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Changes in Flemish Cap Cod Distribution and its Relationship with Environmental Changes[1]

by

Santiago Cerviño
Instituto de Investigaciones Marinas (CSIC), Eduardo Cabello, 6
36208 Vigo (Spain)

Julio Gil
Instituto Español de Oceanografía, Promontorio de San Martin
39080 Santander (Spain)

Ricardo Sanchez
Universidade do Algarbe, Av 16 Junho
P-8700-311 Olhào (Portugal)

Abstract

Since 1988, when the Flemish Cap survey started, it has been observed a shift of cod population towards shallow waters. Although similar concentrations were related with dense-dependent effects in adjacent areas, it is not clear why in Flemish Cap this shrink happens in the shallow part of the bank. This behaviour could affect the survey catchability and so the trends of the indices of abundance-at-age that are the main information in the assessment of the Flemish Cap cod status. This work has different goals: the first one is to assess the temporal trend in the shoaling movement by age group; the second one is to discuss the possible causes of this behaviour: changes in the population structure, dense-dependent factors or environmental changes, taking into account the physical features of water masses and the circulation over the Cap; by the end is also discussed the assessment implications of this behaviour.

Introduction

Bottom trawl surveys provide a major source of fisheries independent information for management purposes of demersal stocks in the North Atlantic area. Indices of abundance of fish populations obtained from bottom trawl survey can be used to evaluate the state of a fishery by itself (Pennington and Strome, 1998; Korsbrekke *et al.*, 2001) or together with catches by way of virtual population analysis (Shepherd, 1999). In both cases, with and without catch data, the indices of abundance at age show the trend in the abundance of the fishery and the accuracy of these indices determine the quality of the assessment. Factors affecting the validity of these indices are of main concern since an accurate assessment depends on them.

The EU-Flemish Cap survey in Flemish Cap began in 1988 with the aim of studying the cod population although in the following years the survey goals have included the main commercial species. Regarding to cod stock, the EU-Flemish Cap survey showed the decline of the cod population and the current collapse; mean densities at age from 1988 to 2001 are showed in Table 1. The cod stock was evaluated by way of a VPA calibrated with the indices of abundance-at-age provided by the survey (Vázquez and Cerviño, 2002). These indices were a crucial piece of information in the determination of the stock status. During the survey series it was also observed an apparent shrink

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in the aggregation of cod and a shoaling movement of the population (Vázquez, 2002). Until now, this apparent observation was not described neither analyzed.

In order to study effect of some factors on a stock it's important to take into account the age structure of this stock because it explains better the stock dynamic. Furthermore, there is evidence that age aggregated indices that relates abundance and environmental effects varied with age (Swain and Wade, 1993), then age aggregated indices confound age effects with abundance effects (Marshal and Frank, 1994). In this work we will disaggregate the cod abundance at each haul station in order to get trends of disaggregated indices for each year class of cod and describe the spatial dynamic of cod in Flemish Cap.

The objectives of this work are three: first, to describe and to quantify the spatial dynamic of Flemish Cap cod taking into account the age structure; second, to study the possible causes of the shoaling movement with three main hypothesis: changes in age structure, effects dense-dependents and environmental changes; and third, to analyze the possible consequences of this movement on the assessment of the cod stock in Flemish Cap.

Material and Methods

The data sets for this study were obtained from the EU-Flemish Cap survey that is carried out since 1988 with the aim of evaluate the main commercial species in the area (Vázquez, 2002). The stratified random sampling, that usually has 120 hauls, follows the NAFO specifications as described by Doubleday (1981). The survey area spreads out until 720 m covering all the cod area distribution that is considered an independent stock.

Cod abundance at age was calculated as a stratified mean density of a haul of 1 mille distance. Abundance at age for each haul was calculated applying the annual age-length key (ALK) to each haul size-distribution and rising to the total haul catch. EU-Flemish Cap survey uses one ALK for all hauls assuming there aren't differences in growth inside Flemish Cap.

Hydrographic data were obtained at the end of each haul with Seabird Electronics (SBE) CTDs (Models SBE19 and SBE25). Cruises were between 10-15 days duration with approximately 110 sampling stations per cruise. The mean station separation was approximately 18.5 km although stations were randomly stratified following standard methods described in Vázquez (2000). Dynamic calculations, based upon the dynamic topography field, were computed using a 200 dbar reference level, similar to previous studies (e.g., Kudlo and Burmakin, MS 1972; Kudlo and Borovkov, MS 1975; Kudlo *et al*., 1984).

Indices of depth preference

For each age and each year, it was calculated an index that relates the density of cod with the depth preference. The index of depth preference consists basically on a stratified mean depth weighted with the density of each haul. Haul weights were applied in log scale (+1) in order to reduce the weight of an extraordinary catch.

$$I = \frac{1}{N} \sum_{str} I_{str} * N_{str}$$

$$I_{str} = \frac{\sum_{i=1}^{n} \ln(N_i + 1) * d_i}{\sum_{i=1}^{n} \ln(N_i + 1)}$$

where: N is the abundance; str is the sub index for strata and i the sub index for haul; d_i is the depth in meters of each haul. Index units are meters. Each year and each age have their own index of depth preference. Results are showed in Fig. 1

Abundance at age of each haul was used to produce contour maps of density by linear kriging. Trends in the distribution are showed in figures 2 to 8.

Results

The first result presents the summary of depth preference of Flemish Cap cod at age. The mean value (Table 2) for years 1998 to 2001 shows that one-year-old cod prefers 188 m and the depth preference increases with age until the estimated value of 254 for ages 7 and 8. This result shows a well construct red distribution of cod in Flemish Cap with young cod (1 year old) in shallow water and older cod in deeper waters.

Figure 1 shows the change in depth preference for each age from 1988 to 2001. In order to clarify the trend, a linear model was fitted to each age. R-square values show a general good fit and the slope of the line shows the rate of change in depth preference. All the age groups presents a change in depth preference during the analysed period (1988 to 2001); the rate of change ranges between 2.15 m/year of age 2 to 7.21 m/year of age 8, although values higher than 5 are frequents (Table 2).

Estimated density for 1 mille trawl is presented in Table 1 where we can see that mean density was decreasing for all age classes. Correlations among temporal trends in abundance and temporal trends in depth preference shows a positive relationship among both processes for all age classes (Table 2) with coefficients ranging from .17 or .26 (ages 8 and 2) to .76 or .79 for ages 4 and 5.

Figures 2 to 8 show the contour plots for cod-at-age distribution in Flemish Cap. In this plot we can see the continuous trend in decreasing abundance-at-age and the shoaling movement along the analyzed period; nevertheless, these trends were better represented in Table 2. The most important information from these contour plots is the distribution pattern. Many of these plots shows a circular distribution around an area of no cod that is centred on the cap that remember a “donut” shape; clear examples of this behaviour are age 1 and 2 of 1992 although other plots shows a similar behaviour. There are different ages of year 1991 or 1996 that shows the opposite behaviour, where the distribution is not circular and there isn’t a central hole. In general, all the plots shows an intermediate pattern with a more or less “donut” shape, although this shape is more frequent in younger ages (Fig. 2 and 3). In recent years, when abundance is low and cod occurs in just some hauls, this pattern can’t be well evaluated.

With the aim of relating the fronts to the nutrients and primary productivity, the dynamical situation in July of 1998 was studied. The Fig. 9 shows a close relation among the dynamical front due to the gyre over the bank and the higher values of nitrate, phosphate, silicate and fluorescence. Besides this, the oxygen concentration is high out of the gyre core. So, the governing mechanism of supply nutrients and high values of primary production is close to the fronts. Therefore, the high productivity will depend on the front situation: in deep Cap waters if a gyre does not exists, and in shallow Cap waters if a conspicuous gyre is over the Cap.

Discussion

Since 1988, when the EU Flemish Cap survey started, it was observed a general shoaling movement in the cod population. At the same time the abundance decreased and eventually the stock collapsed. The causes and consequences of this shoaling behaviour are now discussed. We speculate with three possible causes: changes in population structure, dense-dependent response and environmental effects. The main consequences discussed here are the change in survey at age catchability, its effects on the Flemish Cap cod assessment.

Flemish Cap Cod are distributed gradually regarding to age and depth. Young individuals prefer shallow waters and, with ageing, they change gradually its preferences to deeper waters (Table 2). A change in the population structure at age could have explained the observed trend of Flemish Cap cod population towards shoal waters if old cod disappear; nevertheless our results show that all ages had this shoaling movement during the analysed period (1988 to 2001) with a rate of about 5 m by year. This behaviour eliminates the change in population structure as an explanation for the shoaling movement.

Although there is a positive correlation among depth preference and abundance for all the age classes (Table 2), this doesn’t mean a causal relationship. The theory of density dependent habitat selection predicts the distribution of foragers among habitats assuming that foragers behaviour follows the ideal free distribution i.e. competitors have equal abilities, resources are patchily distributed and movement among patches has no cost (Giske *et al.*, 1998). This theory predicts that foragers will choose places where the profit rate is higher. For a population whose abundance is increasing the best habitats will be first occupied and, as the density increases, competition also increases and other poorer habitats get relatively better and they will be eventually occupied. The theory predicts that the profit rate will be equal in all occupied habitats then, the preferred habitats shows high density.

Density dependent theory of habitat selection explains the observed reduction in the area occupied by cod in Flemish Cap (Fig. 2 to 8) but it can't explain by itself the shoaling movement. The theory doesn't explain why, when abundance decreases, the preferred habitats are now shallow waters as is showed by the trend in the index of depth preference for all ages (Fig. 1).

An alternative explanation may be related with a change in environmental preference. The observed cod behaviour in Flemish Cap implies a change in relative preference towards shallow waters. I mean with "relative" that not necessarily shallow environment is now better than before but also that deeper environment may be now worst than before.

Causes for deeper environment worsening could be the competition with other species like Greenland halibut. Greenland halibut abundance in Flemish Cap increases during the EU Flemish Cap survey series (Vázquez, **) and as well as with cod it was observed a shoaling movement. Greenland halibut occurs in deeper waters than cod and their intrusion on areas usually occupied by cod in Flemish Cap could be a cause for environmental worsening and a lost in the profit rate in the areas usually occupied by the Flemish Cap cod.

Causes for shallow waters environment improvement could be related with changes in circulation around the cap. The analysis of the 1988-2000 dynamic topographies shows that although water circulation in July is essentially anticyclonic around Flemish Cap, there are significant year-to-year differences. Circulation patterns were classified into two main types: (i) a well-developed anticyclone gyre with a well-defined core anchored to the top of the bank and (ii) highly variable circulation where the central gyre is poorly defined and there are numerous mesoscale eddies (Gil *et al*., 2004). When a well-developed anticyclone eddy is present over the Cap a conspicuous front encircled a central core in which a number of stations bore approximately the same geopotential anomaly, and this front is located in the Cap shallow waters. However, when the central gyre is poorly defined, the fronts are due to the Labrador Current and they are located in deeper waters. Since in recent years it was observed a higher frequency of conspicuous gyres (Gil *et al*., 2004), this can explain an increase in the primary production towards shallow waters that could drive the food chain in the same direction.

Trawl survey yields an abundance index that shows the stock trend in a temporal series. The method to estimate the abundance is the swept area method that depends on the measure of trawled surface; i.e. gear width by trawl longitude. Nevertheless the lateral opening depends on the rope length that is a function of depth. Then, the deep the trawl the wider the lateral opening (Godo and Engas, 1989). The width of the Loffoten gear used in the EU-Flemish Cap survey is expected to be of 13.5 m, and is kept constant in the abundance calculations, in all the hauls in all the series. This doesn't affect the indices value if depth preferences at-age doesn't change along the time. If a year class of cod moves during a temporal series toward shoal waters, it is expected that the sweep area for this year class decreases. Given that all cod classes move to shallower waters, their estimated survey abundance in Flemish Cap is expected to be underestimated and the observed decreasing trend in abundance, from 1988 to 2001 are probably less than the survey index shows. The quantity of this underestimation is unknown although is not expected a change in the present stock status that is at the lower historical level. An estimation of lateral opening in function of depth in the EU Flemish Cap survey will allow a correction of Flemish Cap indices of abundance.

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Table 1.- Flemish Cap cod stratified mean abundance at age (numbers by 1 mille haul).

	1	2	3	4	5	6	7	8
1988	3.112	50.555	28.425	7.501	0.794	0.121	0.155	0.046
1989	15.263	7.982	60.105	35.102	13.244	0.901	0.111	0.096
1990	1.771	8.329	3.268	10.687	10.139	2.971	0.242	0.112
1991	100.945	18.481	11.032	1.374	4.444	1.190	0.211	0.051
1992	50.980	26.755	3.458	1.397	0.227	0.870	0.155	0.009
1993	3.037	95.129	19.844	0.702	0.878	0.116	0.343	0.070
1994	2.252	2.691	17.126	3.189	0.084	0.046	0.005	0.082
1995	1.097	8.073	0.875	2.529	0.628	0.023	0.017	0.016
1996	0.027	2.085	4.377	0.586	1.611	0.134	0.005	0.004
1997	0.029	0.100	2.247	3.133	0.256	0.648	0.014	0.000
1998	0.017	0.054	0.060	0.807	1.026	0.051	0.102	0.000
1999	0.004	0.056	0.073	0.075	0.467	0.296	0.013	0.005
2000	0.123	0.009	0.193	0.121	0.059	0.285	0.113	0.008
2001	0.320	1.173	0.005	0.077	0.049	0.003	0.105	0.061

Table 2. Statistics for the index of cod depth preference. *Mean*, *min* and *max* refers to the index values for the series (1988 to 2001). *Slope* refers to regression of index on year (units in meters by year). *Correl* refers to the correlation among survey mean abundance and index of depth preference.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
***Mean* (1988-01)**	188	212	209	226	239	251	254	254
***Min* (1988-01)**	133	169	148	184	196	214	211	175
***Max* (1988-01)**	231	245	253	294	313	307	316	356
***Slope* (I-Year)**	-5.28	-2.15	-3.83	-5.59	-6.83	-6.26	-5.55	-7.21
***Correl* (I-Survey)**	0.54	0.26	0.45	0.76	0.79	0.62	0.38	0.17

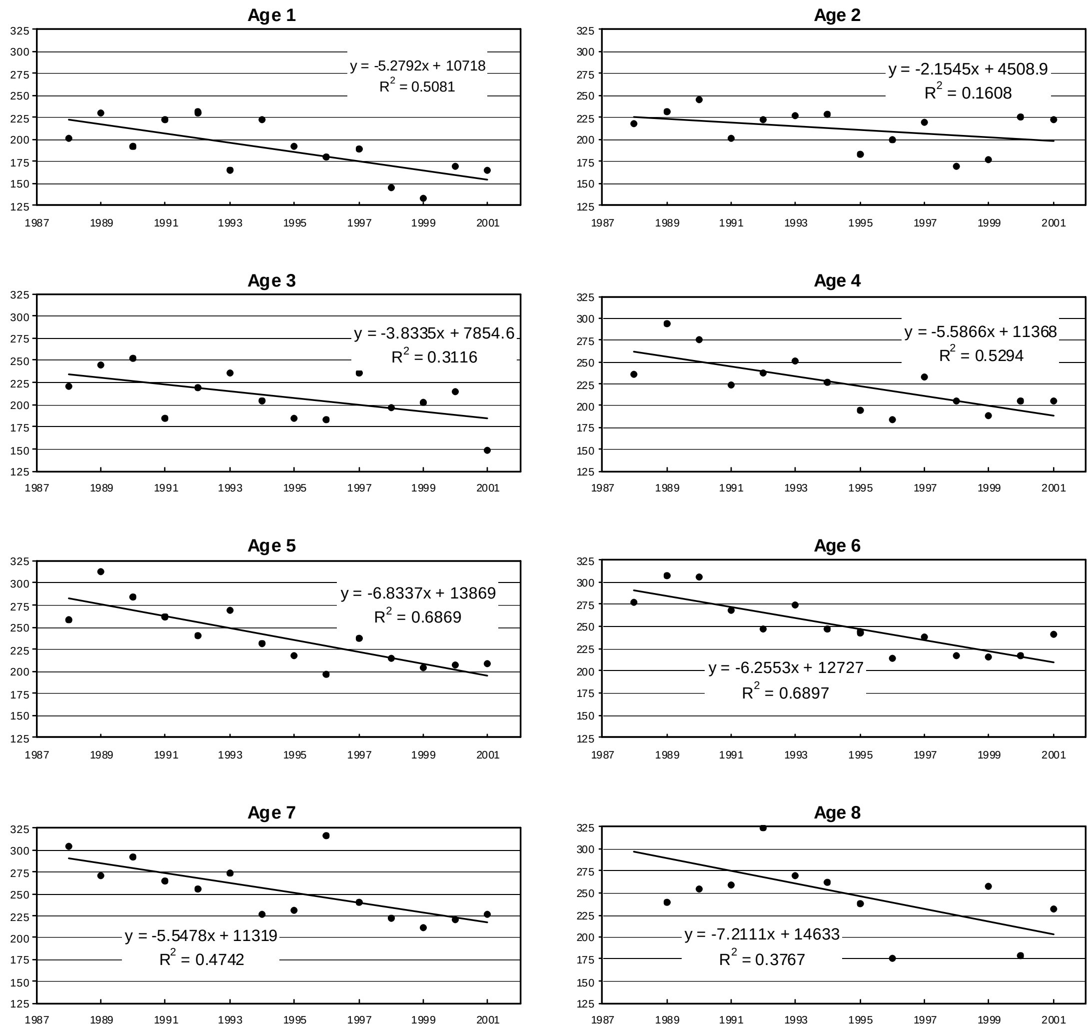

Fig. 1. Trends in depth preference by age (y axis in meters) from 1988 to 2001 (x axis). Each plot was fitted linearly showing the resulting equation and the R square. All ages show a trend preference towards shallower waters in recent years as is showed by the negative slope.

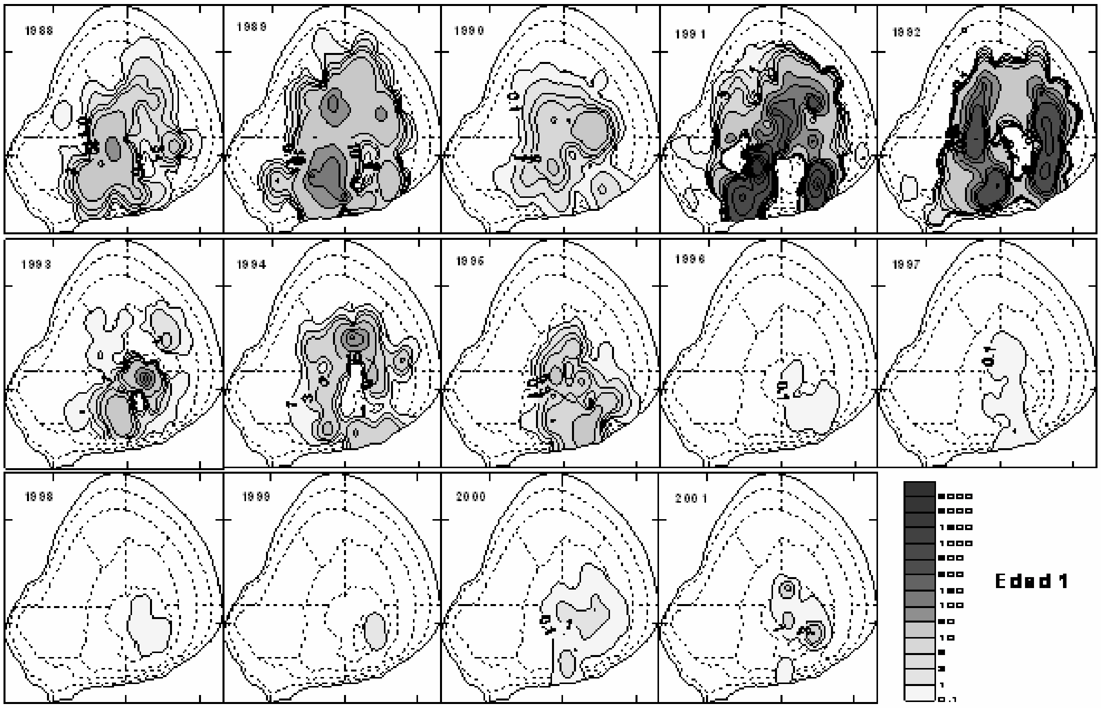

Fig. 2. Age 1 cod distribution from 1988 to 2001 in numbers by mille of trawl.

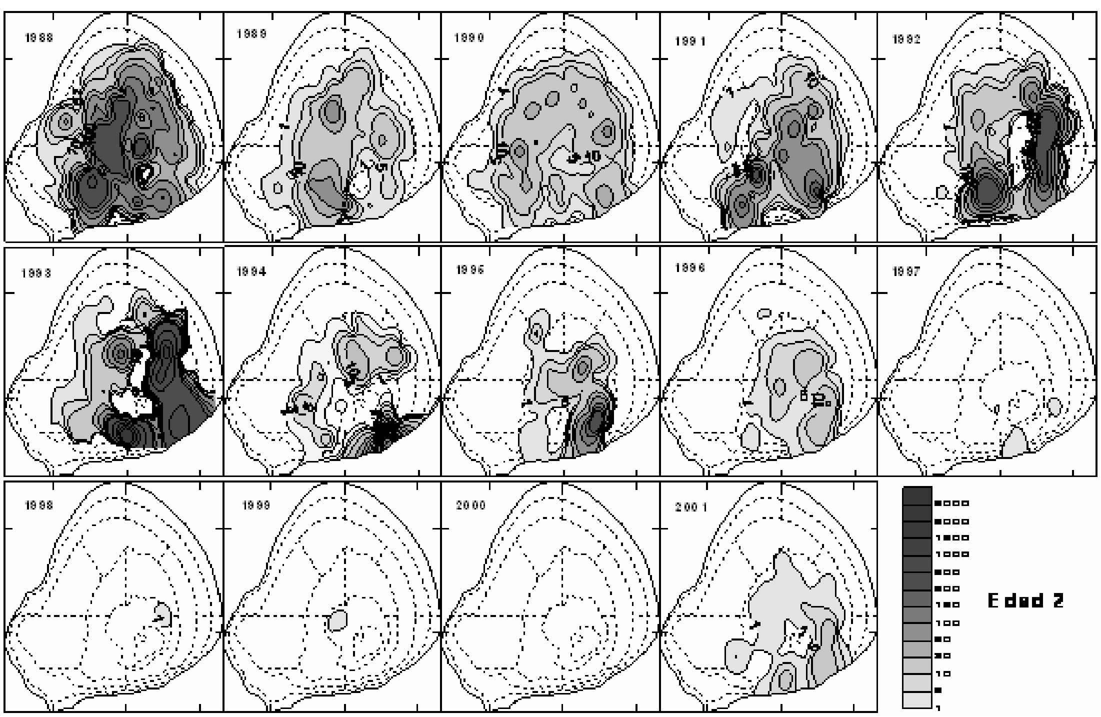

Fig. 3. Age 2 cod distribution from 1988 to 2001 in numbers by mille of trawl.

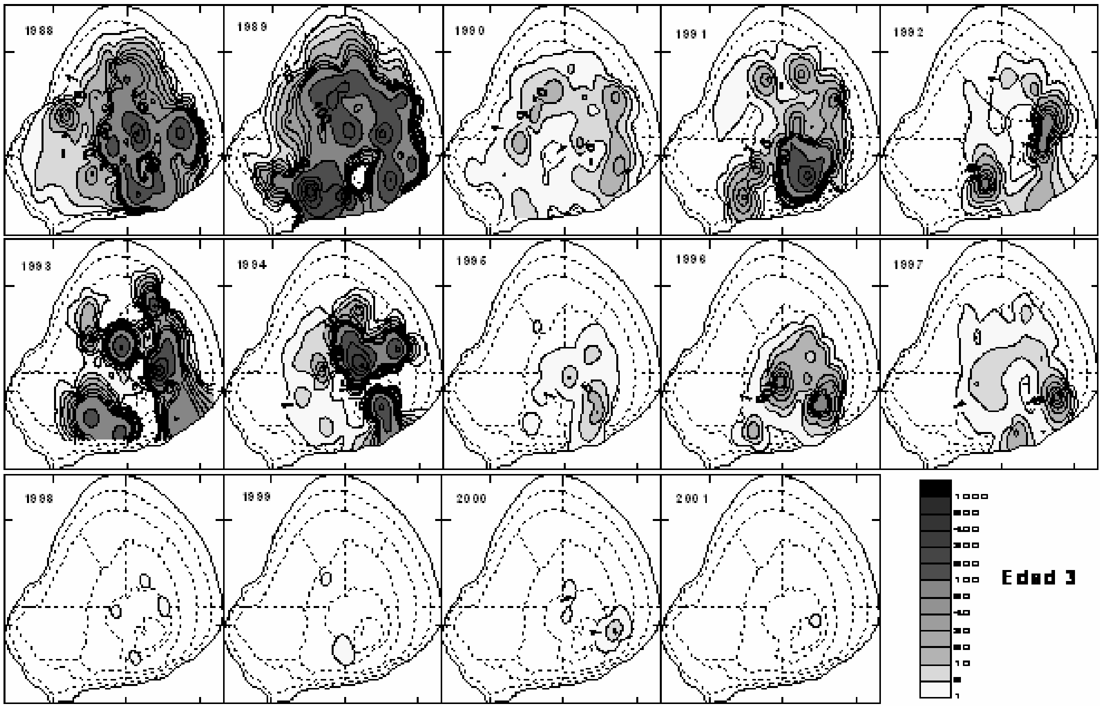

Fig. 4. Age 3 cod distribution from 1988 to 2001 in numbers by mille of trawl.

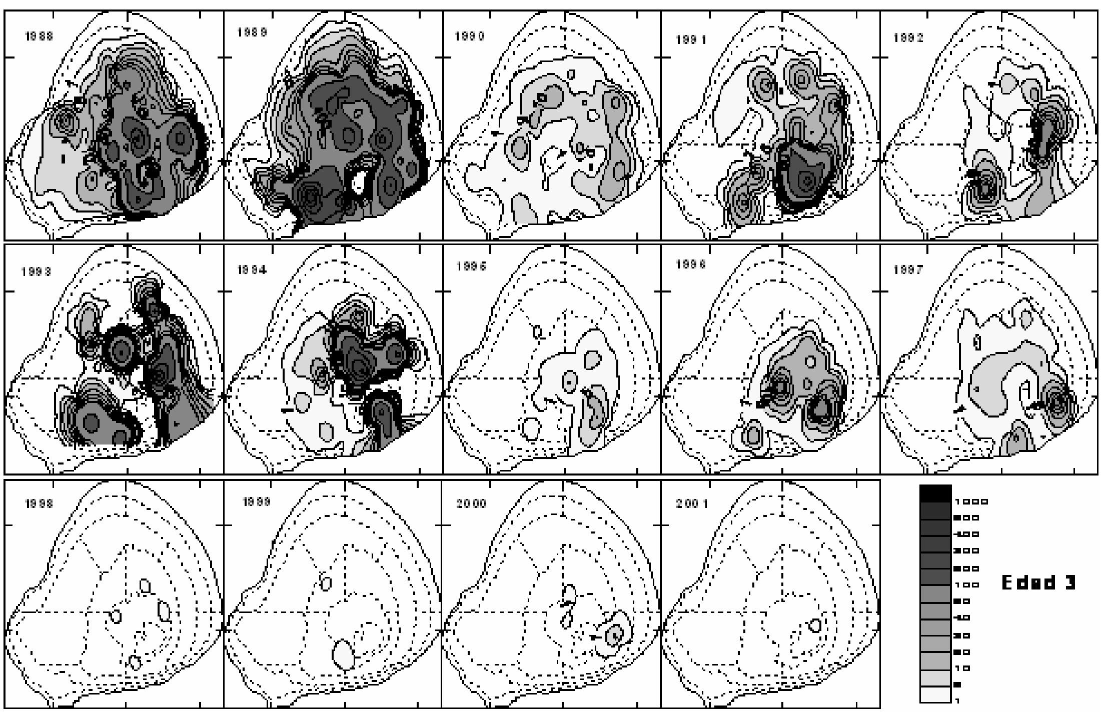

Fig. 5. Age 4 cod distribution from 1988 to 2001 in numbers by mille of trawl.

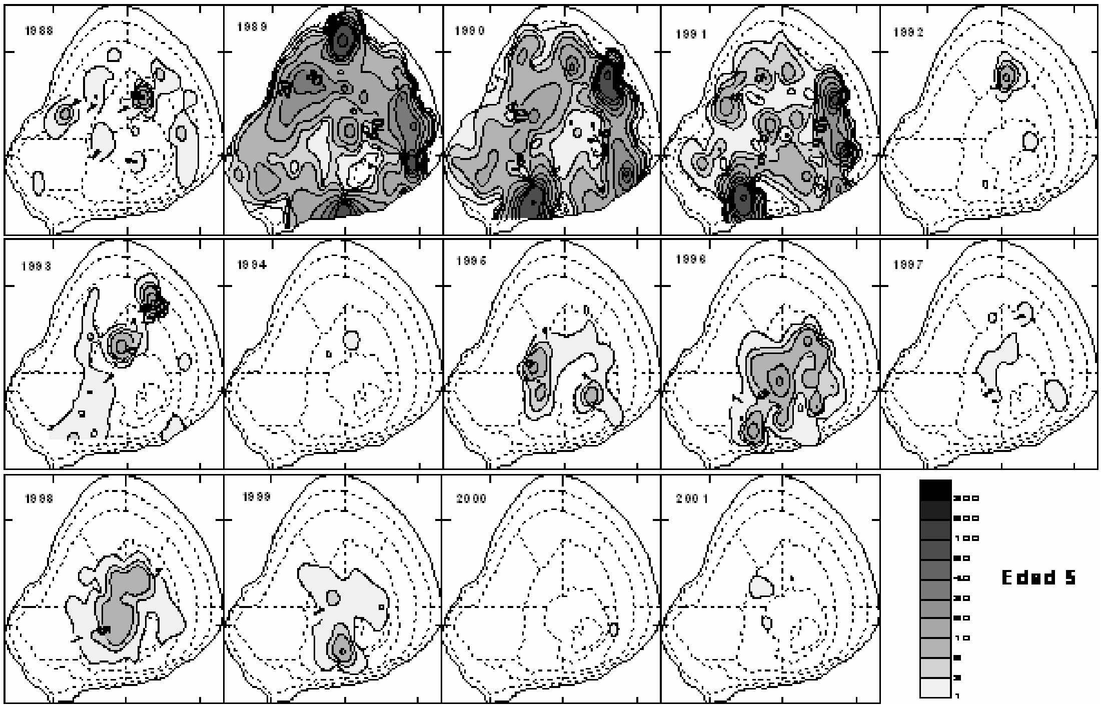

Fig. 6. Age 5 cod distribution from 1988 to 2001 in numbers by mille of trawl.

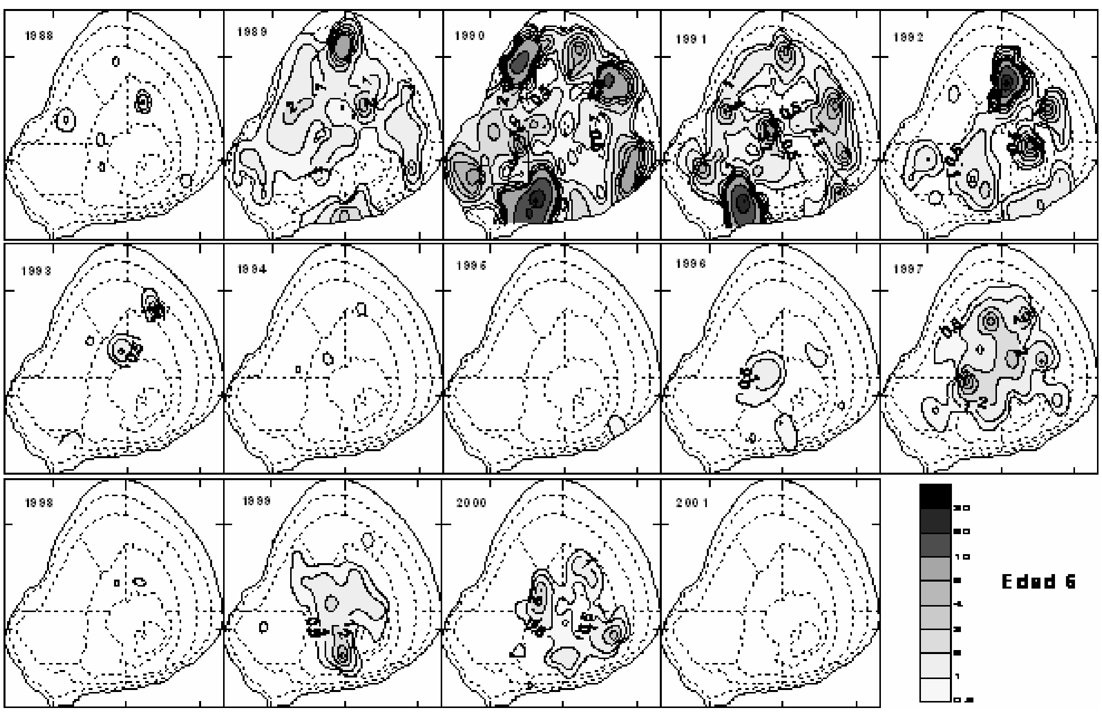

Fig. 7. Age 6 cod distribution from 1988 to 2001 in numbers by mille of trawl.

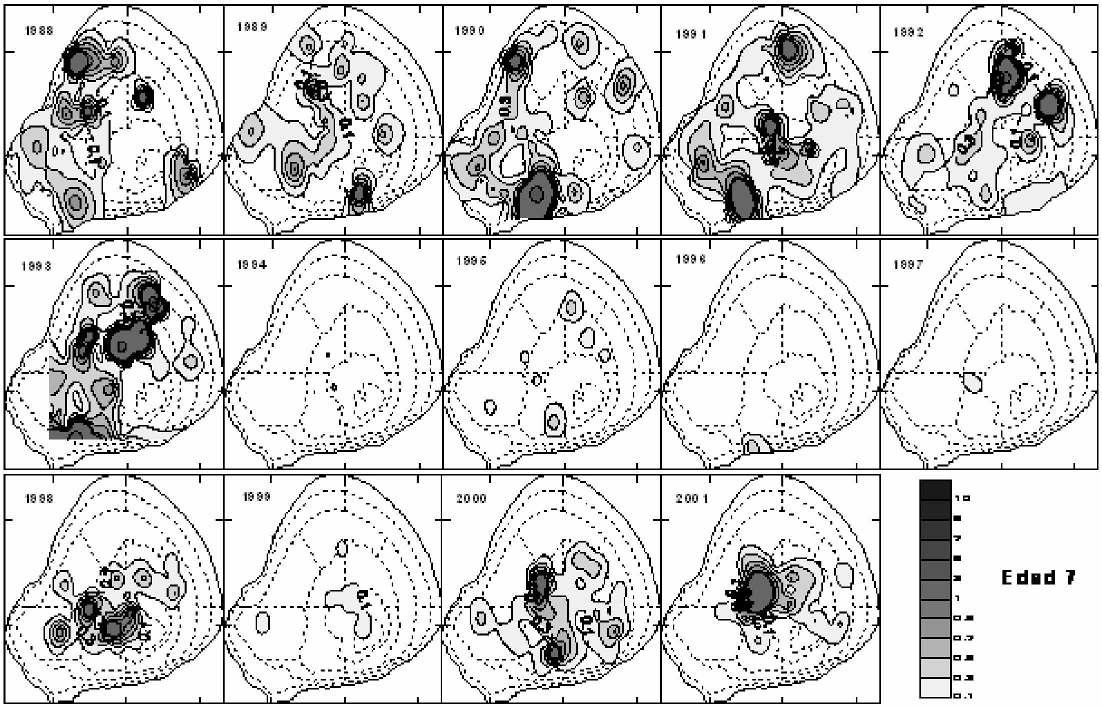

Fig. 8. Age 7 cod distribution in Flemish Cap from 1988 to 2001 in numbers by mille of trawl.

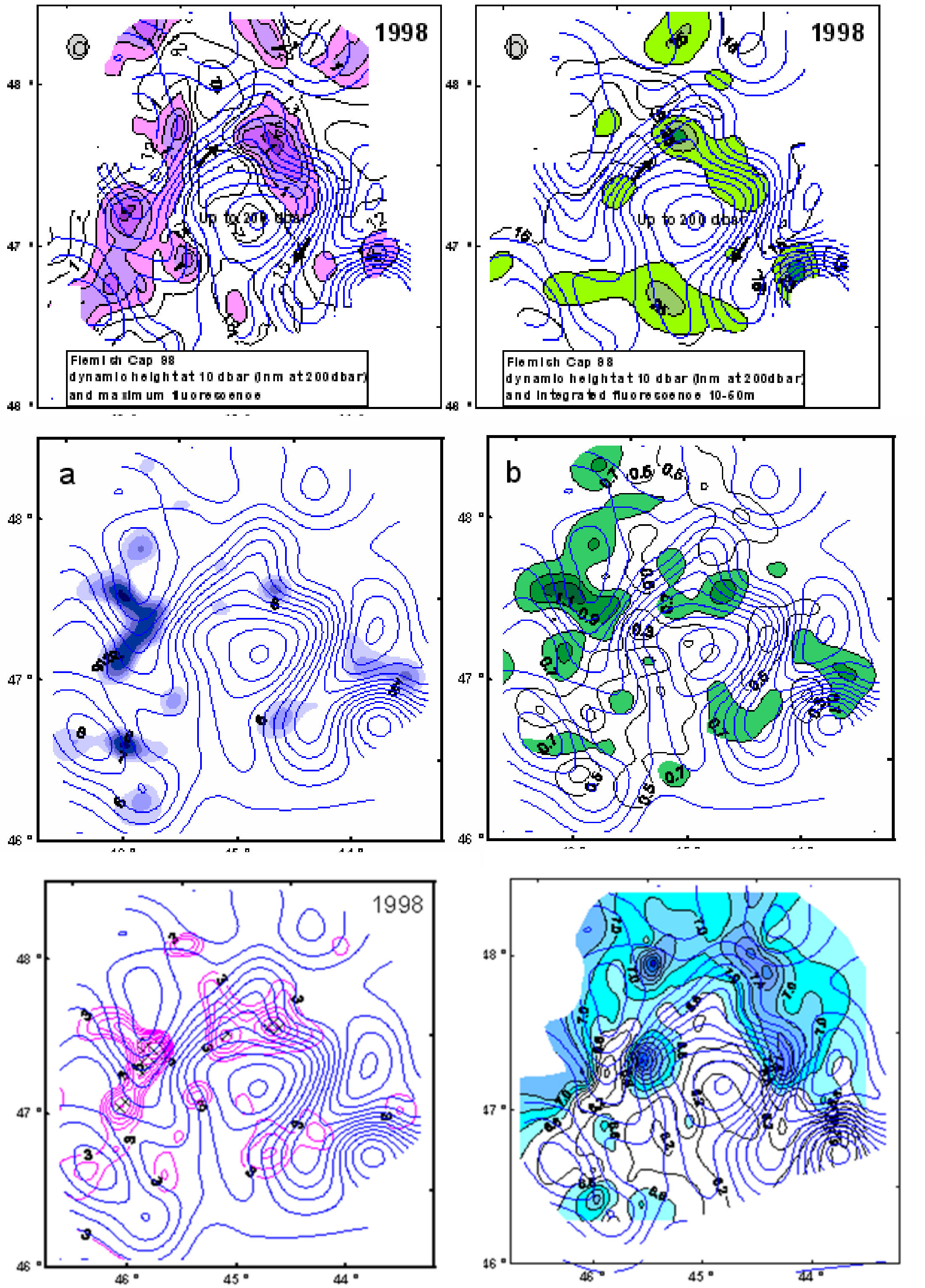

Fig. 9. Oceanographic variables related with gyre intensity in 1998. Gyre intensity is showed as dynamic height in blue contour lines in all the plots. Upper plots show fluorescence. Middle plots represent nitrates (left) and phosphates (right) at 40 m depth. Lower plots show silicates at 40 m depth (left) and oxygen in ml/l at 50 m depth (right).