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A Study on Oceanic Environmental Conditions for Pacific Saury in Korean Waters*

Yeong GONG[1], Toshiyuki HIRANO[2] and Chang Ik ZHANG[3]

Abstract

Oceanic environmental conditions for Pacific saury, *Cololabis saira* (BREVOORT), were studied by means of meteorological data (1959-1982), oceanographic observations (1957-1982), and catch and effort data of the Korean drift gill net fishery (1959-1982).

The wind had considerable influence upon the variation of the surface water temperature in the Japan Sea off Korea. The distribution and strength of the currents, the location of the thermal front, and the circulation pattern could be easily determined by the horizontal distribution of water temperatures, as the horizontal and vertical salinity gradients in winter-spring were small at the upper layer of this area. In winter-spring seasons having low water temperatures (for example in 1963, 1970, 1977 and 1981) the oceanic fronts were formed from east to west and were farther south in the Japan Sea (between Lat. 36°N and 37°N) compared to normal years, and water temperatures north of the fronts were very low. No periodicity was recognized in the annual variations of oceanographic conditions at the upper layer of the area. From this phenomenon it was recognized that annual variations in oceanographic conditions were substantial in the area and did not correspond to conditions of the Korea Strait side.

The range of surface water temperatures suitable for commercial fishing of Pacific saury was 10-20°C. The water temperature for the best fishing ranged from 13-18°C centered around 15°C and the salinity for the best fishing was 34.1‰. In spring-summer (March to July), the relationship between the movement of the 15°C isotherm and the shift of centers of fishing grounds of Pacific saury had a positive significant correlation. The high temperature and low salinity of superficial water which originates from the East China Sea hastened the northward movement of Pacific saury in the Japan Sea.

The oceanic front, when Pacific saury begin the northward movement from wintering ground, is a cold barrier to these migrations. The density of fish shoals tended to be high around the front in spring-summer. The density of fish shoals in the Japan Sea off Korea was higher than that off Japan which was related to the structure and position of the oceanic front.

1. Introduction

Pacific saury, *Cololabis saira* (BREVOORT), are mainly taken by gill nets in Korean waters. Recently the Pacific saury gill net fishery has operated in the southwestern Japan Sea, south of Lat. 38°30′N. The fishery operates year-round except in August and September, and the main fishing period varies year after year. The annual catch of Pacific saury in Korean waters ranged from 10,000 to 40,000 metric tons during 1960-1970, but in the early 1980s declined sharply to less than 10,000 mt. With the sharp decline in catches of Pacific saury and the onset of annual variations in rich and poor harvests, forecasting of fishing conditions would be extremely valuable.

Oceanographic observations in the Japan Sea off Korea were initiated in the 1920s. Since the 1930s, large scale observations encompassing the entire Japan Sea area have been conducted (NISIDA 1927, 1930, 1933; Fisheries Experiment Station of Governmental-General of Tyosen 1928-42, 1936a, 1936b, 1936c, 1943; Fisheries Research

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[1] National Fisheries Research and Development Agency, Pusan, Korea

[2] Ocean Research Institute, University of Tokyo, Tokyo, Japan

[3] College of Ocean and Fishery Sciences, University of Washington, Seattle, WA 98195, U.S.A.

and Development Agency 1979). SUDA and HIDAKA (1932), SUDA *et al.* (1932), UDA (1934a, 1934b, 1936a), MIYAZAKI (1953), LEONOV (1948, 1958), RADZIKHOVSKAYA (1961), KAJIURA *et al.* (1958), MIYATA (1958), GONG (1962), FUJII *et al.* (1976), LEE and BONG (1968), NAGANUMA (1972, 1979), KAWABE (1982a, 1982b) and YOON (1982a, 1982b, 1982c) described the oceanographic structure and water movements of the Japan Sea. GONG *et al.* (1983) explained variations of oceanographic conditions of the Japan Sea off Korea.

A number of studies have been conducted on the influences of oceanic fronts on fishing grounds and fishing conditions (FUKUSHIMA 1958, 1979; MATSUMIYA and TANAKA 1976; NOVIKOV 1982; SABLIN and PAVLYCHEV 1982). HATANAKA (1956) stated that oceanic conditions can change migration patterns of Pacific saury and cause fluctuations in rates of fishing. MATSUDAIRA *et al.* (1956) noted that seasonal migrations of Pacific saury are dependent on the seasonal transition zones of high plankton production which are mainly formed in boundary zones of the northwestern Pacific Ocean including the East China Sea and the Japan Sea. SHUNTOV (1967) stated that the accumulations of flotsams and food organisms in the boundary zones between currents in the Japan Sea may govern the location of spawning schools of Pacific saury. NAGANUMA (1967) and HAN and GONG (1970) indicated that oceanic fronts were closely related to the fishing conditions for Pacific saury in the Japan Sea. Patterns of thermal stratification and oceanic fronts were considered to be important factors for the success of saury fishing off the coasts of the U.S.S.R. and Japan (UDA 1936b; KUNDIUS 1966; NOVIKOV 1966).

Many studies on the range of water temperatures and salinities inhabited by Pacific saury in the Japan Sea have been reported (RUMJANTSEV 1947; KOTOVA 1958; TABATA 1963; HAN and GONG 1965; SANO 1966; NISHIMURA 1969; KIM and GONG 1978). However, these studies didn't encompass the entire season and the limits of distributions of Pacific saury.

In order to determine the reasons for and to predict variations in catch, it will be necessary to understand the interrelationships between abundance, fishing intensity, and environmental factors. Moreover, if differences in distribution and migration of Pacific saury by size groups are affected by oceanographic conditions, the movements and abundance of these size groups would be of concern here, since the success or failure of the fishery would be controlled by environmental factors (GONG *et al.* 1983).

The objective of this study is to analyse meteorological and oceanic environments which are basically related to the distribution of Pacific saury stock, and from these analyses, contribute to the development of method of accurate forecasting conditions for Pacific saury.

We would like to express our sincere appreciation to Drs. Takashige SUGIMOTO, Hideaki NAKATA, Denzo INAGAKE, Mikio NAGANOBU, and Ichiro AOKI of Ocean Research Institute, the University of Tokyo for suggesting problems and for their valuable help during the study. Our gratitute is extended to Mr. Sung Hwan HA and Mr. Sang Hwa CHUNG, current and former Director-Generals of the National Fisheries Research and Development Agency of Korea. Many members of the same agency including Mr. Hack Kern SUH, Mr. Song Jeong SON, Mr. Won Seok YANG and Mr. Dae Won PARK put a great deal of work into the actual production of this paper. Our gratitude is also extended to Miss Kyong Sook OK and Miss Yeong Ja LEE for calculation and typing of the text.

2. Materials and methods

As Pacific saury are one of the typical epipelagic species, they are mainly caught by drift gill nets which are usually set near the sea surface. Thus, the structure of the upper layer was analysed, based on oceanographic observations.

Meteorological data on daily wind direction and force were derived from Monthly Weather Reports (Central Meteorological Office 1959–1982). The wind stress index was estimated by multiplying the monthly average wind force by 100 for southerly (between 135° and 225°) and northerly (between 315° and 45°) values. As wind stress indices together with air temperatures were assumed to affect surface water temperatures, they were compared with surface water temperature anomalies. Wind stress indices were also correlated with catch records of Pacific saury to determine the influence of wind stress on fishing conditions.

Water temperature and salinity data were derived from coastal and offshore oceanographic observations (Central Fisheries Experiment Station 1954–1963; Fisheries Research and Development Agency 1964–1982a), CSK (Cooperative study of the Kuroshio and Adjacent Regions) Data Report (Japan Oceanographic Data Center 1966–1970), the Marine Environmental Atlas (Japan Oceanographic Data Center 1978), charts of horizontal temperature distributions derived from the Pacific Saury Fishing Ground Surveys compiled by the authors from 1961 to 1982 and Oceanographic Prompt Report in Japan Sea Fishing Grounds (Japan Sea Regional Fisheries Research Laboratory 1957–1982). Fig. 1 shows stations where oceanographic observations were made by the National Fisheries Research and Development Agency in Pusan, Republic of Korea. Variations of oceanographic characteristics in fishing grounds were analysed by seasonal

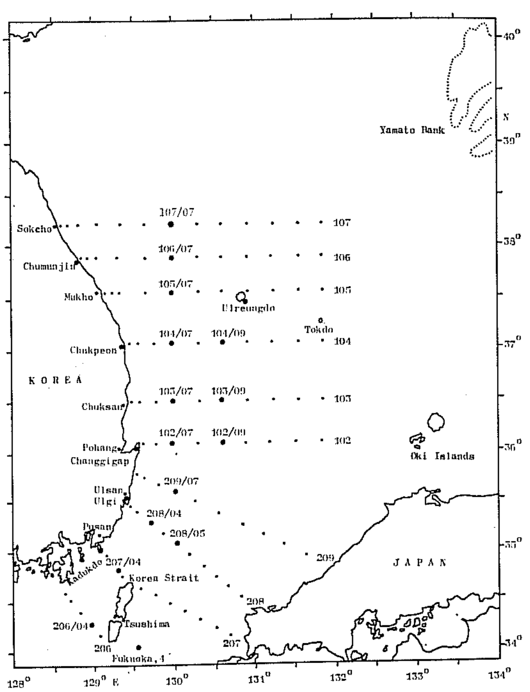

Fig. 1. Locations of stations for oceanographic observations in Korean waters.

variations of water temperatures and salinities at each station and were shown in the horizontal and vertical distributions of water temperatures and salinities.

Average 10-day surface water temperature anomalies for each month in 1957–1981 were obtained from the coastal and offshore oceanographic observations and standardized values of variation in water temperature were classified (GONG *et al.* 1983).

Positions of thermal fronts were considered to correspond to mid-isotherms having greater than 0.1°C/mile horizontal gradient of water temperatures in dense isothermal zones. The ranges of the optimum water temperature and salinity for Pacific saury fishing were obtained from distributions of catches, surface water temperatures, and salinities by statistical block (0.5° Lat. × 0.5° Long.) from those blocks having both oceanographic observations and fishing records.

Annual Pacific saury catch data were obtained from catch by species records (Government General of Tyosen, Production Bureau 1930), Catch Statistics (Central Fisheries Experiment Station 1961), and Yearbook of Korean Fisheries Statistics (Korea, Office of Fisheries, Ministry of Agriculture and Fisheries 1960–1982). Catch and effort data by year, month, week and statistical block from the Pacific saury gill net fishery were derived from both Reports of Weekly Fishing Conditions (Central Fisheries Experiment Station 1959–1963; Fisheries Research and Development Agency 1964–1982b). Some of the effort data (1959–1967) were obtained from monthly reports of the Pacific saury gill net fishery compiled by the authors.

The smallest unit of fishing effort used was a drift gill net "set". A "set" of drift gill net is a half of a "pil" net (1 pil = 100 ken = 151.5 m). Catch per unit of effort (CPUE) is in terms of weight of catch per set (kg/set). The mesh size of the drift gill nets used by the fishery ranges from 9.5 (36.6 mm) to 10.5 knots (31.9 mm) and averages 10 knots (33.6 mm). The nets were constructed with cottons in the 1950s, but since 1961 the nets have been made of synthetic fibre (GONG *et al.* 1984). Because the length of gill net in a "set" was kept constant during the period of 1959 ot 1981, it was not necessary to standardize fishing effort in the calculation of CPUE. The abundance and centroids of fishing grounds were calculated by the formulae of GONG *et al.* (1983).

Monthly mean catches combined overall years were compared with variations in oceanographic conditions obtained from isopleths of monthly distributions of surface water temperature and salinity. From this data the relationship between centers of fishing grounds based on monthly mean abundance indices and locations of optimum water temperature and salinity for Pacific saury was estimated.

3. Environmental characteristics of fishing grounds

(1) Seasonal distribution of southerly and northerly winds

Monthly indices of wind stress at Ulreungdo in 1959-1982 were estimated to examine the influence of winds on sea surface thermal conditions and fishing operations (Fig. 2). In general, winds were predominantly northerly during spring-summer months (April to August) and southerly during winter months (January to February). In early spring (March) and autumn (September to December) wind stress was about equally from the south and north. The periods of January 1959 through March 1961, August 1975 through December 1976, and September 1978 through March 1980 were characterized by weak southerly and northerly winds.

(2) Variation in oceanographic conditions

A. Horizontal distributions of oceanographic characteristics

Horizontal distributions of water temperature in April or May 1961-1978 for colder than normal and warmer than normal years were illustrated to examine annual variations in surface water temperatures and the thermal structure in spring in the Japan Sea off Korea.

Oceanic fronts usually represent boundaries between two water masses. It generally appears as a discontinuous zone of density, but when the salinity gradient is relatively small, it appears as a discontinuous zone of temperature.

Fig. 3 shows the horizontal distribution of temperature at the surface in late June and late July 1961 and at 50 m in mid-June 1969. In

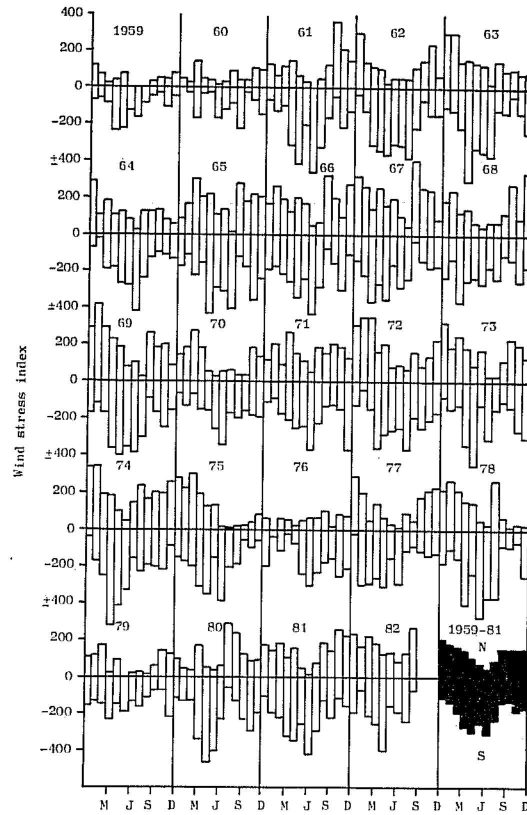

Fig. 2. Monthly southerly (135°-225°) and northerly (315°-45°) wind stress indices at Ulreungdo, 1959-1982. Positive values denote northerly wind stress and negative values southerly wind stress.

June 1961 temperatures were 16-18°C in coastal waters along the southeastern part of the Korean Peninsula and 19-21°C along Long. 130°E. In late July, temperatures along the southern coast were lower (13-16°C) than those one month earlier, but in offshore areas, they were higher (24-25°C) than in the previous month. The decrease of coastal surface temperature in July suggests that there was strong coastal upwelling induced by the strong southerly winds. The temperature distribution at 50 m in June 1969 showed a thermal front with a large temperature gradient extending southward from near Ulreungdo Island and then eastward, passing near Tokdo Island.

Fig. 4 shows the position of thermal fronts at 0, 50, 100, and 200 m in July 1961, June 1969,

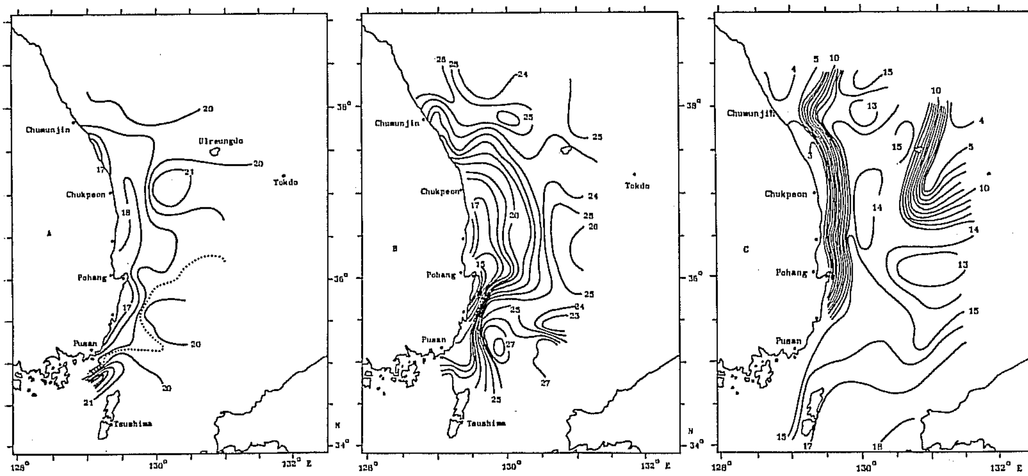

Fig. 3. Horizontal distribution of temperature (°C) at the surface during June 17-27, 1961 (A), July 22-August 2, 1961 (B) and at the 50 m layer during June 8-21, 1969 (C) in the Japan Sea off Korea.

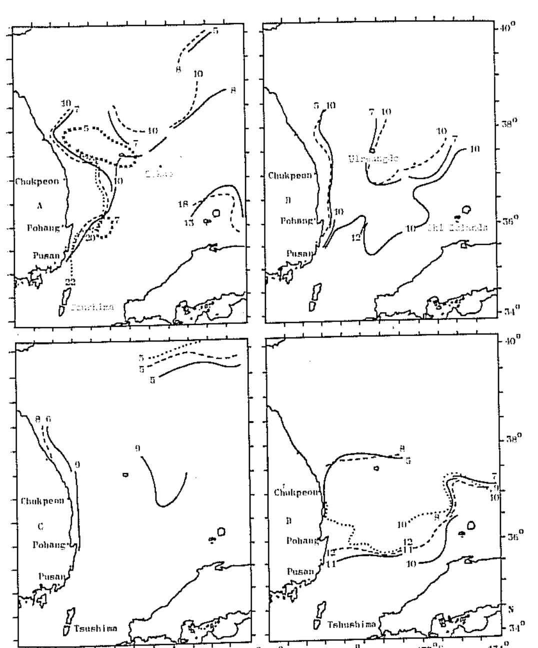

Fig. 4. Oceanic thermal fronts at the surface (dotted line), 50 m (dashed line), 100 m (full line) and 200 m layer (Xs line) in July 1961 (A), June 1969 (B), February 1976 (C) and April 1977 (D) in the southern Japan Sea. Numbers represent the temperature (°C) at the center of the frontal zone.

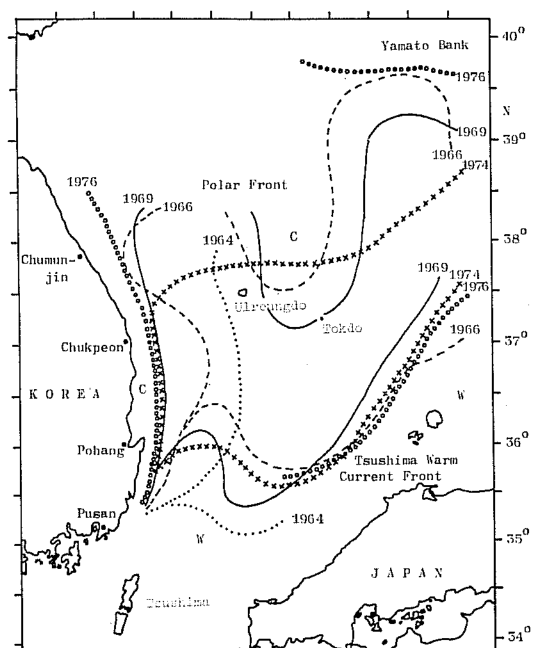

Fig. 5. Locations of thermal fronts at the 100 m in the southwestern Japan Sea in 1964 (abnormal cold type), 1966 (southern coast cold type), 1969 (normal water type), 1974 (northern coast cold type) and 1976 (abnormal warm type). W denotes high temperature region and C low temperature region.

February 1976, and April 1977. The positions of thermal fronts at 50 and 100 m in each of these periods were the same. However, in February 1976 it was apparently located to the north. In June 1969 there was a thermal front located in the vicinity of Ulreungdo and Tokdo Islands, and an additional front to the south at 100 m. In April 1977 Polar Fronts were recognized at 50 and 100 m between Lats. 37°00′N and 37°30′N, and in the south between Lats. 35°30′N and 36°00′N, passing near Tokdo and Oki Islands.

Fig. 5 shows the annual average position of thermal fronts at 100 m, and illustrates five kinds of thermal fronts which are typical off Korea; abnormally cold water type (1964), abnormally warm water type (1976), northern coast cold water type (1974), southern coast cold water type (1966), and normal water type (1969). In 1964 the thermal front at 100 m extended northward along Long. 130°30′E, surrounding the low temperature region developed in the coastal area along the Korean Peninsula. In 1966 the thermal front which was formed around the Chukpeon and Chuksan low temperature region, approached the Chumunjin coastal area and then extended to the northeast and to the south, reaching the Yamato Bank, surrounding the tongue-like north Ulreungdo low temperature region. In 1969 the thermal front at 100 m, like that at 50 m, extended from coastal waters near Ulsan to the north, and then turned south forming a tongue between Ulreungdo and Tokdo Island, and then approached the Yamato Bank. In 1974, while the thermal front approached coastal area in the south, the cold water along the northern coast dominated, and caused the front to turn eastward parallel to Lat. 38°N and then proceed northeastward to north of Tokdo Island. In 1976, because of the predominance of the East Korean Warm Current, and the recession of the coastal low temperature water and the north Ulreungdo low temperature water, the thermal front extended northward near the east of the Korean Peninsula and did not form in the vicinity of Ulreungdo Island.

Another thermal front which originated near the southeastern part of the Korean Peninsula and extended toward the mainland of Japan changed direction at Lat. 35°30′N, Long. 131°30′E, and then extended northeastward, passing between Tokdo and Oki Islands. This branch was called the Tsushima Warm Current Thermal Front, and it's position was relatively stable from year to year. As shown in the figure the thermal front off the north Korean Peninsula corresponded to the Polar Front. The front off the south Korean Peninsula, however, did not always correspond to the discontinuous density zone. When the warm current water was dominant, such as in February 1976, the Tsushima Warm Current Thermal Front moved northward and overlapped with the Polar Front. In all cases, when the horizontal salinity gradient was small in winter and spring (January to June), thermal fronts at each depth layer corresponded to the Polar Front. It is apparent that the winter-spring distribution of the water system off Korea is reflected by the structure and location of thermal fronts.

In summer and autumn (July to December) salinity gradients were large, and temperature gradients small at the surface and, therefore it was impossible to detect the Polar Front at the surface. However, because horizontal salinity gradients in subsurface waters were small each year, the thermal front could be detected by the horizontal temperature gradient which approximately corresponded to the Polar Front. The Polar Front was detected by the differences of densities.

As already mentioned, the vertical temperature and salinity gradients from winter to spring were small. Accordingly, the circulation pattern could be determined by the distributions of vertical integrated mean temperatures using the following methods. The relationship between water temperature (t) and salinity (s) at depth (z) can be expressed as follows:

$$\frac{\partial t}{\partial z} \approx \frac{\partial \rho}{\partial z} \qquad (1)$$

and the dynamic depth (D) can be expressed,

$$D = \int_0^z g\rho \, dz = \int_0^z \varphi(t; s; z) \, dz \qquad (2)$$

from (1) and (2), $D \approx \int_0^z \varphi(t; z) \, dz$, where, ρ de-

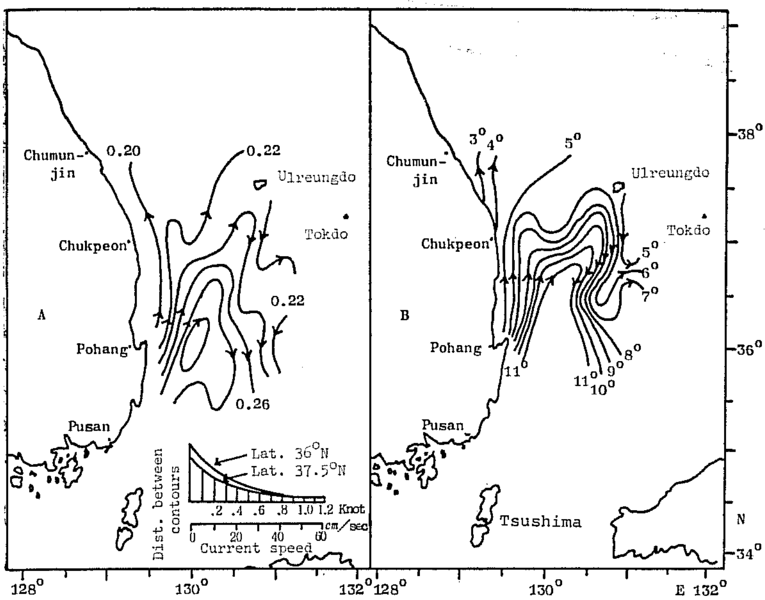

Fig. 6. Surface geostrophic circulation referenced to the 200 db level (A) and integrated mean temperature from surface to the 200 meters (B) in May 1963. Current speed at a particular location is determined by measuring the distance between adjacent contour lines (drawn at 0.02 dyn. meters intervals) and comparing the distance to a nomogram curve for the specific latitude.

notes density and g, acceleration of gravity. Thus the change of the scalar field shown by isotherms can be considered to reflect changes in the pressure field and therefore currents (YAMASHITA 1941; MIYATA 1960).

Fig. 6 shows the surface geopotential topography referred to the 200 db in May 1963 and the horizontal distribution of the vertical integrated mean temperature from the surface to 200 m as expressed by:

$$\bar{T}_{200}=\frac{1}{200}\int_{0}^{200} t\cdot dz$$

In cases where the dynamic depth anomalies were high, water temperatures were also high, and where anomalies were low, water temperatures were low. Where the horizontal gradients of the integrated mean temperatures were large, the horizontal gradients of the dynamic depth anomalies were also large. Therefore, there was correspondence in these features as there was in distribution patterns. When the positions of thermal fronts at 0, 50 and 100 m in May 1963 were compared with distributions of the dynamic depth anomalies and vertical integrated mean temperatures, they had similar distribution patterns. Consequently, the location of thermal fronts which are formed by contact between warm and cold water corresponded to the discontinuous zone which was defined by the distributions of the vertical integrated mean temperatures or the geopotential topography. However, this correspondence occurred regularly only in January to June when the horizontal salinity gradient was small. There was not always correspondence in other seasons.

The horizontal distribution of surface salinities were examined to determine possible effects of salinity on fishing conditions in spring-summer. The mean salinities in July 1961 to 1978 and the salinities in July, August or September of each year were grouped into above and below 33.0 ‰, in order to examine the distribution of the low salinity surface water during summer in the East Korean Warm Current region (Fig. 7). In July the low salinity water ($\leq$33.0

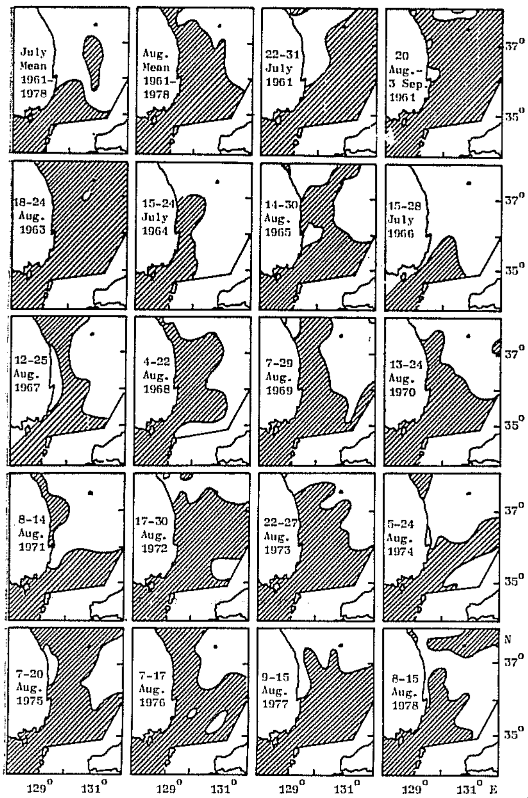

Fig. 7. Distribution of sea surface salinities less than 33.0 ‰ (shaded area) in the Japan Sea off Korea, July and August 1961–1978.

‰) extended from near the Korea Strait to south of Ulreungdo Island in normal years, but in August it extended along the entire Korean Peninsula and the East Korean Warm Current region. The figure shows that the distribution of low salinity water was extensive in August 1963, 1972, 1973 and 1975, but limited in August 1971 and 1974.

B. Vertical distributions of oceanographic characteristics

As previously described, the East Korean Warm Current overrides the upper layer of the Japan Sea Proper Cold Water as it moves northward and where it contacts the North Korean Cold Current the Polar Front is formed. In order to describe the oceanic structure of the East Korean Warm Current area, vertical distributions of temperature, salinity and density (σ_t) along the oceanographic observatory line 104

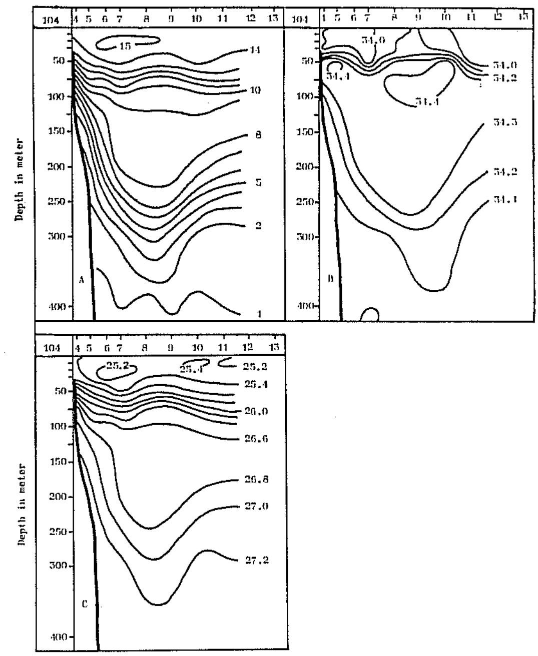

Fig. 8. Vertical sections of temperature (°C) (A), salinity (‰) (B) and density (σ_t) (C) along oceanographic observation line 104 (parallel with Lat. 37°03′N from coast to Long. 131°30′ E) in the Japan Sea off Korea during December 6–7, 1968.

(Lat. 37°03′04″N) in early December 1968 were examined (Fig. 8). The vertical section of temperatures shows the seasonal thermocline, which was located near the 12°C isotherm, at the layer of 50 to 80 m, and the permanent thermocline, which was located near the 5°C isotherm at the layer of 100 to 300 m. In the vertical section of salinity, a halocline, which was located near the 34.2 ‰ isohaline, was formed at the layer of 50 m. The vertical sections of density showed that the upper mixed layer depth was 40 m, and the seasonal pycnocline was present at about 50 m in coastal areas and at 70 m in offshore areas. The pattern of vertical sections of density was similar to that of water temperatures and salinities.

The distributions of temperature and salinity in longitudinal section along the northward flow pattern of the East Korean Warm Current are shown in Fig. 9. The figure shows that mean water temperatures and salinities of April (1961–

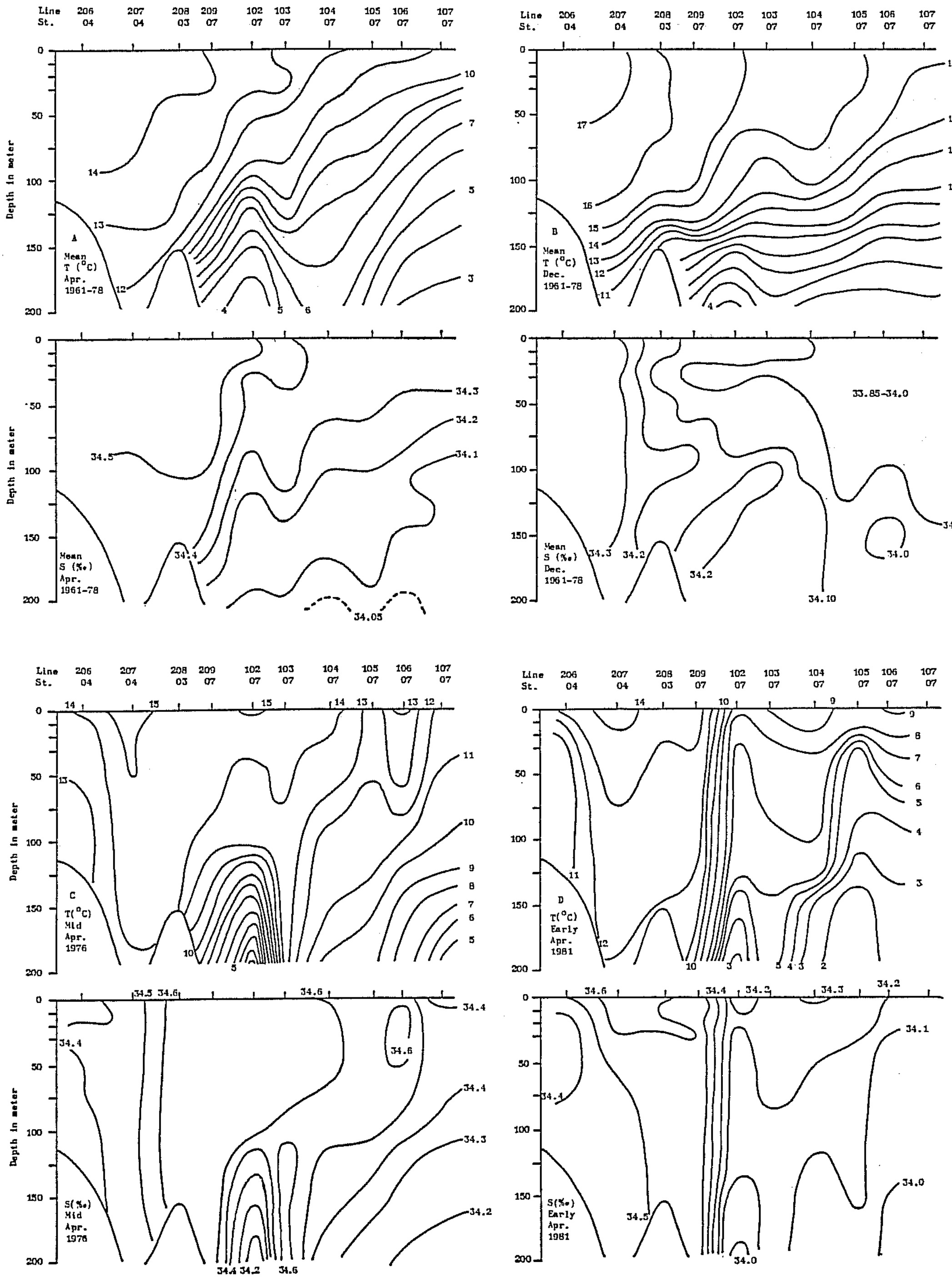

Fig. 9. Vertical sections of mean temperatures (°C) and salinities (‰) in April (1961–1978) (A) and in December (1961–1978) (B), and temperatures and salinities in April 1976 (C) and in April 1981 (D) along the west channel of the Korea Strait (between station 206/04 and 209/07) and along Long. 130°E (between station 209/07 and 107/07) in the southern Japan Sea off Korea.

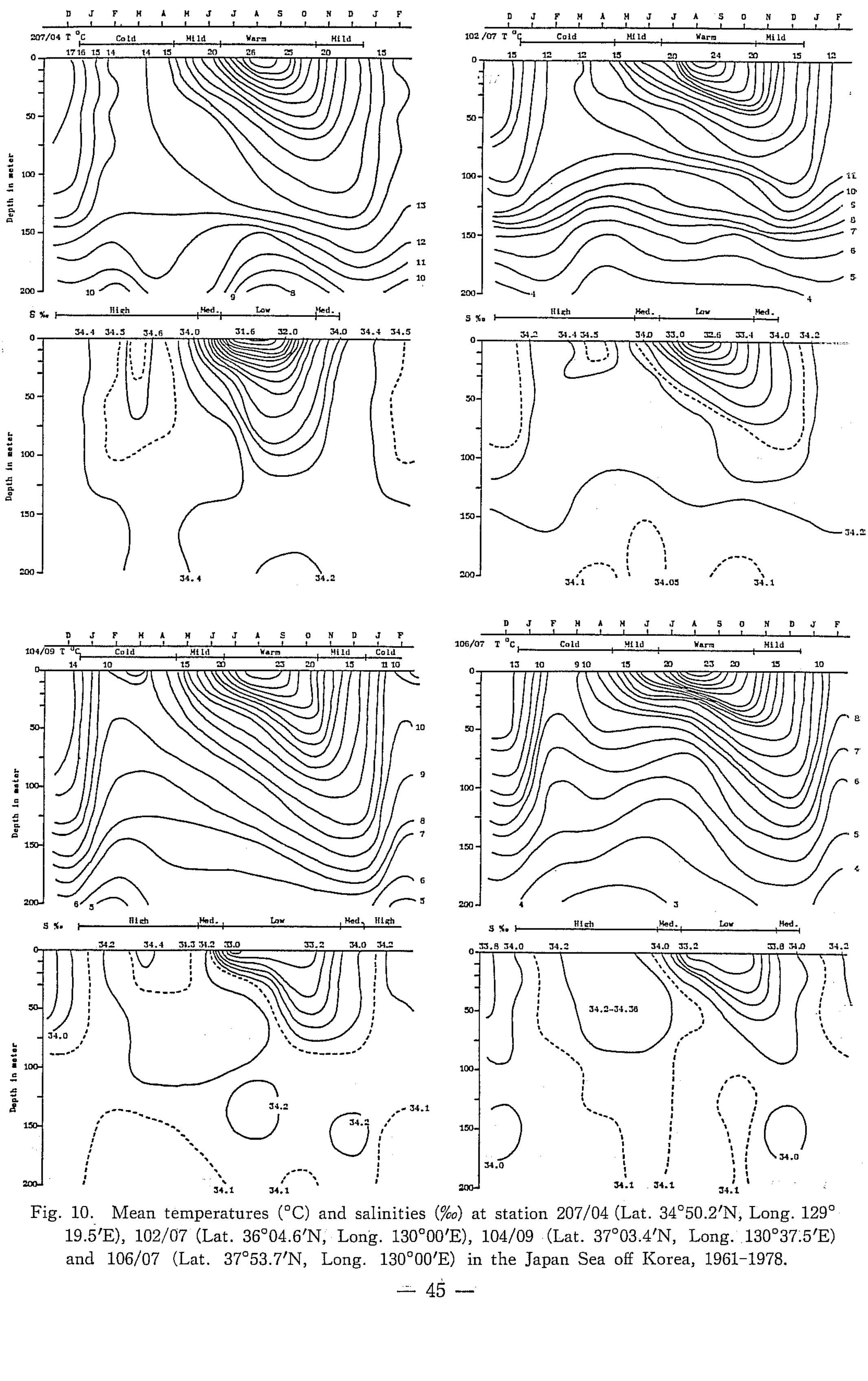

Fig. 10. Mean temperatures (°C) and salinities (‰) at station 207/04 (Lat. 34°50.2′N, Long. 129° 19.5′E), 102/07 (Lat. 36°04.6′N, Long. 130°00′E), 104/09 (Lat. 37°03.4′N, Long. 130°37.5′E) and 106/07 (Lat. 37°53.7′N, Long. 130°00′E) in the Japan Sea off Korea, 1961–1978.

1978) in the Korea Strait (206/04–209/07) were homogeneous from surface to bottom, and those along Lat. 130°E (209/07-107/07) were low at the upper layer in the northern part of the sampled area. In December 1961–1978 the upper layer of the water mass had higher temperatures and lower salinities than that in April. In April 1976, which was a warmer than normal year the vertical sections of temperature and salinity showed that the water mass had higher temperatures and salinities than other years. However, in April 1981, which was an abnormally cold year, conditions were similar to other years in the Korea Strait, but north of Lat. 36°N (north of station 102/07) the water mass had low temperatures and salinities, and thus the discontinuous zone of temperature and salinity was formed from the surface to the layer of 200 m between stations 209/07 and 102/07.

C. Seasonal variations in water temperatures and salinities

Isopleths of mean sea temperature and salinity at four stations were examined to gain an understanding of the patterns of seasonal variations in temperatures and salinities (Fig. 10). In the west channel of the Korea Strait (St. 207/04) the water temperatures in winter (January to March) were quite homogeneous throughout the water column and declined to less than 14°C in February, which is the period of minimum water temperatures during the year. From about April temperatures began to rise gradually. Peak temperatures occurred at later time period with increasing depth. In September water temperatures began to decrease and the seasonal summer thermocline began to disappear in October because of vertical mixing. In December the seasonal thermocline disappeared and the decline in water temperatures continued with minimum water temperatures occurring in February.

With regard to changes in salinity at the surface, it began to decrease from about June or July and reached a minimum in July, August and September, and then began to increase from October. Accordingly, there was a two-month time lag between the beginning of the increase in water temperature and the decrease in salinity. Since water temperatures began to decline from September, and salinity began to increase from October, there would also be an one-month time lag between the beginning of the decrease in water temperature and that of the increase in salinity.

At station 102/07 east of Changgigap, the permanent thermocline is formed at the 100 to 150 m depth layer. The distribution patterns of water temperature and salinity by month and depth layer and the time lags between increases or decreases in water temperature and decreases or increases in salinity were similar to those in the west channel of the Korean Strait. At St. 104/09 east of Chukpeon and at St. 106/07 east of Chumunjin, the water temperature began to increase from May, therefore there would be a two or three-month time lag between this increase and the beginning of the decrease in salinity. There would also be one-or two-month time lag between the decrease in water temperature and the increase in salinity, since the former took place from about September and the latter from about October or November.

As shown above, processes of change in water temperature and salinity didn't correspond in time even at the same station, but these processes also lag differently.

In general, there are two periods of differing surface conditions in the East Korean Warm Current area, that is, a low temperature and high salinity period which occurs in the winter season and a high temperature and low salinity period which occurs in the summer season. However, if classified in more detail, there would also be two intermediate periods of mild temperature and mild salinity between the above seasons, one in spring (May and June) and the other in autumn (November and December). The autumn period had a somewhat lower salinity than the spring period.

D. Long-term fluctuations in oceanographic conditions, and the relationship between sea surface temperature anomalies and wind stress

In order to determine annual and seasonal variations in sea surface temperatures in fishing grounds for Pacific saury, monthly temperature anomalies were estimated and their standardized fluctuation indices plotted (Fig. 11), based on

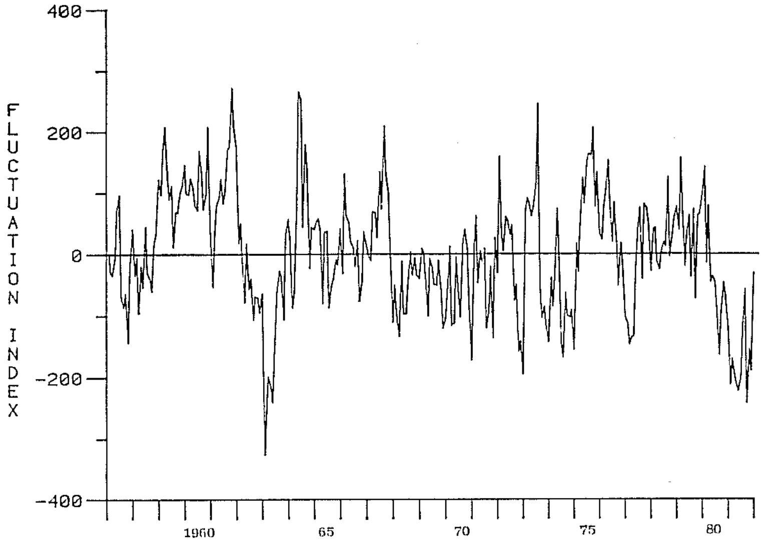

Fig. 11. Monthly changes of fluctuation indices (FI) of sea surface temperatures for 1957-1981 period at the 17 selected stations in the Japan Sea off Korea. FI represents the percentage of deviations from mean ($\bar{X}$) to standard deviation (σ) ($FI=(X-\bar{X})/\sigma\times 100$) (After GONG *et al.* 1983).

10-day mean water temperatures in 1957-1981 at 17 coastal and offshore stations (GONG *et al.* 1983). Fluctuation indices in the summers of 1959, 1960, 1961, 1964, 1967 and 1975 were higher than 200, and thus surface temperatures were abnormally high. The indices in winter and spring of 1972, 1976, 1979 and 1980 were higher than 130 and thus surface temperatures were pretty high. On the other hand, the indices for 1963 and 1981 were lower than −200, showing that surface temperatures were abnormally low. The indices for autumn 1957, spring 1968, winter 1969/70, autumn 1972, summer and autumn 1974, winter 1976/77, and spring 1977 were lower than −130, indicating pretty low surface temperatures. There was no apparent cycle in variations of surface water temperatures.

In relation to wind stress indices, surface water temperatures were high when southerly and northerly winds were weak, and low when these winds were strong (Figs. 2 and 11). The relationship between annual wind stress indices at Ulreungdo Island (Fig. 2) and annual mean sea surface temperature anomalies from the 17 selected stations is shown in Fig. 12. In 1959 and 1960 water temperatures were high while wind stresses

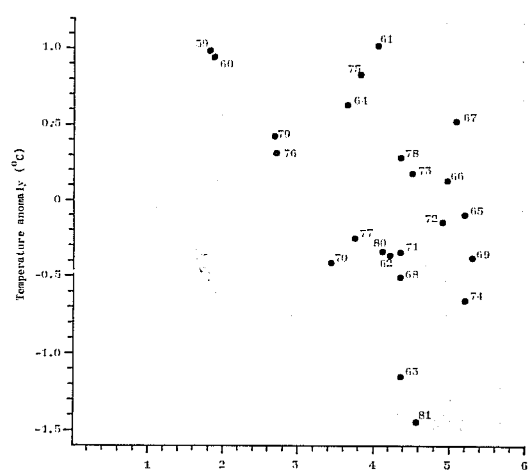

Fig. 12. Relationship between the index of annual wind stress for combined northerly and southerly winds at Ulreungdo and annual mean sea surface temperature anomalies at the 17 selected stations off Korea, 1959-1981.

were weak, and in 1963 and 1981 water temperatures were low while wind stresses were strong. This relationship had a significant negative correlation ($r=-0.508$, $n=23$, $P>0.05$) when all 23 years (1959-1981) of data were used. Moreover, the wind stress indices and the anomalies of water temperatures for the 276-monthly periods from January 1959 to December 1981 showed a highly significant negative correlation ($r=-0.255$, $n=276$, $P>0.01$). Accordingly, the stronger the northerly and southerly wind stresses, the lower the surface water temperatures in the East Korean Warm Current region off Korea.

4. Relationship between distributions of fishing grounds and oceanic fronts

As shown in the previous chapter, the position of thermal fronts which extended north along

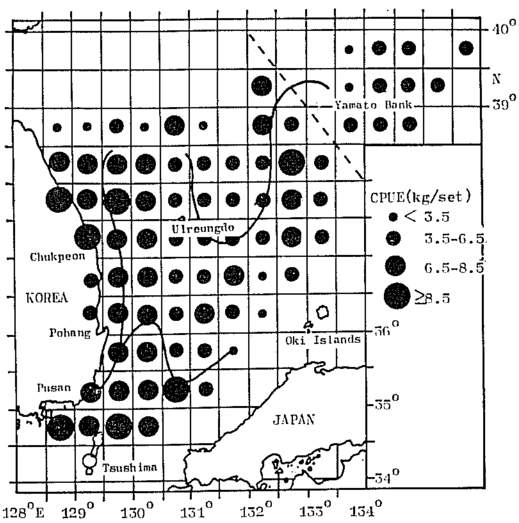

Fig. 13. Catch per unit of effort by statistical block from the Korean Pacific saury gill net fishery in the Japan Sea off Korea, 1959-1982. The solid line represents the position of the oceanic thermal front in a normal water temperature year in summer.

the coast of the Korean Peninsula varied in location from east to west annually, and the thermal front near Ulreungdo Island showed large south to north variation in location. However, cold water regions always developed in the area between Ulreungdo and Tokdo Islands except in abnormally warm years like 1976 when the East Korean Warm Current area was unusually warm, and made contact with the warm water from the south and formed a tongue-like southward thermal front.

As shown in Fig. 13 by the distribution of CPUEs, the areas of high density which were extended south to north along the coast of the Korean Peninsula, were located along the thermal front which extended south to north along the periphery of the low temperature region. On the other hand, high densities north of Tsushima Island were located along the Tsushima Warm Current Thermal Front and between Ulreungdo Island and the east coast of the Korean Peninsula as well as between Tokdo Island and Yamato Bank along the Polar Front. Therefore, good fishing grounds corresponded to the distributions of thermal fronts.

5. Influence of winds on Pacific saury gill net fishing activities

Recently about 500 Pacific saury drift gill net fishing vessels have operated in Korean waters. Most were in 10 to 50 gross tonnage class with less than 1% in the 50 to 100 gross tonnage class. In January and February 1963 fishing operations could not be carried out not only because of strong prevailing northerly winds but also because of abnormally cold weather. In the winter of 1975/76, however, northerly winds were weak and it was also warm, so that fishing

Table 1. Relationship between number of days with low wind speeds (≤8.0 m/sec) or wave height (≤2 m) and fishing effort, catch and catch per unit effort (CPUE) for the Korean saury gill net fishery, 1959-1978

	May			November		
	Operation days	Catch landed	CPUE	Operation days	Catch landed	CPUE
n	20	20	20	20	20	20
r	0.076	−0.041	−0.094	−0.015	0.065	0.099
Significant	no	no	no	no	no	no

r; Correlation coefficient

operations could be conducted throughout the winter. Table 1 shows the relationship between days of fishing, catch, and CPUE of the Korean Pacific saury fishery and days having winds of less than 8 m/sec at Ulreungdo Island in months of good fishing (May and November). As shown in the table, there was no significant correlation between wind speed and fishing operations for Pacific saury in these months.

6. Optimum water temperatures and salinities for saury fishing

Gill net fishing for Pacific saury off Korea is carried out in surface waters shallower than 2.5 m. The distribution of surface water temperatures observed during 132 cruises of research vessels in 1959–1981 were compared with corresponding weekly catch distributions by statistical block to determine the water temperatures that corresponded to good catches. Salinities observed during 98 cruises were also compared in the same manner to determine optimum salinities for Pacific saury fishing. The ranges of monthly weighted mean water temperatures and salinities in which Pacific saury were caught and the means of these values and ±1 and 2 SD of these means are shown. The means represent the most favorable conditions for Pacific saury fishing (Fig. 14).

The most favorable water temperatures in the spring-summer season (March to July) during the northward migration of Pacific saury tended to increase in succeeding months; it was 11.1°C in March, 13.3°C in April, 14.8°C in May, 17.6°C in June, and 20.2°C in July with an overall seasonal mean of 15.4°C. The most favorable water temperature in the autumn-winter season (October to February), during the southward migration of Pacific saury tended to decrease in succeeding months; it was 17.2°C in October and November, 14.9°C in December and 11.3°C in February with an overall seasonal mean of 14.8°C. The most favorable annual water temperature was 15.2°C. The range of the water temperatures in which Pacific saury were caught throughout the year in the study area was 6.5–23.5°C, and the range of the mean ±1 SD was 12.7–17.7°C, and that for ±2 SD was 10.1–20.2°C.

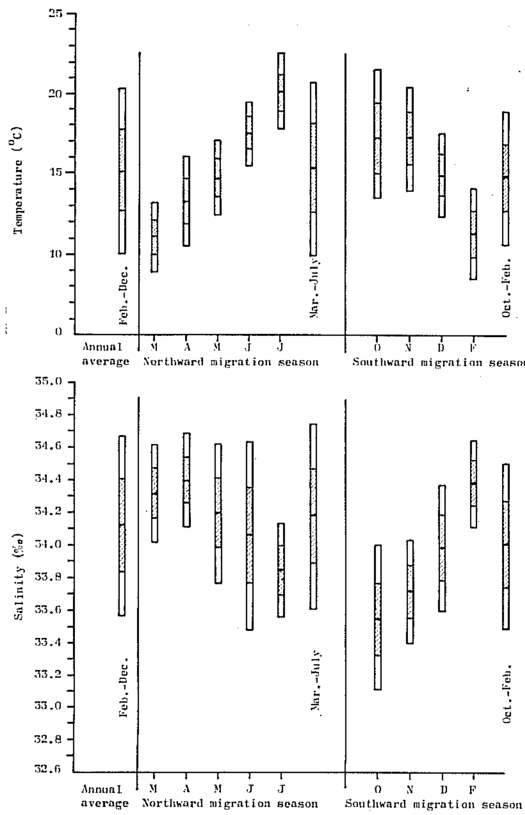

Fig. 14. Optimum temperature and salinity at the sea surface for Pacific saury fishing off Korea. Midpoints of each bar represent means, the darkened part of the bar one standard deviation and the entire bar two standard deviations.

The most favorable salinity in the spring-summer season (March to August) tended to decrease in succeeding months; it was 34.3‰ in March, 34.4‰ in April, 34.2‰ in May, 34.1‰ in June and 33.9‰ in July, with an overall seasonal mean of 34.2‰. The optimum salinity in the autumn-winter season (October to February) tended to increase in succeeding months; it was 33.6‰ in October, 33.7‰ in November, 34.0‰ in December, and 34.4‰ in February, averaging 34.0‰ over the entire season. The optimum salinity throughout the year was 34.1‰. The range of salinities in which Pacific saury were caught throughout the year in the study area was 33.2–34.8‰ and the range of the mean ±1 SD was 33.8–34.0‰, and that for

±2 SD was 33.6-34.7‰.

In summary, the best catches of Pacific saury in Korean waters were made in water temperatures ranging from 13°C to 18°C, and averaged 15.2°C. Good fishing grounds were located in salinities of 34.1‰. The temperature and salinity values corresponding to good fishing in the spring-summer season were slightly different from those in the autumn-winter season.

7. Relationship between fishing periods and superficial water

The superficial water with high temperature and low salinity which entered the Japan Sea through the Korea Strait from the East China Sea extended to off the south portion of the Korean Peninsula in about July (Fig. 7). The areas having surface salinities less than 33.0‰ were shaded in Fig. 7. The low salinity area in July 1961 was wider than that in July of normal years. The salinity in July 1966 was high. The salinity in July 1974 was nearly normal being low in Korean waters of the Japan Sea and high in Japanese waters. The salinities in August of 1961, 1963, 1972, 1973, 1975 and 1976 in Korean waters were normal or a little lower than normal. Areas of high salinity were much wider than normal in August 1971 and 1974.

Comparing salinities to anomalies of surface water temperatures revealed that when salinities were abnormally low, water temperatures were higher than normal, and when salinities were abnormally high, water temperatures were low. One exception was in 1963 when low salinities and low temperatures occurred simultaneously.

Pacific saury are mainly taken off Korea in May during their northward migration and by June and July the main shoals have moved to north of Lat. 38°30′N. During this period the high temperature and low salinity warm current surface water enters the Japan Sea. When this low salinity water extends earlier than normal, the period of fishing for Pacific saury in Korean

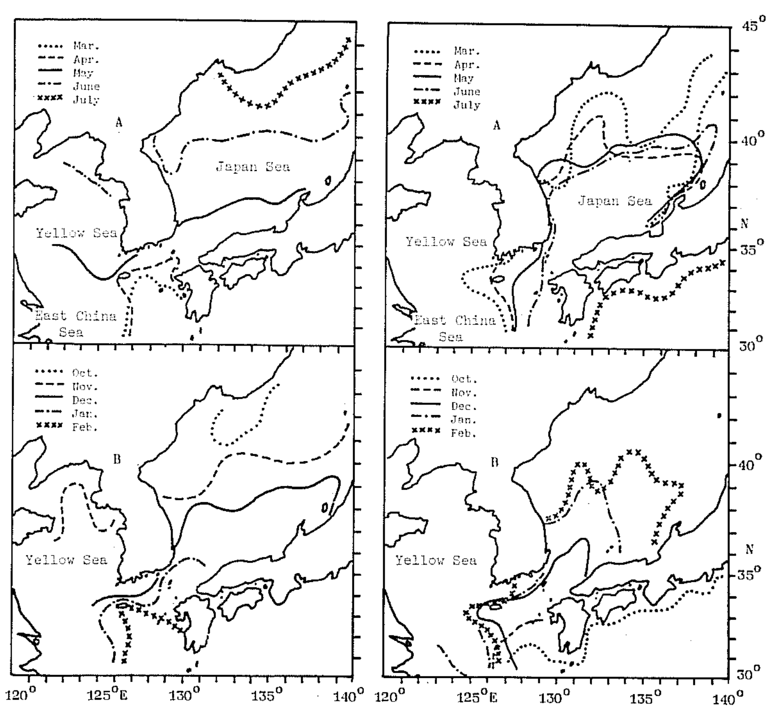

Fig. 15. Monthly distribution of the 15°C isotherms (left panel) and the 34.1‰ isohalines (right panel) at the surface which represent the optimum temperature and salinity for Pacific saury fishing. A; Northward migration season, B; Southward migration season.

waters ends in July, but when the low salinity water extends later than normal, fishing continues until August.

8. Distribution of optimum water temperatures and salinities and centers of fishing grounds

Fig. 15 shows the monthly distribution of 15°C isotherms and 34.1 ‰ isohalines considered to be optimum water temperature and salinity for Pacific saury fishing in the entire Korean waters. The 15°C isotherm moved northward between March and July in Korean waters and southward between October and February. However, the 34.1 ‰ surface isohaline moved very little between January and July in these waters, and remained between Lat. 37°N and Lat. 40°N. Off the west coast of the Korean Peninsula, the 15°C isotherm was present in May, June, and November, but the 34.1 ‰ isohaline in these months remained east of Long. 125°E.

Fig. 16 shows the relationship between the positions of centers of abundance indices for Pacific saury and the positions of the 15°C isotherm. In spring-summer (March to July) the centers of abundance indices and the variables were positively correlated ($N=5$, $r=0.966$, $P>0.05$). In autumn-winter (October to February) the positions of the optimum water temperature (15°C) as well as centers of fishing grounds tended to move southward.

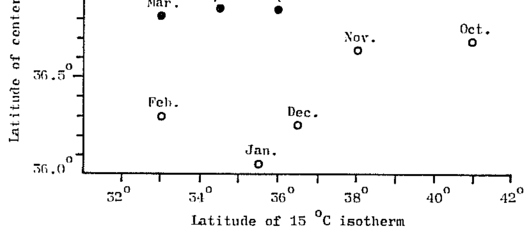

Fig. 16. Relationship between the monthly mean location of the 15°C isotherm and the centers of abundance indices for Pacific saury off Korea in spring-summer (dark circle) and autumn-winter (open circle), 1959-1982.

9. Discussion

Pacific saury are a typical epipelagic species and are caught by gill nets in the upper layer of the sea. Therefore, variations in the oceanographic structure at the upper layer were analysed to examine the relationship between changes in fishing grounds and oceanic environmental conditions.

Oceanographic conditions at the upper layer in the East Korean Warm Current area are classified into two periods each year, that is, a low temperature and high salinity period peaking in winter, and a high temperature and low salinity period peaking in summer. There are also intermediate periods of mild temperature and mild salinity conditions in May and June and in November and December (Fig. 10). OGAWA (1981) stated that November was a period of high salinity off southern Japan, but off Korea November and December was a period of lower salinity than in spring and lower than that off southern Japan.

The time when the salinity begins to decline in early summer is later in the northern than southern Japan Sea which is attributed to the high temperature and low salinity superficial water originating from the East China Sea. The fact that the salinity in the western Japan Sea is lower than that in the eastern Japan Sea is due to the west Korean (Yellow Sea) coastal water which is made less haline by summer runoff and is chilled by cold-air in fall, and moves southward and eastward through the Cheju Strait and the Korea Strait into the Japan Sea (HUH 1982a).

The gradient of horizontal and vertical salinity in winter-spring (January to June) is small and thus the water temperature distribution pattern at the surface layer is similar to that at the 50 m layer in the East Korean Warm Current area, because the intrusion of high temperature and low salinity warm current surface water comes later. Moreover, the thermal water mass boundary at the surface layer is the same as that at the subsurface layer (50 to 100 m layer), and the position of the thermal front at the surface layer is the same as that at the subsurface layer in the winter-spring season.

The pattern of water movement in this season can be estimated by the horizontal distribution of vertical integrated mean water temperatures as well as the geopotential topography (Fig. 6). The horizontal distribution of water temperatures at the layer of 100 m was similar to the geopotential topography (0/300 db) (TANIOKA 1968; GONG and PARK 1969; SHUTO 1982).

However, in summer-autumn (July to October) as the high temperature and low salinity warm current surface water covers the surface layer, and the seasonal thermocline is developed, the structure of the surface layer is different from that of the subsurface layer. Accordingly, the positions of thermal fronts at the surface, 50 m, and 100 m are different. But in summer-autumn, as the high temperature and low salinity warm current surface water is restricted to the superficial layer in the peripheral area of the Polar Front, the positions of thermal fronts of depth greater than 50 m have no significant difference. Therefore, the structure at the upper layer in the East Korean Warm Current area and adjacent region can be determined by the distribution of surface water temperatures at least in the winter-spring season (January to June).

The distribution of surface water temperatures in spring were significantly different from the mean distribution for the year (GONG *et al.* 1983). Accordingly, because warm currents were strong in spring (April or May) 1960, 1966, 1972 and 1976, the surface thermal front was formed north of Lat. 36°N and extended northward and eventually northeastward. The thermal fronts in spring 1963, 1970, 1977 and 1981 were between Lat. 36°N and Lat. 37°N and north of the thermal front temperatures were remarkably low compared to the mean value. It is well known that abnormally low temperatures were recorded and the thermal front was shifted to the south in the southwestern Japan Sea including the East Korean Warm Current area in spring 1963 (HAN and GONG 1965; NAGANUMA 1966; HAN and GONG 1970; GONG and OH 1977; KITANI and UDA 1969; GONG and SON 1982; GONG and LIE 1984; KOLPACK 1982; Japan Sea Regional Fisheries Research Laboratory 1976). The positions of the thermal fronts at the surface in 1972 and 1981 could be seen by satellite infrared imagery (HUH 1974, 1982a, 1982b).

However, in 1970 the temperature in the east channel of Korea Strait was lower than that in the East Korean Warm Current area (MIITA 1967; NAGANUMA 1977; INOUE 1981; TOMOSADA 1982; Japan Sea Regional Fisheries Research Laboratory 1970; KAWAMOTO and OGAWA 1981). UDA (1958) stated that variations of oceanographic conditions in the Japan Sea, especially in Korean waters, were large. HIDAKA and SUZUKI (1950) and NAGANUMA (1981) stated that there was a 6.5 or 7 year periodicity in variations of oceanographic characteristics in the southern Japan Sea and in the strength of the Tsushima Warm Current. On the other hand, in waters off Korea there was no apparent periodicity in surface water temperatures and seasonal and annual variations were large (Fig. 11).

Considering the relationship between surface water temperature anomalies and winds in the East Korean Warm Current area, years having weak winds have high temperatures and conversely years having strong winds have low temperatures (Figs. 2, 11 and 12). However, in 1966 and 1967 water temperatures had positive anomalies while the wind stress indices were high. This discrepancy suggests that there would be other factors affecting on the relationship between the two variables. The East Korean Warm Current is strong in summer and weak in winter. However, the Tsushima Warm Current is apparent throughout the year in the southern Japan Sea. Strong cold northwesterly seasonal winds in winter accelerates cooling of the sea surface and impedes the northward movement of the warm current water. On the contrary, weak wind stress in winter allows the warm current to extend northward which reduces the cooling of the surface water.

In summer southerly winds prevail (Fig. 2). If the southerly winds are continuous in early summer when the upper mixed layer is thin, temperatures in Korean coastal waters are reduced by coastal upwelling and high temperature water accumulates offshore. If the wind is strong and coastal upwelling doesn't occur, surface water temperatures will be lower because of the wind mixing of the surface layer. In practice, surface water temperatures in July were lower than in June in the area off the southeast coast of the Korean Peninsula because of coastal upwelling induced by southerly winds between June and July of 1961 (Fig. 3). Surface water temperatures in the south and central areas of the Japan Sea off Korea fluctuate according to the strength of the Tsushima Warm Current and the North Korean Cold Current water, but the northerly winter and southerly summer winds greatly influence variations in surface water temperatures.

According to ASAI and KATO (1981), annual fluctuations in water temperatures result from variations in the volume of the Tsushima Warm Current rather than air-sea heat exchange during the summer, but during the winter variations in the air-sea heat budget contribute to variations in water temperatures. This is because cold northwesterly winds in winter facilitates the heat exchange (MIYAZAKI 1952; Maizuru Marine Observatory 1972). However, if coastal upwelling also occurs in summer, the temperature of coastal waters becomes lower and that in offshore waters becomes higher because of the accumulation of warm current water. Oscillations of the thermal front are irregular and are affected largely by the air in the East Korean Warm Current area. Thus variations in oceanographic conditions in this area are not related to the periodicity of variations in the Tsushima Warm Current which occurs commonly in the Korea Strait and in the costal areas off Japan.

Winds influence Pacific saury fishing activities in two ways; one is that fishing operations can not be conducted when northwesterly winds in winter are strong, and the second is that it is impossible to conduct fishing activities during Typhoons in summer and winter. But in summer, Pacific saury already leave south Korean waters and thus are no longer targets of the Korean gill net fishery. Winds in spring and summer do not significantly affect the operations of the fishing vessels (Table 1).

Many studies report on the range of temperature and salinity inhabited by Pacific saury in the Japan Sea, but they differ from the results of this study. The reason is that different regions and seasons were studied (GONG *et al.* 1983). FUKATAKI (1966), from analyses of data from KOTOVA (1958) and HOTTA (1964), suggested that during periods of decreasing water temperatures, Pacific saury inhabit areas warmer than about 10°C. NISHIMURA (1969) estimated that the range of optimum water temperature for saury was 13–19°C.

It is reasonable that the range in water temperature for commercial fishing is 10–20°C and the range of the most favorable water temperature is 13–18°C centered around 15°C, even though conditions tend to change seasonally as shown in the previous chapter (Fig. 14).

In Korean waters the 15°C surface isotherm is usually located west of Kyushu in winter, in the area between Lat. 37°N and Lat. 40°N in spring (May and June) and autumn (November and December), but moves to the northernmost part of the Japan Sea in summer. Thus the seasonal movement is extensive. However, the 34.1 ‰ isohaline at the surface remains in the area between Lat. 37°N and Lat. 40°N without much geographic variation in winter-spring (January to June) (Fig. 15).

Variations in oceanographic conditions at the upper layer in the East Korean Warm Current area in winter-spring (January to June) are dependent upon changes in water temperatures rather than salinities, but in summer-autumn (July to December) they are dependent upon changes in salinities as well as temperatures. The south-north movements of the 15°C isotherm in spring-summer (March to July) and the shifts in centers of fishing grounds for Pacific saury were strongly correlated (Figs. 14, 15 and 16). In winter and summer there is not a direct correspondence because Pacific saury move out of the Korean fishing grounds with the belt of the optimum water temperatures.

10. Summary

1. Pacific saury is a typical epipelagic fish of the Japan Sea and the East China Sea. Oceanic environmental conditions for Pacific saury were studied by means of meteorological data (1959–

1982), oceanographic observations (1957–1982), and catch and effort data of the Korean drift gill net fishery (1959–1982).

2. In the East Korean Warm Current area the stronger the southerly and northerly winds, the lower the surface temperatures. As the horizontal and vertical salinity gradients in winter-spring were small in this area, the distribution and strength of the water currents, the locations of the thermal front, and the water circulation pattern could be determined by the distribution of water temperatures. Oceanographic conditions (the strength and position of fronts and annual surface water temperature anomalies) during the period of lowest water temperatures in this area remained the same from February until March or April.

3. The surface water temperatures in winter-spring (December to April) 1958/59 and 1959/60 were pretty high, and those in 1970/71, 1975/76 and 1978/79 were fairly high. On the other hand, the surface water temperatures in winter-spring 1962/63 and 1980/81 were abnormally low, and those in 1967/68, 1969/70 and 1976/77 were pretty or fairly low.

In winter-spring seasons having low water temperatures (for example in 1963, 1970, 1977 and 1981) the oceanic fronts were formed from east to west and were farther south in the Japan Sea (between Lat. 36°N and Lat. 37°N) compared to normal years, and water temperatures north of the fronts were very low.

It was recognized that annual variations in oceanographic conditions were substantial in the upper layer of the East Korean Warm Current area of the Japan Sea off Korea and did not relate to the periodicity of variations in the Tsushima Warm Current which occurs commonly in the Korea Strait and in the southern Japan Sea off Japan.

4. The range of surface water temperature suitable for commercial fishing of Pacific saury was 10–20°C. The water temperature for the best fishing ranged from 13–18°C and were centered around 15°C. The salinity for the best fishing was 34.1‰. In spring-summer (March to July), the relationship between the movement of the 15°C isotherm and the shift of centers of fishing grounds of Pacific saury had a positive significant correlation.

5. The high temperature and low salinity superficial water which originates from the East China Sea had an effect on the northward movement of Pacific saury in the Japan Sea. The oceanic front, when Pacific saury begin the northward movement from wintering grounds (in the southern Japan Sea and the East China Sea), is a cold barrier to these migrations.

6. Correspondingly, based on the distribution of annual CPUE values by statistical block from the Pacific saury drift gill net fishery, the density of the fish shoals tended to be high around the front in spring-summer. The density of fish shoals in the Japan Sea off Korea was higher than that off Japan which was related to the structure and position of the oceanic front.

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韓国近海産サンマ漁場の海洋環境に関する研究

孔　　泳*・平野敏行**・張　昌　翼***

要旨: 気象観測資料 (風向, 風速), 海洋観測資料 (水温, 塩分) およびサンマ漁獲量, 努力量資料を利用して韓国近海産サンマ (*Cololabis saira*, BREVOORT) 漁場の海洋環境に関して研究した。日本海の韓半島側における風が表面水温の変動に大きな影響を与えている。

日本海南西部の上層では, 冬春季 (1～6月) には, 塩分の水平および鉛直分布傾度が小さいので, 水系の分布, 海洋前線, 上層の海洋構造は表面水温の水平分布によって容易に判断する事ができる。低温期 (1963, 1970, 1977 および 1981年) の冬春季には, 海洋前線は平年に比べて南部海域に偏っており前線以北では平年に比べて著しく低い水温を示した。韓半島東岸の東韓暖流域では以上に示したように海況の経年的な変動が著しく, 大韓海峡側にみられるような海況変動の周期性はみとめられなかった。

漁獲対象となるサンマ魚群が出現する水域の表面水温範囲は 10°～20°C, 最多漁獲水域の水温は 15°C を中心とする 13°～18°C であり, 最多漁獲水域の塩分は 34.1 ‰であった。日本海における春夏季 (3～7月) の 15°C 等温線の移動とサンマの豊度指数の分布からみた漁場重心の移動との間には, 有意な相関関係がみられた。すなわち, 初夏季 (7月頃) に東シナ海および韓国南海から流入して日本海に拡張する高温, 低塩の暖流表層水はサンマの北上移動を促進する。

サンマの越冬場 (日本海南部～東シナ海) から日本海に北上移動を開始する北上初期 (3～4月) には海洋前線はサンマ魚群に対して冷水障壁の役割を果たしている。前線の縁辺にサンマ密度が高い傾向が認められた。日本海の韓国側漁場におけるサンマの密度が日本側のそれより高いのは, 前線の配置と構造の違いによると考えられる。

以上, 日本海南西部における風と上層海況との関係, 海洋構造とサンマ魚群密度および漁場形成との関係に関した新たな知見は, サンマ漁場の予測に寄与すると思う。

* 国立水産振興院, 韓国釜山市影島区南港洞2-16
** 東京大学海洋研究所,
〒164 東京都中野区南台1-15-1
*** Washington 大学校　海洋水産科学大学,
Seattle, WA 98195, U.S.A.