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Variability of Abundance Indices and its Progression Through Age-structured Models: an Stochastic Simulation with Flemish Cap Cod

by

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Abstract

The assessment of many fish stocks in the North Atlantic are based on age-structured models like XSA or ADAPT. The abundances and fishing mortalities provided by these models are of main interest and their errors are calculated analytically from the catchability relationship. Assumptions on this relationship are explored by Monte Carlo simulation of a XSA analysis of Flemish Cap cod tuned with survey abundance indices for which variance-covariance was previously calculated by bootstrap. Two different Monte Carlo simulations were carried out: with and without covariance among those abundance indices.

The results show that the XSA applied to the Flemish Cap cod is quite robust against these assumptions, but the errors are best evaluated by Monte Carlo simulation, which provides more accurate and precise results. Covariance of indices does not promote different results but correlation of the results should be taken into account on short-term projections. The Monte Carlo simulation, or stochastic XSA, also provides directly the probability profile for spawning stock biomass if variance estimates of the maturity ogive and stock weight at age are included. This probability profile could be an important tool to evaluate the risk of reopening fisheries in the context of a precautionary approach.

Introduction

The XSA is an age structured model frequently used to evaluate fisheries based on a long series of catch at age data and independent indices of abundance, such as CPUE's or survey catches; furthermore, the model needs an estimate of natural mortality (M). The XSA focuses on the relationship between abundance index (I) and population abundance (N) (Darby and Flatman 1994). The input data are combined in the XSA in two stages: firstly by a cohort analysis (a), and then this cohort analysis is forced to fit the error-prone abundance indices by an assumed catchability relationship (b).

$$N_t = N_{t+1} * e^{M} + C_t\, e^{M/2} \qquad \text{(a)}$$

$$I = q * N \qquad \text{(b)}$$

The model states some assumptions about variables: in the cohort analysis M is considered known and without error and catches at age are considered exacts and caught uniformly along the year (classical VPA) or totally in the middle of the year (cohort analysis). Under this condition VPA results are considered to be the best estimate of the true abundance, which for calibration purposes are considered error-free (Shepher 1999). In the second stage, the catchability model is the key of the XSA calibration and the catchability relationship is the basis for error estimation on XSA results.

The availability of uncertainty associated with advice parameters, such as fishing mortality or spawning stock biomass, became of increased interest in the last years associated to the precautionary approach (PA) framework (Punt and Butterworth 1993, Mohn 1993). The NAFO PA framework was first defined in 1997 (Serchuck *et al*. 1997), giving definitions for limit, buffer and target reference points for both spawning stock biomass and fishing mortality (B_{lim}, F_{lim}, B_{buf}, F_{buf}, B_{tr} and F_{tr}). Since then, the PA has been applied to some stocks in the NAFO area (Sinclair 1997, Mohn and Black 1998, Stansbury *et al*. 1998, Rivard and Walsh 2000).

The Flemish Cap cod stock is assessed by an XSA since 1998 with a 30 years catch series and it is calibrated with abundance indices from the EU-survey, carried out since 1988 (Cerviño and Vázquez 2000). The stock is under moratoria since 1999 being now at its lowest historical level due to the high catches in the early 90's and the poor recruitments from 1996 to 1999. The SSB estimated in the last year assessment was near 10 000 t but this was considered to be an overestimation of the present condition due to a bad fit of the model. The stock-recruitment plots show a SSB level of 14 000 tons below which the recruitment is poor; then, an initial B_{lim} at such level was proposed for this stock.

There are several sources of uncertainty in any fish stock assessment that should be taken into account: measurement error, process error, model error, estimation error and implementation error (Rosenberg and Restrepo 1994). Some of these errors cannot be quantified by analytical methods but by resampling methods such as bootstrap or Monte Carlo simulation (Manly 1997, Davison and Hinkley 1997) that have been proved to be useful tools for this task (Smith *et al*. 1993). Another source of uncertainty is the effect of the covariance among the indices used in the catchability model. Pennington and Godo (1995) and Myers and Cadigan (1994) have demonstrated that taking into account this covariance reduces the variability and bias of the survivors' estimates.

In this paper we quantify and analyse some of these sources of uncertainty in the estimate of current stock status of the Flemish Cap cod; *measurement error* of abundance indices and their covariance were calculated by bootstrap and were later used in applying a Monte Carlo to the XSA to evaluate the *model error* on the calibration process of the XSA. The procedure also produces probability profiles of the predicted spawning stock biomass; the *estimated error* of this variable is of prime interest on the context of the precautionary approach.

Material and Methods

Flemish Cap survey

Abundance indices for tuning the XSA were obtained from the EU-Flemish Cap survey that has been carried out since 1988 with the aim of evaluate the main commercial species in the area (Saborido and Vázquez 2001). The stratified random sampling, that usually have 120 hauls, follows the NAFO specifications as described by Dobleday (1981) and covers the bank up to 730 meters depth, including the complete area distribution of the cod, that is considered an independent stock.

Sampling and errors in numbers at age. Bootstrap algorithm

Errors in numbers at age as well as correlations among them in each year were calculated by bootstrapping. Bootstrap is a robust statistical method that is based on the idea that the distribution of the values of a random sample is the best estimate of the distribution of the real population without any other consideration as parametric assumptions. Then, the observed sample of *n* values, each one with probability *1/n* is used to model the unknown real population by a resampling with replacement of size *n* (Manly 1997). When this routine is applied to complex surveys designs like this (to calculate abundance at age from stratified random designs), it is necessary to take special care to provide the same probability of being chosen to each sample in the resampling process (Smith 1996). This is reached following the onboard sampling scheme and applying bootstrap in each one of the variability sources (Vázquez and Cerviño 1998):

1- Resampling hauls by strata with replacement keeping the original number of pseudohauls in each stratum.
2- Resampling with replacement the size distributions of every pseudohaul keeping the numbers of measurements in each pseudohaul.
3- Apply the age-length-key to each individual matching the size with its correspondent pseudoage. Pseudoage means that every fish can have different probability of match with more than an age, then this probability is applied each time that an age is assigned. The age-length-key is the same for all the strata.

The survey abundance indices at age are calculated in the usual way, weighting hauls with their catches standardised by swept area. We have applied this bootstrap algorithm 5000 times getting 5000 values for each age. These values were used to calculate the mean, bias, standard error and variance-covariance for the age survey indices, to be used in the Monte Carlo simulation.

XSA model

The inputs for the XSA were total catches since 1972, EU-survey abundance indices since 1988 and a constant natural mortality coefficient of 0.2. The XSA model applied in the last year (Cerviño and Vázquez 2000) was criticized because of its high negative residuals on the most abundant ages of 1999, ages 6 and 7, which are the 90 % of the spawning stock biomass in 2000. For the current model, we have modified some settings in order to improve this undesirable result. We have applied the constant catchability model for all ages, that is: ages 1 to 6, instead of those of last year: ages 2 to 4. We have also changed the weight of the shrinkage from 0.5 to 2. These new settings give more freedom to the model in order to fit the survey index, especially in older ages. The new model have also more precision on the abundances indices that are now expressed in thousands instead of ten thousands. The scarce year-classes of the most recent years are now better defined and this change alone represents a 20 % reduction in the estimated SSB. The residuals have improved and the estimated SSB for the year 2000 has moved from 10 to 6 thousands, closest to the survey estimate.

Monte Carlo simulation

Monte Carlo methods are the parametric way of the bootstrap; in fact, Monte Carlo methods are also called *parametric bootstrap*. It is necessary to take some statistical assumptions about the distribution of the variables and then, the pseudosample is derived from this assumed distribution. The software used to perform the simulation were two add-ins developed to work under Excel spreadsheet: Fishlab (Kell and Smith, in prep.) and @Risk (Palisade 2000).

This simulation was designed to evaluate the statistical properties of the state variables of the XSA, i.e. catchability by age (q) and terminal population numbers at age (Pt). In order to check the effects of the annual covariance among abundance indices at age, two simulations were performed, using indices with and without covariance. The statistical model applied to the indices distribution was lognormal (Smith and Gavaris 1993, Patterson 1998); mean values were calculated by Vázquez (2000) and their variance-covariance was calculated as described before. No bias correction was applied to the mean since their values are quite similar to those calculated by bootstrap. Convergence criteria was evaluated every 100 samples and the simulation stopped when the change in mean and standard error of all selected outputs (q and Pt) were less than 1.5%. The total number of samples was 2000.

SSB distribution: numbers, ogive and weights.

It was necessary to assign a proxi for the proportion of maturity at age and for weight at age as well as their variance in order to evaluate the statistical properties of the spawning stock biomass (SSB) predicted by the model, i.e. in 2000. The SSB was included as output in the Monte Carlo simulation and the weights and maturities at age in 2000 were used as inputs. The expected values for weights at age were those of 1999 and their standard errors were calculated as the maximum observed value between two consecutive years in the last five years; the distribution assumed was lognormal. The expected values for the proportion of maturity at age were those of 1999; binomial distribution is that best describes the distribution of the values upon which the analysis is based (Hosmer and Lemeshow 1989).

Results

Variability of survey indices

The mean values of the survey indices and the standard error calculated by bootstrap and used in the simulation are showed in the Table 1.

The coefficients of variation (c.v.) for the abundance indices are provided in Figure 1. The c.v. is a more straightforward measure of variability than the standard error because the calibration in the XSA is made with logtransformed values and the c.v. is a good proxi of the standard error of the logarithm of a variable (Darby and Flatman 1994). The results are given for a survey in July; the effect of the modification towards the start of the year was not taken into account. The c.v. for each age ranges from 0.1 to 0.5 except in age 1 where the difference is higher (0.15-1.25), particularly in the last four years (Figure 1 - up). These results could lead to a poor fit in the catchability model because of the violation of the assumption of constant variance. In the bottom panel, 6 plots show the relation among abundance and their c.v.: the c.v. is the highest at low abundance numbers for all the ages, giving low stability to the fit of the catchability regression.

Correlation coefficients of the Flemish Cap survey abundance indices calculated by bootstrap are showed in Table 2: high positive correlations are frequent in all the years, particularly between consecutive ages with several values higher than 0.8. It is also clear that correlation was more important in the past years than in former years when values higher than 0.5 are scarce.

Simulation results.

The results of the simulation: survivors at age, catchability at age and spawning stock biomass as well as their main statistics (standard errors, coefficient of variation, bias and percentiles) are shown in the Table 3 and Figure 2 to compare them with the original results.

Survivors in the simulations are similar to the original values; bias ranges between –4% and 7%. Nevertheless, differences in errors are more important, specially between the simulations and the original values.

Catchabilities from simulations are always lower than the original ones. These differences range between –0.3% and –4.4%. Differences between the two simulations are negligible. The original software does not supply catchability errors, but differences between simulations are small. Their coefficient of variation ranges from 0.08 to 0.17.

Correlations between state variables for the two simulations are shown in Table 4. In general, correlations are negative between N's and Q's and positive among N's and among Q's. The absolute values are higher among the old ages but not too much in the simulation with uncorrelated inputs. Nevertheless, these coefficients increased when correlated inputs are used; the correlation coefficients were higher than 0.5 in four cases, being particularly high between consecutive catchabilities for old ages.

SSB results are shown in Table 3. Both simulations, with and without covariance, give lower values than the original: 5798 and 5767 against 5919 tons. Bias for correlated simulation is –2% and –2.5% for uncorrelated simulation, and coefficient of variation are 0.27 and 0.26, quite similar results for the two simulations. The distribution of SSB obtained from the Monte Carlo simulation is shown in Figure 2. The two plots show the frequency distribution for the 2000 simulations grouped in ranges of 500 tons, their mean and percentiles are also shown in the same plot. No value reach B_{lim} (14000 t) in the uncorrelated simulation and just one in the correlated one; this mean that the probability of being up to B_{lim} is 1/2000 (0.05%).

The results of the sensitivity analysis are shown in Figure 3: the linear correlation between SSB in 2000 and the state variables are presented in the upper plots. The main responsible of the SSB variability are the survivors at age 7, with a correlation coefficient of 0.8 in the two simulations. The catchability has a general negative effect that rarely exceeds -0.4. The down plots show the linear correlation between the SSB and the simulation input variables (abundance indices, stock weights and maturity ogive) for the ten highest correlations. The main effect on the SSB is related to data from the 1993 cohort (age 2 in 1995, age 7 in 2000), which represents about the 70 % of the SSB in 2000. The weight at age 7 and the survey abundance at age 2 in 1995 give the highest correlations with about 0.5 in the two simulations.

Discussion

The main conclusion related to the assessment of Flemish Cap cod is that the model applied, the XSA, is quite robust against the assumptions related to the error distribution of abundance indices and those related to the catchability regression. Nevertheless the work done has other implications on the stability of the model and also on the precision and accurate of its results, discussed below.

Under a precautionary approach framework, uncertainties and errors in assessment need to be investigated in depth. For depleted stocks like Flemish Cap cod, an important reference for the reopening criteria is the SSB and its relationship with B_{lim}. The uncertainty associated to the SSB calculated from age-structured models need to be analysed step by step, starting with the measurement and estimation of variance on input variables until reaching the SSB probability profiles (Rosemberg and Restrepo 1994).

The first step is related to the variance and distribution of the model inputs, these are catches at age, natural mortality and abundance indices. Errors in catches at age can be due to misreported catches or to age estimation (Patterson 1998); the effect of natural mortality errors on stock size estimates was investigated by some authors (Clark 1999, Mertz and Myers 1997) and finally, errors in abundance indices are those that are taken into account in age-structured models like XSA and ADAPT (Shepher 1999, Gavaris 1988), but these errors are calculated inside the model in an analytical way based on the catchability relationship between the abundance indices and the real abundance.

There are two possible catchability relationships: constant catchability (i) and catchability proportional to the abundance (ii).

$$I_{y,a} = q_a * Nvpa_{y,a} \qquad \text{(i)}$$

$$I_{y,a} = j * Nvpa_{y,a}{}^{g} \qquad \text{(ii)}$$

The assumptions are the same in both cases and are typical of a conventional linear regression when the explanatory variable is the VPA abundance (*Nvpa*) and the error prone variable is the abundance index (*I*). Nevertheless, the XSA doesn't take into account the error on dependent variable in order to weight the model and this error is frequently unknown. The accuracy and precision of the model also depend on the linear regression assumptions: normal distribution of the errors, constant variance and independence of errors. The logarithmic transformation of both dependent and explanatory variables helps to normalise the distribution of data, linearises the relationship between the variables and promotes homocedasticity (Shepher 1997), but this transformation doesn't guarantee that the log abundance indices have the best conditions for linear regression: errors can be highly dependent on abundance or can be highly correlated among them (Vázquez and Cerviño 1998) and, in such a case, can lead to an inaccurate catchability or bias in the estimation of the terminal population abundance as well as in their associated errors.

The variance of the survey abundance indices from the Flemish Cap cod was calculated by bootstrap: The results show that errors, expressed as coefficient of variation, are not homocedastic (Figure 1, top panel). Furthermore, these errors are dependent on the abundance, i.e. the highest coefficients of variation occur at low abundance levels (Figure1, down panels). These violations on the linear regression assumptions can lead to an inaccurate estimate of catchability and this has happened on the simulations where all the catchabilities estimated are lower than those calculated by the XSA. This is particularly clear at age 1 where the heterocedasticity is more evident (Table 3).

The dependence of the variance on abundance is a violation of regression assumptions, but is also a warning on the statistical distribution of indices of abundance that are usually considered as log-normal. Nevertheless this is not a characteristic of log-normal statistical distributions that should have constant variance. Future work should be focus on investigating the error distribution of abundance indices as a basis to build more accurate models.

Correlations in abundance indices structured by age were proposed as an important source of imprecision and bias on the results of age-structured models (Pennington and Godo 1995, Myers and Cadigan 1994). Nevertheless, our results in simulations show that the correlations calculated by bootstrap have not effect on precision or bias of the results. This could be due to the distribution on time of these correlations. In recent years the correlation couldn't be high enough as to have a significant effect on current results (N in 2000). From 1988 to 1993, when the correlations are higher (table 2), they have less effect on the results due to the their smaller sensitivity related to the present VPA abundance (Pope 1972). When covariance is considered, the main effect is observed on the correlation matrix of state variables (Table 4). The highest correlations observed among parameters in consecutive ages have different interpretations: one is about the stability of the model, i.e. high correlated parameters can lead to undefined fit of the model although this doesn't seem to be the case of the Flemish Cap cod where both simulations have quiet similar results. The other implication is on the estimate of SSB and on the projections, i.e. if correlations among terminal N's are high then these should be taken into account in the estimate of SSB and its errors as well as on short and medium term projections. Future investigations should be focused on quantifying the correlation necessary to produce inaccurate results or model misspecifications.

Since errors in age-structured models are just evaluated from the catchability relationship, the Monte Carlo simulations can be seen not only as a way to evaluate sensitivity on model assumptions but also as an stochastic age-structured model saving those assumptions on catchability regression. This stochastic model gives a more precise and accurate results in last year F's and terminal N's than the deterministic model does. At the same time, once we have evaluated the error distribution for maturity ogive and weights, and once these errors have been included on the simulation, the stochastic model can also be used as a way to give probability profiles for spawning stock biomass as well as the provision of confidence limit estimates. Furthermore, age-structured models like ADAPT or XSA don't take into account errors in natural mortality neither in catches at age, then stochastic simulations can be useful on the implementation of these errors on assessment-related parameters like SSB.

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Table 1 - Mean and standard error in survey abundance. Mean was calculated analytically and standard error was calculated by bootstrap.

Mean	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	4576	20803	2492	137814	71190	4364	3147	1546	39	39	25	6
2	72615	11028	11937	25600	37060	132237	3835	11365	2964	139	76	78
3	40564	84280	4755	15381	4748	28403	24599	1238	6131	3146	85	102
4	10665	49151	15469	1928	2033	1010	4562	3595	820	4360	1137	105
5	1230	18573	14660	6283	332	1269	120	885	2247	358	1449	655
6	191	1270	4298	1674	1255	168	66	33	187	902	73	415
7	223	157	350	296	222	491	7	25	8	20	144	19

Std. Err.	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	1364	3125	517	45657	14289	2008	678	370	22	23	16	8
2	11032	1851	1500	4695	9589	54013	1513	5057	397	52	33	33
3	5418	11530	644	3201	1549	6675	7467	294	1274	798	28	43
4	2096	5462	2367	369	822	312	1293	744	172	823	136	39
5	368	2576	2083	1549	168	502	46	204	387	73	209	129
6	60	232	596	386	437	77	30	18	47	128	26	71
7	74	52	90	70	79	140	8	16	10	12	43	12

Table 2 – Correlation coefficients among abundance indices in the Flemish Cap survey. Dark values are higher than 0.5.

1988	1	2	3	4	5	6	7
1	1.00						
2	0.65	1.00					
3	0.18	0.35	1.00				
4	0.07	0.14	0.76	1.00			
5	0.03	0.09	0.14	0.33	1.00		
6	0.00	0.04	0.03	0.14	0.55	1.00	
7	-0.03	0.01	-0.02	0.05	0.28	0.33	1.00

1989	1	2	3	4	5	6	7
1	1.00						
2	0.77	1.00					
3	0.33	0.42	1.00				
4	0.01	0.05	0.55	1.00			
5	-0.01	0.00	0.22	0.72	1.00		
6	-0.04	-0.03	0.03	0.39	0.62	1.00	
7	-0.07	-0.03	-0.04	0.00	0.00	0.08	1.00

1990	1	2	3	4	5	6	7
1	1.00						
2	0.24	1.00					
3	0.08	0.54	1.00				
4	-0.03	0.13	0.57	1.00			
5	-0.04	0.04	0.06	0.48	1.00		
6	-0.05	-0.03	0.00	0.28	0.69	1.00	
7	-0.04	-0.06	0.03	0.24	0.42	0.62	1.00

1991	1	2	3	4	5	6	7
1	1.00						
2	0.81	1.00					
3	0.17	0.30	1.00				
4	0.23	0.36	0.59	1.00			
5	0.18	0.32	0.26	0.72	1.00		
6	0.19	0.35	0.16	0.55	0.82	1.00	
7	0.08	0.17	0.07	0.24	0.37	0.48	1.00

1992	1	2	3	4	5	6	7
1	1.00						
2	0.60	1.00					
3	0.31	0.87	1.00				
4	-0.07	0.02	0.13	1.00			
5	-0.10	-0.09	0.01	0.87	1.00		
6	-0.09	-0.09	-0.01	0.91	0.84	1.00	
7	0.00	0.00	0.02	0.62	0.57	0.67	1.00

1993	1	2	3	4	5	6	7
1	1.00						
2	0.10	1.00					
3	0.03	0.45	1.00				
4	-0.02	0.09	0.66	1.00			
5	0.02	-0.01	0.48	0.78	1.00		
6	0.01	0.00	0.40	0.65	0.77	1.00	
7	0.01	-0.02	0.37	0.60	0.71	0.60	1.00

1994	1	2	3	4	5	6	7
1	1.00						
2	0.18	1.00					
3	0.16	0.41	1.00				
4	0.55	0.30	0.71	1.00			
5	0.33	0.12	0.32	0.48	1.00		
6	0.07	-0.01	0.03	0.14	0.20	1.00	
7	0.00	-0.01	-0.01	0.02	0.04	0.09	1.00

1995	1	2	3	4	5	6	7
1	1.00						
2	0.46	1.00					
3	0.27	0.74	1.00				
4	-0.03	0.10	0.51	1.00			
5	-0.04	0.01	0.23	0.66	1.00		
6	0.00	0.02	0.07	0.19	0.20	1.00	
7	0.07	0.02	0.00	-0.01	-0.02	-0.01	1.00

1996	1	2	3	4	5	6	7
1	1.00						
2	0.30	1.00					
3	0.05	0.33	1.00				
4	0.01	0.29	0.76	1.00			
5	-0.04	0.22	0.50	0.67	1.00		
6	-0.05	0.03	-0.01	0.10	0.32	1.00	
7	-0.02	0.00	0.01	0.02	0.03	-0.01	1.00

1997	1	2	3	4	5	6	7
1	1.00						
2	0.32	1.00					
3	0.10	0.50	1.00				
4	0.09	0.41	0.90	1.00			
5	0.06	0.24	0.56	0.65	1.00		
6	0.09	0.09	0.21	0.32	0.34	1.00	
7	-0.01	0.02	0.03	0.06	0.07	0.16	1.00

1998	1	2	3	4	5	6	7
1	1.00						
2	0.00	1.00					
3	-0.05	0.16	1.00				
4	-0.12	0.01	0.17	1.00			
5	-0.09	-0.12	0.10	0.54	1.00		
6	-0.04	-0.02	0.05	0.24	0.37	1.00	
7	-0.05	-0.08	-0.02	0.17	0.28	0.15	1.00

1999	1	2	3	4	5	6	7
1	1.00						
2	-0.06	1.00					
3	-0.03	-0.04	1.00				
4	0.02	-0.05	0.52	1.00			
5	0.02	-0.19	0.54	0.60	1.00		
6	0.04	-0.15	0.37	0.41	0.53	1.00	
7	-0.01	-0.06	-0.06	0.00	0.01	-0.04	1.00

Table 3 - Estimated values and their standard error, coefficient of variation (cv), bias and percentiles for the standard XSA (expected) and the simulations with and without correlation.

		N 2	*N 3*	*N 4*	*N 5*	*N 6*	*N 7*	*N 8+*	*Q 1*	*Q 2*	*Q 3*	*Q 4*	*Q 5*	*Q 6*	*SSB 00*
expected	**mean**	10	49	47	49	691	1134	21	0.54	1.31	1.20	0.94	1.04	0.98	5919
	s.e. (int)	9	21	16	14	201	313	8							
	s.e. (ext)	0	9	11	10	78	353	3							
	cv	0.88	0.44	0.33	0.29	0.29	0.31	0.38							
No correlated	**mean**	11	49	46	49	693	1091	22	0.52	1.28	1.18	0.92	1.01	0.98	5767
	bias	0.59	-0.08	-1.88	-0.83	2.12	-42.90	1.03	-0.02	-0.04	-0.02	-0.02	-0.03	0.00	-152
	bias %	5.7%	-0.2%	-4.0%	-1.7%	0.3%	-3.8%	5.0%	-4.4%	-2.8%	-1.7%	-1.8%	-2.6%	-0.3%	-2.6%
	std err	13.6	17.7	14.5	12.7	102.6	324.3	16.4	0.06	0.11	0.09	0.07	0.10	0.16	1515
	cv	1.23	0.37	0.32	0.26	0.15	0.30	0.76	0.12	0.09	0.08	0.08	0.10	0.17	0.26
	0.05	1.4	25.8	25.6	29.9	532.6	612.7	5.3	0.42	1.10	1.03	0.81	0.86	0.72	3623
	0.95	33.4	81.5	72.1	71.1	867.9	1680.9	53.9	0.62	1.47	1.34	1.05	1.18	1.26	8616
correlated	**mean**	11	49	46	49	695	1096	21	0.52	1.28	1.18	0.92	1.01	0.97	5798
	bias	0.79	0.07	-1.59	-0.74	4.31	-37.05	0.79	-0.02	-0.04	-0.02	-0.02	-0.03	-0.01	-118
	% bias	7.6%	0.1%	-3.4%	-1.5%	0.6%	-3.3%	3.8%	-4.1%	-2.7%	-1.7%	-1.8%	-2.5%	-1.1%	-2.0%
	std err	15.0	17.9	14.7	12.4	105.6	307.6	16.4	0.06	0.12	0.09	0.07	0.10	0.15	1554
	cv	1.36	0.37	0.32	0.26	0.15	0.28	0.77	0.12	0.10	0.08	0.08	0.10	0.16	0.27
	0.05	2.1	25.9	25.9	30.5	536.7	656.7	5.7	0.42	1.09	1.04	0.80	0.85	0.74	3668
	0.95	30	80	72	70	881	1636	50	0.63	1.49	1.34	1.05	1.18	1.24	8732

Table 4 - Correlation matrix among the state variables on the XSA. Simulation without correlated inputs (upper panel) and with correlated inputs (lower panel). N 2 to N 7 are the abundance in terminal population fro 2 to 7. Q 1 to Q 6 are the catchability at ages 1 to 6. Absolute values higher than 0.25 are filled in grey.

	N 2	N 3	N 4	N 5	N 6	N 7	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6
N 2	1.00											
N 3	-0.01	1.00										
N 4	0.00	0.04	1.00									
N 5	0.00	0.06	0.08	1.00								
N 6	0.06	0.04	0.10	0.15	1.00							
N 7	0.03	0.01	0.05	0.13	0.39	1.00						
Q 1	-0.09	-0.16	-0.15	-0.09	-0.16	-0.19	1.00					
Q 2	-0.01	-0.21	-0.07	-0.12	-0.23	-0.09	0.01	1.00				
Q 3	-0.01	0.01	-0.15	-0.16	-0.20	-0.31	0.08	0.00	1.00			
Q 4	0.00	0.01	-0.05	-0.16	-0.38	-0.38	0.08	0.06	0.14	1.00		
Q 5	-0.04	-0.03	-0.05	-0.08	-0.39	-0.45	0.11	0.12	0.18	0.28	1.00	
Q 6	-0.04	-0.02	-0.05	-0.09	-0.24	-0.45	0.10	0.16	0.22	0.26	0.40	1.00

	N 2	N 3	N 4	N 5	N 6	N 7	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6
N 2	1.00											
N 3	0.05	1.00										
N 4	0.00	0.05	1.00									
N 5	0.04	0.04	0.29	1.00								
N 6	0.02	0.07	0.18	0.44	1.00							
N 7	0.01	0.04	0.03	0.22	0.57	1.00						
Q 1	-0.08	-0.26	-0.20	-0.19	-0.28	-0.20	1.00					
Q 2	-0.05	-0.18	-0.09	-0.26	-0.29	-0.14	0.33	1.00				
Q 3	-0.06	-0.08	-0.18	-0.22	-0.36	-0.21	0.21	0.45	1.00			
Q 4	-0.02	-0.03	-0.03	-0.24	-0.49	-0.42	0.17	0.28	0.55	1.00		
Q 5	-0.01	-0.02	-0.04	-0.10	-0.45	-0.45	0.17	0.19	0.36	0.74	1.00	
Q 6	0.00	-0.02	-0.02	-0.10	-0.35	-0.49	0.12	0.16	0.22	0.48	0.65	1.00

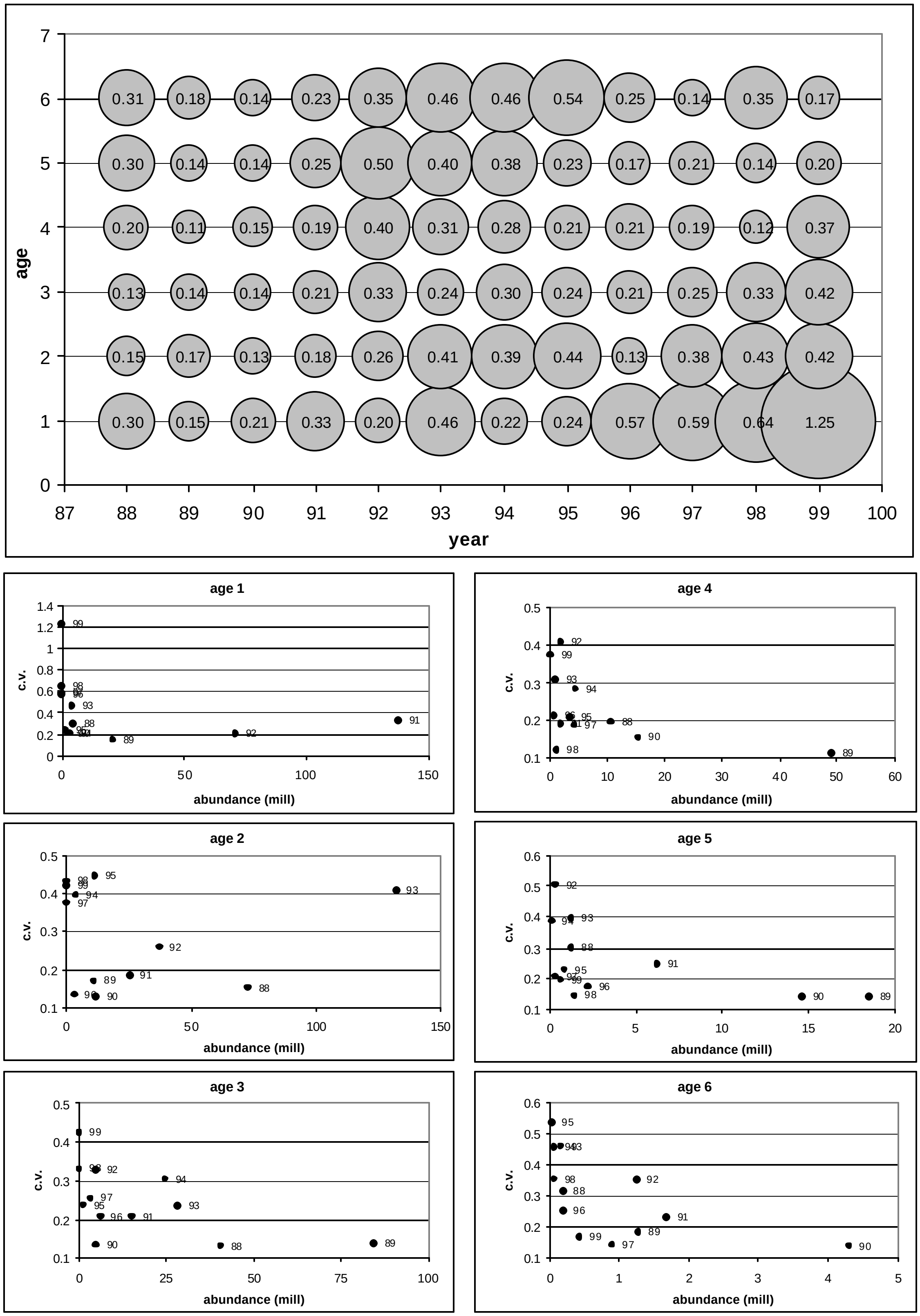

Figure 1 - Coefficient of variation by age and year in the Flemish Cap survey abundance indices (up). The c.v. against abundance indices (mill) for ages 1 to 6 (down).

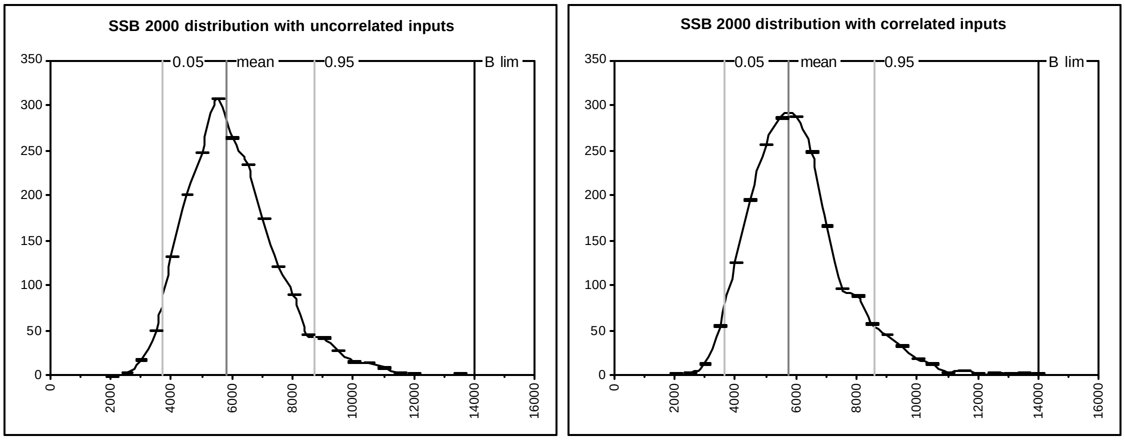

Figure 2 - SSB frequency distributions for 2000 simulations without correlations (left panel) and with correlations (right panel).

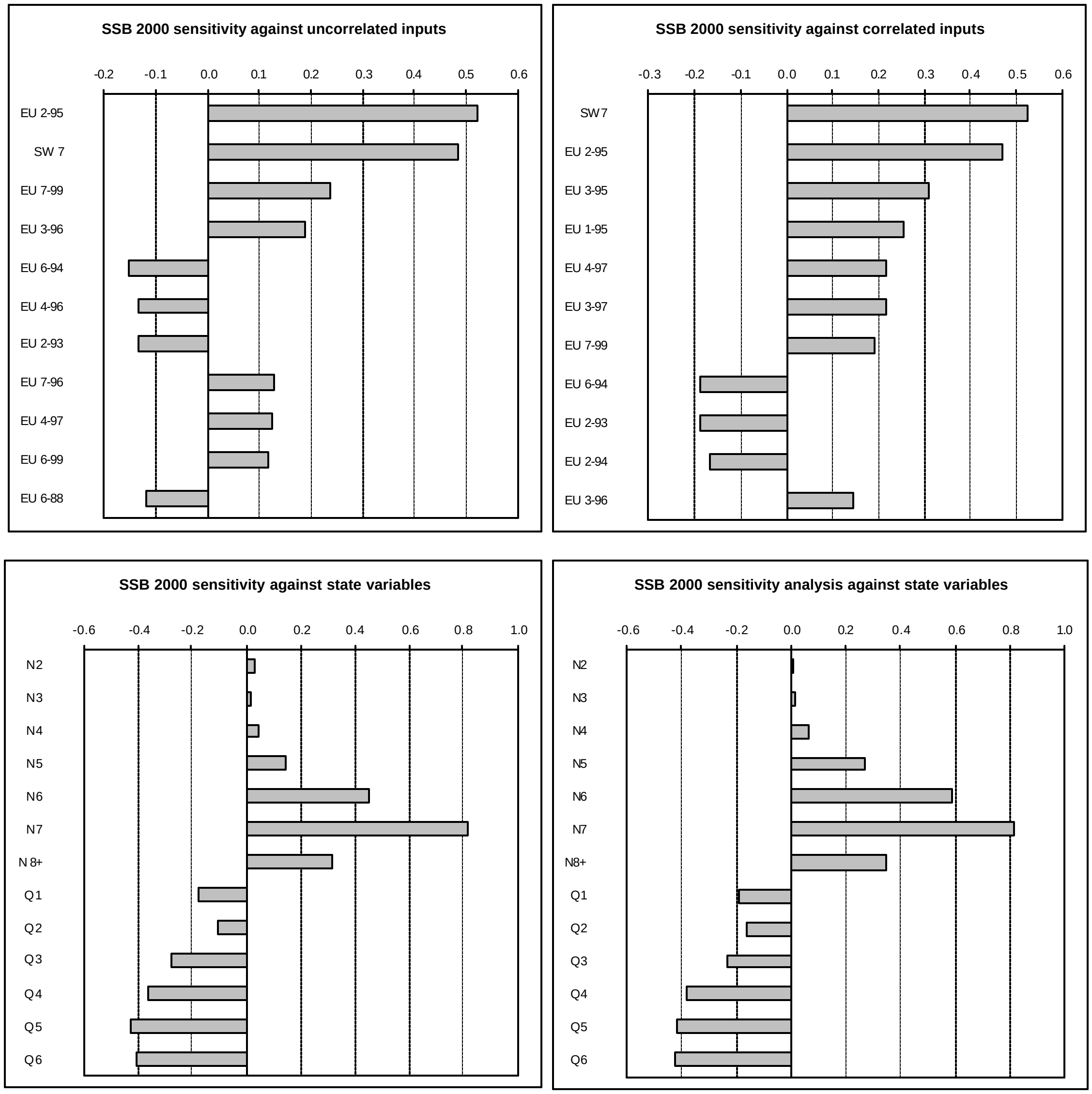

Figure 3 - SSB sensitivities without covariance (left panels) and with covariance (right panels). Correlations against state variables (top panels) and against inputs variables (down panels).
(N – number of survivors; Q – catchability; EU – EU survey indices; SW – stock weight)