because of the extension of the warm current surface water. Around July Pacific saury rapidly move northward and almost get out of the Korean fishing grounds of Lat. 38° 30′ N owing to the superficial water with high temperature and low salinity which was extended from the south. In the north of the Polar Front the large size group proceeds and the medium and small size groups follow the large size group. In summer the center of the distribution of the large size group is near the line of Lat. 42° N, and the medium and small size groups are distributed in the south of the line. After Pacific saury spend summer in the north Japan Sea, they conduct the southward migration in autumn. In the eastern coast of the Korean Peninsula the medium and small size groups occur first and thereafter the large size group occurs in the early southward migration period (October to November). When Pacific saury move to the winter ground, the large size group and the extra large size group get ahead of the medium and small size groups and reach the winter ground earlier. Therefore, in the fishing grounds of the south of the Japan Sea off Korea the large size group is scarce and the medium size group represents the main component. In the southward migration period as the depth of the upper mixed layer reaches 30 m and the front is not formed at the surface layer and the surface water drifts to the south Japan Sea together with the strengthening of northwesterly seasonal wind, southward migrating Pacific saury with the drift of surface water move to the south faster than the speed of the northward migration. As Pacific saury which move to the north along the coast of the Japan Sea off Japan follow the warm area of the south of the Polar Front which is operated as the temperature barrier, there is no fish accumulation in the area. However, Pacific saury which move to the north along the coast of the Japan Sea off Korea don't move to the north easily owing to the barrier of the Polar Front and stay for a while in the early northward migration period (around March to April), and then together with succeeding northward groups they form a dense fish accumulation of spawning group due to accumulated food organisms and flotsams. Accordingly, the density of Pacific saury is high near the Polar Front and the good fishing time of the Korean Pacific saury drift gill net fishery is May.

When the water temperature is abnormally high compared to other years, even in the wintering period (around February) all the size group of the southward migrating Pacific saury in the Japan Sea stay in the south Japan Sea of the north of the Korea Strait, too. Accordingly, the large and medium size groups of Pacific saury are caught together in the fishing grounds of the Korean Pacific saury drift gill net fishery from December to March continuously (example, winter of 1975/76 to spring of 1976). In this case the Polar Front is partial to the north compared to normal years. In the early northward migration period (late March) the medium and small size groups are distributed in the north and the large size group is in the south, but in spring (April to May) when they reach near the Polar Front the large size group gets ahead of the medium and small size groups and afterward the latter follows the former. In the high water temperature period before and after 1960 the proceeding northward migrating Pacific saury reached the East Korea Bay which is on the line of Lat. 30° N even in March (SHUNTOV 1967). Around June they reach the line of Lat. 40° N and in summer (July to August) the center of distributions of the large size group is on the line of Lat. 44° N and those of the medium and small size groups are in the south of that of the large size group. The southward migrating Pacific saury in autumn move to the south with a slow speed, when the strength of the high temperature and low salinity warm current surface water prevails continuously. At this time the density of Pacific saury is low even in October in the fishing grounds of the Korean Pacific saury drift gill net fishery, and the fishing periods in autumn-winter season begin in November unlike normal years.

When the water temperature is abnormally low compared to normal years, the large and medium size groups of the southward migrating Pacific saury in the Japan Sea move to the west of Kyushu, getting out of the Japan Sea in the wintering period (around February). If the northerly wind which accompanies the cold water is strong, the northward flowing Tsushima Warm Current is impeded considerably and the front is extended in parallel with latitude in the south Japan Sea, and finally the cold water barrier which hinders the advance of Pacific saury is formed. In the early northward migration period (March to April) the large size group doesn't recruit to the Korean fishing grounds. In such a case that the water temperature of spring is not considerably low, the large size group occurs around May (spring of 1970). In such a case that the water temperature in winter-spring season is abnormally low (example, 1963, 1977 and 1981), the proportion that the large size group recruits to the Korean fishing grounds is extremely small or sometimes nil in spring-summer season (March to July). Even in such a case that in spring the large size group recruits late or does not recruit entirely, according as the Polar Front moves to the north since July and the warm current surface water extends, Pacific saury which were already got out of the winter grounds migrate northward rapidly and spend summer in the north Japan Sea for a little while. When it is very cold (1963) in winter (January to February), fishing operations are not usually carried out. In fishing grounds which were formed in normal years as the medium size group consists of the main component of the catch and the large size group does not recruit, the abundance index is low and fishing conditions are poor. Though the large size group occurs, it occurs late, and thus good fishing periods by catch or abundance index in spring (March to July) are delayed to June unlike normal years (May). In this case the interval between monthly distribution centers of fishing grounds is large and the dispersion from the center is also large. The positions of distribution centers of each size group in spring and summer are partial to the south compared to normal years. The southward migrating Pacific saury in autumn are pushed by the strong northwesterly seasonal wind and thus move to the south with a great speed. In this case, Pacific saury die in large quantities from contacting with the low salinity surface water which was extended to the south Japan Sea. In all the three types of the migration model the range of distribution and the distance of movement for the large size group are considerably larger than those for the medium or small size group. Because the ranges in the model denote distribution centers, real ranges of the distribution would be much wider. On the other hand, it seems that those in the Japan Sea off Japan have the similar distribution pattern as in the Japan Sea off Korea. However, since eggs and larvae of Pacific saury are drifted at the surface layer, they have a quite different distribution pattern from adults.

In conclusion, this study is on the migration of Pacific saury based on the biological information as well as oceanographic factors, and we think this kind of study has not been done yet. The results of this study may be used to forecast fishing conditions with high precision, predicting qualities (size group) and quantities of Pacific saury by means of estimating the condition of the recruitment to the fishing ground, based on oceanographic observations. In future, further studies on the validity of this migration model as well as the mathematical expression of the model should be continued from now on.

7. Summary

1. We studied the migration of Pacific saury by means of oceanographic observations (1957–1982), length frequency distributions (1957–1982), and catch and effort data of the drift gill net fishery (1959–1982), considering that Pacific saury in the Japan Sea off Korea and the East China Sea are one of typical epipelagic fish.
2. In the Japan Sea off Korea no periodicity of variations of surface water temperatures was recognized and their seasonal and annual

variations were great. The surface water temperatures from winter of 1962/63 to spring of 1963 and from winter of 1980/81 to spring of 1981 were abnormally low, and those in spring of 1970 and 1977 were lower-than-normal. For each period above oceanic thermal fronts with great temperature gradient were formed further south compared to normal years in the Japan Sea off Korea.

3. Monthly shifts of Pacific saury drift gill net fishing grounds (south of Lat. 38°30′ N) were examined by centers of abundance indices and their dispersions from the centers. The highest abundance indices occurred from April to June with the peak in May, and fish shoals continuously recruited from the south to the fishing ground until May and suddenly they moved to the north from June. The speed of the southward migration of Pacific saury in autumn was faster than that of the northward migration in spring.
4. In the length frequency distributions of Pacific saury in the fishing ground of the Japan Sea off Korea in winter-spring season, when the water temperature was lower-than-normal, the composition rate of the large size group was low. And when it was high, the large size group spent winter in the fishing ground.
5. When the surface water temperature in the fishing ground off Korea was low in winter-spring season, the oceanic thermal front was shifted to the south compared to normal years, the composition rate of the small size group was high, the center of the fishing ground was shifted to the south, the dispersion of the fishing ground was great, the abundance index was low, and the catch in spring was also low. On the other hand, when the surface water temperature was high in the same season, most phenomena described above were reversed except that the catch in spring was not always high due to the earlier northward movement of Pacific saury.
6. It was necessary that the oceanographic environmental conditions should be fully taken into consideration for the study of migration pattern of Pacific saury. Thus, a schematic migration model of Pacific saury was suggested, being divided into three oceanographic types, that is, normal, abnormally warm and cold types.
   1) In the normal type, Pacific saury which are spending winter in the southern part of the Japan Sea off Korea and the East China Sea are distributed separately by size group, that is, the smaller in the northern part, the larger in the southern part. In the northward migration period in spring or in the southward migration period in autumn, the larger fish migrate to get ahead of the smaller fish.
   2) In the warm type, as the winter ground is shifted to the northern part compared to the normal condition, even the larger fish remain in the south of the Japan Sea off Korea to spend winter.
   3) In the cold type, the center of the winter ground is shifted to the south of Kyushu, and in the northward migration period the large size group doesn't move to the middle part of the Japan Sea due to the barrier of the thermal front which is formed in the southern part of the Japan Sea, and then it moves northward rapidly in early summer.
7. As a result, this study can be used to predict the Pacific saury stock structure qualitatively and quantitatively, understanding the conditions of temporal recruitment of Pacific saury by size group to the fishing grounds, based on the information of variations of oceanographic environmental characteristics.

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韓国近海産サンマの回遊と海況との関係

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韓国東海(日本海)および東シナ海産サンマ(*Cololabis saira*, BREVOORT)の体長組成と，漁獲量，努力量および海洋観測資料(1957〜81年)を利用してサンマの回遊状況を分析した。典型的表層性魚類の一種であるサンマの回遊パターンを分析するには，海洋環境条件を充分に考慮する必要性が認められる。そこで海況を平年海況型，低温型および高温型の三つの類型に分けて，サンマの体長階級別回遊モデルを設定した。

平年海況型においては，韓国東海南部および東支那海で越冬するサンマの体長階級別分布位置は，北方に行くにつれて小型群で形成されている。また，春季の北上期や秋季の南下期には大型魚であるほど，小型魚を追い越して回遊する。

高温型においては，越冬場が平年に比べ北部海域にかたよって形成されるので，大型魚であっても日本海南部海域で越冬する。一方，北上回遊時の大型群の分布中心は，Lat. 44°N 付近にある。

平年に比べ低温型では大型群の越冬中心位置は九州西南方にかたよって分布し，春季の北上期に日本海南部で形成される熱前線の障壁によって遮られるようになり大型群は日本海中部まで北上する事が出来ない。しかし，夏季の初めになると急速度で北上するようになる。

本研究結果は，海洋環境の変動に関する情報を基礎にして，サンマの体長階級別，時期別漁場への加入状態を把握する事によって，サンマの質的，量的構造を予測するのに使用する事が出来ると考える。

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