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Distribution and size composition of juvenile short-finned squid (*Illex illecebrosus*) in the Northwest Atlantic in relation mechanisms of transport, February 4 - April 30, 1982

by

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INTRODUCTION

Until recently the life history of short-finned squid had only been described for the period May-December when large juveniles inhabit the continental shelf. Since 1974 *Illex* larvae have been collected near the continental shelf of the mid-Atlantic states (Lu and Roper 1979; Vecchione MS 1978). More recently, small juveniles have been collected in Slope Water near the northern boundary of the Gulf Stream, and aspects of their distribution and biology have been described (Fedulov and Froerman MS 1980, Dawe et al. MS 1981, Froerman et al. MS 1981). To date spawning stock and egg masses have not been located but some understanding of these stages of the life history comes from laboratory experiments (Durward et al. 1980, O'Dor et al. MS 1981).

This paper presents oceanographic and biological data collected during a joint Canada/USSR survey during winter and spring of 1982. Distribution of catches and sizes of juvenile *Illex illecebrosus* are described in relation to characteristics of the water masses toward elucidating mechanisms of transport. Also, results of detailed studies of warm core eddies are presented in assessing their possible significance in determining observed patterns of distribution.

MATERIALS AND METHODS

This joint Canada/USSR survey was conducted aboard the Soviet Research Vessel EVRIKA during Feb. 4 - April 30, 1982. The survey area extended from 66°30'00"W to 38°28'00"W and sampling was conducted within all water masses extending from shelf waters to the Sargasso Sea (NAFO Subareas 3, 4 and 5). The survey was composed of four distinct cruises (82-03, 82-06, 82-07 and 82-08).

A complete hydrographic station consisted of collecting water samples to a depth of 1^00 m, or occasionally 1200 m. Samples were collected using reversing bottles at depths of 0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 500, 600, 800 and 1000 m. On occasion samples were also collected at 250 and 900 m. These samples were analyzed on board for temperature, salinity and dissolved oxygen. Nutrient samples were frozen for analysis ashore. Plankton sampling was conducted using 0.333 µm mesh bongos until March 17, after which 0.505 µm mesh bongos were used. Plankton sampling usually involved both an oblique bongo tow to 200 m according to standard MARMAP technique, as well as a 15 min. step bongo tow at 10, 5 and 1 m. Where swell was greater than 3 m a step bongo tow was not carried out. Results of plankton sampling are not described here. Midwater trawling at various depths was conducted using an Engels 400-mesh midwater trawl (EMT), which has a horizontal opening of 10 m and a vertical opening of 8 m. This net was towed at fishing depth for 15 min. at a speed of 2 knots. During the last cruise (82-08) a large pelagic trawl (LPT) with an opening of 40 m x 40 m was also used. This net was towed at fishing depth for 30 min. During several parts of the survey XBT casts were conducted between hydrographic stations. At an XBT station bongo tows or midwater trawl sets may also have been carried out. Location of the Gulf Stream was identified with the aid of data obtained from Satellite Facsimile Charts from the National Earth Satellite Service and a continuously recording sea surface temperature probe.

Methodology varied considerably among the four cruises. Thus details of biological and hydrological sampling are presented in Appendix A. Salinity was determined on board using an electric salinometer (Australian model 601 MK III). Dissolved oxygen was determined by the Winkler iodenemetric method. Plankton analysis on board was carried out for samples for one bongo net. Fish larvae and cephalopods were sorted and wet seiston biomass was recorded. Illex larvae were measured to the nearest 0.1 mm. The sample from the second net was fixed in 4% formalin for analysis ashore. Sampling of the midwater trawl catch involved initially weighing the entire catch and sorting it for cephalopods and fish. For the remainder of the catch a subsample was sorted. Cephalopods were identified, weighed and measured to the nearest mm. For Illex illecebrosus a maximum of 100 specimens were sampled for detailed biological analysis (dorsal and ventral mantle length, sex, weight, stomach and caecum fullness and in females length of nidamental glands, if present). All cephalopods were fixed in 4% formalin. Although sampling varied considerably among cruises general features of the operational scheme for each cruise are described.

Cruise 82-03 (Feb 4-22)

The area of this cruise was between 61°57'W and 66°29'W. The first part consisted of three transects extending from Slope Water to the Sargasso Sea (Fig. 1). These transects were occupied in sequence from East to West. On transects complete hydrographic stations with step and oblique bongo tows were generally located at 10 mile intervals. An XBT cast and a step bongo tow were placed midway between hydrographic stations. Midwater trawling consisted of an EMT tow at 100 m depth at approximately every third hydrographic station. Stations 68-74 were not part of the squid survey.

The second part of this cruise was a more detailed survey of the area of the northern extreme of the third transect (Fig. 1). This phase, directed toward investigating distribution and transport mechanisms of larvae, involved an XBT cast and two bongo tows (oblique and step) at each station. At some stations an EMT set at 100 m depth was also conducted.

The third part of this cruise consisted of a transect (stations 49-57) and other stations (58-60) within and near a Gulf Stream Warm Core Eddy (Fig. 1) toward investigating their possible significance in the transport of larval or juvenile squid. At each station operations included either a complete hydrographic station or XBT casts, as well as an oblique bongo tow. At each station an EMT set, was conducted generally at 100 m (Appendix A).

Cruise 82-06 (Feb 23 - March 21)

This cruise, between 49°50'W and 60°00'W, was directed toward investigating distribution of Illex along the northern boundary of the Gulf Stream. In the first part of the survey (February 25 - March 1) the vessel operated in the Northeast to Southwest direction beginning with a transect extending south at 54°W and ending with a similar transect at 59°W (Fig. 2). Stations conducted between these transects extended from east to west in two Gulf Stream meanders. With the exception of stations 76 and 77 (Table 1) stations along transects at 54°W and 59°W as well as two other stations (Fig. 2) consisted of hydrography, oblique and step bongo tows, as well as EMT sets, generally at 50 m, 100 m, 300 m and 500 m. An XBT cast was exectued at 10 mile intervals along transects. At the other stations in Gulf Stream meanders (68-74, Fig. 2) operations generally consisted of an XBT cast and an EMT set at 100 m.

The second part of this cruise included a transect extending south-west from the southern tip of the Grand Bank (Fig. 2). At regular intervals along this transect detailed stations were conducted, consisting of hydrography, step and oblique bongo tows and EMT sets (usually at 50, 100, 300 and 500 m) (Appendix A). Between detailed stations and at the end of the transect, stations consisted of an XBT cast and fewer EMT sets, usually a single set at 100 m. After completing this transect, a series of 7 separate stations (105-111) were occupied from 53°00'W to 59°55'W (Fig. 2). Operations varied considerably among these stations (Appendix A).

Cruise 82-07 (March 25 - April 7)

This cruise, between 59°35'W and 64°55'W began by occupying a standard hydrological transect. This hydrological transect, ending with station 112 and 113 was extended into a transect which extended southeast from the slope of the Scotian Shelf and involved detailed biological sampling (Fig. 3). Station placement and sampling scheme along this transect was similar to that described for the last transect of Cruise 82-06, which extended from the southern tip of the Grand Bank (Fig. 2, Appendix A).

The second part of this cruise consisted of 3 transects and two other stations extending through a warm core eddy (Fig. 3). Complete stations involved hydrography, oblique and step bongo tows, and EMT sets at 50 m, 100 m, 300 m and 500 m. Stations located between these consisted of XBT casts, oblique and step bongo tows, and EMT sets at 100 m and 300 m (Appendix A).

Cruise 82-08 (April 11-30)

Initially during this cruise a series of stations (154-162) were sampled, generally near the northern boundary of the Gulf Stream, as the vessel proceeded east from 60°46'W to 51°18'W (Fig. 4). Where possible stations were sampled during darkness. The sampling regime varied greatly among these stations (Appendix A).

The second part of this cruise was an investigation of distribution of larvae and juveniles at the eastern extreme of their range (between 48°30'W and 38°28'W, Fig. 4). This aspect consisted of three transects immediately south and east of the Grand Bank, and two transects extending southeast; one beginning east of Grand Bank and the other terminating at the slope of the Flemish Cap. For the first three transects stations included hydrography or an XBT cast and step on oblique bongo tows. Where EMT sets were executed, they were at various depths. Along the 2 most easterly transects the general operational scheme involved complete stations at approximately 60 mile intervals. At these stations sampling generally included hydrography, step and oblique bongo tows, and a variable number of sets using the large pelagic trawl (LPT) at various depths (Appendix A). Maximum fishing depth using the LPT is considered approximate due to the large vertical opening of this trawl. Between complete stations a station consisted of XBT casts and step and oblique bongo tows. Sampling resolution for hydrography was further increased in that an XBT cast was executed midway between consecutive stations.

RESULTS

Distribution of Catches

Cruise 82-03 (Feb 4-22)

The magnitude of catches of juveniles from EMT sets is shown in relation to vertical temperature and salinity profiles for the three transects which extended from Slope Water to the Sargasso Sea (Fig. 5-7). Along the first transect, located at 62°00'W, (Fig. 1) there was a small catch of juveniles in Slope Water at station 10 (Fig. 5). The Gulf Stream extended between stations 8 and 2. There were no catches at station 7, within the Gulf Stream, or to the south at station 1 within the Sargasso Sea. On the second transect, located at 64°W, moderate catches occurred at stations 11 and 15 (Fig. 6). The catch at station 11 occurred near the Shelf Water front. The catch at station 15 was from within the Gulf Stream. There was not catch from station 19, located in the Sargasso Sea. On the most western transect there was only one small catch of juveniles, at station 38, located within Slope Water (Fig. 7). There were no catches at stations within the Gulf Stream (station 28 and 34), or the Sargasso Sea (station 22).

Distribution of catches along two transects extending northeast and east through a warm core eddy (Fig. 1) is shown in Fig. 8 and 9. The longer transect extending northeast passes through the centre of the eddy at EMT station 54, where a small catch of juveniles occurred (Fig. 8). There were no catches at stations 51-53, located inside the periphery of the eddy, or at station 48, between the eddy periphery and the Gulf Stream. Catches occurred at all five stations within, or very near and inside, the periphery. Greatest catches were at station 49, 56 and 57, within the transition zone between water of Gulf Stream origin and Slope Water. This region represents the true periphery of the eddy. The second transect within this warm core eddy extended east through the eddy periphery from a point southwest of its centre (Fig. 9). An interesting feature of these profiles is the incursion of a meander of low temperature and salinity shelf water into the area of the eddy periphery at station 59. A moderate catch of juveniles occurred in this transition zone. No juveniles were caught at either station 58, inside the eddy periphery, or station 60 outside the periphery.

The magnitude of catches within the various water masses for the entire cruise is summarized using a temperature-salinity (T-S) diagram (Fig. 10). Catches occurred at most stations near the northern boundary of the Gulf Stream and in the warm core eddy periphery as indicated approximately by temperatures 13-15°C and salinity 35.0-36.1°/oo. At higher temperature and salinity, there was only one moderate catch within the Gulf Stream and a small catch in the centre of the warm core eddy. Juveniles were not usually caught within the Gulf Stream or Sargasso Sea. There was one small catch in Shelf Water, as indicated by salinity less than 35.0°/oo.

Cruise 82-06 (Feb. 23 - March 21)

Within the area of this cruise (Fig. 2) mixing between the Gulf Stream and water masses to the north occurred to a greater extent than further west. Mixing was caused by Gulf Stream meanders and eddy formation between 56°W and 66°W. East of 56°W meanders occurred to a greater extent and the warmer water masses mixed with incursions of cold Labrador Water. Thus the Slope Water and Gulf Stream were colder in this region than it was further west in the area of the earlier cruise. This is seen in vertical temperature and salinity profiles for this cruise (Fig. 11-15). It appeared (Fig. 11) that the warm centre of the Gulf Stream in this region is smaller in cross sectional area and colder than further west. Temperatures and salinity throughout the Gulf Stream were lower than during the first cruise. Also in this area, catches of Illex illecebrosus juveniles were fewer and smaller than they were west of this area.

Along the first transect, extending south from Slope Water to the Gulf Stream (Fig. 2) the maximum temperature of the Gulf Stream was 18.4°C (Fig. 11). Only five small catches occurred at stations within Slope Water and near the northern edge of the Gulf Stream, where temperature and salinity in the upper 200 m were 13-15°C and less than 36.10°/₀₀ respectively. No juveniles were caught within the Gulf Stream or from four other sets near the northern boundary of the Gulf Stream. Along a transect extending northwest (Fig. 12) there were no juveniles caught in either the Gulf Stream (station 66) or in Slope Water near its northern boundary (station 67). Similarly, there were no catches at 6 stations within the Gulf Stream between station 68 and 74. Along the transect extending south in Slope Water at 59°W there was a moderate catch from only one of eight sets (Fig. 13).

The transect extending southwest from the tip of the Grand Bank appeared to pass through a dissipating warm core eddy (Fig. 14). For most EMT sets there were no juveniles caught. Although the EMT fishes obliquely during retrieval there were no catches from sets below 100 m, indicating that juveniles are distributed in the near-surface water. There were occasional catches throughout the eddy but at station 86 a moderate and large catch occurred in the transition region between the northeastern eddy periphery and cold shelf water. These catches occurred at unusually low temperatures (5-9°C, Fig. 15). Station 95 was located within the periphery of a warm core eddy. At this station 24 juveniles were captured in sets at 50 m and 100 m.

Temperature-salinity diagrams (Fig. 16) show that catches were small and few throughout this cruise. However, the greatest proportion of catches were located in the northern periphery of the Gulf Stream at 13-15°C (Fig. 16A). Of all sets within the Gulf Stream there were only two catches (Fig. 16A and B). Two catches also occurred at low temperature and salinity near shelf water outside the periphery of a warm core eddy (Fig. 16A). Temperature-salinity relationships differ between Fig. 16A and B because of the greater depths and different water masses sampled for the latter. It is also noted that since the EMT fishes during retrieval, characteristics of the water masses described for greater depths may not be representative of the location of catch.

Cruise 82-07 (March 25 - April 7)

This cruise, south of the Nova Scotian Shelf, consisted of a transect in Shelf and Slope Water extending southeast from the continental Shelf, as well as three transects through a warm core eddy. Figure 17 shows the location of these transects and depicts the location of warm core eddy stations in relation to the changing position of the eddy. Vertical temperature and salinity profiles are presented for all transects in Fig. 18-20.

Juvenile squid catches were generally small and only occurred in approximately 50% of EMT sets along the Shelf and Slope Water transect (Fig. 18). Near-surface temperatures were generally less than 13°C. A single specimen was captured in Shelf Water (station 112) at 7.4°C and 34.08°/₀₀. The warm core eddy surveyed was relatively weak and it is believed that no transect extended through its centre of maximum temperature and salinity (Fig. 17). The maximum temperatures encountered along these transects ranged 14-16°C. Catches throughout this warm core eddy were numerous and frequently very large relative to both the nearby transect in Shelf and Slope Water as well as the eddy surveyed in the same general area during February 17-19 (Fig. 8 and 9). A catch of 1155 juveniles was experienced at a depth of 50 m at station 135 (Fig. 17).

The first transect (stations 126-139) extended through the eddy probably near its centre, as indicated by salinity greater than 36.00°/₀₀. During this period the eddy moved northeast (Fig. 17). Although greatest catches occurred at station 135, inside the outermost periphery, most sets between stations 133 and 137 resulted in no catches (Fig. 19). Other large catches occurred in transition zones between water masses. Large catches at stations 129-131 were in close proximity to an incursion of cold Shelf Water with salinity less than 35.00°/₀₀. Very large catches at station 126 occurred in a region between Shelf Water and Warm Slope Water. The second transect (stations 139-146, Fig. 17) passed through the southwestern periphery of the eddy (Fig. 20). Largest catches occurred at 13-14°C in the periphery. Smaller catches occurred at station 139, where the near-surface layer is Shelf Water. Few and small catches occurred in Slope Water generally colder than 13°C at stations 145 and 146. The last transect passed through the southeastern periphery of the eddy as it moved southwest (Fig. 17). Large catches generally occurred within the periphery, between stations 147 and 150 (Fig. 20). Catches also occurred at station 153, a region of transition between Slope Water and over-lying Shelf Water. Catches were fewer at stations 151 and 152, located within Slope Water.

Temperature-salinity diagrams (Fig. 21) show that catches were fewer and much smaller in Slope Water (Fig. 22A) than throughout the periphery of the warm core eddy (Fig. 21A and B). Throughout the entire survey, catches were greatest and most frequent within the periphery of this eddy. Although it is believed that the centre of this eddy was not sampled, large catches were experienced in all regions of its periphery, including the area closest to its centre, where temperature and salinity characteristics most closely resemble those of the Gulf Stream (Fig. 21B).

Cruise 82-08 (April 11-30)

The most western transect of this cruise (Fig. 4) extended south through Labrador Sea Water to the northern periphery of a warm core eddy (Fig. 22). Two large catches of juveniles occurred at station 165 in a transition zone between Shelf Water and the periphery of a meander of the Gulf Stream. There was also a large catch at station 168, within the northern periphery of the eddy. There was no catch at station 170, inside the periphery of the eddy, or at station 163, in cold Shelf Water. The second transect, extending northeast passed through these same water masses and nearer the periphery of the Gulf Stream meander (Fig. 23). There were two large catches within the periphery of the warm core eddy (station 171) but only small catches at low temperatures within Labrador Sea Water (station 172) and in an area thought to be near the periphery of the Gulf Stream meander (station 173). There were no catches at station 175, near the northern boundary of the Gulf Stream meander. The third transect (Fig. 4) extended northwest, crossing the northern boundary of the Gulf Stream meander and into Labrador Sea Water (Fig. 24). There were no catches within or near the periphery of the meander (stations 175 and 177) and only a single specimen was captured at station 179, in Labrador Sea Water.

The last two transects, extending southeast (Fig. 4) were located within the North Atlantic Current, with Mixed Water at the northwestern extreme of transects. These transects were sampled for juveniles using the large pelagic trawl (LPT). Thus catches are not comparable to those from the EMT. Along the most southern of these transects (Fig. 25) there were large catches within the North Atlantic Current (stations 185 and 187). At station 187 catches were 1375 and 333 juveniles at 50 m and 450 m respectively. At station 183 catches were 402, 6 and 224 specimens at 30 m, 100 m and 430 m respectively. Vertical temperature and salinity profiles show that this station was situated in the North Atlantic Current, where temperature is always less than 15°C. Of particular interest is the lack of catches at station 189. From Satellite Facsimile Charts it is felt that this station was located very near the Gulf Stream in the area where it turns to flow in a southeastern direction. There were no catches at station 180, located at the northwestern edge of the North Atlantic Current in close proximity to Mixed Water. Along the most northern transect (Fig. 26) greatest catches occurred in the North Atlantic Current at the most eastern station (station 192). Only one other catch occurred in the North Atlantic Current (station 198) near its northwestern edge. Four juveniles were captured at stations 200 and 202, within the Mixed Water between the North Atlantic Current and Labrador Sea Water, at conditions of very low temperature and salinity.

Temperature-salinity profiles show that within the time and area of these two transects, distribution of juveniles is related to conditions of lower temperature and salinity (Fig. 27). Large catches occurred at temperatures as low as 11-12°C, in close proximity to Mixed Water (Fig. 27A). Further, most sets which were unsuccessful in catching juveniles were associated with conditions of maximum temperature and salinity.

Distribution of Sizes

Mantle length distribution are described for all water masses unencountered throughout this survey. Length-frequency distributions are also compared over the broad area and time of the survey toward elucidating mechanisms of transport. Further, length composition is desribed for various regions of a warm core eddy to determine the possible significance of eddies in the transport of juveniles.

Size Compositions Within Water Masses

Lengths are described for the period February 8-19 within the most western portion of the survey area (Fig. 28 and 29). Length composition in relation to water masses encountered is presented in Fig. 28A. Smallest juveniles where captured within the Gulf Stream (station 15) where modal length was 2.0 cm. Specimens collected from a region near the northern boundary of the Gulf Stream (station 46) were larger, with a moaal length of 3.5 cm. A greater range of sizes occurred in this region of sharp temperature gradients (1.5-5.5 cm). Juveniles collected from northern and southern regions of the periphery of a warm core eddy were also larger than those from the Gulf Stream and were generally similar to those from the northern boundary region of the Gulf Stream. For these transition areas temperature in the near-surface layer was 13-15°C. Apparent bimodality of the sample from the southern periphery of the eddy is attributed to small sample size (N = 36, Fig. 28A). Over the size range encountered during the first cruise males and females did not differ in size, with comparable range and mode of length (Fig. 28B).

Size composition is shown in relation to temperature for the first cruise (Feb. 8-19) in Fig. 29. Clearly, smallest juveniles were captured within the Gulf Stream, as identified approximately by temperatures of 18°C and greater. Largest specimens occurred north of the Gulf Stream boundary zone and outside the periphery of warm core eddies, at temperatures of less than 11°C. Where catches were largest, in the periphery of both the Gulf Stream and warm core eddies, juveniles were of intermediate sizes.

Size compositions of juveniles later in the survey and further east is shown for similar water masses in Fig. 30. During April 12-14 juveniles from the northern periphery of the Gulf Stream were similar in size to those sampled in the Gulf Stream during the first cruise, with modal length 2.0 cm (Fig. 30A). However, specimens as large as 6.5 cm were also caught in this region. Along a transect extending southwest from the tip of the Grand Bank, very small juveniles with modal length 2.0 cm were caught at station 95 in the periphery of a warm core eddy (Fig. 30B). At the northern extreme of this transect much larger juveniles (modal length 4.0 cm) were caught at station 86 in a region between the periphery of the eddy and cold Shelf Water (Fig. 30B). Small juveniles collected in the periphery of the eddy (Fig. 30B) were comparable in size to those caught later in the northern periphery of the Gulf Stream, (Fig. 30A) and especially to those caught in the Gulf Stream further west during the first cruise (Fig. 28A).

East of the Grand Bank at 47°50'W juveniles were larger (Fig. 30C). In this area smallest juveniles with modal length 4.5 cm occurred at the most southern station at the outer edge of the periphery of a warm core eddy. Large squid with modal length 6.0 cm were caught further north in an area between the eddy periphery and cold Labrador Sea Water. At this station temperatures in the upper 300 m ranged 5-12°C. Largest juveniles were caught furthest north (station 165) in an area of transition between cold Labrador Sea Water and the periphery of a meander of the Gulf Stream. These squid ranged greatly in length from 3.0 cm to 12.0 cm, with the mode at 10.0 cm (Fig. 30C).

Length composition along two transects at the northeastern extreme of the survey area is shown in Fig. 31A in relation to sexed specimens collected throughout the survey (Fig. 31B). Throughout this region between Mixed Water and the North Atlantic Current juveniles were of a fairly uniform large size, with modal length 4.5 cm. Size composition in this area (Fig. 31A) where surface temperature was generally 12-14°C, was very similar to that of the sample collected nearby using EMT, in the periphery of a warm core eddy (Fig. 30C). A few specimens as large as 13.0 cm were also collected in the North Atlantic Current (Fig. 31A).

Specimens from the North Atlantic Current were generally larger than those collected througout the survey as a whole (modal length 3.0-3.5 cm, Fig. 31B). However, for the entire survey the female length composition exhibits an unusual secondary mode, at 4.5 cm, comparable to that for the sample collected using LPT from the North Atlantic Current. This indicates that juveniles are larger in this area. However, it may reflect size selectivity of the LPT. The presence of this mode, for females only, resulted in an overall sex composition slightly in favour of females (53%). For sexes combined, over the entire survey (Fig. 31B) length composition was biomodal with a small mode of large juveniles at 8.5 cm. Juveniles of this size were not caught within the North Atlantic Current (Fig. 31A). At these larger sizes there was no difference in size between sexes (Fig. 31B).

Size Composition Throughout A Warm Core Eddy

Size compositions are described in Fig. 32 for samples collected from various regions of a warm core eddy during the period March 30 - April 6. Figure 17 depicts approximately the changing position of this eddy in relation to times when stations were sampled. This eddy was in the same general area but further north of an eddy surveyed during the first cruise (Fig. 3). Smallest sizes were caught within the true periphery of the eddy, where modal lengths for sets in the upper 100 m were 3.0 cm at the northeastern periphery (Fig. 32A) and 3.5 cm near the centre and at the southern periphery (Fig. 32B). These sizes are similar to those found in peripheral areas of the Gulf Stream and an eddy during the first cruise (Fig. 28A). Small numbers of large squid up to 9.5 cm mantle length were also captured within the southeastern periphery (Fig. 32A).

Much larger juveniles were caught in more northern regions, outside the periphery of the eddy, in close proximity to the Shelf Water (Fig. 32C and D). Temperatures in the upper 100 m were generally 12-13°C, but in close proximity were surface temperatures as low as 4°C. The smaller mode of Fig. 32D may be attributed to low sample size or the fact that some specimens were collected from inside the periphery of the eddy.

Size composition was biomodal for stations 126-128 (Fig. 32E). Most of this sample was collected at station 126, near an extension of cold Shelf Water. Smaller juveniles are attributed to the influence of the Gulf Stream in this area. The larger specimens with modal length 8.5 cm represent actively swimming juveniles which become concentrated near the Shelf Water.

DISCUSSION AND CONCLUSIONS

General features of the distribution of juveniles in relation to water masses described here are considered together with results from similar surveys conducted earlier. Some conclusions can be drawn regarding transport of young stages throughout their range of distribution.

The exact location of spawning remains unresolved, but is believed to occur over a broad area southwest of the Nova Scotian Shelf (Froerman et al. MS 1981). This is indicated by the prominent decline in frequency and magnitude of catches of juveniles east of 62°W. The absence of minimum sizes among catches of larvae at 56°W during surveys in 1980 and 1981 (Dawe et al. this meeting) provides further evidence that spawning does not occur that far East.

Very young stages are initially transported northeast by the maximum velocity of current flow, within the Gulf Stream and or at its northern boundary. This is supported by the fact that only the minimum sizes encountered were found within the Gulf Stream and near its northern boundary. Juveniles found at the northern boundary of the Gulf Stream were in greater abundance, indicating that young stages become concentrated within this zone by mechanical processes. However, catches within the Gulf Stream were few and small indicating that even younger stages are transported by the Gulf Stream System. It is believed that larvae and possibly egg masses are transported by the Gulf Stream and its northern boundary zone (Froerman et al. MS 1981). Similar sizes from southwest to northeast (Fedulov and Froerman MS 1980, Froerman et al. MS 1981) along the northern boundary of the Gulf Stream reflect recruitment of small juveniles to the sampling gear due to growth of younger stages. It is known from previous surveys that larvae are transported by the Gulf Stream System as far east as 55°W (Dawe and Beck, this meeting). It is also considered that egg masses may be transported within these water masses, since temperature within these regions is above the minimum temperature for embryonic development (O'Dor et al. MS 1981).

Throughout the time and area of this survey juveniles were generally not greater than 4.0 cm within regions of concentration near the northern boundary of the Gulf Stream and in the periphery of warm core eddies. At approximately this size juveniles move actively out of areas where they have become concentrated by passive transport and become broadly dispersed within Slope Water. It is at 4-5 cm that juveniles become active predators (Froerman et al. MS 1981). Largest juveniles encountered were found in more northerly regions where they become concentrated in close proximity to cold Shelf Water. Such areas of abrupt change in temperature and salinity are well mixed, oxygen-rich and highly productive. Thus, apparant biomodality of the overall length frequency distribution reflects both an uneven distribution of sampling effort, as well as uneven distribution of different sizes of juveniles among the water masses. It has been shown that during surveys in 1979 and 1980 there was a regular increase in size composition from the Gulf Stream toward the continental shelf (Fedulov and Froerman MS 1980, Froerman et al. MS 1981). However, it is noted that observed bimodality of the length frequency distribution could be interpreted as reflecting two peaks of spawning over a prolonged period.

Minimum size juveniles, with modal length 2.0 cm, were found along the the northern boundary of the Gulf Stream as far east as the southern tip of the Grand Bank (51°W). However, juveniles sampled to the east of the Grand Bank were generally greater than 4.0 cm. This probably reflects growth of juveniles in the area where transport of young stages occurs at a much reduced rate. Southeast of the Grand Bank is where the Gulf Stream diminishes in strength most rapidly (Worthington 1976). There are conflicting theories regarding circulation of the Gulf Stream and North Atlantic Current in this area (Clark et al. 1980, Worthington 1976). However, if the North Atlantic Current represents an anticyclonic gyre which is separate from the Gulf Stream gyre (Worthington 1976) then large juveniles would have moved to this area by active swimming. This is consistent with the fact that in other years larvae were not captured to the east of 55°W (Dawe and Beck, this meeting). Very few of the juveniles collected in the North Atlantic Current using a large pelagic trawl were sufficiently large that they may grow to sizes encountered during May and June on the Southwest Slope of the Grand Bank. It is felt that some of the smallest juveniles within the North Atlantc Current may be lost by passive transport into the North Atlantic Ocean

Warm core eddies may play a significant role in limiting transport of larvae and small juvenile to the east (Froerman et al. MS 1981). Large quantities of young stages are entrained in the periphery of these eddies and removed from the region of maximum passive transport. These eddies may remain stationary or move to the southwest within Slope Water, while young stages grow to a size at which they become active swimmers. Thus, in years such as 1982, frequent formation of warm core eddies in the southwest may limit transport of young stages as far east as the Grand Bank. Frequency of eddy formation is probably related to the degree of Gulf Stream meandering. More extreme meandering of the Gulf Stream occurs to the east of the Nova Scotian shelf, where volume transport decreases. Meandering of the Gulf Stream probably facilitated mixing with Labrador Sea Water, which resulted in cooling of the warm water masses to the east of the Nova Scotian Shelf.

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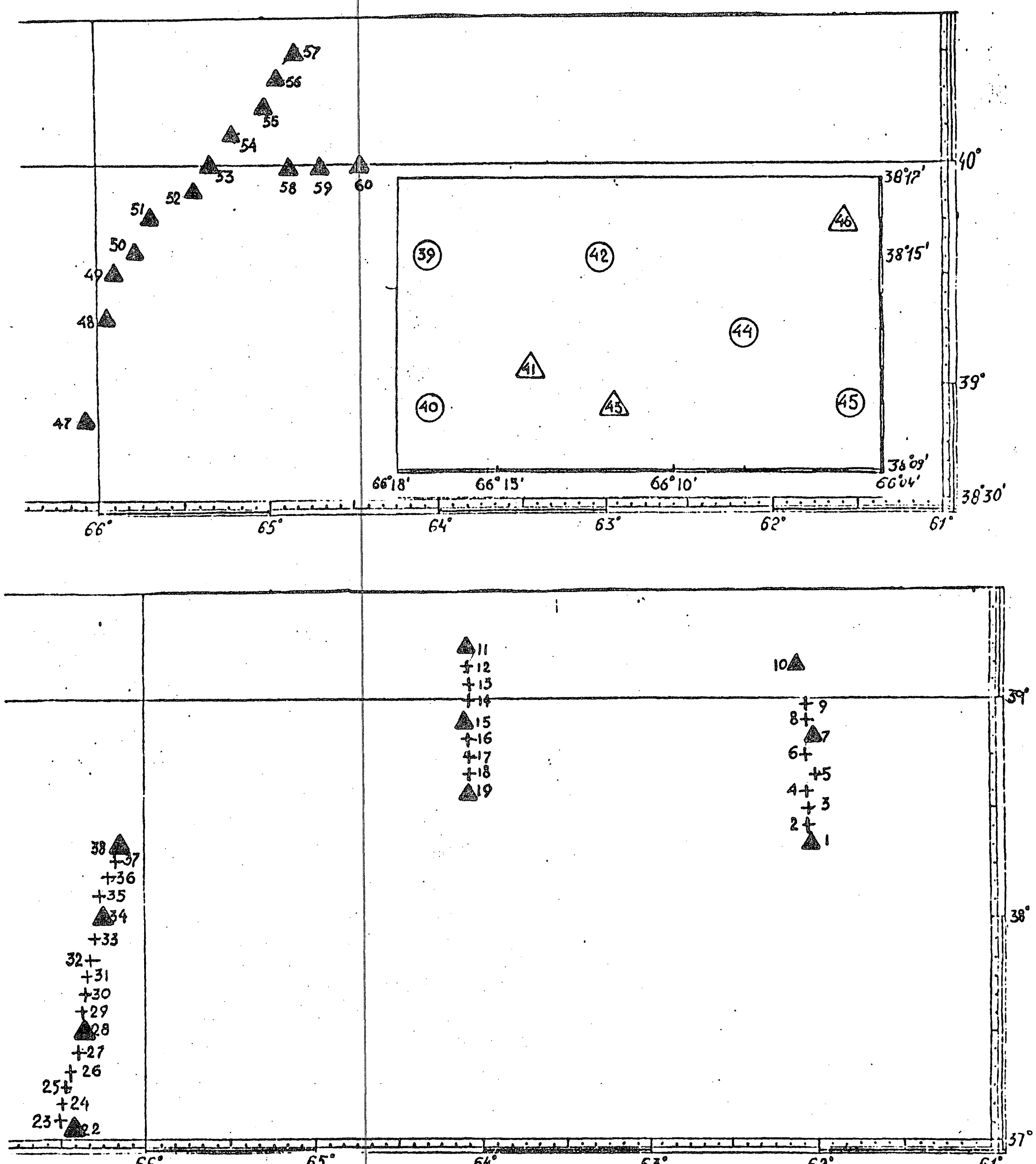


Fig. 1. Location of stations and sampling scheme for Cruise 82-03, February 4-22.

○ ● 4 trawl sets, plankton tows, hydrography, or XBT

△ ▲ less than 4 trawl sets, plankton tows, hydrography, or XBT

■ Stations without plankton tows

\+ Stations with plankton tows but no trawl sets.

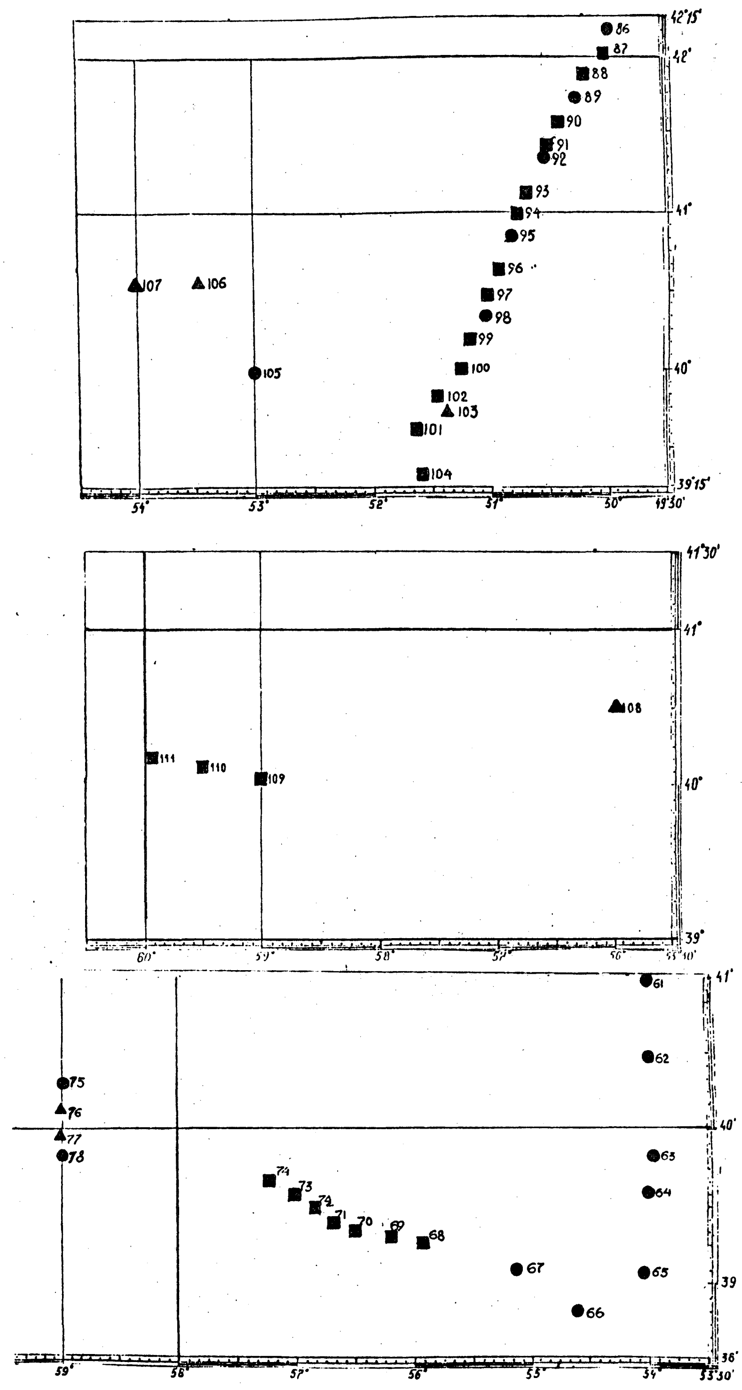


Fig. 2. Location of stations and sampling scheme for Cruise 82-06, February 23-March 21. Legend as in Fig. I.

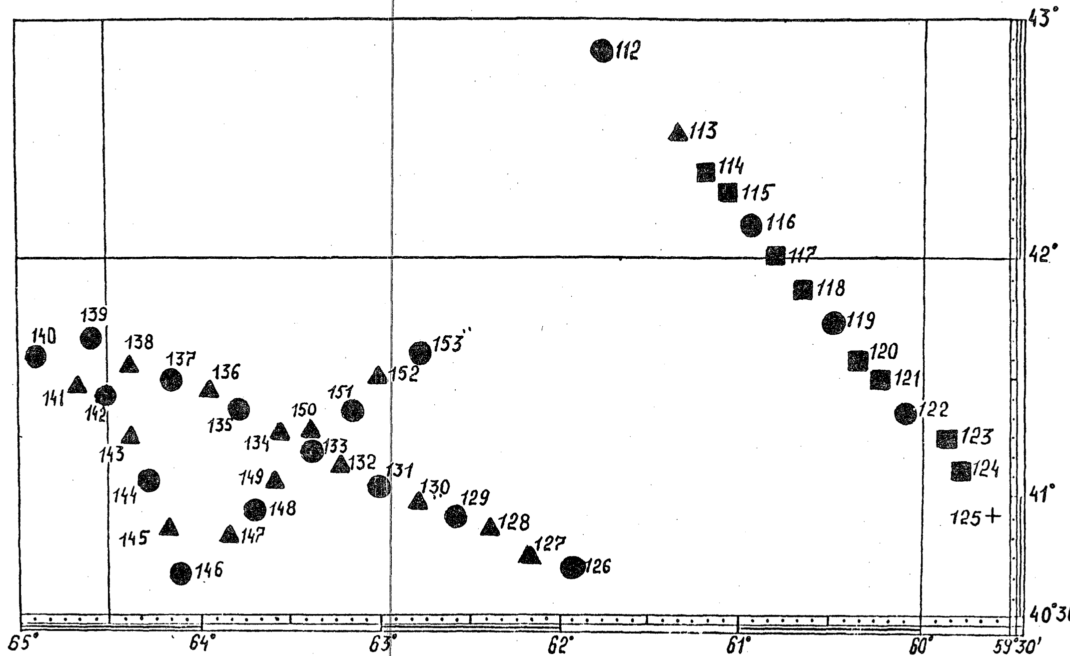


Fig. 3. Location of stations and sampling scheme for Cruise 82-07, March 25-April 7. Legend as in Fig. 1.

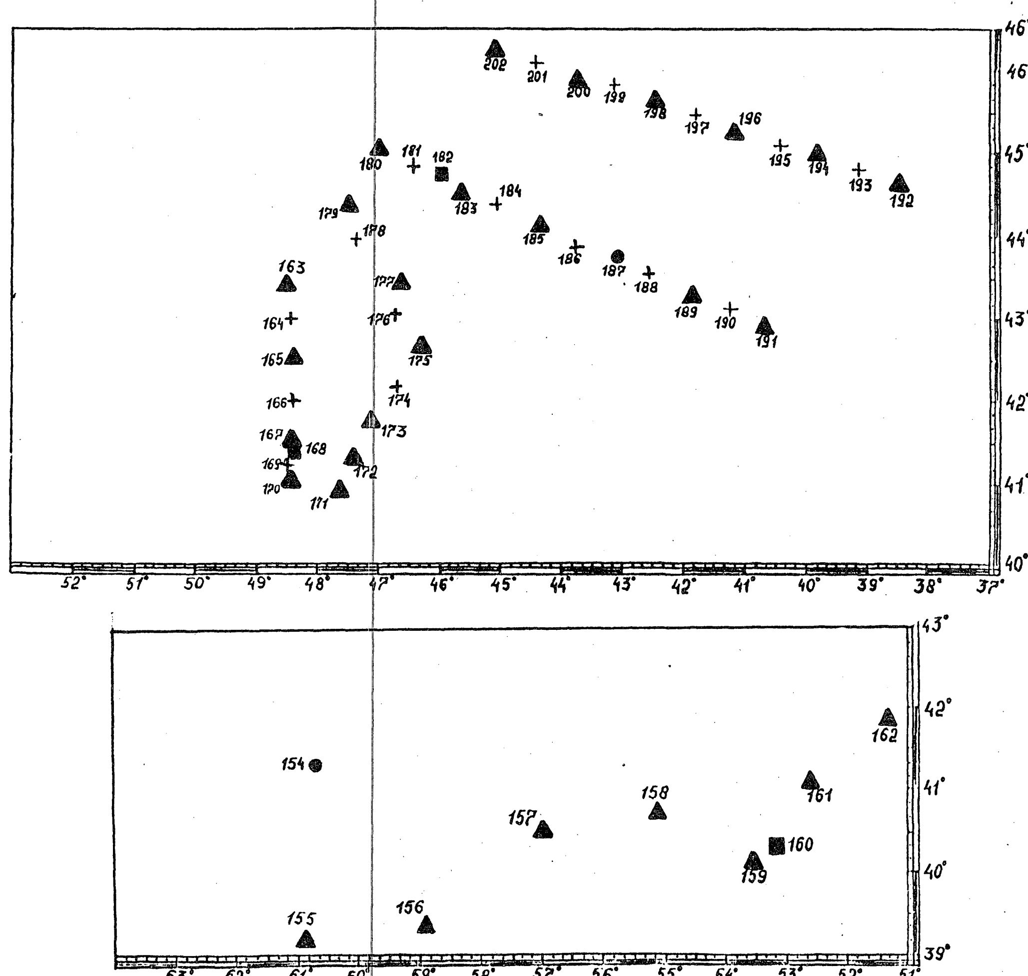


Fig. 4. Location of stations and sampling scheme for Cruise 82-08, April 11-30. Legend as in Fig.

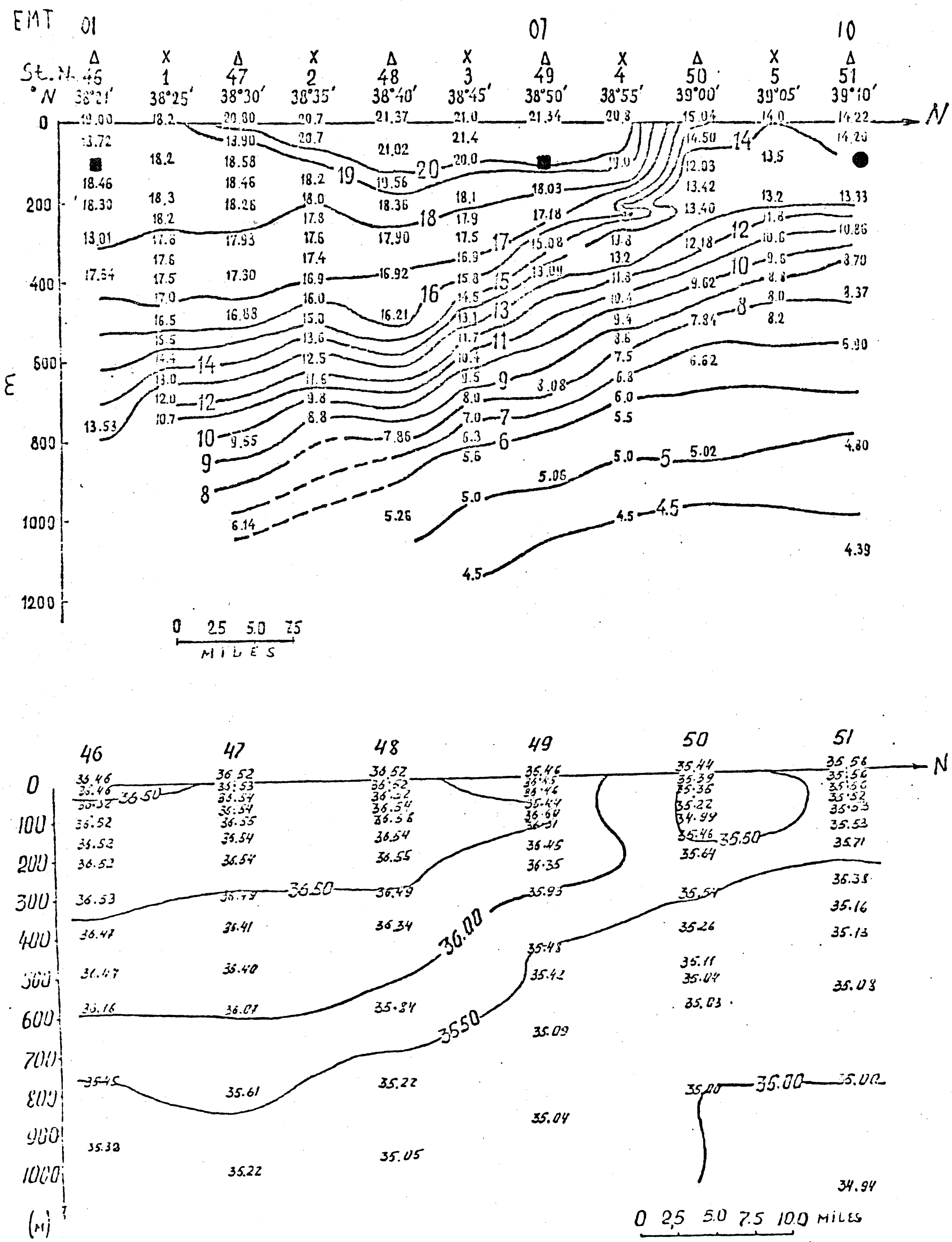


Fig. 5. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 1 of Cruise 82-03 (Stations 1-10).

■ - no Illex

● - 1-5

● - 6-20

● - 21-100

● - >100

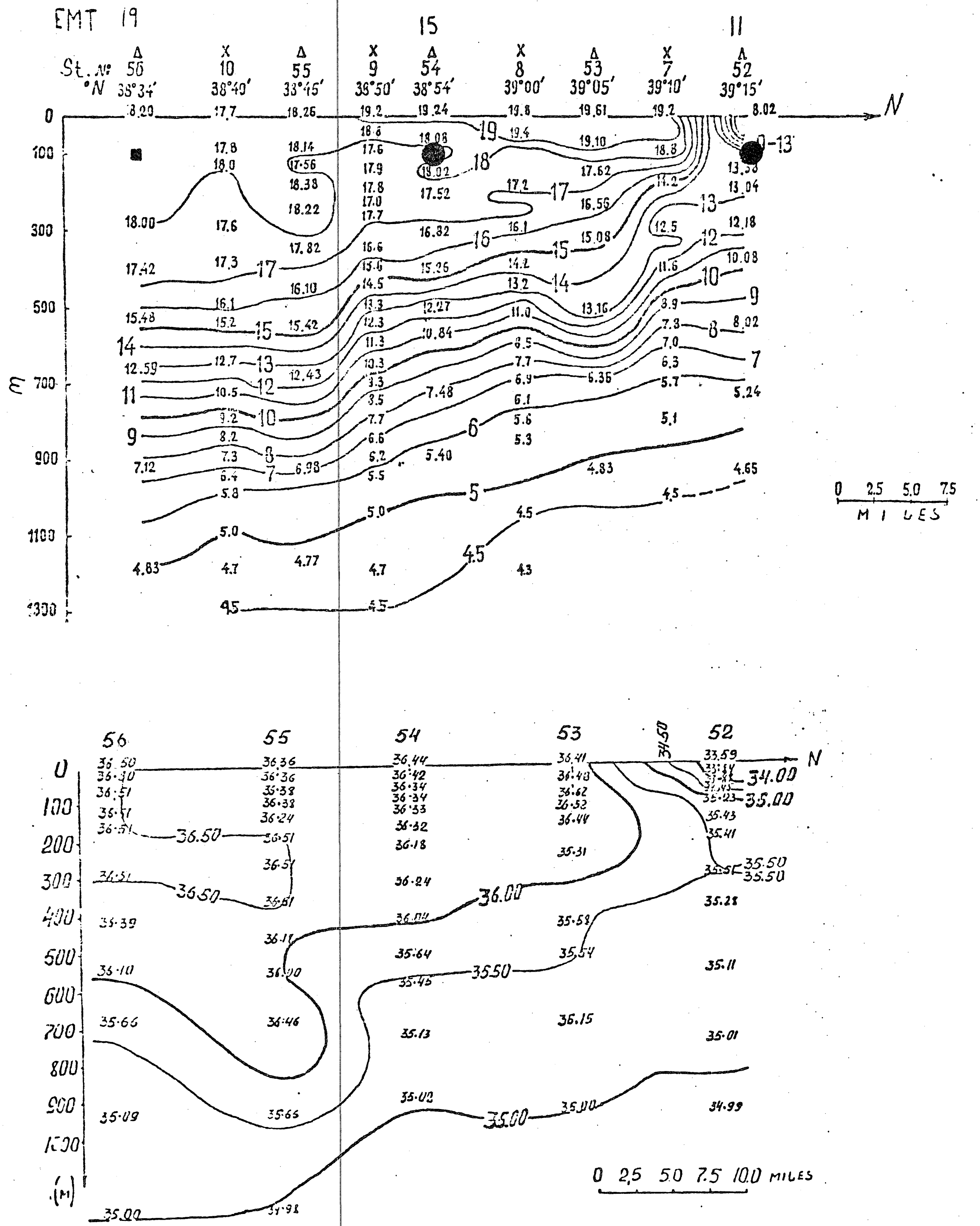


Fig. 6. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 2 of Cruise 82-03 (Stations 11-19). Legend as in Fig. 5.

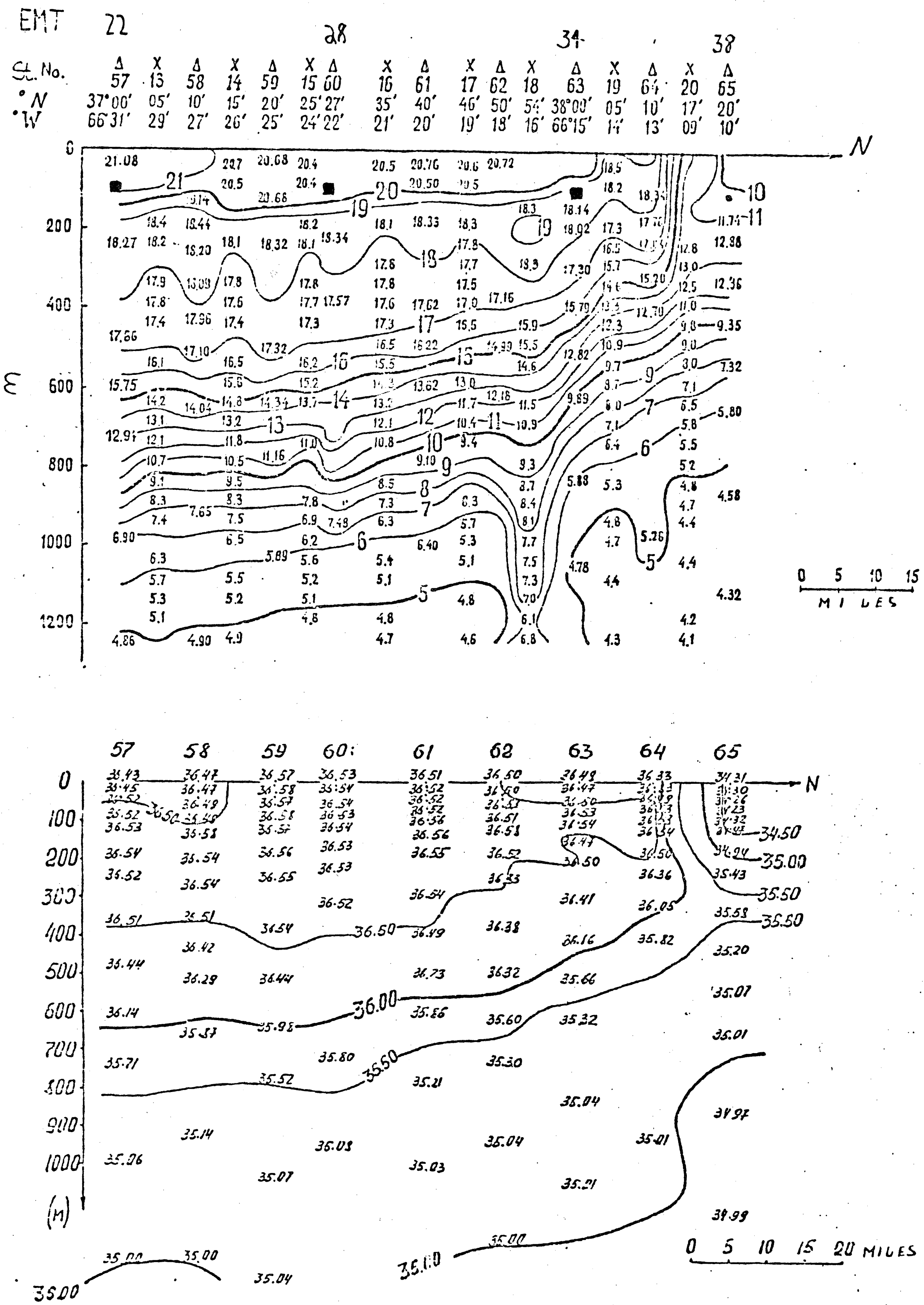


Fig. 7. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 3 of Cruise 82-03 (Stations 22-28). Legend as in Fig. 5.

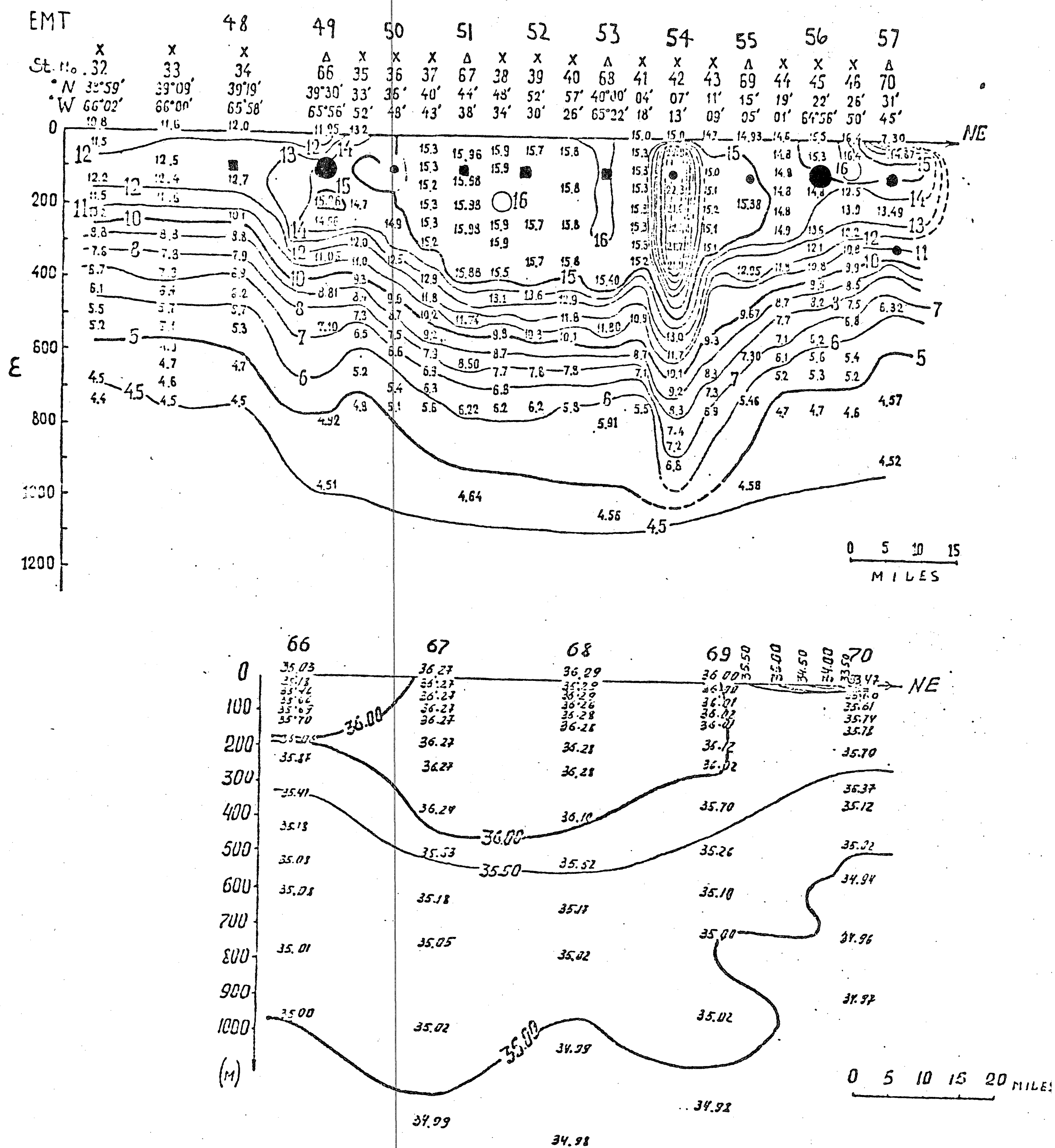


Fig. 8. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 4 of Cruise 82-03 (Stations 48-57). Legend as in Fig. 5.

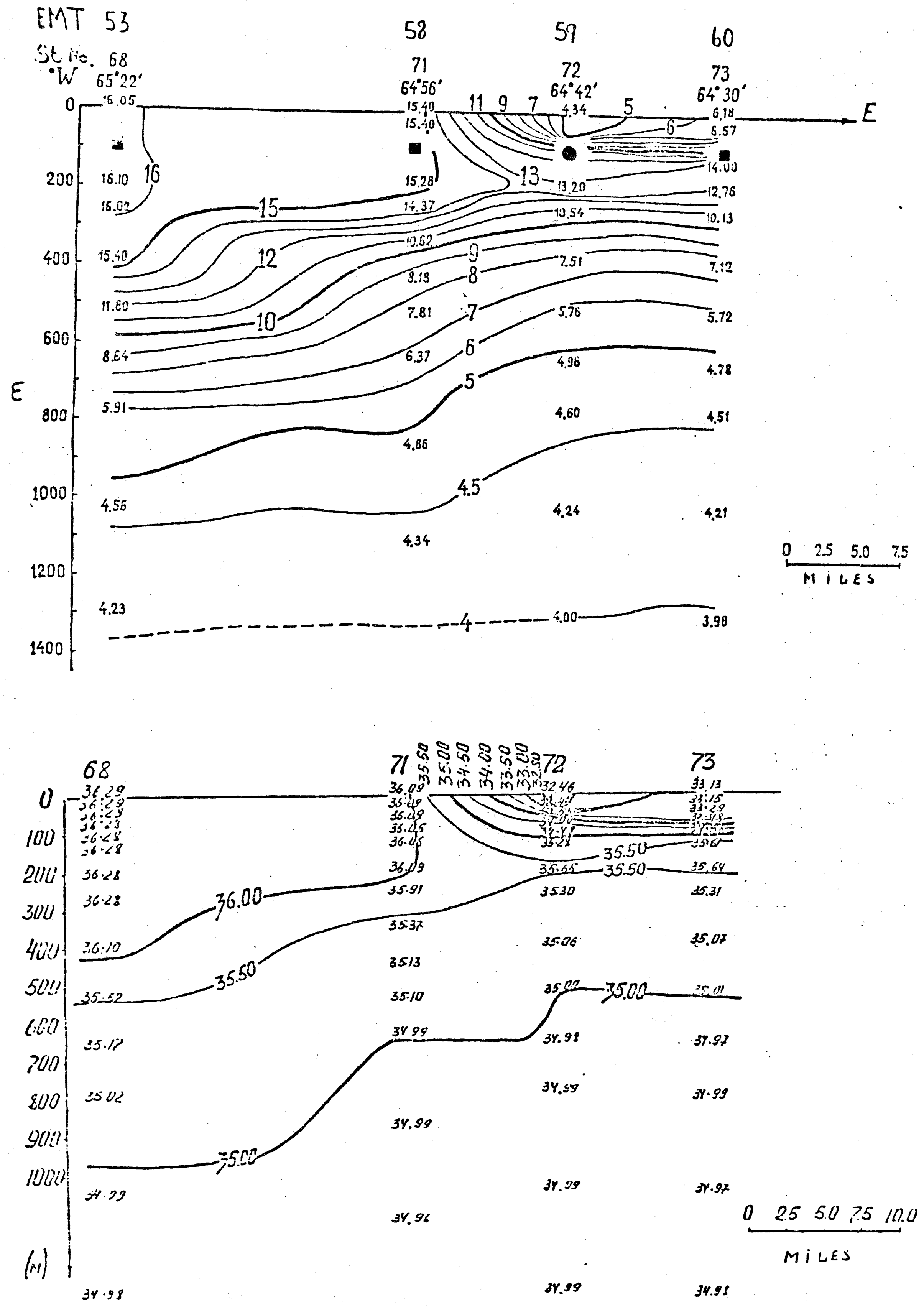


Fig. 9. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 5 of Cruise 82-03 (Stations 53-60). Legend as in Fig. 5.

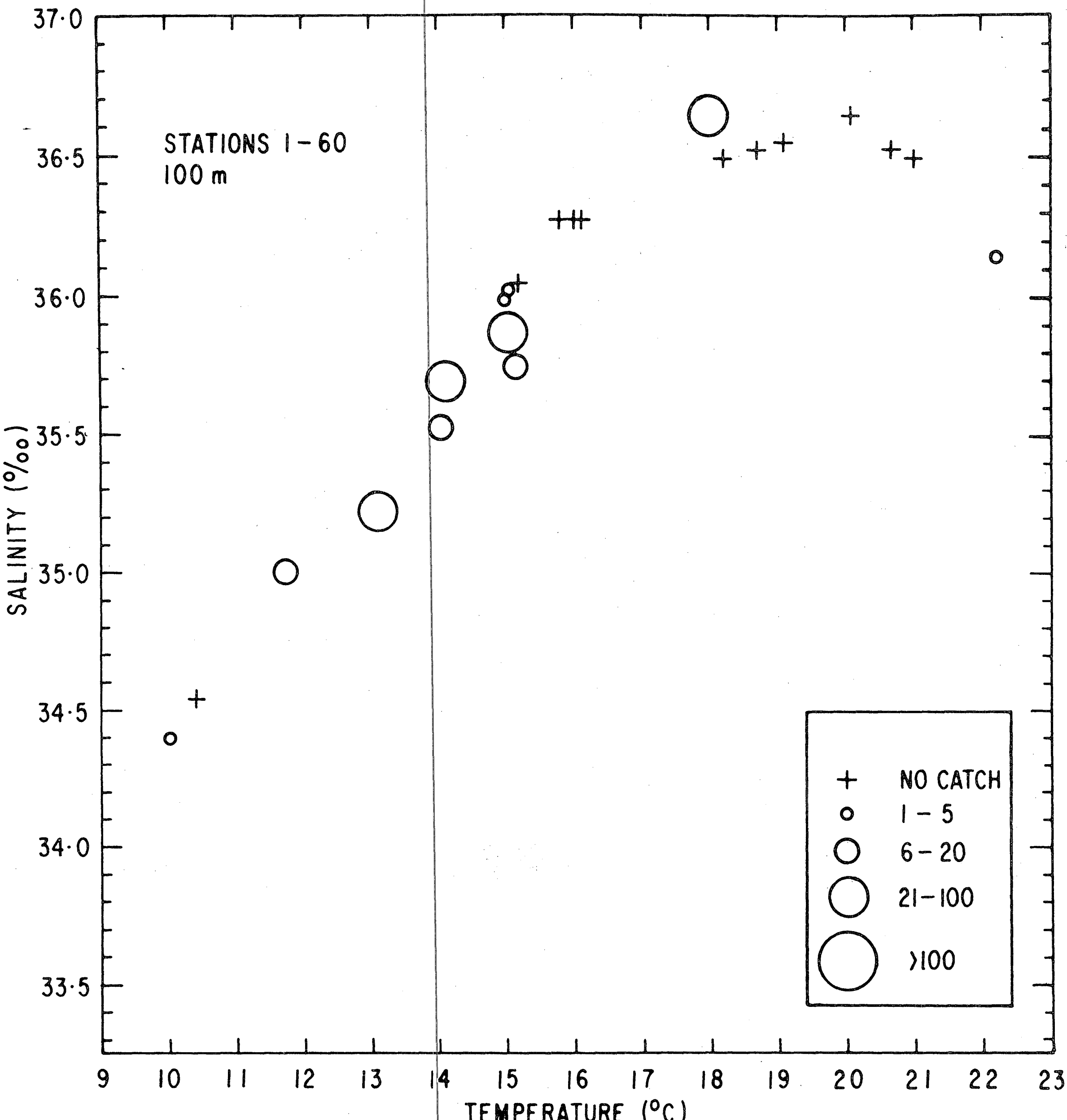


Fig. 10. Catch magnitude in relation to a Temperature-Salinity diagram for sets of Cruise 82-03.

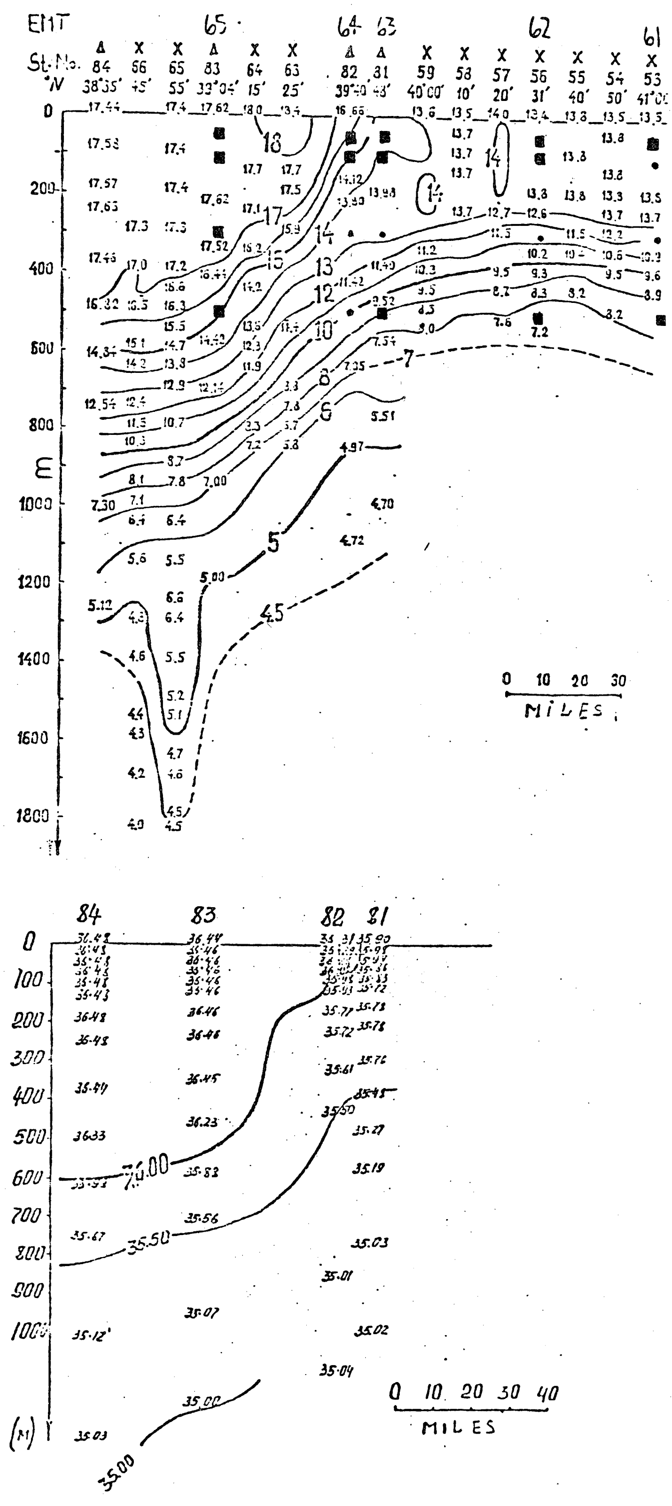


Fig. 11. Catch magnitude in relation to vertical temperature and salinity profile for Transect 1 of Cruise 82-06 (Stations 61-65). Legend as in Fig. 5.

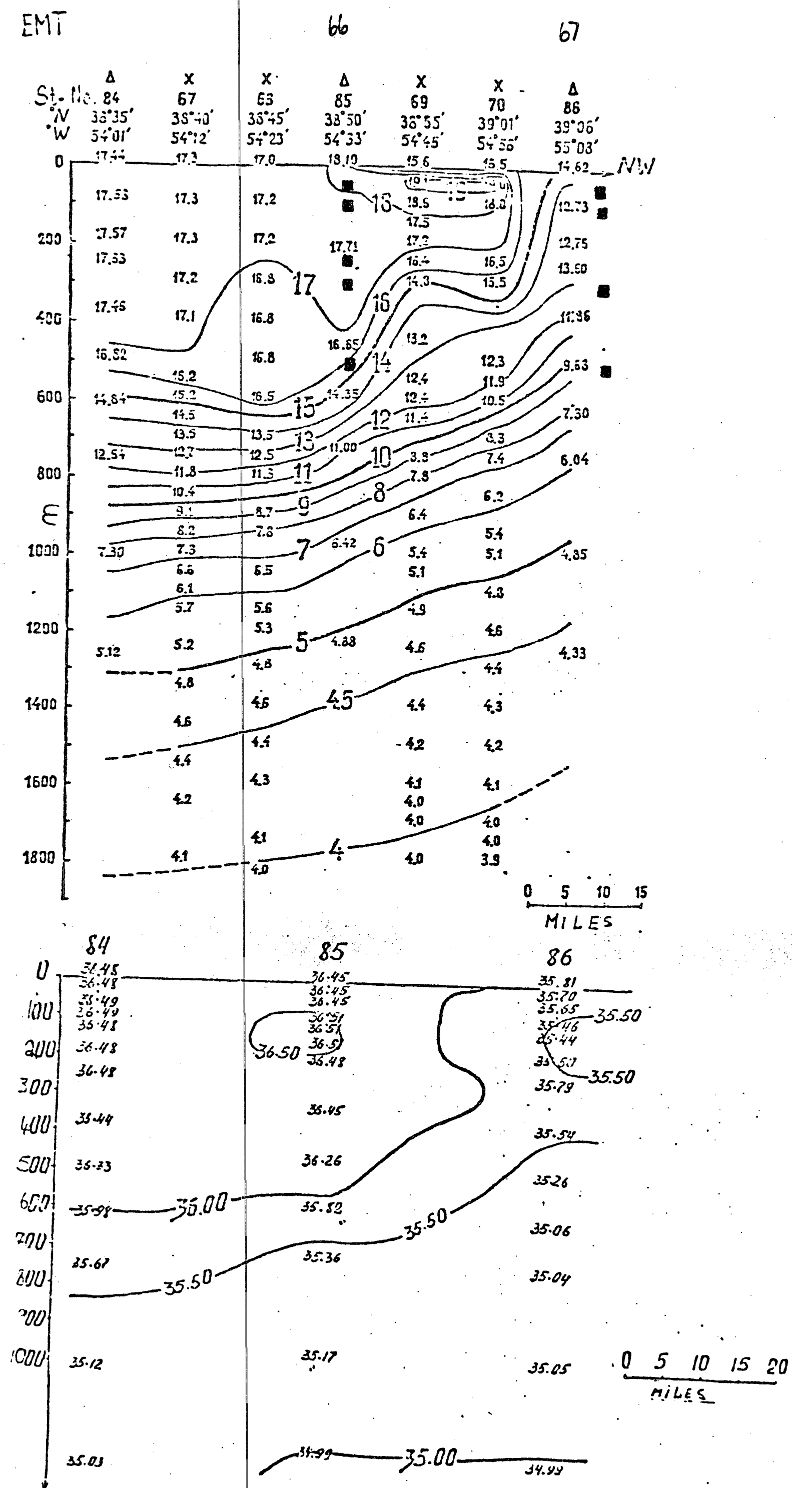


Fig. 12. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 2 of Cruise 82-06 (Stations 66-67). Legend as in Fig. 5.

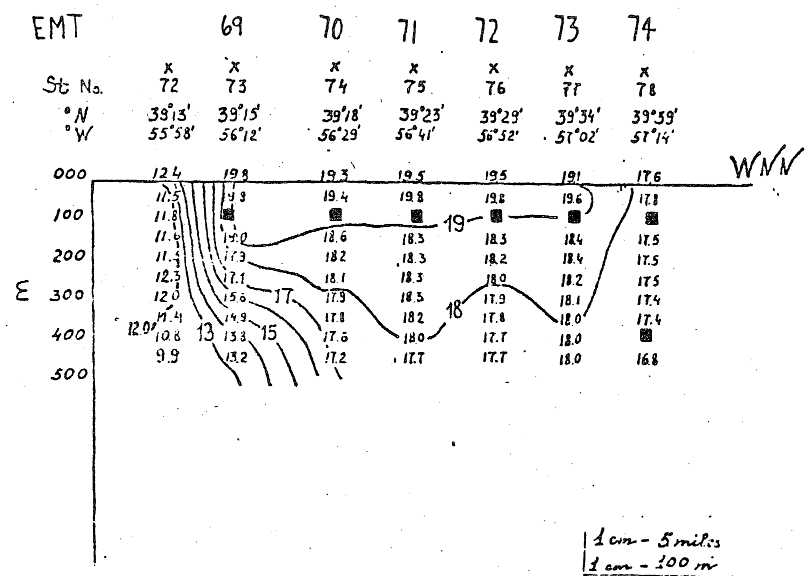


Fig. 13. Catch magnitude in relation to vertical temperature profile for Transect 3 of Cruise 82-06 (Stations 69-74). Legend as in Fig. 5.

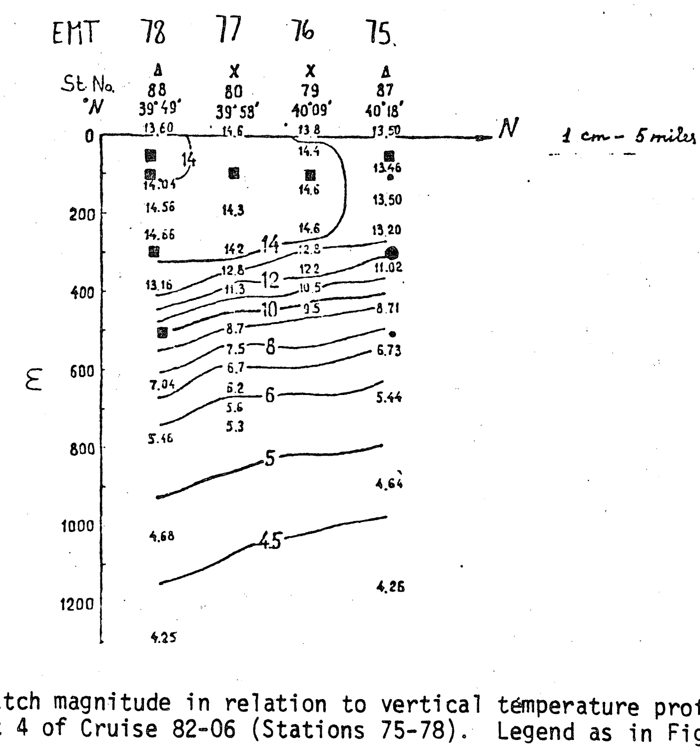


Fig. 14. Catch magnitude in relation to vertical temperature profile for Transect 4 of Cruise 82-06 (Stations 75-78). Legend as in Fig. 5.

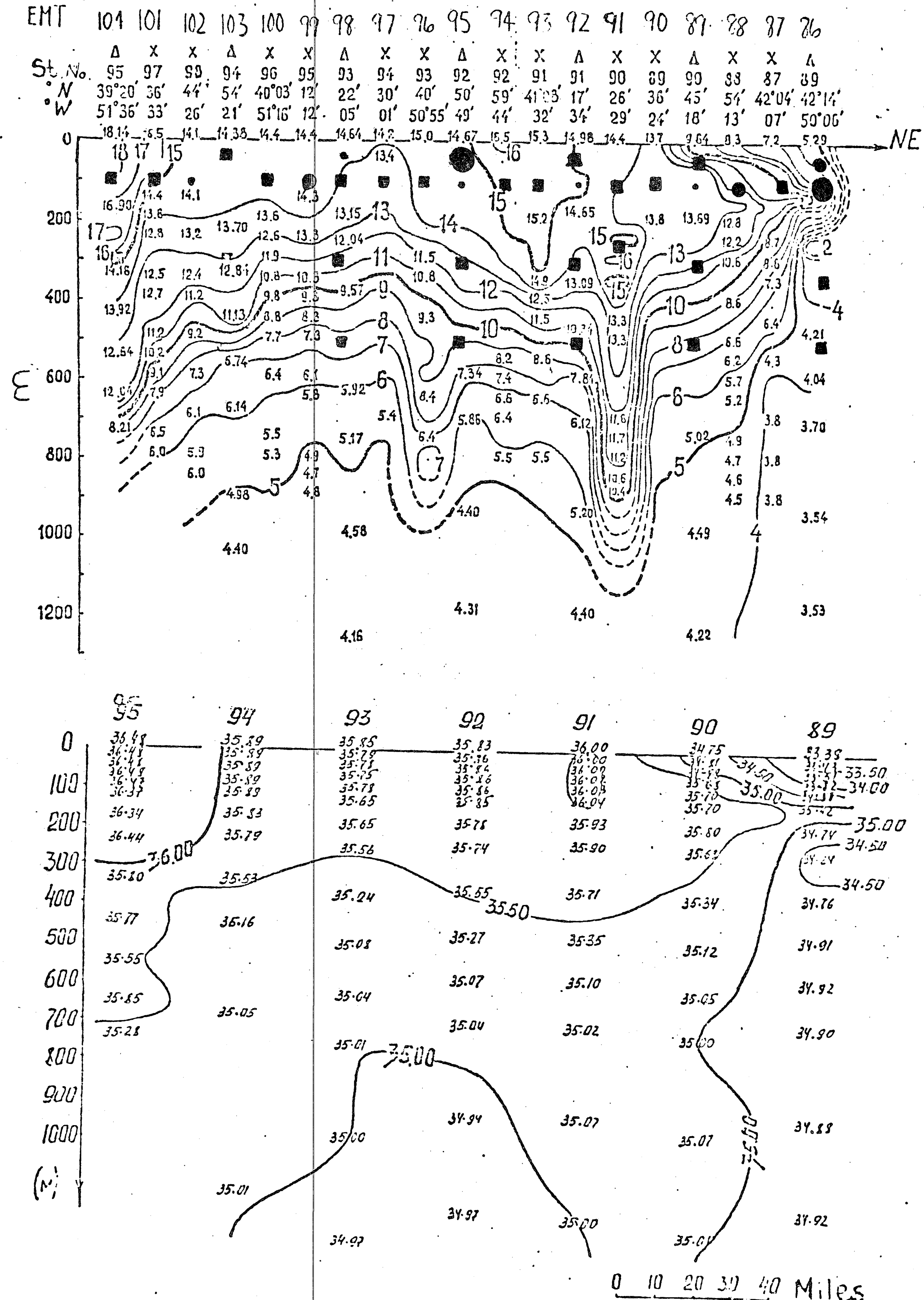


Fig. 15. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 5 of Cruise 82-06 (Stations 86-104). Legend as in Fig. 5.

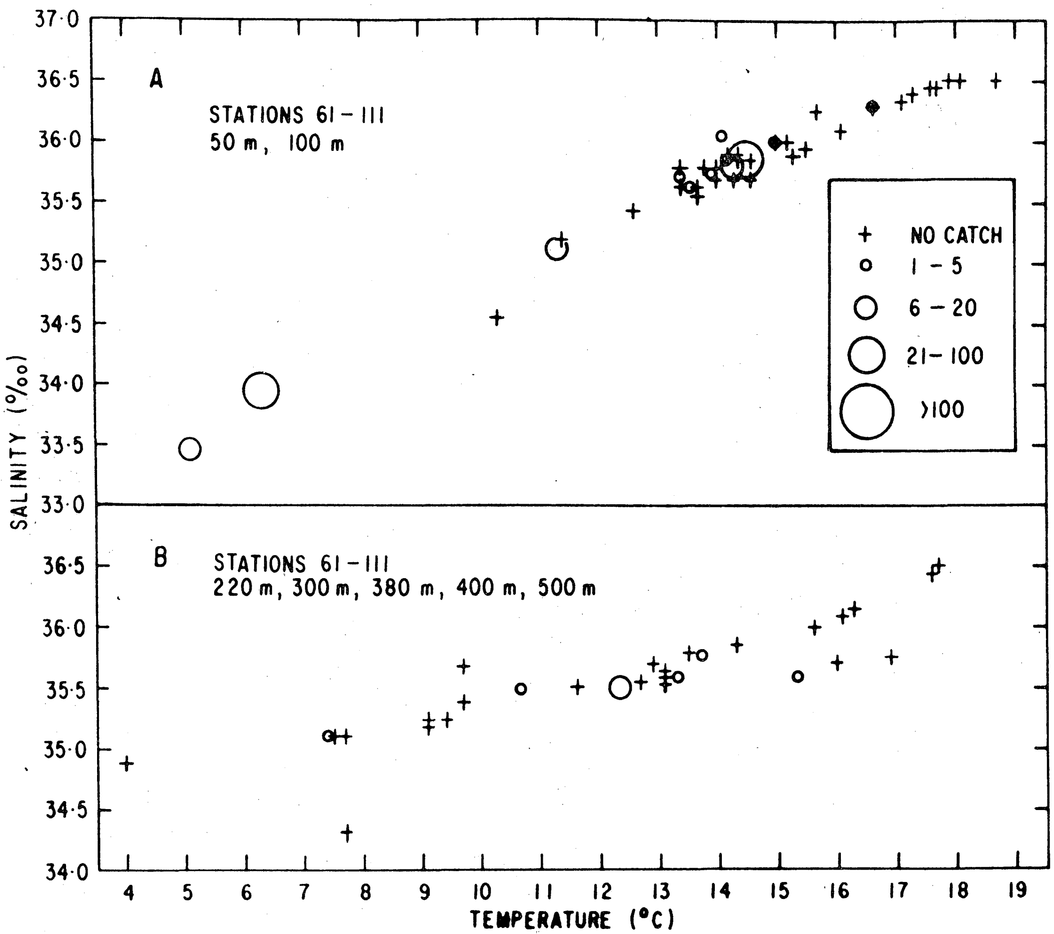


Fig. 16. Catch magnitude in relation to a Temperature-Salinity diagram for sets of Cruise 82-06.

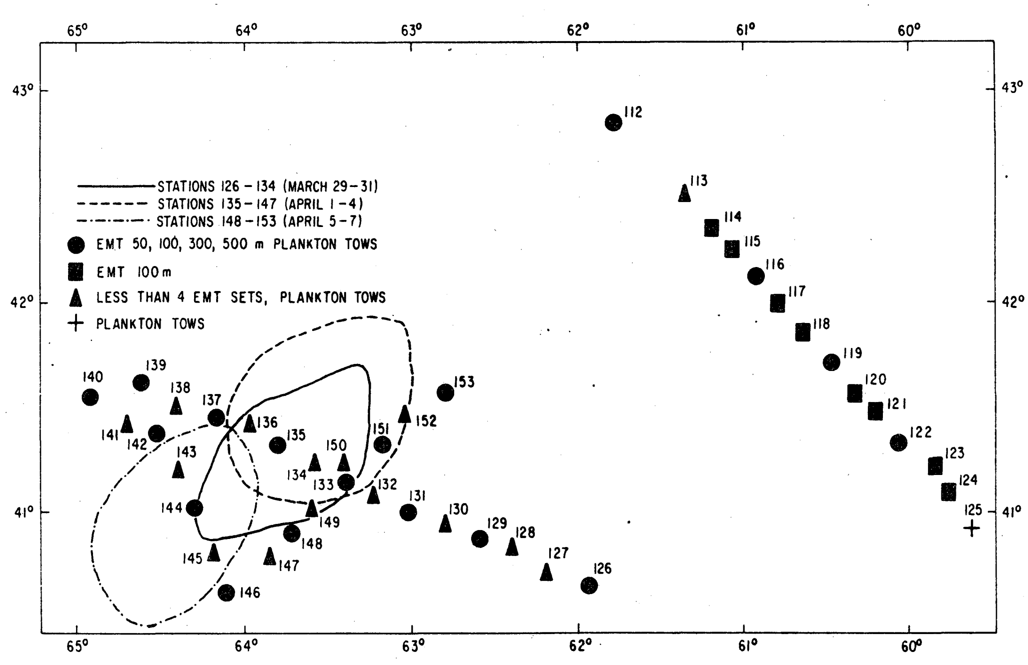


Fig. 17. Location of stations and time when stations were occupied in relation to the changing position of a warm core eddy during Cruise 82-07.

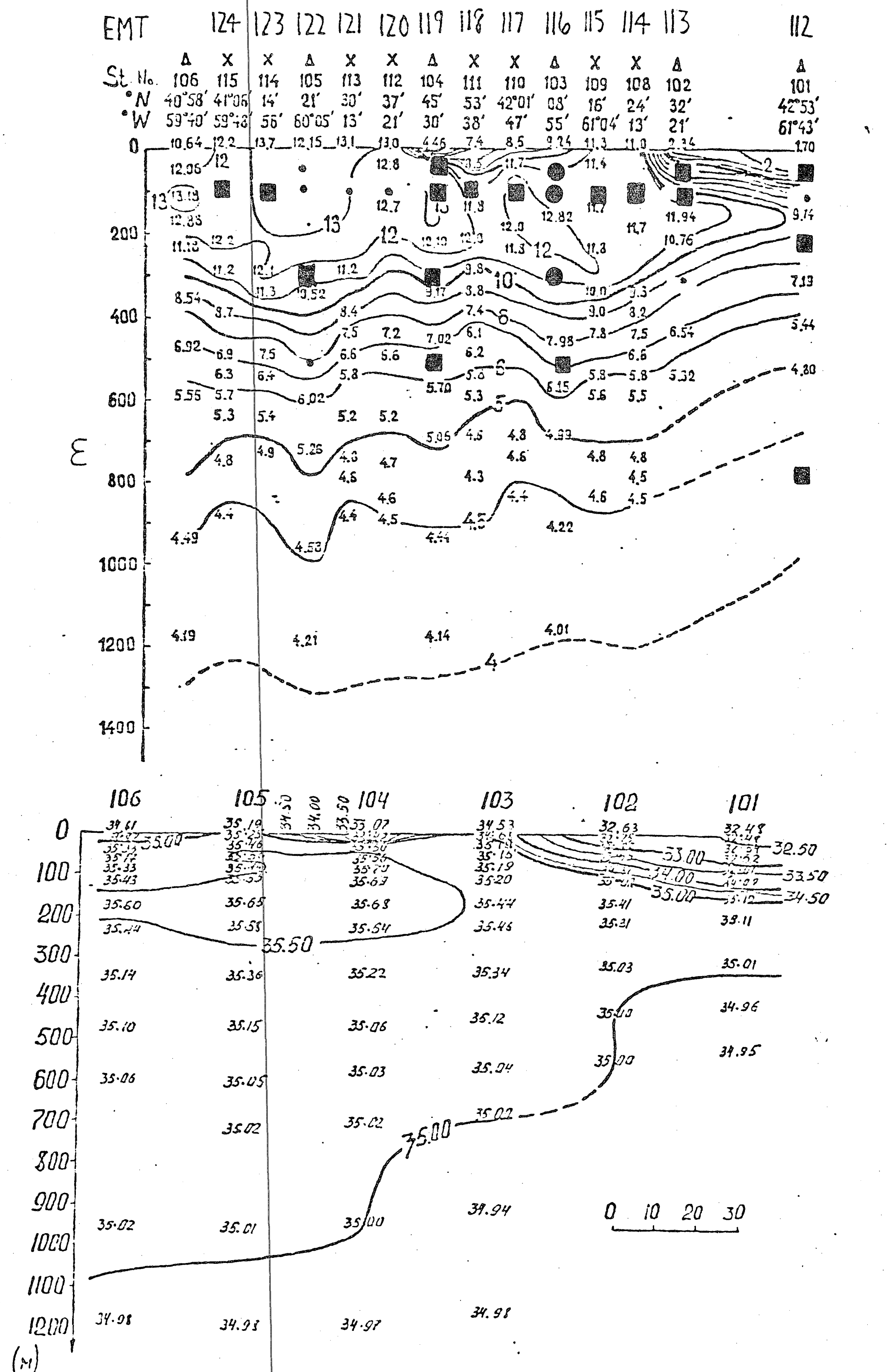


Fig. 18. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 1 of Cruise 82-07 (Stations 112-124). Legend as in Fig. 5.

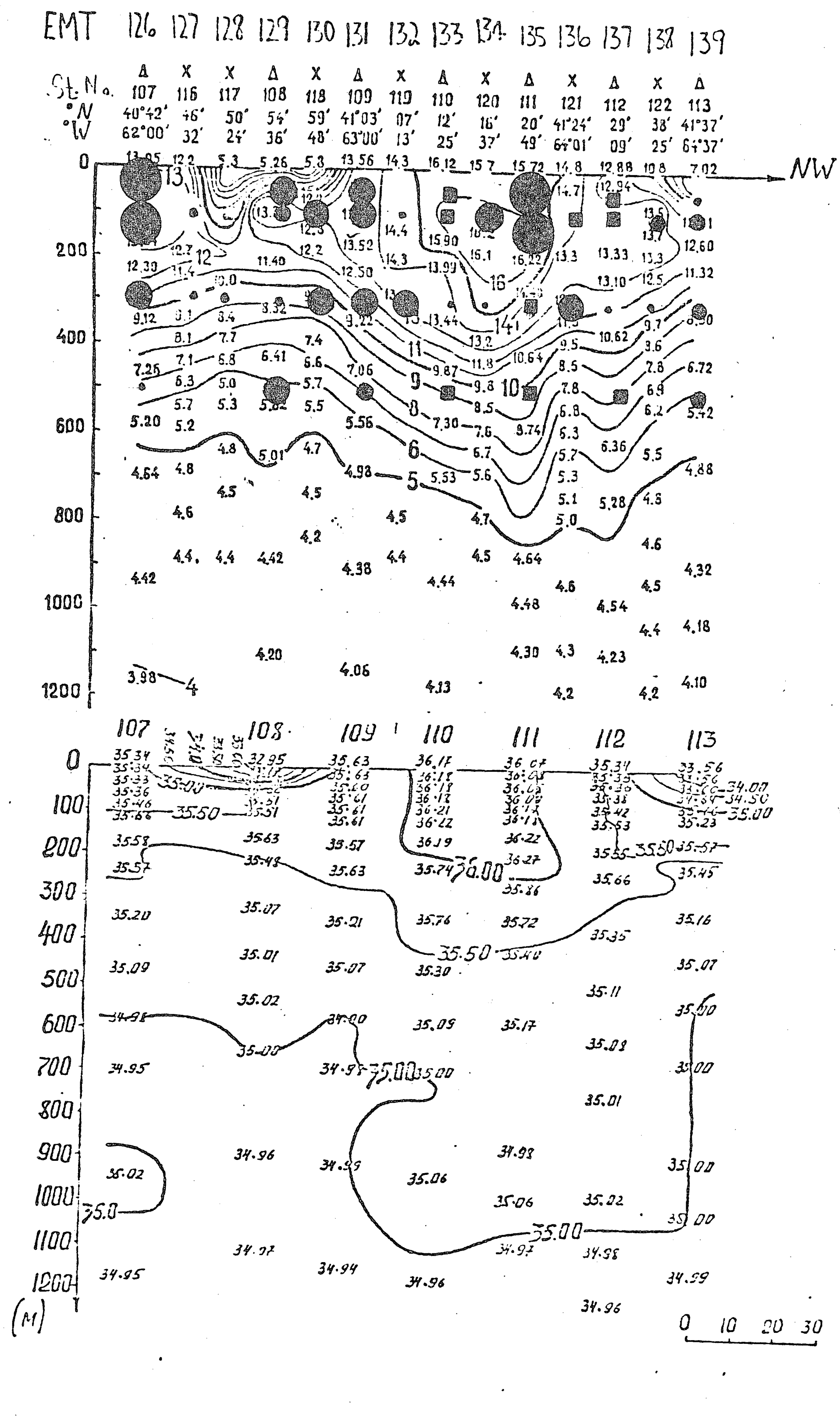


Fig. 19. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 2 of Cruise 82-07 (Stations 126-139). Legend as in Fig. 5.

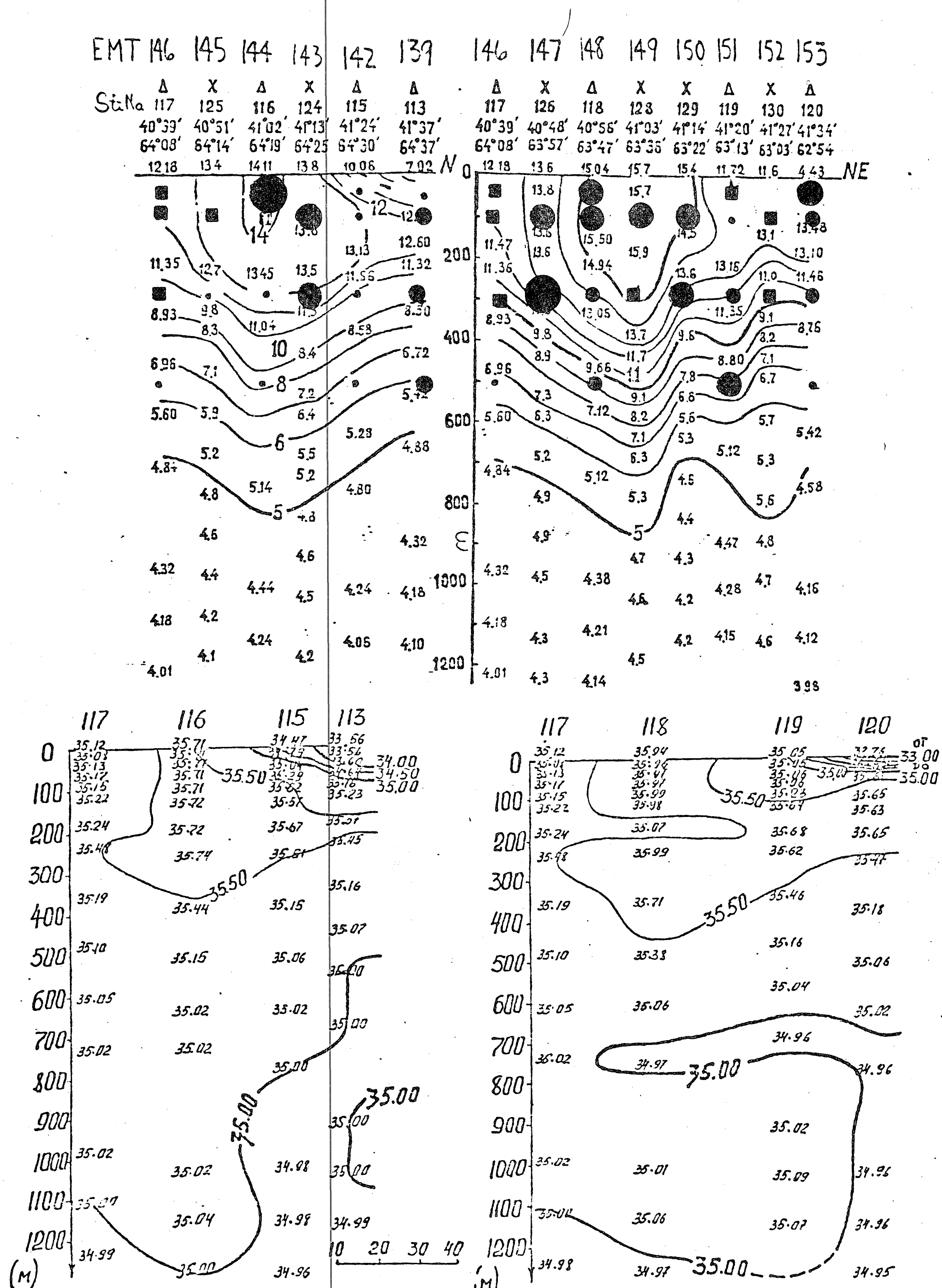


Fig. 20. Catch magnitude in relation to vertical temperature and salinity profiles for Transect 3 (Stations 139-146) and Transect 4 (Stations 146-153) of Cruise 82-07. Legend as in Fig. 5.

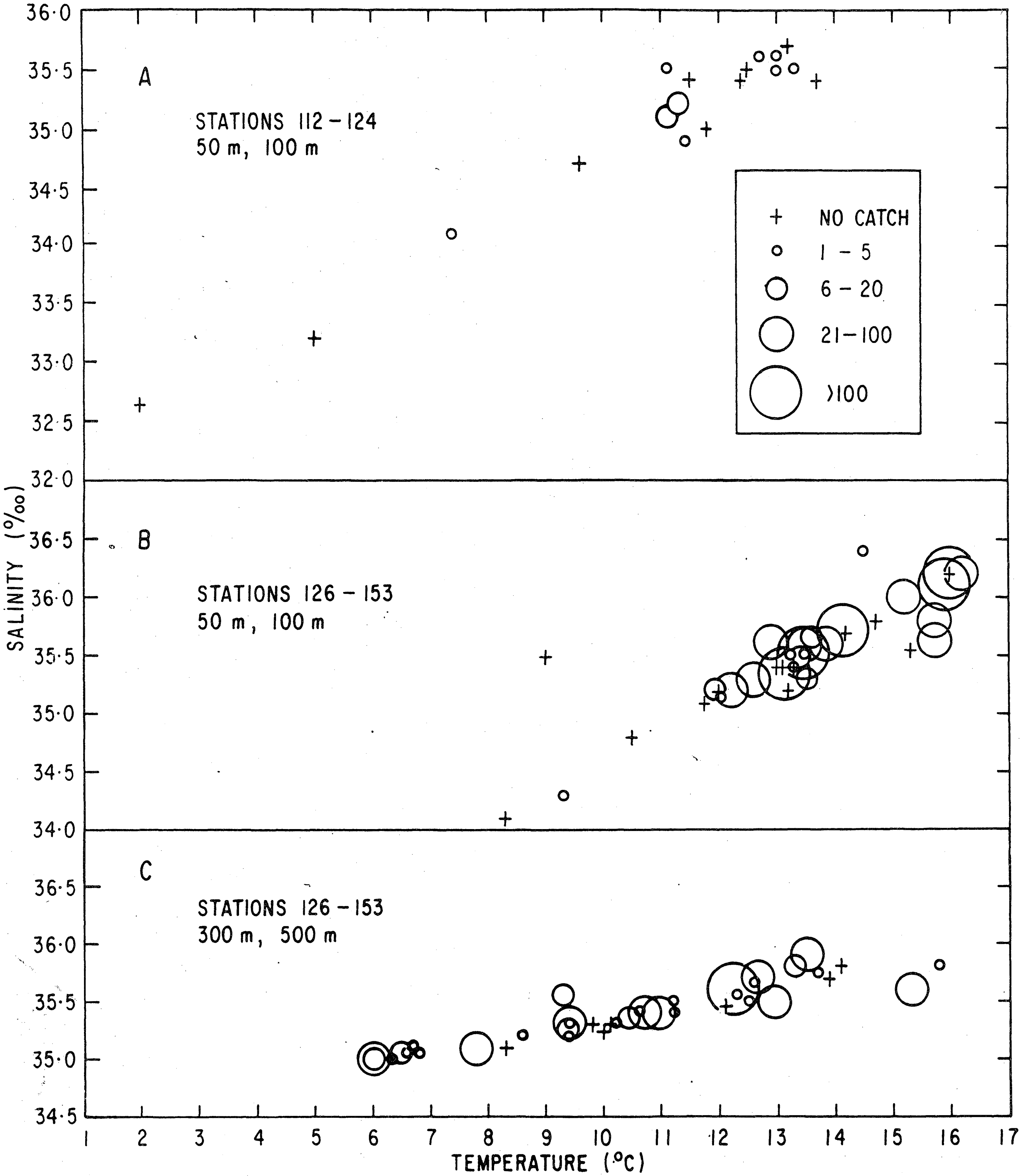


Fig. 21. Catch magnitude in relation to Temperature-Salinity diagrams for a transect within Slope Water (A) and for stations within and near a warm core eddy (B and C) during Cruise 82-07.

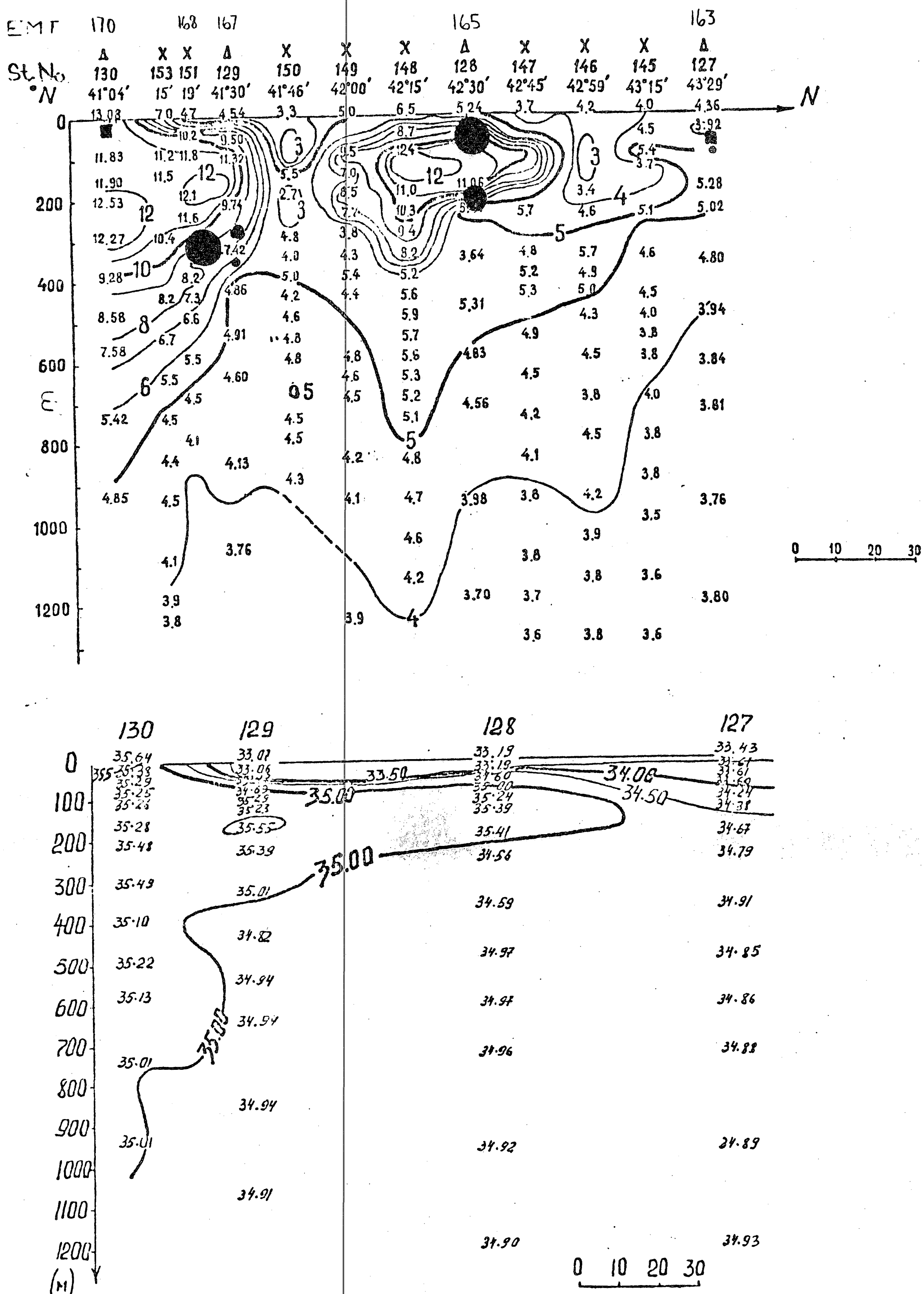


Fig. 22. Catch magnitude using EMT in relation to vertical temperature and salinity profiles for Transect 1 of Cruise 82-08 (Stations 163-170). Legend as in Fig. 5.

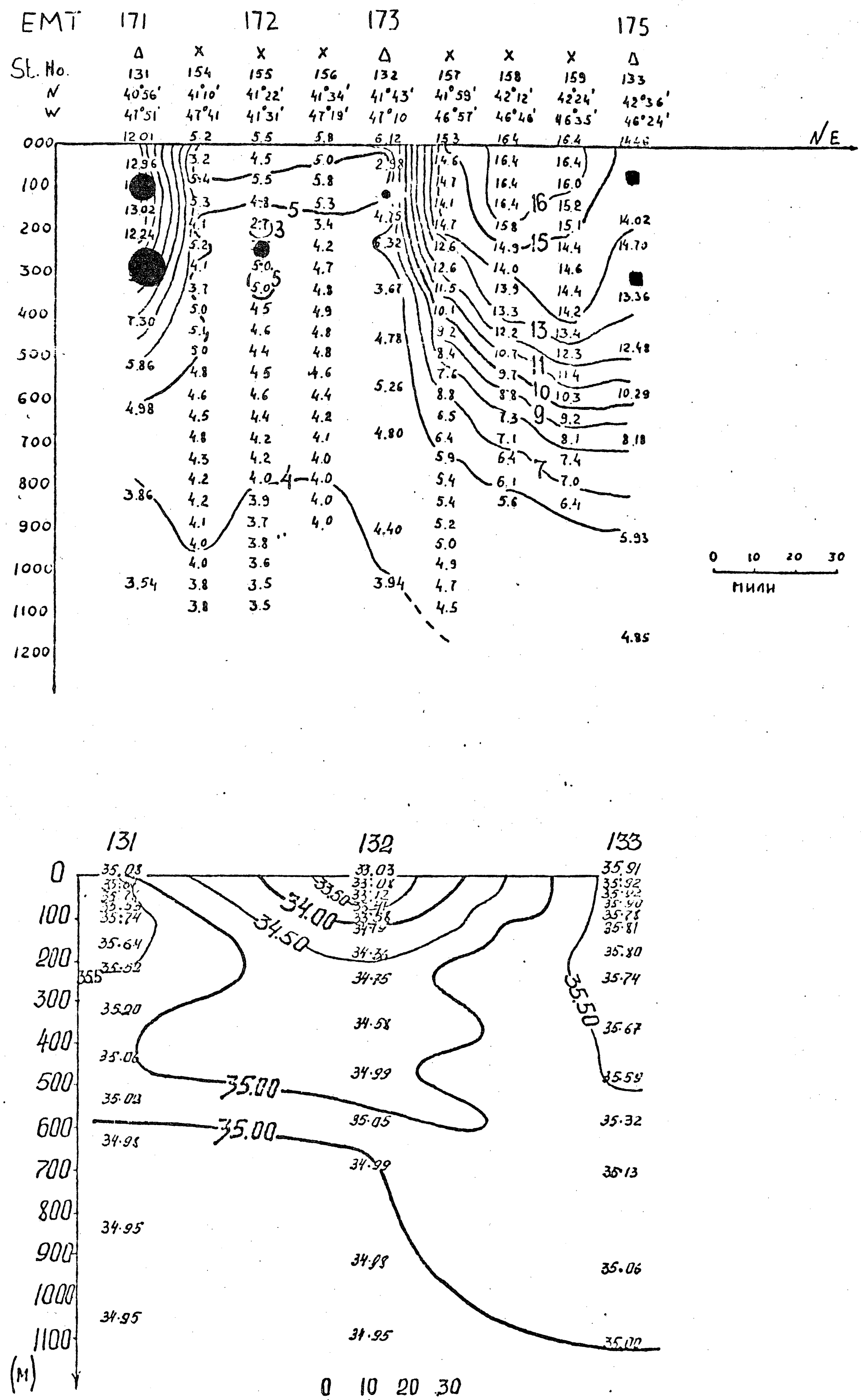
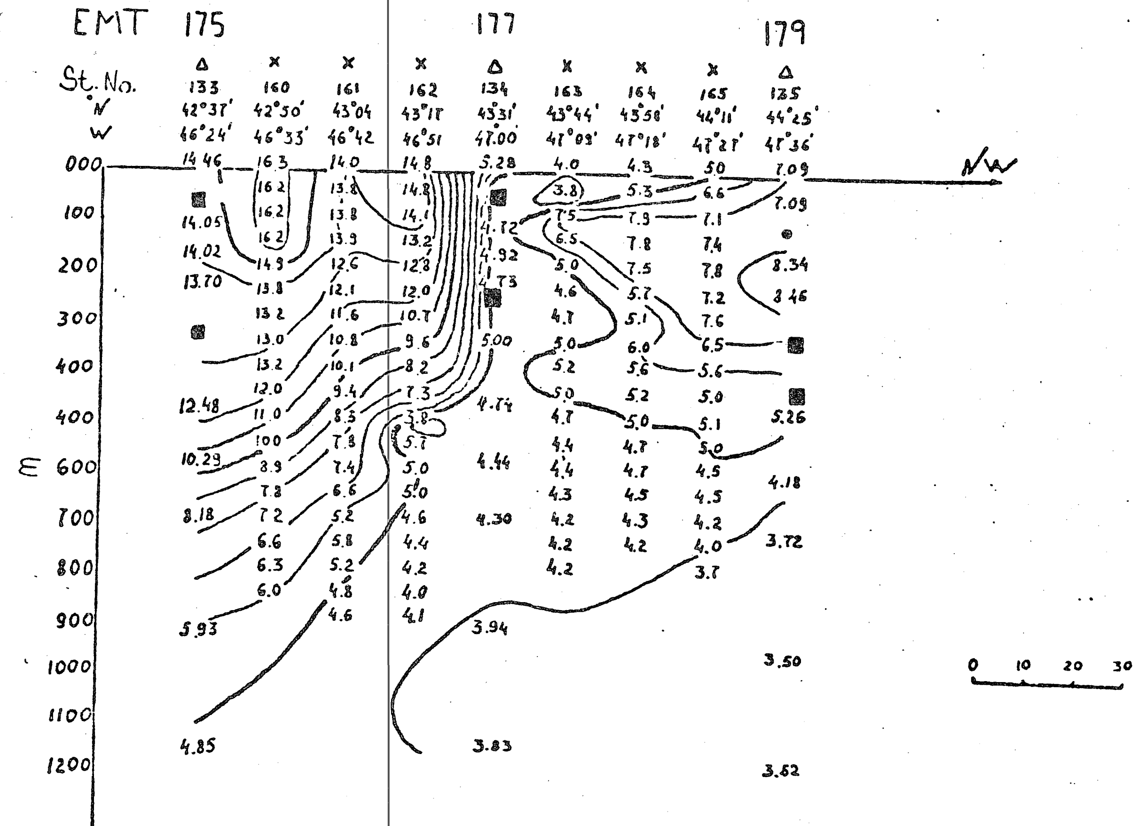


Fig. 23. Catch magnitude using EMT in relation to vertical temperature and salinity profiles for Transect 2 of Cruise 82-08 (Stations 171-175). Legend as in Fig. 5.



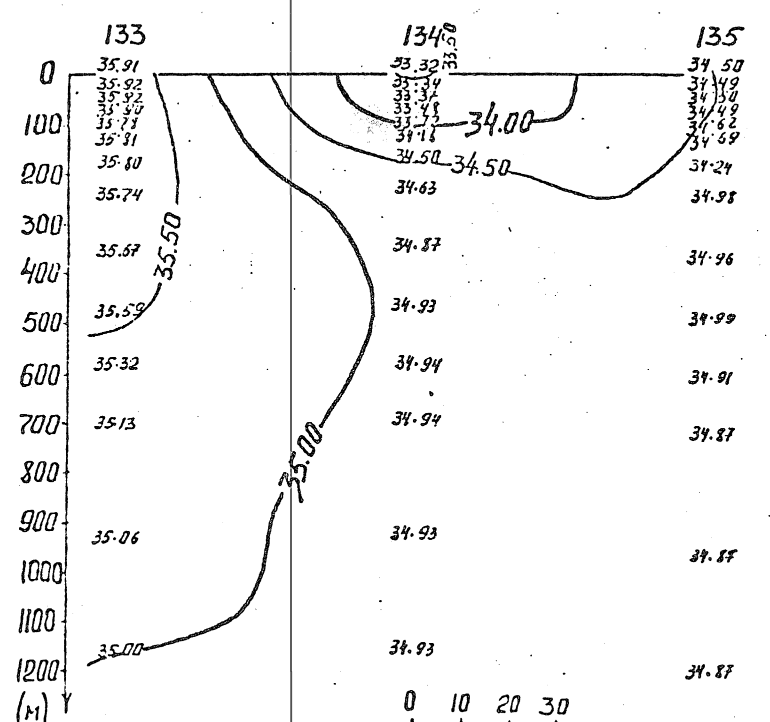


Fig. 24. Catch magnitude using EMT in relation to vertical temperature and salinity profiles for Transect 3 of Cruise 82-08 (Stations 175-179). Legend as in Fig. 5.

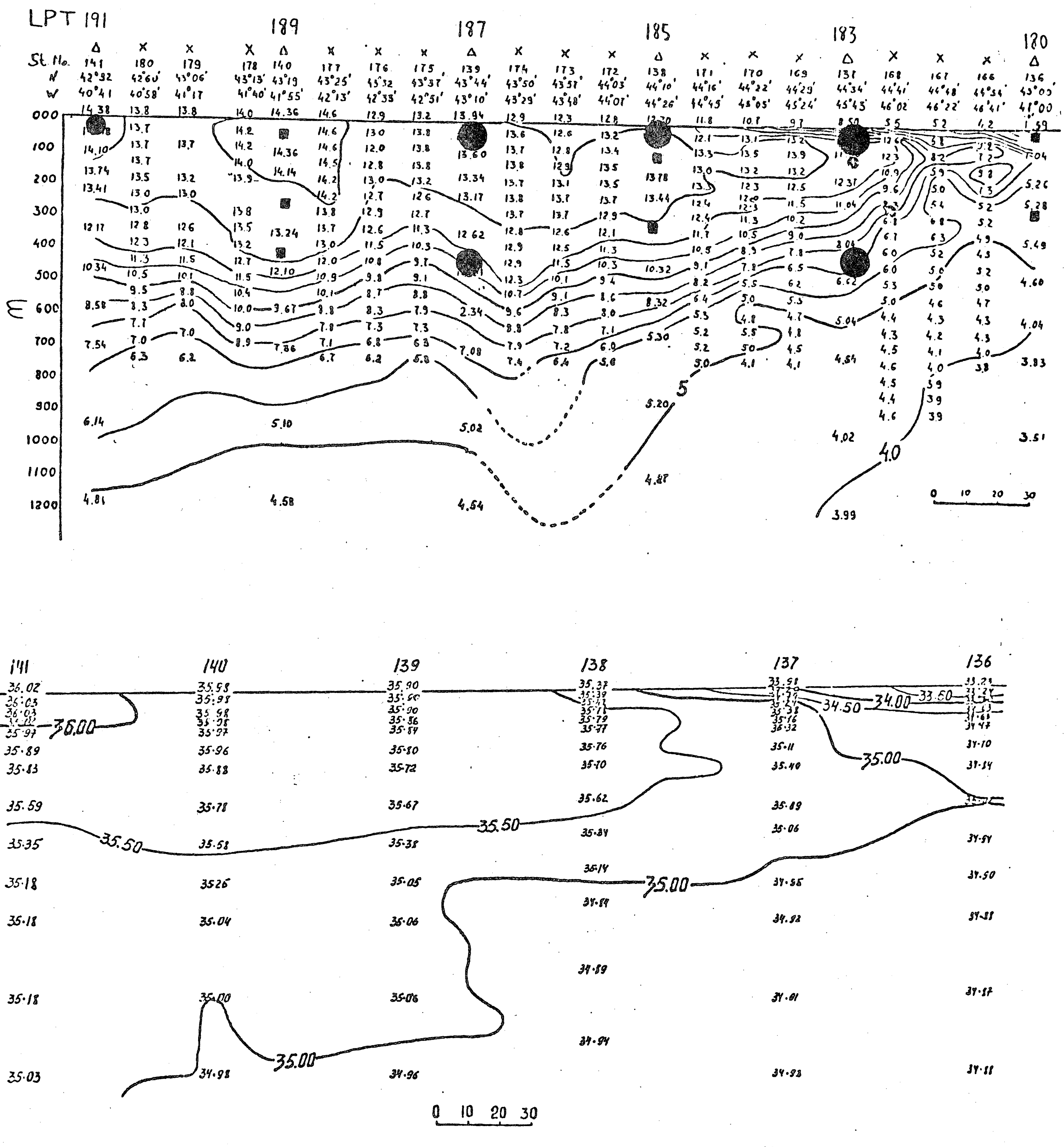
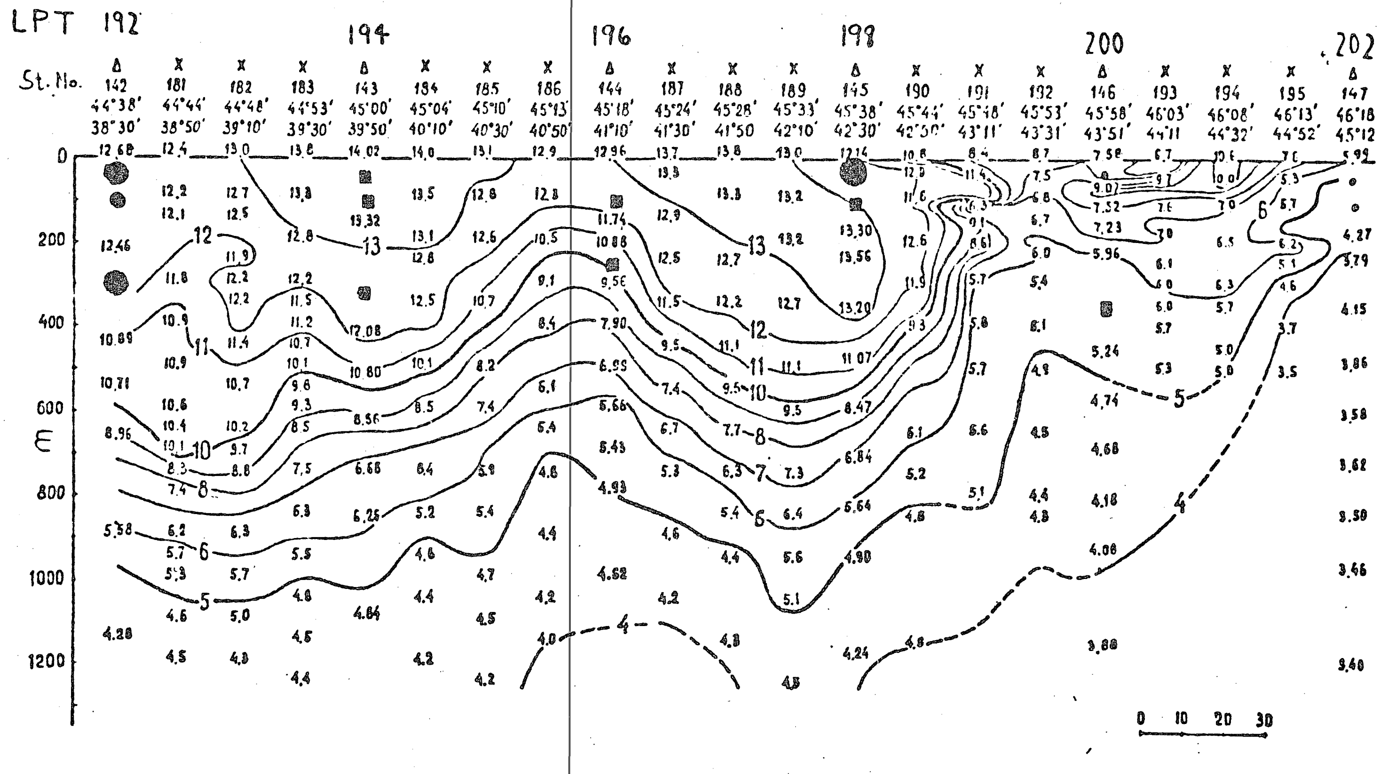


Fig. 25. Catch magnitude using a large pelagic trawl in relation to vertical temperature and salinity profiles for Transect 4 of Cruise 82-08. (Stations 180-191). Legend as in Fig. 5.



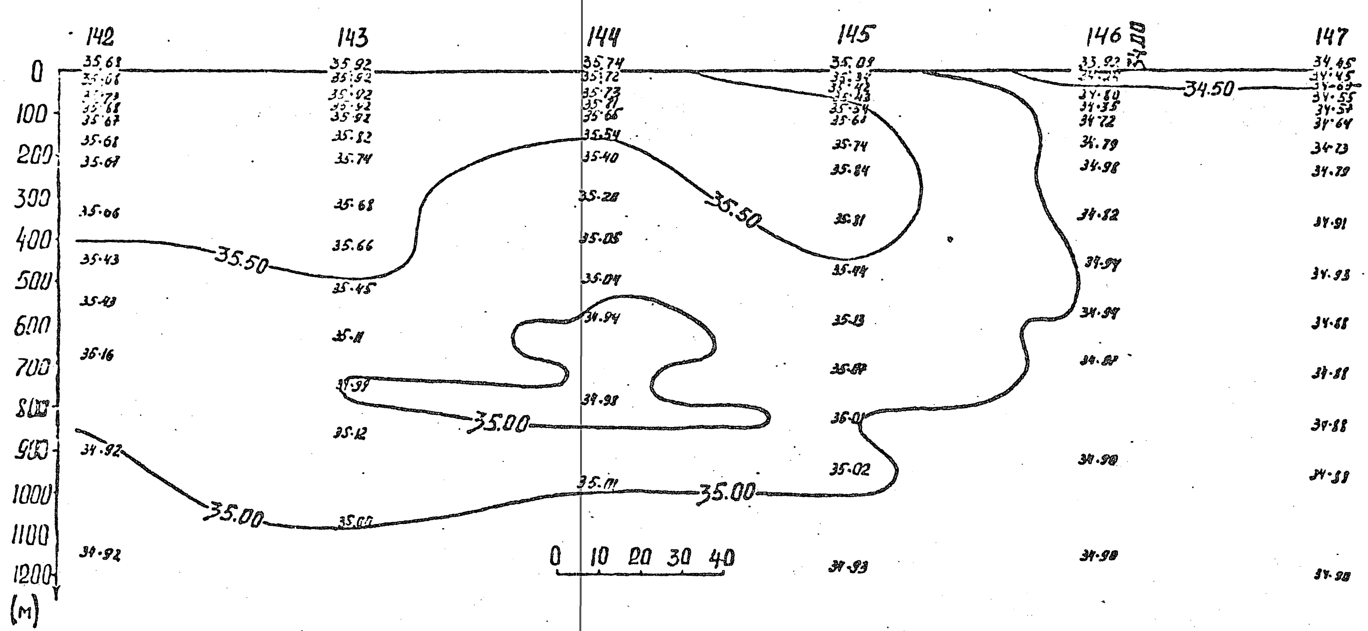


Fig. 26. Catch magnitude using a large pelagic trawl in relation to vertical temperature and salinity profiles for Transect 5 of Cruise 82-08. (Stations 192-202). Legend as in Fig. 5.

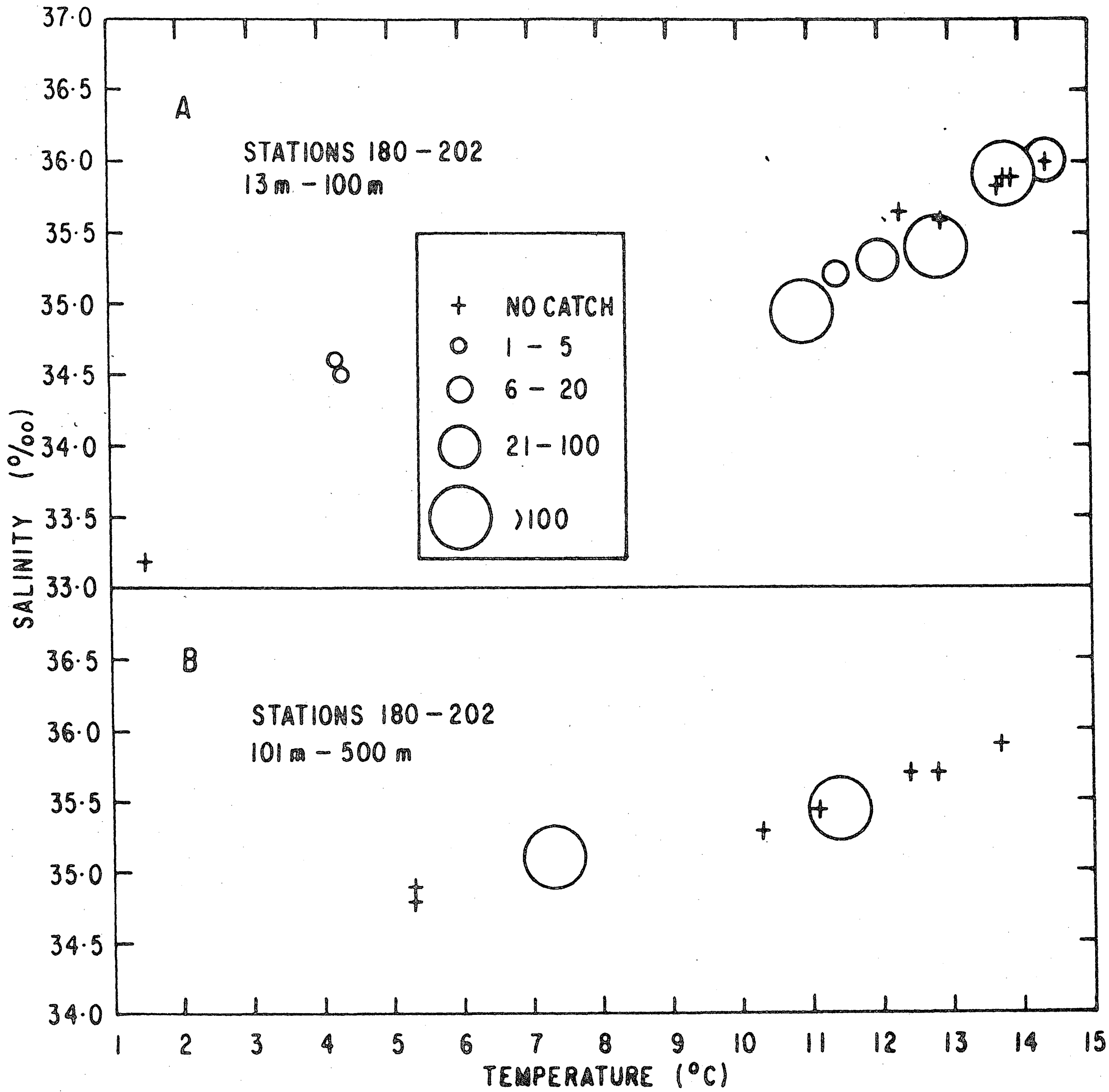


Fig. 27. Catch magnitude using a large pelagic trawl in relation to a Temperature-Salinity diagram for Transects 4 and 5 of Cruise 82-08 (Stations 180-202). Legend as in Fig. 5.

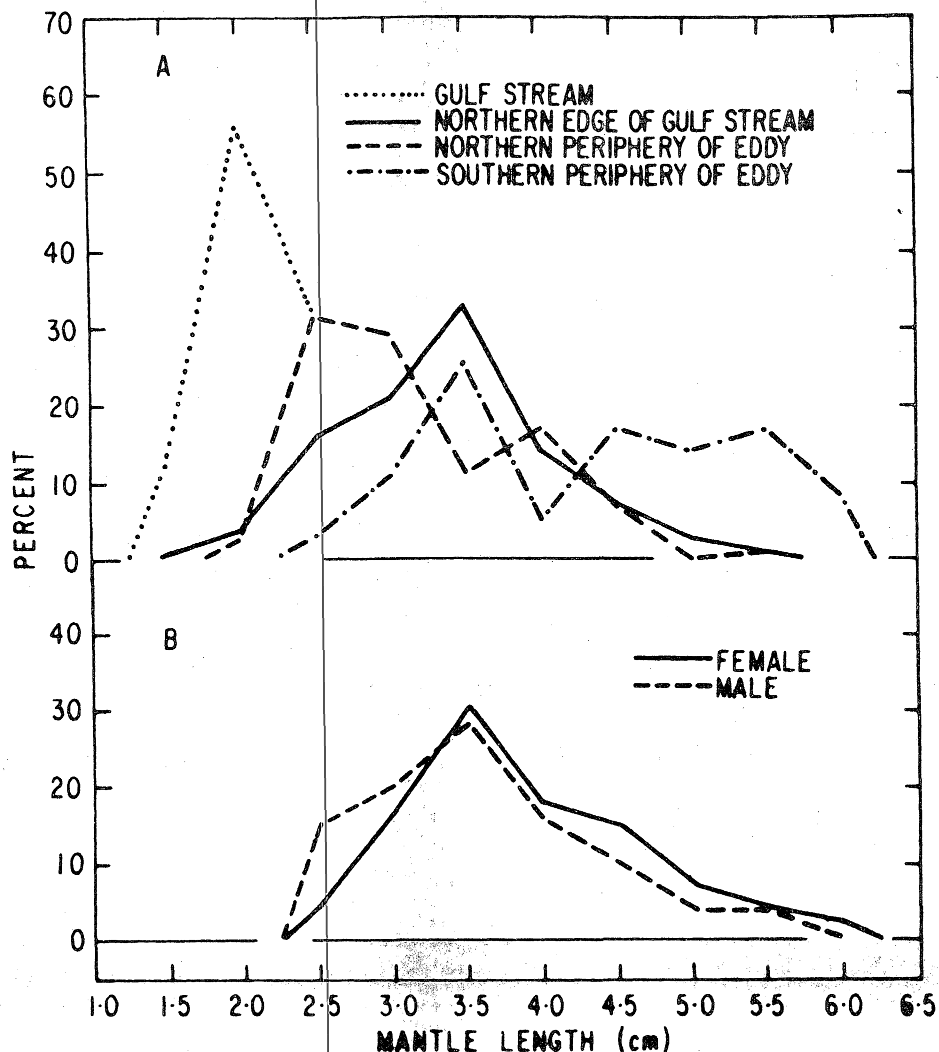


Fig. 28. Length frequency distributions for Cruise 82-03 for samples from different water masses (A) as well as for sexed specimens collected throughout the cruise (B).

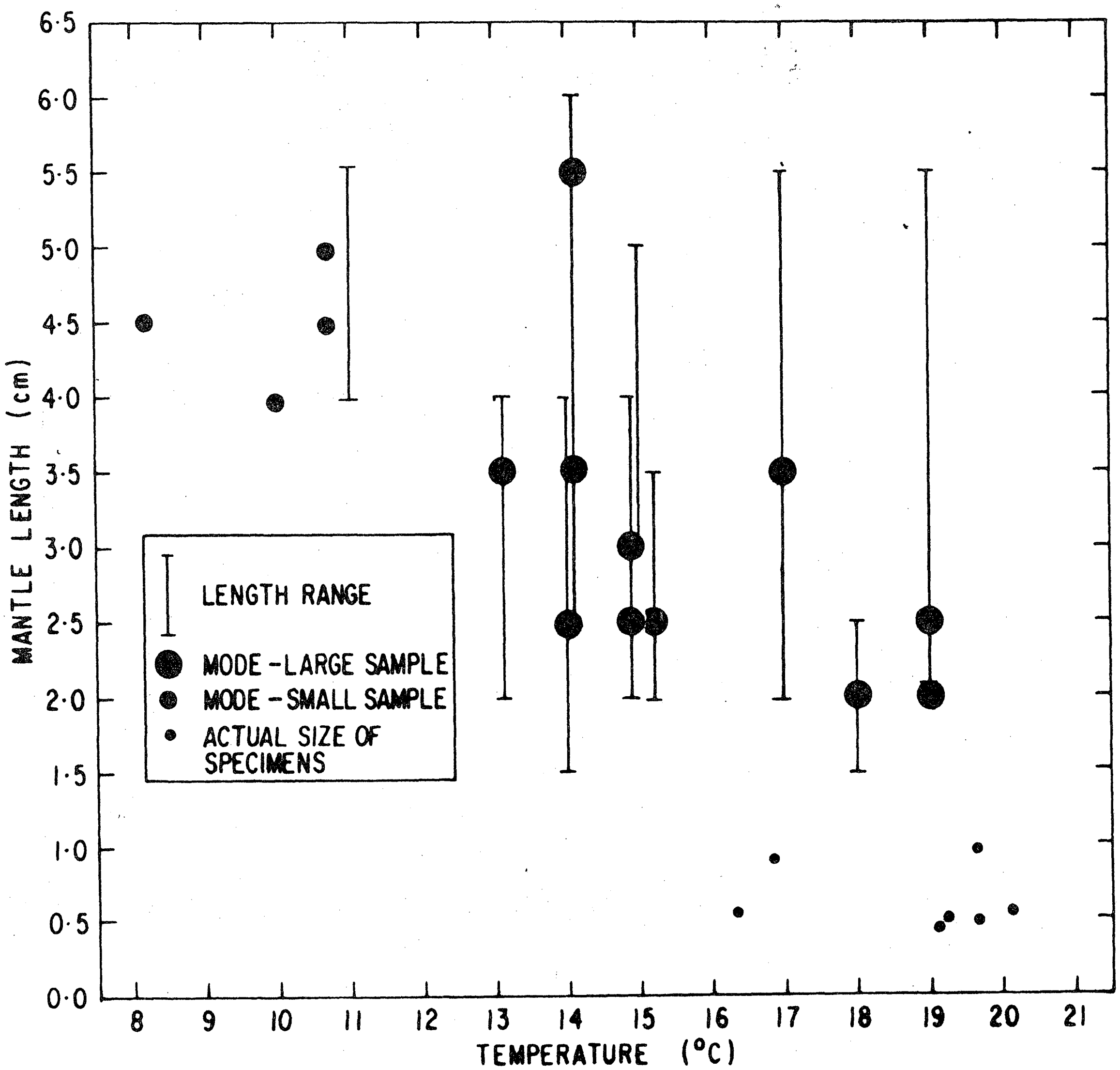


Fig. 29. Range and mode of length vs. temperature for samples collected during Cruise 82-03.

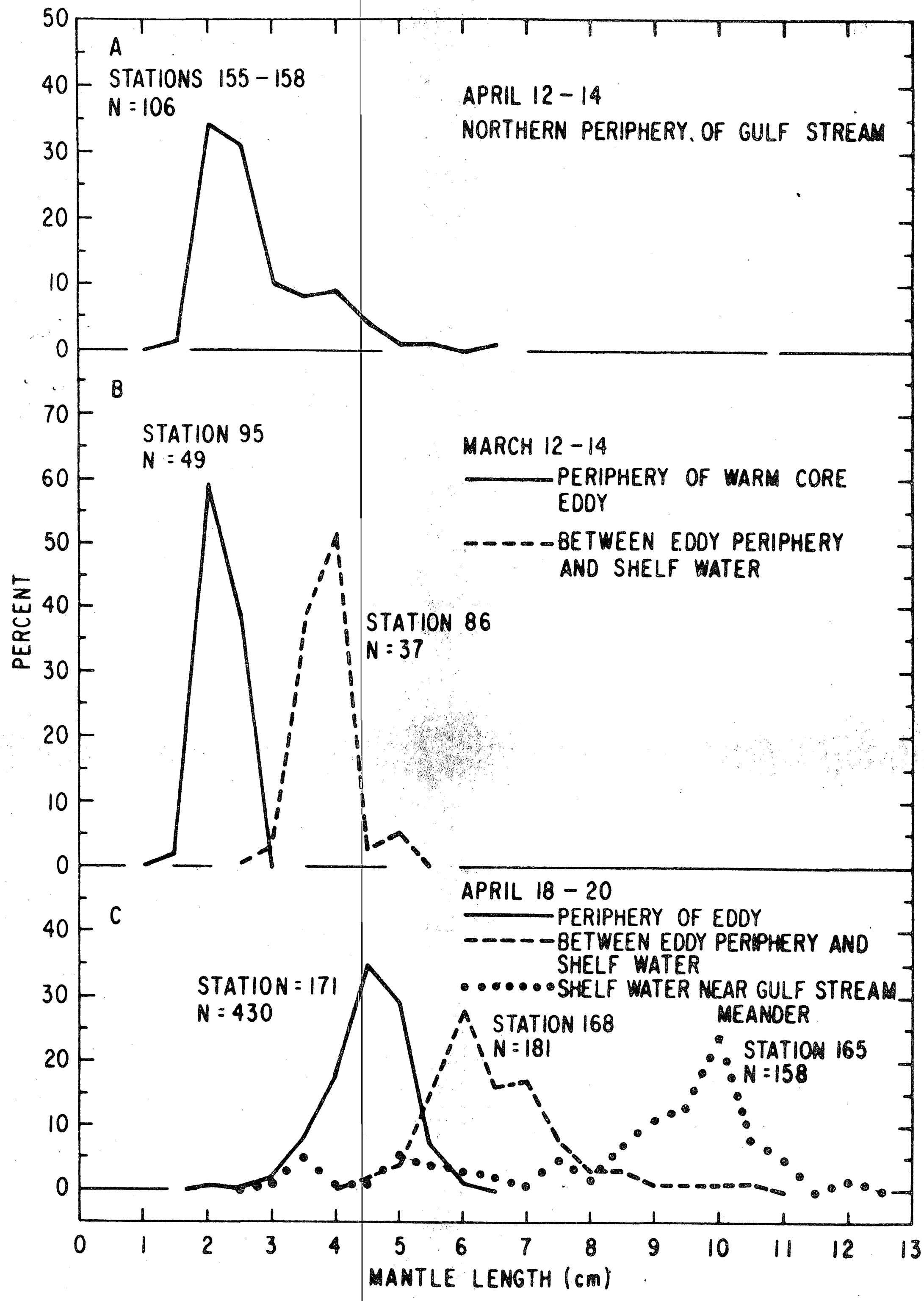


Fig. 30. Length frequency distribution of juveniles collected from various water masses at approximately 51°W-61°W (A), 50°W-50°40'W (B), and east of the Grand Bank at 48°30'W (C).

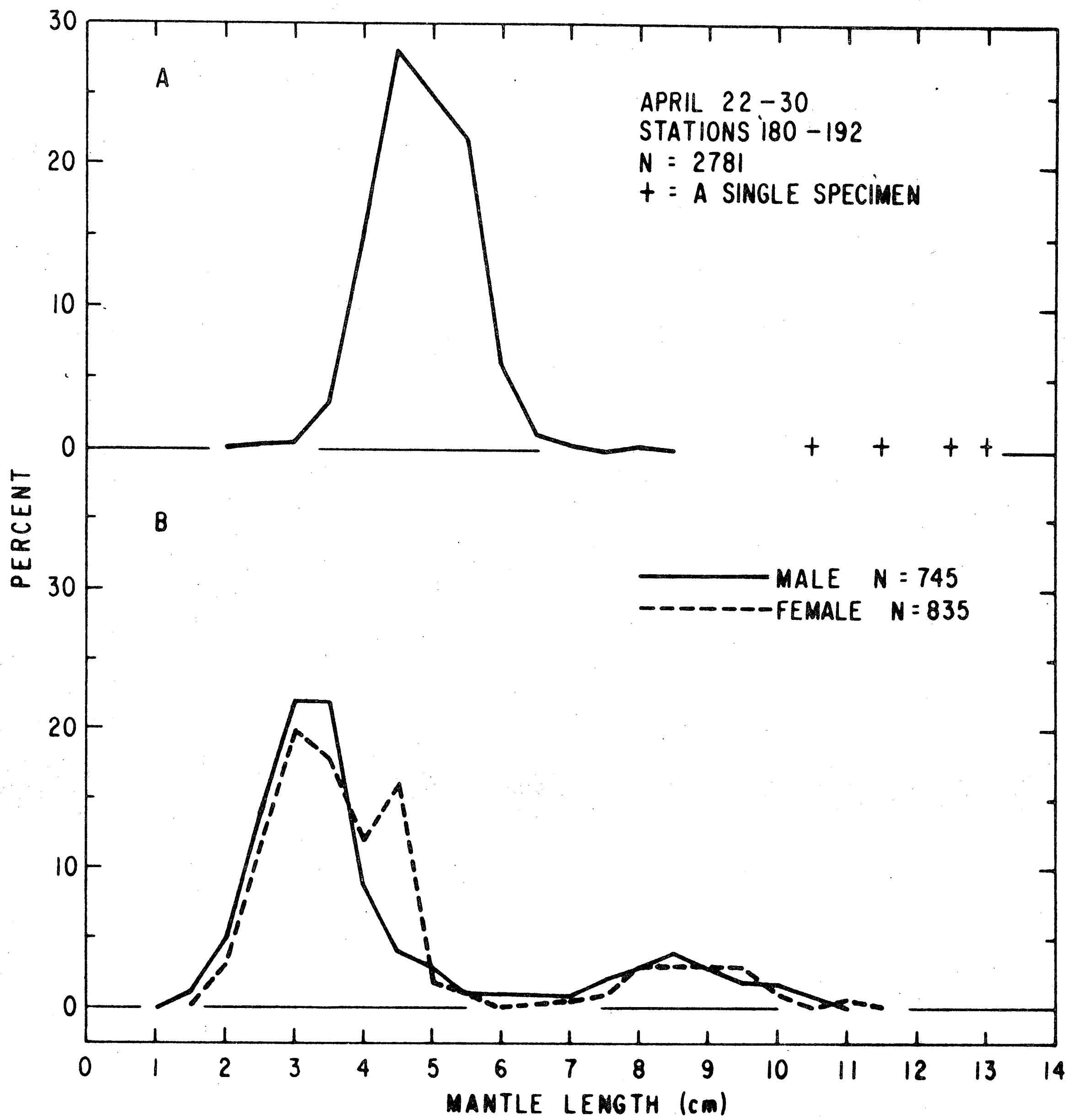


Fig. 31. Length frequency distributions of juveniles collected using a large pelagic trawl at the northeastern extreme of the survey area (A) and of sexed juveniles collected throughout the survey (B).

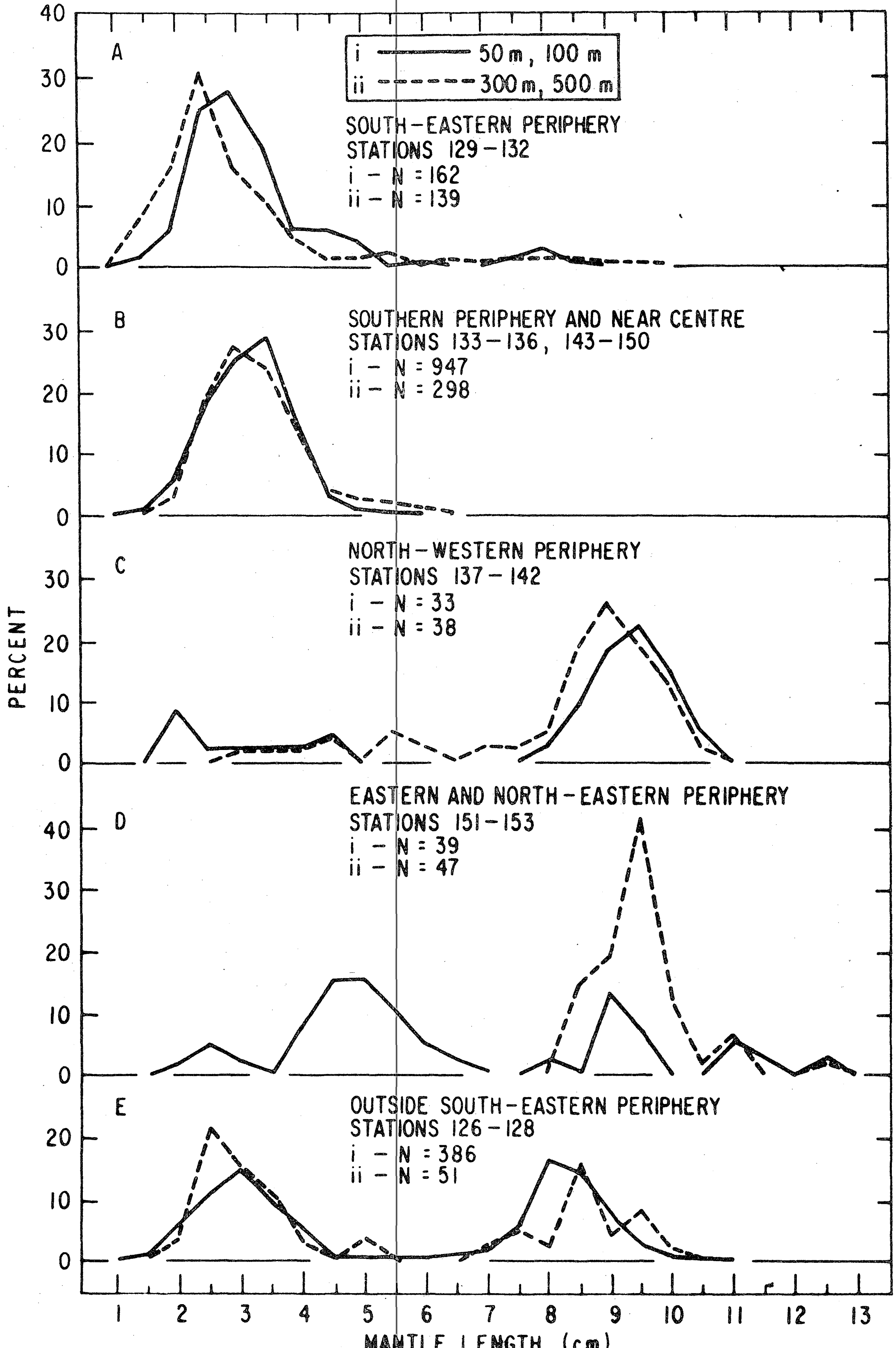


Fig. 32. Length frequency distributions of juveniles collected at various regions within and near a warm core eddy during Cruise 82-07.

Appendix A

Sampling operations at stations occupied by the EVRIKA during the entire survey, February 4-April 30, 1982

Station No.	Depth of Midwater Trawl (m)					Depth of Bongo Tows		Hydrography	
	50	100	300	500	Others	0-200	10, 5, 1	Bathy.	XBT
		EMT							
82-03									
1		+				+	+	+	
2							+		+
3						+	+	+	
4							+		+
5						+	+	+	
6							+		+
7		+				+	+	+	
8							+		+
9						+	+	+	+
10		+				+	+	+	
11		+				+	+	+	+
12							+		+
13						+	+	+	
14							+		+
15		+				+	+	+	
16							+		+
17						+	+	+	
18							+		+
19		+				+	+	+	
20						+	+		+
21						+	+		+
22		+				+	+	+	
23							+		+
24						+	+	+	
25							+		+
26						+	+	+	
27							+		+
28		+				+	+	+	
29							+		+
30						+	+	+	
31							+		+
32						+	+	+	
33							+		+
34		+				+	+	+	
35						+	+		+
36						+	+	+	
37						+	+		+
38		+				+	+	+	
39						+	+		+
40						+	+		+
41		+				+	+		+
42						+	+		+
43		+				+	+		+
44						+	+		+
45						+	+		+
46		+				+	+		+
47		+				+	+		+
48		+				+	+		+
49		+				+		+	
50		+				+			+
51		+				+		+	
52		+				+			+
53		+				+		+	
54		+				+			+
55		+				+		+	
56		+				+			+
57		+			350	+		+	
58		+				+		+	
59		+				+		+	
60		+				+		+	

Station No.	Depth of Midwater Trawl (m)					Depth of Bongo Tows		Hydrography	
	50	100	300	500	Others	0-200	10, 5, 1	Bathy.	XBT
82 06									
61	+	+	+	+		+		+	+
62	+	+	+	+		+	+		+
63	+	+	+	+		+	+	+	
64	+	+	+	+		+	+	+	
65	+	+	+	+		+	+	+	
66	+	+	+	+	220	+	+	+	
67	+	+	+	+		+	+	+	
68		+							+
69		+							+
70		+							+
71		+							+
72		+							+
73		+							+
74		+			400				+
75	+	+	+	+		+		+	
76		+					+		+
77		+					+		+
78	+	+	+	+		+	+	+	
86	+	+		+	350	+	+	+	
87		+							+
88		+							+
89	+	+	+	+		+	+	+	
90		+							+
91		+			285				+
92	+	+	+	+		+	+	+	
93		+							
94		+							
95	+	+	+	+		+	+		
96		+							
97		+							
98	+	+	+	+		+	+		
99		+							
100		+							+
101		+							+
102		+							+
103	+		+			+	+	+	
104		+	+					+	
105	+	+	+	+		+			+
106	+	+	+			+	+	+	
107	+	+	+			+			+
108	+	+	+			+			+
109	+	+							+
110		+			40				+
111		+	+						+
82-07									+
112	+	+			780, 230	+	+	+	
113	+	+	+			+	+	+	
114		+							+
115		+							+
116	+	+	+	+		+	+	+	
117		+							+
118		+							+
119	+	+	+	+		+	+	+	
120		+							+
121		+							+
122	+	+	+	+		+	+	+	
123		+							+
124		+							+
125						+		+	
126	+	+	+	+		+	+	+	
127		+	+			+	+		+
128		+	+			+	+		+
129	+	+	+	+		+	+	+	
130		+	+			+	+		+

Station No.	Depth of Midwater Trawl (m)					Depth of Bongo Tows		Hydrography	
	50	100	300	500	Others	0-200	10, 5, 1	Bathy.	XBT
82-07									
131	+	+	+	+		+	+	+	
132		+	+			+	+		+
133	+	+	+	+		+	+	+	
134		+	+			+	+		+
135	+	+	+	+		+	+	+	
136		+	+			+			+
137	+	+	+	+		+		+	
138		+	+			+			+
139	+	+	+	+		+	+	+	
140	+	+	+	+		+	+	+	
141		+	+			+	+		+
142	+	+	+	+		+		+	
143		+	+			+			+
144	+	+	+	+		+	+	+	
145		+	+			+	+		+
146	+	+	+	+		+	+	+	
147		+	+			+	+		+
148	+	+	+	+		+	+	+	
149		+	+			+			+
150		+	+			+	+		+
151	+	+	+	+		+	+	+	
152		+	+			+	+		+
153	+	+	+	+		+	+	+	
82-08									
154	+	+		+	200	+	+	+	
155		+	+	+		+			+
156		+	+			+	+	+	+
157		+	+			+	+	+	
158		+	+			+			+
159		+	+			+	+	+	
160			+						+
161		+	+			+	+	+	
162		+	+			+	+	+	
163					80, 60	+	+	+	
164						+	+		+
165	+				200	+	+	+	
166						+	+		+
167					280, 350	+	+	+	
168					302				+
169						+	+		+
170					25	+	+	+	
171		+			295	+	+	+	
172					250	+	+		+
173					135	+	+	+	
174						+	+		+
175					65, 315	+	+	+	
176						+	+		+
177	+				240	+	+	+	
178						+	+		+
179		+	+		400	+	+	+	
			LPT						
180					250, 13	+	+	+	
181						+	+		+
182					250				+
183		+			30, 430	+	+	+	
184						+	+		+
185					30	+	+	+	
186						+	+		+
187	+	+			240, 450	+	+	+	
188						+	+		+
189	+				255	+	+	+	
190						+	+		+
191					430, 25	+		+	

Station No.	Depth of Midwater Trawl (m)					Depth of Bongo Tows		Hydrography	
	50	100	300	500	Others	0-200	10, 5, 1	Bathy.	XBT
82-08									
192		+	+		30	+	+	+	
193						+	+		+
194		+			320, 40	+	+	+	
195						+	+		+
196		+			250	+	+	+	
197						+	+		+
198		+			20	+	+	+	
199						+	+		+
200					350, 40	+	+	+	
201						+	+		+
202	+	+				+	+	+	