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# HYDROGRAPHIC FEATURES AND DYNAMICS OF BLUE WHITING, MACKEREL AND HORSE MACKEREL IN THE BAY OF BISCAY, 1994-1996. A MULTIDISCIPLINARY STUDY ON SEFOS.

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## ABSTRACT

Hydrographic and climatic conditions have been found to be one of the most important factors that can influence the distribution and behaviour of adults, juveniles and early stages of fish. This relationship, which has been pointed out by several authors, is also the main objective of the SEFOS project, which studies the relationship between the distributions and migrations of commercially important fish species and the oceanography of the European shelf edge. Within this framework, the Bay of Biscay presents special oceanographic and climatic conditions that could influence the aggregations of food and larvae in retention areas throughout this area, which is one of the most important nursery areas for several fish species and seasonal migrations of blue whiting, horse mackerel and mackerel.

This paper presents the results of a multidisciplinary study of the relationship between the oceanographic conditions of the Bay of Biscay and the distribution of both early stages - eggs and larvae - and adult fish of horse mackerel, mackerel and blue whiting for the period 1994-1996.

## INTRODUCTION

A central aim in pelagic ecology is to identify the spatial distribution patterns of species and to understand the causal mechanisms that lead to them. In the pelagic domain these patterns are a result of complicated interactions between attributes of the biology of the organism and the environmental characteristics of the ocean. Specific attributes include behaviour, predator-prey interactions, diel and ontogenic vertical migration, etc. Environmental characteristics include the physical-chemical and biological features of a region. The nature of this dispersive environment and the behaviour of the organisms within it has an important influence on the survival and recruitment of populations.

The Shelf Edge Fisheries Oceanography Study (SEFOS) is a multi-disciplinary project which studies the interaction of physical processes at the shelf edge with commercially important fish species such as mackerel (*Scomber scombrus*, L), horse mackerel (*Trachurus trachurus*, L), blue whiting (*Micromesistius poutassou*, R) and hake (*Merluccius merluccius* sp, L). One of the main objectives in the SEFOS project was to detect the hydrographical features that determine the distribution of eggs, larvae, recruits and adults and to explore the effects of the observed dynamics on the planktonic forms during the spawning season of the fish species that spawn on the shelf edge in the Bay of Biscay.

Meteorological conditions determine to a great extent the formation and evolution of the hydrological structures of the Bay of Biscay. In winter the Azores high pressure cell is situated on the northwestern coast of Africa and a deep low pressure area is located in Greenland. This system forces wind of a WNW component onto the western edges of the Iberian peninsula and Bay of Biscay. In summer the Azores high pressure moves to the central Atlantic and produces fluxes from the NE in the north and northwest of the peninsula. This pattern causes upwelling in summer in the north and west of the Iberian Peninsula (Blanton *et al.*, 1984).

In the upper layers of the oceanic region surrounding the Iberian Peninsula, three water masses can be distinguished: Surface Water, highly variable and influenced by meteorological conditions and coastal runoff; Northern Atlantic Central Water (NACW), seasonally variable and found between approximately 60 and 600 m depth; and Mediterranean Intermediate Water (MIW) (Cabanas *et al.*, 1992; Lavín *et al.*, 1992).

The general circulation in the Biscay area is weak because there are no density gradients which might produce potential currents in the south of the Bay, although the flow suggests a weak clockwise circulation (Pingree, 1993). Over the shelf-break of the Iberian peninsula and Armorican shelf a current drives mainly poleward and eastward. The currents on the continental shelfs are affected by strong fluctuations on different time scales; the current regime changes seasonally in surface layers over the Continental Shelf and coastal area. In autumn-winter a poleward flux from the western Iberian Peninsula appears (Pingree & Le Cann, 1990, Haynes & Barton, 1990; Frouin *et al.*, 1990). It produces winter warming in the area and may cause the development of eddies. The circulation over the continental slope may become unstable, especially in the southern part of the Bay of Biscay. These instabilities have been detected in the proximities of topographic accidents such as the canyon of Cap Ferret and Cabo Ortegal (Pingree *et al.*, 1992).

In the Bay of Biscay, the important dynamic features that govern the exchange of properties between regions include Ekman currents, mesoscale rings, fronts and filaments. These patterns affect the spatial displacement (e.g. advection, diffusion, retention) of larvae and determine the observed distribution of these early life stages until their recruitment.

Available data on blue whiting eggs and larvae distribution in the Bay of Biscay are scarce as most of the literature refers to the Porcupine and surrounding area between the south and west of Ireland and the west of Scotland (Bainbridge & Cooper, 1973; Coombs, 1974, 1979; Coombs & Pipe, 1978; Bailey, 1974, 1982). In the Bay of Biscay only very sparse patches of larvae were described (Arbault & Boutin, 1969; Sola & Franco, 1984; Solá & Franco, 1985).

Mackerel and horse mackerel eggs and larvae have been sampled periodically almost every year from 1987 and their abundances and distribution studied in the context of the ICES triannual egg surveys as well as in other plankton surveys in the Cantabrian Sea and off Galicia during the spawning seasons of both species, and the results have already been published (Anom 1996). To the North of Spain, spawning takes place in spring (Solá *et al.*, 1990, 1994; Lago de Lanzós *et al.*, 1993) and that the patterns in the observed distribution are consistent through the years studied, however, as most of the surveys were carried out in the contest of the evaluation of spawning stock biomass, no attempt of relate observed distributions with hydrographical features were undertaken before the present SEFOS project..

Horse mackerel and mackerel are highly migratory species, and there are many references to their movements in northeastern Europe (Macer, 1977; Lockwood, 1988; Walsh & Martin, 1986; Eltink *et al*, 1986; Anon, 1990a; Walsh, 1994; Borges *et al.*, 1995), as well as in the Bay of Biscay in the case of mackerel (Uriarte, 1995; Villamor *et al.*, 1996). The blue whiting has a widespread distribution along the continental slope in the North Atlantic ocean (Zilanov, 1980). This species has been studied by means of acoustic methods since 1972 (Anon, 1982; Anon, 1996). One of the most important features of this species is its ability to migrate from feeding areas to spawning ones and vice-versa (Carrera *et al.*, 1996). Mackerel and horse mackerel are important species for the Spanish fishing fleet operating in the Bay of Biscay. The average yearly catch in the Bay of Biscay during the period 1992-1995 (Anon, 1993, 1995a, 1996) was 22 500 tons of mackerel and 35 500 tons of horse mackerel. For blue whiting the catch has remained stable over the last 20 years, with approximately 30 000 tons landed each year.

## MATERIAL AND METHODS

### Surveys

In the spring of 1994, from 15th March to 14th April, and in 1996 from 11th March to 13th April, two joint acoustic, hydrographic and ichthyoplankton surveys (SEFOS 0394 and SEFOS 0396) were carried out on board R/V "Cornide de Saavedra", in order to identify the spawning, larvae retention and recruitment areas of blue whiting, and to study the oceanographic conditions in the Bay of Biscay during the spawning season. The area covered for both surveys was from 41°50' N , 9°38'W (north Atlantic coast of Spain) to 47°40'N, 7°W (French Brittany coast) (Fig.1a,b).

In 1995 two surveys were performed: the first survey (MPH/95) from 25 March to 15 April, covered the area from Lisbon up to 45°N (Arcachon, France), while the second survey (SEFOS/95) from 28 May to 18 June, covered the northern Cantabrian area and the west of France (Fig.1c,d). In both surveys the sampling grid was designed in accordance with the procedure described by AEPM (Anon, 1994) in cross-shelf transects every 15-30 nm and with CTD & plankton stations 15 nm apart.

### Physical procedures

In the SEFOS 0394 survey, 113 CTD stations and 5 SSS (SEFOS Standard Sections) were performed. In the two cruises of 1995, there were 112 CTD stations and 6 SSS in the MPH/95, and 122 CTD stations and 4 SSS in SEFOS/ 95. In SEFOS 0396 114 CTD stations and 7 SSE were sampled. The CTD cast (SBE 25 and Falmouth Scientific) was performed, SEFOS Standard Sections were sampled (Turrell *et al*, 1995) and water samples were taken for CTD salinity calibrations..

| | *1994* | *1995* | | *1996* |
|---|---|---|---|---|
| | *SEFOS 0394* | *MPH/95* | *SEFOS/95* | *SEFOS 0396* |
| **CTD stations** | 113 | 112 | 122 | 114 |
| **Sefos St.Sect.** | 5 | 6 | 4 | 7 |

Continuous recording of thermohaline and fluorescence characteristics of surface water, and satellite images of the area were taken into account for further analysis. Also three current meter lines were moored from February 1995 to February 1996 in the shelf, shelf-break and slope waters in the Southern part of the Bay of Biscay ( Diaz del Río *et al*, 1996).

## Plankton sampling

In the SEFOS 0394 survey a total of 113 plankton stations were made on a zig-zag line. The stations were situated every 8-12 nm and distributed as follows: 37 stations over the shelf (depth <200 m), 34 stations over the shelf break (depth 200-1000 m), and 42 stations over the ocean basin (depth >1000 m). In 1995 a total of 112 and 120 stations were sampled in the MPH/95 and SEFOS/95. In both surveys the sampling grid was designed in accordance with the procedure described by AEPM (Anon, 1994) in cross-shelf transects every 15-30 nm and with plankton stations 15 nm apart.

In SEFOS 0394, plankton sampling was carried out at each station using a Bongo net (50 cm diameter and mesh size of 200 mm) on double oblique tows in water shallower than 300 m and vertical tows in deeper water. In the 1995 surveys (MPH/95 and SEFOS/95), plankton sampling was carried out using a Bongo net (20 cm diameter and mesh size of 250 mm) which was hauled in double oblique tows down to a maximum depth of 200 m, or 5 m above the bottom in shallower water. In the three surveys tows were worked at a ship's speed of 2-3 knots and a depth recorder was fixed to the net cable in order to register the maximum depth reached. A General Oceanics flowmeter was used to determine the water volume sampled. Samples were immediately sorted and counted for target species. Samples were preserved in 4% buffered formaldehyde, and once in the laboratory all fish eggs and larvae were counted and classified to species level. Mackerel and horse mackerel eggs were staged (Lockwood *et al.*, 1977; Pipe & Walker, 1987) and the larvae of all target species measured to the nearest 0.1 mm for information on size frequency distribution. Abundances were converted to number per square metre following standard techniques (Smith & Richardson, 1977).

## Acoustic sampling

The survey grid was designed to provide the best coverage for acoustic sampling. In SEFOS 0394 the survey grid consisted of a zig-zag track design with 20 nautical miles between peaks, with random start, whereas a parallel track design with 24 nautical miles between transects was performed in SEFOS 0396. The main transect direction, in both cases, was normal to the isobath contour, over the shelf break. In addition, in SEFOS 0396, in the Spanish area, extra transects were allocated in order to evaluate the Spanish fraction of sardine. The distance between transects varied between 12 miles as a general distance and 6 miles in specific areas.

A Simrad EK-500 echointegrator with a 38kHz split beam transducer was used. In 1994, due to bad weather conditions, it was not possible to calibrate this equipment and the results of the previous calibration (November 93) were assumed. In 1996 the calibration was performed before the survey. Both surveys were conducted day and night at a ship speed of 10 knots. Integrated values ($S_A$ values) (Bodholt, 1990) were directly collected every nautical mile and stored in a PC, which controlled the main settings of the echosounder. Geographical position was also taken by GPS. Total $S_A$ values were allocated to different species, according to the information obtained at both pelagic and bottom fishing stations.

## RESULTS

### *HYDROLOGY*

In the Bay of Biscay shelf and slope surface waters (down to a depth of 200 m) the thermohaline characteristics, during the months of April and May, are greatly influenced by the presence, during the winter months, of the poleward current in the west and by a large influx of fresh water in the east.

For each cruise, salinity at sigma-t 26.9 and 27.1 (fig. 2), temperature (fig. 3) and salinity at 100 m depth (fig. 4) was presented as indicatives to show the dynamic and termohaline characteristics .

In 1994 most of the water in the Bay came from higher latitudes, which also gave rise to a flux towards the Spanish coast. There was a more superficial haline front in the Bay due to the presence of large runoffs of fresh water and that of a pocket of water at $\tilde{o}_t > 26.9$ which recirculates in the Bay (Fig. 2a). At the level of upper NACW (180m) the waters are homogeneous between Finisterre and La Rochelle, except for in the corner of the Bay of Biscay, where salinity is lower and the temperature is higher, (Fig. 3a, 4a).

In April 1995 the situation of the haline fronts in the Bay was similar to that found in 1994, although temperatures were higher and salinity lower in the SE corner of the Bay, extending as far as 4°W. Incipient eddies were also found. In the surface layers a frontal zone appeared at the northwest corner of the Iberian peninsula which separated the Cantabrian and Atlantic circulations, and a second frontal zone in the eastern part of the Cantabrian Sea isolated the inner part of the Bay. The thermohaline circulation in the gulf was limited, in contrast to that of 1994 (Fig. 3b, 4b).

In May-June a frontal zone with steep temperature and saline gradients appeared over the French slope along all its length, which led to the formation of eddies, especially in the inner areas of the Bay. The thermohaline characteristics at the level of upper NACW (100m) showed a gradient over the whole area, with warmer and less saline water between 5°W and 45°N and the SE corner of the Bay, and indications of connection with colder and more saline waters around 6°W. In the lower NACW (500m) the same characteristics could be observed between the Asturias-Cape Ortegal zone and the Armorican shelf. Over the Cantabrian shelf the circulation is westward and parallel to the coast. Measurements of the current taken at a depth of 75m on the slope off Cape Peñas (Díaz del Río *et al.*, 1996) show a steady current with an average speed of 10cm/s flowing westward (Fig. 3c, 4c).

In 1996 a higher level of salinity than that of previous years was recorded in the whole of the Cantabrian, which indicates a greater influence of southern Atlantic waters (winter poleward current). The layer of water corresponding to NACW (100-500m) indicated an association of the central parts of the French and Spanish shelf and the Ortegal-Coruña area with colder and less saline waters, although there was a lack of continuity off Cape Ortegal. A pocket of warmer and more saline water was found between this zone and the SE corner of the Bay (Fig. 3d, 4d).

With regard to surface waters, in 1994 there was a strong circulation in the SE corner of the Bay towards the Spanish coast and a frontal zone in Finisterre; in 1995 there was a greater homogeneity and in 1996 the influence of the winter poleward current was noticeable and a front was detected in Ortegal. In addition to this a mainly haline front associated with the French slope appeared in all the cruises.

The most noticeable differences between the three years were the greater influence of the northern part of the Bay and a net flow towards the south in 1994, a lesser degree of circulation and regular thermohaline characteristics in 1995 and a greater influence of the southern part of the Bay (west Iberian Peninsula) in 1996, due to the greater intensity of the winter circulation. In addition to this, the cyclonic circulation in the SE corner of the Bay and the appearance of fronts in Ortegal produce an interannual variation over the period studied which is reflected in the biological communities.

*EGGS AND LARVAE*

The first observation that arises from our results is that more than 50% of the larvae remain in the spawning areas and the other half are transported equally to inshore as well as offshore waters. So, although the bulk of the population is retained over the spawning grounds, there is still a large proportion of the larvae whose spatial distribution seems to be in some way related to hydrographic features (Fig. 5a, b, c).

**Blue whiting:**

Blue whiting larvae were identified in 57 of the 113 plankton sampling stations during the SEFOS94 cruise (March/April). A total of 852 blue whiting larvae were sorted and measured. The most intense spawning area appeared in the north (west of France, betweeen 46° and 47° N) where relatively high numbers were recorded even quite far offshore, with a maximum value of 137.34 larvae/$m^2$. Significant spawning also occurred in a small area off Cape Peñas. These two main areas account for 88.92% of total blue whiting larvae. The rest of the sampled area shows very low abundances.

Blue whiting larvae collected were in the size range of 2 to 24 mm. The size frequency distribution was bimodal with peaks at 4.5 and 9.5 mm. In the area west of France there was a significantly higher abundance of newly hatched larvae in the smaller range (2-6 mm) which corresponded to an area where quite strong spawning was taking place or had recently occurred (Fig. 6).

Mackerel:

The egg and larvae abundances for the whole area sampled in each survey are shown in Figures. 7 & 8. Mackerel eggs were quite abundant and widely distributed over the continental shelf, particularly on the shelf edge. Mackerel larvae were found at greater depth in the offshore stations, during March-April in the SEFOS 94 and MPH 95 surveys when first spawning took place. The highest concentration of mackerel eggs was found in April 1995 (MPH/95) off the northern coast of Galicia with a maximum value of 3 072 eggs/$m^2$, coinciding with the highest concentration of the smallest larvae (886 larvae/$m^2$). In the SEFOS95 survey carried out in June, eggs were less abundant, and very few larvae were found. However, some important concentrations of larvae appeared in the northern area covered (47°N) and in the furthermost offshore stations coinciding with an area of high fluorescence. Plankton data support the hypothesis that the spawn occurs while adults move into the Gulf of Biscay folloving the coastline of France and Spain in the same way the adult population does.

The size of larvae ranged from 2.8 to 17 mm, while the most abundant were from 5 to 7.5 mm (excluding the highest concentration of those found recently hatched off Galicia). A pattern in larval distribution can be observed, from spawning areas in the shelf break, where the highest abundance of eggs and larvae was found, to offshore areas, where the abundance of larger sized larvae was greater (Figures 9 & 12).

**Horse Mackerel:**

The egg and larvae abundances for the whole area sampled in each survey are shown in Figure 10 & 11. Except for an important nucleus of eggs found off the west coast of France (47°N) during SEFOS/94 (March/April) very few eggs and larvae were found that year. However, eggs and larvae of horse mackerel appeared in great abundances in the SEFOS/95 survey (May/June). At this time, there were two areas of high abundance of eggs on the continental shelf, one being found off the Cape Ortegal coast with a maximum value of 1 252 eggs/m2, and the other off the French coast. This difference between the first survey in 1994 and the later survey in 1995 indicates that the main spawning occurs later in the year, at late spring, and that spawning progress northwards from waters in the South of Portugal to the North of Spanish and West of France. Larvae seem to be distributed in a similar pattern to that of eggs throughout the continental shelf, but high densities were found close to the shelf break (Fig. 11).

***ADULTS***

Figure 13 shows $S_A$ values for blue whiting for each transect and survey, split by age group, and figure 14 shows the maps with the $S_A$ values for each nautical mile. Both surveys show more or less the same distribution pattern. Important changes of density were found along transects, with the greatest density in North France and North Galicia and the lowest in East Cantabrian. In addition, there was an area in West Cantabrian with scarce density.

In 1994 age group III was the most abundant in the whole area, whereas age group II was also important in North France and age group I was only found, with a low density, in West Cantabrian. In 1996 age groups I and II were the most abundant. Age group II was the most abundant in North France and in the eastern part of North Galicia whereas age group I was the most important in West and East Cantabrian and in the western part of North Galicia. In East Cantabrian only age group I was found.

In French waters blue whiting was mainly distributed along the continental shelf-break and its distribution spreads further offshore in a pelagic layer at 200-300 m depth, but in Spanish waters it was mainly distributed over the continental shelf, close to the slope, with only a small proportion in a pelagic layer, mainly in the inner part of the Bay of Biscay.

Blue whiting juveniles were found in 1994 in the corner of the Bay of Biscay (East Cantabrian and South France). They had a mean of 3.7 cm (0.6 s.d.) and formed large pelagic schools close to the sea surface over 1000-2000m water depth. In addition, juveniles of 10.7 cm (0.6 s.d.) were found at 46°40' N, 5°40'W, at 100-150 m depth close to the shelf-break. In 1996 juveniles were detected in the corner of the Bay of Biscay, but their density was lower than in 1994.

## DISCUSSION

In several fish species that spawn offshore, the postlarvae and early juveniles recruit inshore, so at some critical moment in the early fish stages, eggs and/or larvae should be transported from offshore spawning areas to the nearshore nurseries (Koutsikopoulos *et al.*, 1991). Transport from the spawning grounds to the nearshore region is not well understood, and many authors have encouraged active collaboration between physical oceanographers and biologist in the hope that this will lead to a better understanding of this keystone of marine fish ecology. Spawnings of SEFOS target species are spatially related to the shelf-break, and early life stages are found all along the Bay of Biscay during the sampling months, so for this reason they can be used as good tracers for comparing spatio/temporal observations of hydrographic features and larvae and adult distribution.

When considering the circulation of the upper layers of the southern part of the Bay of Biscay a distinction has to be made between that which takes place over the shelf-break and that over deep waters. The latter is markedly anticyclonic due to the influence of the North Atlantic flow (Pingre 1993), and gives rise to an influence of the northern waters of the Bay on the central area of the Cantabrian Sea. Superimposed on this general pattern of circulation is the influence of the topography of the sea-bottom (shelf-break) and seasonal atmospheric conditions (sunshine, rainfall, wind stress) and runoff, all of which affect circulation in the upper layers. Other noticeable seasonal influences are those of upwelling (spring-summer), the poleward current (winter) in the western part of the Iberian Peninsula and runoff in the eastern part of the Bay. These all combine to induce a front in Finisterre-Ortegal and a circulation cell in the SE corner of the Bay, which together with the formation of eddies are the most outstanding features of the surface waters of the Cantabrian Sea. Over the continental slope there is a countercurrent with net eastward flow, although seasonal changes of direction occur due to the aforementioned factors.

Variability in the observed distribution of eggs and larvae obtained in the SEFOS project can be reasonably explained by the biological behaviour of the spawning stock (which was shown to spawn close to the shelf-edge) and by the hydrographical features that occured in these years

The distribution of the larvae in the central region of the Cantabrian sea suggests some limited eastward transport of a fraction of the spawning during this period when very few larvae were found in the outer stations in this area. This feature was consistent in our results and the continuity in the distribution of mackerel and horse mackerel eggs and larvae suggests little net displacement of the planktonic stages from the spawning grounds to offshore. In those areas where circulation is governed by topography, wind forcing will tend to favour alongshore movements of the larval population rather than cross-shelf movements. In fact, circulation in these areas was characterized by weak eastward currents (10-15 cm/s) ( Diaz del Rio, 1996) generated by dominant SW and NW winds and also the intrusion of water from the centre of the Bay of Biscay detected during the period studied. These features are coherent with the spatial larvae distribution observed in the central part of the Cantabrian.

Some large larvae of mackerel and horse mackerel were found further off the coast. These larvae were distributed across the oceanic waters in two areas: off the Armorican platform (47°N) and off Cape Ortegal (8°W).This front was detected in June-95 when the biological and environmental conditions changed abruptly in the cross-shelf direction, and both phytoplankton (measured as fluorescence) and zooplankton (displacement volume) increased their abundance. Hydrographical measurements also suggest a displacement of waters off the coast, and quite high numbers of mackerel and horse mackerel larvae in very healthy conditions were caught. Abundant information about the Armorican shelf front is available in the literature, and a revision on the physical, chemical and biological processes has been published recently (Sournia *et al.*, 1990).

At 8° W the forcing was more energetic and resulted in a much larger and more continuous displacement of the larvae compared to the Armorican platform where larvae were not continuously distributed over and off the shelf. This pattern of distribution in Cape Ortegal has been repeatedly observed in previous years since 1992 (Lago de Lanzos *et al.*, 1993; Franco *et al.* 1993) and it seems to be associated with the connection between Atlantic and Bay of Biscay waters. The hydrographical processes described in the Armorican platform and in Cape Ortegal may explain the large numbers of planktonic stages of different fish. Moreover, these dynamics in Cape Ortegal have an important influence on food availibity and its quality for adult fish. Abaunza *et al* (1995) have found different infestation levels of *Anisakis simplex* (Nematoda: Ascaridata) for horse mackerel westward and eastward of Cape Ortegal; since this fish species feeds on zooplankton and planktonic crustaceans among others, the high hydrodynamic activity at west Cape Ortegal gives a high primary production, ensuring favourable conditions for the development of the life-cycle of *Anisakis simplex* and, therefore, a greater abundance of this parasite may occur in Galician waters.

The SE corner of the Bay has peculiar oceanographic and climatic conditions which set it apart from the rest of the Cantabrian Sea. The main features are the presence of thermohaline fronts and a cell of cyclonic circulation, which differentiate this area for larvae as well as for juveniles and adults. The thermohaline front and the cyclonic circulation lead to a concentration of larvae, and make the Bay an important nursery area (Schmidt, 1909; Maucorps, 1979; Bailey, 1982; Porteiro, 1996). In 1994 the presence of a strong southwards thermohaline current in the eastern sector of the Bay could explain the large concentration of juvenile blue whiting found in this zone. On the other hand, in both 1994 and 1996 the density of adult blue whiting surveyed in this zone was low in comparison to other sectors of the Bay, the only noticeable feature being the presence of specimens in age group I.

Adult blue whiting were unevenly distributed horizontally, with areas of high density alternating with others of scarcity. One feature of note was the difference in density found in the western corner of the Iberian Peninsula (North Galicia) in both 1994 and 1996, but especially in the latter, in comparison with the adjacent zone of the Cantabrian Sea (between 6° and 7°W). This difference may be explained by the thermohaline features and the dynamics of the NACW. In 1996 a break in continuity was discernible off Cape Ortegal, which coincided with low numbers of blue whiting in the area. On the other hand the density of blue whiting in the central area of the Cantabrian Sea was lower in 1994 than in 1996, which may also correspond to the lower salinity found in this zone in 1994 compared to 1996; this sector of the Cantabrian Sea was also more stable and homogeneous in 1996 than in 1994.

Blue whiting is a migratory species whose patterns of behaviour are still not completely understood. Nevertheless, the greatest changes in distribution at this time of year are to be found in north France (Carrera, 1996), and therefore the difference in spatial distribution to be found in the rest of the Cantabrian Sea may also be explained by changes in hydrographic conditions.

The vertical distribution of blue whiting is reasonably homogeneous, with an average depth of 200-250 m, which coincides with its ideal depth (Bailey, 1982). However its behaviour in French waters varies radically from that in Spanish waters. In French waters blue whiting was found from 200 m downwards on the slope, with almost no presence on the shelf, and in 1996 extended as far as 6-10 miles offshore from the shelf in a pelagic layer at around 200-300 m. However in Spanish waters blue whiting was found from 150 m downwards, with maximum abundance from 200 m, but always over the shelf, with almost no extension in a pelagic layer like that found in France except for in the SE corner of the Bay. The Spanish shelf is narrower than the French shelf, but it is also deeper, going down as far as 250m in comparison to the 150m of the French shelf before the slope begins. This topographical difference may explain the presence of blue whiting over the Spanish shelf, but it would not explain its lack of extension in a pelagic layer like that in French waters. The higher degree of hydrodynamic activity in the NW of the Iberian peninsula, which spreads eastwards into the Cantabrian Sea, makes this area less stable and homogeneous than the SE corner of the Bay and its French waters, which could be the reason for a difference in the behaviour of blue whiting in the two waters.

On the other hand, the presence of a circulation cell in the SE corner of the Bay of Biscay, which reaches into both French and Spanish waters and produces a concentration of larvae and the early stages of different species, casts doubt on the whose argument that the Cape Breton Canyon marks a dividing line for the distribution of species. In the light of the present results, at least as far as the early stages of the species studied are concerned, the definition of the so-called Southern stocks of different species (horse mackerel, blue whiting or mackerel), whose distribution is said to begin at the Cape Breton Canyon, is not consistent with the real distribution of juveniles and larvae of these species.

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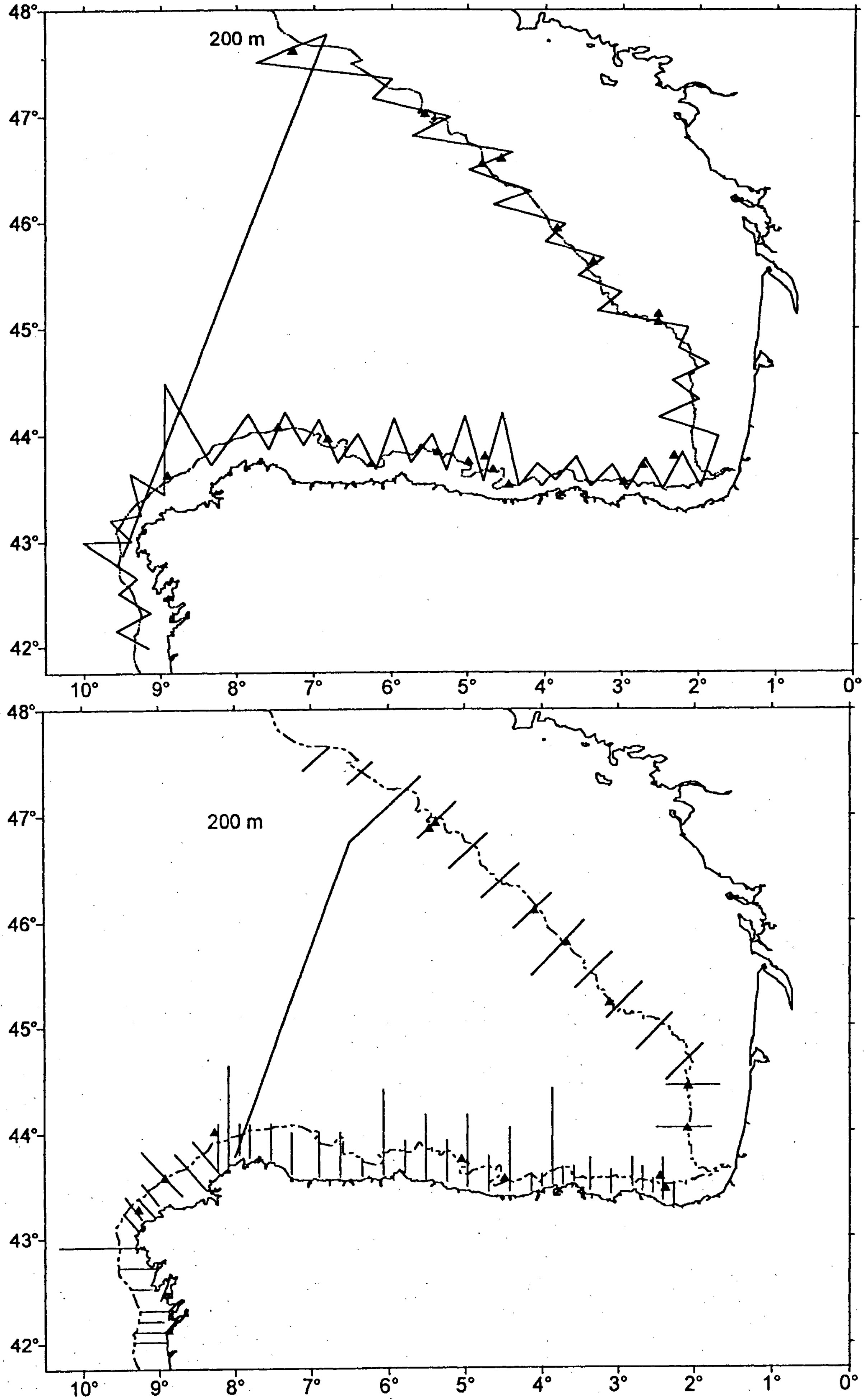


Fig 1a,b: Acoustic track and fishing stations during SEFOS 0394 (above) and SEFOS0396 (below) cruises

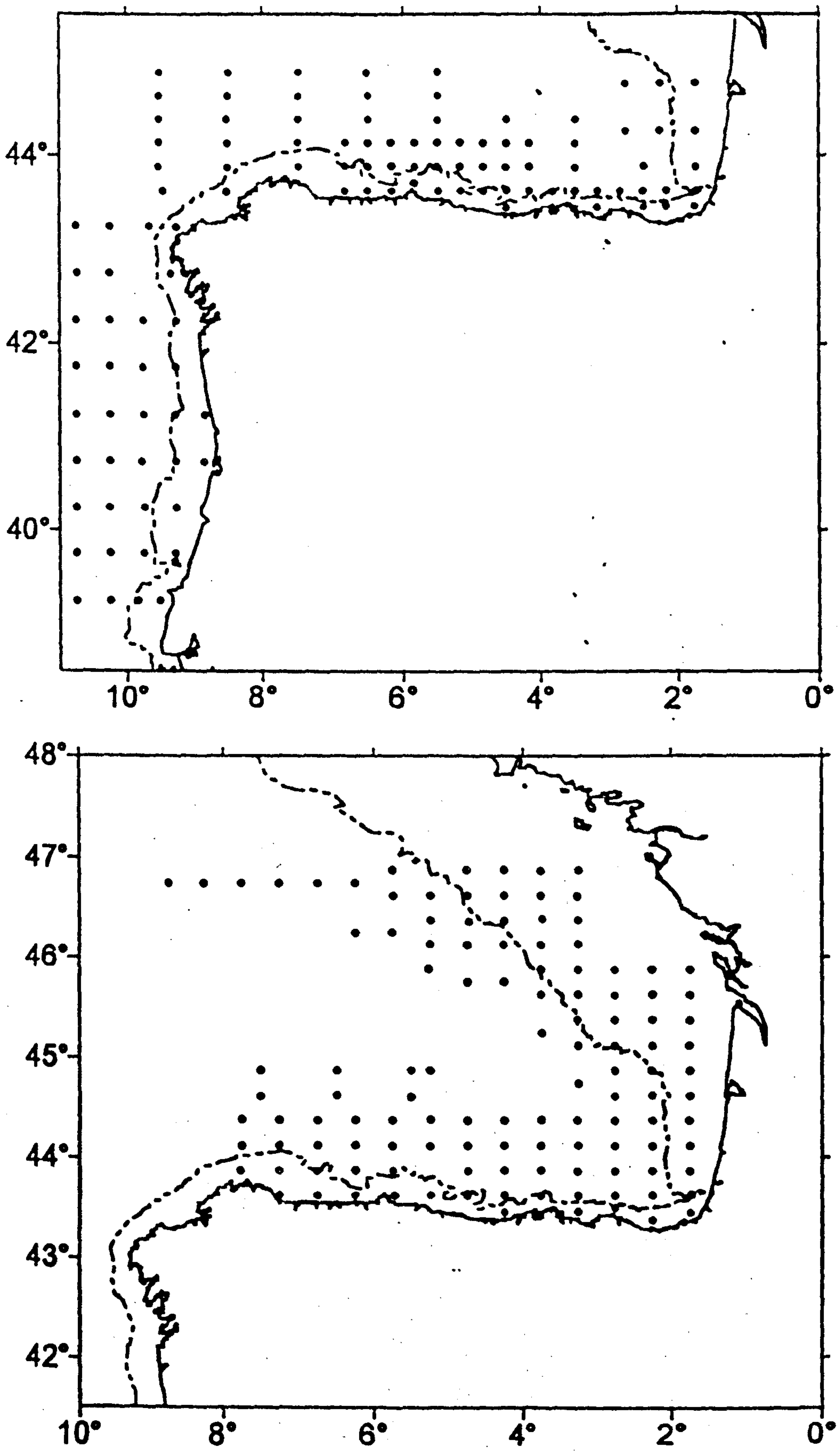


Fig 1c, d: CTD & Plankton stations during MPH/95 (above) and SEFOS/95 cruises.

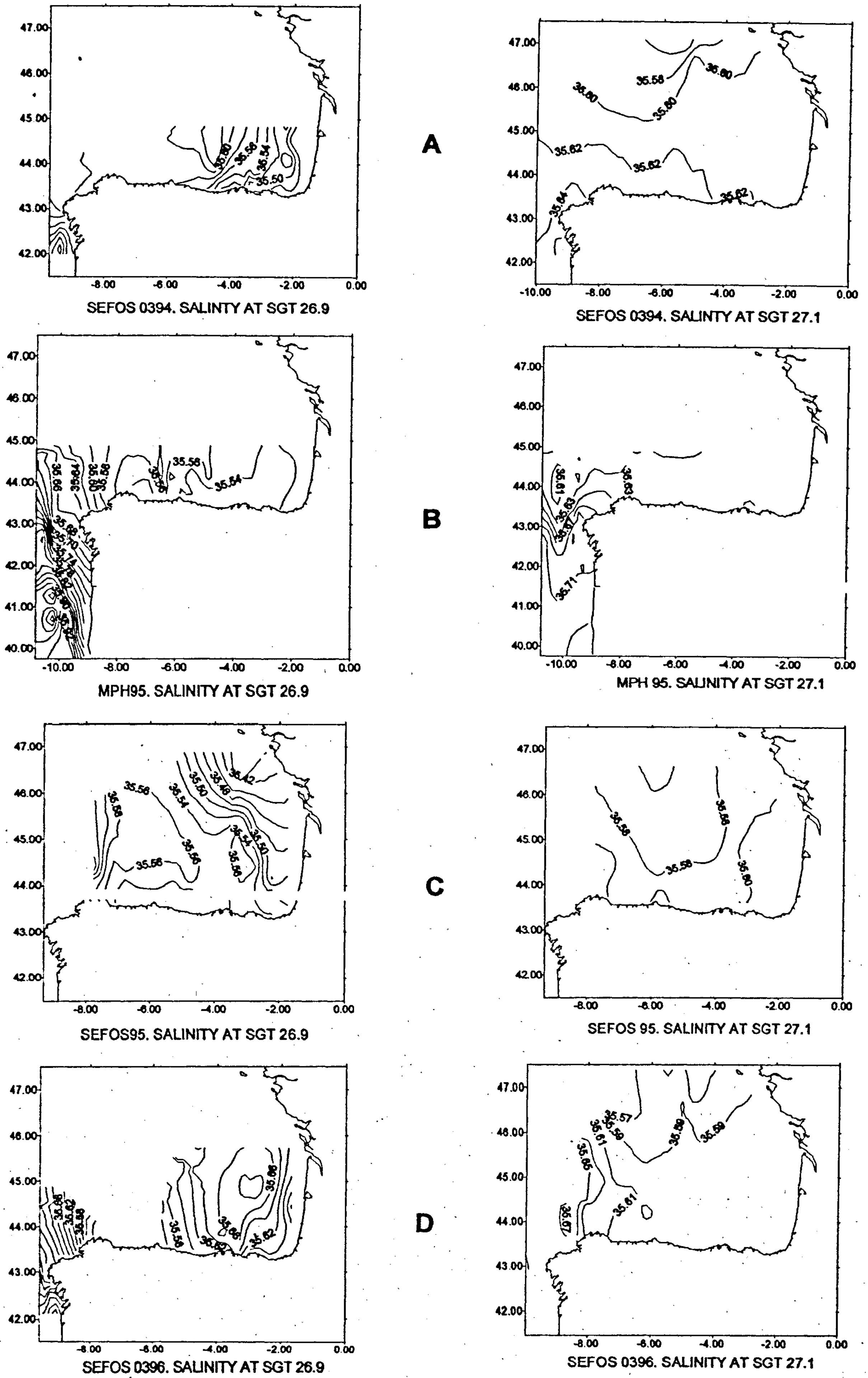


Fig. 2.- Salinity at sigma-t 26.9 and 27.1

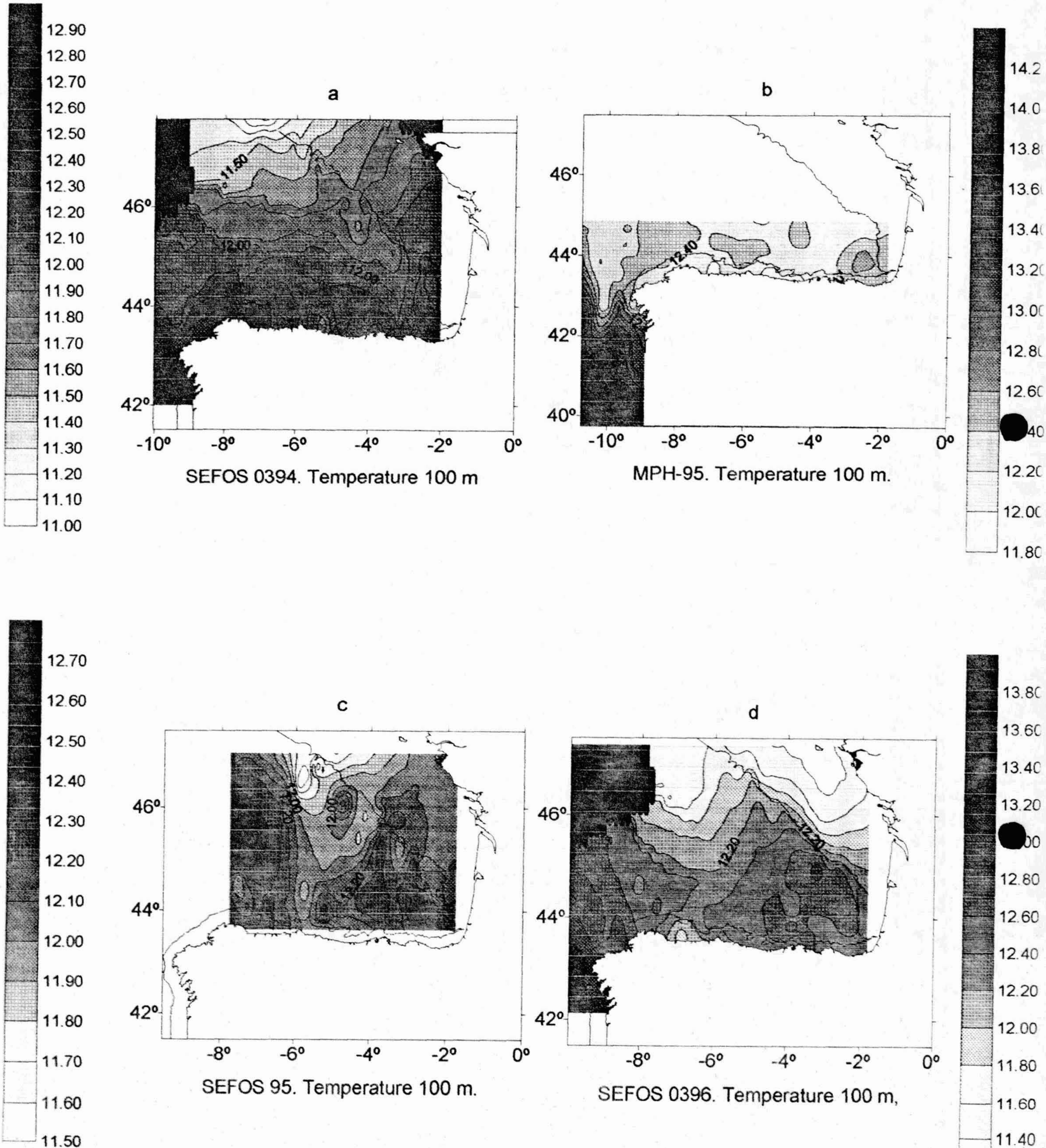


Figure 3.- Temperature distribution at 100 m. for the cruises a) SEFOS 0394
b) MPH-95, c) SEFOS 95, d) SEFOS 0396

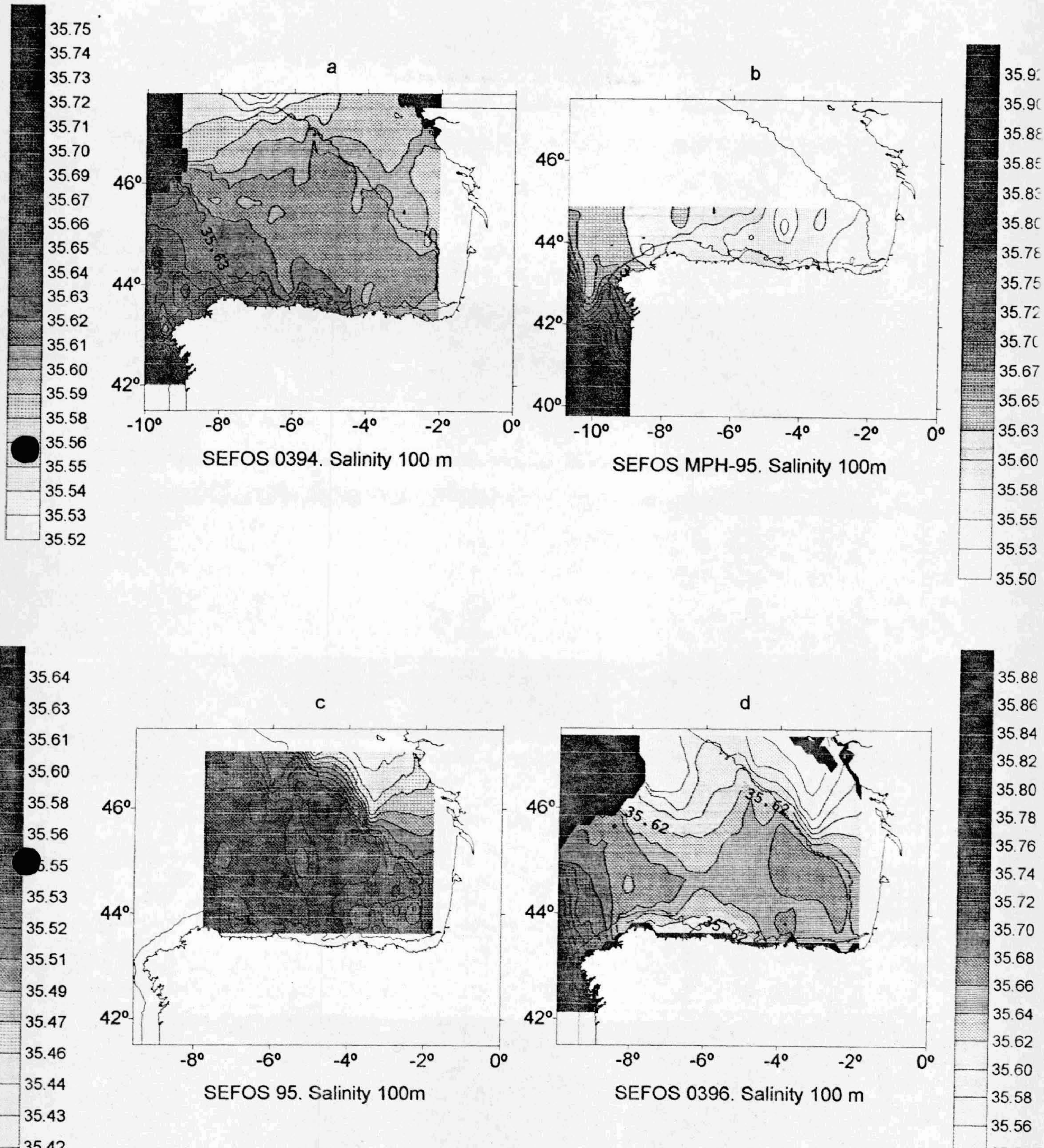


Figure 4.- Salinity distribution at 100 m. for the cruises a) SEFOS 0394
b) MPH-95, c) SEFOS 95, d) SEFOS 0396

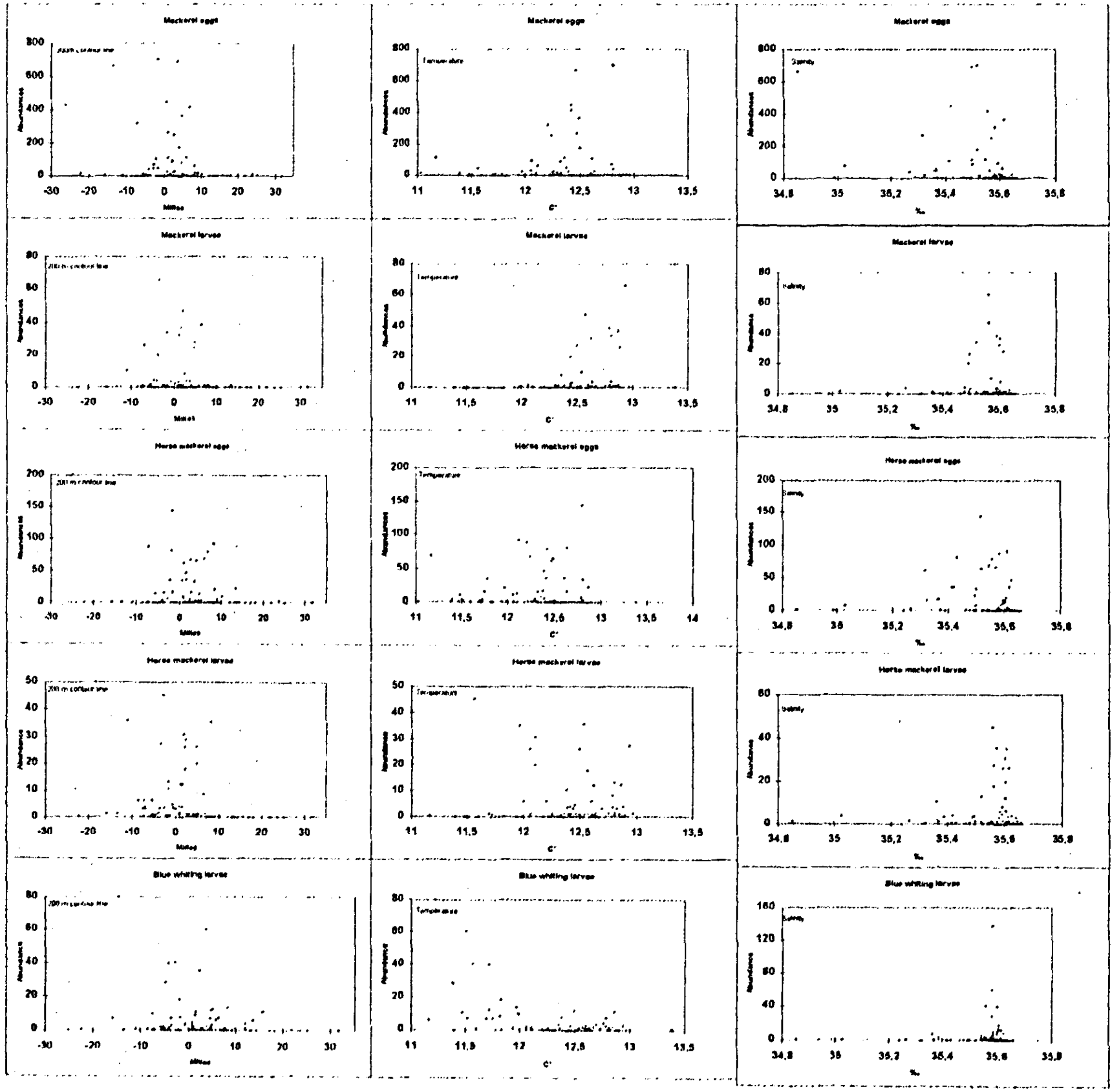

Figura 5a. Scatterplots of eggs and larvae abundance of the target species vs. topographic and environmental variables (survey: SEFOS XXX).

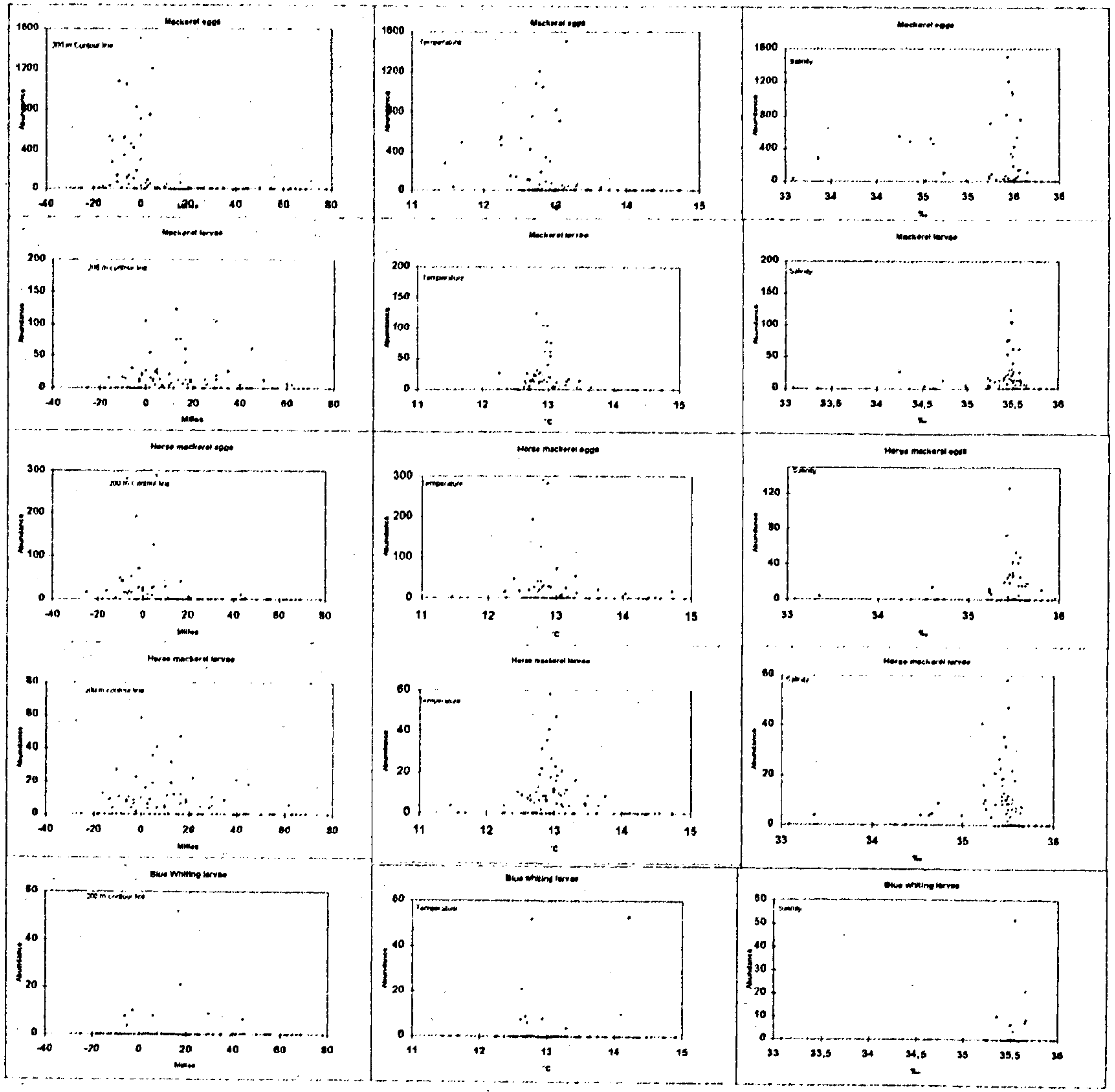

Figura 5b. Scatterplots of eggs and larvae abundance of the target species vs. topographic and environmental variables (survey: SEFOS XXX).

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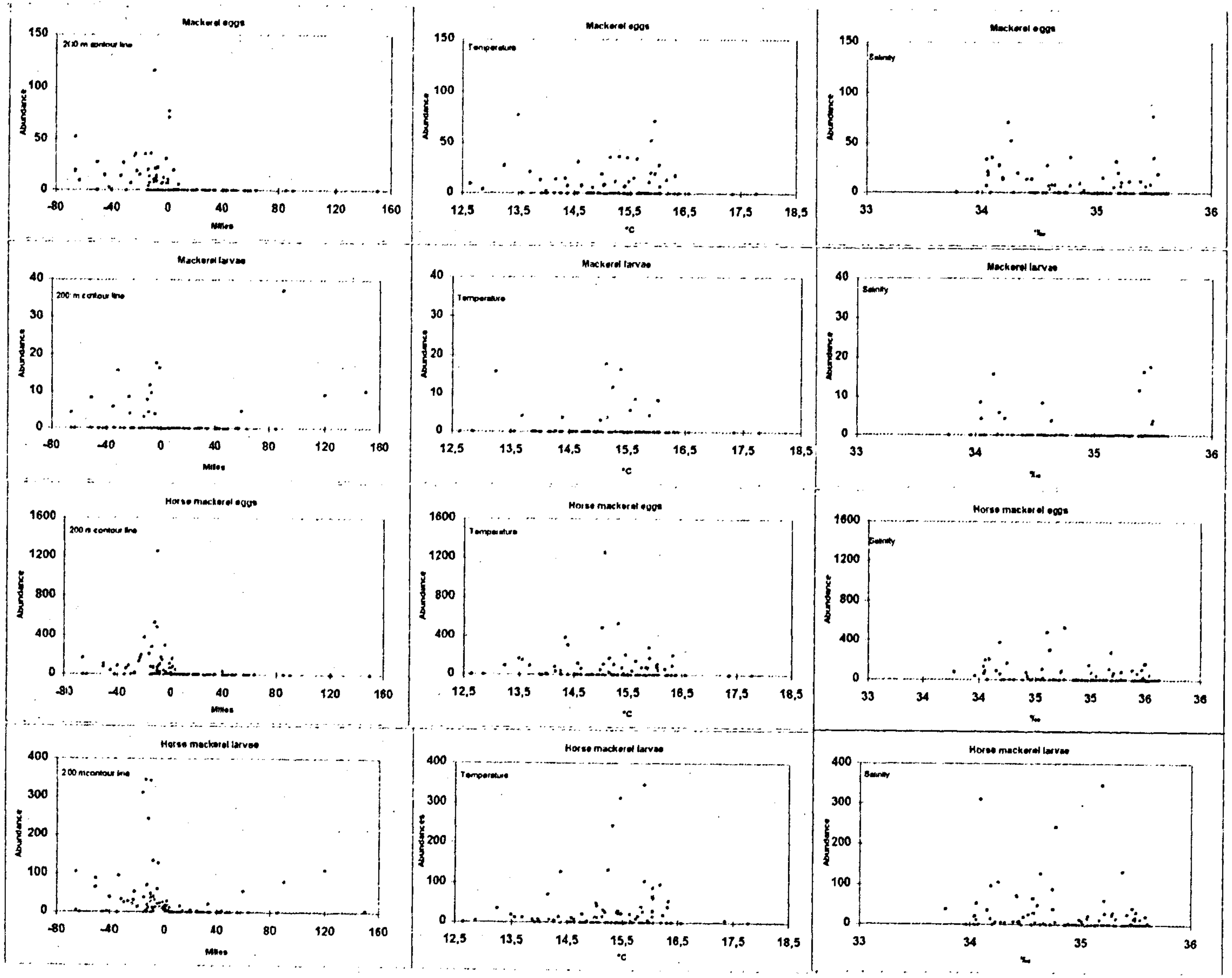


Figura 5c. Scatterplots of eggs and larvae abundance of the target species vs. topographic and environmental variables (survey: SEFOS XXX).

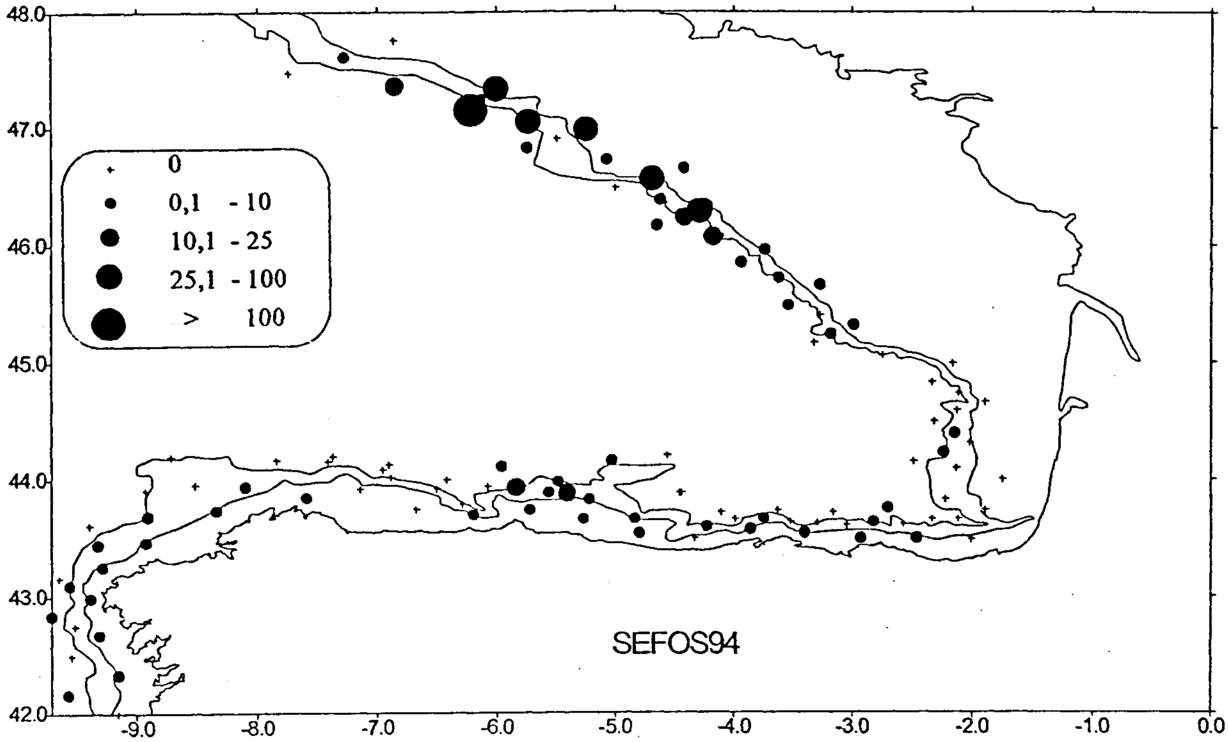


Figure 6. Distribution and abundance of blue larvae larvae/m²

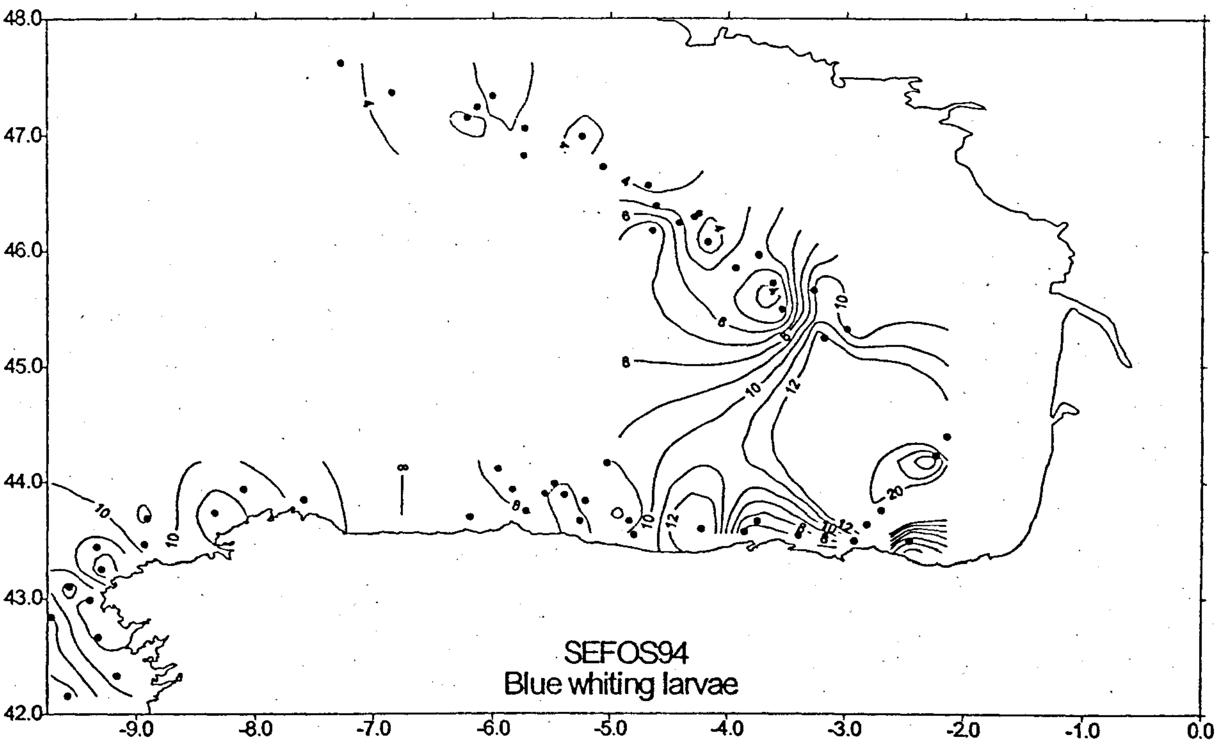


Figure 7. Distribution of blue whiting larvae mean sizes (only positive stations)

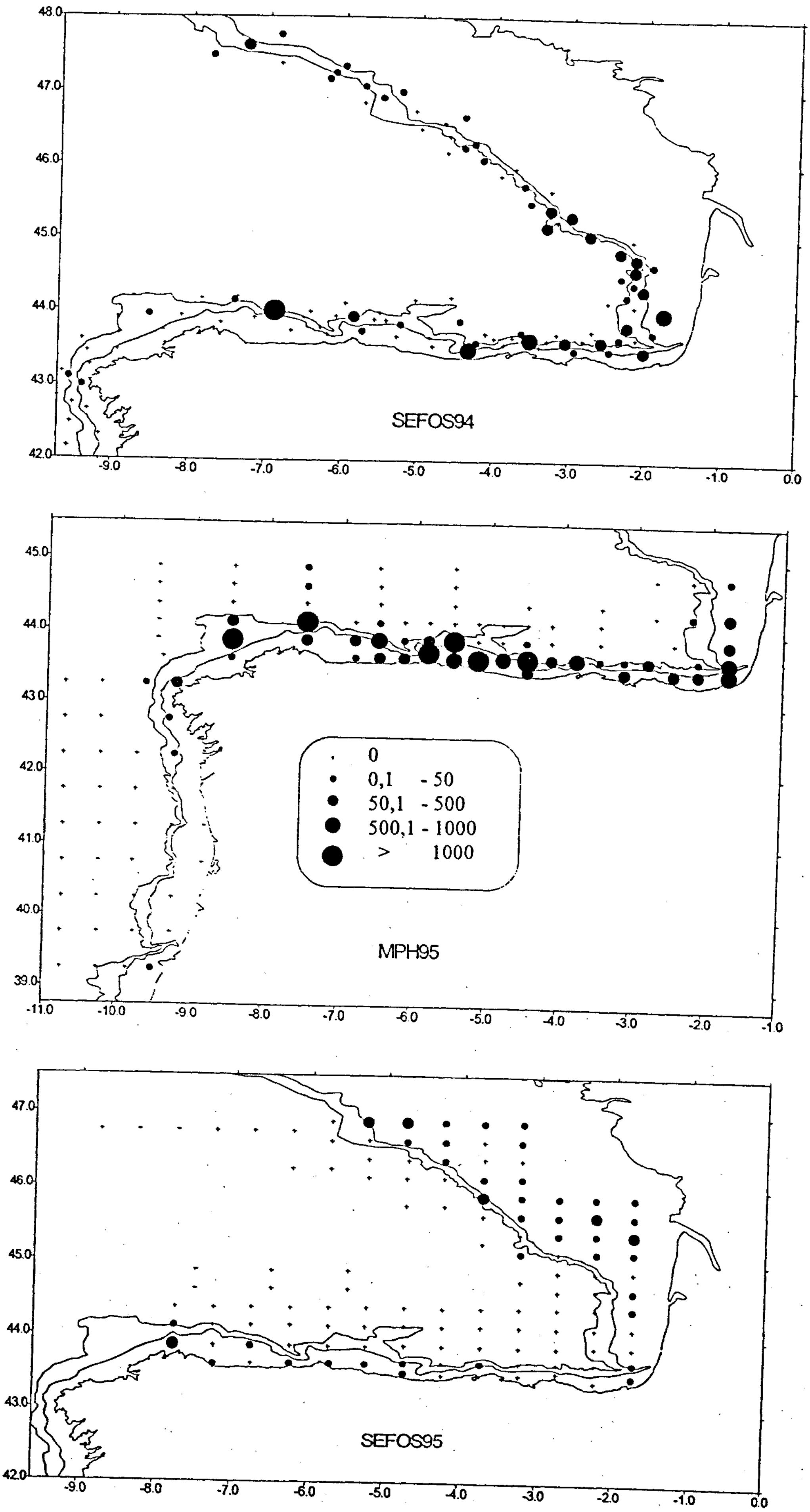


Figure 8. Distribution and abundance of mackerel eggs/m²

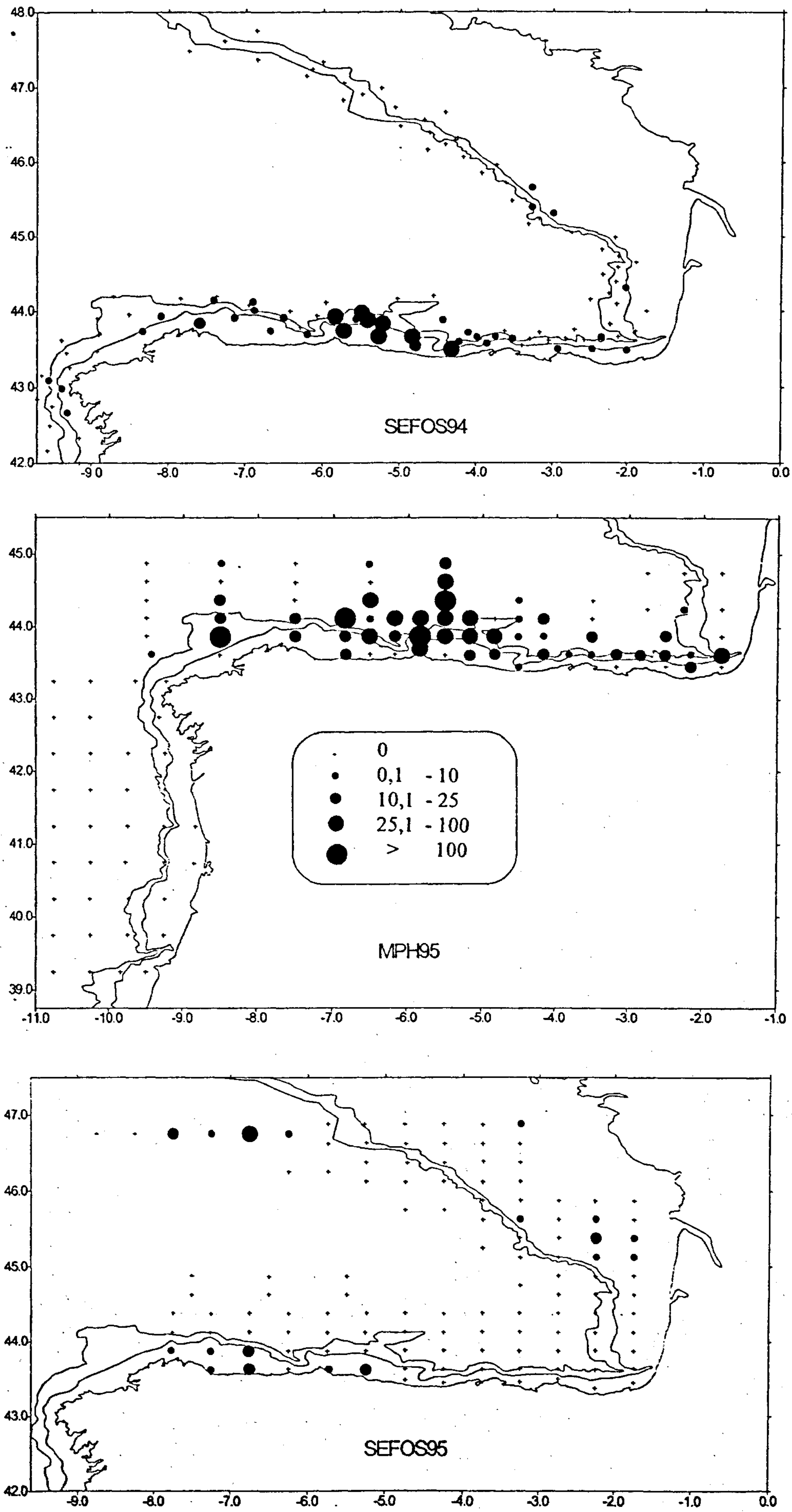


Figure 9. Distribution and abundance of mackerel larvae/m²

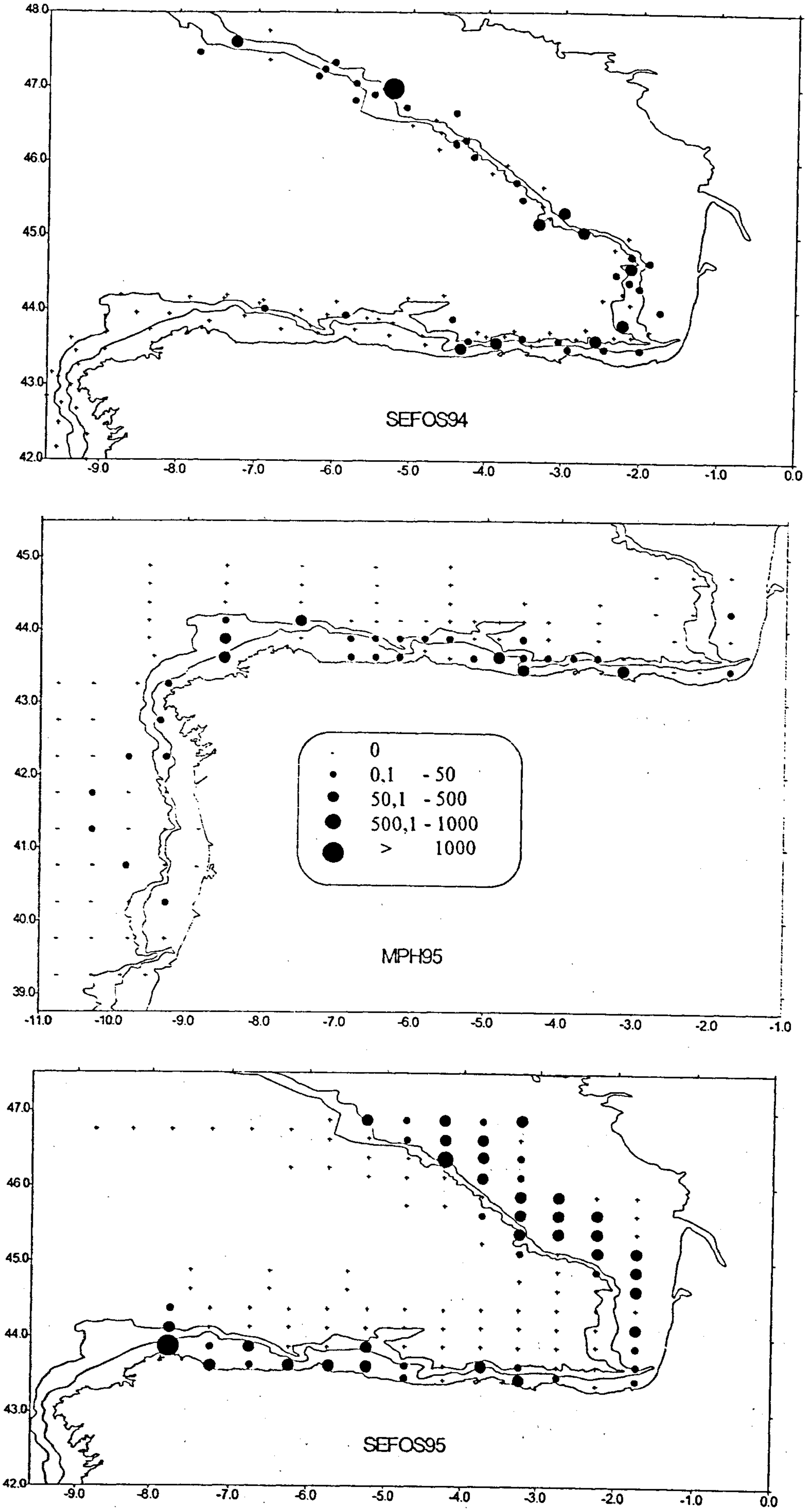


Figure 10 Distribution and abundance of horse mackerel eggs/m²

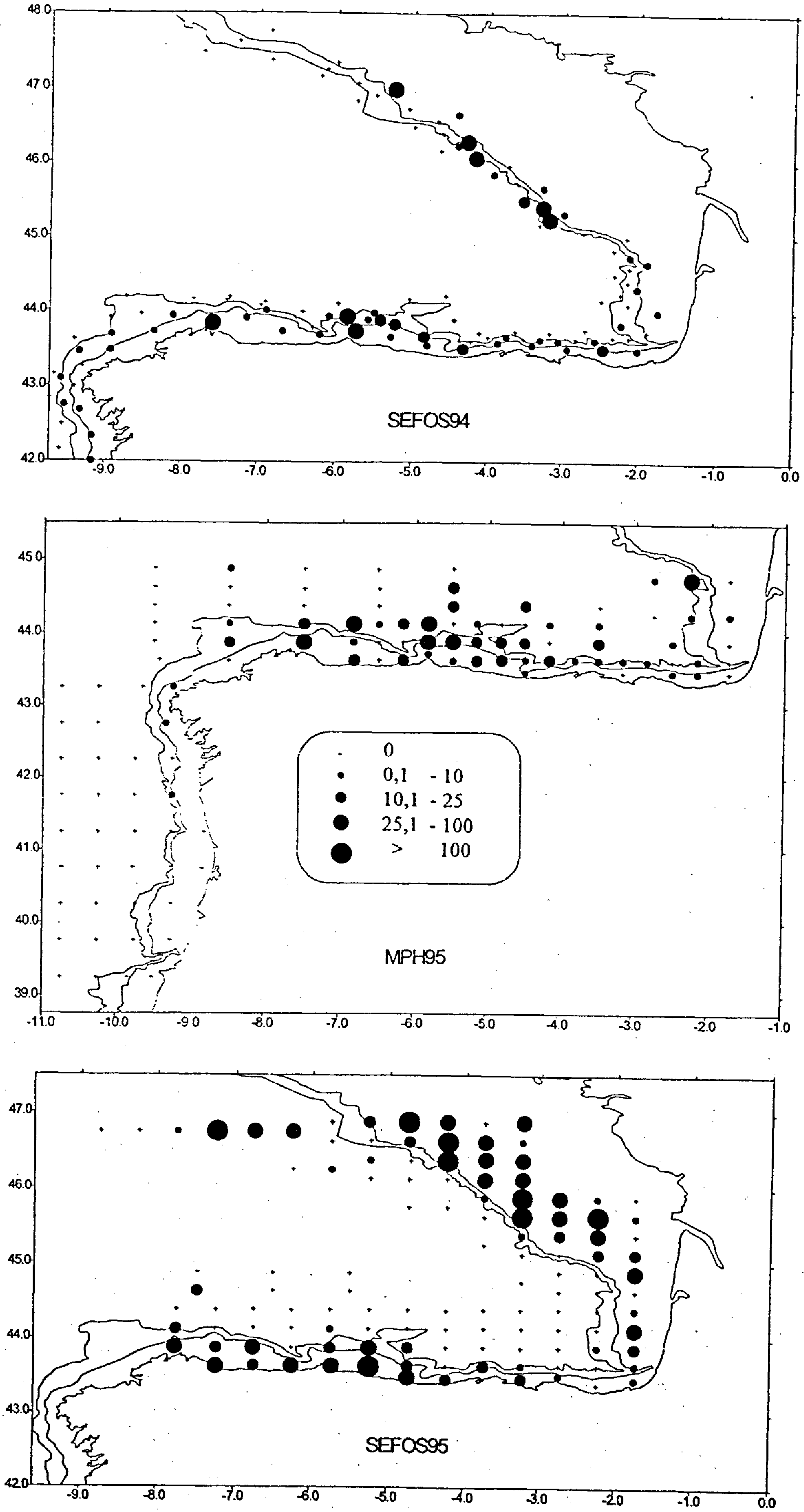


Figure 11 Distribution and abundance of horse mackerel larvae/m²

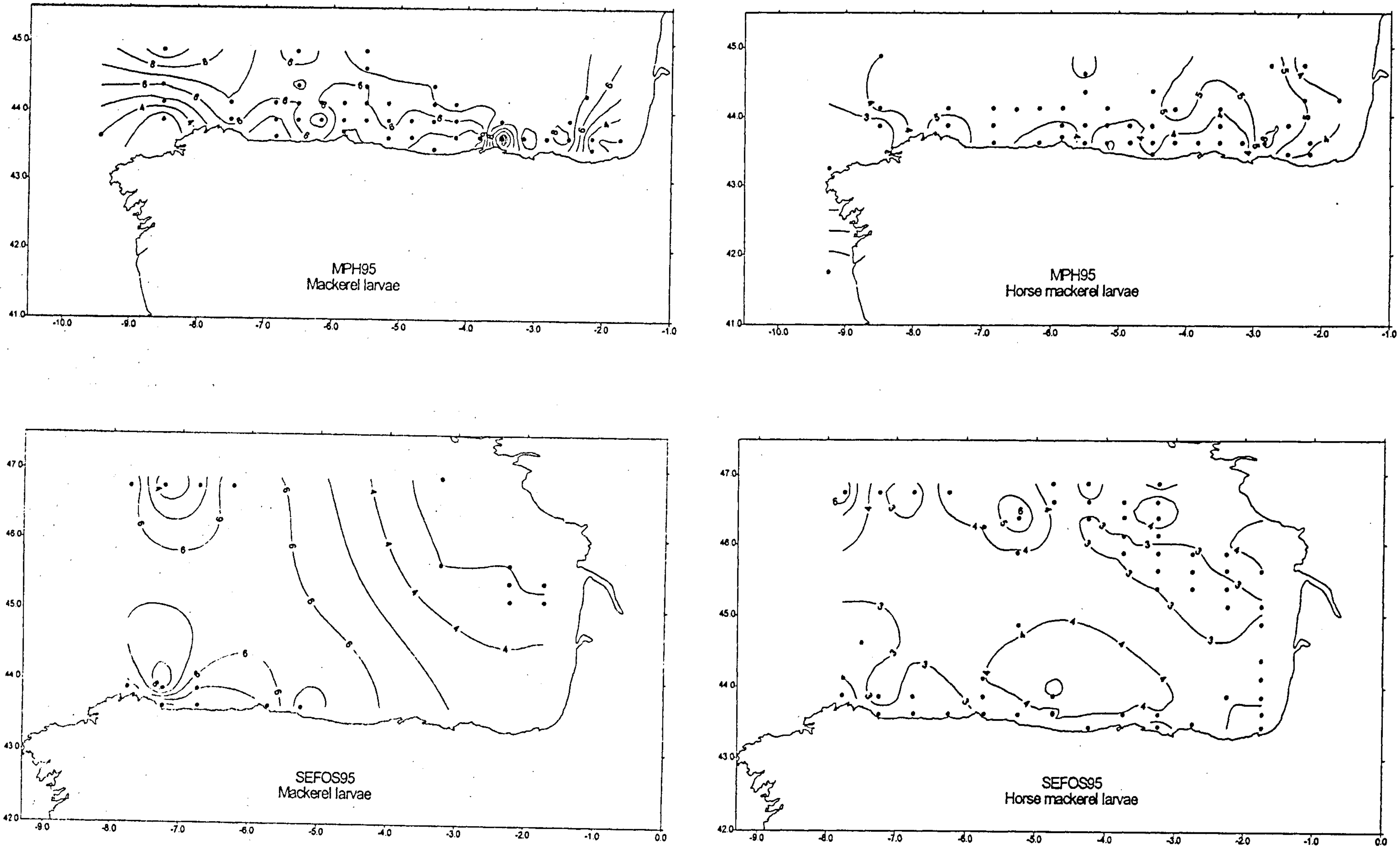


Figure 12 Distribution of mackerl and horse mackerel larvae mean sizes (only positive stations)

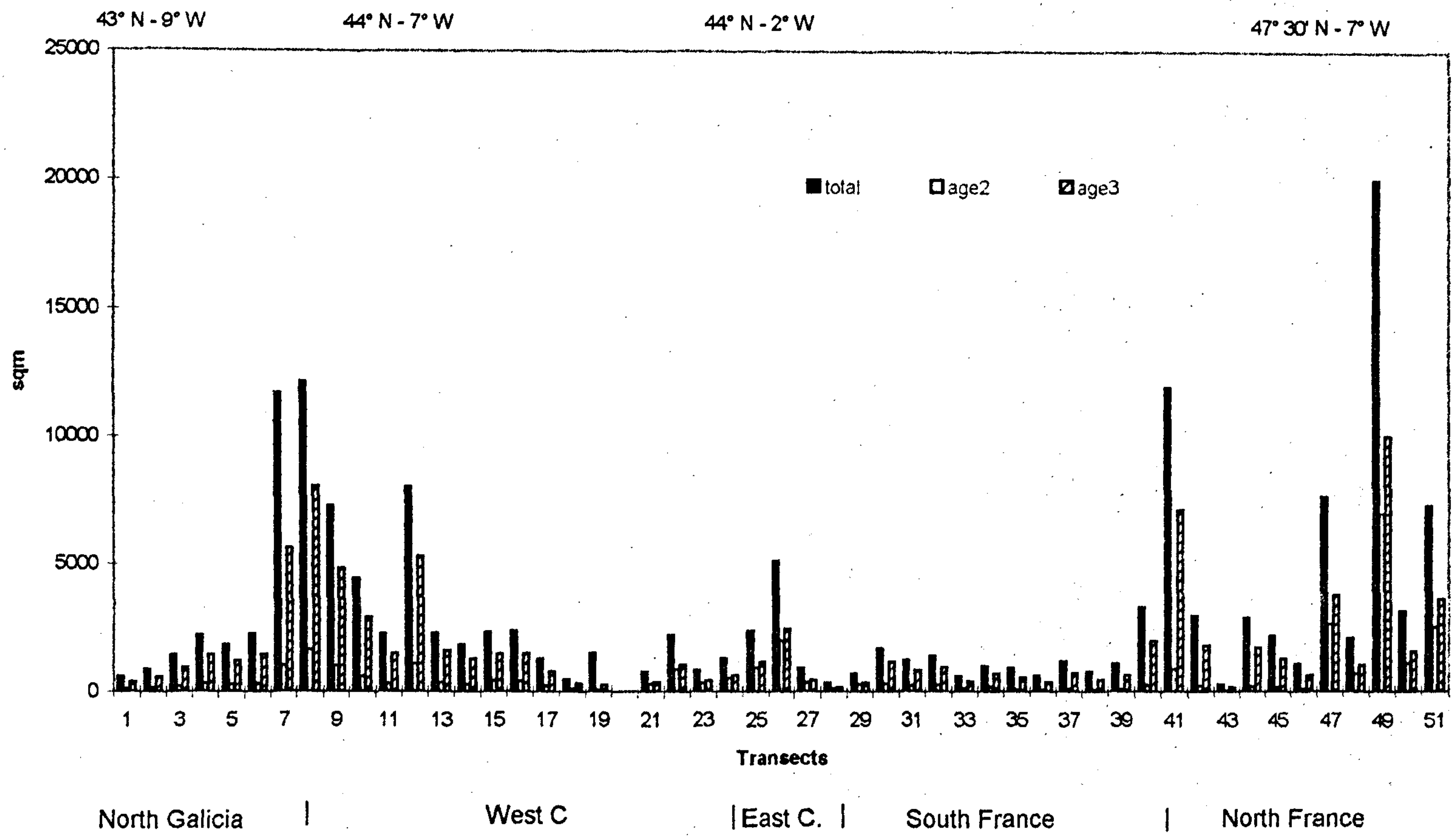


Figure 13a: $S_A$ values of blue whiting by transect during SEFOS 0394 survey

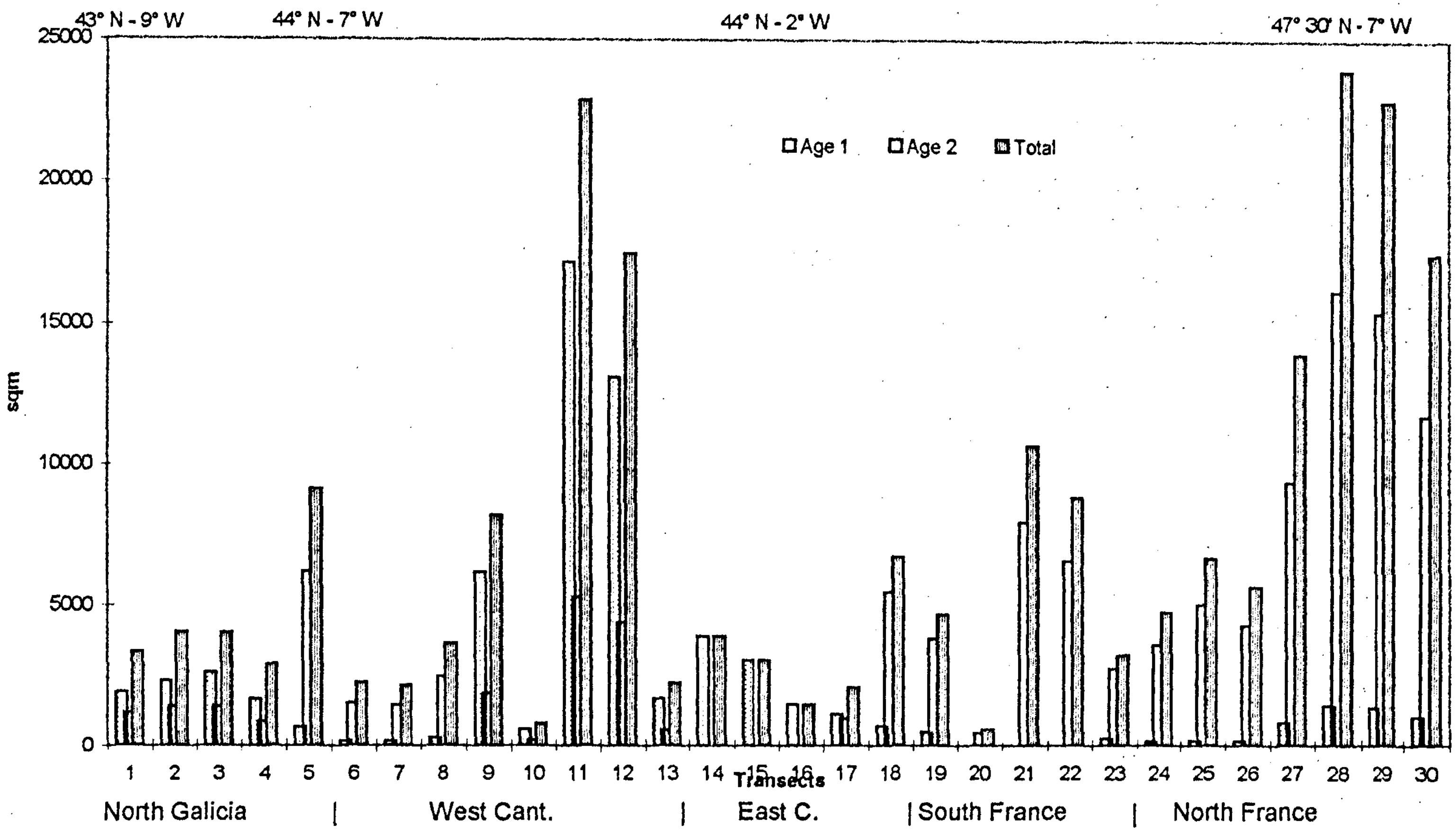


Figure 13b: $S_A$ values of blue whiting by transect during SEFOS 0396 survey

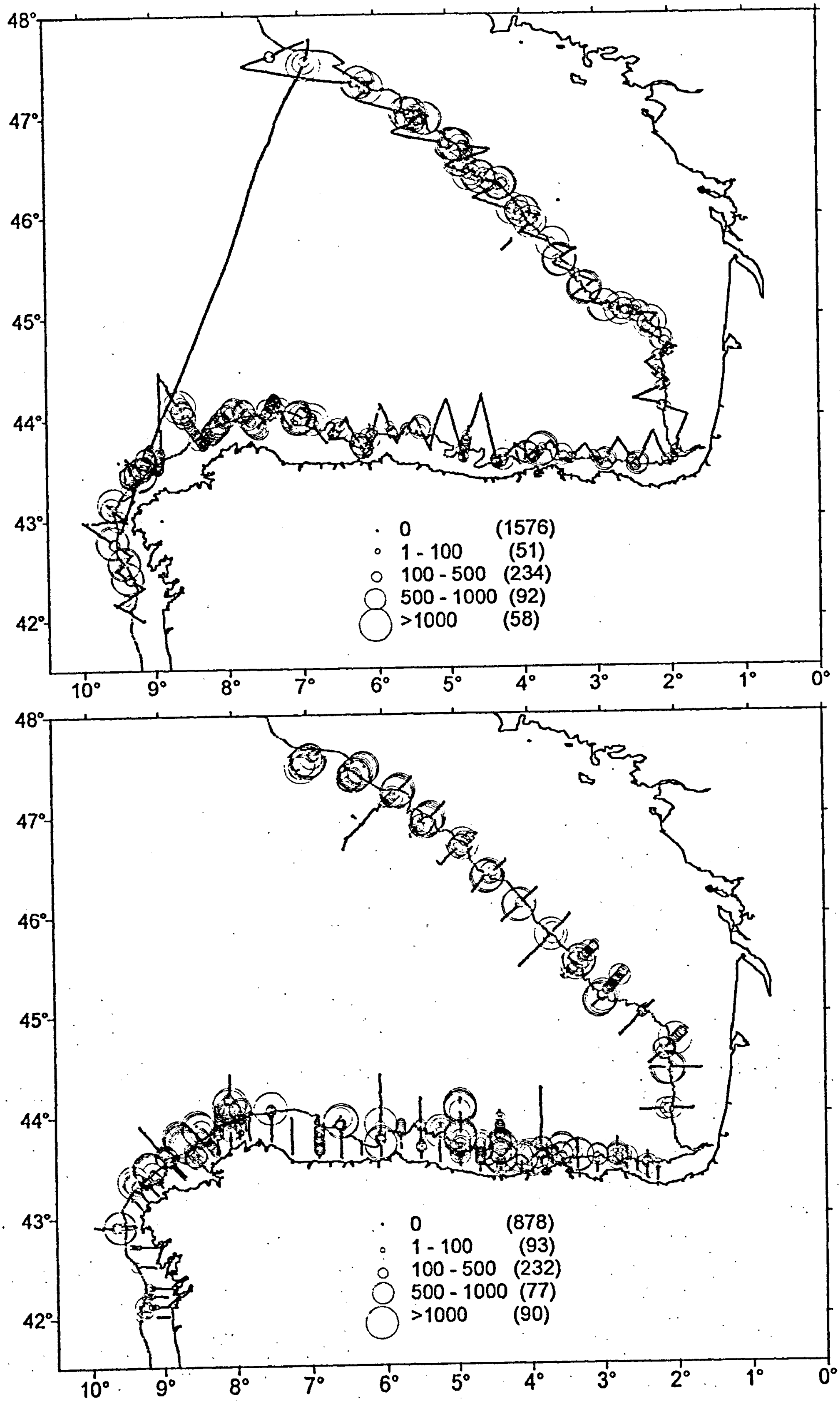


Figure 14: Echointegrated values by nautical mile during SEFOS 0394 (above) and SEFOS 0396 (below) cruises