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INFLUENCE of CLIMATE on
RECRUITMENT and MIGRATION of
FISH STOCKS in the NORTH SEA

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ABSTRACT

For several decades one of the prime targets within fishery science has been to be able to understand and explain the great variability in the success of survival from egg to mature fish. One of the reasons why such effort has not lead to any clear and quantifiable conclusions, is probably that the direct and indirect influence of the physical climate has so far been underestimated.

22 years of hydrographic data taken during summer over most of the northern and central North Sea, and meteorological data from a station outside western Norway, have been used to derive climatic parameters assumed to be of prime importance for the biological productivity of the North Sea. These time-series together with recruitment and spawning stock size data from the individual ICES working groups, have been used to construct empirical models demonstrating that e.g. more than 70% of the year to year recruitment variability of several of the fish stocks may be explained by the climate/weather prior to and during the time of larval stages.

In addition to demonstrate which climatic factors being most important for the biological processes, the results of the models indicate that realistic forecasts of recruitment can be given already within the summer of the spawning year. This possibility is of great importance to better manage the fish resources.

INTRODUCTION

With respect to the ecology of the ocean, and especially in fishery biology, it is commonly suspected that the physical climate has a strong influence on population dynamics, in terms of e.g. recruitment success and migration pattern. It has, however, often been difficult to demonstrate such relations directly. This may be because many of such investigations consider only one single physical parameter at a time (often temperature), which not necessarily is a prime ecological steering factor. Corten (1990) suggested that most of the observed changes in the pelagic fish stocks in the North Sea (NS) could be explained by a theory assuming a long term reduction of the inflow of Atlantic Water (AW) to the NS during the period 1960-1980, and an increase of this inflow in later years. However, he also states that there is as yet no physical evidence that such a change occurred.

During the 1970's an ocean climate event, the Great Salinity Anomaly (Dickson et al. 1988), was experienced. This strongly influenced most of the fish stocks in the North Atlantic. This anomaly manifested itself by both reduced salinity and temperature in the north-east Atlantic, including the Norwegian Sea, the Barents Sea and the NS, and was partly a direct effect of changes in the transport and mixed composition of AW and Arctic Water. It was also coupled to a clear anomaly in the large scale atmospheric climate, causing locally anomalies (over e.g. the NS), of climate parameters such as air-sea heat exchange, wind speed and direction etc.

There is no doubt that correlations exist with such drastic climatic variations on a time scale of 5-10 years. However, drastic biological variabilities are often observed from one year to the next. To understand which (of several partly correlated) climatic factors are of vital importance for the biology, one has to be able to quantify the possible connections on a year to year time scale.

The Institute of Marine Research (IMR) in Bergen has yearly surveys around June/July in the northern and central NS. About 3-500 hydrographic (CTD) stations are taken in this period, giving in general a good areal coverage at least north of 57°N. These salinity and temperature data for the years 1968 to 1990 are the physical basis for this study, together with wind and cloud observations (obtained from the Norwegian Meteorological Institute, DNMI) at Utsira, an island outside western Norway. However, we do not believe that e.g. the actual salinity and

temperature necessarily are prime ecological steering factors. Therefore, these data have been combined to give integrated measures of the physical conditions, such as e.g. the areal coverage of AW in the NS, believed to represent an index of the year to year variability of the inflow of AW.

Also one of our parameters is associated with the heat exchange, which Colebrook and Taylor (1984) indicate as being related to a 3-4 year periodic fluctuation in the plankton abundance. Colebrook (1985) also indicates that the influence of wind and temperature on zooplankton abundance might primarily be through processes involved in vertical mixing and stability, both represented by our derived parameters. A more detailed description of the derived physical variables used in this work is given by Svendsen and Magnusson (1991).

PHYSICAL VARIABLES

Since no time series of the above mentioned physical processes are available, it has been a major task to derive parameters (from the data we have) which indirectly describe the physical variabilities believed to be of main importance causing biological variability. These are (Svendsen and Magnusson, 1991):

1. **Subsurface inflow of AW**, represented by the area covered by water with high salinity (averaged from 50-200m depth), greater than specified values (AW_{deep})
2. **Heat**, represented by the area covered by water with temperatures (averaged from 50-200m depth), greater than specified values (AW_{heat})
3. **Surface inflow of AW**, represented by the area covered by water with high salinity (averaged from 0-30m depth), greater than 35.0 (AW_{surf})
4. **Stable surface layer**, represented by the area covered by water with salinity (averaged from 0-30m depth), less than 34.0 (NCW_{34})

Examples of some relatively extreme years of these distributions are presented in Figs 1-4. Clearly the subsurface inflow of AW (Fig.1) was rather weak in 1978, being connected to the "late 1970's anomaly"

(Dickson et al. 1988). In 1990 the inflow was quite strong (although not extreme), covering major parts of the northern NS and parts of Skagerrak. Although the measurements are taken during a relatively short period each year, it is believed that the distribution represents the integrated effect of the inflow which took place up to half a year prior to the observations.

Fig.2 shows the drastic differences in the heat content, from being quite low (cold) in 1987, to the extreme warm situation in 1990, probably the warmest during the past 50 years. The subsurface heat content is mainly a combined effect of the inflow of AW and the surface cooling during the previous winter (Svendsen and Magnusson, 1991).

The spread of relatively low saline Norwegian Coastal Water (NCW) and /or continental water (Fig.3) was at its maximum in 1987, covering more than 50% of the area north of 57°N, coinciding with an extreme maximum in the abundance of the phytoplankton *Ceratium* (Dickson et al., 1991).

The surface inflow of AW east of Shetland might be of special interest in this context, since the nutrients in this water are directly available for primary production. Large differences from year to year were observed (Fig.4), however it is somewhat uncertain if this parameter describes the inflow representatively. In some years a relative thin layer of NCW might mask the AW signature, which was probably the case in 1987 (Fig.4).

The 22 year time series of the available ocean parameters are shown in Fig.5 (from Svendsen and Magnusson,1991). The curves denoted respectively with $S > 35.1$, $T > 6.5$, $S < 34$ and $S > 35.0$ are taken as the main hydrographic climate variables, and it is seen that none of these are highly correlated.

The meteorological variables assumed to influence biological parameters significantly are:

5. Wind stress, represented by the monthly/seasonal mean stress components (proportional to wind velocity squared) towards north (STRESSN) and towards east (STRESSE). (Dimension N/m^2)

6. Wind effect, (EFF) represented by the monthly/seasonal means of nondirectional wind (proportional to the cubed wind speed). (Dimension

Watt/m²)

7. Cloudiness, (CLM) represented by the monthly/seasonal means of low and medium clouds.

The windstress is chosen since this is the parameter driving major parts of the current system. The wind effect is more proportional to the turbulent energy input to the ocean, creating entrainment of nutrients into the euphotic zone etc. The turbulence is also shown to have a direct effect on the contact rates between prey and predators (Sundby and Fossum, 1990).

The cloudiness parameter is incorporated since it affects the light conditions being particularly important during the spring bloom (Sakshaug and Skjoldal, 1989), and also important for the prey/predator interactions depending on visibility (Aksnes and Giske, 1990). The light conditions are especially sensitive to the concentration of low and medium clouds, which also to a large extent regulates both cooling during winter and heating during summer.

BIOLOGICAL EFFECTS OF THE CLIMATE

The different ICES working groups for assessing fish stocks produce yearly updated timeseries of recruitment (for individual age groups) and spawning stock biomass/number for individual fish stocks. These data (and their quality) are essential for our task to resolve the effect climate has on the year to year variability.

The most critical phase for a fish is during the very early stages, which is the period within a few months after spawning. It seems that particularly the so-called match-mismatch theory is relevant. Here it is critical that high abundance of food (zooplankton) are available where and when the larvae finish its yolk sack stage (Hjort, 1914, Ellertsen et al., 1989). The recruitment success is probably also dependent on the predation pressure by other fish stocks or by its own relatives (cannibalism)(Øyestad, 1985). Clearly the climate affects processes that are relevant for both these theories. Later research comparing potential with actual fecundity of cod deprived for food prior to spawning, showed

that only 20 to 80 % of the potential fecundity was realised dependent on the nutritional status of the fish (Kjesbu et al., 1991). This indicates that also the climate prior to spawning might influence the recruitment through its impact on the feeding condition of the spawners.

In the following these aspects are not deeply considered, rather discussing what climatic parameters giving good or bad chances for survival based on statistics and general knowledge. Since the oceanic climatic parameters used in this study only have a time resolution of one year, it must be looked upon as being yearly measures of the environmental stage being potential good or bad for the total biological process leading to recruitment success or failure for each individual fish stock. The meteorological parameters having a monthly resolution, might pick up events during each year being critical for the survival of the individual larvae populations.

Model

It seems that several independent climatic variables might be important from a biological point of view. To find a combination of a few (from many) parameters which are of main importance, multiple linear regression analysis (Wilkinson, 1989) has been chosen. This gives the coefficients a,b,c..... based on the measured or estimated timeseries in the equation:

$$(1) \text{ Biol. Variable} = \text{Const.} + a(\text{AW})_{\text{deep}} + b(\text{AW})_{\text{heat}} + c(\text{NCW}) + d(\text{AW})_{\text{surf}} + e_1(\text{STRESSN}_1) + e_2(\text{STRESSN}_2) + \dots + f_1(\text{STRESSE}_1) + f_2(\text{TRESSE}_2) + \dots + g_1(\text{EFF}_1) + g_2(\text{EFF}_2) + \dots + h_1(\text{CLM}_1) + h_2(\text{CLM}_2) + \dots + k_1\text{BIO}_1 + k_2\text{BIO}_2 + \dots$$

where the indexes (1,2...) indicate specific months or "seasons". It must be mentioned that the statistics do not require that these variables are independent. The oceanic variables AW_{deep} , AW_{heat} , NCW_{34} , AW_{surf} , might be any of the curves in Fig. 5, and the BIO variables can e.g. be a function of the spawning stock biomass and the abundance of zooplankton.

The requirements set for selecting independent variables are that each selected coefficient has to be significantly different from zero, with a 95% confidence level (preferably better), and that the number of variables must be as few as possible (most of the coefficients equal to

zero) to reach a total squared multiple correlation coefficient preferably above 0.7. Another important requirement is that the results should be reasonably explained common oceanographical and biological knowledge. The use of this type of correlation analysis might be discussed. However, knowing that the variability of certain environmental parameters are in general a combined function of several variables, some kind of multi-variate analysis is required to estimate the significance of each variable. It is not claimed that the applied statistical method necessarily is the best for this purpose.

Results and discussion

Phytoplankton

Since it is assumed that climate has a large impact on primary and secondary production, some time series were obtained from the British Continuous Plankton Recorder (CPR) program (CPR Survey Team, 1991). The time series of the first principle component of the yearly mean abundance of phytoplankton is given as number of standard deviations from the 1958-1989 mean. Since the main focus is on spring spawning fish and autumn spawning herring, only meteorological data from October until June/July has been implemented. Therefore it was not expected to obtain good correlation with these data. Fig. 6 shows the comparison between the CPR measurements and the obtained empirical correlation model. The model equation is:

$$2) \quad \text{MODPHYTO} = -2.41 + 0.021(\text{AW}_{\text{deep}}) - 0.25(\text{CLM}_{\text{Mar}}) + 0.27(\text{CLM}_{\text{Feb}}) + 0.021(\text{NCW}_{34}) + 0.021(\text{STRESSE}_{\text{Mar}}) + 0.010(\text{STRESSN}_{\text{Mar}})$$

indicating that a good (versus bad) phytoplankton year is a function of:

- a) Strong inflow of AW bringing large amounts of nutrients.
- b) Reduced cloud cover in March giving light for a strong spring bloom.
- c) Cloudy weather in February hindering extreme cooling due to surface radiation.
- d) Large areas covered with a stable surface layer.
- e) Strong or persistent winds from west-south-west in March.

Although we cannot directly explain why these wind conditions are

important, it seems that the dependence of the other variables are within reason. However, even if the statistics show a very good fit as shown in the scatter plot, we are somewhat sceptic to the high number of explanatory variables. Anyhow, it will be very interesting to compare the high phytoplankton abundance from the model for 1990 (Fig. 6) with the actual measurements when they become available. Such high values were previously recorded for the whole period 1958-1965 (CPR Survey Team, 1991).

Zooplankton

As for the same reason as mentioned for phytoplankton, it was not expected to obtain good results against the first principle component of the variability of the CPR measured zooplankton. This was also the case until the phytoplankton time serie was introduced as an independent variable. The results are shown in Fig.7, and the simple model equation is:

$$3) \quad \text{MODZOOPL} = -2.240 + 1.168(\text{PHYTO}) + 0.534(\text{CLM}_{1,\text{QU}})$$

This shows that apart from the phytoplankton abundance (which explains about 60% of the zooplankton variability), cloudy weather during the first quarter of the year also contributes to a good zooplankton year. One explanation for this might be that cloudy weather extends the spring bloom, giving a prolonged time for the zooplankton to graze before the "grass" dies, or in general there might be a better match if the spring bloom is delayed somewhat due to heavy clouds during the first months of the year.

Mackerel

During the initial phase of this work, the question was raised wether the climate had any influence on why variable fractions of the western mackerel stock (WMACK), spawning west and southwest of Ireland, migrates into the NS to feed during summer and fall (Iversen and Skagen, 1989). The spawning stock size of WMACK is in the order of 2 million tons (Anon, 1990a). For the time period considered, the main biomass of mackerel in the NS consists of WMACK. The local NS mackerel stock dissappeared to a large extent during the 1970's, and is still on a level below 100 000 tons (Iversen et al., 1991).

WMACK enters probably the NS mainly along the western slope of the

Norwegian Trench, associated with the area of the main influx of AW. Walsh and Martin (1986) found that the main transport of AW (into Norwegian waters) is important for the migration of WMACK. They suggest that in periods of weak flow most of the AW and the mackerel population associated with it, find its way into the NS, while in periods of strong flow more water and mackerel is likely to find its way into the Norwegian Sea. Although it is quite unlikely that most of the AW transport under any circumstances enters the NS, they might be correct in the way that a larger fraction of the AW enters the NS during periods of weak flow.

Our hypothesis is that the main mechanism for the WMACK to "choose" to enter the NS must be the food availability (zooplankton), and probably also the temperature since the mackerel prefers warm water. This hypothesis therefore also depends on good food production, which is assumed to be determined by: previous large influx (spread) of AW carrying nutrients, zooplankton and heat into the NS, large spread of a stable surface layer giving large areas for possible good primary production, and relative strong winds (wind effect) for vertical entrainment of nutrients and therefore continuation of good primary production necessary for good growth of the zooplankton. The experience is that the mackerel prefers water warmer than 9-10 °C in the NS. In general the subsurface core of the AW is colder than this, so probably the migration into the NS mainly takes place in or above the pycnocline after the temperature in the surface layer reaching this temperature limit. A representative measure of the surface temperature is lacking since this increases very fast at this time of the year. However, still the spread of heat in the lower layer might be an important preconditioning factor for the heating of the surface layer.

Fig.8 shows yearly measurements/estimates of WMACK compared with our empirical regression model. The model equation is:

$$6) \quad \text{MODWMACK} = -31.27 + 0.44x(\text{AW}_{\text{heat}}) + 37.26x(\text{EFF}_{2,\text{QU}})$$

showing that large fractions occur in years with large areal coverage of "deep" water warmer than 6.5 °C and high mean wind effect during second quarter (April-June), and vice versa. This means that the mackerell prefers entering the NS after a mild winter (probably connected to a relatively strong inflow of AW), and relatively strong turbulent mixing during spring, assumed being in favour of production of phytoplankton and

thereby zooplankton being the main food for mackerel. Unfortunately only 9 years (1973-1981) of reasonable migration estimates are available, but it seems that the "guestimated" values for 1982-1988 (Iversen and Skagen, 1989) are not too far off if we the model is trusted (Fig.8). The reason why the abundance of zooplankton from the CPR measurements does not come out as an explanatory variable, might be that the yearly average is not representative for the situation around June/July when the WMACK enters the NS.

The following fish stocks studied by this method are all assumed to be "pure" NS stocks. As mentioned earlier, the only hypothesis being used is the assumption that it is the climate prior to and during the first months after spawning which are most critical for the success of survival.

Whiting

The causes for good versus bad recruitment of 0-group whiting (Anon, 1991a) were obtained with the same two parameters as for mackerel migration. However, the whiting prefers a weak mean wind effect during 2. quarter, as seen from the model equation:

$$7) \quad \text{MODWHIT}(0) = 57.72 + 0.52(AW_{\text{heat}}) - 36.69(\text{EFF}_{2.QU})$$

At present we cannot explain why general weak winds during the egg and larvae stages of whiting is positive for producing a good year class. It seems that with just these two variables we are able to explain more than 70% of the variability which has occurred during the years 1970-1988 (Fig.9).

Herring

During the second half of the 1970's the NS herring stock (Anon, 1991b) was drastically low, and under this situation one should expect to find the recruitment (Anon, 1991b) being dependent also on the spawning stock size (SSB). So was also the case as seen from the obtained model equation:

$$8) \quad \text{MODHERR}(0) = -57.76 + 13.34(\text{EFF}_{4.QU}) + 0.58(\text{STRESSN}_{\text{Mar}}) + 78.69(1 - e^{-0.25(\text{SSB})})$$

As seen in Fig.10 this model picks up most of the variability in VPA estimates of the recruitment for the period 1968-1988. Since the NS herring larvae are hatched in late autumn - early winter and stay as larvae through the winter and spring, we have chosen to relate the recruitment to the hydrographic conditions during the first half of the following year and to wind data for the 4. quarter of the present year and first half of the following year. It is interesting to note once more that the mean wind effect just after hatching (4. quarter=Oct.-Dec.) seems to be important for the recruitment. In addition to strong winds in this period, a good recruitment also seems to depend on some strong/persistent southerly winds around March. This may imply that at the end of its larvae stage it needs a final wind "push" to be transported to and/or kept at favourable feeding areas such as Skagerrak-Kattegatt.

The stock-recruitment scatter plot (Fig.11 top) shows a clear different relationship for the yearclasses 1967 to 1976, compared to the yearclasses 1978 to 1986. When adjusting the VPA recruitment estimates by the climatic terms in equation (8), the difference between these periods disappears, and a fairly good stock-recruitment relationship is obtained (Fig.11 bottom). These findings support the hypothesis raised by Corten (1986 and 1990) that the recruitment failure of the NS herring in the 1970's was not only caused by a low spawning stock, but also to a large extent by climatic conditions.

Haddock

The next fish stock considered was the haddock (0-group, Anon, 1990a). However, with the quality requirements initially set, it was impossible to explain the recruitment variabilities with the present climatic variables. Therefore it seems that the haddock behaves quite differently than the whiting.

Cod

In the ICES roundfish assessment working group report (Anon, 1991a), the recruitment numbers for cod and saithe is given for the first time at the 1-group stage, so these numbers are used in the regression analysis with the climatic variables one year earlier (during their larval stages). The results for cod are shown in Fig. 12, and the model equation is:

$$9) \quad \text{MODCOD}(1) = 901.05 - 17.78(AW_{\text{heat}})^{>7.5} - 15.59(\text{NCW}_{34}) + 169.70(\text{EFF})_{1.QU}$$

In this case the best fit was obtained with AW_{heat} represented by the $T > 7.5$ curve in Fig.5. This indicates that the cod prefers situations with large areas of cold (at least colder than 7.5 °C) subsurface water (and possibly reduced inflow of AW), reduced spread of NCW and strong winds during the 1. quarter of the year. This means that the NS cod stock may be severely reduced if the "predictions" of the greenhouse effect are correct. As seen in the figure unrealistically low estimates for the 1990 year class (or actually the 1-group in 1991) is modelled. This is caused by the heat content in 1990 probably was the highest (warmest) of the past 50 years. The low estimate indicates that under such extreme conditions the recruitment does probably not respond linearly to the AW_{heat} . Again it is seen that the turbulent wind energy during the early stages are important for the recruitment success.

Saithe

For the saithe, the response to heat is opposite the cod. The model equation is:

$$10) \quad \text{MODSAITHE}(1) = -125.09 + 4.95(AW_{\text{heat}})^{>7.0} + 61.10(\text{EFF}_{\text{Mar}}) + 67.23(\text{EFF}_{\text{Apr}})$$

giving good recruitment with large areas of subsurface water warmer than 7 °C, and strong wind mixing in March and April. This response to heat shows that the 1990 year class (or actually the abundance of 1-group in 1991) of saithe is probably the best of all these 20 years (Fig.13), but the future will show. In relation to cod and whiting, it seems that the wind effect on the critical stages of saithe comes somewhat later than for cod and somewhat earlier than for whiting. This might reflect typical differences in the peak spawning time between these fish stocks.

Sandeel

The last stock considered is the NS sandeel (0-group, Anon, 1990). Although smaller parts of the time series indicate correlation between SSB and recruitment, such a relation seems not to be general. The model

equation:

$$11) \text{ MODSANDEEL}(0) = 2.36 - 4.89(\text{STRESSE}_{\text{May}}) + 1.21(\text{AW}_{\text{heat}})$$

indicates that reduced westerly (or increased easterly) wind stress in May and a large spread of heat (and possibly increased inflow of AW) are positive for good recruitment (and vice versa). About 80% of the variability is explained with these two parameters. As seen in Fig.14 only VPA estimates from 1976-1989 has been available. Very large year to year fluctuations have taken place. The sandeel larvae are known to drift for only a few months after spawning and then settle at the bottom in July-August in rather specific areas. Based on the results from the model it is assumed that the wind stress about May are critical with respect to this larvae drift. This might be coupled to the wind driven coastal/continental water sometimes flushing the larvae away from their preferred settling areas.

Evaluation of the models' predictive ability

The empirical model results shown so far looks promising with respect to estimate the recruitment success of 0-group whiting and herring already within the same summer of the spawning year, and predicting the recruitment of 1-group cod and saithe for the following year. However, the actual forecasting/nowcasting capability is not shown. To do so, the last three years (near 20%) of the VPA data assumed to be good (1986-1988) were hidden and the regression analysis run again with the already selected parameters. Comparing these results with the actual data, now not used in the empirical models, would be similar to go back to 1985, having the knowledge about which climatic factors being important, and forecast the recruitment for 1986, 87 and 88 as soon as the climatic data became available, and with no extra information on the size of the fish stocks except for the herring SSB. This should indicate the forecasting capability of the models for the years to come, although such empirical models in principle are improving as more data become available.

The results are shown in Table 1, where we also have included the phytoplankton and the zooplankton. (The mackerel and sandeel stocks are

not included here since the available time series are so short).

	1986			1987			1988			St.Err
	PRED	MEAS	DIFF	PRED	MEAS	DIFF	PRED	MEAS	DIFF	
PHYTOPL	-.47	-.23	-.24	-.51	-.61	.10	-.67	-.23	-.44	0.20
ZOOPL	-.36	-.40	.04	-.58	-.40	-.18	-.03	.47	-.50	0.50
WHIT(0)	23	39	-16	36	24	12	49	72	23	12
HERR(0)	130	103	27	107	89	18	70	40	30	11
COD(1)	456	257	199	108	142	-34	459	360	99	73
SAITHE(1)	372	245	127	283	255	28	333	??	??	133

Table 1 Comparison of prediction/nowcasting capability for the years 1986, 87 and 88 based on biological data up to 1985. Bold values show those years where the prediction lies within one Standard Error of Estimate obtained from the initial regression analysis.

This demonstrates that the results are not so promising as were indicated by the comparisons between the empirical models based on all data and the data themselves. This means that new information lies in these 3 years being tested which have combinations related to climate which are not experienced earlier in the time period considered. While running this predictability test we observed that some of the initially selected variables did not come out with a statistically significant weight. This means that further work has to be done to combine these methods to select the best combination of climate variables for each biological variable. However, most of the predictions are within two Standard Error of Estimate (obtained from the initial regression analysis), and we believe that at least for some of the species, we are on the right track. In this test clearly the herring came out as the worst case.

CONCLUSIONS

From routine hydrographic surveys in the NS during the last 22 years, integrated parameters are derived which we believe represent major features of the year to year climatic variability in the North Sea. The time series of these physical oceanic parameters combined with some derived atmospheric variables, are used to explain significant parts of the variability of phytoplankton and zooplankton abundance, the fraction of western mackerel entering the North Sea and the recruitment of whiting, cod, saithe, sandeel and herring. Some of these parameters seem

to be of prime importance for directly or indirectly regulating the year to year biological variability. The climate parameters is assumed to describe the variability of: the subsurface and near surface inflow of Atlantic Water, the combined effect of this inflow and winter cooling on the subsurface heat distribution, the areal coverage of a stable surface layer, directional wind stress, nondirectional wind input of turbulent energy and the atmospheric light conditions.

It can of course be discussed if these extracted parameters (of which the heat and turbulence parameters seems most important) are the best choice. However, this is a first try (in cooperation with Svendsen and Magnusson, 1991) on using an extensive amount of collected data to quantify the integrated effect of several (hopefully the most) important climatic factors affecting marine life.

Even if we cannot explain the total connection between the physics, through chemistry, primary and secondary production, fish spawning, areal distribution and predation, to e.g. the recruitment success, the results indicate that the climate has an effect on most (maybe all) stages. It also indicates that just using one single climatic parameter to explain biological variability will in general be misleading.

Today, realistic recruitment numbers are estimated (by back-calculation, VPA) several years after the year of spawning. From these results it seems that the climate during the early stages of some of the fish stocks is so important that the recruitment numbers can be estimated already within the summer of the spawning year. This gives interesting outlooks for better management of the fishery resources.

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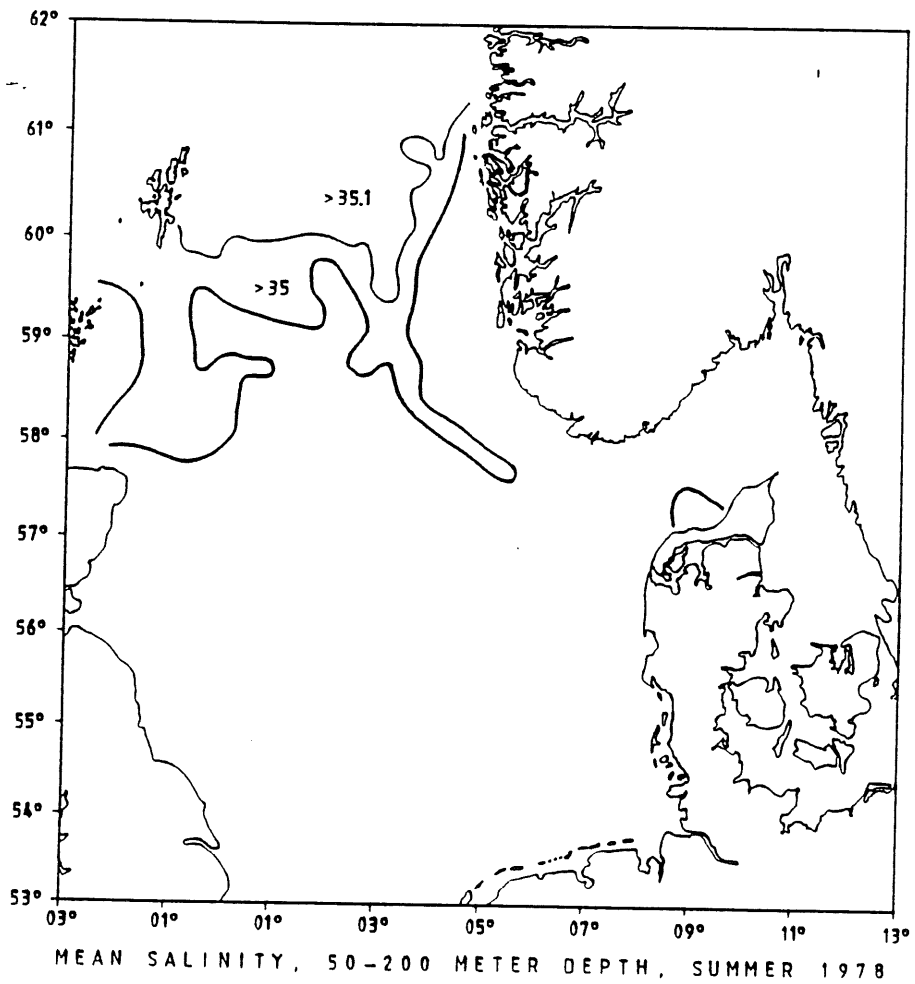
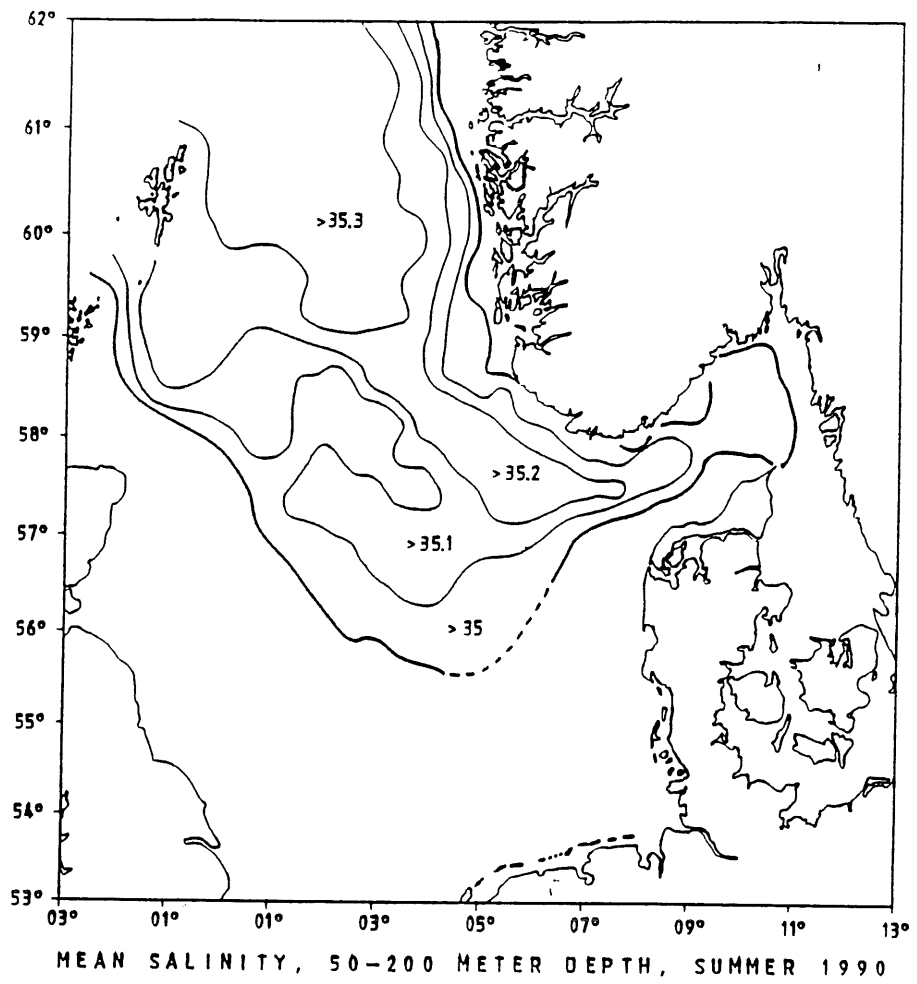


Fig. 1 Depth mean (50-200m or bottom) salinity distribution, for the summers of 1990 (top) and 1978.

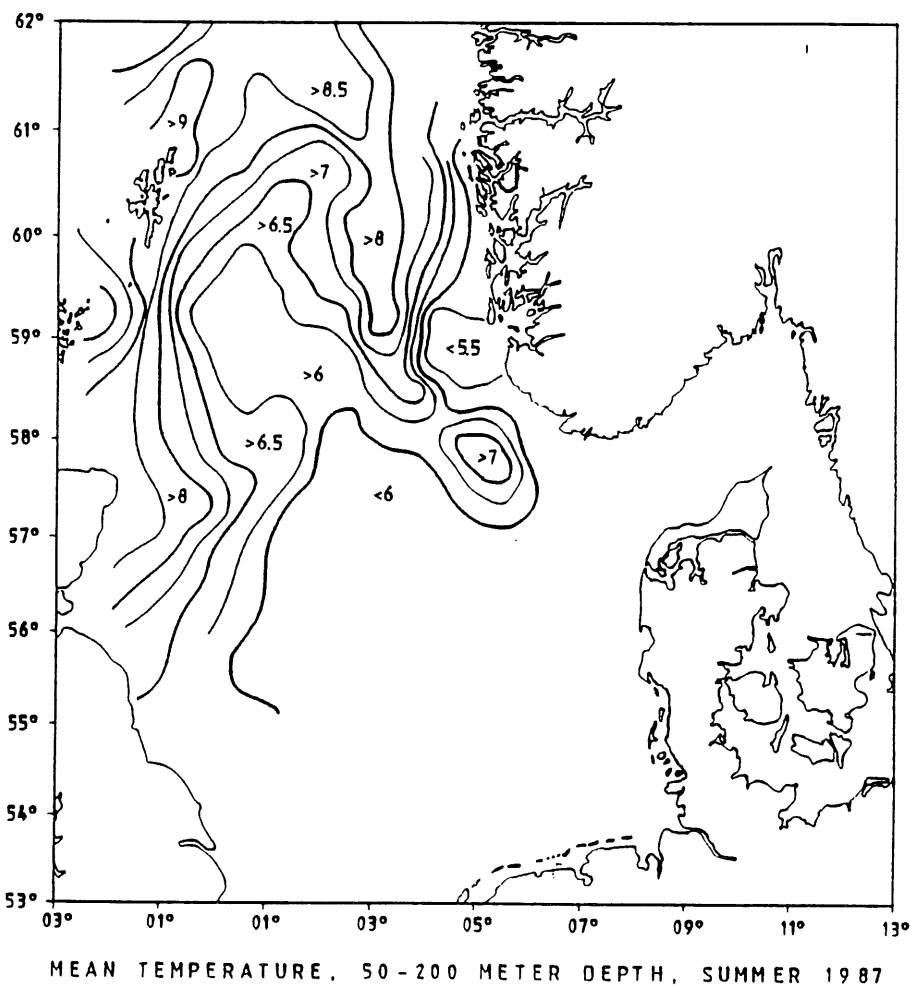
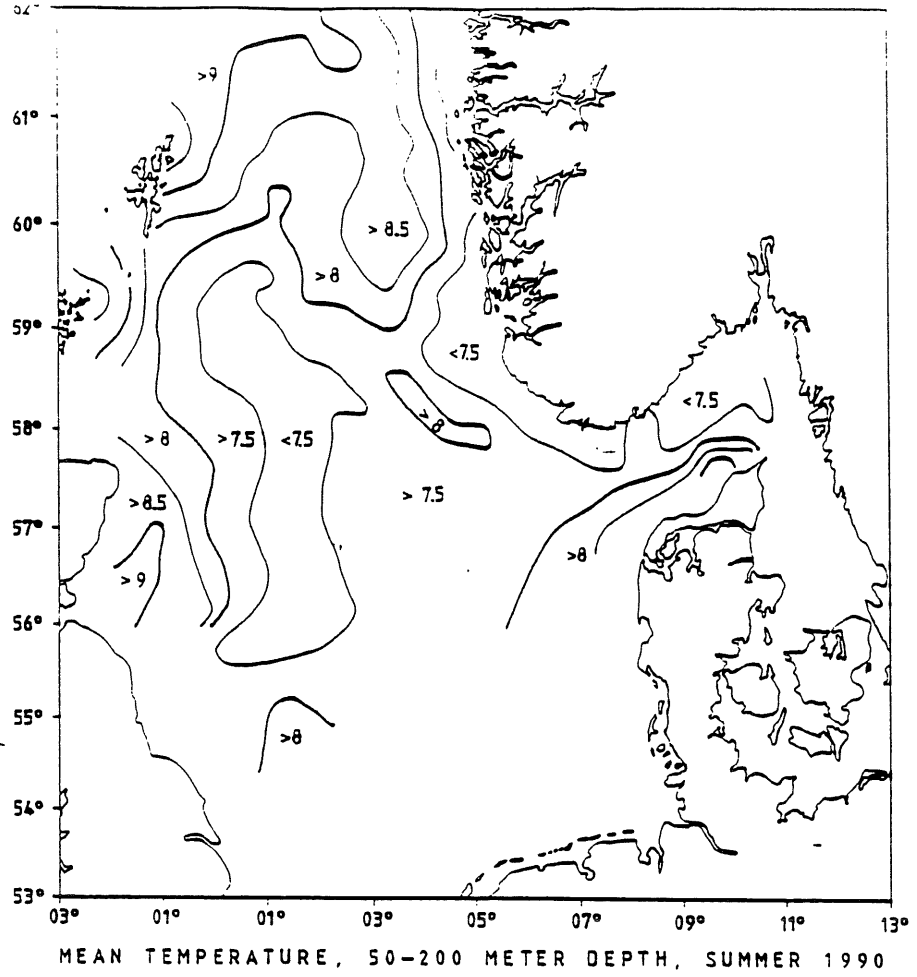


Fig. 2. Depth mean (50-200m or bottom) temperature distribution, for the summers of 1990 (top) and 1978.

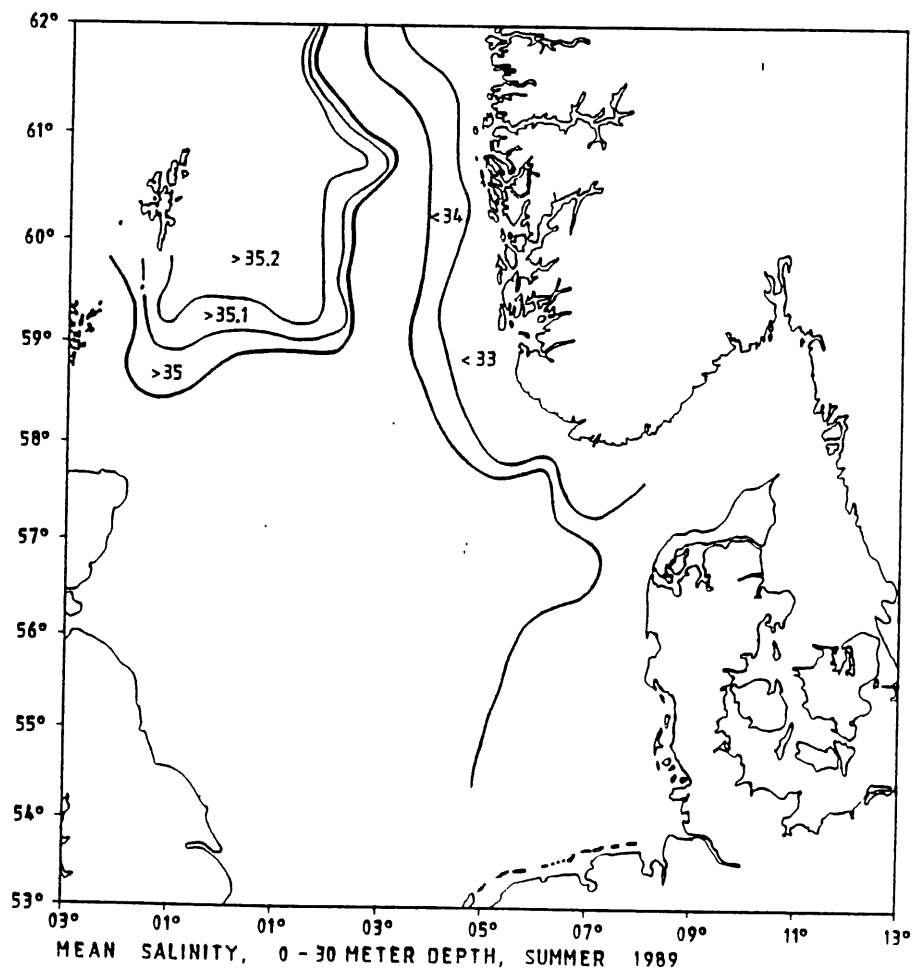
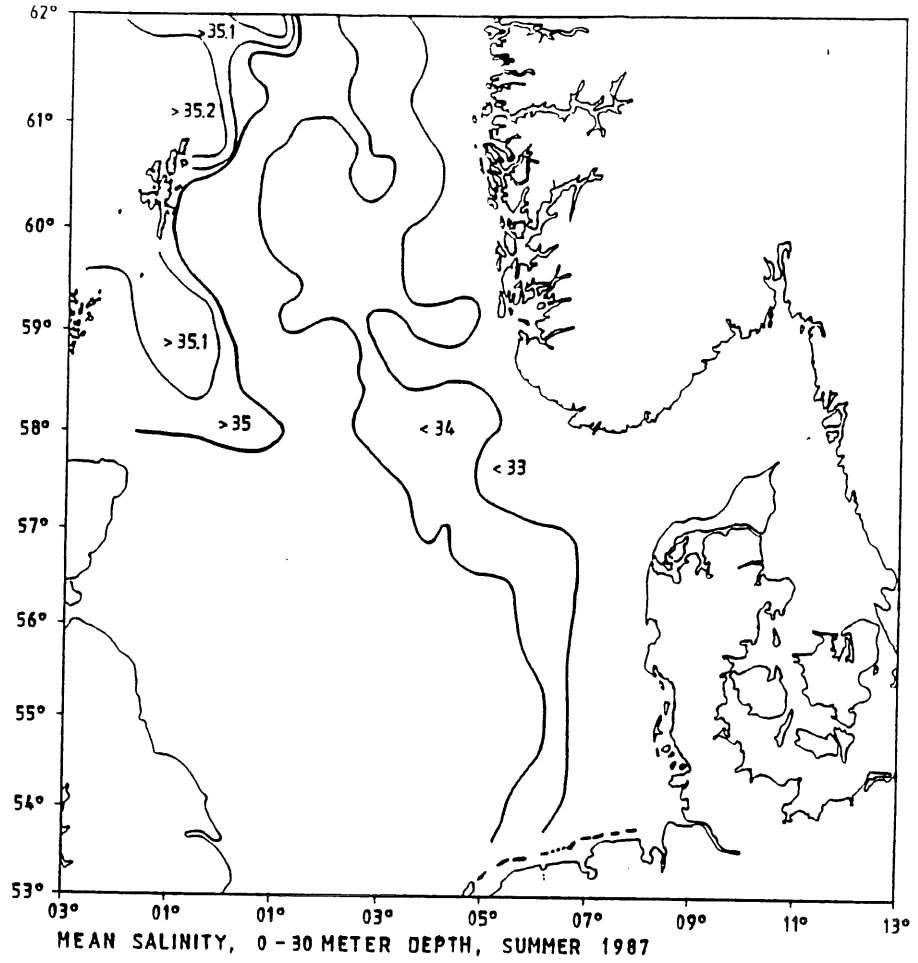


Fig. 3. Depth mean surface (0-30m) salinity distribution, for the summers of 1987 (top) and 1989.

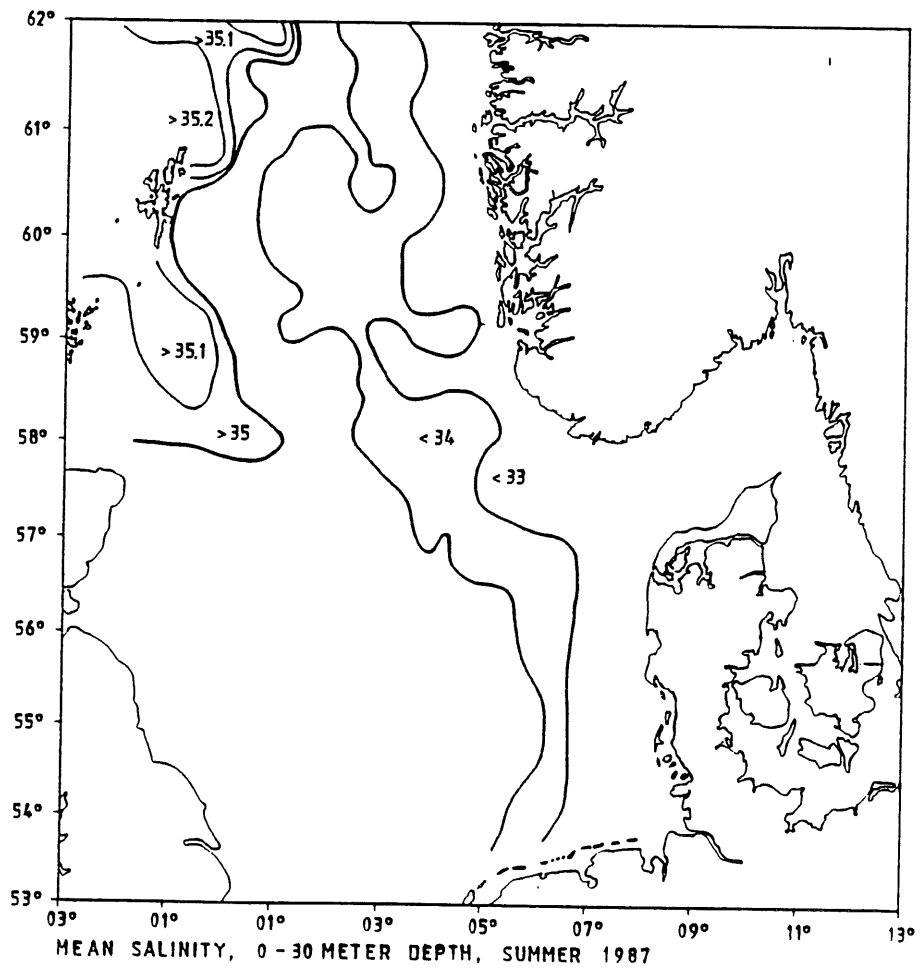
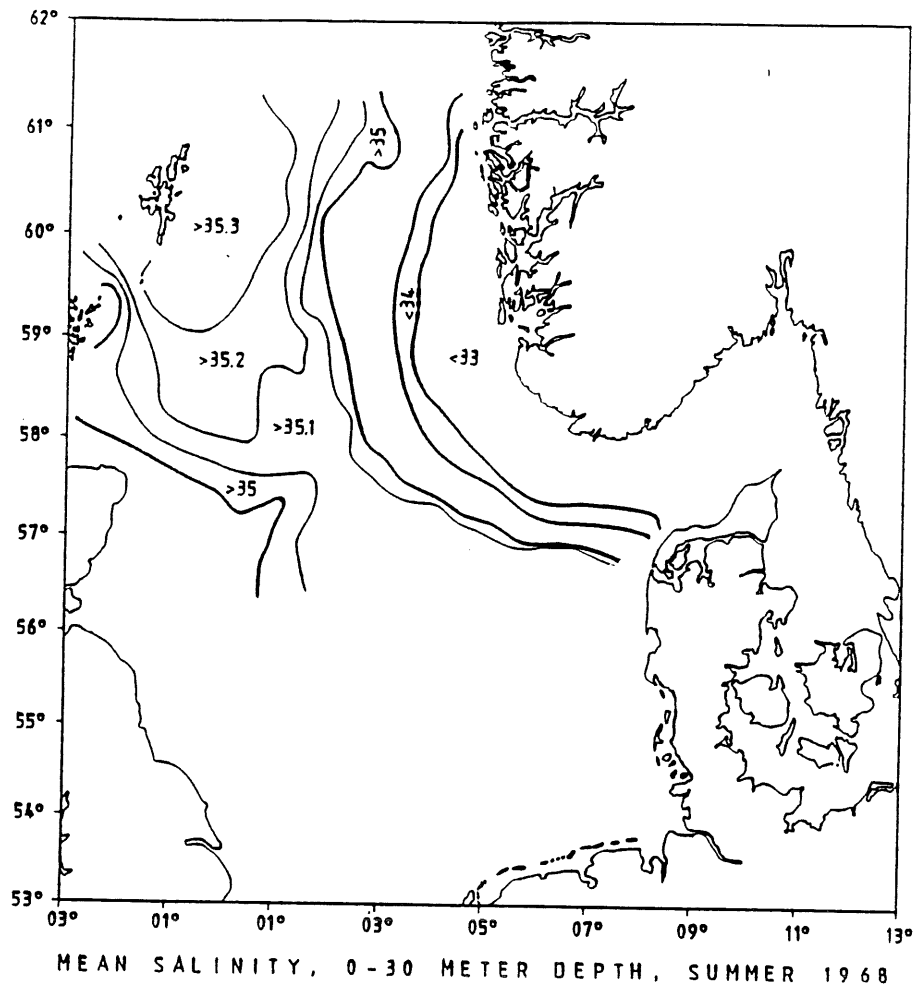


Fig. 4. Depth mean surface (0-30m) salinity distribution, for the summers of 1968 (top) and 1987.

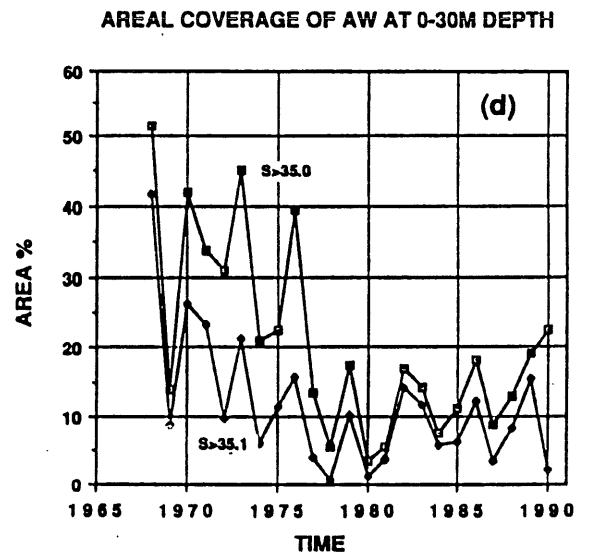
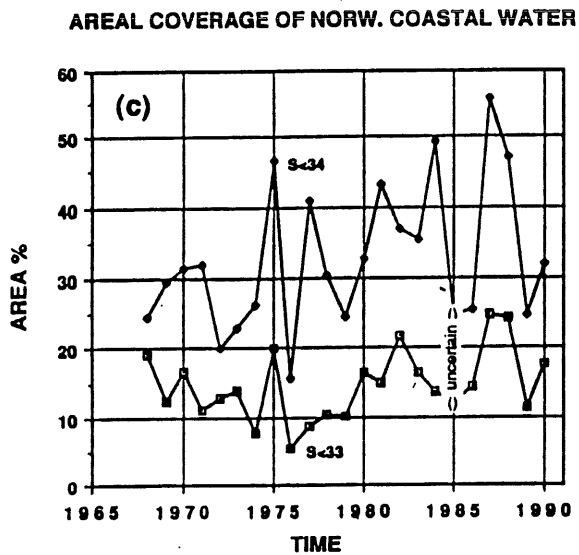
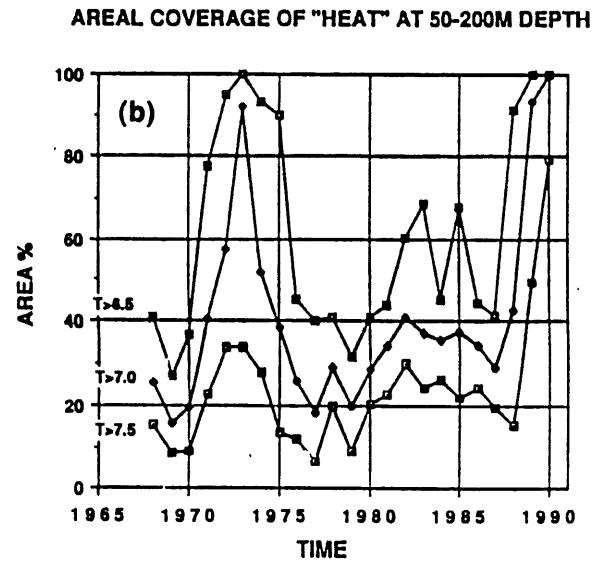
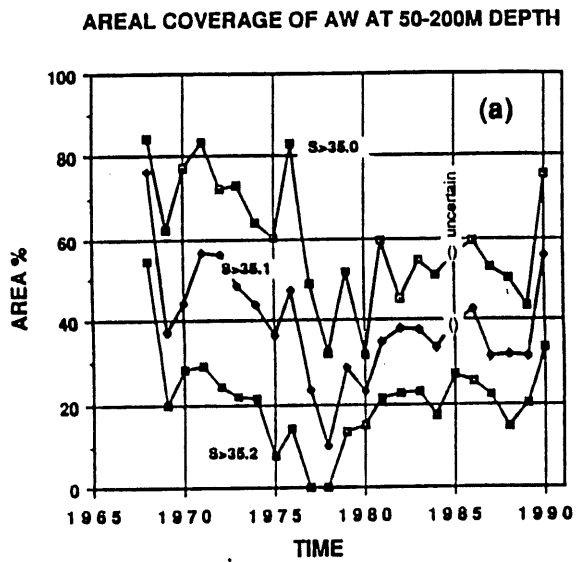
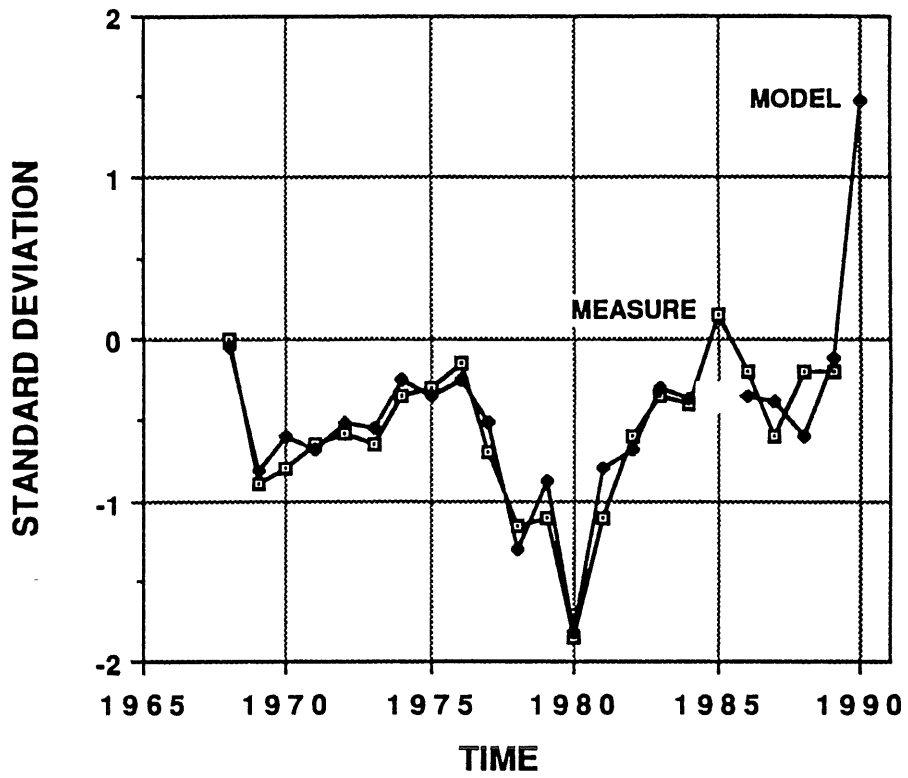


Fig. 5. Time series of the fraction of the area north of 57°N covered with a) mean salinity >35.0 , 35.1 and 35.2 (AW_{deep} , ref. Fig.1), b) mean temperature >6.5 , 7.0 and 7.5°C (AW_{heat} , ref. Fig.2), c) mean salinity <34.0 and 33.0 ($\text{NCW}_{34,33}$, ref. Fig.3) and d) mean salinity >35.1 and 35.0 (AW_{surf} , ref. Fig.4).

PHYTOPLANKTON ABUNDANCE



PHYTOPLANKTON ABUNDANCE

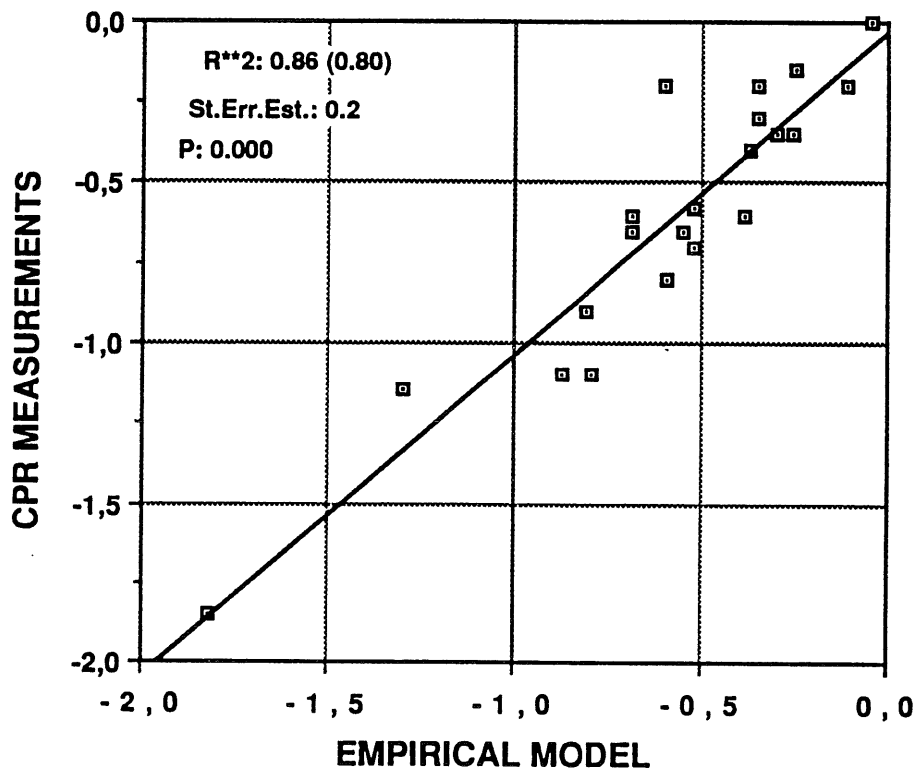
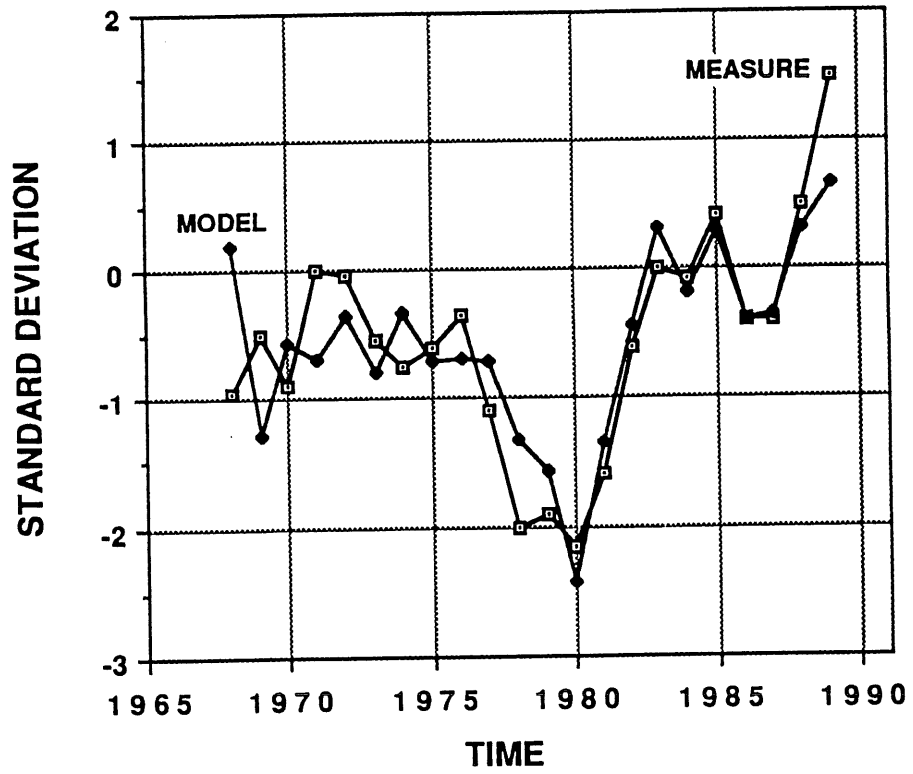


Fig. 6. Comparisons (annual time-series and scatter plot) between measurements (CPR) and empirical model for the abundance of phytoplankton (given in units of standard deviations from the measured time series 1958-1989).

ZOOPLANKTON ABUNDANCE



ZOOPLANKTON ABUNDANCE

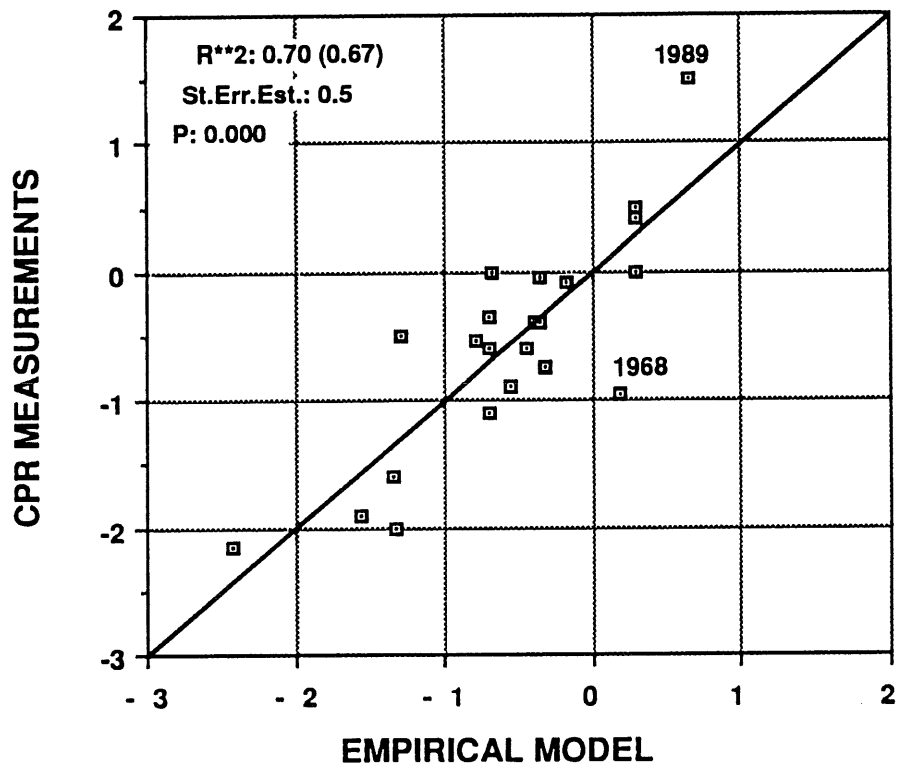
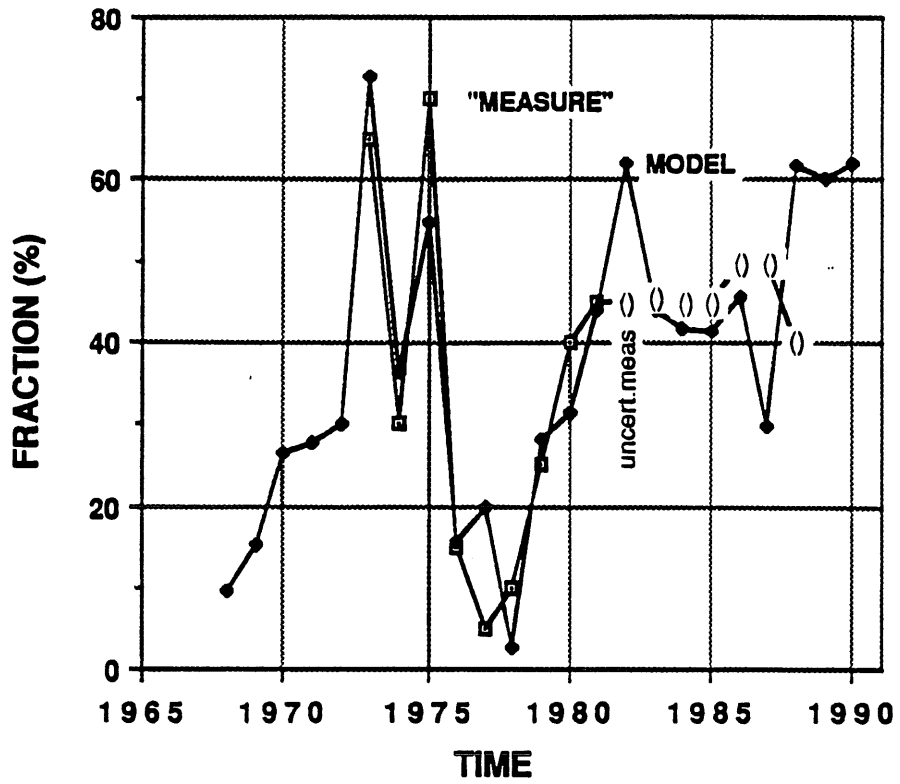


Fig. 7. Comparisons (annual time-series and scatter plot) between measurements (CPR) and empirical model for the abundance of zooplankton (given in units of standard deviations from the measured time series 1948-1989).

WESTERN MACKEREL in the NORTH SEA



WESTERN MACKEREL in the NORTH SEA

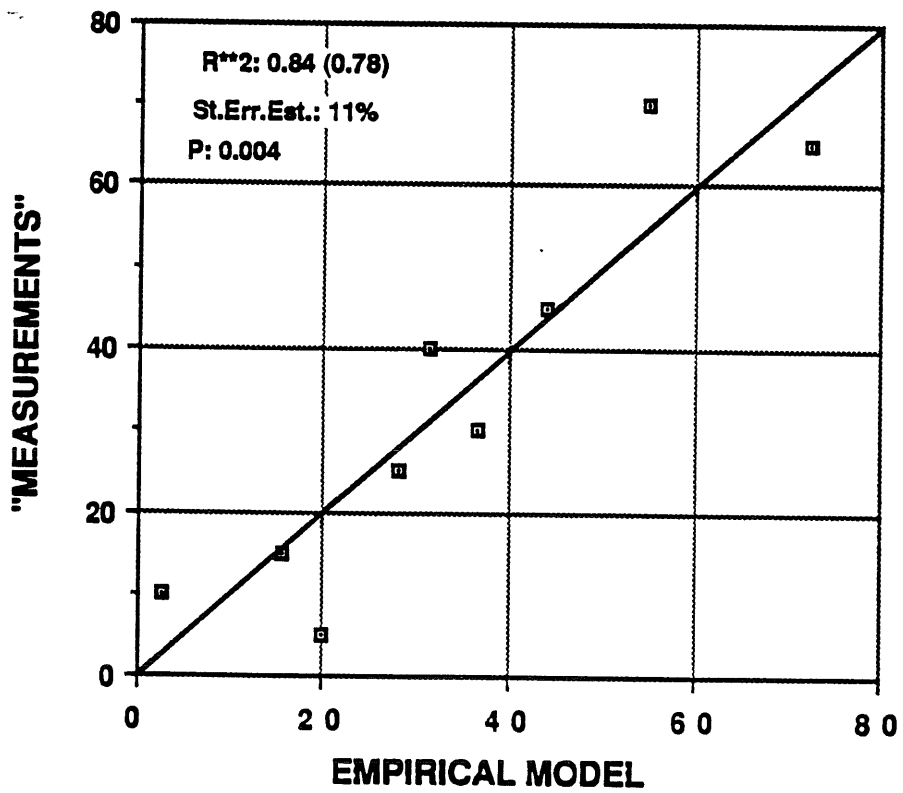
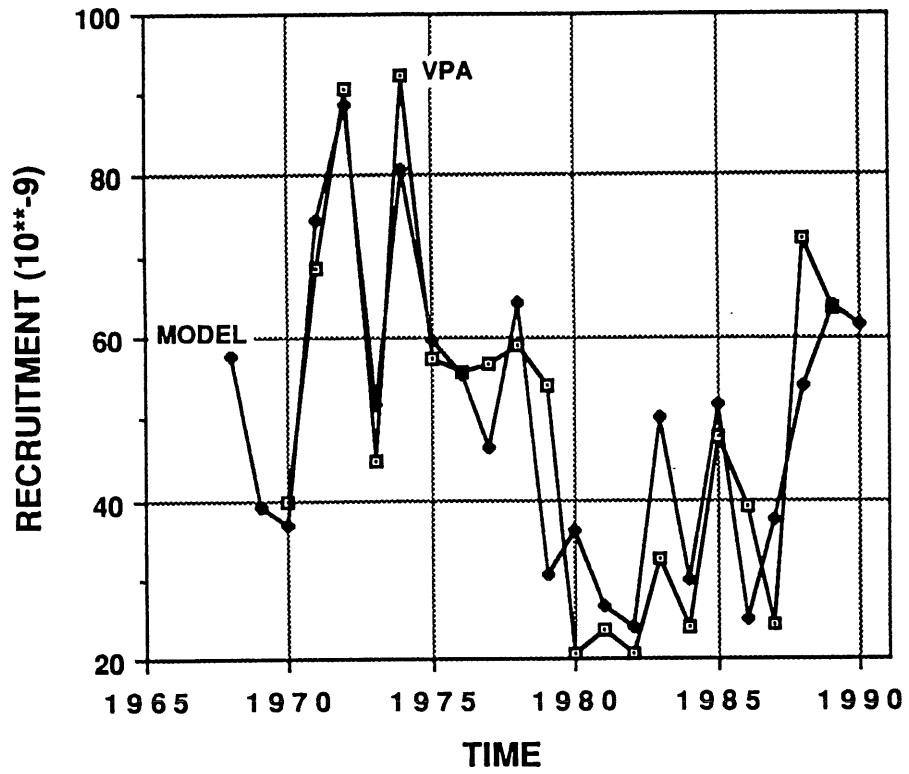


Fig. 8. Comparisons (annual time-series and scatter plot) between measurements and empirical model for the fraction of the western mackerel stock migrating into the North Sea.

0-GROUP WHITING



0-GROUP WHITING

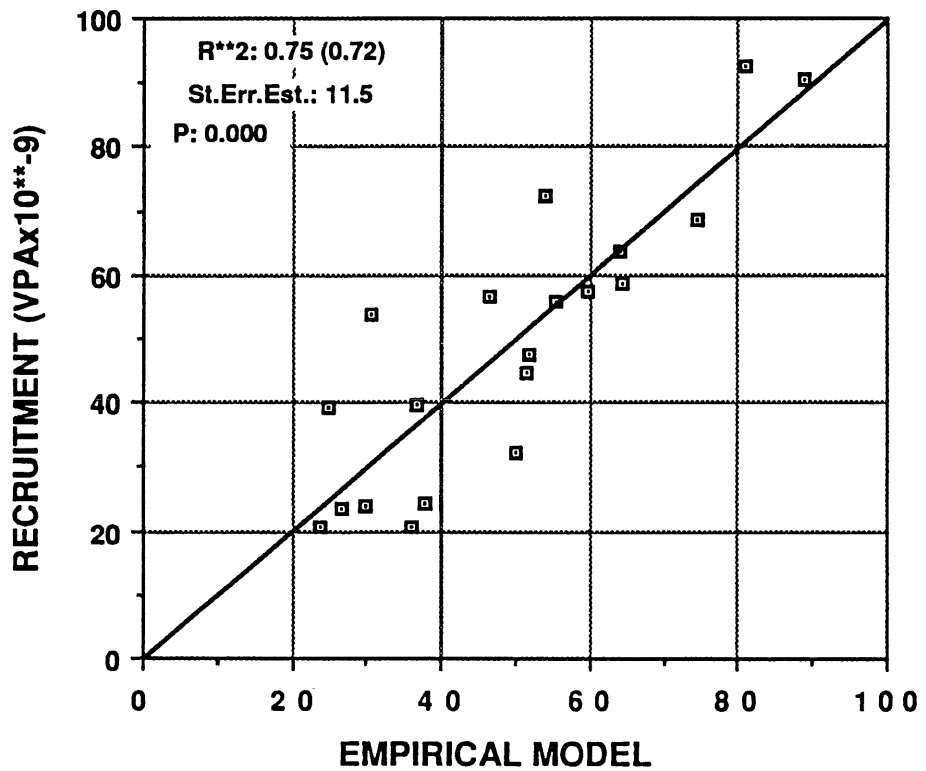
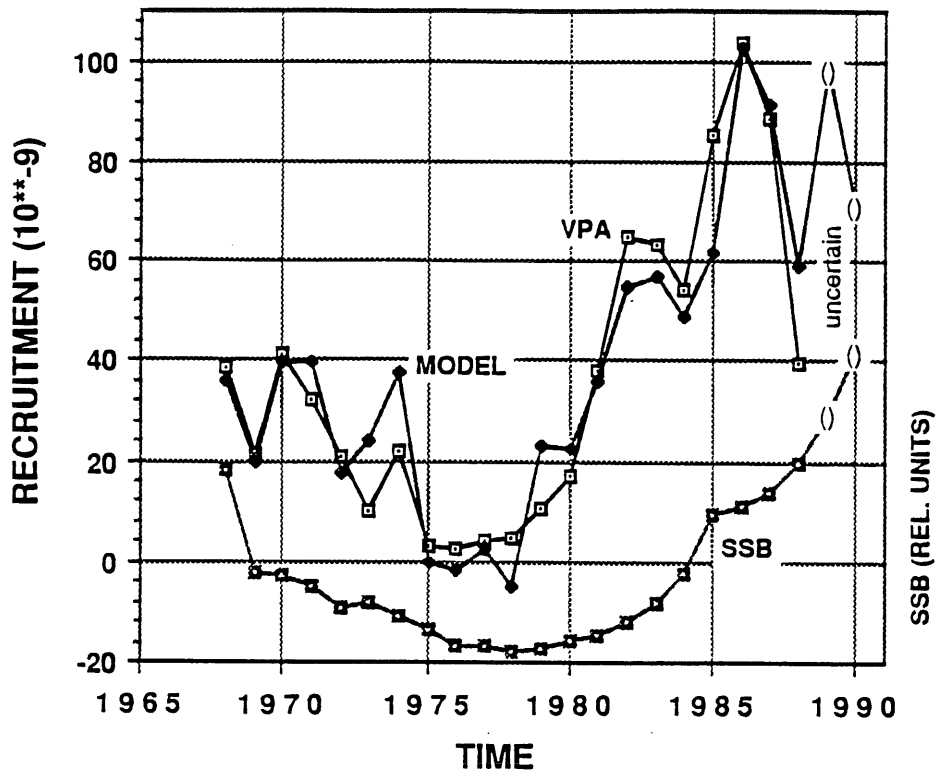


Fig. 9. Comparisons (annual time-series and scatter plot) between measurements (VPA) and empirical model for the recruitment of 0-group whiting.

NORTH SEA HERRING



NORTH SEA HERRING

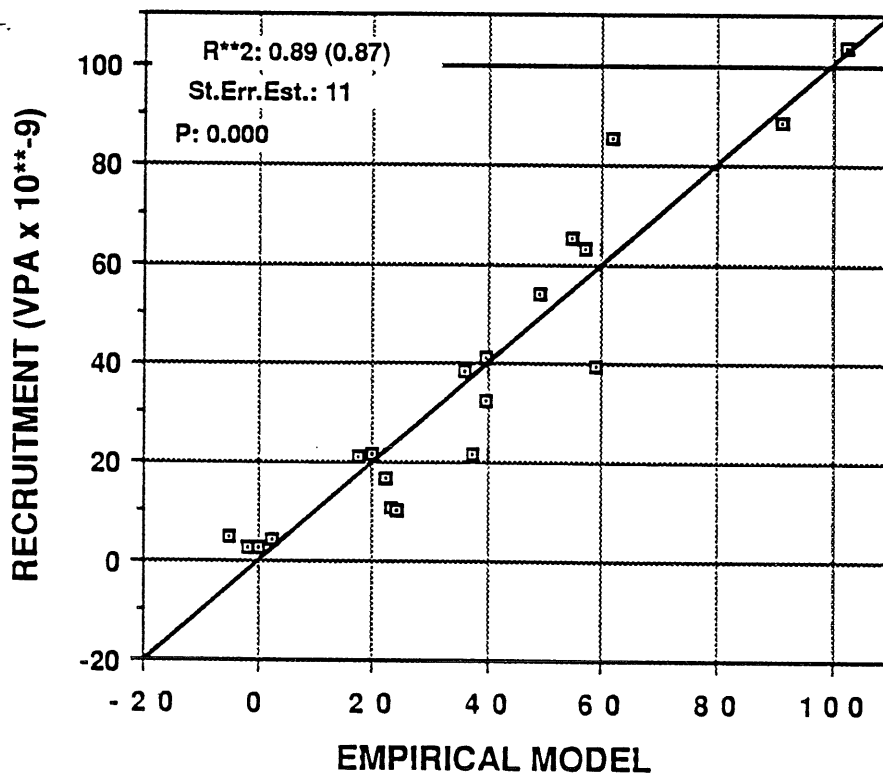
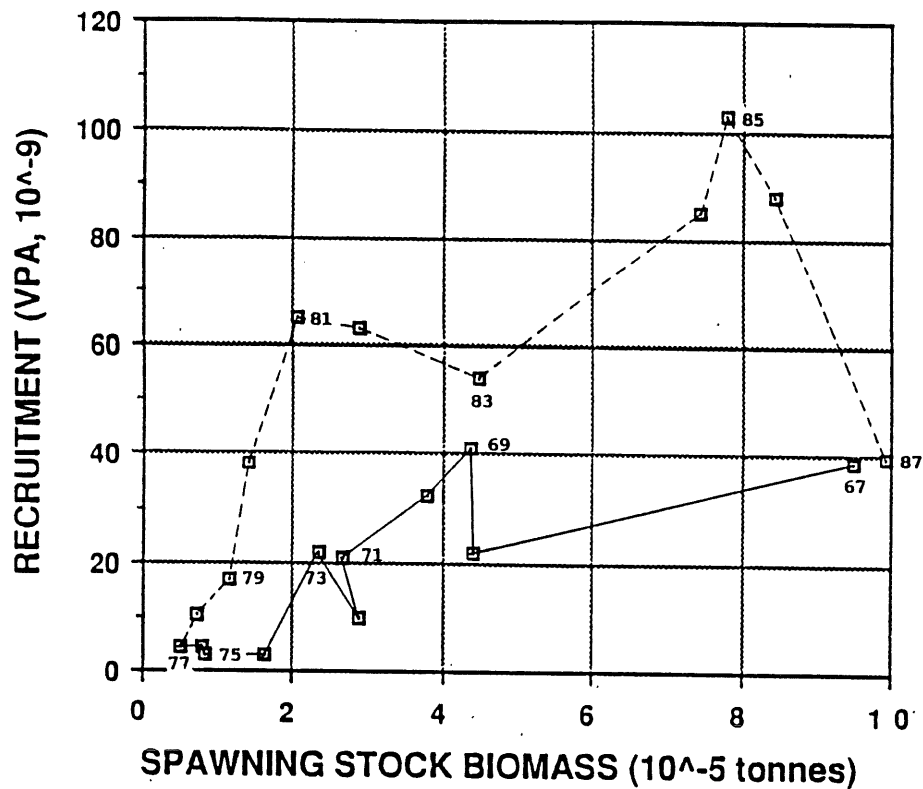


Fig. 10. Comparisons (annual time-series and scatter plot) between measurements (VPA) and empirical model for the recruitment of 0-ringer North Sea herring. Also shown are the parent stock size (SSB). Note that the time axis refers to the recruiting year (n), which means that the year-class and SSB refers to year n-1.

NORTH SEA HERRING



NORTH SEA HERRING

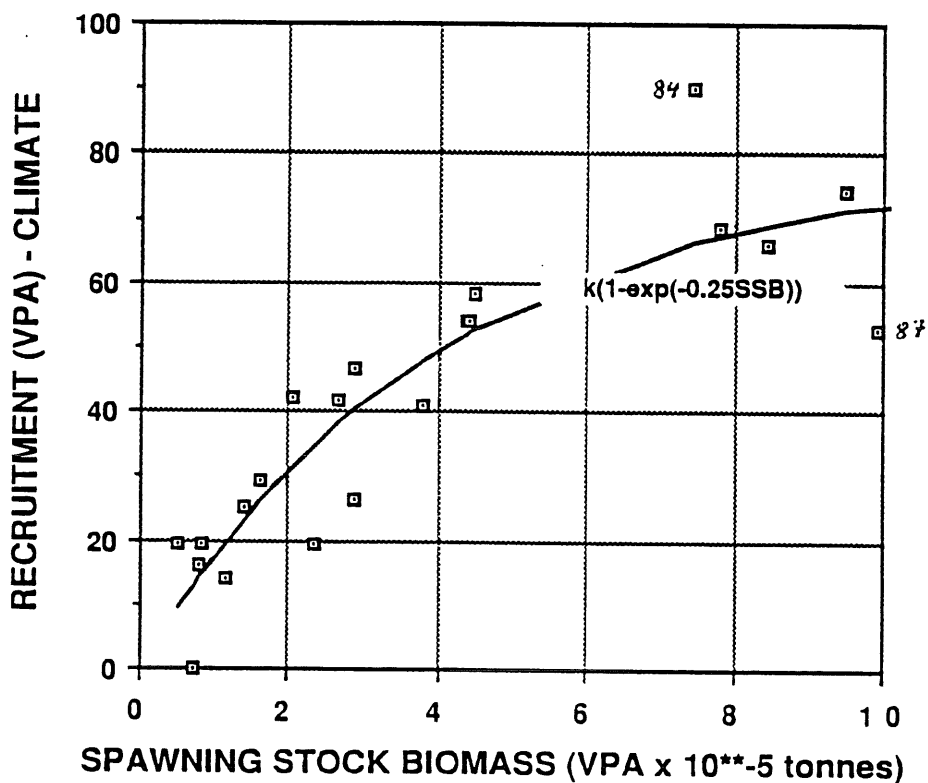
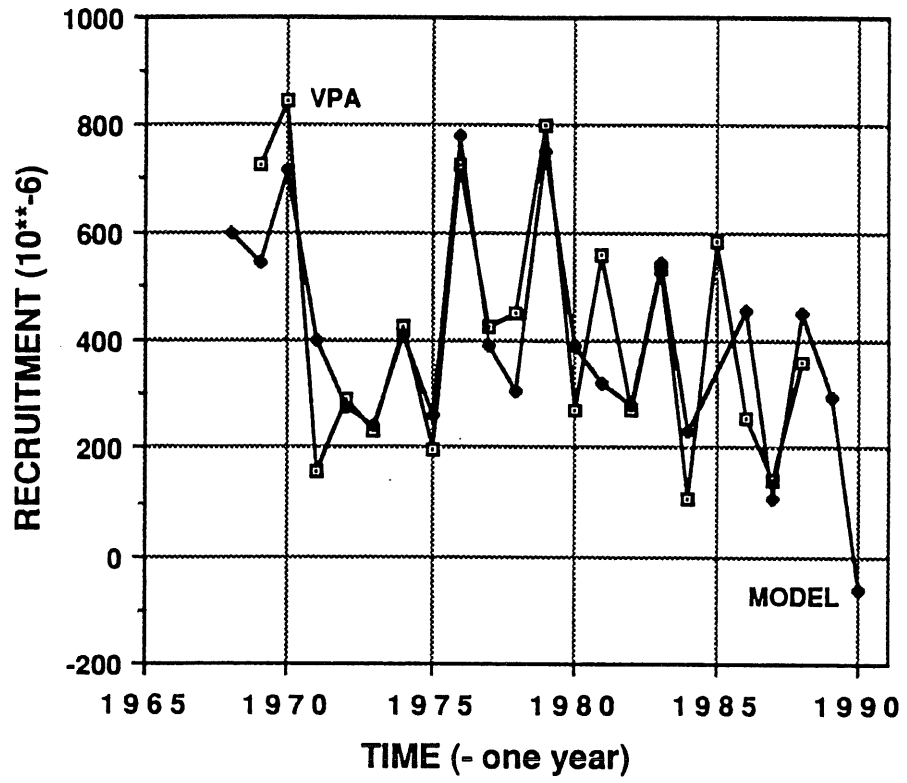


Fig. 11. Scatter plots of VPA estimates of parent stock versus recruitment (0-ringers) of North Sea herring (labels refer to year-class). In the lower plot the recruitment is adjusted for the climatic (wind) terms in equation (8). The exponential curve relating to the SSB is shown for comparison.

1-GROUP COD



1-GROUP COD

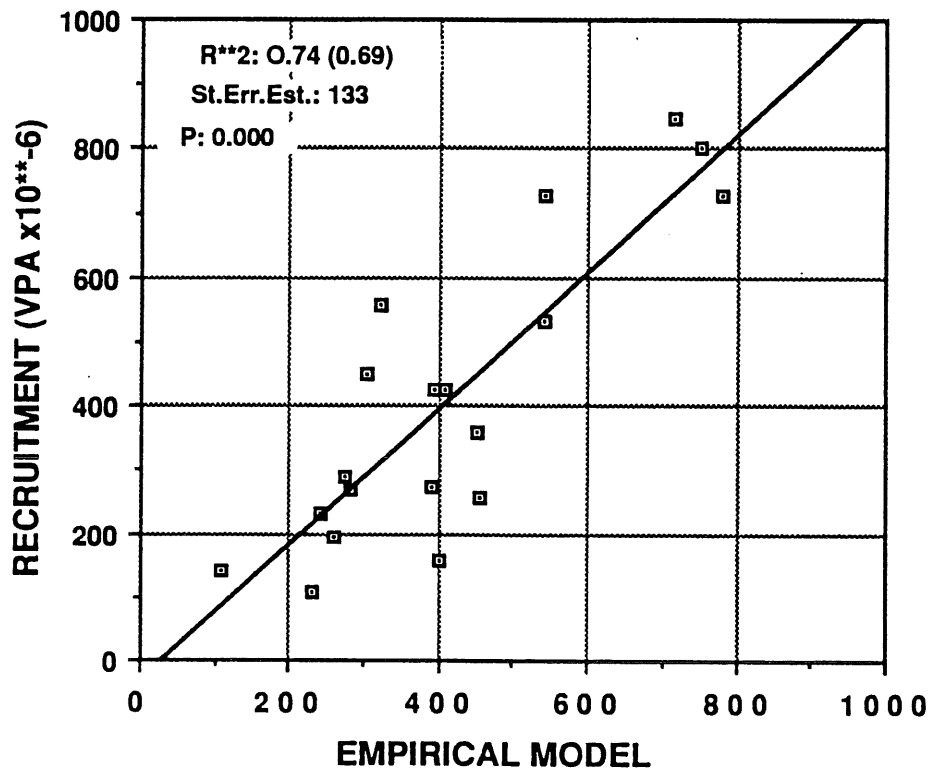
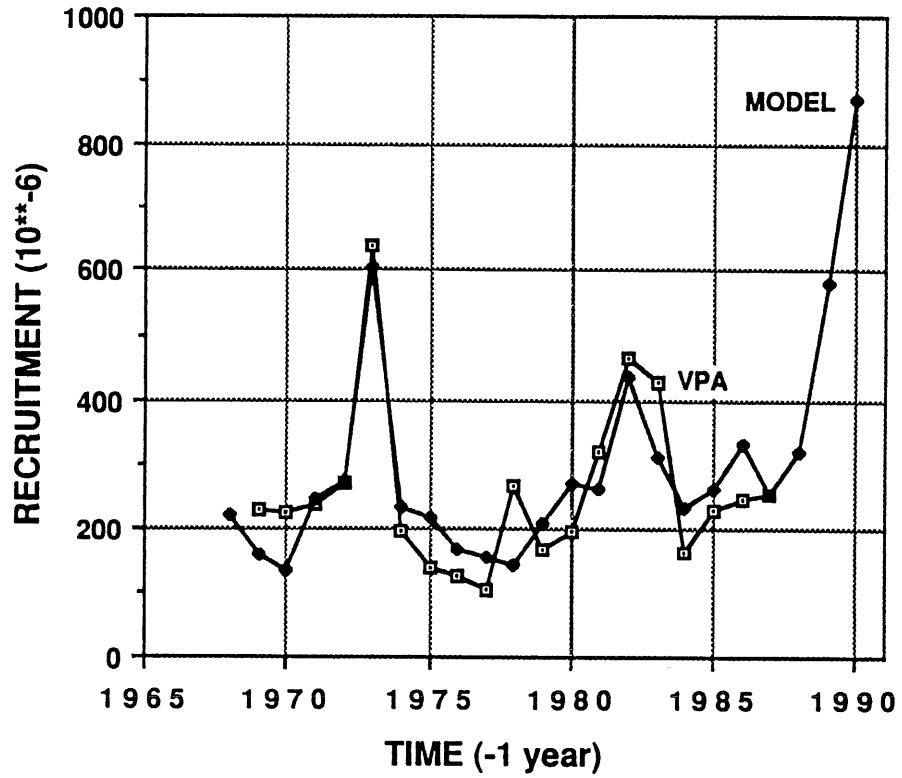


Fig. 12. Comparisons (annual time-series and scatter plot) between measurements (VPA) and empirical model for the recruitment of 1-group cod. Note that the time axis refers to the year-class.

1-GROUP SAI THE



1-GROUP SAI THE

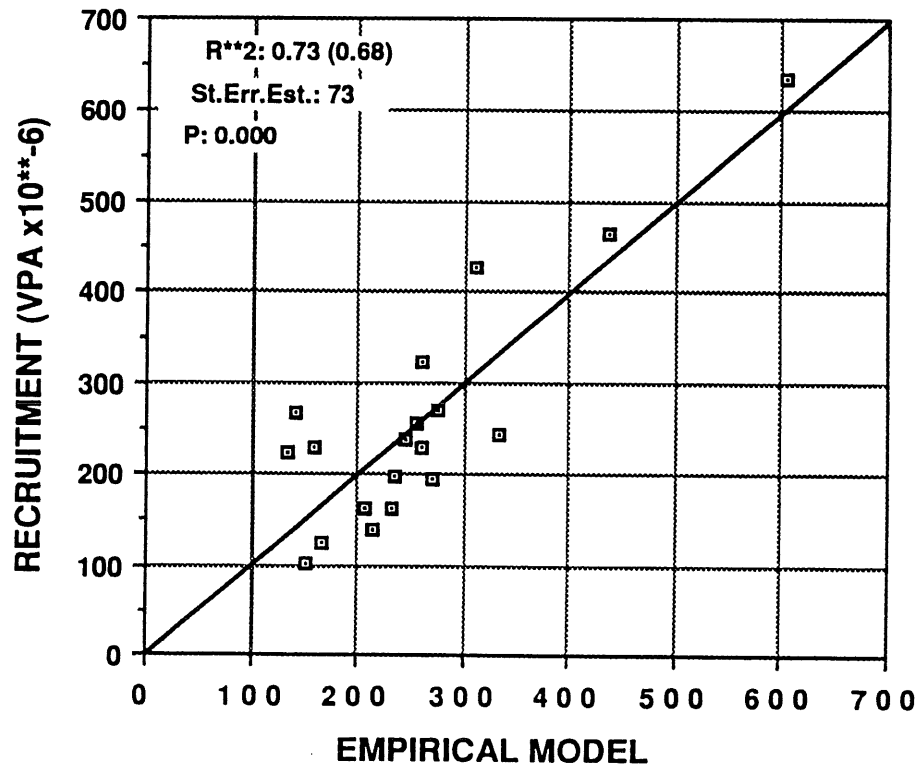
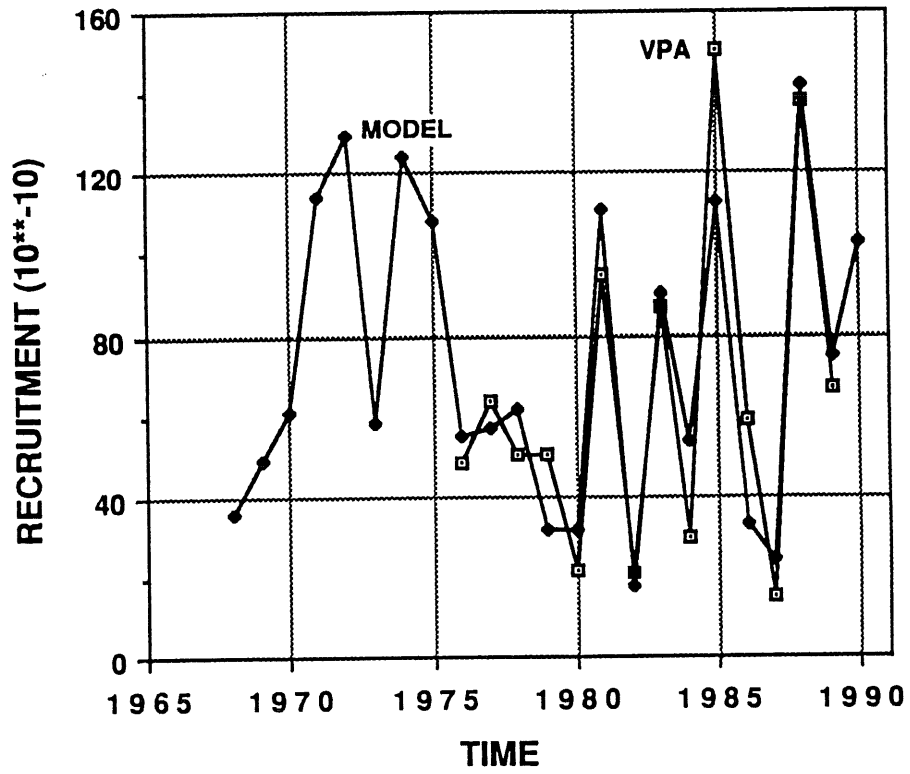


Fig. 13. Comparisons (annual time-series and scatter plot) between measurements (VPA) and empirical model for the recruitment of 1-group saithe. Note that the time axis refers to the year-class.

0-GROUP SANDEEL



0-GROUP SANDEEL

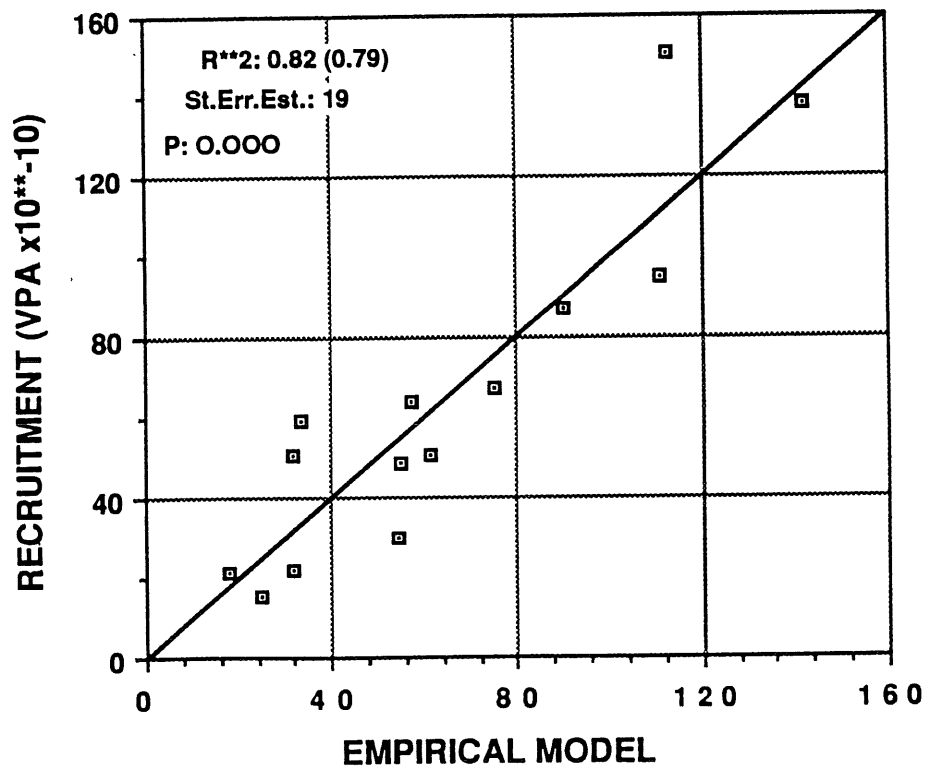


Fig. 14. Comparisons (annual time-series and scatter plot) between measurements (VPA) and empirical model for the recruitment of 0-group sandeel.