DISTRIBUTION AND ABUNDANCE OF SQUIDS CAUGHT IN SURFACE GILLNETS IN THE SUBARCTIC PACIFIC, 1977–1981

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Reprinted from Memoirs of the Faculty of Fisheries,
Hokkaido University, Vol. 30, No. 1/2, pp. 1～49
November, 1983

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Contents

I. Introduction

Although many regional studies have been conducted on the systematics and distribution of squids of the North Pacific Ocean (Berry, 1912; Sasaki, 1929; Akimushkin, 1963; Young, 1972; Nesis, 1973; Okutani, 1973, 1974), little is known about the distribution and abundance of epipelagic squids from the entire Subarctic Pacific. Squids are known to be important in the food-web in these oceanic waters. They are a principal prey of salmonid fishes (Allen and Aron, 1958; Ito, 1964; LeBrasseur, 1966; Ueno, 1969; Takeuchi, 1962; Machidori, 1972; Sato and Hirakawa, 1976), sea birds (Ogi and Tsujita, 1977; Ogi et al., 1980), and marine mammals (Spalding, 1964; Okutani and Nemoto, 1964; Okutani et al., 1976; Clarke, 1977; Okutani and Satake, 1978) in this sea area. Squids of the Subarctic Pacific have also been identified as a underutilized fishery resource (Voss, 1973; Okutani, 1977).

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During the last decade, distributional and biological studies have been published on epipelagic squids of the northwestern North Pacific as a result of the development of a fishery for *Ommastrephes bartrami*. Murakami (1976) described general distributional and migrational patterns of *O. bartrami*, *Gonatopsis borealis*, *Onychoteuthis borealijaponica* and *Todarodes pacificus* caught by surface gillnets and squid jigging during spring to summer. Murata et al. (1976) reported on the distributions and migrations of these four species caught by squid jigging in the waters off northeastern Japan during June to October. Murata and Ishii (1977) provided data on growth, maturity, sex ratio, spawning seasons and life spans of *O. bartrami* and *O. borealijaponica* in this same area. Naito et al. (1977a) further clarified the offshore distribution and migration of *O. bartrami* and *O. borealijaponica* and *G. borealis* during spring to summer in the western Subarctic Pacific from off northeastern Japan about 175°W, including the Bering Sea and Sea of Okhotsk, based on extensive data from surface gillnets and squid jigging. They also discussed growth and food habits of these four species gave data on the distribution of *Berryteuthis magister* on the continental slope from off Japan to the Bering Sea (Naito et al., 1977a, b). Growth, distribution and migration of *O. bartrami* were recently described by Murakami et al. (1981) for almost the entire North Pacific from off Japan to North America based mainly on the data from squid jigging.

Little information is available on the distribution and abundance of epipelagic squids in the northeastern North Pacific. Pearcy (1965) reported on the species composition and distribution of pelagic squids in the waters off Oregon, and Roper and Young (1975) provided data on the vertical distributions of pelagic cephalopods found off southern California. Bernard (1980, 1981) discussed fisheries potential for some squids in the waters off British Columbia. Fiscus and Mercer (1982) summarized the catches of squids taken incidentally in surface gillnets from most of the northeastern North Pacific by the Pacific Salmon Investigations Program during 1955 to 1972. Although much of the catch was treated collectively as only squid, they identified three species and two genera of squids and noted the commercial potential of *O. borealijaponica* and *O. bartrami*.

This paper analyzes the 1977–1981 surface gillnets catches of squids from both the eastern and western Subarctic Pacific. We compare data with previous information for this region and attempt to describe the zoogeography and abundance of epipelagic squids from the entire Pacific.

We are indebted to Professors K. Kyushin, T. Igarashi and T. Suzuki, Faculty of Fisheries, Hokkaido University for their helpful advice and assistance, to Dr. S. Odate, Far Seas Fisheries Research Laboratory for making data available for us, to Mr. K. Masuda and Mr. K. Ishii, Faculty of Fisheries, Hokkaido University for their kind help, and to Dr. K. Takagi and Dr. K. Jefferts for helpful comments on the manuscript. Our heartfelt thanks also go to the captains and crews of the research vessels for their cooperation in collecting the present materials.

This research was supported in part by the Japan Society for the Promotion of Science, the Foundation for Promotion of Fisheries Science of Hokkaido University and a contract of the National Marine Fisheries Service, Northwest and Alaska Fisheries Center, USA (81–ABC–00912, Programmatic 10).

II. Materials and Methods

This study is based on the catch records and specimens of squids caught incidentally in the salmon research gillnets operated by the Japanese Salmon Research Vessels and the *Oshoro-Maru* and *Hokusei-Maru* (training vessels of Hokkaido University) (Data Rec. Oceanogr. Obs. Expl. Fish., Hokkaido Univ. 1979–1982) under salmon research programs of the Far Seas Fisheries Research Laboratory. The catch records used in this study were that part of the data from Far Seas Fisheries Research Laboratory that were available through the Kushiro Fisheries Experimental Station from May to August, 1979–1982. In total, 21550 individual squids were caught in 1286 gillnets sets (Table 1). Most of the effort and catches were from the northwestern Pacific (38°N to 53°N and 152°E to 175°W) although the *Oshoro-Maru* completed 15 gillnet sets along the 145°W longitudinal line from 47°N to 56°N in the Gulf of Alaska in 1980 and 1981 (Fig. 1).

The research area and number of sets varied from year to year and month to month. The major differences in fishing intensity among years and months are illustrated in Fig. 4, which shows the location of gillnet stations, and are summarized below.

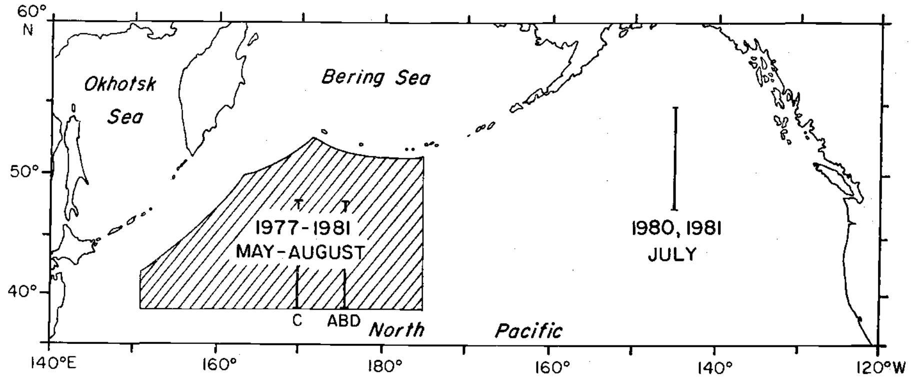

Fig. 1. Research area where squids were captured in surface gillnets, 1977–1981. A-D designate north-south transects for comparison of vertical features of temperature and salinity and the CPUE of squids in the surface layers (Fig. 17).

May; Only eight sets were completed in 1977. From 1978 to 1981, more than 80 sets were completed in each year, except for 1979 when 45 sets were made. The research area was mainly from 41°N to 51°N and 157°E to 175°E in 1979 and 152°E to 177°W in 1980 and 1981. In 1978, area of fishing was biased southwesterly and extended farther south to 39°N.

June; The research area extended from 42°N to 51°N and 152°E to 177°W in 1977 and 1978. In 1977, effort was concentrated in the western area along 45°N. A total of 187 sets was made. A total of 91 sets was made in 1978. This was about one-half the number completed in 1977, but the area fished was nearly the same. From 1979 to 1981, only about 50 sets were made. The transects along 180 from 39°N to 46°N were completed in 1980 and 1981.

Table 1. Number of squid taken in surface gillnets in the northern North Pacific by year, month and vessel, 1977–1981.

Year	Month[1]	Vessel	No. Shackles[2]	No. Sets	Corrected No. Sets[3]	No. Positive Sets	No. Squids	CPUE[4]	No. Squids Examined
1977	May	Iwate-Maru	3×10	1	1.0	1	4	4.0	0
		Iwaki-Maru	3×10	4	4.0	0	0	0.0	0
		Kumamoto-Maru	3×10	1	1.0	0	0	0.0	0
		Koyo-Maru	3×10	1	1.0	1	2	2.0	0
		Shinyo-Maru	3×10	1	1.0	0	0	0.0	0
		Subtotal		8	8.0	2	6	0.8	0
	June	Hokushin-Maru	3×10	22	22.0	14	96	4.4	0
		Iwate-Maru	3×10	22	22.0	19	139	6.3	109
		Miyako-Maru	3×10	16	16.0	4	33	2.1	33
		Iwaki-Maru	3×10	18	18.0	5	21	1.2	21
		Kumamoto-Maru	3×10	19	19.0	10	84	4.4	41
		Riasu-Maru	3×10	17	17.0	6	35	2.1	35
		Wakashio-Maru	3×10	25	25.0	14	67	2.7	0
		Koyo-Maru	3×10	21	21.0	20	84	4.0	0
		Shinyo-Maru	3×10	11	11.0	7	14	1.3	0
		Hokuho-Maru	5×10	16	26.7	15	219	8.2	0
		Subtotal		187	197.7	114	792	4.0	239
	July	Hokushin-Maru	3×10	15	15.0	10	147	9.8	0
		Iwate-Maru	3×10	19	19.0	19	161	8.5	89
		Miyako-Maru	3×10	20	20.0	10	208	10.4	112
		Iwaki-Maru	3×10	23	23.0	6	65	2.8	41
		Kumamoto-Maru	3×10	25	25.0	22	258	10.3	146
		Wakashio-Maru	3×10	10	10.0	9	63	6.3	0
		Koyo-Maru	3×10	16	16.0	14	116	7.3	0
		Subtotal		128	128.0	90	1,018	8.0	388
		Total		323	333.7	206	1,816	5.4	627

Table 1. (Cont.)

Year	Month[1]	Vessel	No. Shackles[2]	No. Sets	Corrected No. Sets[3]	No. Positive Sets	No. Squids	CPUE[4]	No. Squids Examined
1978	May	Hokushin-Maru	3×10	11	11.0	3	8	0.7	0
		Iwate-Maru	3×10	11	11.0	6	9	0.8	5
		Iwaki-Maru	3×10	19	19.0	3	5	0.3	0
		Kumamoto-Maru	3×10	18	18.0	11	40	2.2	0
		Hokuho-Maru	5×10	5	8.3	2	9	1.1	0
		To-o-Maru	3×10	18	18.0	0	0	0.0	0
		Subtotal		82	85.3	25	71	0.8	5
	June	Hokushin-Maru	3×10	11	11.0	5	93	8.5	0
		Iwate-Maru	3×10	13	13.0	12	76	5.8	56
		Iwaki-Maru	3×10	21	21.0	15	88	5.9	51
		Kumamoto-Maru	3×10	20	20.0	14	90	4.5	63
		Hokuho-Maru	3×10	5	8.3	3	11	1.3	3
		To-o-Maru	3×10	21	21.0	8	56	2.7	0
		Subtotal		91	94.3	57	414	4.5	173
	July	Hokushin-Maru	3×10	18	18.0	15	269	14.9	41
		Iwate-Maru	3×10	22	22.0	17	179	8.1	166
		Iwaki-Maru	3×10	24	24.0	0	0	0.0	0
		Kumamoto-Maru	3×10	22	22.0	20	477	21.7	125
		Hokuho-Maru	5×10	8	13.3	5	200	15.0	20
		To-o-Maru	3×10	14	14.0	12	327	23.4	0
		Oshoro-Maru	5×10	13	21.7	12	1,325	61.2	556
		Subtotal		121	135.0	81	2,777	20.6	908
	August	Hokuho-Maru	5×10	4	6.7	3	65	9.8	22
		Total		298	321.3	166	3,327	10.4	1,108
1979	May	Hokushin-Maru	3×10	10	10.0	4	20	2.0	0
		Iwaki-Maru	3×10	11	11.0	5	21	1.9	0
		Kumamoto-Maru	3×10	16	16.0	11	42	2.6	16
		Hokuho-Maru	5×10	8	13.3	3	15	1.1	0
		Subtotal		45	50.3	23	98	1.9	16

Table 1. (Cont.)

Year	Month[1]	Vessel	No. Shackles[2]	No. Sets	Corrected No. Sets[3]	No. Positive Sets	No. Squids	CPUE[4]	No. Squids Examined
1979	June	Hokushin-Maru	3×10	11	11.0	2	23	2.1	0
		Iwaki-Maru	3×10	13	13.0	7	59	4.5	0
		Kumamoto-Maru	3×10	17	17.0	10	24	1.4	9
		Hokuho-Maru	5×10	5	8.3	1	10	1.2	0
		Subtotal		46	49.3	20	116	2.4	9
	July	Hokushin-Maru	3×10	18	18.0	16	336	18.7	30
		Iwaki-Maru	3×10	22	22.0	14	545	24.8	63
		Kumamoto-Maru	3×10	25	25.0	18	1,009	40.4	184
		Hokuho-Maru	5×10	10	16.7	8	536	32.2	292
		Hokusei-Maru	3×10	7	7.0	7	608	129.7	601
		Subtotal		82	88.7	63	3,034	34.2	1,170
	August	Hokuho-Maru	5×10	3	5.0	3	238	47.6	39
		Hokusei-Maru	3×10	4	4.0	3	197	49.3	197
		Subtotal		7	9.0	6	435	48.3	236
		Total		180	197.3	112	3,681	18.7	1,431
1980	May	Hokushin-Maru	3×10	22	22.0	9	41	1.9	0
		Iwaki-Maru	3×10	21	21.0	5	17	0.8	0
		Kumamoto-Maru	3×10	24	24.0	9	52	2.2	0
		Hokuho-Maru	5×10	11	18.3	7	20	1.1	0
		No. 2 Riasu-Maru	3×10	8	8.0	8	22	2.8	0
		Subtotal		86	93.3	38	152	1.6	0
	June	Hokushin-Maru	3×10	9	9.0	8	259	28.8	0
		Iwaki-Maru	3×10	15	15.0	5	45	3.0	0
		Kumamoto-Maru	3×10	16	16.0	14	155	9.7	0
		Hohuho-Maru	5×10	1	1.7	1	1,304	768.8	0
		No. 2 Riasu-Maru	3×10	4	4.0	3	13	3.3	0
		Oshoro-Maru	5×10	8	13.3	7	201	3.4	0
		Subtotal		53	59.0	38	1,977	33.5	0

Table 1. (Cont.)

Year	Month[1]	Vessel	No. Shackles[2]	No. Sets	Corrected No. Sets[3]	No. Positive Sets	No. Squids	CPUE[4]	No. Squids Examined
1980	July	Hokushin-Maru	3×10	18	18.0	17	385	21.4	0
		Iwaki-Maru	3×10	17	17.0	7	104	6.1	0
		Kumamoto-Maru	3×10	26	26.0	24	500	19.2	0
		Hokuho-Maru	5×10	12	20.0	10	333	16.7	0
		No. 2 Riasu-Maru	3×10	8	8.0	7	625	78.1	0
		Hokusei-Maru	3×10	7	7.0	7	2,069	295.6	0
		Oshoro-Maru	5×10	6	10.0	4	25	2.5	0
		Subtotal		94	106.0	76	4,041	38.1	0
	August	Hokusei-Maru	3×10	4	4.0	4	22	5.5	0
		Oshoro-Maru	5×10	6	10.0	6	976	97.6	0
		Subtotal		10	14.0	10	998	71.3	0
		Total		243	272.3	162	7,168	26.3	0
1981	May	Hokushin-Maru	3×10	14	14.0	5	10	0.7	0
		Iwaki-Maru	3×10	25	25.0	18	62	2.5	0
		Kumamoto-Maru	3×10	27	27.0	14	54	2.0	0
		Hokuho-Maru	5×10	11	18.3	7	19	1.0	0
		No. 2 Riasu-Maru	3×10	11	11.0	6	69	6.3	0
		Subtotal		88	95.3	50	214	2.2	0
	June	Hokushin-Maru	3×10	9	9.0	9	61	6.8	0
		Iwaki-Maru	3×10	12	12.0	11	90	7.5	0
		Kumamoto-Maru	3×10	13	13.0	8	68	5.2	0
		Hokuho-Maru	5×10	3	5.0	2	37	5.5	0
		No. 2 Riasu-Maru	3×10	2	2.0	1	8	4.0	0
		Oshoro-Maru	4×10	8	10.7	5	21	2.0	0
		Subtotal		47	51.7	36	285	5.5	0

Table 1. (Cont.)

Year	Month[1]	Vessel	No. Shackles[2]	No. Sets	Corrected No. Sets	No. Positive Sets	No. Squids	CPUE[4]	No. Squids Examined
1981	July	Hokushin-Maru	3×10	19	19.0	13	125	6.6	0
		Iwaki-Maru	3×10	16	16.0	14	148	9.3	0
		Kumamoto-Maru	3×10	24	24.0	23	535	22.3	0
		Hokuho-Maru	5×10	11	18.3	11	1,690	92.3	0
		No. 2 Riasu-Maru	3×10	9	9.0	9	1,362	151.3	0
		Hokusei-Maru	3×10	14	14.0	14	1,074	76.7	0
		Oshoro-Maru	4×10	9	12.0	8	44	3.7	0
		Subtotal		102	112.3	92	4,978	44.3	0
	August	Hokusei-Maru	3×10	5	5.0	5	81	16.2	0
		Total		242	264.3	183	5,558	21.0	0
		Grand Total		1,286	1388.9	829	21,550	15.5	3,166

[1] Month; we used the date at which gillnets were set for summarizing the data.
[2] No. shackles; number of shackles used in each mesh size × number of mesh sizes (10 different mesh sizes from 48, 55, 63, 72, 82, 93, 106, 121, 138 and 157 mm in stretched mesh).
[3] Corrected no. sets; number of standard sets as using 30 shackles (3 shackles in each 10 different mesh sizes) per one set.
[4] CPUE; number of squid/corrected no. sets.

July; The number of sets varied from 82 in 1979 to 128 in 1977, but nearly the same area, from 42°–43°N to 51°N and 157°E to 177°W, was fished in each year. One or two longitudinal transects along 170°E, 175°30′E, 180°, 157°W from 38°30′N were completed in each year, except for 1977. In 1977, effort was concentrated in the western area along 48°N. In the Gulf of Alaska, one longitudinal transect of gillnet sets was made along 145°W from 48°30′N to 56°N in 1980 (6 sets) and 1981 (9 sets).

August; Only 4–10 sets were made between 165°E–172°W and north of 47°N in early August in 1978–1981. In 1980, additional research was completed from 40°N to 46°N along 180°.

Squids were usually identified to species on board the vessels and numbers of each species were counted. A total of 3166 individuals was randomly selected from the catches and frozen for later examination in the laboratory; 2056 individuals at Kushiro Experimental Station, and 1292 individuals at the Research Institute of North Pacific Fisheries, Hokkaido University, during 1977 to 1979. Some specimens that were unidentified on board were also preserved for later identification. Dorsal mantle length (DML), body weight (BW) and weights of some genital organs (ovaries and nidamental glands in females, and testes and spermiducts in males) were measured in the laboratory after thawing.

The gillnets that provided the principle data for this study were surface gillnets consisting of ten different mesh sizes, namely 48, 55, 63, 72, 82, 93, 106, 121, 138 and 157 mm stretched mesh. This series of mesh sizes comprises a uniform catch efficiency for salmonid fishes from 25 to 70 cm fork length (i.e., "nonselective" gillnets, see Takagi, 1975) and for flying squid (*Ommastrephes bartrami* from 18 to 50 cm DML (Kubodera and Yoshida, 1981). We assumed that this 10-mesh size gillnets had the same efficiency for all species of squids in the size range from 18 to 50 cm DML. Almost all vessels used three shackles of each mesh size for a total of 30 shackles. Each shackle is about 50 m long and 6 m deep. Therefore, the 10-mesh size gillnets were usually 1500 m long. Other gillnets with 111–115 mm mesh sizes, were usually set simultaneously with the 10-mesh size gillnets but these catch data were not used if they were differentiated from the catches of the 10-mesh size gillnets except for rare species. Gillnets were generally set at 1600–1700 hours (local mean time), were adrift at the surface during the night, and were retrieved at 0400–0600 hours the next morning. Catches in the research gillnets are therefore restricted to nighttime periods and from the surface to about 6 m depth.

Since almost all vessels used the same length, mesh sizes and fishing duration (three shackles of each 10 different mesh sizes, fished 10–14 hours at night), we used the catch per one such overnight gillnet set as the standard catch per unit effort (CPUE). The catches by a few vessels that used different numbers of shackles in each mesh size were adjusted to this standard CPUE.

Water temperatures were measured with bathythermographs from the surface to 125 m depth at each gillnet station. The *Oshoro-Maru* and *Hokusei-Maru* measured temperature and salinity from the surface to about 1200 m depth at oceanographic observation stations, including the stations where gillnets were set.

III. Results

1. Species Composition

Two species of Onychoteuthidae, three species and one unidentified group of Gonatidae and three species of Ommastrephidae were identified from the squid taken in the salmon research gillnets in the northern North Pacific from 1977 to 1981 (Table 2). *Ommastrephes bartrami* was numerically the most abundant and comprised about 46% of the catch. *Onychoteuthis borealijaponica* was the second and *Gonatopsis borealis* the third most common species, comprising about 33% and 20% of the catch, respectively. These three species comprised over 99% of the catch. The remaining catch included *Berryteuthis magister*, *Moroteuthis robusta*, *Todarodes pacificus*, *Eucleoteuthis luminosa*, *Gonatus* spp. and *Gonatus madokai*, in that order.

Table 2. Species composition of squids taken in surface gillnets in the northern North Pacific, 1977–1981.

	No.	%
ONYCHOTEUTHIDAE		
Onychoteuthis borealijaponica Okada	7, 108	32. 98
Morotheuthis robusta (Verrill)	7	0. 03
GONATIDAE		
Gonatopsis borealis Sasaki	4, 386	20. 35
Gonatus madokai Kubodera & Okutani	1	0. 01
Gonatus spp.	3	0. 01
Berryteuthis magister (Berry)	49	0. 23
OMMASTREPHIDAE		
Todarodes pacificus Steenstrup	6	0. 03
Eucleoteuthis luminosa (Sasaki)	3	0. 01
Ommastrephes bartrami (Lesueur)	9, 962	46. 23
Unidentified	25	0. 12
TOTAL	2, 1550	

2. Annual and Monthly Fluctuations in the Catch

The frequency of occurrence, total number of individuals caught and average CPUE of three common species of squids are summarized by year and month in Table 3 and Fig. 2. The average CPUE for all years was highest for *O. bartrami* followed by *O. borealijaponica* then *G. borealis*. The frequency of occurrence of these three species was reversed however; *G. borealis*, *O. borealijaponica*, *O. bartrami*. *Gonatopsis borealis* was caught in most sets in relatively low number whereas *O. bartrami* occurred infrequently but in large numbers.

The average CPUE of all species combined increased from 5.4 in 1977 to 26.3 in 1980 with a slight decrease to 21.0 in 1981 (Table 1). CPUE of the three most recent years was four or five times higher than that of 1977. Annual CPUE of *G. borealis* showed similar fluctuations, increasing from 2.2 in 1977 to 4.8 in 1980 with a slight decrease to 3.5 in 1981. CPUE of *O. borealijaponica* was 3.0 in 1977 and 3.8 in 1978, then sharply increased to 11.4 in 1979 and gradually decreased to 6.1

Table 3. Frequency of occurrence, number of individuals caught, and average CPUE of *Gonatopsis borealis*, *Onychoteuthis borealijaponica* and *Ommastrephes bartrami* by year and month.

Year	Month	No. Sets	Corrected No. Sets	*Onychoteuthis borealijaponica*				*Ommastrephes bartrami*				*Gonatopsis barealis*			
				No. Positive Sets	%	N	CPUE	No. Positive Sets	%	N	CPUE	No. Positive Sets	%	N	CPUE
1977	May	8	8.0	1	12.5	2	0.25	0	0.0	0	0.00	1	12.5	4	0.50
	June	187	197.7	62	33.2	371	1.88	3	1.6	29	0.15	89	47.6	368	1.86
	July	128	128.0	50	39.1	633	4.95	4	3.1	8	0.06	68	53.1	380	2.97
	Subtotal	323	333.7	113	35.0	1,006	3.01	7	2.2	37	0.11	158	48.9	752	2.25
1978	May	82	85.3	3	3.7	7	0.08	2	2.4	4	0.05	20	24.4	60	0.71
	June	91	94.3	22	24.2	146	1.55	1	1.1	1	0.01	47	51.6	255	2.71
	July	121	135.0	45	37.2	1,017	7.53	17	14.0	1,367	10.12	61	50.4	393	2.91
	August	4	6.7	2	50.0	44	6.57	0	0.0	0	0.00	3	75.0	21	3.14
	Subtotal	298	321.3	72	24.2	1,214	3.78	20	6.7	1,372	4.27	131	44.0	729	2.27
1979	May	45	50.3	8	17.8	27	0.54	0	0.0	0	0.00	19	42.2	70	1.39
	June	46	49.3	7	15.2	18	0.37	0	0.0	0	0.00	18	39.1	98	1.99
	July	82	88.7	33	40.2	1,807	20.37	8	9.9	758	8.64	52	58.6	461	5.20
	August	7	9.0	4	57.1	390	43.33	0	0.0	0	0.00	6	85.7	45	5.00
	Subtotal	180	197.3	52	28.9	2,242	11.36	8	4.4	758	3.84	95	52.8	674	3.42
1980	May	86	93.3	10	11.6	23	0.25	0	0.0	0	0.00	30	34.9	127	1.36
	June	53	59.0	19	35.8	392	6.64	8	15.1	1,371	23.24	26	49.1	208	3.53
	July	94	106.0	26	27.7	1,206	11.38	10	10.8	1,906	18.15	63	67.7	926	8.82
	August	10	14.0	3	30.0	51	3.66	4	40.0	906	64.71	5	45.5	41	2.93
	Subtotal	243	272.3	58	23.9	1,672	6.14	23	9.5	4,183	15.36	124	51.0	1,302	4.78
1981	May	88	95.3	8	9.1	20	0.21	0	0.0	0	0.00	43	48.9	166	1.74
	June	47	51.7	11	23.4	55	1.06	4	0.1	12	0.23	29	61.7	217	4.20
	July	102	112.3	48	47.1	842	7.50	22	21.8	3,600	32.35	70	69.3	524	4.71
	August	5	5.0	2	40.0	57	11.40	0	0.0	0	0.00	3	50.0	22	4.40
	Subtotal	242	264.3	69	28.5	974	3.69	26	10.7	3,612	13.67	145	59.9	929	3.51
	Grand Total	1,286	1388.9	364	28.3	7,108	5.12	84	6.5	9,962	7.17	653	50.8	4,386	3.16

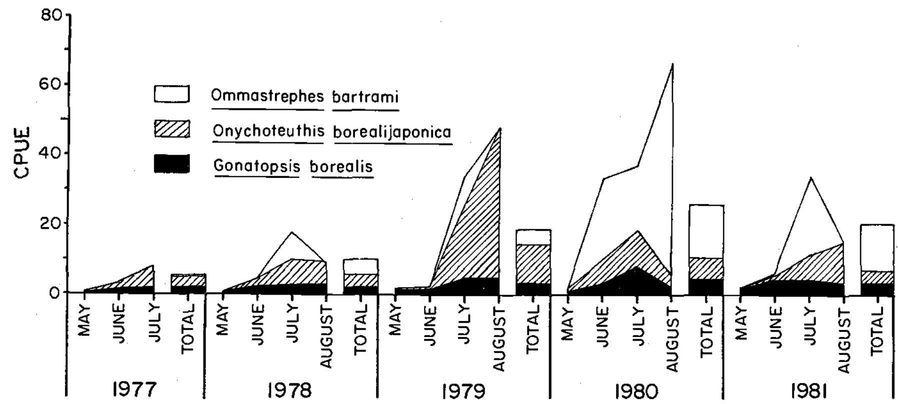

Fig. 2. Annual and monthly fluctuations in the relative abundance of the three common species of squids caught by surface gillnets in the northern North Pacific.

in 1980 and 3.7 in 1981. CPUE of *O. bartrami* was 0.1–4.3 during 1977 to 1979 and increased to 15.4 in 1980 and 13.7 in 1981. The high CPUE in the three most recent years was mainly attributed to *O. borealijaponica* in 1979 and *O. bartrami* in 1980 and 1981.

Seasonal variations were also obvious. Monthly CPUE of all species combined (Table 1, Fig. 2) was always lowest in May and June and highest in July and August. CPUE of *G. borealis* increased from 0.5–1.7 in May to 3.0–8.8 in July and August. *Gonatopsis borealis* appeared in over 40% of sets from May to August with highest frequency of occurrence in July or August. Frequency of occurrence and CPUE of *O. borealijaponica* also increased with the month from 10–15% and 0.1–0.5 in May to 30–45% and 5.0–20.3 in July, respectively. *Ommastrephes bartrami* was not caught in May of 1977 and 1979–1981. Only four were caught in May, 1978. It was also infrequent in June, except for June 1980 when the highest CPUE for June, 23.2, occurred. Highest CPUE and frequency of occurrence of *O. bartrami* occurred in July and August, especially in 1980 and 1981.

In summary, abundance of squids in the epipelagic waters in the northern North Pacific was generally low in spring and high in summer due to a gradual increase of *G. borealis* through the period and rapid increases of *O. borealijaponica* and *O. bartrami* in summer. Catches of *O. borealijaponica* and *O. bartrami* were higher in 1979–1981 than 1977 and 1978. Although these seasonal and annual trends are influenced by differences in fishing effort, we believe that they also represent real changes in availability of these squids in surface waters.

3. Distribution and Abundance of Squids

Geographic variation in the catch per set of each of three common species of squids is discussed relative to surface water temperature in this section. The relationships between mean CPUE and mean surface water temperature are illustrated for each month, May-August, based on the five years of data (Fig. 3).

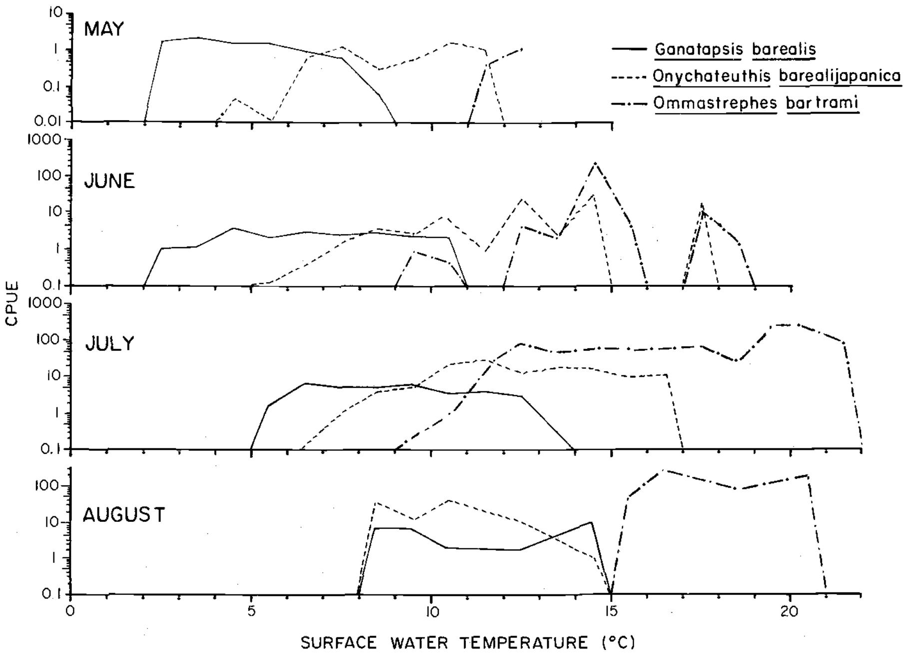

Fig. 3. Relationships between mean CPUE and surface water temperature by species and month based on five year data (1977–1981).

Gonatopsis borealis

May (Figs. 4a–d); *Gonatopsis borealis* was broadly distributed throughout the area sampled in May to 1978 through 1981. It occurred in 24% to 49% of the sets during these years. CPUE of most sets was less than 10 and in only one set exceeded 20.

All catches of this species occurred between 2° and 8°C. Mean CPUE was always less than 2.2 through this temperature range, with higher CPUE at lower temperatures (Fig. 3). During May 1978, sea surface temperatures were warmer than in the other years in the southwestern portion of the area sampled, probably due to extension of the Kuroshio Current (Fig. 4a). Here temperatures over 13°C were encountered. *Gonatopsis borealis* was not captured in any sets west of 160°E, even as far north as 44–45°N where temperatures lower than 4°C were encountered.

This species was caught in the tongue of cold (<3°C) water produced by the East Kamchatka Current in the northwest portion of the sampling area in 1979 (Fig. 4b) and 1980 (Fig. 4c), but it was absent from this cold-water tongue in 1981 (Fig. 4d).

June (Figs. 5a–e); A broad geographic distribution with generally low catches is also evident during June. However, catches increased slightly over the area sampled and in some sets the CPUE exceeded 20. Frequency of occurrence varied from 39% in 1979 to 62% in 1981.

This species was caught in a wider range of water temperatures in June than

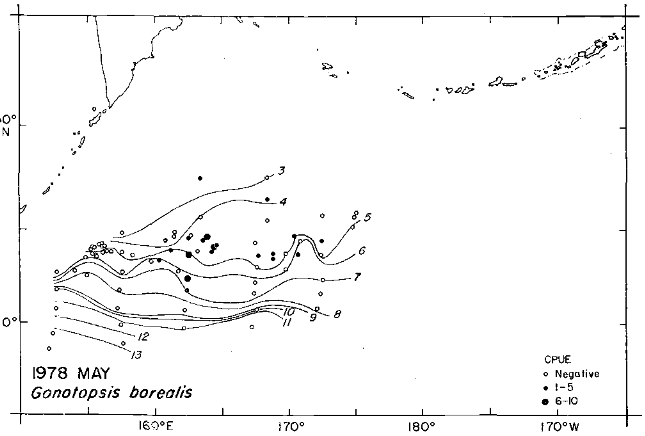

Fig. 4a.

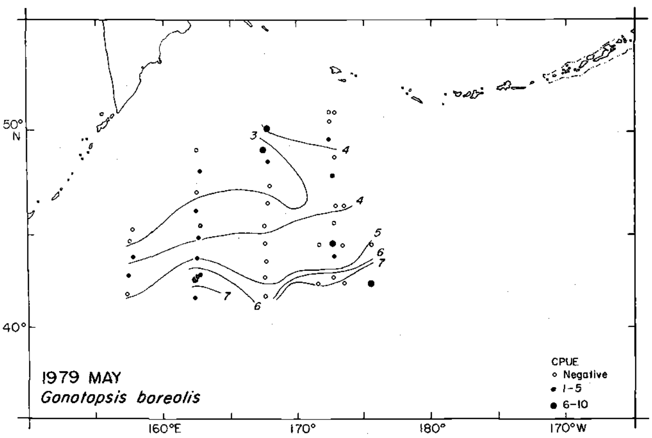

Fig. 4b.

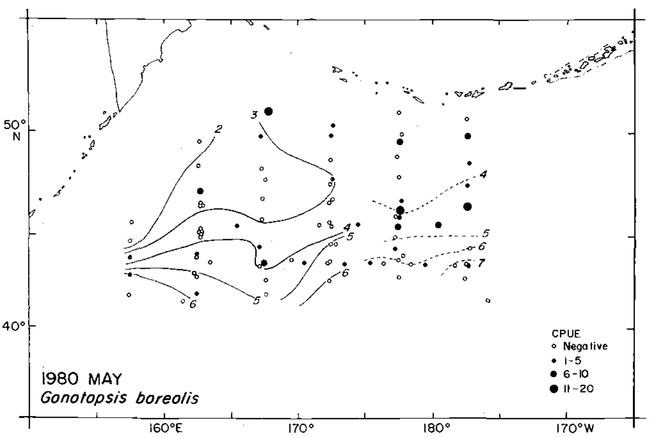

Fig. 4c.

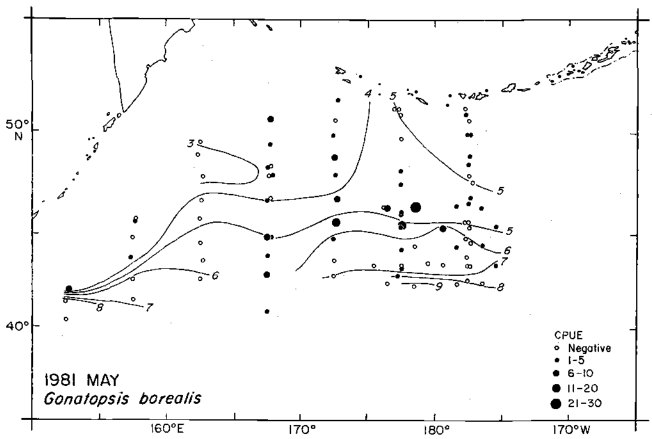

Fig. 4d.

Figs. 4a-d. Distribution and relative abundance of *Gonatopsis borealis* caught by surface gillnets and surface isotherms in May.

May, between 3° and 11°C. Mean CPUE, which was nearly uniform in this temperature range, was slightly higher than in May, ranging from 1.0–3.8 with lower CPUE at lower temperatures (Fig. 3). Again, it was absent from areas of higher water temperatures in the southern portions of the sampling area.

Distribution extended slightly farther south in June than in May of 1978 (Fig. 5b), probably because the Kuroshio Current affected the southern area more in May than June. In general, however, geographic variation in the catch and north-south movements were not obvious between May and June.

July (Figs. 6a–e); *Gonatopsis borealis* was broadly distributed in the area sampled in July of 1977 through 1981, except for the portion of the sampling area south of about 43–44°N. Frequency of occurrence was usually higher in July than in June and varied from 50% in 1978 to 69% in 1981. CPUE in July was also higher than in June.

Gonatopsis borealis was caught in warmer waters in July (5–13°C) than in June. Mean CPUE was again fairly even within this temperature range and was slightly higher (3.2–7.2) than in June except at the margins of the range (Fig. 3). It was also absent from areas of higher water temperatures in the southern portions of the sampling area.

CPUE of most positive sets was less than 20 in 1977 (Fig. 6a) and 1978 (Fig. 6b) but CPUE higher than 30 appeared in some sets in 1979–1981 (Figs. 6c–e). In 1980 (Fig. 6d), CPUE was higher than 50 in some sets between the 9°C and 11°C isotherms. In July 1978, like May 1978, it was rare west of 165°E (Fig. 6b).

In the Gulf of Alaska in July (Fig. 7), *G. borealis* appeared in four out of six sets in 1980, and in six out of nine sets in 1981. All catches were north of about 50°N in both years, irrespective of slight differences in surface water temperature. The CPUE of most of the positive sets was less than 5 and only one set at 54°N had a CPUE of 12 in 1981. Compared with the western Subarctic Pacific in July, catches were relatively low and restricted to northern waters.

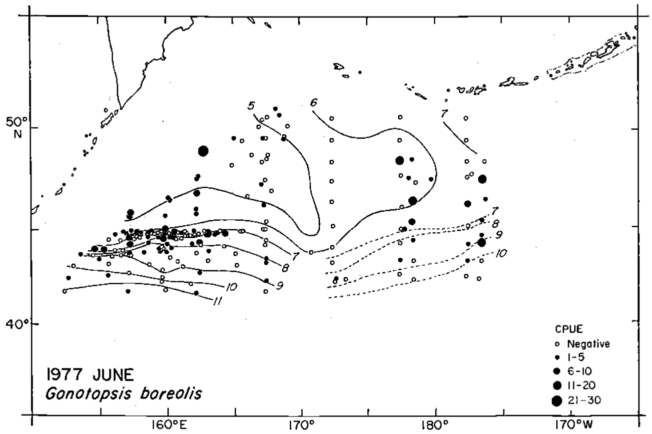

Fig. 5a.

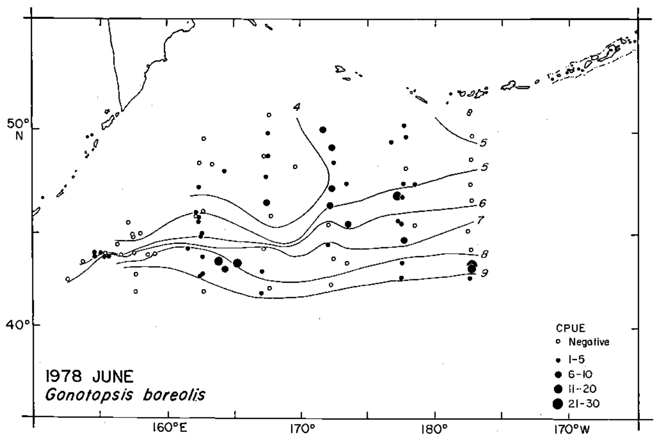

Fig. 5b.

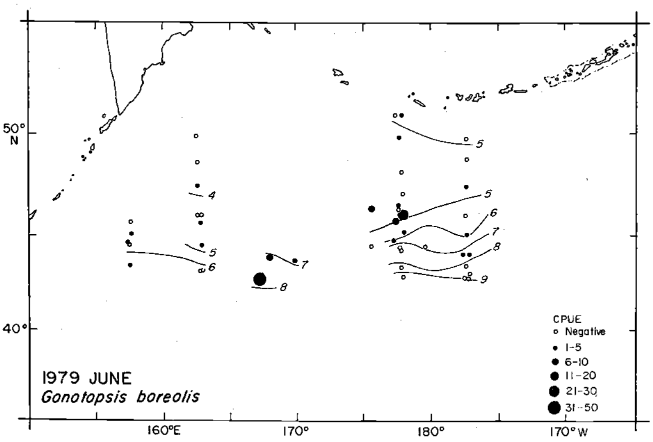

Fig. 5c.

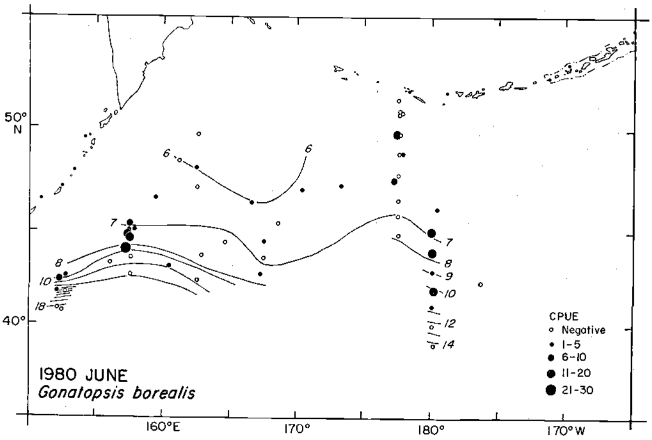

Fig. 5d.

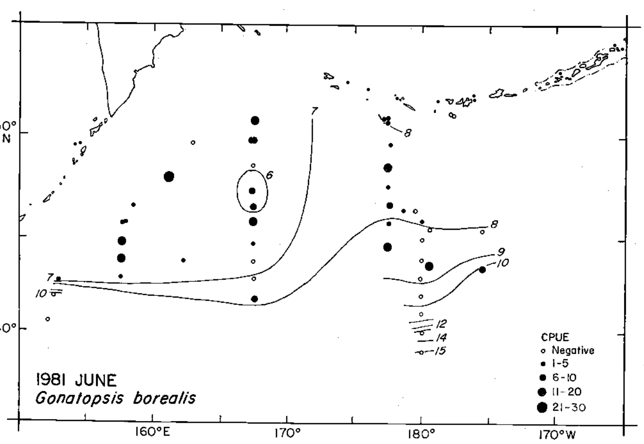

Fig. 5e.

Figs. 5a-e. Distribution and relative abundance of *Gonatopsis borealis* caught by surface gillnets and surface isotherms in June.

August (Fig. 8); *Gonatopsis borealis* appeared in three out of four sets in 1978, six out of seven in 1979, five out of 10 in 1980 and three out of five in 1981. Water temperatures where catches occurred were slightly higher in August (8–14°C) than in July. The southern boundary of occurrence was shifted farther to the north in August than in July to about 45°N. The CPUE of positive sets was less than 20 and no geographic pattern of abundance was obvious.

Onychoteuthis borealijaponica

May (Figs. 9a–d); *Onychoteuthis borealijaponica* occurred infrequently in the area sampled in May, appearing in only 10–18% of the sets. It was never caught in large numbers. Most positive sets had CPUEs of less than 5. It was only found south of 43°–44°N.

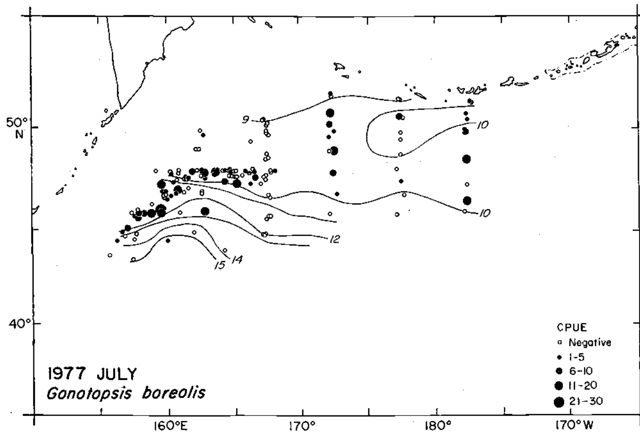

Fig. 6a.

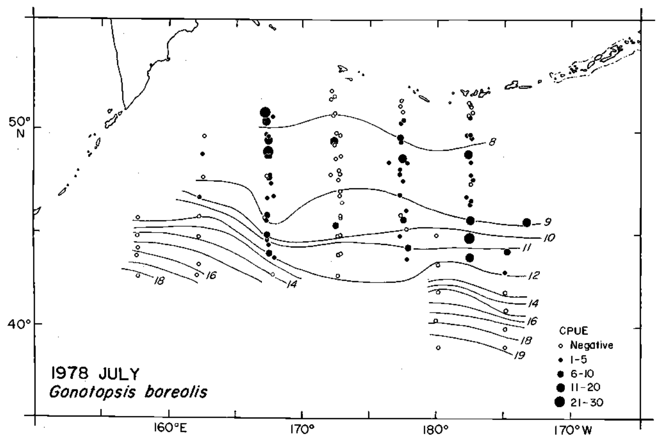

Fig. 6b.

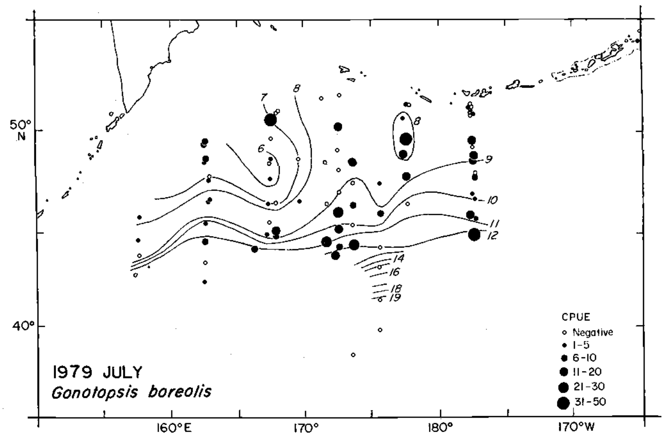

Fig. 6c.

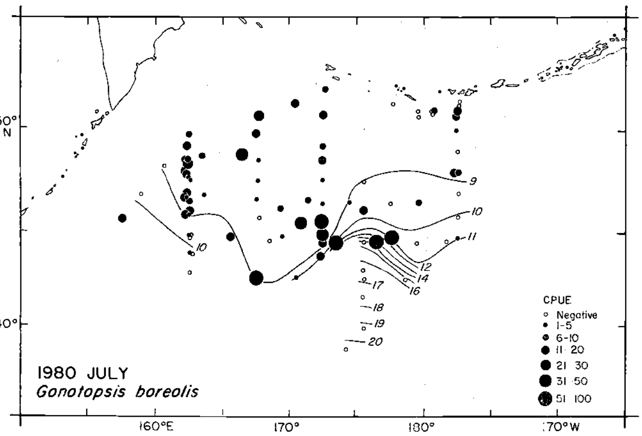

Fig. 6d.

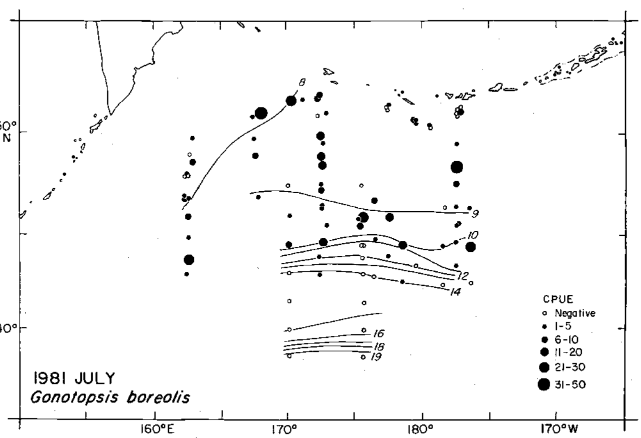

Fig. 6e.

Figs. 6a-e. Distribution and relative abundance of *Gonatopsis borealis* caught by surface gillnets and surface isotherms in July.

Onychoteuthis borealijaponica was caught where surface water temperatures were between 4°–11°C, but most were captured between 6°–11°C. The mean CPUE was low, about 0.5–1.6 (Fig. 3). In 1978 (Fig. 9a), when warm (>9°C) water was encountered in the southwestern region, only a few *O. borealijaponica* were captured, and none was taken in waters above 10°C.

June (Figs. 10a–e); In June, frequency of occurrence varied from 15% in 1979 to 35% in 1980. Increased occurrence compared to May is correlated with the expanded area of waters above 7°C in the southern region. The CPUE of positive sets also increased in June and occasionally exceeded 10.

Onychoteuthis borealijaponica was caught where surface temperatures ranged from 6°C to 17°C. Mean CPUE was lower than 1.6 below 7°C and fluctuated between 1.0–33.0 at higher temperatures (Fig. 3). It appeared only in southern part of

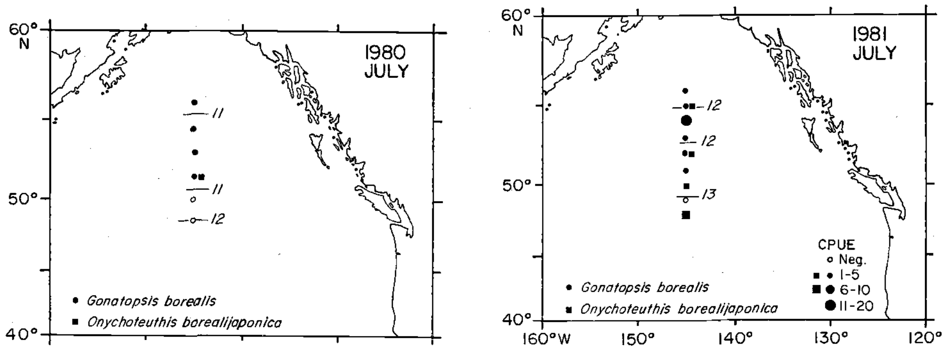

Fig. 7. Distribution and relative abundance of *Gonatopsis borealis* and *Onychoteuthis borealijaponica* caught by surface gillnets and surface isotherms in the Gulf of Alaska in July, 1980 and 1981.

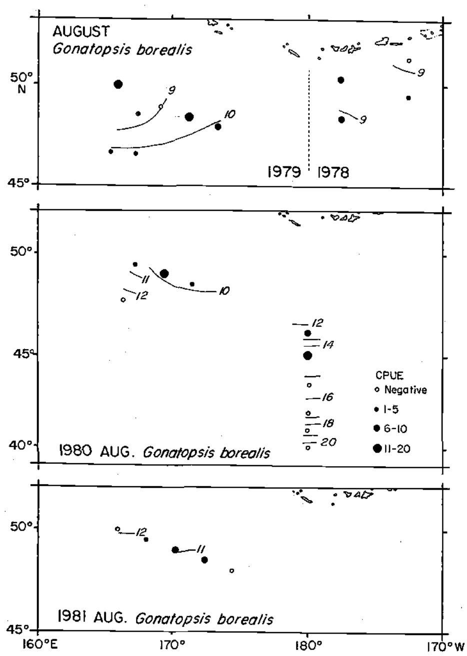

Fig. 8. Distribution and relative abundance of *Gonatopsis borealis* caught by surface gillnets and surface isotherms in August.

the research area and the northern boundary of occurrence usually coincided with the 7°C isotherm. Compared to May, this boundary shifted slightly to the north to about 44°–45° N. In 1977 (Fig. 10a), catches were relatively low around the northern border of distribution but were high in the southern portion of the area sampled. In 1980 (Fig. 10d), it was caught at an unusually high latitude, about 51°N just south of the Aleutians, where surface water temperature was 5.1°C.

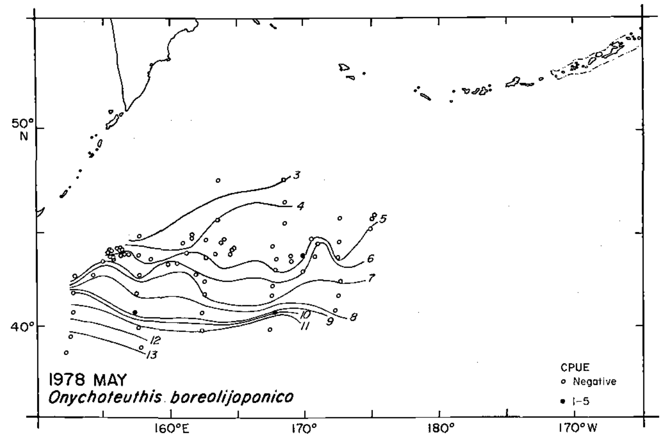

Fig. 9a.

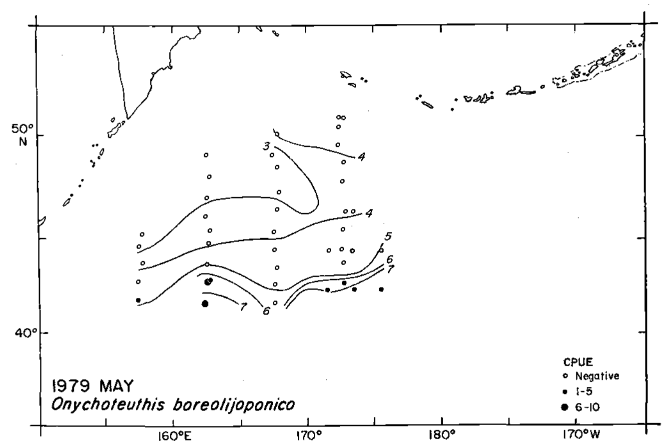

Fig. 9b.

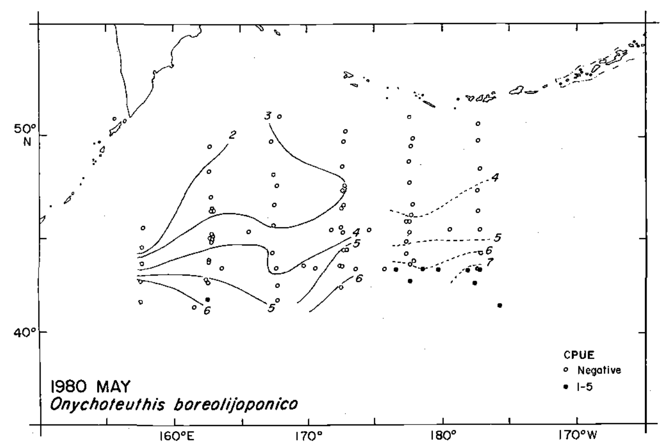

Fig. 9c.

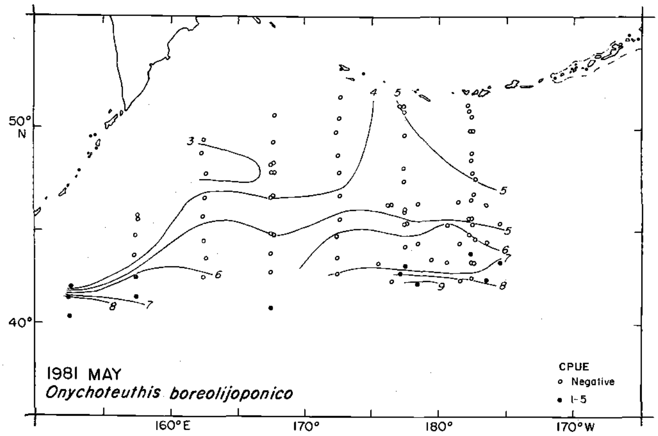

Fig. 9d.

Figs. 9a-d. Distribution and relative abundance of *Onychoteuthis borealijaponica* caught by surface gillnets and surface isotherms in May.

July (Figs. 11a–e); *Onychoteuthis borealijaponica* occurred over a large part of the research area in July. The frequency of occurrence increased markedly to about 40% of the sets in all years except 1980, when it occurred in 28% of the sets. Compared to June, the CPUE was high and often exceeded 50. The catch per set was lowest in 1977 and 1981 and highest in 1978, 1979 and 1980. Extremely large catches (CPUE>200) were made in some of the sets in 1979 and 1980.

During July, it was caught where water temperatures were between 6–16°C. Mean CPUE was low (<5.6) below 9°C and high (about 10.5–29.8) between 10°–16°C. Highest catches generally occurred in the waters of about 10°–12°C (Fig. 3). Even though surface waters in the northernmost area in July warmed to over 7°C, a temperature that coincided with the northern boundary of occurrence in June, this species occurred only south of about 48–49°N where surface water temperatures were about 8°–9°C. Nevertheless, a definite northward movement occurred between June and July. The northern boundary of occurrence shifted nearly 4°–5° to the north between these two months. The southern boundary of occurrence coincided with the 15°–16°C isotherms. The distribution of *O. borealijaponica* was therefore restricted to a zone between the 8°–9°C and the 15°–16°C surface isotherms during this month.

In July 1980, four *O. borealijaponica* were caught in one set at 51°30′N out of six sets in the Gulf of Alaska (Fig. 7). In 1981, it was taken in four out of nine sets from 48°30′N, with all positive sets having CPUEs of less than 5, except for the southernmost set. It appeared where water temperatures were between 10.4°–13.6°C. Compared with the western Subarctic Pacific in July it was found farther to the north, and the CPUE was low.

August (Fig. 12); *Onychoteuthis borealijaponica* occurred frequently, appearing in about 30%–57% of the sets. The CPUE of positive sets was high as same as in July.

It appeared in water of 8°–14°C with highest mean CPUE (13.6–41.1) at

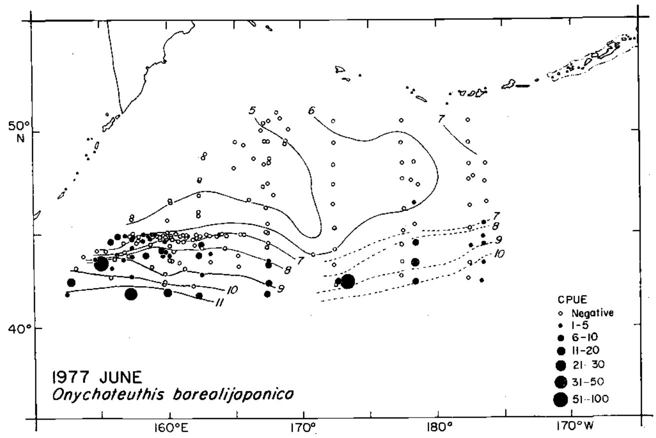

Fig. 10a.

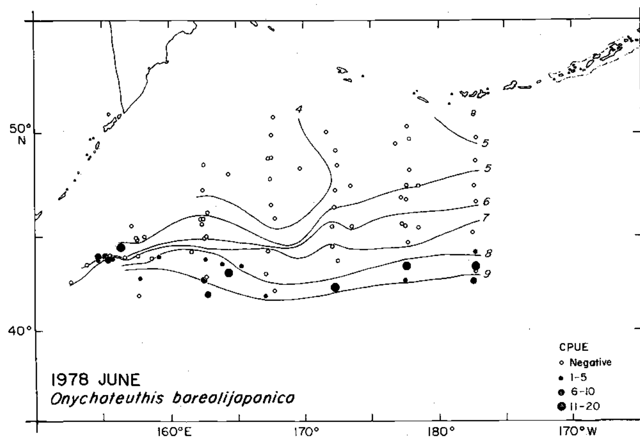

Fig. 10b.

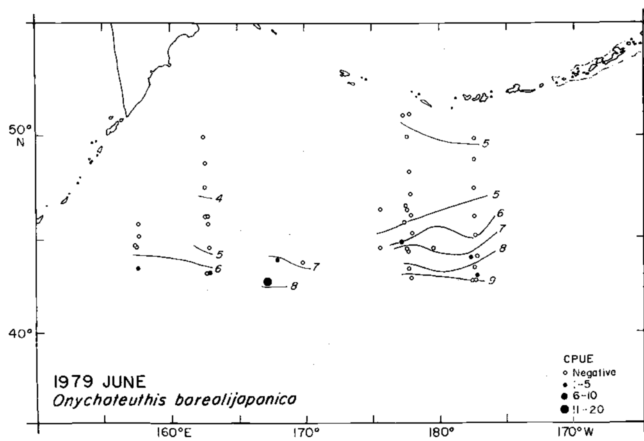

Fig. 10c.

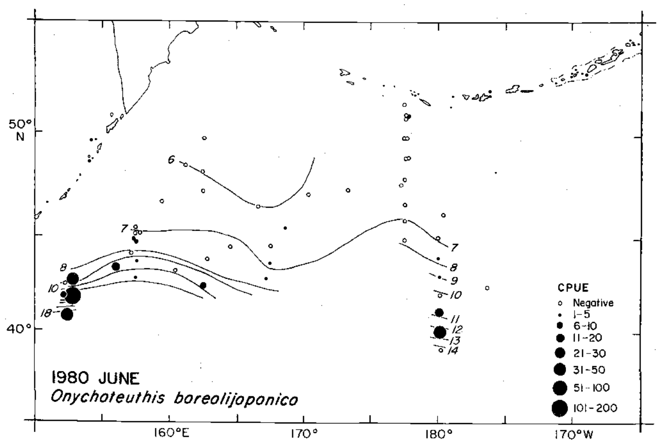

Fig. 10d.

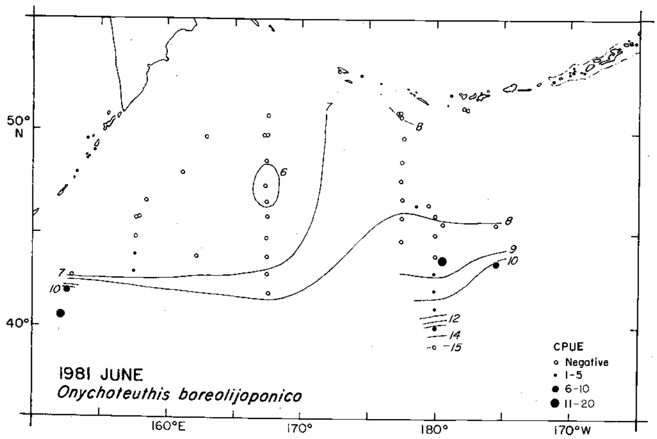

Fig. 10e.

Figs. 10a-e. Distribution and relative abundance of *Onychoteuthis borealijaponica* caught by surface gillnets and surface isotherms in June.

temperatures below 11°C (Fig. 3). The northern boundary of occurrence was located at about the same latitude as observed in July, about 49°N, despite the warmer surface waters in August. Again, no catches were made in the southern waters where surface water temperatures were higher than 16°C.

Ommastrephes bartrami

May (Fig. 13); During the five years that research was conducted in May, *O. bartrami* was caught in only two sets. Both were in 1978 in the southernmost area sampled where surface water temperatures were higher than 11°C, unusually warm for this area in May (Figs. 4a–d).

June (Figs. 14a–d); Both frequency of occurrence and CPUE of positive sets were low, less than 1.5% and 20 respectively. An exception was 1980 when *O.*

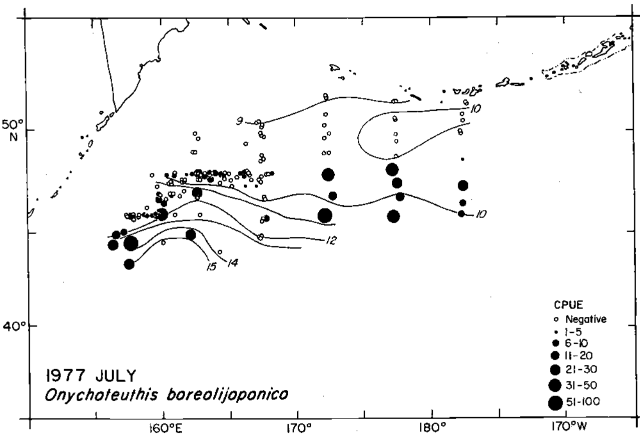

Fig. 11a.

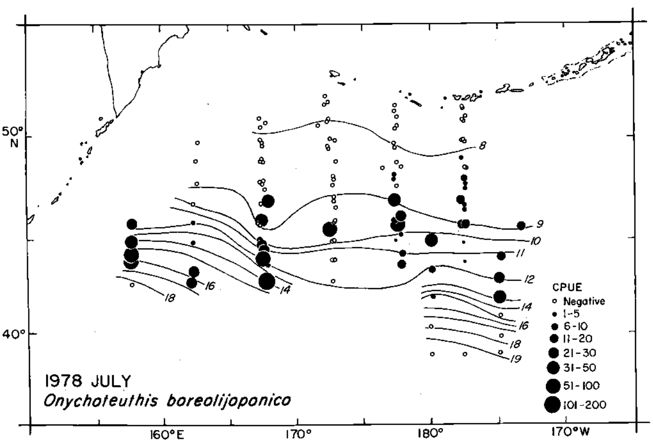

Fig. 11b.

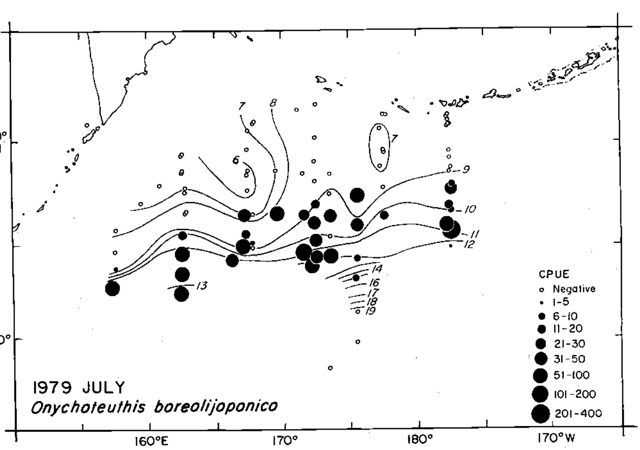

Fig. 11c.

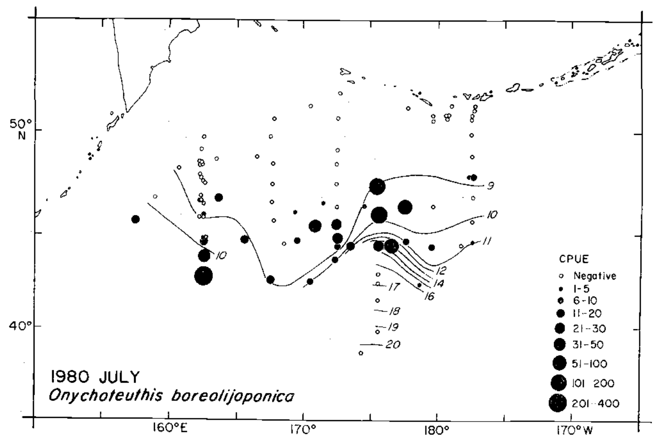

Fig. 11d.

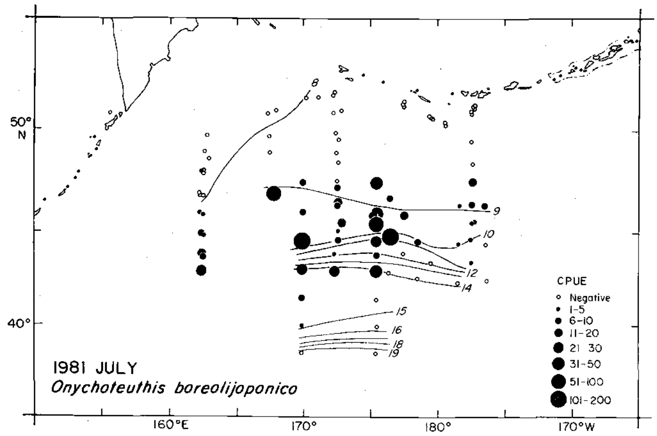

Fig. 11e.

Figs. 11a-e. Distribution and relative abundance of *Onychoteuthis borealijaponica* caught by surface gillnets and surface isotherms in July.

bartrami occurred in 15% of the sets, and one set at 42°30′N, 176°30′W provided a remarkably large catch (CPUE of 782).

It appeared where water temperatures were 9°–18°C, with lowest mean CPUE at low temperatures (Fig. 3). The extremely high catch in a June 1980 was made in late June, in 14°C water several weeks later than the other catches during this month (Fig. 14c). *Ommastrephes bartrami* was usually taken in small numbers at stations located in the southern portion of the research area where surface water temperatures were higher than about 9°C in June. An exception was the catch in much colder waters, about 6°–7°C, in 1977 (Fig. 14a). In 1980 (Fig. 14c), relatively high catches were made at a strong thermal front in the southwestern area.

July (Figs. 15a–e); The frequency of occurrence varied from 3.1% in 1977

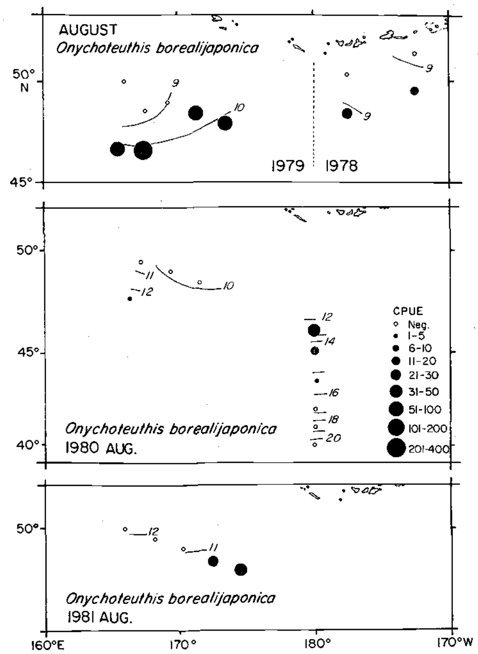

Fig. 12. Distribution and relative abundance of *Onychoteuthis borealijaponica* caught by surface gillnets and surface isotherms in August.

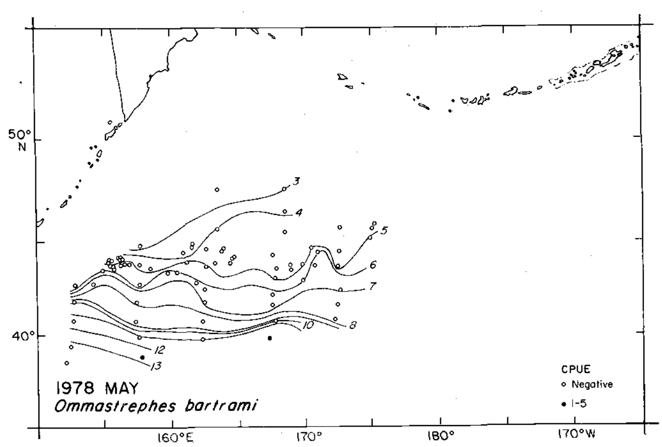

Fig. 13. Distribution and relative abundance of *Ommastrephes bartrami* caught by surface gillnets and surface isotherms in May, 1978.

to 21.8% in 1981. These positive sets were restricted to south of about 45°N in July. The CPUE of positive sets increased dramatically in July compared to June, but a definite northward shift in distribution was not evident.

Ommastrephes bartrami was caught over a wider temperature range in July (9°C–21°C) than in June. Mean CPUE was low below 10°C, high (about 14.7–82.6) between 11°–18°C, and extremely high (>250) in waters of 19°–20°C (Fig. 3).

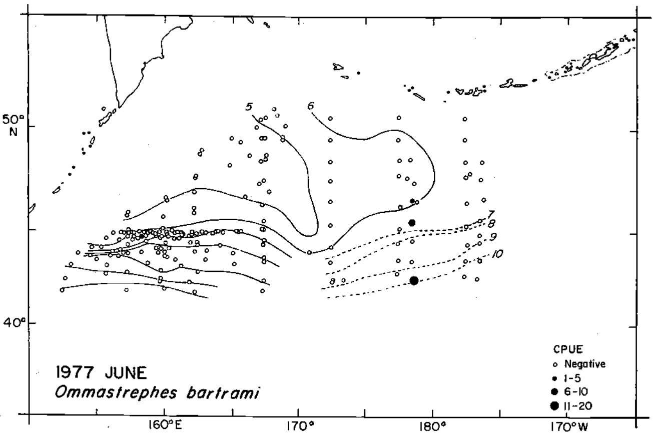

Fig. 14a.

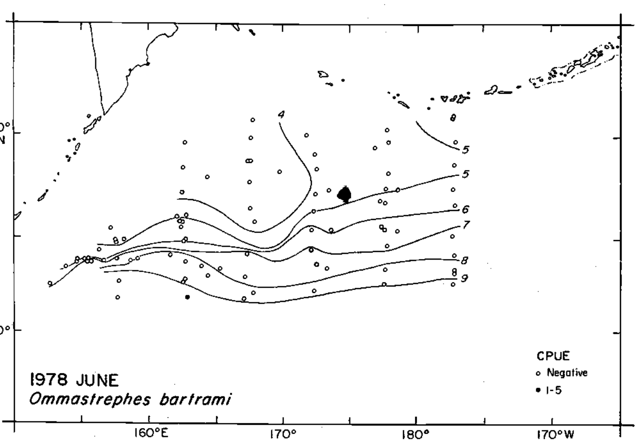

Fig. 14b.

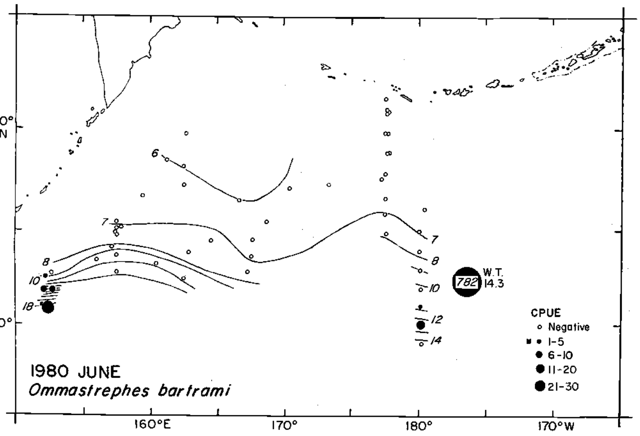

Fig. 14c.

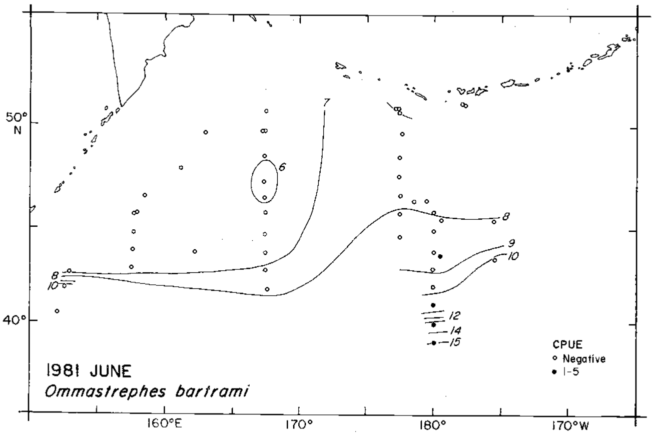

Fig. 14d.

Figs. 14a-d. Distribution and relative abundance of *Ommastrephes bartrami* caught by surface gillnets and surface isotherms in June.

Few positive sets and low CPUE were found around the northern border of occurrence, which usually coincided with 10°–11°C isotherms. In spite of the fact that a large part of southwestern area included waters warmer than 11°C in 1977 (Fig. 15a) and 1978 (Fig. 15b), only a few sets caught small numbers of *O. bartrami*. In all years after 1977, largest catches of *O. bartrami* were made east of 170°E where surface water temperatures were 12°–20°C. The CPUE for these positive sets was generally higher than 50–100, and a CPUE over 400 occurred at some stations in the southernmost area, where surface temperatures were 18–20°C in 1978 (Fig. 15b) and 1980 (Fig. 15d). In 1981 (Fig. 15e), exceptionally high catches were seen along the 11°–14°C thermal front at about 43–44°N and 175°E–178°W.

No *O. bartrami* was taken during the research in the Gulf of Alaska in July.

August (Fig. 16); *Ommastrephes bartrami* appeared only at the four stations located south of 44°N in 1980 where surface water temperatures were higher than 15°C. The CPUE of positive sets was 44.8–260.0, and the highest catch was made at 16.9°C.

In summary, seasonal changes of distributions and abundances of three species appeared to be closely correlated with surface water temperatures. Northward extensions of catches of *O. borealijaponica* and *O. bartrami* were especially obvious.

4. Relationship between Vertical Distribution of Temperature and Salinity and Abundance of Squids in the Surface Layer

As seen in the previous section, large catches of *O. borealijaponica* and *O. bartrami* were sometimes made along the northern border of their distributions during the summer. These high catches in surface waters are related to vertical features of temperature and salinity in Fig. 17, which shows vertical sections of temperature and salinity from the surface to 125 m along with CPUE for each

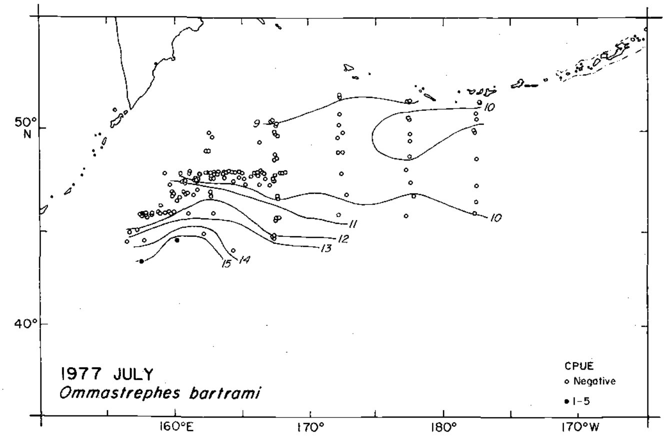

Fig. 15a.

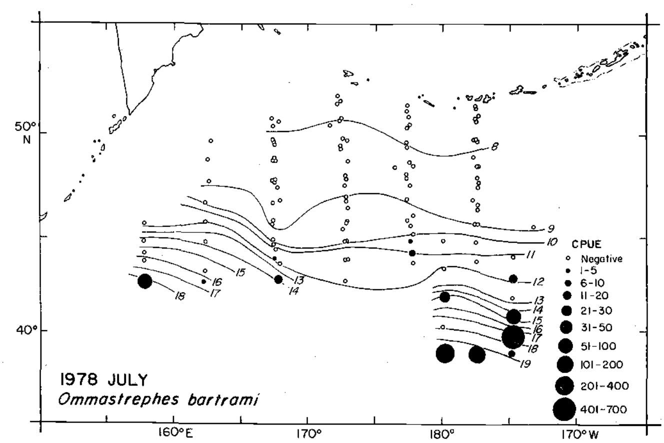

Fig. 15b.

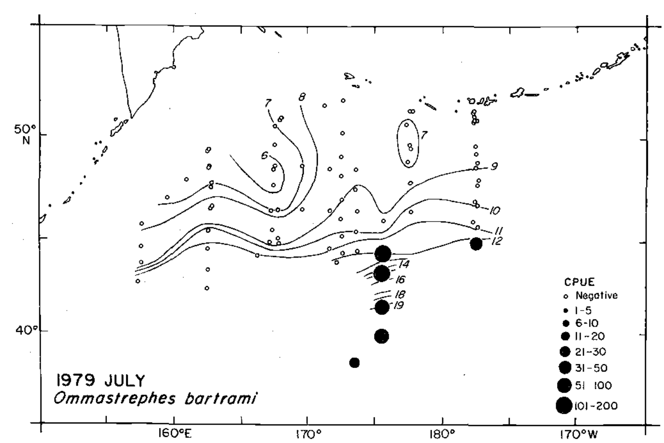

Fig. 15c.

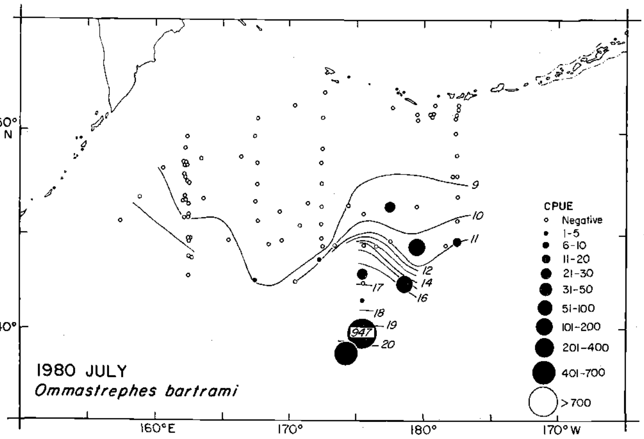

Fig. 15d.

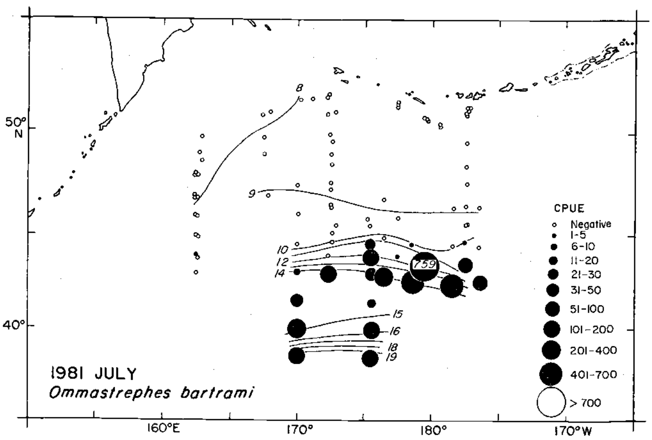

Fig. 15e.

Figs. 15a-e. Distribution and relative abundance of *Ommastrephes bartrami* caught by surface gillnets and surface isotherms in July.

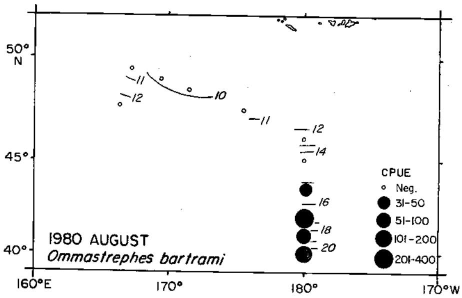

Fig. 16. Distribution and relative abundance of *Ommastrephes bartrami* caught by surface gillnets and surface isotherms in August, 1980.

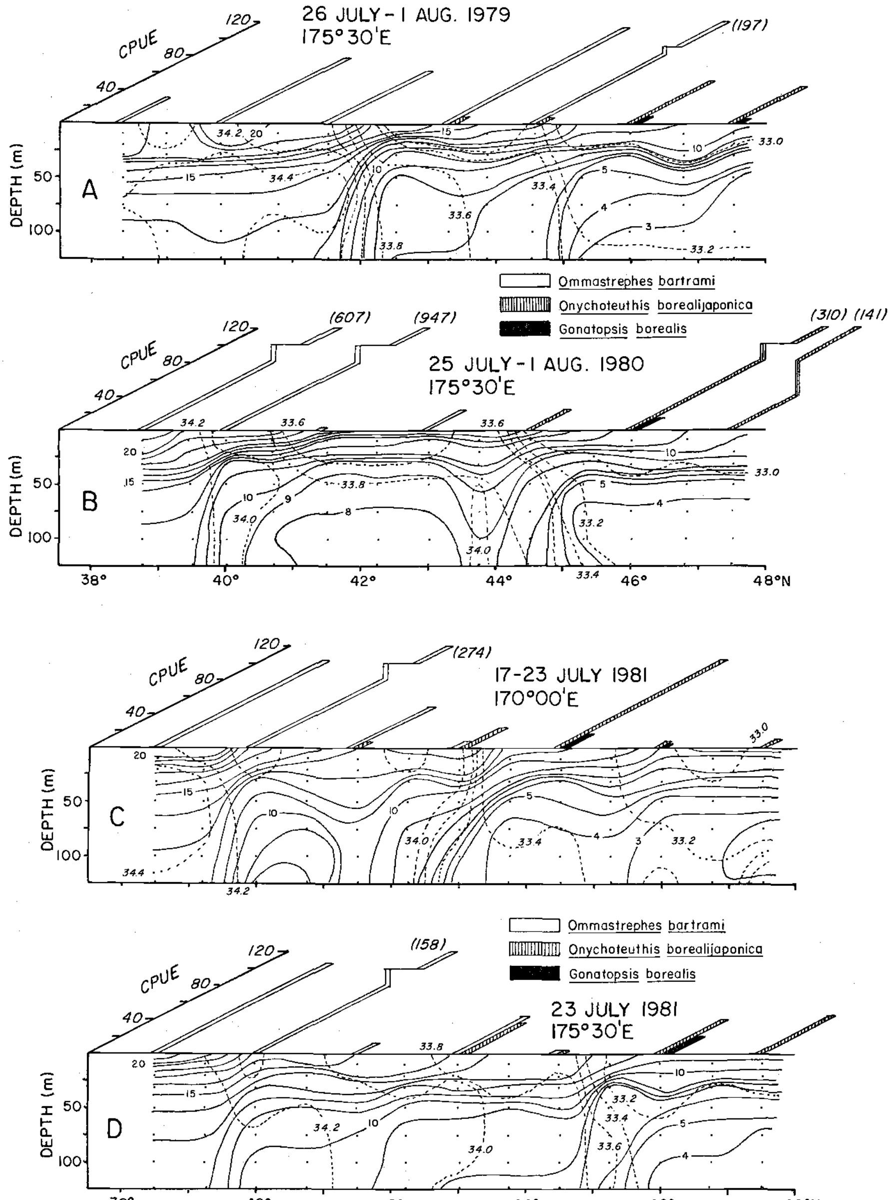

Fig. 17. Vertical features of temperature and salinity from the surface to 125 m depth along with CPUE of *Gonatopsis borealis*, *Onychoteuthis borealijaponica* and *Ommastrephes bartrami* in the surface layers at north-souh transects from 38°30′N to 47°30′N (see Fig. 1) in late July, 1979–1981.

species of squid in surface layers from 38°30′N to 47°30′N along 175°30′E and 170° E in late July in 1979, 1980 and 1981 (see Fig. 1 for locations).

Although temperature and salinity varied from year to year at the same station, the upper 25 m layer was usually 17–20°C at 38°30′N and 7°–10°C at 47° 30′N. A thermocline was present along the transects between 25–50 m depth. Below the thermocline, two distinct thermal fronts were present as indicated by latitudinal convergence of the 10°–12°C and 5°–6°C isotherms. The 10°–12°C front was located at about 42°N in 1979 (Section A) and 40°N in 1980 (Section B) and 1981 (Sections C, D). It coincided with the 34.0‰ isohaline in 1979 and 1980, indicating the boundary between Subtropical and Subarctic Regions. In 1981 (Section D), the 34.0‰ isohaline was found farther north. The 5°–6°C front was located at about 45°N in each year along 175°30′E (Sections A, B, C) and at 43°N along 170°E in 1981 (Section C). Convergence of the 33.4–33.6‰ isohalines was usually associated with this thermal front, indicating the boundary between Transitional and Western Subarctic Domains (see Dodimead et al., 1963; Favorite et al., 1976).

Ommastrephes bartrami appeared in the surface waters of the Subtropical Region and Transitional Domain but not in the Western Subarctic Domain. Its northern limit of distribution seemed to be transitional waters between the Subarctic front and Western Subarctic Waters. CPUE was highest in waters of the Subtropical Region, except in 1977 (Section A) when highest catches were made in the Transitional Domain at the northern end of its distribution. The extremely high catches in the surface waters between the Subtropical and Subarctic Regions (Sections B, C, D) suggests that migrants from the south accumulate along this barrier to northward migration. Some migrants penetrated farther north in warm surface waters where they are found in highest numbers at the thermo-halo-convergence zone between the Transitional and Western Subarctic Domains (Section A).

Onychoteuthis borealijaponica, on the other hand, appeared mainly in the surface waters of the Western Subarctic Domain and seldom in the Transitional Domain (Fig. 17). CPUE was low in Transitional waters and high in the Western Subarctic Domain. It was especially high in surface waters where the thermocline was shallow below 10°–11°C surface waters. Since *O. borealijaponica* appears to tolerate temperatures as low as about 7°–8°C, the front associated with the 6°–7°C isotherms may limit the northward migration of this species and restrict its distribution to northward extensions of warm surface water in the Western Subarctic Domain. Such vertical reduction of habitable space may result in concentrations of *O. borealijaponica* in surface waters as they migrate northward into the Subarctic Domain.

Gonatopsis borealis appeared only in the surface waters of the Western Subarctic Domain, had low CPUE and did not show any obvious relationship to the vertical structure of temperature and salinity (Fig. 17). Vertical thermal gradients did not appear to be an barrier for this cold-water species which sometimes was caught in surface waters of 2°–3°C in May. Therefore *G. borealis* may have a large vertical range in the Subarctic Region. Its presence in surface waters in southern area was probably restricted by the warm waters that extend to the surface into the Transitional Domain. *Gonatopsis borealis* may be found farther south to the Subarctic Boundary in the deeper waters below thermocline.

Vertical stratification among the three species was indicated at 43°15′N in 1979 (Section A) where large numbers of *O. bartrami* were taken in the research gillnets in surface waters, some *O. borealijaponica* were caught by jigging from about 50 m depth and some *G. borealis* were caught on jigs fished below 50 m depth.

Abundances of *O. borealijaponica* and *O. bartrami* in the surface waters of the northern Pacific are therefore correlated with thermohaline structure. Accessibility to gillents may be high in areas where these species are confined to surface waters by vertical thermal gradients that develop during their summer migrations.

5. Size Composition and Maturity

To study the size structure and sexual maturity of the three common species, dorsal mantle lengths (DML), body weights, and reproductive organ (ovary, nidamental gland, testis and spermiduct) weights were determined from specimens randomly selected from the catches and brought to the laboratory.

Gonatopsis borealis; Length-frequency distributions by sex, month and year were examined for about 35–50% of the total catch from each month except May of 1979 (Fig. 18). Females were usually more numerous than males. The sex ratio (male/female) was low (0.62–0.68) in June and slightly higher (0.71–0.83) in July, except for months with small samples. Two distinct size groups were evident for both female and male *G. borealis* in the summer of all three years. The range of the small size group was about 11–18 cm DML, with a peak at about 15 cm DML for females and 14 cm for males. The large group, which appeared mainly in July (except for 1977), ranged in size from about 20–27 cm DML for females and 20–25 cm for males. The largest specimens were a 31.5 cm DML female and a 25.5 cm male.

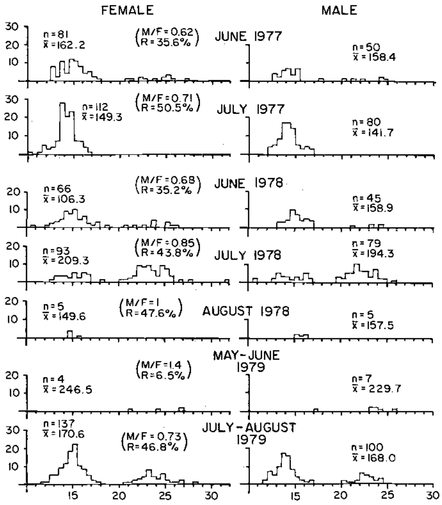

Fig. 18. Frequency distribution of dorsal mantle length of *Gonatopsis borealis* caught by surface gillnets in the northwestern North Pacific in summer, 1977–1979. M/F=male/female, R=number examined/total number of catch ×100.

A gonadosomatic index (GSI=gonad weight/body weight ×100) was used to indicate the development of reproductive organs. Fig. 19 shows the relationship between DML and GSI by sex and month for June and July 1978. In the small size group, the GSI for ovaries increased from less than 1% in females smaller than about 14 cm DML to 3–4% in some females larger than 15 cm DML. The GSI of the large size group was almost always lower than about 2%, and no increase of GSI was seen with size during either June or July. Based on visual observations, small granulated eggs were present in the ovaries of individuals with a GSI of 2% or higher, and the egg size increased with an increase in GSI. However, copulated mature females were not observed. Both groups apparently were maturing during this June-July period.

Nearly all males of both small and large size groups had GSI of less than 1%, except for a few individuals in the small size group. Although the GSI tended to be higher in small individuals than in large individuals within each group, many individuals larger than 15 cm DML in the small size group and 22–23 cm DML in the large size group possessed mature spermatophores in the spermiducts. Some individuals of the small size group were fully mature, and spermatophores were easily detached from the tip of penis, which extended nearly to the mantle opening, by applying pressure to the spermiduct.

Relationships between the reproductive organ weight and DML are shown in Fig. 20 for *G. borealis* captured in July 1979 in gillnets and by jigging. All organs except the testis increased in weight with increasing DML. In both size groups, testis weight decreased slightly with size as spermiduct weight increased

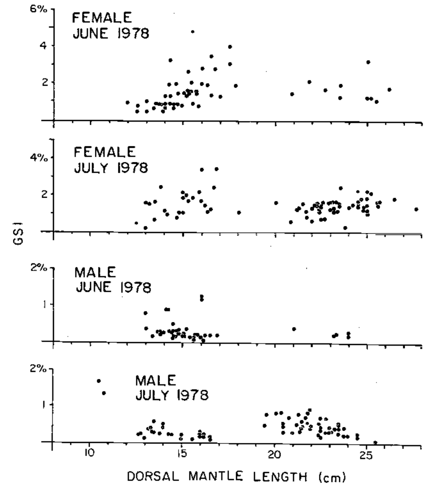

Fig. 19. Relationship between gonadosomatic index (GSI) and dorsal mantle length of *Gonatopsis borealis* caught by surface gillnets in the northwestern North Pacific in the summer of 1978. GSI=gonad weight/body weight ×100.

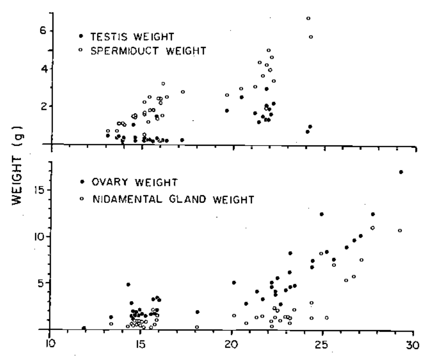

Fig. 20. Relationships between weights of reproductive organs and dorsal mantle length of *Gonatopsis borealis* caught by surface gillnets and jigging in the northwestern North Pacific in July, 1979.

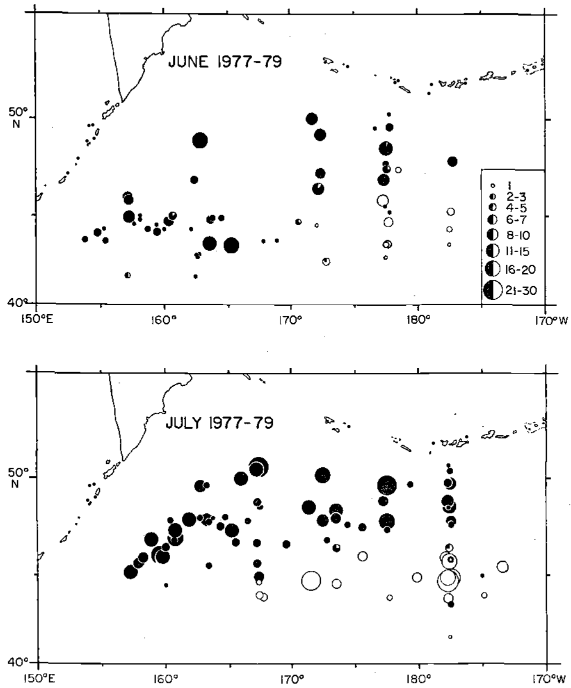

Fig. 21. Distribution and relative abundance of *Gonatopsis borealis* caught by surface gillnets in June and July, 1977–1979. The small size group (smaller than 20 cm DML) is indicated by solid and the large size group (larger than 20 cm DML) is indicated by open.

with size due to the storage of spermatophores in the spermiduct. The discontinuity in the trends for spermiduct and ovary weights between the small size group and large size group, and the higher GSI in the small size group, indicates that reproductive organs develop independently in each group.

The two size groups of *G. borealis* have different geographic distributions in the ocean. Fig. 21 shows the distribution and abundance of size groups larger and smaller than 20 cm DML in June and July for three years. Only one size group was taken at most stations. The large size group was mainly found in the southeastern area sampled, south of about 47°N and east of 167°E, while the small size group was more broadly distributed in the northern and western portions of the area sampled in both June and July. Latitudinal changes of size composition of *G. borealis* along 173°–175°E (Fig. 25) also indicated geographic segregation of these groups during summer. All these differences suggest that *G. borealis* has two geographically segregated subpopulations, each with a distinct size composition and independent development of reproductive organs.

Onychoteuthis borealijaponica; Length-frequency distributions by sex, month and year are shown in Fig. 22. About 24–46% of total catch was measured in each month. In 1977, the sex ratio (male/female) was low, below 0.5 in both

June and July, indicating nearly twice as many females as males. In 1978, the sex ratio varied from 0.16 in June to 0.59 in July and 1.38 in August, but again females outnumbered males. In 1979, only a few specimens were taken in June, but males and females were found in nearly equal numbers in July and August. Most females were 19–32 cm DML; the largest was 35.5 cm DML. Most males were 18–25 cm DML; the largest was 34.5 cm DML. The mean DML of females was usually 3–4 cm larger than for males in every month. The size composition of both males and females was complex, often with several modes. A clear trend for growth was not evident among months. The size composition and sex ratio of *O. borealijaponica* taken in the surface waters of Subarctic Pacific during the summer may be complicated by differences in the sizes of squid that migrate from the south.

The relationship between DML and GSI by sex and month for 1978 (Fig. 23) shows that the GSI of females of a given size tends to be higher in June than in July. In June, many females of about 20 cm DML had a GSI above 1% and some individuals larger than 25 cm DML had a GSI higher than 3%. In July, on the other hand, almost all females smaller than 25 cm DML had a GSI of less than 1%, and only a few individuals larger than 25 cm DML had a GSI which exceeded 3%. No granulated eggs were observed in ovaries in either month, even in the females having high GSI. No copulated females were present.

The GSI of males between 19–23 cm DML increased from less than 1% to nearly 7–8% and then decreased abruptly in individuals larger than 23–24 cm DML.

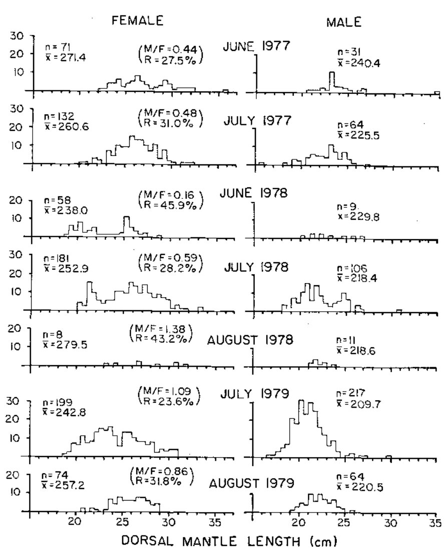

Fig. 22. Frequency distribution of dorsal mantle length of *Onychoteuthis borealijaponica* caught by surface gillnets in the northwestern North Pacific in summer, 1977–1979. M/F=male/female; R=number examined/total number of catch ×100.

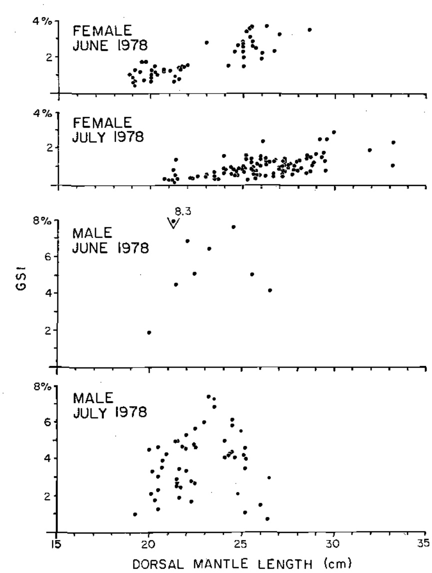

Fig. 23. Relationship between gonadosomatic index (GSI) and dorsal mantle length of *Onychoteuthis borealijaponica* caught by surface gillnets in the northwestern North Pacific in June and July, 1978. GSI=gonad weight/body weight ×100.

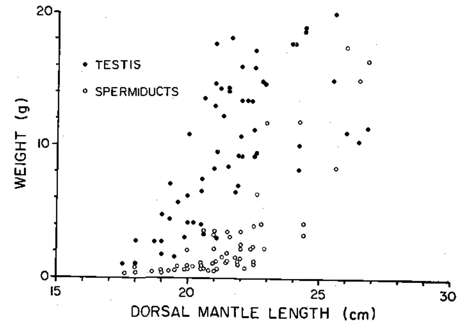

Fig. 24. Relationships between weights of male reproductive organs and drosal mantle length of *Onychoteuthis borealijaponica* caught by surface gillnets in the northwestern North Pacific in July, 1979.

This decrease in the GSI with size in larger males corresponded with loss of testis weight due to storage of spermatophores in the spermiduct (Fig. 24). Many individuals larger than about 23–24 cm DML possessed almost complete spermatophores in their spermiducts.

In general, collections of *O. borealijaponica* taken in the surface waters of the Subarctic Pacific during the summer are composed of immature females, some of which are maturing, and maturing males, with males larger than about 23–24 cm DML being nearly mature. These maturing *O. borealijaponica* apparently migrate northward into the Subarctic Region in June and July. Latitudinal changes in the size composition of this species along 173°–175°E in July 1979 (Fig. 25) indicated that the larger individuals tended to migrate farther to the north where highest concentrations were found.

Ommastrephes bartrami; Latitudinal changes of size composition of *O. bartrami* are shown in Fig. 25, along with those of *G. borealis* and *O. borealijaponica* based on the catches along 173°–175°E from 38°30′N to 50°00′N by *Hokusei Maru* during late July to early August in 1979. The size composition of *O. bartrami* changed radically at about 42°–43° N where the Subarctic Boundary was seen along this longitudinal transect in Fig. 17 (section A). The two northern stations were located in the Transitional Domain and provided many large-size individuals of 34–48 cm DML, but no individuals smaller than 34 cm DML. The three southern stations were located in the Subtropical Region where only a few large-size individuals were caught and small individuals (about 15–25 cm DML with a peak about 20 cm DML) were common. The size of this small size group increased toward the north.

Without exception, all the specimens examined in the large size group were females. The sex ratio was nearly equal in the small size group. The size range was about 15–48 cm DML for females and about 15–26 cm DML for males (Fig. 26).

The GSI of females was higher in large size group than in the small size group, but even in the large size group the GSI was less than 1.5% suggesting a low degree of maturity (Fig. 26). All males in the small size group had a GSI of less than 0.5% and were immature, except for the two largest individuals of 25–26 cm DML which had a GSI of higher than 2% but no spermatophores in their spermiducts.

In summary, two groups of *O. bartrami* taken in the surface waters in the northern North Pacific in July. One is composed of small individuals with a nearly

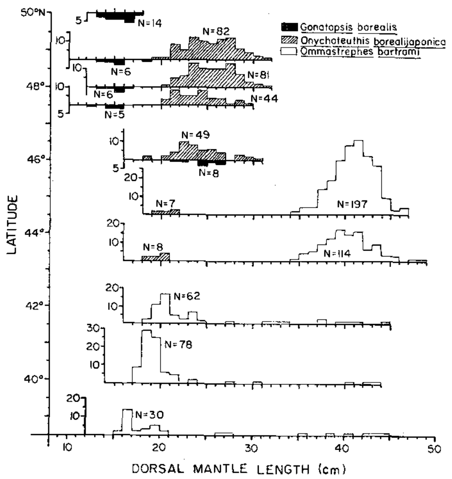

Fig. 25. Frequency distribution of dorsal mantle length of *Ommastrephes bartrami*, *Onychoteuthis borealijaponica* and *Gonatopsis borealis* caught by surface gillnets along 173°–175°30′E from 38°30′N to 50°N (section shown in Fig. 17 A) in the northwestern North Pacific in late July to early August, 1979.

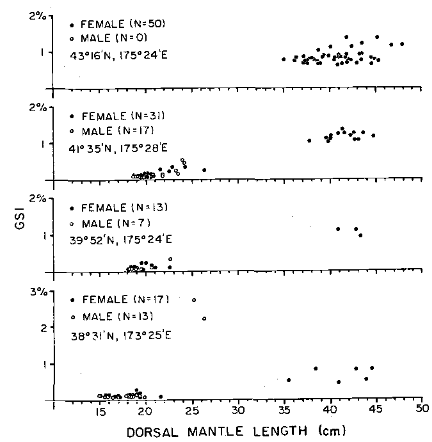

Fig. 26. Relationship between gonadosomatic index (GSI) and dorsal mantle length of *Ommastrephes bartrami* caught at the stations corresponding to Fig. 25. GSI=gonad weight/body weight ×100.

equal sex ratio and is restricted to the Subtropical waters. The other group consists of large females that migrate northward into the Transitional Domain. Both groups are immature in July.

6. Distribution of Rare Species

Five additional species and one unidentified group occurred rarely in the surface gillnets catches in the Subarctic Pacific.

Berryteuthis magister (Fig. 27); It appeared from May to July at surface water temperatures of 3.1–9.6°C. A total of 49 individuals was collected from 16 stations scattered in the area from 42°N to 51°N and 162°E to 177°W. Some of these stations located between about 45°–47°N and 178°E–178°W provided more than five individuals per set but most had one or two individuals per set.

Berryteuthis magister is a bathyal-benthic species, distributed on the continental slope between 200 and 500 m depth from Sea of Japan (Kasahara et al., 1978) and off northeastern Japan through the Kurile and Aleutian Islands to the Bering Sea (Naito et al., 1977a) and off northeastern North America (Berry, 1912; Pearcy, 1965; Bernard, 1980). Spawning was estimated to occur during June to October after reaching one year of age (Naito et al., 1977a,b). Our catches of *B. magister* in offshore surface water indicates that some individuals have an oceanic distribution.

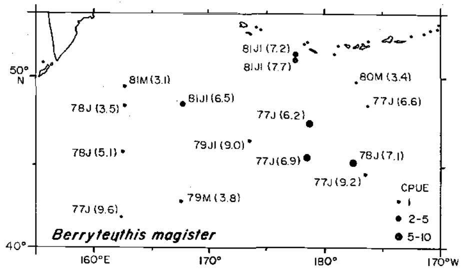

Fig. 27. Stations at which *Berryteuthis magister* was taken in surface gillnets. Year is indicated by the first two digits, month by the initial, and surface water temperature is shown in parenthesis.

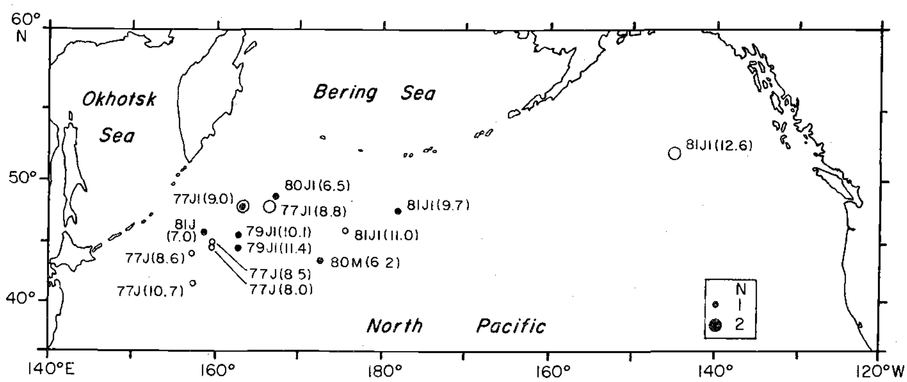

Fig. 28. Stations at which *Moroteuthis robusta* was taken in surface gillnets. Year is indicated by the first two digits, month by the initial, and surface water temperature is shown in parenthesis. Solid circles show catch by research gillnets, open circles by commercial gillnets.

Moroteuthis robusta (Fig. 28); A total of 17 individuals was collected from 14 stations; 13 of these were in the western area between 42°–49°N and 158°E–178°W and one was in the Gulf of Alaska at 52°N, 145°W. Almost all were collected during June and July at 6.5°–12.6°C surface water temperatures, except for one specimen taken in May at 6.2°C.

Moroteuthis robusta has been reported from the stomach contents of sperm whales from the Bering Sea, off the Aleutian Islands, from the Gulf of Alaska (Okutani and Nemoto, 1964), and off northeastern Japan (Okutani et al., 1976; Okutani and Satake, 1978), and has been collected along the west coast of North America (Clarke, 1966; Hochberg, 1974; Jefferts, 1983). It is considered to be an inhabitant of the continental shelf and slope in the North Pacific, but the capture of *M. robusta* in surface gillnets in this study indicates that some immature individuals are distributed in oceanic waters. Six specimens out of 17 examined were immature females about 90–120 cm DML.

Todarodes pacificus (Fig. 29); It appeared in two stations at about 43°–44°N, 175° 30′E. Two specimens were collected at 14.3°C in July 1977 and four specimens were collected at 9.9°C in June 1980.

The distribution, abundance and life history of *T. pacificus* is well known (Hamabe and Shimizu, 1966; Kasahara and Ito, 1968; Araya, 1967; Murata et al., 1971; etc.). It is found in waters adjacent to Japan and has seasonal migrations

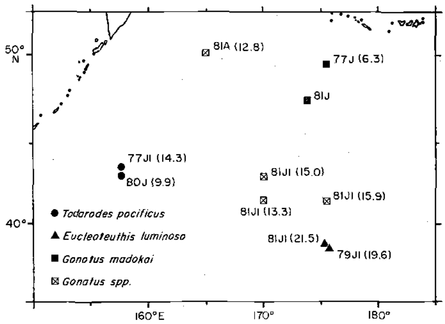

Fig. 29. Stations at which *Todarodes pacificus*, *Eucleoteuthis luminosa*, *Gonatus madokai* and *Gonatus* spp. were taken in surface gillnets. Year is indicated by the first two digits, month by the initial, and surface water temperature is shown in parenthesis.

from south to north with a one year life span. It was caught in our study along the northeastern margin of its migratory range.

Eucleoteuthis luminosa (Fig. 29); Three specimens were taken at 38°30′N, 175°30′E in July 1979, where the surface water temperature was 19.6°C. Four specimens were taken at nearly the same position in July 1981 when the surface temperature was 21.5°C.

Eucleoteuthis luminosa is a Subtropical species that was never found in the Subarctic Region during the five years that we studied. It is distributed across the Pacific Ocean from off Japan (Sasaki, 1929) to North America (Young, 1972).

Gonatus madokai and ***Gonatus*** spp. (Fig. 29); One specimen of *G. madokai* was taken at 49°30′N, 175°30′E in June 1977 and the other was taken in commercial gillnets set at 47°30′N, 173°30′E in June 1981. Unidentified species of *Gonatus* were collected during the research cruise of *Hokusei-Maru* in July 1981. Three were from the research gillnets set at 41°30′N, 175°30′E, 49°00′N, 169°20′E and 50°00′N, 165°00′E. Seven were from small mesh size gillnets attached to the research gillnets at 41°30′N, 175°30′E (two specimens) and 43°00′N, 170°00′E (five specimens).

Gonatus madokai was recently described by Kubodera and Okutani (1977). They reported that larvae were abundant in the waters off southwestern Kamchatka. Besides *G. madokai*, four *Gonatus* species have been described from off California (Young, 1972) and one from the northwestern North Pacific (Kubodera and Okutani, 1981). In addition two or three undescribed *Gonatus* species have been reported in the northeastern North Pacific and the Bering Sea (Bublitz, 1981; Jefferts, 1983). Some of the *Gonatus* spp. in this study may be *G. middendorffi* (Kubodera and Okutani, 1981) which is large enough to be caught in the smaller mesh sizes of the research gillnets used in this study and is found in the northwestern North Pacific.

IV. Discussion

Utilizing the data of Fiscus and Mercer (1982) we attempted to provide information on the distribution and abundance of squid in the northeastern North Pacific that would be comparable to those of the northwestern North Pacific. Since they provided data for only stations where squid were caught and most squids were unidentified, this proved to be difficult. The surface gillnets used in their study normally consisted of four different mesh sizes; 64, 83, 114, 131 mm, with four shackles (each usually 94 m long) of the 64, 83 and 131 mm mesh sizes and 12 shackles of the 114 mm mesh size, for a total of 24 shackles. Some catches from our study were recorded by mesh size, so the percent of the total catch of each species by each mesh size was calculated and is shown in Fig. 30 by species and year. Most *G. borealis* was caught in 48 mm and 55 mm meshes. Most *O. borealijaponica* was caught in mesh sizes between 48–82 mm, with the peak at 63 mm. *O. bartrami* was captured over a broad size of meshes, form 48 mm to 157 mm, with a peak in the 121 mm mesh in 1979.

Based on Fig. 30, the catches of the four mesh sizes of gillnets used by Fiscus and Mercer were compared to the catches of our ten mesh size gillnets. Assuming that the area of each shackle and the number of each mesh size were the same, the four mesh size combination gillnets used by Fiscus and Mercer would have captured about 40–50% of the catch of our ten mesh size gillnets for *O. borealijaponica* and *O. bartrami* and about 10–20% for *G. borealis*. However, the number of shackles used by Fiscus and Mercer varied from 12 to 40 during the years studied, and additional mesh sizes (51, 57 and 91 mm) were used in some years. Further, although the length of each shackle was usually 91.4 m, the depth varied from 7.3 m to 21.9 m in different years. The area of each shackle therefore was about two to six times larger than in our study. Such variations made accurate calculation of equivalent CPUE from the data of Fiscus and Mercer impossible. Consequently, we simply assumed that their catches per one overnight set of 15 shackles of 4–5 different mesh sizes to be roughly equivalent to the CPUE used in our study. The largest error is probably for *G. borealis* since Fiscus and Mercer did not use small mesh gillnets. We also assumed that the species identified in a small part of the catches was representative of the species composition in the entire catch of a gillnet set.

Onychoteuthis borealijaponica, *G. borealis* and *O. bartrami* (in that order) were also the most common species identified by Fiscus and Mercer (1982). The distribution and relative abundance (catch per standardized set) of these common species (as well as unidentified squids) are shown in Fig. 31. (Negative sets are not shown.) *Onychoteuthis borealijaponica* was the most numerous, comprising about 94% of the identified specimens. It was common in waters just south of Aleutian Islands along about 51°N latitude in August. Some of the sets had CPUEs of hgiher than 30. In September and October, higher catches tended to be found south of 51°N suggesting a migration to the south during the fall. *Gonatopsis borealis* occurred from January to October, distributed sparsely between 48°N and 53°N. Small numbers of *O. bartrami* rarely appeared in their catches of north of 50°N in July and August.

Obvious seasonal changes in the relative abundance of unidentified squids are seen in the data of Fiscus and Mercer (1982) from the northeastern North Pacific

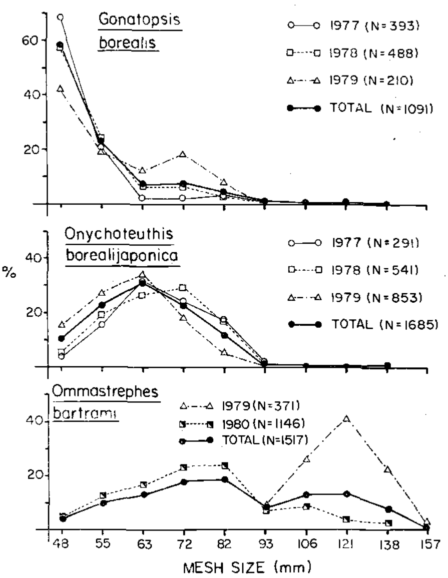

Fig. 30. Percentage composition of the total catch of *Gonatopsis borealis*, *Onychoteuthis borealijaponica* and *Ommastrephes bartrami* by each of ten different mesh sizes from 48–157 mm in research gillnets.

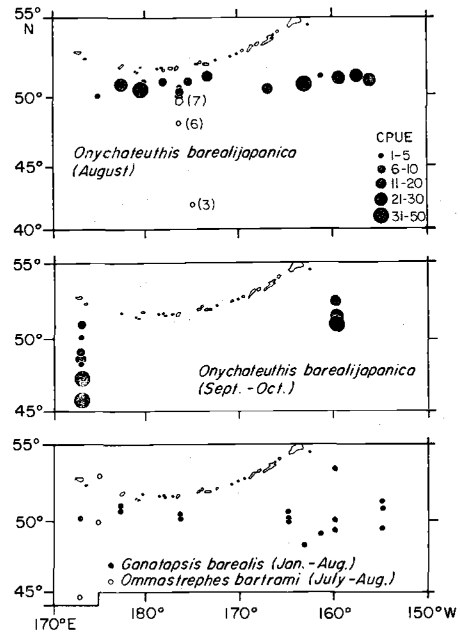

Fig. 31. Distribution and relative abundance of *Onychoteuthis borealijaponica*, *Gonatopsis borealis* and *Ommastrephes bartrami* caught by surface gillnets in the central northern North Pacific from Fiscus and Mercer (1982). For *O. borealijaponica*, open circles with (3) indicats CPUE in March, (6) in June and (7) in July.

(Figs. 32a–d). During January to May, the CPUE was low and squids were sparsely distributed in the area. Because of cool water temperatures we believe that most of these squid caught in winter were *G. borealis*. Catches gradually increased over the area during June and July when some high catches occurred in the southern part of the region. Catches of squids increased markedly in August, especially in the central region south of the waters between 180°–165°W and in the southeastern area. These high catches may be caused by large number of *O. borealijaponica* migrating into the central area and by *O. bartrami* migrating into the southeastern area. In September, the highest catches were found farther south, below the Aleutian Peninsula, perhaps due to a southward migration of *O. borealijaponica*. In general, the abundance of squids was lowest in the waters between 145°W–155°W and in the Gulf of Alaska. We also found low catches of *G. borealis* and *O. borealijaponica* in the Gulf of Alaska compared to the western areas of the Subarctic Pacific (see Figs. 6, 7, 11).

Based on the results obtained in this study and on previous information, the distribution and biological characteristics of the common species of squids caught in the surface gillnets in the Subarctic Pacific can now be summarized.

Gonatopsis borealis; This species, called a species of the Oyashio Current system by Murakami (1976) and a Subarctic oceanic species by Naito et al. (1977a), is broadly distributed in the epipelagic waters of Subarctic Pacific from off northeastern Japan (Murata et al. 1976), in the Sea of Okhotsk, Bering Sea (Naito et al., 1977a), and in the Gulf of Alaska. The southern limit of distribution of this species shifts to the north as surface waters are heated during summer (Naito et al., 1977a).

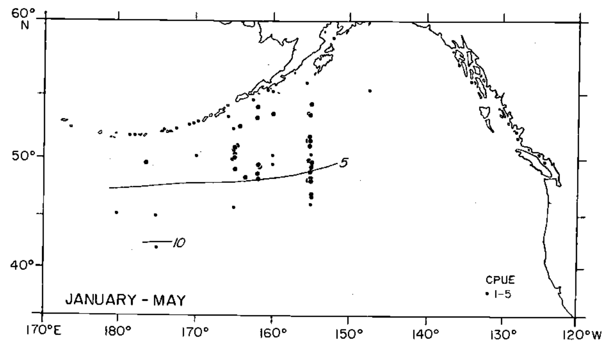

Fig. 32a.

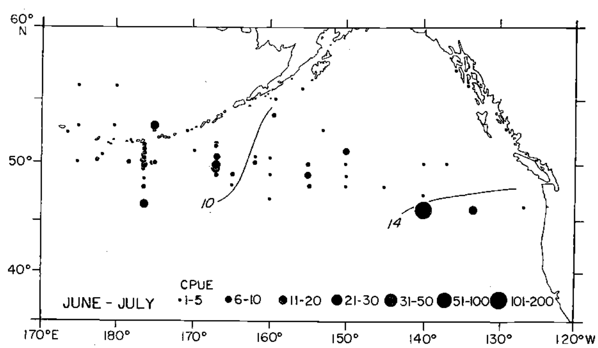

Fig. 32b.

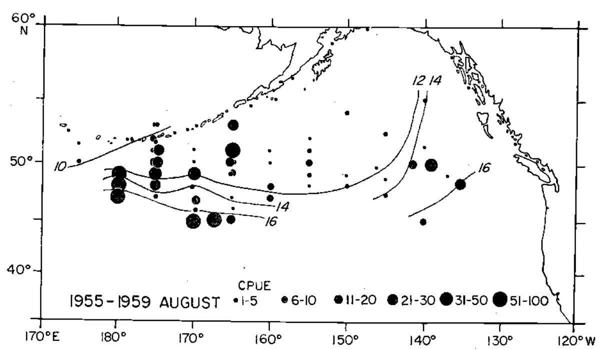

Fig. 32c.

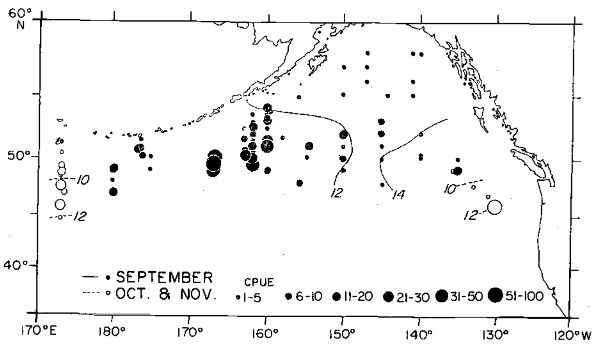

Fig. 32d.

Figs. 32a-d. Seasonal changes of relative abundance of squid caught by surface gillnets in the northeastern North Pacific and surface isotherms from Fiscus and Mercer (1982).

Gonatopsis borealis was generally caught over a broad geographic area and does not demonstrate marked seasonal migrations. As a result, the temperature of water inhabited by *G. borealis* increased progressively during the summer; from 3°–10°C in June, to 5°–13°C in July, and to 8°–14°C in August. It was restricted to the area north of about 44°–45°N in the western area and north of 50°N in the Gulf of Alaska in July. Abundances in surface waters of these regions were generally low from winter to spring and gradually increased in the summer. The abundance in the surface waters of Subarctic Pacific was roughly 3–4 times greater in July than in May. The CPUE of *G. borealis* was fairly even within the range of occurrence from May to July, indicating lack of massive schooling behavior or large concentrations. This species may occupy a wide depth range in the Subarctic Region.

Naito et al. (1977a,b) found two different size groups of *G. borealis*; a small size group with maturing gonads that was distributed widely in the Subarctic zone and the large size group with immature gonads that was concentrated more in the southern area, south of 47°N. Our study has confirmed different geographic distributions for these two size groups. They may be different age groups of the same population or completely separate populations with different biological characteristics. Individuals of the large size group may be survivors of the small size group which did not mature in the previous year. Murata et al. (1976) and Naito et al. (1977b) suggested that *G. borealis* spawns in late spring to early fall and has a one year life cycle. In our study, females of both groups were maturing in June and July, so spawning might begin in late summer at the earliest. Additional research throughout the year is needed to clarify the reproductive process and the relationship between the small size group and large size group of *G. borealis*.

Onychoteuthis borealijaponica; This species was found in the Kuroshio Countercurrent system by Murakami (1976) and in oceanic waters intermediate between the Subtropical and Subarctic zones by Naito et al. (1977a). *Onychoteuthis borealijaponica* is a Transitional-Subtropical species that shows zonal distributions north of 45°N and undertakes extensive migrations into Subarctic waters in summer.

It is distributed across the Pacific Ocean from off northeastern Japan (Murakami, 1976; Naito et al., 1977a) to off the western coast of North America, from California (Young, 1972) to British Columbia (Bernard, 1980).

It is found in sparse numbers around the Subarctic Boundary in spring, migrates into the Subarctic Region after warming of surface water of this region during summer, and reaches waters just south of Kuril Islands in August but does not invade the Bering Sea, Sea of Okhotsk (Naito et al., 1977a) or the Western Subarctic Gyral region (Murata et al., 1976). As the result of the northward migration, abundance in the surface waters of Subarctic Pacific increases substantially and concentrations occur in surface waters within the vertical thermal gradient develop between warm surface waters and deeper cold Subarctic waters. Average catch per gillnet set of *O. borealijaponica* in the surface waters of Subarctic Pacific in summer was roughly 3-4 times that of G. borealis.

Summer migrants into Subarctic waters are composed mainly of immature or early maturing females and maturing and some almost mature males. The most mature stages of both sexes appear to lead the migration north. After inhabiting the Subarctic Region during summer, some individuals appear to migrate southward during September and October. Spawning of *O. borealijponica* during its southward migration to the waters adjacent of Japan was noted by Murata et al. (1976). Murata et al. (1981) found copulated females off Hokkaido in August and October. Okutani (1969,1969) reported the larvae of *O. borealijaponica* off southwestern Japan during winter to spring. Spawning is thought to occur during late fall and winter in the countercurrent waters of the Kuroshio Current and the life cycle has generally been estimated to be one year (Murakami, 1976; Murata and Ishi, 1977; Naito et al., 1977).

Ommastrephes bartrami; This species has a trans-Pacific distribution in the Subtropical Region from off Japan to North America (Naito et al., 1977a; Murakami et al., 1981). Migrants from the south reach the vicinity of the Subarctic Boundary in July where they are prevented from migrating farther north by the thermal front and become concentrated in surface waters around this boundary. Only large immature females, larger than about 35 cm DML in July, migrate into the Transitional Domain through northward extensions of warm surface water where they are sometimes found in large numbers near the salinity front between the Transitional and the Subarctic Domains. A reverse, southward migration begins in September to October (Murakami et al., 1981). During the summer, *O. bartrami* is the most abundant squid in the surface waters around the Subarctic Boundary and the Transitional Domain.

According to Murakami et al. (1981), there are two spawning age groups and two peaks in spawning period for *O. bartrami*. Most of the females and all the males mature after about one year and spawn in winter and spring in the southern Subtropical waters. Some females originating from the late spawning period live to be over a year in age and migrate north before the younger age groups. The large females in the Transitional Domain in July in our study corresponds to this group of two year old females.

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