ICES C. M. 1996

Theme Session S
ICES CM 1996/S:25

The effect of currents and hydrography on the distribution of blue whiting eggs and larvae on Porcupine Bank

by

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Abstract

In March/April 1994 the Porcupine Bank area west of Ireland was surveyed to determine the distribution of eggs and larvae of blue whiting (*Micromesistius poutassou*) as well as to investigate the corresponding hydrography. Blue whiting eggs were found in a rather restricted area above the western slope of the bank and were abundant in waters cooler than 10 °C, either to the east of a thermal front on the Porcupine Bank or in deeper waters (400 - 600 m) off the bank. In contrast to the egg distribution, larvae of blue whiting were not restricted by the frontal structure and were found in a wider area, both in the cool waters on Porcupine Bank and to the west of the bank in water warmer than 10 °C. The distribution of eggs and larvae is discussed in relation to hydrography and currents. Larvae hatching at the western slope of Porcupine Bank are transported to the northern parts of Porcupine Bank. Here they may be retained above the bank by a Taylor column circulation associated with cold and low saline water. Larvae hatching off the slope are entrained by warm and saline waters of the Shelf Edge Current and may be transported northwards into the Rockall Trough. These two divergent circulation and drift patterns suggest that the early life history stages of two distinct spawning populations were caught.

Introduction

The major spawning region of the European blue whiting (*Micromesistius poutassou*) stock lies to the west of the British Isles (BAILEY 1982). During the spawning season between March and April large quantities of eggs and larvae can be found in an area stretching from Porcupine Bank to an area northwest of the Hebrides (see e. g. BELIKOV et al. 1986; MONSTAD et al. 1995). According to Bailey (op. cit.) two stocks spawn in this area: The northern stock in the Hebrides area and the southern stock in the Porcupine Bank area. However, in recent years a discussion on the population structure of these stocks has been raised (see e. g. ISAEV and SELIVERSTOV 1991; ANON. 1991) and thus the separation into different stocks has been postponed until the question on the identity of blue whiting populations has been clarified (ANON. 1995). Marine populations often constitute themselves according to physical oceanographic features affecting the drift or retention of their early life history stages (SINCLAIR, 1988). Within the Shelf Edge Fisheries and Oceanography Studies (SEFOS), a EU/AIR funded project, the recruitment of blue whiting (one of the target species) is studied in relation to the oceanography of the European shelf edge. Results from these studies should also elucidate the population structure discussion. Among a series of surveys conducted within SEFOS, German RV Heincke carried out a cruise to Porcupine Bank in March/April 1994 to study the horizontal and vertical distribution of blue whiting eggs and larvae in relation to their physical and biological environment. The results of this cruise are presented in this paper.

Material and Methods

A station grid above Porcupine Bank was sampled from 24 March to 10 April 1994 from board RV Heincke. The station grid and chronological course of sampling is shown in figure 1. Prevailing bad weather conditions with wind forces up to 12 Bft. caused several interruptions of the sampling procedure and was the main reason for the somewhat "strange" course. Thus the quasi-synoptic presentations of the results have to be treated with some care.

At each station one CTD profile to 1000 m depth or 5 - 10 m above the sea floor was collected. The ME-CTD was attached to a General Oceanics Rosette water sampler. In order to calibrate conductivity, up to 3 water samples were taken during each CTD cast. Stratified plankton sampling was done by one or two (depending on water depth) consecutive multiple-opening-closing-net (MCN, see e. g. KLOPPMANN 1994) hauls down to a maximum depth of 650 m or 5 to 10 m above the sea bed. The water column was divided into 9 discrete depth strata according to table 1.

NET NO.	SAMPLED DEPTHS (SHALLOW)	SAMPLED DEPTHS (DEEP)
1	200 - 150 m	650 - 500 m
2	150 - 100 m	300 - 400 m
3	100 - 50 m	400 - 300 m
4	50 - 25 m	300 - 200 m
5	25 - 0 m	200 - 0 m

Table 1: The sampled depth strata of the MCN tows during Heincke cruise to Porcupine Bank.

The MCN was equipped with a built in CTD to record depth, in-situ temperature and conductivity and flowmeters to measure the amount of water filtered. The net gauze had a mesh width of 150 µm. After each haul the content of each net was thoroughly washed into the cod end buckets. All plankton samples were preserved and stored in 4 % buffered formaldehyde seawater solution.

In the laboratory the samples were sorted for fish eggs and larvae. Eggs and larvae of blue whiting were then identified and the larvae measured to the nearest 0.5 mm below standard length (SL). No corrections have been made for shrinkage of the larvae. For the horizontal distribution the larvae were grouped into 4 length classes: < 3 mm; 3 - < 4 mm; 4 - < 5 mm and ≥ 5 mm. Numbers of blue whiting eggs and larvae were standardised to numbers per 100 m³ for the presentation of the vertical distribution and in numbers under 1 m² sea surface for the horizontal distribution.

Results

Weather and hydrography

This cruise was characterised by prevailing bad weather conditions during the entire course. Prevailing strong winds from the southwest to northwest with an average force of about 8 Bft. caused waves up to 10 m high. Only during very short periods moderate winds below 6 Bft. were encountered.

The surface temperature and salinity distributions are shown in figures 2a and 2b. Both isothermals and isohalines generally follow the bottom topography. Above the deeper areas (> 1000 m) to the west of Porcupine Bank and in the Porcupine Seabight warmer and more saline surface waters with values above 10 °C and S > 35.43 respectively were observed. In contrast, surface waters above the bank and on the shelf are cooler and less saline. Strong temperature and salinity gradients along the Irish shelf break clearly show the course of the Irish shelf front.

The vertical temperature and salinity distributions for transects B to F are given in figures 3 and 4. These show a warm core of high saline water from the surface down to 300 m (T > 10.5 °C, S = 34.49 at 51° 30' N, transect F) west of Porcupine Bank, which cools and freshens along its northward path. The slight decrease of the core temperature north of 52° 30' N and the position of the core on transects D and C suggests a westward deflection of this warm, saline subsurface core south of 52° 30' N and a northeastward movement farther north.

Between 500 and 800 m an intrusion of relatively cold and less saline water at the westernmost casts between 51° 30' N and 52° 30' N can be seen on transects D, E and F. At approximately 900 m a clear signal of Gibraltar Water (GW) is present in the vicinity of the continental slope west of Porcupine Bank at 51° 30' N (transect F). This water freshens and moves westward at 52° 00' N (transect E), but to the north these characteristics are no longer visible.

Above the western slope of Porcupine Bank a front is evident and it separates the warm, saline waters off the bank from the cooler and fresher waters on the bank. Above Porcupine Bank a dome of cold, less saline water is present between 51° 30' N (transect F) and 52° 30' N (transect D). The S-shape of the isolines at 53° N and 53° 30' N (transects C and B) is probably due to the mixing and stirring effects of two storms that passed over this area only a few days before sampling took place at these stations. A rapid cooling and freshening of waters of the entire water column can be seen to the east of the Irish shelf break.

Horizontal distribution of blue whiting eggs and larvae

Eggs of blue whiting occurred in high abundances only in a rather restricted area above the western slope of Porcupine Bank (figure 5). Due to a large number of stations with zero or low abundance only a relatively small mean abundance of 64.3 eggs per 1 m² (s = 191.8; median = 2.5) was estimated. However, in the area of high abundance density values well above 500 eggs per 1 m² with a peak value of 1113.5 eggs/m². were found. Highest abundances occurred at or eastward of the thermal front and in waters less than 1000 m depth.

Contrasting to the rather condensed distribution of the eggs, the larvae of blue whiting occurred in high abundances over a much wider geographical range. Accordingly the mean density was higher with a value of 117.8 larvae/m² (s = 197.4; median = 28.1). The standard length of the larvae ranged from 1.5 to 8.5 mm with most of the larvae falling into the 3.0 mm length class (figure 6).

Figure 7 shows the horizontal distribution of the four specified length classes of blue whiting larvae. Overall the highest abundances of larvae were observed above the western slope of Porcupine Bank and on one coastal station on transect F right above the 200 m depth contour. Except for most of the shelf stations larvae < 3 mm were found on every station sampled. Similar to the egg distribution most of the smallest larvae occurred in a rather restricted area above the western slope of Porcupine Bank. However, their range of high abundance is extended further to the south. The core of abundance seems to be shifted from waters beyond the 1000 m depth contour on the two southern transects to waters inside the 1000 m contour in the north. The larvae of 3 - < 4 mm SL showed high abundances but a wider geographical distribution than the smallest larvae and seem to spread towards the shallower areas of the Bank in the north. In contrast, on the two southernmost transects their core of abundance seems to remain in waters deeper than 1000 m. An apparent divergent drift can be seen in the distribution pattern of larvae larger than 4 mm SL. For larvae of SL ≥ 5 mm we find three major areas where these larvae concentrate: Firstly on the shallower parts (< 200 m) of Porcupine Bank, secondly along the 200 m depth contour of the Irish shelf, both in cooler waters (< 10 °C) of relatively low salinity (about 35.40) and thirdly above greater depths (> 1000 m) in the southwest in warmer water (> 10.2 °C) with relatively high salinity (> 35.43 - 35.45). Only on station F2 an exception from this picture is observed: High abundances of larger larvae occur in warmer waters of higher salinity in water depths of only 200m. These larvae might represent the northern tip of a more southerly distributed larval population.

The vertical distribution of blue whiting eggs and larvae

The vertical distribution of all blue whiting eggs on each transect is shown in figure 8. Blue whiting eggs occurred in all depth strata sampled and modes were discovered in both, shallow and deep layers. It is evident that high densities of eggs were only found in waters of temperatures less than 10 °C. Westward of the thermal front where the 10 °C isothermal runs deep we find a mode of the egg distribution below 400 m depth and only few eggs in the top 100 m. In the cooler waters above the bank eggs occur throughout the whole water column in comparatively high densities and modes in the top 100 m are by no means the exception.

Figure 9 shows the vertical distribution of all blue whiting larvae and the mean larval lengths on each transect. Like the eggs, larvae were found in all depth strata sampled. Modes occurred in the deep and shallow layers. The mean length distribution indicates that the deep modes principally correspond to small mean lengths while the shallow modes correspond to the larger mean lengths. Blue whiting larvae found at depth are thus almost exclusively recently hatched larvae.

Transects B and C show that blue whiting larvae become larger from the deeper to the shallower layers and from the west towards the shallow parts of Porcupine Bank. From

Porcupine Bank to the Irish shelf the mean length decreases first and increases again when reaching the shelf break. On transect B larger larvae in the shallower layers of the two westernmost plankton stations were observed. It should be noted that the deep dispersed distribution of the large larvae on station C6 was found right after a 48-hour storm of force 10 Bft. Thus this distribution can be interpreted as a result of deep mixing. A shallower distribution of these larvae is usually more likely (COOMBS et al. 1981).

Distributions on transect D generally resemble the distributions on transects B and C but centres of high densities are scattered over a wider area than in the two northern transects. From transect E on the distribution changes somewhat. The highest densities were observed on the two westernmost stations but the largest mean lengths are still evident in the shallower layers above the bank. On transect F higher larval blue whiting densities occurred on the outermost stations on both the eastern and the western side. These larvae were larger than those encountered in between.

Discussion

The upper water masses in the European Basin are part of the Subpolar Mode Water (SPMW), which is characterised by a decrease of temperature and salinity of the original North Atlantic Central Water (NACW), as it moves eastward across the Atlantic (MCCARTNEY and TALLEY, 1982). In the vicinity of the Rockall Trough two components of the SPMW can be distinguished:

1. Eastern North Atlantic Water (ENAW), which enters the Rockall Trough from the south, is characterised by typical temperatures between 8 and 12 °C (HARVEY, 1982; ELLETT et al. 1986).

2. Modified North Atlantic Water (MNAW), which enters the northeastern boundaries of the Rockall Trough west of Hatton Bank (ELLETT et al. 1986).

Mid-depth waters are dominated by Subarctic Intermediate Water (SAIW), which is entrained near the polar front (HARVEY, 1982) with core characteristics of T = 5.7 °C and S = 34.85 (ELLETT et al. 1986). Another important water mass observed in this area is Gibraltar Water (GW), formed within the Mediterranean outflow.

Figure 10 shows TS diagrams for each transect of the RV Heincke cruise CTD casts. Along 53° 30' N (transect B) the upper water masses at the westernmost stations B10 to B11 are dominated by ENAW (above 600 m). Below this the decrease in temperature and salinity suggests an increasing influence of SAIW. In the shelf areas above and east of Porcupine Bank the TS characteristics show homogenous water, probably influenced by strong vertical mixing due to the strong winds that prevailed during the cruise (station B4).

A similar situation is evident along 53° N and 52° 30' N (transects C and D). However, along 52° N and 51° 30' N (transect E and F) the influence of SAIW is still present, but less pronounced (westernmost stations E9 to E10 and F12). Near 900m GW is clearly evident west of Porcupine Bank (stations E10 and F10 to F11) and in the Porcupine Seabight (stations E4 and F5). The isolated TS feature of station E1 is typical for the water masses of the Irish shelf front during that season (HUANG et al., 1991).

The observed doming of cool and low saline waters above Porcupine Bank is a prominent feature typical for the area (see e. g. TITOV et al. 1993; MCMAHON et al. 1995). The disturbance of the dome like appearance on the two northernmost transects of this investigation can be attributed to the stirring and mixing effect of two strong storms passing over the study area shortly before sampling. Following the investigations of MEINCKE (1971), HUPPERT and BRYAN (1975) and VASTANO and WARREN (1976) on the theory and natural occurrence of Taylor column circulation effects, the temperature and salinity data suggests such a phenomenon over Porcupine Bank: cold and low salinity water is trapped over the bank causing a quasi-persistent, anti-cyclonic eddy like circulation feature. The existence of such a Taylor column may explain the observed drift pattern of the blue whiting larvae onto the shallow parts of the bank. The significance of Taylor columns for the recruitment of fish populations inhabiting submarine rises has often been addressed in recent publications (see e. g. HEATH 1992 and ROGERS 1994 for review) but evidence for retention of fish larvae by Taylor column circulation is still sparse (BOEHLERT and MUNDY, 1993). However, the existence of such a quasi-persistent circulation pattern above Porcupine Bank may generate a small retention area supporting the existence of a local, self sustaining spawning population of blue whiting. The eggs which are laid above the western slope of Porcupine Bank are entrained into the Taylor column circulation and after hatching the larvae are retained above the bank. Analysis of the feeding environment and of the feeding success of the larvae showed that the area may support successful recruitment (HILLGRUBER et al. 1995, 1996).

During their rise to the surface layers larvae that hatched off the slope of Porcupine Bank become entrained in the warm and saline subsurface waters. The temperature and salinity data suggest that this water forms a northward flow that is deflected from the bank just south of 52° 30' N while it moves northeastwards and towards the bank again further north (transect B). This northward flow is in essence the shelf edge current. Larvae entrained into this current may thus be transported northwards into the Rockall Trough. This assumption is corroborated by the larger larvae observed in the shallower layers of the westernmost station of transect B. It seems likely that these larvae derive from the large Porcupine population spawning above the deeper waters west of Porcupine Bank (ISAEV and SELIVERSTOV, 1991; ISAEV et al. 1992) of which only the eastern margin of their occurrence was sampled.

The identity of these two populations remains unclear. High abundances of blue whiting larvae above Porcupine Bank have not always been observed as earlier studies have shown (HALBEISEN 1982; BELIKOV et al. 1986). The spawning characteristics of both populations are identical: As the results from this study have shown both populations spawn in waters of similar temperature and salinity characteristics. It is thus possible that the larvae retained above Porcupine Bank derive from expatriates of the so called Porcupine Population that moved up the bank and spawned there.

Acknowledgements

This study was funded as part of the EU/AIR grant no. AIR2-CT93-1105. We are very grateful to the Captain and crew and the scientific co-workers on board RV Heincke who all worked to their limits during this very strenuous cruise.

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Captions to the figures

Figure 1: The station grid of the RV Heincke cruise to Porcupine Bank in March/April 1994. The arrows and the dates indicate the course of the sampling exercise. Isobaths at 200m, 500m and 1000m are indicated.

Figure 2: The horizontal distribution of the sea surface temperatures (a) and salinities (b) above Porcupine Bank in March/April 1994.

Figure 3: The vertical distribution of the potential temperature along transects B (top) to F (bottom) in the Porcupine Bank area in March/April 1994.

Figure 4: The vertical distribution of salinity along transects B (top) to F (bottom) in the Porcupine Bank area in March/April 1994.

Figure 5: The horizontal distribution of blue whiting eggs above Porcupine Bank in March/April 1994.

Figure 6: The representative length distribution of blue whiting larvae from waters above Porcupine Bank in March/April 1994.

Figure 7: The horizontal distributions of the four specified length classes of blue whiting larvae above Porcupine Bank in March/April 1994.

Figure 8: The vertical distribution of blue whiting eggs along transects B (top) to F (bottom) in the Porcupine Bank area in March/April 1994.

Figure 9: The vertical distribution of blue whiting larvae and of mean larval lengths along transects B (top) to F (bottom) in the Porcupine Bank area in March/April 1994. The presentation of larval mean length distribution is exclusively based on undamaged larvae. Depth strata with exclusively damaged larvae were excluded from the estimation.

Figure 10: TS diagrams of selected stations from RV Heincke transects B - F. Station numbers, water depths (*10^2 m) and $\sigma_{t,s}$ contours are indicated. Thick lines represent the TS characteristics of ENAW and GW.

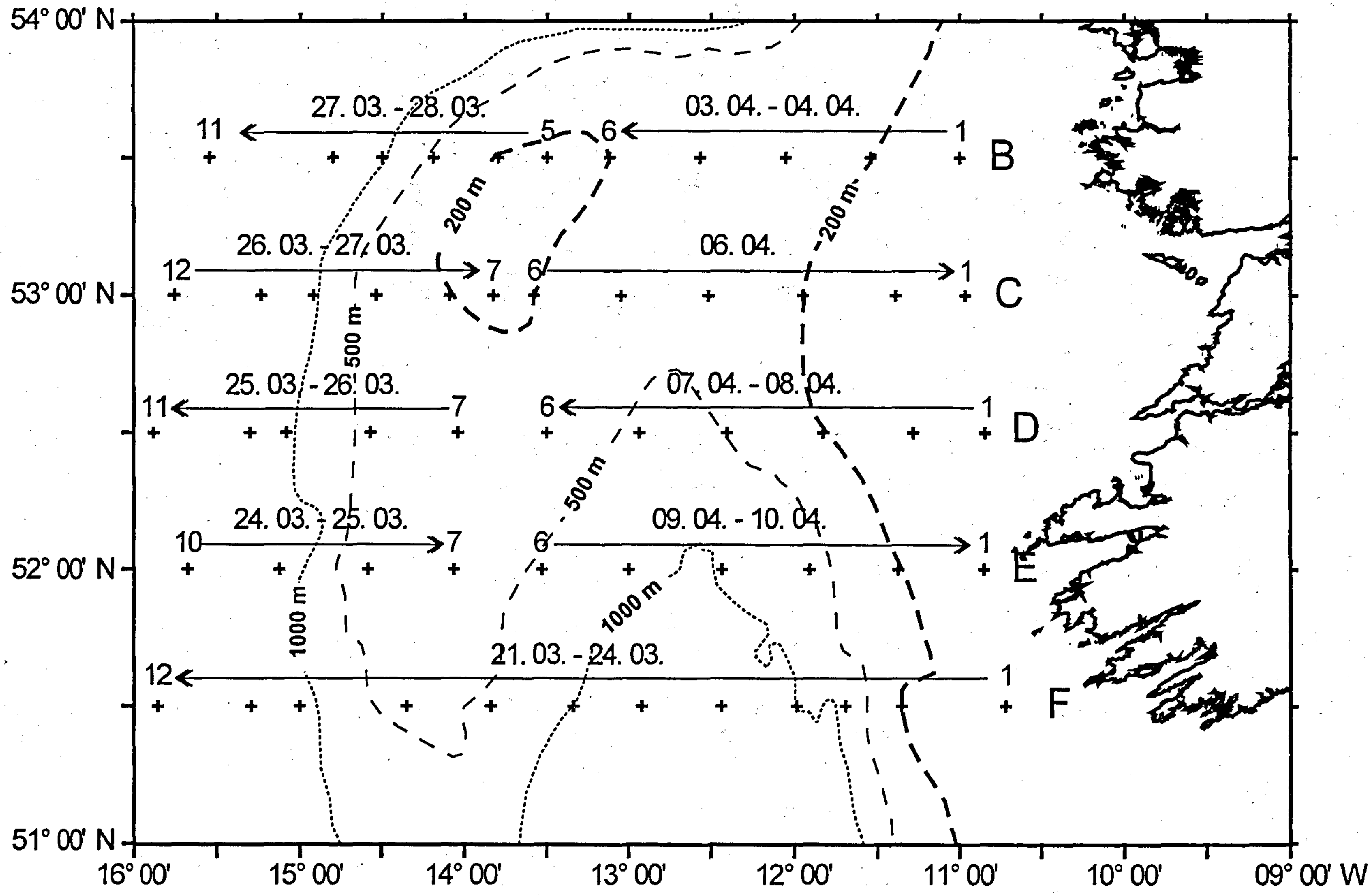
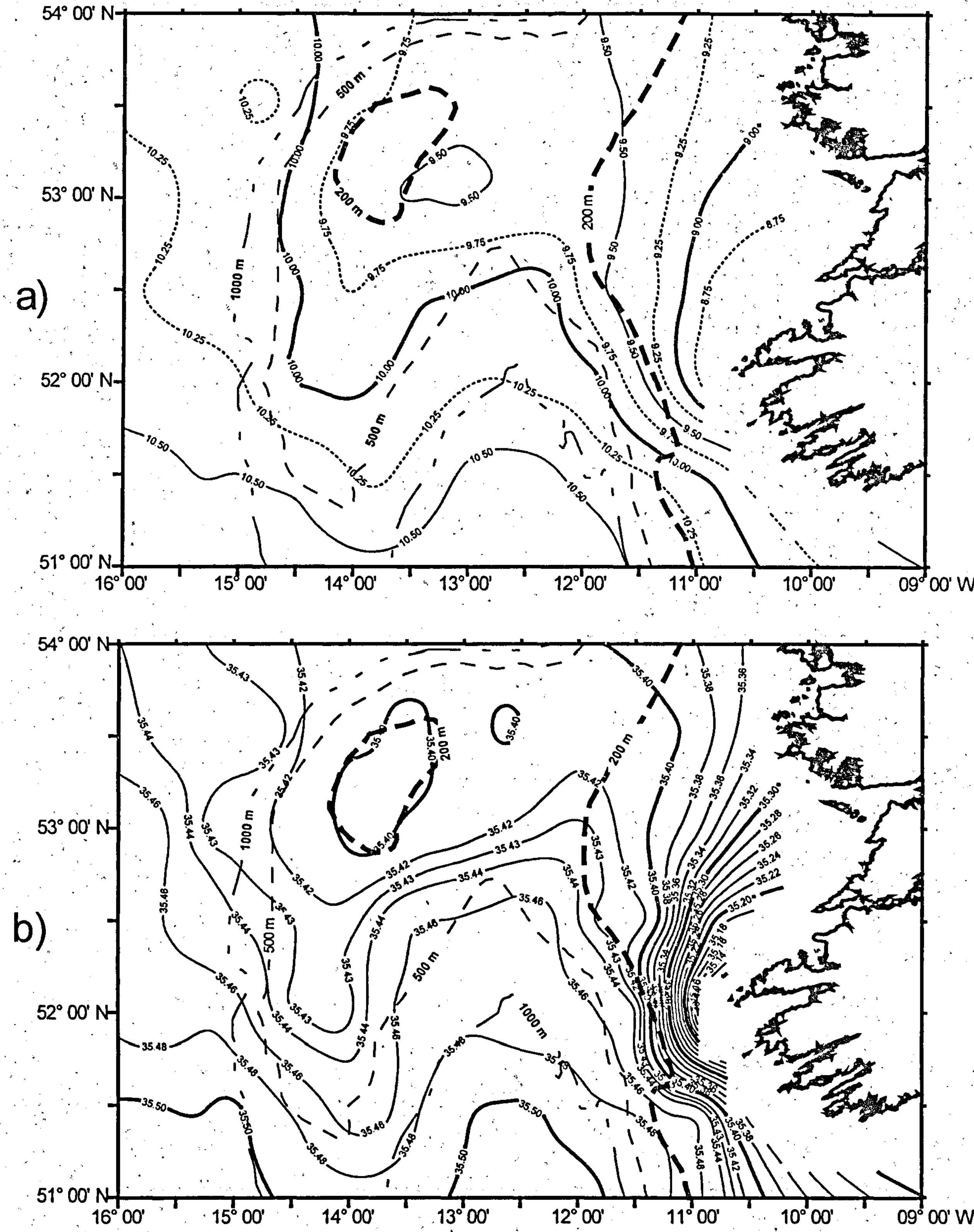

54° 00' N
53° 00' N
52° 00' N
51° 00' N
16° 00'
15° 00'
14° 00'
13° 00'
12° 00'
11° 00'
10° 00'
09° 00' W
27. 03. - 28. 03.
03. 04. - 04. 04.
26. 03. - 27. 03.
06. 04.
25. 03. - 26. 03.
07. 04. - 08. 04.
24. 03. - 25. 03.
09. 04. - 10. 04.
21. 03. - 24. 03.
B
C
D
E
F
200 m
500 m
1000 m

Figure 1


a)
b)
54° 00' N
53° 00' N
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51° 00' N
16° 00'
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09° 00' W
200 m
500 m
1000 m

Figure 2

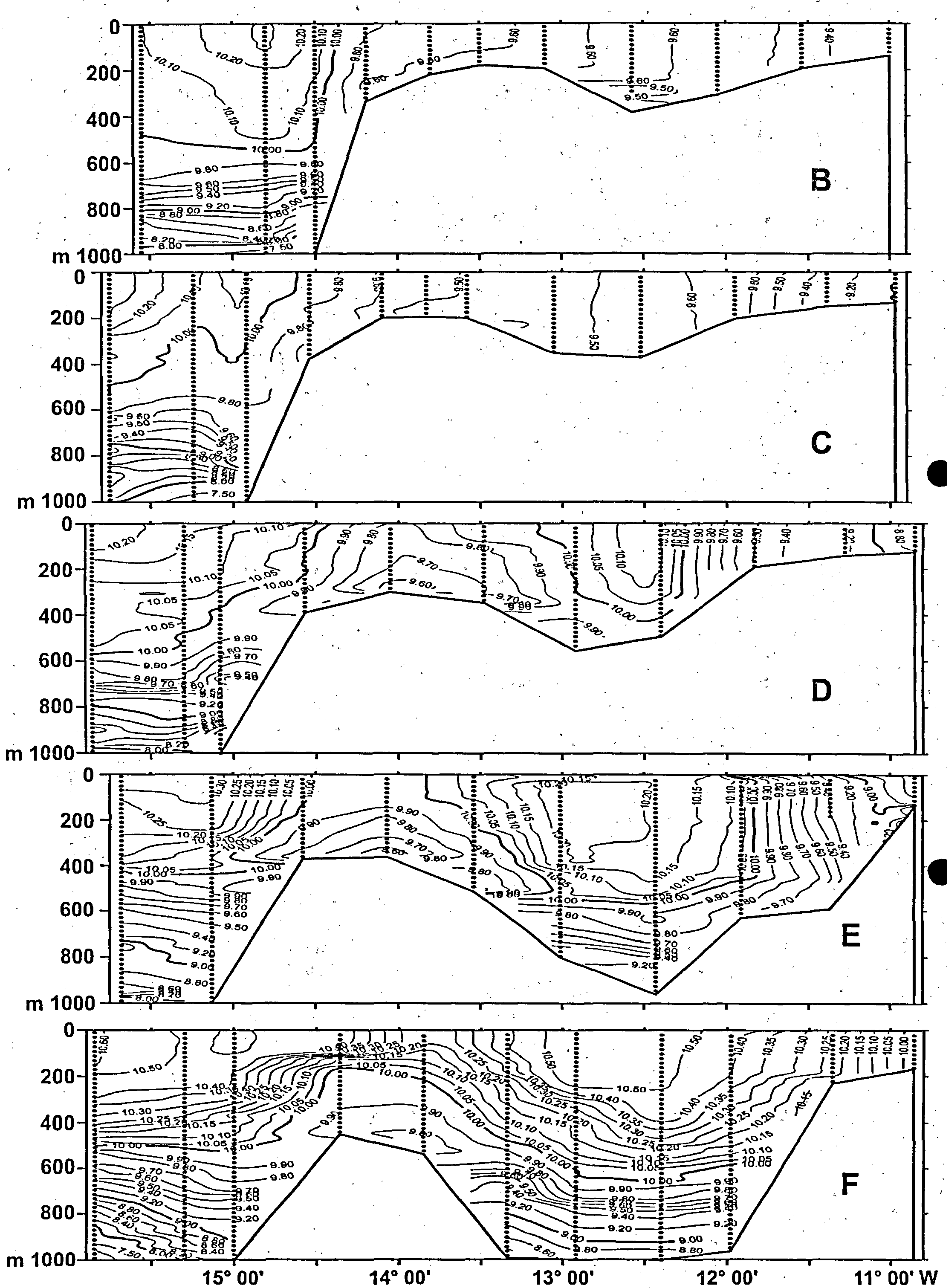


Figure 3

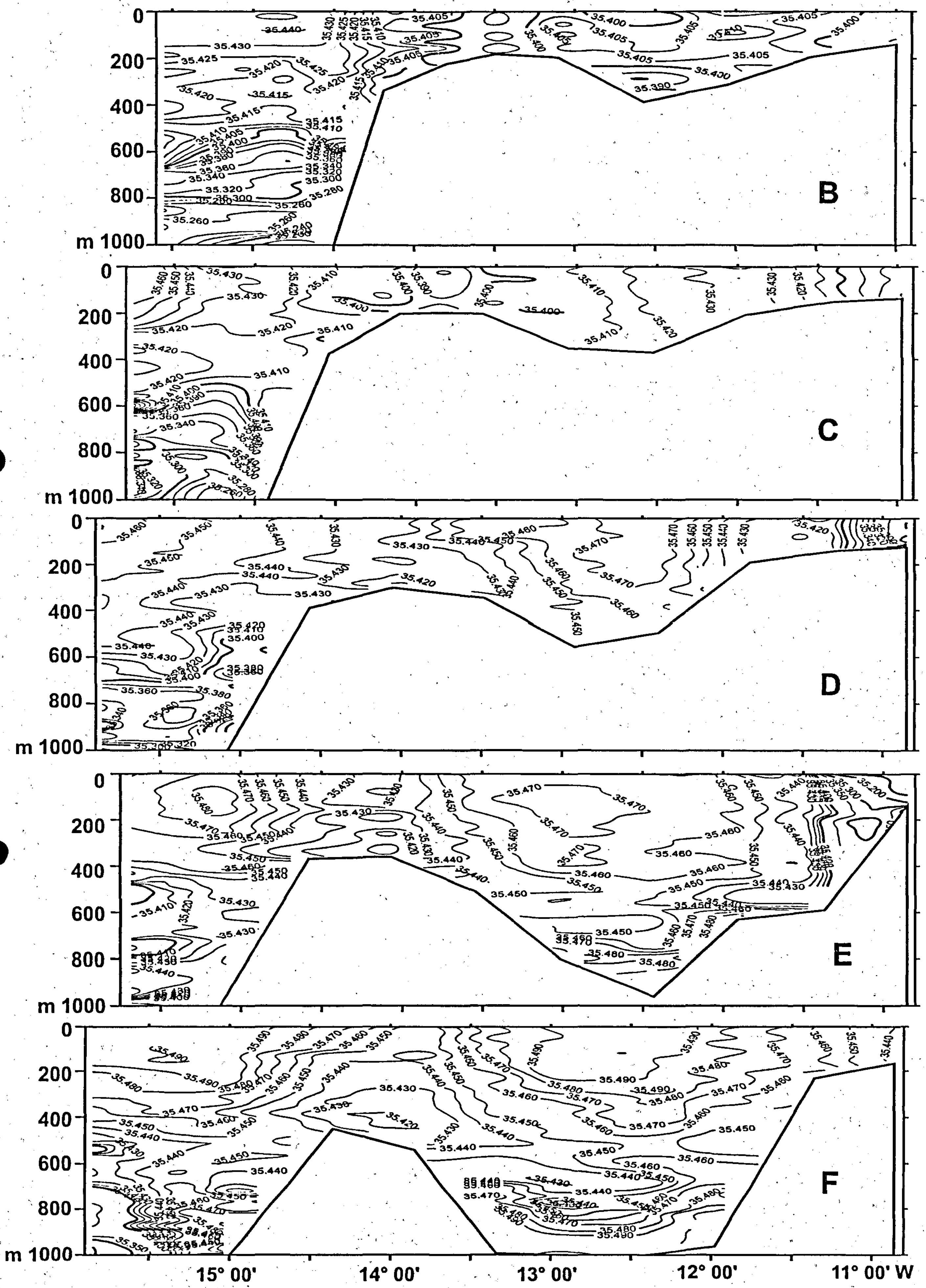


Figure 4

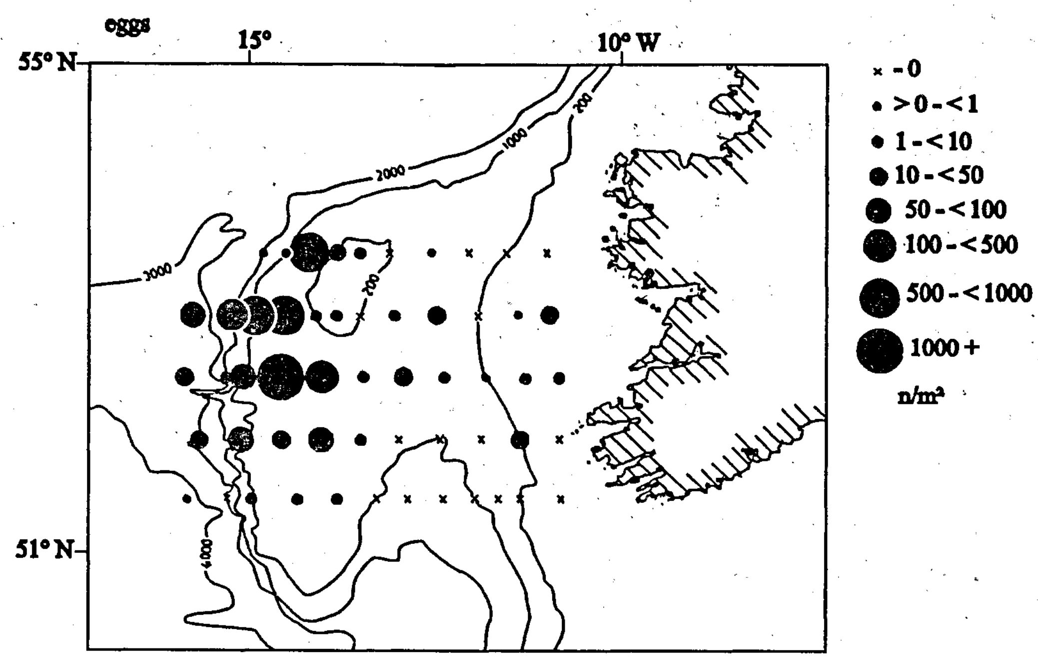


Figure 5

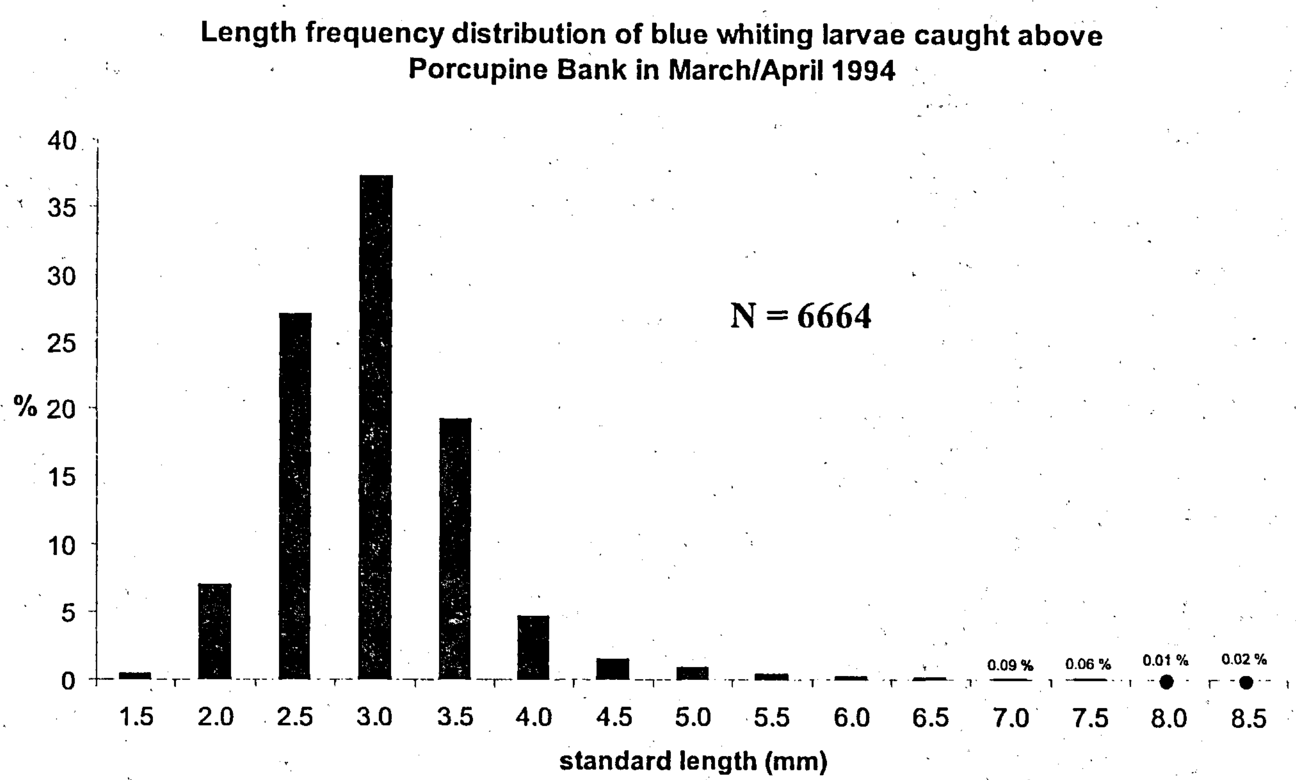
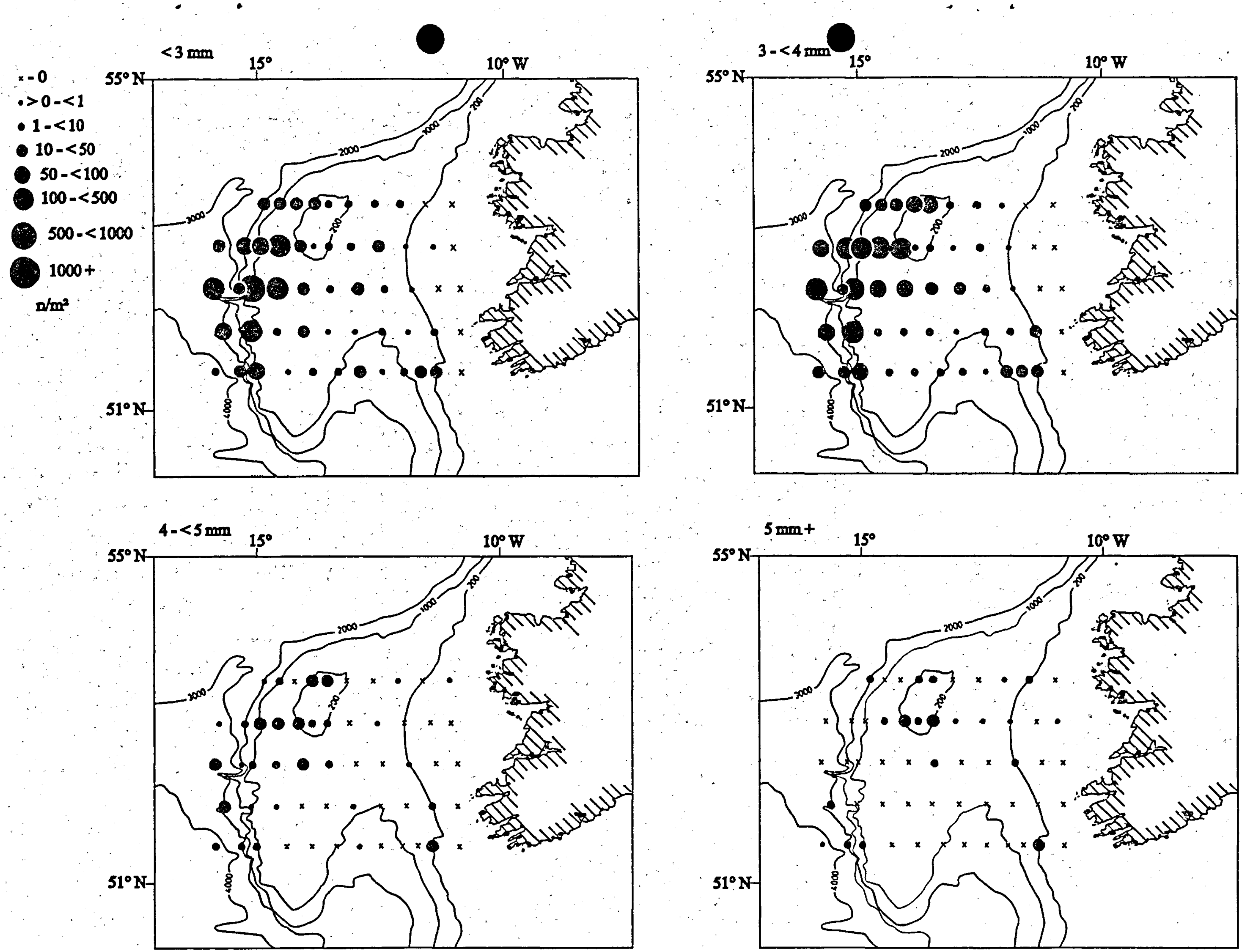
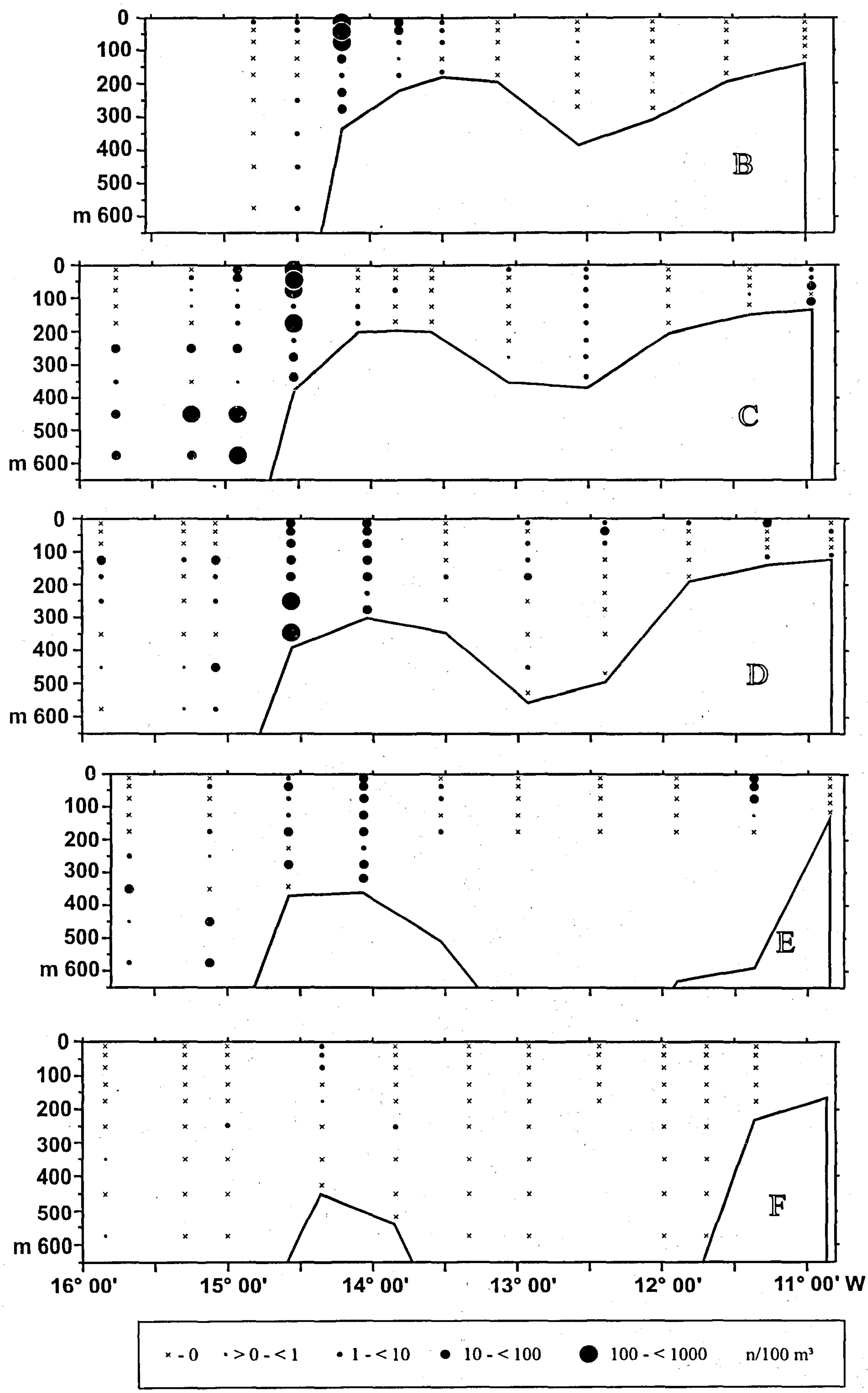


Figure 6



<3 mm
3 - <4 mm
4 - <5 mm
5 mm +
15°
10° W
55° N
51° N
x - 0
• > 0 - < 1
1 - < 10
10 - < 50
50 - < 100
100 - < 500
500 - < 1000
1000 +
n/m²
200
1000
2000
3000
4000

Figure 7



0
100
200
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400
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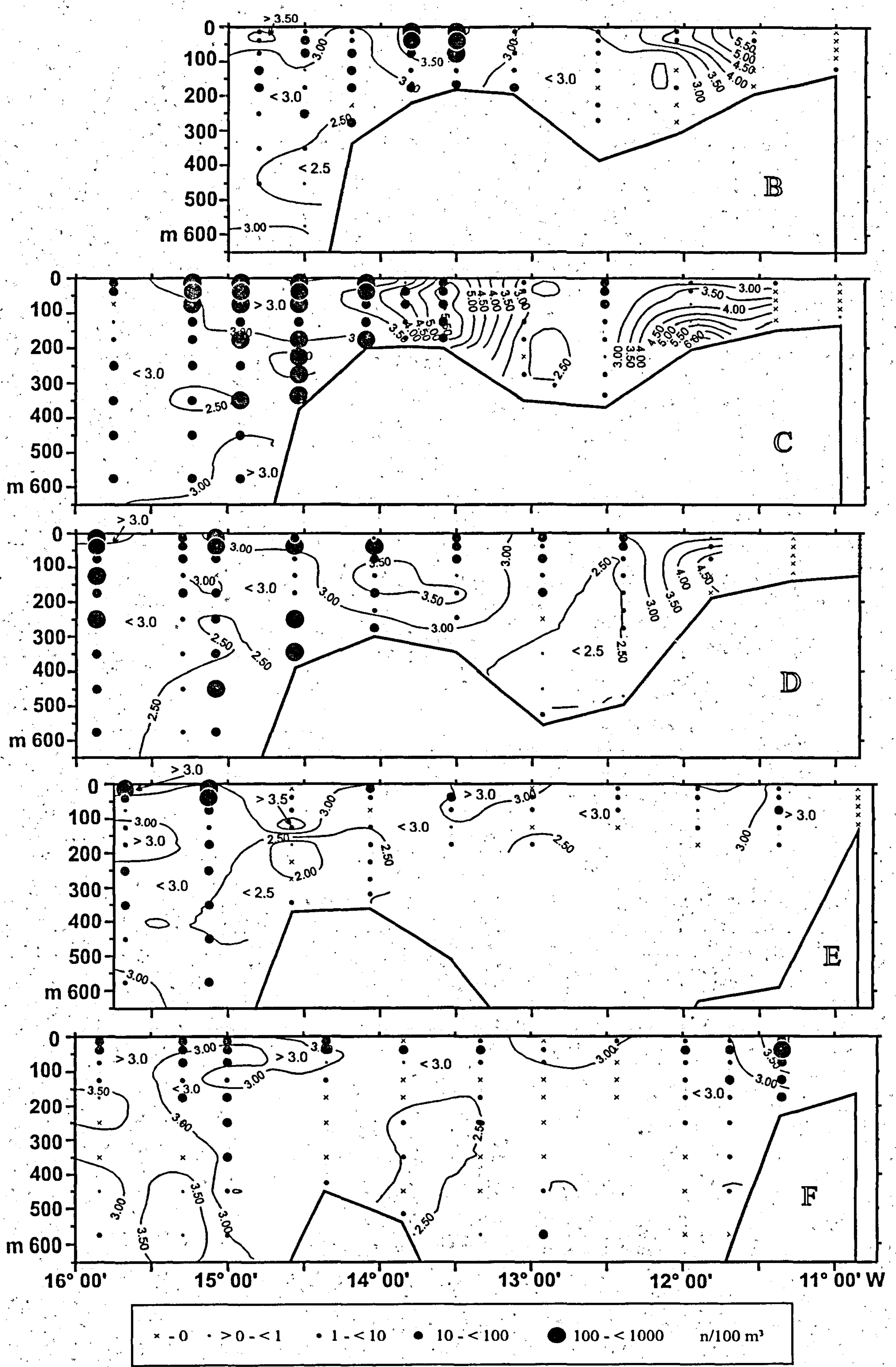
m 600
B
C
D
E
F
16° 00'
15° 00'
14° 00'
13° 00'
12° 00'
11° 00' W
× - 0
• > 0 - < 1
• 1 - < 10
● 10 - < 100
● 100 - < 1000
n/100 m³

Figure 8


B
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E
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m 600
16° 00'
15° 00'
14° 00'
13° 00'
12° 00'
11° 00' W
× - 0   • > 0 - < 1   • 1 - < 10   ● 10 - < 100   ● 100 - < 1000   n/100 m³

Figure 9

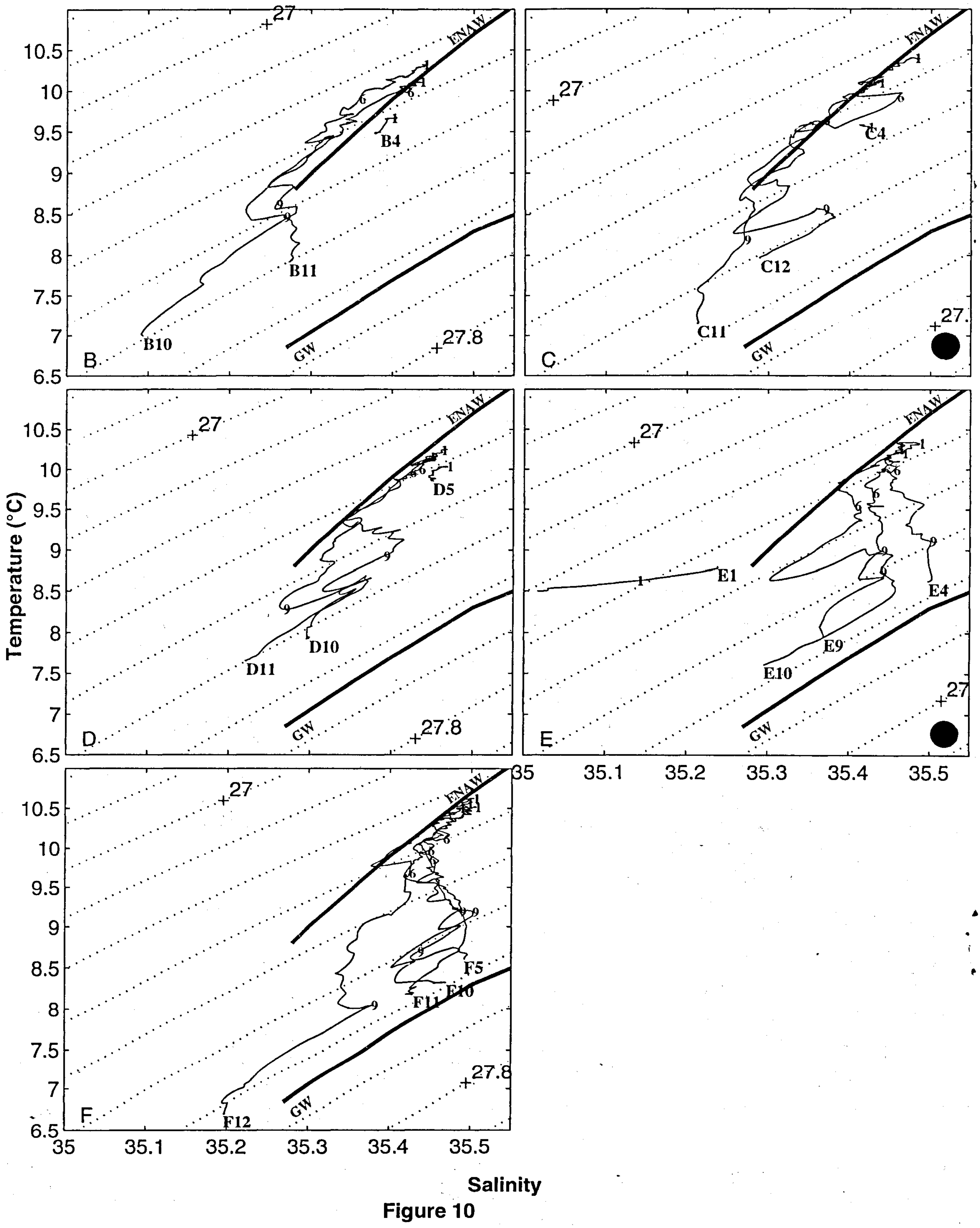
Temperature (°C)
Salinity
ENAW
GW
27
27.8
B4
B10
B11
C4
C11
C12
D5
D10
D11
E1
E4
E9
E10
F5
F10
F11
F12

Figure 10