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Geographical and Vertical Distribution of Short-finned Squid (*Illex illecebrosus*) Larvae in the Northwest Atlantic*

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Abstract

In January-March 1982, a joint survey was conducted by Japanese, Canadian and United States scientists aboard the Japanese research vessel *Kaiyo Maru* to determine the geographical and vertical distribution of larval *Illex illecebrosus* (family Ommastrephidae) in the western North Atlantic (latitude 35°-45°N, longitude 57°-74°W). Larvae were found to be widely distributed in the Gulf Stream and associated water masses where the surface temperatures were higher than 13°C. They were most abundant in water layers above the thermocline along the northern edge of the Gulf Stream. The Gulf Stream is considered to play an important role in the transport of these larvae from the spawning areas which are presently unknown. The timing and location of spawning of this species is discussed.

Introduction

The short-finned squid (*Illex illecebrosus* (Lesueur)) occurs widely in the western North Atlantic, from Florida in the south to Newfoundland and Labrador waters in the north. The fishery for this species developed rapidly in the Northwest Atlantic during the 1970's, with the nominal catch attaining a peak of 180,000 (metric) tons in 1979 (NAFO, 1984). Short-finned squid represented an important component of Japanese, Spanish, Italian and Cuban fisheries in the Northwest Atlantic and also in the domestic fisheries of Canada and the United States.

The life history of *I. illecebrosus* can be divided into three phases: early growth period from egg to juvenile in the Gulf Stream System, period of feeding and growth on the continental shelf, and period of emigration to spawning grounds and spawning. Considerable biological information exists for the period of feeding and growth on the continental shelf (Squires, 1967; Amaratunga *et al*., MS 1979; Durward *et al*., 1979; Amaratunga, MS 1980; Dawe and Drew, 1981; Lange and Sissenwine, MS 1981). Extensive surveys have recently been conducted in Slope Water and the Gulf Stream southeast of the Scotian Shelf and south of the Grand Bank, and some information on the distribution of *Illex* larvae and juveniles have been reported (Amaratunga *et al*., MS 1980; Froerman *et al*., MS 1981; Dawe *et al*., MS 1981, MS 1982). Also, Roper and Lu (1979) reported the capture of larvae and juveniles in the region from Cape Hatteras to Georges Bank. Spawning and larval development of *I. illecebrosus* in captivity were described by Durward *et al*. (1980) and O'Dor *et al*. (1982, MS 1982). However, information on the spawning of *I. illecebrosus* and the distribution of larvae is still insufficient to identify the factors which influence annual fluctuations in abundance.

To obtain biological and oceanographic information on short-finned squid during the breeding and early growth periods in oceanic waters off the northeastern United States and southeastern Canada, a joint Japan-Canada-USA survey was conducted in January-March 1982. In this paper, geographical and vertical distributions of larval *I. illecebrosus* are described, and the season and location of spawning are discussed.

Materials and Methods

The joint survey was conducted by Japanese, Canadian and United States scientists aboard the Jap-

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anese research vessel *Kaiyo Maru* (2,540 gross tons). The survey in 1982 was composed of two cruises, the first from 16 January to 5 February and the second from 11 February to 5 March. Ninety-one bongo-sampler (0.5-mm mesh in each net) tows were made between 57° and 74° W longitude and between 35° and 45° N latitude where the water masses varied from Shelf Water through Slope Water and the Gulf Stream to the Sargasso Sea (see Fig. 1). The sampler, with flowmeter and depth recorder, was lowered usually at 50 m/min and retrieved at 20 m/min, the ship's speed being about 2 knots. A double oblique tow was made generally to about 200 m at each of 31 and 28 stations during the first and second cruises respectively. Standard Marine Monitoring, Assessment and Prediction (MARMAP) program procedures were used (Posgay and Marak, 1980). In addition, depth-stratified tows, using a bongo sampler with opening-closing apparatus, were made at some stations where fairly large numbers of larvae were taken in the double oblique tows. At these stations, an attempt was made to sample five depth strata (surface, 0–50, 50–100, 100–200, and 200–300 m) for 15 min each during day and night tows. Frequent problems with the opening-closing apparatus resulted in inadequate data for the 100–200 and 200–300 m layers. Detailed information on survey methods and operations are given in the cruise report by Japanese scientists (Anon., 1982).

The samples from the bongo tows were preserved in 5% buffered formalin. For each tow, the catch in one net was retained by Japanese scientists for deposit in Japan and the catch in the other net was shared between Canadian and United States scientists. Rhynchoteuthion-type larvae on deposit in Japan were identified to species according to Roper and Lu (1979), based primarily on the suckers on the tip of the proboscis, absence of photophores on the eyes and liver, and the shape of the liver. Dorsal mantle length (ML) was measured to the nearest 0.1 millimeter. Most of the specimens were rhynchoteuthion larvae (98% with size range of 1.9–8.2 mm ML), and a few were classified as juveniles (2% with size range of 6.3–8.3 mm ML). These juveniles were treated as larvae in this paper.

In an attempt to capture mature *I. illecebrosus*, 39 tows were made with midwater trawl in depths from the surface to 1,000 m (one tow to 1,745 m) and squid-jigging equipment was used at 15 stations.

Results

More than 1,000 *I. illecebrosus* larvae were caught during the survey (see Appendix Table). The numbers of larvae from the double oblique bongo-net tows during the two cruises are shown in Fig. 1 in relation to schematic surface distributions of water types, the latter being based on satellite sea-surface temperature charts (received by facsimile aboard ship from the Canadian Meteorological and Oceanographic Centre) that were modified by observed oceanographic data. Larvae were found to be widely distributed in areas of relatively warm water (i.e. Sargasso Sea, Gulf Stream, Slope Water, and warm-core and cold-core eddies) between 57° W and 72° W. However, the largest catches (more than 10 specimens per tow) were obtained mainly along the northern edge of the Gulf Stream and in the boundary zone between the Gulf Stream and Slope Water. The single exception to this was a large catch within a warm-core eddy on the 62° W transect north of the Gulf Stream.

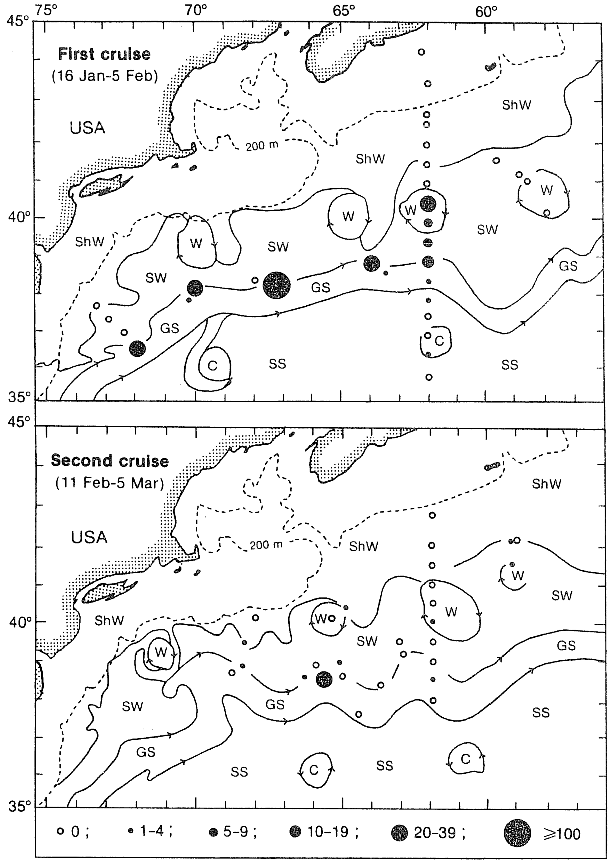

Fig. 1. Station locations and catches of *I. illecebrosus* larvae in double oblique bongo-net tows relative to the Gulf Stream and associated water masses during the first and second cruises of the squid survey in January–March 1982. (ShW = Shelf Water, SW = Slope Water, W = Warm-core Eddy, C = Cold-core Eddy, GS = Gulf Stream, and SS = Sargasso Sea.)

Water-temperature profiles from expendable bathythermograph (XBT) casts at stations where larvae were and were not caught are shown in Fig. 2. Larvae were not caught at stations where the surface temperature was lower than 13° C. Catches of 10 or more larvae were made at stations where the surface temperature was higher than 16.5° C and a thermocline was prominent in the 50–200 m layer (except one station). These stations were all situated either at the

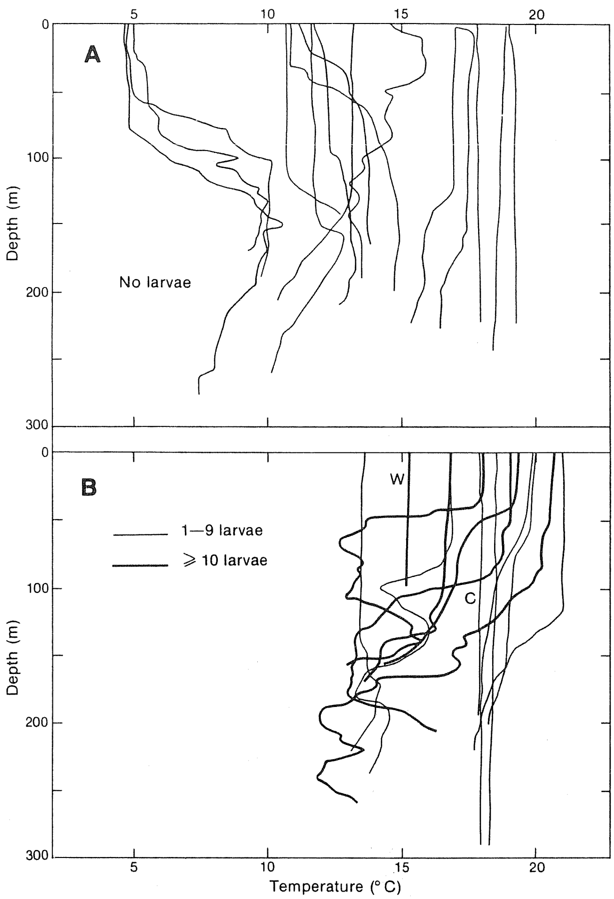

Fig. 2. Temperature-depth profiles from bathythermograph casts at stations where *I. illecebrosus* larvae were not caught (**A**) and where larvae were caught (**B**) in double oblique bongo-net tows during the first cruise (16 January-5 February 1982). (W and C indicate stations in warm-core and cold-core eddies respectively.)

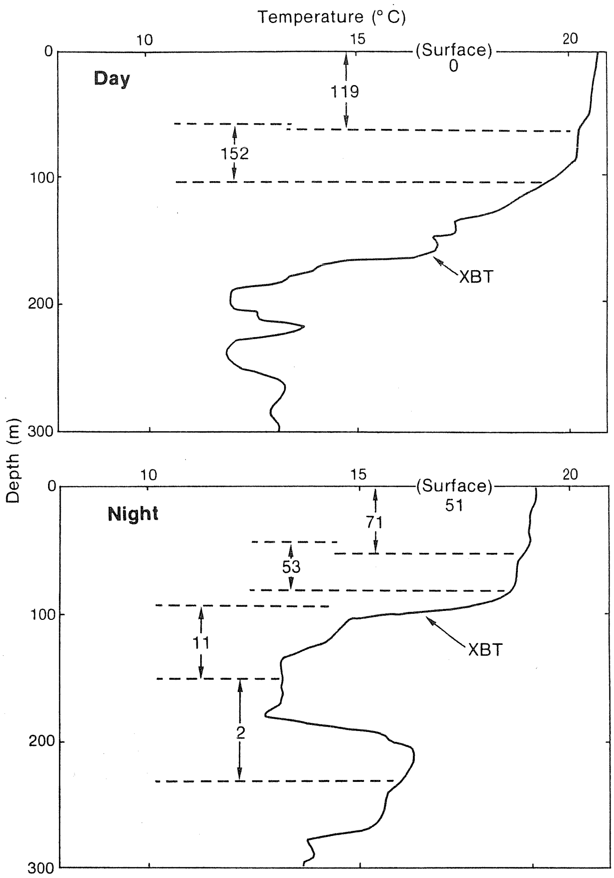

Fig. 3. Catches of *I. illecebrosus* larvae per 1,000 m³ of water filtered in depth-stratified bongo-net tows during daylight and darkness, and the associated temperature-depth profiles. (In the Appendix table, day tows are No. 6-8 and night tows are No. 28-32.

northern edge of the Gulf Stream or in the boundary zone, the one exception being a station in a warm-core eddy north of the meandering Gulf Stream.

Although the depth-stratified sampling was inadequate at some stations for depths greater than 100 m due to malfunction of the opening-closing apparatus (Fig. 3A), catch rates (number of larvae per 1,000 m^3 of water filtered) at stations where the opening-closing apparatus operated properly were higher in the layers above the thermocline than in the layers below it (Fig. 3B). As noted previously, a prominent thermocline was usually evident at stations where the catches of larvae exceeded 10 specimens. It is suggested, therefore, that most of the larvae were distributed in the warmer water above the thermocline.

Trends in catch rates by depth were somewhat different for the day and night tows (Fig. 4). During the daytime, larvae were evidently more abundant in the 50–100 m layer than at shallower depths and very few were caught at the surface. Catch rates at night indicate that the larvae were probably distributed homogeneously throughout the 0–100 m depth zone. These observations indicate a diel movement of larvae from their daytime residence in the near surface layer to greater depths above the thermocline at night.

No adult *I. illecebrosus* were caught with the mid-water trawl or the squid-jigging equipment, indicating that they were distributed somewhere outside the survey area.

Discussion

Roper and Lu (1979) described three types of rhynchoteuthion larvae and identified Type C as short-finned squid (*I. illecebrosus*). Durward *et al.* (1980) reported that larvae of *I. illecebrosus* which were reared in the laboratory resembled rhynchoteuthion Type C. However, Type C larvae may also include a related species (*Illex oxygonius*) which is found in coastal waters from New Jersey to Florida. All of the Type C larvae that were obtained during the survey in January-March 1982 were considered to be *I. illecebrosus*, because they were taken in offshore waters far eastward of the known range of *I. oxygonius*.

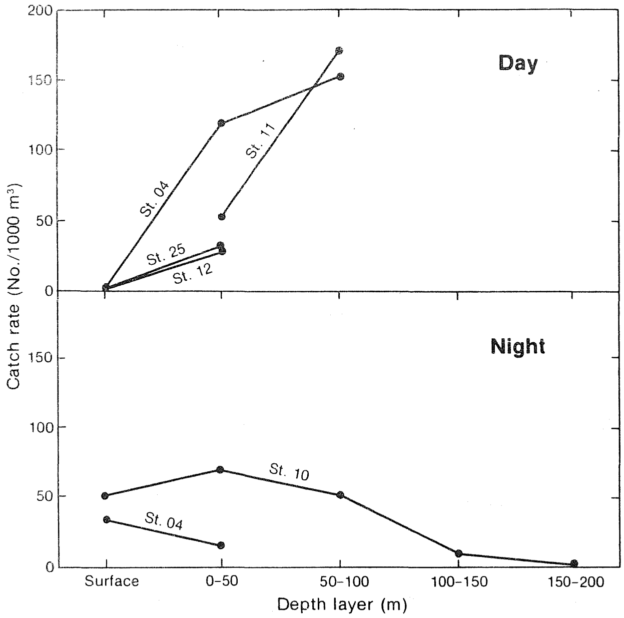

Fig. 4. Catches of *I. illecebrosus* larvae per 1,000 m³ of water filtered in depth-stratified bongo-net tows during day and night at various stations in relation to depth of capture.

Roper and Lu (1979) found 14 *I. illecebrosus* larvae and juveniles in a large number of samples that were collected off the eastern United States by the MARMAP Program of the National Marine Fisheries Service and by the Deepwater Dumpsite 106 Program of the Smithsonian Institution. However, the collection of more than 1,000 specimens during the 2-month survey in January-March 1982 encompassed the hatching season and the distributional range of larval *Illex* better than earlier surveys. The results from this survey, coupled with information on ocean currents in the surrounding waters and laboratory observations on the incubation time of eggs, provide some evidence as to the spawning season and area for *I. illecebrosus*.

O'Dor *et al.* (1982) reported that eggs of short-finned squid required incubation of 11 days at 14° C and 8 days at 21° C. Durward *et al.* (1980) observed that newly-hatched larvae were about 1 mm ML. All the larvae from the 1982 survey were in the range of 1.9-8.3 mm ML and were therefore not newly-hatched. Most of the larvae were caught during the first 2 weeks of the survey (19-31 January) and few were taken afterward, even though seven additional tows were made in the Gulf Stream-Slope Water boundary zone where large catches were obtained previously. It is likely, therefore, that peak spawning occurred sometime in January and that the larval period in the warm Gulf Stream water is probably quite short.

O'Dor *et al.* (1982) reported that the minimum temperature for normal development of the embryo of *I. illecebrosus* is about 13° C. Therefore, water types suitable for spawning are limited to the Slope Water-Gulf Stream boundary zone, Gulf Stream, Sargasso Sea, and warm-core eddies. *I. illecebrosus* larvae were caught in these relatively warm waters and were most abundant along the northern edge of the Gulf Stream, including the boundary zone. Spawning probably occurs in the boundary zone and/or the Gulf Stream. If spawning occurs in the centre or in the southern part of the Gulf Stream, the eggs and larvae would accumulate along its northern edge by the convergence effect of the current. On the other hand, if the larvae hatch in Slope Water or in warm-core eddies, they would not be found within the Gulf Stream and the Sargasso Sea. Thus, the Gulf Stream, especially its northern edge, and the Slope Water-Gulf Stream boundary zone are the most likely spawning areas on the basis of water types.

The velocity of the current was highest along the northern edge of the Gulf Stream and in the Gulf Stream-Slope Water boundary zone, averaging 2.7 knots (90 m/min) at the surface. If the eggs incubated for at least 10 days, they could have drifted about 700 nautical miles (1,300 km) prior to hatching. The larvae that were caught in the western part of the survey area could have originated off Florida. However, because the eggs and larvae would not necessarily be in the strongest part of the current, the actual distance of transport could be considerably less. Therefore, it is suggested that the major spawning site lies in the Gulf Stream System between the western part of the survey area (72° W) and the waters off Florida. This suggestion agrees with the opinion of Trites (1983) whose hypothesis resulted from the theoretical considerations of the physical oceanography of the region and from information on laboratory-reared larvae by O'Dor *et al.* (MS 1982).

Lange and Sissenwine (MS 1981), from length-frequency distributions of juvenile and adult *I. illecebrosus* that were taken off the northeastern United States at different times of the year, indicated that spawning may occur in the summer as well as in the winter, and Roper and Lu (1979) found larvae during most of the year in that area. However, the major component of the stock, especially that portion which immigrates onto the continental shelf off Canada in late spring and early summer (Squires, 1967; Amaratunga, MS 1980) and leaves the shelf in autumn, is believed to spawn in southern offshore waters during the winter. The foregoing discussion on timing and location of spawning, based on the results presented in this paper, do not discount the possibility of minor spawnings in other seasons and areas of the Northwest Atlantic.

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Appendix

Station data for double-oblique (DO) and depth-stratified (DS) bongo-net tows by the R/V *Kaiyo Maru* during the squid survey in January-March 1982 are listed in the table below. Numbers of *Illex illecebrosus* from one net of the bongo sampler (preserved in Japan) were identified as rhynchoteuthion larvae (R), transition larvae (T) and juveniles (J). Numbers of specimens from the other net of the sampler (preserved in Canada and United States) are included with the total from both nets in parentheses. Asterisks (*) indicate depth-stratified tows where the opening-closing apparatus did not function properly.

Date	St. No.	Tow No.	Tow method	Diel period	Position Lat(N)	Position Long(W)	Sampling depth (m)	Number of *Illex* caught R	T	J	Total
					First cruise						
18 Jan	1	1	DO	Night	37° 41′	73° 17′	0–142	—	—	—	— (—)
	2	2	DS	Day	37° 20′	72° 45′	Surface	—	—	—	— (—)
	2	3	DO	Day	37° 20′	72° 46′	0–204	—	—	—	— (—)
	3	4	DO	Night	36° 59′	72° 19′	0–262	—	—	—	— (—)
19 Jan	4	5	DO	Night	36° 29′	71° 50′	0–260	17	6	—	23 (37)
	4	6	DS	Day	36° 29′	71° 49′	Surface	—	—	—	— (—)
	4	7	DS	Day	36° 31′	71° 46′	0–60	34	7	1	42 (111)
	4	8	DS	Day	36° 31′	71° 43′	57–102	59	6	1	66 (120)
	4	9*	DS	Day	36° 34′	71° 26′	89–155	—	—	—	— (—)
	4	10	DS	Day.	36° 30′	71° 41′	Surface	—	—	—	— (—)
	4	11	DS	Day	36° 30′	71° 39′	0–61	—	—	—	— (—)
	4	12*	DS	Night	36° 31′	71° 33′	0–182	2	—	—	2 (3)
	4	13*	DS	Night	36° 32′	71° 30′	0–120	3	—	—	3 (3)
20 Jan	4	14	DS	Night	36° 45′	71° 25′	0–70	9	1	—	10 (12)
	4	15*	DS	Night	36° 46′	71° 24′	57–148	—	—	—	— (—)
	4	16*	DS	Night	36° 48′	71° 22′	0–219	7	3	—	10 (15)
	4	17	DS	Night	36° 50′	71° 21′	Surface	7	1	—	8 (14)
	4	18	DS	Night	36° 46′	71° 23′	Surface	1	—	—	1 (1)
	4	19*	DS	Night	36° 46′	71° 20′	0–55	—	—	—	— (4)
	4	20	DS	Night	36° 49′	71° 19′	44–91	5	3	—	8 (11)
	4	21*	DS	Night	36° 51′	71° 17′	0–141	14	2	—	16 (22)
	4	22	DS	Dawn	36° 53′	71° 13′	23–60	17	2	—	19 (19)
	6	23	DO	Night	37° 44′	70° 24′	0–221	2	1	—	3 (3)
21 Jan	7	24	DO	Night	38° 15′	69° 55′	0–161	9	2	—	11 (21)
	7	25	DS	Dawn	38° 16′	69° 50′	Surface	—	—	—	— (—)
	9	26	DO	Day	38° 27′	67° 54′	0–190	—	—	—	— (—)
	10	27	DO	Night	38° 22′	67° 22′	0–207	63	2	—	65 (108)
22 Jan	10	28	DS	Night	38° 25′	67° 11′	Surface	20	2	—	22 (48)
	10	29	DS	Night	38° 26′	67° 07′	0–52	21	10	2	33 (76)
	10	30	DS	Night	38° 30′	67° 03′	44–80	21	2	—	23 (42)
	10	31	DS	Night	38° 30′	66° 59′	92–150	2	—	—	2 (5)
	10	32	DS	Night	38° 29′	66° 54′	153–230	1	—	—	1 (1)
	11	33	DS	Day	38° 32′	66° 31′	0–32	16	2	—	18 (41)
	11	34	DS	Day	38° 32′	66° 26′	47–70	56	23	—	79 (159)
	11	35	DS	Day	38° 32′	66° 22′	91–122	1	—	—	1 (1)
23 Jan	12	36	DS	Day	38° 38′	66° 10′	0–40	8	5	2	15 (21)
	12	37	DS	Day	38° 38′	66° 08′	Surface	—	—	1	1 (1)
	12	38*	DS	Day	38° 38′	65° 47′	0–118	4	1	—	5 (11)
26 Jan	15	39	DO	Day	38° 56′	63° 54′	0–169	7	3	—	10 (26)
	16	40	DO	Day	38° 36′	63° 22′	0–290	1	—	1	2 (2)
28 Jan	19	41	DO	Day	35° 50′	61° 58′	0–219	—	—	—	— (—)
	20	42	DO	Night	36° 27′	61° 59′	0–189	—	—	1	1 (4)
29 Jan	21	43	DO	Night	36° 59′	62° 01′	0–232	—	—	—	— (—)
	22	44	DO	Day	37° 30′	62° 01′	0–240	—	—	—	— (—)
	23	45	DO	Day	37° 58′	62° 01′	0–290	—	—	—	— (2)
	24	46	DO	Night	38° 30′	62° 00′	0–198	—	—	—	— (1)
30 Jan	25	47	DO	Night	38° 57′	61° 55′	0–155	3	1	1	5 (14)
	25	48	DS	Day	38° 57′	61° 32′	Surface	—	—	—	— (—)
	25	49	DS	Day	38° 57′	61° 28′	0–41	7	7	—	14 (26)

Appendix (continued)

Date	St. No.	Tow No.	Tow method	Diel period	Position Lat(N)	Position Long(W)	Sampling depth (m)	Number of *Illex* caught R	T	J	Total
					First cruise (continued)						
31 Jan	26	50	DO	Night	39° 30′	62° 01′	0-219	1	—	—	1 (5)
	27	51	DO	Night	40° 04′	62° 00′	0-240	—	1	—	1 (7)
	28	52	DO	Day	40° 32′	61° 59′	0-110	10	8	1	19 (33)
	29	53	DO	Day	41° 01′	62° 00′	0-210	—	—	—	— (—)
	30	54	DO	Night	41° 30′	61° 58′	0-164	—	—	—	— (—)
01 Feb	31	55	DO	Night	41° 59′	62° 00′	0-190	—	—	—	— (—)
	32	56	DO	Day	42° 31′	62° 02′	0-166	—	—	—	— (—)
	33	57	DO	Day	42° 45′	62° 01′	0-275	—	—	—	— (—)
02 Feb	34	58	DO	Twilight	40° 17′	57° 57′	0-223	—	—	—	— (—)
03 Feb	35	59	DO	Night	41° 05′	58° 30′	0-220	—	—	—	— (—)
	36	60	DO	Day	41° 15′	58° 47′	0-202	—	—	—	— (—)
	37	61	DO	Twilight	41° 38′	59° 36′	0-118	—	—	—	— (—)
04 Feb	40	62	DO	Day	43° 31′	61° 58′	0-50	—	—	—	— (—)
	41	63	DO	Night	44° 22′	62° 11′	0-154	—	—	—	— (—)
					Second cruise						
12 Feb	42	64	DO	Night	40° 08′	67° 59′	0-180	—	—	—	— (—)
14 Feb	43	65	DO	Day	39° 27′	68° 25′	0-179	—	1	—	1 (1)
	44	66	DO	Night	38° 48′	68° 31′	0-175	2	—	—	2 (3)
15 Feb	45	67	DO	Night	38° 40′	68° 47′	0-188	—	—	—	— (—)
	47	68	DO	Night	38° 41′	65° 27′	0-168	10	5	—	15 (22)
16 Feb	49	69	DO	Night	38° 56′	65° 09′	0-189	1	—	—	1 (1)
	50	70	DO	Day	40° 06′	65° 24′	0-180	—	—	—	— (—)
	51	71	DO	Night	40° 16′	65° 00′	0-195	—	—	—	— (1)
17 Feb	54	72	DO	Night	42° 44′	62° 00′	0-173	—	—	—	— (—)
18 Feb	56	73	DO	Night	42° 00′	62° 00′	0-225	—	—	—	— (—)
	57	74	DO	Day	41° 31′	61° 59′	0-190	—	—	—	— (—)
	59	75	DO	Night	41° 01′	61° 57′	0-200	—	—	—	— (—)
	60	76	DO	Night	40° 29′	61° 58′	0-170	—	—	—	— (—)
19 Feb	61	77	DO	Night	39° 52′	62° 12′	0-200	—	—	—	— (2)
	62	78	DO	Day	39° 29′	62° 01′	0-200	—	—	—	— (—)
	63	79	DO	Day	38° 59′	61° 59′	0-196	—	—	—	— (—)
21 Feb	65	80	DO	Night	38° 31′	61° 55′	0-168	—	—	—	— (1)
22 Feb	66	81	DO	Night	38° 05′	61° 54′	0-181	—	—	—	— (—)
25 Feb	72	82	DO	Night	42° 04′	59° 19′	0-163	—	1	—	1 (1)
	73	83	DO	Day	42° 12′	58° 58′	0-171	—	—	—	— (—)
	74	84	DO	Day	41° 29′	59° 13′	0-170	2	1	—	3 (3)
28 Feb	75	85	DO	Day	39° 30′	63° 05′	0-194	—	—	—	— (—)
	76	86	DO	Day	39° 11′	63° 04′	0-150	—	—	—	— (—)
01 Mar	77	87	DO	Night	38° 23′	63° 38′	0-170	—	—	—	— (—)
	78	88	DO	Day	37° 37′	64° 29′	0-220	—	—	—	— (—)
02 Mar	79	89	DO	Night	38° 34′	64° 55′	0-220	—	—	—	— (—)
	80	90	DO	Day	38° 58′	65° 50′	0-180	—	—	—	— (—)
	81	91	DO	Night	38° 35′	66° 24′	0-205	1	1	—	2 (4)
					Total:	First cruise		428	101	11	540 (1030)
						Second cruise		16	9	—	25 (39)
						Both cruises		444	110	11	565 (1069)