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Variability of the drift patterns of Spring Spawned herring larvae and the transport of water along the Norwegian shelf

by

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Summary

A 3-dimensional baroclinic hydrodynamic model implemented for the North Sea, the Norwegian coast and part of the Norwegian and Barents Seas has been run for 18 years. This model has been used to study the Norwegian spring spawned herring larval transport from the main spawning areas at the coast of Norway. Currents from this model are fed into a Lagrangian particle tracking model to simulate the varying transports of larvae/juveniles. The simulations can explain much of the observed year to year variations in the distribution of herring larvae and juveniles, and significant larvae/juvenile transport into the Barents Sea seems to be a nessesary condition for good recruitment. In addition the model simulate a significant ·long-shelf larval mixing also observed in larval age investigations. Good r· lts are also obtained with respect to volume transport estimates, and it is postı ·d that a major recirculation of about 15-20 Sverdrup takes place in the Norwegian Sea.

1. Introduction

The obvious limitations in space and time (and large costs) of traditional oceanographic ship sampling, and the rapid advances in computing capacity, have led to increasing efforts in 3-dimensional ocean circulation modelling. There is also an increasing demand for model results simulating the effects of the physical processes on the environment for fish and the chemical and biological consequences of possible changes in anthropogenic inputs of nutrients, nuclear waists etc. to specific ocean areas (North Sea Task Force, 1993). In this paper we try to evaluate the modeling capability of realistic simulation of larval distribution, describe some of the year to year variability of the distributions and water transports, and speculate on what possible effects this might have on recruitment. The biological background information comes from mapping of spring spawned herring larvae and juveniles *(Clupea harengus L.)* along the Norwegian coast on separate cruises in April, May, July and August in most years since 1985. In addition to this, hatching investigations of herring larvae have been carried out over the spawning beds (Fossum, 1995).

In Norway a coupled Physical-Chemical-Biological (P-C-B) modelling activity of different parts of the Nordic Seas started in 1990-91 through close cooperation between the Institute of Marine Research (IMR) in Bergen, the Institute of Fishery- and Marine Biology (IFM) and the Mathematical Institute (MI) at the University of Bergen, and The Norwegian Meteorological Institute (DNMI) in Oslo. Related to the above problem areas and that the hydrodynamics of the ocean areas is quite complex, it was found that to obtain any realism in the biological results, the model system must be based on a sophisticated 3-dimensional physical model (Skogen et al., 1994, Aksnes et al., 1994, Skogen et al., 1995, Svendsen et al., 1995). Therefore the physical module is based on a model by Blumberg and Mellor (1987). This model performed favorably in a recent Norwegian model evaluation project, MOMOP (Martinsen et al., 1990, Slørdal et al., 1991), focusing on model intercomparison around relatively "clean" problems with partly known analytical solutions. The first real application of this model related to fish is presented by Berntsen et al., (1994) on the transport of sandeel in the North Sea. The total model system is now referred to as the NORWegian ECOlogical Model system (NORWECOM) (Skogen, 1993).

Still the main weakness of most 3-D modelling activities claiming to simulate nature is the lack of comparison with adequate real data. We have therefore compared the model results with some of the extensive herring larvae data set, focusing the attention around the simulation of the distribution in May and July.

2) The model design

2.1 *The basic oceanographic model.*

The three dimensional circulation model due to Blumberg and Mellor (1987) is used to approximate the circulation of the North Sea, the Norwegian coast and parts of the Norwegian and Barents Seas (Fig. 1). The prognostic variables of this model are the three components of the velocity field, temperature, salinity, surface elevation and two quantities which characterize the turbulence, the turbulent kinetic energy and the turbulent macroscale. The governing equations are the momentum equations, the continuity equation, conservation equations for temperature and salinity and a turbulence closure model for the turbulent kinetic energy and macroscale (Mellor and Yamada, 1982). The equations are approximated by finite difference techniques. In the vertical a sigma-coordinate representation is used. In this representation the sea surface is mapped to 0 and the sea bottom to -1.

The model is implemented with a 20x20 km^2 horizontal resolution. The features common to the two model setups are summarized below. Vertically 11 sigma-coordinate layers are used. The layers are chosen to give high resolution near the surface. At 100 m depth the layers are 0.5 m, 0.7 m, 1.3 m, 2.5 m, 5 m, 10 m, 20 m, 20 m, 20 m, 15 m and 5 m thick and 10 times these values at 1000 m bottom depth.

The model is run with hindcast atmospheric forcing (momentum flux and surface pressure every 6 hour) provided by the Norwegian Meteorological Institute, DNMI (Eide *et al.*, 1985, Reistad and Iden, 1995). At all open boundaries of the model domain boundary conditions must be specified. At these boundaries, except at the inflow from the Baltic, a Flow Relaxation Scheme (FRS), (Martinsen et al., 1987) is implemented. In lack of information on the surface heat fluxes, we apply a method of "relaxation towards climatology" due to Cox and Bryan (1984). The surface "heat flux", T_z, (actually simplified to a temperature flux) is specified by

$$K * T_z = \gamma (T^* - T) \quad (1)$$

where T is temperature and K is the vertical diffusivity in the top layer. The vertical diffusivity is computed in the model from the turbulent kinetic energy and the turbulent macroscale. T^* is the climatological value of the sea surface temperature. γ is a time constant. γ is selected to be $1.736*10^{-5}$ m/s which means that temperature in the upper 15 m of the surface layer adjust to their respective climatological values on a time scale of 10 days in calm weather. This means that the sea surface temperature is not a fully prognostic variable. For more real simulations the same approach could be applied with input of "real" surface temperature distributions instead of climatological fields. However, such digitized fields are at present not available for the authors. A similar, but weaker drag towards climatological sea surface salinity is used due to lack of realistic freshwater input in the northern region.

To advance the numerical approximations of the prognostic variables in time, a mode splitting technique is applied. In the external mode computations of the water level and vertically integrated velocities are updated. Due to stability constraints the time-step of the external mode (2-dimensional) computations must be much smaller than the time-step of the internal mode computations. In the internal mode all 3-dimensional prognostic variables are updated.

Any such nonlinear model will (as in the real world) produce motion on smaller and smaller horizontal scales as time goes by. Then, to avoid aliasing, energy on scales not resolved by the model must be removed. This is done through horizontal viscosity and diffusivity terms in the basic equations after a formulation due to Smagorinsky (1963). A choice of too large diffusivity parameter removes much of the structure that are observed in the oceanographic fields, and a too small value leads to "$2\Delta x$" noise and sometimes instabilities.

The vertical eddy viscosity and diffusivity are computed from the modelled turbulent kinetic energy and turbulent macroscale and added to some constant minimum values. In stratified water with relatively weak tidal and/or wind mixing, these minimum values are reached, and therefore the results depend on the choice of these constants.

2.2 The circulation model setup.

The model is used to approximate the prognostic variables from February 15 to September 15 each year in the 18 year period 1976-1993. Horizontally 125*81 (20*20 km^2) grid cells are used. Climatological fields for horizontal velocity, temperature, salinity and water elevation for February are used as initial fields (Martinsen et al., 1992). Corresponding fields for later months for these variables are also used on the open boundaries. The three most important constituents of the tide is also forced through the boundary zone by varying the water level and the velocities. Both climatology and tidal fields are provided by DNMI.

The inflow from the Baltic (placed at Storebelt) is implemented after an algorithm due to Stigebrandt (1980). This flow is determined from the difference in modelled water level between the southern Kattegat and the Baltic, taking into account climatological freshwater input to the Baltic. The water entering Kattegat from the Baltic is given a salinity of approximately 8.0 (slightly varying with season).

In the North Sea monthly mean river runoff from the Rhine, Meuse, Scheldt, Ems, Weser, Elbe, Thames, Humber, Tyne and Tees is used. Daily river runoff from the 6 largest Swedish rivers between Øresund and the Norwegian border, and the fresh water runoff from the coast of Norway, including Glomma, is based on monthly climatological mean fluxes and distributed on 19 outlets along the Norwegian coast. All the freshwater inputs are gathered and provided by several different institutions around the North Sea. At each external time-step the water level of the coastal cell closest to the river outlet is increased according to the volume of fresh water discharged during the external step. The fresh water is mixed with the saline water down to 15 meter. The external time-step is 30 seconds and the internal time-step is 15 minutes.

2.3 The particle tracking module

Daily mean currents from the circulation module are fed into a Lagrangian particle tracking module to simulate the transport of the larvae/juveniles. The short term (hours) variability of the currents are used to produce along and across track particle diffusion terms. The particles assumed to represent herring larvae are released in the spawning areas according to mean hatching curves. At the main spawning grounds (Sunnmøre/ Buagrunnen, Fig. 3a) the peak hatching is around March 30, starting around March 5 and ending around April 25. The particles are given a vertical migration pattern as a function of light and turbulent mixing according to Heath et al. (1988).

At present no mortality is introduced in the model. The same amount of particles are introduced each year, so basically we compare the distribution and drift patterns of observed larvae vs. modeled particles, and not the actual numbers of larvae.

At earlier times, major spawning also took place at 5 other well known spawning grounds along the Norwegian coast. Even though very weak or no spawning at all took place in these areas during these 18 years of model runs, separate particles are also released here to study possible interesting drift patterns from these spawning grounds.

3. Results

3.1 *Model validation and larval distributions.*

As an example, a monthly mean modeled velocity distribution is shown in Fig. 1. This shows well known features of the circulation, but it is difficult to validate. During 1993 a satellite positioned drifting Argos buoy with a drough at 20 m depth were released in one of the earlier important spawning grounds (Karmøy) during peak hatching. Around the buoy release site, several particles were released in the model. The individual tracks of the modeled particles went in many different directions and with quite varying speeds. This would also be the case if many buoys were released in the same area. A comparison of the drift of this single buoy to one of the "best fit" particle tracks are shown in Fig. 2. Although this demonstrates a very good simulation, it does not prove the precision of the model, but it indicates that the model probably copy some of the main hydrodynamic processes.

In Fig. 3, several observed herring larvae distributions are compared with similar modeled distributions. For comparison the differences between model isolines is $\sqrt{10}$, similar to the observations. The years and times selected here are based on all the best ship coverages of the total larvae distributions, and not periods with best fit with model results. One should keep in mind that the observations are taken over 1-2 weeks periods while the model results are "snapshots" in the middle of each observational period. Here only modeled particles from the Sunnmøre/ Buagrunnen spawning grounds (see Fig. 3a) are presented. In July 1981 the northernmost larval front towards Bear Island is well simulated. The westernmost patch of high concentration is also picked up by the model. However, no larvae were observed being left around the spawning grounds (maybe due to heavy predation) such as simulated by the model. There is also a tendency of the larvae having progressed slightly further into the Barents Sea than postulated by the model.

In May 1987 (Fig. 3b) the northern transport along the coast and the westward extension is well simulated. West of Haltenbanken (see Fig. 3a) and around the spawning areas the model shows some particles where no larvae were found (again maybe due to heavy predation). Outside western Norway to the south, some larvae were found not being simulated by the model, however the large size of these larvae show that they belong to autumn spawned (previous year) herring from the North Sea (Bjørke and Sætre, 1994, Nedraas and Smestad, 1987).

Two months later, in July 1987 (Fig. 3c), the northern boundary of larvae had moved about 400 km northeast to the entrance of the Barents Sea. This is realistically simulated together with two distinct large patches of larvae, one south and one north of Lofoten (see Fig. 3a). The total westward extension of the larvae were not properly monitored this year. The little black squares in all the model distribution maps indicate the center of gravity of the particles. In 1987 this was extremely far west due to long periods of persistent north and northeasterly winds.

In May 1989 (Fig. 3d), the wavelike herring front towards west was well simulated, and so was the northward extension. The area with the northernmost modeled patch were not mapped by the ship.

A quite similar distribution occurred in May 1991 (Fig. 3e), also quite realistically simulated with respect to north and westward extension. This year, quite a few larvae were left at the spawning site.

Two months later, in July 1991 (Fig. 3f), a large spread has occurred. Clearly the shape of the distribution up towards Spitsbergen and slightly into the Barents Sea is realistically simulated. The modeled residence of larvae around the spawning grounds is not confirmed due to lack of observations, but the very high number of larvae near the Haltenbanken indicates that more larvae also were present further to the south.

3.2 *Volume transports*

The volume transports north along the Norwegian coast is strongly coupled to the supply of Atlantic Water from the south. However, it is very difficult to estimate realistic integrated volume transports over deep water from sporadic measurements of currents and/or hydrography, and we believe that validated numerical models are promising tools for estimating the ocean transports.

In 1990 and 1991 the Institute of Marine Research, Bergen surveyed the hydrographic Svinøy section (northwest from the Sunnmøre spawning ground, Fig. 3a) once a month. Based on these data, Blindheim (1993) calculated the geostrophic volume transports through the section, using 1000 m depth as a zero velocity reference layer (partly due to lack of deeper data). Along the same section, (somewhat extended into the Norwegian Sea) an example of modeled velocity and salinity distributions are presented in Fig. 4, averaged for April 1990. The transport of the Atlantic water northward along the Norwegian continental slope is nicely shown, together with the westward spread of the Atlantic and Norwegian coastal water and the subsurface low salinity intermediate water. At 1000 m depth the model indicates velocities around 2-4 cms^{-1} where Blindheim used 0 velocity. From simple calculations the model results therefore should give transports in the upper 1000 m of about 10 SVerdrup (1 SV=$10^6 m^3 s^{-1}$) higher than Blindheim. It is worth noting in Fig. 4 that together with the deep circulation around 2 cms^{-1}, the total transport (based on monthly mean velocities) adds up to about 30 Sverdrup.

A comparison between Blindheim and monthly mean model results of the upper 1000 m are shown in Fig. 5. The model results is as expected about 11-12 Sverdrup higher than the Blindheim estimates, and the obvious seasonal cycle seems well simulated.

The monthly mean modeled volume transports through the total section and in the upper 1000 for all the 18 years and the months March to August are presented in Fig. 6a. This clearly demonstrates part of the seasonal cycle occurring in all years. Especially in 1989 and 1990 the transports were quite high during March, April, and other model results (Danielssen et al., 1995) clearly shows that maximum transports also occurred into the North Sea during these winters. That very large transports into the North Sea took place in 1990 is confirmed by measurements of the highest salinities ever observed in the northern North Sea (Heath et al., 1991, Ellett and Turrell, 1992).

For comparison similar monthly mean volume transports northeastward through the Gimsøy (Lofoten) and the Fugløya (Norway)-Bjørnøya (Bear Island) sections (see Fig. 1) are shown in Fig. 6b. The transport through the Gimsøy section is down to about half of the transport through the Svinøy section further south. The seasonal variation is less pronounced, but stronger year to year variability seems to occur.

Into the Barents Sea through the Bjørnøya-Fugløya section the modeled flows in the summer months are about 3 SV and somewhat higher in the early spring (Fig. 6b). In September-October 1978, nine current-meter rigs across the section were in operation. From these data Blindheim (1989) estimated the transport to be 3.1 SV into and 1.2 SV out through the section. Our nearest modeled month to this is August 1978 which gave 3.0 SV into and 0.7 SV out through the same section.

Discussion

Total volume transports into the Nordic Seas through the Faeroe-Shetland channel has been modelled and estimated by several typically to vary between 5 and 10 SV. There are also good reasons to believe that a significant transport of several Sverdrup also flows in west of the Faeroe Islands. Even if this adds up to say 10-15 SV, there are still 15-20 SV left to fill the modeled transports of about 30 SV through the Svinøy section (Fig. 6). If we choose to believe in the model, this means that a very large and deep recirculation takes place of about 15-20 SV in the Norwegian Sea, which to our knowledge never earlier has been quantified.

This is partly confirmed by the transports through the Gimsøy section further north with transports around 15 SV. However some northward transport probably takes place west of this section, and to fully confirm these results the model should be extended all the way to Greenland. The agreement with Blindheim´s transport estimates from hydrographical data along the Svinøy section and from current meter measurements along the Fugløya-Bjørnøya section is exciting, but further detailed intercomparisons is needed before we fully can trust the model results.

One of the goals with this modeling activity was to study what possible effects the drift of herring larvae might have on recruitment. So far this is only a beginning of the study. For many of these years the recruitment was close to zero due to a very small spawning stock, but the 1983 stands out as a peculiar yearclass. The survival index (number of one year old in January relative to the spawning stock biomass) jumped from zero in the previous years to a very large number above 80 [no.pr.kg] and back to zero. The large 1983 yearclass started slowly to reproduce in 1988-89 (survival index 2 and 4 respectively) with stronger survival in 1990 and 91(survival indexes of 13 and 21 respectively) and very strong survival in 1992 (survival index 68). 1993 became a very peculiar year where the survival rate dropped to zero even if very large amounts of larvae were found during summer.

There has been speculations on that for some unknown reason good recruitment depends on significant larval drift into the Barents Sea. Fig. 7 demonstrates the modeled larval distribution on August 20 for the years 1991 and 1992 (where particles has been released also from the spawning grounds Karmøy and Haltenbanken although very little spawning took place in these areas). The figure shows clearly that many more larvae had entered the Barents Sea in 1992 than in 1991, and the center of gravity of all the larvae were about 70 nautical miles further northeast in 1992. It is interesting to note that if significant spawning had taken place in 1991 on the Karmøy spawning ground, parts of the larvae would have drifted southward with the inflow of Atlantic water and into the Skagerrak all the way to the Swedish coast. This may have been a very important recruitment process in earlier days when Karmøy was one of the best spawning grounds.

Similar to Fig. 7, the modeled larval distribution in August 1983 (with the strongest survival index) is compared in Fig. 8 with the distribution in 1993 (with zero survival but many young larvae). Very many larvae seems to have drifted into the Barents Sea in 1983, while most of the larvae in 1993 were transported towards Spitsbergen. For the same two years, the cumulative numbers of the larvae entering and staying within the Barents Sea east of the Bjørnøya (Bear Island)-Fugløya(Norway) section are presented in Fig. 9. A few larvae seems to have entered the Barents Sea also in 1993, but it is worth noting that the transport northward has been much faster in 1983 when significant amounts of larvae started to enter the Barents Sea about 40 days earlier than in 1993.

To compare all years of particle inflow to the Barents Sea, the number of particles east of the Bjørnøya-Fugløya section on August 20 and September 12 are presented in Fig. 10. In this respect the theoretical larvae from the Haltenbanken can be neglected. Clearly 1983 stands out as the year with the strongest inflow to the Barents Sea. Also in 1992 (with strong survival) the inflow were large. However, quite large and early inflows also occurred in 1976, 1979 and 1986, so why did these not produce good survival years? First of all probably due to the very small spawning stock in these years giving too few larvae to measure. Secondly the upper ocean environment in these years was cold on the Norwegian shelf where the larvae were drifting northward, probably reducing the chances for survival. Also in 1983 the spawning stock was small, but the temperature was high. From earlier work by Krysov et al. (1995) it is concluded that good recruitment statistically depends on a high number of larvae (related to the spawning stock size), high near-surface temperature and reduced northerly winds. In 1993 there were a very high number of larvae and relatively high temperature, but northerly winds hindered the larvae to be transported into the Barents Sea.

Since the spawning typically takes place over a period of 50 days, one should generally assume that the first spawned larvae are those being transported furthest to the north. However, studies of otolith micro-structure show no significant age difference between the larvae found in the Haltenbanken region (64-66 ^{0}N), south of the Lofoten (66-68 ^{0}N) and north of (68 ^{0}N) Lofoten (see Fig. 3a) (Fossum and Moksness, 1993 and 1995). This is also tested out in the model, and on average at about May 20 the larvae are about 9 days older in the neighbour area to the north. At about July 5 this difference has decreased to about 3 days which is not significant in relation to measurements. Obviously this mixing of ages must be caused by mesoscale circulation features making larvae in some areas/at times being stationary or even flow southward while younger larvae are passing bye. This process takes place on many different scales, and the lack of fine-scale horizontal resolution in the model must be the cause for this process seeming to be slightly stronger in nature than simulated by the model.

Finally, it may be argued that the larvae after metamorphosis (at an age of about 100 days) may be capable of significant horizontal migration, and therefore can not be treated as lateral passive particles as we do in the model. To our knowledge nobody has proven such migration in offshore waters. However, if it happens, there are good reason to believe that such migration is steered by food availability. Food (zooplankton) concentration is to a large extent steered by the circulation and frontal structures, and we therefore believe that a potential migration roughly would follow the general circulation.

Conclusions

Based on 18 years (1976-1993) model simulations of 3-dimensional ocean circulation and particle (herring larvae) drift in the North Sea, along the Norwegian coast and in parts of the Norwegian and Barents Seas, together with several years of measured herring larval distribution, the following conclusions can be drawn:

1) On a large scale the model seems quite realistically to simulate several years of measured distributions of Norwegian spring spawning herring larvae about 2 and 4 months after hatching at the Sunnmøre/Buagrunnen spawning areas.

2) Modeled volume transports compared with transport estimates from hydrographic data and current meter measurements demonstrates the ability to simulate seasonal changes in the Norwegian Sea and realistic inflow to the Barents Sea.

3) The model results indicate that recirculated volume transports of about 15-20 Sverdrup takes place in the Norwegian Sea

4) It seems that significant larval transports into the Barents Sea may be necessary for good recruitment, and together with warm upper ocean temperature during spring, these may be the most important factors for producing good yearclasses when the spawning stock is above a certain minimum. This fits well with the extremely different years of 1983 with good recruitment in spite of a small spawning stock, and 1993 with bad recruitment in spite of a large spawning stock and a very large number of young larvae.

5) The model demonstrates that larvae from the Karmøy spawning ground can drift into the Skagerrak, which may have been an important process for recruitment in the old days when Karmøy was (one of) the main spawning ground.

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Figure legends

Figure 1. Model area and monthly mean current pattern at 20 m depth in July, 1993 (max. current 63 cms^{-1}). Some names on spawning grounds are inserted.

Figure 2. Intercomparison of modeled tracer (dashed line and weekly dots) and drifting Argos buoy (with drough at 20 m depth) in the period April 23 to July 30, 1993.

Figure 3a. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in July, 1981.

Figure 3b. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in May, 1987.

Figure 3c. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in July, 1987.

Figure 3d. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in May, 1989.

Figure 3e. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in May, 1991.

Figure 3f. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in July, 1991.

Figure 4. Average (April 1990) modeled velocity [cms^{-1}] and salinity distributions accross the vertical section northwest from Svinøy, Norway into the deep Norwegian Sea.

Figure 5. Intercomparison between geostrophic volume transport estimates (Blindheim, 1993) from monthly (in 1990 and 1991) hydrographic data along the Svinøy section (zero velocity reference layer at 1000 m) and monthly mean modeled transports.

Figure 6a. 18 years (1976-1993) of modeled monthly mean volume transports through the total Svinøy section and through the upper 1000 m.

Figure 6b. 18 years (1976-1993) of modeled monthly mean volume transports through the Fugløya (Norway)-Bjørnøya (Bear Island) (upper) and the Gimsøy (Lofoten) sections.

Figure 7. Modeled particle distribution on August 20 for the years 1991 and 1992, where particles has been released also from the spawning grounds Karmøy and Haltenbanken in addition to Sunnmøre/Buagrunnen

Figure 8. Modeled particle distribution on August 20 for the years 1983 and 1993, where particles has been released also from the spawning grounds Karmøy and Haltenbanken in addition to Sunnmøre/Buagrunnen.

Figure 9. Cumulative numbers of the modeled larvae in 1983 and 1993 having entered and stayed within the Barents Sea east of the Bjørnøya (Bear Island)-Fugløya(Norway) section.

Figure 10. 18 years (1976-1993) of modeled number of particles from Sunnmøre/Buagrunnen and Haltenbanken situated east of the Bjørnøya-Fugløya section on August 20 and September 12.

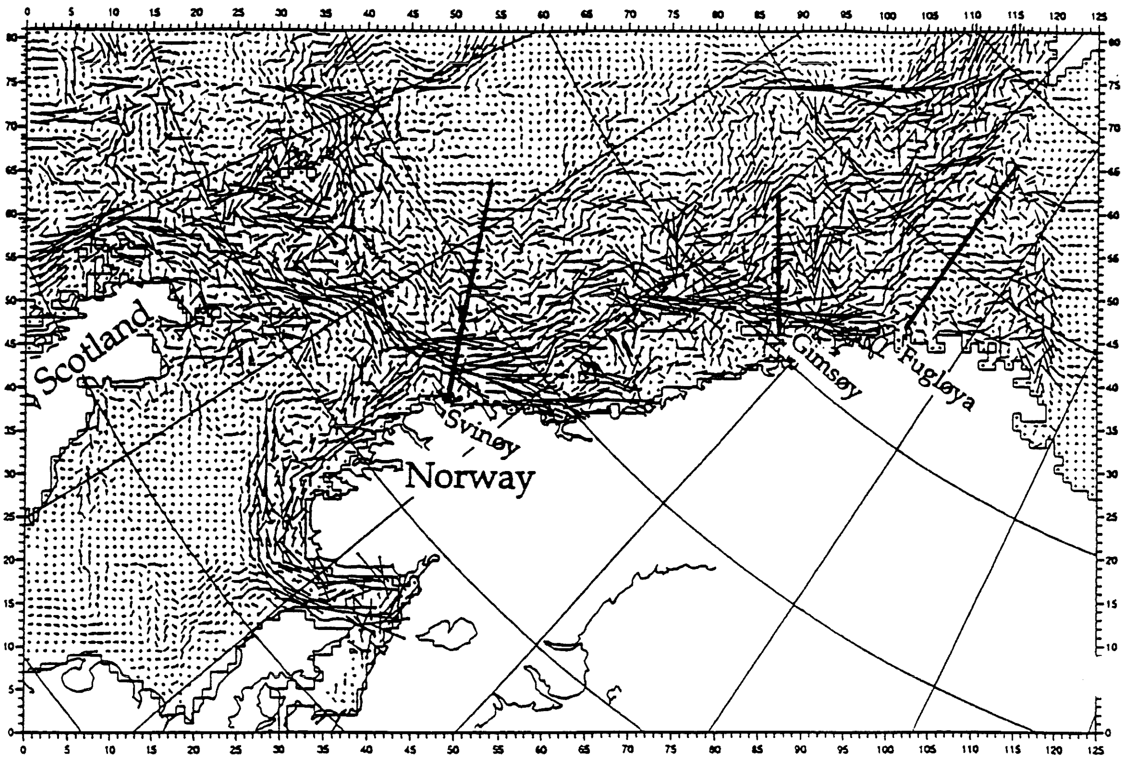


Figure 1. Model area and monthly mean current pattern at 20 m depth in July, 1993 (max. current 63 cms^{-1}).

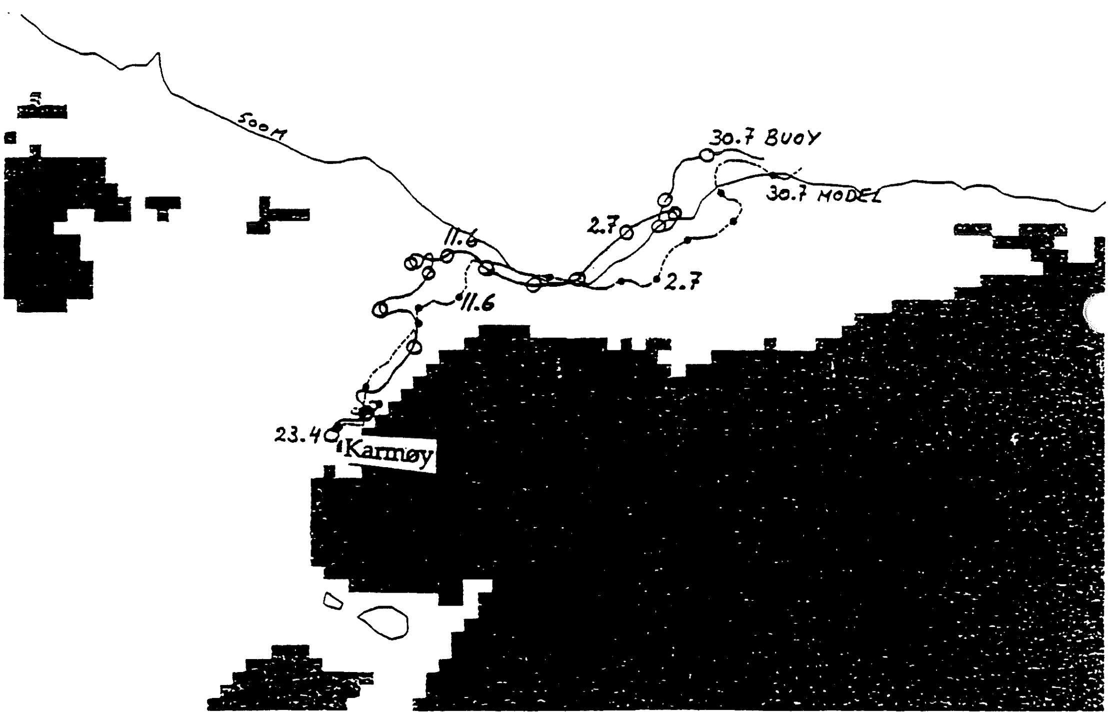


Figure 2. Intercomparison of modeled tracer (dashed line and weekly dots) and drifting Argos buoy (with drough at 20 m depth) in the period April 23 to July 30, 1993.

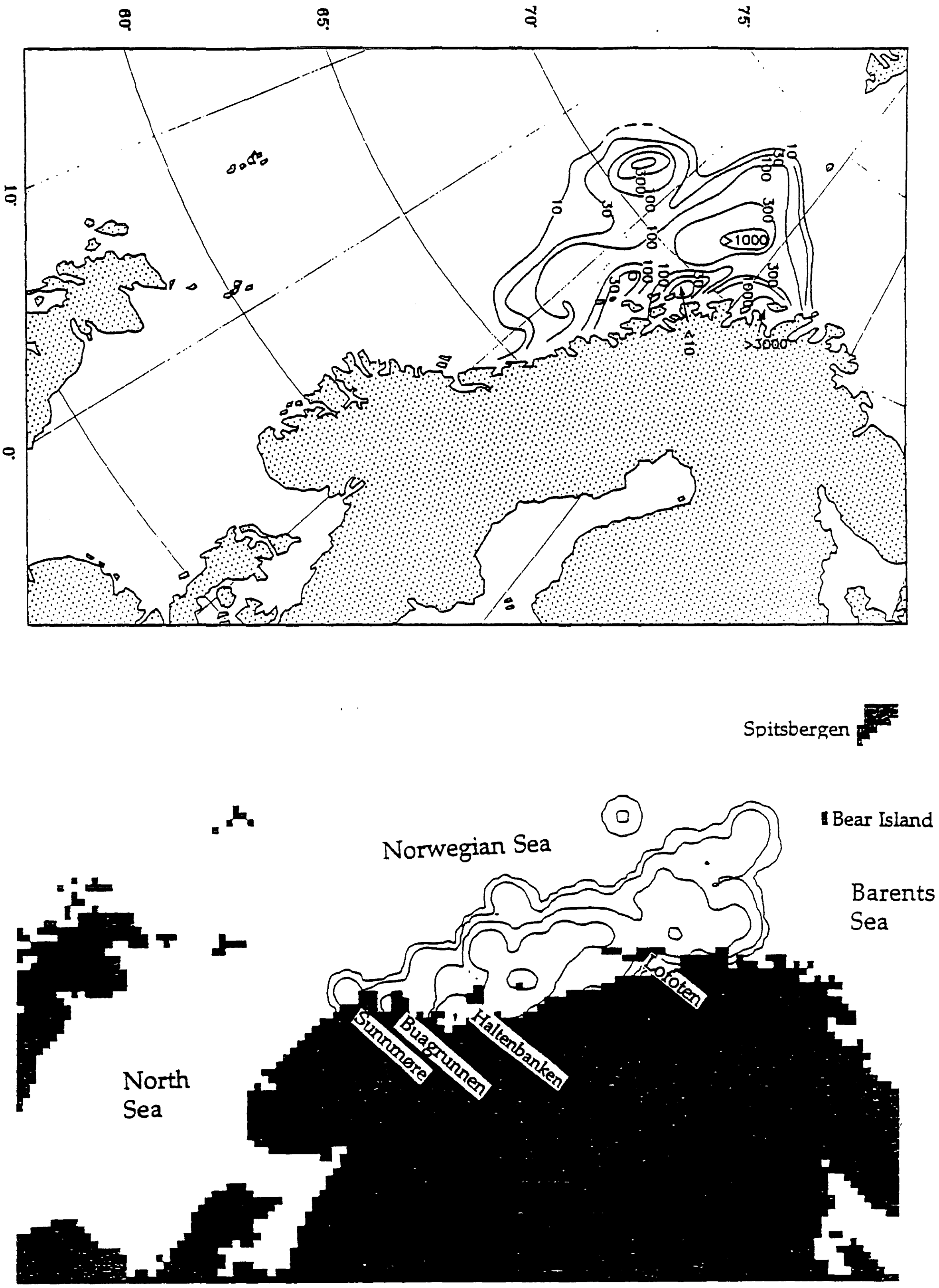


Figure 3a. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in July, 1981.

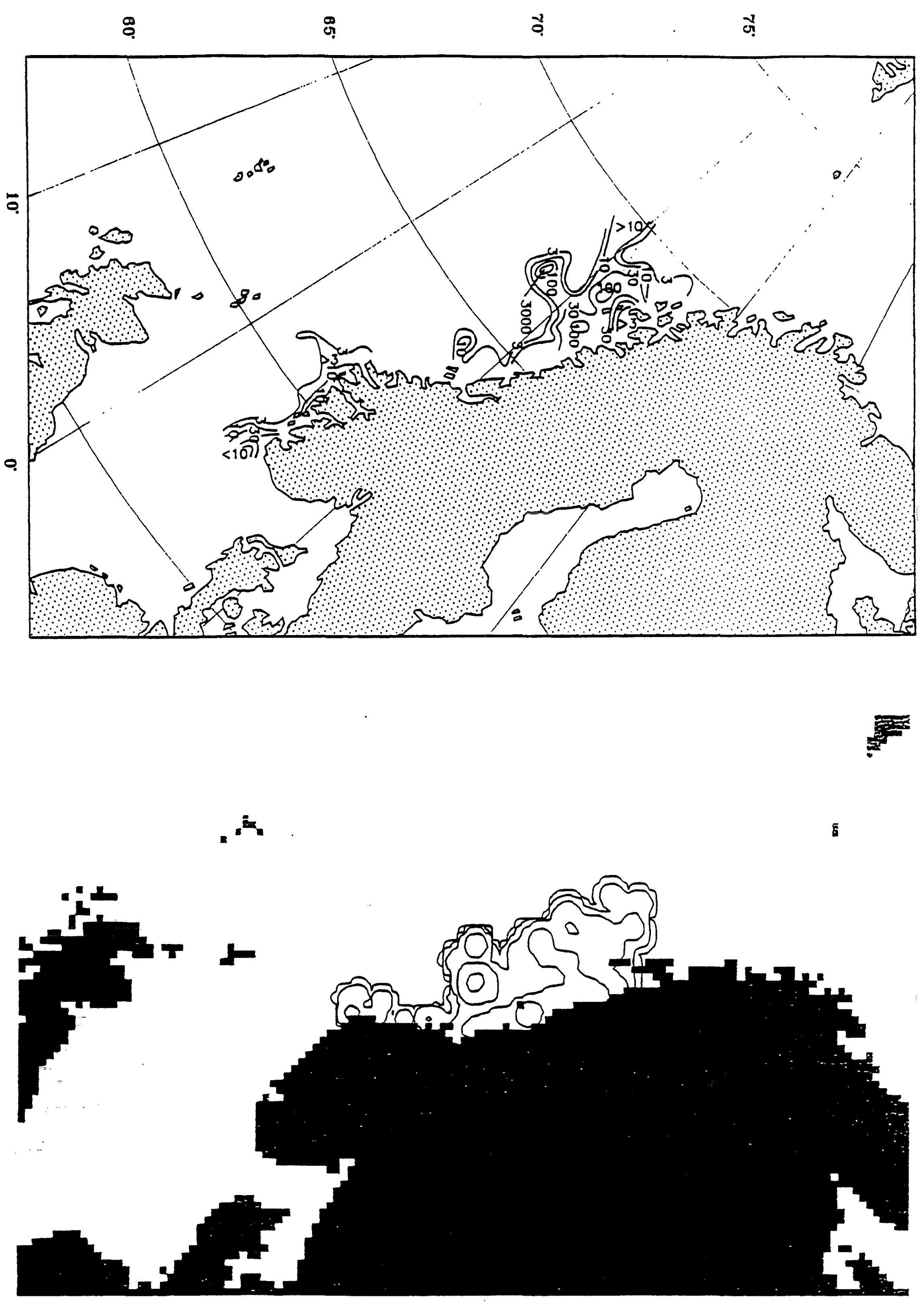


Figure 3b. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in May, 1987.

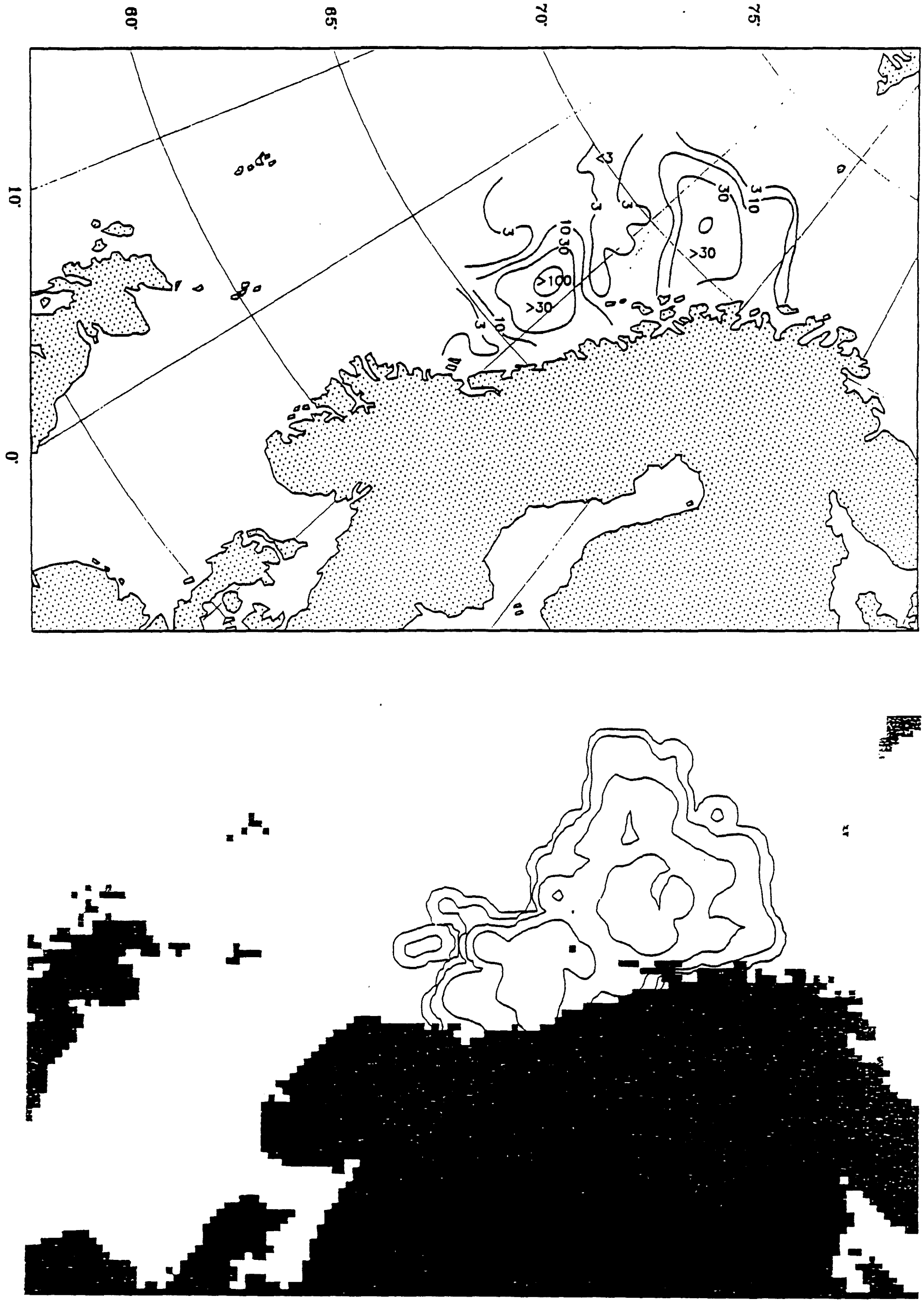


Figure 3c. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in July, 1987.

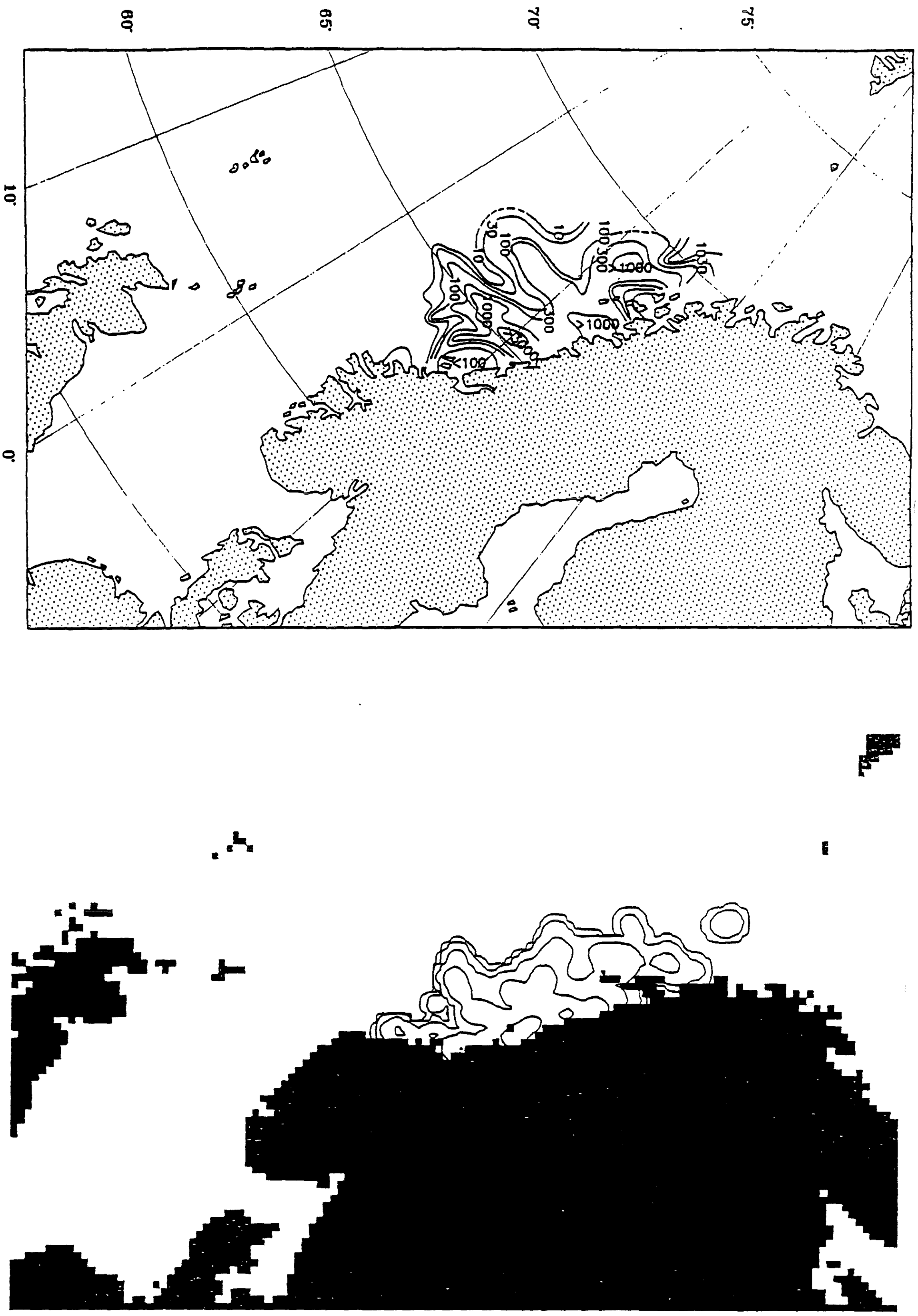


Figure 3d. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in May, 1989.

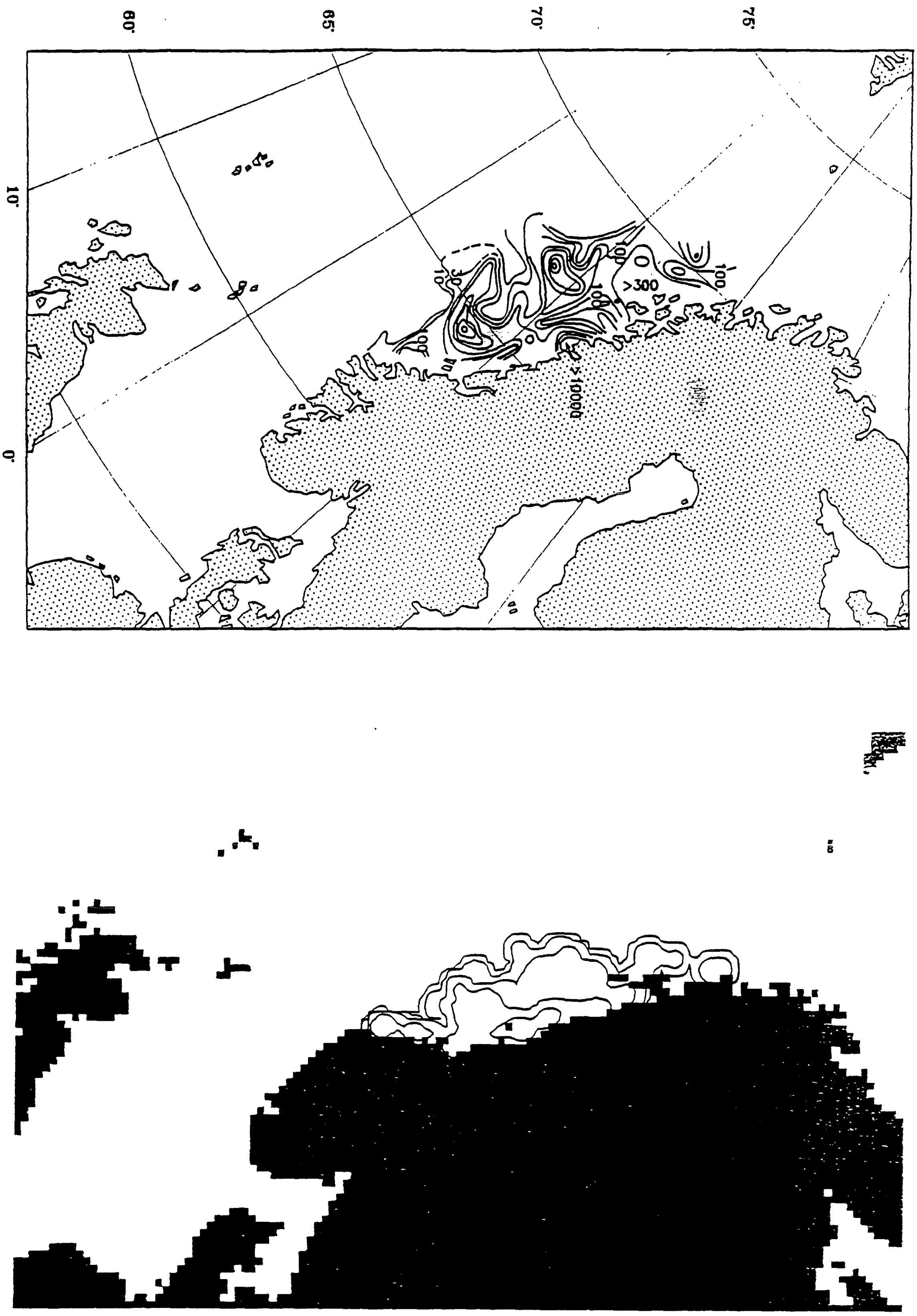


Figure 3e. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in May, 1991.

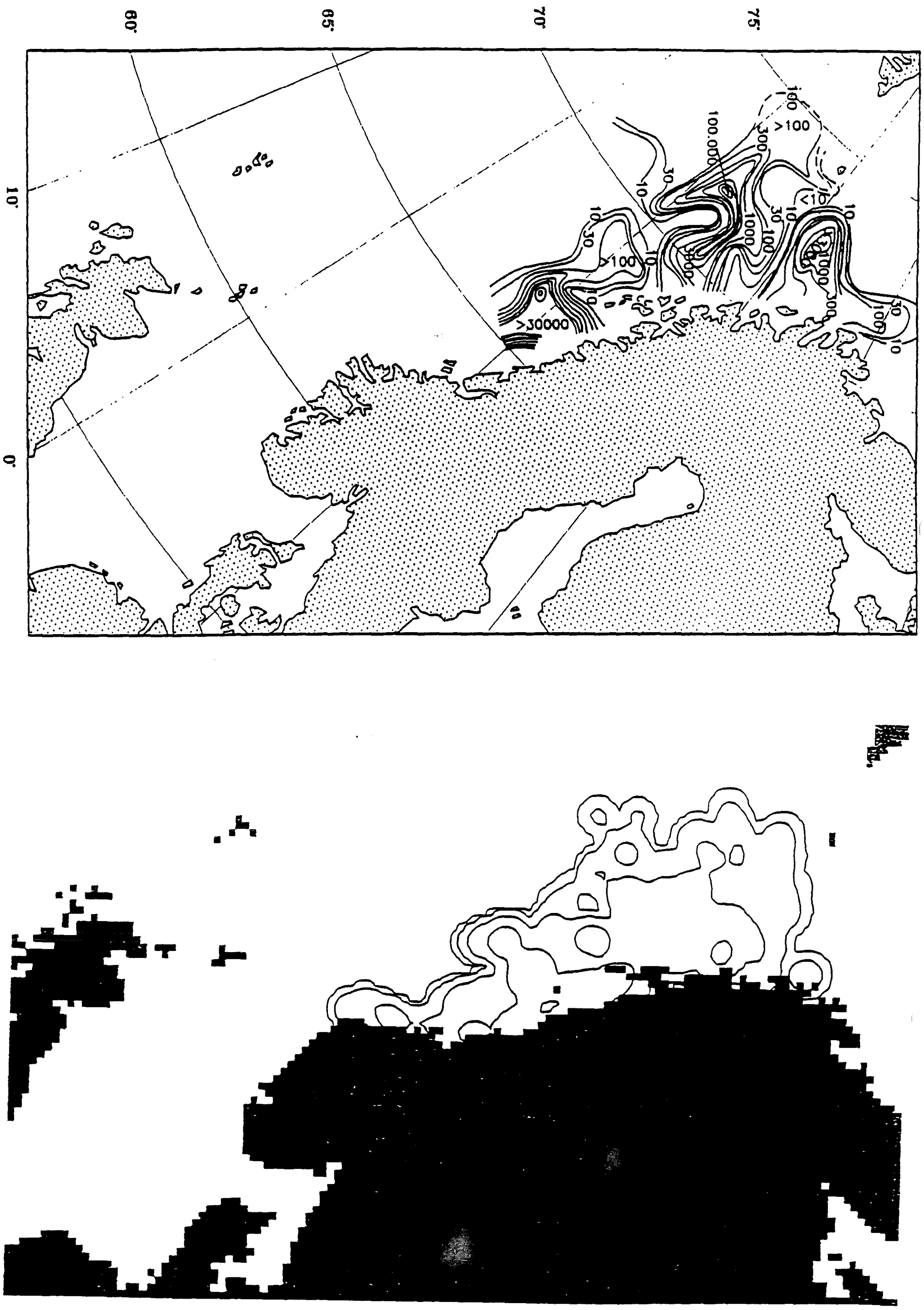
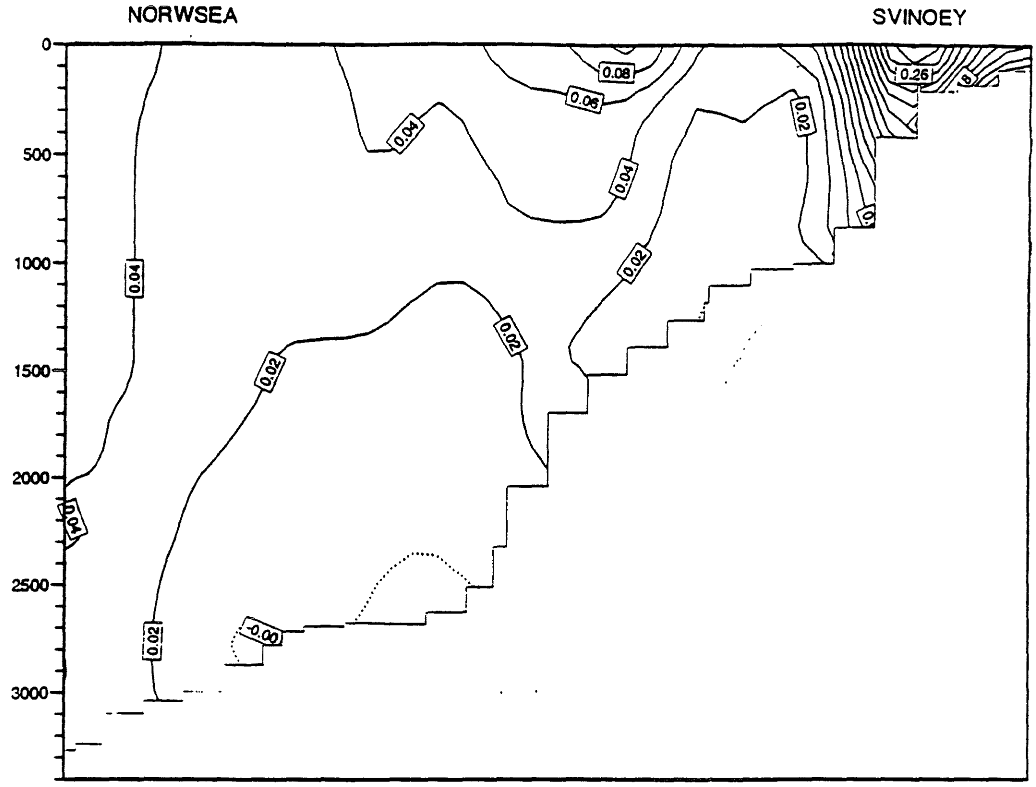
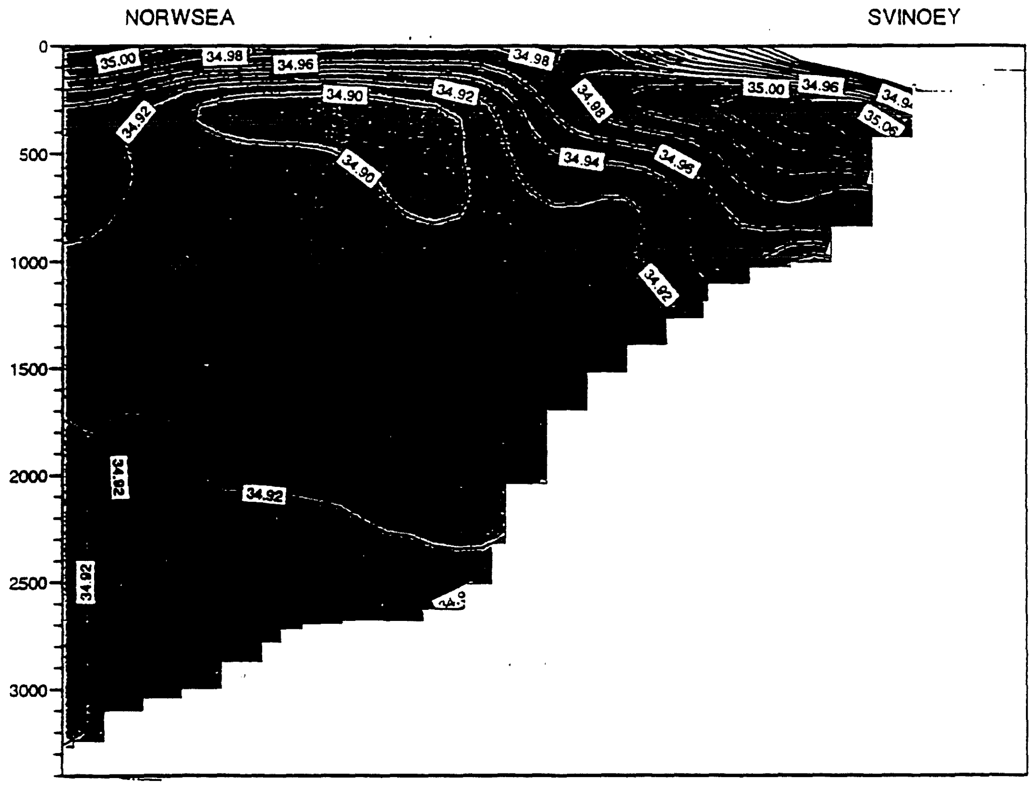


Figure 3f. Observed (upper, no.pr.1.5 nm trawling) and modeled (relative concentration) distribution of herring larvae in July, 1991.



HOR.VELOCITY MODELRESULTS, APR 1990

Transport = 28.9 Sverdrup (31.0 , -2.2)



SALINITY MODELRESULTS, APR 1990

Salinity transport = 1006 KiloTons/s (1082 , -75)

Figure 4. Average (April 1990) modeled velocity [cms-1] and salinity distributions accross the vertical section northwest from Svinøy, Norway into the deep Norwegian Sea.

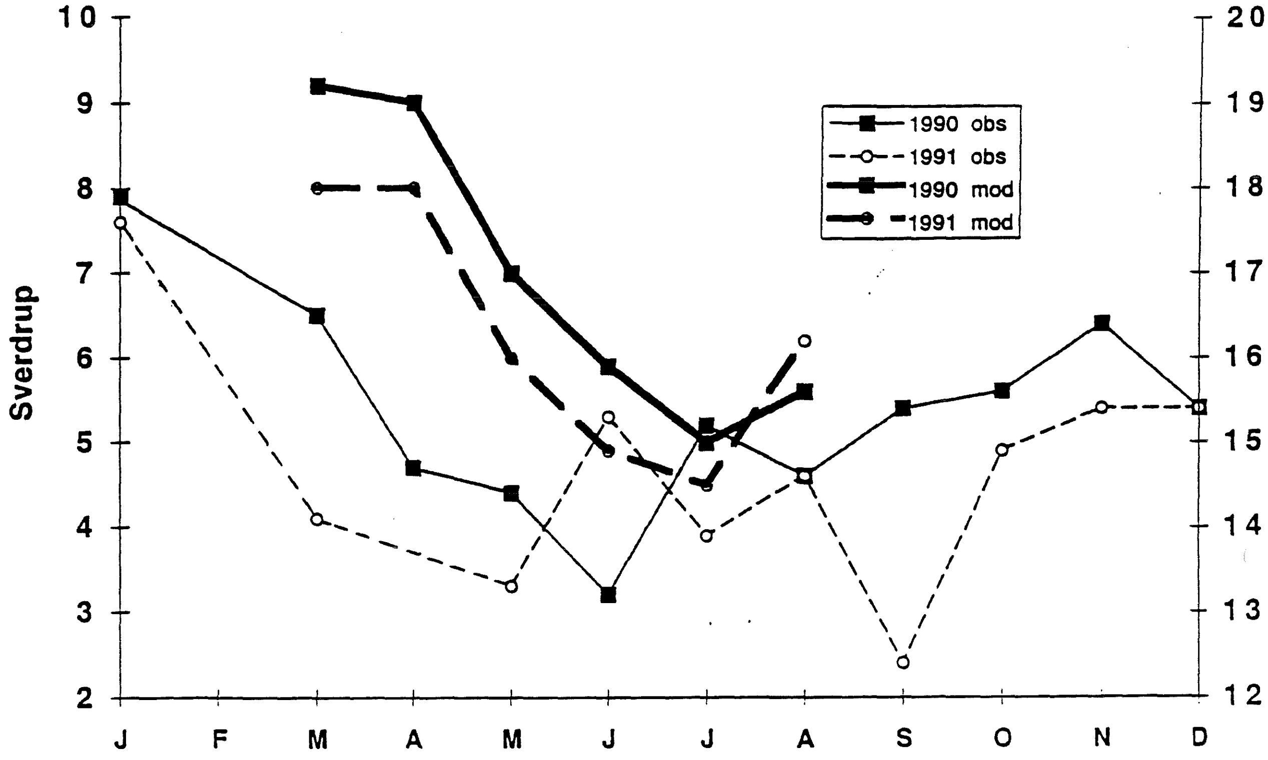


Figure 5. Intercomparison between geostrophic volume transport estimates (Blindheim, 1993) from monthly (in 1990 and 1991) hydrographic data along the Svinøy section (zero velocity reference layer at 1000 m) and monthly mean modeled transports.

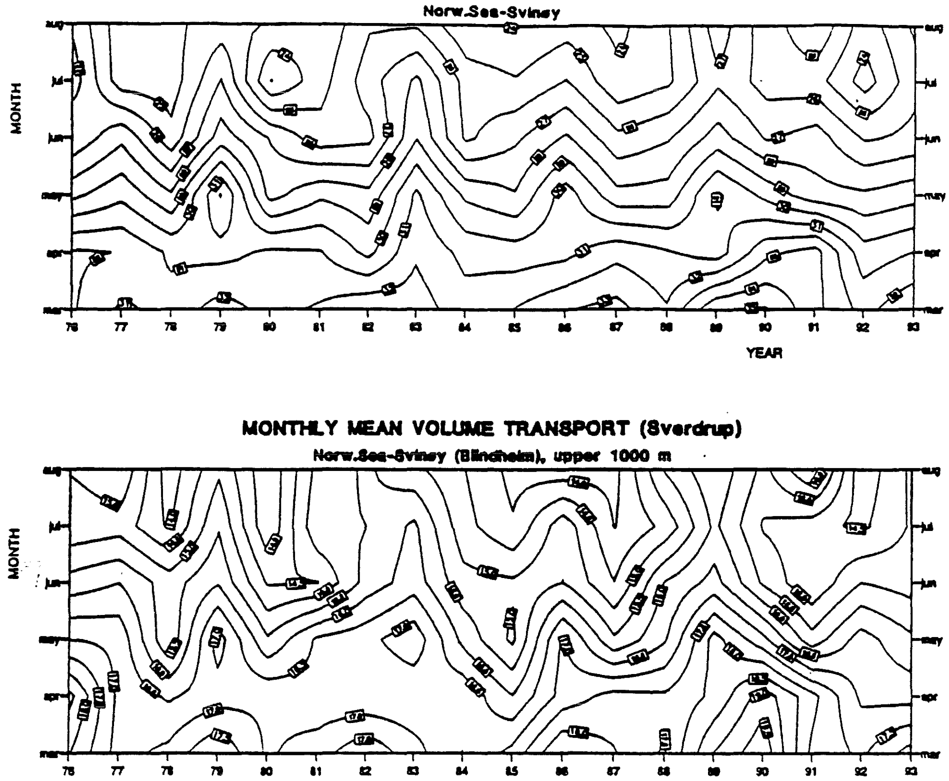


Figure 6a. 18 years (1976-1993) of modeled monthly mean volume transports through the total Svinøy section and through the upper 1000 m.

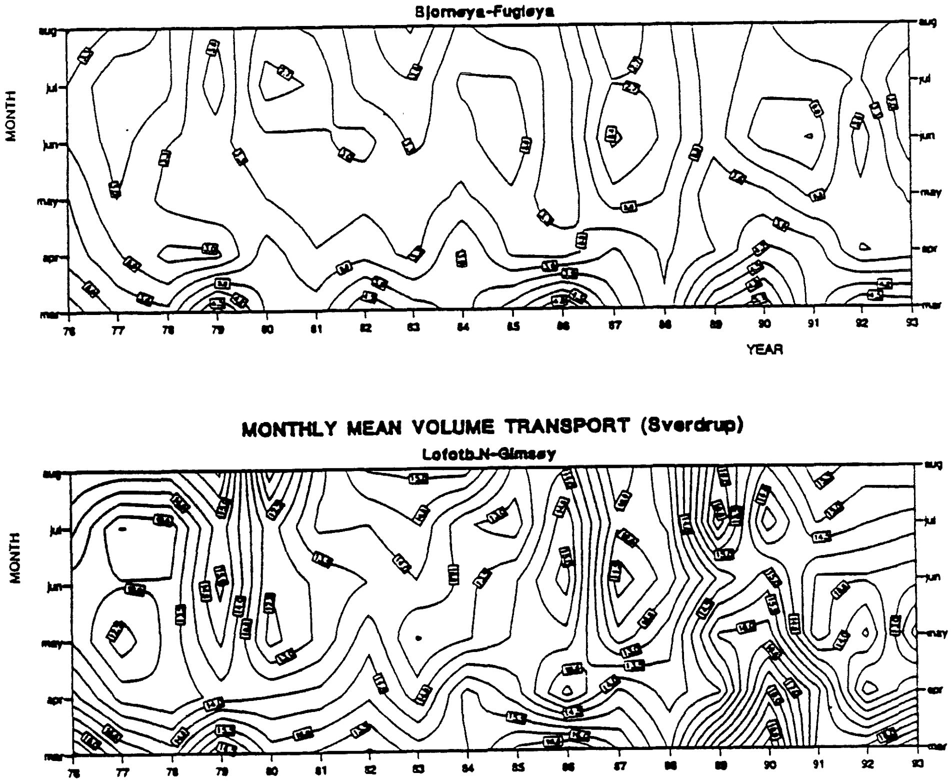
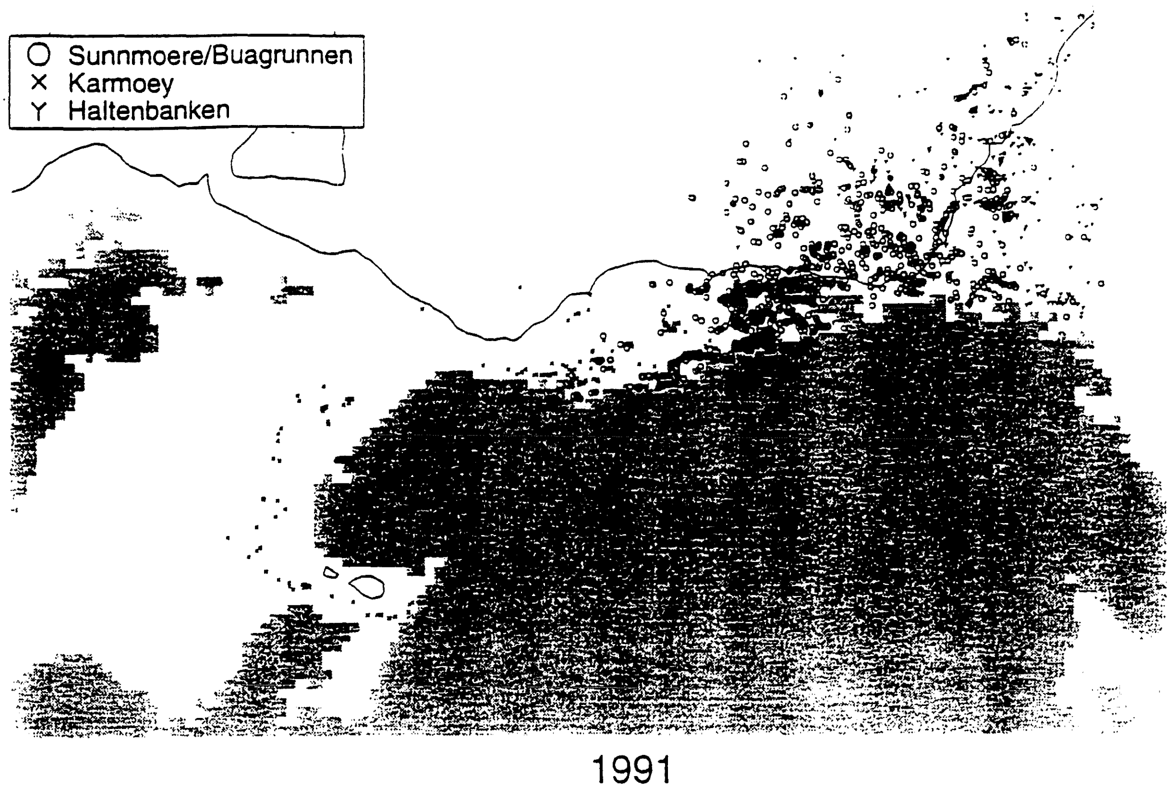


Figure 6b. 18 years (1976-1993) of modeled monthly mean volume transports through the Fugløya (Norway)-Bjørnøya (Bear Island) (upper) and the Gimsøy (Lofoten) sections.



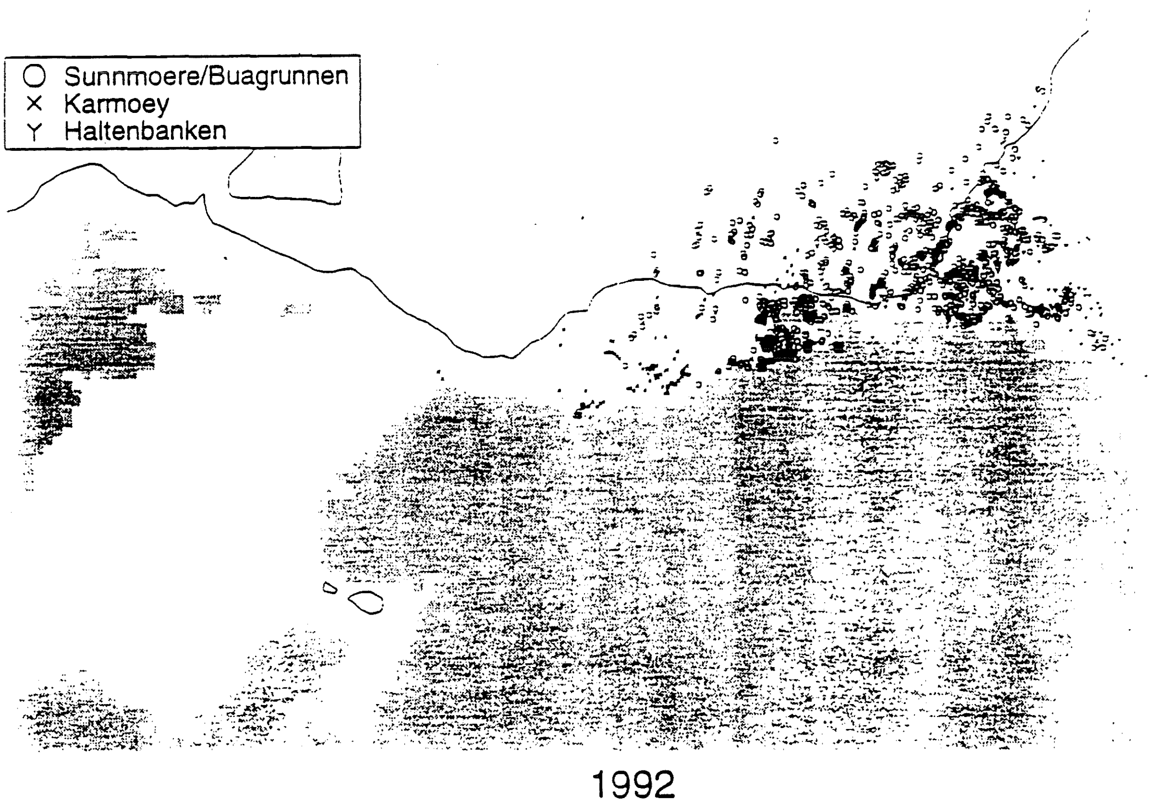


Figure 7. Modeled particle distribution on August 20 for the years 1991 and 1992, where particles has been released also from the spawning grounds Karmøy and Haltenbanken in addition to Sunnmøre/Buagrunnen

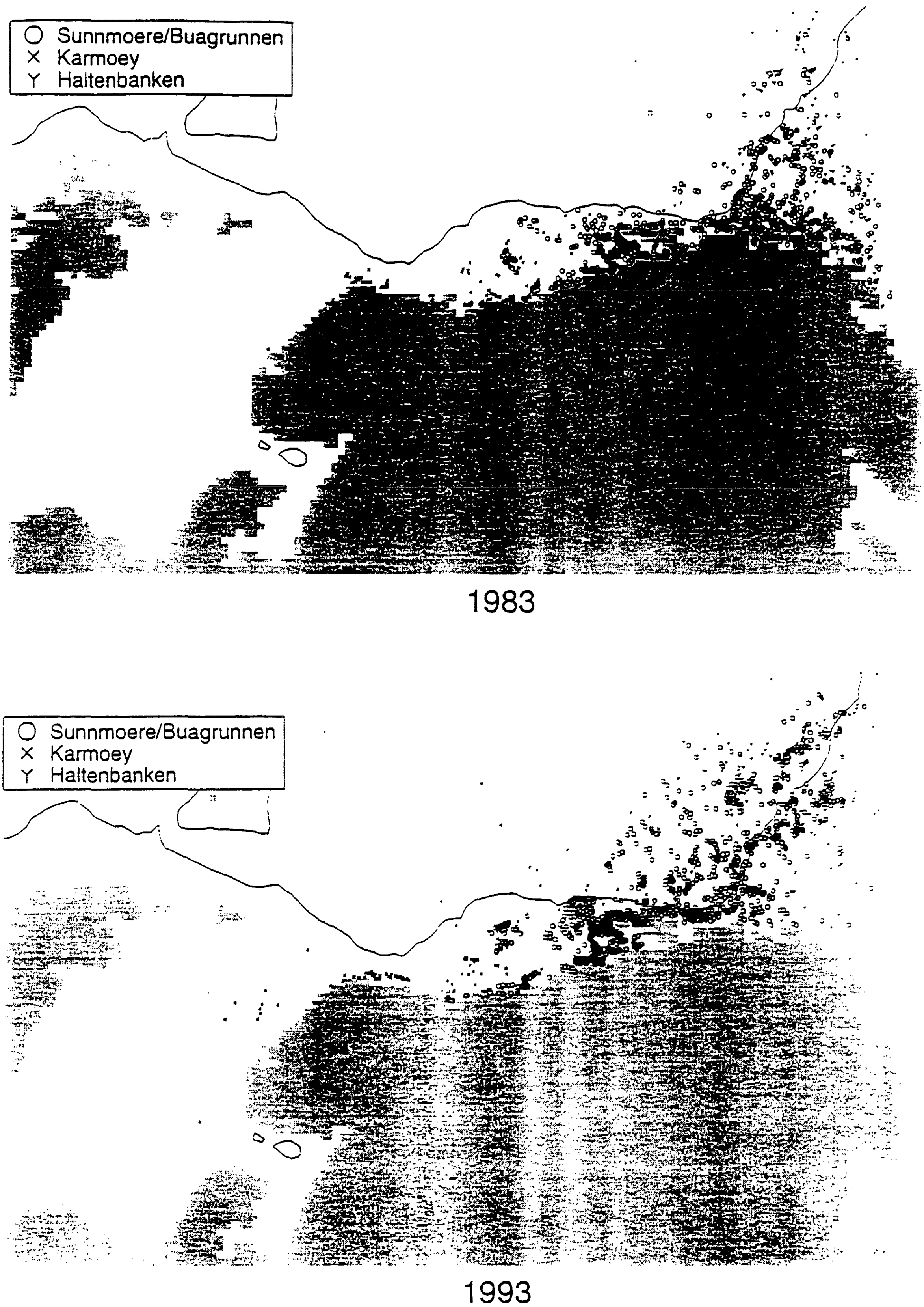
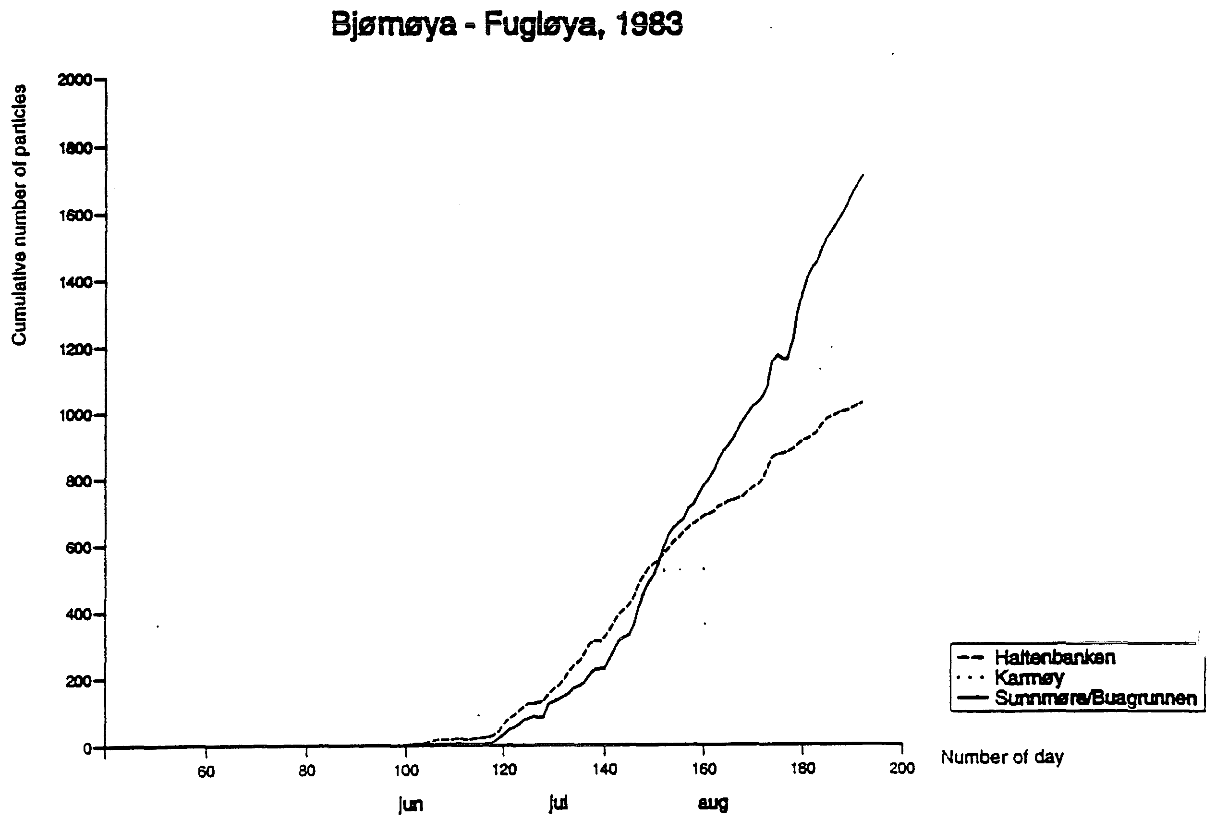


Figure 8. Modeled particle distribution on August 20 for the years 1983 and 1993, where particles has been released also from the spawning grounds Karmøy and Haltenbanken in addition to Sunnmøre/Buagrunnen.



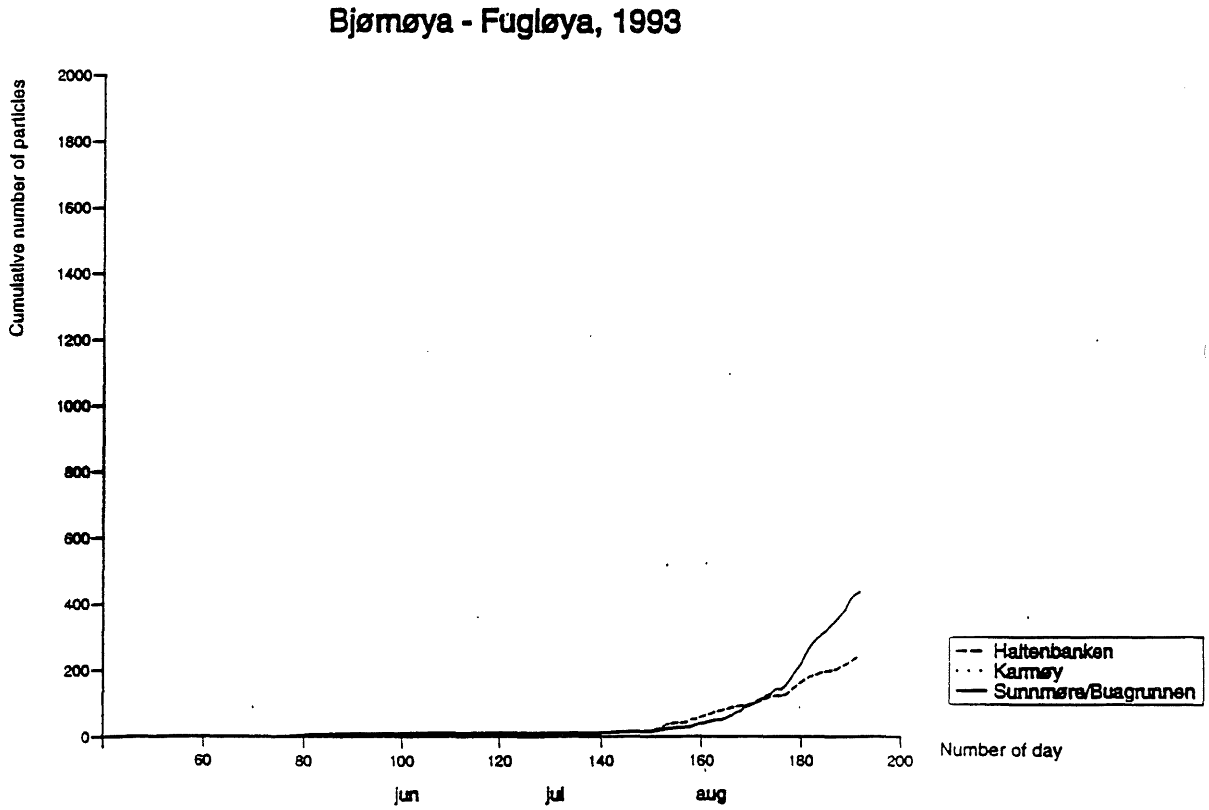


Figure 9. Cumulative numbers of the modeled larvae in 1983 and 1993 having entered and stayed within the Barents Sea east of the Bjørnøya (Bear Island)-Fugløya(Norway) section.

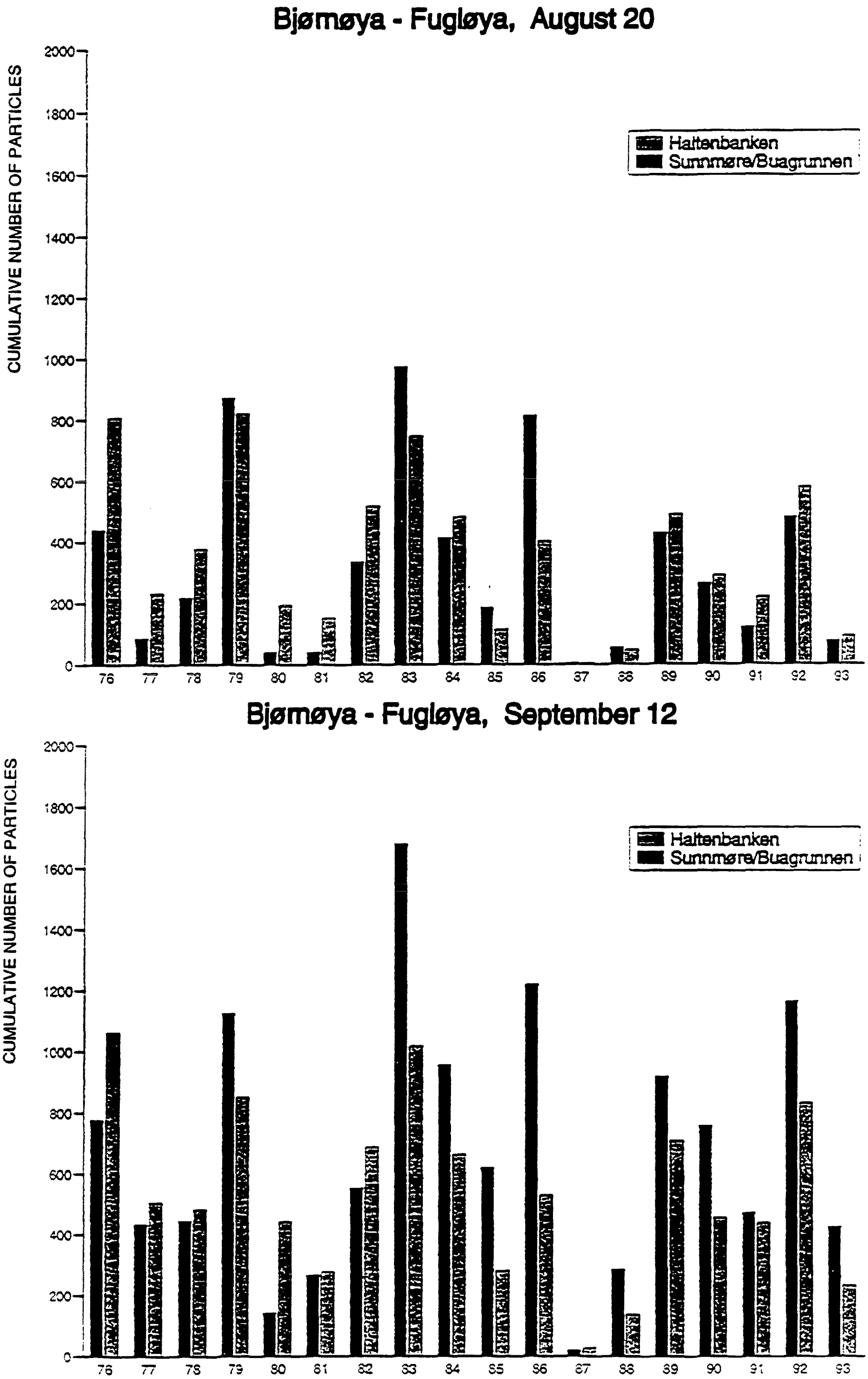


Figure 10. 18 years (1976-1993) of modeled number of particles from Sunnmøre/Buagrunnen and Haltenbanken situated east of the Bjørnøya-Fugløya section on August 20 and September 12.

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