International Council for the Exploration of the Sea

C.M. 1995/J:24
Baltic Fish Committee

ABUNDANCE AND DISTRIBUTION OF LARVAL COD (*GADUS MORHUA*) IN THE BORNHOLM BASIN

by

Grønkjær P.[1], Möllmann C.[2] & Voss, R.[2]

[1] Institute of Biological Sciences; Department of Ecology and Genetics
University of Aarhus; Building 540, NY Munkegade; DK 8000 Aarhus C

[2] Institute for Marine Research, Department of Fisheries Biology
University of Kiel; Düsternbrooker Weg 20; D-24116 Kiel

ABSTRACT

Ichthyoplankton-samples from Bongo net surveys in the Bornholm Basin between 1987 and 1995 were analysed. The temporal variation of cod larval abundance during the years is described and the horizontal and vertical distribution for selected cruises is plotted.
The results showed a shift of larval peak abundance from spring to late summer and a general decline of abundance throughout the historical time series. Various causes for this decline are discussed, putting emphasis on mortalities in the larval stage.
From the horizontal distribution a drift of older larvae to the margins of the study area is indicated. Suggestions to improve the sampling strategy for future research are presented.
A bimodal vertical distribution was found. Partitioning of larvae into size groups showed younger larvae to be concentrated below and older ones above the halocline. The reason and the importance of this migration into the surface layer is discussed.

INTRODUCTION

The recent decline of Eastern Baltic cod stock is supposed to be due to a combination of intensive fishery and the special hydrographic regime of the Baltic Sea (Anon., 1994; Bagge & Thurow, 1993). Fishery acts through diminishing the spawning stock biomass and through changing its composition, whereas the hydrographic conditions limit the volume of water where successful development of eggs is possible (Plikshs et al., 1993).
Larval abundance can be used as a first estimate of the recruitment, influenced by the biomass and composition of the spawning stock as well as the mortality of the eggs. However, little work has been done to understand the factors influencing the developmental success within the larval stage.
In this paper we describe the temporal variation of cod larval abundance in the Bornholm basin during 1987 to 1995. Furthermore the horizontal and vertical distribution for selected cruises is plotted. Additionally possible causes for variable mortalities in the larval stage are reviewed.
Implications for sampling strategies within the AIR2-project *Mechanisms influencing long term trends in reproductive success of Baltic cod: Implications for fisheries management* are discussed.

MATERIALS AND METHODS

1.) Abundance and horizontal distribution

Sampling took place in years 1987-1995 with different research vessels in the Bornholm Basin. The standard station grid was enlarged from 30 stations (1987-90) to 36 stations (1991-93) and 45 stations (1994-95). Sampling was performed using a 61cm diameter Bongo net with 335 µm meshes. The tows were oblique extending to within 4m from the bottom. Flow through the net was recorded by a mechanical flow meter. The samples were conserved in a 4% buffered formaldehyde-seawater solution.
Abundance values (n/m^2) for each station were calculated using numbers of cod larvae on each station, filtered water volume and the maximum gear depth. Therefore these values strictly refer only to the maximum sampling depth on each station. A mean n/m^2 value for all stations was calculated.
Standard lengths were measured using a videosystem. No correction for shrinkage of the conserved larvae was made.
For description of possible changes in the horizontal distribution during development it seemed to be sensible to devide the larvae into different length groups :
- < 4.5 mm for yolk-sac larvae, occuring mainly below the halocline (see vertical distribution)
- 4.5 - 6.5 mm for intermediate larval stages
- > 6.5 mm for older cod larvae

From the distribution of the smallest length group the main hatching area may be identified, while the largest fraction might give some hint for larval drift and presents a basis for modelling the drift to areas reached while metamorphosis takes place.

2.) Vertical distribution

Based on results from the bongo grid, a station with high larval abundance was selected for studying the vertical distribution of larvae in early May and June 1994 (55°22.5N; 15°52.5E and 55°17.5N; 15°45.0E, respectively). Sampling of ichthyoplankton was performed with a 1

m^2 BIOMOC, a multiple opening/closing net with 335µm mesh size in 5 meter depth intervals. Two hauls combined (17 nets) constituted a depth profile from 5 to 85 metres. This profile was sampled every 4 hours during a 24 hour period. Profiles were treated as day samples if sampling was commenced between sunrise and sunset.
Towing time in a specific depth was about 3 minutes. The flow through each net was recorded with a mechanical flowmeter. Plankton samples were immediately fixed in 4% buffered formaldehyde-seawater solution. After minimum three weeks fixation the cod larvae were sorted out and preserved in 70% ethanol. Standard lengths of the larvae were measured as above. No corrections for shrinkage was made. The staging of larvae was based on descriptions from Fossum (1986).
To test for differences in vertical distribution between day and night a heterogeneity chi-squared test was used (McCleave et al., 1987), and depths were pooled in 10 m intervals to satisfy the requirement of expected catch numbers > 5 .
Hydrographic parametres were measured with a ME OTS 1500 CTD/O_2 probe at the beginning and at the end of each study.

RESULTS

1.) Abundance

Mean abundances for all cruises from 1987-1995 are presented in fig. 1. This figure includes additionally results from Polish surveys carried out in July 1993 as well as August and September 1994 (Linkowski et al., unpubl.) based on a different station grid. For detailed information on survey characteristics and abundance values see tab. 1.
The number of sampling dates varies between years. The time series shows 3 points of very high abundance with 3.16 n/m^2 in May 1988, 2.27 n/m^2 in August 1991 and 3.82 n/m^2 in August 1994.
Throughout the time-series the peak of larval abundance in each year has appeared in different months indicating a shift of peak abundance to later months of the year. In 1988 the maximum values occured in May with 2,27 n/m^2 while in 1994 the highest value of 3,82 n/m^2 was reached in August (fig. 2). An exception appeared in 1993 with larval peak abundance already in April, however on a very low abundance level (0.39 n/m^2).
In fig. 3 the estimated abundance values for May/June 1987 to 1995 are combined with historical data of Plikshs et al. (1993). The figure shows a general decline of the abundance of cod larvae from the maximum values at the end of the 1970ties to minimum values at the end of the 1980ties.

2.) Horizontal distribution

For most of the sampling dates the results are not suitable to plot horizontal distributions. The reasons were either too few larvae caught or missing length measurements. Presented are horizontal distributions for May 1988 and July 1994. In May 1988 a total of 324 larvae was caught. The larvae < 4,5 mm showed 2 centers of distribution both situated in the central basin (fig. 4). Highest densities were found in the length fraction 4,5 - 6,5 mm. These cod larvae were spread over the whole study area with highest concentrations in the south-east. The largest individuals (> 6,5 mm) concentrated in the north-west and the eastern edge of the station grid.

Fig. 5 shows the horizontal distribution for July 1994. It is based on a total of 31 cod larvae. The smallest fraction (< 4,5 mm) seemed to be restricted to the central basin, while the intermediate length-group was distributed also to the western margin of the basin.

3.) Vertical distribution

Hydrography

The depth of the stations in May an July 1994 was 95 and 98 m. As it is typical for the estuarine conditions in the Baltic Sea, we found a halocline located at approximately 45 m (fig. 6). The salinity in the upper 45 m was stable at 7 psu, while below 45 m it increased to 18 psu. The density of the water at the two study dates varied along with salinity from 1005.5 to 1014.5 kg m^{-3}. Water temperatures in May were 6 °C down to a thermocline at 22 m. Here the temperature decreased to 3 °C. In June the surface warming results in a more pronounced stratification and deeper thermocline (33 m). Surface temperature was 8 - 9 °C decreasing to 3 °C in the deep winter water. On both occasions there were indications of a slightly warmer bottom water layer.
In both months 50 % oxygen saturation was found at 77 m, dropping below 30% near the bottom. Large saturation differences were found between the two CTD casts on the same station.

Cod larvae

A total of 145 and 160 cod larvae were caught in May and June (fig. 7), equal to a density of 4.14 ± 1.19 (5) and 4.67 ± 1.12 (6) larvae/1000 m^3. Mean lengths were 4.90 ± 0.1 mm and 4.74 ± 0.08 mm. No significant differences were found between the two cruises with regard to the mean length (ONEWAY, $p > 0.05$) or density (t-test, $p > 0.05$). The day to night catch ratio varied between 1.4 and 2.3 yielding no indication of visual gear avoidance for all larval sizes combined.
Chi-squared tests performed on 10 m intervals showed that the cod larvae on the 2 stations were not uniformly distributed with depth ($p < 0.01$) (fig. 8). The number of cod larvae peaked above the halocline at 25 to 40 m, and below it at 60 to 75 m. Only very few larvae were found below 75 m, and in the halocline region at 45 to 55 m. At night the cod larvae in the upper 45 m concentrated just above the thermocline, while they during day were more scattered. Below the halocline no day/night effect was obvious. No evidence for vertical migration could be detected between day and night samples pooled in 10 m intervals (Chi-squared, $p < 0.01$).
Partitioning of larvae into size groups revealed differences in vertical distribution of these groups (fig. 9). By size the larvae were split in yolk-sac larvae (< 4.5 mm), first-feeding larvae (4.5 - 5.5 mm) and feeding larvae (5.5 - 7.5 mm). It was apparent that the smallest larvae were concentrated below the halocline both day and night. Single depth intervals comprised up to 45 % of the larvae (75 m, May, night). Larvae from 4.5 to 5.5 mm had clear peaks in abundance above and below the halocline. In May, and to a lesser extent in June, this group seemed to be deeper distributed in day than in night catches. Interpretation of this as vertical migration is difficult because of the low numbers caught. In May only one larvae in the size group 5.5 to 7.5 mm was caught during night sampling (not shown). In June the feeding larvae seemed to aggregate in the upper 45 m at night, while they scattered throughout the water column during day. It appears that this group undertakes daily migrations.
Larvae larger than 7.5 mm were very sparse (n = 11). and almost exclusively caught during day, where they were found very scattered.

DISCUSSION

1.) Abundance

Fig. 1 & 2 contain mean abundance values of cod larvae resulting from different station grids. Strictly speaking these values are not directly comparable and should therefore be interpreted carefully. Therefore standardized station grids should be used for future work.
The described shift of larval peak abundance coincides with a shift of peak spawning time observed from egg abundance values (Wieland, 1995; Bagge et al., 1994). This shift may be the reason for the low abundance values encountered in May/June 1989-1995 compared to former years (fig. 3). However, comparing May/June values from the historical time series with peak abundance values from August 1991 and 1994 a general decline is still obvious. This decline may have several reasons. Concerning the egg stage, factors like the structure of SSB, fecundity, egg quality (Larsson, 1995), vertical distribution and hydrographic situation (Wieland 1995) as well as predation mortalities (Köster & Schnack, 1994) have to be considered.
Concentrating in this paper on the larval stage, numbers of larvae hatched per season estimated by Wieland (1995) for years 1987 to 1991 are compared to resulting O-group numbers obtained from the MSVPA (Anon., 1996) (fig. 10). Especially 1989 with quite high numbers of hatched larvae but very few resulting O-group fish appears to be an example for mortality in the larval stage as an important factor controlling year-class strength. This mortality could be governed by several influences. Even in the larval stage, hydrographic factors are probably relevant for the developmental success. However, until now the influence of different oxygen contents on larvae survival rates is largely unknown. Studies are in progress (Schnack et al., 1995). Nissling et al. (1994) found no significant influence of different salinities. Food availability is supposed to be also no limiting factor for cod larvae in the Bornholm Basin because the prey densities seem to be sufficient over the whole development period (Krajewska-Soltys & Linkowski, 1994; Dahmen, 1995). Another possibility explaining high mortality rates could be predation by clupeid stocks. However, a recent study showed that cod larvae are not substantially affected by predation (Köster, 1994). Another problem in the larval stage could be deseases caused by contamination with heavy metals or organic pollutants (Larsson, 1995) and virus infections (Pedersen et al., 1993). Furthermore the drift of larvae in relation to the mesoscale current-system has to be taken in consideration. Different current systems may lead the metamorphosing larvae to variable areas with different capability for surviving. To study this topic more detailed information on larvae and current systems are necessary (see below). Studies are in progress (Voss in prep.).

2.) Horizontal distribution

The horizontal distributions in fig. 4 & 5 indicate a slight drift of older larvae out of the central basin. This interpretation, however, assumes a stability in the location of the spawning center and in current conditions as the distribution pattern is compared from different cohorts of larvae sampled during the same survey. A much more appropriate approach to describe larval drift would be to monitor cohort development either by sampling the entire area repeatedly or by following an initial larval aggregation marked by a drift buoy. However, sufficient larval densities are a prerequisite for such studies, situations very seldom encountered in the Bornholm Basin. Thus, a more feasable approach may be an analysis of the horizontal distribution monitored by regular ichthyoplankton surveys covering the distribution area and spawning time suffiently and taking into consideration the mesoscale current system.

Another topic to be studied is the patchiness of larval cod to check the so far used linear interpolation between the grid stations.
For a better prediction of year-class strength from larval abundance indices it appears to be helpful to use a distinct size fraction of larvae only. This should be a representative sampled and not too young feeding size group which has an as far as possible constant and comparably low mortality.

3.) Vertical distribution

Vertical distribution of newly hatched larvae is determined by the distribution of the late stage eggs. In the Bornholm Basin the density of the cod eggs and hydrographic characteristics confines these late stage and hatching eggs to the deep water (Wieland & Zuzarte, 1991).
The results presented here show that the Baltic cod larvae are spread throughout the water column in a non-uniform manner. The bimodal distribution found is expected to be a result of the egg distribution and a vertical migration undertaken around first-feeding. Between the 2 modes an area of low abundance was obvious, i.e. the 10 to 15 m, corresponding to the upper part of the halocline. Although Yin & Blaxter (1987) have shown that fish larvae tolerate very low salinities, the large changes in salinity and density taking place here might be unfavourable for cod larvae not yet fully capable of coping with the resulting osmotic stress. Another explanation may be, that salinity gradients are important inducers for behavioural changes, including migrations (Boehlert & Mundy, 1988) and the halocline in the Baltic therefore could aid in directing the larvae to the upper water masses. The few larvae found in this depth range were primarily intermediate or large sized larvae (> 5 mm).
The importance of the proposed first-feeding migration is obvious. Baltic cod larvae are visual predators and hatched at a depth where light is weak and not above the feeding threshold found by Ellertsen et al. (1980). Furthermore the density of suitable prey in the Bornholm Basin, especially copepod nauplii, is shown to be higher above the halocline than in the deep water (Dahmen, 1995; Krajewska-Soltys & Linkowski, 1994). This makes migration towards the surface a prerequisite for successful feeding. The first-feeding migration becomes evident when the cod larvae are split into size groups. Almost no larvae < 4.5 mm were found above the halocline in May and June. 4.5 mm corresponds well with the size around first-feeding estimated from a length-stage key set up for each sampling date. The timing of migration coincides with the time of highest vertical activity of larvae in laboratory experiments (approx. day 8 after hatching), measured as proportion of larvae near the surface of 400 ml beakers (Nissling et al., 1994).
In the size group from 4.5 mm to 5.5 mm a part of the larvae are still encountered in the deep water. This fraction might contain individuals not able to ascend to upper water layers. Hence they should be faced with sub-optimal feeding conditions and be subject to an increased mortality. Supporting our hypothesis of increased mortality of the larvae in the deep water , all larvae surviving to a size larger than 5.5 mm were found above the halocline. They have all accomplished the migration to the surface.
This study reveals no variation of depth distribution between day and night hauls for larvae < 4.5 mm, and although they have completed the first-feeding migration only small variations were seen in the group from 4.5 to 5.5 mm. In comparison the few larger larvae apparently used the whole water column for vertical migrations. This is in concordance with the findings of Ellertsen et al. (1981) and Lough & Potter (1993) stating that the diel migration of cod larvae commences at 6 to 8 mm.
Our results showed that Baltic cod larvae migrate to the surface layer at a length of approximately 4.5 mm. This is probably a response to suboptimal feeding conditions in the deep water. Furthermore a substantial part of the larger larvae were found still in the deep

water, suggesting that not all larvae are able to undertake this migration which is the cause of increased mortality.

Acknowledgments

We would like to thank Prof. Dr. D. Schnack as well as Dr. Ole Bagge and K. Thomas Jensen for supervising this work. Furthermore thanks to Drs. F.W. Köster and K. Wieland for reviewing the manuscript.
We are indebted to F. Zuzarte for supplying data material on the abundance and distribution of larvae before 1990.

References

Anon., 1994: Prognose og biologisk rådgivning for fiskeriet i 1995. DFH-rapport.

Anon., 1996: Report of the Working Group on Multispecies Assessments of Baltic fish. ICES. C.M. 1996/Assess: in prep.

Bagge, O. & F. Thurow 1993: The Baltic cod stock, fluctuations and the possible causes. ICES 1993/ CCC Symposium/No. 14.

Bagge, O. et al. 1994: The Baltic cod. DANA 10: Special issue on fish and fisheries in the Baltic: 1-28.

Boehlert, G.W. & B.C. Mundy 1988: Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. American Fisheries Society Symposium 3: 51-57.

Dahmen, K. 1995: Vertikalverteilung und produktionsbiologische Bedeutung des Mesozooplanktons im Bornholmbecken (südliche Ostsee). Ber. Inst. f. Meeresk. Kiel Nr. 273, 194 pp.

Ellertsen, B. et al. 1980: Some biological aspects of cod larvae (*Gadus morhua*) FiskDir. Skr. Ser. Hav. Unders. 17: 29-47.

Ellertsen, B. et al. 1981: Feeding and vertical distribution of cod larvae in relation to availability of prey organisms. Rapp. P.-V. Réun. Cons. int. Explor. Mer. 178: 317-319.

Fossum, P. 1986: A staging system for larval cod. FiskDir. Skr. Ser. Hav. Unders. 18: 69-76.

Köster, F.W. 1994: Der Einfluß von Bruträubern auf die Sterblichkeit früher Jugendstadien des Dorsches (*Gadus morhua*) und der Sprotte (*Sprattus sprattus*) in der zentralen Ostsee. Ber. Inst. f. Meeresk. Kiel Nr. 261, 286 pp.

Köster, F.W. & D. Schnack 1994: The role of predation on early life stages of cod in the Baltic. DANA10: Special issue on fish and fisheries in the Baltic; 179-201.

Krajewska-Soltys, A.& T.B. Linkowski 1994: Densities of potential prey for cod larvae in deep-water basins of the southern baltic. ICES, C.M. 1994/J:17 (mimeo.).

Larsson, P.-O. 1995: Recent development of the cod stocks around sweden and possible reproduction disturbances. Report from the Uppsala Workshop on reproduction disturbances in fish, 20-22 Oct.1993. L. Norrgren (ed.).; Swedish Environmental Protection Board.

Lough, R.G. & D.C. Potter 1993: Vertical distribution patterns and diel migrations of larval and juvenile haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*) on Georges Bank. Fishery Bulletin 91 (2): 281-303.

Mc Cleave, J.D. et al. 1987: Statistical methods for analysis of plankton and nekton distribution, with application to seletive tidal stream stream transport of juvenile American eels (*Anguilla rostrata*). J. Cons. int. Explor. Mer. 40: 262-271.

Nissling, A. et al. 1994: Survival, activity and feeding ability of Baltic cod (*Gadus morhua*) yolk-sac larvae at different salinities. Journal of Fish Biology 45: 435-445.

Pedersen, B.H. et al. 1993: Baltic larval cod *Gadus morhua* are infested with a protistan endoparasite in the yolk sac. Dis. aquat. Org. 16: 29-33.

Plikshs, M. et al. 1993: The influence of environmental conditions and spawning stock size on the year-class strength of the eastern Baltic cod. ICES, C.M. 1993/J:22 (mimeo.).

Schnack, D. et al. 1995: Baltic Cod Recruitment Project. ICES, C.M. 1995/J:23 (mimeo.).

Voss, R. in prep.: Horizontalverteilung und Drift von Dorschlarven in der südlichen zentralen Ostsee in Abhängigkeit vom mesoskaligen Strömungssystem. Diplomarbeit Institut für Meereskunde Kiel.

Wieland, K. & F. Zuzarte 1991: Vertical distribution of cod and sprat eggs and larvae in the Bornholm Basin (Baltic Sea) 1987-1990. ICES, C.M. 1991/J:37 (mimeo.).

Wieland, K. 1995: Einfluß der Hydrographie auf die Vertikalverteilung und Sterblichkeit der Eier des Ostseedorsches (*Gadus morhua callarias*) im Bornholmbecken, südliche zentrale Ostsee. Ber. Inst. f. Meeresk. Kiel Nr. 266, 114 pp.

Yin, M.C. & J.H.S. Blaxter 1987: Temperature, salinity tolerance and buoyancy during early development and starvation of Clyde and North Sea herring, cod and flounder larvae. J. Exp. Mar. Biol. Ecol. 107: 279-290.

Tab. 1: Survey characteristics and mean cod larval abundances (n/m²)

ship	survey midpoint year	month	day	number of stations	cod larvae mean n/m²	
Alkor	1987	4	24	28	0,04	
Alkor	1987	4	30	28	0,22	
Littorina	1987	6	1	20	0,3	
Alkor	1987	7	4	28	0,3	
Alkor	1987	7	9	28	0,2172	
Poseidon	1987	8	17	24	0,0298	
Alkor	1987	9	8	28	0,1272	
Dana	1988	3	22	17	0,09	
Alkor	1988	4	7	30	0,2596	
Littorina	1988	5	19	30	3,1625	
Littorina	1988	5	24	28	2,9711	
Poseidon	1988	6	29	30	0,28	
Littorina	1988	7	31	30	0,11	
Alkor	1988	9	22	30	0	
Poseidon	1988	10	12	30	0	
Dana	1989	3	15	19	0	
Alkor	1989	4	22	23	0,332	
Alkor	1989	5	26	30	0,59	
Alkor	1989	6	25	30	0,04	
Alkor	1990	5	28	25	0,11	
Littorina	1991	4	18	29	0,18	
Littorina / Alk	1991	5	25	29	0,04	
Alkor	1991	7	7	36	0,08	
Alkor	1991	7	17	36	0,38	
Poseidon	1991	8	11	36	2,27	
Poseidon	1991	8	17	36	3,09	
Alkor	1992	5	20	35	0,1	
Poseidon	1992	7	8	35	0,08	
Alkor	1993	4	22	36	0,39	
Alkor	1993	5	24	36	0,11	
Alkor	1993	7	7	36	0,03	
Baltica	1993	7	30	50	0,02	@
Alkor	1994	4	29	45	0,09	
Alkor	1994	5	31	45	0,13	
Alkor	1994	7	9	45	0,16	
Baltica	1994	8	22	15	3,82	@
Baltica	1994	9	4	11	1,35	@
Alkor	1995	4	10	45	0	
Alkor	1995	5	14	45	0,04	
Alkor	1995	7	21	45	0	

@ Data from Linkowski (unpubl.)

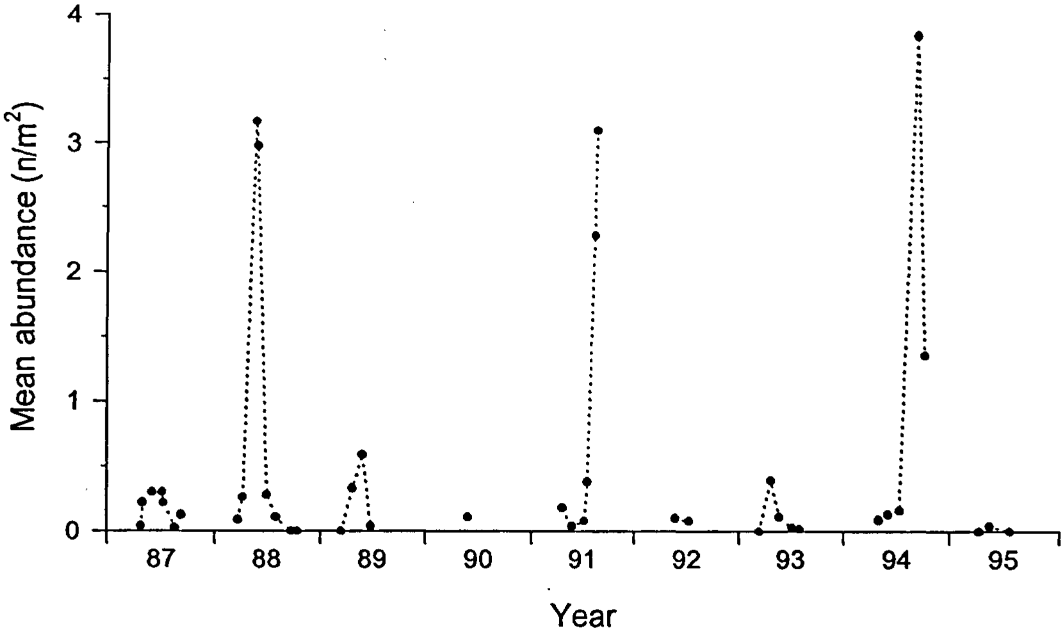

Fig. 1: Abundance (n/m^2) of cod larvae for different sampling dates in years 1987 to 1995 (see tab. 1 for survey specific information)

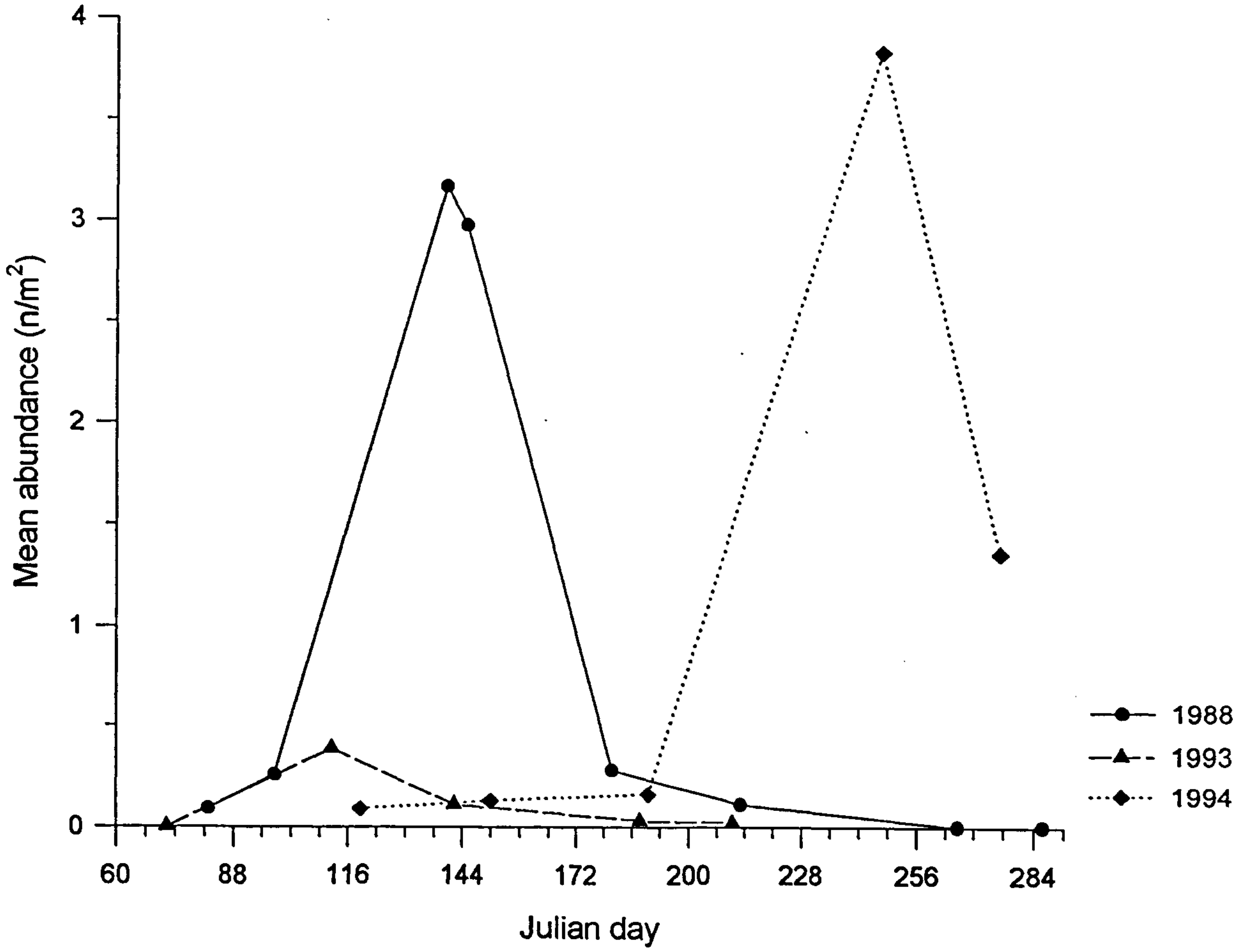

Fig. 2: Annual cycle of cod larval abundance (n/m^2) for years 1988, 1993 and 1994

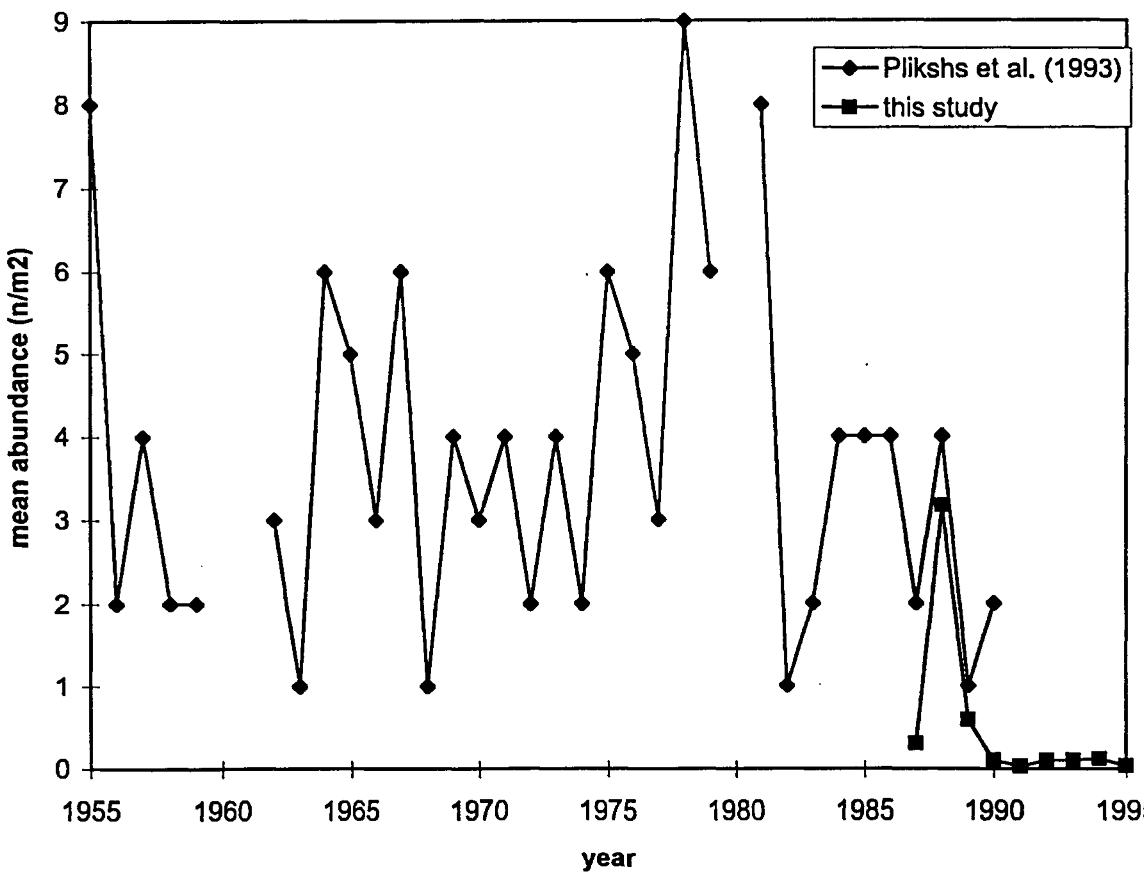

Fig. 3: Historical time series of cod larval abundance; mean values for May/June

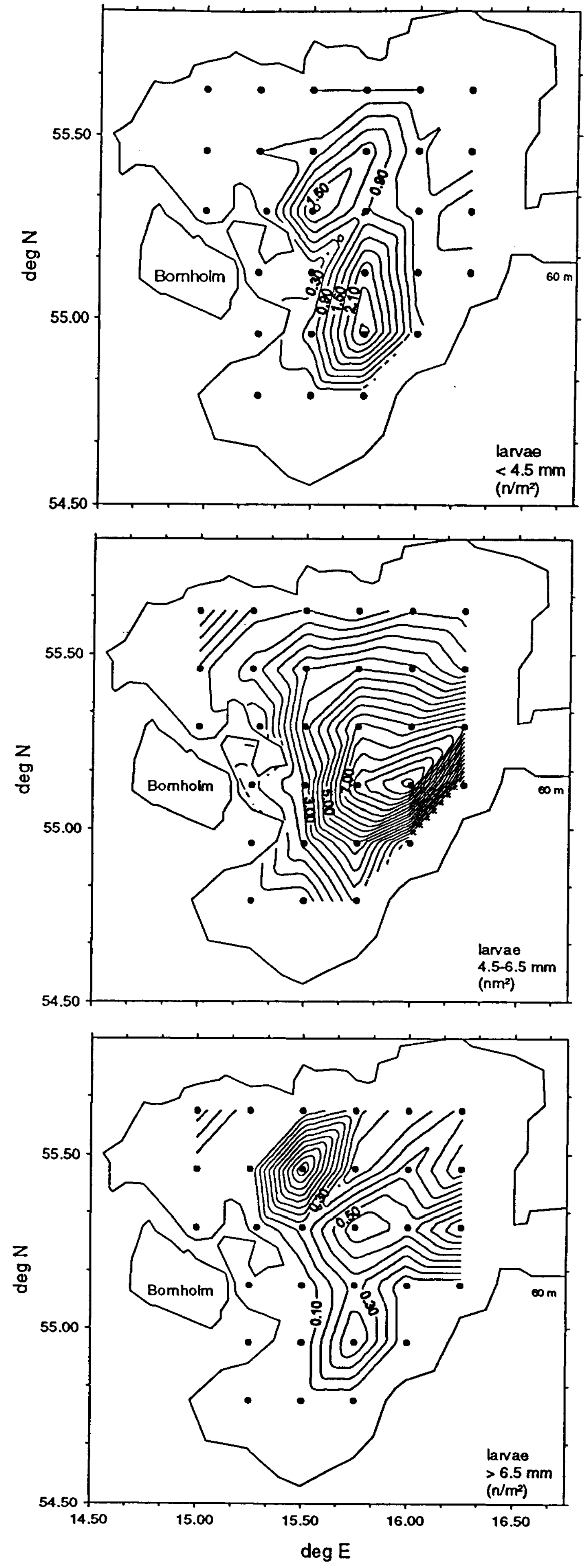

Fig. 4: Horizontal distribution of cod larvae (n/m²) in May 1988 for different length groups; dots indicate sampling positions

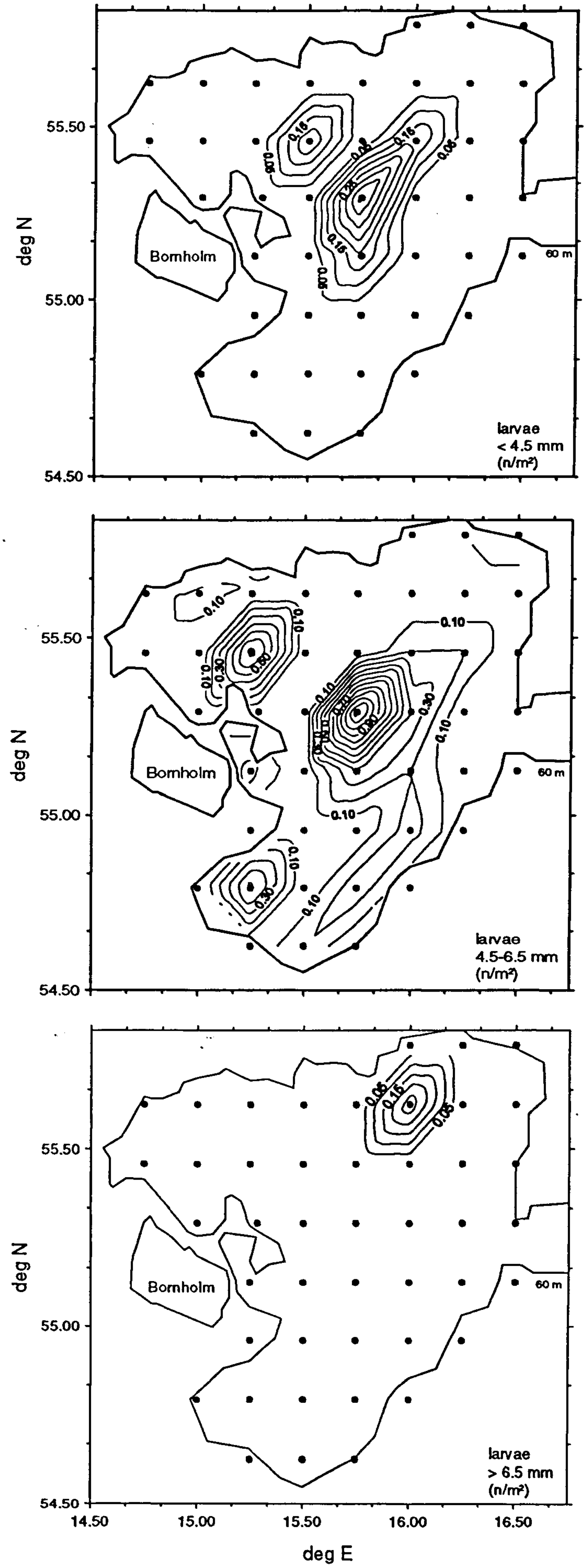

Fig. 5: Horizontal distribution of cod larvae (n/m²) in July 1994 for different length groups; dots indicate sampling positions

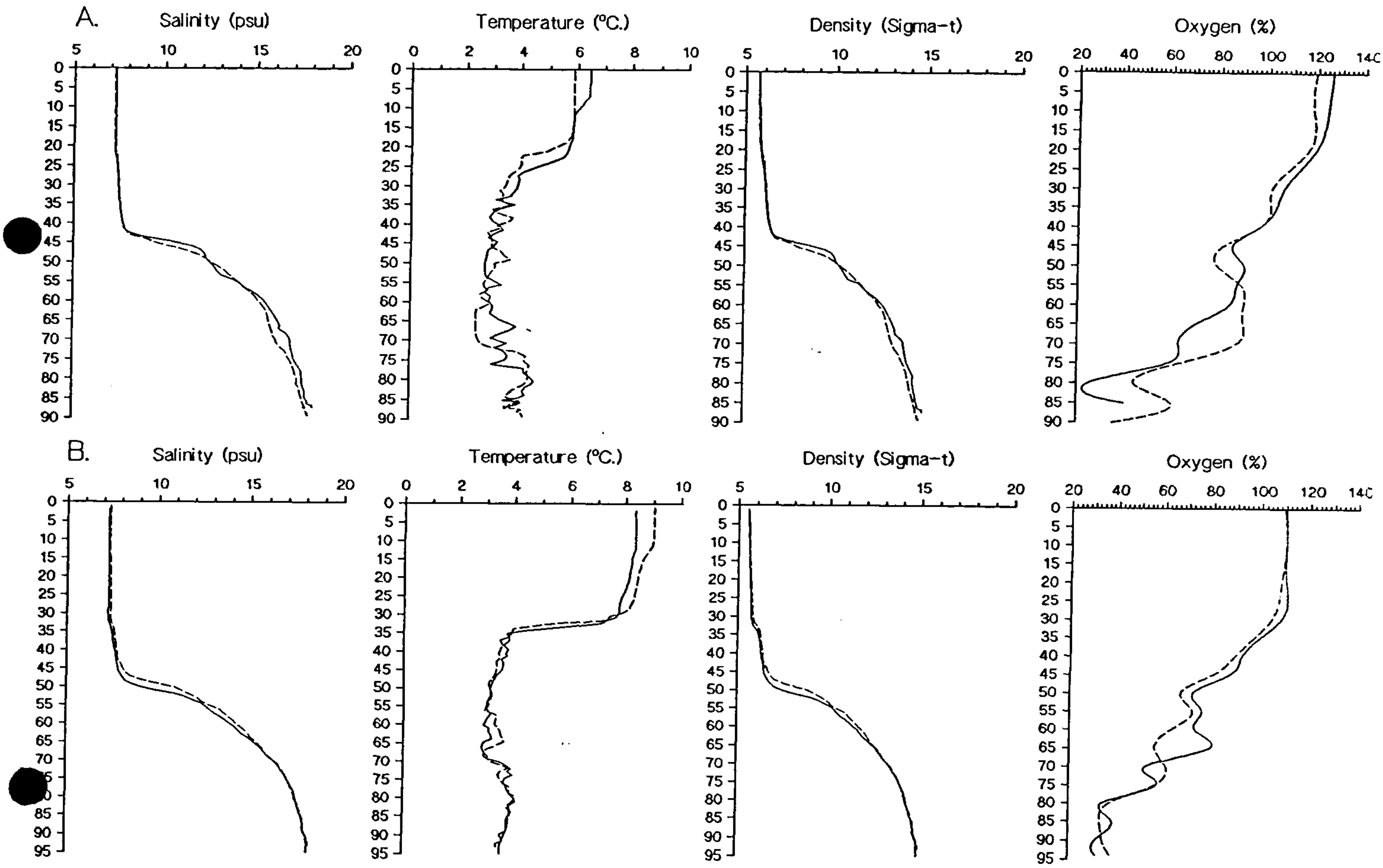

Fig. 6: Hydrographic conditions on the May (A) and June (B) stations

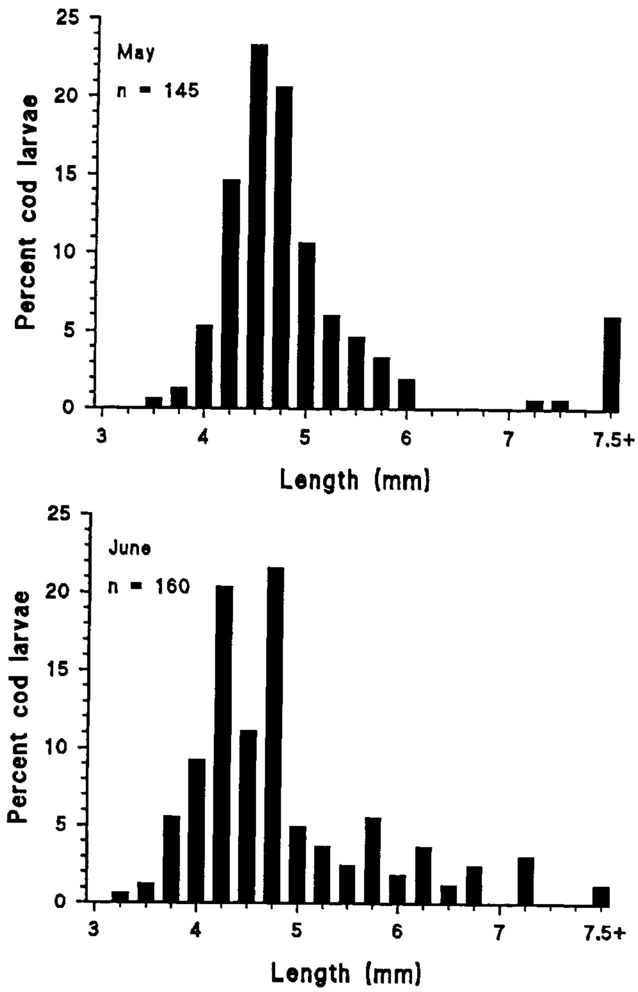

Fig. 7: Length frequencies of cod larvae for May and June 1994

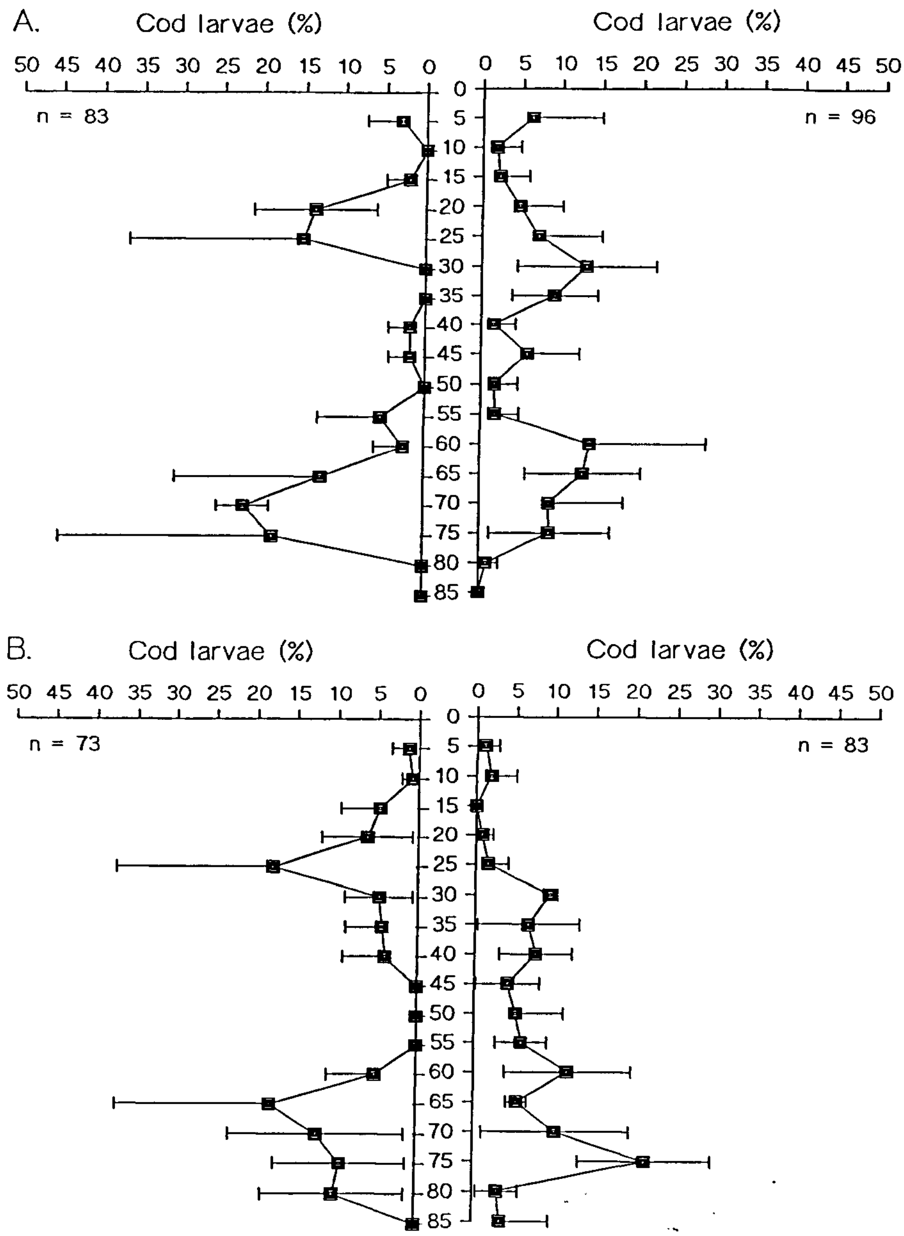

Fig. 8: Day (right) and night (left) vertical distribution of cod larvae in May 1994 (A) and June 1994 (B)
bars indicate standard errors

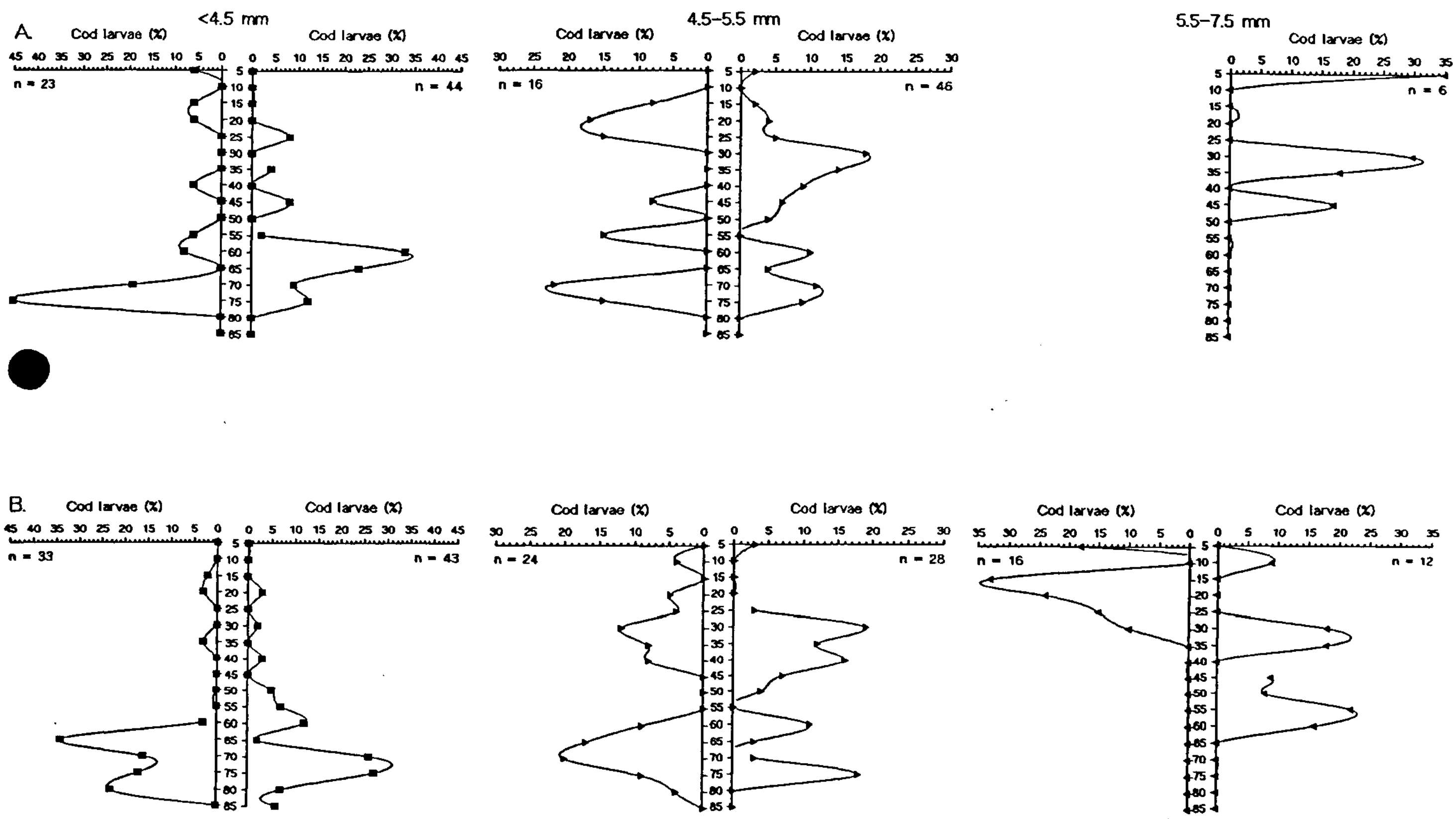

Fig. 9: Day (right) and night (left) vertical distribution for different length groups of larvae. May 1994 (A) and June 1994 (B)

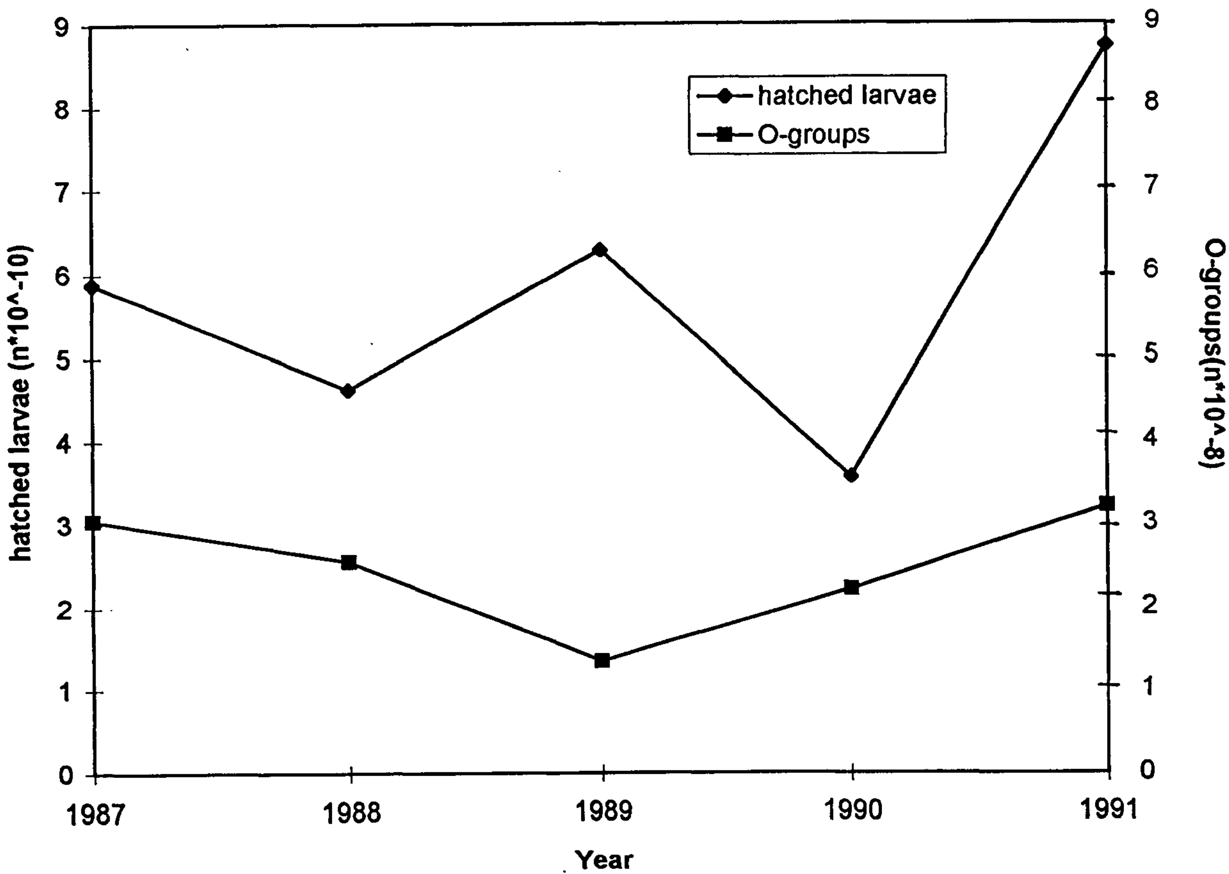

Fig. 10: Estimated numbers of hatched larvae (Wieland 1995) and O-group numbers at the begin of 3rd quarter (Anon. 1996)