J. of the Environmental Sciences
Vol. 12, No. 11, 1137~1144, 2003

Effect of the Environmental Conditions on the Structure and Distribution of Pacific Saury in the Tsushima Warm Current Region

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(Manuscript received 1 August, 2003 ; accepted 15 November, 2003)

To provide evidence that the changes in oceanic environmental conditions are useful indices for predicting stock structure and distribution of the Pacific saury (*Cololabis saira*), the body length compositions and catch per unit fishing effort were examined in relation to the sea surface temperature(SST) anomalies in the Tsushima Warm Current(TWC) region. The size of the fish became larger(smaller) than the average in the same size category during the season of higher SST(lower SST) as opposed to the normal SST. The year-to-year changes in body size caused by the changes in the environmental conditions led the stock to be homogeneous during the period of high stock level from the late 1950s to early 1970s and in the 1990s.

The changes in body size manifested by higher(lower) occurrence rates of larger (smaller) sized groups in relation to temperature anomalies suggest that the changes in the environmental conditions affect the distribution and the structure of the stock in the TWC region. Therefore, if the SST anomaly derived from satellite data is large enough in the early spring months(Mar. or Apr.), it is possible to predict whether or not sea temperature will be favorable for large sized groups of saury at normal or slightly earlier time of commencement of the fishery in spring(Apr.~June).

Key words : Tsushima Warm Current, Oceanic front, Pacific saury, Stock structure, Body sized group, Distribution, Satellite images

1. Introduction

Stock of Pacific saury (*Cololabis saira*) in the Tsushima Warm Current region is known to undertake large-scale migrations between summer feeding grounds in the northern East/Japan Sea (EJS) and its wintering areas in the northern East China Sea (ECS).

Previous studies have shown that the distribution and migrations of size groups have varied widely in relation to changes in oceanic conditions[1,2,3]. The timing of migration of larger fish to a certain area is of considerable importance to commercial fishermen since the boundary(e.g. 38° 30'N Lat.) of the fishing grounds separates into two exploiting or management areas. The later the arrival and the faster the movements of the fish, the shorter the fishing season for many fishermen. While the year to year changes in body size and the number of different sized groups of saury were noticeable in the northward and southward migrations in the EJS[4~8], it was not clear whether the changes were due to variable availability in relation to environmental changes or due to varied abundance.

The objective of this study is to assess whether thermal conditions are responsible for the changes in body size and timing of occurrence of different sized groups in fishing grounds, and to provide evidence that the sea surface temperature (SST) anomalies are a useful index for predicting seasonal availability of commercially harvestable groups and abundance in the central and southern

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East/Japan Sea.

2. Data and Methods

The basic types of different sized groups of Pacific saury in the northward and southward migrations were identified on the basis of monthly body length compositions in the southwestern (1957-1982), southeastern(1951-1964), and north-eastern(1951-1977) East/Japan Sea. Time sequences of SST anomalies(1951-2001) from three regions in the Tsushima Warm Current (TWC) system were used to examine the differences in body length compositions of saury in response to changes in the temperature regime.

Abundance indices were estimated as $P=\sum(Y_i/f_i)\cdot A_i$, where, Y_i/f_i represents catch per unit effort (set ; Pok in Korean and Tan in Japanese) and Ai is the number of 0.5° ×0.5° statistical sea blocks.

The relationship between seasonal abundance indices and the numbers of modes of the different sized groups was examined on the basis of Korean gillnet fishing in the area ranging from 35° N to 38° 30'N and from 128° E to 133° E. The seasonal dominant sized groups and their changes in response to oceanic conditions were identified on the basis of the above analysis.

3. Results and Discussion

3.1 Thermal regime and distribution of different sized groups of Pacific saury

The time series of SST anomaly showed that the observed temperatures were higher than normal in the late 1950s, 1970s and early 1990s, while they were lower than normal in the early 1960s and 1980s in the Tsushima Warm Current region from the East China Sea to the central EJS (Fig.1 and 2). The SSTs were lower than normal in the winter of 1962/63, 1980/81 and 1995/96 in the East Korea Warm Current (EKWC) region (Fig. 2-a).

The SSTs of spring are affected by the winter air temperatures in the EJS[16]. The SST anomalies were lower than normal in the ECS(32° N, 128° E) (Fig. 2-b, B), while they were higher than normal in the EKWC region in 1975/1976 (Fig. 2-a and b) when the wind stress indices were small because of the mild winter monsoon[7].

The large sized group(L, 28.0~31.9cm) and the small sized group (S<24.9cm) of Pacific saury are dominant, while the medium sized group(M, 25.0~27.9cm) often appears during the northward migrating season(Mar. or Apr.~July) in the East Korea Warm Current region (Fig. 3-a). However, M group occurs scarcely in the eastern side (toward the coast of Japan) of the EJS[4] (Fig. 3-b).

In the monthly body length compositions of the saury taken by the Korean gillnet fishery (Fig. 4-a) and by Japanese experimental gillnet fishing (Fig. 4-b), thermal conditions (normal, warm and/or cold) are indicated based on the SST anomalies of Fig. 2. In the early southward migrating season(Oct.~Dec.) medium(M) and large(L) or extra-large sized groups (LL>32.0cm) appear in the central and southern EJS. The colder the surface water, the earlier the disappearance of the larger sized group from the region. In the late southward migrating season(Jan.~Feb.) most of the L and LL groups migrate further to the southern stock area and/or die. Then only M group occurs in the southern EJS and northwestern Kyushu. However, L groups still occur there when

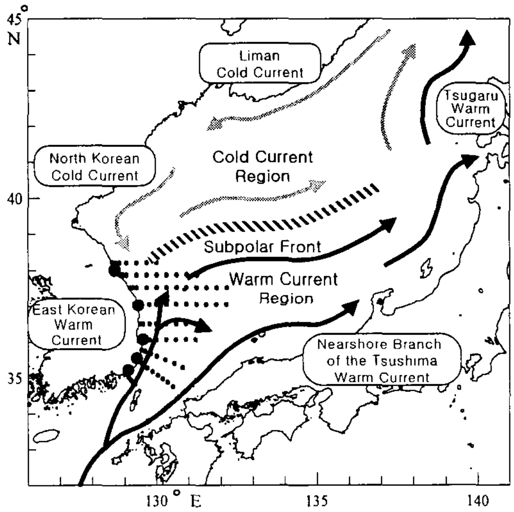

Fig. 1. Schematic picture of surface current structures after Uda in 1934 and map showing the oceanographic observations at 5 coastal stations and 71 offshore stations in the East Korea Warm Current region. Black arrows indicate warm currents and gray ones indicate cold currents[17].

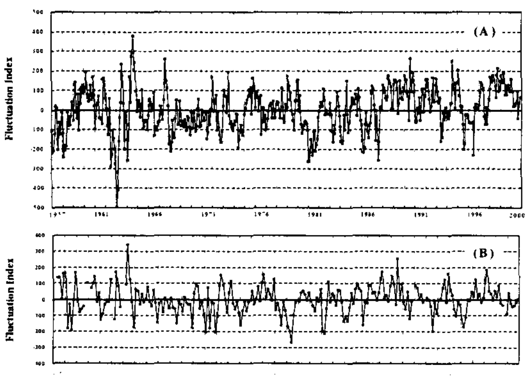

Fig. 2-a. SSTs anomalies in the East Korea Warm Current region from 5 coastal station, 1957～2000 (A) and 67 offshore stations, 1961～2000 (B).
Fluctuation Index=100(x-xbar) / σ (x : SST, σ : standard deviation).

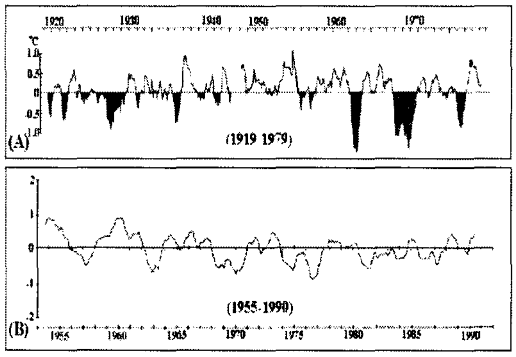

Fig. 2-b. SST anomalies in 12-month running average in the East channel of Korea Straits, 1919-1979 (Data; Fukuoka Fish. Exp. St.) (A) and in the Tsushima Warm Current region (32° N, 128° E), 1955-1990 (Data; Nagasaki Marine Observatory) (B).

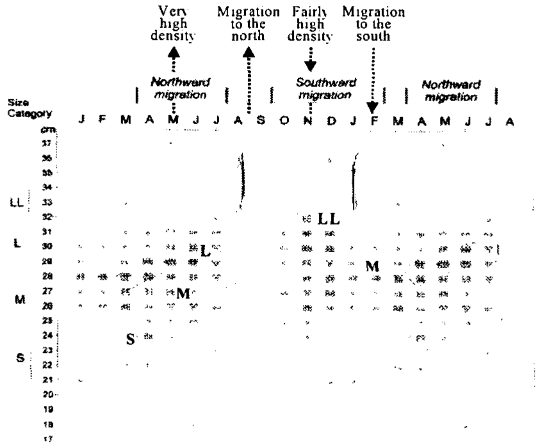

Fig. 3-a. Seasonal changes in monthly modes of length compositions of Pacific saury caught by gillnet for 26 years (1957-1982) in the southwestern East/Japan Sea.

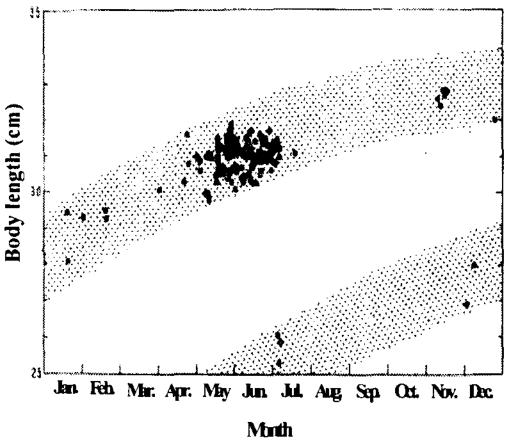

Fig. 3-b. Seasonal changes in monthly mean body length of Pacific saury in the eastern East/Japan Sea, 1962 (Fukataki 1963).

the surface water is warm enough (Fig.4-a and b). A comparison of the appearance of different sized groups with the SST anomalies during migrations in the southern EJS indicated that the changes in thermal regimes were responsible for the significant variations in body size of the fish. It is suggested that dominant groups can be shifted to smaller or larger sizes depending on environmental conditions. Therefore, an additional group (M) appears in the western EJS in association with the variable oceanic conditions.

The seasonal occurrence of different sized groups of the fish in relation to oceanic conditions are summarized on the basis of the above analysis (Table 1). In the late southward migrating season(Jan.～Feb.) most of the LL group migrates further to southern stock areas or die (reach the end of their life span). The larger the size, the lower are the rates of occurrence in late winter depending on the thermal conditions of a severely cold winter.

Highly variable oceanic conditions, such as chlorophyll a and flotsams in the western EJS, are easily checked by the year to year and seasonal

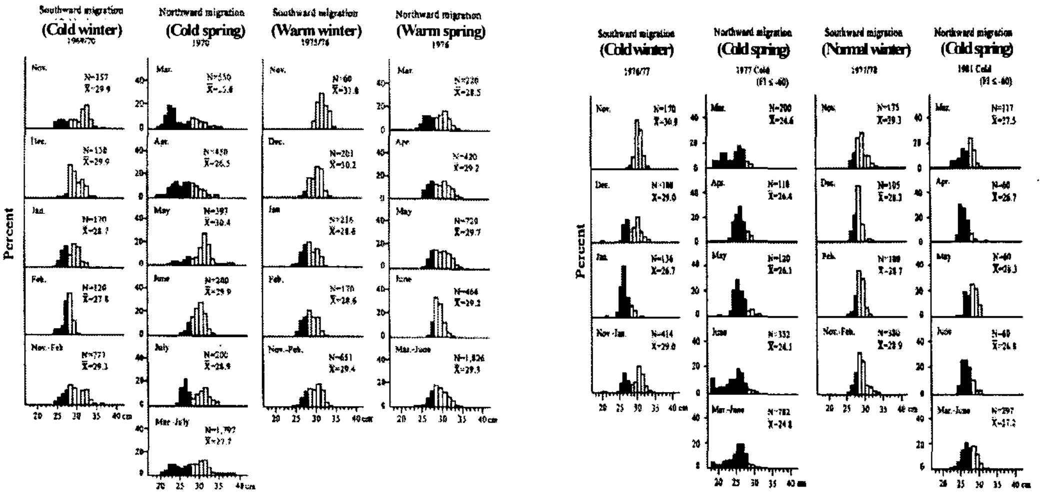

Fig. 4-a. Monthly length(folk) frequency distribution of saury taken by gillnets in the East/Japan Sea during the southward migration season in 1969/70(cold winter), 1975/76(warm winter), 1976/77(cold winter), 1977-78(normal winter), and northward migration season in 1970(cold spring), 1976(warm spring), 1977(cold spring) and 1981(cold spring). The dark shading represents the small and medium sized groups of Pacific saury.

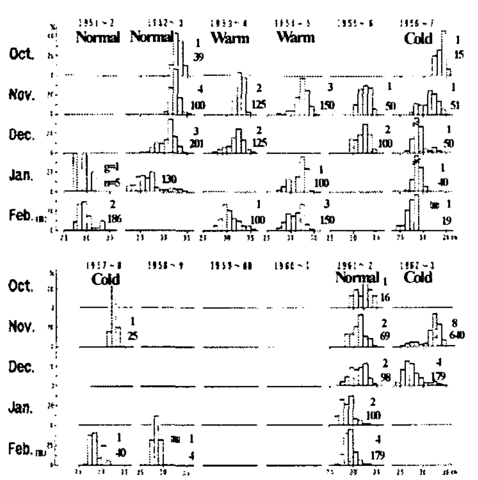

Fig. 4-b. Annual changes in monthly body length compositions of Pacific saury in the East/Japan Sea and northern East China Sea off Kyushu, 1951-1963 (Fukataki, 1963). The thermal conditions are based on the SST anomalies of Fig. 2.

shifting of the positions of thermal fronts[9,10] (Fig. 5), particularly in winter-spring season. Pacific saury are sensitive to water temperature gradients throughout their life cycle. Saury larger than 6 cm occur at the water temperature of 7 to 23℃. However, high concentrations of saury usually occur at temperatures of 13 to 18℃, with a peak in 15℃ in the central and southern EJS[7].

Saury in winter and early spring inhabit the warm and haline Tsushima warm Current system. Thereafter they undertake a northward migration. Therefore, the main fishing grounds with high aggregation of different sized groups of fish around the frontal zone can be easily detected by a remote sensing satellite (Fig. 5) and ocean color (Fig. 4) during the northward migrating season (Apr.~June), before advection of the low haline-warm superficial water originating from the East China Sea.

3.2 Stock structure in terms of catch rates by size group in abnormal oceanic conditions

The catch rates of small and medium sized groups combined during the northward migrating season were 90% in 1977, and 73% in 1982, when the SSTs were far below average in the East Korea Warm Current (EKWC) region, as in the winter-spring of 1962/63 (Fig.2-a, b, Fig.4-b and Table 1). The large sized groups of Pacific saury are dominant during the northward migrating season.

However, the catch(occurrence) rates of the medium sized group (M) were highest (59.7%) among the three different sized groups in 1963 when the temperatures in the upper layer of the

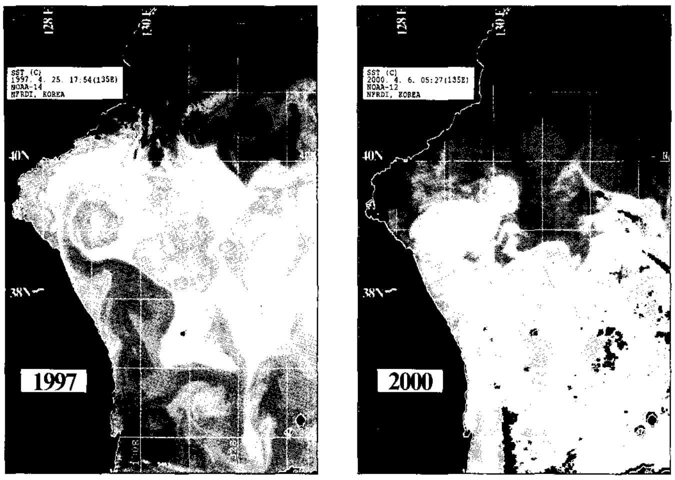

Fig. 5-a. Satellite images showing year to year variations in positions of the sub-polar thermal fronts in the western East/Japan Sea in April 25, 1997 (left) and in April 6, 2000 (right).

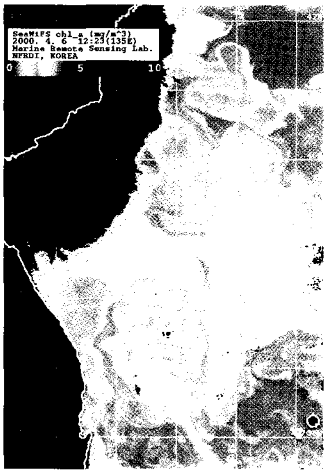

Fig. 5-b. SeaWiFS Satellite image showing distribution of the estimated chlorophyll *a* in April 6, 2000.

Table 1. Occurrence of sized groups of the Pacific saury in relation to oceanic conditions in the southern East/Japan Sea (EJS) during northward and southward migration. Sized groups are classified as small (S<24.9cm), medium (M, 25.0~27.9cm), large (L, 28.0~31.9cm) and extra large (LL>32.0cm)

Season	Thermal conditions	Year	Sized group	Seasonal mean size	Occurring pattern
Northward migration; Mar. or Apr.~July	Warm	1976, 79, 88, 89, 90, 98	S, (M), L	Larger	• Larger than normal size in the same group
	Normal	1969, 72, 78, 85, 87, 97	S, (M), L		• M group scarcely occurs in the eastern EJS
	Cold	1963 77 81 84 86	S, M, (L)	Smaller	• L scarcely occurs depending on thermal conditions
Southward migration; Oct.~Feb. or Mar.	Warm	1954/55 1975/76 1978/79 1989/90 1998/99	(A)M,L,LL (B)M,L	Larger	• The colder the surface water, the ealier disappear the larger sized group in A and B
	Normal	1952/53, 1961/62 1968/69, 1971/72 1977/78, 1990/91	(A)M,L,LL (B)M(L)		• Most of the L group disappear in B
	Cold	1956/57, 1962/63 1969/70, 1980/81 1983/84, 1985/86 1995/96	(A)M,L,LL (B)M	Smaller	• Only smaller M group occur in B

A : Early southward migrating season (Oct.~Dec.)
B : Late southward migrating season (Jan.~Feb. or Mar. in relation to oceanic conditions)

region were far below average (Table 2 and Fig. 2-a). The higher rates of the medium sized group (M) in 1963 suggest that the abnormally cold winter of 1962/63 had strong adverse effects on the growth of the fish in the TWC region.

Unusually, only the small sized group (S, 25cm

Table 2. The catch rates(%) of the different sized group of the saury taken by gillnet in the eastern EJS during the northward migrating season (Apr. ~ July) of 1963 and 1964[5];

	S (<24cm)	M (25-28cm)	L (>29cm)
1963	0.8	59.7	39.6
1964	0.9	45.0	54.1

in mode) occurred in the northeastern EJS (off Hokkaido) during the northward migrating season of 1977[6]. The abnormal body length compositions manifested by lower (higher) rates of the larger (smaller) sized group or the disappearance of the large sized group in relation to temperature anomalies in the upper layer suggest that the changes in oceanic environmental conditions affect the distribution and the structure of the TWC stock of Pacific saury.

The abnormal catch rates by size groups in relation to cold water in winter 1976/77 and spring 1977 were found in the southern region (35° N-37° 30'N, 129° 30' E-132° 30'E) and the northwestern region (39° N-43° N, 129° E-136° E), suggesting that the phenomena was a big event over the wide range of the stock area. It may be connected to the climate-driven oceanic changes in the north Pacific[11~12]. The sharp decrease in the catch rates of the large sized group in the late 1970s and throughout the 1980s seems to be attributed to the disturbance of the ecosystem during the climate regime shift in the entire stock area.

3.3 Relationship between numbers of size groups and abundance indices of the Pacific saury

The relationship between monthly numbers of modes of sized groups of the fish and abundance indices (r=0.69, p<0.01) from the Korean gillnet fishing in the southern EJS (35° N-38° 30'N, 129° E-133° E) from 1957 to 1982 indicats that the larger the numbers, the higher the abundance during the northward and southward migrating seasons (Table 3).

The large numbers of the different sized groups might be related to the aggregation and migration patterns of Pacific saury[15]. The aggregation of the different sized groups around the frontal zone is responsible for the high abundance in the southwestern EJS in the spring from April to June of the 1950s, 1960s and the early 1970s (Fig. 2). The fast southward migration of the large sized groups (L and LL) from late autumn (Nov. ~ Dec.) to mid winter (Jan. ~ Feb. or Mar.) leads to a the sharp decrease in the numbers of the sized groups, resulting in the low availability for the fishing fleets operating in the southern EJS. Therefore the fishing conditions manifested by catch and abundance indices were higher in the northward migrating season than in the southward migrating season during the period of high catch level from the 1960s to early 1970s. However, thereafter the conditions were reversed.

From the results it is suggested that if the sea temperature anomaly is large enough in autumn -winter it is possible to predict whether or not the sea temperature will be favorable for the large sized Pacific saury at the normal time of

Table 3. Monthly number of sized groups of Pacific saury and abundance indices from the Korean gillnet fishing in the East (Japan) Sea, 1957 ~ 1982

	Southward migration						Northward migration					
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.
No. of sized groups	7	35	30	10	10	24	30	32	28	15	( )**	( )
Abundance indices*	59	246	216	129	100	175	324	706	326	59	( )	( )

Note; * : Abundance index $P=\sum(Yi/fi) \cdot Ai$, where, Yi/fi is catch per unit effort and Ai is the number of 30′ × 30′ statistical sea blocks

** : Most of the sized groups of the fish moved to the north of the boundary (38° 30′ N) separating two fishing grounds in summer months(Aug. ~ Sep.)

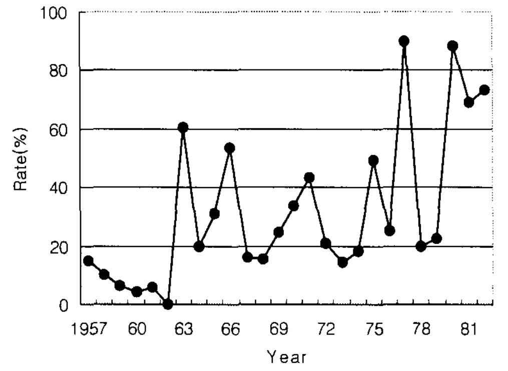

Fig. 6. Composition (catch) rates (%) of small and medium size group of Pacific saury taken by Korean gill-netters in April, May and June, 1957～1982 (Data; App. Table 10 of Gong (1984)).

commencement of the fishery in spring-summer months, as in the case of the abnormally warm winter-spring of 1954/55～1955 and 1975/76～1976. However, wide spread cold water was detrimental to the success of the fishery because of the low catch rates of large sized group of saury, as in 1962/63, 1976/77 and 1980/81 (Fig. 6).

As described in the previous sections, the continuous disappearance of large sized groups of Pacific saury in the Tsushima Warm Current region from 1976/77 to the late 1980s suggests that changes in stock structure in that period was the most significant event among the decadal climate impacts on the stock area of the fish[3]. The changes in the stock structure of the fish seems to be controlled by a wide range of common environmental impacts, which were examined by cooperative research in the source area from the East China Sea to the East/Japan Sea.

4. Conclusions

Among the abrupt changes in the stock structure of Pacific saury, which occurred in 1953/54, 1962/63, 1976/77, 1982/83, 1987/88 and 1997/98, the changes in 1976/77 and 1982/83 were the most noticeable events, manifested by the continuous low catch rates of the large sized group in the TWC region. The data on body size of the Pacific saury in the East/Japan Sea in relation to temperature anomalies suggests that changes in the environmental conditions affect the distribution and structure of the fish in the TWC region. The changes in catch rates of the different sized groups in the northward and southward migrating seasons in relation to thermal conditions suggest that if the SST anomaly is large enough in the early spring months(Mar. or Apr.), it is possible to predict whether or not sea temperatures will be favorable for large sized groups of saury at a normal or slightly earlier time of commencement of the fishery in spring(Apr.～June). The fishing sites with high abundance around the frontal zone can be traced by remote sensing satellites.

Acknowledgements

This study was funded by the research project "the application of satellite data for fisheries oceanography" of the Korea Aerospace Research Institute. Our gratitude is extended to Dr. H. G. Kim and Dr. B. K. Kim of the Natl. Fish. Res. and Dev. Inst. for their valuable help during the study.

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