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FISHERY, BIOLOGY AND STOCK ASSESSMENT OF *OMMASTREPHES BARTRAMI* IN THE NORTH PACIFIC OCEAN

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Abstract

Fishing for the squid, *Ommastrephes bartrami* in the Pacific waters adjacent to Japan began in 1974. By 1978 the *O. bartrami* catch had increased to about 150 000 tons, making it second in squid catch in Japan, surpassed only by *Todarodes pacificus.* Since the establishment of the ordinance for fishery control by the Japanese Government in 1979, the fishery has been by jigging in the waters west of 170°E and by drift gilnetting in the waters east of 170°E in the Pacific north of 20°N.

In the north Pacific, *O. bartrami* is distributed extensively between Japan and North America, and the squid populations in these waters consist of several groups in different stages of growth. Population densities in the north Pacific are high in the waters west of 165°E and east of 170°E, and low in the area between 165°E and 170°E. It is therefore assumed that the two populations are independent of each other.

Based on ecological studies of the *O. bartrami* population in the waters west of 165°E, the squid migration follows the movement of the Kuroshio branch current, northward in spring-summer and southward in fall-winter. The squid fishing season is mainly from summer to fall; the fishing grounds are in the warm branch of the Kuroshio current and in the boundary zone of the warm branch and the cold Oyashio current. In the fishing grounds, a spring layer with temperatures over 10°C forms in the upper stratum, and squid generally congregate in and above this layer. *O. bartrami* feeds mainly on fish, most commonly on Lantern fish, Myctophidae. The growth of *O. bartrami* is remarkably rapid; squid hatched in the Kuroshio counter-current area grow to juveniles during the northward migratory season from spring to summer and to adolescents in the waters off eastern Hokkaido from summer to fall. In the southward migratory season, both sexes become adult, and when the gonads begin to mature, the mantle lengths have increased to 29-35 cm. The life span of *O. bartrami* is estimated to be about one year, as the male dies after copulation and the female after spawning.

Judging from statistical analysis and differences in mantle length of the squid caught every year, it is estimated that the resource of *O. bartrami* in the waters west of 170°E is declining. This is considered to be caused by over fishing.

Introduction

Until 1974, *Todarodes pacificus* Steenstrup was the major squid caught in waters adjacent to Japan, followed by sepiids and loliginids. In 1970, the catch of *T. pacificus* started to decline and *Ommastrephes bartrami*, which had been neglected until then, became a new target species to cover the decrease of *T. pacificus.* Beginning in 1974 the annual catch of *O. bartrami* continued to increase until it now occupies second position in the squid fishery following *T. pacificus.* After several years of fishing for this species, however, a remarkable change appeared in the condition of the population, and a method is urgently needed to estimate and assess the resource of *O. bartrami* for proper control.

The condition of the *O. bartrami* fishery is discussed in this paper. Information on the biology and changes in the resource also are presented.

1. General description of Fishery

(1) *Catch.* The presence of *O. bartrami* in the Pacific Ocean adjacent to Japan has been well-known for a long time. However, a high abundance was demonstrated for the first time in 1973 when cooperative investigations were initiated by the Fisheries Research Laboratory and the Fisheries Experimental Station. Based on this investigation the fishery for *O. bartrami* began in 1974. The *Ommastrephes* fishery developed raidly with improved food processing techniques and increased demand. The catch was 17 000 tons in 1974, increased each year and reached 151 000 tons in 1978 (Fig. 1). This enormous increase in catch was achieved mainly by expanding the fishing grounds, increasing the number of fishing boats, and improving fishing gear and methods. Drift gillnet fishing began in 1978 and was a great success. Nevertheless, in 1979, the catch decreased for the first time to 124 000 tons. Of these catches, 40 000-50 000 tons are estimated to be by the drift gillnet fishery for the years 1978 and 1979.

(2) *Fishing season and fishing grounds.* The jigging fishery for *O. bartrami* usually begins in July, peaks from August to October, and

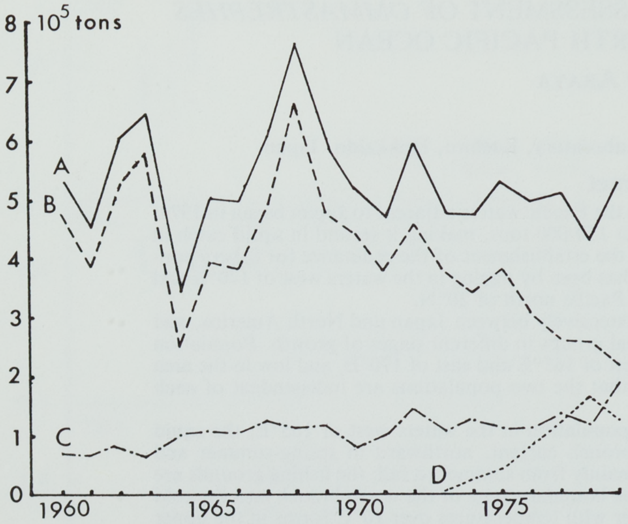


Figure 1. Squid landings in Japan
A: Total catch B: *Todarodes pacificus*
C: Other species (Sepiidae and Loliginidae)
D: *Ommastrephes bartrami*

rapidly declines in November. The squid jigging ground has continued to expand eastward from year to year. The eastern limit of the jigging ground which was 150°E in 1974 and 1975, extended to about 165°E in 1978 and 1979 (Fig. 2).

Let me illustrate seasonal changes of the jigging grounds in 1978. During the early season (July) the main ground was situated between 39° and 40°N Lat. and between 152° to 160°E Long. in the North Pacific. A small ground appeared also along the Joban Coast. During the height of the fishing season, the jigging grounds shifted northward to 40° to 46°N Lat., making three major grounds: west of 149°E, 150°-159°E and 160°-165°E. Small-sized boats of less than 30 tons operated west of 149°E, medium-sized boats between 30 and 99 tons fished west of 159°E and large boats over 100 tons fished between 150° and 165°E. From late October through November, the grounds east of 159°E diminished and moved southward or westward. The grounds west of 150°E also moved southward in November and December (Figure 3).

The drift gillnet fishery of *O. bartrami* began in September of 1978 and a number of boats took part in this fishery in the area west of 150°E until December of that year. However, the fishery was totally prohibited in the area north of 20°N and west of 170°E from January of 1979. Thus, the main ground from August to December of 1979 changed its location to the area 40°-47°N and 170°E-173°W.

(3) *Fishing gear and methods.* Jigging gear and fishing methods for *O. bartrami* are similar to those for *T. pacificus.* Both are principally fished at night using bright lamps and automatic jigging machines supplemented by hand line jigging. However, the jig hooks are larger than those for *T. pacificus* in order to prevent *O. bartrami* from dropping off while being raised. A large boat or a boat with large crew generally is superior in fishing efficiency, because the efficiency depends on the number of jigging machines and hand line jiggers. The fishing efficiency of drift gillnet fishing is 2-4 times higher than jigging. In the latter method, the efficiency per boat is controlled by the dimensions and mesh size of the net.

2. **Biology**

(1) *Distribution. Ommastrephes bartrami* is the most widely distributed of all the Ommastrephidae. It is recognized in the Pacific, Indian, and Atlantic Oceans. It occurs only rarely off east China, in the Japan, Okhotsk, and Bering Seas, in contrast to its extensive distribution in the North Pacific Ocean between Japan and North America (Figure 4).

In the waters adjacent to Japan the population of *O. bartrami* is most dense in the northern branch of the Kuroshio Current and its frontal zone (36°-38°N Lat. and 144°-156°E Long.) between May to June. In July through December the main distribution area is assumed to be in the area between 39° to 46°N and west from 165°E, first northward and northeastward from July to September, then diminished southward and southwestward from October to December. Population density is highest in the boundary zone between warm and cold waters where isothermal lines converge. This trend is limited to areas where the surface water temperature ranges from 15°-°24°C (July to August) and 10°-22°C (September to December). Distribution from January through May has not been elucidated yet. However,

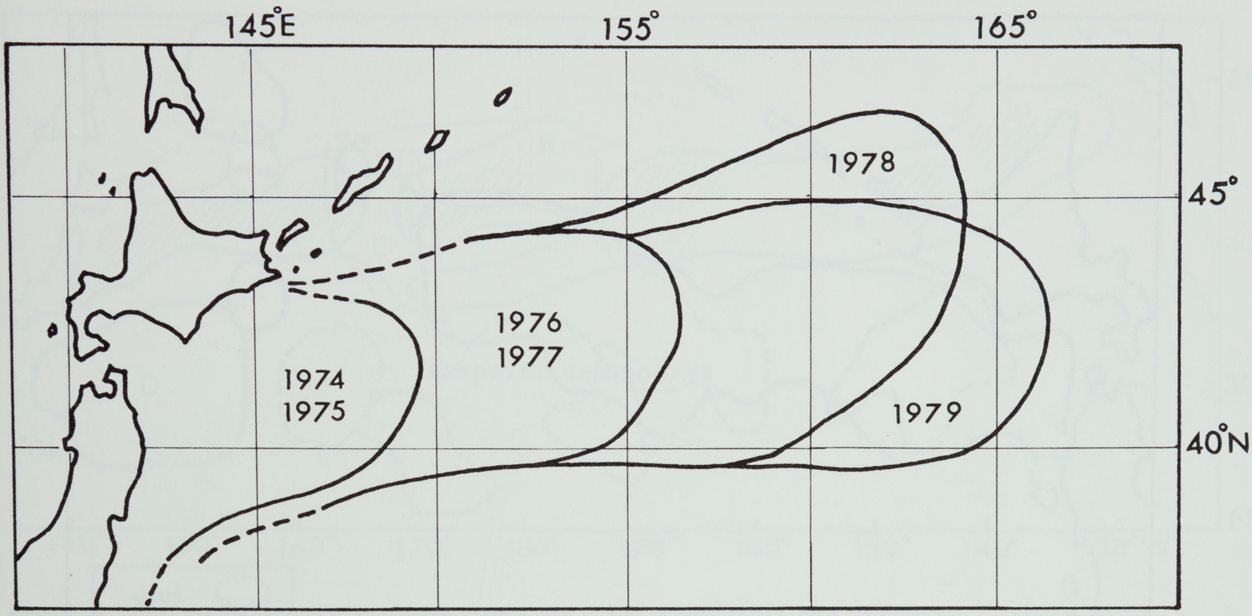


Figure 2. *Ommastrephes bartrami:* General view of the expansion of the squid jigging ground.

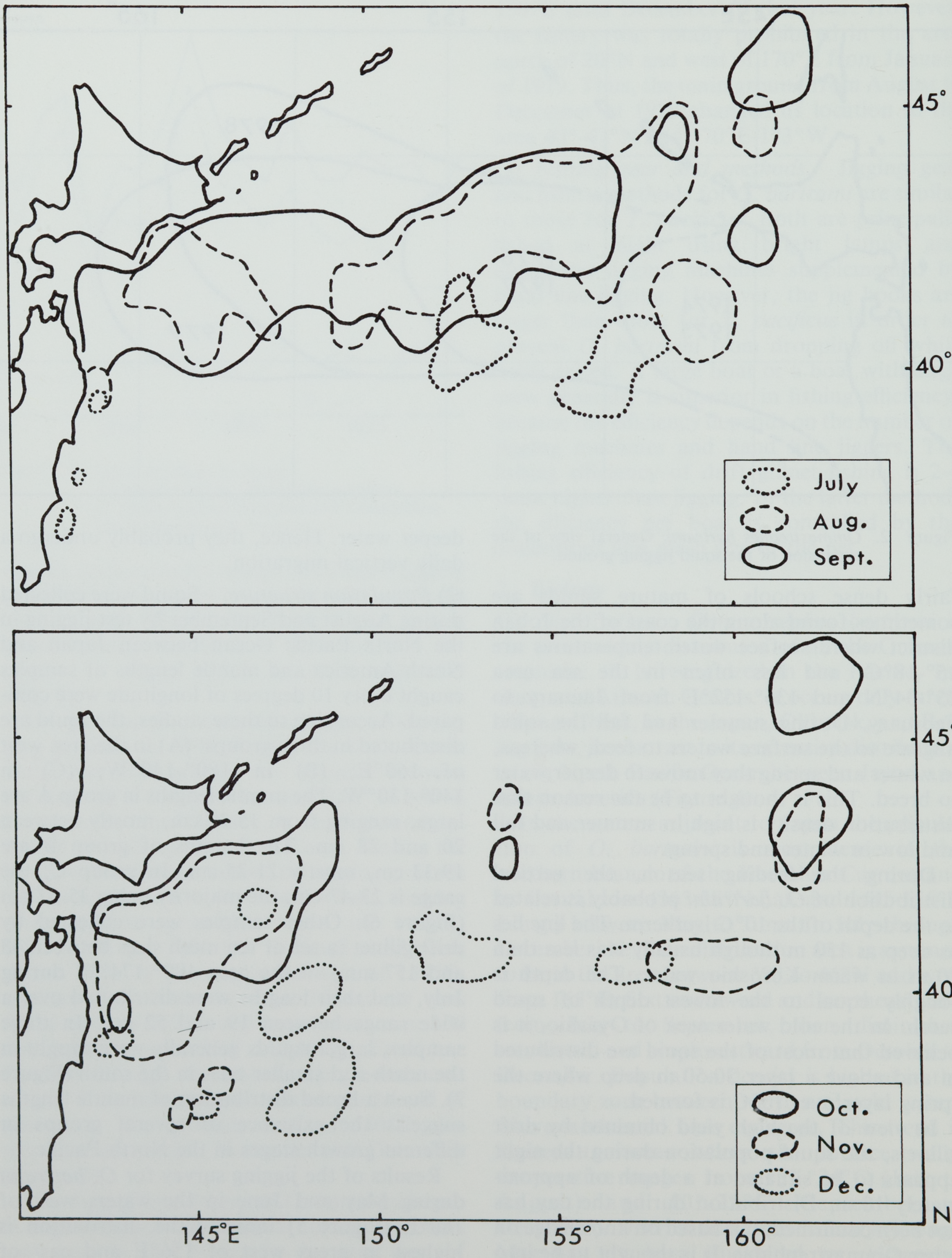
fairly dense schools of mature squids are sometimes found along the coast of the Joban district where surface water temperatures are 15°-18°C, and less often in the sea area 25°-34°N and 136°-152°E from January to February. During summer and fall the squid migrate to the surface waters to feed, whereas, in winter and spring they move to deeper water to breed. This is thought to be the reason that distribution density is high in summer and fall and low in winter and spring.

During the feeding season, the vertical distribution of *O. bartrami* probably is related to the depth of the 10°C isotherm. The line lies as deep as 150 m though usually it is less than 70 m in warm Kuroshio water. The depth is roughly equal to the lowest depth of squid catch. In the cold water area of Oyashio, it is believed that most of the squid are distributed in and above a layer 30-50 m deep where the spring layer over 10°C is formed.

In view of the high yield obtained by drift gillnets, the squid population during the night appears to be situated at a depth of approximately 10 m. Distribution during the day has not been confirmed, but based on knowledge on other Ommastrephidae, it is thought to be into deeper water. Hence, they probably undergo a daily vertical migration.

(2) *Population structure.* Squid were collected during August and September by test jigging in the North Pacific Ocean between Japan and North America and mantle lengths of samples caught every 10 degrees of longitude were compared. According to these studies, the squid are distributed in three groups: (A) in the area west of 160°E; (B) in 180°-140°W; (C) in 140°-130°W. The mantle lengths in group A are large, ranging from 15-39 cm, mostly between 20 and 28 cm. The lengths of group B are 19-33 cm, mostly 21-25 cm. In group C, the range is 23-47 cm, the majority being 35-42 cm (Figure 6). Other samples were collected by drift gillnet (a set of ten mesh sizes between 48 and 157 mm) in the area 180°-174°W during July, and their lengths were distributed over a wide range between 19 and 52 cm. In these samples, larger squids generally were caught in the north and smaller ones in the south (Figure 7). Such a broad distribution of mantle lengths suggests the existence of several groups in different growth stages in the North Pacific.

Results of the jigging survey for *O. bartrami* during May and June in the waters west of 180°E (Figure 5) indicate the distribution is highest in areas west of 156°E and east of


45°
40°
July
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Sept.
45°
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Oct.
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N
145°E
150°
155°
160°

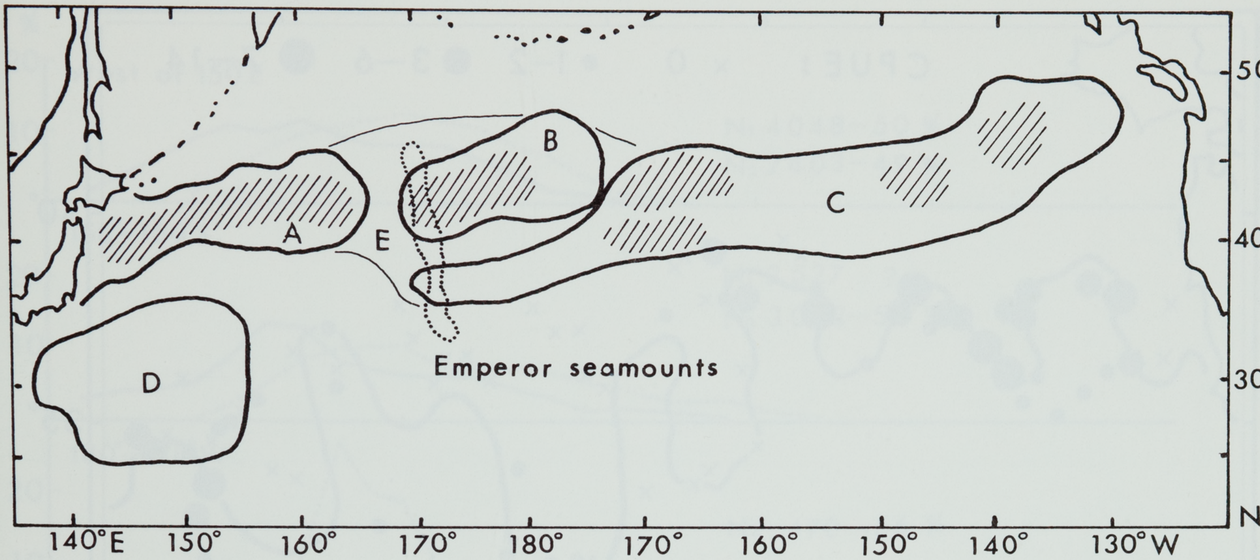


Figure 4. Main distribution areas of *Ommastrephes bartrami* in the North Pacific Ocean.
A: Jigging ground B: Drift gillnet fishing ground
C: Distribution area of squid taken by research vessel
D: Distribution area of mature female squid taken by research vessel
E: Rare distribution area
⁄⁄⁄⁄ High density of squid population.

170°E and lowest in between these areas. During the fishing season after July, the density is highest in the jigging area west of 165°E and also in the drift gillnet area east of 170°E and low in between (Figure 4). Moreover, in tagging experiments in the area west of 165°E no tagged squids were recaptured to the east of 170°E (Figure 10). These results and seasonal changes of the fishing ground suggest that the population west of 165°E rarely interacts with the population east of 170°E.

The population in the area west of 165°E consists of two to three size classes (Figure 9). Difference in size classes can be explained in terms of either age differences or independency. However, since this species does not live more than one year and the breeding season lasts from winter through spring, it can be assumed that the difference probably reflects variations in the time of hatching.

Figure 3. *Ommastrephes bartrami*: Monthly jigging ground formation in 1978.

(3) *Movement and migration.* The distribution of *O. bartrami* from summer through winter is concentrated principally in and around the area where the warm water branch derived from the Kuroshio runs northward. This suggests that squid migrations follow the movement of the Kuroshio branch, namely north- and northeastward in summer, and south- and southwestward in fall. This prediction was verified by release and recapture experiments of tagged squids. Squid released during May and June in the area between 36°-38°N and west of 155°E mostly moved northeastward and were recaptured in the area between 40°-45°N and 145°-162°E. Those released in July and August also generally moved northeastward and eastward. On the other hand, the squid tagged and released in the area 42°-44°N and 149°-154°E during September and October moved southward and southwestward (Figure 10). The average distance travelled per day was estimated to be approximately 5 miles from May to August, one mile from August to October, and 10 miles from October to December.

The tagging experiments, seasonal change of distribution, marine environments, and development-growth relationship of squids (discussed later) suggest the following pattern of squid migration in the area west of 165°E. Squid larvae, which are generated during winter

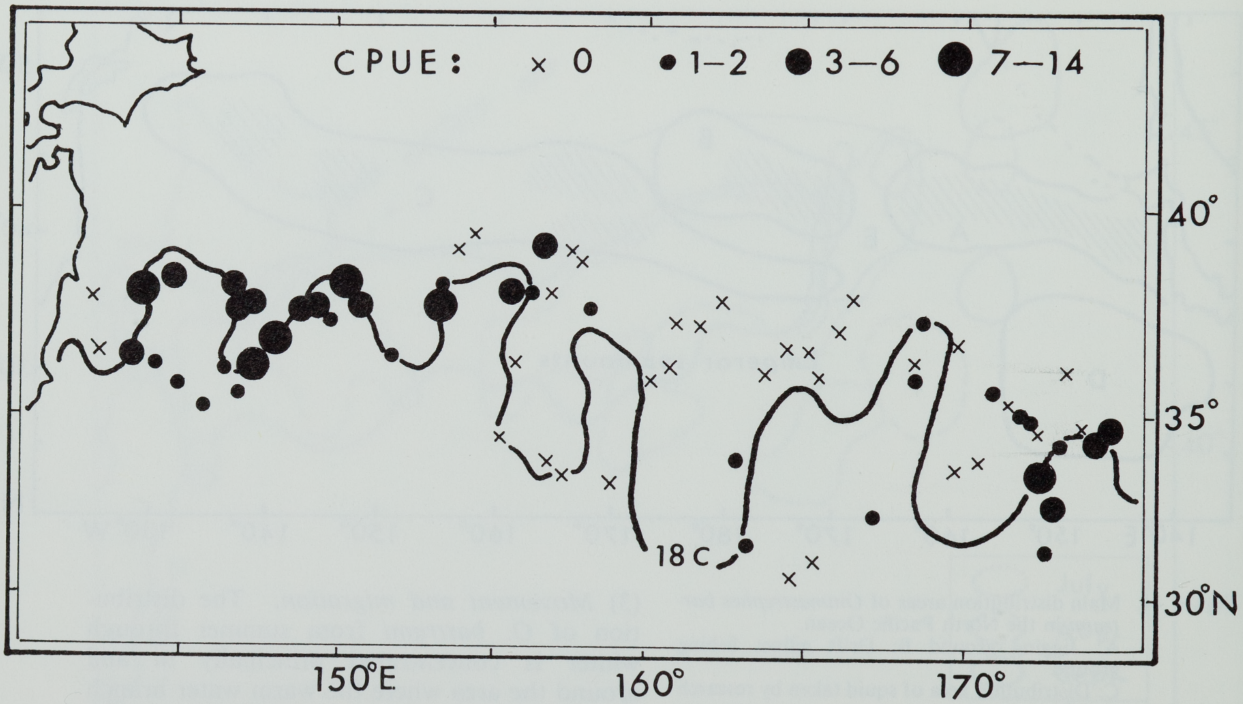
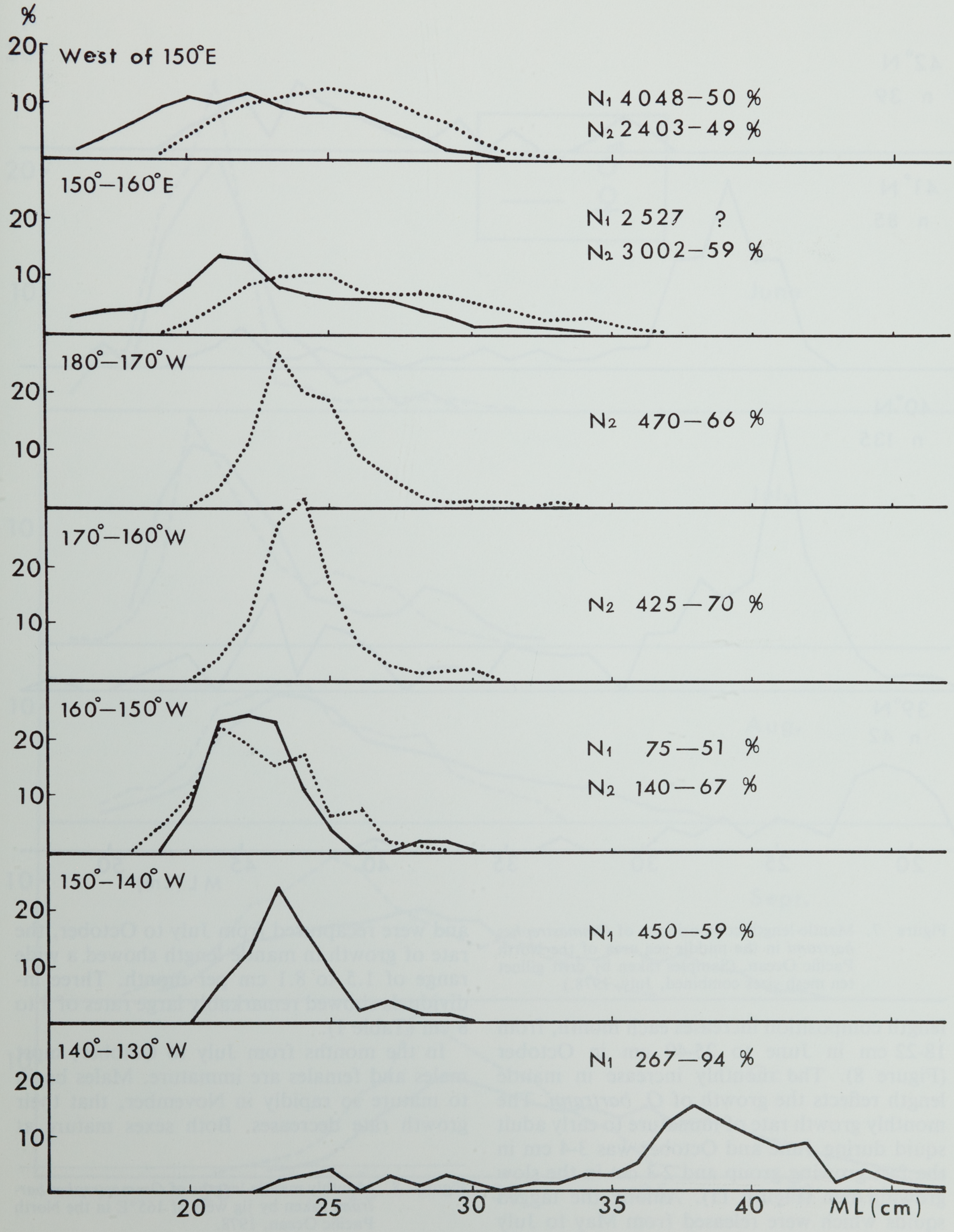


Figure 5. Relationship between distribution of *Ommastrephes bartrami* and the May and June front of the Kuroshio.
CPUE: Number of squid per one jigger an hour.

and spring in the area of the Kuroshio countercurrent south of 35°N and west of 155°E, supposedly remain there or in and near the Kuroshio until they become juveniles. The juveniles probably then move northward to the front of the Kuroshio. The population, which enters the subadult stage from May to August, migrates northward and northeastward through the area 35°-40°N where the Kuroshio meets the Oyashio. The main route of migration proceeds along the north warm water branches derived from the Kuroshio, in the areas 144°-146°E, 148°-151°E, and 154°-156°E. Populations of immature squid are distributed in the surface warm water area in and near the front of the Oyashio in 40°-46°N from August to October. After October and November, most of the squid attain the premature stage and change their migration courses southward and southwestward, while surface warm waters retreat southward due to the progress of cold water from the Oyashio. The relationship between the southerly course of migration and sea conditions is not yet clear. Grown and mature squids start the southerly migration. Since males mature earlier than females, they presumably depart southward earlier than females. During winter and spring they are thought to return to their hatching place, the area of the Kuroshio counter current, for spawning. Although the precise conditions and locations for spawning are still unknown, there are several possible areas such as shoal, reef or insular shelf margin; areas with uneven bottom topography such as seamounts, ridges or basins; and surface layer or midwater of the open sea.

(4) *Growth and life span.* Analysis of monthly mantle-lengths of populations caught in the area west of 165°E indicates that until July the size of females is equal to that of males. The females gradually grow larger than the males after August. The female-male mode of mantle

Figure 6. Mantle-length compositions of *Ommastrephes bartrami* in the North Pacific Ocean.
—— Aug. (N_1), ... Sept. (N_2)
Number of squid measured. Percentage: Females



%
West of 150°E
N1 4048—50 %
N2 2403—49 %
150°—160°E
N1 2527 ?
N2 3002—59 %
180°—170°W
N2 470—66 %
170°—160°W
N2 425—70 %
160°—150°W
N1 75—51 %
N2 140—67 %
150°—140°W
N1 450—59 %
140°—130°W
N1 267—94 %
20
10
20
25
30
35
40
ML (cm)

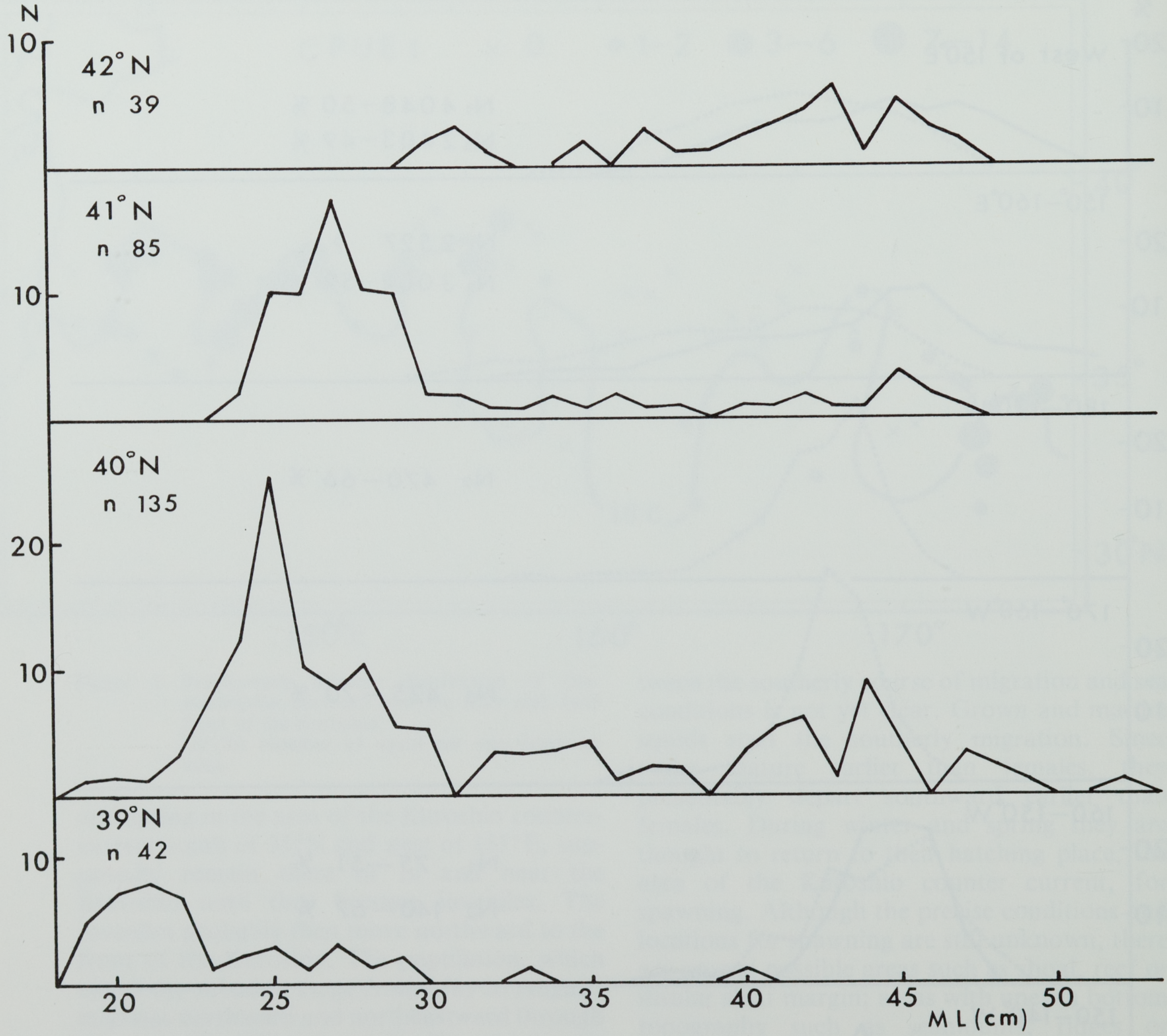
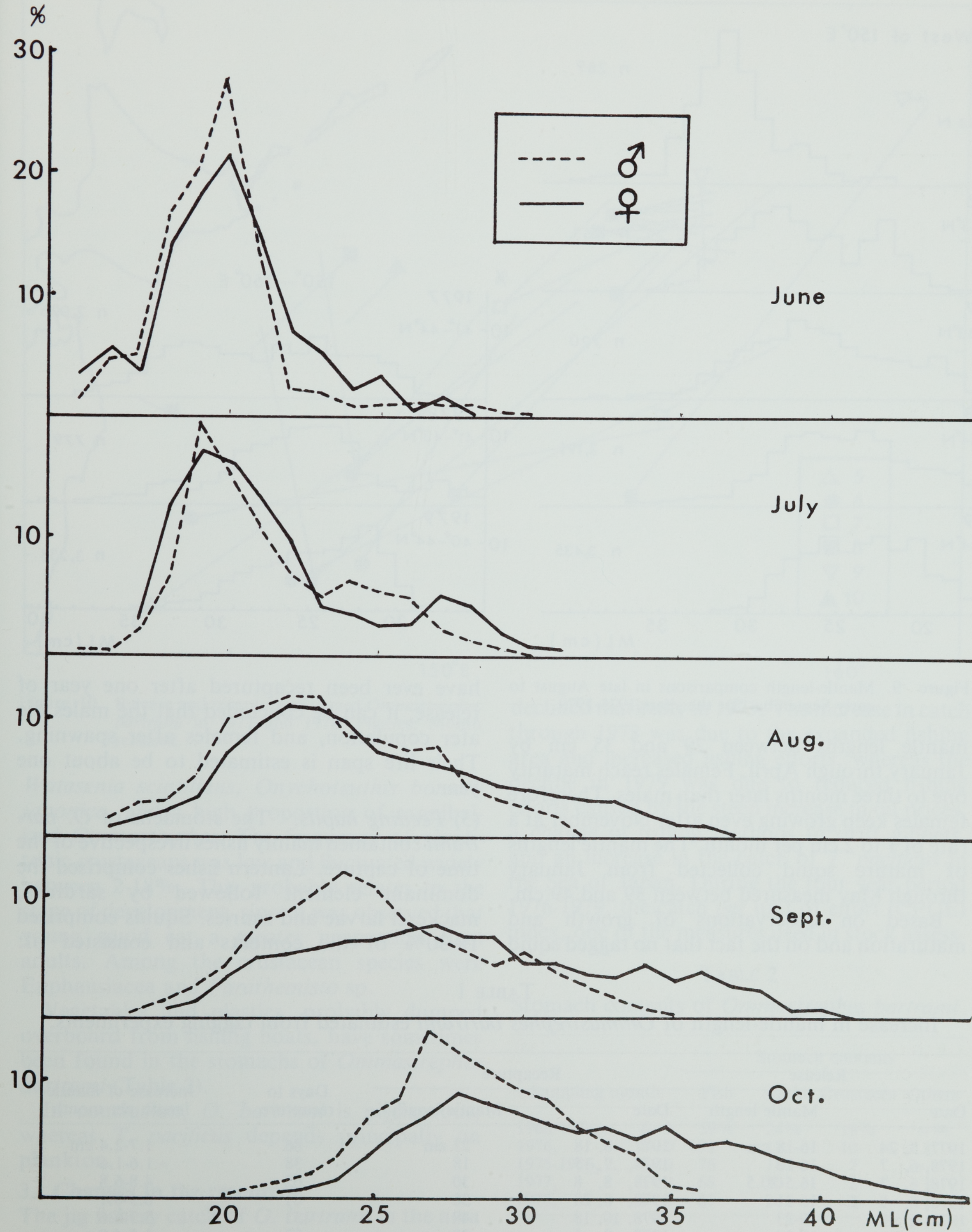


Figure 7. Mantle-length compositions of *Ommastrephes bartrami* in the middle sea area of the North Pacific Ocean. (Samples taken by drift gillnet ten mesh sizes combined, July, 1978.)

length composition increases each month, from 18-22 cm in June to 25-40 cm in October (Figure 8). The monthly increase in mantle length reflects the growth of *O. bartrami*. The monthly growth rate of immature to early adult squid during June and October was 3-4 cm in the fast growing group and 2-3 cm in the slow growing one (Figure 11). Among the tagged squids which were released from May to July and were recaptured from July to October, the rate of growth in mantle length showed a wide range of 1.5 to 8.1 cm per month. Three individuals showed remarkably large rates of 5 to 8 cm (Table 1).

In the months from July to October, most males and females are immature. Males begin to mature so rapidly in November, that their growth rate decreases. Both sexes mature at

Figure 8. Monthly mantle-lengths of *Ommastrephes bartrami* taken by jig west of 165°E in the North Pacific Ocean, 1978.


%
30
20
10
June
July
Aug.
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♂
♀
20
25
30
35
40
ML(cm)

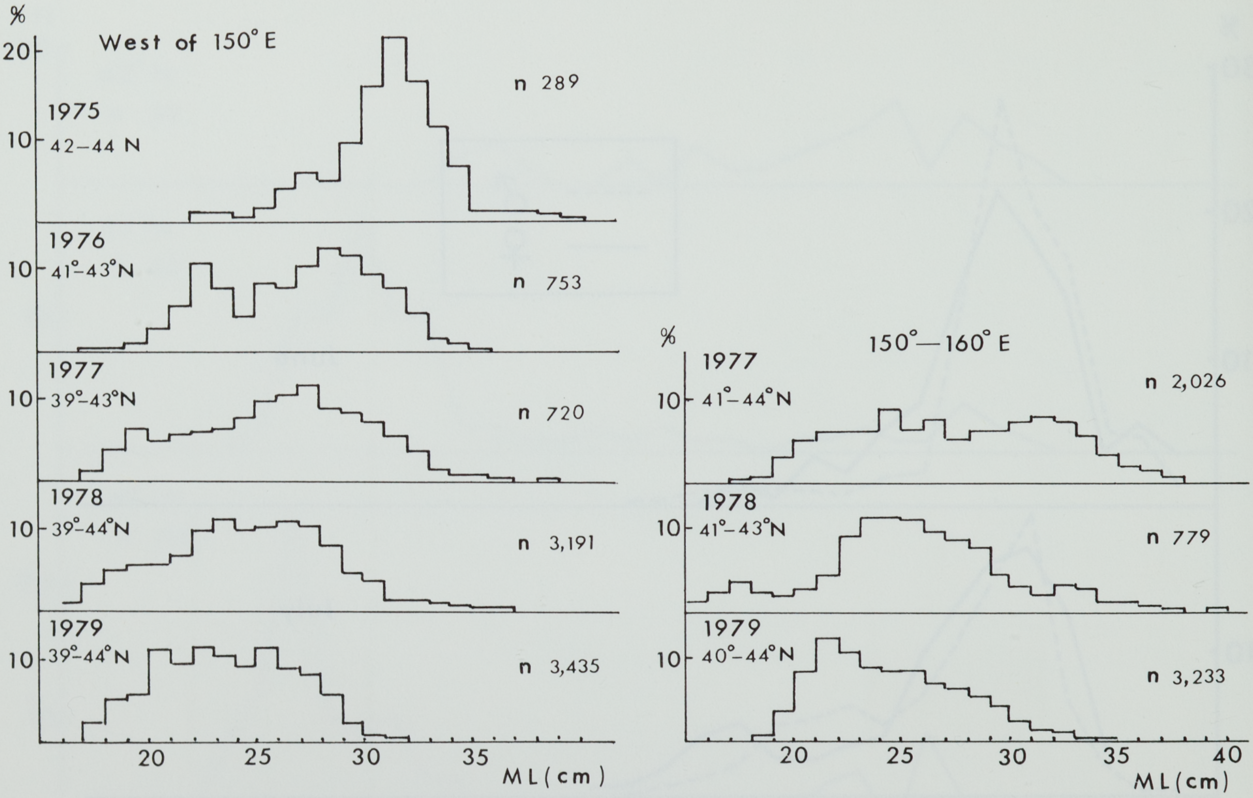

Figure 9. Mantle-length comparisons in late August to early September for the years 1975-1979.

mantle lengths between 29 and 35 cm by January through April. Females reach maturity one to three months later than males. Therefore females keep growing even after November at a rate of 1 to 2 cm per month. The mantle lengths of mature squid collected from January through May measured between 39 and 49 cm.

Based on observations of growth and maturation and on the fact that no tagged squid have ever been recaptured after one year of release, it can be concluded that the males die afer copulation, and females after spawning. Their life span is estimated to be about one year.

(5) *Feeding habits.* The stomachs of *O. bartrami* contained mainly fishes irrespective of the time of capture. Lantern fishes comprised the dominant element followed by sardines, mackerel larvae and sauries. Squids comprised 18-30% of the contents and consisted of:

TABLE 1

Increase in mantle-length of *Ommastrephes bartrami* estimated from tagging experiments.

Release		Recapture		Days to recapture	Increase of mantle length per month
Date	Mantle length	Date	Mantle length		
1977, 5, 24	16-18 cm	1977, 8, 18	23 cm	86	1.7-2.4 cm
1978, 6, 7	16-20	1978, 7, 15	18	38	−1.6-1.6
1978, 6, 7	16.5-20.5	1978, 8, 8	30	62	4.8-6.8
1978, 6, 9	16-21	1978, 8, 28	38	81	6.3-8.1
1978, 6, 10	19-23	1978, 10, 18	48	131	5.7-6.6
1977, 6, 12	17-24	1978, 9, 2	28	82	1.5-4.0

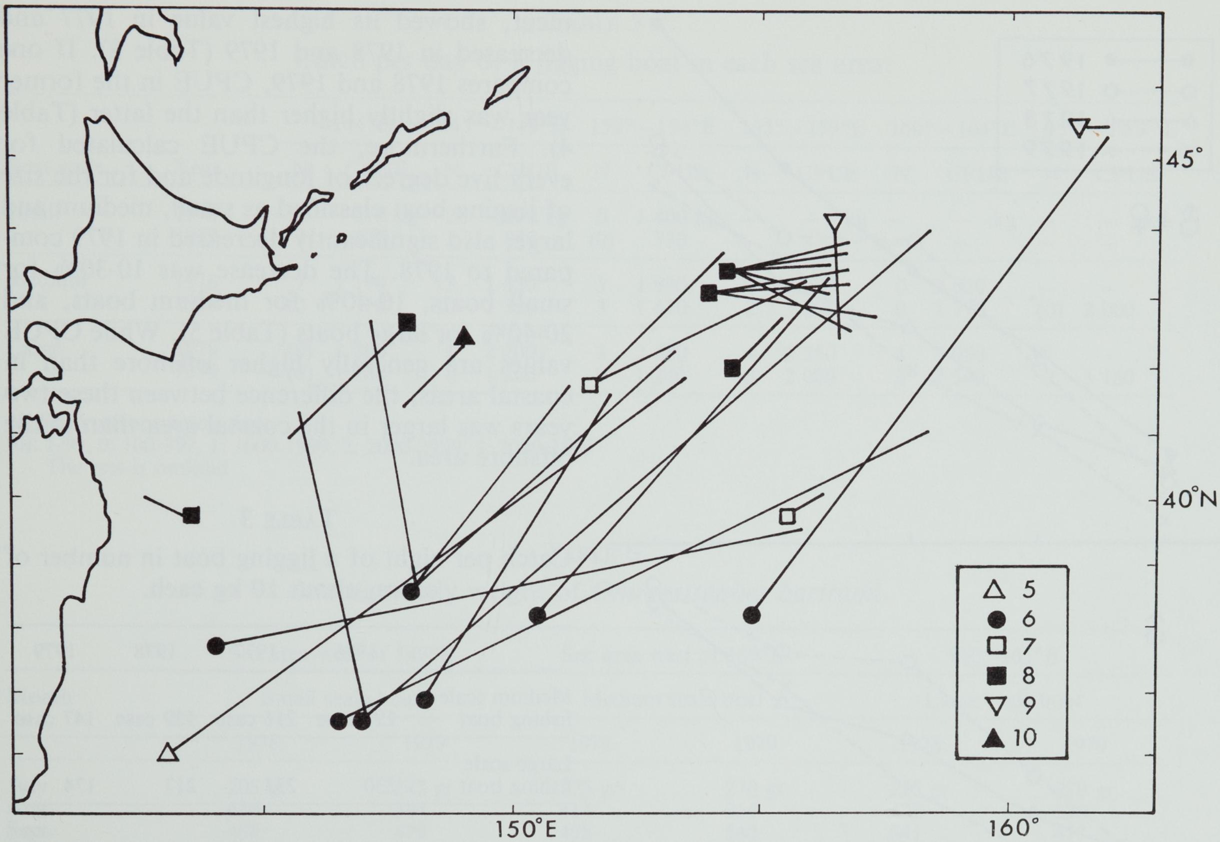

Figure 10. Release and recapture of tagged *Ommastrephes bartrami* in 1977 and 1978. Figures: Month released.

Watasenia scintillans, *Onychoteuthis borealijaponica*, and a high proportion of cannibalized *Ommastrephes*. The frequency of planktonic crustaceans was low and fluctuated widely between 2-18%. This probably relates to the stage of development, since it was observed that young squid eat a greater proportion than adults. Among the crustacean species were Euphausiacea and *Parathemisto* sp.

Vegetables and plastics, probably dumped overboard from fishing boats, have sometimes been found in the stomachs of *Ommastrephes bartrami* (Table 2).

In conclusion, *O. bartrami* is piscivorous, whereas *T. pacificus* depends principally on plankton.

3. Changes in the resources.

The jig fishery catch of *O. bartrami* in the area west of 170°E rapidly increased until 1978 but declined markedly in 1979. The increase in catch through 1978 was due to the expanded fishing area and increased fishing efforts, whereas the decline in 1979 was due to reduced fishing efforts caused by the steep increase in oil prices, a change in fishing methods to drift gillnets, and an increase in the catch of *T. pacificus* in the Sea of Japan. During the four year period 1976-1979, the catch per unit of effort (CPUE) index, one of the measures used in stock assess-

TABLE 2

Stomach contents of *Ommastrephes bartrami*.

Sampling month		Stomach contents			
		Fish	Squid	Crustacea	Others
1968-1974,	6- 9	59%	24%	18%	— %
1976,	9-10	71	18	10	1
1975-1976, 2,	6-10	76	18	7	—
1977,	1- 3	66	30	2	1
1978,	1- 3	67	20	2	11

Others; vegetables, plastics, etc.

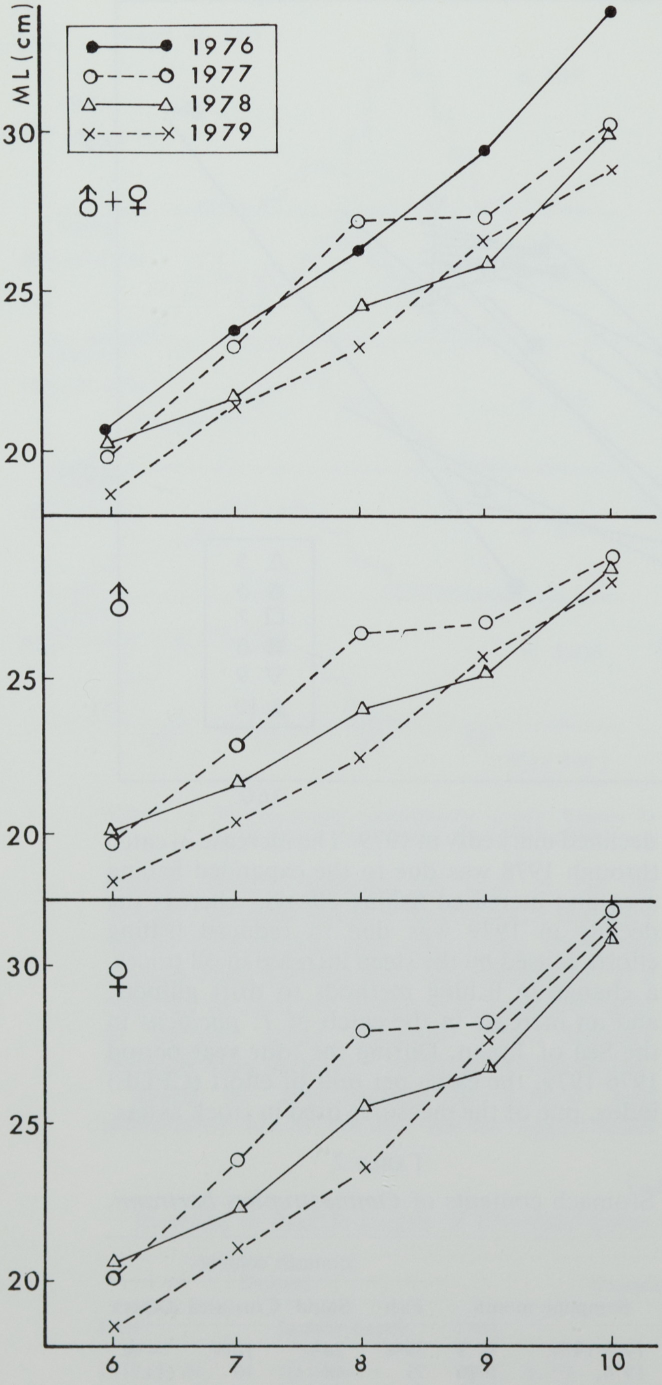

Figure 11. Monthly changes of mean mantle-length of *Ommastrephes bartrami* taken in the sea area west of 160°E in the North Pacific Ocean.

ment, showed its highest value in 1977 and decreased in 1978 and 1979 (Table 3). If one compares 1978 and 1979, CPUE in the former year was slightly higher than the latter (Table 4). Furthermore, the CPUE calculated for every five degrees of longitude and for the size of jigging boat classified as small, medium and large, also significantly decreased in 1979 compared to 1978. The decrease was 10-30% for small boats, 10-40% for medium boats, and 20-40% for large boats (Table 5). While CPUE values are generally higher offshore than in coastal areas, the difference between these two years was larger in the coastal area than in the offshore area.

TABLE 3

Catch per night of a jigging boat in number of cases, about 10 kg each.

	1976	1977	1978	1979
Medium scale fishing boat	191 case	216 case	139 case	147 case
Large scale fishing boat	230	233	217	174

While the total level of resources in these waters can be grossly estimated, it is nearly impossible to calculate absolute numbers in each year because of the lack of complete fishing statistics and ecological information. Nevertheless, we tentatively estimated the amount of the original resource by DeLury's methods using monthly CPUE of medium jigging boats and monthly total catch in the whole fishing area. CPUE and accumulated catch which had been indexed by weight were converted into the number of squid by dividing with average

TABLE 4

Catch per day of a jigging boat.

	Year	Small boat	Medium boat	Large boat
Catch weight kg	1978	759	1 722	2 491
	1979	529	1 347	2 303
Number of squid	1978	1 420	3 330	4 980
	1979	1 140	2 500	5 820

TABLE 5

Catch per day of a jigging boat in each sea area.

Boat scale	Year	−144°E N	−144°E CPUE	145°−149°E N	145°−149°E CPUE	150°−154°E N	150°−154°E CPUE	155°−159°E N	155°−159°E CPUE	160°−164°E N	160°−164°E CPUE	165°−169°E N	165°−169°E CPUE
Small	1978	5	570 kg	2	970 kg	0	1 400 kg	–	– kg	–	– kg	–	– kg
	1979	7	420	2	880	(0)	730	–	–	–	–	–	–
Medium	1978	7	1 190	13	1 630	5	1 990	3	2 290	0	2 020	–	–
	1979	10	770	10	1 390	3	1 670	2	1 990	0	1 770	(0)	2 000
Large	1978	(0)	1 560	1	2 200	3	2 080	4	2 550	4	3 050	–	–
	1979	(0)	1 160	0	1 240	0	1 240	3	2 080	2	2 540	0	3 160

N: Rank of operation days
(0): 1-99, 0: 100-999, 1: 1000-1999, 2: 2000-2999, 3: 3000-3999
The rest is omitted

TABLE 6

Average body weight of *Ommastrephes bartrami*.

Month	Sea area west of 149°E		Sea area west of 159°E		150°-165°E	
	Small scale boat		Medium scale boat		Large scale boat	
	1978	1979	1978	1979	1978	1979
July	205 gr	242 gr	275 gr	270 gr	275 gr	270 gr
Aug.	436	344	414	354	427	330
Sept.	488	479	498	540	641	477
Oct.	920	881	826	703	916	628

TABLE 7

Monthly accumulated catch and catch per day of a medium scale jigging boat.

Month	Monthly accumulated catch by jigger	Monthly accumulated catch by jigger and gill-net	Catch per day a medium scale jigging boat
8	45 (10^6) indiv	45 (10^6) indiv	4 810 indiv
9	123	123	3 160
10	155	167	1 700
11	161	208	1 490

weight per individual (Figure 12). The initial stock recruited into the fishery thus calculated amounted to 219 to 264 million individuals. The catch rate on the other hand turned out to be about 0.8, too high to allow optimism for the future of the fishery.

According to our studies on *O. bartrami*, the monthly average mantle length was largest in 1976 but has been decreasing since 1977. This trend probably is caused by a decline in the number of large squids as shown in Fig. 9 where the lengths of squids caught between August and September are compared for several years. Although a number of factors still remain unknown, a hypothesis to explain this decline in size is described below.

While several populations differing in maturity stage emerge every year, those containing

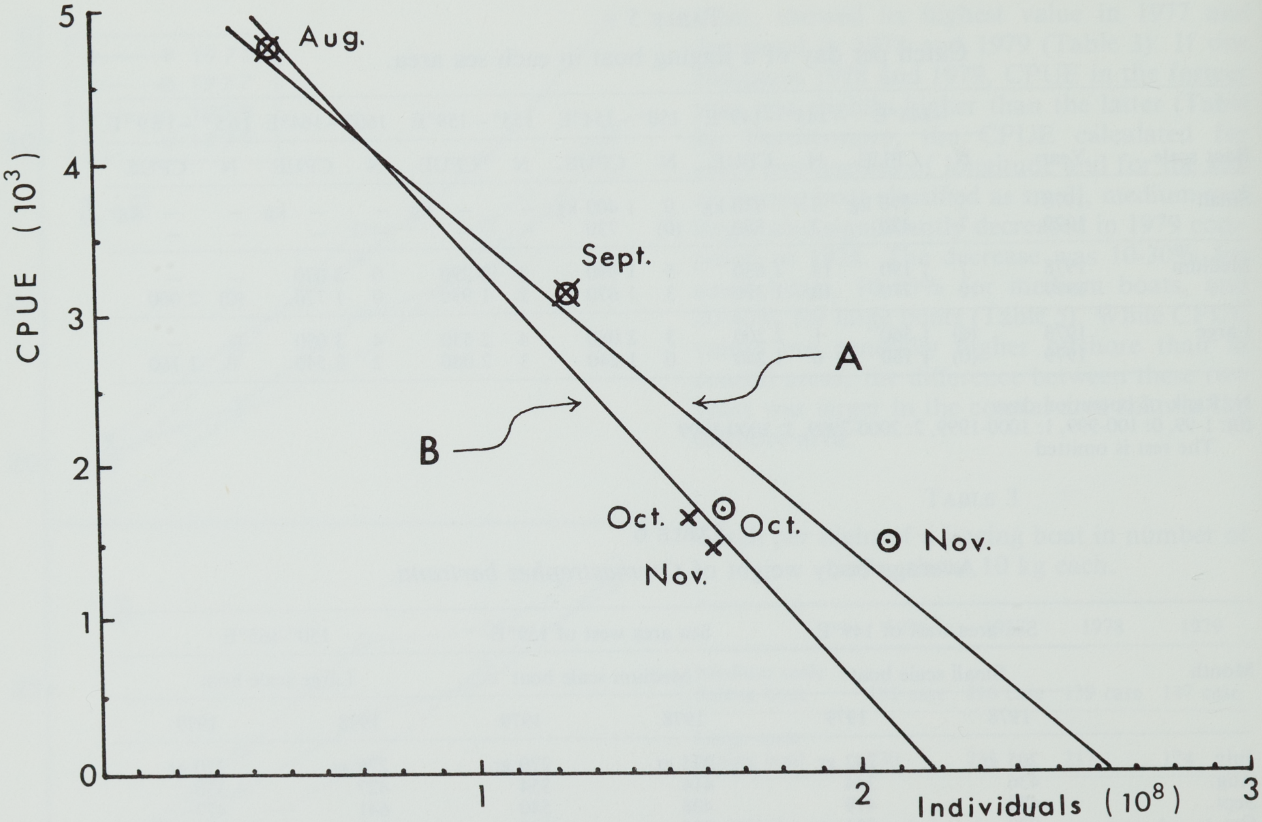

Figure 12. Relation between accumulated catch and average catch per night of a medium scale fishing boat for each month in 1978.
A⊙: Number of squid caught by both jig and gillnet
B×: Number of squid caught by jig only.

large squids which are hatched early in the winter-spring spawning period and which grow fast will migrate first into the fishing grounds where they are readily captured. As a result, the rate of squid hatched in spring has gradually increased relative to those hatched in winter. According to this model, the resource is in danger and susceptible to overfishing. Further promotion of fishing effort will severely interfere with reproduction and viability of the resource.

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