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Distribution and Migration of Flying Squid, *Ommastrephes bartrami* (LeSueur), in the North Pacific

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The seasonal distribution and migration of flying squid, *Ommastrephes bartrami* (LeSueur), in the North Pacific were studied by means of mantle length, surface temperature, and catch and effort data of the Korean drift gillnet fishery from 1980 to 1983.

The water temperature for the best fishing ranged from 15° to 16°C in May through July and from 13° to 18°C in August through January. High densities of flying squid were found in the thermal fronts with 18°C isotherm in August and with 15°C isotherm in September. The densities of flying squid were higher in the western region than in the eastern region in the North Pacific. The high densities of flying squid in the northwestern Pacific were attributed to the high gradients of oceanographic properties in the region.

Migration models for flying squid were hypothesized based on the monthly distributions of catch per unit net, mantle length compositions by statistical blocks, and the hydrographic features of the North Pacific. The large flying squid moved to the northern region and to the central Pacific region earlier than the small sized group in the northward migration period (from June to August). Flying squid begin the reverse southward migration from the Subarctic Frontal Zone in autumn with onset of cooling and the development of Oyashio Current. The large sized group starts their southward return migration from more northern waters than the small sized group but the former moves past the later and reaches the spawing ground first.

I. Introduction

Exploratory fishing with Korean drift gillnets for flying squid, *Ommastrephes bartrami*(LeSueur), was initiated in the North Pacific in 1979. About 100 Korean vessels operated in 1983 season. Annual catches of this species in the North Pacific by Korea, Japan and Taiwan averaged about 300,000 metric tons in recent years.

Even though there are many reports describing the distribution and movement of flying squid in the northwestern Pacific, mostly by Japanese scientists, these reports have not contained information on the seasonal distribution and migration routes of the squid in the North Pacific because they could not have combined data from the central North Pacific with those from the northwestern Pacific region (Murakami 1976, Murakami et al. 1981, Murata and Ishii 1977, Naito et al. 1977a, 1977b, Murata et al. 1976, 1981, 1983a, 1983b and Kubodera et al. 1983).

Objectives of this study are (1) to examine the seasonal distribution and migration of flying squid in the North Pacific based on seasonal density distribution, oceanographic conditions and body size composition from sampling boats of the Korean drift gillnet fishery from 1980 to 1983 seasons, and (2) from these analyses, to contribute to the development of rational exploitation and management of the resources.

Ⅱ. Materials and Methods

About 207 gillnet vessels operated in the North Pacific during 1980~1983 fishing seasons, of which 132 vessels provided 871 vessel-month data for catch and effort. Korean drift gillnet fishing vessels for flying squid in the North Pacific ranged from 150 to 500 gross tons (GT). Half of them were in the 200~300 GT range. Mesh sizes of the drift gillnet ranged from 96 to 115 mm. The length of the unit gillnet was 50 m and the depth 8 m(Table 1). The average number of nets used by one vessel per day was about 200 in 1980 and increased to about 540 in 1983 season (Table 2).

Annual and monthly catch and effort (number of gillnet unit) and catch per unit net (kg/net) by statistical block (lat. 1°×1° long.) were calculated based on the daily records in the formats circulated by the Deep Sea Resources Research Division of the Korean National Fisheries Research and Development Agency. Monthly dorsal mantle length (DML) compositions by area of 1° lat. and 5° long. were analysed.

The optimum temperature for flying squid fishing was calculated as a weighted mean from distribution of catch and surface temperatures by statistical block (lat. 1°×1° long.) from these blocks having temperature measurement and fishing records. Catch per unit effort by statistical block (lat. 1°×1° long.) was plotted in the surface thermal structure derived from the infrared data of NOAA Satellite in the northwestern Pacifc (Japan Fisheries Information Service Center 1983).

From results of the above analyses, an attempt was made to describe the density distribution and migration by size group of flying squid in the North Pacific.

Ⅲ. Results

1. Distribution of catch per unit effort

The distribution of annual catch per unit effort (kg/net; CPUE) by statistical block (lat. 1°×1° long.) for the Korean flying squid gillnet fishery

Table 1. Details of the Korean flying squid gill net

Mesh size (*mm*)	Length of float line (*m*)	Hanging ratio		Depth of net (*m*)	Materials
		Udper	Lower		
96	50	0.446	0.457	8.79	Nylon monofilament 0.497 *mm*
105	50	0.446	0.454	8.74	〃
110	50	0.459	0.470	12.30	〃
115	50	0.461	0.471	7.80	〃

Table 2. Annual fishing efforts, catches and catch per unit effort for Korean flying squid gillnet fishery in the North Pacific, 1980~1983

Year	No. of vessels registered	No. of sampling vessel	No. of operation days	No. of unit gillnets	Catches by sampling vessels (mt.)	Average number of gillnets per vessel-month	Average number of gillnets per vessel-day	Catch per vessel-month (mt./ves.-mon.)	Catch per unit net (*kg*/net)
1980	14	9(44)	684	139,638	3,017.3	3,173.6	204.1	68.6	21.6
1981	34	9(73)	1,374	394,060	6,061.6	5,398.1	286.8	83.0	15.4
1982	60	56(327)	6,375	2,733,635	21,371.3	8,359.7	428.8	65.4	7.8
1983	99	56(419)	7,560	4,070,372	27,130.5	9,714.5	538.4	64.8	6.7
Total or Average	207	132(871)	15,379	7,337,705	57,341.8	8,424.5	477.1	65.8	7.8

( ): No. of vessel-month

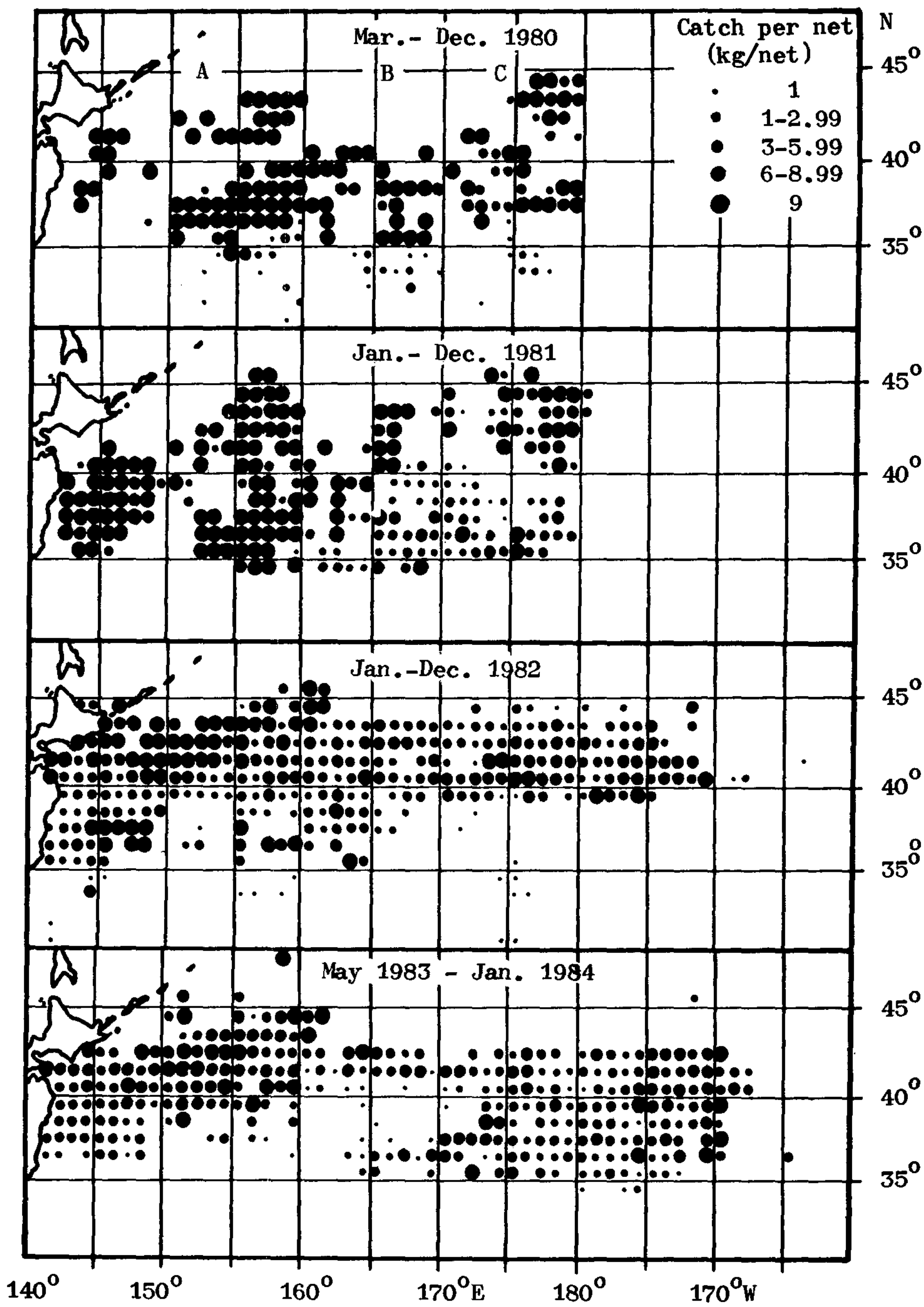

Fig. 1. Annual flying squid catch per unit net (*kg*/net) by 1° square from the Korean gillnet fishery in the North Pacific, 1980~1983.

in the North Pacific from 1980 to 1983 is shown in Fig. 1. The fishing grounds are found in the region of lat. 30°～45°N and long. 143°E～180° in 1980 and lat. 34°～46°N and long. 142°E～179°W in 1981. The ranges of the fishing grounds in 1982 and 1983 expanded to the central North Pacific west of 160°W. The number of statistical blocks with high CPUEs in the same region west of 180° tended to decrese in succeeding years from 1981 to 1983.

The distribution of monthly catch per unit net (kg/net; CPUE) by statistical block (lat. 1°×1° long.) in 1983 season is shown in Fig. 2. The number of blocks having CPUEs higher than 6 kg/net

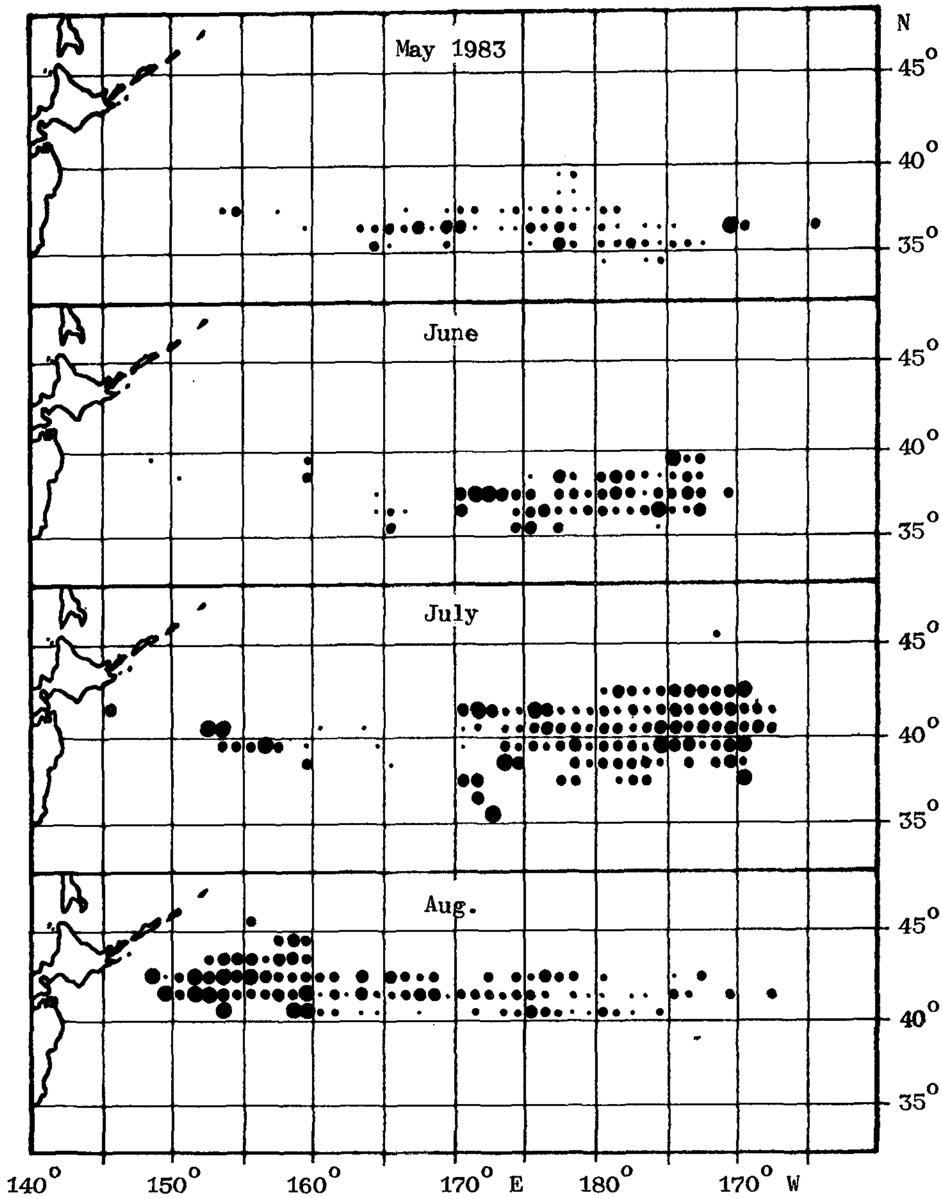

Fig. 2. Monthly flying squid catch per unit net (*kg*/net) by 1° square from the Korean gillnet fishery in the North Pacific, May 1983～January 1984.

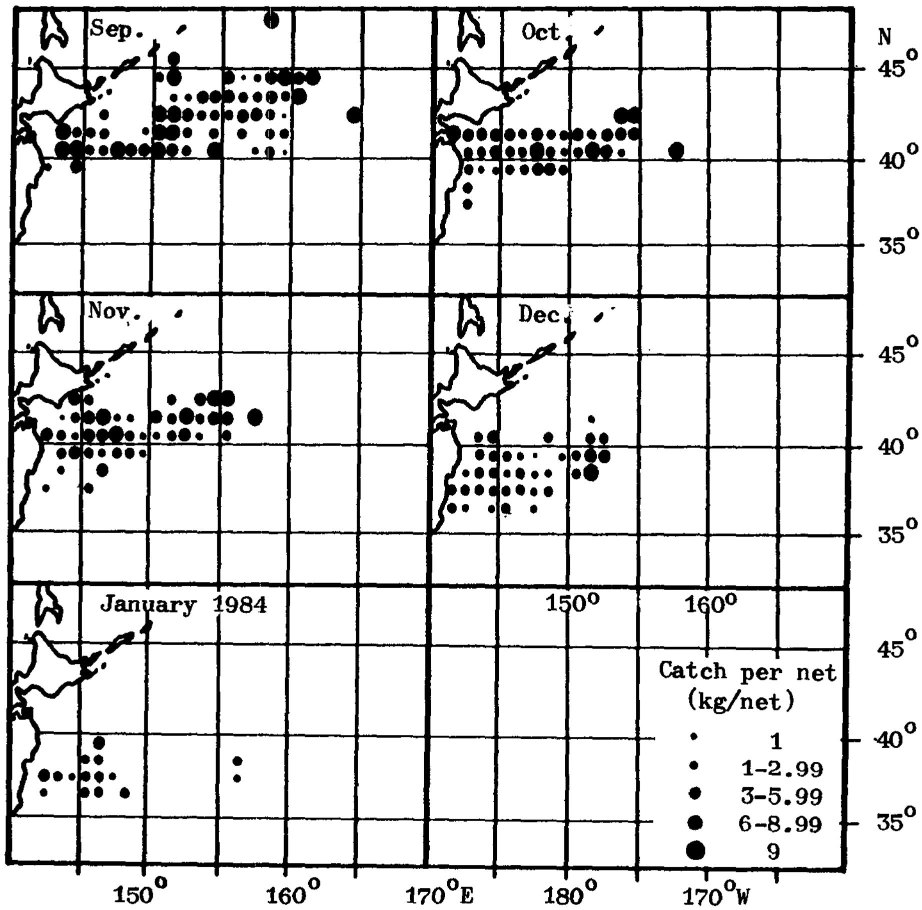

Fig. 2. Cont.

increased in succeeding months from May to July. In August, the fishing grounds were formed north of lat. 40°N and the center of the grounds was in the northwestern Pacific. In September, the fishing grounds extended from the southwest to the northeast. The centers of fishing grounds tended to shift to the north by two or three degrees in succeeding months from May to September. The CPUEs by statistical block in December were lower than in November. The centers of the fishing grounds in December shifted farther southward compared to October and November.

2. Thermal structure in the surface and density distribution

Monthly changes in frequency of catch of flying squid and surface temperatures at the locations where Korean gillnet vessels operated in the North Pacific are shown in Fig. 3. The range of surface temperatures for commercial fishing of the squid was 9°~22°C. The water temperature for the best fishing ranged from 15°~16°C in May through July and from 13°~18°C in August through January.

Catch per unit net of flying squid by statistcal block (lat. 1°×1° long.) was plotted in the horizontal distribution of temperatures and water masses derived from the infrared data of NOAA Satellite in the northwestern Pacific (Fig. 4). High densities of flying squid were found in the thermal fronts with 18°C isotherm in August and with 15°C isotherm in September.

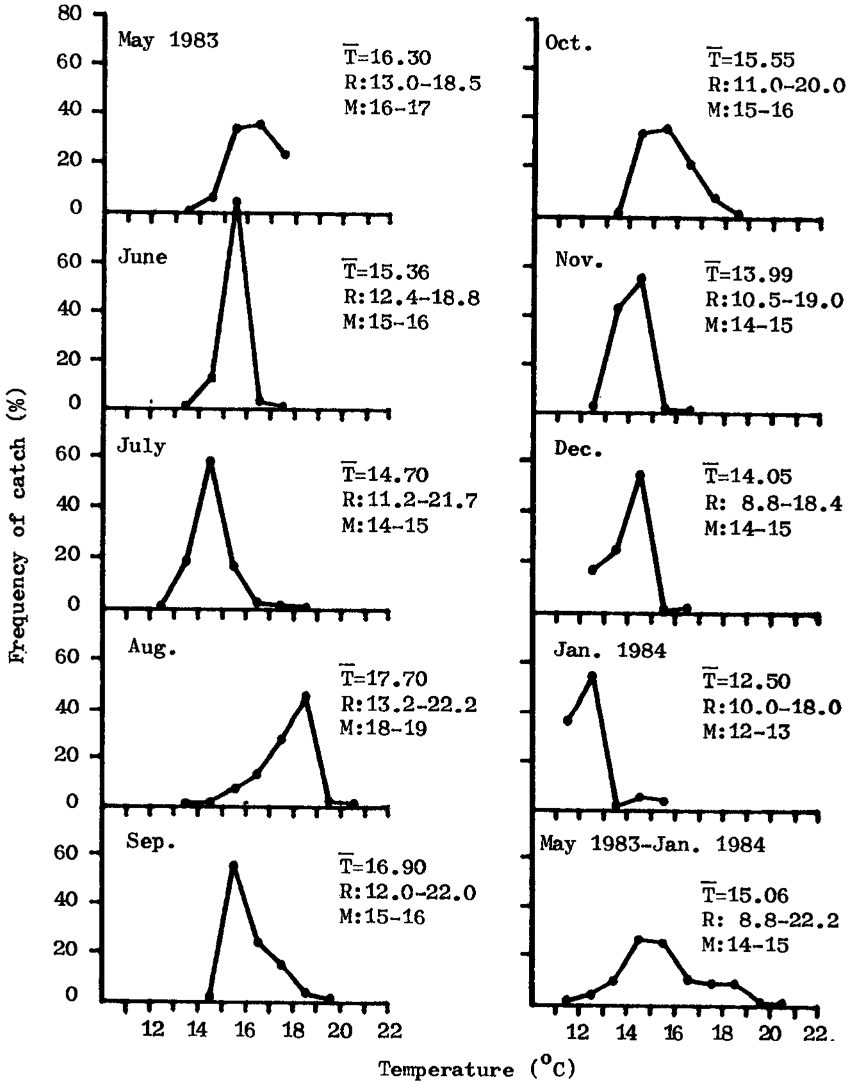

Fig. 3. Monthly changes in frequency of catches and surface water temperature (0°C) at the locations where Korean gill netters operated for fishing flying squid in the North Pacific, May 1983~January 1984. $\bar{T}$, weighted mean temperature °C; R, temperature range; M, mode.

3. Mantle length compositions of flying squid

Monthly modes derived from monthly dorsal mantle length (DML) compositions(sexes combined) in 1983 seasons are shown in Table 3. Based on the distribution of modes, catches were divided into four size groups: small (less than 25 cm), medium (27~32 *cm*), large (35~39 *cm*) and extra large sized (larger than 40 *cm*) groups. Dominant modes were at large sized group(38~39 *cm*) in the central North Pacific (region C) from June to July and at medium sized group (30~31 *cm*) in the northwestern Pacific (region A) from September to December.

Monthy DML frequency distributions of flying squid captured by the Korean gillnets by 1° latitude in the North Pacific in 1983 season are shown in Fig. 5-a. In June modes were at large sized group in the area south of lat. 39°N and at medium sized group in the area north of lat. 39°N. From July to September the larger size group were found in the northern area while the smaller size group in the southern area in each month. Large sized group with mode at 40 *cm* were found in the area

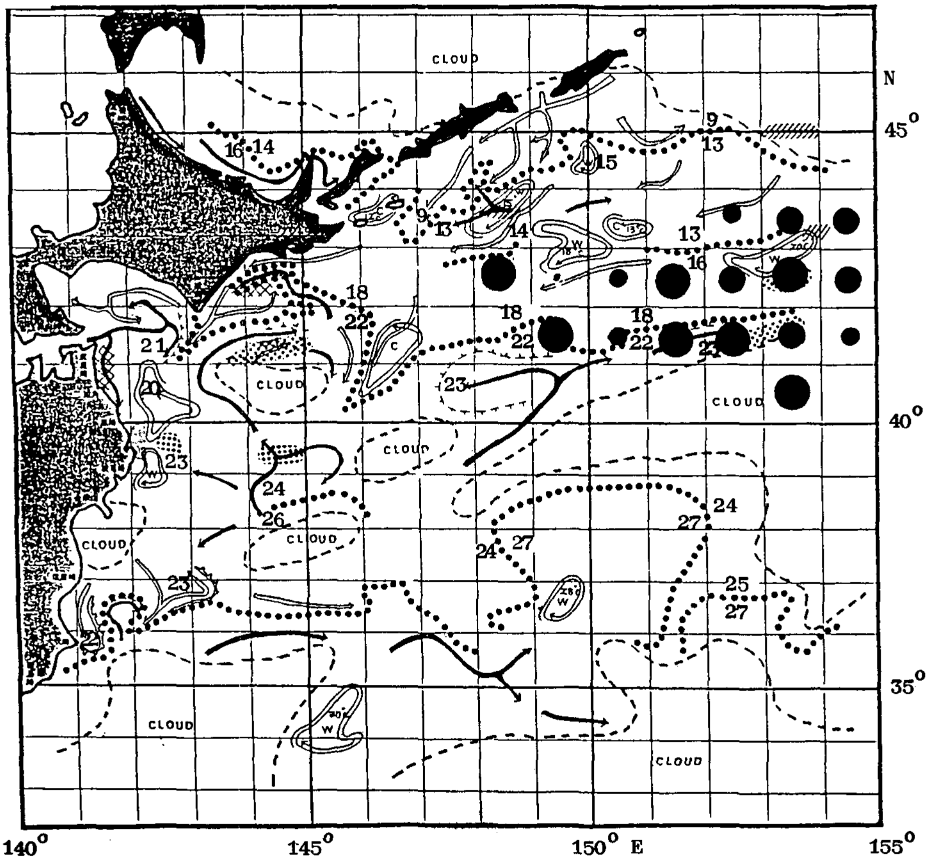

Fig. 4-a. Surface thermal structure based on the infrared imagery from Meteorological Satellites of NOAA and the catch per unit net of flying squid by statistical block (lat. 1°×1° long.) from Korean gillnet fishery in the northwestern Pacific in August 1983. Thermal structure was traced by Japan Fisheries Information Service Center(1983). Dark circle denotes catch per unit net. Small dotted lines denote the thermal fronts. Figures denots temperature, 0°C.

Table 3. Monthly modes of dosal mantle length (DML) compositions (sexes combined) of flying squid from the Korean gillnet fishery in the North Pacific in 1983 fishing season

Month	Number of specimens	Mode							Main fishing area
		S	M		L		L L		
May	143	25	29	32	**35**	38	41*cm*		B, C
June	638		28	32		**39**			C
July	698			32		**38～39**	42		C
Aug.	639	25		**32**	35		40		A, B, C
Sep.	635			**30**	36				A
Oct.	718	25		**30**	35		40		A
Nov.	590		29	**31**		39			A
Dec.	569			**31**	35		40		A
Jan.	217	22	27	**31**			43～45	49	A
May 1983 ～Jan. 1984	4,847	25	27～32		35～39		40	49	

A, West of Long. 160°E; B, Long. 160°E～170°E; C, East of Long. 170°E. Figures in Gothic letter denote the most dominant mode. S, M, L and LL represent the small, medium, large and extra large sized group, respectively.

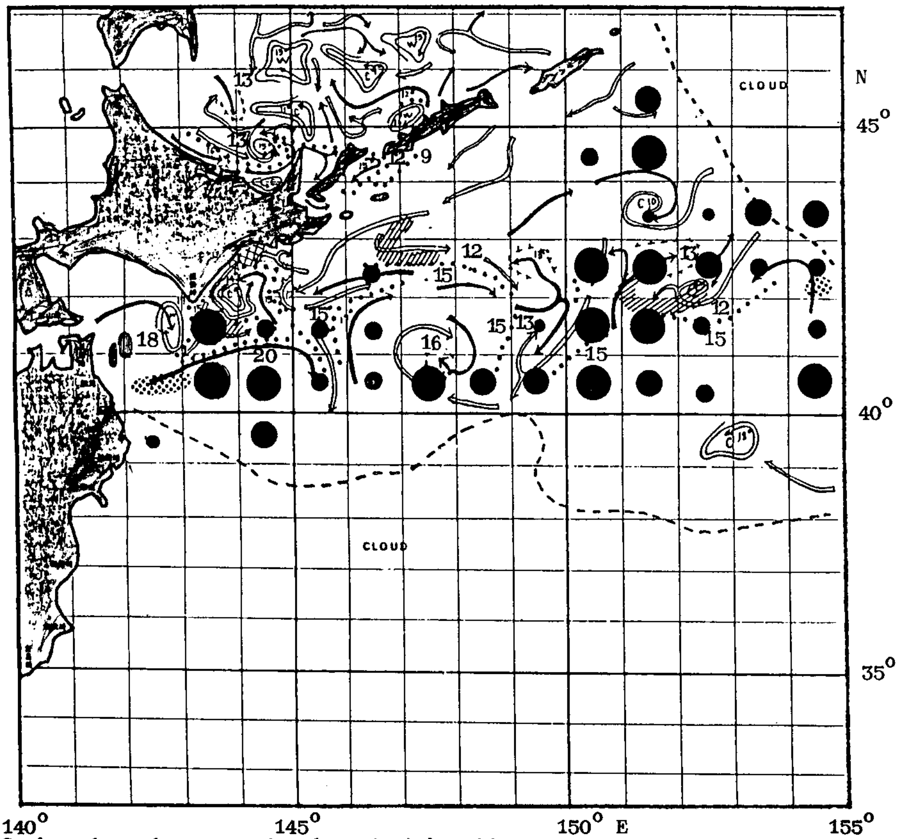

Fig. 4-b. Surface thermal structure based on the infrared imagery from Meteorological Satellites of NOAA and the catch per unit net of flying squid by statistical block (lat. 1°×1° long.) from Korean gillnet fishery in the northwestern Pacific in September 1983. Thermal structure was traced by Japan Fisheries Information Service Center (1983). Dark circle denotes catch per unit net. Small dotted lines denote the thermal fronts. Figures denote temperature, °C.

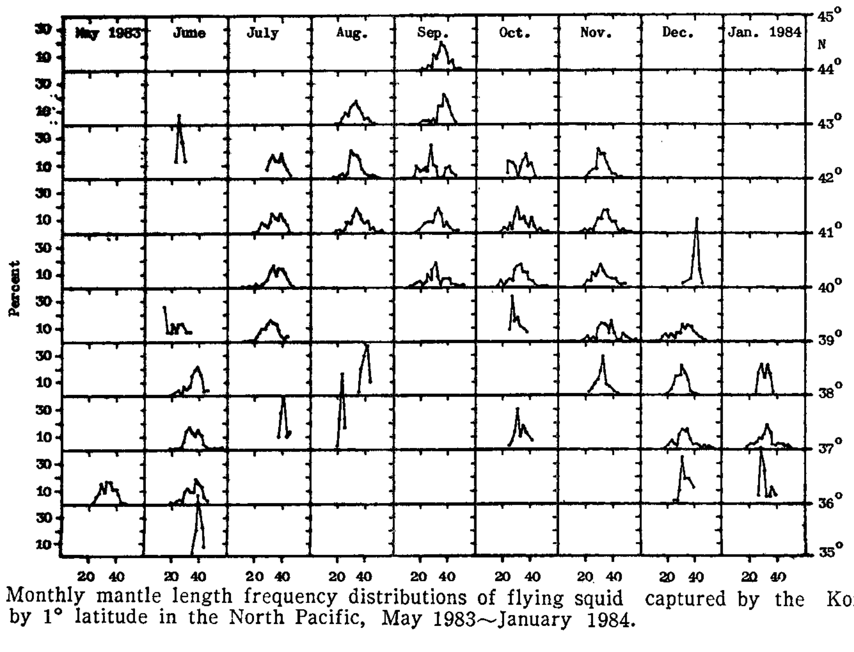

Fig. 5-a. Monthly mantle length frequency distributions of flying squid captured by the Korean gill nets by 1° latitude in the North Pacific, May 1983~January 1984.

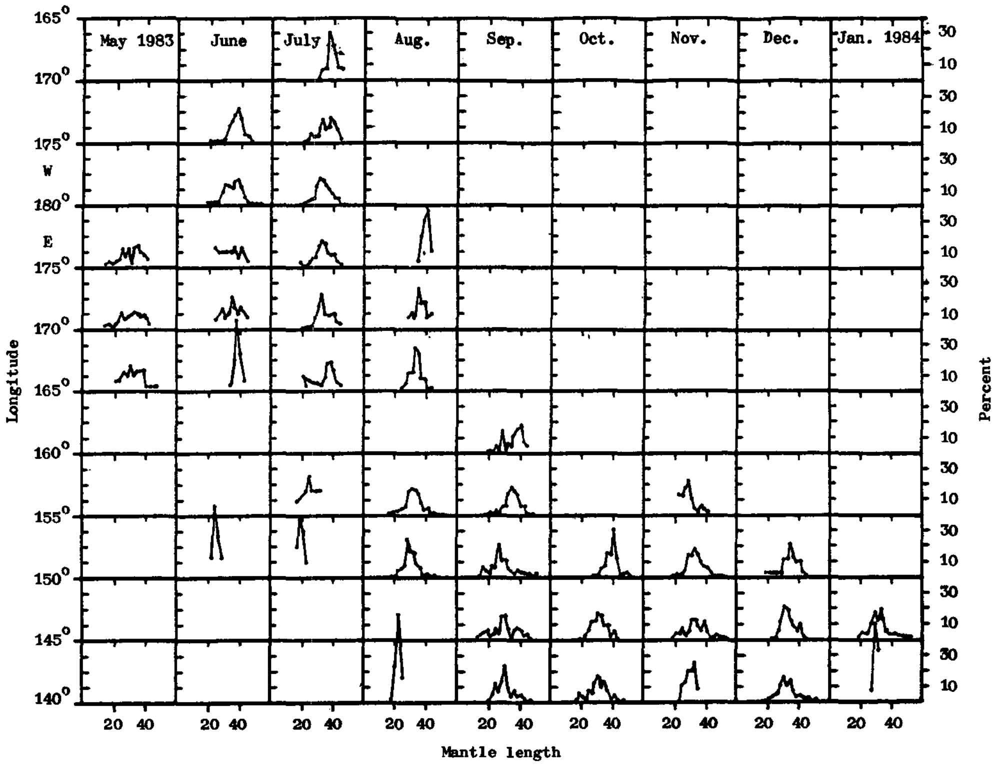

Fig. 5-b. Monthly mantle length frequency distributions of flying squid captured by the Korean gill nets by 5° longitude in the North Pacific, May 1983~January 1934.

of lat. 41°~43°N in October and in the area of lat. 39°~40°N in November. The composition rate of large sized group decreased in the area south of lat. 38°N in December.

Monthly DML frequency distributions of flying squid by 5° longitude in 1983 season are shown in Fig. 5-b. The larger the body size the higher their composition rates in the DML compositions in the east from May to October. Dominant modes were at medium sized group in the western region from November to December.

IV. Discussion

1. Exploitation of flying squid

Flying squid in the North Pacific have been caught by the Japanese jigging fishery since 1974 and by the drift gillnet since 1978 (Akabane et al. 1979, Kubota and Yasui 1980, Murata et al, 1980, 1981, 1982, 1983a, 1983b, 1984, Suisan Sekai 1982 and Ogura 1984).

With the decline of the stocks of *Todarodes pacificus* in the Japan Sea and with the economic difficulties in the tuna longline fishery, Korean deep sea gillnet vessels, most of which have been converted from tuna longliners, have increasingly shifted their efforts to the exploitation of flying squid in the North Pacific, and since 1982 catch and effort levels for this species have gone beyond the exploratory stage. The catch by 56 sampled vessels was 27,131 metric tons in the North Pacific (lat. 34°~47°N. long. 141°E~161°W) in 1983 (Table 2), indicating that the total catch by 100 vessels would be about 50,000 metic tons during 1983 season.

The Korean gillnet fishing grounds have been extended eastward year by year since 1979 and reached as far east as long. 161°W in 1983 (Fig. 1). The fishing season lasted about nine months from May through January with peak catches from July to November (Gong et al. 1984). As shown in the monthly distribution of catch per net, the center of the Korean gillnet fishing grounds tended to move from east to west in succeeding months during the 1983 fishing season (Fig. 1 and 2).

2. Fishing gear and method

The methods of fishing for cephalopods are very diverse (Voss 1973). However, the method of drift gillnet for squids has recently been developed. After searching fishing grounds, Korean fishermen began to cast their nets from about 15:00 or 16:00 hours. It takes about 2 or 3 hours to set the full string of nets at a vessel speed of 5 or 6 knots. After 7 or 8 hours the haul begins at 02:00 or 03:00 hours. It takes about 8 hours to haul all the nets. About 200 or 250 unit nets were connected as one set in summer and 150 or 200 nets in winter. The number of average gillnets used was 540 per vessel per day in 1983 season. Because fishermen use variable mesh sizes according to the body size of squid in each area, it can be assumed that gillnets used for flying squid are not selective in the analyses of catch and effort data for describing the abundance and qualitative structure of the population.

3. Life history of flying squid

Omastrephes bartrami has a trans-oceanic distribution in the subtropical region of the North Pacific Ocean from off Japan to North America (Naito et al. 1977a, Murakami et al. 1981, Baba and Akabane 1980, Murata et al. 1981, 1983b, Ogura 1984, Okutani 1973 and Young 1972). Recently it was reported that this species also occurred in the eastern Japan Sea (Kasahara 1984, Sato et al. 1984).

Based on geographically seperated spawning grounds, some authors (Murata et al. 1980, 1981, 1982, Baba and Akabane 1980) devide the flying squid into two groups; northwestern Pacific group (west of long. 170°E) and central North Pacific group. However, it is difficult to separate the population into two groups because the catch per unit effort from Korean gillnet fishing is rather high around long. 170°E.

It carries seasonal migrations. The spawning season is rather extended (January to May) and it is reported that spawning occurs in Kuroshio waters south of lat. 35°N and west of 155°E. However, considering that fishing grounds of the Korean gillnet fishery in winter and spring covered a broad area (Fig. 1 and 2), it would appear that spawning grounds of flying squid in the North Pacific are quite large extending to the central North Pacific.

Baba and Akabane (1980) indicated, from migration routes of flying squid in the northwestern Pacific, that the northward migrations turn to the northeastward. It is possible to distinguish fast-groowing and slow growing groups, and the former occurs earlier in the northern area than the latter (Murakami 1976, Murata and Ishii 1977, Roper et al. 1984). Naito et al. (1977a) and Murakami et al. (1981) reported that the large mantle size group always appears ahead of the small one during both the northward and southward migrations and the distributional range of the large squid extends farther offshore than the smaller squid.

The monthly mantle length compositions from Korean catches show that the large sized group occurs in the northern area earlier and is distributed farther eastward than the small sized group (Figures 5-a and 5-b). However, it is noticed that the large sized group does not always appear ahead of the small sized group.

Ishii (1977), Murata and Ishii(1977) and Tamura and Nakata (1983) believed that the flying squid spawns from late autumn to winter and the life span is one year. On the other hand Murakami et al. (1981) and Kubodera et al. (1983) stated that the large sized group with DML 40 *cm* and over are 2 years old.

4. Oceanographic structure and density distribution of flying squid

There are many reports on temperatures in the flying squid fishing grounds in the northwestern Pacific (Amano et al. 1984, Murata and Araya 1970, Murakami 1976, Murata et al. 1976, 1980, 1983a, 1983b, 1984, Naito et al. 1977a, and Kubodera et al. 1983). However, their fishery data have not been related to oceanographic conditions. Kawakami (1983) reviewed the temperature range and optimum temperatures for squid fishing in the Kuril Front region. According to those reports, the range of water temperatures in which flying squid were caught throughout the fishing season in the north Pacific was 6°~24°C with highest catches in 15°~20°C waters. In particular, Kubodera et al. (1983) stated that seasonal changes in ditstribution and abundance of *Omastrephes bartrami* appeared to be closely correlated with surface water temperature. Sea surface temperatures in the Korean drift gillnet fishing grounds west of long. 161°W ranged from 9°~22°C and the most favorable temperature for flying squid fishing was 15°C in terms of weighted mean temperature (Fig. 3).

Kubodera et al. (1983) indicated that the thermal front and salinity front in the Subarctic Boundary zone could be a barrier to flying squid in the northward migration season. The northern limit of the Korean flying squid gillnet fishing ground as shown by catch per net in statistical block (lat. 1°×1° long.) and oceanographic data in the region(Figures 1, 2 and 4) reached the Subarctic Domain in autumn. The horizontal gradients of temperature and salinity in the Subarctic Boundary zone were higher in the west than the east (Muromtsev 1958, Dodimead et al. 1963, Favorite et al. 1976). It is easy to understand why the density of flying squid in the west would be higher than the east based on the oceanographic structure.

5. Migration model of flying squid in the North Pacific

A migration model for flying squid was hypothesized based on the monthly distributions of abundance indices, monthly mantle length compositions by statistical block and the hydrographic features of the North Pacific (Fig. 6).

As shown above from the horizontal distribution of oceanographic characteristics, the oceanic structure of North Pacific is devided into three different waters. The further westward, the narrower the Transitional Domain and the higher the horizontal gradient of oceanographic characteristics. Based on monthly mantle length compositions of flying squid captured by the Korean gillnets, by 1° latitude and 5° longtude, the large sized groups of flying squid occurred more frequently in the northern and eastern areas of the fishing grounds. Naito et al. (1977a) indicated that the larger squids migrate faster and move ahead of the smaller squids during the northward and southward migration period. In the beginning of the migration period all groups start to migrate at the same time. However, the large sized group starts to move southward from the northern area while the small sized group from the southern area. In the fishing grounds, the larger group moves ahead of the smaller group during the southward migration period. Accordingly

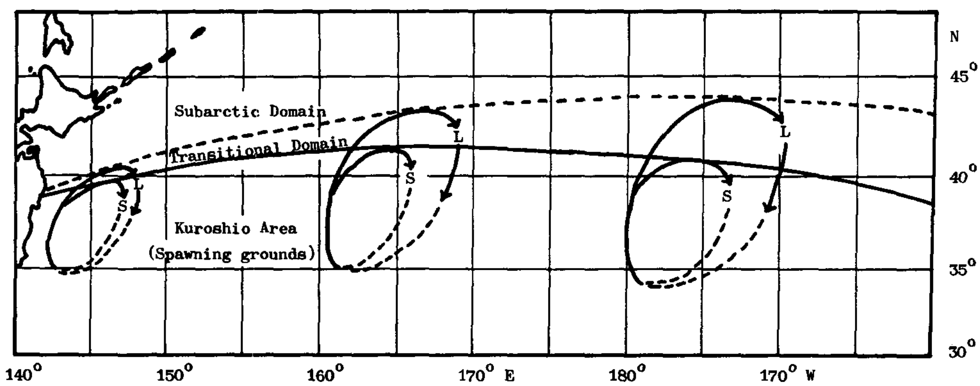

Fig. 6. Hypothesized migration routes by size groups of flying squid in the North Pacific. Full line denotes the Subarctic Boundary and dashed line the salinity front. L denotes the large sized group and S the small sized group of flying squid. Dashed portions in the migration circuit indicate the period of southward migration at the subsurface layer.

the larger sized group does not always move ahead of the smaller squid everywhere in the North Pacific.

The flying squid which are spawned south of the Subarctic Boundary in winter carry out northward migration in the warm water system of Kuroshio and grow relatively fast in spring and summer. The first born and faster growing large sized group of flying squid enter the Transitional Domain after passing the thermal front in the Subarctic Boundary but they are prevented from migrating farther north by the salinity front between the Transitional and Subarctic Domain. On the other hand the slow growing small sized group become concentrated in the thermal front. They begin the reverse southward migration in autumn with the onset of cooling and the development of the Oyashio Current. The large size group starts to return from the northern area and the small size group from more southern area but the former reaches the spawning ground earlier because they move ahead of the small size group during the migration. The density of flying squid in the northwestern area is higher than that in the central North Pacific area because of the oceanographic structure. Distances between oceanographic boundaries are narrower and the size of migration circuits smaller in the northwest than in the central areas as shown by the migration model (Fig. 6).

The general pattern of movement and migration of flying squid is clockwise in the North Pacific. However, the monthly movement of the center of the Korean drift gillnet fishing grounds was counterclockwise.

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北太平洋에 있어서 빨강오징어 *Ommastrephes bartrami* (LeSueur)의 分布 및 回遊

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1980年 부터 1983年까지의 韓國流刺網 漁船에 의한 빨강오징어의 漁獲量, 努力量, 胴長 및 表面水溫 資料를 基礎로 빨강오징어의 季節別 分布와 回遊를 밝혔다.

빨강오징어의 漁獲이 좋았던 水溫은 5~7月에는 15°~16°C, 8~1月에는 13°~18°C이었다. 높은 分布密度는 8月에는 18°C等溫線 그리고 9月에는 15°C等溫線을 中心으로 한 熱前線域에서 나타났다. 北太平洋에 있어서 分布密度가 東部海域보다 西部海域에서 더 높은 것은 海洋特性値의 分布傾度가 높기 때문이다.

努力當漁獲量, 胴長組成 및 海洋構造를 基礎로 北太平洋에 있어서 빨강오징어의 回遊모델을 作成하였다. 北上期(6~8月)에 大型群은 小型群보다 먼저 北上하고 먼저 東方에 出現한다. 秋季에는 冷却과 親潮의 발달에 따라 亜寒帶前線域으로부터 南下回遊를 시작한다. 大型群은 小型群보다 더 北部海域에서 南下를 始作하나 南下途中에 小型群을 追越하여 産卵場에 먼저 到達한다.