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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 moratorium since 2000. The low catches collected since then make difficult to apply a VPA based assessment to evaluate the current stock status. Hereby, a survey-based assessment method was used to evaluate the present status in a stochastic way; a method that takes into account uncertainties in survey sampling as well as in catchability estimates. The results show that the spawning stock biomass is at the lowest observed level of the survey's series (1988 to 2003) and all its stochastic estimates are under B_{lim}. Current abundance at age of pre-mature year-classes are also at very low levels and, consequently, a recovery of the stock is not expected in a sort or medium term.

Introduction

Historical catches are shown in Table 1, where decline of the fishery is clearly observed.

A VPA based assessment of the cod stock in Flemish Cap was approved in 1999 by the first time. In that assessment, the stock status was qualified as collapsed, which was attributed to three possible causes: a stock decline due to overfishing, an increase in catchability at low abundance levels, and a very poor recruitment since 1995. The 2002 last assessment concluded that both total biomass and SSB were at such low levels that the stock would be unable to produce good recruitments in most recent years. Consequently, the recovery of the stock was not expected in a short or medium term time period (Vázquez and Cerviño, 2002).

Since 1974, when a TAC was established for the first time, catches ranged from 48,000 tons in 1989 to a minimum of 37 tons estimated for 2000. Annual catches were about 30,000 tons in the late-1980's, when the fishery was under moratoria, and they decline since then as a consequence of the stock collapse. Since 1997 catches were less than 1,000 tons and since 2000 they were less than 100 tons, mainly attributed to by-catches of Spanish and Portuguese fleets in the area.

The former 1999 VPA based assessment was annually updated until 2002. However, most recent catches were small, under 100 tons, and VPA based assessment are quite sensitive to natural mortality (M) values when catches are at low levels, as in this case. The F estimates from last analysis were at the same level than M in both 1998 and 1999 and lower than M in 2000 and 2001 (Vázquez and Cerviño, 2002). XSA results are not reliable under these conditions.

A B_{lim} of 14,000 tons was established in 2001 (Cerviño and Vázquez, 2000), and it remains as the only reference point accepted for this stock. Given the present moratorium, the fishery re-opening criterion may include a decision on the current SSB estimates being above that level in probabilistic terms. The survey-based assessment proposed here is similar to the method described by Cerviño and Vázquez (2003). It combines survey abundance indices at age with the estimated catchability at age from recent XSA. Indices and catchability uncertainty are used to calculate the statistical distribution of SSB estimates and its probability of being above B_{lim}.

Material and Methods

Data

Data needed to estimate SSB probability distribution are: indices of abundance at age and their errors; survey catchability at age and their errors; weight at age and maturity at age percentages. Errors in these last two variables were not taken into account. An estimate of total mortality is also needed to transform the abundance at survey time (in summer) to the beginning of the year.

The EU bottom trawl survey of Flemish Cap was carried out since 1988 targeting the main commercial species inside the 730 meters bathymetric contour. The surveyed zone includes the complete area distribution for cod, which rarely occurs deeper than 500 meters. The sampling procedure did not change along the series, although the research vessel used in 1989, 1990 and 2003 was not the same as used for the rest of the series. Sampling of main species includes age, length, weight and maturity. The 2003 survey was carried out with the new R/V *Vizconde de Eza* (Casas *et al.*, 2004) keeping the same gear and survey procedure. A comparative fishing trial with the R/V *Cornide the Saavedra* was performed in 2003, but the 60 paired hauls were not considered enough for calibration given the low cod abundance. The trial will be continued in 2004. The 2003 survey results for cod are used without transformation for this paper. Estimates of cod abundance at age, their standard errors and their auto-correlations were calculated following Cerviño (2002) and they are presented in Table 2; weight and maturity at age are presented in Table 3.

Catchability at age was derived from a XSA based on catch data until 1999. Annual catches after 1999 are too low and they introduce more uncertainty on XSA results. Age 1 was calibrated with a two-parameters model. Catchability for ages 2, 3 and 4 were estimated from a one-parameter model, and catchability for older ages was considered constant and equal to age 4 catchability. Variance of catchability estimates from XSA has two components: one due to the survey sampling variability and other due to the year to year catchability variability. A *bootstrap*-subtracting algorithm based on the XSA model was defined to quantify the second component, assuming additivity and independence among both components. The algorithm has three steeps:

1. Total error in catchability parameters is estimated by conditioned *bootstrap*. Covariance matrix is presented in Table 4 (upper panel).
2. Partial errors due to indices variability are estimated by unconditioned *bootstrap*. Covariance matrix is presented in Table 4 (intermediate panel)
3. Catchability covariance matrix is calculated by subtracting the two previous matrices: the one due to survey variability from the one due to total variability. The result is presented in Table 4 (lower panel)

Catchability used for simulation: values, standard errors and correlation matrix, is presented in Table 5.

The stochastic model

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

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

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

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

where the super-index * indicates stochastic values. *I* and *q* are assumed to follow a lognormal distribution with expected value and standard errors as described before. *Q* covariances were included in the model, but *I* covariances were not included because they are low in the last years.

The abundance (*N*) needs to be corrected to the beginning of the year (N^0) because that is the scale for B_{lim}. Since the UE survey is carried out in the middle of the year, the assumed total mortality (*Z*) included natural mortality (*M*) equal 0.2, and fishing mortality (*F*) from 2002 assessment, which was considered negligible.

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

SSB was calculated from survey results as the sum of products of abundance at age (*N*), mean weight (*W*) and maturity rate (*Mat*) at age.

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

SSB distribution was calculated by a 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 variance, skewness, statistical bias and percentiles.

Results

Deterministic results for abundance at age and for SSB are presented in Table 6. Abundances at age in that table were estimated independently for each year from survey results and do not follow any SPA results; it implies that cohort abundances are not forced to decrease year to year necessarily. The 2003 SSB are at the lowest observed level, 846 tons, well below the figure for all other years in the series. Abundance at ages 2 to 8+ in 2003 are at the lowest observed level; recruitment at age 1 in 2003 is the highest since 1995, however it remains at a low level in relation to the abundance in years before 1995.

Results are presented in Tables 7 and 8, and in Figures 1 and 2. Table 7 shows the *bootstrap* statistics for abundance at age. All the means are lightly above their deterministic values due to bias in the range between 0.8% and 1.8%, except for age 1, which had a bias of 50.2%. Abundance at age 1 was estimated with the two parameters model and it is likely that its distribution doesn't match properly to the assumed lognormal distribution. Coefficient of variance ranges from 1.29 for age 7 to 0.18 for age 3. All values have positive skewness.

SSB estimates are showed in Table 8. Their means are also lightly over their deterministic values, and their bias are about 1.5% in the whole series. Coefficients of variance range from 0.15 in 1990 to 0.26 in 1992, being 0.24 in 2003. All the skewness are positive. Figure 1 shows the trend in SSB with the 90 % percentiles as well as the values derived from last XSA (Vázquez and Cerviño, 2002). 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 are under B_{lim} since 1996. Figure 2 shows the most important result for reopening fishery advice: the cumulative SSB distribution that shows the probability of being over B_{lim}, which is 14,000 tons for 3M cod. Any of the 2000 *bootstrap* values are below B_{lim}.

Discussion

The observed trends of the EU bottom trawl survey abundance at age are clear enough to realize that 3M cod stock continues collapsed. All year-classes are at similar or lower level than in previous years, and no signal of recovery is observed. The abundance at age 1 in the EU survey in 2003 is the highest observed since 1996, nevertheless it is far away from the values observed before 1996, and it is not expected a recover the stock based on the observed low level of all cohorts.

The proposed survey-based method doesn't modified the survey perception about the current stock status, nevertheless it has other advantages, particularly when, thinking in a future stock recovery, the Scientific Council has to advise about re-opening the fishery and the risk associated with that decision.

- The method avoids the use of a VPA based method, which results became unrealistic year after year given the low catch levels that occurred since 2000.

- The method uses abundance indices and catchability at age from SPA as input variables to produce an absolute SSB estimate, 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 the survey sampling errors and the survey catchability errors.

- The method provides the distribution SSB estimates, which allows calculating the probability of being above B_{lim}, avoiding the need of setting B_{buff} as a precautionary decision reference.

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

- 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 are only needed.

In summary, the current SSB, being estimated as 846 tons, is at its lowest observed level in the whole series and, although recruitment at age 1 shows a lightly increase respect to previous years, this is not enough to expect a stock recovery in a short or medium term.

References

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

	Esti-	Reported											
year	mated	Faroes	Japan	Korea	Norway	Portugal	Russia	Spain	UK	France-m	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

Table 2 - EU bottom trawl survey abundance indices (in '000) for ages 1 to 14 and years 1988 to 2003 (upper panel); corresponding standard errors (intermediate panel); and correlation matrix for year 2003 (lower panel).

Abundance Indices	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	4644	20803	2492	37814	71190	4364	3147	1546	39	39	25	6	172	452		665
2	72082	11028	11937	25600	37060	32237	3835	11365	2964	139	76	78	13	1651	1154	53
3	39819	84280	4755	15381	4748	28403	24599	1238	6131	3146	85	102	276	6	557	615
4	10585	49149	15469	1928	2033	1010	4562	3595	820	4360	1137	105	170	108	26	132
5	1171	18571	14660	6283	332	1269	120	885	2247	358	1449	655	84	70	65	22
6	177	1270	4298	1674	1255	168	66	33	187	902	73	415	405	4	32	41
7	224	157	350	296	222	491	7	25	8	20	144	19	161	148	26	7
8	65	140	159	71	12	100	118		6			6	11	86	97	8
9		8	88	35				23			7		17	12	32	39
10		6	29	7			7	7						7		23
11				13	7									7	6	
12										6			6			
14													6			

Standard Error	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	1432	3053	536	45079	14664	2097	643	370	20	23	15	8	42	135		327
2	11262	1794	1524	4707	9743	54717	1556	5043	387	52	32	33	14	181	81	26
3	5366	11448	662	3285	1587	6747	7275	290	1283	791	28	45	132	8	56	82
4	2143	5486	2396	361	849	316	1287	761	170	824	132	39	47	40	13	37
5	363	2610	2157	1538	173	507	45	211	385	74	208	127	28	27	20	16
6	58	240	626	385	454	80	30	17	48	125	25	69	79	5	13	22
7	70	49	90	67	81	137	8	16	9	12	44	13	41	43	12	9
8	34	68	65	30	12	35	40		8			8	10	29	22	9
9		9	45	20				16			9		13	11	13	21
10		8	21	8			9	8						9		17
11				13	9									8	5	
12										8			9			
14													9			

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.22	1								
3	-0.07	-0.10	1							
4	0.00	0.00	0.16	1						
5	0.00	0.02	-0.11	0.00	1					
6	0.02	0.00	-0.08	-0.01	0.02	1				
7	0.00	0.02	-0.01	0.09	0.13	0.00	1			
8	-0.01	-0.01	0.11	0.00	0.01	-0.04	-0.02	1		
9	-0.09	-0.01	-0.02	0.02	0.04	0.10	-0.04	0.00	1	
10	-0.12	-0.02	0.10	0.09	0.08	-0.03	0.10	0.03	-0.03	1

Table 3 - Weight and maturity at age estimated from EU bottom trawl survey.

Weight at age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
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
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
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
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
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
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
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
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

Maturity at age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	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
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
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
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
6	0.75	0.75	0.5	0.91	0.86	1	1	1	1	0.96	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
8+	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	0.0222				
exp 1	-0.0131	0.0111			
q 2	0.0045	-0.0030	0.0203		
q 3	0.0024	-0.0014	0.0044	0.0241	
q 4	0.0009	-0.0004	0.0031	0.0031	0.0134

Unconditioned	***q' 1***	***exp 1***	***q 2***	***q 3***	***q 4***
q' 1	0.0082				
exp 1	-0.0055	0.0048			
q 2	0.0012	-0.0010	0.0092		
q 3	0.0005	-0.0005	0.0000	0.0061	
q 4	0.0005	-0.0004	0.0003	0.0009	0.0038

Con.-Uncon.	***q' 1***	***exp 1***	***q 2***	***q 3***	***q 4***
q' 1	0.0139				
exp 1	-0.0076	0.0063			
q 2	0.0033	-0.0020	0.0111		
q 3	0.0018	-0.0009	0.0043	0.0179	
q 4	0.0004	0.0000	0.0028	0.0023	0.0095

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				
exp 1	1.17	0.08	0.07	***exp 1***	-0.81	1			
q 2	1.13	0.11	0.09	***q 2***	0.26	-0.24	1		
q 3	1.04	0.13	0.13	***q 3***	0.12	-0.08	0.31	1	
q 4	0.79	0.10	0.12	***q 4***	0.03	0.00	0.27	0.17	1

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

Abundance	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	9801	35275	5761	177347	100880	9293	7029	3831	164	167	113	34	588	1339	0	1862
2	72462	10774	11730	25308	43324	132776	5343	11080	2949	136	75	76	18	1621	1125	51
3	52072	110364	5708	21036	8251	42776	48468	1548	7604	4745	95	118	378	7	593	654
4	19311	104158	36104	3216	5623	2616	11584	10362	1702	8344	1845	167	240	158	36	184
5	2140	49303	40167	11708	1478	3146	204	4844	5308	883	2618	1050	118	99	91	31
6	368	2759	12734	3456	3503	901	133	414	395	2007	150	638	571	6	45	57
7	623	484	885	739	1348	1123	23	198	12	72	215	29	225	208	36	10
8+	179	432	403	177	72	229	394	0	9	0	0	10	15	121	136	11
SSB (tons)	10946	81361	62153	27546	15307	13441	13027	19035	8861	11257	7252	3867	3160	1956	1545	846

Table 7 - *Bootstrap* statistics for the 2003 abundance at age.

Abundance 2003	1	2	3	4	5	6	7	8+
Mean	2797	52	665	187	32	58	10	11
Standard Deviation	1826	26	123	57	23	33	13	13
cv	0.65	0.50	0.18	0.31	0.73	0.57	1.29	1.10
Skewness	1.99	1.50	0.55	0.91	2.39	2.41	5.29	3.65
Bias	50.2%	0.8%	1.6%	1.5%	1.8%	1.5%	1.4%	0.7%
5%	853	21	482	106	9	21	1	2
10%	1090	25	513	121	11	26	2	2
50%	2323	46	654	179	25	51	6	7
90%	4937	84	828	260	58	98	22	24
95%	6205	102	888	292	76	118	32	34

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

SSB survey (bootstrap)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Mean	11118	82613	63110	27962	15539	13662	13226	19336	8990	11425	7363	3927	3209	1985	1570	858
Standard Deviation	2058	12860	9718	5466	3979	3194	3158	3911	1657	1860	1165	686	567	424	280	204
cv	0.19	0.16	0.15	0.20	0.26	0.23	0.24	0.20	0.18	0.16	0.16	0.17	0.18	0.21	0.18	0.24
Skewness	0.53	0.57	0.40	0.70	0.95	0.92	0.76	0.85	0.60	0.53	0.48	0.61	0.60	0.59	0.59	1.19
Bias	1.6%	1.5%	1.5%	1.5%	1.5%	1.6%	1.5%	1.6%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.6%	1.5%
5%	8099	63588	48392	20040	10020	9375	8844	13896	6528	8633	5590	2932	2389	1358	1166	587
10%	8617	67286	51475	21429	11007	10025	9486	14879	7016	9202	5927	3123	2525	1478	1232	639
50%	10966	81424	62317	27520	14997	13229	12837	18859	8841	11208	7263	3861	3154	1932	1546	827
90%	13847	98950	76095	35045	20985	17839	17405	24450	11180	13930	8932	4825	3933	2558	1935	1115
95%	14705	105895	80339	37521	22841	19470	18774	26305	11976	14696	9389	5209	4215	2744	2062	1242

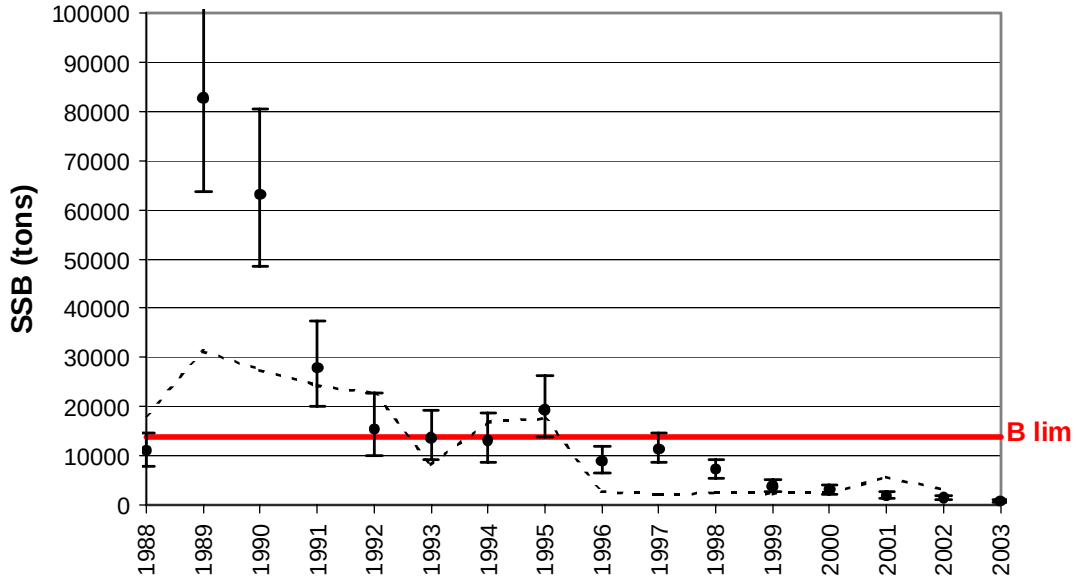

Figure 1 - SSB values and confidence intervals [0.05-0.95] for years 1988 to 2003 estimated with the stochastic survey-based method. The broken line represents the SSB values estimated from XSA in the 2002 assessment. The red thick line is the B_{lim} level at 14 000 tons.

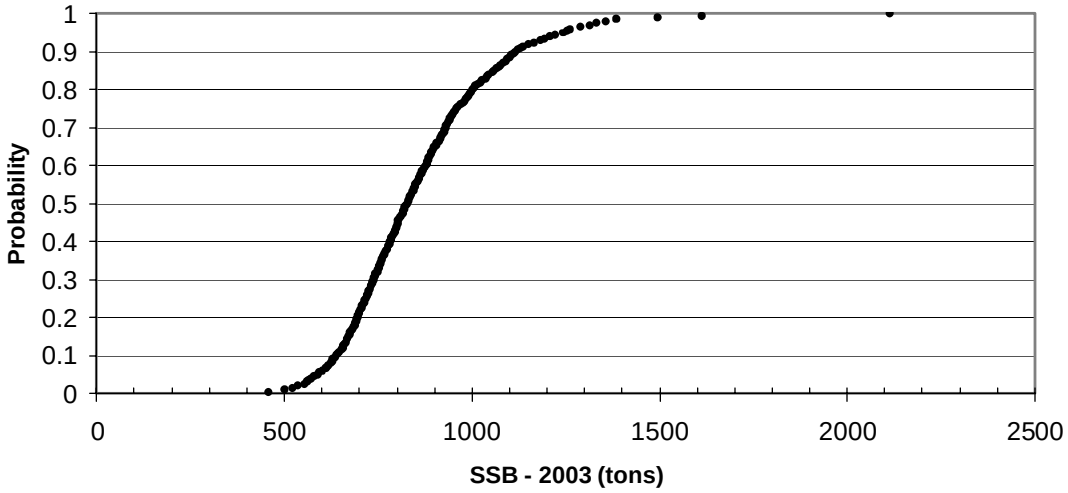

Figure 2 - Cumulative distribution of the 2003 SSB estimates.