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Northwest Atlantic Fisheries Organization

Serial No. N5800 **NAFO SCR Doc. 10/41**

SCIENTIFIC COUNCIL MEETING – JUNE 2010

Assessment of the Cod Stock in NAFO Division 3M

by

Diana González-Troncoso[1] and Antonio Vázquez[2]

[1] Instituto Español de Oceanografía,
[2] Instituto de Investigaciones Marinas

Abstract

An assessment of the cod stock in NAFO Division 3M is performed. A Bayesian model, as used in the two last assessments, was used to perform the analysis. Results indicate a fairly substantial increase in SSB, reaching a value well above B_{lim}. The six-years retrospective plot shows that the recruitment is overestimated every year. Three year projections indicate that fishing at the F_{bar} level currently estimated for 2009 should allow SSB to increase, although abundance will remain at lower levels. If the fishing mortality were return to the levels seen before 1995, stock recovery would become very improbable.

Introduction

This stock had been on fishing moratorium since 1999 to 2009 following its collapse, which has been attributed to three simultaneous circumstances: a stock decline due to overfishing, an increase in catchability at low abundance levels and a series of very poor recruitments starting in 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, Spawning Stock Biomass (SSB) was estimated to increase a bit in 2004, 2005 and 2006 (Fernández, *et al.*, 2007) and above average recruitment levels were estimated for 2005 and 2006. Data from 2007-2009 indicate another large increase in SSB in 2008 and 2009, largely due to the recruitments in 2005-2006, although their levels were well below those in late 80´s and early 90´s (González-Troncoso and Fernández, 2009).

Since 1974, when a TAC was established for the first time, estimated catches ranged from 48000 tons in 1989 to a minimum value of 5 tons in 2004. Annual catches were about 30000 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 1000 tons and from 2000 to 2005 they were under 100 tons, mainly attributed to by-catches from other fisheries. Estimated commercial catches in 2006, 2007, 2008 and 2009 are 339, 345, 889 and 1161 tons (Table 1 and Figure 1), respectively, which represent more than a ten-fold increase over the average yearly catch during the period 2000-2005.

A VPA based assessment of the cod stock in Flemish Cap was approved by NAFO Scientific Council (SC) in 1999 for the first time and was annually updated until 2002. However, most recent catches were very small undermining the VPA based assessment, as its results are quite sensitive to assumed natural mortality when catches are at low levels. 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. The method estimates abundances at age with their associated uncertainty and allows to calculate the SSB distribution and, hence, the probability that SSB is above or below any reference value. The method has been used to assess the stock since 2003. In 2007 results from an alternative Bayesian model were also presented (Fernández *et al.*, 2007) and in 2008 this Bayesian model was further developed and approved by the NAFO SC (Fernández *et al.*, 2008).

In years 2008 and 2009 the stock was fully assessed, and the next full assessment had to be in 2011. The results of the 2009 assessment led to a reopening of the fishery with 5500 tons of catch. Noting that the short term development of this stock will be dependent on recent year classes and therefore, STACFIS recommended in 2009 *that the stock be fully assessed in 2010*.

An assessment of this stock using the Bayesian model used last years is presented. A B_{lim} of 14000 tons was proposed in year 2000 for this stock by the NAFO Scientific Council. In 2008 the appropriateness of this value given the results from the new method used to assess the stock was examined, reaching the conclusion that it is still an appropriate choice. Three year stochastic projections for several F_{bar} levels are presented. Results indicate that fishing at the F_{bar} level seen in recent years should allow SSB to increase to higher levels than those estimated for the late 1980's, although abundances will remain at lower values. If fishing mortality were to return to the levels seen until 1995, stock recovery would become very improbable.

Material and Methods

Used data

Commercial data

Length distributions

In 2009 length sampling of catch was only conducted by Portugal (Vargas *et al.*, 2010), measuring 9436 individuals in 183 samples. Length frequency distributions from the commercial catch and from the EU survey (Vázquez, 2010) are shown in Figure 2. The length distribution of Portugal has an unique mode in 60 cm. The EU survey has a four-mode length distribution: 18, 33, 45 and 60. The commercial Portuguese length distribution was applied to the catches from the countries with no length sampling to obtain the length distribution of the commercial catch.

Catch-at-age

Catch-at-age is presented in Table 2. As no age-length keys (ALK) were available for commercial catch from 1988 to 2008, each year the corresponding ALKs from the EU survey were applied in order to calculate annual catch-at-age. A commercial ALK was available for 2009. The range of ages in the catch goes from 1 to 8+. No catch-at-age was available for 2002-2005 due to the lack of length distribution information because of low catches.

Figure 3 shows a bubble plot of catch proportions at age over time (with larger bubbles corresponding to larger values), indicating that the bulk of the catch is comprised of 3-5 years age cod. In years 2006 and 2009, catches containing mostly age 4 individuals. In 2007 there has been much more spread over the ages, and in 2008 the greatest presence was ages 2 to 4.

Figure 4 shows standardised catch proportions at age (each year standardised independently to have zero mean and standard deviation 1 over the range of years considered). Grey and black values indicate values above and below the average, respectively, and the larger the bubble size the larger the magnitude of the value. Assuming that the selection pattern at age is not too variable over time, it should be possible to follow cohorts from such figure. Some strong and weak cohorts can be followed, although the pattern is not too evident.

Mean weight-at-age

Mean weight-at-age has been computed separately for the catch and for the stock, using length-weight relationships from the Portuguese commercial sampling and from the EU survey, respectively. Both are presenting in Figure 5. The commercial weights that are higher than those from the EU survey. The Portuguese length-weight relationship was applied to the commercial data to calculate weight-at-age in the catch. Results are showed in Table 4.

The estimated total catch and the SOP (sum over ages of the product of catch weight-at-age and numbers at age) only differs in 3.6%.

Survey data

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 distribution area for cod, which rarely occurs deeper than 500 m. The survey procedures have been kept constant throughout the entire period, although in 1989 and 1990 a different research vessel was used. Since 2003, the survey has been carried out with a new research vessel (R/V *Vizconde de Eza*, replacing R/V *Cornide de Saavedra*) and conversion factors to transform the values from the years before 2003 have been implemented (González- Troncoso and Casas, 2005).

Survey indices of abundance at age are presented in Table 3. Figure 6 displays the estimated biomass and abundance indices over time. Biomass and abundance show a high increase since 2005, higher in biomass than in abundance, following an extremely low period starting in the mid 1990's. It must be noted that 2009 biomass is at the level of the first years of the assessment but abundance is roughly the same as in 1994. Figure 7 shows a bubble plot of the abundances at age, in logarithmic scale, with each age standardised separately (each age to have mean 0 and standard deviation 1 over the range of survey years). Grey and black bubbles indicate values above and below average, respectively, with larger sized bubbles corresponding to larger magnitudes. The plot indicates that the survey is able to detect strength of recruitment and to track cohorts through time very well. It clearly shows a series of consecutive recruitment failures from 1996 to 2004, leading to very weak cohorts. Cohorts recruited from 2005 onwards appear to be above average.

Mean weight-at-age in the stock shows a strong increasing trend since the late 1990's, although in 2008 all the ages decreased their mean weight-at-age. In 2009 youngest and oldest ages increased theirs mean weight-at-age with respect to 2008, while the ages 3-4 decreased them, but still remain higher than at the beginning of the series (see Table 5 and Figure 8).

Maturity at age

Maturity ogives from the EU survey are available for years 1990-1998 and 2001-2006. For those years logistic regression models for proportion mature at age have been fitted independently for each year. For 1988 and 1989 the 1990 maturity ogive was applied. For 1999 and 2000 maturity ogive was computed as a mixture of 1998 and 2001 data. Maturity data for 1991 were of poor quality and did not allow a good fit, so a mixture of the ogives for 1990 and 1992 was used. Maturity data for the period 2007-2009 were not available. So, it was necessary to calculated it from the years in which it is available. Several alternatives were considered, namely, the same ogive as in 2006, a mixture of 2004-2006 ogives and a mixture of 1998-2006 ogives, as this is the period in which the age of first maturity starts to decrease. The median of the three ogives are very similar (Figure 9), so the one for 2004-2006 was chosen for performing the assessment. Figure 9 also shows the mixture of the maturity data for the 1988-1995 period, in which the maturity was very different from recent years. The median of the maturity ogives used on the whole period are presented in the Table 6.

Figure 10 displays the evolution of the a50 (age at which 50% of fish are mature) through the years (estimate and 90% uncertainty limits). The figure shows a continuous decline of the a50 through time, from above 5 years of age in the late 1980's to just above 3 years of age since about year 2000.

Figure 11 shows the evolution of the L50 (length at which 50% of fish are mature) through the years, estimated applying logistic regression to proportion mature at length data, separately for each year. The figure shows a steep decline of the L50 until the mid 1990's, followed by a slower increase since then. This is not inconsistent with the idea of fish growing faster (Figure 8) while maturing at younger ages (Figure 10).

Assessment methodology

The Bayesian model used last year (González-Troncoso and Fernández, 2009) was updated with 2009 data. The Bayesian model has been developed in a way that allows maximal incorporation of catch information. For the years with catch-at-age data, it works starting from cohort survivors and reconstructing cohorts backwards in time using catch-at-age and the assumed mortality rate. For the rest of the years, if an estimate of total catch weight is available, this information can be incorporated in the model by means of an observation equation relating (stochastically) the estimated catch weight to the underlying population abundances (hence aiding in the estimation of fishing mortalities). An advantage of the model is that it allows to combine years for which catch-at-age is available with years where only estimates of total catch weight are available. Years with no information on commercial catch are also allowed. A detailed description of the model is in Fernandez *et al.*, 2008. The priors were chosen this year as last assessment. The inputs of the assessment of this year are as follow:

Catch data for 22 years, from 1988 to 2009

Years with catch-at-age: 1988-2001, 2006-2009

Tuning with EU survey for 1988 to 2009

Ages from 1 to 8+ in both cases

Catchability analysis

Catchability dependent on stock size for ages 1 and 2

Priors over parameters:

Priors over the survivors:

For (2009, a), a=1,…,7 and (y, 7), y=1988,…,2008

$$surv(y,a) \sim LN\left(median = medrec \times e^{-medM - \sum_{age=1}^{a} medFsurv(age)}, cv = cvsurv \right),$$

where medrec=15000

medFsurv(1,…,7)={0.0001, 0.1, 0.5, 0.7, 0.7, 0.7, 0.7}

cvsurv=1

Prior over F for years with no catch-at-age:

For a=1,…,7 and y=2002,…,2005

$$F(y,a) \sim LN\left(median = medF(a),\ cv = cvF\right)$$

where medF=c(0.0001, 0.005, 0.01, 0.01, 0.01, 0.005, 0.005)

cvsurv=0.7

Prior over the total catch in the years with no catch-at-age data:

For y=2002,…,2005

$$CW(y) \sim LN\left(median = CW_{\text{mod}}(y),\ cv = cvCW\right)$$

where CW_{mod} is arised from the Baranov equation

cvCW=0.05

Prior over the EU survey abundance at age indices:

For a=1,…,8 and y=1988,…,2009

$$I(y) \sim LN\left(median = \mu(y,a),\ cv = \sqrt{e^{\frac{1}{\psi(a)}} - 1} \right)$$

$$\mu(y,a) = q(a)\left(N(y,a)\frac{e^{-\alpha Z(y,a)} - e^{-\beta Z(y,a)}}{(\beta-\alpha)Z(y,a)} \right)^{\gamma(a)}$$

$$\gamma(a)\begin{cases} \sim N(\text{mean}=1, \text{variance}=0.25),\ if\ a=1,2 \\ =1,\ if\ a \ge 3 \end{cases}$$

$$\log(q(a)) \sim N(\text{mean}=0, \text{variance}=5)$$

$$\psi(a) \sim gamma(shape=2, rate=0.07)$$

where I is the EU survey abundance index

q is the survey catchability at age

N is the commercial abundance index

α = 0.5, β = 0.58 (survey made in July)

Z is the total mortality

Prior over natural mortality, M:

$$M \sim LN(\text{median} = 0.218, cv = 0.3)$$

In 2008 STACFIS recommended *that retrospective analysis be performed as a standard diagnostic of the assessment with the Bayesian model*. So, six year retrospective plot was made.

Three years projections were made with six different scenarios, as later described, in order to see the possible evolution of the stock. The settings and the results are explained above.

Results

Table 7 and Figure 12 contain the assessment results regarding to total biomass, SSB, recruitment and F_{bar} (ages 3-5). The solid lines in the figure are the posterior medians and the dashed lines show the limits of 90% posterior credible intervals (capturing uncertainty in the estimates).

The SSB graph also includes the expected value at the beginning of the year 2010. To calculate it, weight-at-age and maturity-at-age random draws from the three last years with data were used (assuming always that maturity at age 1 is equal to 0, as there is no estimate of recruitment in 2010). The results indicate that there has been a substantial increase in SSB in the last few years, with the largest increase occurring from 2007 onwards, and in 2009 SSB (and even its confidence intervals) are well above B_{lim}, reaching the second highest value of the time series, only lower than in 1989. The expected SSB at the beginning of 2010 is the maximum in the time series, although the uncertainty associated with this value is very high, mainly due to that no recent maturity data is available from the EU survey or commercial catch. The red horizontal line in the SSB graph represents B_{lim} = 14000.

It must be noted that, although SSB is in 2009 at the level of the beginning of the time series, total biomass and abundance are under the level of the year 1994, which indicated a change in the age of first maturity.

Years 2005-2009 have seen an improvement in recruitment related to the period studied, although the actual recruitment levels for these years can not yet be precisely estimated (see the wide uncertainty limits in the figure and table).

F_{bar} (mean for ages 3-5) continues to be at very low levels (Figure 12), although an unusual high value has been estimated for 2006. F_{bar} has again fallen to a very low value in 2007-2009, with a slight increase in 2008. Table 8 and Figure 14 provide more detailed information on the estimated F-at-age values, indicating that the increase in F_{bar} in 2006 is mostly due to fishing mortality at age 3. In 2008 the highest fishing mortalities are in ages 5 and 6, and in 2009 in ages 7 and 8+.

Figure 13 shows total biomass and abundance by year. Except in the first years of the assessment, there is a good concordance between numbers and weight, although in last years biomass increased more than abundance.

Estimates of stock abundance at age for 1988-2010 are presented in Table 9 and Figure 15. For 2010, only abundances of ages older than age 1 can be estimated, as they are the survivors from individuals in the last assessment year (2009).

Figure 16 depicts the prior distribution (in red) and posterior (in black) of survivors at age at the end of the final year of the assessment, where by survivors(2009, a) it is meant individuals of age a + 1 at the beginning of 2010 (in other words, survivors(2009, a) = N(2010, a + 1)). The plotting range for the horizontal axis is the 95% prior credible interval in all cases (the same procedure will be followed in all subsequent prior-posterior plots), to facilitate comparison between prior and posterior distributions. For survivors of ages 4 and older there has been very substantial updating of the prior distribution. This is much less the case for younger ages, with prior and posterior distributions being much closer for those ages. Similarly to the comment made regarding uncertainty in recruitment estimates, the latter was to be expected as few ages of these cohorts have been observed to date.

Figure 17 displays prior distributions (in red) and posterior distributions (in black) for survivors of the last true age at the end of every year. By survivors(y, 7) it is meant individuals of age 8 (not 8+) at the beginning of year y + 1. Whereas the prior distribution is the same every year, posterior distributions vary substantially depending on the year, displaying particularly low values between 2002 and 2005 and in year 2008.

For the four years without catch-at-age, there are also prior distributions on F-at-age and the same prior distribution has been chosen in each of those years. Prior (in red) and posterior (in black) densities are displayed in Figure 18, indicating that there is enough information to update the prior distribution.

Bubble plot of raw residuals (observed minus fitted values) for the EU survey abundance indices at age in logarithmic scale is presented in Figure 19. No obvious trends over time or any other particular patterns emerge from the residuals plot.

Bubble plot of standardised residuals (observed minus fitted values divided by estimated standard deviations) for the EU survey abundance at age indices in logarithmic scale is displayed in Figure 20. As the residuals have been standardised, they should be mostly in the range (—2, 2) if model assumptions about variance are not contradicted by the data. This graph should highlight year effects, identified as years in which most of the residuals are above or below zero. In 1988 all residuals are negative except for the one for age 7, whereas the opposite happens in 1996 and 1997, suggesting year effects (i.e. survey catchabilities that are below average in 1988 and above average in 1996 and 1997). In 2008 and 2009, all residuals are positive except the one for age 1 for 2008 and ages 1 and 2 for 2009.

Results regarding the EU survey's catchabilities are displayed in Figures 21 and 22. The first of these figures shows results for the parameter $\log(\varphi(a))$, which corresponds to log(catchability) for ages $a \geq 3$. For ages $a = 1, 2$ catchability depends also on stock abundance and this dependence is regulated via the parameter $\gamma(a)$, for which results are in Figure 22. The posterior probability that $\gamma(a) > 1$ for $a = 1, 2$ is very high, pointing towards an increase in survey catchabilities for the younger ages as abundance of those ages increases.

Biological Referent Points

Figure 23a shows a SSB-Recruitment plot and Figure 23b a SSB-F_{bar} plot, both with the 14 000 value of B_{lim} indicated with a vertical red line. The value of B_{lim} appears as a reasonable choice for B_{lim}: only low recruitments have been observed with SSB below this level whereas both high and low recruitments have been seen at higher SSB values. SSB is well above B_{lim} in 2010. Figure 24 shows the Bayesian Yield per Recruit with respect to F_{bar}, in which the estimated values for $F_{0.1}$ (0.13), F_{max} (0.23) and F_{2009} (0.033) are indicated.

Retrospective pattern

A retrospective analysis of six years was made. Figure 25 shows that the recruitment is over estimated year by year. The recruitment is overestimated every year. The patterns for total biomass, SSB and F_{bar} seem to be stable.

Projections

Stochastic projections over a three years period (2011-2013) have been performed. Variability of input data was taken from the results of the Bayesian assessment. Input data are as follows:

Numbers aged 2 to 8+ in 2010: estimates from the assessment

Recruitments for 2010-2013: Recruits per spawner were estimated for each year (Figure 26). As the variability over the years of the assessment is very high, using just the last 3 years was not considered realistic. Hence, in the projections, recruits per spawner were drawn randomly from all years (1988-2009).

Maturity ogive: Drawn randomly from the maturity ogives (with their associated uncertainty) of years 2004, 2005 and 2006 (as it was made to perform the assessment).

Weight-at-age in stock and weight-at-age in catch: Drawn randomly from the last 3 years (2007-2009) (Tables 4 and 5).

PR at age for 2010-2013: The recent years fishery were only bycatch and it is unlikely to have the same PR as the direct fishery, so an average of the PRs for 1988-1998, the period in which the fishery was open, was chosen (Figure 27).

F_{bar}(ages 3-5): Six options were considered. All Scenarios assumed that the 2010 catch is the agreed TAC (5 500 tons):

1. Average of F_{bar} in 2007-2009 (median value at 0.042).
2. $F_{0.1}$ (median value at 0.130).
3. Average of F_{bar} in 1988-1995 (median value at 0.960), as these years correspond to the period when SSB was above B_{lim}.
4. F_{max} (median value at 0.230).
5. F=0.
6. $F_{statusquo}$ (median value at 0.033).

Results for the three years projection period are presented in Tables 10-21 and Figures 28 and 29. They indicate that, when fishing at any of the F_{bar} level chosen except at the average of F_{bar} in 1988-1995 (option 3), total biomass and SSB have a very high probability of reaching levels higher than all the 1988-2010 estimate, although the increase in SSB is higher then in total biomass. However, the huge increase predicted for SSB does not have a counterpart in terms of population abundances, which are projected to remain at levels below these of the late 1980´s. This is largely due to the fact that weight-at-age and maturity-at-age used for the projection period, namely random draws from the last 3 assessment years, are much higher than those assumed to have applied at the end of the 1980's.

The projected values for the period 2011-2013 are heavily reliant on the relatively abundant five most recent cohorts, namely those recruited in 2005-2009, rather than on healthy population abundances across all ages, making the stock status much more fragile than suggested by SSB values alone.

Additional analysis

In order to know how much the fact that weight-at-age and maturity-at-age used for the projection period are much higher than those assumed to have applied at the end of the 1980's affects the abundance and the SSB, an additional analysis was made for the case in which the maturity is equal to the first part of the assessment period (maturity ogive and weight-at-age as a mix of those indices from 1988 and 1995). Figure 30 shows the result plots for the posterior results and Figures 31-32 for the six different projection scenarios. In this case the view of the stock is completely different, with SSB below B_{lim} in 2009. The projected SSB for 2010 is above B_{lim}, although the 5% confidence interval is still below that value. Nevertheless, three years projections in all the scenarios except the third (average of F_{bar} in 1988-1995) show that the SSB can be above B_{lim} at the end of the projection period. In the case that the F came back to the values of the final 1980´s and the beginning of the 1990´s, the stock probably would collapse again.

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Acknowledges

Thanks to Fernando González for his valuable comments. The authors would like to thank too to all the people that make possible this type of works: onboard observers, both in commercial and survey vessels, who obtain the data, and lab people who process them.

This study was supported by the European Commission (Program for the Collection of Data in Fisheries Sector), the IEO and the CSIC.

Table 1.- Total commercial cod catch in Division 3M. 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
961		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	2,838	1	1416	26			1,203	8989
1992	25089	747	2	18		2,201	1	4215	5			6	7226
1993	15958	2931		3		3,132		2249				1	8316
1994	29916	2249			1	2,590		1952					6885
1995	10372	1016				1,641		564					3221
1996	2601	700				1,284		176	129			16	2305
1997	2933					1,433		1	23				1457
1998	705					456							456
1999	353					2							2
2000	55					30	6						36
2001	37					56							56
2002	33					32	1						33
2003	16					7						9	16
2004	5					18	2					3	23
2005	19	7				16						3	26
2006	339					51	1	16				55	123
2007	345		10			58	6	33				18	125
2008	889		25			214	74	43				42	398
2009	1161	22				857	87	86				123	1175

Table 2.- Catch-at-age (thousands)

	1	2	3	4	5	6	7	8+
1988	1	3500	25593	11161	1399	414	315	162
1989	0	52	15399	23233	9373	943	220	205
1990	7	254	2180	15740	10824	2286	378	117
1991	1	561	5196	1960	3151	1688	368	76
1992	0	15517	10180	4865	3399	2483	1106	472
1993	0	2657	14530	3547	931	284	426	213
1994	0	1219	25400	8273	386	185	14	182
1995	0	0	264	6553	2750	651	135	232
1996	0	81	714	311	1072	88	0	0
1997	0	0	810	762	143	286	48	0
1998	0	0	8	170	286	30	19	2
1999	0	0	15	15	96	60	3	1
2000	0	10	54	1	1	4	1	0
2001	0	9	0	4	2	0	2	2
2002								
2003								
2004								
2005								
2006	0	22	19	81	2	10	2	0
2007	0	2	30	1	27	1	14	5
2008	1	89	136	133	3	40	1	3
2009	0	23	51	210	108	0	32	7

Table 3.- EU bottom trawl survey abundance at age (thousands)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1988	4850	78920	49050	13370	1450	210	220	60	0	0	0	0	0	0
1989	22100	12100	106400	63400	23800	1600	200	100	0	0	0	0	0	0
1990	2660	14020	5920	19970	18420	5090	390	170	90	30	0	0	0	0
1991	146100	29400	20600	2500	7800	2100	300	100	0	0	0	0	0	0
1992	75480	44280	6290	2540	410	1500	270	10	0	0	10	0	0	0
1993	4600	156100	35400	1300	1500	200	600	100	0	0	0	0	0	0
1994	3340	4550	31580	5760	150	70	10	120	0	10	0	0	0	0
1995	1640	13670	1540	4490	1070	40	30	0	20	10	0	0	0	0
1996	41	3580	7649	1020	2766	221	9	6	0	0	0	0	0	0
1997	42	171	3931	5430	442	1078	24	0	0	0	0	6	0	0
1998	27	94	106	1408	1763	87	165	0	6	0	0	0	0	0
1999	7	96	128	129	792	491	21	7	0	0	0	0	0	0
2000	186	16	343	207	100	467	180	11	17	0	0	5	0	5
2001	487	2048	15	125	81	15	146	101	6	6	6	0	0	0
2002	0	1340	609	24	68	36	28	96	33	0	6	0	0	0
2003	665	53	610	131	22	47	7	8	37	25	0	0	0	0
2004	0	3379	25	602	168	5	10	3	5	16	0	0	0	0
2005	8069	16	1118	78	708	136		17	8	8	0	0	0	0
2006	19710	3883	62	1481	86	592	115	7	0	7	14	0	7	0
2007	3910	11620	5020	21	1138	58	425	74	13	20	0	0	0	0
2008	6090	16670	12440	4530	70	940	60	230	80	0	10	0	0	0
2009	5139	7479	16150	14310	4154	26	1091	0	335	0	0	14	0	0

Table 4.- Weight-at-age (kg) in catch

	1	2	3	4	5	6	7	8+
1988	0.058	0.198	0.442	0.821	2.190	3.386	5.274	7.969
1989		0.209	0.576	0.918	1.434	2.293	4.721	7.648
1990	0.080	0.153	0.500	0.890	1.606	2.518	3.554	7.166
1991	0.118	0.229	0.496	0.785	1.738	2.622	3.474	6.818
1992		0.298	0.414	0.592	1.093	1.704	2.619	3.865
1993		0.210	0.509	0.894	1.829	2.233	3.367	4.841
1994		0.289	0.497	0.792	1.916	2.719	2.158	4.239
1995			0.415	0.790	1.447	2.266	3.960	5.500
1996		0.286	0.789	1.051	1.543	2.429		
1997			0.402	0.640	0.869	1.197	1.339	
1998			0.719	1.024	1.468	1.800	2.252	3.862
1999			0.92	1.298	1.848	2.436	3.513	4.893
2000		0.583	0.672	1.749	2.054	2.836	3.618	
2001		0.481		1.696	2.560		3.905	5.217
2002		0.588	1.323	1.388	2.572	3.770	5.158	5.603
2003		0.462	1.063	1.455	2.978	3.696	5.859	6.120
2004		0.839	1.677	2.009	3.353	5.576	6.241	8.273
2005		0.895	1.618	2.368	3.259	4.767	6.177	6.553
2006		1.081	1.462	2.283	3.966	5.035	6.332	
2007		0.974	1.858	3.388	4.062	6.128	6.809	9.440
2008	0.088	0.448	1.364	3.037	3.498	5.248	6.643	8.251
2009	0.172	0.507	1.026	2.087	3.727		5.900	9.534

Table 5.- Weight-at-age (kg) in stock

	1	2	3	4	5	6	7	8+
1988	0.03	0.10	0.31	0.68	1.97	3.59	5.77	6.93
1989	0.04	0.24	0.54	1.04	1.60	2.51	4.27	6.93
1990	0.04	0.17	0.34	0.85	1.50	2.43	4.08	5.64
1991	0.05	0.17	0.50	0.86	1.61	2.61	4.26	7.69
1992	0.05	0.25	0.49	1.38	1.70	2.63	3.13	6.69
1993	0.04	0.22	0.66	1.21	2.27	2.37	3.45	5.89
1994	0.06	0.21	0.59	1.32	2.26	4.03	4.03	6.72
1995	0.05	0.24	0.47	0.96	1.85	3.16	5.56	8.48
1996	0.04	0.25	0.53	0.80	1.32	2.27	4.00	5.03
1997	0.08	0.32	0.64	1.00	1.31	2.10	2.00	9.57
1998	0.07	0.36	0.75	1.19	1.66	1.99	3.10	7.40
1999	0.10	0.37	0.92	1.30	1.85	2.44	3.51	4.89
2000	0.10	0.58	0.96	1.61	1.91	2.83	3.47	5.28
2001	0.08	0.48	1.25	1.70	2.56	3.42	3.91	5.22
2002	0.00	0.42	1.12	1.43	2.47	3.59	4.86	5.31
2003	0.05	0.33	0.90	1.50	2.86	3.52	5.52	5.80
2004	0.07	0.6	1.42	2.07	3.22	5.31	5.88	7.84
2005	0.02	0.64	1.37	2.44	3.13	4.54		6.21
2006	0.09	0.7	1.06	2.49	3.57	4.69	5.76	9.55
2007	0.05	0.59	1.60	3.40	4.01	5.69	6.27	8.76
2008	0.07	0.38	1.34	2.69	3.19	5.02	6.32	7.94
2009	0.08	0.41	0.98	2.07	3.88	6.96	6.58	9.46

Table 6.- Maturity at age (median values of ogives)

	1	2	3	4	5	6	7	8
1988	0.046	0.088	0.161	0.276	0.432	0.602	0.751	0.887
1989	0.046	0.088	0.161	0.276	0.432	0.602	0.751	0.887
1990	0.046	0.088	0.161	0.276	0.432	0.602	0.751	0.887
1991	0.015	0.041	0.103	0.236	0.453	0.689	0.863	0.959
1992	0.003	0.011	0.047	0.181	0.492	0.811	0.950	0.992
1993	0.001	0.007	0.050	0.278	0.739	0.955	0.994	0.999
1994	0.000	0.003	0.067	0.649	0.979	0.999	1.000	1.000
1995	0.000	0.000	0.026	0.796	0.998	1.000	1.000	1.000
1996	0.000	0.001	0.036	0.630	0.987	1.000	1.000	1.000
1997	0.001	0.009	0.118	0.663	0.967	0.998	1.000	1.000
1998	0.000	0.007	0.180	0.870	0.995	1.000	1.000	1.000
1999	0.000	0.004	0.182	0.888	0.998	1.000	1.000	1.000
2000	0.000	0.003	0.188	0.906	0.999	1.000	1.000	1.000
2001	0.000	0.002	0.195	0.967	1.000	1.000	1.000	1.000
2002	0.000	0.020	0.615	0.992	1.000	1.000	1.000	1.000
2003	0.003	0.053	0.519	0.955	0.998	1.000	1.000	1.000
2004	0.000	0.001	0.148	0.961	1.000	1.000	1.000	1.000
2005	0.040	0.170	0.499	0.828	0.958	0.991	0.998	1.000
2006	0.000	0.016	0.366	0.953	0.999	1.000	1.000	1.000
2007	0.001	0.019	0.386	0.941	0.998	1.000	1.000	1.000
2008	0.001	0.019	0.391	0.941	0.998	1.000	1.000	1.000
2009	0.001	0.020	0.392	0.939	0.998	1.000	1.000	1.000

Table 7.- Posterior results: total biomass, SSB, recruitment (tons) and F_{bar}.

	B quantiles			SSB quantiles			R quantiles			F_{bar} quantiles		
Year	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**	**50%**	**5%**	**95%**
1988	64886	60084	71527	18546	14858	23197	14360	11860	18300	0.511	0.467	0.547
1989	105030	98854	113559	32545	26522	39549	19230	16350	23611	0.867	0.805	0.910
1990	64607	60938	69841	24985	21314	29338	24290	20960	29291	0.903	0.848	0.950
1991	44398	41232	49359	17636	14876	21602	61500	54060	72531	0.497	0.463	0.525
1992	58190	55028	62434	20914	18449	23803	55780	48570	66460	1.545	1.466	1.607
1993	46124	43080	50386	10663	8991	13400	3046	2641	3674	1.029	0.959	1.086
1994	50140	46771	55971	22224	19078	27913	4431	3308	6574	0.952	0.905	0.990
1995	22820	21469	24832	19416	18156	21226	2239	1842	2896	1.382	1.230	1.493
1996	6027	5298	7153	3608	3139	4361	144	95	226	0.629	0.516	0.729
1997	5236	4369	6633	3561	2870	4686	139	89	224	0.687	0.543	0.837
1998	4068	2914	5966	3838	2714	5706	206	148	309	0.270	0.197	0.371
1999	2989	1973	4728	2826	1827	4546	35	25	52	0.258	0.191	0.343
2000	2802	1710	4751	2620	1540	4568	349	213	569	0.176	0.122	0.248
2001	2235	1563	3285	2013	1348	3034	612	388	983	0.031	0.022	0.046
2002	2607	1911	3633	2275	1596	3277	72	44	118	0.014	0.007	0.029
2003	2898	2203	3887	2594	1923	3569	1303	850	2039	0.011	0.006	0.018
2004	4627	3701	5863	3831	2956	5006	81	58	121	0.003	0.002	0.005
2005	5004	4119	6116	4133	3343	5125	4594	2748	7765	0.006	0.004	0.011
2006	8383	6565	10837	4402	3522	5539	11305	6525	19770	0.205	0.153	0.273
2007	16755	12628	22580	7143	4917	10365	10840	5946	20251	0.027	0.020	0.037
2008	26711	19778	36440	14691	10070	20872	8112	3793	17811	0.065	0.046	0.092
2009	39702	29762	52815	28958	21151	39858	10690	3960	28550	0.032	0.022	0.046
2010				55992	39872	79316						

Table 8.- F at age (posterior median)

	F at age							
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**
1988	0.000	0.067	0.435	0.554	0.550	0.741	1.274	1.274
1989	0.000	0.005	0.439	0.864	1.302	0.871	1.150	1.150
1990	0.000	0.017	0.255	1.078	1.378	1.457	1.062	1.062
1991	0.000	0.030	0.521	0.365	0.608	0.784	0.972	0.972
1992	0.000	0.384	1.017	1.381	2.247	1.492	2.504	2.504
1993	0.000	0.062	0.719	1.269	1.105	1.768	1.178	1.178
1994	0.000	0.708	1.257	1.206	0.394	0.639	0.330	0.330
1995	0.000	0.000	0.304	1.433	2.429	3.160	1.451	1.451
1996	0.000	0.047	0.274	0.674	0.949	0.492	0.000	0.000
1997	0.000	0.000	0.825	0.501	0.731	0.684	0.520	0.520
1998	0.000	0.000	0.087	0.379	0.338	0.308	0.079	0.079
1999	0.000	0.000	0.174	0.222	0.364	0.104	0.043	0.043
2000	0.000	0.453	0.492	0.015	0.020	0.022	0.002	0.002
2001	0.000	0.033	0.000	0.057	0.036	0.000	0.013	0.013
2002	0.000	0.006	0.015	0.010	0.012	0.005	0.012	0.012
2003	0.000	0.005	0.009	0.010	0.010	0.005	0.004	0.004
2004	0.000	0.001	0.005	0.002	0.002	0.004	0.001	0.001
2005	0.000	0.005	0.004	0.009	0.005	0.003	0.003	0.003
2006	0.000	0.006	0.432	0.115	0.063	0.043	0.015	0.015
2007	0.000	0.000	0.010	0.021	0.049	0.046	0.071	0.071
2008	0.000	0.010	0.018	0.052	0.121	0.092	0.058	0.058
2009	0.000	0.004	0.007	0.033	0.053	0.000	0.093	0.093

Table 9.- N at age (posterior median), with the total number and number of matures by year.

	N at age									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**Total**	**Matures**
1988	14360	58505	78440	28400	3584	858	473	239	184859	28908
1989	19230	12280	46820	43430	13940	1756	348	319	138123	29113
1990	24290	16440	10460	25800	15660	3232	626	191	96699	20719
1991	61500	20770	13830	6931	7502	3367	641	131	114672	11231
1992	55780	52605	17240	7027	4115	3476	1307	540	142090	9449
1993	3046	47740	30645	5335	1508	371	665	327	89637	5809
1994	4431	2600	38380	12770	1283	425	54	697	60640	13299
1995	2239	3790	1092	9329	3268	737	191	321	20967	11965
1996	144	1912	3226	687	1895	245	27	1	8137	2694
1997	139	123	1558	2093	298	625	128	1	4965	2614
1998	206	119	104	583	1080	123	269	28	2512	2021
1999	35	176	102	82	341	657	77	26	1496	1192
2000	349	30	150	73	56	203	505	1	1367	859
2001	612	298	16	79	61	47	170	169	1452	527
2002	72	524	246	14	64	50	40	286	1296	616
2003	1303	62	445	206	12	53	43	276	2400	819
2004	81	1111	52	376	174	10	45	272	2121	871
2005	4594	69	948	44	320	148	8	273	6404	1439
2006	11305	3931	59	806	37	271	126	23	16558	1310
2007	10840	9639	3339	33	612	30	221	74	24788	2450
2008	8112	9252	8261	2826	27	497	24	66	29065	6687
2009	10690	6909	7848	6939	2285	21	386	87	35165	12515
2010		9095	5872	6641	5733	1848	18	368	29575	

Table 10.- N-at-age in prediction years (medians) with $F_{bar}=F_{bar}$(mean 2007-2009) including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2010	8512	9095	5872	6641	5733	1848	18	368	38087	17494
2011	11491	7238	7624	4737	5164	4367	1400	297	42318	20413
2012	13161	9904	6114	6337	3866	4188	3532	1392	48494	25659
2013	16940	11145	8448	5082	5148	3123	3389	4052	57327	34648

Table 11.- Projections results with $F_{bar}=F_{bar}$(mean 2007-2009).

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2010	50195	69875	98447	39998	56029	79593	0.0000	3299	5498	8218
2011	65018	93991	145744	54022	75053	105081	0.0000	1626	3285	5642
2012	80147	128653	243623	70199	101735	156630	0.0000	2358	4570	8740
2013	93292	175934	400448	80658	134750	295378	0.0000	3201	6380	14948

Table 12.- N-at-age in prediction years (medians) with $F_{bar}=F_{0.1}$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2010	8469	9095	5872	6641	5733	1848	18	368	38044	17572
2011	11495	7327	7630	4732	5159	4364	1401	297	42405	20238
2012	13596	9692	6115	5971	3514	3749	3143	1254	47034	23572
2013	16393	11612	8145	4792	4414	2544	2691	3262	53853	31016

Table 13.- Projections results with $F_{bar}=F_{0.1}$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2010	50220	70256	99303	39835	56308	79528	0.0000	3322	5512	8285
2011	64790	94226	148921	53597	75072	105421	0.0000	4783	9682	16888
2012	74204	119863	239329	63939	92972	146804	0.0000	6225	12361	24338
2013	78713	154829	382444	66737	113959	279337	0.0000	7706	16174	41592

Table 14.- N-at-age in prediction years (medians) with $F_{bar}=F_{bar}$(mean 1988-1995) including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2010	7938	9095	5872	6641	5733	1848	18	368	37513	17556
2011	11340	6781	7626	4733	5162	4368	1401	297	41708	20261
2012	12588	9743	5177	3378	1463	1330	1074	476	35229	12127
2013	8674	10751	7402	2265	1047	377	328	440	31284	13315

Table 15.- Projections results with $F_{bar}=F_{bar}$(mean 1988-1995).

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2010	50204	69670	99334	39760	55899	79465	0.0000	3302	5509	8228
2011	65017	94100	146688	53679	75027	105021	0.0000	25598	49109	75811
2012	32673	62594	162091	26084	40172	76612	0.0000	14872	29192	75328
2013	17770	63762	212194	12059	30578	114681	0.0956	8594	27401	104122

Table 16.- N-at-age in prediction years (medians) with F_{max} including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2010	8471	9095	5872	6641	5733	1848	18	368	38046	17487
2011	10748	7246	7627	4733	5163	4365	1401	297	41580	20144
2012	13434	9158	5984	5562	3140	3279	2749	1118	44424	21832
2013	13714	11407	7646	4369	3706	2004	2085	2549	47480	27203

Table 17.- Projections results with $F_{bar}=F_{max.}$

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2010	50151	69942	99080	39940	56031	79583	0.0000	3280	5483	8284
2011	65067	94178	146667	53363	75026	104981	0.0000	7985	16080	28606
2012	65876	108048	220560	56144	83773	132574	0.0000	9200	18837	38137
2013	63055	133604	345060	52493	95144	235423	0.0000	10133	22858	62052

Table 18.- N-at-age in prediction years (medians) with F_{bar}=0 including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2010	8353	9095	5872	6641	5733	1848	18	368	37928	17509
2011	11077	7185	7630	4732	5162	4367	1401	297	41851	20282
2012	13585	9590	6115	6518	4038	4412	3727	1463	49448	26600
2013	16804	11481	8158	5191	5536	3448	3777	4489	58884	36522

Table 19.- Projections results with F_{bar}= 0.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2010	49913	69908	99450	39703	56227	79872	0.0000	3280	5470	8251
2011	64796	93760	148209	53895	75014	105070	0.0000	0	0	0
2012	84172	132653	246573	74120	106220	162721	0.0000	0	0	0
2013	101951	187135	411235	89029	145673	318474	0.0000	0	0	0

Table 20.- N-at-age in prediction years (medians) with $F_{bar}=F_{statusquo}$ including total number and number of matures.

Year/Age	1	2	3	4	5	6	7	8+	Total	Matures
2010	7764	9095	5872	6641	5733	1848	18	368	37339	17480
2011	12077	6622	7628	4735	5162	4367	1400	297	42288	20167
2012	14145	10334	5622	6374	3905	4232	3574	1409	49595	25858
2013	17125	12007	8740	4686	5233	3203	3474	4150	58618	35198

Table 21.- Projections results with $F_{bar}= F_{statusquo}$.

	Total Biomass quantiles			**SSB quantiles**			**P(SSB<B_{lim})**	**Yield quantiles**		
Year	5%	50%	95%	5%	50%	95%		5%	50%	95%
2010	49666	69628	99058	39763	55740	79926	0.0000	3311	5495	8244
2011	64542	93803	147487	53244	75142	105728	0.0000	1316	2603	4215
2012	81677	130552	247053	71502	103343	156388	0.0000	1919	3613	6586
2013	94840	177909	396185	82680	136867	294768	0.0000	2669	5095	11652

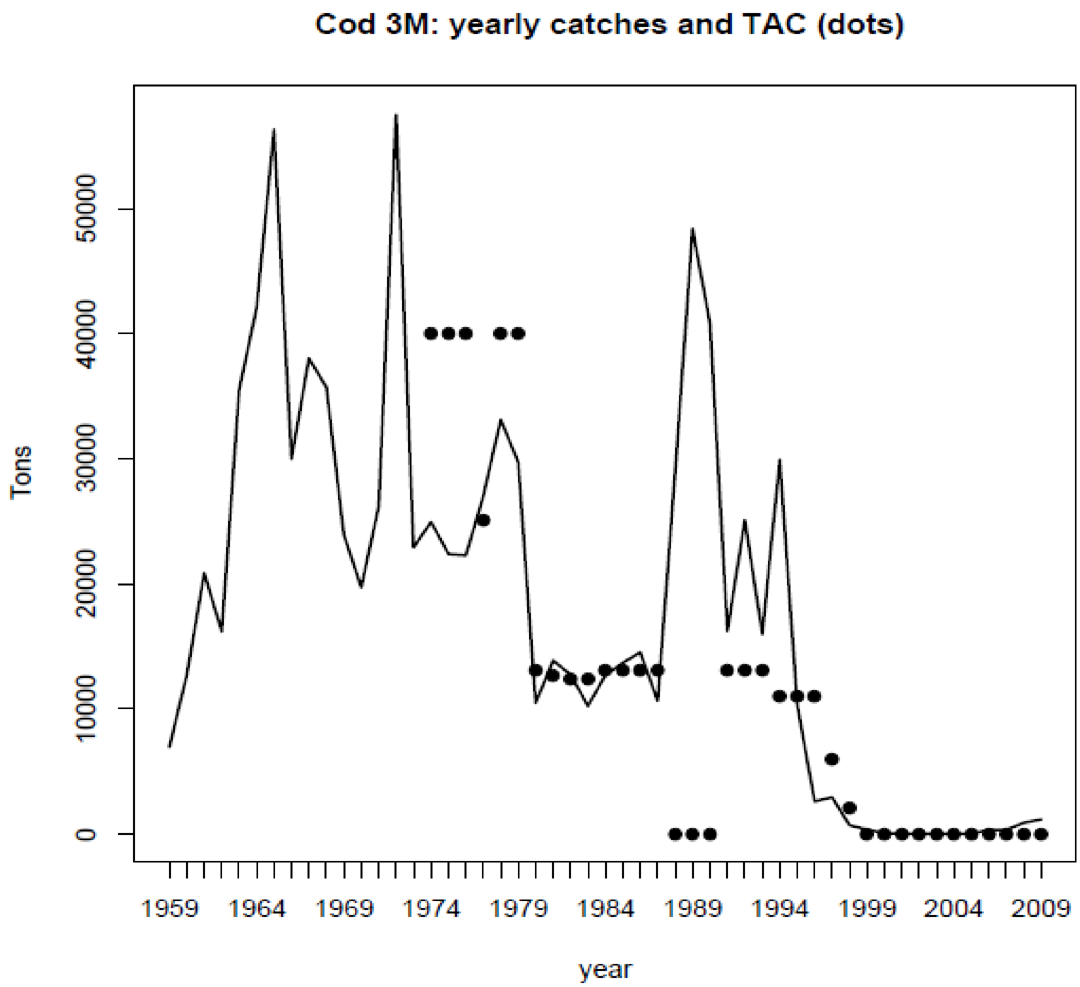

Figure 1.- Catch and TAC of the 3M cod for the period 1959-2009

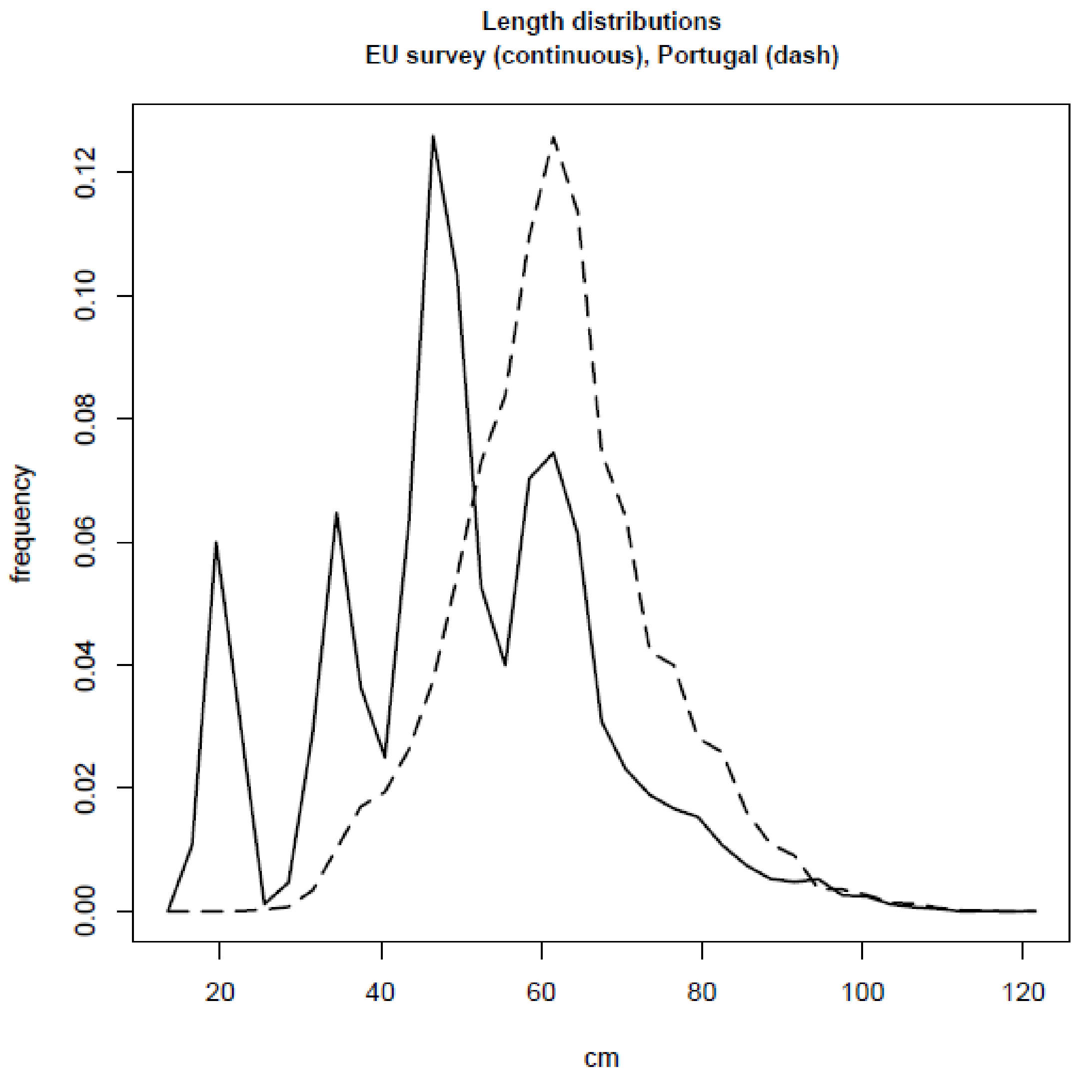

Figure 2.- Length frequencies in 2009

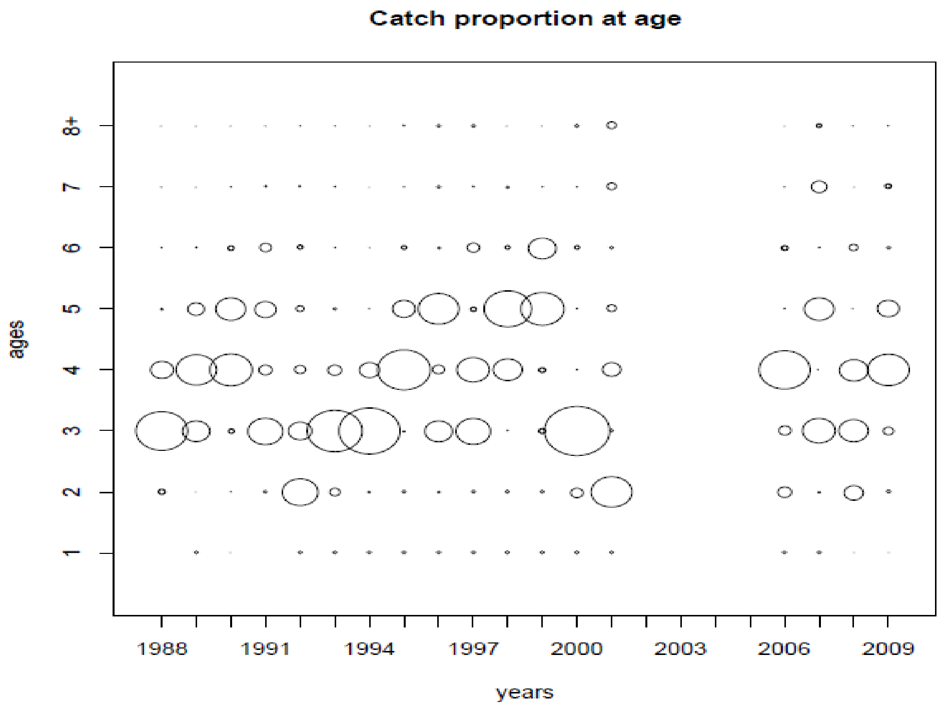

Figure 3.- Commercial catch proportions at age

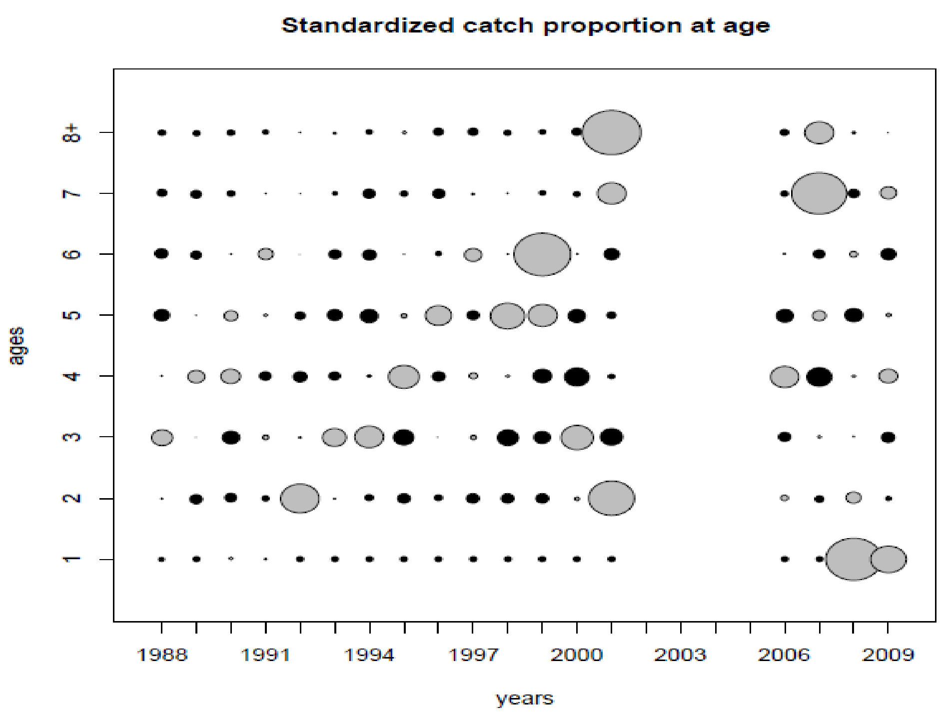

Figure 4.- Commercial catch standardised proportions at age

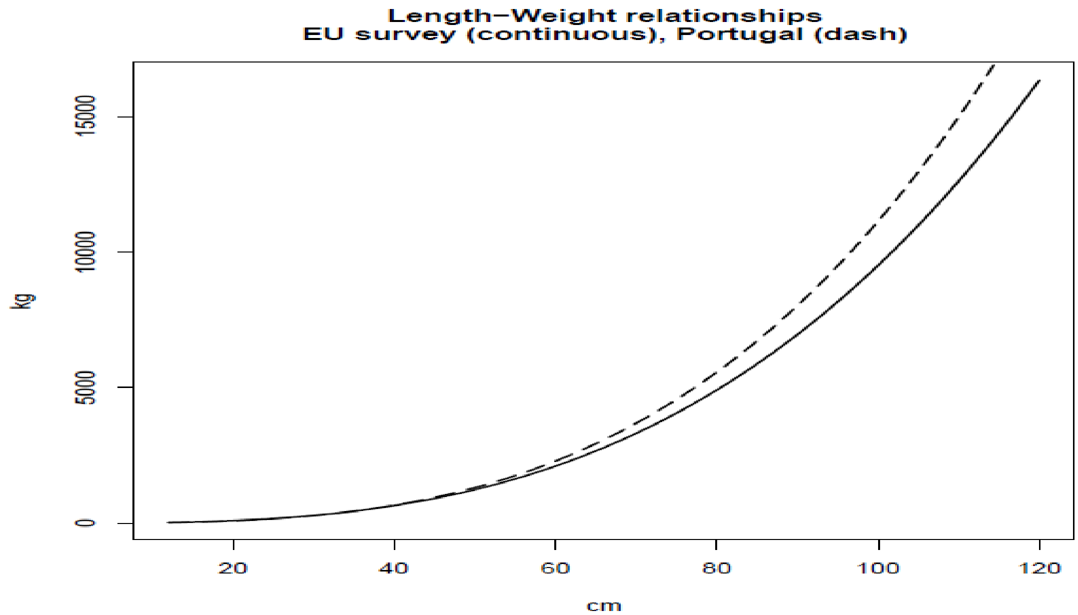

Figure 5.- Length-weight relationships for commercial and survey catches

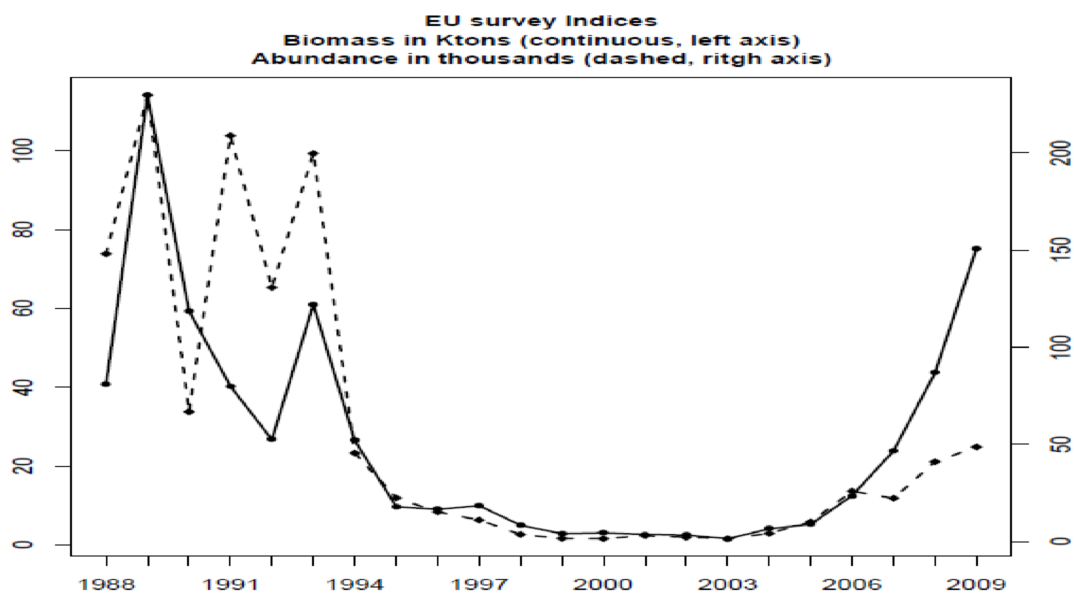

Figure 6.- Biomass and abundance from EU survey

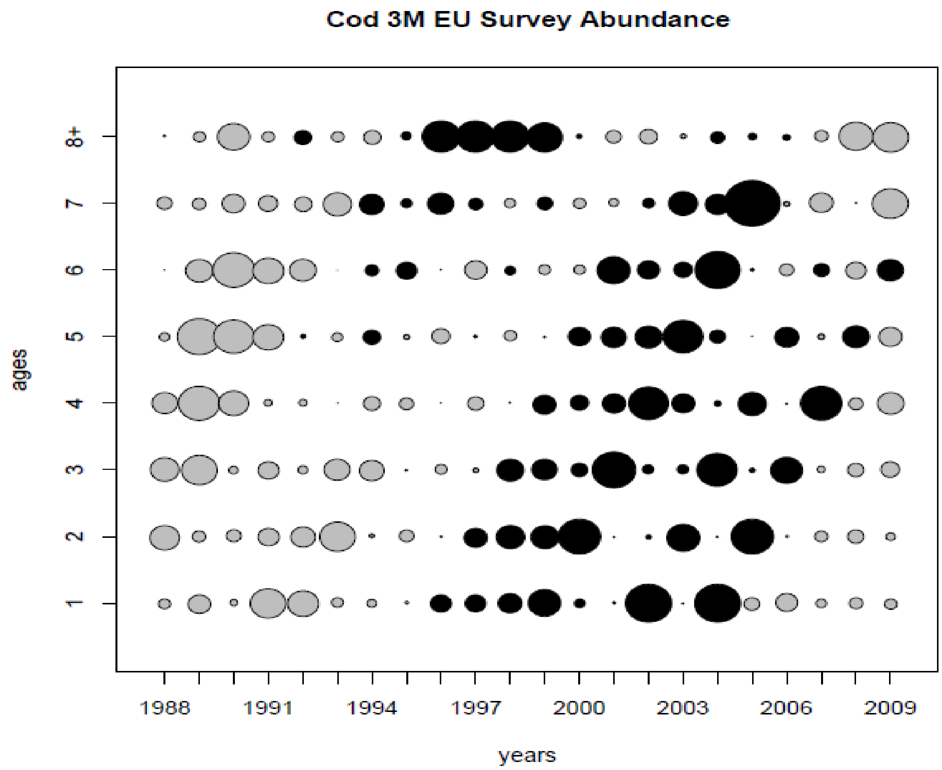

Figure 7.- Standardised log(1+Abundance at age) indices from EU survey

Figure 8.- Stock mean weight at age

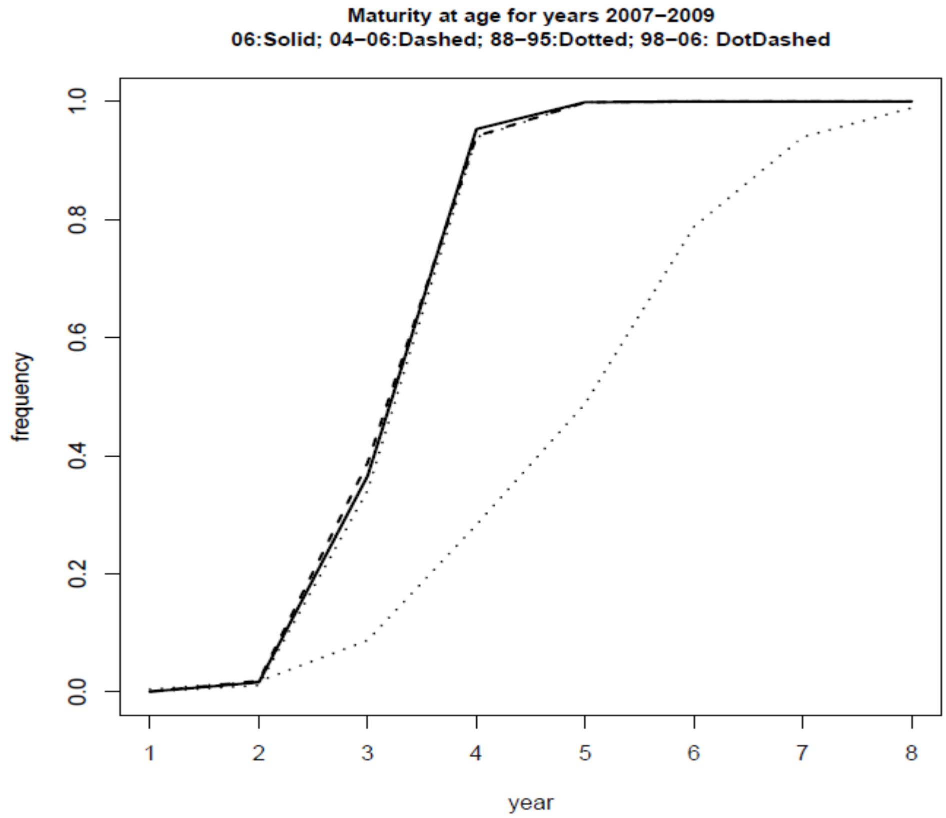

Figure 9.- Maturity frequency at age for years 2007-2009 from four maturity ogives

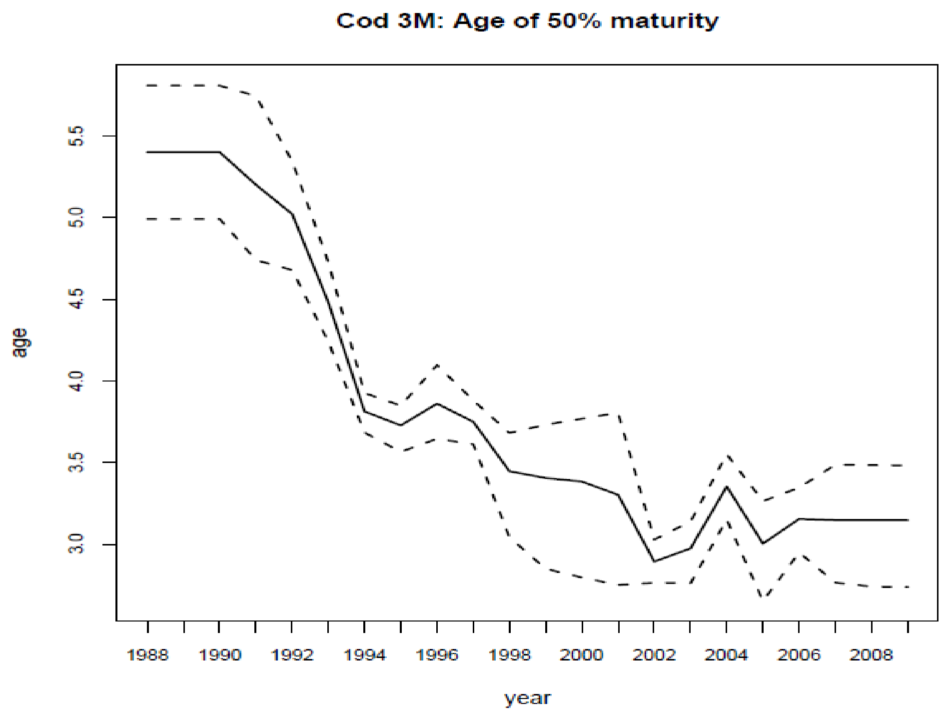

Figure 10.- Age at which 50% of fish are mature

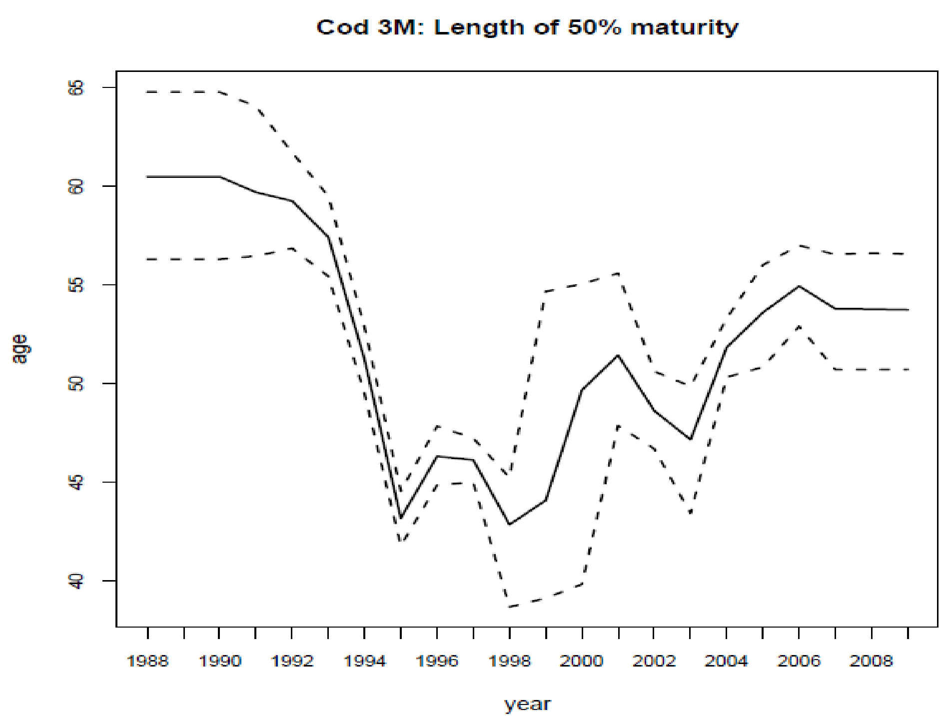

Figure 11.- Length at which 50% of fish are mature

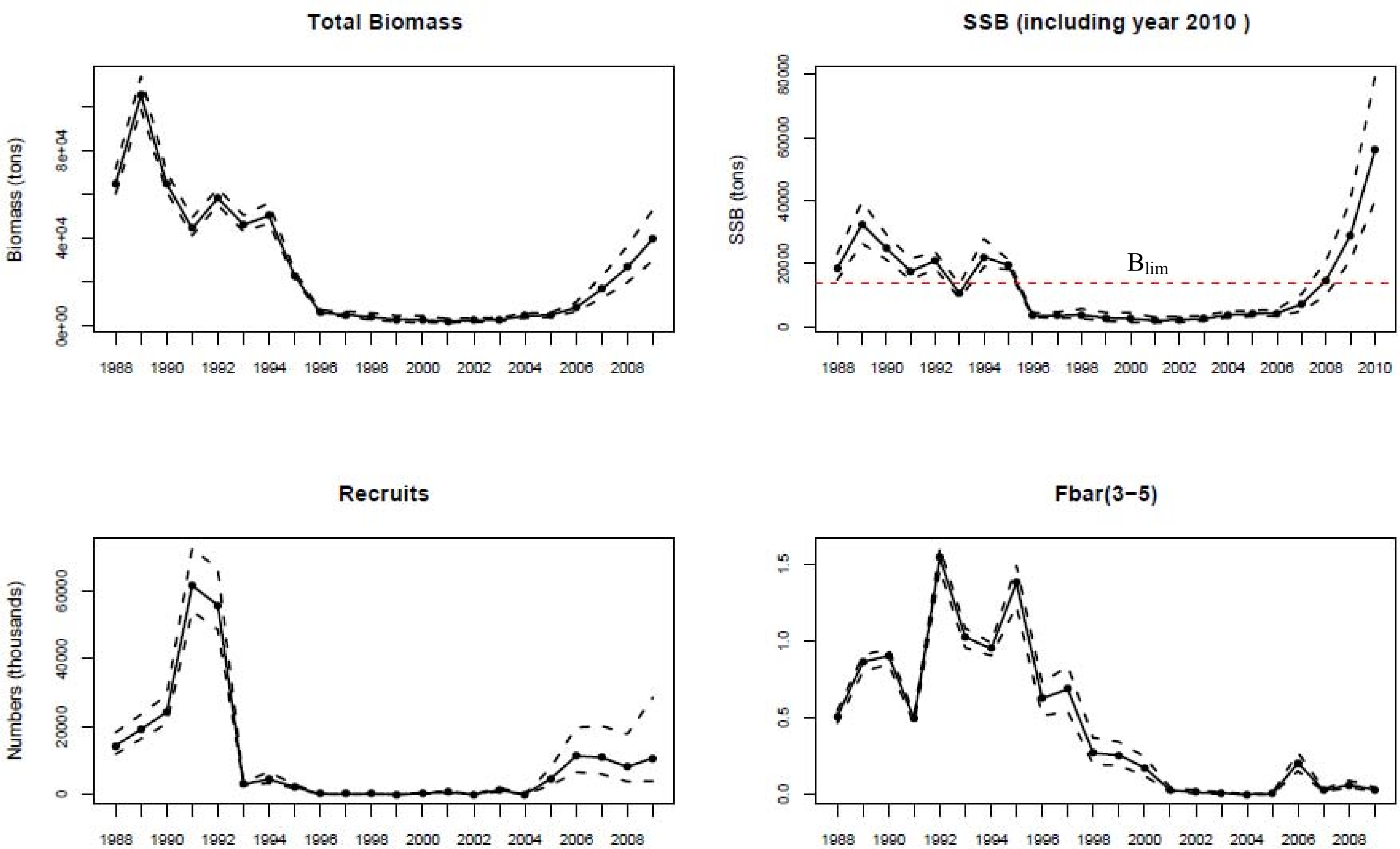

Figure 12.- Estimated trends in biomass, SSB, recruitment and F_{bar}.

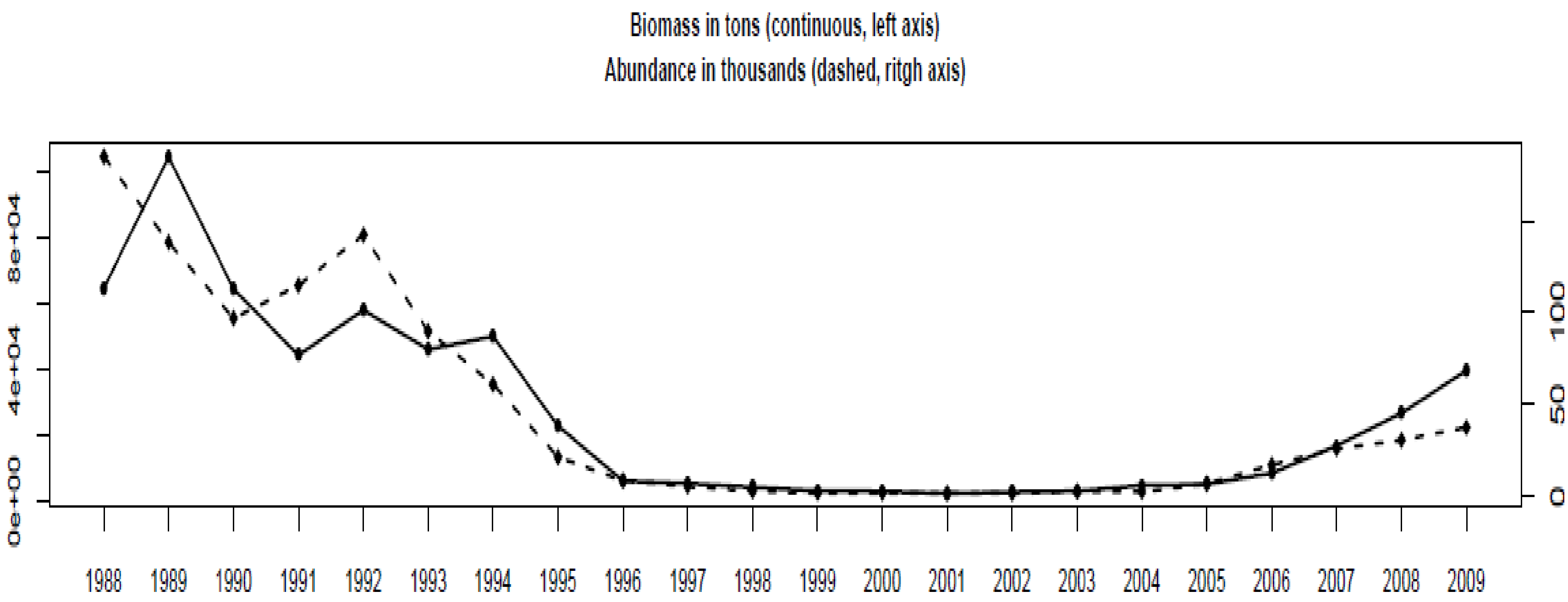

Figure 13.- Estimated trends in biomass and abundance.

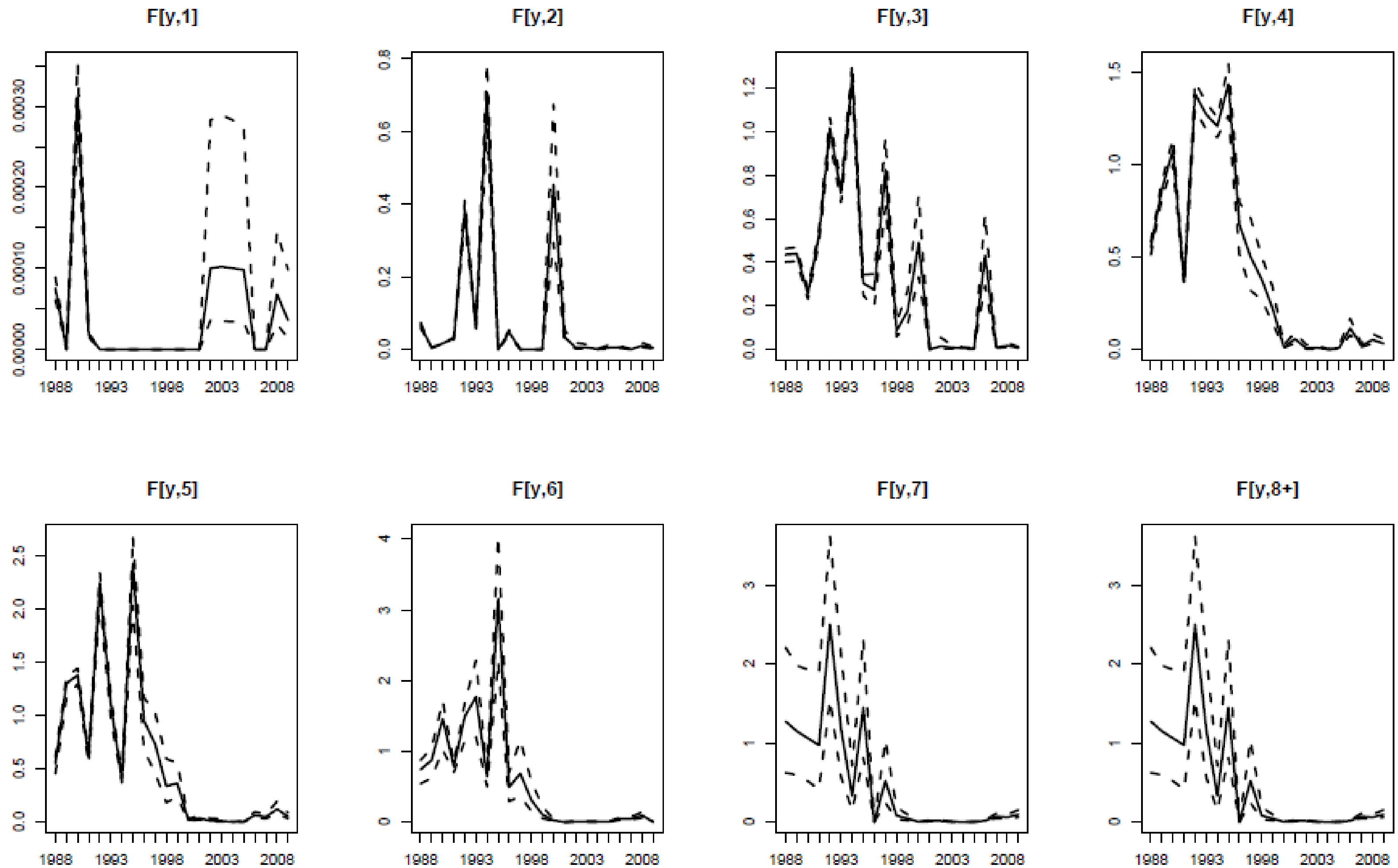

Figure 14.- Estimated fishing mortality at age.

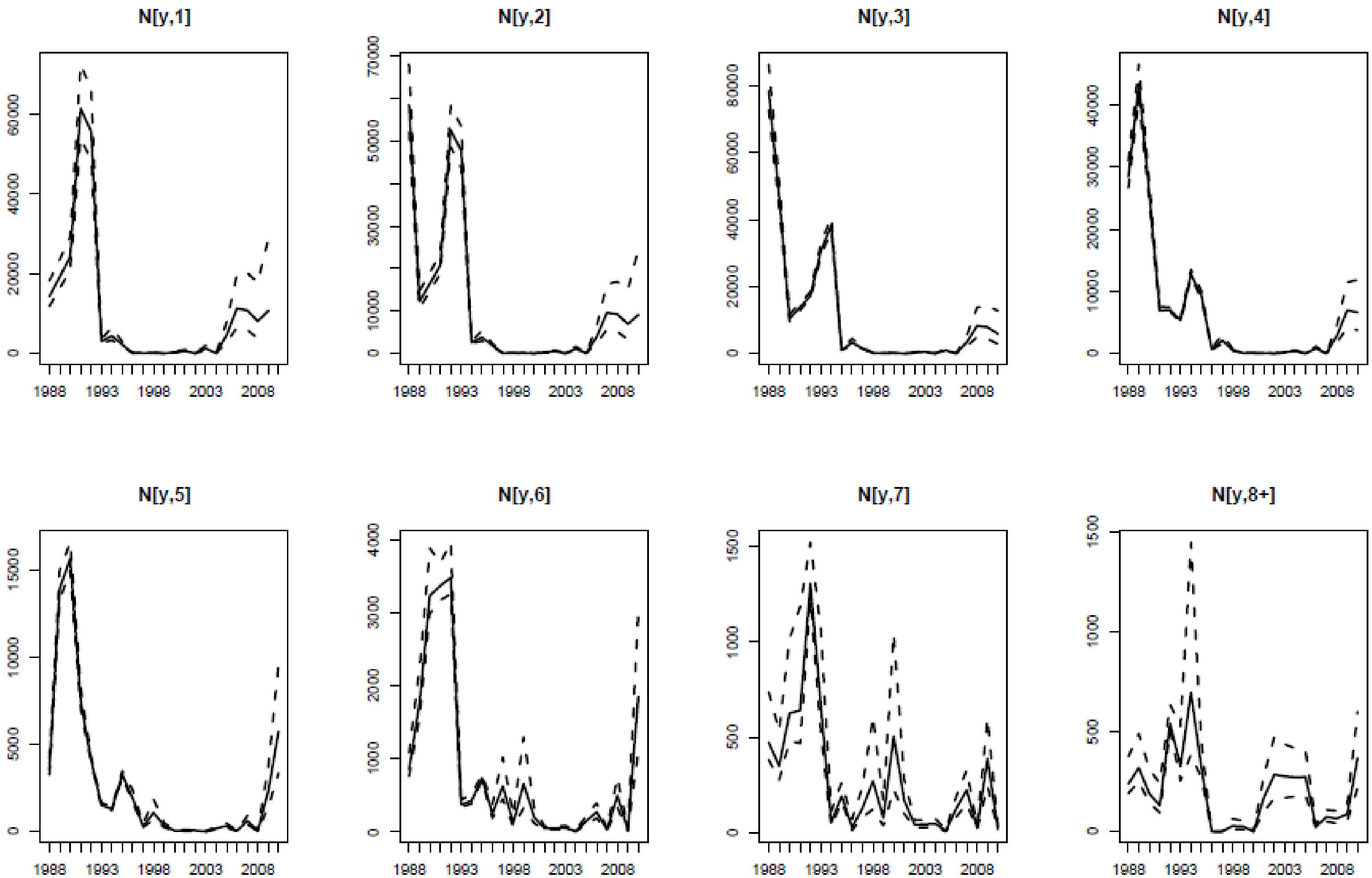

Figure 15.- Estimated numbers at age.

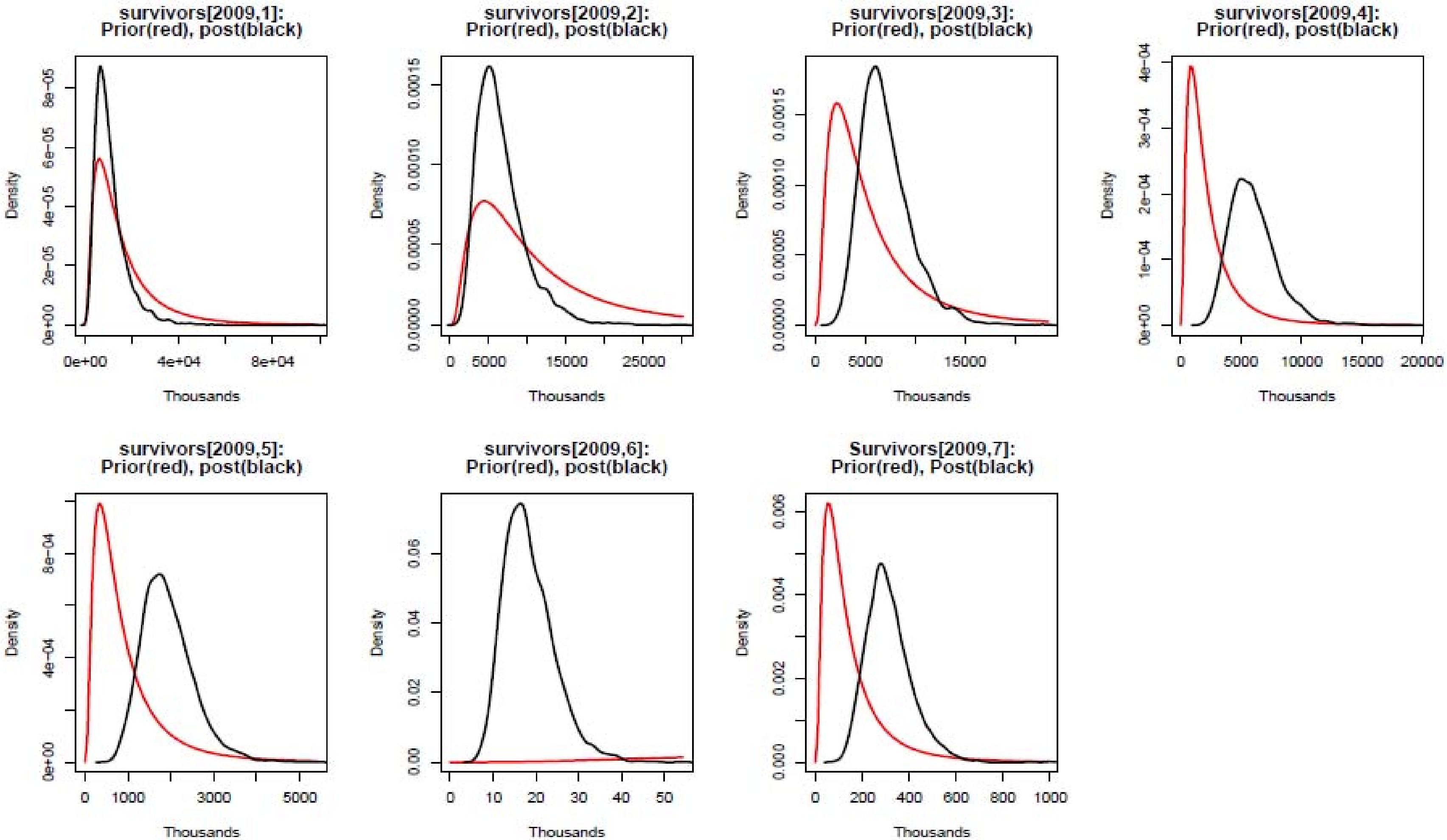

Figure 16.- Survivors at age at the end of 2009 (*survivors* (2009,a) are the number of individuals of age a+1 at the beginning of 2010).

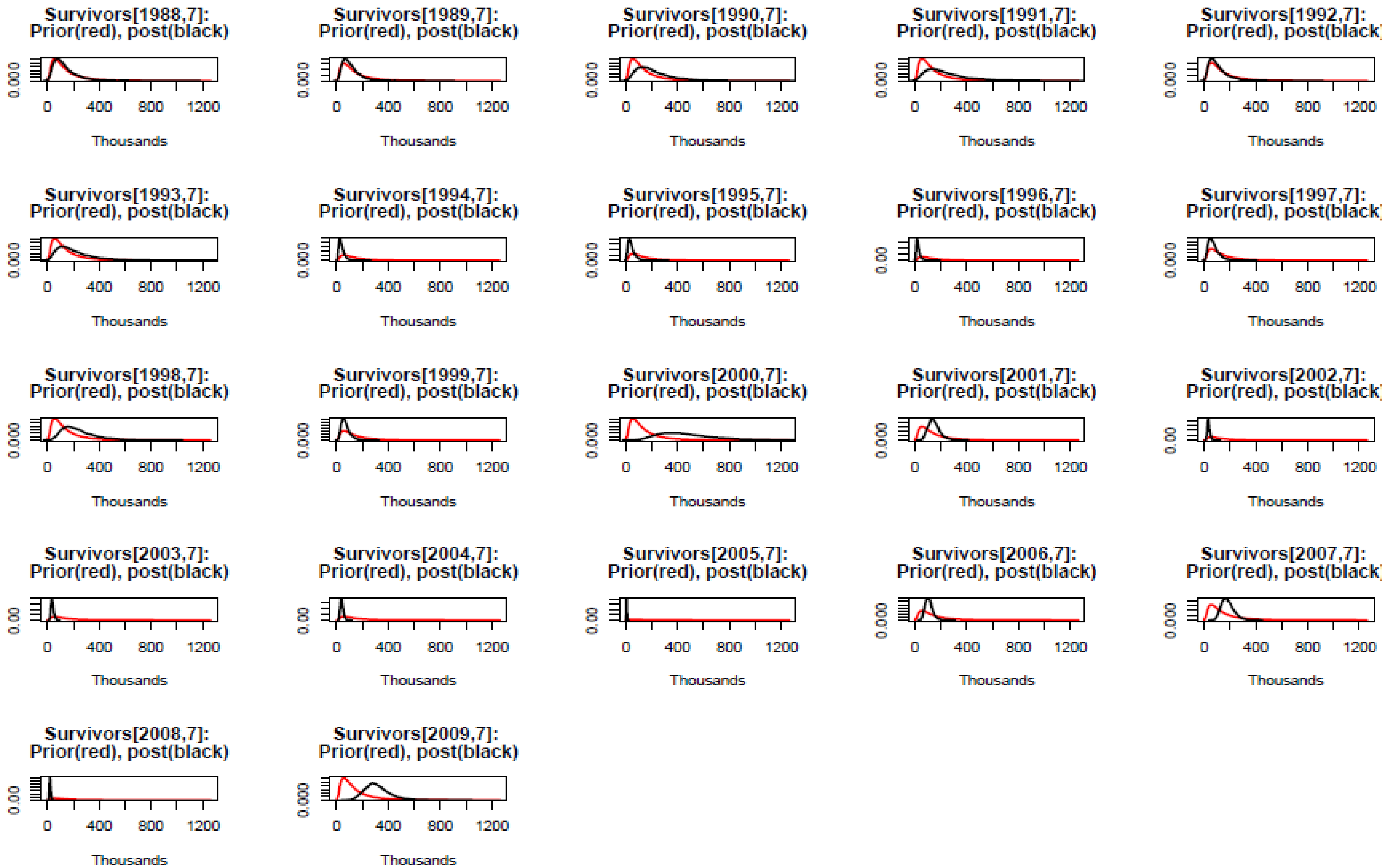

Figure 17.- Survivors from age 7 in each year (*survivors* (y,7) are the individuals of age 8 at the beginning of year y+1).

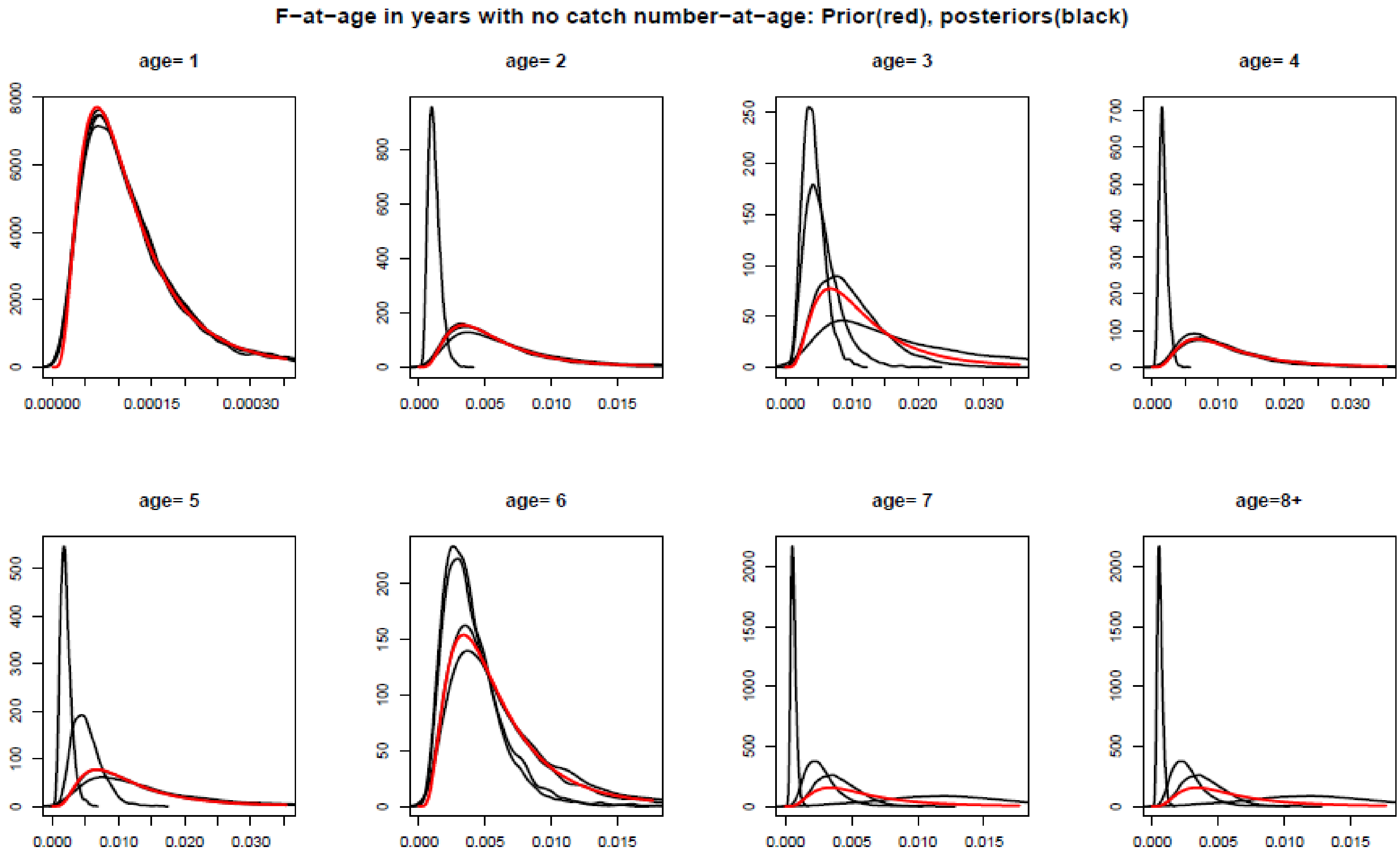

Figure 18.- F at age in years without catch numbers at age.

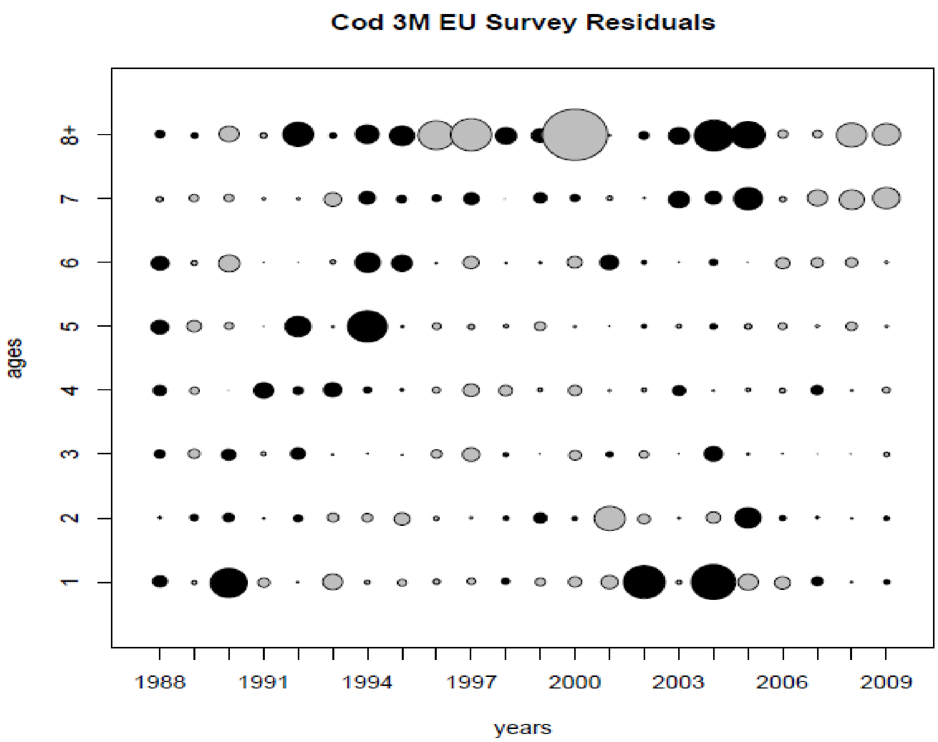

Figure 19.- Raw residuals (observed minus fitted value) in logarithmic scale of EU survey abundance indices at age.

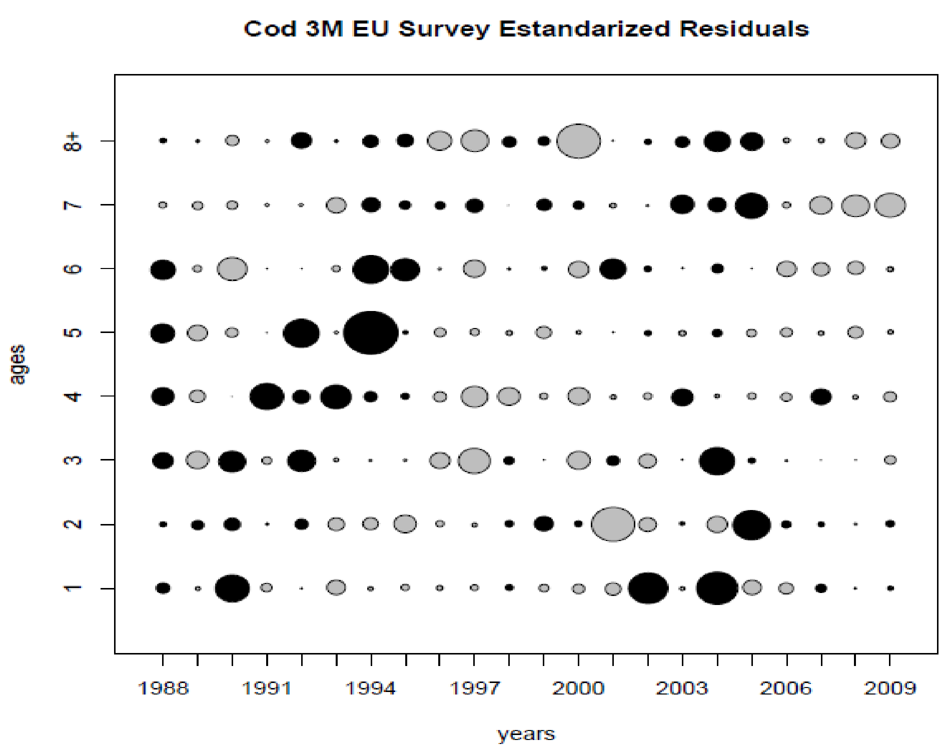

Figure 20.- Standardised residuals (observed minus fitted value) in logarithmic scale of EU survey abundance indices at age.

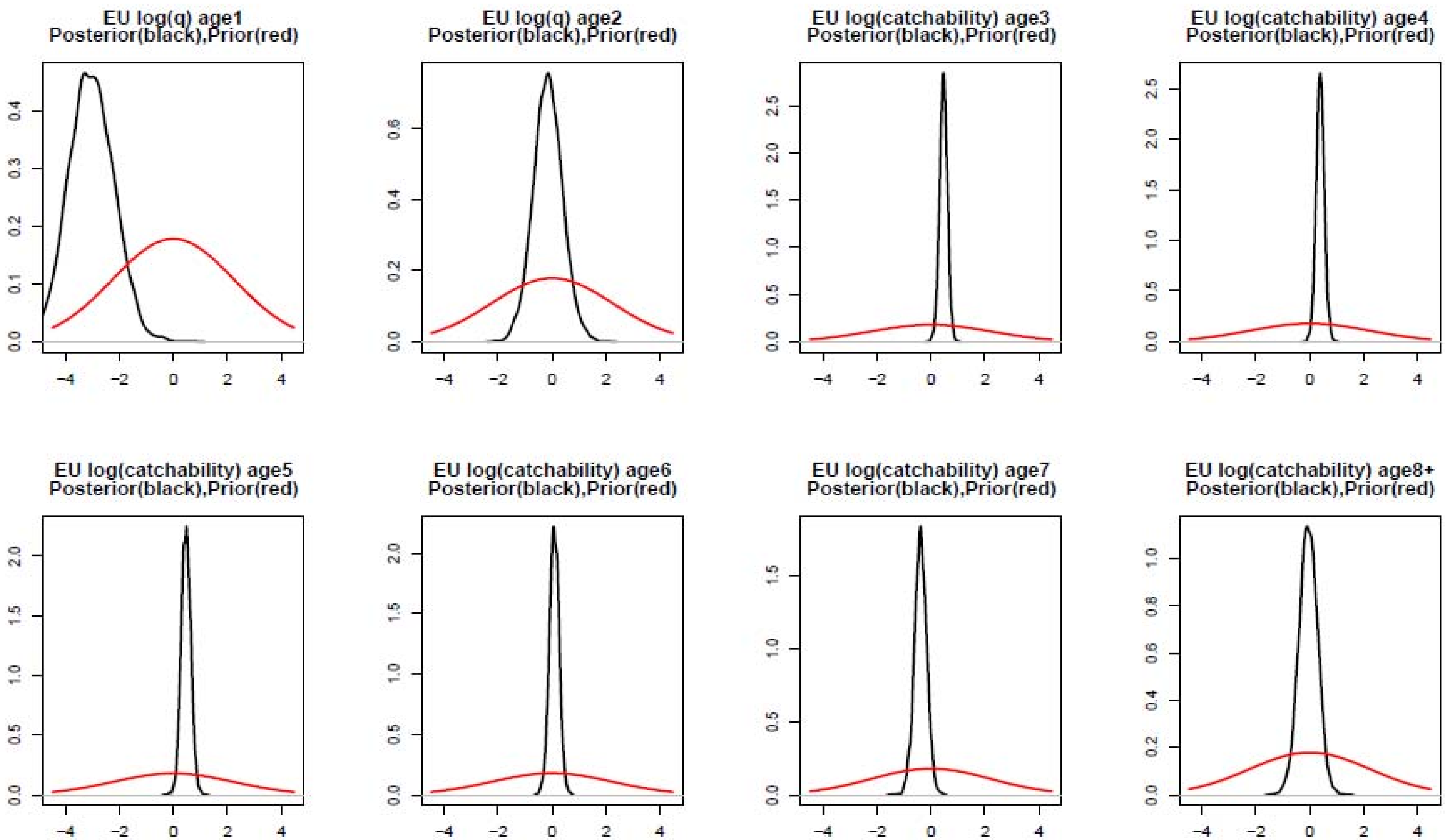

Figure 21.- Results for log(q(a)) of EU abundance at age indices.

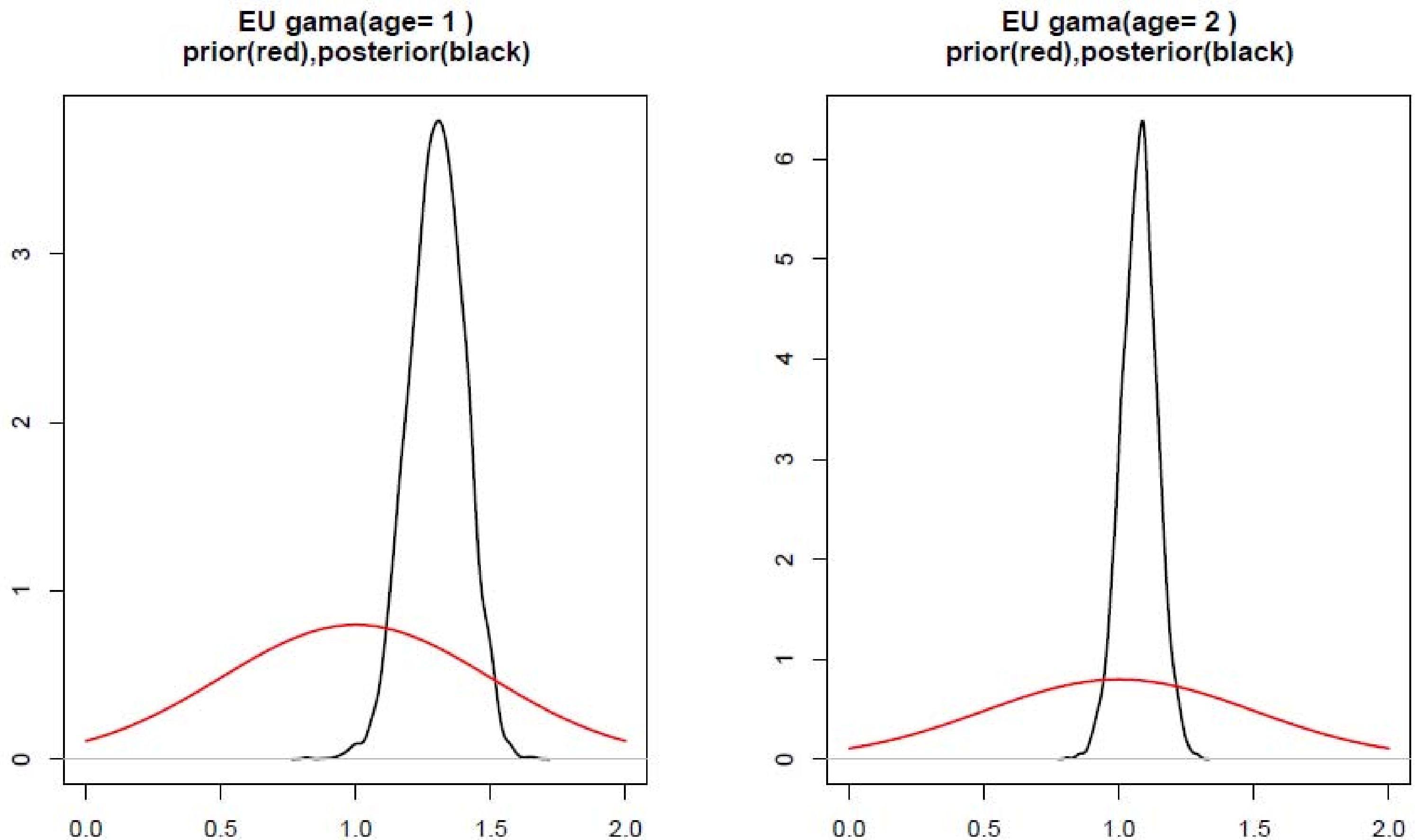

Figure 22.- Results for γ(a) of EU abundance at age indices.

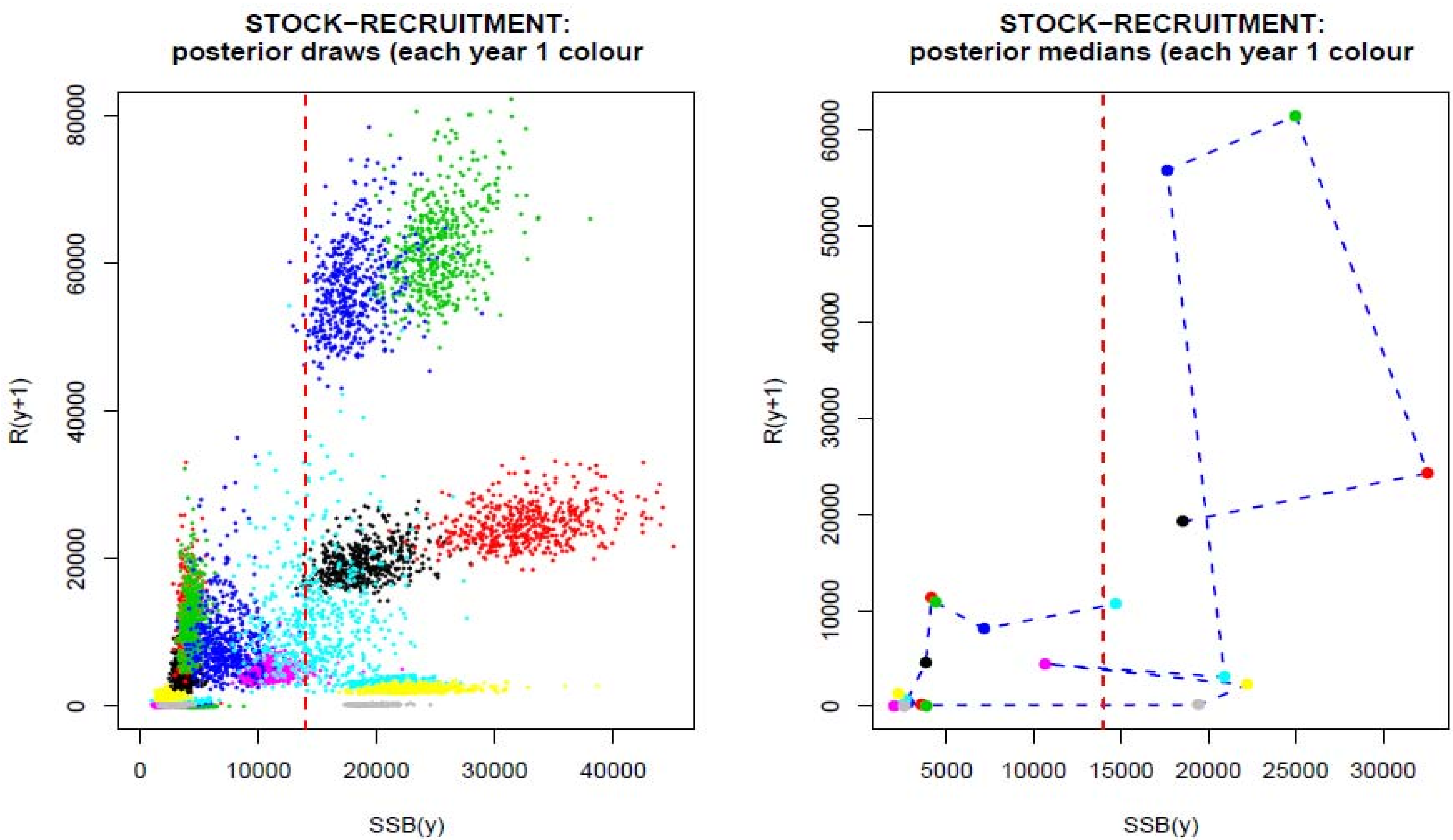

Figure 23a.- Stock-Recruitment plots. B_{lim}=14000 is shown as the red vertical line.

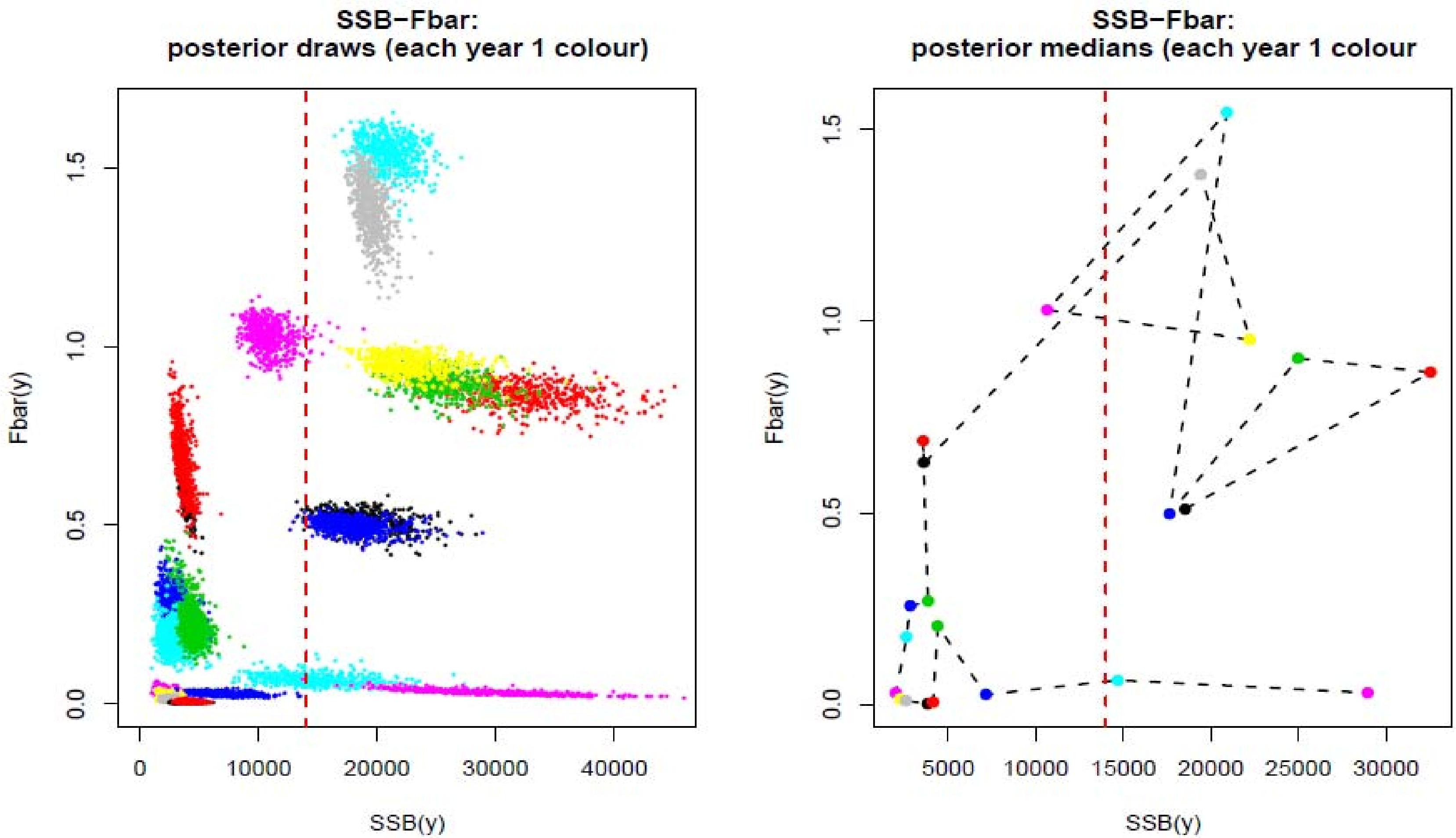

Figure 23b.- F_{bar} versus SSB plots. B_{lim}=14000 is shown as the red vertical line.

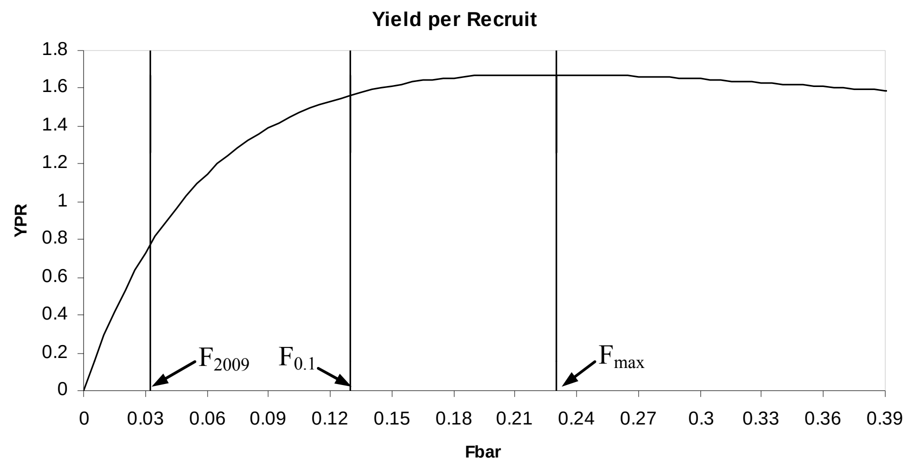

Figure 24.- Bayesian Yield per Recruit versus F_{bar}. The values of $F_{0.1}$, F_{max} and F_{2009} are indicated

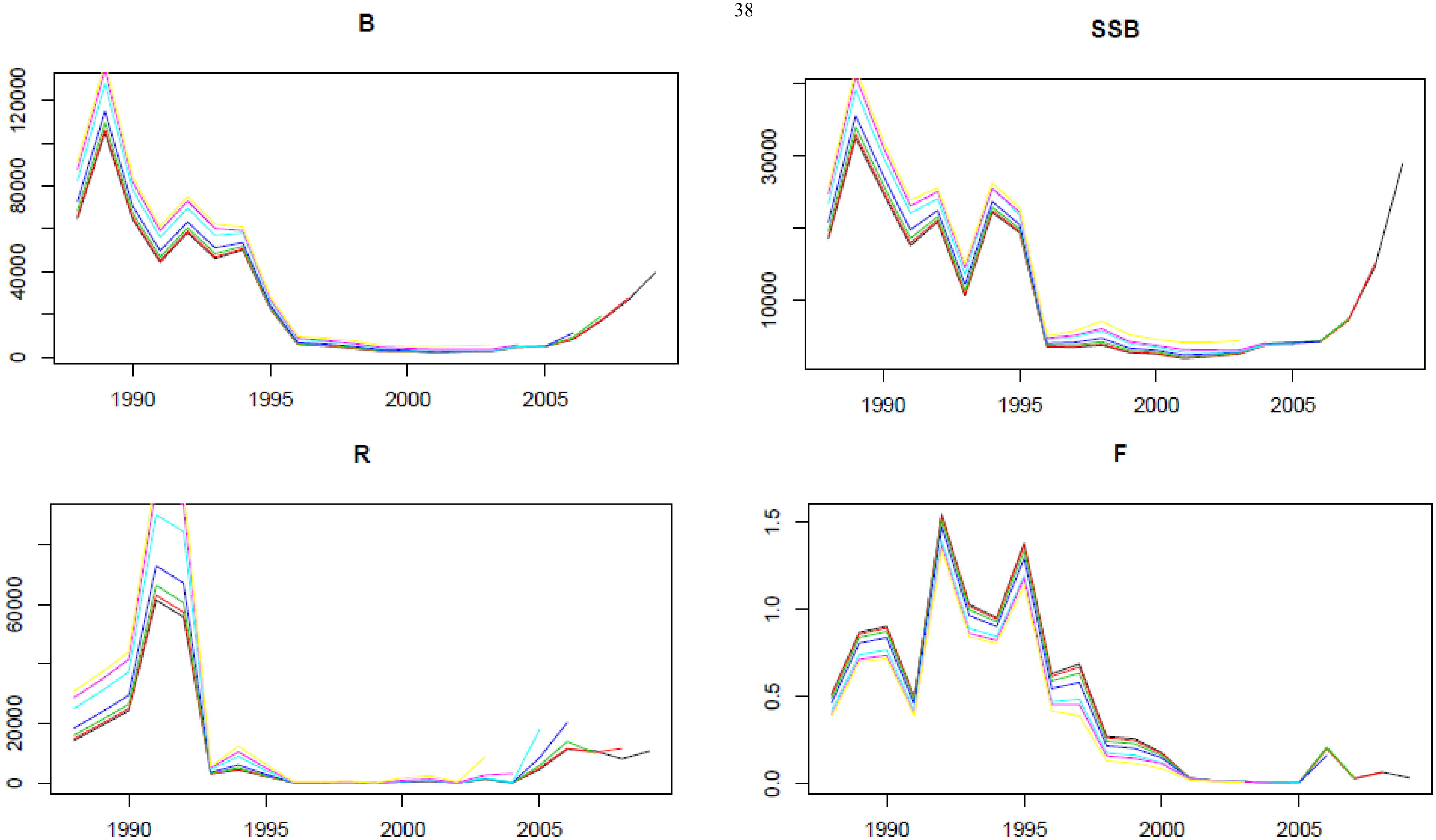

Figure 25.- Retrospective patterns.

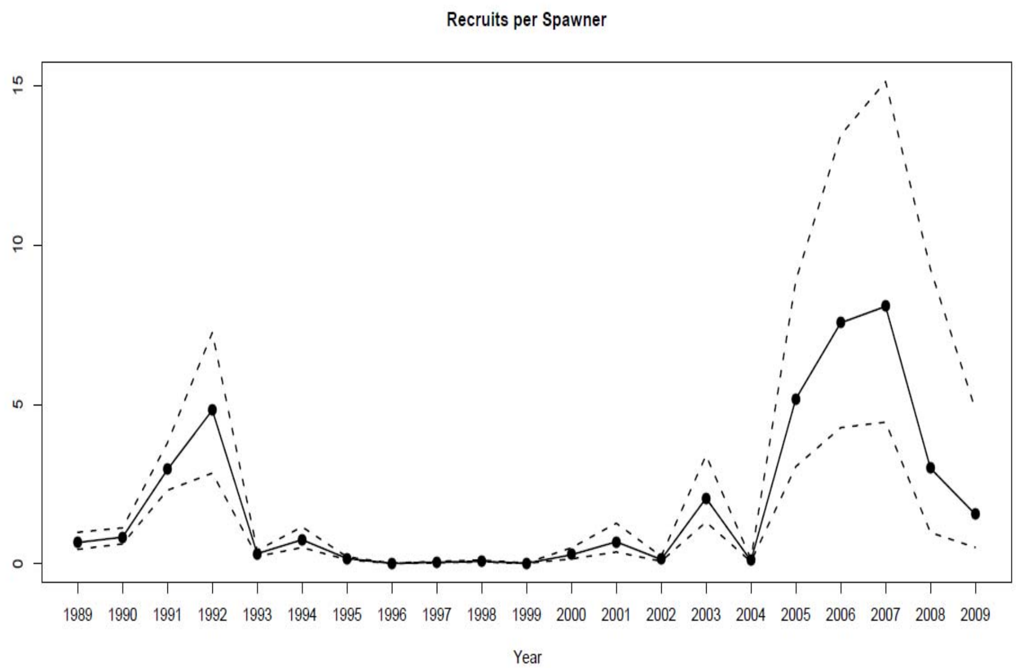

Figure 26.- Estimated recruits (age 1) per spawner.

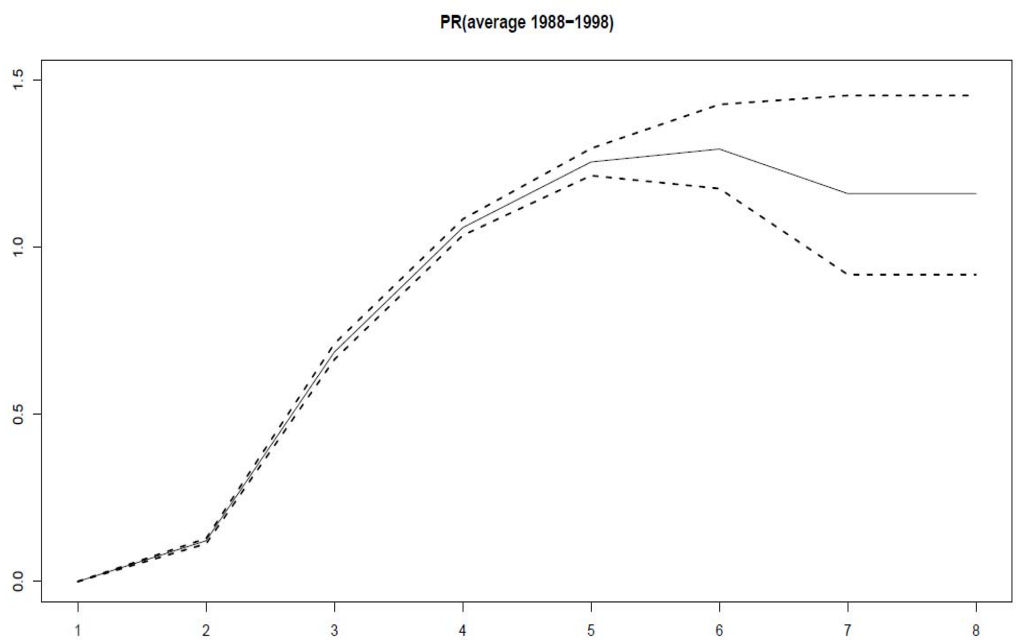

Figure 27.- Estimated PR, averaged over the years 1988-1998.

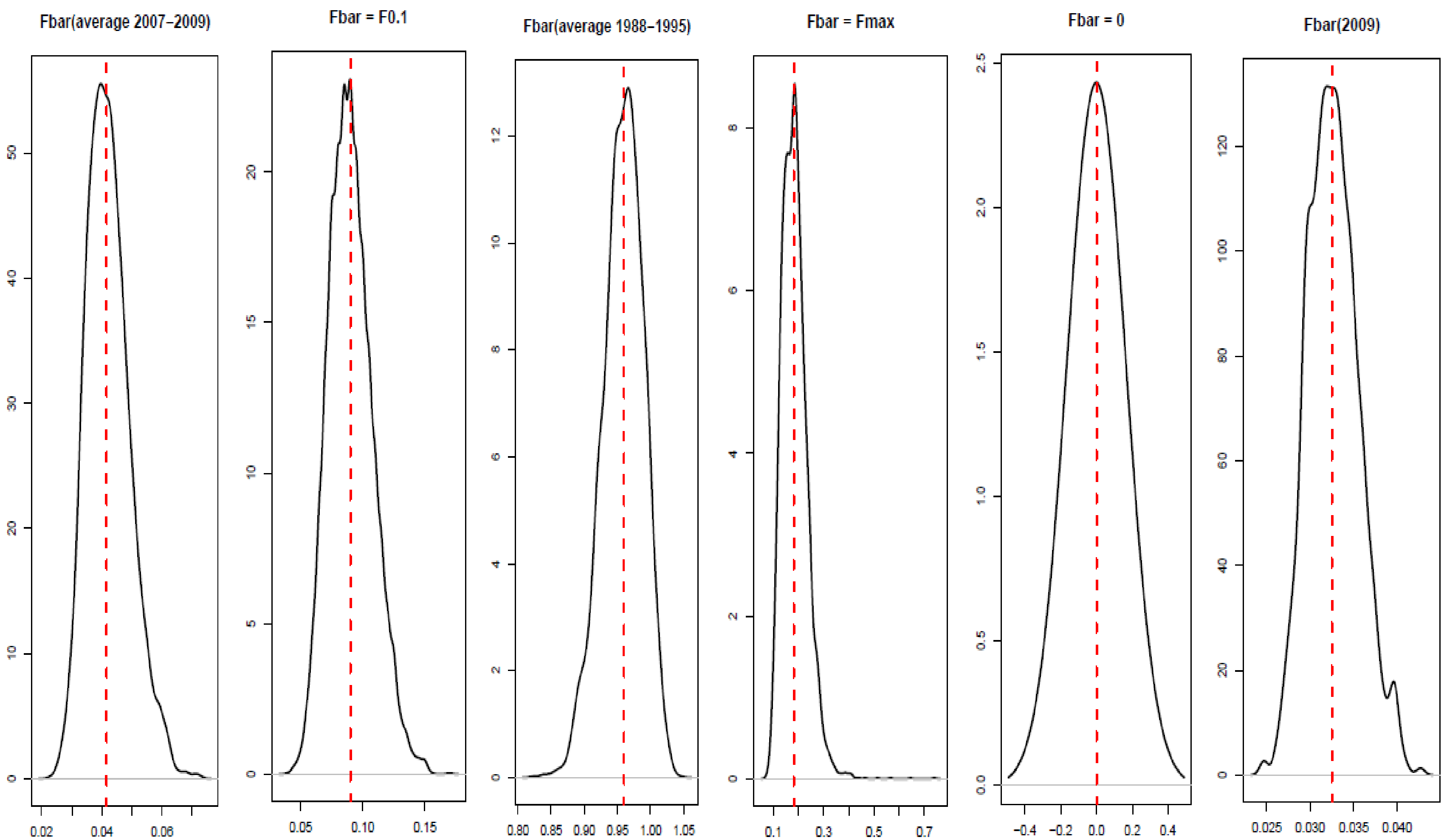

Figure 28.- Distribution and median values of F_{bar} over the different scenarios.

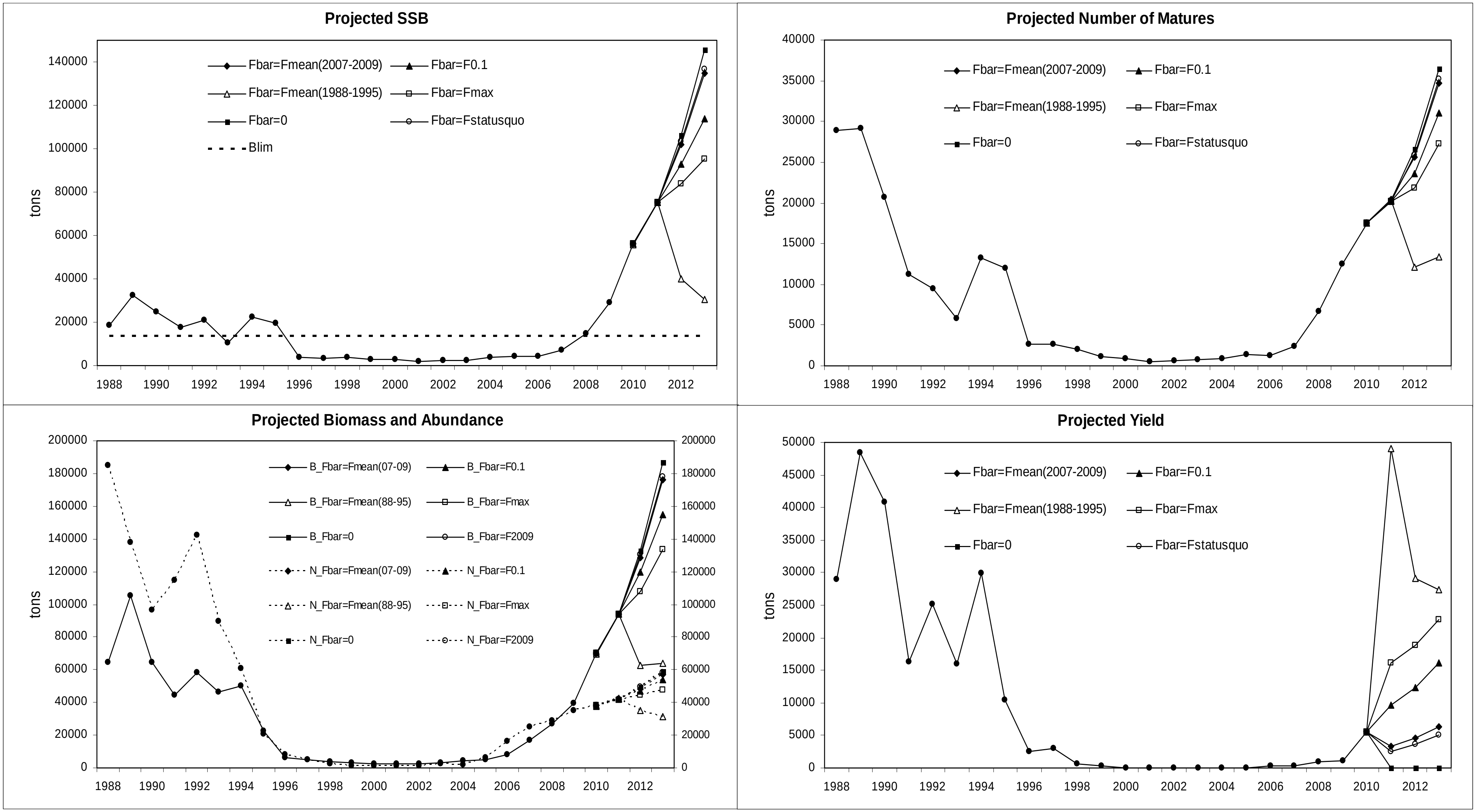

Figure 29.- Projections for SSB, number of matures, Total Biomass and Abundance and Yield with different scenarios.

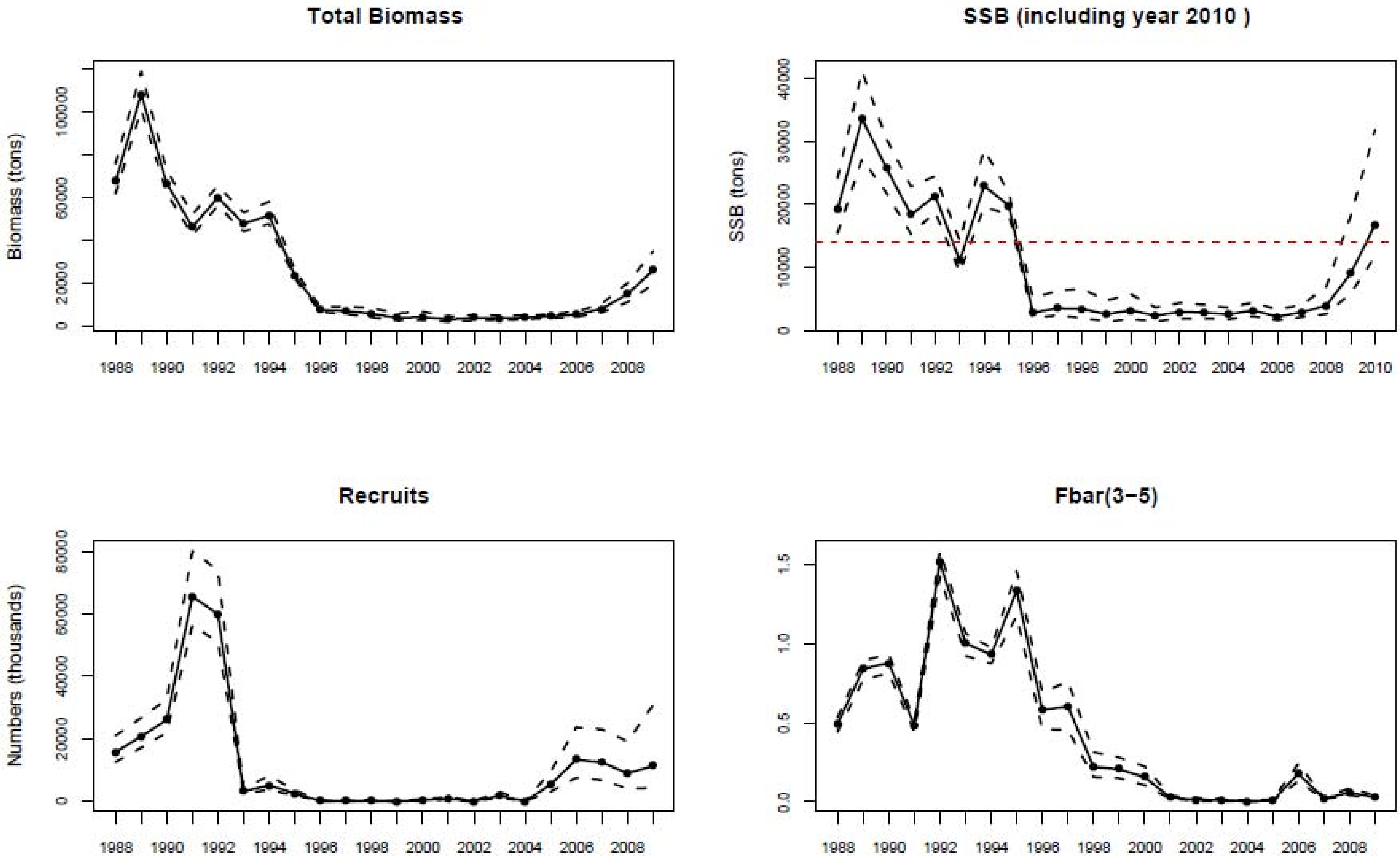

Figure 30.- Estimated trends in biomass, SSB, recruitment and F_{bar} with the maturity ogive and weight-at-age constant and equal to the mean of years 1988-1995.

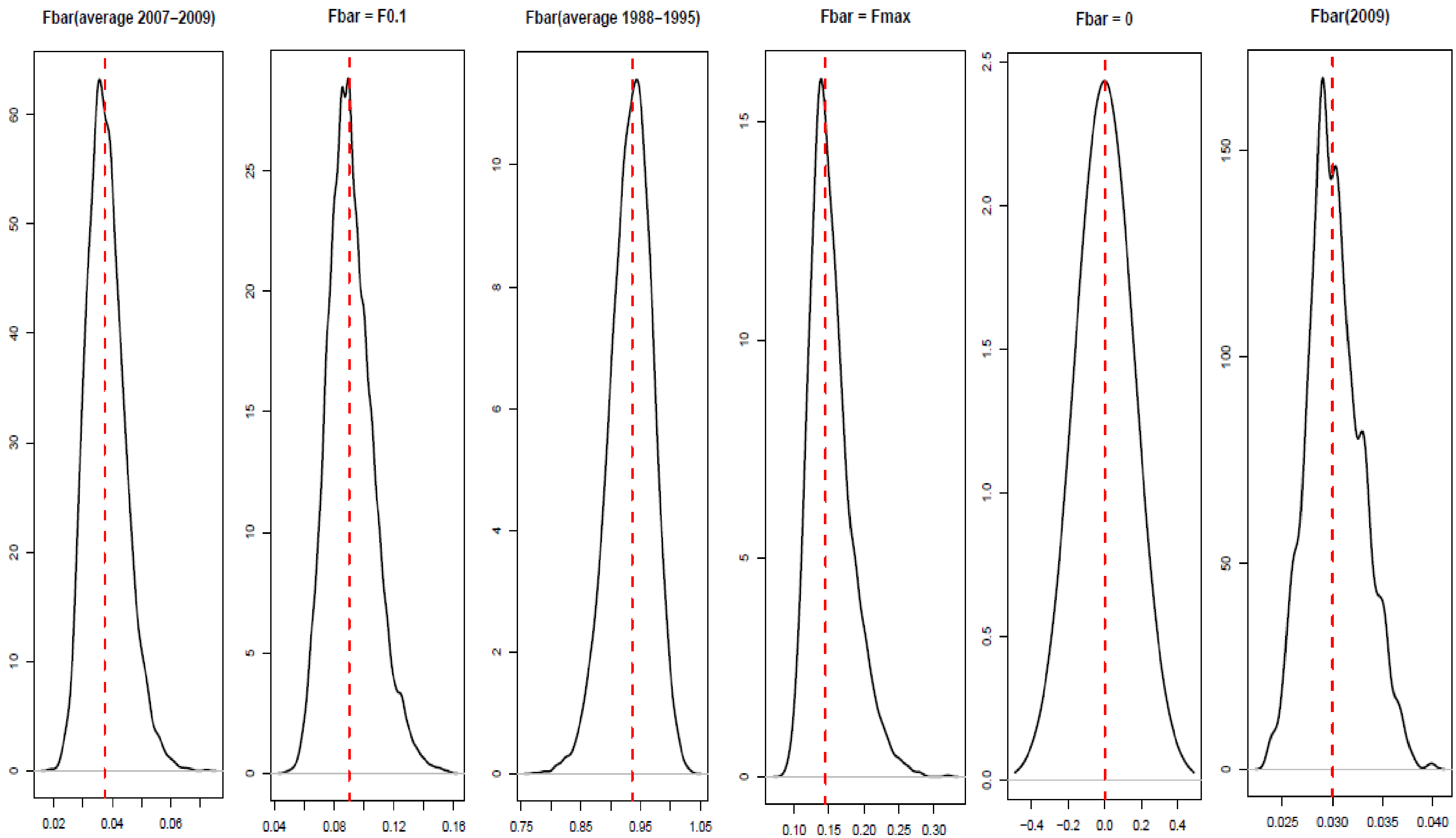

Figure 31.- Distribution and median values of F_{bar} over the different scenarios with the maturity ogive and weight-at-age constant and equal to the mean of years 1988-1995.

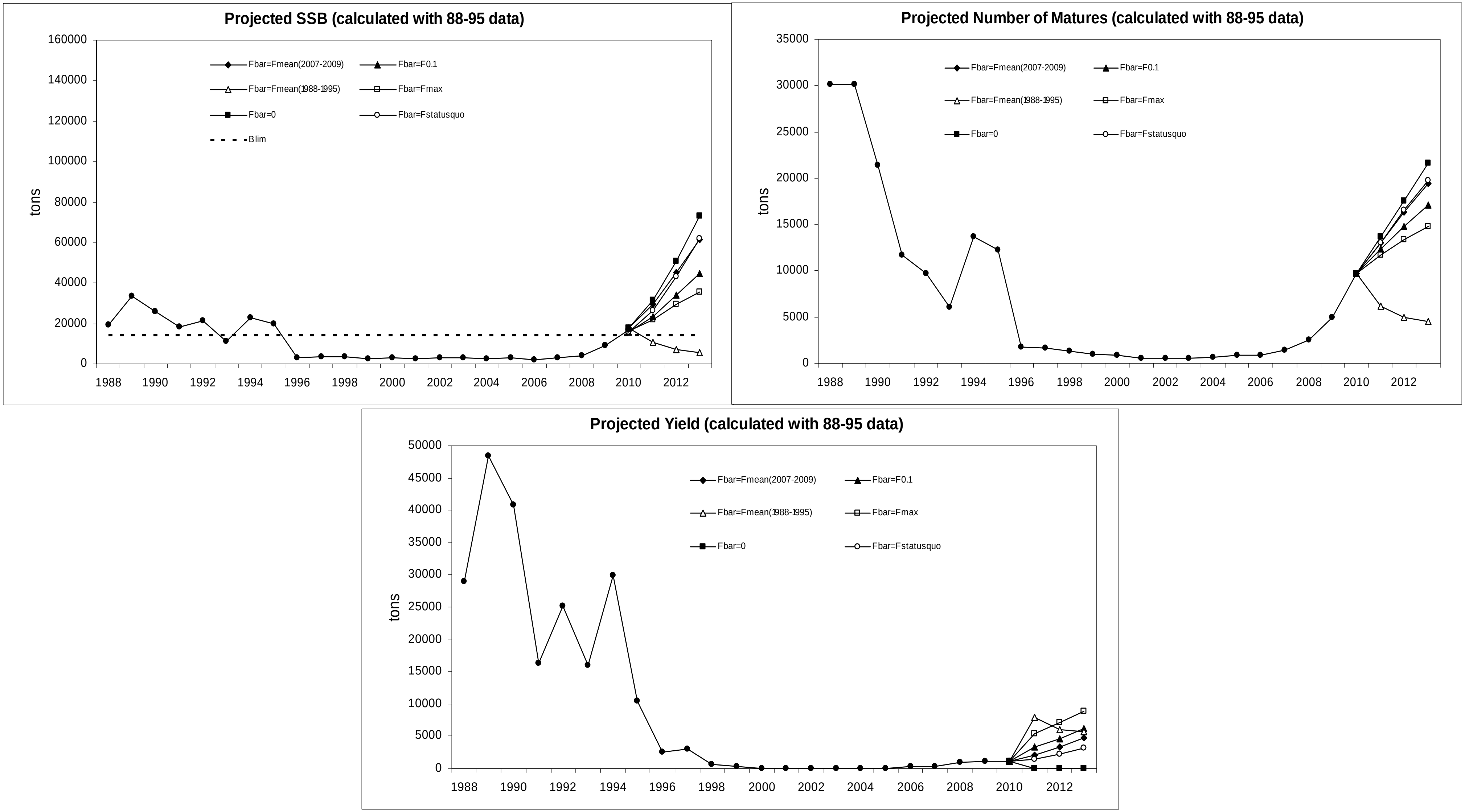

Figure 32.- Projections for SSB, number of matures and Yield with different scenarios with the maturity ogive and weight-at-age constant and equal to the mean of years 1988-1995.