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Why is Autumn the Main Spawning Season of the Common Squid in the Japan Sea ?

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Abstract

Monthly changes in catch, mantle length, and prey of the common squid, *Todarodes pacificus*, in the Japan Sea were analysed in relation to the seasonal variation in spawning quantity. First, the mantle length for each month did not represent the poly-modal distribution as a whole, but there were some different trends among fishery areas. Second, the seasonal changes of prey and main fishery area corresponded well to the distributions of zooplankton and small fish. We propose that the common squid spawn all year round with variation of quantity and that natural selection favours the squid which synchronize their life cycle with the seasonal change in the amount of prey. This can explain why the spawning quantity of common squid is a maximum in autumn and a minimum in spring in the Japan Sea.

Key words common squid, spawning season, population structure, mantle length, prey, Japan Sea

Introduction

The common squid, *Todarodes pacificus*, distributed around Japan has an extended spawning season, and there is a large amount of spawning from summer to winter (SOEDA 1956; ARAYA 1958; HAMABE and SHIMIZU 1966; SHOJIMA and HOTTA 1972). HAMABE and SHIMIZU (1966) recognized the three groups of summer, autumn, and winter by analysing the growth, maturity, and migration pattern in the Japan Sea. Although they provided rather obscure definition, the concept has not been confuted and has been used in many studies with some modifications. However, it is controversial whether or not groups sprung from these seasons remain so completely separated from each other that one can regard them as local populations (SHINGU 1982). It is estimated that in the Japan Sea, the largest number of squid mature in autumn, the next largest in winter, and the least in summer (e.g., KASAHARA 1991). It is reasonable to presume that the spawning quantity

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depends on the amount of mature squid to some extent. KASAHARA (1987) found a linear relationship between the catch of the common squid in the open water and the relative amount of larvae in autumn in the Japan Sea. In this study, we consider the following as facts and proceed with our discussion. First, the spawning of common squid is eminent from summer to winter, although the squid spawns almost all year round. Second, among these seasons, the autumn spawning, of which the main months are October and November, is dominant in the Japan Sea and the winter spawning, February and March, in the Pacific.

Although studies on the population of the common squid have often supposed that there are three seasonal groups (e.g., ADACHI 1989), few studies have discussed why there are three seasonal groups. ITO *et al*. (1965) emphasized the importance of prey environment to the biological characteristics of the common squid in the Japan Sea. In this paper, we discuss the issue from the aspect of availability of prey. We analysed monthly changes in catch, mantle length, and prey of the common squid in the Japan Sea and found a clear relationship between the distributions of the common squid and prey. We adopted a hypothesis that an individual maximizes its fitness if it grows most rapidly when prey organisms are most abundant. Using this hypothesis, we schematically explain the difference in spawning quantity between the seasons as a result of seasonal change in the distribution of prey.

Materials and Methods

Prefectural fisheries experimental stations*, high schools**, and the Japan Sea National Fisheries Research Institute have performed angling experiments on the common squid systematically in the Japan Sea. We used the biological data obtained by the experiments from 1973 to 1977. Because of the 200 mile economic zone, few data have been available in the Russian region since 1978. The catch data of the common squid are available for each sub-area by official statistics. Fig. 1 shows the map of areas that were designated by the Fisheries Agency of Japan for the common squid fishery statistics.

The data of mantle length were classified according to where and when they were obtained. In this paper, mantle length is examined with the data for 1974 only, because 1974 has the most data and there is much incompleteness in other years. We think that the data for 1974 can represent that for the early 1970s, when the common squid maintained a hign level of the resource in the Japan Sea. Table 1 lists the number of samples for each area and month in 1974. A sample consists of specimens which were sampled from an angling expeiment during one night. The number of specimens measured in a month were not weighted by its CPUE of experiment but simply added. The histogram of mantle length was estimated with the catch in number. The number of squid caught in each area and month was calculated with the catch in weight and length-weight relationship. If the length-weight relationship for a certain area and month was not available, we used the average weight for adjacent areas.

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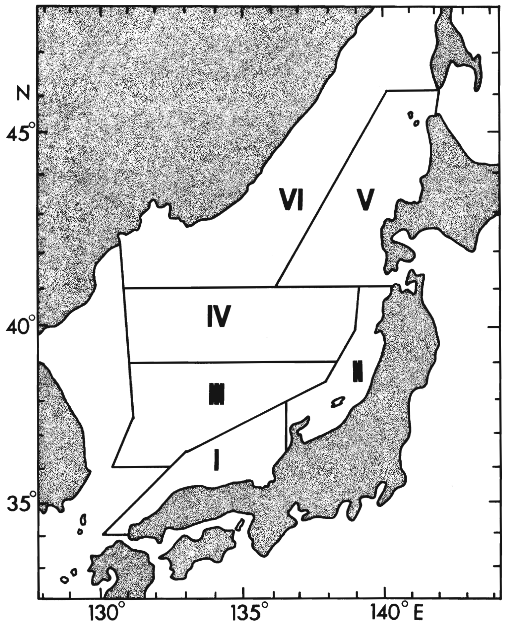

Fig. 1. Map of areas in Japan Sea designated by Fishery Agency of Japan for common squid fishery statistics. Roman numerals correspond to area numbers in Table 1.

Table 1. Number of mantle length samples of common squid in each area of Japan Sea in 1974.

Area number	Area	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.
I	Western coast of Japanese Mainland	0	2	2	0	0	0	0
II	Northern coast of Japanese Mainland	0	2	4	0	1	0	0
III	Southern open water	14	19	14	5	6	13	12
IV	Northern open water	8	14	30	24	25	15	0
V	Coast of Hokkaido	0	0	12	11	3	3	0
VI	Coast of Russia	0	0	14	17	20	3	0

The data of stomach contents were also classified according to fishery areas and months. The stomach contents were categorized as fish, zooplankton, and squid.

Results

1 Mantle length distribution

The monthly change in catch is as follows. Table 2 and Fig. 2 show catches in weight and number for each area and month in 1974. The total catch in number reached its maximum in July and catch in weight in August, and then they slowly decreased. The

Table 2. Catch in weight, catch in number, and average body weight of common squid in each area of Japan Sea in 1974. Upper, middle, and lower numbers show catch in tons, catch in 10^3 number, and body weight in g, respectively.

Area number	May	Jun.	Jul.	Aug.	Sept.	Oct.
I	349 2,187 160	1,258 7,289 173	211 1,506 140	313 1,174 267	27 78 346	222 672 330
II	2,142 13,775 156	6,679 34,111 196	6,520 36,445 179	2,884 11,109 260	1,569 4,730 332	587 1,929 304
III	3,096 19,398 160	5,023 27,968 180	3,533 17,700 200	2,135 8,005 267	5,130 14,234 360	6,321 19,149 330
IV	2,199 14,524 151	8,717 45,026 194	15,135 72,382 209	18,894 70,134 269	14,682 43,709 336	13,907 41,024 339
V		1,215 6,240 195	701 3,493 201	9,123 37,574 243	9,191 55,501 166	4,361 17,888 244
VI		2,842 14,680 194	10,194 45,428 224	10,846 39,383 275	10,644 35,129 303	9,142 31,470 291

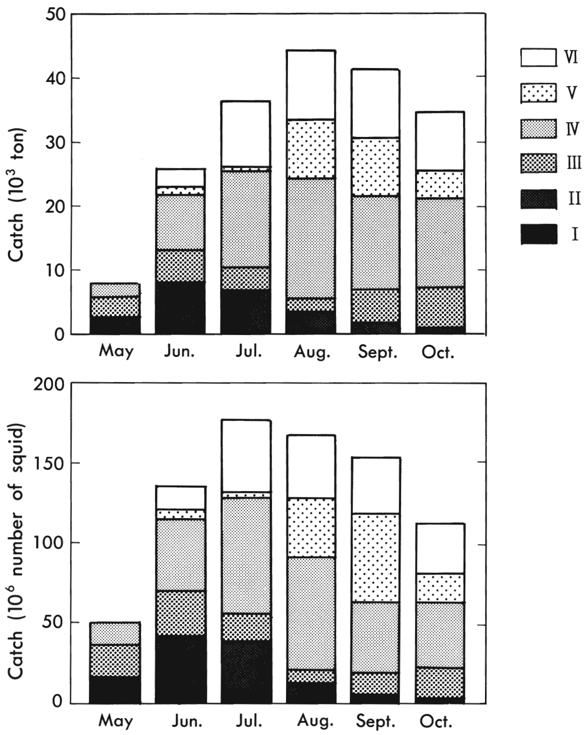

Fig. 2. Monthly changes in catch in weight (upper) and number (lower) of common squid in Japan Sea. Roman numerals represent area numbers in Table 1.

northern part of open water, area IV, and the coast of Russia, area VI, produced approximately 60% of total catch in weight, and their catch leveled off from July. In the southern open water, area III, there are two peaks of catch in weight in June and October. Along the Japan islands, the coastal areas of the Japanese Mainland, areas I and II, were main fishery grounds from May to July and the coast of Hokkaido, area V, from August to October. The main fishery ground moved from the southwestern to northeastern part of the Japan Sea and returned to southern areas in the late period of the fishery season.

Fig. 3 shows the histogram of mantle length for each area and month. There is a trend, which is typical in area IV, that the mantle length increased with each month until August and leveled off from September. The length at mode increased 1 or 2cm per month

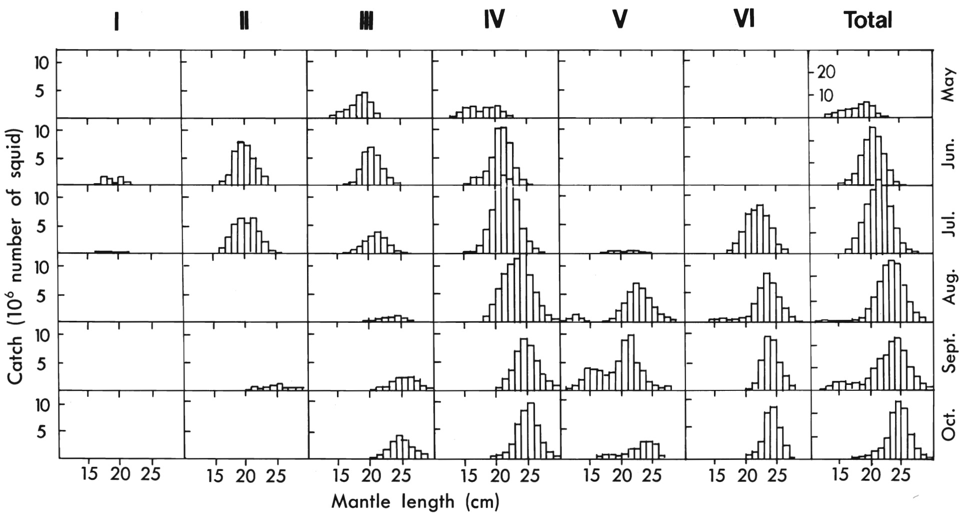

Fig. 3. Histograms of mantle length of the common squid caught in Japan Sea. Roman numerals represent area numbers in Table 1.

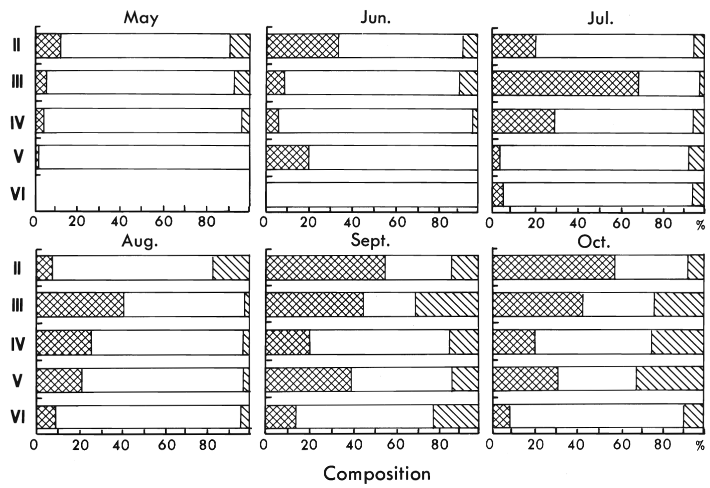

Fig. 4. Stomach contents of common squid caught in Japan Sea from 1973 to 1977. Mesh, blank, and shaded poritions indicate fish, zooplankton, and squid, respectively. Roman numerals represent area numbers in Table 1.

until August. There are some differences among areas. Areas V and VI had two modes in the histogram, and other areas had one mode. In June and July, the length at mode was larger in the northern areas than in the southern areas. From August, it was larger in areas III and IV than in areas VI and V. However, the mantle length distribution that summed up all areas showed one mode, except for September.

2 Stomach contents

We examined the monthly change in stomach contents of the common squid. Fig. 4 shows the composition of stomach contents for each area from 1973 to 1977. Zooplankton was the most common prey, and it occupied a larger share in the early months and northern areas. The share of fish was large in the late fishery season and in the southern areas. The occurrence of squid was rather sparse. It was restrained only in southern areas in the early fishery season, and it occurs in both the southern and northern areas in the late season.

In order to compare the stomach contents and prey distribution, we outline the distributions of zooplankton and small fish in the Japan Sea. The distribution of zooplankton is as follows (Fig. 5). NISHIMURA (1965) suggested that it is a feature of the Japan Sea that large meso-bathypelagic zooplankton move to the surface layer and that the productivity of zooplankton increases rapidly in spring. He reported that these zooplankton include *Themisto japonica* and *Euphausia pacifica*, which are important prey of the common squid (OKIYAMA 1965). MORIOKA (1980) calculated the average standing crops in the two areas of north and south, divided by latitude 40°N. The standing crops of both

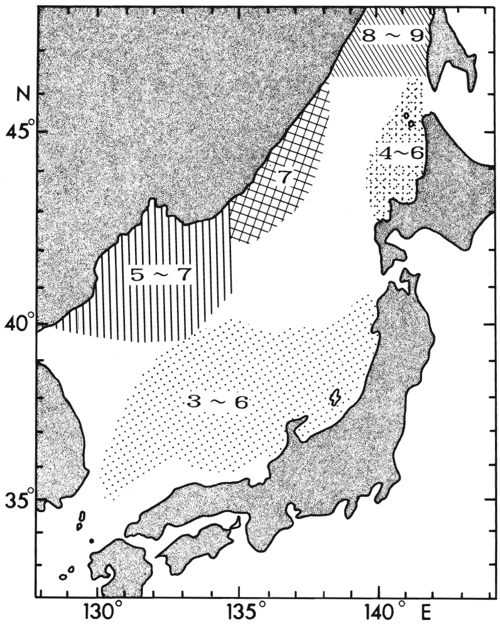

Fig. 5. Schematic map of zooplankton bloom in Japan Sea. Figures represent months in which zooplankton biomass is most abundant.

areas reach their peak in April. MESCHERYAKOVA (1960) summarized seasonal change in the amount of zooplankton as follows. The increase of zooplankton begins in the south-eastern and middle part of the Japan Sea in March and disappears in the southeastern part in late May or early June. In the Peter the Great Bay and in the southwestern coast of Sakhalin, the peak of zooplankton quantity occurs in April to early July. In the Strait of Tartary and in the northern coast of Eurasia Continent, namely Primorye (Enkaishu) coast, copepods begin to increase from August and reach their maximun in September and October. In the southern and eastern part of the Japan Sea, the amount of zooplankton is lowest from late October to February, and it is also very low in the northern part of the Japan Sea in February.

The distribution of small fish is as follows. OKIYAMA (1965) reported that the common squid consumes large amounts of Japanese pearlsides *Maurolicus muelleri*, Pacific saury *Cololabis saira*, and Japanese anchovy *Engraulis japonica*. NISHIMURA (1965) reported that species of the coastal area spread their distribution to the open water during summer when the low salinity and high temperature water of the Tsushima Current extends widely in the Japan Sea. These species include Japanese pearlsides and Japanese anchovy (OKIYAMA 1978).

The monthly change in the stomach contents of the common squid relates well to the distributions of zooplankton and small fish. In May, when the amount of zooplankton is highest in the Japan Sea, zooplankton occupies nearly all of the stomach contents. Afterwards, when Japanese pearlsides and Japanese anchovy begin to spread their distributions to the open water after the disappearance of zooplankton, the rate of fish in the stomach contents increases particularly in the southern part. Even in autumn, zooplankton still occupies more than half of the stomach contents in Primorye, where the amount of zooplankton is prominent.

Furthermore, the seasonal change in fishery ground fits the distribution of prey species. From May to July, the main fishery ground moves to the north as the region which is most abundant in zooplankton moves. In the northern area, the mantle length of the common squid is larger than for other areas. In August, large-sized specimens move to the middle region where the prey fish are distributed densely. From September, this tendency becomes more distinct because of the migration induced by maturity. In the northern area, in which zooplankton flourishes in autumn, the mantle length of the common squid is smaller than for other areas.

Discussion

Although the data examined only covers from May to October and there are few data for area I, we can safely infer some points from the results. First, as a whole, the mantle length for each month did not represent the poly-modal distribution which suggests the existence of clearly separated seasonal groups. However, there were some different trends among fishery areas. A reasonable interpretation is that the common squid continuously spawns all year round with variation of quantity, and it changes its distribution as it grows by migration for feeding. Second, seasonal changes in prey and the main fishery areas correspond well to the distritbutions of zooplankton and small fish. These results suggest the importance of prey quantity to the growth of the common squid. We will discuss in detail the relationship between prey distribution and seasonal variation in the spawing quantity of the common squid.

In January and February, there is rather small amount of prey available to the common squid. From May or April to October, the common squid can find an area with rich prey somewhere in the Japan Sea. If the seasonal change of the standing crop of prey is stable for long time, a common squid that synchronizes its life cycle with the change seems to attain higher fitness with respect to feeding. Let us estimate the month that produces the common squid whose rapid growth period starts in spring. MURAYAMA (1987) analysed the seasonal change in mantle length of the common squid in the western part of the Japan Sea. He concluded that the weight of the common squid increases rapidly from the age of five months and reaches its maximum at the age of eight or nine months. Therefore, it is the period from October to November that prouduces the common squid which starts to growth rapidly in March or April. This can explain the fact that the spawning of the common squid is most abundant in autumn.

The amount of spawning of the common squid appears to be a minimum in spring in the Japan Sea. The hypothesis can explain this because the squid that rise in April and May still remain in their rapid growth period in November and December, which are the most poor months with respect to the amount of prey, according to the calculation by MURAYAMA (1987).

If the relationship between the prey amount and the life cycle of the common squid is valid, it will be applicable to the common squid in the Pacific. ARAYA and ISHII (1972) gave a monthly change in mantle length distribution in the Pacific coast of Hokkaido. By comparing the mantle length with that in the Japan Sea, one can find that there is a difference of two months between the two regions (Fig. 6). In Fig. 6, the mode of mantle length for each month in the Pacific is almost the same as that in the Japan Sea two months before. This means that the main group in the Japan Sea is born two months earlier than in the Pacific. If our hypothesis is right, the month in which the amount of prey begins to increase in the Japan Sea will be two months earlier than in the Pacific. According to ODATE (1980), the monthly mean of wet weight of zooplankton obtained in the northeastern Pacific coast of Japan is already high in March and April, reaches its maximun in May, and is continuously high until July or August. However, the surface temperature for most of the region is below 5℃* and it is too low for the common squid to feed vigorously. It is not until May or June that the temperature becomes higher than 7℃* which is the lower limit of suitable temperature for the common squid**. On the other hand, the surface water temperature already exceeds 10℃ in the southern part of the Japan Sea in March and April (NAGANUMA and ICHIHASHI 1985). This may explain the difference of two months.

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* Nihon kinkai kaikyozu (1985–1988): Japan Oceanographic Data Center.

** Fisheries Agency, unpublished.

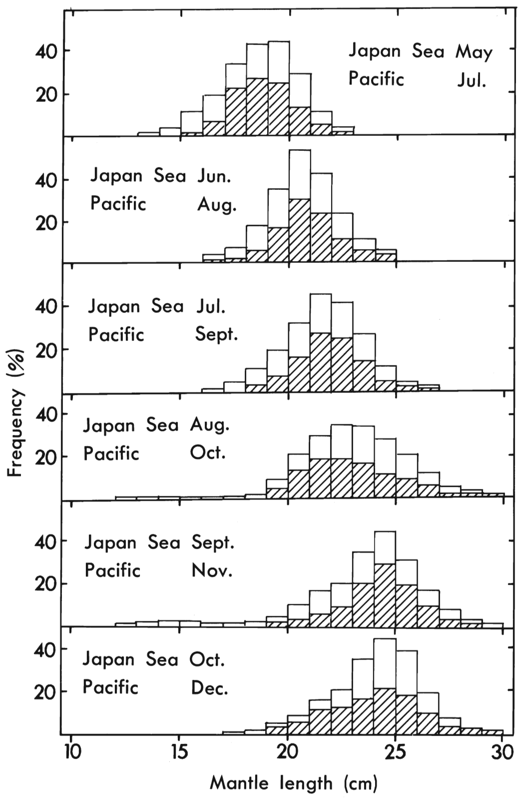

Fig. 6. Histograms of mantle length of the common squid. Shaded portion represents squid caught in Pacific coast of Hokkaido in 1969 (after ARAYA and ISHII 1972) and blank portion in Japan Sea in 1974.

We schematically explained why the spawning quantity of the common squid varies seasonally with a hypothesis. We only addressed a qualitative and general aspect of spawning seasons, and it is another problem why the spawning quantity fluctuates yearly. Furthermore, we admit that there are important factors in addition to prey distribution which may cause the variation in spawning, such as the spawning success. The data analysed in this paper had spatial and temporal limitations. It is desirable that more accurate studies should be performed with the multitude data for the coastal areas and winter.

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日本海のスルメイカ産卵量はなぜ秋に多いのか？

村山達朗・檜山義明・笠原昭吾

スルメイカ産卵量の季節的な変異に関連して，日本海の漁獲量，外套長組成と胃内容物のデータを解析した．外套長組成は，海域によっていくつかの異なる傾向を示したが，日本海全体の各月の組成は，複数のモードを持たなかった．胃内容物と主漁場の季節変化は，動物プランクトンと小型の魚類の分布によく対応していた．著者らは，自然選択圧が，餌生物量の季節変化にスルメイカの生活史を適合させる方向に働くという仮説を提唱する．この仮説は，日本海において，秋季の産卵量が最も多く，春季に最も少ないことを説明する．