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A Survey-based Assessment of Cod in Division 3M

by

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ABSTRACT

The cod stock in NAFO division 3M is in fishing moratorium since 1999. Commercial catches have been very low since then, although they were noticeable in 2006. During the last few years a survey-based assessment method has been used to evaluate the stock status in a stochastic way. The method takes into account uncertainties in survey results as well as in catchability estimates. The present document updates the results of the assessment conducted in 2006 (details in Murua et al. 2006) incorporating the survey data from 2006. The results indicate a strong age 1 abundance value in 2006 and an increasing trend in spawning stock biomass (SSB) after its lowest value attained in 2003. Nevertheless, the probability that SSB is presently below B_{lim} is still very high. The abundances at age 1 estimated for 2005 and 2006 are the highest since 1993. As a consequence, there is some expectation that the increasing SSB trend may continue during the next few years.

INTRODUCTION

This stock is in fishing moratorium since 1999 following its collapse, which has been attributed to three possible factors: a stock decline due to overfishing, an increase in catchability at low abundance levels and very poor recruitment levels since 1993. The assessments performed since the collapse of the stock confirmed the poor situation, with SSB at very low levels, well below B_{lim} (Vázquez and Cerviño, 2005). Nevertheless, SSB was estimated to have increased a bit in 2004 and 2005 (Murua et al., 2006). The new data from 2006 indicate another increase of SSB in 2006.

Since 1974, when a TAC was established for the first time, estimated catches ranged from 48 000 tons in 1989 to a minimum value of 5 tons in 2004. Annual catches were about 30 000 tons in the late 1980's (notwithstanding the fact that the fishery was under moratorium in 1988-1990) and diminished since then as a consequence of the stock decline. Since 1998 yearly catches have been less than 1 000 tons and from 2000 to 2005 they were under 100 tons, mainly attributed to by-catches from other fisheries. Estimated commercial catch in 2006 is 339 tons, which represents more than a ten-fold increase over the average yearly catch during the period 2000-2005. This increase could indicate some kind of directed fishery, which would be quite detrimental for stock recovery. Historical catches are shown in Table 1, where the decline of the fishery can be clearly observed.

A VPA based (XSA) assessment of the cod stock in Flemish Cap was approved in 1999 for the first time and it was annually updated until 2002. However, most recent catches were very small, under 100 tons, undermining the VPA based assessment as the results of VPA are based on catches and are quite sensitive to assumed natural mortality (M) values when catches are at low levels. The F estimates from the last XSA analysis were at the same level as M in both 1998 and 1999 and lower than M in 2000 and 2001 (Vázquez and Cerviño, 2002). Therefore, as the XSA depends solely on the precision of M, the quality of the result is not considered reliable.

Cerviño and Vázquez (2003) developed a method which combines survey abundance indices at age with catchability at age, the latter estimated from the last reliable accepted XSA, in order to estimate total abundance at age. Uncertainty in survey abundance and catchability are estimated from sampling theory and bootstrapping the XSA, respectively. With this method, estimates of abundance at age from surveys with their associated uncertainty form the basis to calculate the SSB distribution and the probability that SSB is above or below any reference value. The method allows assessing stocks without catches provided that survey abundance indices and an estimate of catchability are available, as is the case of the Flemish Cap cod. It could also be useful if a VPA based assessment were considered to give unrealistic results.

This assessment updates the status of the stock using the method proposed by Cerviño and Vázquez (2003) based on the Flemish Cap survey abundances at age and the survey catchability estimates from the 1999 accepted XSA (Cerviño and Vazquez 2000). A B_{lim} value of 14 000 tons was proposed in 2001 for this stock by the NAFO Scientific Council. Indices and catchability uncertainty are used to calculate the statistical distribution of SSB estimates and the probability of SSB being below B_{lim}. Given the present moratorium, the fishery re-opening criteria may include a decision on SSB estimates being below that level in probabilistic terms. Once the re-opening criteria were achieved, this kind of analysis could also allow a stochastic examination of catch options with projections for the short or medium term.

MATERIAL AND METHODS

Data

Survey indices of abundance at age and their errors, survey catchability at age estimates and their errors, weight at age and maturity at age are the inputs used to implement the survey-based assessment method. Errors in maturity and weight at age were not taken into account. An estimate of total mortality is also used to transform the abundance at survey time (Summer) to the beginning of the year.

The EU bottom trawl survey of Flemish Cap has been carried out since 1988 targeting the main commercial species down to 730 m of depth. The surveyed zone includes the complete area distribution for cod, which rarely occurs at depths of more than 500 m. The fishing procedure was kept constant throughout the series, although the research vessel used in 1989 and 1990 was not the same one used in other years. From 2003 onwards the survey was carried out with the new R/V Vizconde de Eza (Casas, 2004) keeping the same gear and survey procedure. Comparative fishing trials with the former vessel, R/V Cornide de Saavedra, were performed in 2003 and 2004 in order to calibrate the two series (Casas and González-Troncoso, 2005). In total, 130 paired hauls with Cornide de Saavedra and Vizconde de Eza were carried out (cod appeared in 68 of these) and conversion factors to transform the Cornide de Saavedra values to Vizconde de Eza equivalents estimated (González-Troncoso and Casas, 2005). The transformed data of cod abundance at age and their standard errors calculated following Cerviño (2002) are presented in Table 2. Weight and maturity at age are presented in Table 3. These tables update those presented in Murua et al. (2006) by including the 2006 values.

Catchability at age was derived from XSA based on catch data until 1999 (with survey indices transformed to the new vessel R/V Vizconde de Eza equivalents), because since then annual catches have been very low introducing high uncertainty in XSA results (Cerviño and Vázquez, 2003). In this XSA, abundance at age 1 was calibrated with a two-parameter model or dependence on stock abundance, catchabilities for ages 2, 3 and 4 were estimated as independent of stock size from a one-parameter model, and catchabilities for older ages were considered to be equal to age 4 catchability. Variance of catchability estimates from XSA has two components implicitly: one due to the survey sampling variability and another one arising from genuine year to year variability in catchability. To separate these two sources of variability, a *bootstrap*-subtracting algorithm was devised assuming additivity and independence among both components. The algorithm has three steeps:

1. Total error in catchability estimates is estimated by *conditioned bootstrap*. This corresponds to bootstraping the residuals from the XSA analysis and re-running XSA for each bootstrap sample. The resulting covariance matrix for the catchability estimates is given in Table 4 (upper panel).

2. Partial errors in catchability estimates arising from the sampling variability of the indices are estimated by *unconditioned bootstrap*. Different samples (3000 of them) of survey indices were obtained via Montecarlo simulation assuming a log-normal error distribution with means equal to the observed survey values (upper panel of Table 2) and with standard errors as given in the lower panel of Table 2. XSA was run in turn for each sample. The resulting covariance matrix of catchability estimates is presented in Table 4 (intermediate panel).
3. The catchability covariance matrix capturing inter-annual variability in catchability is calculated by subtracting the two previous matrices: the one corresponding to survey variability from the one corresponding to total variability. The result is presented in Table 4 (lower panel)

The mean values, standard errors and correlation matrix of the catchability resulting from this procedure are presented in Table 5.

<u>The stochastic model</u>

The model follows the catchability equation, which relates the true abundance (N) to an abundance index (I):

$$I_{y,a} = q_a * N_{y,a} * \varepsilon_{y,a}$$

where q is the catchability and ε an error factor; the subscript y relates to the year and a to age. Based on this equation, N is estimated from the abundance index and estimated catchability according to:

$$\boldsymbol{N_{y,a} = I^*_{y,a} / q^*_a}$$

where the superscript * indicates stochastic values. I and q are assumed to follow a lognormal distribution with expected values and standard errors as described before (and given in Tables 2 and 5, respectively). q covariances were included in the model, but I covariances were not included because they have low in recent years.

The estimated abundance (N) needs to be corrected to the beginning of the year (N^0) because that is the scale for B_{lim}. The assumed total mortality (Z) included natural mortality (M=0.2) and fishing mortality (F, estimated from the 2002 XSA assessment and assumed to have been zero since 2002). Since the EU survey takes place in the middle of the year, we have:

$$N^0_{y,a} = N_{y,a} * \exp(t * Z_{y,a})$$

where t=0.5 is the proportion of the year elapsed from January 1 to survey time. SSB was calculated as the sum of products of abundance at age (N), mean weight (W) and maturity proportion (Mat) at age:

$$\boldsymbol{SSB = \sum_{a=1}^{n} N^0_{y,a} * W_{y,a} * Mat_{y,a}}$$

The SSB distribution was calculated via bootstrap where I and q were re-sampled independently 2000 times. The method allows estimating the *bootstrap* statistical properties of abundance at age and SSB: mean, standard deviation, coefficient of variation, skewness, statistical bias and percentiles.

RESULTS

The mean catch per tow and the mean numbers per tow in the Flemish Cap survey decreased continuously from 1989 to the lowest observed level in 2003. They increased slightly in 2004 and 2005 and much more substantially in 2006 (Figure 1). The abundance at age 1 from the 2005 EU survey was the highest observed since 1993, although it was well below the values observed before 1993, when the population was in a healthy state (Table 2). Abundance at age 1 from the 2006 EU survey has more than doubled that observed in 2005, becoming closer to the values seen before 1993 (albeit still well below some of them).

Deterministic results for abundance at age and for SSB are presented in Table 6. Abundances at age were estimated independently for each year from the survey results. As a consequence, cohort abundances are not forced to decrease from year to year necessarily as with VPA. Estimated SSB has increased substantially in 2006, reaching a value of 10 208 tons, which is higher than any of the estimates after 1997. Ages 1, 2 and 4 appear to be particularly abundant.

Probability distributions of abundance at age in 2006 and of SSB, calculated by bootstrap, are presented in Tables 7 and 8 and in Figures 2 and 3. Table 7 shows the *bootstrap* statistics for abundance at age in 2006. All the means are slightly above their deterministic values due to bias in the range between 1.3 % and 3.2 %, except for age 1, which has a bias of 52.9 %. Abundance at age 1 was estimated with the two parameter model and it is likely that its distribution does not match properly with the assumed lognormal distribution. For ages up to 7, coefficients of variation range from 0.25 for age 2 to 0.60 for age 1. CVs are above 1 for the ages that conform the group plus.

Stochastic SSB estimates are showed in Table 8. The stochastic SSB means are also slightly above the deterministic values with a bias of around 2.7 % in the whole series. Coefficients of variation range from 0.18 in 1989 and 1990 to 0.27 in 2003, with a value of 0.22 in 2006. Figure 2 shows the time trend in estimated SSB with 90 % percentiles as well as the values derived from the last XSA, carried out in 2002 (Vázquez and Cerviño, 2002; Cerviño and Vázquez, 2003), albeit it has been redone due to the conversion of R/V Cornide de Saavedra survey indices to R/V Vizconde de Eza equivalents. Although XSA values are in some cases outside the confidence margins of survey-based values, both series show similar trends and both XSA and survey-based SSB estimates are under B_{lim} since 1998. An increasing trend in SSB estimates is apparent starting in 2004. Figure 3 displays the cumulative probability function of SSB in 2006 and indicates that the probability that current SSB is below B_{lim} (=14 000 tons) is still more than 90%.

We conclude this section with two final comments:

There are some new data that will allow to update the maturity ogives since the year 2000. The updated maturity ogives have not been finalised, but preliminary examination of the new data suggests that they will be similar to the ones currently used. Hence, they should not affect the conclusions of the assessment in any substantial way. The new maturity ogives will be incorporated in the assessment to be performed in 2008.

A Bayesian implementation of XSA was also tried. The model assumptions parallel those made by XSA, with prior distributions set for survivors of each cohort. The model was tuned with the EU survey abundance indices presented in Table 2, employing also the standard errors associated with these indices. The catch at age data matrix until 2001 was used. From 2002 onwards two possible scenarios were considered, one with no fishing mortality and a second one with small stochastic fishing mortalities. Both scenarios led to similar SSB estimates and here we present only the results corresponding to the second one, which we consider more realistic. Figure 4 presents SSB point estimates and corresponding 95% probability intervals from the Bayesian model and compares the results with those obtained in the last approved XSA (conducted with data up to 2001 and with survey values transformed to R/V Vizconde de Eza equivalents). The overall conclusion is similar to that reached with the survey-based method, with estimated SSB showing an increase in the last few years, albeit this increase is less pronounced than with the survey-based method. We plan to explore the potential of the Bayesian model in the full cod assessment to be conducted in 2008.

DISCUSSION

Based on the observed trends of the EU bottom trawl survey abundance at age it could be concluded that the cod stock in Division 3M shows some signs of recovery. There has been an increasing trend in biomass since 2004 and SSB is currently estimated at about 10 200 tons. However, the probability that SSB was below B_{lim} in 2006 is still more than 90%. The abundance at age 1 in the EU survey in 2005 was the highest observed since 1993 and the value observed in 2006 has more than doubled that of 2005, getting closer to (albeit still below) the values observed before 1993, when the population was in a healthy state.

The survey-based method used reinforced this perception of the state of the stock. This method has advantages with respect to traditional VPA in situations where there are no catches. Moreover, the method gives the probability distribution of SSB, which fits immediately within the NAFO Precautionary Approach framework. Thus, it can be used by Scientific Council to provide advice about re-opening the fishery and the risk associated with that decision.

- The method avoids the use of a VPA based procedure, whose results became unrealistic given the low catch levels since the year 2000.

- The method uses abundance indices and catchability at age from VPA as input variables to produce an absolute SSB estimate, in the same scale used to set B_{lim} (14 000 tons for 3M cod).

- The method provides the error distribution of state variables, SSB and abundance at age, taking into account survey sampling errors and catchability errors.

- The method provides the distribution of SSB estimates, which allows calculating the probability that SSB is below or above B_{lim}, avoiding the need to set B_{buff} as a precautionary reference.

- The abundance at age distribution allows the use of stochastic projections as a tool to advice on the fishing mortality that could be applied after re-opening the fishery.

- The method can be applied to other stocks in a situation similar to Flemish Cap cod. A survey with estimated errors of abundance at age and estimates of catchability at age is all that is needed.

In summary, the recent increasing trend in estimated SSB (with SSB in 2006 estimated at around 10 200 tons) and the abundances of age 1 fish observed in 2005 and 2006 indicate a possible recovery of the stock in the near future. However, the current estimated value of SSB is below B_{lim} and the increasing trend in SSB refers only to the last 3 years, so it is premature to be conclusive in that direction.

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Table 1 – Total cod catch in Flemish Cap. Reported nominal catches since 1959 and estimated total catch since 1988 in tons.

Year	Estimated	Faroes	Japan	Korea	Norway	Portugal	Russia	Spain	UK	France	Poland	Others	Total
1959					11		6470	466				2	6949
1960		260			166	9	11595	607			2	96	12735
1961		246			116	2155	12379	851	600	2626	336	1548	20857
1962		188	1		95	2032	11282	1234	93		888	363	16176
1963		969	35		212	7028	8528	4005	2476	9501	1875	853	35482
1964		1518	333		1009	3668	26643	862	2185	3966	718	1172	42074
1965		1561			713	1480	37047	1530	6104	2039	5073	771	56318
1966		891			125	7336	5138	4268	7259	4603	93	259	29972
1967		775			200	10728	5886	3012	5732	6757	4152	802	38044
1968		852	223		697	10917	3872	4045	1466	13321	71	235	35699
1969		750	30		1047	7276	283	2681		11831		42	23940
1970		379	34		1347	9847	494	1324	3	6239	53	1	19721
1971		708	6		926	7272	5536	1063		9006	19	1647	26183
1972		6902			952	32052	5030	5020	4126	2693	35	693	57503
1973		7754			417	11129	1145	620	1183	132	481	39	22900
1974		1872			383	10015	5998	2619	3093		700	258	24938
1975		3288			111	10430	5446	2022	265		677	136	22375
1976		2139			1188	10120	4831	2502		229	898	359	22266
1977		5664	24		867	6652	2982	1315	1269	5827	843	1576	27019
1978		7922	22		1584	10157	3779	2510	207	5096	615	1239	33131
1979		7484	74		1310	9636	4743	4907		1525	5	26	29710
1980		3259	37		1080	3615	1056	706		301	33	381	10468
1981		3874	9		1154	3727	927	4100		79		3	13873
1982		3121	10	4	375	3316	1262	4513	33	119			12753
1983		1499	1		111	2930	1264	4407				3	10215
1984		3058	9		47	3474	910	4745				459	12702
1985		2266	5		405	4376	1271	4914				438	13675
1986		2192	6			6350	1231	4384				355	14518
1987		916	269			2802	706	3639		2300			10632
1988	28899	1100	5	6		421	39	141				6	1718
1989	48373		38	321		170	10	378					917
1990	40827	1262	24	815		551	22	87				1	2762
1991	16229	2472	54	82	897	2838	1	1416	26			1203	8989
1992	25089	747	2	18		2201	1	4215	5			6	7226
1993	15958	2931		3		3132		2249				1	8316
1994	29916	2249			1	2590		1952					6885
1995	10372	1016				1641		564					3221
1996	2601	700				1284		176	129			16	2305
1997	2933					1433		1	23				1475
1998	705					456							456
1999	353					3							3
2000	55					30	6						36
2001	37					54							54
2002	33					32	1						33
2003	16					7						9	16
2004	5						2					3	5
2005	19					16							3
2006	339					51	1					54	106

Table 2 - EU bottom trawl survey abundance indices (in '000) for ages 1 to 14 and years 1988 to 2006 (upper panel); corresponding standard errors (lower panel).

Abundance Indices

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	4850	22100	2660	46100	75480	4600	3340	1640	41	42	27	7	186	487	0	665	0	8069	19710
2	78920	12100	14020	29400	44280	56100	4550	13670	3580	171	94	96	16	2048	1340	53	3379	16	3883
3	49050	06400	5920	20600	6290	35400	31580	1540	7649	3931	106	128	343	15	609	610	25	1118	62
4	13370	63400	19970	2500	2540	1300	5760	4490	1020	5430	1408	129	207	125	24	131	602	78	1481
5	1450	23800	18420	7800	410	1500	150	1070	2766	442	1763	792	100	81	68	22	168	708	86
6	210	1600	5090	2100	1500	200	70	40	221	1078	87	491	467	15	36	47	5	136	592
7	220	200	390	300	270	600	10	30	9	24	165	21	180	146	28	7	10	0	115
8	60	100	170	100	10	100	120	0	6	0	0	7	11	101	96	8	3	17	7
9	0	0	90	0	0	0	0	20	0	0	6	0	17	6	33	37	5	8	0
10	0	0	30	0	0	0	10	10	0	0	0	0	0	6	0	25	16	8	7
11	0	0	0	0	10	0	0	0	0	0	0	0	0	6	6	0	0	0	14
12	0	0	0	0	0	0	0	0	0	6	0	0	5	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
14	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0

Standard Error

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	1575	3358	590	49587	16130	2307	707	407	22	25	17	9	46	149	0	360	0	727	7753
2	12388	1973	1676	5178	10717	60189	1712	5547	426	57	35	36	15	199	89	29	320	10	881
3	5903	12593	728	3614	1746	7422	8003	319	1411	870	31	50	145	9	62	90	10	204	28
4	2357	6035	2636	397	934	348	1416	837	187	906	145	43	52	44	14	41	95	36	349
5	399	2871	2373	1692	190	558	50	232	424	81	229	140	31	30	22	18	38	151	30
6	64	264	689	424	499	88	33	19	53	138	28	76	87	6	14	24	5	53	138
7	77	54	99	74	89	151	9	18	10	13	48	14	45	47	13	10	7	0	41
8	37	75	72	33	13	39	44	0	9	0	0	9	11	32	24	10	3	14	8
9	0	10	50	22	0	0	0	18	0	0	10	0	14	12	14	23	5	7	0
10	0	9	23	9	0	0	10	9	0	0	0	0	0	10	0	19	10	7	10
11	0	0	0	14	10	0	0	0	0	0	0	0	0	9	6	0	0	0	13
12	0	0	0	0	0	0	0	0	0	9	0	0	10	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
14	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0

Table 3 - Weight (in kg) and maturity at age estimated from EU bottom trawl survey.

Weight at age

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	0.03	0.04	0.04	0.05	0.05	0.04	0.06	0.05	0.04	0.08	0.07	0.10	0.10	0.08	0.00	0.05	0.07	0.02	0.09
2	0.10	0.24	0.17	0.17	0.25	0.22	0.21	0.24	0.25	0.32	0.36	0.37	0.58	0.48	0.42	0.33	0.60	0.64	0.70
3	0.31	0.54	0.34	0.50	0.49	0.66	0.59	0.47	0.53	0.64	0.75	0.92	0.96	1.25	1.12	0.90	1.42	1.37	1.06
4	0.68	1.04	0.85	0.86	1.38	1.21	1.32	0.96	0.80	1.00	1.19	1.30	1.61	1.70	1.43	1.50	2.07	2.44	2.49
5	1.97	1.60	1.50	1.61	1.70	2.27	2.26	1.85	1.32	1.31	1.66	1.85	1.91	2.56	2.47	2.86	3.22	3.13	3.57
6	3.59	2.51	2.43	2.61	2.63	2.37	4.03	3.16	2.27	2.10	1.99	2.44	2.83	3.42	3.59	3.52	5.31	4.54	4.69
7	5.77	4.27	4.08	4.26	3.13	3.45	4.03	5.56	4.00	2.00	3.10	3.51	3.47	3.91	4.86	5.52	5.88		5.76
8+	6.93	6.93	5.64	7.69	6.69	5.89	6.72	8.48	5.03	9.57	7.40	4.89	5.28	5.22	5.31	5.80	7.84	6.21	9.55

Maturity at age

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.04	0.04	0.07	0	0	0.02	0.02	0	0.02	0.08	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
4	0.18	0.18	0.34	0.23	0.23	0.16	0.57	0.77	0.56	0.69	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
5	0.63	0.63	0.52	0.78	0.79	0.73	0.97	1	1	0.91	1	1	1	1	1	1	1	1	1
6	0.75	0.75	0.50	0.91	0.86	1	1	1	1	0.96	1	1	1	1	1	1	1	1	1
7	0.85	0.85	0.71	0.84	0.74	0.95	1	1	1	1	1	1	1	1	1	1	1	1	1
8+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4 - Variance-covariance matrix for catchability parameters from XSA with calibration data from 1988 to 1999. Upper panel shows covariance estimated by conditioned *bootstrap*. Intermediate panel shows covariance estimated by unconditioned *bootstrap*. And the lower panel shows the difference among conditioned and unconditioned covariance.

Conditioned	***q' 1***	***exp 1***	***q 2***	***q 3***	***q 4***
q' 1	0.021				
exp 1	-0.013	0.011			
q 2	0.005	-0.003	0.029		
q 3	0.002	-0.001	0.006	0.039	
q 4	0.002	-0.001	0.004	0.004	0.022

Unconditioned	***q' 1***	***exp 1***	***q 2***	***q 3***	***q 4***
q' 1	0.007				
exp 1	-0.005	0.005			
q 2	0.001	-0.001	0.011		
q 3	0.001	-0.001	0.000	0.008	
q 4	0.001	0.000	0.001	0.001	0.005

Con.-Uncon.	***q' 1***	***exp 1***	***q 2***	***q 3***	***q 4***
q' 1	0.014				
exp 1	-0.008	0.007			
q 2	0.004	-0.002	0.018		
q 3	0.001	-0.001	0.005	0.031	
q 4	0.001	0.000	0.004	0.003	0.017

Table 5 - Catchability parameters applied in the simulation. Expected values were estimated from XSA with calibration data from 1988 to 1999. Standard errors and correlation were estimated from the *bootstrap*-subtracting algorithm.

Q	***Mean***	***s.e.***	***cv***	***corr***	***q' 1***	***exp 1***	***q 2***	***q 3***	***q 4***
q' 1	0.11	0.12	1.07	***q' 1***	1.00				
exp 1	1.17	0.08	0.07	***exp 1***	-0.81	1.00			
q 2	1.13	0.13	0.12	***q 2***	0.23	-0.19	1.00		
q 3	1.04	0.18	0.17	***q 3***	0.05	-0.05	0.23	1.00	
q 4	0.79	0.13	0.16	***q 4***	0.07	-0.05	0.21	0.14	1.00

Table 6.- Abundance at age (‘000) and spawning stock biomass (SSB t) estimated from the deterministic algorithm.

Abundance

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	10171	37145	6090	186415	106050	9721	7396	4029	173	176	121	36	629	1428	0	1862	0	15710	33686
2	79337	11822	13776	29064	51764	156736	6339	13327	3561	167	92	94	22	2010	1306	51	3294	16	3786
3	64144	139331	7106	28174	10931	53314	62223	1926	9487	5929	119	147	471	16	648	649	27	1190	66
4	24392	134359	46608	4171	7026	3368	14626	12940	2118	10392	2285	207	291	182	34	184	841	109	2069
5	2651	63186	50470	14534	1824	3718	255	5856	6534	1090	3184	1270	142	115	95	30	235	989	120
6	437	3477	15082	4336	4186	1072	141	501	466	2399	180	754	657	21	50	65	7	190	827
7	610	615	987	750	1638	1372	33	241	13	87	246	32	253	205	39	10	14	0	161
8+	166	308	734	250	121	229	435	241	8	22	9	10	55	167	189	98	34	46	50
SSB	12390	102558	78259	33969	18765	15893	15953	25369	10854	14008	8878	4627	3857	2316	1888	1372	2667	5044	10208

Table 7 - *Bootstrap* statistics for abundance at age in 2006.

	age 1	age 2	age 3	age 4	age 5	age 6	age 7	age 8	age 9	age 10
mean	51494	3836	68	2125	123	851	165	10	0	10
s.d.	31064	976	33	618	48	248	66	12	0	15
cv	0.60	0.25	0.49	0.29	0.39	0.29	0.40	1.16		1.50
skewness	2.08	0.81	1.44	0.90	1.24	0.84	1.25	4.42		8.25
bias	52.9%	1.3%	2.9%	2.7%	2.8%	2.8%	2.8%	2.9%		3.2%
5.0%	18393	2455	29	1301	61	505	82	1	0	1
10.0%	22066	2714	34	1410	70	564	93	2	0	1
50.0%	43467	3717	61	2037	115	815	153	7	0	6
90.0%	90505	5093	111	2912	185	1182	252	22	0	22
95.0%	108074	5642	133	3253	211	1290	294	30	0	33

Table 8 - *Bootstrap* statistics for Spawning Stock Biomass. Bias expressed as percentage $[100*(\bar{x}_{boot} - x_{obs})/x_{obs}]$.

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Mean	12721	105307	80342	34891	19282	16317	16393	26044	11144	14385	9118	4748	3958	2378	1939	1409	2738	5182	10491
s.d.	2607	18868	14547	7522	5084	3924	4023	5526	2290	2742	1705	924	786	556	392	385	555	1124	2329
cv	0.20	0.18	0.18	0.22	0.26	0.24	0.25	0.21	0.21	0.19	0.19	0.19	0.20	0.23	0.20	0.27	0.20	0.22	0.22
skewness	0.69	0.59	0.59	0.76	0.99	0.80	0.79	0.70	0.63	0.57	0.59	0.59	0.61	0.64	0.65	1.03	0.56	0.70	0.67
bias	2.7%	2.7%	2.7%	2.7%	2.8%	2.7%	2.8%	2.7%	2.7%	2.7%	2.7%	2.6%	2.6%	2.7%	2.7%	2.7%	2.7%	2.7%	2.8%
5%	9045	77687	58879	24289	12449	10857	10649	17999	7787	10293	6625	3401	2800	1589	1379	897	1918	3602	7123
10%	9713	82414	62823	25971	13532	11786	11745	19390	8422	11080	7111	3627	3016	1721	1474	977	2073	3871	7746
50%	12350	103544	79297	33985	18598	15718	15841	25481	10915	14170	8941	4668	3865	2320	1894	1343	2689	5040	10229
90%	16291	130563	99504	44676	25962	21461	21704	33278	14143	17953	11408	5957	5004	3107	2471	1923	3461	6679	13517
95%	17467	139120	106251	48669	28710	23453	23461	35812	15190	19245	12145	6423	5364	3405	2648	2135	3717	7240	14704

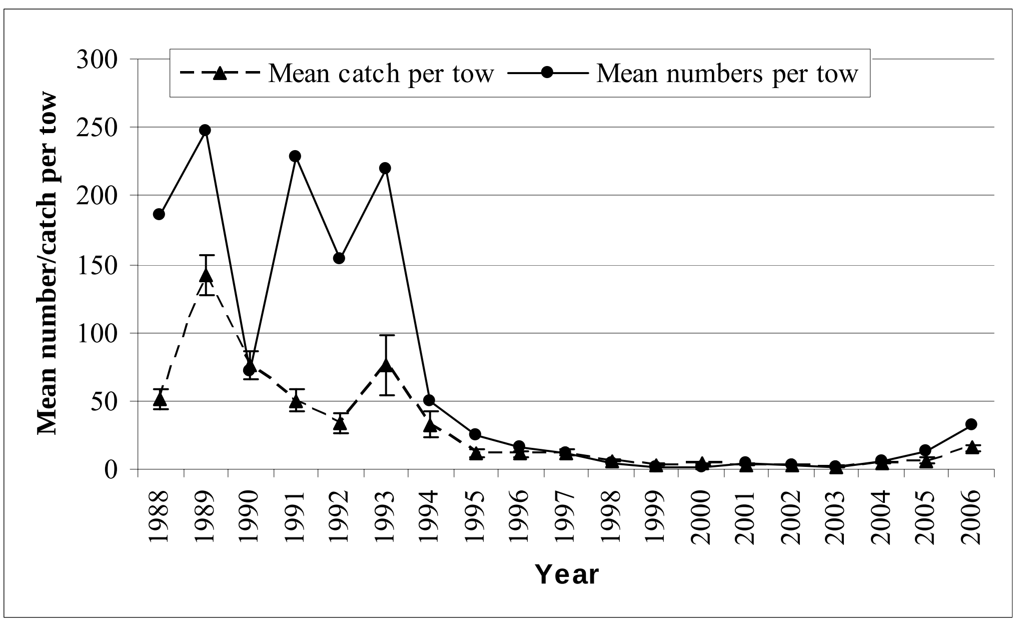

Figure 1. Mean catch per tow (kg) with s.d., and mean number per tow of Atlantic cod in EU Flemish Cap survey (1988-2006). The values from the period 1998-2002 have been transformed from R/V Cornide de Saavedra to R/V Vizconde de Eza equivalents. Values from 2003-2006 are the original data from R/V Vizconde de Eza.

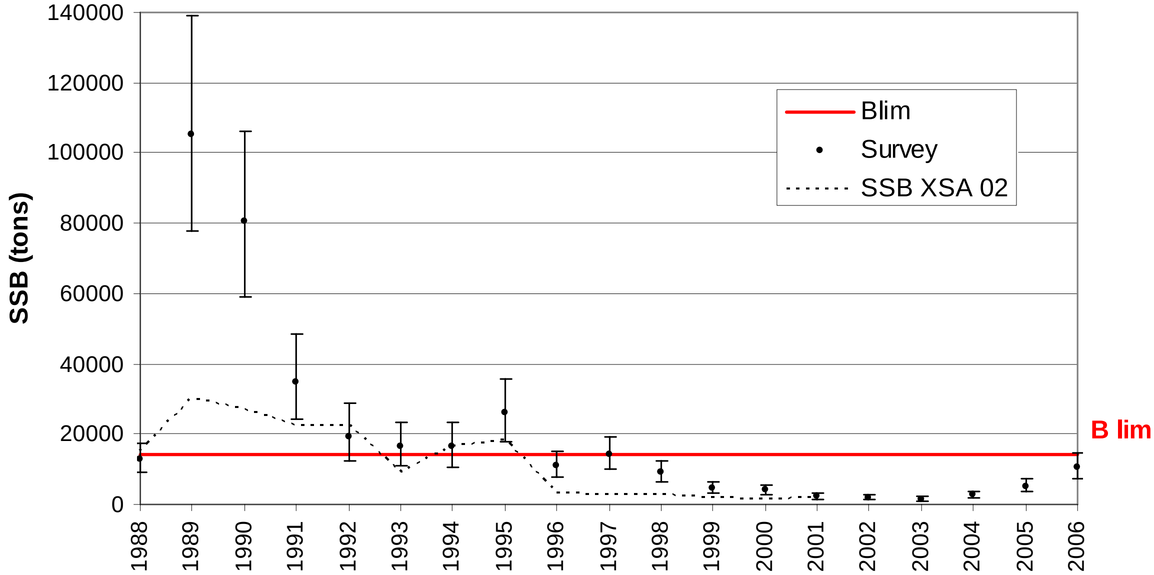

Figure 2 - SSB values and confidence intervals [0.05-0.95] for years 1988 to 2006 estimated with the stochastic survey-based method. The broken line represents the SSB values estimated from the last XSA assessment in 2002. The thick horizontal line is the B_{lim} level at 14 000 tons.

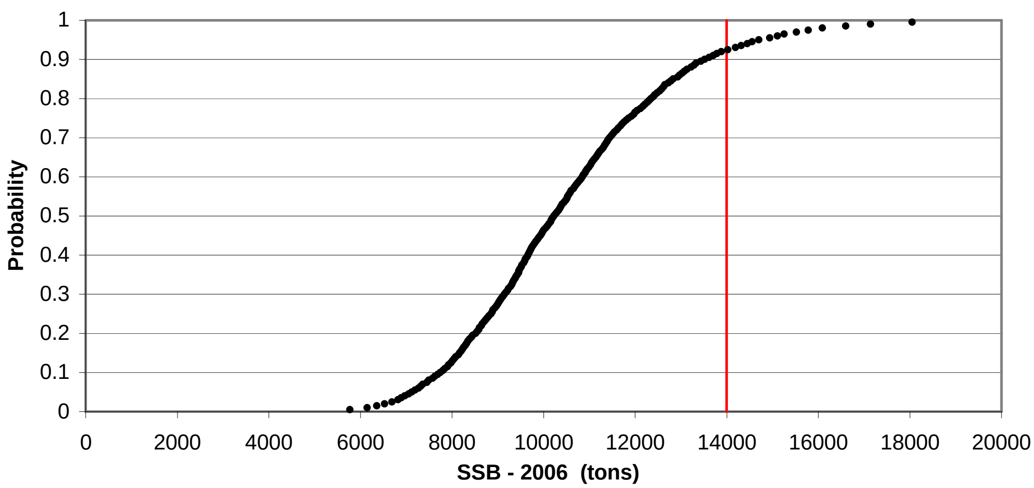

Figure 3 - Cumulative distribution of the 2006 SSB estimates.

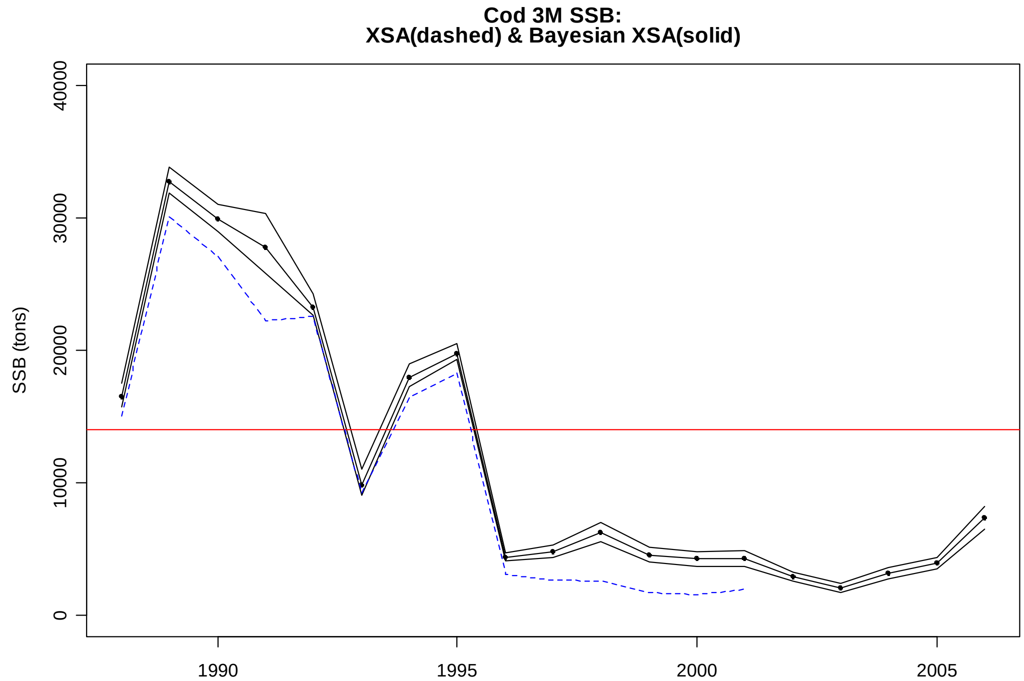

Figure 4 - Comparison of standard XSA using data until 2001 (dashed line) and Bayesian XSA (solid lines). For the Bayesian method, estimates and 95% probability limits are displayed. The horizontal line corresponds to B_{lim}=14 000 tonnes