NAFO Sci. Coun. Studies, 9: 77-92

Distribution of Short-finned Squid (*Illex illecebrosus*) Larvae and Juveniles in Relation to the Gulf Stream Frontal Zone Between Florida and Cape Hatteras

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Abstract

Catches of rhynchoteuthion type C' larvae, which are considered to be *Illex illecebrosus*, and *I. illecebrosus* juveniles over the edge of the continental shelf between Cape Hatteras and Florida are examined in relation to the water masses and their dynamics along the Gulf Stream-Slope Water frontal zone. All larvae and juveniles were captured at stations where the temperature-salinity (T-S) properties of the upper 50 m of the water column were closely grouped, with temperatures of 21.0° to 23.5° C and salinities of 36.30 to 36.80, which are very similar to those of Continental Edge Water. Although the actual depths of capture of the larvae and juveniles in the bongo and midwater trawl tows are unknown, it is likely that the majority were taken in the upper 50 m. Larvae and juveniles were intermixed along the entire frontal zone, but there are indications of some differences in microscale distribution. Although juveniles were nearly always captured at stations where larvae were taken, larvae were captured at only 44% of the stations where juveniles were found. The intermixture of larvae and juveniles with a broad range of size (mantle length) indicates that spawning occurs either along the Gulf Stream-Slope Water frontal zone south of Cape Hatteras or in a relatively small area to the south of the surveyed area. The possible role of frontal eddies in causing the intermixture of larvae and juveniles is discussed.

Introduction

With the development of a major international fishery for short-finned squid (*Illex illecebrosus*) off the northeastern United States and on the Scotian Shelf in the 1970's, and the parallel rapid increase in squid catches from Newfoundland inshore waters, the International Commission for the Northwest Atlantic Fisheries (ICNAF) and its successor (NAFO) recognized the need to develop a biological basis for management of the fisheries. At that time, knowledge of the biology and distribution of *I. illecebrosus* was restricted largely to the May-December period when squid were present in fishing areas on the continental shelf (Verrill, 1882; Mercer, 1969a, 1969b, 1970, MS 1973; Squires, 1967; Lange, MS 1980). Little was known about squid during the period from November or December, when maturing males and females departed from the fishing area, until the following April or May, when small squid appeared on the continental shelves. Only a few fully mature females have been captured in the western North Atlantic, as reported by Dawe and Drew (1981), who noted seven records in the region from Cape Henry, Virginia (36° 31'N, 79° 29'W) to Newfoundalnd (49° 07'N, 58° 05'W). Spawning adults and egg masses have not been encountered in nature, but characteristics of egg masses, egg development and larval hatching have been described by O'Dor and Durward (1979), Durward *et al.*, (1980), O'Dor *et al.* (MS 1980, 1982, MS 1982), and O'Dor (1983). Roper and Lu (1979) and Vecchione (1979) have described the rhynchoteuthion type C' larvae of *I. illecebrosus* from plankton samples that were taken in the Mid-Atlantic Bight off New Jersey and Virginia. Dawe and Beck (1985) summarized the distributional aspects of previously reported rhynchoteuthion type C' larvae in the Northwest Atlantic as far east as 55° W (South of the Grand Bank) as well as previously unreported captures from Blake Plateau between Cape Canaveral, Florida, and Charleston, South Carolina.

Joint Canada-USSR surveys in February-May 1979 provided the first large collection of *I. illecebrosus* juveniles and indicated the possible importance of the Gulf Stream System in the life history of the species (Amaratunga *et al.*, MS 1980; Fedulov and Froerman, MS 1980). Subsequent coordinated research under the general guidance of the Scientific Council of NAFO has resulted in greatly expanded knowledge of larval and juvenile distribution in the Northwest Atlantic, particularly in the region north of 38° N (Amaratunga, MS 1981; Amaratunga and Budden, MS 1982; Dawe *et al.*, MS 1981, MS 1982; Froerman *et al.*, MS 1981; Arkhipkin *et al.*, MS 1983; Fedulov *et al.*, MS 1984; Dawe and Beck, 1985; Hatanaka *et al.*, 1985).

Trites (1983) examined and modelled the environmental factors and oceanographic processes which are likely to influence spawning and subsequent distribution of larval and juvenile *I. illecebrosus* in the western North Atlantic. He concluded that the shelf-slope region southwest of Chesapeake Bay seemed to be an appropriate place to conduct a detailed search for the spawning area of *I. illecebrosus* during the December-January period. The survey in the winter of 1983 was designed to sample the Slope Water-Gulf Stream frontal zone in the region from Chesapeake Bay to Florida for fully mature or spawning *I. illecebrosus* as well as for concentrations of larvae and juveniles, and to determine their distribution relative to particular water masses and their dynamics.

Materials and Methods

The survey was carried out by the research vessel *Alfred Needler* from 28 January to 2 March 1983. Sampling was concentrated along the northwestern edge of the Gulf Stream from 39° 00'N, 72° 48'W (in the northeast) to 28° 43'N, 79° 54'W (in the southwest). No *Illex* larvae were caught north of Cape Hatteras (35° N), and so the data in this paper pertain to the region from Cape Hatteras, North Carolina, to Cape Canaveral, Florida. Biological and oceanographic sampling was carried out along transects which generally extended across the landward edge (western boundary) of the Gulf Stream. The survey was functionally divided into two parts: the first part (Leg I), during 28 January-14 February, as the vessel proceeded southward toward Jacksonville, Florida, and the second part (Leg II), during 18 February-2 March, as the vessel cruised northward. Oceanographic and biological sampling was conducted at 71 stations on 16 transects during Leg I and at 41 stations on 11 transects during Leg II (see Fig. 1). Generally, the stations were spaced at intervals of 5-10 miles along the transects.

Oceanographic sampling at each station involved the collection of temperature and salinity data to a depth of 300 m with a portable salinity-temperature-depth (STD) system. Expendable bathythermograph (XBT) casts were made midway between stations along the transects and at frequent intervals as the vessel proceeded between transects, in order to provide additional resolution of the temperature structure in the survey area. Plots of temperature-depth profiles as the survey progressed were used to locate the western boundary of the Gulf Stream.

Biological sampling was generally consistent within each leg of the cruise but varied between legs. An oblique tow was made at each station with a 61-cm paired bongo sampler containing 0.505 mm mesh nets, which was operated according to standard procedures (Smith and Richardson, 1977). The tows were mainly to a maximum planned depth of 300 m during Leg I, but they were consistently less than 200 m during Leg II. When possible, a 0.333 mm mesh neuston net (Sameoto and Jaroszynski, 1969) was towed at the surface for 30 min, but high winds prevented the deployment of that sampler at many stations. A Diamond IX midwater trawl with 12 mm knotless nylon codend liner was used in midwater trawling for juveniles. Thirty-minute oblique hauls from 300 m were made during Leg I, whereas the trawl was towed for 30 min at a fixed depth of 92 m during Leg II. Midwater trawling was less extensive than plankton sampling, but generally a midwater-trawl set was executed on at least one station per transect.

Plankton catches were initially scanned for cephalopod larvae before preservation at sea and were examined in the laboratory for remaining cephalopods. *Illex* sp. larvae were identified and, where possible, dorsal mantle lengths were measured to the nearest 0.1 mm. Midwater-trawl catches of cephalopods were sorted at sea and *Illex* sp. juveniles were immediately measured as dorsal mantle length to the nearest millimeter. All cephalopods were initially preserved in 10% buffered formalin at sea and transferred to 70% ethanol in the laboratory.

General Biological and Oceanographic Features

Biological features

Adult *I. illecebrosus* are seasonally distributed from the Gulf of Mexico to the Labrador Sea (Clarke, 1966; Roper and Lu, 1979). During the period of rapid growth and development on the continental shelf, the greatest concentrations of maturing squid are found in the northern areas, i.e. Georges Bank, Scotian Shelf and inshore Newfoundland waters (Squires, 1957; Mercer, MS 1973, Lange, MS 1980; Amaratunga, MS 1981; Dawe and Drew, 1981; Lange and Sissenwine, 1983). Distribution within these areas of concentration appears to be influenced by temperature and abundance (Koeller, MS 1980; Mohn, MS 1981; Dupouy and Minet, MS 1982; Rowell and Young, MS 1984). Although catches of *I. illecebrosus* have been recorded from the surface to depths exceeding 1,000 m (Rathjen, 1981), the bulk of the population appears to be concentrated over and on the continental shelves, almost certainly in response to availability of prey species, and to be caught in areas where bottom temperatures are in the range of 6° and 12° C (Dupouy, MS 1981; Poulard *et al.*, MS 1984).

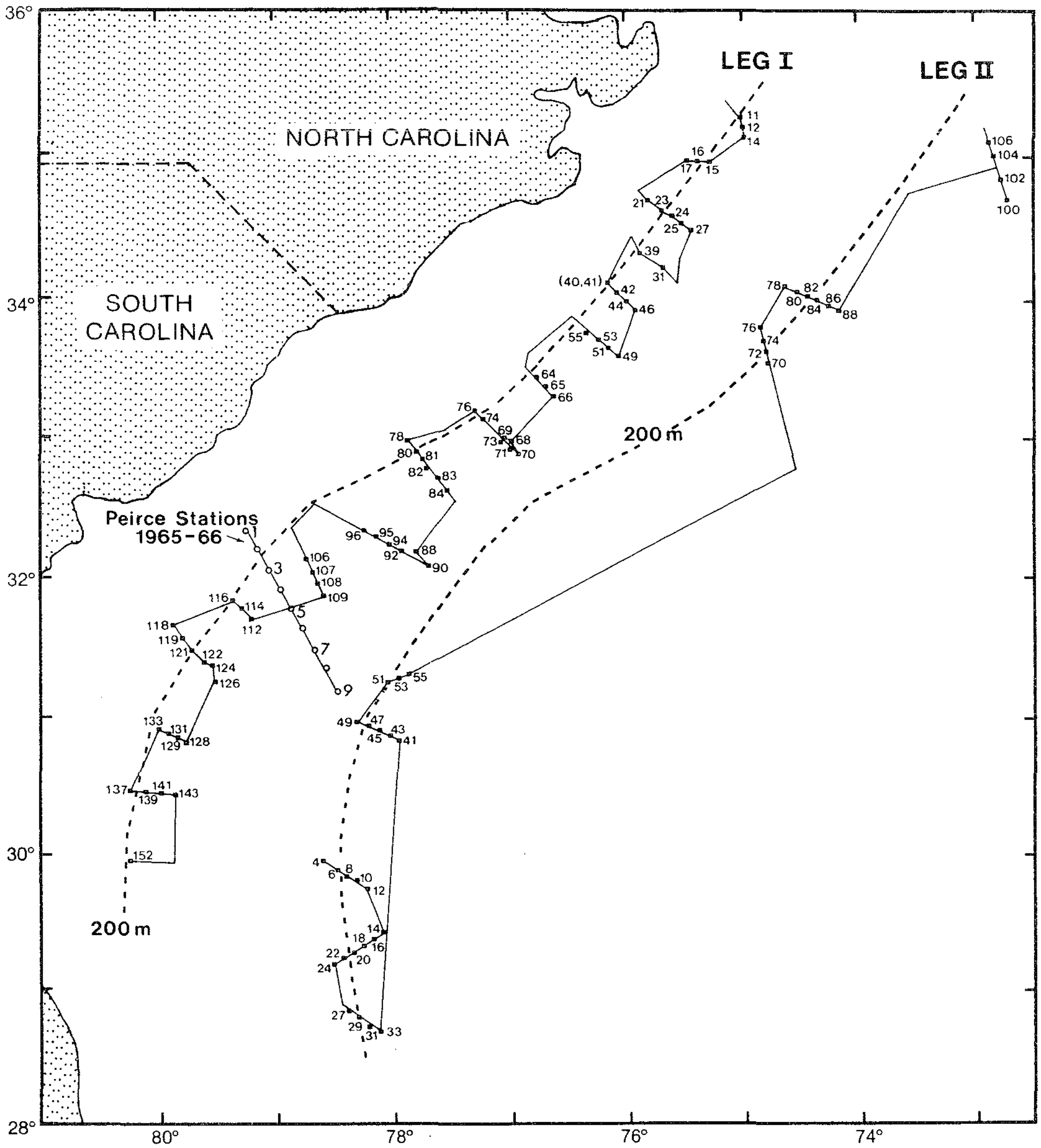

Fig. 1. Cruise track with locations of bongo stations for Legs I and II of the survey in February 1983. (*Peirce* stations off Charleston, South Carolina, in 1965-66 are also indicated.)

I. illecebrosus have not yet been aged, but concentric rings in the statoliths have been investigated and may ultimately provide a useful ageing technique (Lipinski, MS 1978; Hurley *et al.*, MS 1979). It is generally believed that the life span is approximately 1 year (Squires, 1967), but life cycles of 18-24 months have been proposed (Mesnil, 1977; Lange and Sissenwine, MS 1981). The bulk of the population is believed to result from a protracted winter spawning. Length distributions of catches in Newfoundland waters are generally unimodal but secondary and tertiary modal groups of smaller squid are seen regularly in later summer and autumn on the Scotian Shelf (Squires, 1957, 1967; Amaratunga, MS 1980; Dupouy, MS 1981; Poulard *et al.*, MS 1984; Rowell and Young, MS 1984). In the Georges Bank and southern New England areas, the length distributions also show several modal groups (Mesnil, 1977; Lange, MS 1980; Lange and Sissenwine, ,MS 1981), and the dominance of the winter-spawned population is occasionally superceded by a cohort of later spring-spawned or summer-spawned squid. In some years, the summer-spawned component in this southern area has been estimated to constitute up to 86% of the population in the autumn (Lange and Sissenwine, MS 1981).

When adult squid leave the continental shelves in the northern areas of late autumn, the males are in an advanced stage of maturity but the females are generally less advanced, indicating that some time remains before mating and spawning occur. Autumn-tagging studies in inshore Nova Scotia and Newfoundland waters (Amaratunga, MS 1981; Dawe *et al.*, 1981) indicate a general southwestward movement, and one tagged squid migrated from northeastern Newfoundland to Maryland, a minimum distance of 2,300 km in 107 days. The sporadic fishery for *I. illecebrosus* off Cape Canaveral and the large catches by the research vessel *Anton Dohrn* on the Blake Plateau in the autumn of 1979 (Rathjen, 1981) are evidence of large-scale concentrations south of Cape Hatteras. There is little monitoring of the squid fishery in these southern areas, and, hence, there is a lack of information on abundance, distribution and biology. Of the seven mature females (stages IV and V) that were reported by Dawe and Drew (1981), three of the four stage V specimens were captured between Georges Bank and Cape Hatteras and all three had mated, as indicated by the presence of spermatophores in the mantle cavity. Laboratory experiments have indicated that mating and spawning may occur on bottom or pelagically (O'Dor *et al.*, 1982, MS 1982). The spherical gelatinous egg masses are negatively buoyant, but water density changes of 0.004 g cm^{-3} are sufficient to make them neutrally buoyant (O'Dor, 1983). If the egg masses are transported passively, prevailing currents and developmental time to hatching may greatly influence the distribution of newly-hatched larvae. Although the minimum temperature for fertilization has not been determined, it is known that eggs which are fertilized at temperatures as low as 7° C will develop if the incubation temperature is increased to 13° C or higher (O'Dor *et al.*, 1982). Full development of eggs does not occur at temperatures below 12° C, and the rate of development of eggs to hatching increases with temperature, 16 days being required at 13° C and about 9 days at 21° C. Mantle lengths of larvae at hatching are 1.10–1.25 mm (Durward *et al.*, 1980; O'Dor *et al.*, 1982). Dawe and Beck (1985) reported the capture of larvae as small as 1.1 mm ML in the Blake Plateau area in February 1969. The capture of small rhynchoteuthion type C' larvae (1.5–2.0 mm ML) as far to the northeast as 40° 30'N, 60° 00'W in the Slope Water–Gulf Stream frontal zone (Froerman *et al.*, MS 1981) indicates that, with passive transport of egg masses and larvae for 2 weeks or more after spawning, the spawning area may be in the vicinity or to the south of Cape Hatteras. Trites (1983) described the oceanographic features and processes which define possible areas of spawning and which act to transport egg masses and larvae to the northeast of Cape Hatteras where large catches of larvae and small juveniles have been taken since 1979 (Amaratunga *et al.*, MS 1980; Fedulov and Froerman, MS 1980; Froerman *et al.*, MS 1981; Amaratunga and Budden, MS 1982; Dawe *et al.*, MS 1982; Arkhipkin *et al.*, MS 1983; Fedulov *et al.*, MS 1984; Dawe and Beck, 1985; Hatanaka *et al.*, 1985).

In the area of larval and juvenile *I. illecebrosus* distribution northeast of Cape Hatteras, there is an indication of progression in size of juveniles toward the northeast (Dawe *et al.*, MS 1981) and also from the Gulf Stream toward the continental shelves (Froerman *et al.*, MS 1981; Hatanaka *et al.*, 1985). Juveniles of 10–30 mm ML are common in the Gulf Stream–Slope Water frontal zone, and 40 mm specimens have small amounts of food in their stomachs, indicating they they are capable of significant movement. Evidence of successive spawnings is indicated by the predominance of small juveniles in an area where larger juveniles were found a few weeks earlier (Fedulov *et al.*, MS 1984). The largest catches of larvae and juveniles in the region northeast of Cape Hatteras generally have been associated with the Gulf Stream–Slope Water frontal zone and the periphery of warm-core eddies. Although a few larvae and juveniles have been taken in the Gulf Stream and at the centre of cold-core eddies in the Sargasso Sea (Hatanaka *et al.*, 1985), it is unlikely that they originated from spawning within these water masses.

Oceanographic features

The dominant oceanographic feature of the continental slope between Florida Straits and Cape Hatteras is the intense western North Atlantic boundary current, which is part of the Gulf Stream system (Stommel, 1965). Although Iselin (1936) introduced well-defined nomenclature for various parts of the western North Atlantic current system, the high velocity current which flows northward from Florida Straits is referred to in this paper as the Gulf Stream. Off the east coast of Florida, the shoreward edge of the Gulf Stream, on the average, can be delineated approximately by the 200 m isobath. Northward off South Carolina, the Gulf Stream is located further offshore, but it returns to about the 200 m isobath just south of Cape Hatteras. Examination of sea-surface temperature maps, which are prepared by the National Earth Satellite Service (NESS) of the U.S. National Oceanic and Atmospheric Administration (NOAA), reveals that the Gulf Stream has a meandering or wave-like characteristic, with the shoreward boundary consistently displaying a folded-wave pattern (frontal eddies). These eddies appear as tongue-like extrusions of the Gulf Stream, oriented upstream, nearly parallel to the Steam (and the continental slope), and often resembling "shingles" (Legeckis, 1979; Bane *et al.*, 1981; Lee *et al.*, 1981). In the area between Florida and Charleston, South Carolina, lateral movements of the Gulf Stream are quite small (about 10 km) and the frontal eddies or filaments are narrow and very elongated. There is a rapid increase in the magnitude of the meanders after the Gulf Stream is deflected seaward by the Charleston Bump (31° 45'N) and the lateral movements may be as great as 40 km from the mean (Bane and Brooks, 1979). The shoreward crest of the meanders appear to propagate downstream at speeds of 30–40 km/day (Legeckis, 1979; Brooks and Bane, 1981; Lee and Waddell, 1983). Filaments tend to develop along the shoreward edge of the meanders and usually, but not always, grow rapidly in length. Chew (1981) noted that, although a filament is assumed to be part of a cyclonic vortex, the merging of the filament near its tongue has never been observed. Filaments are very shallow features, typically less than 50 m in depth.

Transport and velocity of the Gulf Stream have been reported by several researchers (e.g. Parr, 1937; Worthington, 1954, 1976; Knauss, 1969; Richardson *et al.*, 1969; Kirwan *et al.*, 1976). Volume transport increases from about 30 Sverdrups (1 Sverdrup = 10^6 m^3/sec) in Florida Straits to about 80 off Cape Hatteras and to a maximum of about 150 south of Nova Scotia, and diminishes thereafter toward the east. Maximum surface velocities in the core of the Gulf Stream between Florida Straits and Cape Hatteras are generally in the range of 150-200 cm/sec, with the velocities gradually diminishing with depth. Kirwan *et al.* (1976) reported that a satellite-tracked buoy (drogued at 35 m), which was launched in the Gulf Stream at 30° N, was off Cape Hatteras 5 days later and was east of 60° W in 15 days.

Although it is well established that the volume transport of the Gulf Stream increases as it flows northward off the United States, it is much less clear as to the proportions of water that are supplied from different sources. In a study of the water mass properties of Florida Straits and related waters, Wennekens (1959) identified two water types in the southern Florida Straits: Yucatan Water and Continental Edge Water. The water that passes through Yucatan Straits either passes around the western end of Cuba and directly into Florida Straits or flows clockwise in the eastern Gulf of Mexico before entering Florida Straits. According to Wust (1964) and Nowlin (1971), the water that flows through Yucatan Straits is made up of Subtropical Underwater, characterized by maximum salinity of 36.60-36.80 at depths between 50 and 200 m. Atlantic Intermediate Water is present below about 600 m and is characterized by minimum salinity (<35.00) at 800-1,000 m. According to Nowlin (1971), the warm (>17° C) water beneath the surface-mixed layer is the only distinct water mass that was formed in the Gulf of Mexico. This water, referred to as Continental Edge Water by Wennekens (1959), is characterized by an increase in salinity from about 36.00 to 36.45 with decreasing temperature from about 25° to 18° C. Thus, the salinity of Continental Edge Water at a given temperature is considerably less than that of water referred to as Yucatan Water by Wennekens (1959).

During 1965 and 1966, the U.S. Coast and Geodetic Survey ship *Peirce* sampled an oceanographic section (Fig. 1) across the Gulf Stream off Charleston, South Carolina, on 21 occasions by measuring temperature, salinity and dissolved oxygen and observing near-surface currents with parachute-drogued buoys. According to Hazelworth (1976), the water masses consisted of Continental Edge Water, Florida Straits (Yucatan) Water, Antilles Current Water and Sargasso Sea Water. Station mean T-S curves for the entire year of data indicated the presence of coastal water of local

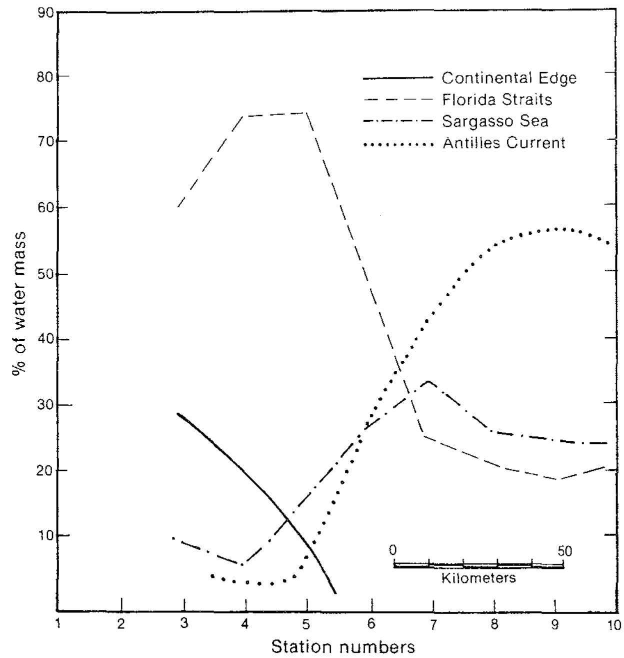

Fig. 2. Percentages of Continental Edge Water, Florida Straits (Yucatan Straits) Water, Antilles Current Water and Sargasso Sea Water in water masses along the *Peirce* section off Charleston, South Carolina, in 1965-66. (Adapted from Hazelworth, 1976.)

origin at stations 1 and 2 and a layer of Continental Edge Water (30-50 m) at station 2. Stations 4 and 5 exhibited a mixture of Continental Edge Water and Florida Straits Water, with the latter type predominanting (Fig. 2). Seaward of station 6, Sargasso Sea Water and Antilles Current Water were the dominant types. It is not possible to differentiate between Florida Straits Water, Antilles Current or Sargasso Sea Water at temperatures between 18° and 22° C. Also, Antilles Curent Water cannot be differentiated from Sargasso Sea Water at temperatures between 11° and 18° C. The drogued-buoy movements at the surface indicated that the axis of the Gulf Stream was usually in the vicinity of stations 5 or 6 but on occasion touched stations 4 and 7. The velocity at the core of the Gulf Stream averaged 179 cm/sec but varied from a low of 142 cm/sec to a high of 219 cm/sec. Currents at stations 2 and 3 sometimes flowed in the direction of the Gulf Stream and sometimes in the reverse direction.

Results and Discussion

Distribution and size of larvae

South of Cape Hatteras, rhynchoteuthion type C′ larvae were caught in 16 of 71 Bongo tows during Leg I and in 4 of 41 tows during Leg II of the survey (Fig. 3), the north-to-south range being from 33° 59′N to 28° 43′N. North of Cape Hatteras, no larvae were found in four Bongo tows as far north as 39° 00′N during Leg I or in five tows as far north as 37° 45′N during Leg II.

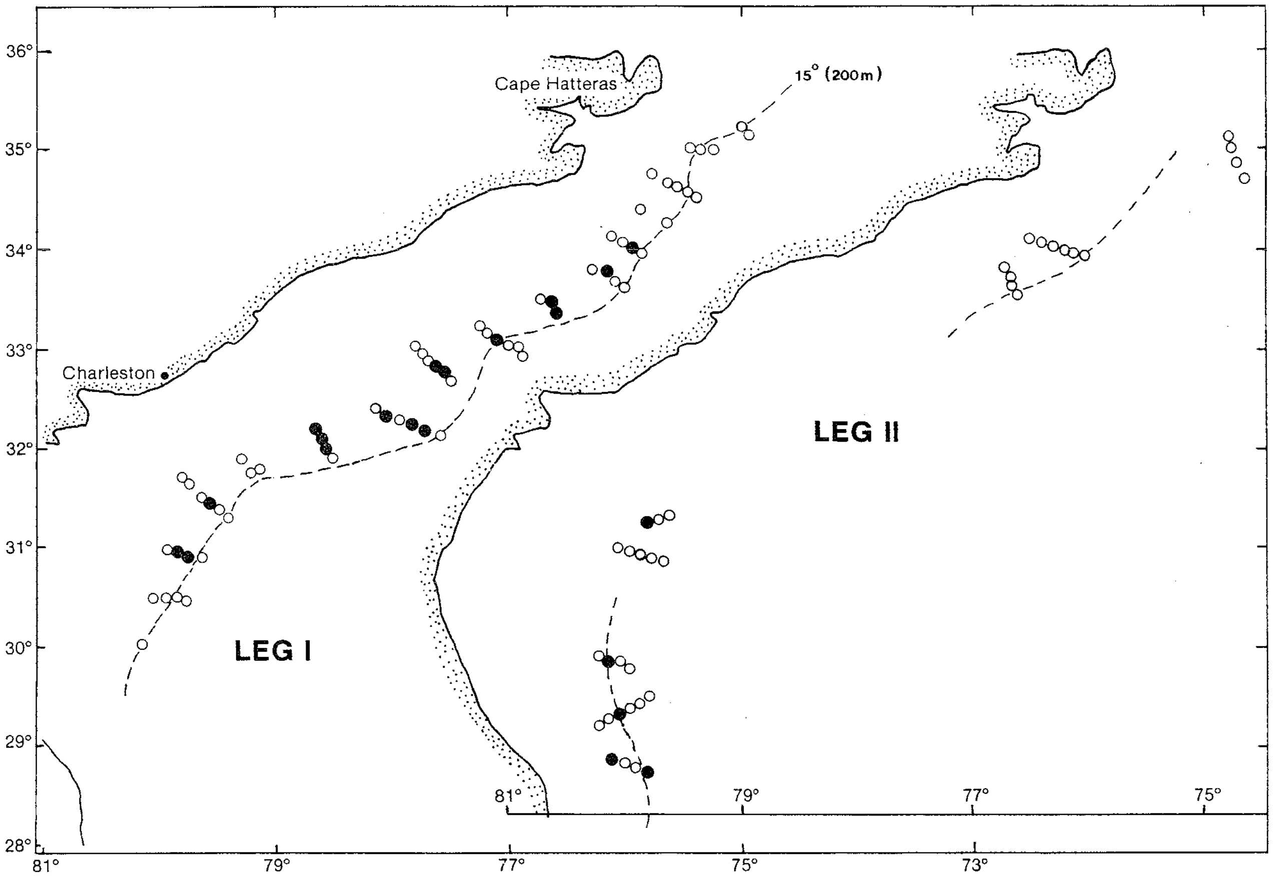

Fig. 3. Bongo station locations and captures of *Illex* larvae (closed circles) during Legs I and II of the cruise in February 1983. (Dashed line indicates the approximate position of the Gulf Stream core, as defined by the 15°C isotherm at 200 m.)

A total of 25 larvae were captured along the Slope Water-Gulf Stream frontal zone during Leg I of the survey (Table 1), with sizes ranging from 2.5 to 6.4 mm ML ($\bar{x}$ = 3.8). Only five larvae were caught during Leg II, all in the southern part of the survey area, with sizes of 1.0-3.0 mm ($\bar{x}$ = 1.8 mm). Although there is no direct evidence of a progression in larvae size from northeast to southwest during 4-12 February (Leg I), relatively more larger larvae (>4.0 mm ML) were taken in the more southerly catches (i.e. south of 32°N). The larvae during 19-22 February (Leg II) were, with one exception, smaller than those taken during Leg I. This, together with the complete absence of larvae during 23-25 February in the northeastern part of the area indicates that two distinct cohorts were sampled and that the brood which was sampled during Leg I had been transported from the survey area or had advanced to the juvenile stage in the 2-3 week period between samplings.

The larvae in the Leg II catches may have been recent hatchlings, and, in the case of the 1.0 mm ML specimens, may have been precociously hatched. From observations on spawning and egg development of *I. illecebrosus* in the laboratory, Durward *et al.*

TABLE 1. Number and size of measurable *Illex* larvae from northeast to southwest along the axis of the Gulf Stream during Legs I and II in February 1983. (Leg II data in **bold**.)

Station	Latitude NE to SW	Date	No. of larvae	Length (mm ML)
44	33° 59′	04 Feb	1	2.5
53	33° 43′	05 Feb	2	3.5,4.8
65	33° 22′	06 Feb	3	3.5,>3.5,3.9
66	33° 19′	06 Feb	1	3.5
69	33° 04′	06 Feb	1	3.0
82	32° 46′	08 Feb	1	3.0
83	32° 43′	08 Feb	2	3.0,4.9
95	32° 17′	09 Feb	2	>3.5,3.9
92	32° 11′	08 Feb	1	4.0
88	32° 09′	08 Feb	1	3.3
106	32° 06′	09 Feb	1	>3.5
107	32° 02′	09 Feb	3	2.8,3.2,6.4
108	31° 58′	10 Feb	3	>3.0,>5.0,5.4
122	31° 24′	11 Feb	1	4.8
51	**31° 13′**	**22 Feb**	**1**	**1.0**
131	30° 58′	12 Feb	1	>4.0
129	30° 51′	12 Feb	1	>4.0
8	**29° 50′**	**19 Feb**	**1**	**3.0**
27	**28° 51′**	**20 Feb**	**2**	**1.0,2.0**
33	**28° 43′**	**21 Feb**	**1**	**2.0**
	Leg I		25	$\bar{x}$=3.8(2.5-6.4)
	Leg II		**5**	**$\bar{x}$=1.8(1.0-3.0)**

(1980) reported that hatching occurred at 1.1 mm ML. R. K. O'Dor (Dalhousie University, Halifax, N.S., pers. comm.) believes that damage to the egg masses in these laboratory studies may have led to early hatching, and he suggests that 1.25 mm ML is more probably the size of hatching in undisturbed egg masses. However, Dawe and Beck (1985) reported the capture of 1.1 mm ML *Illex* larvae between Cape Hatteras and Florida in 1969.

The variation in size of larvae from different locations along the Slope Water-Gulf Stream frontal zone (Table 1) indicates that spawning may be widely dispersed in the area roughly parallel to the Gulf Stream axis, and that there may be some mechanism for retention and eventual mixing of egg masses, larvae and juveniles in the area, despite the potential for rapid transport by the Gulf Stream. If spawning and retention of egg masses and larvae occurs along the frontal zone, it is also possible that development to hatching and subsequent larval growth are influenced by temperature clines and other factors.

Dawe and Beck (1985) reported the capture of 29 *Illex* larvae and 4 juveniles in February 1969 along the 183 m isobath between Cape Canaveral (28° 30'N) and Charleston (33° 00'N). The distributional range of these captures overlaps that where larvae were taken during the 1983 survey (28° 43'N to 33° 59'N), and, since the Slope Water-Gulf Stream frontal zone tends to follow this isobath, it is likely that the 1969 captures were made in similar water masses. The size range of the 1969 larvae was 1.1-6.2 mm ML, with 24% being 20 mm or less. Dawe and Beck (1985), from recent surveys south of Newfoundland in late February-early March, also reported the collection of 38 *Illex* larvae (2.4-5.4 mm ML) in 1981 and 18 larvae (3.6-6.6 mm ML) in 1982. All were taken along a transect at 56° W between 37° and 41° N except for one specimen at 40° 09'N, 53° 00'W. These most northeasterly captures and the collections of larvae in Gulf Stream and associated water masses southwestward to Cape Hatteras (Roper and Lu, 1979; Vecchione, 1979; Amaratunga *et al.*, MS 1980; Amaratunga and Budden, MS 1982; Dawe *et al.*, MS 1982; Arkhipkin *et al.*, MS 1983; Fedulov *et al.*, MS 1984; Hatanaka *et al.*, 1985) indicate that spawning may be pelagic over an extensive area along the Slope Water-Gulf Stream frontal zone or (and) that egg masses are transported over long distances from spawning on the continental shelf from the vicinity of Cape Hatteras southward.

Distribution and size of juveniles

South of Cape Hatteras, *Illex* juveniles were caught in 16 of 22 midwater trawl tows during Leg I and in 11 of 13 tows during Leg II (Fig. 4). Three additional tows north of Cape Hatteras at the end of Leg II yielded

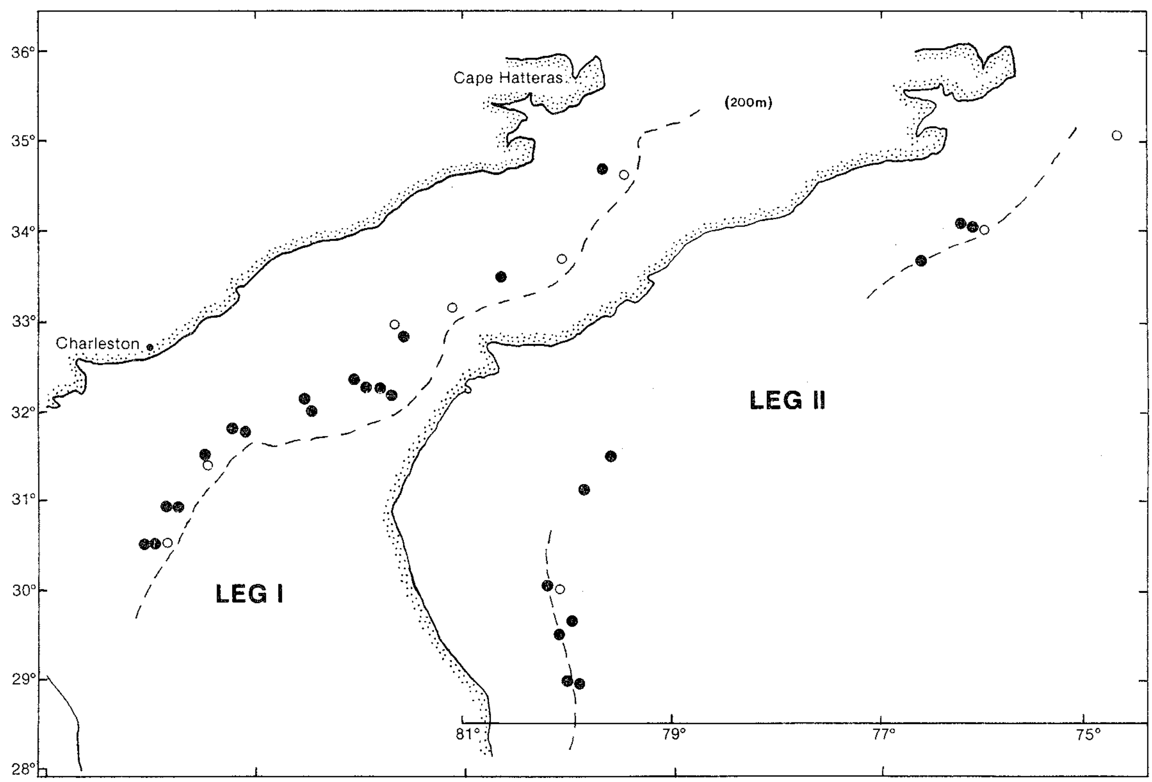

Fig. 4. Midwater-trawl station locations and captures of *Illex* juveniles (closed circles) during Legs I and II of the cruise in February 1983. (Dashed line indicates the approximate position of the Gulf Stream core, as defined by the 15° C isotherm at 200 m.)

TABLE 2. Number and size of *Illex* juveniles from northeast to southwest along the axis of the Gulf Stream during Legs I and II in February 1983. (Leg II data in **bold**; bracketed rows indicate sets during both legs at approximately the same position.)

Station	Latitude NE to SW	Date	No. of juveniles	Length (mm ML) Range	Length (mm ML) Median
120	**37°39′**	**27 Feb**	**2**	**23-30**	**26.5**
24	34°38′	01 Feb	38	9-18	13.5
84	**33°55′**	**24 Feb**	**126**	**14-86**	**32.2**
86	**33°53′**	**24 Feb**	**3**	**24-43**	**31.0**
{**70**	**33°29′**	**23 Feb**	**20**	**16-20**	**23.5**}
{65	33°28′	06 Feb	7	13-27	16.0}
82	32°47′	08 Feb	5	21-53	24.0
95	32°18′	09 Feb	4	19-23	19.5
94	32°13′	09 Feb	15	7-30	13.0
92	32°12′	08 Feb	34	7-30	10.3
88	32°08′	08 Feb	4	9-13	12.5
107	32°05′	09 Feb	1	—	29.0
108	31°56′	10 Feb	1	—	14.0
114	31°45′	10 Feb	5	44-56	47.0
112	31°43′	10 Feb	5	14-24	22.0
122	31°25′	11 Feb	4	11-27	22.5
55	**31°16′**	**22 Feb**	**4**	**19-76**	**44.5**
{**45**	**30°53′**	**21 Feb**	**7**	**20-68**	**43.0**}
{129	30°51′	12 Feb	5	15-37	20.0}
131	30°51′	12 Feb	29	13-72	31.0
137	30°27′	12 Feb	359	9-66	30.9
139	30°27′	12 Feb	1	—	36.0
8	**29°49′**	**19 Feb**	**4**	**20-51**	**35.0**
16	**29°23′**	**20 Feb**	**1**	**—**	**22.0**
20	29°17′	**20 Feb**	**64**	**19-92**	**31.5**
31	**28°44′**	**20 Feb**	**2**	**32-37**	**34.5**
33	**28°43′**	**21 Feb**	**13**	**18-35**	**22.3**
	Leg I		517	7-72	
	Leg II		**246**	**14-92**	

TABLE 3. Catches of *Illex* at stations where both bongo (for larvae) and midwater trawl (for juveniles) sets were made during Legs I and II in February 1983. (Numbers in parentheses are juveniles in bongo sets and larvae in MWT sets.)

Cruise	Station	Latitude	Number of *Illex* Bongo	Number of *Illex* MWT
Leg I	24	34°38′	—	38
	53	33°43′	2	—
	65	33°28′	3	7
	82	32°47′	1	5
	88	32°08′	1	4
	92	32°12′	1	32(2)
	94	32°13′	—	15
	95	32°18′	1	4
	107	32°02′	3(1)	1
	108	31°56′	3	1
	112	31°33′	—	5
	114	31°45′	—	5
	122	31°25′	1(1)	4
	129	30°51′	4	5
	131	30°51′	1	24
	137	30°27′	—	359
	139	30°27′	—	1
Leg II	8	29°49′	—	4
	16	29°23′	—	1
	20	29°17′	—(1)	64
	31	28°44′	—	2
	33	28°43′	1	13
	45	30°53′	—	7
	55	31°16′	—	4
	70	33°29′	—	20
	84	33°55′	—	126
	86	33°53′	—	3
	120	37°39′	—	3

two juveniles at the northernmost station (37° 27′N, 72° 17′W). Apart from fewer midwater tows than Bongo tows, the distributions of the stations where juveniles were caught during Legs I and II were very similar to those for larvae (Fig. 3).

A total of 517 juveniles were captured during Leg I (Table 2), with median sizes ranging from 10.3 to 47.0 mm ML and an overall size range of 7-72 mm ML. From northeast to southwest, the median size progressively became larger and the overall size range also increased. During Leg II, the juveniles were generally larger than during Leg I, and there was no indication of progression in size along the Slope Water-Gulf Stream frontal zone. A total of 246 juveniles were caught, with median sizes in the range of 22.0-44.5 mm ML and an overall size range of 14-92 mm ML.

Comparison of catches at stations where both Bongo and midwater trawl tows were made (Table 3) indicates an association between larvae and juveniles at some stations but not at others. At all stations (except Sta. 53) where larvae were caught in Bongo tows, juveniles were caught in the midwater trawl tows, but, at stations where the midwater trawl caught juveniles, the Bongo caught larvae in only 10 of 16 tows (63%) during Leg I and 2 of 11 tows (18%) during Leg II. The possibility that the smaller juveniles might have a greater distributional overlap with the larvae was considered, but examination of median sizes and ranges indicated no size differential between juveniles that were caught at stations associated with larval catches and those not associated. Additionally, examination of the oceanographic data revealed no difference in water masses for the associated and unassociated catches of juveniles.

Water temperatures and squid distribution

The aim of the survey was to work a series of short transects across the Slope Water-Gulf Stream frontal zone between Cape Hatteras and Florida. The 15° C isotherm, which is usually nested within closely-spaced isotherms on a temperature plot at 200 m (Worthington, 1954; Webster, 1961; Fuglister, 1963), is frequently taken to indicate the geographic position of the high-velocity core of the Gulf Stream. Upstream from its seaward deflection off Charleston, South Carolina, the Gulf Stream may at times and places be shoreward of the 200 m isobath so that temperatures

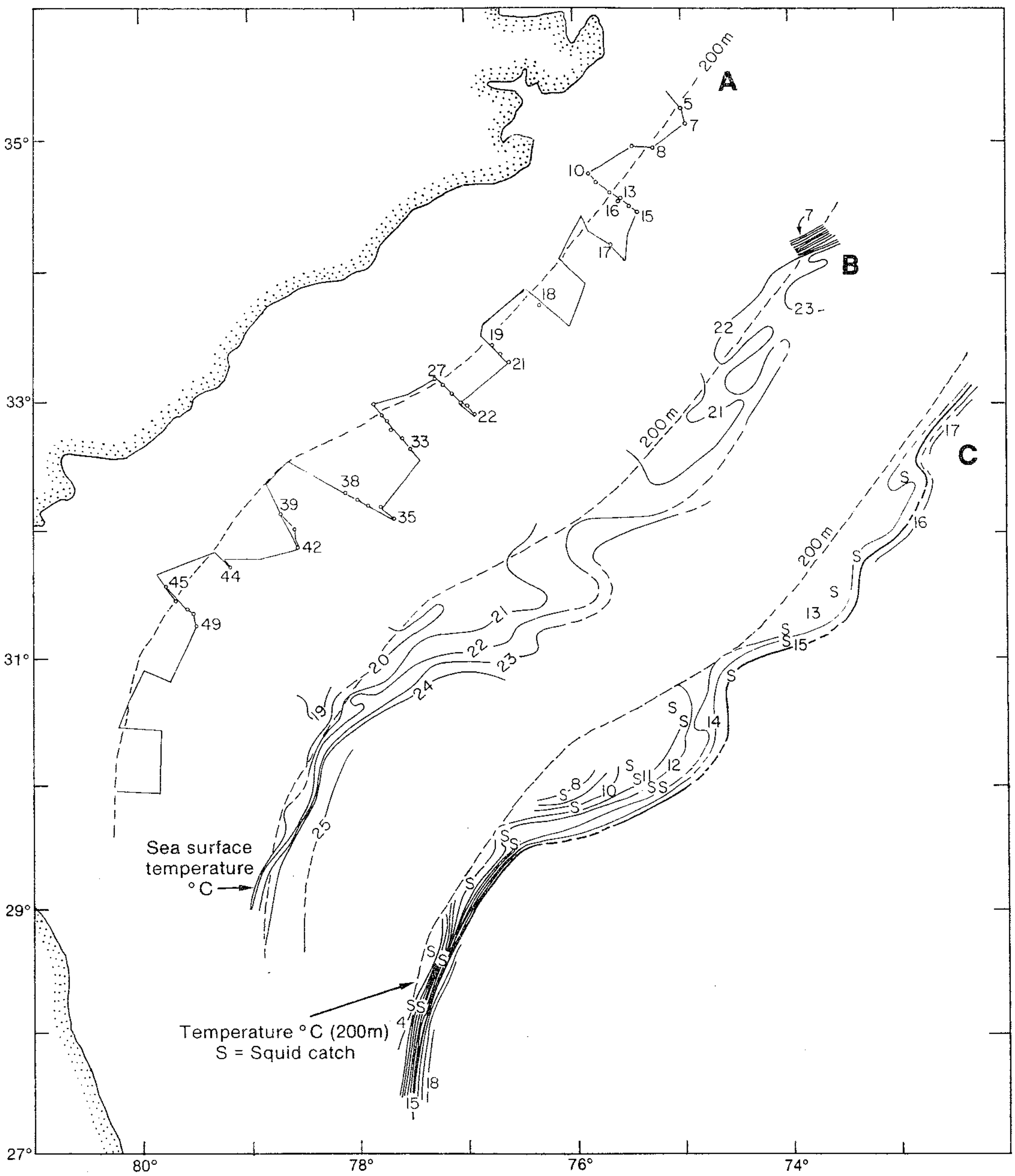

Fig. 5. Map of the survey area showing for Leg I during 31 January–13 February 1983. **A**, cruise track along which XBT casts were made and station numbers of STD casts; **B**, surface temperature contours along the cruise track; and **C**, temperature contours at 200 m and capture locations (S) of *Illex* larvae and juveniles. (**B** and **C** are offset for visual clarity.)

throughout the water column are all higher than 15° C. However, its position, as judged from the surface thermal front, is usually close to the 200 m isobath with lateral movement generally less than 15 km (Bane and Brooks, 1979). During Leg I of the survey (Fig. 5), surface temperatures were usually 20° to 23° C on the northern transects and 20° to 25° C in the south. The 15° C isotherm was located seaward of the 200 m isobath, and all squid catches were taken on the shoreward size of this isotherm, indicating that most of the squid were probably distributed shoreward of the high-velocity core of the Gulf Stream.

The temperature distributions in Fig. 5 should not be considred in any way to be synoptic or to represent the average condition during the 2-week period of the survey. Only the observations which were made along individual transects within a few hours may be considered approximately synoptic. An indication of the dynamic nature of conditions in the area of sampling

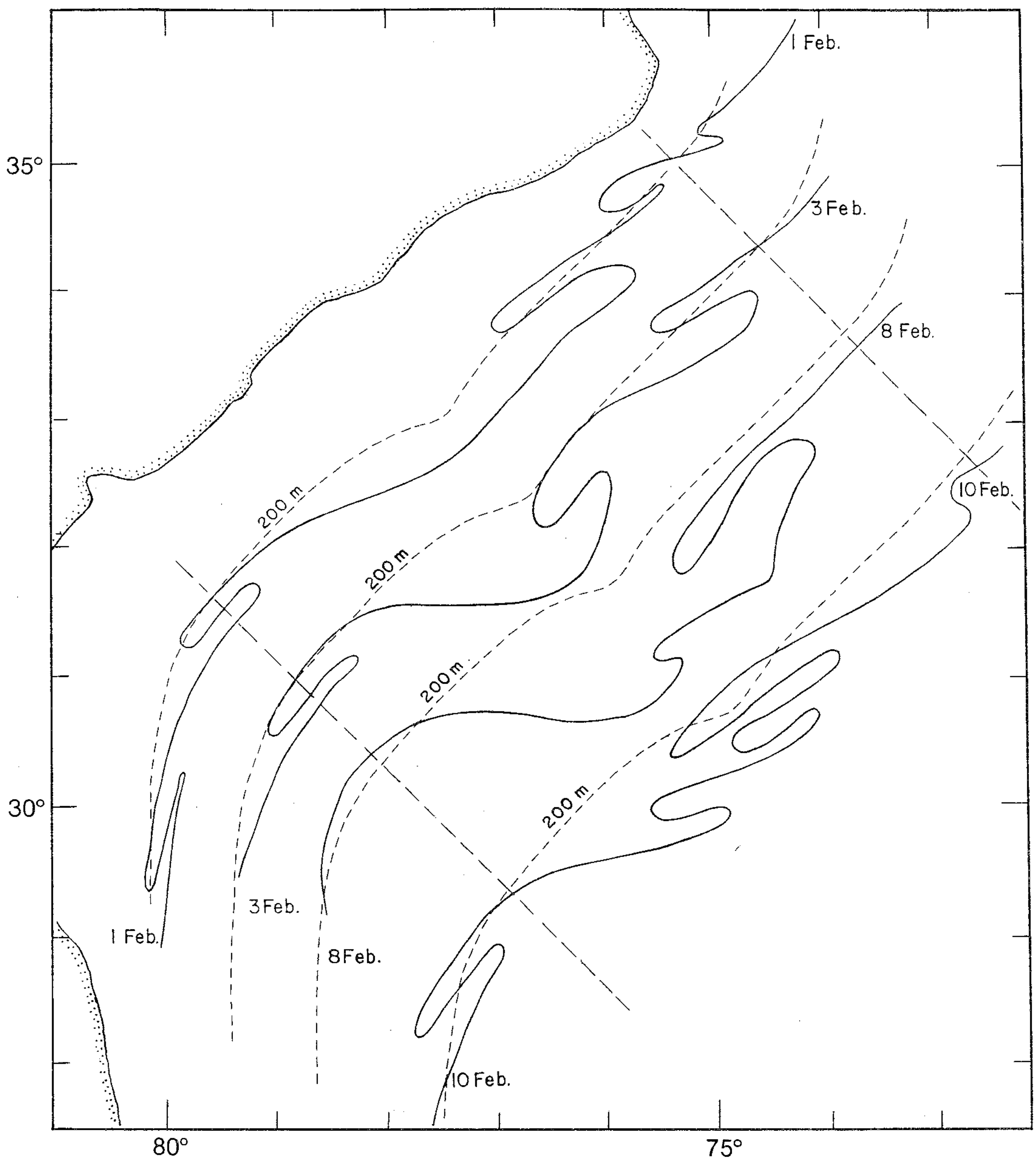

Fig. 6. Progressively offset locations of the Gulf Stream-Slope Water front, as determined from NOAA/NESS satellite-derived oceanographic analysis maps for 1, 3, 8 and 10 February 1983.

and the speed at which changes occur, at least in the surface layer, may be obtained from the NOAA/NESS satellite-derived oceanographic analysis maps, which are produced twice weekly (Wednesday and Friday). Progressive offsets of the Slope Water-Gulf Stream front on 1, 3, 8 and 10 Feburary 1983 (Fig. 6) show a complex series of filaments or shingles which varied in number, position, size and shape. Additionally, the high-velocity core of the Gulf Stream appears to have been moving farther offshore during 1-8 February in the area downstream of the Charleston Bump. By 10 February, the meander appears to have been moving shoreward again. Thus, the time when the ship was operating downstream of the Charleston Bump (prior to 8 February) coincided with the major deflection of the Gulf Stream and the developing filaments or shingles.

During Leg II of the survey (Fig. 7) surface temperatures were generally similar to those during Leg I, and the 15° C isotherm continued to be located seaward of the 200 m isobath. However, most of the squid catches appear to have been taken within or on the seaward side of the high-velocity core of the Gulf Stream, exceptions being noted for catches at stations 27, 31, 84 and 86. This contrasts significantly with sampling

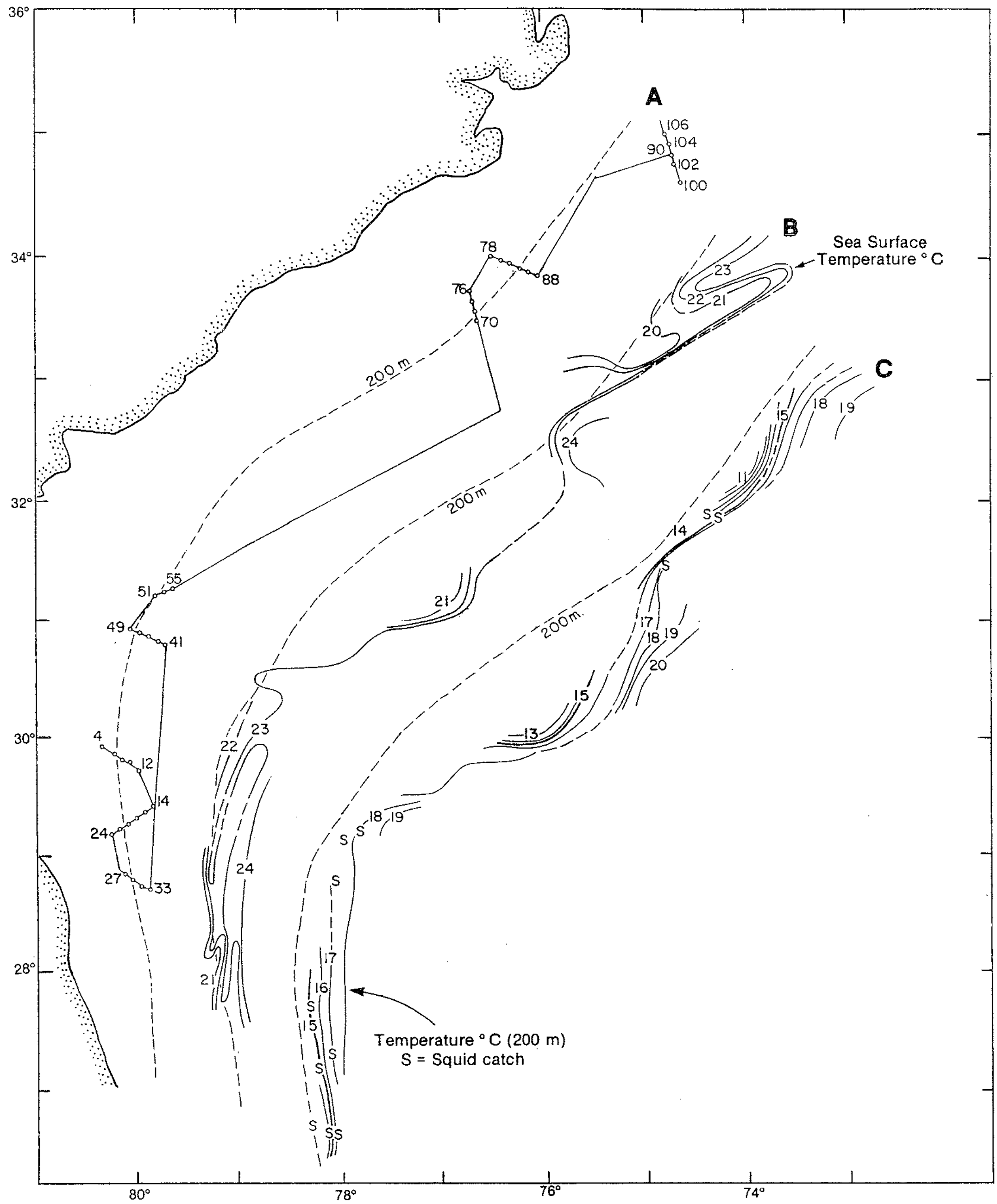

Fig. 7. Map of survey area showing for Leg II during 18–25 February 1983: **A**, cruise track along which XBT casts were made and station numbers of STD casts; **B**, surface temperature contours along the cruise track; and **C**, temperature contours at 200 m and capture locations (S) of *Illex* larvae and juveniles. (**B** and **C** are offset for visual clarity.)

during Leg I, when the catches of squid were confined to areas shoreward of the Gulf Stream core.

Temperature-salinity characteristics and squid distribution

For Leg I of the cruise, comparison of T-S plots for stations where larval and/or juvenile *I. illecebrosus* were caught with those for seaward stations where none were caught (Fig. 8) shows distinct differences in the upper 100–150 m of the water column. The T-S characteristics of the water mass in the upper 100 m, where catches were made (Fig. 8B) are very similar to those for Continental Edge Water, as defined by Wennekens (1959), whereas the water further offshore (Fig. 8C) corresponds more closely to Yucatan Water. Curiously, the T-S curves for stations shoreward of those where catches were obtained (Fig. 8A) seem to indicate a mixture of Continental Edge Water and Yucatan Water, except that the temperature is frequently lower in the near-surface layer. The presence of Yucatan Water may be the result of frontal eddy activity which,

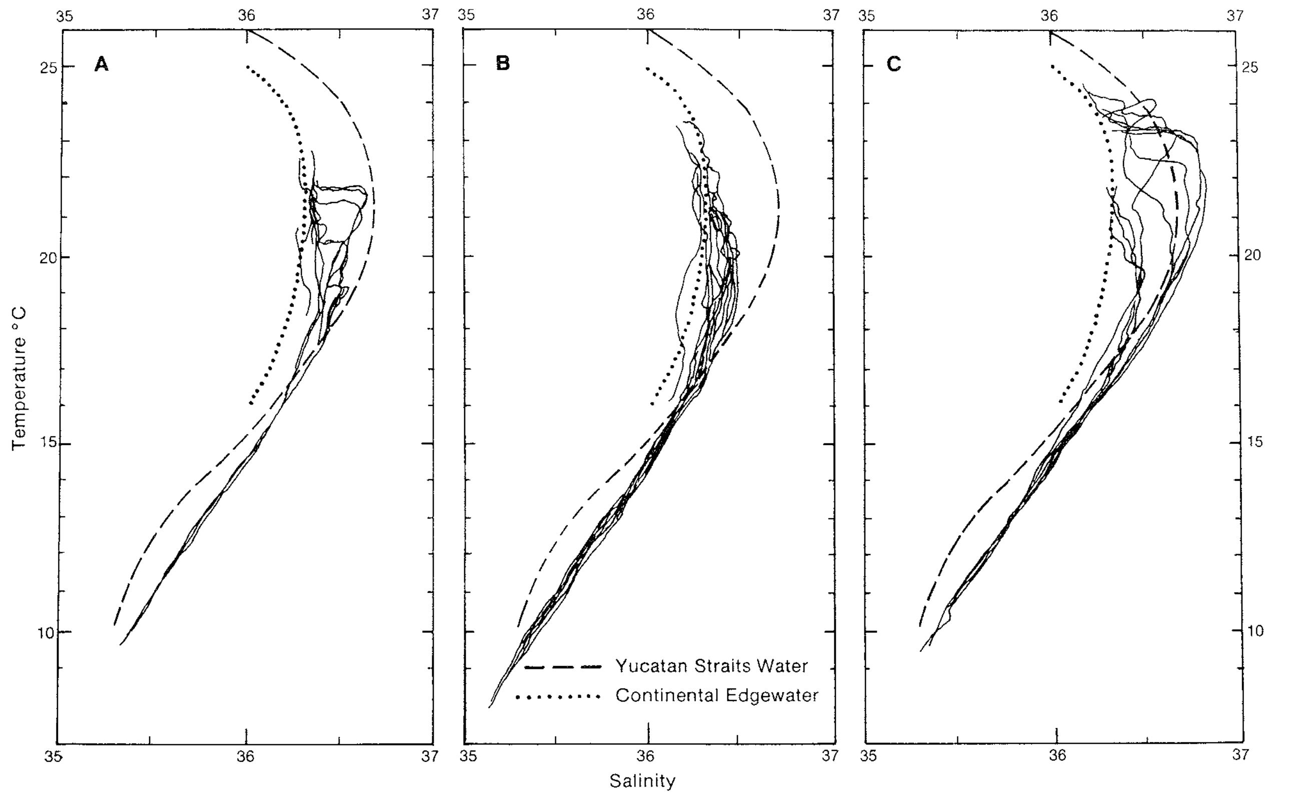

Fig. 8. Temperature-salinity plots for stations occupied during Leg I of the cruise: **A**, stations shoreward of those with catch; **B**, stations where *Illex* larvae and/or juveniles were caught; and **C**, stations seaward of those with catch.

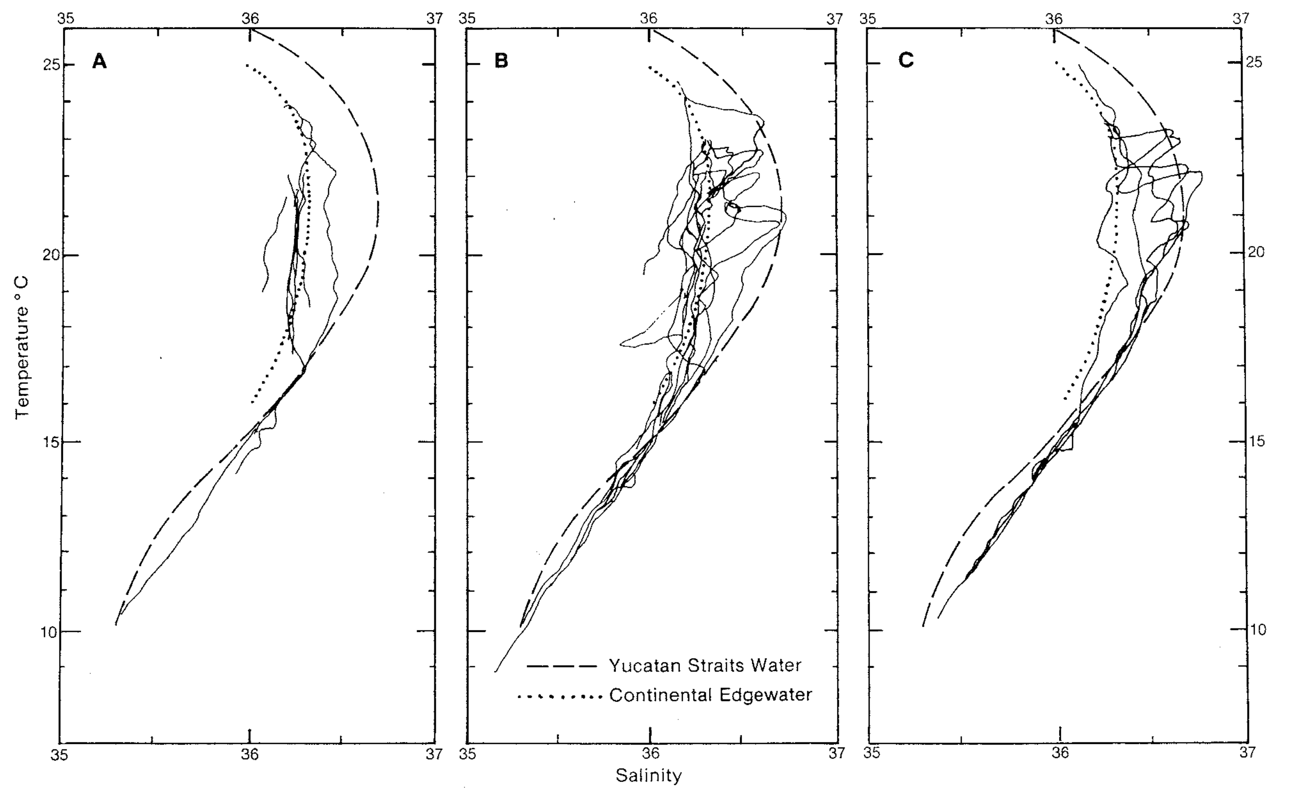

Fig. 9. Temperature-salinity plots for stations occupied during Leg II of the cruise: **A**, stations shoreward of those with catch; **B**, stations where *Illex* larvae and/or juveniles were caught; and **C**, stations seaward of those with catch.

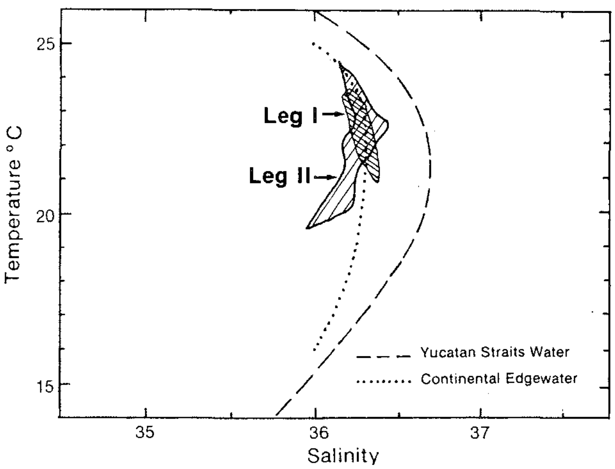

Fig. 10. Envelopes of temperature-salinity curves for the upper 50 m, that incorporates all stations where *Illex* larvae and/or juveniles were caught during Legs I and II of the cruise.

at times, creates filaments of warm, saline water that extent shoreward from the Gulf Stream core.

For Leg II of the cruise, the T-S characteristics of the water at stations where squid larvae and juveniles were caught (Fig. 9) also tend to conform more closely to those of Continental Edge Water than to Yucatan Water, although there is more scatter in the curves than was the case for Leg I stations. However, plots of T-S curves for only the upper 50 m indicate close conformity to Continental Edge Water.

The envelopes of the T-S curves for the upper 50 m at all stations where squid were caught (Fig. 10) exhibit similar characteristics. The T-S envelope for Leg I, bounded by salinity isohalines of 36.15 and 36.40 and temperatures of 20.8° and 23.6° C, is centered approximately at salinity of 36.3 and temperature of 22.5° C. For Leg II, the envelope is larger, with salinity ranging

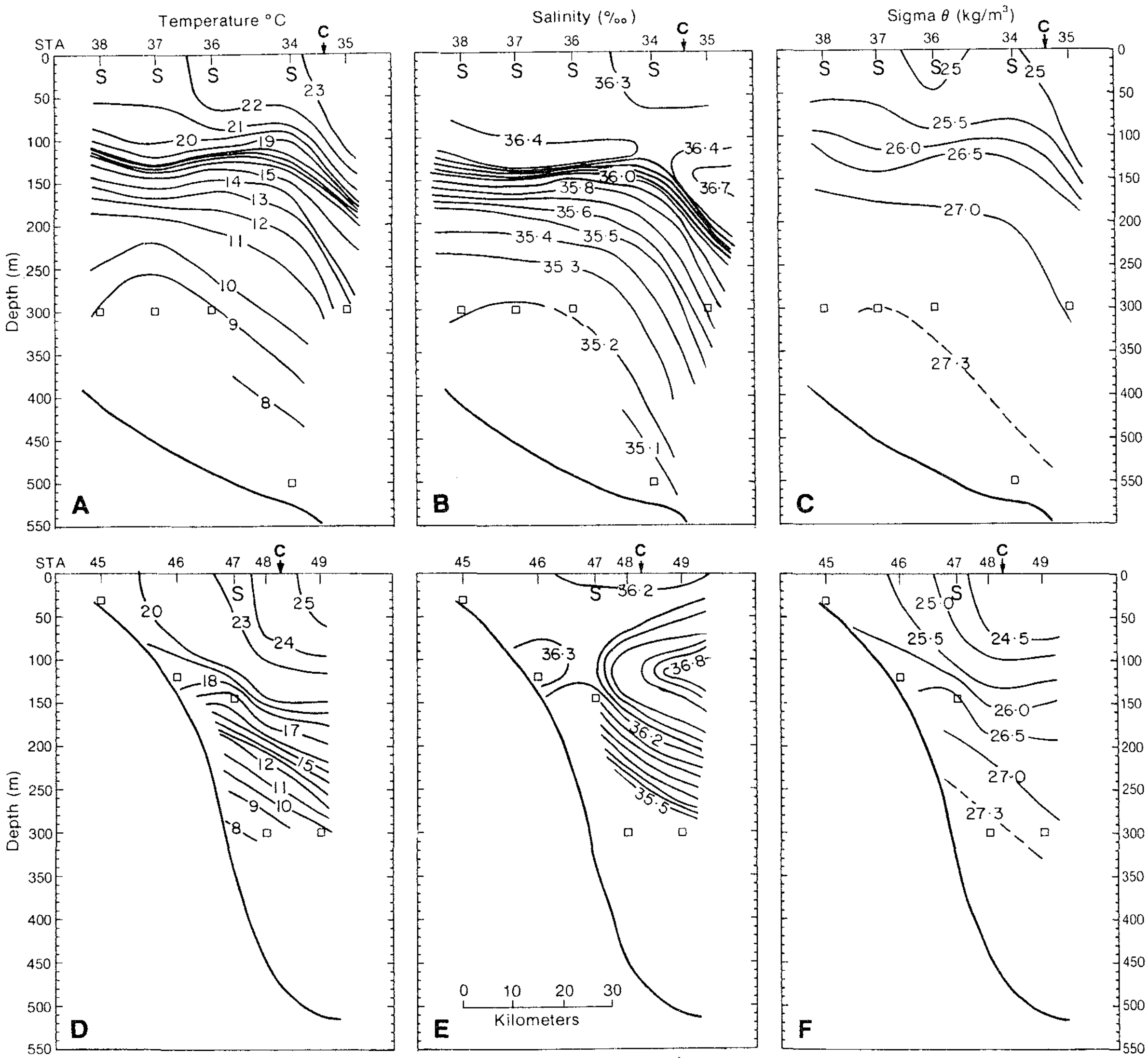

Fig. 11. Cross sections of temperature, salinity and density (sigma θ) for two sections (stations 34–38 and 45–49, Fig. 5) occupied during Leg I of the cruise. (Stations with squid catches are indicated by S and the approximate locations of the Gulf Stream core by C.)

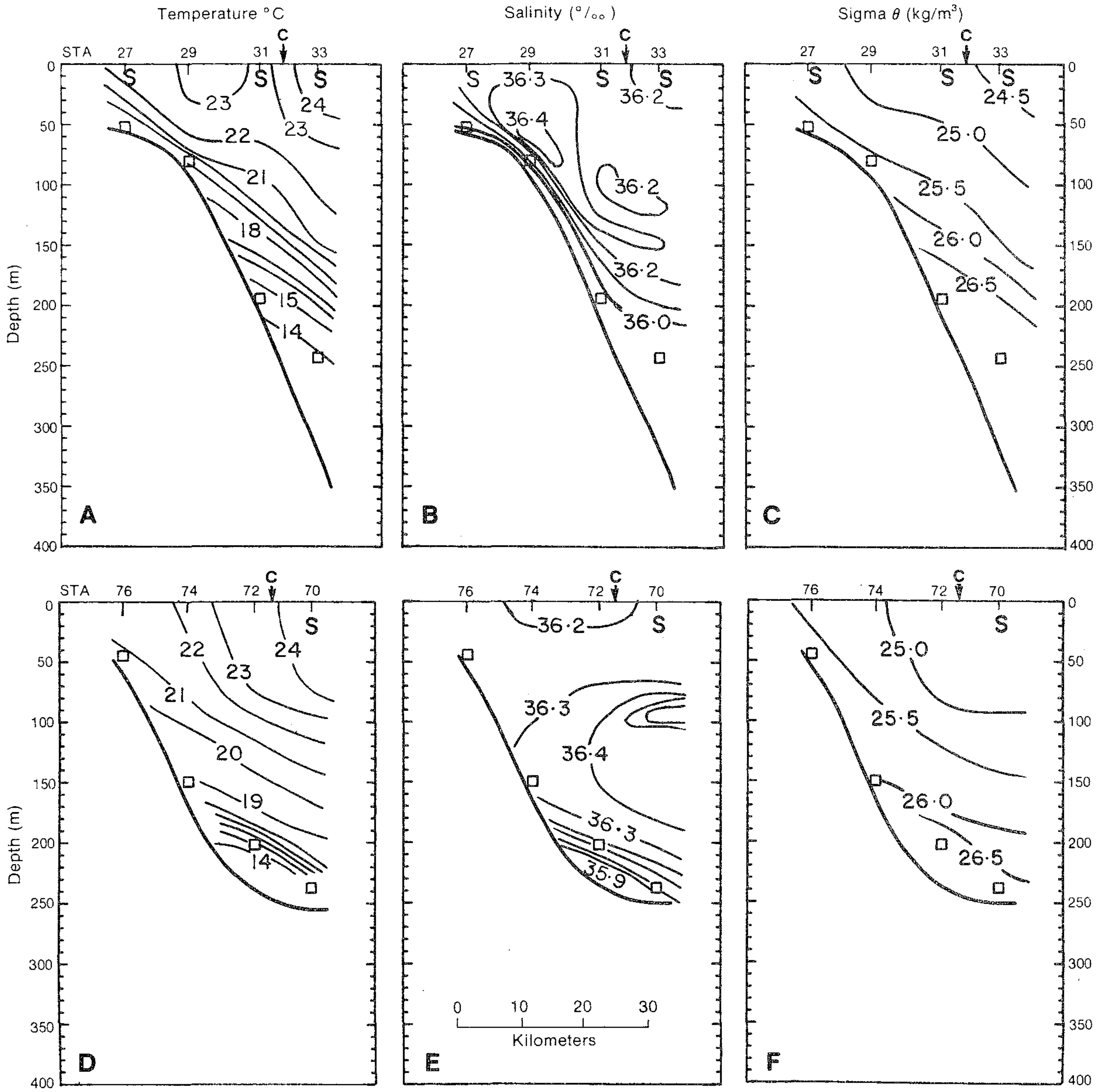

Fig. 12. Cross sections of temperature, salinity and density (sigma θ) for two sections (stations 27–33 and 70–76, Fig. 7) occupied during Leg II of the cruise. (Stations with squid catches are indicated by S and the approximate locations of the Gulf Stream core by C.)

from 35.95 to 36.45 and temperature from 19.5° to 24.5° C, but its center is approximately the same as that for the Leg I envelope. Since the sampling gear did not have opening-closing devices, it was not possible to identify the depth at which the larvae and juveniles were caught, but the close similarity of the T-S properties in the upper 50 m of the water column during both legs of the cruise indicates that most of the specimens may have been caught in the near-surface layer (0–50 m).

Temperature, salinity and density observations along two of the transects during Leg I (Fig. 11), both transects being oriented more or less perpendicular to the axis of the Gulf Stream, also confirm that the catches of larvae and juveniles were almost always shoreward of the Gulf Stream core, in the frontal zone, and were in water masses which moved in the same direction as the Gulf Stream. To be noted as well in both transects are two cores of high salinity water, centered at about 100 m. The inshore core is similar to Continental Edge Water and the offshore core to Yucatan Water. On the more northerly transect (Fig. 11, A, B, C), squid catches were at stations 34, 36, 37 and 38, which were located on the shoreward side of the Gulf Stream core. Essentially the same oceanographic features were evident on the more southerly transect (Fig. 11, D, E, F), with the squid catches on the shoreward side of the core.

During Leg II of the cruise, larvae and juveniles were captured at stations both shoreward and slightly seaward of the Gulf Stream core, as indicated in the temperature, salinity and density observations along two transects (Fig. 12) which were oriented approximately perpendicular to the axis of the Gulf Stream. From the density patterns in both transects (Fig. 12, C, F), it appears that the water masses in which squid were caught were moving in the same direction as the Gulf Stream.

Spawning events and larval broods

From the differences in size and distribution of larvae and juveniles betwen Leg I and Leg II of the cruise, it appears that the sampled populations were from different spawning events. The larvae from Leg I in early February ($\overline{x}$ = 3.8 mm ML) were presumably hatched some days or weeks earlier than their times of capture, whereas those from Leg II later in February ($\overline{x}$ =1.8 mm ML) were recently hatched and represented a new broad. The juveniles from Leg I (medians of 10.3–47.0 mm ML) and Leg II (22.0–44.5 mm ML) may have resulted from spawning at similar times but much earlier than the larvae which were taken during Leg I. By the time of Leg II, all evidence of the first larval brood(s) had disappeared, because no larvae were captured at the northern stations and all except one (3.0 mm ML) were smaller than the smallest larva (2.5 mm ML) captured during Leg I.

That spawning is protracted and is composed of a number of spawning events has been documented from the other studies. Fedulov *et al.*, (MS 1984) noted the occurrence of large numbers of juveniles (30–35 mm ML) in March 1983 and again in May of the same year. The regular appearance of groups of small squid (100–150 mm ML) in late summer on the continental shelf, particularly in the Georges Bank and adjacent areas (Mesnil, 1977; Lange and Sissenwine, MS 1981) supports the hypothesis of protracted spawning, with a number of spawning events of variable intensity.

Acknowledgements

We thank R. K. O'Dor, D. Webber, L. Coelho, D. Themelis, T. Brakoniecki and L. Van Guelpen, who participated voluntarily in the cruise, as well as G. L. Voss who was kind enough to assist in the identification of some of the larvae. Thanks also go to G. Taylor, J. Prezioso, and C. Griswald for their assistance during the cruise and to F. Budden and L. Petrie for their technical support in the preparation of the paper.

References

AMARATUNGA. T. MS 1980. Growth and maturation patterns of the short-finned squid (*Illex illecebrosus*) on the Scotian Shelf. *NAFO SCR Doc*., No. 30, Serial No. N062, 17 p.

MS 1981. Biology and distribution patterns in 1980 for squid, *Illex illecebrosus*, in Nova Scotian waters. *NAFO SCR Doc*., No. 36, Serial No. N318, 10 p.

AMARATUNGA, T., and F. BUDDEN. MS 1982. The R. V. *Lady Hammond* larval-juvenile survey, February 1982, in Subarea 4. *NAFO SCR Doc*., No. 34, Serial No. N523, 21 p.

AMARATUNGA, T., T. ROWELL, and M. ROBERGE. MS 1980. Summary of joint Canada-USSR research program on short-finned squid (*Illex illecebrosus*), 16 February to 4 June 1979: spawning stock and larval survey. *NAFO SCR Doc*., No. 38, Serial No. N069, 36 p.

ARKHIPKIN, A. I., P. P. FEDULOV, and V. V. PEROV. MS 1983. Diurnal movement of young *Illex illecebrosus* and some other cephalopods in relation to vertical water structure off the Nova Scotia Shelf. *NAFO SCR Doc*., No. 62, Serial No. N722, 20 p.

BANE, J. M., Jr., and D. A. BROOKS. 1979. Gulf Stream meanders along the continental margin from the Florida Straits to Cape Hatteras. *Geophys. Res. Lett*., **6**: 280–282.

BANE, J. M., Jr., D. A. BROOKS, and K. R. LORENSON. 1981. Synoptic observations of the three-dimensional structure and propagation of Gulf Stream meanders along the Carolina continental margin. *J. Geophys. Res*., **86**(C7): 6411–6425.

BROOKS, D. A., and J. M. BANE Jr. 1981. Gulf Stream fluctuations and meanders over the Onslow Bay upper continental slope. *J. Phys. Oceanogr*., **11**: 247–256.

CHEW, F. 1981. Shingles, spin-off eddies and an hypothesis. *Deep-Sea Res*., **28A**: 379–391.

CLARKE, M. R. 1966. A review of the systematics and ecology of oceanic squids. *Adv. Mar. Biol*., **4**: 91–300.

DAWE, E. G., and P. C. BECK. 1985. Distribution and size of short-finned squid (*Illex illecebrosus*) larvae in the Northwest Atlantic from winter surveys in 1969, 1981 and 1982. *J. Northw. Atl. Fish. Sci*., **6**: 43–55.

DAWE, E. G., and H. J. DREW. 1981. Record of a mature female short-finned squid, *Illex illecebrosus*, captured inshore at Newfoundland and previous captures of mature females in the Northwest Atlantic. *J. Northw. Atl. Fish. Sci*., **2**: 61–65.

DAWE, E. G., P. C. BECK, and H. J. DREW. MS 1981. Distribution and biological characteristics of young short-finned squid (*Illex illecebrosus*) in the Northwest Atlantic, February 20 to March 11, 1981. *NAFO SCR Doc*., No. 23, Serial No. N302, 20 p.

DAWE, E. G., P. C. BECK, H. J. DREW, and G. H. WINTERS. 1981. Long-distance migration of a short-finned squid, *Illex illecebrosus*. *J. Northw. Atl. Fish. Sci*., **2**: 75–76.

DAWE, E. G., Yu. M. FROERMAN, E. N. SHEVCHENKO, V. V. KHALYUKOV, and V. A. BOLOTOV. MS 1982. Distribution and size composition of juvenile short-finned squid (*Illex illecebrosus*) in the Northwest Atlantic in relation to mechanisms of transport, February 4–April 30, 1982. *NAFO SCR Doc*., No. 25, Serial No. N513, 41 p.

DUPOUY, H. MS 1981. Biological characteristics and biomass estimates of the squid, *Illex illecebrosus*, on the Scotian Shelf (Div. 4VWX) in late summer of 1980. *NAFO SCR Doc*., No. 38, Serial No. N320, 13 p.

DUPOUY, H., and J. P. MINET. MS 1982. Biological characteristics and biomass estimate of the squid (*Illex illecebrosus*) on the Scotian Shelf (Div. 4VWX) in late summer 1981. *NAFO SCR Doc*., No. 20, Serial No. N508, 12 p.

DURWARD, R. D., E. VESSEY, R. K. O'DOR, and T. AMARATUNGA. 1980. Reproduction in the squid, *Illex illecebrosus*: first observations in captivity and implications for the life cycle. *ICNAF Sel. Papers*, **6**: 7–13.

FEDULOV, P. P., and Yu. M. FROERMAN. MS 1980. Effect of abiotic factors on distribution of young shortfin squid, *Illex illecebrosus* (LeSueur, 1821). *NAFO SCR Doc*., No. 98, Serial No. N153, 22 p.

FEDULOV, P. P., A. I. ARKHIPKIN, E. N. SHEVCHENKO, and T. W. ROWELL. MS 1984. Preliminary results of the R/V *Gizhiga* research cruise on the short-finned squid, *Illex illecebrosus*, in NAFO Subareas 3 and 4 during March to June 1983. *NAFO SCR Doc*., No. 13, Serial No. N786, 15 p.

FROERMAN, Yu. M. MS 1980. Biomass estimates of young *Illex illecebrosus* (LeSueur, 1821) from a survey in Subareas 3 and 4 in March–April 1979. *NAFO SCR Doc*., No. 36, Serial No. N067, 16 p.

FROERMAN, Yu. M., P. P. FEDULOV, V. V. KHALYUKOV, E. N. SHEVCHENKO, and T. AMARATUNGA. MS 1981. Preliminary results of the R/V *Atlant* survey for short-finned squid, *Illex illecebrosus*, in Subarea 4 between 3 March and 4 May 1981. *NAFO SCR Doc.*, No. 41, Serial No. N323, 13 p.

FUGLISTER, F. C. 1963. Gulf Stream '60. *Progr. Oceanogr.*, **1**: 365-373.

HATANAKA, H., A. M. T. LANGE, and T. AMARATUNGA. 1985. Geographical and vertical distribution of larval short-finned squid (*Illex illecebrosus*) in the Northwest Atlantic. *NAFO Sci. Coun. Studies*, **9**: 93-99 (this volume).

HAZELWORTH, J. B. 1976. Oceanographic variations across the Gulf Stream off Charleston, South Carolina, during 1965 and 1966. *U.S. Dept. Commerce, NOAA Tech. Rep.*, ERL 383, AOML 25, 73 p.

HURLEY, G. V., P. BECK, J. DREW, and R. L. RADTKE. MS 1979. A preliminary report on validating age readings from statoliths of the short-finned squid (*Illex illecebrosus*). *ICNAF Res. Doc.*, No. 26, Serial No. 5352, 6 p.

ISELIN, C. O'D. 1936. A study of the circulation of the western North Atlantic. *Pap. Phys. Oceanogr.*, **4**(4): 1-61.

KIRWAN, A. D., G. McNALLY, and J. COELHO. 1976. Gulf Stream kinematics inferred from a satellite-tracked drifter. *J. Phys. Oceanogr.*, **6**: 750-755.

KNAUSS, J. A. 1969. A note on the transport of the Gulf Stream. *Deep-Sea Res.*, **16**(suppl.): 117-123.

KOELLER, P. A. MS 1980. Distribution, biomass and length frequencies of squid (*Illex illecebrosus*) in Divisions 4TVWX from Canadian research vessel surveys: an update for 1979. *NAFO SCR Doc.*, No. 17, Serial No. N049, 11 p.

LANGE, A. M. T. MS 1980. The biology and population dynamics of the squids, *Loligo pealei* (LeSueur) and *Illex illecebrosus* (Lesueur), from the Northwest Atlantic. M.Sc. Thesis, University of Washington, Seattle, Wash., 178 p.

LANGE, A. M. T., and M. P. SISSENWINE. MS 1981. Evidence of summer spawning of *Illex illecebrosus* (Lesueur) off the northeastern United States. *NAFO SCR Doc.*, No. 33, Serial No. N315, 17 p.

1983. Squid resources of the Northwest Atlantic. *In* Advances in assessment of world cephalopod resources (p. 21-54), J. F. Caddy (ed.), *FAO Fish. Tech. Pap.*, **231**: 452 p.

LEE, T. N., and E. WADDELL. 1983. On Gulf Stream variability and meanders over the Blake Plateau at 30° N. *J. Geophys. Res.*, **88**(C8): 4617-4631.

LEE, T. N., L. P. ATKINSON, and R. LEGECKIS. 1981. Observations of a Gulf Stream frontal eddy on the Georgia continental shelf, April 1977. *Deep-Sea Res.*, **28A**: 347-378.

LEGECKIS, R. V. 1979. Satellite observations of the influence of bottom topography on the seaward deflection of the Gulf Stream off Charleston, South Carolina. *J. Phys. Oceanogr.*, **9**: 483-497.

LIPINSKI, M. MS 1978. The age of squids, *Illex illecebrosus* (LeSueur), from their statoliths. *ICNAF Res. Doc.*, No. 15, Serial No. 5167, 4 p.

MERCER, M. C. 1969a. *A. T. Cameron* Cruise 130, otter-trawl survey from southern Nova Scotia to Cape Hatteras, March-April 1967. *Fish. Res. Board Can. Tech. Rep.*, **103**: 24 p.

1969b. *A. T. Cameron* Cruise 150, otter-trawl survey of the Mid-Atlantic Bight, August-September 1968. *Fish. Res. Board Can. Tech. Rep.*, **122**: 47 p.

1970. *A. T. Cameron* Cruise 157, otter-trawl survey of the southwestern North Atlantic, February 1969. *Fish. Res. Board Can. Tech. Rep.*, **199**: 66 p.

MS 1973. Distribution and biological characteristics of the ommastrephid squid *Illex illecebrosus* (LeSueur) on the Grand Bank, St. Pierre Bank and Nova Scotia Shelf (Subareas 3 and 4). as determined by otter-trawl surveys, 1970-1972. *ICNAF Res. Doc.*, No. 79, Serial No. 3031, 11 p.

MESNIL, B. 1977. Growth and life cycle of squid, *Loligo pealei* and *Illex illecebrosus*, from the Northwest Atlantic. *ICNAF Sel. Papers*, **2**: 55-69.

MOHN, R. K. MS 1981. Abiotic factors relating to squid abundance as determined from groundfish cruises, 1970-1980. *NAFO SCR Doc.*, No. 34, Serial No. N316, 11 p.

NOWLIN, W. D. Jr. 1971. Water masses and general circulation of Gulf of Mexico. Oceanology International, Feb. 1971, p. 28-33.

O'DOR, R. K. 1983. *Illex illecebrosus*. *In* Cephalopod life cycles (vol. 1, p. 175-199), P. R. Boyle (ed.), Academic Press, New York, N.Y., 475 p.

O'DOR, R. K., and R. D. DURWARD. 1979. A preliminary note on *Illex illecebrosus* larvae hatched from eggs spawned in captivity. *Proc. Biol. Soc. Wash.*, **91**: 1076-1078.

O'DOR, R. K., N. BALCH, and T. AMARATUNGA. MS 1982. Laboratory observations of midwater spawning by *Illex illecebrosus*. *NAFO SCR Doc.*, No. 5, Serial No. N493, 7 p.

O'DOR, R. K., E. VESSEY, and T. AMARATUNGA. MS 1980. Factors affecting fecundity and larval distribution in the squid *Illex illecebrosus*. *NAFO SCR Doc.*, No. 39, Serial No. N070, 9 p.

O'DOR, R. K., N. BALCH, E. A. FOY, R. W. M. HIRTLE, D. A. JOHNSTON, and T. AMARATUNGA. 1982. Embryonic development of squid, *Illex illecebrosus*, and the effect of temperature on development rates. *J. Northw. Atl. Fish. Sci.*, **3**: 41-45.

OKUTANI, T. 1983. *Todarodes pacificus*. *In* Cephalopod life cyles. (vol. 1, p. 201-204), P. R. Boyle (ed.), Academic Press, New York, N. Y., 475 p.

PARR, A. E. 1937. Report on hydrographic observations at a series of anchor stations across the Straits of Florida. *Bull. Bingham Oceanogr. Coll.*, **6**(3): 1-61.

POULARD, J. C., T. W. ROWELL, and J. P. ROBIN. MS 1984. Biological characteristics and biomass estimates of the squid (*Illex illecebrosus*) on the Scotian Shelf (Div. 4VWX) in late summer, 1983. *NAFO SCR Doc.*, No. 71, Serial No. N860, 14 p.

RATHJEN, W. F. 1981. Exploratory squid catches along the eastern United States continental slope. *J. Shellfish Res.*, **1**: 153-159.

RICHARDSON, W. S., W. J. SCHMITZ Jr., and P. P. MILLER. 1969. The velocity structure of the Florida Current from the Straits of Florida to Cape Fear. *Deep-Sea Res.*, **16**(suppl.): 225-231.

ROPER, C F. E., and C. C. LU. 1979. Rhynchoteuthion larvae of ommastrephid squids of the western North Atlantic, with a first description of larvae and juveniles of *Illex illecebrosus*. *Proc. Biol. Soc. Wash.*, **91**: 1039-1059.

ROWELL, T. W., and J. H. YOUNG. MS 1984. Update of the distribution, biomass and length frequencies of *Illex illecebrosus* in Divisions 4VWX from Canadian research vessel surveys, 1970-1983. *NAFO SCR Doc.*, No. 69, Serial No. N858, 12 p.

SAMEOTO, D. D., and L. O. JAROSZYNSKI. 1969. Otter surface sampler: a new neuston net. *J. Fish. Res. Board Can.*, **26**: 2240-2244.

SMITH, P. E., and S. L. RICHARDSON. 1977. Standard techniques for pelagic fish egg and larval surveys. *FAO Fish. Tech. Pap.*, No. 175: 100 p.

SQUIRES, H. J. 1957. Squid, *Illex illecebrosus* (Lesueur), in the Newfoundland fishing area. *J. Fish. Res. Board Can.*, **14**: 693-728.

1967. Growth and hypothetical age of the Newfoundland bait squid, *Illex illecebrosus illecebrosus*. *J. Fish. Res. Board Can.*, **24**: 1209-1217.

STOMMEL, H. 1965. The Gulf Stream. University of California Press, Berkeley, Calif., 248 p.

TRITES, R. W. 1983. Physical oceanographic features and processes relevant to *Illex illecebrosus* spawning in the western North Atlantic and subsequent larval distribution. *NAFO Sci. Coun. Studies*, **6**: 39-55.

VECCHIONE, M. 1979. Larval development of *Illex* (Steenstrup, 1880) in the northwestern Atlantic, with comments on *Illex* larval distribution. *Proc. Biol. Soc. Wash.*, **91**: 1060-1074.

VERRILL, A. E. 1882. Report of cephalopods in the northeastern coast of America. *Rep. U.S. Comm. Fish.*, 1879: 211-455.

WEBSTER, F. 1961. A description of Gulf Stream meanders off Onslow Bay. *Deep-Sea Res.*, **18**: 130-143.

WENNEKENS, M. P. 1959. Water mass properties of the Straits of Florida and related waters. *Bull. Mar. Sci.*, **9**(1): 1-52.

WORTHINGTON, L. V. 1954. Three detailed cross-sections of the Gulf Stream. *Tellus*, **VI**: 116-123.

1976. On the North Atlantic circulation. John Hopkins Univ. Press, Baltimore, MD, 110 p.

WUST, G. 1964. Stratification and circulation in the Antillean-Caribbean Basin. I. Spreading and mixing of the water types, with an oceanographic atlas. Columbia University Press, N.Y., 201 p.