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An Assessment of the Cod Stock in NAFO Division 3M

by

A. Vázquez[1] and L. Motos[2] and J.-C. Mahé[3]

[1] Instituto de Investigaciones Marinas, Eduardo Cabello 6, 36208 Vigo, Spain
e-mail: avazquez@iim.csic.es
[2] AZTI - Technological Institutes for Fisheries and Food, Satrustegui 8, 20008 San Sebastián, Spain
e-mail: lorenzo@rp.azti.es
[3] IFREMER, Station de Lorient, 8, Rue François Toullec, 56100 Lorient, France
e-mail: jcmahe@ifremer.fr

Abstract

This paper reviews past analyses of the cod stock in NAFO Division 3M (Flemish Cap) and presents an updated one. An Extended Survivor Analysis (XSA) was carried out for ages 1 to 8+ and years 1973 to 1998. This analysis link past sequential population analysis for the 1972 to 1983 period with the period since 1988. The analysis was tuned with EU survey results.

High fishing mortalities are observed throughout the age range of the exploited population during those years, although at a lower level than previously assumed. Fishing mortality (F 3-5) was higher than 1 in 1994 and 1995, when total biomass sharply declined.

The present status of the stock can be qualified as collapse. It seems likely to be a consequence of three factors, i.e. an increase in catchability at low abundance levels, a stock decline due to fishing, and a very poor recruitment regime since 1995.

KEYWORDS: Cod, Flemish Cap

Introduction

A review of the last year analysis on the cod stock on Flemish Cap, NAFO Division 3M, is presented. The sequential population analysis for the period 1988-1997 (Vázquez and Motos, 1998) is reviewed, extending the data series back to 1973 and updating it with the 1998 data.

The historical record catches over 50,000 tons reported for 1965 and 1972 contributed to the myth of Flemish Cap being a fishery where huge catches had been made in the past and where a continuous stock decline have occurred since then. The stock was considered to be at a very low level in 1977 (Mari and Terre, 1977), even annual catches were over 20,000 tons. However, there is no confidence that such high catches over 50,000 tons have been taken. The record catch of 57,000 tons in 1972, for example, could be overestimated because al that time ICNAF was deciding to establish a TAC for this stock for the first time, to be distributed by countries according to historical catch records. Other example of inaccurate catch report could be the catch sharp decline occurred in 1980, after TAC was lowered from 40,000 to 12,000 tons.

Catches

Total cod catches since 1959 are presented in Table 1, including estimated catches since 1988. A last review of commercial catches by countries from 1960 to 1990 is available from NAFO Statistical Bulletin (Anon., 1995). In some of those years, particularly before 1972, the nominal catches were not reported by divisions; those have been allocated on the basis of the catches by other countries which reported by divisions. The new figures are lower than those previously accepted, particularly before 1972.

Total annual catch since 1988 have been independently estimated because large discrepancies were observed from 1988 to 1990, the period when a moratorium to fish cod was in action. An extended revision of skippers' logbooks from each component of the Spanish and Portuguese fleets was carried out for year 1988 to 1994 (Vázquez *et al*., 1995). The Canadian Surveillance reports were also an important source of information. Spanish catch and effort data from 1995 onwards was derived from STATLANT 21B. Portuguese catch and effort data for 1995 were derived the same way as in the previous period, and since 1996 they were taken from Portuguese STATLANT 21B. The use of STATLANT data for those years is justified by the fact that all EU vessels fishing in NAFO Regulatory Area had an independent observer on board since May 1995.

The 1998 fishery

The 1998 cod fishery was at the same low level as in 1996 and 1997: most of the fleets traditionally aimed to 3M cod didn't participate, particularly Portuguese gillnetters and Faroese longliners. Only two Spanish pair-trawlers came to the fishery but they moved to fish for Greenland halibut.

The 1998 total cod catch is estimated to be around 705 tons (Table 1), including 205 tons attributed to vessels from Non-Contracting Parties, according to Canadian Surveillance reports.

Input data

Catch in numbers

Catches before 1988 were not considered in previous sequential population analysis (Vázquez and Motos, 1998), because it was generally assumed that reported catches were inaccurate. Even so, an effort was made to link the current SPA for years 1988-1998 to the two analyses of previous years: 1959-1968 and 1972-1973. Catch in number for the years 1959-1968 was presented by Wells (1973) and later modified by Wells (1980), who also included data from years 1972 to 1979. In the three years between 1968 and 1972 catches were not sampled. So data of the former series could not be linked to the later series y they were not included in the present analysis. Data from 1972 were also excluded due to the extraordinary high level of the catch in that year.

Total cod catches for years 1972-1983, as used in the former analyses (Wells et al., 1984), were not modified in the last revision made by NAFO (Anon., 1995), so the catch at age matrix was taken at it was.

Catch at age for 1984 was calculated by Baird and Wells (1986). Catch at age for 1985 was calculated using sampling results for Portuguese otter trawl catch (4376 t) (Godinho, 1986) and Spanish pair-trawl catch (4914 t) (Vázquez, 1986). It was assumed that the Faeroes long-line catch (2266 t) had the same age distribution as the Spanish pair-trawl, and that the age distribution of all other countries (2119 t) was equal to the Portuguese and the Spanish one in the same proportion.

Catch at age for 1986 was also calculated using sampling data for Portuguese side-trawlers (6350 t) (Godinho, 1987) and Spanish pair-trawlers (4384 t) (Vázquez, 1987). It was also assumed that the Faeroes long-line catch (2192 t) had the same age distribution as the Spanish pair-trawl, and that the age distribution of all other countries (1592 t) was equal to the Portuguese and the Spanish one in the same proportion.

Catch at age for 1987 was calculated in the same procedure. Both Portuguese (2802 t) (Godinho, 1988) and Spanish pair-trawl sampling of the catch (3639 t) (Vázquez, 1988) were available. The same criterion was followed with Faeroes catch (916 t) and the catch of all other countries (3275 t). Calculation of catch in number is in all cases accompanied of the estimation of the weight at age in the catch.

Catches from 1988 to 1998 were used as in the last analysis (Vázquez and Motos, 1998).

Biological information of cod catches in Div. 3M is available for Portuguese stern trawlers in January and for the period from June to September (Alpoim et al., 1999). Dominant lengths were between 42 and 60 centimetres with a mode at 51 cm. The 1994 and 1993 year-classes, with 4 and 5 years old in 1998, dominated the trawl catches (Table 2). The 1998 cod catch by Non-Contracting Parties was considered to have a length and age structure similar to the Portuguese trawl catch. The total numbers for 1998 were then incorporated in the catch-at-age data file (Table 2).

Mean weight in the stock for the period 1973 to 1985 was calculated by Baird and Wells (1986) based on survey results. Data from the EU survey (Vázquez, 1999) were used for the years 1988 to 1998.

The 1998 mean weights-at-age, used to update the catch weights-at-age data file, were derived from Portuguese trawl data. The stock weights-at-age were calculated using survey data (Table 3).

Survey indices of abundance at age

Abundance at age indices, as calculated in the EU survey (Vázquez, 1999), was used for tuning the analysis (Table 4). Survey indices of abundance at age are also available from the Canadian survey from 1977 to 1985 (Wells and Baird, 1985), and the Russian survey from 1977 to 1996 (Kiseleva and Vaskov, 1994; Kiseleva, 1996; 1997). Data of the Canadian survey were not used to calibrate the SPA because the contribution of data from many in advance is insignificant to the XSA fit. Data of the Russian survey were not used to calibrate the SPA due to their poor results in previous catchability analysis (Vázquez and Motos, 1998).

A Canadian survey of Flemish Cap in 1996 estimated total cod biomass by swept area method as 9,300 tons (Brodie *et al*., 1997), but the survey was discontinued afterwards.

Maturation ogive

Length at 50% maturity was calculated at 52 centimetres in January-February 1979 (Wells, 1979), and it corresponds to same intermediate age between 4 and 5 years old cod. Kuzmin (1990) calculated the proportion of mature cod at age for the period 1986 to 1989. The 50% maturity occurred at age 5 (Table 5a). The deepest change in this stock was observed during the last years. According to most recent analysis, cod spawned at a younger age in the last years than in the past: first maturity occurred at age 4 and younger since 1994.

Kiseleva (1999) presents the proportion of mature females from 1980 to 1996 according to survey results. Age at first maturation (50%) estimates have a noticeable interannual variability and ranged between 4.6 and 7.4 year old in the period 1960 to 1993 and decreased below those levels in 1995 and 1996. The observations are coincident with the same data presented by Saborido-Rey (1997) which covers only the 1992 to 1996 period. Even so, these latter data were preferred because they, joint to the 1997 and 1998 data (Saborido-Rey and Junquera, 1999) show a more progressive change in the last years, when the deepest change is supposed has occurred. Percentage of maturation prior to 1992 was supposed assumed to be constant with 50% maturation at age 5 (Table 5b).

Other data files for Extended Survivors Analysis (XSA)

Natural mortality was assumed at 0.2.

No effort/catch at age matrices from commercial CPUE series were used in the present analysis due to the discrepancy observed between survey biomass and CPUE trends over the time period considered (Avila de Melo and Alpoim, 1996). The series was discontinued in 1997.

Status of the stock

General production models

Results of past analyses with general production models are summarised in the text table below:

Author	MSY	Y 2/3Fmsy	Bmsy	years
Mari and Terre (1976)	40000			1963-1974
Mari and Terre (1977)	37000-40350			1957-1975
Mari and Dominguez (1978)	37500-39720			1956-1976
Wells (1978)	39400	36800		1962-1976
Tabares (1978)	33600			1966-1976
Gavaris (1979)	38930	34000		1960-1977
Gavaris (1980)	33000		175000	1960-1979
Gavaris (1981)	29000			1960-1980

Most of the catch data used in these analyses have been revised. CPUE values from 1960 to 1980 as presented by Gavaris (1981) are the most complete series and inconsistent data were already excluded. The results of those analyses show a MSY in the range of 30,000 to 40,000 tons, which is consistent with a fishery beyond that MSY point, with an annual catch of 20,000 to 30,000 tons and the perception of overfishing.

Sequential population analysis

An Extended Survivor Analysis (XSA) (Darby and Flatman, 1994) was carried out for ages 1 to 8+ and years 1973 to 1998 (Table 5). A first analysis was carried out with the same settings that in the last year (Vázquez and Motos, 1998) achieving results consistent with the former analysis. The analysis was repeated setting catchability independent of year-class strength for all ages (instead of 3 onwards), because slopes of catchability regression were not dependent on stock abundance, they were not significantly different from 1. The age at which catchability is considered independent of age was set in age 6 (instead of 4), to avoid some high residuals in the oldest ages. Figure 1 shows the catchability analysis plots for the EU survey. Residuals of the catchability regressions for the EU survey are presented in Figure 2. Results from the retrospective analysis appear reasonably consistent (Figure 3), although F (3-5) in 1995 appeared to be badly underestimated in the yearly analysis.

Spawning stock biomass (SSB) was calculated from XSA results on abundance-at-age, mean weights-at-age in stock and percentages of maturity-at-age.

Total biomass and recruitment abundance from 1973 to 1998, all of them from XSA, and spawning stock biomass, calculated as described above, are presented in Figure 4. First maturity at younger ages, together with the relatively abundant survivors of the 1991 year-class, allowed for maintenance of the spawning stock biomass level in 1994 and 1995, although total biomass sharply decreased. However, this relatively high level of spawning stock was not reflected in the strength of the 1994 and 1995 year-classes, which are among the weakest in the time series, according to the EU survey results. This could be due either to the fact that younger spawners are less fecund that older ones or, alternatively, to the effect of bad surviving conditions for pre-recruit stages in those years. Spawning stock decreased after 1995, and the recruitment further decreased in 1996 and 1997.

Total biomass, according XSA results, presents stable values of about 30,000 tons during early 80's and around 55,0000 tons during the late 80's and early 90's. Total biomass peaked in 1976 and in 1989, around 90,000 and 110,000 tons, respectively. Total biomass declined after 1993 to a level below 20,000 tons, that had been never observed before. This decline seems to be related with the reduction by fishing of the abundant 1985 and 1986 cohorts.

High fishing mortalities are observed throughout the age range of the exploited population during those years (Figure 5), although at a lower level than previously assumed. Fishing mortality (F 3-5) reached the highest value in the 1992 to 1995 period, and total biomass sharply declined later. Such a high fishing mortality and reduction in total biomass could in part be explained by the behaviour of cod, which forms dense shoals when its abundance declines. This behaviour could make it possible a profitable fishery even at very low total biomass levels, as it could happen in 1995. This possibility was already noticed during the 1994 EU survey, when half of the catch has been taken in a single tow. That tow was not taken into account for biomass estimates to avoid an abrupt change in total survey biomass from the 1994 to the 1995 level.

It was also observed that the cod stock in Flemish Cap reduced its distribution to the shallowest portion of the bank in last years, contributing to produce higher densities than expected according to total biomass levels. These two features appearing at low biomass levels, i.e. the aggregation in dense shoals and the reduction of the distribution area should have contributed to an increase in catchability and consequently an increase in fishing mortality. The abundant 1991 and 1990 year-classes supported the fishery in those years. Total biomass declined to a level below 20,000 tons since 1994, the lowest recorded in the time series. The failure of recruitment since 1992 impedes the recovery of the stock, even at the current low level of fishing effort.

The evolution of fishing mortality and spawning stock biomass from 1988 to 1997 period deduced from XSA results are presented in Figure 6.

The stock-recruitment relationship for this stock is presented in Figure 7, using the XSA results for spawning stock biomass and abundance at age 1 as recruitment indices.

Biological reference points

Yield per recruit analysis

Gavaris (1981) calculated that the F0.1 value for 3M cod was 0.13, based on data from 1978 to 1980. This result was considered somewhat low because growth of cod should be slower at higher densities

The F0.1 and F_{max} reference points for the current exploitation pattern were calculated with partial recruitment, calculated by averaging fishing mortalities at ages for all years in XSA results and scaling to a flat-top for ages 4 onwards; mean weights at age, calculated as mean weight at age in the surveys (Table 2), and natural mortality equal 0.2 (Table 6). It is clear from Figure 6 that fishing mortality has been well above the F 0.1 level for the current exploitation pattern at least since 1988.

PA biological reference points

The output of the XSA assessment was used to derive biological points of reference for the stock using PAsoft software. The results are presented here for discussion. The data input is presented in table 8 and the outputs are presented in figure 8.

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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	795	2838	1	1416	26			1296	8980
1992	25089	747	2	18		2201	1	4215	5				7189
1993	15958	2075		3		3130		2249				1	7458
1994	29916					2587		1952					4539
1995	10372	1125	2		1	1670		563				444	3805
1996	2601	715	2			1284		176				49	2226
1997	2933					1432		1					1433
1998	705					455							455

Table 2 - Catch in numbers. ('000)

	Age													
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1959	0	0	170	921	3375	858	74	57	40	17	1	1	1	1
1960	0	0	1074	886	386	3544	2408	250	198	261	719	281	52	1
1961	0	0	1173	3933	3065	920	4736	3546	348	299	194	304	64	24
1962	0	0	593	1174	2342	1861	549	2424	1833	191	146	119	57	29
1963	0	0	1	363	7766	6990	3168	2031	2443	822	266	145	145	48
1964	0	0	15	1243	1889	11792	4695	1678	276	729	453	1	1	1
1965	0	0	794	1479	4660	7732	16772	3169	448	533	897	170	1	1
1966	0	0	43	801	595	3702	4795	5725	1486	175	743	661	43	89
1967	0	0	18	1759	5365	1798	2902	3136	3620	914	120	462	381	77
1968	0	0	1	35	3049	8628	2565	1399	717	639	121	35	69	9
1969	0													
1970	0													
1971	0													
1972	0	0	278	19303	12372	6555	3083	1672	1106	269	96	34		
1973	0	0	2035	116	11709	3470	853	271	504	39	155	116		
1974	0	0	5999	11130	2232	1894	271	21	75	43	75	43		
1975	0	0	7090	2436	1241	238	281	96	35	46	31	50		
1976	0	0	17564	10653	386	100	63	1	1	1	1	1		
1977	0	0	119	17581	8502	436	267	45	151	90	16	16		
1978	0	0	428	3092	18077	3615	329	91	95	50	13	21		
1979	0	0	167	2616	5599	5882	316	63	19	27	27	1		
1980	0	0	551	500	1423	1051	1318	92	1	1	1	1		
1981	0	0	1732	6768	161	326	189	495	33	9	1	1		
1982	0	0	21	3040	1926	310	97	124	206	25	1	1		
1983	0	0	2818	713	765	657	94	16	33	73	1	8		
1984	0	0	9	2229	966	59	90	70	38	10	7	21		
1985	0	0	19	5499	3549	1232	931	46	166	0	0	6		
1986	0	2549	2266	4251	2943	1061	169	74	51	18	4	0		
1987	814	1848	3102	1915	1259	846	313	71	26	12	0	0		
1988	1	3500	25593	11161	1399	414	315	113	31	14	0	2		
1989	0	52	15399	23233	9373	943	220	154	42	8	1	0		
1990	7	254	2180	15740	10824	2286	378	81	33	2	0	0		
1991	1	561	5196	1960	3151	1688	368	42	14	14	4	1		
1992	0	15517	10180	4865	3399	2483	1106	380	18	60	14	0		
1993	0	2657	14530	3547	931	284	426	201	6	1	3	0		
1994	0	1219	25400	8273	386	185	14	124	38	17	0	2		
1995	0	0	264	6553	2750	651	135	27	147	53	3	0		
1996	0	81	714	311	1072	88	0	0	0	0	0	0		
1997	0	0	810	762	143	286	48	0	0	0	0	0		
1998	0	0	8	170	286	30	19	2	0	0	0	0		

Table 3 - Weights at age in the stock. Mean weights at age in the last line are based on the surveys: 1977-1985 and 1988-1998. (Kg)

	Age											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1972	0	0	0.811	0.722	0.981	1.500	1.930	1.820	2.540	3.570	3.140	5.300
1973	0	0	0.633	0.314	1.300	0.994	0.828	3.340	3.180	6.180	3.180	4.140
1974	0	0	0.657	0.805	1.769	2.829	3.983	5.923	4.684	6.619	9.043	12.571
1975	0	0	0.697	1.636	1.798	2.658	3.766	4.225	5.702	5.724	7.448	11.445
1976	0	0	0.671	1.293	4.192	5.085	5.923	7.555	5.278	5.278	6.381	7.000
1977	0	0	0.314	0.845	1.400	3.433	5.156	5.403	8.203	8.748	6.381	5.278
1978	0	0	0.374	0.600	1.102	1.582	2.658	3.557	7.712	6.765	11.375	8.205
1979	0	0	0.790	1.070	1.480	2.450	4.350	5.340	6.610	7.210	11.040	15.080
1980	0	0	0.859	1.137	1.747	2.466	3.167	4.420	6.667	6.667	12.029	16.901
1981	0	0	0.620	1.250	1.880	2.680	3.190	4.550	6.870	6.230	5.590	17.930
1982	0	0	0.760	1.340	2.450	2.870	4.680	5.510	6.070	9.380	11.900	14.210
1983	0	0	1.330	1.140	2.240	3.530	4.760	6.480	6.670	10.000	13.500	16.630
1984	0	0	0	0.460	1.866	3.695	3.660	6.588	6.878	3.466	8.180	9.664
1985	0	0	0.283	0.851	1.605	2.816	4.522	7.000	8.066	0	0	13.000
1986	0	0.165	0.411	0.784	1.631	2.836	4.317	5.590	7.493	8.458	7.800	0
1987	0.091	0.133	0.327	1.040	1.890	2.993	4.440	6.629	8.166	10.150	0	0
1988	0.031	0.103	0.308	0.678	1.973	3.594	5.772	6.926	0	0	0	0
1989	0.044	0.243	0.541	1.040	1.595	2.505	4.269	6.930	7.561	15.030	0	0
1990	0.039	0.170	0.342	0.846	1.501	2.426	4.083	5.635	7.614	8.844	0	0
1991	0.054	0.166	0.495	0.855	1.611	2.606	3.771	3.911	9.862	6.103	15.226	0
1992	0.054	0.246	0.490	1.377	1.702	2.633	3.133	6.685	0	0	14.577	0
1993	0.043	0.222	0.655	1.209	2.270	2.371	3.449	5.890	0	0	0	0
1994	0.060	0.207	0.591	1.323	2.261	4.031	4.034	6.457	0	9.806	0	0
1995	0.046	0.235	0.466	0.961	1.850	3.159	5.555	0	6.406	10.557	0	0
1996	0.041	0.251	0.531	0.804	1.324	2.267	4.000	5.025	0	0	0	0
1997	0.077	0.324	0.636	1.004	1.309	2.097	2.001	0	0	0	0	9.573
1998	0.069	0.358	0.753	1.189	1.664	1.990	3.095	0	7.403	0	0	0
m.w.	0.051	0.230	0.586	0.999	1.742	2.760	3.989	6.232	7.115	7.308	10.974	12.989

Table 4 - EU survey abundance-at-age used for tuning XSA ('0000). B n+ = biomass of fish age n and older (tons).

	YEARS										
Age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	458	2418	237	13780	7118	438	315	155	4	4	3
2	7196	6062	1179	2560	3706	13274	385	1137	297	14	8
3	4037	6964	467	1538	475	2852	2459	123	613	315	9
4	1085	2819	1588	193	203	102	456	361	82	436	114
5	128	227	1453	628	33	127	12	90	225	36	145
6	22	33	394	168	127	17	6	1	19	90	7
7	28	12	32	31	21	50	0.1	2	1	2	14
8	11	8	24	14	2	10	13	2	1	1	1
B1+	33,038	88,301	51,155	37,845	22,780	55,170	22,942	8,763	8,161	8,924	4,513
B2+	32,896	87,237	51,063	30,404	18,937	54,982	22,753	8,692	8,160	8,920	4,511
B3+	25,484	72,507	49,059	26,154	9,820	25,513	21,956	6,020	7,414	8,875	4,483
B4+	13,050	34,832	47,461	18,541	7,493	6,833	7,423	5,447	4,159	6,872	4,415
B5+	5,694	5,514	34,027	16,891	4,697	5,599	1,390	1,977	3,500	2,494	3,059

Table 5 – Proportion of mature cod at age.

a) For the period 1986 to 1989 according to Kuzmin (1990).

Age	females	% mature
1	67	0
2	148	0
3	225	0
4	148	7
5	133	56
6	53	77
7	25	92
8	3	100
9	2	100
10	2	100
11	2	100
12		-
13	1	100

b) Data used for the assessment period 1972-1998

	AGE							
YEAR	1	2	3	4	5	6	7	8+
1972	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1973	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1974	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1975	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1976	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1977	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1978	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1979	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1980	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1981	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1982	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1983	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1984	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1985	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1986	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1987	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1988	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1989	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1990	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1991	0.00	0.00	0.00	0.00	0.50	1.00	1.00	1.00
1992	0.00	0.00	0.00	0.18	0.57	0.84	0.80	1.00
1993	0.00	0.00	0.03	0.27	0.76	1.00	0.95	1.00
1994	0.00	0.00	0.04	0.67	0.91	1.00	1.00	1.00
1995	0.00	0.00	0.00	0.80	1.00	1.00	1.00	1.00
1996	0.00	0.00	0.04	0.55	1.00	1.00	1.00	1.00
1997	0.00	0.00	0.06	0.74	0.90	0.97	1.00	1.00
1998	0.00	0.00	0.20	0.86	1.00	1.00	1.00	1.00

Table 6 - Results of the Extended Survivors Analysis.

Lowestoft VPA Version 3.1

8/06/1999 21:05

Extended Survivors Analysis

Cod 3M 8+
1998

CPUE data from file d:\nafo\cod3m\COD99.Tun

Catch data for 27 years. 1972 to 1998. Ages 1 to 8.

Fleet	First year	Last year	First age	Last age	Alpha	Beta
EU-SURV	1988	1999	1	7	0.5	0.6

Time series weights :

Tapered time weighting applied
Power = 3 over 20 years

Catchability analysis :

Catchability independent of stock size for all ages

Catchability independent of age for ages >= 6

Terminal population estimation :

Terminal year survivor estimates not shrunk towards mean F

Oldest age survivor estimates shrunk towards the mean F of the final 2 ages.
S.E. of the mean to which the estimates are shrunk = 9.000

Minimum standard error for population estimates derived from each fleet = .500

Prior fleet weighting not applied

Tuning converged after 21 iterations

	1									
Regression weights	0.751	0.82	0.877	0.921	0.954	0.976	0.99	0.997	1	1

Fishing mortalities

Age	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	0	0	0	0	0	0	0	0	0	0
2	0.004	0.016	0.028	0.363	0.058	0.511	0	0.025	0	0
3	0.405	0.241	0.501	0.979	0.694	1.213	0.194	0.116	0.367	0.107
4	0.829	0.975	0.355	1.363	1.227	1.191	1.366	0.369	0.175	0.121
5	1.225	1.328	0.517	2.325	1.137	0.386	2.649	0.875	0.288	0.092
6	0.742	1.261	0.751	1.053	2.836	0.722	3.571	0.721	0.608	0.09
7	1.085	0.774	0.687	2.26	0.496	3.395	2.868	0	1.216	0.07

1

XSA population numbers (Thousands)

	AGE						
YEAR	1	2	3	4	5	6	7
1989	2.21E+04	1.38E+04	5.11E+04	4.56E+04	1.47E+04	1.99E+03	3.67E+02
1990	2.77E+04	1.81E+04	1.13E+04	2.79E+04	1.63E+04	3.53E+03	7.75E+02
1991	6.88E+04	2.26E+04	1.46E+04	7.25E+03	8.63E+03	3.53E+03	8.18E+02
1992	6.32E+04	5.64E+04	1.80E+04	7.23E+03	4.16E+03	4.22E+03	1.36E+03
1993	4.11E+03	5.17E+04	3.21E+04	5.55E+03	1.51E+03	3.33E+02	1.20E+03
1994	1.07E+04	3.37E+03	3.99E+04	1.31E+04	1.33E+03	3.98E+02	1.60E+01
1995	4.45E+03	8.77E+03	1.65E+03	9.72E+03	3.27E+03	7.40E+02	1.58E+02
1996	1.29E+02	3.65E+03	7.18E+03	1.11E+03	2.03E+03	1.89E+02	1.70E+01
1997	7.57E+01	1.06E+02	2.91E+03	5.23E+03	6.31E+02	6.94E+02	7.54E+01
1998	5.92E+01	6.20E+01	8.68E+01	1.65E+03	3.60E+03	3.87E+02	3.09E+02

Estimated population abundance at 1st Jan 1999

0.00E+00	4.85E+01	5.07E+01	6.38E+01	1.20E+03	2.68E+03	2.90E+02

Taper weighted geometric mean of the VPA populations:

5.48E+03	7.51E+03	9.19E+03	7.63E+03	3.35E+03	9.78E+02	2.67E+02

Standard error of the weighted Log(VPA populations) :

2.7073	2.3486	1.8334	1.0369	0.9226	1.0208	1.541

1

Log catchability residuals.

Fleet : EU-SURV

Age	1988
1	-0.62
2	-0.16
3	-0.46
4	-0.32
5	-0.42
6	-0.47
7	0

Age	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	0.77	-1.78	1.37	0.8	0.74	-0.54	-0.38	-0.49	0.04	0
2	1.21	-0.69	-0.13	-0.49	0.7	0.14	-0.01	-0.46	0.01	-0.02
3	0.58	-0.7	0.38	-0.75	0.31	0.23	-0.14	-0.05	0.33	0.14
4	0.39	0.38	-0.72	-0.11	-0.61	0.01	0.17	0.31	0.33	0.11
5	-0.75	1.06	0.41	-0.82	0.89	-1.75	0.6	1.02	0.04	-0.42
6	-0.83	1.36	0.23	-0.06	1.44	-0.94	-1.79	0.96	1.15	-1.1
7	0.03	0.1	-0.04	-0.07	-0.05	-0.35	0.06	0.02	-0.1	-0.2

Mean log catchability and standard error of ages with catchability independent of year class strength and constant w.r.t. time

Age	1	2	3	4	5	6	7
Mean Log q	-2.8726	-1.9215	-2.2404	-2.605	-2.6334	-2.7494	-2.7494
S.E(Log q)	0.8676	0.523	0.4393	0.3894	0.9185	1.1428	0.147

Regression statistics :

Ages with q independent of year class strength and constant w.r.t. time.

Age	Slope	t-value	Intercept	RSquare	No Pts	Reg s.e	Mean Q
1	0.94	0.543	3.17	0.92	11	0.85	-2.87
2	0.99	0.085	1.96	0.96	11	0.55	-1.92
3	1.01	-0.164	2.15	0.95	11	0.47	-2.24
4	1	0.011	2.61	0.9	11	0.41	-2.6
5	0.9	0.327	3.15	0.6	11	0.88	-2.63
6	0.99	0.021	2.78	0.48	11	1.2	-2.75
7	0.97	1.198	2.89	0.99	11	0.13	-2.81
1							

Terminal year survivor and F summaries :

Age 1 Catchability constant w.r.t. time and dependent on age

Year class = 1997

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	48	0.91	0	0	1	1	0

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
48	0.91	0	1	0	0

1

Age 2 Catchability constant w.r.t. time and dependent on age

Year class = 1996

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	51	0.47	0.026	0.05	2	1	0

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
51	0.47	0.03	2	0.054	0

Age 3 Catchability constant w.r.t. time and dependent on age

Year class = 1995

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	64	0.361	0.149	0.41	3	1	0.107

Weighted prediction :

Survivors at end ofyear	Int s.e	Ext s.e	N	Var Ratio	F
64	0.36	0.15	3	0.411	0.107

1
Age 4 Catchability constant w.r.t. time and dependent on age

Year class = 1994

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	1199	0.339	0.178	0.53	4	1	0.121

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
1199	0.34	0.18	4	0.526	0.121

Age 5 Catchability constant w.r.t. time and dependent on age

Year class = 1993

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	2685	0.319	0.137	0.43	5	1	0.092

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
2685	0.32	0.14	5	0.43	0.092

1
Age 6 Catchability constant w.r.t. time and dependent on age

Year class = 1992

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	290	0.414	0.199	0.48	6	1	0.09

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
290	0.41	0.2	6	0.48	0.09

Age 7 Catchability constant w.r.t. time and age (fixed at the value for age) 6

Year class = 1991

Fleet	Estimated Survivors	Int s.e	Ext s.e	Var Ratio	N	Scaled Weights	Estimated F
EU-SURV	236	0.464	0.179	0.39	7	0.997	0.07
F shrinkage mean	180	9				0.003	0.091

Weighted prediction :

Survivors at end of year	Int s.e	Ext s.e	N	Var Ratio	F
236	0.46	0.17	8	0.358	0.07

Table 7 – Data used in Yield per recruit analysis: weight at age and partial recruitment (p.r.)

	Gavaris (1981)		Cardenas and Pereiro (1990)	Hodder (1964)	Vázquez and Motos (1998)		present analysis	
Age	Weight	p.r.	p.r.	p.r	weight	p.r.	weight	p.r.
1					0.052	0	0.051	0
2					0.199	0.158	0.230	0.064
3	0.305	0.2	0.04	0.07	0.507	0.638	0.586	0.379
4	0.469	0.5	0.40	0.37	0.960	1	0.999	0.517
5	1.022	1	1.00	0.90	1.585	1	1.742	0.680
6	1.820	1	0.97	1	2.496	1	2.760	0.812
7	3.171	1	0.62	1	4.094	1	3.989	1
8	6.148	1	0.60	1	6.578	1	6.232	1
9	8.948	1	0.50	1			7.115	1
10	9.022	1	0.50	1			7.308	1
11	10.813	1	0.50	1			10.974	1
12	13.782	1	0.50	1			12.989	1
13	14.199	1						
14	14.966	1						
15	13.279	1						
16	15.982	1						
17	15.576	1						
18	22.978	1						
19	13.942	1						
F 0.1	0.13				0.141		0.139	
Y 0.1					0.653		0.839	
F max					0.220		0.229	
Y max					0.691		0.893	

Table 8: Input data for the estimation of BRP in 3M cod.

a) Biological parameters

Age	N	M	CWt	SWt	Mat	F	FPreSpwn	MPreSpwn
1	83.408	0.200	0.113	0.053	0.000	0.000	0	0
2	48.480	0.200	0.251	0.242	0.000	0.013		
3	50.730	0.200	0.532	0.550	0.032	0.077		
4	63.830	0.200	0.838	1.061	0.329	0.105		
5	1198.790	0.200	1.494	1.709	0.633	0.138		
6	2685.000	0.200	2.178	2.609	0.810	0.165		
7	290.050	0.200	3.144	3.787	0.950	0.203		
8	260.520	0.200	4.292	5.405	1.000	0.203		
	NCV	**MCV**	**CWtCV**	**SWtCV**	**MatCV**	**FCV**		
1	0.500	0.100	0.276	0.241	0.000	1.083		
2	0.910	0.100	0.242	0.250	0.000	1.534		
3	0.470	0.100	0.244	0.209	1.936	0.609		
4	0.343	0.100	0.178	0.192	0.994	0.212		
5	0.288	0.100	0.214	0.197	0.600	0.364		
6	0.273	0.100	0.218	0.228	0.383	0.495		
7	0.288	0.100	0.327	0.249	0.166	0.777		
8	0.288	0.100	0.621	0.538	0.000	0.777		

b) S/R data.

Year	SSB	Recruitment	Yield	Fbar
1973	20585	66496	22900	0.5663
1974	15438	133622	24938	1.2714
1975	9824	24945	22375	0.6441
1976	9652	11094	22266	0.3432
1977	21622	3415	27019	0.469
1978	27943	22902	33131	0.4609
1979	32011	15796	29710	0.7174
1980	12911	8577	10468	0.5259
1981	7934	23170	13873	0.4572
1982	5996	23223	12753	0.4934
1983	3275	14151	10215	0.2436
1984	19401	16440	12702	0.2284
1985	9110	63669	13675	0.5411
1986	14331	127701	14518	0.6992
1987	7973	81918	10632	0.4216
1988	12813	16879	28899	0.4758
1989	21103	22077	48373	0.8197
1990	34751	27653	40827	0.8477
1991	9245	68841	16229	0.4575
1992	13001	63182	25089	1.5554
1993	8048	4111	15958	1.0193
1994	18362	10713	29916	0.93
1995	14175	4455	10372	1.403
1996	3663	129	2601	0.4534
1997	5592	76	2933	0.277
1998	9606	59	705	0.1067

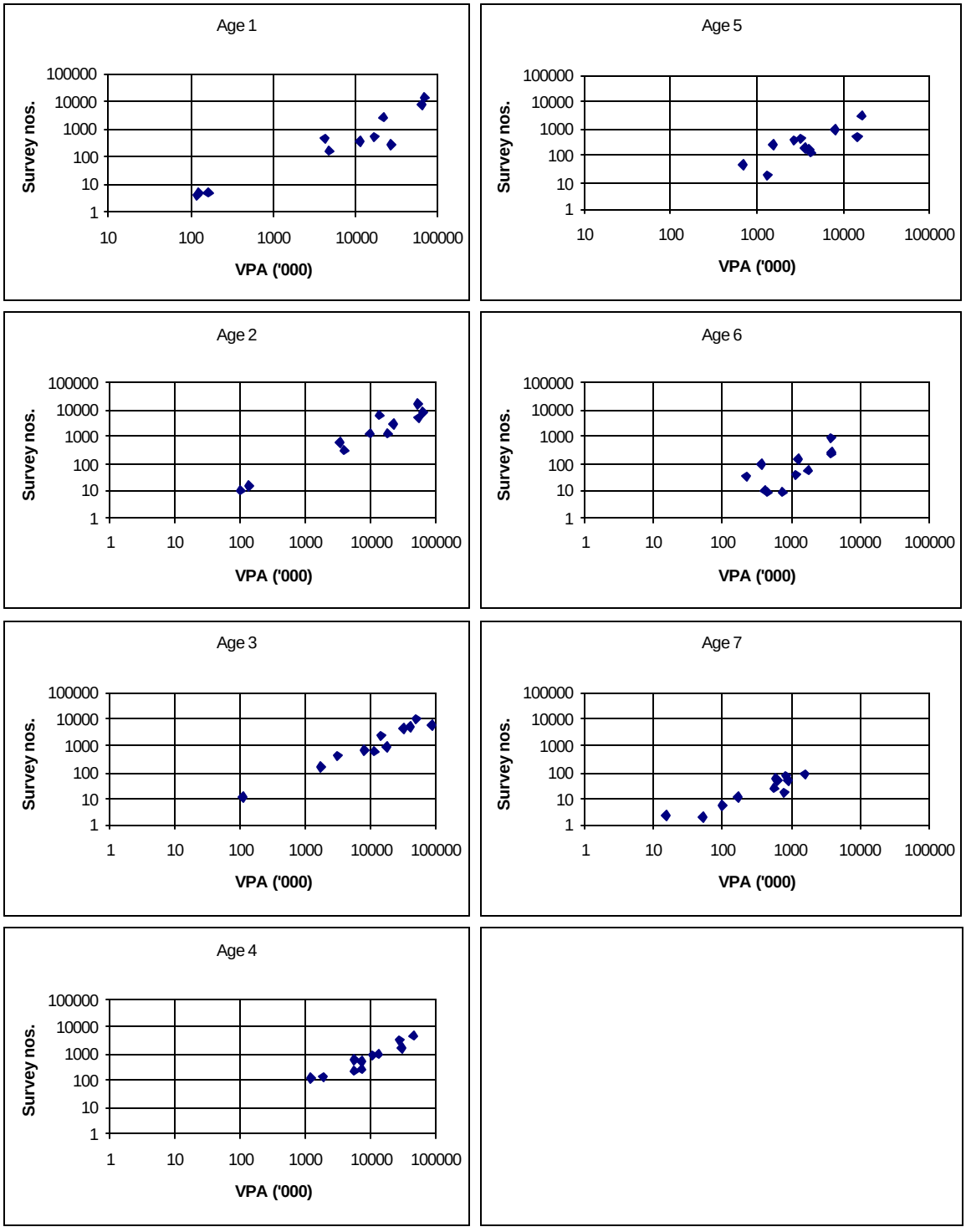


Figure 1 - Plots of catchability analysis by age for cod 3m abundance index from the EU bottom trawl survey plotted again VPA results on stock number at age.

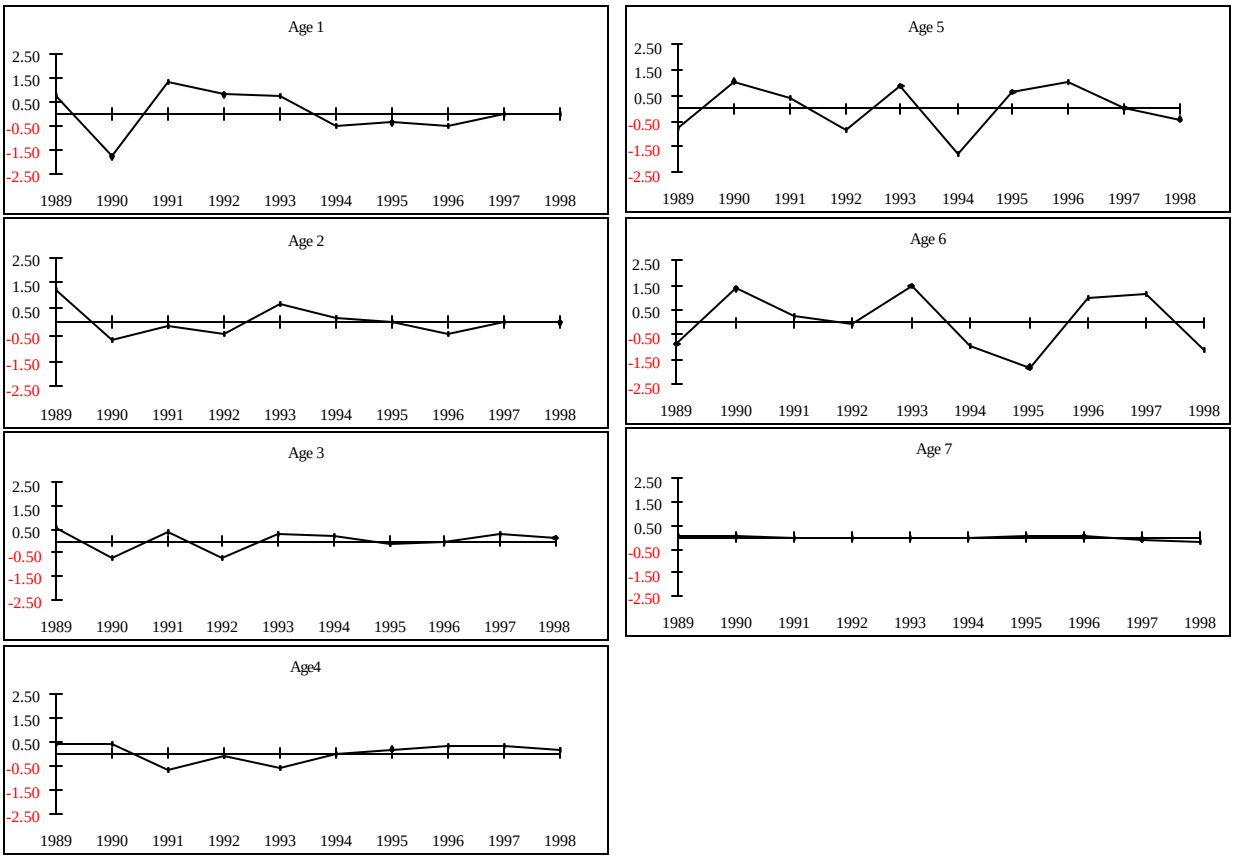


Figure 2 - Residuals of the catchability regression for ages 1 to 7.

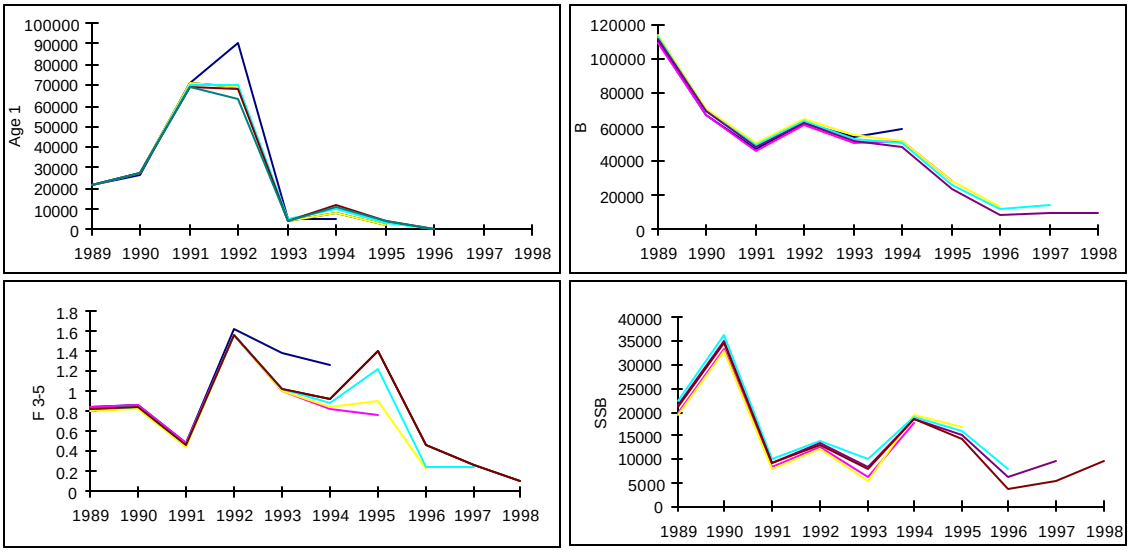


Figure 3 - Results of the retrospective analysis.

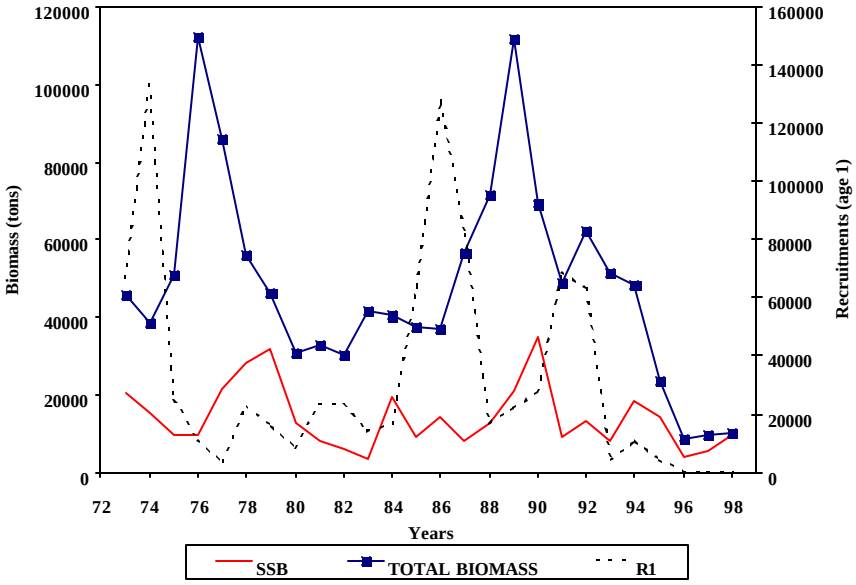


Figure 4 - 3M cod: total biomass. spawning stock biomass (SSB) and abundance of recruitment at age 1 according to XSA results.

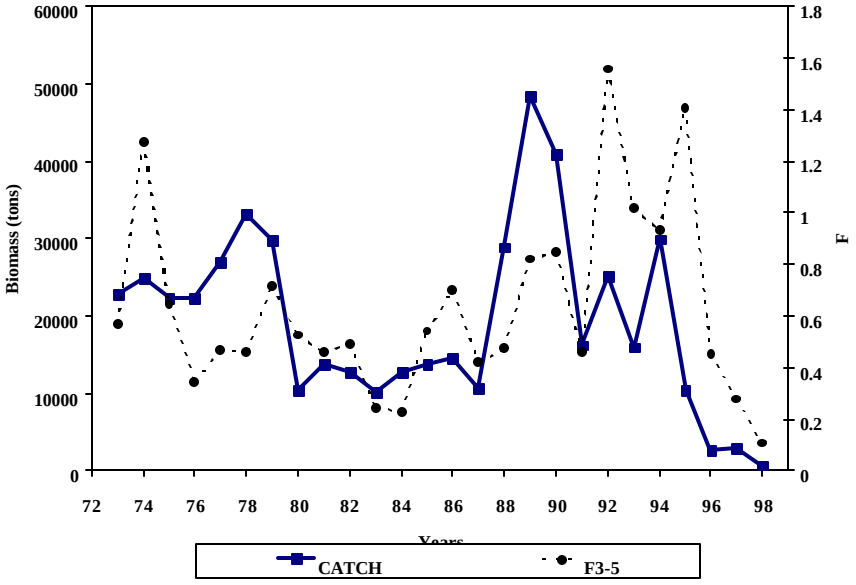


Figure 5 - 3M cod: total annual catch and fishing mortality (as F 3-5) according to XSA results.

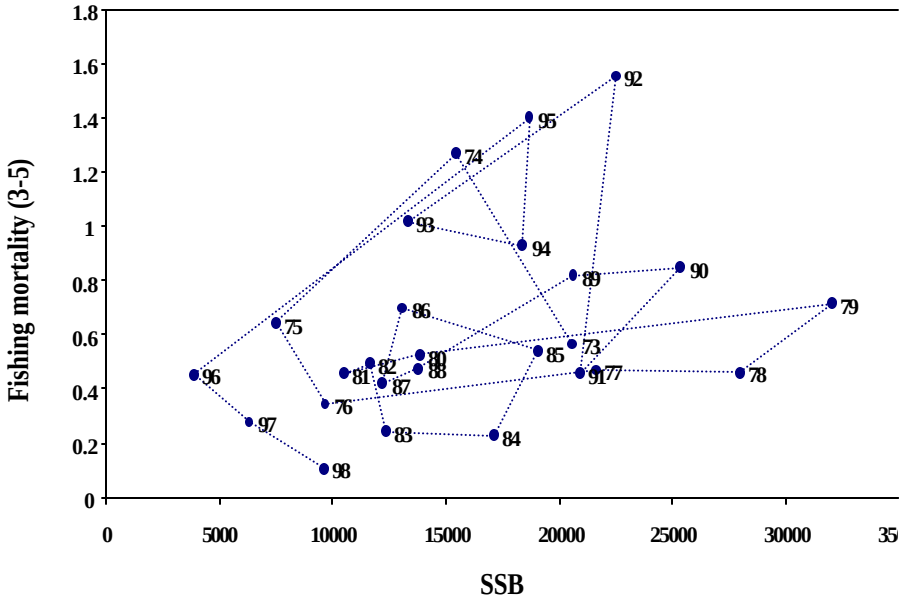


Figure 6 - Fishing mortality and spawning stock biomass (SSB) from 1973 to 1998 according to XSA results.

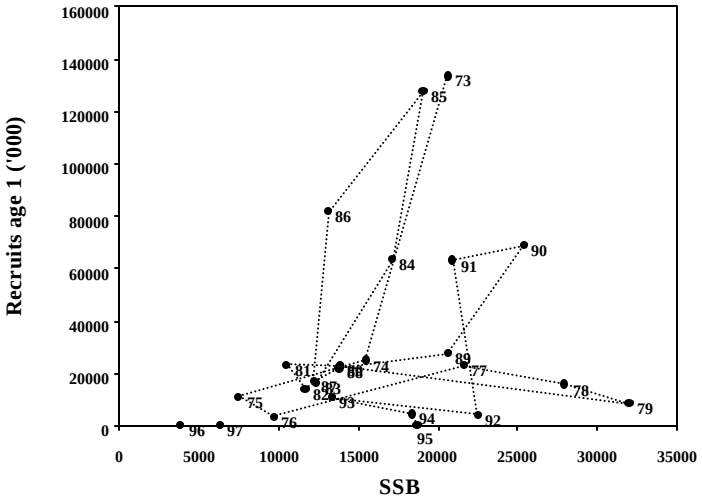
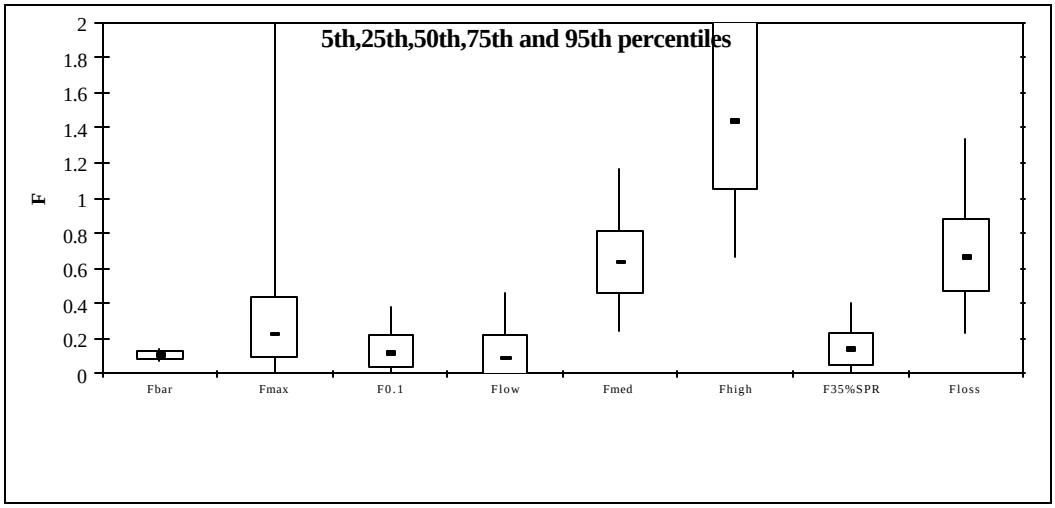


Figure 7 - Spawning stock biomass (SSB) and recruitment at age 1 (R1) from 1973 to 1998 according to XSA results.

Figure 8a - Output plots and tables of PAsoft BRP estimations for 3M cod.

RefPts - provides stochastic output in the form of a table of reference points and a chart summarising the distributions of some reference points.



Reference point	Deterministic	Median	95th percentile	80th percentile	Hist SSB < ref pt %
MedianRecruits	14960	14960	17373	15567	
MBAL	0				0.00
Bloss	3832				
SSB90%R90%Surv	14179	18185	22145	20365	50.00
SPR%ofVirgin	40.96	42.83	70.87	59.99	
VirginSPR	15.54	15.29	316973.58	284.33	
SPRloss	0.99	0.97	1.88	1.32	
	Deterministic	**Median**	**5th percentile**	**20th percentile**	**Hist F > ref pt %**
FBar	0.11	0.11	0.07	0.09	96.15
Fmax	0.19	0.23	0.00	0.07	96.15
F0.1	0.10	0.12	0.00	0.02	100.00
Flow	0.11	0.09	0.00	0.00	96.15
Fmed	0.61	0.63	0.25	0.42	38.46
Fhigh	1.52	1.44	0.66	0.99	3.85
F35%SPR	0.13	0.15	0.00	0.02	96.15
Floss	0.65	0.66	0.23	0.43	34.62

For estimation of Gloss and Floss:
A LOWESS smoother with a span of 1 was used.
Stock recruit data were log-transformed
A point representing the origin was included in the stock recruit data.
For estimation of the stock recruitment relationship used in equilibrium calculations:
A LOWESS smoother with a span of 1 was used.
Stock recruit data were log-transformed
A point representing the origin was included in the stock recruit data.
Steady state selection provided as input
FBar averaged from age 3 to 5

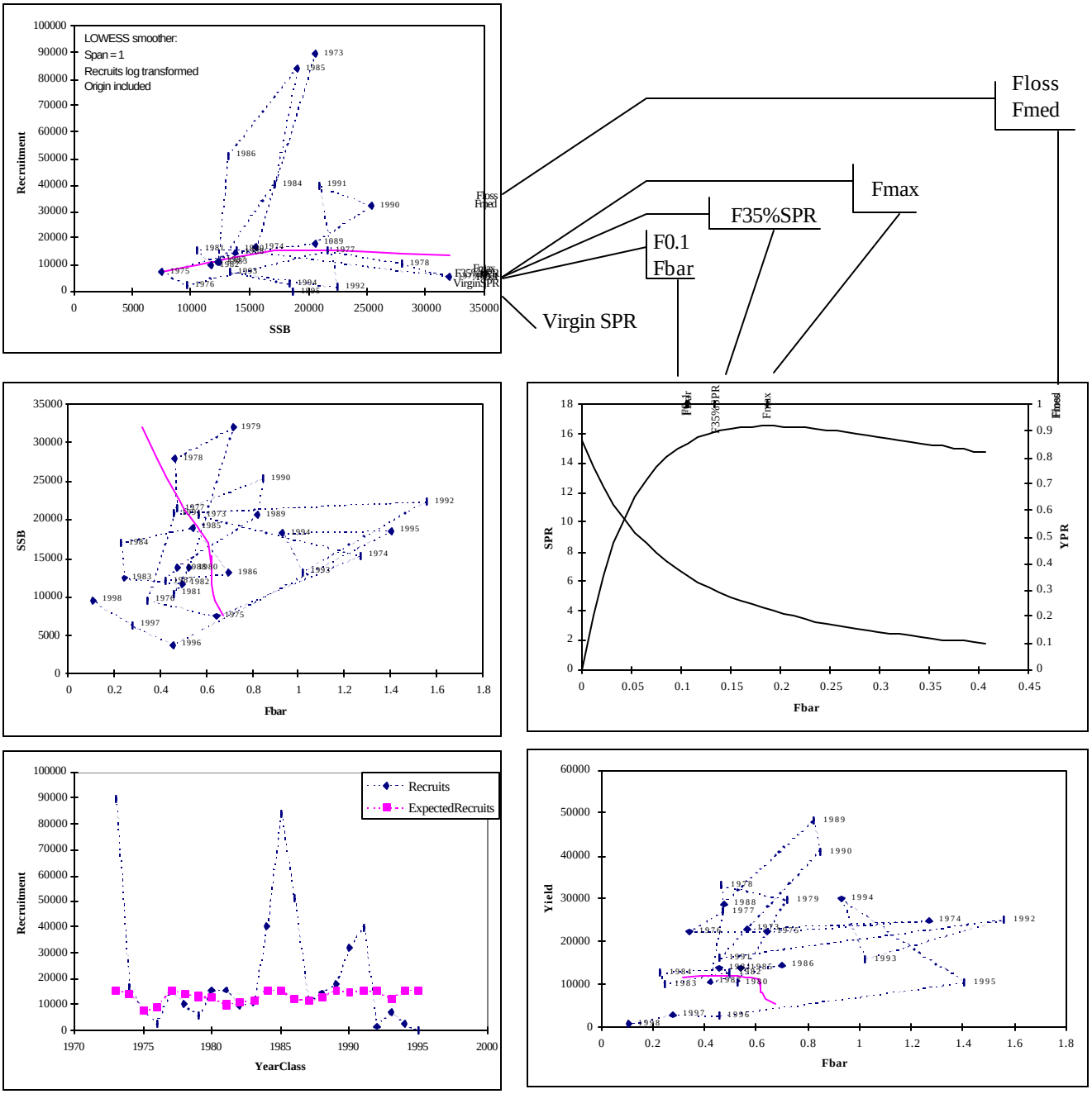


Figure 8b - Output plots and tables of PAsoft BRP estimations for 3M cod

Top/left :	A stock recruitment plot with a LOWESS smoother as a possible stock recruitment relationship. Some reference points are also indicated.
Midle/right:	A plot of YPR and SPR curves with some reference points indicated.
Midle/left:	A plot of historical SSB against Fbar with an equilibrium curve based on the LOWESS stock recruitment relationship.
Bottom/right:	A plot of historical yield against Fbar with an equilibrium curve based on the LOWESS stock recruitment relationship.
Bottom/left:	A plot of the time series of stock and recruitment with expected recruits based on the LOWESS stock recruitment relationship.