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Catch Rate *Versus* Biomass Trends of Cod (*Gadus morhua*) in Division 3M, 1988–95: Why Don't They Match?

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Abstract

The effective use of 130 mm mesh size in the trawl fisheries on the NAFO Regulatory Area since May 1995 had implied a change in the fishing pattern of the Div. 3M cod (*Gadus morhua*). Two series of catch rates were made available for the period 1988–95, one from the observed monthly values of monitored vessels and another derived from the former and corresponding to catch rates that would have occurred over the same interval if a 130 mm mesh size in the codend had been applied. The first series was considered to represent catches from 2 year old cod onwards while the second series was considered to represent catches from an age between 4 and 5 years and older. The different trends observed when comparing the two series with the EU survey biomass estimates of the corresponding two segments of the population, were found to be related with the shrinkage of cod distribution over the recent decline of cod abundance. Taking these apparent contradictions into account it is concluded that for the time being tuning matrices derived from commercial catch rates-at-age should not be used in Div. 3M cod VPA based assessments.

Key words: biomass, catch rate, cod, Flemish Cap, mesh size

Introduction

Cod (*Gadus morhua*) being a traditional priority species for the Portuguese fishery in the NAFO Regulatory Area, the Flemish Cap area (Div. 3M) has been the ground where most of the Portuguese trawl fishing effort on cod has taken place in several years within 1985 and 1995. In fact the appearance of good recruitments in 1985–86 and 1990–91, together with diminishing fishing opportunities on the Nose and Tail of the Grand Bank, led to rapid and high concentrations of trawl effort on Flemish Cap in 1989–90 and from 1993 till the first quarter of 1995. The resulting total estimated cod catches by the Portuguese fleet (including those from pair trawlers, gillnetters, longliners and flags of convenience) were at levels of 40 000 tons and 30 000 tons, respectively. Based on observed data, the Portuguese fishery for cod in Div. 3M peaked in 1994 with 39% of the trawl effort applied to this stock (Ávila de Melo *et al.*, MS 1995), and a maximum standardized CPUE for the period 1988–95 of almost 1 ton/hr. However, compared to the estimate from the revised 1995 assessment of this cod stock (Vazquez *et al.*, MS 1996) and from the results of the EU surveys on Flemish Cap (Vazquez, MS 1996), the total biomass of cod in Div. 3M was at a much lower level in 1994 than in 1989, when a maximum was reached for this time series.

In 1995, the cod trawl CPUE halved the 1994 value. Following this time there was a further drop in the survey biomass, but the impact of the effective use of 130 mm trawl mesh size since May 1995 (with the enforcement of an observer on board of each fishing vessel on behalf of the NAFO Pilot Observer Program) on the catch rates needs to be investigated. The purpose of the present work is to derive a "new" CPUE series from the observed one, corresponding to the yields expected if a 130 mm mesh size was used over the same time period, and to compare the trends of the two catch rate series (observed and estimated) with the corresponding biomasses of the stock components affected by those two different fishing patterns.

Material and Methods

Justification of the Working Hypothesis

A major uncertainty remained with respect to real mesh size of the codend used in the fishery until April 1995. From the length data collected on board by different vessels at the same time and Division under the Portuguese Sampling Program, however, it was possible to estimate an appropriate mesh size for the period. Length frequencies of cod and American plaice trawl catches from Flemish Cap and the Tail of the Grand Bank showed that during the late-1980s/early-1990s there was a high proportion of undersized fish. This fact indicated that not only were the mesh sizes well below 130 mm, but were also similar within the trawl fleet, since no significant differences were detected between samples taken from different vessels at the same time and Division. Furthermore, the 1991 cod catches in Div. 3N and 1988 and 1992 cod catches in Div. 3M showed mean lengths between 24 cm and 27 cm which indicated that a mesh size somewhere around 60 mm/70 mm would have been in use in some of these trawl fisheries. Accordingly, as a working hypothesis we considered that the trawl catch of cod in Div. 3M taken from January 1988 until April 1995, were taken with an effective mesh size of 65 mm.

Collection and Treatment of Raw Catch/effort and Length/weight Data

Observed catch and effort data from eleven Portuguese trawlers fishing for cod on the Flemish Cap on several trips made during the 1988–95 period were reviewed on a haul by haul basis. With the exception of one side trawler (OTB), all the other ten vessels were stern otter trawlers (OTB2) from the early-1970s with quite similar fishing efficiency. The daily catch and effort data from each of these trawlers were used to estimate the directed effort on the cod stock in Div. 3M, and the associated catch on a monthly basis. The catch rates available corresponding to at least 10 hours of directed effort to cod, for each month/year/vessel, were then averaged using the number of fishing days as a weighting factor (no division category is considered in the exercise since this cod stock is confined to Div. 3M). The observed mean monthly CPUEs so obtained for the 1988/95 period were then standardized by an additive model already fully described in a previous paper (Ávila de Melo and Alpoim, 1995) in order to build annual series of observed CPUEs for cod in Div. 3M corrected for the month of each observation. A multiplicative model (Vazquez, 1981) has also been applied to the same set of observed catch rates, but with no prior averaging of catch rates by month and including the fishing power of each vessel as another source of variability.

The Portuguese catches were sampled on board every year, on the months corresponding to the peaks of the fishery on Flemish Cap. Length frequencies of cod in Div. 3M from the trawl catches have been presented annually in the Portuguese Research Reports (Godinho, MS 1989; Avila de Melo *et al*., MS 1990; Godinho *et al*., MS 1991; Alpoim *et al*., MS 1992; Avila de Melo *et al*., MS 1993; Alpoim *et al*., MS 1994; Avila de Melo *et al*., MS 1995; Godinho *et al*., MS 1996) covering the study period, and are representative of the total catch taken each year, including any eventual discards. Mean weights-at-length for each year were available from the respective Div. 3M cod length-weight relationship obtained from EU bottom trawl survey of Flemish Cap in July 1988–95 (Vazquez, MS 1996).

Method to Rebuild a Trawl CPUE Series

In order to derive an estimated CPUE series for a mesh size of 130 mm, and covering the whole study interval, an annual yield rate was calculated and applied to the monthly CPUEs of each year from January 1988 up to April 1995 (considered to correspond to the 65 mm mesh size period). In the additive model, the annual yield rates multiply the mean CPUEs (month/year), while in the multiplicative model the annual yield rates were applied directly to each observation (month/year/vessel). The CPUEs from May to December 1995 (corresponding to 130 mm mesh size period) were then incorporated in this new CPUE matrix prior to standardization.

To calculate the annual yield rates, we need to have the 65 mm and 130 mm selection curves for Div. 3M cod. Halliday and White (1989) considered that the mesh selectivity curves from Northwest Atlantic cod stocks could be derived from the logistic equation:

$$S(L) = 1 / (1+ exp\ (\alpha\ \ (1 - L/L_{50})) \qquad (1)$$

where $S(L)$ is the selection of the L^{th} length group
L_{50} is the length at which 50% of fish is retained in the codend (i.e. $SF \times$ mesh size)

The value of α, the parameter defining the shape of the ogive, can be derived from L_{50} and the selection range (r) by the equation:

$$\alpha = 2\ Ln(3)\ L_{50} / r \qquad (2)$$

where r is the selection range and is the length at which 75% of fish is retained in the codend minus length at which 25% of fish is retained in the codend (*i.e.* L_{75}–L_{25}).

Clay (1979), in Halliday and White (1989), used the predicted value of r for 130 mm mesh size from the regression analysis of cod selection range data compiled by Holden (1971) against mesh size. A selection factor (SF) of 3.75 was also calculated by the same author for 66 mm–168 mm mesh sizes, giving an L_{50} of 48.8 cm for 130 mm. A value for α of 9 was calculated from equation (2) and adopted in the logistic equation (Halliday and White, 1989).

Although not tabled in the Halliday and White (1989) work, the selection range for 130 mm for the present study was derived from equation (2) assuming the α and L_{50} values mentioned above. These values were also assumed in equation (1) to give the 130 mm mesh size selection-at-length (% of retention) for length groups from 19 cm to 112 cm, (these values being the minimum and maximum cod lengths recorded in the trawl catch samples taken during 1988–95 in Div. 3M cod).

If, although with the selection range increasing with mesh size, we assume that the ratio L_{50}/r remained constant, then α is also kept constant and the selection curve for 65 mm mesh size has the same shape than the one for 130 mm. Being so the L_{50} and selection at length for 65 mm mesh size can be easily derived from the former selectivity parameters.

For each length group within the length range of the catch, a retention rate is finally given by the ratio between the selections for 130 mm and 65 mm, representing at each length the proportion of cod retained in a 65 mm codend that will also be caught if the mesh size doubled.

Multiplying the observed per thousand length frequency vector of the annual catch by the 130 mm/65 mm retention rate vector will give the catch in numbers at length if a 130 mm mesh size had been used (the first length frequency vector will totalize a thousand fish and the second a somewhat smaller number). The catch in numbers at length from both length frequency vectors are converted in catch in weight-at-length using the respective mean weights-at-length given by length/weight relationship from the EU survey of the same year. The catch in weight-at-length from each length frequency vector is summed up, giving each year the yield that will be obtained from one thousand cod if a 65 mm or 130 mm had been used in the codend. The annual yield rate was finally given by the ratio between the total catch in weight for 130 mm and 65 mm mesh sizes.

If it is considered that the cod in Div. 3M at the beginning of age two has a length in the vicinity of 24 cm (i.e. L_{50} for the 65 mm mesh size), and that 49 cm (i.e. L_{50} for the 130 mm mesh size) is a length reached somewhere between age four and five, and if recent studies pointing to a shift of spawning to younger ages (Saborido-Rey and Junquera, MS 1995) observed on Flemish Cap over the last years confirm that the first spawn of cod is now occurring at age four, then the observed CPUE series should be related with the age 2+ biomass of this stock and the estimated one with the recent levels of spawning stock biomass. For the purpose of this work, spawning stock biomass was considered to be given by 50% of age 4 biomass added to the 5+ biomass. Yield rates would then reflect the importance (quantified in terms of proportion in weight) of adult fish in the exploitable biomass of Flemish Cap cod. Both age 2+ biomass and spawning stock biomass are calculated from 1988–95 EU survey results as a sum of products of abundances and mean weights-at-age (Vazquez *et al.*, MS 1996).

Results and Discussion

Selectivity parameters, selection at length for mesh sizes 65 mm and 130 mm as well as the 130 mm/65 mm retention rate vector are presented in Table 1.

In Table 2 are given the details of the calculation of the annual yield rates from 1988 to 1995, to be applied to the catch rate observations of each year in order to build the estimated 130 mm catch rate matrix. Obviously for 1995, the length frequency used is representative of the Div. 3M trawl catches only to April. The annual yield rates are shown graphically in Fig. 1.

Observed CPUEs standardized by the additive and multiplicative models are presented in Tables 3 and 4. The 1995 CPUE values can be considered representative of the cod trawl fishery since we estimate that in 1995 about 85% of the Portuguese trawl catches had been taken during the first quarter of the year, prior to the effective enforcement of 130 mm mesh size in the codend. In Fig. 2 annual CPUEs standardized by the two models are compared, both series represented as a proportion of the respective 1990 value (the year with a maximum of CPUE observations recorded). Although showing the same general trend, the multiplicative series presents a large interannual fluctuation of the CPUEs from 1991 to 1994, which is in contrast with the smooth and

TABLE 1. Cod, Division 3M. Selection parameters and retention rates for 130 mm against 65 mm mesh size.

Mesh size (cm)		6.5	13	
SF		3.75	3.75	(Holden, 1971)
$r = L_{75}\text{-}L_{25}$		5.951	11.902	
L_{50}		24.4	48.8	
$L_{75}\text{-}L_{25}/L_{50}$		0.244	0.244	
α	≥	9	9	(Clay, 1979)

Length group	Selection at length 65 mm	Selection at length 130 mm	Retention rate 130 mm/65 mm
19	0.121	0.004	0.034
22	0.294	0.007	0.024
25	0.557	0.012	0.022
28	0.792	0.021	0.027
31	0.920	0.036	0.040
34	0.972	0.062	0.063
37	0.991	0.103	0.104
40	0.997	0.166	0.166
43	0.999	0.257	0.257
46	1.000	0.376	0.376
49	1.000	0.512	0.512
52	1.000	0.646	0.646
55	1.000	0.760	0.760
58	1.000	0.847	0.847
61	1.000	0.906	0.906
64	1.000	0.944	0.944
67	1.000	0.967	0.967
70	1.000	0.981	0.981
73	1.000	0.989	0.989
76	1.000	0.994	0.994
79	1.000	0.996	0.996
82	1.000	0.998	0.988
85	1.000	0.999	0.999
88	1.000	0.999	0.999
91	1.000	1.000	1.000
94	1.000	1.000	1.000
97	1.000	1.000	1.000
100	1.000	1.000	1.000
103	1.000	1.000	1.000
106	1.000	1.000	1.000
109	1.000	1.000	1.000
112	1.000	1.000	1.000

continuous growth of the additive series for the same period of time This interannual variability seems more related with the introduction of the vessel factor in the multiplicative model and the rejection by the model of vessels with a very small number of observations than with abrupt fluctuations in stock abundance, not reflected either in the survey biomass indices or in the additive series (Table 3, Fig.3). Taking into account that the use of the multiplicative model with this small set of observations increased the noise in the results, making more difficult the comparison between commercial and survey indices, we decided for discussion purposes, to focus only in the observed and estimated CPUE series given by the additive model.

Estimated CPUEs for 130 mm mesh size, given by the additive model, and spawning stock biomass, given by 50% of age 4 biomass added to the age 5+ biomass, are presented in Table 5 and Fig. 4.

TABLE 2. Cod, Division 3M. Annual yield rate between a catch weight estimated of 1 000 fish would pass through a 130 mm mesh size codend and the weight of 1 000 fish caught with 65 mm mesh size codend. (Length weight relationships derived from EU 1988–95 July bottom trawl surveys)

Length group	Length frequency 65 mm (‰)	Mean weight 65 mm (g)	Catch weight 65 mm (kg)	Retention rate 130 mm/65 mm	Length frequency 130 mm (‰)	Catch numbers 130 mm (kg)
			1988			
					a = 0.006535 (Vazquez, MS 1996) b = 3.0901	
19	1	58	0.1	0.034	0.0	0.0
22	17	92	1.6	0.024	0.4	0.0
25	61	136	8.3	0.022	1.3	0.2
28	91	194	17.6	0.027	2.4	0.5
31	202	265	53.6	0.040	8.0	2.1
34	252	353	88.9	0.063	16.0	5.6
37	190	458	87.1	0.104	19.7	9.0
40	105	583	61.2	0.166	17.5	10.2
43	50	729	36.5	0.257	12.9	9.4
46	18	898	16.2	0.376	6.8	6.1
49	7	1 092	7.6	0.512	3.6	3.9
52	2	1 312	2.6	0.646	1.3	1.7
55						
58						
61	1	2 148	2.1	0.906	0.9	1.9
64	2	2 492	5.0	0.944	1.9	4.7
67	1	2 871	2.9	0.967	1.0	2.8
Total	1 000		391		94	58
				Yield rate	**88**	**0.149**
			1989			
					a = 0.006734 (Vazquez, MS 1996) b = 3.0801	
22	0.6	92	0.1	0.024	0.0	0.0
25	3.6	136	0.5	0.022	0.1	0.0
28	9.1	193	1.8	0.027	0.2	0.0
31	24.6	264	6.5	0.040	1.0	0.3
34	46.8	351	16.4	0.063	3.0	1.0
37	84.5	456	38.5	0.104	8.7	4.0
40	137.2	579	79.5	0.166	22.8	13.2
43	178.9	724	129.4	0.257	46.0	33.3
46	182.9	891	162.9	0.376	68.7	61.2
49	159.2	1 082	172.2	0.512	81.4	88.1
52	98.8	1 299	128.4	0.646	63.8	82.9
55	46.7	1 544	72.1	0.760	35.5	54.8
58	16.6	1 819	30.2	0.847	14.1	25.6
61	3.7	2 125	7.8	0.906	3.3	7.1
64	2.0	2 463	5.0	0.944	1.9	4.7
67	1.7	2 836	4.8	0.967	1.7	4.7
70	1.4	3 246	4.7	0.981	1.4	4.6
73	1.5	3 694	5.6	0.989	1.5	5.5
TOTAL	1 000		866		355	391
				Yield rate	**89**	**0.451**

TABLE 2. (Continued). Cod, Division 3M. Annual yield rate between a catch weight estimated of 1 000 fish would pass through a 130 mm mesh size codend and the weight of 1 000 fish caught with 65 mm mesh size codend. (Length weight relationships derived from EU 1988–95 July bottom trawl surveys).

Length group	Length frequency 65 mm (‰)	Mean weight 65 mm (g)	Catch weight 65 mm (kg)	Retention rate 130 mm/65 mm	Length frequency 130 mm (‰)	Catch numbers 130 mm (kg)
			1990			
					a = 0.008002 (Vazquez, MS1996) b = 3.0422	
19	0.4	62	0.0	0.034	0.0	0.0
22	4.9	97	0.5	0.024	0.1	0.0
25	14.3	143	2.1	0.022	0.3	0.0
28	10.0	202	2.0	0.027	0.3	0.1
31	17.5	276	4.8	0.040	0.7	0.2
34	40.9	365	14.9	0.063	2.6	0.9
37	81.0	472	38.2	0.104	8.4	4.0
40	132.4	598	79.2	0.166	22.0	13.2
43	161.9	746	120.7	0.257	41.7	31.1
46	146.8	915	134.2	0.376	55.2	50.5
49	124.6	1 109	138.2	0.512	63.7	70.7
52	92.4	1 329	122.7	0.646	59.7	79.3
55	66.4	1 577	104.7	0.760	50.5	79.6
58	44.6	1 853	82.6	0.847	37.7	69.9
61	28.1	2 160	60.8	0.906	25.5	55.0
64	18.0	2 500	44.9	0.944	16.9	42.4
67	8.1	2 874	23.4	0.967	7.9	22.6
70	3.6	3 284	11.7	0.981	3.5	11.5
73	1.0	3 731	3.8	0.989	1.0	3.8
76	0.6	4 217	2.5	0.994	0.6	2.5
79	0.4	4 744	2.0	0.996	0.4	2.0
82	0.7	5 314	3.6	0.998	0.7	3.6
85	0.1	5 928	0.5	0.999	0.1	0.5
88	0.3	6 587	2.2	0.999	0.3	2.2
91	0.2	7 294	1.2	1.000	0.2	1.2
94	0.1	8 051	0.7	1.000	0.1	0.7
97	0.3	8 858	2.3	1.000	0.3	2.3
100	0.1	9 718	0.8	1.000	0.1	0.8
103	0.1	10 633	0.9	1.000	0.1	0.9
106	0.1	11 603	1.0	1.000	0.1	1.0
TOTAL	1 000		1 008		401	552
				Yield rate	**90**	**0.548**
			1991			
					a = 0.00853 (Vazquez, MS 1996) b = 3.0212	
19	1.0	62	0.1	0.034	0.0	0.0
22	5.2	97	0.5	0.024	0.1	0.0
25	16.8	143	2.4	0.022	0.4	0.1
28	17.5	201	3.5	0.027	0.5	0.1
31	70.1	273	19.2	0.040	2.8	0.8
34	109.3	361	39.5	0.063	6.9	2.5
37	128.6	466	60.0	0.104	13.3	6.2
40	140.7	590	83.0	0.166	23.4	13.8
43	130.2	734	95.6	0.257	33.5	24.6
46	54.7	900	49.3	0.376	20.6	18.5
49	26.8	1 090	29.2	0.512	13.7	14.9
52	37.4	1 304	48.8	0.646	24.2	31.5

TABLE 2. (Continued). Cod, Division 3M. Annual yield rate between a catch weight estimated of 1 000 fish would pass through a 130 mm mesh size codend and the weight of 1 000 fish caught with 65 mm mesh size codend. (Length weight relationships derived from EU 1988–95 July bottom trawl surveys).

Length group	Length frequency 65 mm (‰)	Mean weight 65 mm (g)	Catch weight 65 mm (kg)	Retention rate 130 mm/65 mm	Length frequency 130 mm (‰)	Catch numbers 130 mm (kg)
(1991 cont'd)						
55	69.5	1 545	107.4	0.76	52.8	81.6
58	56.1	1 814	101.7	0.847	47.5	86.1
61	47.8	2 112	100.9	0.906	43.3	91.4
64	38.5	2 442	93.9	0.944	36.3	88.6
67	17.1	2 805	48.0	0.967	16.5	46.4
70	21.8	3 202	69.7	0.981	21.3	68.3
73	5.6	3 634	20.5	0.989	5.6	20.2
76	1.3	4 105	5.4	0.994	1.3	5.4
79	2.6	4 614	12.2	0.996	2.6	12.2
82						
85	0.6	5 756	3.4	0.999	0.6	3.4
88	0.3	6 392	1.6	0.999	0.3	1.6
91	0.2	7 073	1.6	1.000	0.2	1.6
94						
97						
100	0.3	9 405	2.4	1.000	0.3	2.4
TOTAL	1 000		1 000		368	622
				Yield rate	**91**	**0.622**
			1992			
					a = 0.008881 (Vazquez, MS 1996) b = 3.0163	
25	12.5	146	1.8	0.022	0.0	0.0
28	130.7	206	26.9	0.027	3.5	0.7
31	358.4	280	100.3	0.040	14.2	4.0
34	217.6	370	80.5	0.063	13.8	5.1
37	114.4	477	54.6	0.104	11.8	5.6
40	61.2	604	36.9	0.166	10.2	6.1
43	43.2	751	32.4	0.257	11.1	8.3
46	22.1	920	20.4	0.376	8.3	7.7
49	10.6	1 113	11.8	0.512	5.4	6.0
52	9.1	1 332	12.2	0.646	5.9	7.9
55	8.9	1 577	14.0	0.760	6.7	10.6
58	4.7	1 851	8.7	0.847	4.0	7.3
61	2.3	2 156	5.0	0.906	2.1	4.5
64	1.6	2 491	4.1	0.944	1.5	3.9
67	0.9	2 861	2.5	0.967	0.8	2.4
70	0.5	3 265	1.7	0.981	0.5	1.7
73	0.5	3 706	1.7	0.989	0.5	1.7
76	0.1	4 184	0.4	0.994	0.1	0.4
79	0.2	4 702	0.8	0.996	0.2	0.8
82	0.3	5 261	1.7	0.998	0.3	1.7
85	0.2	5 864	1.0	0.999	0.2	1.0
TOTAL	1 000		419		101	88
				Yield rate	**92**	**0.209**

TABLE 2. (Continued). Cod, Division 3M. Annual yield rate between a catch weight estimated of 1 000 fish would pass through a 130 mm mesh size codend and the weight of 1 000 fish caught with 65 mm mesh size codend. (Length weight relationships derived from EU 1988–95 July bottom trawl surveys).

Length group	Length frequency 65 mm (‰)	Mean weight 65 mm (g)	Catch weight 65 mm (kg)	Retention rate 130 mm/65 mm	Length frequency 130 mm (‰)	Catch numbers 130 mm (kg)
			1993			
					a = 0.007502 (Vazquez, MS 1996) b = 3.0572	
22	3.2	95	0.3	0.024	0.1	0.0
25	39.5	141	5.6	0.022	0.9	0.1
28	44.0	199	8.8	0.027	1.2	0.2
31	85.3	272	23.2	0.040	3.4	0.9
34	148.9	361	53.7	0.063	9.4	3.4
37	200.6	467	93.7	0.104	20.8	9.7
40	209.9	593	124.4	0.166	34.9	20.7
43	104.7	740	77.4	0.257	26.9	19.9
46	58.8	909	53.5	0.376	22.1	20.1
49	27.1	1 103	29.8	0.512	13.8	15.3
52	17.8	1 322	23.5	0.646	11.5	15.2
55	15.5	1 570	24.4	0.760	11.8	18.5
58	11.0	1 846	20.3	0.847	9.3	17.2
61	8.0	2 154	17.2	0.906	7.2	15.6
64	6.9	2 495	17.3	0.944	6.5	16.3
67	7.8	2 870	22.4	0.967	7.5	21.6
70	3.2	3 281	10.7	0.981	3.2	10.5
73	2.8	3 730	10.3	0.989	2.7	10.2
76	2.5	4 219	10.5	0.994	2.5	10.4
79	0.9	4 749	4.1	0.996	0.9	4.1
82	1.0	5 322	5.1	0.998	1.0	5.1
85	0.4	5 940	2.1	0.999	0.3	2.1
88	0.1	6 605	0.6	0.999	0.1	0.6
91	0.1	7 317	1.1	1.000	0.1	1.1
94						
97	0.05	8 895	0.4	1.000	0.0	0.4
100	0.05	9 763	0.5	1.000	0.0	0.5
103						
106	0.05	11 667	0.6	1.000	0.0	0.6
109						
112	0.05	13 805	0.7	1.000	0.0	0.7
TOTAL	1 000		642		198	241
				Yield rate	**93**	**0.375**
			1994			
					a = 0.006065 (Vazquez, 1996) b = 3.1249	
25	0.1	142	0.0	0.022	0.0	0.0
28	0.4	202	0.1	0.027	0.0	0.0
31	62.5	277	17.3	0.040	2.5	0.7
34	102.7	370	38.0	0.063	6.5	2.4
37	160.2	482	77.3	0.104	16.6	8.0
40	224.4	615	138.1	0.166	37.3	23.0
43	170.5	771	131.5	0.257	43.9	33.8
46	147.3	952	140.3	0.376	55.4	52.7
49	73.0	1 160	84.7	0.512	37.4	43.3

TABLE 2. (Continued). Cod, Division 3M. Annual yield rate between a catch weight estimated of 1 000 fish would pass through a 130 mm mesh size codend and the weight of 1 000 fish caught with 65 mm mesh size codend. (Length weight relationships derived from EU 1988–95 July bottom trawl surveys).

Length group	Length frequency 65 mm (‰)	Mean weight 65 mm (g)	Catch weight 65 mm (kg)	Retention rate 130 mm/65 mm	Length frequency 130 mm (‰)	Catch numbers 130 mm (kg)
(1994 cont'd)						
52	35.5	1 397	49.6	0.646	22.9	32.0
55	12.9	1 665	21.4	0.760	9.8	16.3
58	5.7	1 965	11.2	0.847	4.8	9.5
61	3.2	2 300	7.5	0.906	2.9	6.8
64	1.4	2 673	3.7	0.944	1.3	3.5
67						
70						
73						
76						
79						
82						
85	0.1	6 487	0.9	0.999	0.1	0.9
88						
91	0.1	8 029	1.1	1.000	0.1	1.1
TOTAL	1 000		723		242	234
				Yield rate	**94**	**0.324**
			1995			
					a = 0.007204 (Vazquez, MS 1996) b = 3.0632	
31	0.9	267	0.2	0.040	0.0	0.0
34	19.3	354	6.8	0.063	1.2	0.4
37	48.0	458	22.0	0.104	5.0	2.3
40	126.4	582	73.6	0.166	21.0	12.2
43	215.1	726	156.2	0.257	55.3	40.2
46	176.8	893	157.9	0.376	66.5	59.4
49	122.7	1 084	133.0	0.512	62.8	68.0
52	82.7	1 300	107.5	0.646	53.4	69.4
55	58.4	1 544	90.2	0.760	44.4	68.6
58	46.6	1 817	84.6	0.847	39.4	71.7
61	32.1	2 120	68.1	0.906	29.1	61.7
64	20.1	2 456	49.3	0.944	19.0	46.6
67	8.9	2 826	25.2	0.967	8.6	24.3
70	7.4	3 232	23.9	0.981	7.3	23.5
73	5.7	3 675	21.1	0.989	5.7	20.8
76	7.5	4 158	31.2	0.994	7.4	31.0
79	5.7	4 681	26.9	0.996	5.7	26.8
82	4.5	5 248	23.4	0.998	4.5	23.4
85	3.4	5 858	19.9	0.999	3.4	19.9
88	2.7	6 515	17.3	0.999	2.7	17.3
91	2.2	7 220	15.7	1.000	2.2	15.7
94	1.4	7 974	11.2	1.000	1.4	11.2
97	0.8	8 779	6.6	1.000	0.8	6.6
100	0.3	9 638	2.8	1.000	0.3	2.8
103	0.3	10 551	2.7	1.000	0.3	2.7
106						
109	0.2	12 549	2.7	1.000	0.2	2.7
TOTAL	1 000		1 180		447	729
				Yield rate	**95**	**0.618**

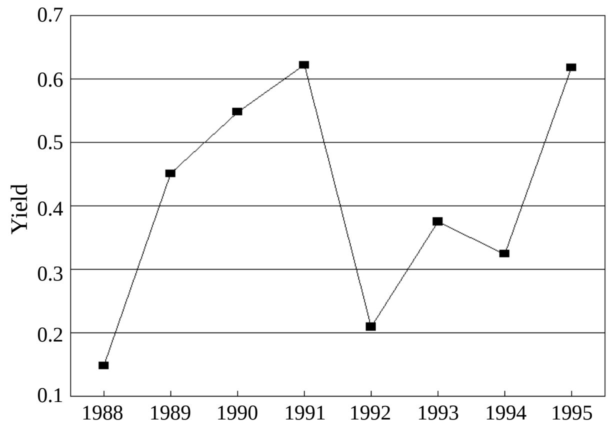

Fig. 1. Yield rates of cod in Division 3M to convert observed to 130 mm CPUEs.

The annual yield rates, presented for each year (Table 2) are as follows:

Year	Yield Rate
1988	0.148
1989	0.451
1990	0.548
1991	0.622
1992	0.209
1993	0.375
1994	0.324
1995	0.618

These values, regarded as conversion factors to estimate CPUEs for 130 mm mesh size from the observed values, two distinct periods of the recent trawl fishery in Div. 3M can be easily identified (Fig. 1). The first one, from 1989 to 1991, presents a steady increase of the yield rates as a consequence of the individual growth from one year to the next of the survivors from both 1985 and 1986 year-classes which, till 1991, were still well represented in the trawl catch (Godinho, MS 1989; Ávila de Melo *et al*., MS 1990; Godinho *et al*., MS 1991; Alpoim *et al*., MS 1992). Over exploitation lead those year-classes to an almost null presence in the trawl catches next year, justifying the drop in the yield rate from 1991 to 1992 (i.e. a sharp decline of the proportion in weight of adult fish in the exploitable stock). The second period, although presenting also an increase of the yield rate from a minimum in the first year (1992) to a maximum in the last (1995), both around the minimum and maximum observed before, do not show, however, the same pattern of variation within years. In fact the yield rate increased in 1993, due to growth of cod from the 1990 cohort, but slightly declined again in 1994. This could mean that the relatively abundant 1990 year-class had a short passage through the fishery, and in 1994 had already started to be replaced by the 1991 year-class (Ávila de Melo *et al*., MS 1993; Alpoim *et al*., MS 1994; Ávila de Melo *et al*., MS 1995). From the 1988–95 survey results (Vazquez, MS 1996), this 1991 year-class was the most abundant cohort at ages 1 and 2, and the individual growth of its survivors was still responsible for the increase in the yield rate in 1995 (Godinho *et al*., MS 1996).

The contradiction between the observed CPUE and the age 2+ biomass trends was evident: the age 2+ biomass presents an overall decline from 1989 onwards, only interrupted in 1993 with the contribution of the 1991 cohort to the exploited stock, while CPUEs steadily increased from 1990 to 1994, just as if a reduction of stock biomass would have, on the short term, a positive effect in the fishery (Table 3, Fig. 3). The "magic" quickly ended in 1995, with the observed CPUE "back to the real world" at the same speed that stock biomass reached the lowest levels. This apparent contradiction can be explained by the behaviour of Flemish Cap cod regarding its distribution over the bank during this recent decline of the population. From the maps presented on Fig. 5 a progressive shrinkage of Div. 3M cod distribution is evident since 1991 and, for 1994 and 1995, the remainder of the population was confined to small patches on the southern central and eastern parts of Flemish Cap. These dense concentrations of cod could easily be tracked by experienced skippers and rapidly produce excellent yields until near exhaustion of the fish stock.

When comparing estimated CPUEs for 130 mm mesh size with spawning stock biomass, each series again presented a different trend, but in this case estimated CPUEs for "adult" cod fluctuated from 1989 onwards around a level three times higher than the one recorded in 1988, while spawning stock biomass fell between 1990 (its maximum in recent years) and 1992, and remained at a very low level thereafter (Table 5, Fig. 4). The survival of the year-classes from the mid-1980s were still big enough to induce an increase in the spawning stock biomass during 1989 and 1990. However, the good recruitments from the early-1990s did not have the same

TABLE 3. Portuguese trawl catch rates for cod in Div. 3M during 1988–95: observed mean annual CPUEs corrected for the month of each observation. Stock biomass 2+ from EC survey. Relative values (BIOMr2+ and CPUEr) to 1988.

Year	CPUE (ton/hr)	ST. ERROR	C.V.	BIOM.2+	BIOMR2+	CPUEr
1988	0.507	0.133	64.1	32 896	0.6	1.0
1989	0.821	0.048	17.4	99 220	1.9	1.7
1990	0.485	0.100	65.0	51 063	1.0	1.0
1991	0.694	0.434	88.5	29 608	0.6	1.4
1992	0.890	0.222	50.0	18 937	0.4	1.8
1993	0.973	0.185	56.9	54 982	1.1	2.0
1994	0.998	0.167	44.3	42 584	0.8	2.1
1995	0.493	0.172	85.5	8 692	0.2	1.0

TABLE 4. Portuguese trawl catch rates for cod in Div. 3M during 1988–95: observed mean and CPUEs standardized by a multiplicative model.

Name of the factor	Cases	Factor	s(f)	Catch	Effort	Y/f
Total	75			8 977	10 683	0.84
FACTOR: Vessel						
1	33	1.000	0.054	4 037	4 644	0.87
4	6	0.806	0.079	310	309	1.00
2	21	1.008	0.139	2 885	3 548	0.81
5	6	0.815	0.169	516	828	0.62
8	9	0.926	0.409	1 230	1 354	0.91
FACTOR: Year						
1988	5	1.271	0.226	378	505	0.75
1989	12	2.116	0.160	2 320	2 770	0.84
1990	21	1.000	0.134	1 337	2 298	0.58
1991	2	1.198	0.651	30	37	0.81
1992	3	2.610	0.639	432	554	0.78
1993	15	1.898	0.191	2 220	1 776	1.25
1994	9	2.994	0.295	1 741	1 786	0.97
1995	8	0.891	0.173	518	957	0.54
FACTOR: Month						
1	8	2.650	0.334	945	832	1.14
2	6	3.399	0.867	370	392	0.94
3	6	1.144	0.376	186	487	0.38
4	5	1.491	0.450	234	315	0.74
5	8	1.979	0.171	1 321	1 403	0.94
6	9	1.000	0.131	651	822	0.79
7	4	1.317	0.286	684	1 074	0.64
8	5	0.871	0.150	735	1 093	0.67
9	6	1.088	0.145	860	1 012	0.85
10	5	1.281	0.159	1 329	1 264	1.05
11	7	1.331	0.225	737	837	0.88
12	6	0.932	0.269	926	1 152	0.80
FACTOR: Area						
Div. 3M	75	0.346	0.015	8 977	10 683	0.84

Power	=	1	
$F_{test\ n\text{-}n}$	=	0.671	39–36
Skew	=	0.271	
Curtosis	=	1.394	
Deternation coefficient:		0.229	

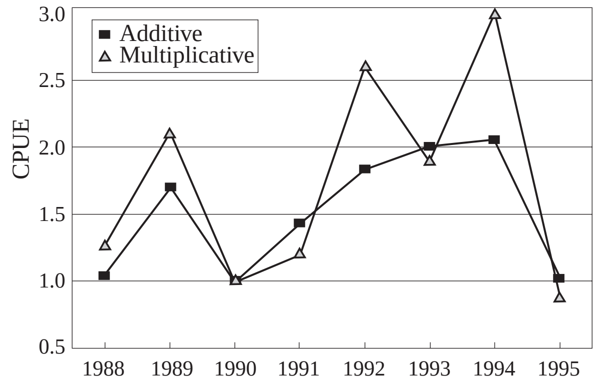

Fig. 2. Observed CPUEs series: additive *versus* multiplicative model.

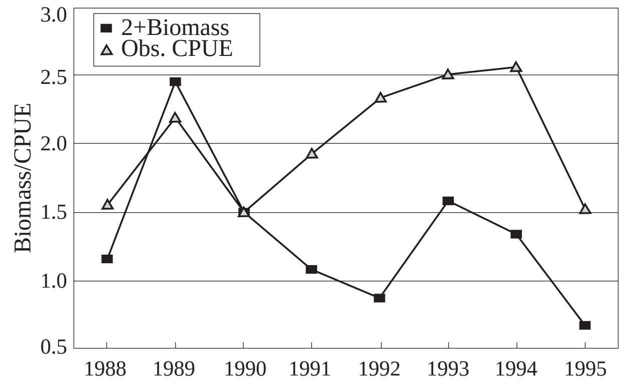

Fig. 3. Age 2+ biomass *versus* observed CPUEs (from EU surveys and Portuguese trawlers).

TABLE 5. Portuguese trawl catch rates for cod Div. 3M, 1988–95: estimated mean annual CPUEs for 130 mm mesh size, corrected for the month of each observation. Spawning stock biomass from EC survey (SSB) as 50% biomass age 4 add to 5+ biomass. Relative values (SSBr and CPUEr) to 1990.

Year	CPUE (ton/hr)	ST. ERROR	C. V.	SSB (tons)	SSBr	CPUEr
1988	0.106	0.032	75.1	9 372	0.2	0.4
1989	0.379	0.028	21.9	24 754	0.6	1.5
1990	0.257	0.062	76.7	40 744	1.0	1.0
1991	0.382	0.170	63.0	16 875	0.4	1.5
1992	0.229	0.068	59.7	6 095	0.1	0.9
1993	0.370	0.073	59.1	6 216	0.2	1.4
1994	0.326	0.053	42.8	7 145	0.2	1.3
1995	0.324	0.078	58.6	3 712	0.1	1.3

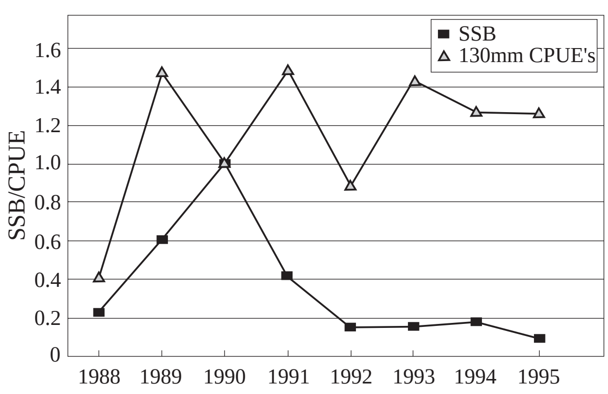

Fig. 4. SSB *versus* 130 mm CPUEs (from EU surveys and Portuguese trawlers).

chance and so the adult component of this stock ended near to collapse in 1995. The corresponding estimated CPUEs first took advantage of the remainder of the abundant cohorts from mid-1980s and for last years of the study period remained at a high level by the shrinkage of the population distribution, also reflected in adult cod.

Conclusions

Flemish Cap is an ecosystem where the abundance of its fish populations is basically determined by fishing mortality. Cod in Div. 3M did not suffer any additional (and unquantified) natural mortality, such as those caused by extreme oceanographic anomalies, predation by seals or starvation in deep waters as have been reported in neighbouring stocks. The state of the stock at the end of the study period was near collapse. Our view is that it is due to a high and rapid concentration of fishing effort on a population that was declining. This stock had shown a pronounced shrinkage of its distribution, while sustaining a fishery prosecuted by an effective fleet which showed improving yields. Therefore, when stock assessments are done for cod in Div. 3M, it is necessary to be cognisant of this opportunistic scenario of recruitment based casual fishery which remains unchanged. Accordingly, tuning matrices derived from commercial catch rates-at-age should not be used in any type of calibration of the previous year's fishing mortalities, for any age in the population.

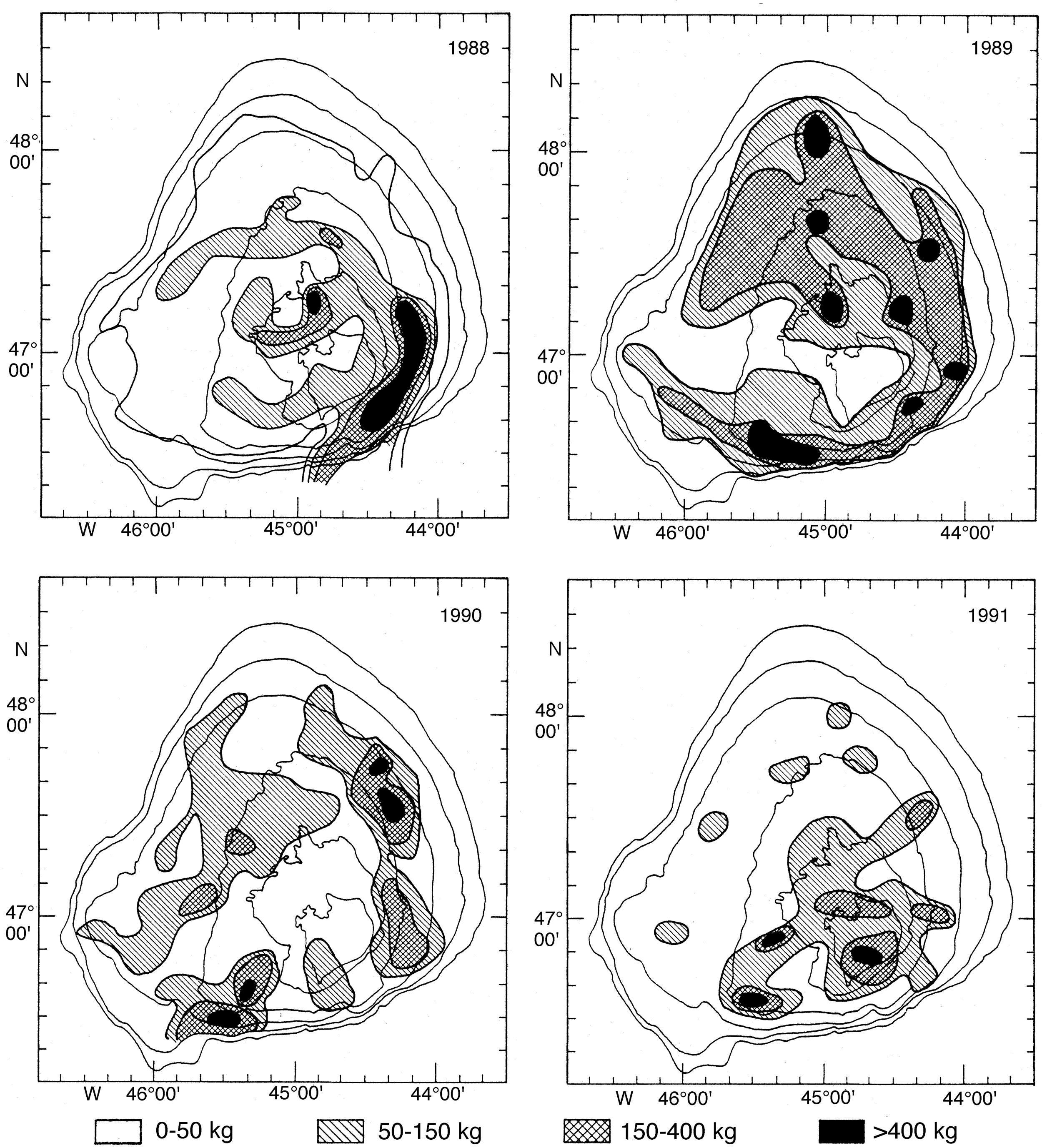

Fig. 5. Distribution of cod in Div. 3M from the half-hour catches of EU bottom trawl surveys on Flemish Cap, 1988–91.

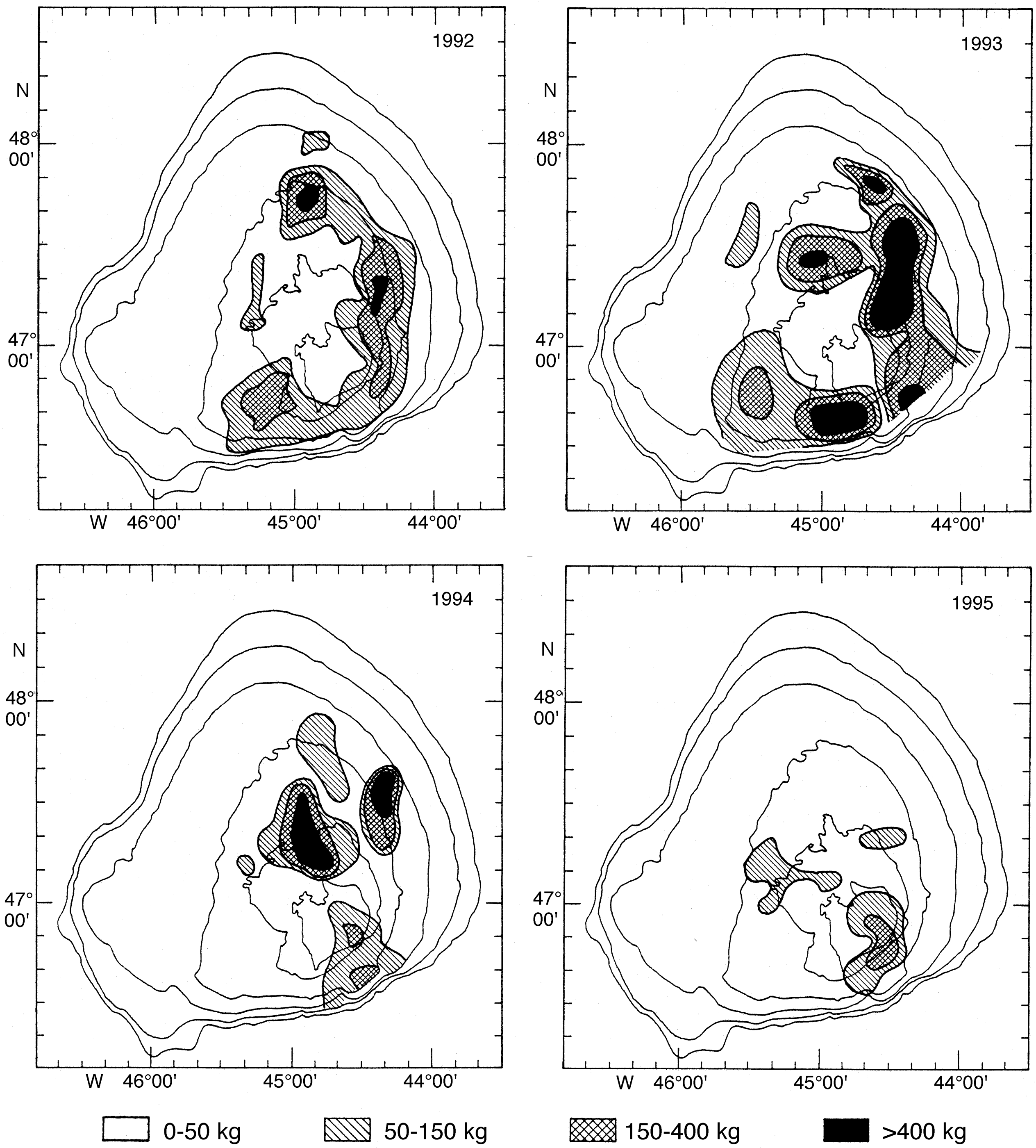

Fig. 5. (Continued). Distribution of cod in Div. 3M from the half-hour catches of EU bottom trawl surveys on Flemish Cap, 1992–95.

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