JARQ 29, 65-72 (1995)

Distribution of Spawning Grounds of Flying Squid, *Ommastrephes bartrami*, in the North Pacific Ocean

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Abstract
Two research cruises, one in the northwestern waters off the Hawaiian Archipelago between Oahu and Midway Islands in April-May 1989, and another along 26°N and 29°N between Ogasawara and Midway Islands in April-May 1993, were organized to investigate the spatial distribution of spawning grounds for the commercially important flying squid. *Ommastrephes bartrami*. Presence of rhynchoteuthion paralarvae and the distribution of mature females suggest that the spawning grounds of *O. bartrami* in April-May lie in the area extending from the waters off Ogasawara Islands to the Hawaiian Archipelago.

Discipline: Fisheries
Additional key words: rhynchoteution paralarvae, mature females

Introduction

Flying squid, *Ommastrephes bartrami*, is widely distributed throughout the subtropical and temperate waters of both the northern and southern hemispheres and is one of the major target for Japanese squid fisheries in the open sea of the North Pacific[18]. In spite of its high commercial importance, various biological and ecological aspects of this species, such as stock structure, age span, spawning season and spawning grounds are still unknown. In the Pacific, the northern and southern populations are separated from each other[17], and the North Pacific population is spread across the epipelagic ocean.

Kubodera[5] postulated that the North Pacific population is subtropical and undertakes a northward feeding migration to reach the subarctic boundary during summer, then returns in the fall, and spawns in the winter to early spring in the southern part of the Kuroshio Current.

Recently, Murata and Hayase[8] have suggested that there are two sub-populations in the North Pacific, namely a "spring-breeding group" which spawns during the winter-spring seasons and a "fall-breeding group" which spawns during summer. They also considered that the spring-breeding group spawns and breeds in subtropical waters (21°-35°N latitudes) extending from Japan to the west coast of North America, while the spawning ground of the fall-breeding group is probably located northeast of that of the spring-breeding group.

Thus, due to the highly migratory movements of the squid, information on the spawning grounds in the North Pacific is limited[3,9,15,20]. Using the data supplied by Murakami et al.[7], Young and Hirota[20] suggested the presence of three spawning regions in the North Pacific on the basis of the distribution data of mature females: one at ca. 140°-150°E long., one at ca. 170°E long., and one between 160°W and 180° long. Okutani[12] and Nakamura[9] presented the evidence for a spawning region based on the presence of paralarvae and the distribution of mature females, respectively.

In this paper the location of the spawning grounds of *O. bartrami* was investigated based on the occurrence of paralarvae and the distribution of mature females in April-May over a large spatial area.

Materials and methods

1) Data collection

Subadults, adults: In May 1989, *O. bartrami* specimens were collected during the Hokuho-maru research cruise in the northwestern waters off the

Table 1. Number of squids caught using bongonet, squid driftnet and squid jigger (Hokuho-maru, April–May 1989)

Stations		2	4	6	9	10	11	12	13	14	15	16
Date (JST)		0424	0426	0427	0505	0506	0507	0508	0509	0510	0511	0512
Morning (M) or Night (N)		M	M	N	N	N–M	N–M	N–M	N–M	N–M	N–M	N–M
N Latitude		2500	2800	2630	2705	2830	3000	3130	3130	3300	3430	3600
W Longitude		17000	17000	16700	16400	16400	16400	16400	16700	16700	16700	16700
Surface water temperature (°C)		23.4	20.8	22.7	20.8	20.6	19.2	18.1	18.5	17.8	17.2	15.9
—Catch (number)—												
Ommastrephes bartrami												
Adult		–	–	–	14	34	134	28	60	78	12	37
Paralarva		1	1	8	1	0	0	0	0	0	0	0
Sthenoteuthis oualaniensis												
Adult		–	–	–	5	6	0	0	0	0	0	0
Paralarva		0	0	2	0	0	0	0	0	0	0	0
Eucleoteuthis luminosa												
Adult		–	–	–	0	0	0	0	0	2	0	0
Paralarva		0	0	0	0	0	0	0	0	0	0	0
Onychoteuthis borealijaponica												
Adult		–	–	–	0	0	0	0	0	0	0	1
Paralarva		0	0	0	0	0	0	0	0	0	0	0
Abraliopsis sp.	Paralarva	0	1	0	0	0	0	0	0	0	0	0
Pterygioteuthis giardi	Paralarva	0	0	0	0	0	0	0	1	0	0	0
Cycloteuthis sp.	Paralarva	0	1	0	0	0	0	0	0	0	0	0
Bathothauma lyromma	Paralarva	0	0	0	0	1	0	0	0	0	0	0
Unidentified species	Paralarva	0	0	0	0	0	0	0	0	1	0	0

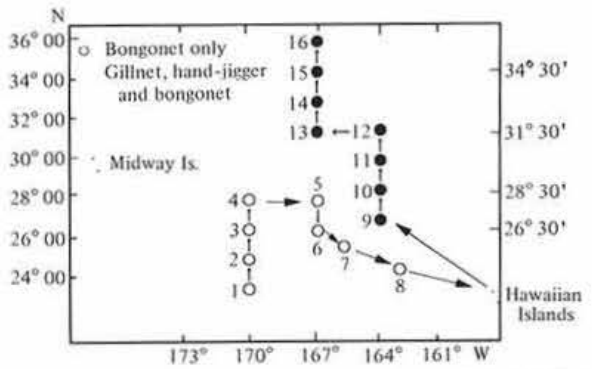

Fig. 1. Location of experimental sampling stations with consecutive operation numbers during the flying squid spawning survey by boat (Hokuho-maru, April–May 1989)

Hawaiian Archipelago between Oahu and Midway Island (Fig. 1). Adult/subadult specimens (N = 397) were captured at 8 stations using research driftnets (mesh size: 150 mm stretch mesh) and hand-jiggers (Table 1). Most of the samples were measured on board, and the remaining samples were frozen (−20°C) upon capture and brought back to the laboratory for detailed analyses.

In April–May 1993, *O. bartrami* specimens were collected during the Kaiun-maru research cruise along meridian 29°, 26° and 25°N lat. between 143° and 176°E long. (Fig. 2). Subadult/adult specimens (N = 73) were captured at 12 stations using hand- and machine-squid jiggers (Table 2). All the *O. bartrami* specimens were frozen upon capture and brought back to the laboratory for detailed analyses.

Paralarvae: In April–May 1989, 20 oblique night and morning tows (0–300 m) were conducted with a bongonet (70 cm diameter, 335 μm mesh) during the Hokuho-maru research cruise. Squid specimens were sorted on board and fixed in 10% formalin. In April–May 1993, 46 night and morning surface tows were conducted with bongonets (70 cm diameter, 335 μm/800 μm meshes) and a larval net (200 cm diameter, 335 μm mesh) during the Kaiun-maru research cruise. Squid specimens were sorted on board and immediately frozen (−20°C) for laboratory analyses.

2) Laboratory analyses

Adult/subadult specimens were sexed and biological measurements were performed, including dorsal mantle length (ML), body weight (BW) and weight of reproductive organs (ovary and oviduct weights, OW & OdW, testis and accessory gland weights, TW & AgW). Specimens were classified into three maturity stages (immature, maturing and mature) which corresponded to the reproductive somatic index

Table 2. Number of squids caught by boat (Kaiun-maru, April–May 1993)

Stations		2	6	8	10	12	13	14	15	16	18	20	31	32
Date (JST)		0426	0428	0429	0430	0501	0502	0502	0503	0503	0504	0505	0512	0512
Morning (M) or Night (N)		N	N	N	N	N	M	N	M	N	N	N	M	N
N Latitude		2900	2856	2902	2903	2859	2903	2855	2901	2902	2902	2859	2500	2601
E Longitude		14431	15031	15332	15631	15930	16100	16234	16347	16527	16830	17132	16530	16359
Surface water temperature (°C)		19.9	21.9	20.7	22.1	21.6	22.3	21.6	21.4	21.9	21.6	22.4	25.0	24.8
—Catch (number)—														
Ommastrephes bartrami														
Adult		20	4	1*	4	2*	–	0	–	2*	9	25	–	1
Paralarva		0	0	0	0	0	7	2	2	0	1	0	44	0
Sthenoteuthis oualaniensis														
Adult		0	0	0	0	0	–	0	–	0	0	0	–	0
Paralarva		0	0	0	0	0	1	0	0	0	0	0	0	0
Eucleoteuthis luminosa	Adult	0	0	0	0	0	–	0	–	0	0	0	–	0
Hyaloteuthis pelagica	Paralarva	2	0	2	34	4	0	0	0	5	7	0	0	0
Nototodarus hawaiiensis	Paralarva	0	2	0	0	0	0	12	1	5	0	1	0	0
Enoploteuthinae	Paralarva	5	0	1	4	0	0	0	0	0	0	0	0	0
Cranchiidae	Paralarva	0	0	0	1	0	0	2	0	0	0	0	7	4
Chiroteuthidae	Paralarva	1	0	0	0	0	0	0	1	0	0	4	0	0
Onychoteuthidae	Paralarva	0	1	0	1	0	0	0	5	2	0	0	0	0
Unidentified ommastrephid	Paralarva	0	0	1	0	0	1	0	0	0	0	0	24	1

Stations		33	34	36	37	38	39	41	42	43	44	45	46	Total	Occ. %
Date (JST)		0513	0513	0514	0515	0515	0516	0517	0517	0518	0518	0519	0519	25/46	54.3
Morning (M) or Night (N)		M	N	N	M	N	M	M	N	M	N	M	N	N:16	M:9
N Latitude		2559	2602	2603	2600	2559	2600	2600	2601	2600	2559	2600	2600	2500	-2900
E Longitude		16230	16105	15801	15631	15458	15330	15030	14859	14724	14601	14431	14300	14300	-17130
Surface water temperature (°C)		25.9	26.7	26.6	25.9	26.0	25.8	24.8	26.0	24.3	23.4	25.9	23.7	19.2	-26.7
—Catch (number)—															
Ommastrephes bartrami															
Adult		–	2	0	–	2	–	–	0	–	1	–	0	73	
Paralarva		21	12	2	11	11	2	27	5	6	4	6	33	196	
Sthenoteuthis oualaniensis															
Adult		–	0	0	–	3	–	–	0	–	0	–	0	3	
Paralarva		0	0	0	0	0	0	0	0	0	0	0	1	2	
Eucleoteuthis luminosa	Adult	–	0	1	–	1	–	–	0	–	1	–	0	3	
Hyaloteuthis pelagica	Paralarva	0	0	0	0	0	0	0	0	0	0	0	0	54	
Nototodarus hawaiiensis	Paralarva	0	13	0	0	0	0	3	0	0	0	0	0	37	
Enoploteuthinae	Paralarva	0	0	0	0	0	0	0	0	0	0	0	0	10	
Cranchiidae	Paralarva	0	0	3	24	0	1	10	1	2	0	0	3	58	
Chiroteuthidae	Paralarva	0	0	0	0	0	0	0	0	0	0	0	0	6	
Onychoteuthidae	Paralarva	0	0	0	0	0	0	0	1	1	1	0	1	13	
Unidentified ommastrephid	Paralarva	0	66	20	12	2	5	15	1	0	0	1	1	150	

* Mature female individual.

(GSI: (OW + OdW)/BW(%) for female, (TW + AgW)/BW(%) for male)[4].

O. bartrami rhynchoteuthion paralarvae were identified with a dissecting microscope. Most of the paralarval identifications followed the procedure of Okutani[11–14], Kubodera and Okutani[6], Harman and Young[2], Young and Harman[19], Young and Hirota[20] and Sweeney et al.[16].

Results

1) Distribution of mature females

Of the 397 adult/subadult specimens captured during the Hokuho-maru cruise in 1989, 211 were males and 186 were females. Mature females accounted for 35% of the total catch in number, while 43% were mature males, and the remaining 22% were immature individuals. Modal mantle lengths ranged from 29 to 32 cm for mature males and from 40 to 45 cm for mature females (Fig. 3). Mature females were mainly distributed in the waters around 30°–33°N lat., along 164° and 167°W long. (SST: surface sea water temperature ranged 18–19°C), and mature males were concentrated farther south (SST: ca. 20°C) than mature females[3] (Fig. 4).

Of the 73 subadult/adult specimens captured during the Kaiun-maru cruise in 1993, 31 were males and 42 were females. Only 5 individuals (7% of

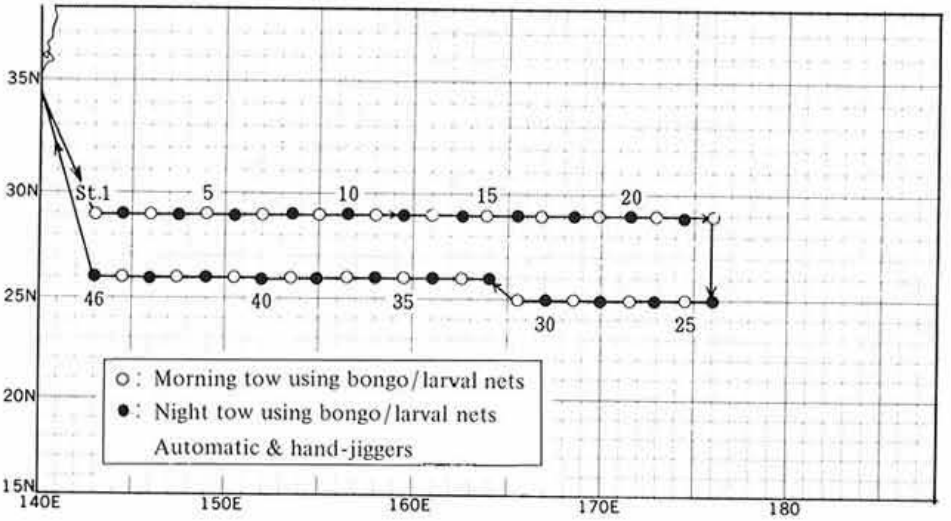

Fig. 2. Location of experimental sampling stations with consecutive operation numbers during the flying squid spawning survey by boat (Kaiun-maru, April–May 1993)

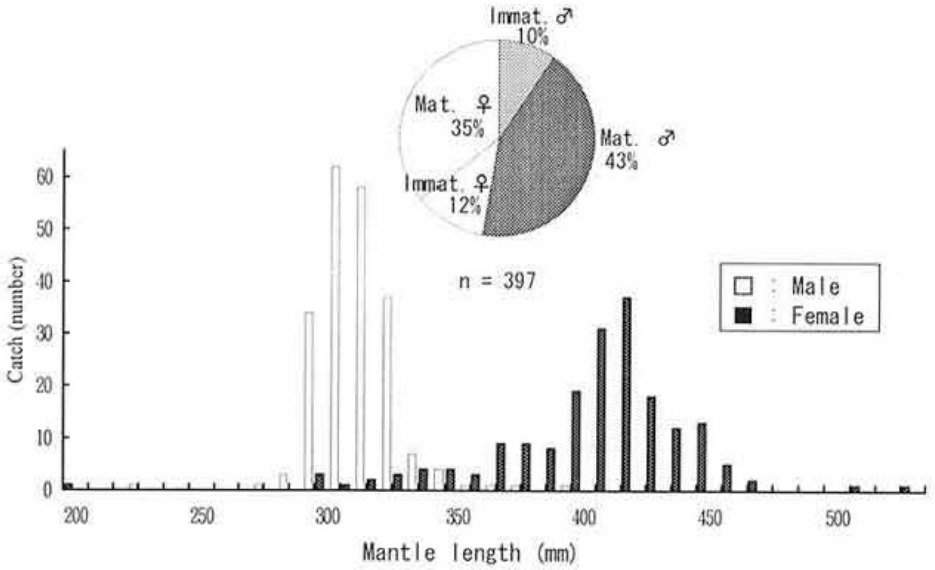

Fig. 3. Length distribution of the flying squids caught by boat (Hokuho-maru, May 1989)

the total catch in number) distributed along 29°N lat., between 153°30′–165°30′E long. (SST ranged 20.5–22.0°C) were graded as mature females with ML ranging from 41 to 46 cm (Figs. 5 and 6).

2) Occurrence of rhynchoteuthion paralarvae

During the 1989 cruise, 11 *O. bartrami* paralarvae were captured from 4 tows out of 20 tows at 16 stations. The biggest catch (8 individuals, 12.5 catch per unit effort (CPUE: No./1,000 m^3)) was obtained from a night tow at St. 6 (26°30′N lat., 167°W long.) (Table 1), although the total CPUE of *O. bartrami* in the 4 stations was very low (4.2/1,000 m^3). All the *O. bartrami* paralarvae were at the rhynchoteuthion stage, and the occurrence of paralarvae was observed for SST ranging from 21 to 23.5°C (Fig. 7).

During the 1993 cruise, a total of 196 *O. bartrami* paralarvae accounting for 51% of the total ommastrephid paralarvae, were captured from 17 tows out of 46 morning and night tows (Table 2). *O. bartrami* paralarvae were particularly concentrated in the waters around 25°–26°N lat., between 143°–165°30′E long., which corresponded to an SST set

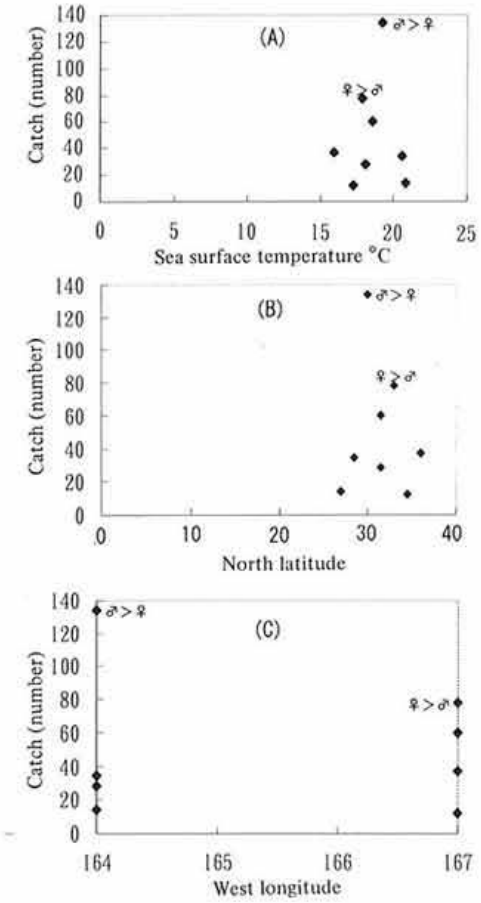

Fig. 4. Relationship between the number of adult flying squids and (A) sea surface temperature, (B) north latitude, (C) west longitude (Hokuho-maru, 1989)

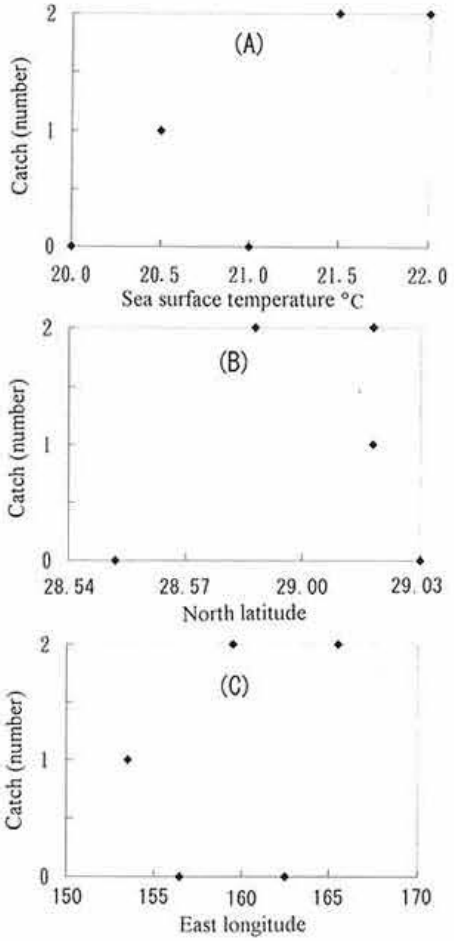

Fig. 6. Relationship between the number of mature females and (A) sea surface temperature, (B) north latitude, (C) east longitude (Kaiun-maru, 1993)

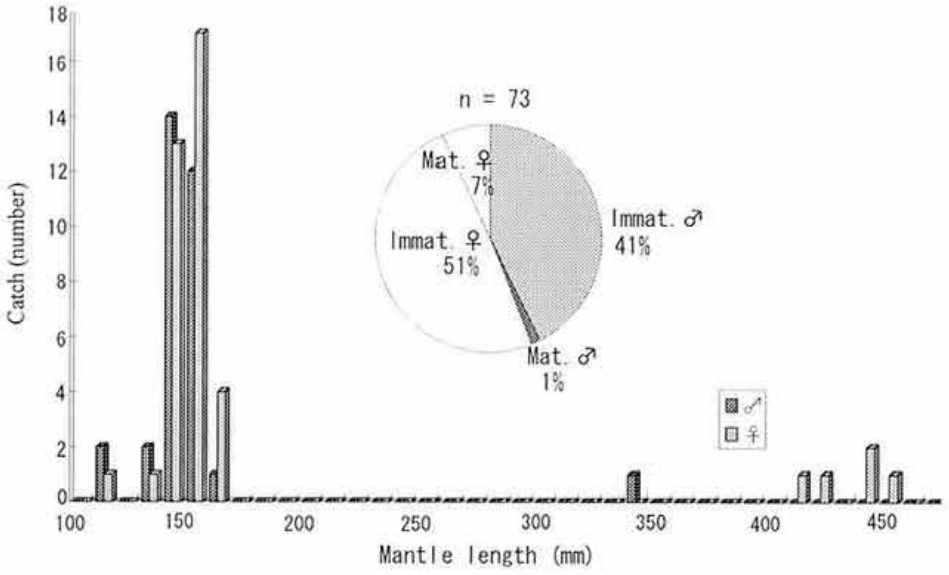

Fig. 5. Length distribution of the flying squids caught by boat (Kaiun-maru, April–May 1993)

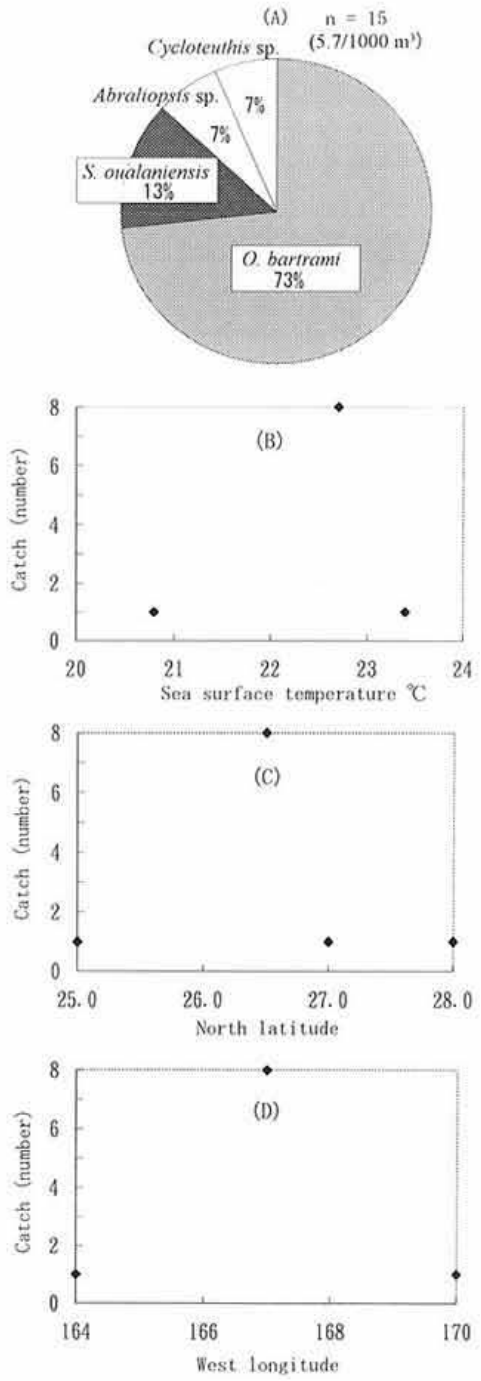

Fig. 7. (A) Percentage in relation to CPUE (No./1,000 m^3) of squid paralarvae caught with *O. bartrami* in selected stations (Sts. 2, 4, 6 and 9), and relationship between the number of *O. bartrami* paralarvae and (B) sea surface temperature, (C) north latitude, (D) west longitude (Hokuho-maru, 1989)

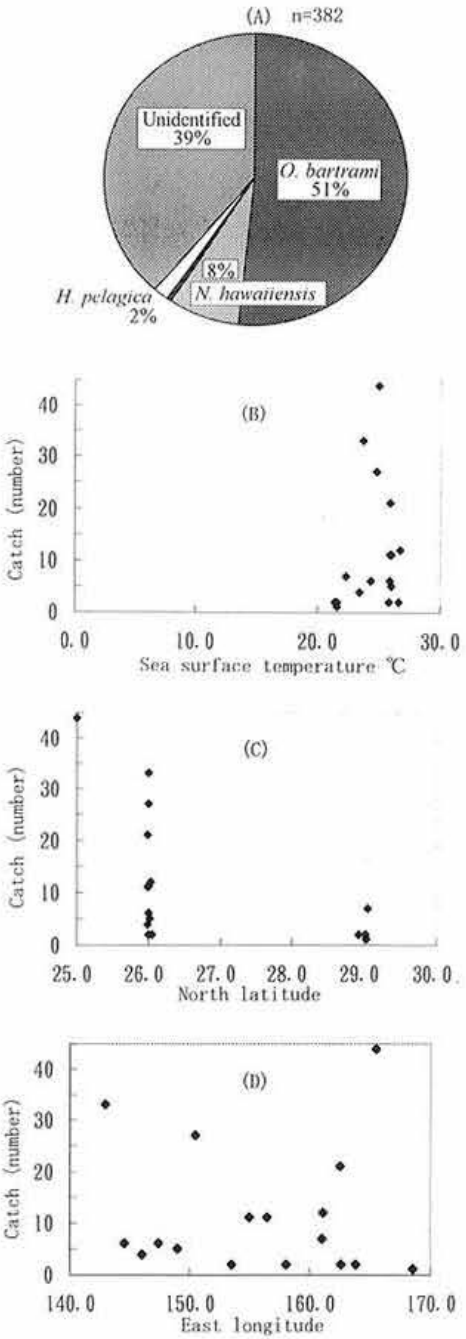

Fig. 8. (A) Percentage of ommastrephid paralarvae caught in 17 sampling stations, and relationship between the number of *O. bartrami* paralarvae and (B) sea surface temperature, (C) north latitude, (D) east longitude (Kaiun-maru, 1993)

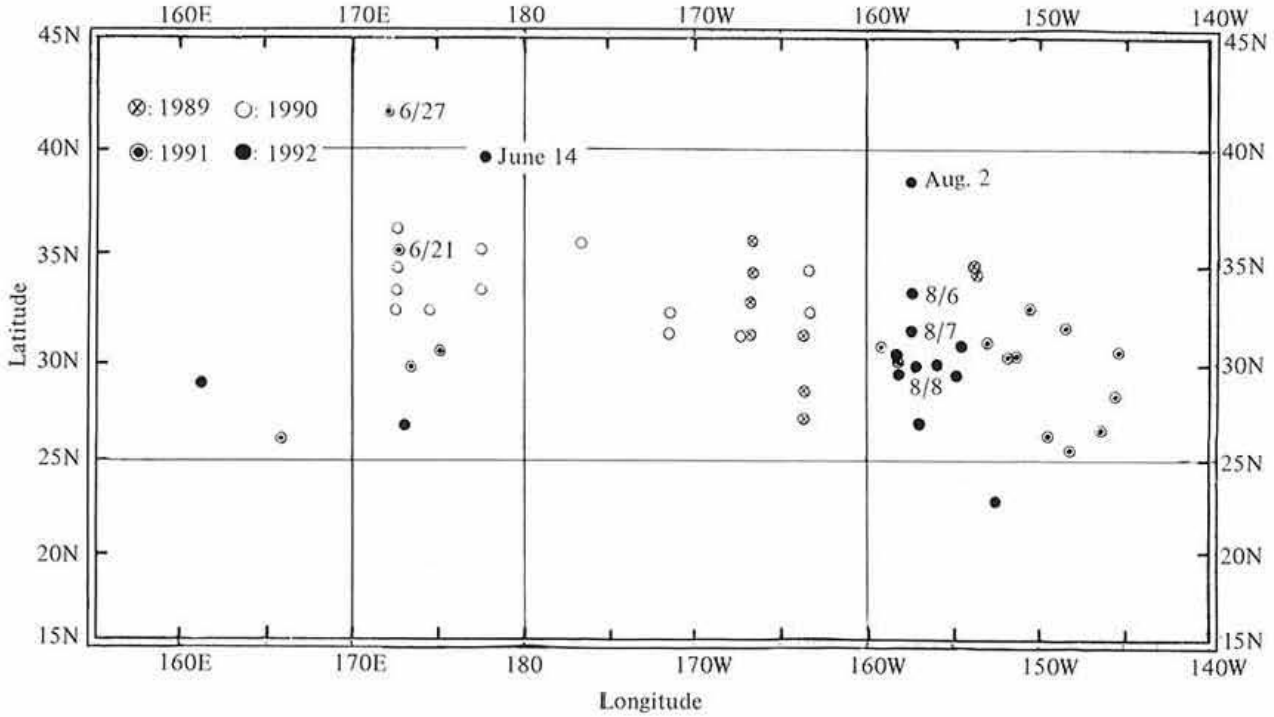

Fig. 9. Location of mature *O. bartrami* females caught using various driftnets, 1989–1992
Most of them were caught during January–April with a few exceptions.

range of 24–26°C (Fig. 8).

Discussion and conclusion

The distribution of *O. bartrami* paralarvae and mature females in April–May 1989 and 1993, suggests that the spawning grounds are located over a wide area along 25–26°N lat. from 143°E to 164°W long. Three sites in particular, one between 143°–150°30′E long., one between 161°–165°30′E long., and one between 164°–170°W long., are assumed to be spawning sites due to the occurrence of *O. bartrami* paralarvae. These locations are in close agreement with the three spawning sites postulated by Young and Hirota[20].

Meanwhile, the distribution of mature *O. bartrami*, particularly that of mature females was slightly different from the occurrence of paralarvae (Tables 1 and 2). According to the accumulated (1989–1992) data for the catch of *O. bartrami* by driftnets, many mature males and females were captured over an extensive area in different seasons and years (Fig. 9). In the case of the spring-breeding group, larger catch of mature females originated from the following three sites, one between 170°E–180° long., one between 163°–175°W long., and one between 145°–160°W long. Thus, based on the distribution of the mature females it was suggested that there were three sites for spawning grounds.

The slight difference in the locations of the paralarvae and mature females may be due to the time lag between the spawning and the successive paralarval development[1], suggesting that the actual spawning site for this species may be located in deeper waters or farther south than 26°N lat. The presence of mature males inhabiting more southern waters than mature females[3] (Fig. 4), mature females inhabiting waters 400–700 m deep in the daytime[10] or mature females caught using hand-jiggers from rather deeper waters at night supports this assumption.

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(Received for publication, April 21, 1994)