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Shelf Edge Current and its
Effects on Fish Stocks

Modelling the Variability of the drift of blue whiting larvae and its possible importance for recruitment.

by

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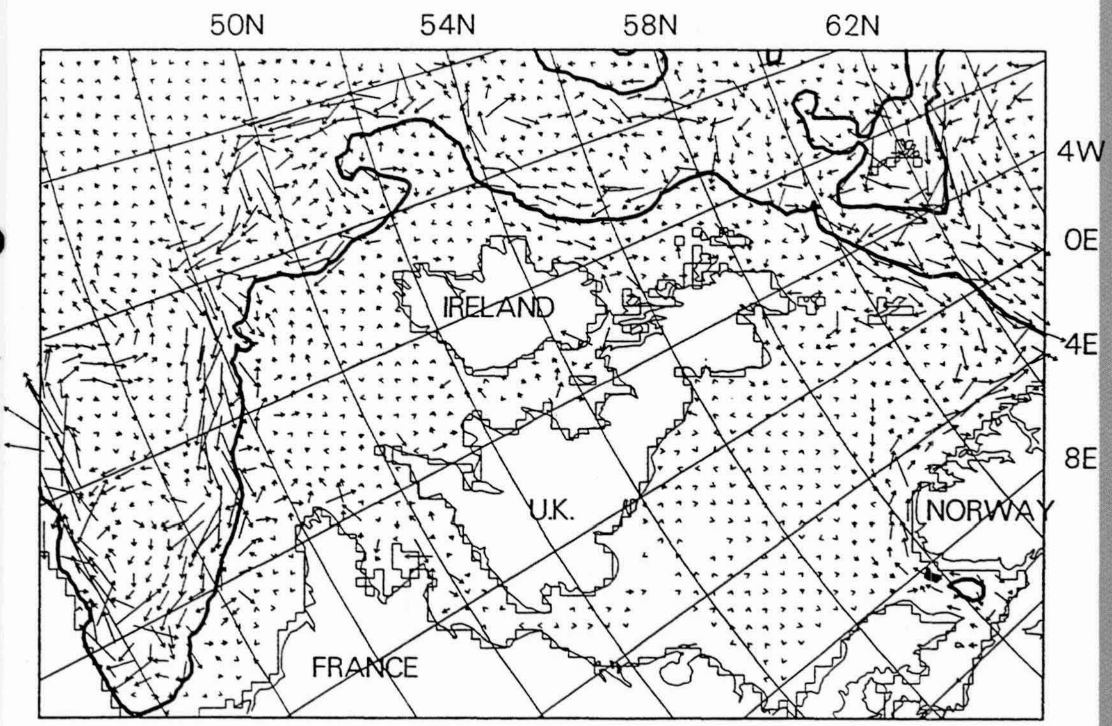
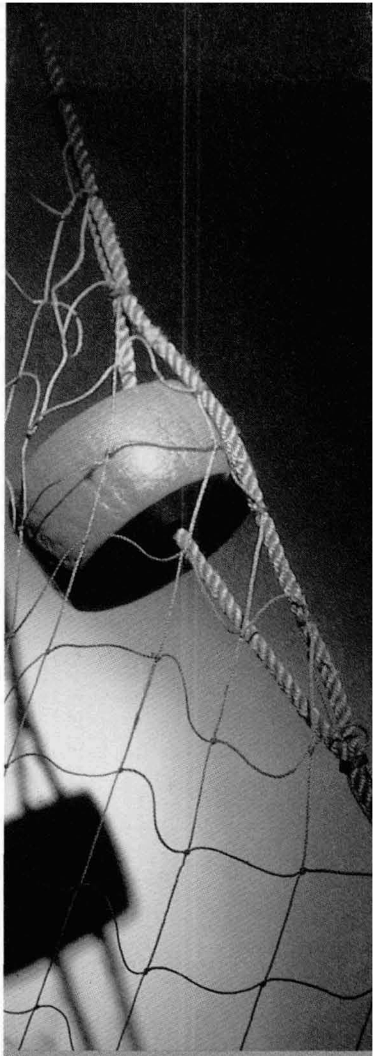


AVERAGE VELOCITY 30 METERS, Apr-Jun 1976-94



HAVFORSKNINGSINSTITUTTET
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Abstract

The first 8 months of the drift of blue whiting larvae has been simulated and studied for the 20 year period 1976-1994, using the 3-dimensional numerical model system NORWECOM (the NORWegian ECOlogical Model system). The model particles assumed to represent larvae are released identically in space and time each year according to best "average" knowledge. Large variations in the drift patterns are seen from year to year, but generally much larger amounts of larvae than expected seems to drift southward from the Porcupine Bank area west of Ireland to the Bay of Biscay. Many of these larvae drift into deep water where chances of survival are assumed to be small. Typically larvae hatched on the northern side of the Porcupine Bank drift northwards through the Faeroe-Shetland Channel, and most of these larvae are located on the shelf. Several distribution parameters are selected and compared with ICES time-series of recruitment.

Introduction

Quantitative knowledge of the actual processes leading to the observed large year to year variability of recruitment are for most fish stocks quite unknown. Much work has been focused on studying empirical relations with temperature and size of spawning stocks, but few clear conclusions has been drawn. We know that temperature has an effect on the whole ecosystem and that the size of the spawning stocks are related to recruitment when the spawning stock is small, being directly related to the amount of eggs and larvae being produced. However no clear relations are found to variations in large spawning stocks, and the correlations with temperature are quite weak (Svendsen et al., 1996). This indicates that other environmental factors are important, and it is generally accepted that it is the processes acting during spawning and early life stages of the fish which are most important for the recruitment variability.

Rothschild and Osborn (1988) showed theoretically the importance of turbulence for plankton contact rates, and Sundby and Fossum (1990) has further confirmed this theory to measured feeding conditions for cod larvae. The turbulence is in most areas directly related to wind conditions. Svendsen et al. (1995) used a multivariat statistical approach to study the recruitment variability of several North Sea stocks, and he indeed found that the wind generated turbulence could explain much of the variability, together with indirect measures of varying inflow of Atlantic Water and heat content in the North Sea.

During the 1990's 3-dimensional numerical circulation models have improved significantly, and access to supercomputers have made it possible to make simulations over many years. Berntsen et al. (1994) used such a model for studying North Sea sandeel larvae, and they concluded that unfortunate drift of the larvae in the northern North Sea may lead to bad recruitment. However the knowledge of the behavior of the larvae (which only drift a few months in the water before settling on the bottom) was too weak to come to firm conclusions on the importance of varying drift on recruitment. Several modelled larval drift studies of other species, particularly of herring in the North Sea has been published (Moksness et al., 1996, Bartsch et al., 1989, Bartsch et al. 1993), and similar work is carried out in Alaska (Stabeno et al., 1995) and on Georges Bank (Werner et al., 1995).

During the EU-project SEFOS (Shelf Edge Fisheries and Oceanography Studies), 19 years of modelled larval drift simulations are performed to study the year to year variability of: retention in spawning areas, drift onto the shelf versus into deep water, drift northward versus southward, and drift into the North Sea. Finally these time-series are related to the 0-group recruitment to see if any of the variability are linked to the larval drift.

The Model

The NORWegian ECOlogical Model system (NORWECOM) is a coupled physical, chemical, biological model system applied to study ocean circulation, primary production, transport of nutrients and dispersion of particles (fish larvae, pollution). The model system is fully described in Skogen (1993), Aksnes et al. (1995) and Skogen et al. (1995).In this study a coupled system with a circulation module and a transport module is used. A fine-scale version of the circulation module is evaluated towards data in the eastern North Sea and Skagerrak by Skogen et al. (1996) and Svendsen et al., (1996) The circulation model is based on the wind and density driven Princeton Ocean Model (Blumberg and Mellor, 1987, Mellor, 1996). A 20 times 20 km horizontal grid covering the whole shelf area from Portugal to Norway, including the North Sea, has been used (Fig.1). In the vertical the model uses 12 sigma layers.

The forcing variables are six-hourly hindcast atmospheric pressure fields provided by the Norwegian Meteorological Institute (DNMI) (Reistad, 1995), 6-hourly wind stress (translated from the pressure fields by assuming neutral air-sea stability), four tidal constituents and information on freshwater runoff obtained from a number of sources. To absorb inconsistencies between forced boundary conditions and model results, a 7 gridcell "Flow Relaxation Scheme" (FRS) zone is used around the open boundaries (Martinsen and Engedahl, 1987). In the lack of data on the surface heat fluxes, a "relaxation towards climatology" method is used (Cox and Bryan, 1984). During calm wind conditions, the surface temperature field will adjust to the climatological values after about 10 days (Oey, 1991). The net evaporation precipitation flux is set to zero.

North of a line going from Brest (France) and passing south of Porcupine Bank, initial values for velocities, water elevation, temperature and salinity are taken from monthly climatologies (Martinsen et al., 1992). South of this line initial values for salinity and temperature are taken from the Levitus dataset (Levitus, 1982), while velocities are computed using the thermal wind equation assuming zero net flux. Interpolation between monthly fields are used at the open boundaries. An exception for this is the velocities north west of the Iberian Peninsula (close to La Coruna). In this area data from continuous moorings in 1993/94 (Alonso, 1995) are used, and assumed valid for all years.

Monthly data for freshwater runoff from main rivers around the North Sea are taken from Balino (1993), and some French rivers from IFREMER. Extra freshwater is added along the Norwegian and Swedish coast to fulfil requirements to estimated total freshwater runoff from these coastlines (Egenberg, 1993). In addition Spanish river discharges from one year (Lavin, pers.comm) is assumed valid all years, and monthly means for freshwater runoff to the Irish Sea is taken from Anon (1990).

Interpolation between daily mean currents from the circulation model are fed into a Lagrangian particle tracking module to simulate the transport of fish larvae. The particles are released and fixed in certain depths. Since the bulk amounts of blue whiting larvae most often are observed in the upper 50 m and since it is unclear whether the larvae do any structured vertical migration, we have chosen to study the results from the runs with the particles fixed at 30 m depth. Particle diffusion are performed using a random walk procedure. No larvae mortality is introduced in the model.

Results

Initial fields

Two initial “mean” concentration fields meant to represent newly hatched larval distribution and timing has been used and kept constant for each individual year. One is based on direct estimates from many years of larval field investigations and referred to as Steve (from Stephen Coombs), and one is based on indirect estimates from many years of spawning stock distributions and referred to as Terje (from Terje Monstad). The main difference between these fields is that while Steve operates with relative concentration differences from area to area over 3 orders of magnitude

(1, 10,100 and 1000 larvae/m2), Terje suggests relative differences of only a factor of 4 (25, 50, 75 and 100). In Steve´s distribution the major parts of the larvae are slightly further to the north and more spread over the Rockall Trough, while Terje´s larvae are more concentrated along the narrow shelf edge. Some of these differences are easily explained by the different methology, since from the spawning locations, which are strongly related to the shelf break (Terje), eggs and larvae are slowly rising towards the surface layer being spread by advection and diffusion (Steve).

The time of spawning are quite similar for the two fields, starting early March south of Ireland and gradually later northwards with the latest in early to mid may north of Scotland. In the model experiment only the two highest of Steve´s concentrations are used with 1 and 10 particles being released, while all four levels of Terje´s concentrations are used with 2, 4, 6 and 8 particles being released in individual grid cells. Totally the number of particles released are about the same (13.000) to give a comparable visual impression.

Looking at the modelled distribution of particles at the end of June in 1989 (Fig.1), it seems that the different initial fields do not have a dramatic effect.. In the north the particles seems to have about the same progress towards the North Sea and the Norwegian Sea. However, witrh the Terje fields, there are particles on the shelf around the Faeroe Islands and significantly more particles in the Faeroe-Shetland Channel. Roughly the same amount of particles and distributional pattern seems to be the result in the Bay of Biscay. However the Terje-fields results in some more particles onto the shelf, while the Steve-fields results in more particles in the Rockall Gyre which also was the case in the initial fields.

A further comparison is presented in Fig. 2, where time series of the amount of particles in late October being located over deep water within and to the west and northwest of the Bay of Biscay is shown, together with the amount of larvae which have been inside the North Sea within late October. In the southern region a good correlation is seen, however the Terje-field results in roughly 5 % more particles than from the Steve-field. In the North Sea there is a difference of 0-2 %, and it varies which of the fields gives the highest/lowest results. One exception is 1988 where the Terje-fields only resulted in 1% of the particles to enter the North Sea, while the Steve fields gave 6 %. Clearly some of these differences are similar to some of the smaller year to year variability. However, being mainly interested in extreme years, we believe from these results that using one fixed initial concentration for all years is realistic for studying if variable drift of larvae may influence recruitment.

In the following and just for simplicity, only the Terje fields has been used.

Model evaluation

Since no mortality is present in the model, and since no knowledge of the number of actual hatched larvae is available for individual years, it is not possible to evaluate the model concentrations against observations. From observations it has also been difficult to follow individual patches of larvae from one place to another. Therefor the evaluation shown here is just qualitative and limited to distributional patterns.

During November 1989 a good survey of blue whiting larvae were performed along the Norwegian coast, and quite a few larvae were found in the North Sea and some also in the Skagerrak between Norway and Denmark. This is shown in Fig. 3 together with the modelled distribution in late October. In good agreement the model predicts the larvae along the Norwegian coast of southern Norway and into the Skagerrak. In the most northern part of the North Sea (between Shetland and Norway) it also shows that the larvae are distributed about 100 km from the coast in agreement with the observations. The most northern observations are outside the model area, however the model has predicted larvae to pass through the model boundary already by the end of august (see Fig. 7).

Very few observations were taken over large areas around Scotland and northern Ireland where the model predicts larvae to be. However south of Ireland and into the Bay of Biscay larvae were present partly on the shelf and all along the shelf edge. In agreement the model results show larvae all along the shelf edge and at the coast of northern Spain. However it seems that the model simulates too few particles onto the shelf, especially in the Celtic Sea. Clearly in October-November the 0-group are 13-17 cm long and are able to perform active horizontal migration (which is not simulated), however to our knowledge it is not known whether this occurs with such a strength and directional stability that it may cause a significant different distribution than what is caused by passive drift.

Large amounts of larvae are seen in the deep water and westward of the Bay of Biscay. Unfortunately there are relatively few observations over deep water in the Bay of Biscay, although in that area the observed generally low levels of plankton abundance suggest that feeding conditions and hence survival of larvae are likely to be poor.

Since it seems that the distribution and timing of 6-8 months simulated larval drift fits relatively good with observations, it can be assumed that the modelled currents are quite realistic. This again suggests that the prognostic density fields probably also are quite realistic. Pilot hydrographical data collected from 15-30 June, 1993 with R/V Johan Hjort in the northern SEFOS area are used to produce horizontal maps of temperature and salinity at 50 m depth. This is compared with modelled temperature and salinity maps averaged over the whole month of June, 1993 (Fig. 4 and 5). Even though some mesoscale features are not resolved in the model (due to limited horizontal resolution), the main hydrographical structures are reproduced, such as: the cold and less saline water to the east of the Faeroe Islands, the narrow warm and saline tongue of the slope current water, the colder and fresher water in the North Sea and the much fresher water in the Norwegian Coastal Current. Except for a relaxation towards climatological sea surface temperature and a very weak relaxation towards climatological deep water salinity, these fields are fully prognostic and has in June been developing freely for approximately 6 months.

Year to year variability

One goal of this study was to see if the drift model results could explain some of the observed recruitment variability. For this we are referring to the time series of 0-group blue whiting (from Virtual Population Analysis (VPA)) obtained through ICES (Anon., 1986, 1989, 1996). This is shown in Fig. 6. The VPA numbers are based on combined back calculations from commercial landings and research cruises. The accuracy of these numbers are debatable, but it is claimed that the outstanding years such as 1982-83 and 1989 with 20-25 * 10^{12} recruits are significantly higher than other years. The most outstanding year-class is 1995 with more than $40*10^{12}$ recruits, but this number is highly uncertain and is therefor not included. In addition this year is at present not modelled. Also the VPA number for 1994 has less precision than the earlier years, and from recent investigations (Monstad et al., 1995, 1996a, 1996b) there are good reasons to believe that this year-class was very rich and roughly similar the 1982, 83 and 89 year-classes. It is therefore guestimated to $20*10^{12}$, the double of what is presented in the VPA (Anon., 1996).

The modelled distributional development in time and for two different years with very different recruitment success shows some interesting features (Fig. 7). Already at the end of April, particles have drifted across the Bay of Biscay and onto the north Spanish coast. However the distribution indicate a drift much further into the Bay in 1989 than in 1992. In both years some particles have clearly concentrated at the westernmost coast of France (Brest).

At the end of June the particle distributions north of the North Sea is quite similar for the two years. In 1992 more particles are situated in the Rockall Gyre and on the north Spanish coast. In both years quite many particles are now located over deep water in the Bay of Biscay.

The distributions at the end of August look quite similar to two months earlier, except in the north. Particles have now in both years drifted into the Norwegian Sea and out of the model domain. Particles have also drifted into the northern North Sea along the well known main inflowing areas of Atlantic Water (Svendsen et al., 1995).

The inflow to the North Sea was more significant in 1989 along the western slope of the Norwegian Trench. At the end of October some of these particles had reached into the Skagerrak between Denmark and Norway (ref. Fig. 3) which was not the case in 1992. More particles were in 1992 situated in the Rockall Gyre and at the north Spanish coast in 1992.

To quantify some of the distributional differences, the area has been separated in boxes after Walsh et al., 1996 (Fig. 8). In addition the North Sea is added as one box, and the the region north (Norwegian Sea) and south of these boxes are defined as two additional areas. The amount of particles located within some of these areas at certain dates of the individual 19 years are presented with the aim of looking for similarities with the recruitment time series (Fig. 6).

The deep areas of the Bay of Biscay and to the west and northwest of this are represented by box 5a and 6a. The percentage of particles within this area are plotted at four dates (end of: April, June, August and October) in Fig. 9. Quite large year to year variations are seen. As expected the amounts of particles in the region are in most years increasing from April to August, typically between 10 and 20 % of the total amount of particles. If these deep ocean areas were a desert as earlier mentioned, one could expect that a high number of particles here could correspond to bad recruitment. Obviously this is not the case for the good 1989 recruitment year where we get the highest number of particles in October of all years. In addition nothing particular with the good recruitment years of 1982-83 is seen in Fig. 9.

A similar study is presented in Fig. 10 for the amount of particles into the North Sea. In no years were any particles inside as early as by the end of June. So this only shows the percentage of particles at the end of August and October, and in addition the percentage of particles which “has been inside” (HBI) sometimes before the end of October. Clearly much less particles ends up in the North Sea (typically 1-4 %) than in the Bay of Biscay area (Fig. 9). 1994 were exceptional with 10 % . Except for this year, 1989 is slightly higher than the other years, and this is partly the case for the end of August amounts (3 %) in 1982 and 83. This might indicate that an early and larger drift into the North Sea may favor good recruitment, but it is far from clear (see e.g. 1978).

It is known that the shelf areas in general are more productive than the deep oceans. Therefore one might expect a certain correlation between good recruitment and increased larval transport onto the shelf areas. As an example the total percentage of larvae present in the coastal area 3b and in the North Sea at the end of August, together with the recruitment numbers are presented in Fig. 11. Clearly the particle drift in 1989 were highly on-shelf coinciding with good recruitment. Also relatively strong on-shelf drift occurred in the good recruitment years of 1982-83, however similar drift also occurred in 1976, 1992 and 1994. Again, this may suggest that on-shelf drift including drift into the North Sea may favor good recruitment, but is clearly not a satisfactory parameter. Similar results are obtained when studying the timeseries of all particles ending on the shelf.

Several other time-series of the particle numbers in different boxes has been studied in relation to the recruitment time series, but no clear correlation is seen. Also the displacement of the center of gravity of particles towards northeast versus southwest seems not to be related to recruitment. Another drift parameter which could be connected to recruitment is the amount of spreading of the larvae, here measured as the variance of the particles related to the center of gravity of the particles (Fig. 12). This parameter may be connected to variations in the winds and indirectly related to turbulence which is known to affect the feeding ratio of larvae (Sundby and Fossum, 1990). However, no clear connection with the recruitment numbers is seen. Especially the variance in the good recruitment years 1982 and 1989 is quite average, while it is high in 1983.

Discussion and Conclusions

A lot of simulated blue whiting larvae (typically 10-20 %) seems to drift southward from the main spawning grounds and ends up in the deep water within, west and northwest of the Bay of Biscay. Several investigations show that this is low productivity areas, which means that these huge amounts of larvae probably are lost. However, quite a few particles are crossing the Bay and ends up on the north Spanish coast, and it is an open question if these larvae would have a chance to survive the "trip through the desert" which is estimated to last 2-4 weeks. There are no clear indications that the variable amounts of larvae drifting into these areas are linked to the varying recruitment success. However, the reason for this may be that the the VPA total recruitment variability is little affected by the variability of the southern part of the stock, which may be strongly linked to this southern drift but not investigated here.

Previous unpublished results from this model and the Hamburg model (Bartsch, pers.com.) show that there is a clear separation zone roughly east-west over the Porcupine Bank area where the larvae to the north are drifting northeastward and larvae to the south are drifting southward. Of the northward drifting particles (not taking mortality into account), about 5-10% normally ends up in the Norwegian Sea and 1-5 % in the North Sea. About 15-30 % of the simulated larvae ends up on the shelf from Ireland to the North Sea. At the end of August still 50-60% are left in the central spawning areas (2a, 2b, 3a, 3b, 4a, 4b, Fig. 8).

There is a slight indication that it may be positive for recruitment that the larvae are drifting into the shelf areas and the North Sea, but this is insufficient for explaining the three outstanding good year-classes of 1982, 83 and 89. However, as stated by Svendsen et al. (1995), there are normally several important environmental factors regulating recruitment, and under such conditions one will fail to find clear relations with individual factors. Therefor, to sort out the importance of larval drift for recruitment success, some sort of multiple variance analysis is required taking into account other important factors such as temperature and wind induced turbulence. Such an approach may of course also fail if predation from e.g. mackerel is the most important regulatory mechanism.

Based on the modelled drift results for the individual boxes, a simple multiple linear regression analysis (Wilkinson, 1989) were performed to further investigate the relation to recruitment. This resulted in a simple relation to the larvae within the North Sea by the end of August and larvae within the Rockall Gyre (box 2a, Fig. 8) at the same time. The relation is:

$$\text{Modelled Recruits} = -2.54 + 2.79*(\text{NS (Aug)}) + 0.72*(\text{RG(Aug)})$$

where NS and RG are the modelled percentage of particles within the North Sea and the Rockall Gyre and the 0-group recruitment numbers are given as 10^{12}. The result is presented in Fig. 13, and this suggests that larval drift into the North Sea and/or retention in/drift into the Rockall Gyre increases the chances for good recruitment. This simple statistical model picks up the good year-classes of 1982, 83, 89 and 94 with a total P-value of 0.015, but it only explains about 40% of the total VPA variance, and the standard error of estimate is $5*10^{12}$ recruits. Since there are large uncertainties in the individual VPA numbers, and since we have not included other important environmental factors, good correlations were not expected to be found. However we believe that this exercise has revealed possible transport mechanisms that seems to favor recruitment, which may help in focussing future investigations.

At last it should be clearly stated that these model results do not tell the truth about the drift and distribution of blue whiting larvae/0-group. The model has insufficient horizontal resolution to properly resolve the narrow slope current which from unpublished hydrographic measurements in general seems to be around 50 km wide. Low resolution and possible errors in the atmospheric forcing, year to year variations in spawning location and timing, varying mortality in time and space, dial vertical migration and possibly significant horizontal migration after a certain age, etc. are factors that all may have significant influence on the actual larval distribution which is not taken into account in this work. However, due to the enormous areal spread of this stock, observations only reveal bits and pieces of the larval distribution with time. We therefor believe that these model runs may give a better quantitative insight into relative year to year variability than by traditional monitoring being used in the past.

Acknowledgement

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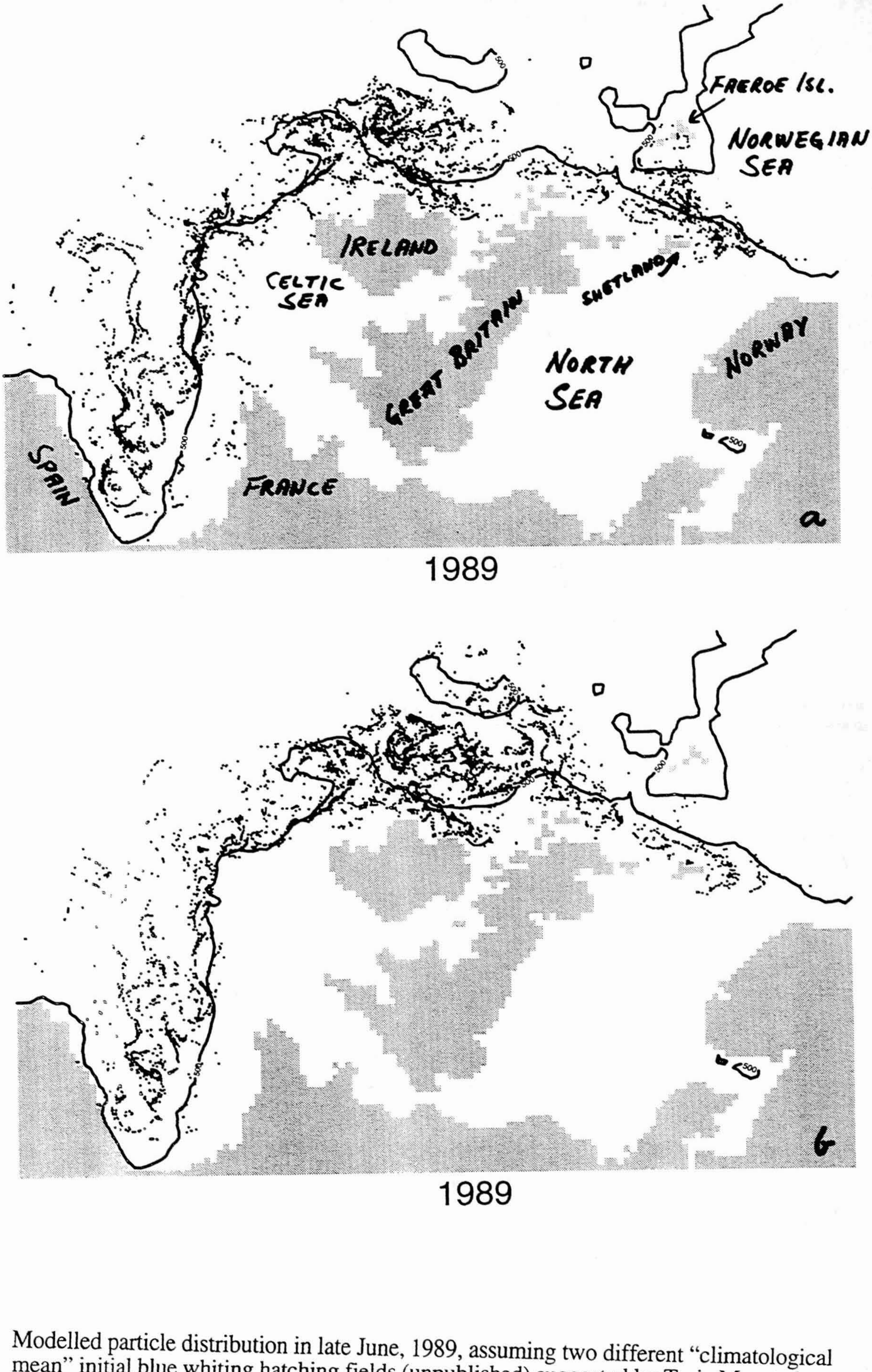

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1989

Fig. 1 Modelled particle distribution in late June, 1989, assuming two different "climatological mean" initial blue whiting hatching fields (unpublished) suggested by Terje Monstad (upper) and Steve Coombs (lower). 500 m bottom depth contour .

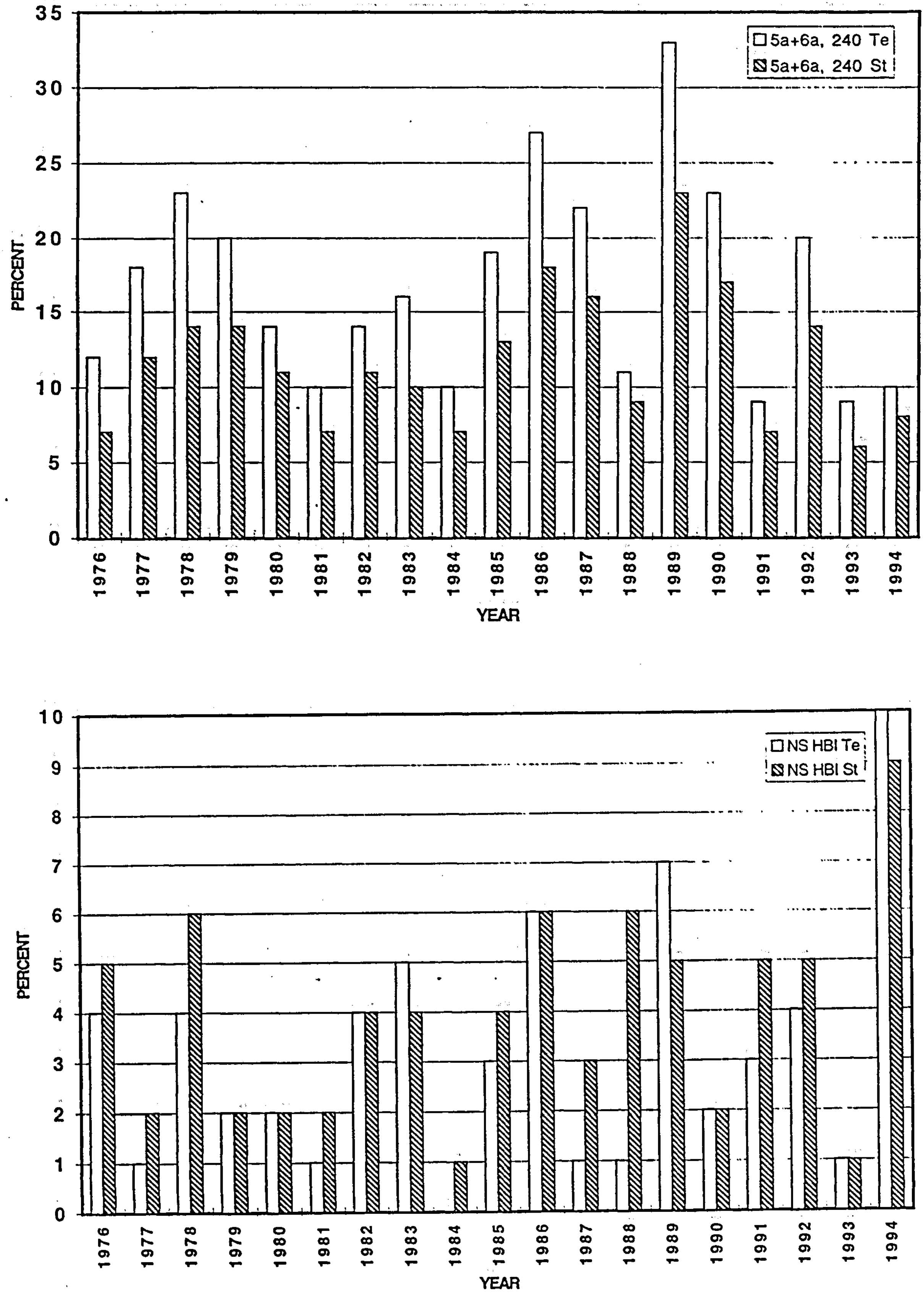

Fig.2 Time series of the modelled (from Terje and Steve´s initial fields) amount of particles in late October being located in deep water within and to the west and northwest of the Bay of Biscay (upper). Amount of particles which have been inside the North Sea within late October each year (lower).

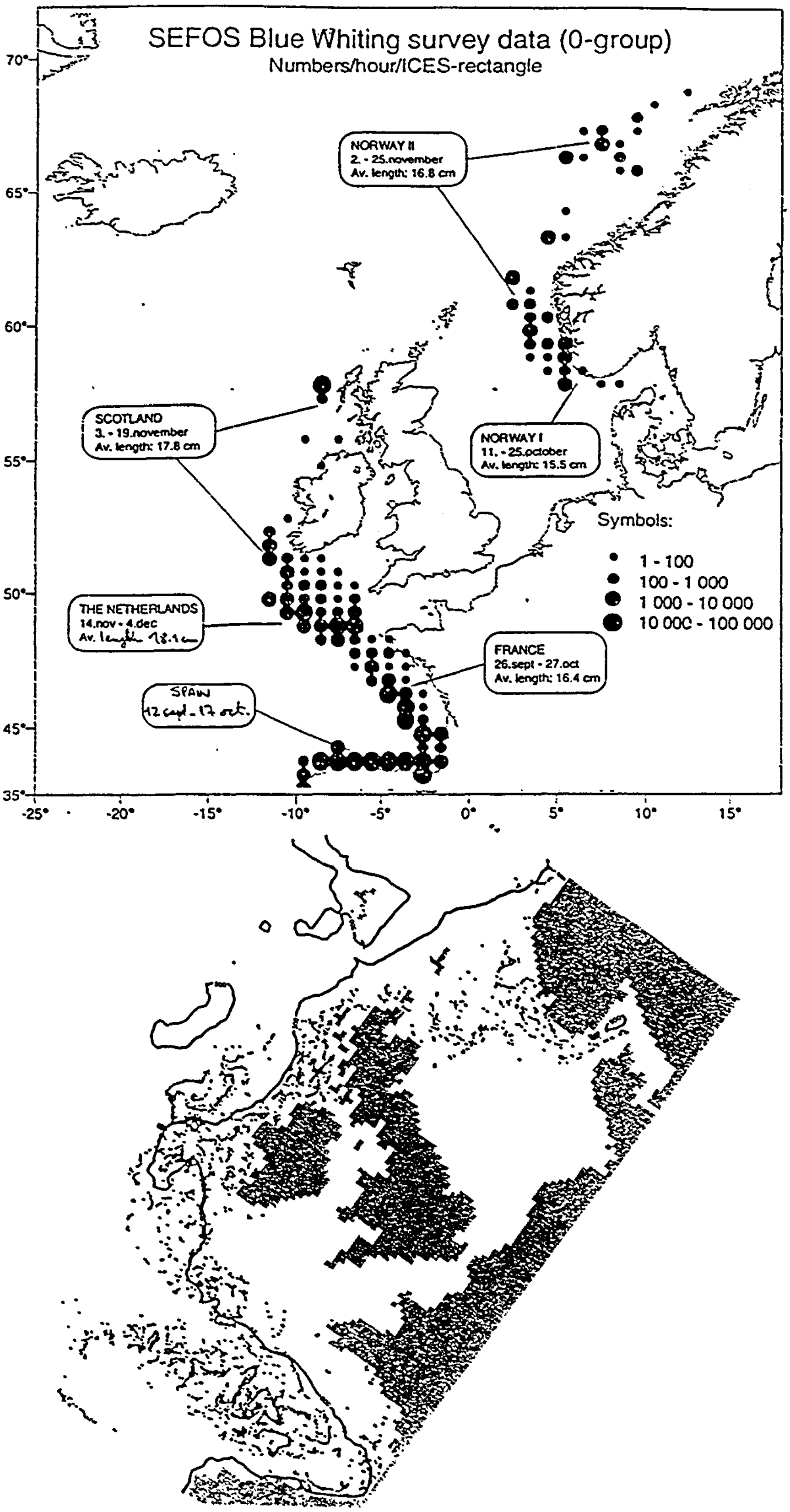

Fig. 3 Comparison between observed (upper) 0-group blue whiting larvae during autumn 1989 and modelled particle distribution in late October same year.

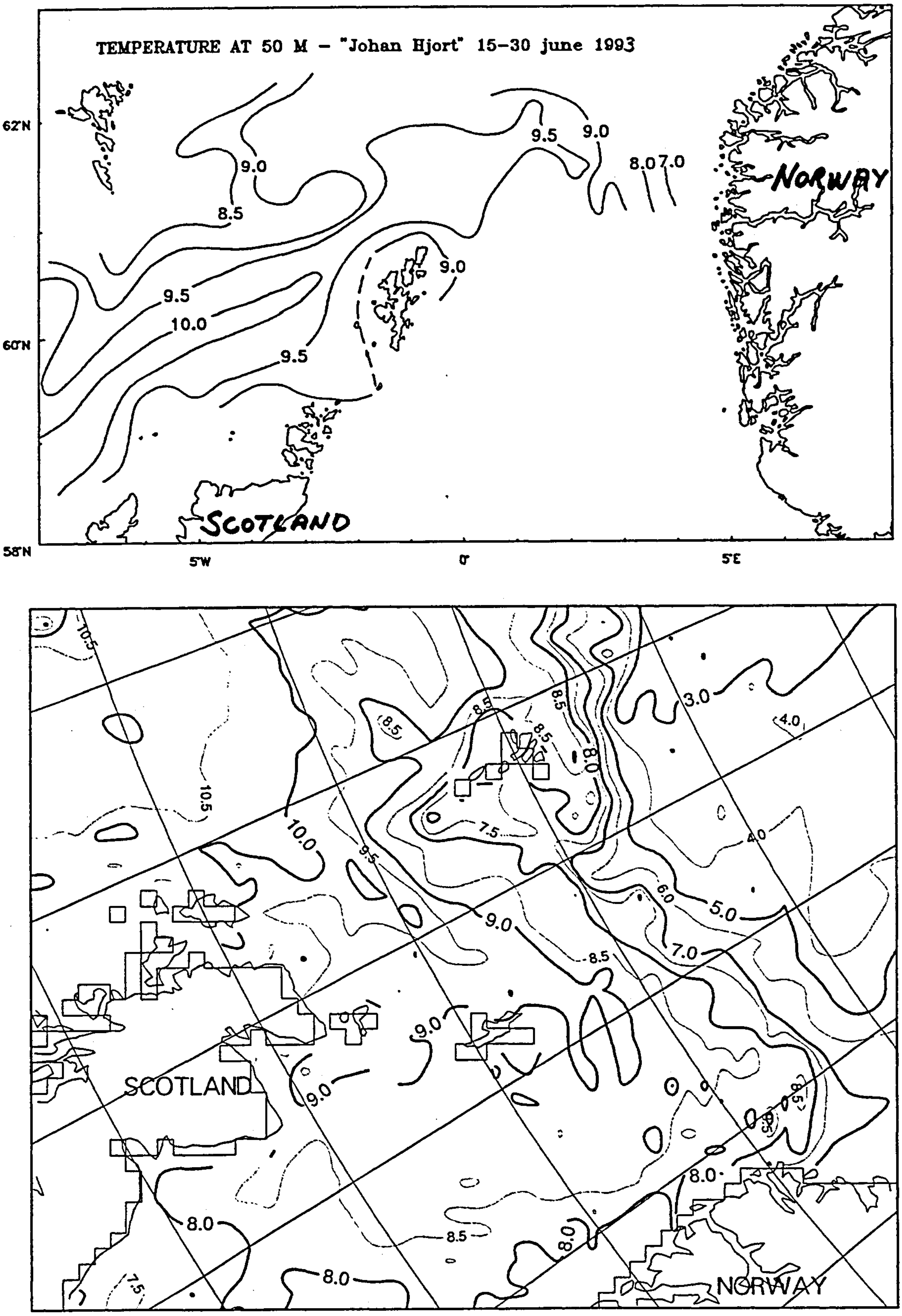

Fig.4 Comparison between measured (upper) and modelled temperature at 50 m depth during SEFOS in June, 1993

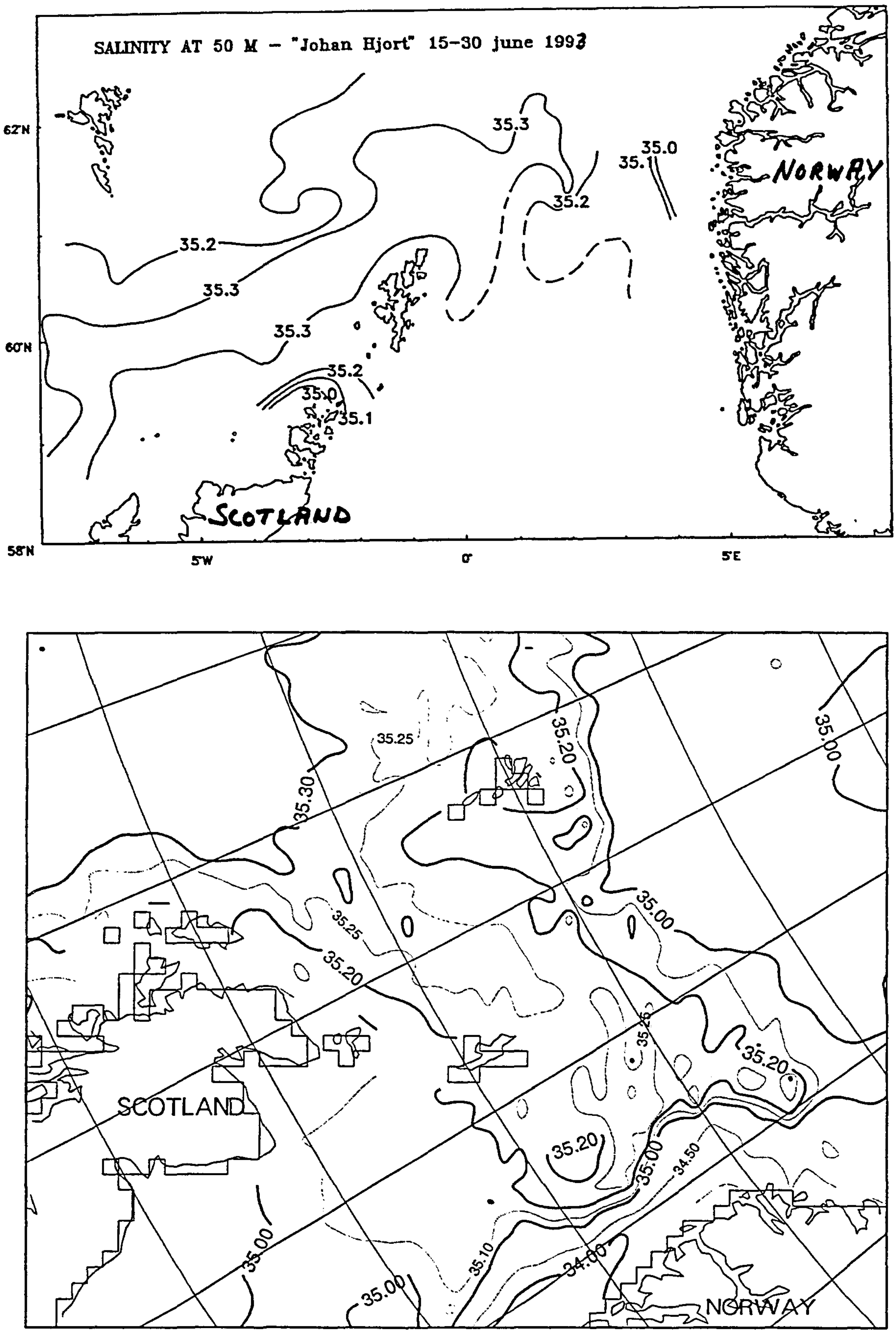

Fig.5 Comparison between measured (upper) and modelled salinity at 50 m depth during SEFOS in June, 1993

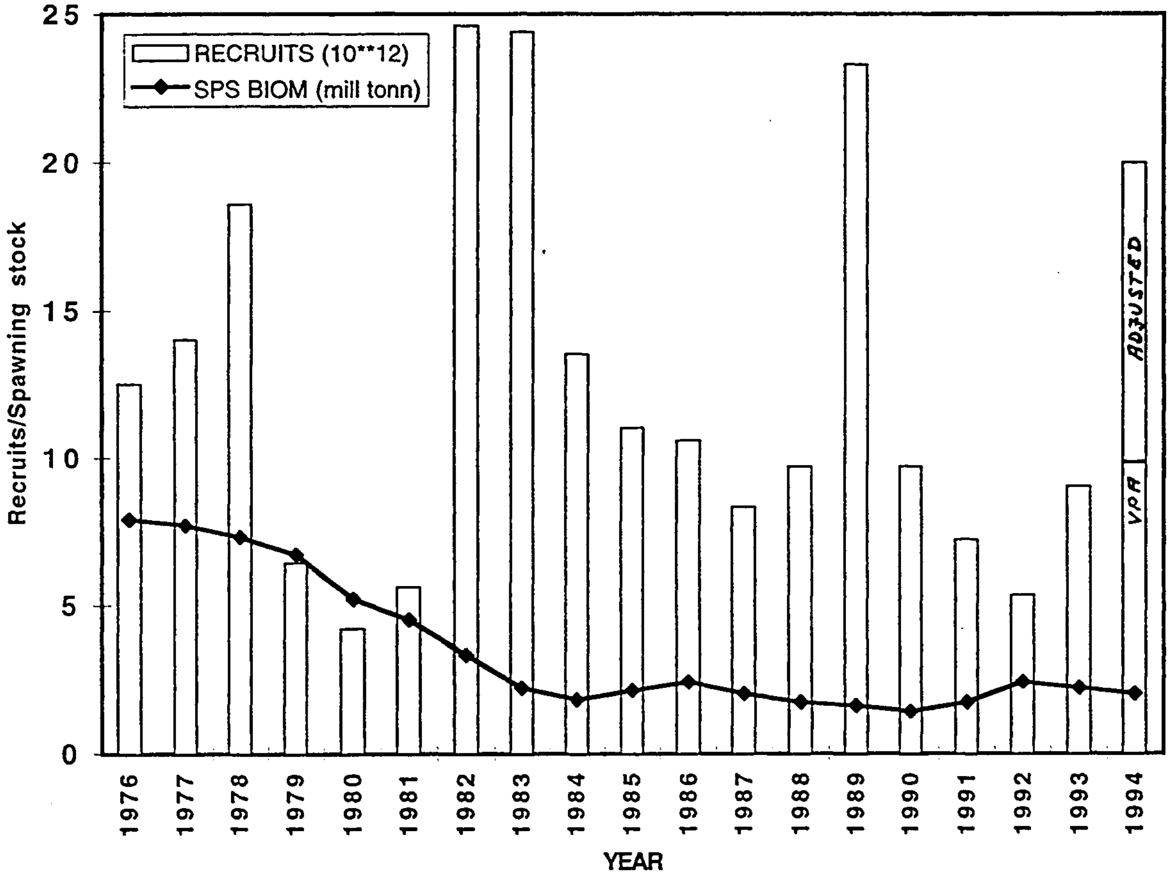

Fig.6 Time series of 0-Group blue whiting recruits from ICES VPA estimates and corresponding spawning stock biomass.

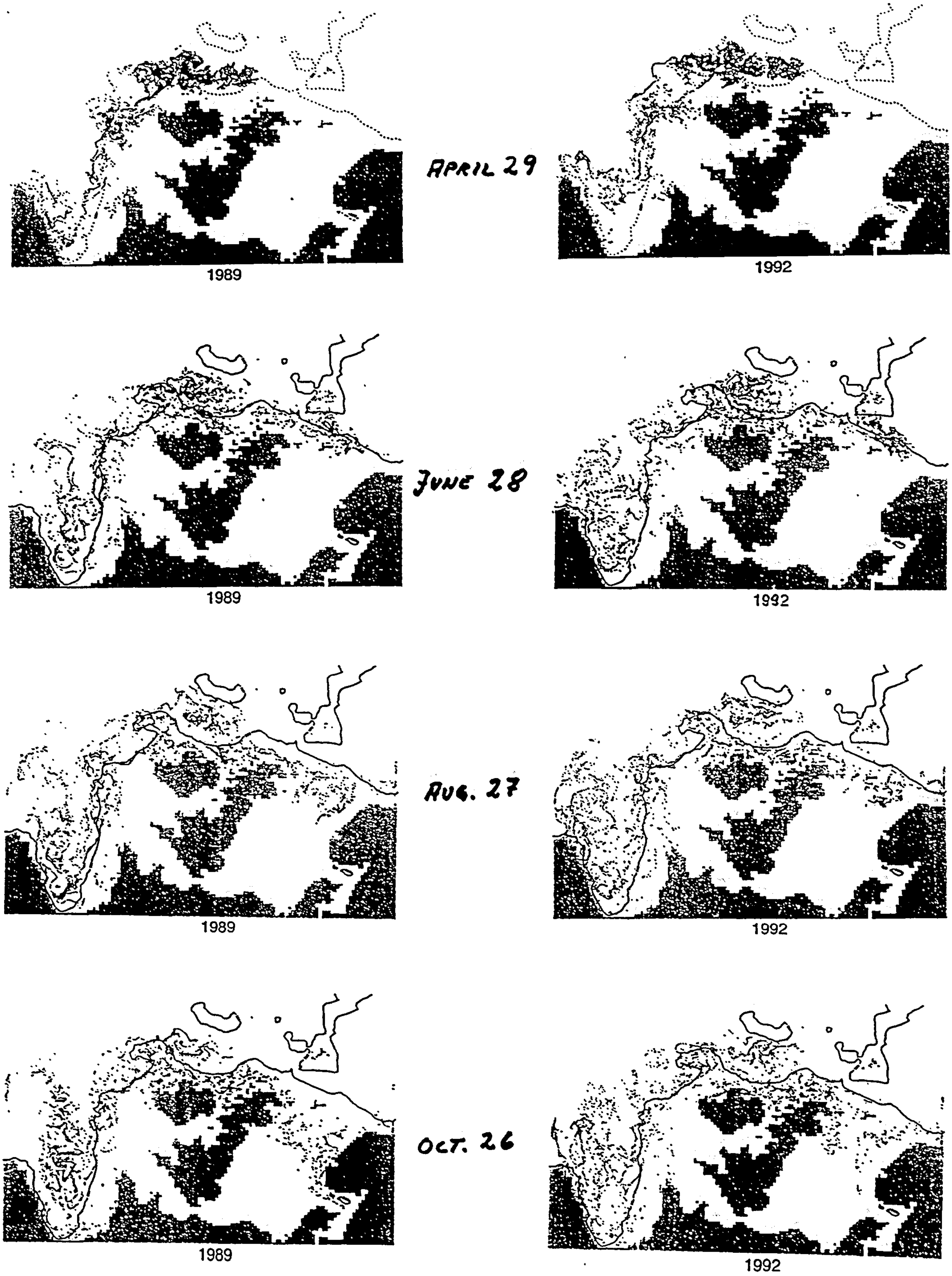

Fig.7 Development of simulated blue whiting larval distributions during 1989 (left) and 1992.

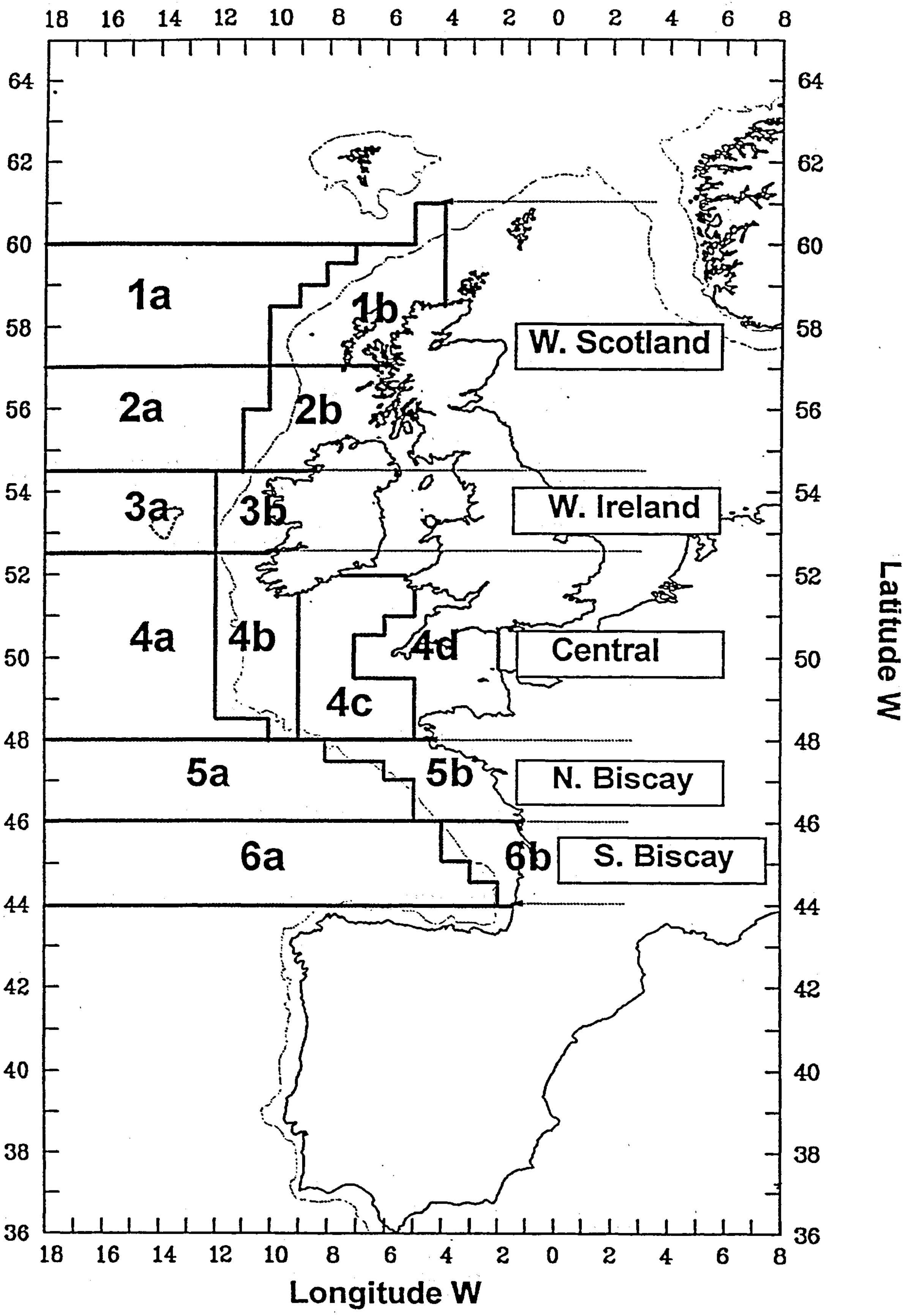

Fig.8 Areas used to study year to year variability of the distributions of simulated blue whiting larvae (from Walsh et al., 1996).

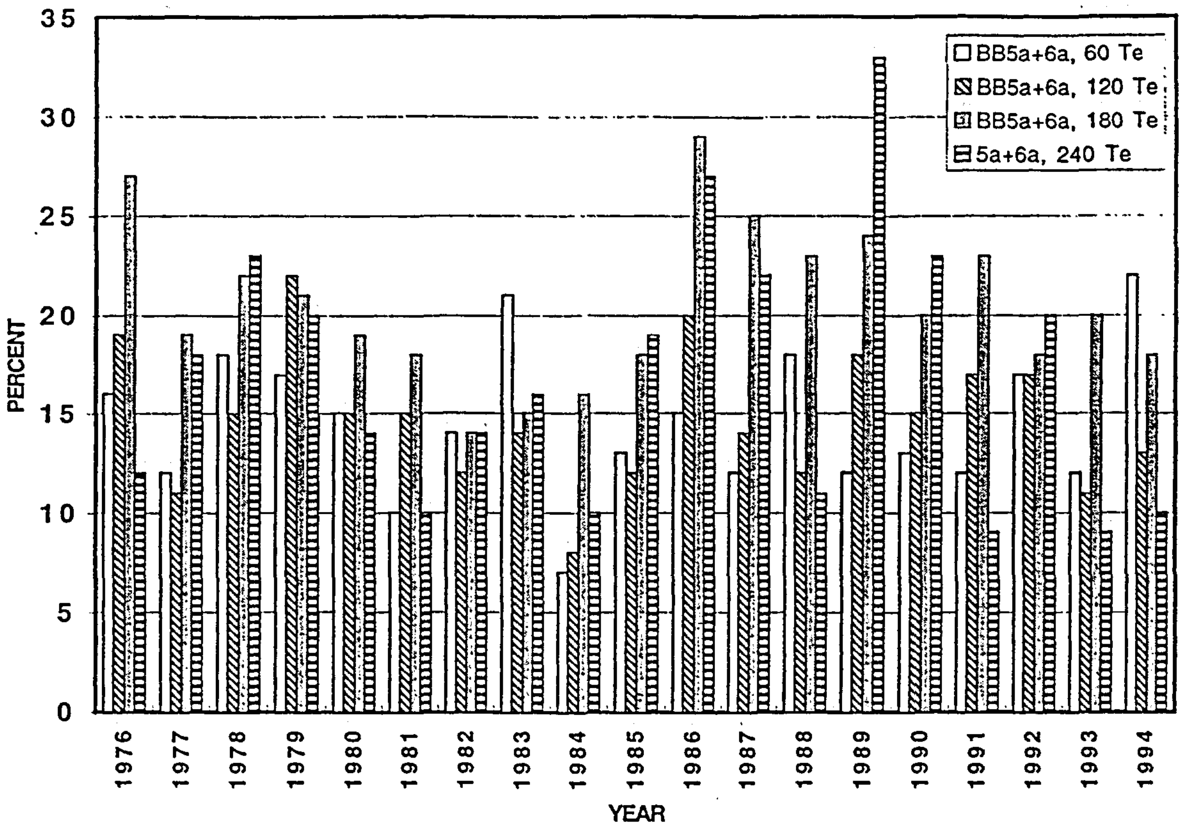

Fig.9 Time series of simulated amounts (%) of 0-group blue whiting within box 5a and 6a (Fig. 8) at certain days after assumed start of hatching on March 1 in the south. Day 60=April 29, day 120=June 28, day 180=August 27 and day 240=October 26.

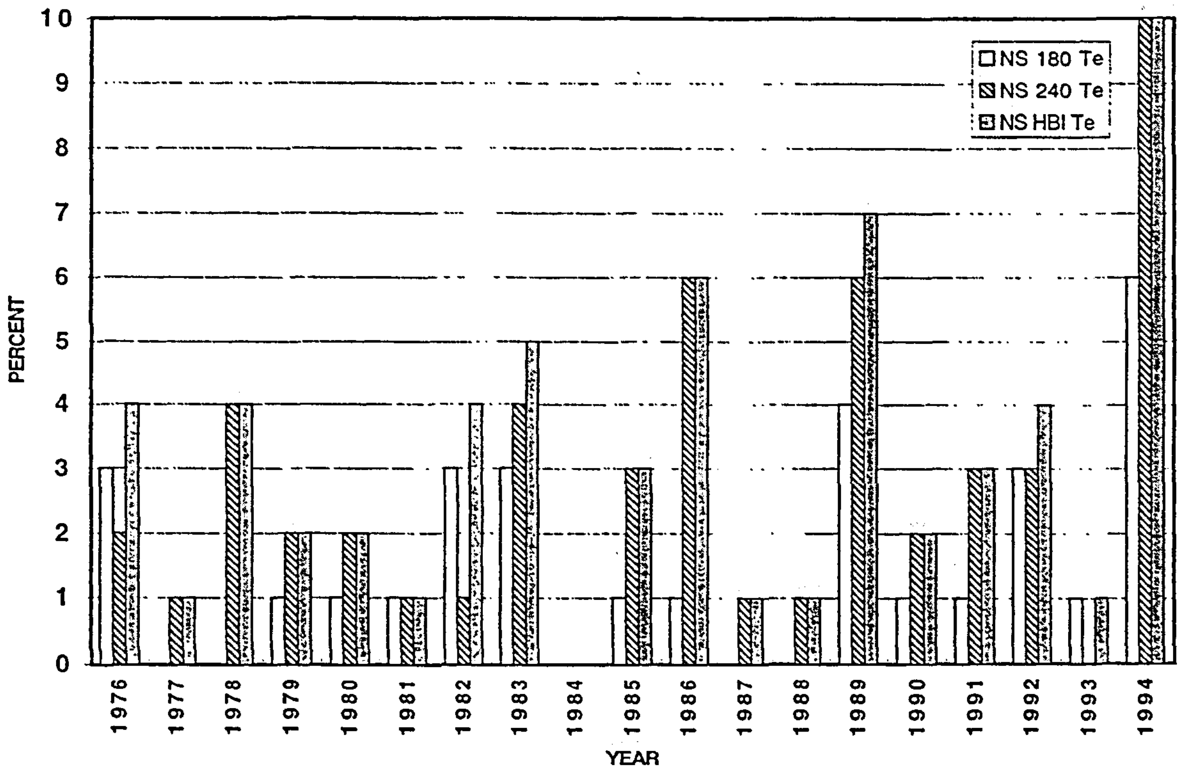

Fig.10 Time series of simulated amounts (%) of 0-group blue whiting within the North Sea at certain days after assumed start of hatching on March 1 in the south. Day 180=August 27, day 240=October 26, HBI="has been inside" before October 26.

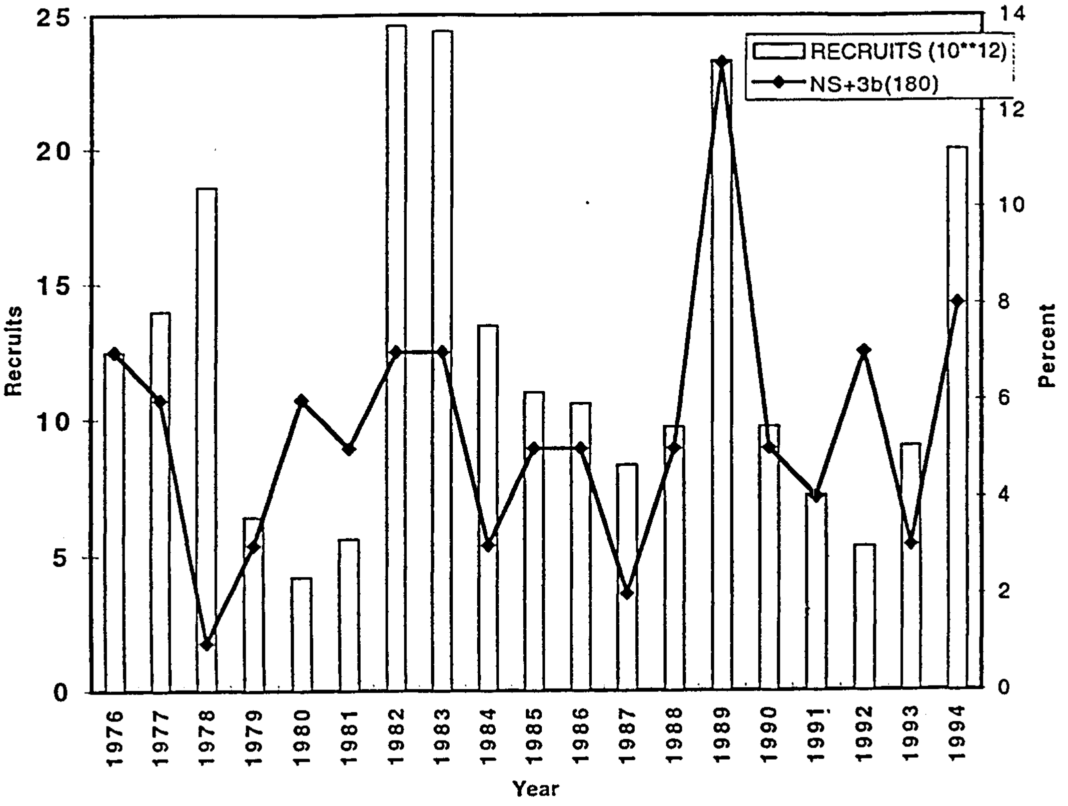

Fig.11 Time series of simulated amounts (%) of 0-group blue whiting within the coastal area of western Ireland (box 3b) and the North Sea at the end of August, and the VPA estimated number of 0-group recruits.

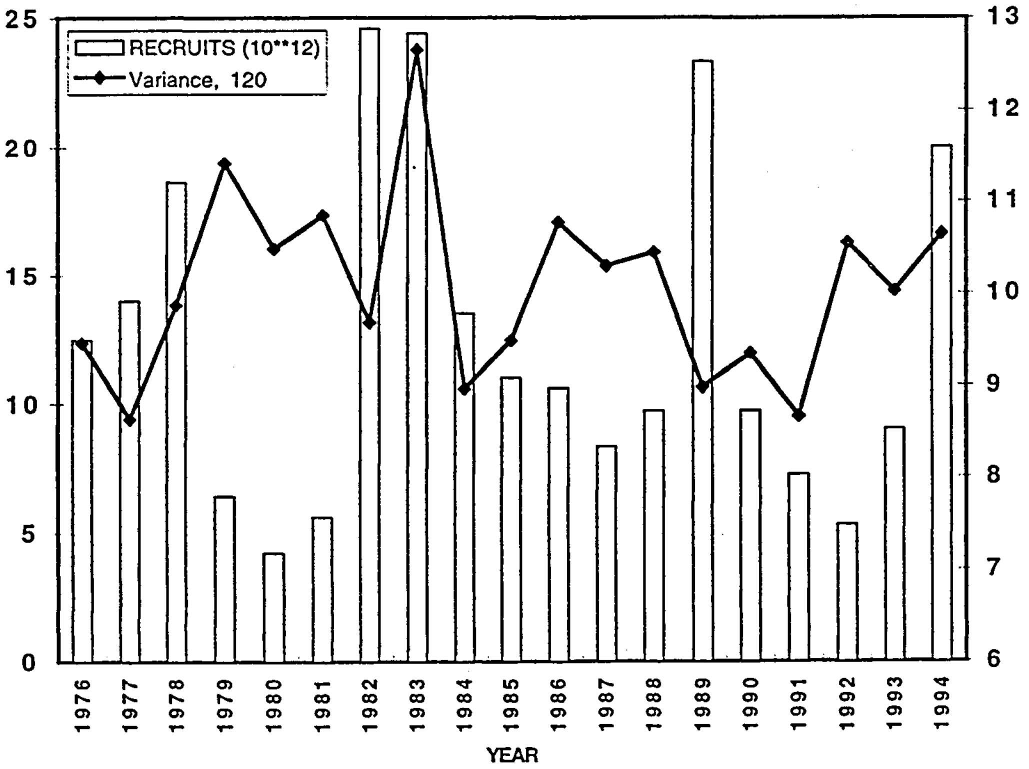

Fig.12 Time series of the variance (related to the center of gravity) of simulated 0-group blue whiting larvae and the VPA estimated number of 0-group recruits.

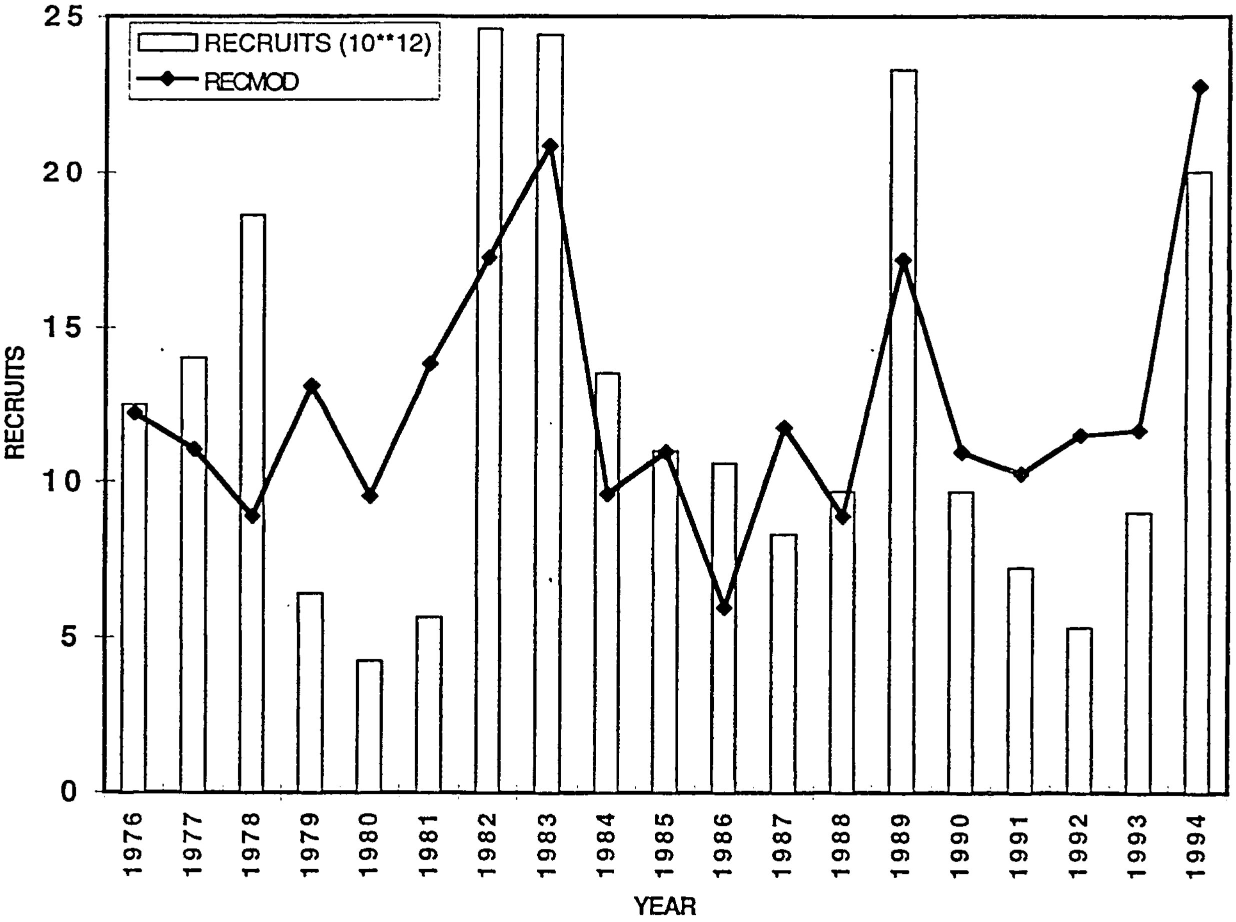

Fig.13 Time series of blue whiting 0-group recruitment numbers from ICES VPA estimates and a simple statistical model based on results from numerical larval drift simulations and the mentioned VPA estimates.

$$RECMOD = -2.54 + 2.79*(NS\ (Aug)) + 0.72*(RG(Aug))$$

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