DISTRIBUTION AND SIZE OF JUVENILE SHORT-FINNED SQUID (ILLEX ILLECEBROSUS) (MOLLUSCA : CEPHALOPODA) SOUTH OF NEWFOUNDLAND DURING WINTER

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DISTRIBUTION AND SIZE OF JUVENILE SHORT-FINNED SQUID *(ILLEX ILLECEBROSUS)* (MOLLUSCA : CEPHALOPODA) SOUTH OF NEWFOUNDLAND DURING WINTER

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SQUID
DISTRIBUTION
SIZE
GULF STREAM SYSTEM

ABSTRACT. — The distribution of juvenile short-finned squid (*Illex illecebrosus*) in relation to water masses was examined from surveys carried out during February-March of 1981, 1982, 1984 and 1985. The pattern of juvenile squid distribution was somewhat variable among years but overall, juveniles were most abundant within either the northern Gulf Stream or Slope Water. They were only occasionally caught within the most seaward portion of the Gulf Stream or Sargasso Sea. Size distributions were consistent among years in showing a distinct increase in mean mantle length from the Gulf Stream landward toward the cooler water masses. Smallest juveniles for all years were those collected near the core of the Gulf Stream in 1981, supporting the proposed importance of the Gulf Stream in initial dispersal of young stages from an upstream spawning site.

CALMAR
DISTRIBUTION
DIMENSION
SYSTÈME DU COURANT DU GOLFE

RÉSUMÉ. — Distribution des Calmars juvéniles (*Illex illecebrosus*) pendant l'hiver. La distribution des Calmars juvéniles à nageoires courtes (*Illex illecebrosus*) par rapport aux masses d'eaux a été examinée à partir d'une étude réalisée au cours des mois de février et mars 1981, 1982, 1984 et 1985. La distribution semble varier quelque peu au cours des différentes années, mais en général les Calmars juvéniles sont plus abondants à l'intérieur du courant du golfe et du talus continental. Les Calmars juvéniles sont rarement capturés dans les zones situées au large du courant du golfe et de la mer des Sargasses. La répartition des dimensions est constante entre les années et indique une augmentation de la moyenne de la longueur du manteau allant du courant du golfe vers l'intérieur des masses d'eaux froides. Durant les quatre années étudiées les Calmars juvéniles les plus petits ont été capturés près de la partie centrale du courant du golfe en 1981, confirmant ainsi l'importance du courant du golfe pour la dispersion des juvéniles à partir du site de ponte.

INTRODUCTION

Although the exact northern and southern limits of distribution of *Illex illecebrosus* remain uncertain, the species is known to range between central Florida in the south and Newfoundland and Labrador waters in the north (Roper *et al.*, 1969; Lu 1973). Longevity is believed to be about one year (Hurley and Beck, 1979; Dawe *et al.*, 1985), with the major spawning period occuring in January-February (Squires, 1967; Hatanaka *et al.*, 1985; Dawe and Beck, 1985). Short-finned squid move from off-shelf waters onto the continental shelf in spring and are fished commercially, off the northeastern United States, on the Nova Scotian Shelf, and at Newfoundland during July to November.

Larval and small juvenile stages of *Illex* sp. were first described by Roper and Lu (1979) and since 1979 many surveys directed for these young stages have been carried out within the January-May period in the Gulf Stream and associated water masses (Fedulov and Froerman, 1980; Froerman *et al.*, 1981, Amaratunga 1981; Dawe *et al.*, 1982; Dawe and Beck, 1985; Hatanaka *et al.*, 1982, 1985; Arkhipkin *et al.*, 1983; Fedulov *et al.*, 1984; Rowell *et al.*, 1985). Based on laboratory experiments (O'Dor and Durward, 1978; O'Dor *et al.*, 1982; O'Dor and Balch, 1985) and the observed pattern of larval distribution (Hatanaka *et al.*, 1985; Dawe and Beck, 1985; Rowell *et al.*, 1985), it is felt that spawning probably occurs south of Cape Hatteras in close proximity to the Gulf Stream, which probably serves as the mechanism for dispersal of young stages (Trites, 1983). Larvae are most abundant in the northern part of the Gulf Stream or at the Gulf Stream frontal zone (Hatanaka *et al.*, 1985; Dawe and Beck, 1985) and, whereas newly-hatched larvae have been collected south of Cape Hatteras (Dawe and Beck, 1985; Rowell *et al.*, 1985), only more advanced larvae have been captured further to the northeast (Roper and Lu, 1979; Vecchione, 1979; Hatanaka *et al.*, 1985; Dawe and Beck, 1985).

The transformation from the larval to juvenile stage, which is characterized by separation of the fused tentacles, occurs within the 6-8 mm mantle length (ML) size range (Roper and Lu, 1979; Vecchione, 1979). Juveniles appear to be most abundant within the upper 100 m (Fedulov and Froerman, 1980; Hatanaka *et al.*, 1982; Froerman *et al.*, 1981) and there is some evidence of a diel vertical migration (Arkhipkin *et al.*, 1983). Depth distribution apparently varies somewhat and it has been reported that greatest juvenile abundance is in nutrient-rich waters above the oxygen minimum (Fedulov and Froerman, 1980).

In this paper, juvenile *Illex illecebrosus* areal distribution in relation to water masses is described from four surveys carried out within the Gulf Stream System south of Newfoundland during February-March of 1981, 1982, 1984 and 1985. The distribution of juvenile size-groups among water masses is also examined. Findings from surveys described here are compared with those from other surveys carried out since 1979. Relevant oceanographic features have been briefly reviewed by Trites (1983) and Dawe and Beck (1985) but more elaborate descriptions of the Gulf Stream System have been provided by other investigators (Iselin 1936; McLellan 1957; Stommel 1958; Gatien 1976; Worthington 1976; Fofonoff 1981).

MATERIALS AND METHODS

All four surveys were carried out aboard the Canadian research vessel GADUS ATLANTICA. The survey period, during February-March, was similar among years but survey design and sampling methodology varied considerably among surveys (Table 1). During all surveys midwater trawling was carried out along transects which extended true south, approximately normal to the general direction of Gulf Stream flow (Fig. 1). During the 1981 survey, sets were executed at several depths on each station whereas in later surveys sets were consistently at a depth of 100 m for 30 minutes each. It is recognized that juveniles may have been caught during retrieval of the trawl and so catches may have occured anywhere in the water column from the maximum depth to the surface. Therefore depth distribution of juveniles will not be addressed here.

Midwater trawls used to sample juveniles varied among surveys (Table 1). Initially during 1981 a

Table 1. — Summary of time, area and methods of sampling juvenile *Illex illecebrosus* during surveys carried out between 1981 and 1985

Year	Dates	Longitude range	Sampling Gear: Type	Liner mesh size (mm)	Depth (m)	No. sets
1981 :	21 Feb-6 Mar	56°W-50°W	Engels 400 mesh	15.0	100	6
			Midwater trawl (EMT-400)		300	6
					500	1
			Engels 80	12.0	100	15
			Midwater trawl (EMT-80)		300	16
					500	7
					1,000	7
1982 :	21 Feb-23 Feb	56°W	Engels 80	12.0	100	10
			Midwater trawl (EMT-80)			
1984 :	24 Feb-9 Mar	55°W-57°30'W	Diamond IX			
			Midwater trawl	12.0	100	57
1985 :	22 Feb -10 mar	55°-60°W	Diamond IX	12.0	100	95
			Midwater trawl			

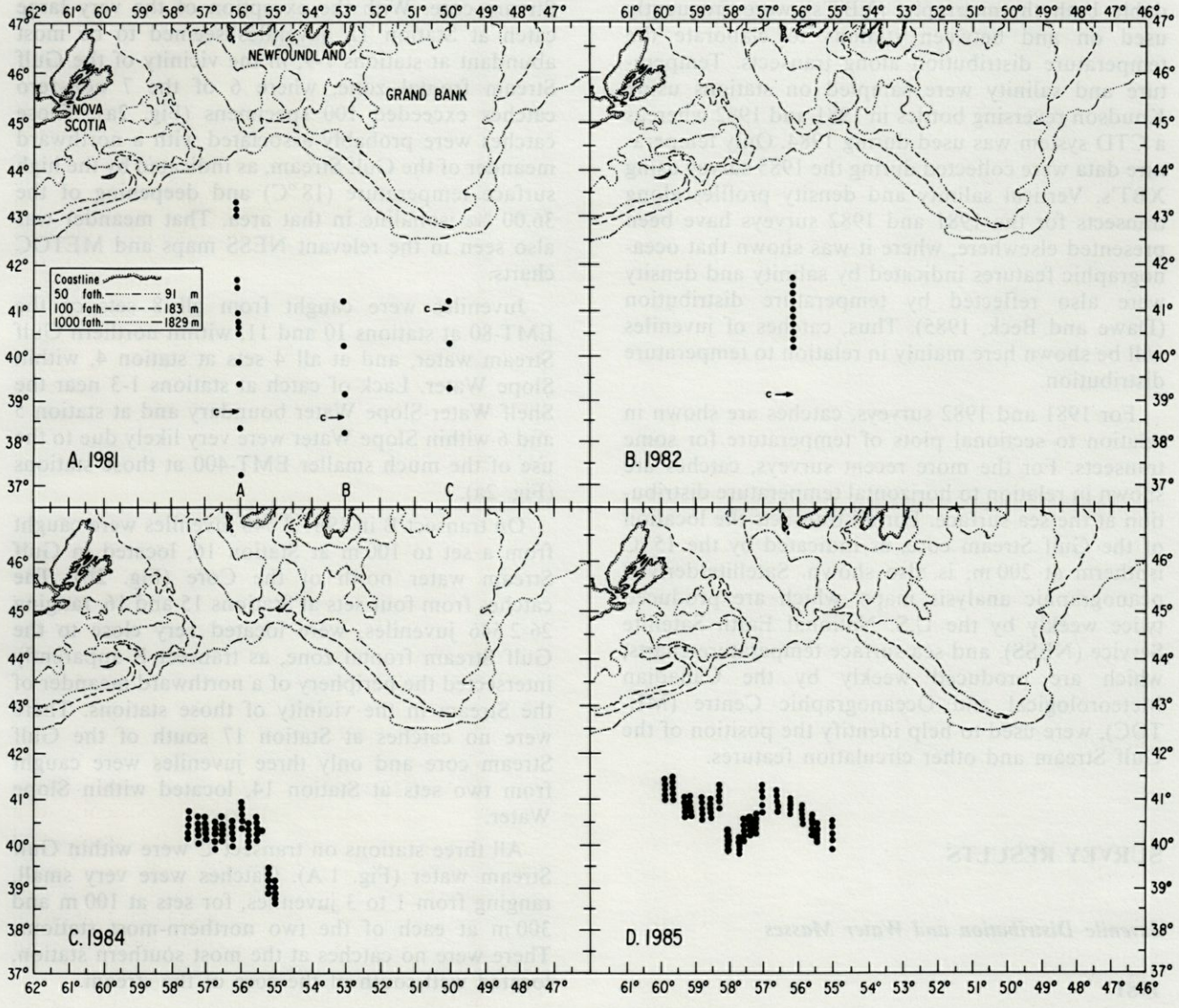


Fig. 1. — Location of stations on transects for surveys during February 21-March 6, 1981 (A), February 21-23, 1982 (B), February 24-March 9, 1984 (C) and February 22-March 10, 1985 (D). 'C' denotes the location of the Gulf Stream core on transects for 1981 and 1982.

small trawl, an Engels 400 mesh midwater trawl (EMT-400) was used but after 13 sets it had not succeeded in capturing any juveniles so the much larger Engels-80 midwater trawl (EMT-80) was used for the duration of the survey. That trawl was also used during the 1982 survey, but after 10 sets it became damaged beyond repair and midwater trawling was discontinued. It was concluded that the EMT-80 was impractical for extensive sampling due to its large size and so a Diamond IX midwater trawl was used during 1984 and 1985 surveys (Table 1).

Surveys in 1981 and 1982 were exploratory, sampling few transects but several water masses. The 1984 and 1985 surveys were aimed at developing an index of juvenile abundance based on catch rates. Toward that end the latter surveys sampled from the northern Gulf Stream northward toward the Shelf Water along randomly placed transects with five stations randomly placed on each transect. The 1981 survey sampled transects in the west to east direction, whereas the reverse was true for the 1985 survey. In 1984 every second transect was occupied while proceeding east to west during February 24-March 4 with the others being sampled during March 4-9 as the vessel returned, proceeding eastward across the survey area. Juvenile *Illex illecebrosus* were measured in dorsal mantle length to the nearest millimeter. Where catches were very large, a minimum of 100 specimens per station were measured.

Methods of oceanographic sampling also varied among the four surveys. During all surveys expen-

dable bathythermographs (XBT's) were frequently used on and between stations to elaborate the temperature distribution along transects. Temperature and salinity were sampled on stations using Knudson reversing bottles in 1981 and 1982 whereas a CTD system was used during 1984. Only temperature data were collected during the 1985 survey using XBT's. Vertical salinity and density profiles along transects for the 1981 and 1982 surveys have been presented elsewhere, where it was shown that oceanographic features indicated by salinity and density were also reflected by temperature distribution (Dawe and Beck, 1985). Thus, catches of juveniles will be shown here mainly in relation to temperature distribution.

For 1981 and 1982 surveys, catches are shown in relation to sectional plots of temperature for some transects. For the more recent surveys, catches are shown in relation to horizontal temperature distribution at the sea surface. For all transects the location of the Gulf Stream core, as indicated by the 15 °C isotherm at 200 m, is also shown. Satellite-derived ocanographic analysis maps, which are produced twice weekly by the U.S. National Earth Satellite Service (NESS), and sea surface temperature charts, which are produced weekly by the Canadian Meteorological and Oceanographic Centre (METOC), were used to help identify the position of the Gulf Stream and other circulation features.

SURVEY RESULTS

Juvenile Distribution and Water Masses

1981

For transects A and B sampled during the 1981 survey (Fig. 1 A), catches at maximum depth of tows are shown in relation to sectional plots of temperature in Fig. 2 and 3. The 35.00 ‰ isohaline is overlain to indicate the approximate position of the Shelf Water-Slope Water frontal zone, whereas the 36.00 ‰ isohaline outlines the distribution of Gulf Stream water.

For transect A (56°W, Fig. 2a) station positions were assigned relative to the 100 m sets only, since in some cases set positions for greater depths deviated from the station locations shown due to navigation problems. Juveniles were caught on Transect A in Slope Water and northern Gulf Stream water. The largest catch (3 462 individuals) was from a 100 m set at Station 12, very close to the Gulf Stream core of maximum surface velocity, where salinity exceeded 36.00 ‰ in the upper 200 m. Juveniles were caught from three of the four sets at that station but were not caught from any of the four sets at Station 13, located well south of the Gulf Stream core. With the exception of the very large catch at Station 12, juveniles seemed to be most abundant at stations 7-9, in the vicinity of the Gulf Stream frontal zone, where 6 of the 7 non-zero catches exceeded 100 specimens (Fig. 2a). Those catches were probably associated with a northward meander of the Gulf Stream, as indicated by the high surface temperature (18 °C) and deepening of the 36.00 ‰ isohaline in that area. That meander was also seen in the relevant NESS maps and METOC charts.

Juveniles were caught from all 8 sets of the EMT-80 at stations 10 and 11, within northern Gulf Stream water, and at all 4 sets at station 4, within Slope Water. Lack of catch at stations 1-3 near the Shelf Water-Slope Water boundary and at station 5 and 6 within Slope Water were very likely due to the use of the much smaller EMT-400 at those stations (Fig. 2a).

On transect B in 1981 2 546 juveniles were caught from a set to 100 m at Station 16, located in Gulf Stream water north of the Core (Fig. 2b). The catches from four sets at Stations 15 and 16, ranging 26-2 546 juveniles, were located very close to the Gulf Stream frontal zone, as transect B apparently intersected the periphery of a northward meander of the Stream in the vicinity of those stations. There were no catches at Station 17 south of the Gulf Stream core and only three juveniles were caught from two sets at Station 14, located within Slope Water.

All three stations on transect C were within Gulf Stream water (Fig. 1 A). Catches were very small, ranging from 1 to 3 juveniles, for sets at 100 m and 300 m at each of the two northern-most stations. There were no catches at the most southern station, located well south of the core of the stream.

1982

Only 10 stations were sampled using the EMT-80 during 1982, along a transect located at 56 °W (Fig. 1 B). All stations were located north of the Gulf Steam (Fig. 3). They extended from Shelf Water in the north (stations 1-4), through Slope Water (stations 5-9), to the periphery of a warm-core eddy. Catches occurred within Shelf Water and in association with the eddy periphery (station 10), but were greatest within Slope Water near the eddy periphery, ranging from 32 to 438 individuals at stations 7-9.

1984

For the 1984 survey station locations and catches are shown in relation to temperature distribution at sea surface (Fig. 4). No juveniles were caught during February 24-March 4 as the vessel sampled transects while proceeding westward (Fig. 4 aA). While returning eastward during March 4-9 (Fig. 4 aB), only

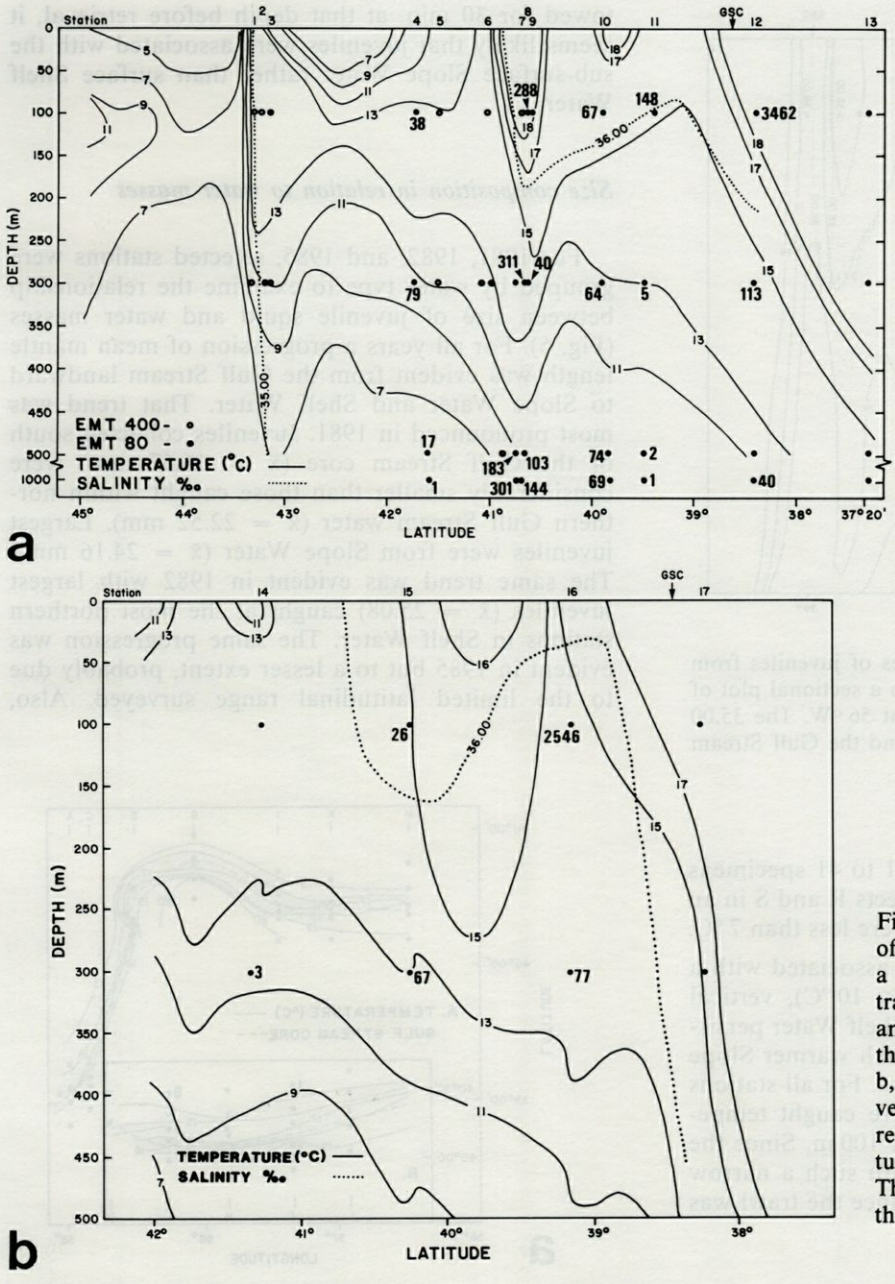


Fig. 2. — a, Location of sets and catches of juveniles during 1981 in relation to a sectional plot of temperature for transect A, located at 56 °W. The 35.00 and 36.00 ‰ isohalines are overlain and the Gulf Stream Core is labelled GSC. b, Location of sets and catches of juveniles from the EMT-80 during 1981 in relation to a sectional plot of temperature for transect B, located at 53 °W. The 36.00 ‰ isohaline is overlain and the Gulf Stream Core is labelled GSC.

8 juveniles were collected. A single specimen was caught south of the Gulf Stream core on transect J. The other 7 specimens were collected at two stations in Slope Water, where the temperature was 13 °C at the surface.

1985

During February 22-March 10, 1985 a section of the Gulf Stream System was surveyed between 55 °W and 60 ° (Fig. 4b). Only two juveniles were caught (transects C, D) within Slope Water, during February 22-March 1 between 55 °W and 57°08'W. However, later in the survey and to the west catches increased in magnitude and frequency. Also to the west, Shelf Water with temperature of less than 10 °C was prominent at surface (Fig. 4b). In that area, surface Shelf Water was in close proximity to the Gulf Stream, to the extent that the Slope Water at surface was generally characterized by a narrow band. Catches of 1-4 juveniles occurred at each of six stations within or very close to the Gulf Stream core on transects I, O, P, Q, and S (Fig. 4b) Some larger catches occurred in Slope Water, ranging from 1 to 19 juveniles on transects P, Q, and S. However, largest and most frequent catches occurred at stations where Shelf Water of less than 10 °C was present at surface. Catches associated with

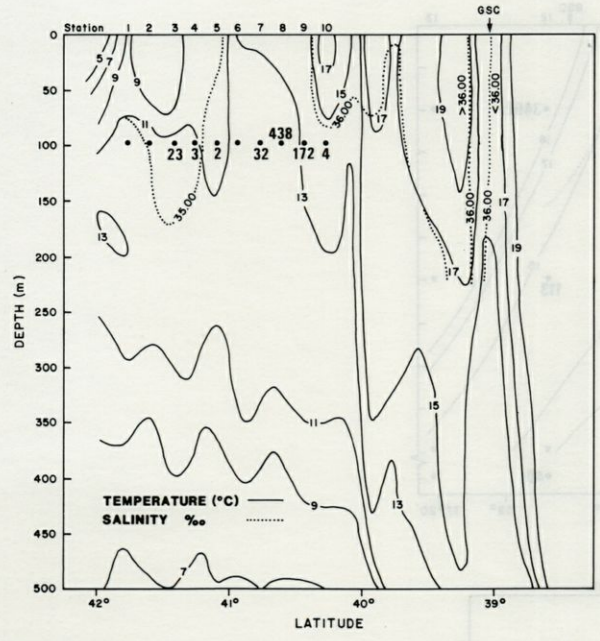


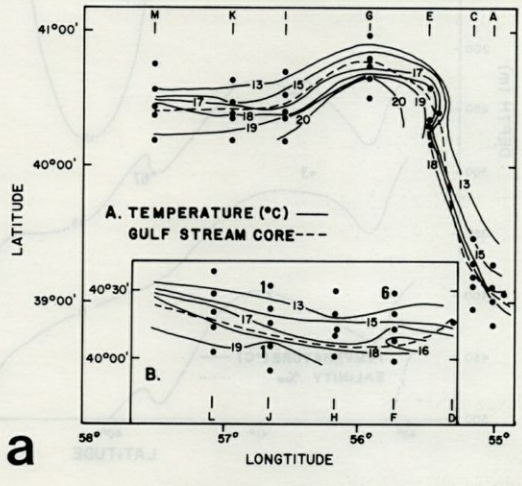
Fig. 3. — Location of sets and catches of juveniles from the EMT-80 during 1982 in relation to a sectional plot of temperature for the transect located at 56 °W. The 35.00 and 36.00 ‰ isohalines are overlain and the Gulf Stream Core is labelled GSC.

surface Shelf Water ranged from 1 to 41 specimens and were especially large on transects R and S in an area where surface temperatures were less than 7 °C.

Although greatest catches were associated with a region of surface Shelf Water (< 10 °C), vertical temperature profiles showed that Shelf Water persisted only to depths of 10-60 m. Much warmer Slope Water was evident at greater depths. For all stations where more than 5 specimens were caught temperatures ranged only 11.3-14.9 °C at 100 m. Since the largest catches were associated with such a narrow temperature range at 100 m, and since the trawl was towed for 30 min. at that depth before retrieval, it seems likely that juveniles were associated with the sub-surface Slope Water rather than surface Shelf Water.

Size composition in relation to water masses

For 1981, 1982, and 1985, selected stations were grouped by water type to examine the relationship between size of juvenile squid and water masses (Fig. 5). For all years a progression of mean mantle length was evident from the Gulf Stream landward to Slope Water and Shelf Water. That trend was most pronounced in 1981. Juveniles collected south of the Gulf Stream core ($\bar{x}$ = 16.57 mm) were considerably smaller than those caught within northern Gulf Stream water ($\bar{x}$ = 22.52 mm). Largest juveniles were from Slope Water ($\bar{x}$ = 24.16 mm). The same trend was evident in 1982 with largest juveniles ($\bar{x}$ = 25.08) caught at the most northern stations in Shelf Water. The same progression was evident in 1985 but to a lesser extent, probably due to the limited latitudinal range surveyed. Also,



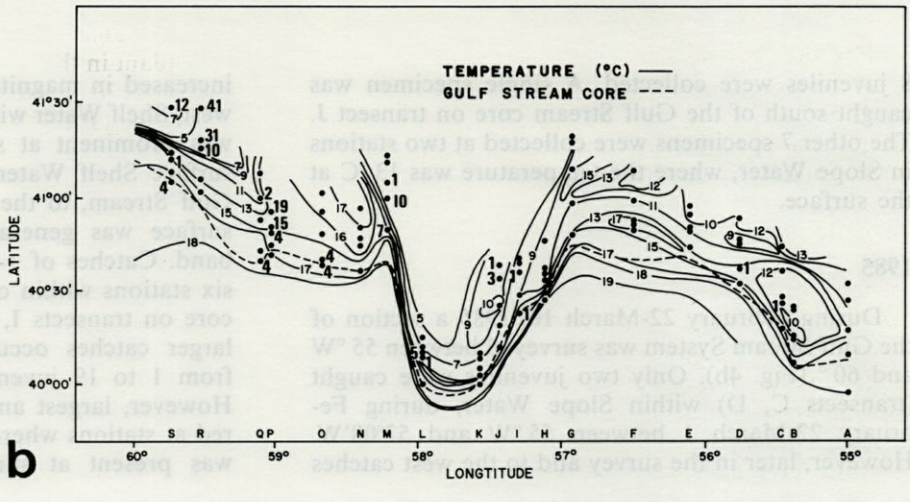


Fig. 4. — a, Location of stations on transects and catches of juveniles during 1984 in relation to surface temperature distribution as the vessel proceeded westward during February 24-March 4 (A) and as it returned eastward during March 4-9 (B, inset). b, Location of stations on transects and catches of juveniles during February 22-March 10, 1985 in relation to surface temperature distribution.

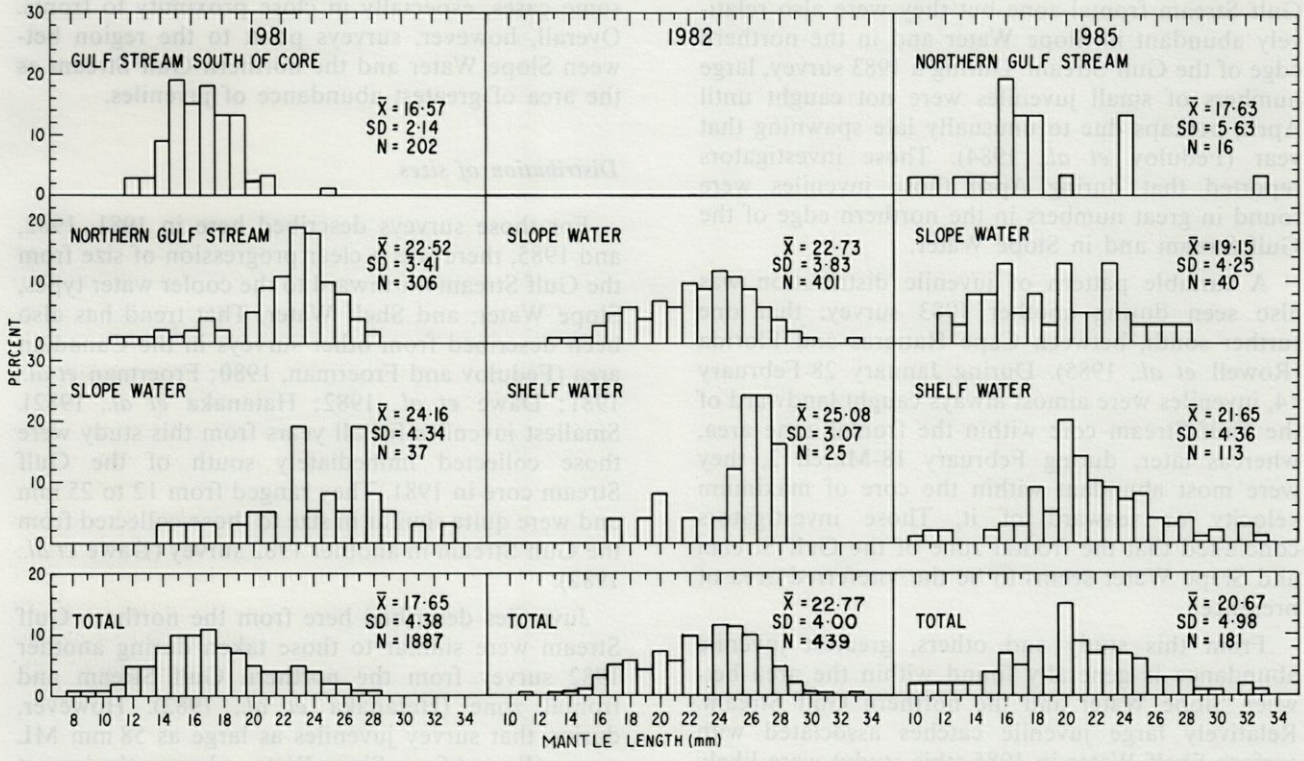


Fig. 5. — Length frequency distributions of juveniles for select stations by water mass and for total juveniles for each year; 1981 (A). 1982 (B) and 1985 (C).

juveniles associated with surface Shelf Water ($\bar{x}$ = 21.65 mm) were likely caught within sub-surface Slope Water. Mantle length ranges for total of juveniles were similar among years, overall ranging from 7 to 42 mm but for all years most juveniles were within the 8-33 mm length range (Fig. 5).

DISCUSSION

Juvenile distribution and water masses

For the four survey years overall, juvenile *Illex* were present in most water masses including the Gulf Stream, both north and south of the core of maximum velocity, Slope Water, Shelf Water, and in the periphery of a warm core eddy. Although the distribution pattern differed among years, greatest juvenile abundance was generally within northern Gulf Stream water, including northward meanders of the stream, or Slope Water immediately north of the stream. These water masses, collectively, include the relatively narrow Gulf Stream frontal zone.

Results of other surveys also describe somewhat conflicting distribution patterns of juveniles with certain similarities to those described here. Those surveys have generally indicated that juveniles are found in most water masses, including warm core eddies, Shelf Water, Slope Water, and the Gulf Stream (Dawe *et al.*, 1982; Fedulov *et al.*, 1984), but Hatanaka *et al.* (1982) reported that during January 16-March 5, 1982 juveniles were not found in the central Gulf Stream or the Sargasso Sea.

From the earliest such survey in Canadian waters during March 10-April 13, 1979 Fedulov and Froerman (1980) reported that juvenile *Illex* were most abundant in Slope Water and that the northern edge ot the Gulf Stream represents the seaward limit of their area of distribution. However, they noted that maximum abundance was associated with salinities of 35.80-36.25 ‰, indicating that juveniles were also abundant in the northern Gulf Stream where salinity exceeds 36.00 ‰. From a survey during March 3-May 4, 1981 Froerman *et al.* (1981) concluded that greatest juvenile abundance was within Slope Water in a zone 50-70 miles wide, close to the northern edge of the Gulf Stream. Within the same general area during a February 4-April 30, 1982 survey, abundance was also greatest within Slope Water, as well as the periphery of warm core eddies (Dawe *et al.*, 1982). Warm core eddies are derived from northward meanders of the Gulf Stream and peripheral areas of eddies are quite similar to the Gulf Stream frontal zone. From another 1982 survey (January 16-March 5), Hatanaka *et al.*, 1982 concluded that *Illex* juveniles were most abundant at the

Gulf Stream frontal zone but they were also relatively abundant in Slope Water and in the northern edge of the Gulf Stream. During a 1983 survey, large numbers of small juveniles were not caught until April, perhaps due to unusually late spawning that year (Fedulov *et al.*, 1984). Those investigators reported that during April those juveniles were found in great numbers in the northern edge of the Gulf Stream and in Slope Water.

A variable pattern of juvenile distribution was also seen during another 1983 survey, that one further south, between Cape Hatteras and Florida (Rowell *et al.*, 1985). During January 28-February 14, juveniles were almost always caught landward of the Gulf Stream core within the frontal zone area, whereas later, during February 18-March 2, they were most abundant within the core of maximum velocity or seaward of it. Those investigators concluded that the frontal zone of the Gulf Stream and Slope Water seems to be the 'preferred area of presence'.

From this study and others, greatest juvenile abundance is generally found within the area between Slope Water and the northern Gulf Stream. Relatively large juvenile catches associated with surface Shelf Water in 1985 (this study) were likely derived from sub-surface Slope Water, as also found by other investigators (Fedulov *et al.*, 1984; Hatanaka *et al.*, 1982; Arkhipkin *et al.*, 1983). However, later in spring (May-June), larger juveniles concentrate in Shelf Water and at the Shelf Water-Slope Water frontal zone (Fedulov *et al.*, 1984).

Although juvenile catches are generally few and small within and seaward of the Gulf Stream core, unusually large catches have occasionally occurred south of the core of maximum surface velocity. From this study the largest catch for all four years occurred immediately south of the core. Similarly during a 1979 survey, the greatest catch occurred south of the core (Fedulov and Froerman, 1980). Other investigators have also shown that very few but relatively large catches occurred south of the Gulf Stream core (Froerman *et al.*, 1981; Dawe *et al.*, 1982). All studies indicate that only rarely are juvenile specimens collected from the southern Gulf Stream or Sargasso Sea.

Accurate description of juvenile squid distribution relative to oceanography is difficult because of the dynamic nature of the Gulf Stream System. Oceanographic features such as current speed and direction, eddies, meanders and fronts are highly variable in time and space, making it frequently difficult to determine exactly were catches occurred. Uncertainty as to the exact depth of capture, using open trawls, adds to the problem. Discrete depth sampling, using opening and closing trawls, can address the problem of depth distribution (Hatanaka *et al.*, 1982), but it is recognized that the location of catches in relation to water masses is uncertain in some cases, especially in close proximity to fronts. Overall, however, surveys point to the region between Slope Water and the northern Gulf Stream as the area of greatest abundance of juveniles.

Distribution of sizes

For those surveys described here in 1981, 1982, and 1985, there was a clear progression of size from the Gulf Stream northward to the cooler water types, Slope Water, and Shelf Water. That trend has also been described from other surveys in the Canadian area (Fedulov and Froerman, 1980; Froerman *et al.*, 1981; Dawe *et al.*, 1982; Hatanaka *et al.*, 1982). Smallest juveniles for all years from this study were those collected immediately south of the Gulf Stream core in 1981. They ranged from 12 to 25 mm and were quite similar in size to those collected from the Gulf Stream in another 1982 survey (Dawe *et al.*, 1982).

Juveniles described here from the northern Gulf Stream were similar to those taken during another 1982 survey from the northern Gulf Stream and frontal zone (Hatanaka *et al.*, 1982). However, during that survey juveniles as large as 58 mm ML were collected from Slope Water whereas the largest juvenile described here from Slope Water and Shelf Water was 42 mm ML. Juveniles larger than those described here have commonly been collected during other surveys as well (Fedulov and Froerman, 1980; Froerman *et al.*, 1981; Dawe *et al.*, 1982; Fedulov *et al.*, 1984). That size disparity is likely related to more intensive sampling of cooler water types and sampling at depths greater than 100 m during other surveys. Arkhipkin *et al.* (1983) showed from a diel Shelf Water-Slope Water station that smallest juveniles were caught beneath Shelf Water at a depth of about 30-75 m, whereas larger juveniles were collected at greater depths.

The capture of smallest juveniles within the Gulf Stream and progression of sizes toward cooler water types is consistent with the observed pattern of larval distribution. Hatanaka *et al.* (1985) found that larvae were most abundant in the northern edge of the Gulf Stream and Dawe and Beck (1985) reported that larvae were caught only within northern Gulf Stream water. Thus, the distribution of juveniles, as well as larvae, supports the proposed importance of the Gulf Stream in the northeastward dispersal of young stages of *Illex illecebrosus* (Trites, 1983).

Surveys described here were carried out within a restricted time period, during February and March. However, the results of other surveys indicate that juveniles ranging approximately 1-4 cm in mantle length are generally found near the Gulf Stream frontal zone during January to April (Hatanaka *et al.*, 1982; Froerman *et al.*, 1980). This suggests that although most intense spawning may occur during January (Hatanaka *et al.*, 1982), spawning and

passive downstream dispersal of young stages occurs to some extent over a prolonged time period.

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