Project no. **502572**

FISBOAT

FISHERIES INDEPENDENT SURVEY-BASED OPERATIONAL ASSESSMENT TOOLS

Instrument : STREP

Thematic Priority : 8.1

FINAL ACTIVITY REPORT
ANNEX

Individual Case Study Reports

Period covered: from 01 March 2004 to 30 June 2007

Start date of project: 01 March 2004 Duration: 40 months

Project coordinator name : Pierre Petitgas
Project coordinator organisation name : IFREMER

Revision : draft 1

Indicator Based Assessment

Simulation Evaluation with FLR

Simulation Evaluation using ALADYM

INDICATOR BASED ASSESSMENT

Template for reporting case studies indicator-based assessments

Case study NAME

Each of the following items with comments (NA if not done)

Data :
- Map of all survey stations overlaid showing polygon used.
- For spatial indices : 2 maps of gravity centres across years for selected ages in immature and mature ages
- Input parameters for spatial indices : function infl() , function NBPatches() , function Microstructure()
- Raw indices : Tables of spatial and non-spatial indices (wp2a tables 1 and 2)
- Combined indices : (retain the 2 first principal axes) fig. of factorial representation, table of indices values

Looking for changes :
- visual inspection : plots of selected indices (raw & combined, expert or MAF-based)
- trend plots of selected indices (provide plots, specify trend method used, fill trend diagnostic table)
- di-cusum plots of selected indices (provide plots, fill cusum diagnostic table)

template for diagnostic tables are in file : indic_diagno_tables_nantes.xls

Interpretation :
comment diagnostics tables results
- trend analysis
- cusum analysis
- interpretation using cusum diagnostic table
- interpretation using cause-effects diagnostic table

Compare approaches (cusum/trends)

What have you learned ?

Summary sheet
- Survey series (Periods / Seasons / Type)
- Non-spatial indices (a few words : has index been analysed ? what method for change? change detected ?)
  Abundance index, Recruitment index
  Lbar, L75, L25
  L50.maturity
  Z by year
- Spatial indices (a few words : index analysed ? by age or stage ? what method ? change detected ?)
  Positive Area, Spreading area, Equivalent area
  Centre of gravity, Inertia, Anisotropy
  Microstructure
- Composite (derived) indices (a few words : method ? index used ? components 1 & 2 dominated by which raw indices ? change detected ?)
  MAF, MFA, PCA
- Reference period (which years ? comments on choice of period)
- Summary of results on the stock (comments on data series, ref period, changes evidenced, which method support summary)

Comparison with traditional assessment of stock status :
traditional assessment = scientific diagnostic by expert groups, not official advice
short text with following topics : have alerts been triggered for similar years ? has an early warning been possible using indicators ? what do we gain with all indicators in comparision to abundance only ?

Formulation of advice (based on all the above, can you formulate an advice ?)

Indicator Based Assessment

Anchovy Bay of Biscay – acoustic surveys

P. Petitgas (IFREMER)

In this case study we use a multivariate approach to summarise the time series of the stock status using the biological and spatial distribution indicators. The multivariate indicators are interpreted by selecting those raw indicators that best express the multivariate structure as well as have with the smoothest time series. The multivariate evolution of stock status is then monitored using a statistical process control scheme which triggers alarms of deviation from a reference status with set stastistical risks of false alarm and no alarm. Last, interpretation of causal effects is investigated.

Data

- **Map of all survey stations and polygon used**

Since 2000, the survey design is fixed and covers the entire French shelf from Hendaye in the South to Penmarc'h in the North, with regularly spaced cross-shelf transects (from coast to shelf break) separated by 12 nautical miles (n.m.). Prior to 2000, this design was applied only inside a polygon (see Fig.1) understood to be the core distribution area of the anchovy (the shelf South of 45°N and from the isobath 100m to the coast from 45°N to 46°30N). In this study we considered the data in this polygon only. The time series covers the period 1989-2005. In the years 1991-92, there was no age-length key for the survey and therefore the estimation of abundance at age was not possible in these years. There was no survey in the years 1993-96 and in 1999.

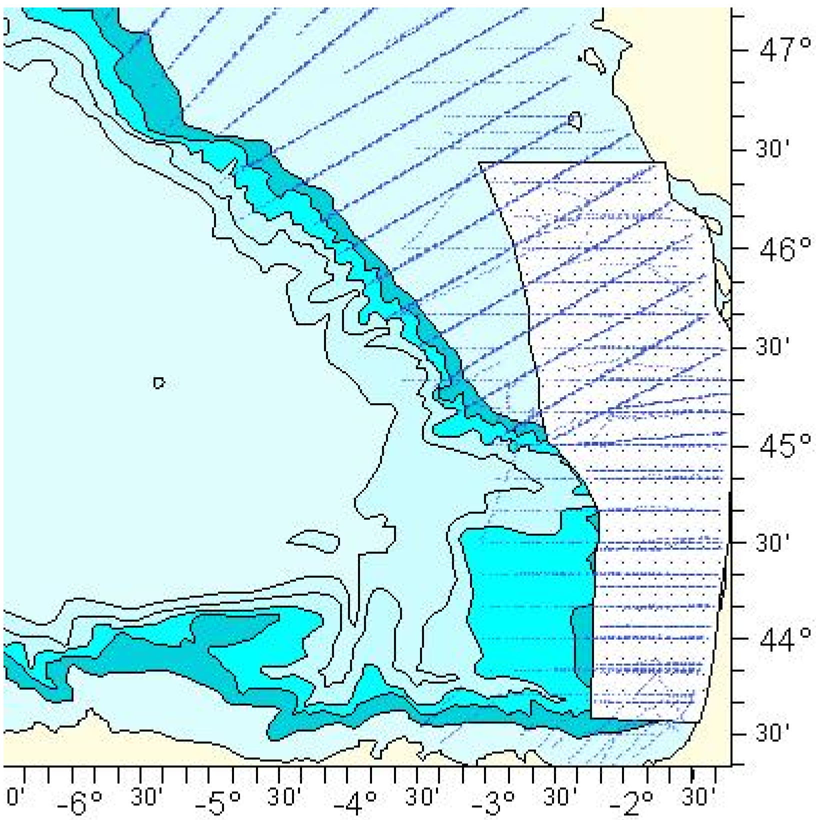


Fig. ancBBac.1 : Map showing the acoustic transects for all the surveys in the period 1989-2005 with the polygon which has always been sampling in all surveys. Prior to 2000, sampling outside this polygon was not done regularly.

Polygon name was FB_pol_GGmini.txt. Polygon vertices are :

Long	Lat	Long	Lat	Long	Lat
-1.7032	46.4396	-1.22969	44.6968	-2.17672	44.6643
-1.65738	46.2604	-1.24497	44.5229	-2.28364	44.827
-1.41299	46.1441	-1.27552	44.3374	-2.49748	44.9893
-1.35189	46.017	-1.30606	44.1952	-2.54331	45.0109
-1.33661	45.8576	-1.33661	43.9868	-2.60441	45.2049
-1.33661	45.7085	-1.36716	43.8327	-2.61968	45.3339
-1.18387	45.5483	-1.39771	43.7114	-2.68078	45.5269
-1.16859	45.3983	-1.45881	43.5566	-2.68078	45.6978
-1.16859	45.1726	-2.23782	43.5788	-2.80298	46.0382
-1.21442	45.0001	-2.20727	44.4248	-3.04737	46.4396
-1.21442	44.827	-2.17672	44.5229	-1.7032	46.4396

- **Maps of gravity centres across years for selected ages**

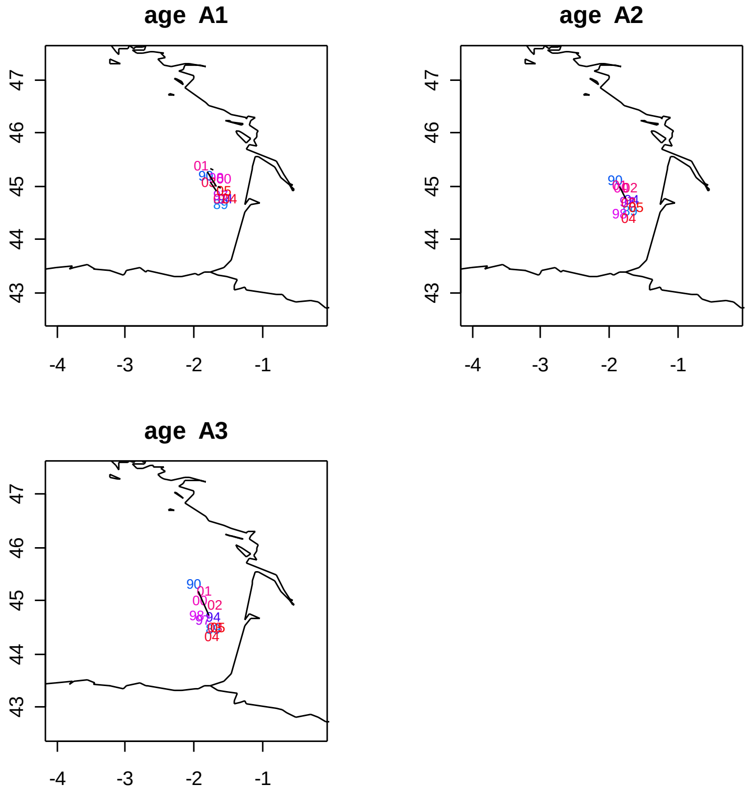


Fig. ancBBac.2 : map showing the gravity centres in each year for the different ages.

Anchovy is a short-live species, living no longer than 3-4 years. Anchovy is sexually mature and reproducing at age 1. Here we considered 3 ages (1 to 3). The gravity centre of the spatial distribution in the different ages (1 to 3) are all contained in the area between 1°30-2°W 44°30-45°30N.

- **Input parameters for spatial indices :**

Spatial indices were calculated using functions in RGeoS (geostatistical library in R developed at Ecole des Mines Centre de Géostatistique). Some of the functions in RGeoS need input parameters which are now given.

Function infl().This is a routine for calculating the area of influence around each sample point (i.e., spatial weight). The surveyed domain is finely discretised. Input parameters were : dlim=7, extend=0.4, ndisc=300.

Function f.spatialpatches().This is a Fisboat routine for calculating the number of patches in the distribution. Input parameters were : Lim.D = 40 (n.m.), B.li = 0.20 (percent).

Function f.covario(). This is a Fisboat routine for calculating Geometric and relative covariogram, the microstructure index and the equivalent area. Input parameters were: num.dir=3, h0=5 (n.m.)

- **Raw indices**

Fisboat wp2a Table 1: Spatial indices

Area	Survey Type	Species	Age	Year	Abundance	Positive Area	Inertia	Anisotropy	xcg	ycg	Microstructure Index	Equivalent Area	Spreading Area	Number Of Patches
Biscay	AC	ENGRENC	A1	1989	1179884000	5053	1151	4.244	-1.6	44.73	0.297	564	1039	1
Biscay	AC	ENGRENC	A1	1990	6871475000	5308	1788	5.022	-1.83	45.26	0.256	2001	2212	1
Biscay	AC	ENGRENC	A1	1994	3028940000	4258	1873	4.946	-1.55	44.84	0.346	416	811	1
Biscay	AC	ENGRENC	A1	1997	6348772000	5461	2114	5.05	-1.6	44.9	0.329	1130	1328	1
Biscay	AC	ENGRENC	A1	1998	4103249000	5801	2201	5.258	-1.67	45.23	0.397	522	1293	2
Biscay	AC	ENGRENC	A1	2000	7303152000	6858	1173	3.088	-1.57	45.19	0.252	1447	1789	1
Biscay	AC	ENGRENC	A1	2001	3674932000	5158	1447	2.56	-1.88	45.44	0.515	572	1156	1
Biscay	AC	ENGRENC	A1	2002	1603504000	5309	2457	6.908	-1.6	44.84	0.47	629	909	2
Biscay	AC	ENGRENC	A1	2003	790330000	4338	3065	2.975	-1.78	45.14	0.472	765	1160	2
Biscay	AC	ENGRENC	A1	2004	2954654000	3253	2031	5.434	-1.47	44.83	0.348	559	701	1
Biscay	AC	ENGRENC	A1	2005	92639000	2207	2369	7.694	-1.55	44.95	0.329	332	385	2
Biscay	AC	ENGRENC	A2	1989	338677000	5053	1074	3.782	-1.69	44.6	0.241	1010	1437	1
Biscay	AC	ENGRENC	A2	1990	95829000	5308	1898	6.029	-1.92	45.18	0.248	1541	1872	1
Biscay	AC	ENGRENC	A2	1994	1375689000	4258	1506	3.976	-1.67	44.8	0.291	969	1242	1
Biscay	AC	ENGRENC	A2	1997	2586140000	5461	2171	3.948	-1.73	44.77	0.334	1378	1731	2
Biscay	AC	ENGRENC	A2	1998	507631000	5801	1539	4.065	-1.84	44.55	0.303	1333	1614	1
Biscay	AC	ENGRENC	A2	2000	1035805000	6858	2200	3.601	-1.82	45.02	0.471	1329	2305	1
Biscay	AC	ENGRENC	A2	2001	1415918000	5158	2135	4.175	-1.83	45.04	0.573	529	1268	1
Biscay	AC	ENGRENC	A2	2002	2690563000	5309	1997	4.614	-1.7	45.02	0.473	637	1026	1
Biscay	AC	ENGRENC	A2	2003	184434000	4338	2439	2.975	-1.72	44.74	0.556	577	1244	2
Biscay	AC	ENGRENC	A2	2004	292813000	3253	1173	3.078	-1.73	44.45	0.362	181	486	1
Biscay	AC	ENGRENC	A2	2005	282713000	2207	2254	7.866	-1.62	44.65	0.339	455	497	2
Biscay	AC	ENGRENC	A3	1989	73350000	5053	1044	3.93	-1.71	44.54	0.228	922	1319	1
Biscay	AC	ENGRENC	A3	1990	11581000	3596	1888	7.436	-2	45.38	0.258	927	1099	1
Biscay	AC	ENGRENC	A3	1994	56744000	4258	1368	3.492	-1.72	44.76	0.322	913	1228	1
Biscay	AC	ENGRENC	A3	1997	54786000	5461	1919	4.122	-1.87	44.69	0.318	1281	1653	2
Biscay	AC	ENGRENC	A3	1998	27386000	4089	1453	4.673	-1.97	44.78	0.242	1128	1276	1
Biscay	AC	ENGRENC	A3	2000	412037000	6858	2624	4.458	-1.91	45.07	0.488	866	1961	2
Biscay	AC	ENGRENC	A3	2001	83505000	5158	2026	3.476	-1.83	45.22	0.513	781	1355	1
Biscay	AC	ENGRENC	A3	2002	568758000	5309	2022	4.413	-1.71	44.99	0.484	628	1046	1
Biscay	AC	ENGRENC	A3	2003	78481000	4338	1735	2.778	-1.69	44.56	0.559	369	1008	2
Biscay	AC	ENGRENC	A3	2004	155309000	3253	1022	3.046	-1.74	44.39	0.359	148	396	1
Biscay	AC	ENGRENC	A3	2005	62826000	2207	1611	6.944	-1.65	44.55	0.405	479	522	1

Fisboat wp2a Table 2 : Biological non-spatial indices

Area	Survey Type	Species	Year	Survey index	Recruit index	Lbar	L25	L75	L50 maturity	Z
Biscay	AC	ENGRENC	1989	1608000	1193000	13.7	12.5	14.5		2.65
Biscay	AC	ENGRENC	1990	6979000	6871000	12.8	11.5	13.5		1.58
Biscay	AC	ENGRENC	1994	4450000	3020000	13.9	12.5	14.5		0.50
Biscay	AC	ENGRENC	1997	9014000	6359000	13.8	12.5	14.5		2.81
Biscay	AC	ENGRENC	1998	4670000	4131000	12.5	10.5	14		1.16
Biscay	AC	ENGRENC	2000	8781000	7325000	13.4	12	14.5		1.76
Biscay	AC	ENGRENC	2001	5043000	3609000	14.2	13	14.5		0.42
Biscay	AC	ENGRENC	2002	4872000	1622000	15.4	14.5	16		2.79
Biscay	AC	ENGRENC	2003	1055000	791000	14.1	12.5	15		0.77
Biscay	AC	ENGRENC	2004	3440000	2986000	13.4	11.5	14.5		2.26
Biscay	AC	ENGRENC	2005	434000	91000	15.1	13.5	16		

- **Multivariate combined indices**

Fisheries survey series result in the estimation of population spatial and biological non spatial indices that are compiled in the Tables 1 and 2 above. These table of population indices constitute a yearly monitoring system with multivariate observations. The evolution of the population can be represented in the factorial (multivariate) space of the indices and its trajectory can be evaluated to stay or go outside control limits. The gravity centre in the factorial space for the reference years is first estimated. Then the distance in factorial space of each year observation to that gravity centre is computed making a time series of distance to the in-control gravity centre. PCA-based distances have been applied to the biological (non-spatial) indices. For the spatial indices, MFA-based distances have been used (because indices are estimated at age). Here, anchovy having only 3 age groups, MFA has not been used, but PCA instead. The stock evolution can then be summarised with two distances, one for the spatial and one for the non-spatial indices. The PCA-based distances characterising the evolution of the anchovy population have been computed in the first factorial plane (principal axes one and two).

PCA-based combination of spatial indices at age

A PCA has been performed on Table 1 after centrering and normalising each column to the column mean and standard deviation (diagonalisation of the correlation matrix between spatial indices at age). The positions of the ages in each year in the factorial space (Fig. 3) are all very close to each others although age 1 is slightly separated from ages 2 and 3. This means that for anchovy all ages have similar spatial patterns unlike long-lived species (e.g., hake in Biscay) where younger and older ages have different spatial distributions. The correlation structure (Fig. 4) in the spatial indices shows high correlation between indices of area (Positive, Equivalent and Spreading areas) as well as good correlation between anisotropy and inertia. The principal components can be interpreted using their correlation with the indices (Fig. 4 and Table 3). Axis 1 is made of the opposition between the Area indices and the Longitude of the gravity centre (the closer to the coast is the gravity centre the smaller are the Areas). Axis 2 is consituted by the Anisotropy and Inertia which tend to be in opposition on Axis 3. Also Latitude of the gravity centre is related with the Anisotropy and Inertia on Axis 2 and Microstructure with Longitude of gravity centre on Axis 1. The major differences across ages and years in the spatial distributions are thus in the Area indices and the E-W location as well as in the Inertia and Anisotropy and the N-S location. The evolution of the spatial distribution is characterised by the multivariate distance dmul (Fig. 5 and Table 4) : the tow last years of the time series 2004-05 have shown very different spatial distributions in comparison to all other years.

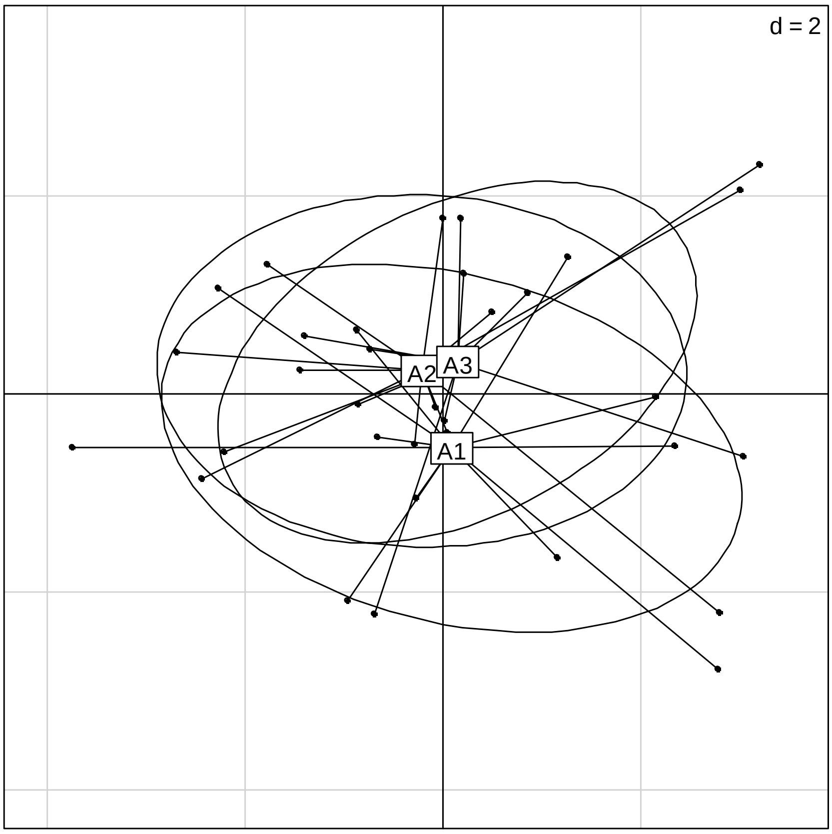


Fig. ancBBac.3 : Position of each age in each year (point) in the factorial space of the spatial indices. Gravity centre for each age are labelled. Reference years are 1990 to 2001. Lines represent departure from the reference.

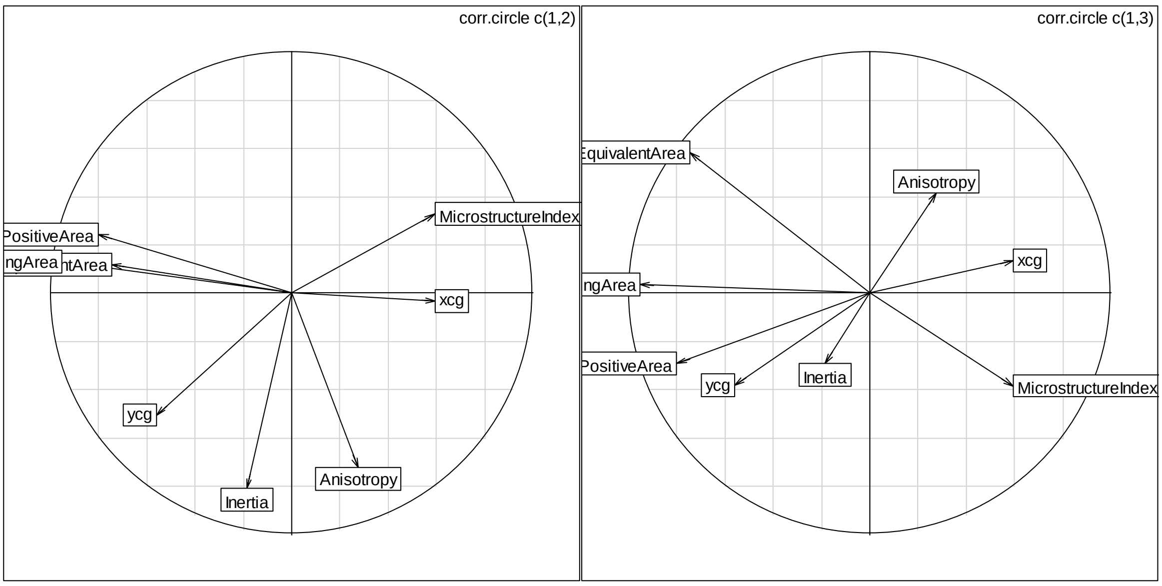


Fig. ancBBac.4 : correlation circle of the spatial indices in the plane of the principal components 1 and 2 (left) and in the plane of the components (1 and 3 (right).

Table 3 : correlation between each spatial index and the first three principal components

	Comp1	Comp2	Comp3
PositiveArea	**-0.80**	0.24	-0.29
Inertia	-0.19	**-0.81**	-0.29
Anisotropy	0.28	**-0.72**	0.42
xcg	**0.60**	-0.03	0.14
ycg	**-0.56**	**-0.50**	-0.38
Microstructure Index	**0.59**	0.33	-0.38
Equivalent Area	**-0.75**	0.12	**0.58**
Spreading Area	**-0.95**	0.13	0.04

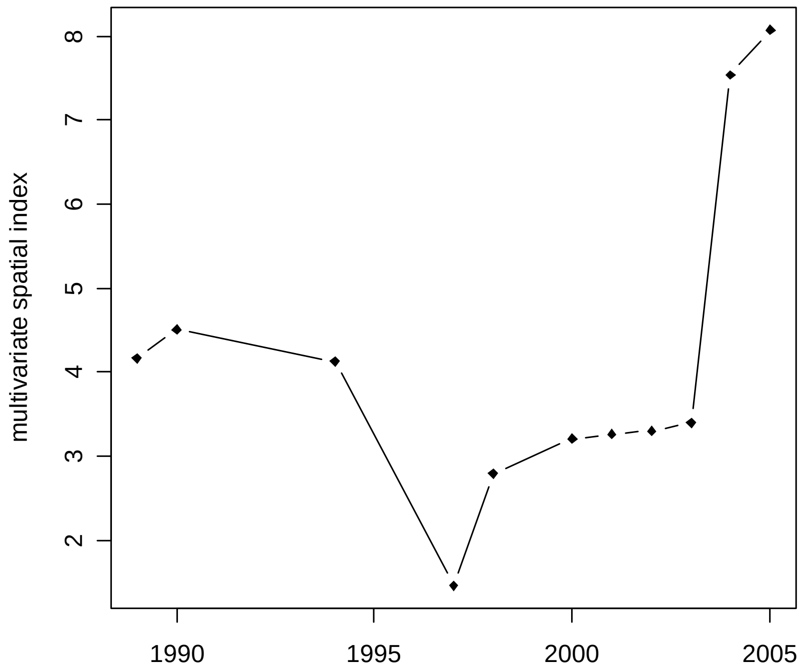


Fig. ancBBac.5 : Multivariate distance (dmul) characterising the evolution of the population spatial distribution.

Table 4 : Time series of the multivariate distance (dmul) characterising the evolution of the population spatial distribution

year	dmul
1989	4.162
1990	4.506
1994	4.125
1997	1.457
1998	2.791
2000	3.207
2001	3.260
2002	3.301
2003	3.395
2004	7.537
2005	8.073

PCA-based combination of biological (non spatial) indices

A PCA was performed on Table 2 after centrering and normalising each column to the column mean and standard deviation (diagonalisation of the correlation matrix between spatial indices at age). The first two principal axes summarise the correlation structure in the biological indices as the eigen values associated to the two first axes are much greater than all others (Fig. 6). The correlation structure in the biological indices (Fig. 7, Table 5) shows a high correlation between the length based indices (Lbar, L25, L75) and their opposition to Mortality (Z). These indices define the first principal component. The correlation between the Recruit and Total abundance indices defines the second principal axis. The reference years are 1990-2001. Each year can be represented in the factorial space (Fig. 7). The reference years are situated in the upper left corner, meaning that abundance was high, length indices low and also was mortality. Some years depart largely from the reference years. Years 1989 and 2003 depart mainly on axis 2, meaning that they differ from the reference by lower abundance indices only. In contrast year 2002 departs mainly on axis 1, meaning that this year differs by higher length indices. Year 2005 departs the most and differs by lower abundance and higher length indices than the reference. The evolution of the biological indices is characterised by the multivariate distance mdbio (Fig. 9 and Table 6) : the last year of the time series 2005 show the most departure from the reference, but years 2002-03 also showed important departure.

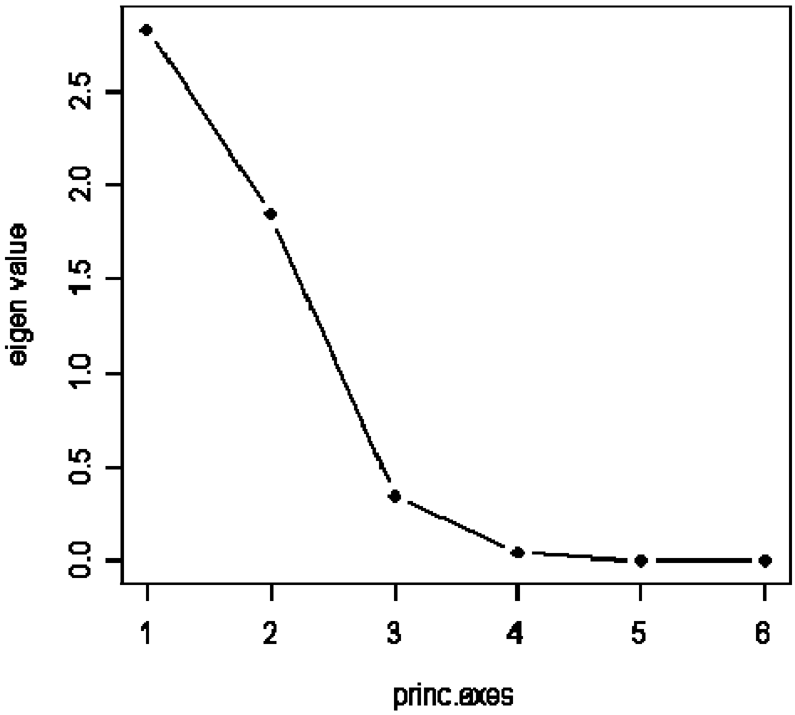


Fig. ancBBac.6 : Decrease in the eigen values associated with the principal components for the PCA on the biological indices

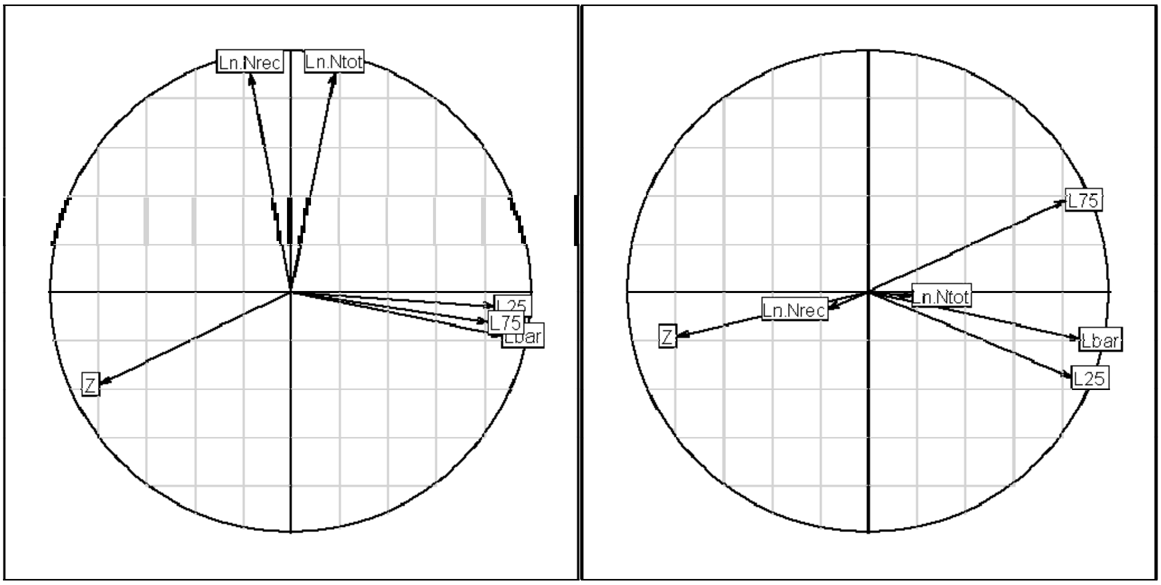


Fig. ancBBac.7 : Correlation circle of the biological indices in the factorial plane of the principal axes 1 and 2 (left) and in that of axes 1 and 3 (right)

Table 5 : Correlation between each biological (non spatial) index and the first three principal components

	Comp1	Comp2	Comp3
Ln.Ntot	0.18	**0.91**	-0.01
Ln.Nrec	-0.17	**0.91**	-0.07
Lbar	**0.87**	-0.18	-0.19
L25	**0.84**	-0.06	-0.35
L75	**0.81**	-0.13	0.38
Z	**-0.80**	-0.38	-0.18

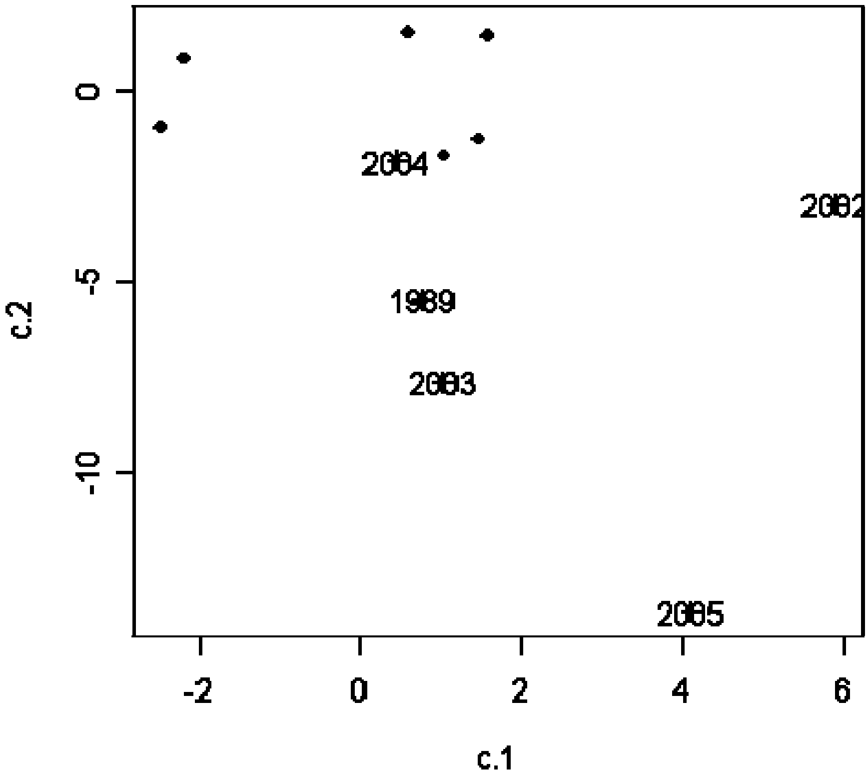


Fig. ancBBac.8 : Monitoring Bay of Biscay anchovy in the factorial sub-space of the two first principal axes using the biological non spatial indicators (Fisboat Table 2). Representation of years in the factorial sub-space (the black diamonds are the reference years); right: the time series of the multivariate distance representing the deviation of the stock from its reference status.

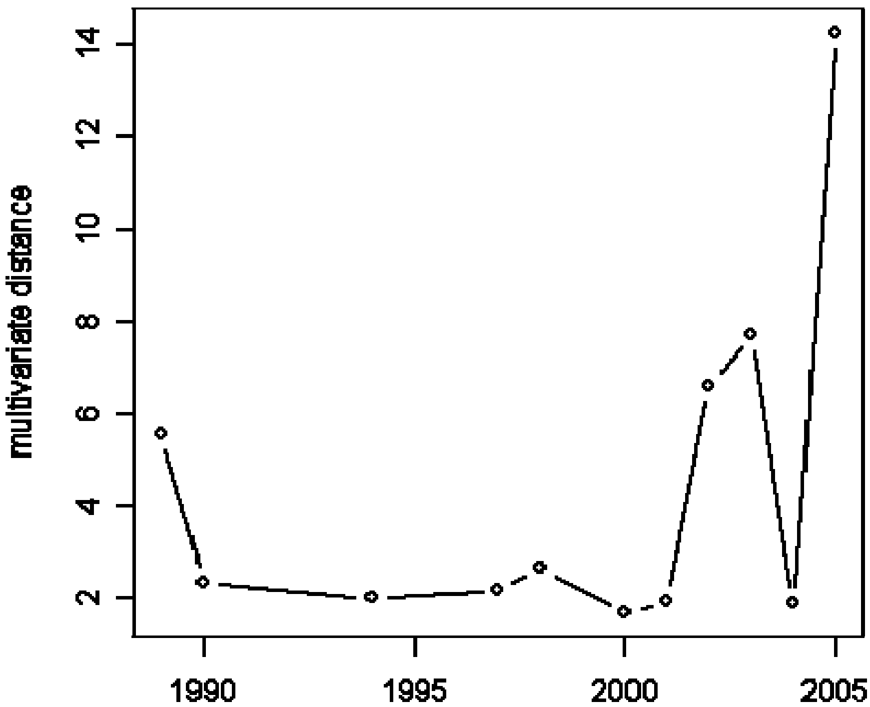


Fig. ancBBac.9 : Multivariate distance (mdbio) characterising the evolution of the population biological non spatial indices.

Table 6 : Time series of the multivariate distance (mdbio) characterising the evolution of the population biological non spatial indices.

year	mdbio
1989	5.532
1990	2.346
1994	1.994
1997	2.159
1998	2.650
2000	1.672
2001	1.923
2002	6.602
2003	7.712
2004	1.905
2005	14.268

- **Selection of informative raw indices**

Though principal components and multivariate indices are efficient in summarizing the multivariate evolution of the population, it is useful to select raw indices to explicitly interpret the changes that have occurred.

The selection of only those indices most correlated to the principal components could suffice to summarize the evolution of the spatial and non spatial indices. Here for anchovy in Biscay, 6 indices could be retained (Tables 3 and 5): PositiveArea, xcg, Inertia, Lbar, Z, Ln-SurveyIndex. But this procedure is not necessarily satisfactory as some of the selected indices show little continuity in their time series and are therefore difficult to interpret (e.g., Z).

In the analysis above, correlation between indices characterised whether the indices fluctuated together or in opposition or without relationship. But continuity along the time series was not considered at all. Continuity is important for characterising the evolution of the population in time. The MAF method (Min/Max Autocorrelation Factors) was used here as an automated procedure to select those indices that best summarise the multivariate information on the stock with highest continuity in time. The MAF method will allow to construct pincipal components (factors), the autocorrelation of which decreases from the first factors to the last ones. Hence the very first factors (MAFs) extract the part of the multivariate information which is the most continuous in time. Therefore, we used the MAF method to select those indices that showed highest continuity in time as well as being the most correlated to the first two MAFs.

The full set of indices (Tables 1 and 2) comprised 35 indices: 27 spatial indices for the 3 age groups, 4 vital trait indices and 4 Ln-transformed abundance indices. The number of years in the time series was 11, which was well below the number of indices. The number of indices was reduced taking advantage of the similarity in the spatial distributions of ages. In the factorial space of the spatial indices (Fig. 3) ages 2 and 3 overlap considerably. Therefore we constructed the age group 2+ by summing numbers at age 2 and 3. We recalculated spatial indices for that age group 2+. In all 24 indices were considered (18 spatial indices for the 2 age groups, 4 vital trait indices and 2 Ln-transformed abundance indices). They were ranked in ascending order of their variogram value at lag 1 year (Fig. 10). To construct MAFs, only those indices were retained which had a variogram value at lag 1 lower than unity (15 indices). The number of years in the time series is 11 : there are less observations than variables to construct MAFs. A procedure was used to robustify the estimation of the MAFs by adding white noise to each index. Then the indices with highest continuity were selected based on their loadings and the variogram of the MAFs.

The MAFs were constructed after centering and normalising each index by its mean and standard deviation along the series. A gaussian white noise with mean 0 and variance 0.1*(nb.indices/(nb.years-1)) was added to each index. MAFs were calculated 600 times on the 600 realisations of indices with added white noise and the median MAF was then estimated.

Let $\lambda_{k,j}$ denote the loading of indicator *j* on MAF *k* and μ_k the variogram value at lag 1 of MAF *k*. The continuity in time for the indicator *j* was estimated considering *p* MAFs as : $\sum_{k=1}^{p} \lambda_{j,k}{}^2 (1-\mu_k)$. Indicators were ranked in descending order of their continuity and the 6 most continuous were selected to represent the evolution in time of the population. By construction, these are the most continuous in time as well as the most correlated to the multivariate structure of all indicators. They should thus allow to interpret the evolution of the populaiton.

On Fig. 10, there are 15 indices with a variogram at lag 1 lower than unity. Visual inspection of the entire 24 indices revealed that 14 only had a signal in their time series that could be interpreted. All of which were in the list of the 15 indices with variogram lower than unity at lag 1. This means that selection based on contuinity is efficient in practice. MAFs were used to select a few indices only that best summarised the multivariate information with highest continuity in time. The time series of indices being variable with important changes at short-term (visual inspection) and MAF3 still showing continuity (Table 6), we considered the first 3 MAFs to select the indices (Figs 12, 13 and Tables 7, 8). It is interesting to keep MAF3 as this MAF is still continuous (Table 7 and Fig. 11) and some indices are more correlated to it than to MAF2 (Table 8). The 7 indices best summarising variation in the stock are then: L75, Longitude of the gravity centre of age 2p, Recruit and Total abundance indices, Area indices in age 1 and 2p and Inertia in age 1.

In summary (Fig. 14) the stock has experienced in the recent years a drop in abundance and recruitment, larger length, higher inertia in the spatial distribution of recruits, gravity centre of older fish spatial distribution more to the coast with higher inertia in the recruits and smaller occupied areas in the recruits and older fish.

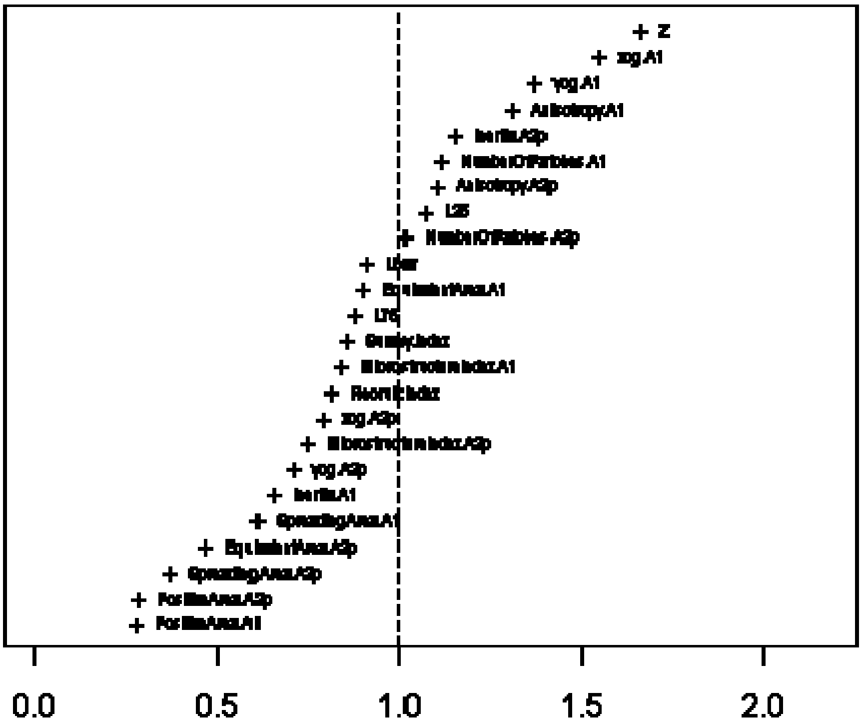


Fig. 10 : Variogram at lag 1 year for the 24 indicators ranked

Table 7 : Variogram at lag 1 year for the first 3 MAFs

	MAF1	MAF2	MAF3
Variogram value	0.087	0.160	0.331

Table 8 : Loadings of the indices on the first 3 MAFs

	MAF1	MAF2	MAF3
L75	**0.60**	-0.24	-0.12
Recruit.index	0.15	-0.27	**-0.57**
xcg.A2p	**-0.46**	**0.30**	0.10
Inertia.A1	**0.42**	-0.16	-0.26
EquivalentArea.A1	0.03	**0.39**	**0.33**
Survey.index	-0.09	-0.25	**-0.42**
EquivalentArea.A2p	**-0.33**	-0.09	**-0.30**
PositiveArea.A1	-0.08	-0.14	**0.45**
SpreadingArea.A1	-0.05	0.21	**0.41**
PositiveArea.A2p	0.08	**-0.30**	**0.31**
SpreadingArea.A2p	0.00	**-0.30**	-0.28
ycg.A2p	-0.25	-0.07	0.20
MicrostructureIndex.A2p	0.27	-0.14	0.07
MicrostructureIndex.A1	-0.02	-0.22	0.25
Lbar	0.01	0.08	0.14

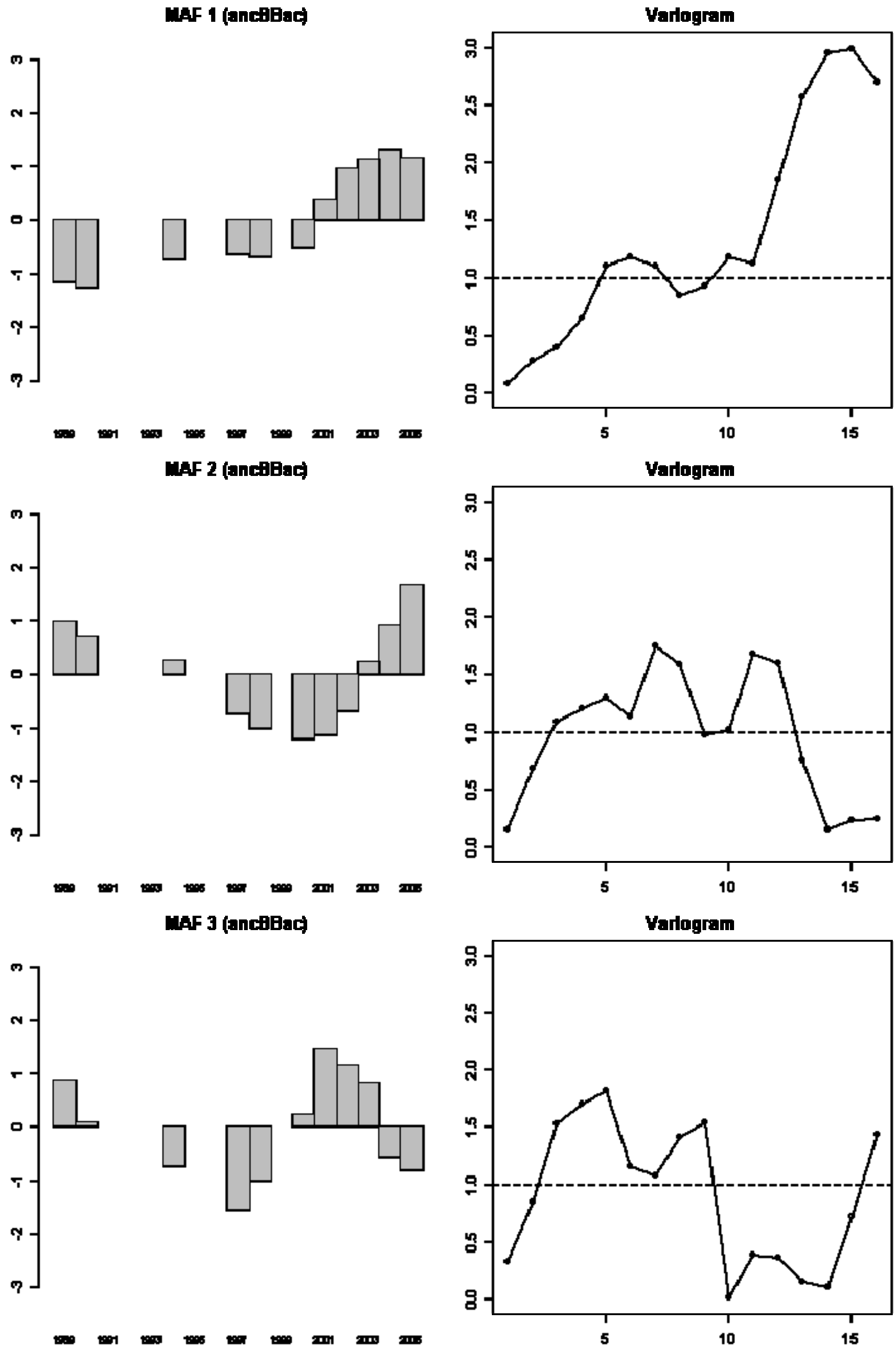


Fig. 11 : MAFs 1 (top) , 2 (centre) and 3 (bottom): time series (left), variogram (right).

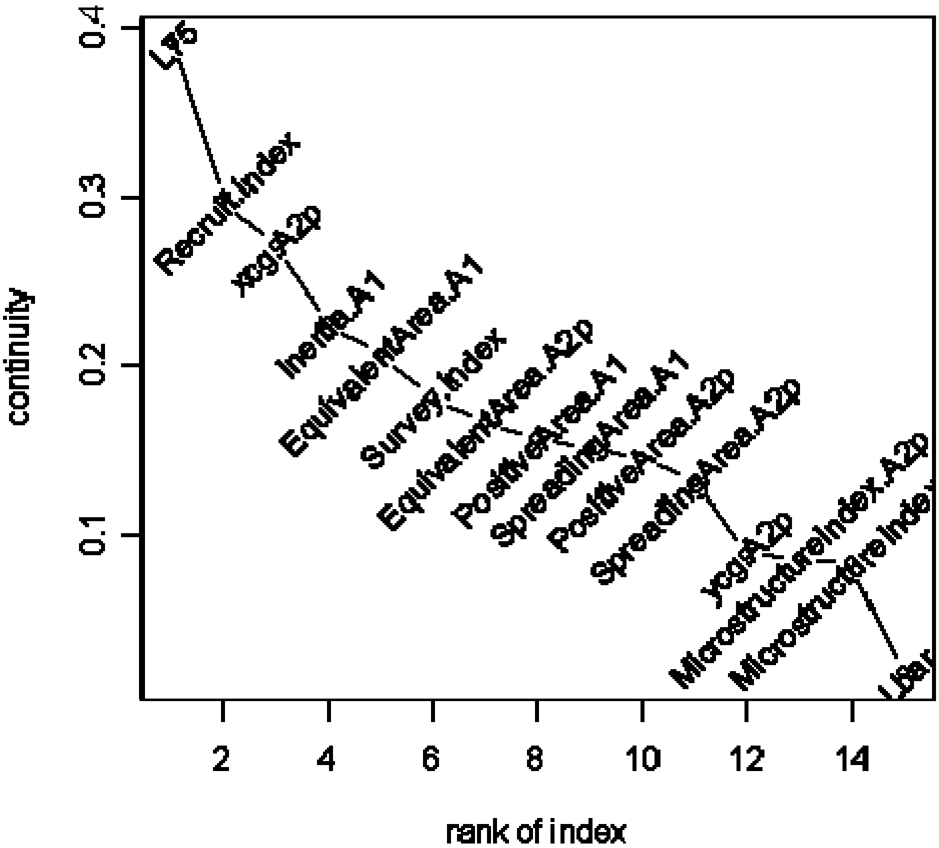


Fig. 12 : Continuity on the first 3 MAFs of indicators ranked

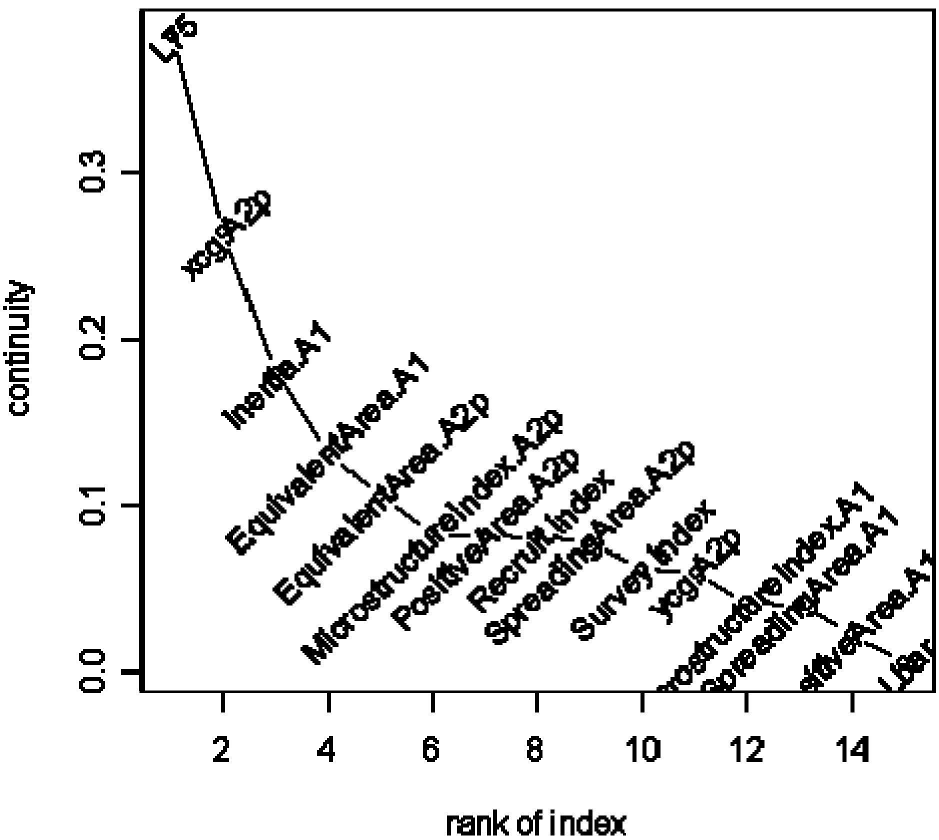


Fig. 13 : Continuity on the first 2 MAFs of indicators ranked

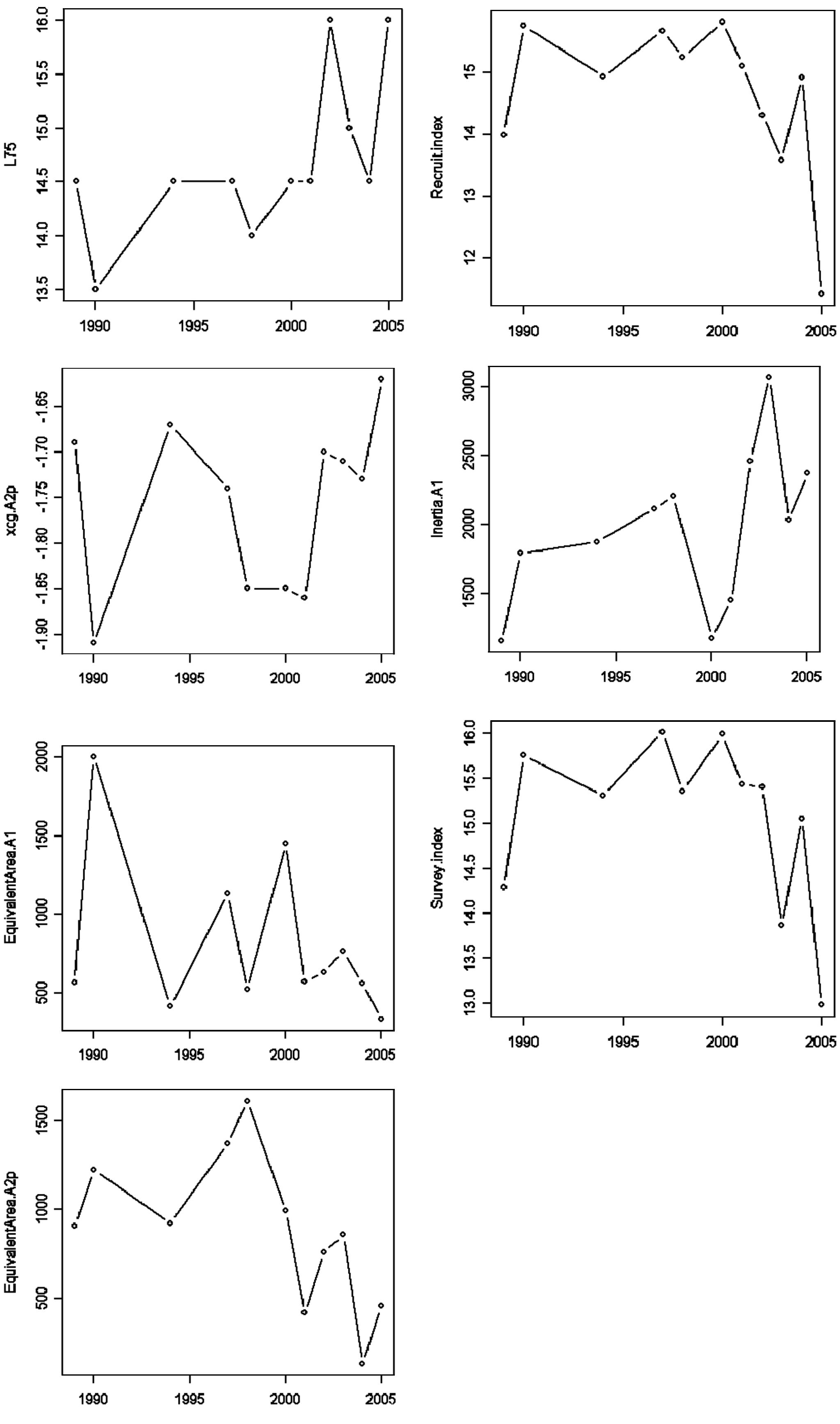


Fig. 14: Time series of the 7 selected indices using MAFs. L75: third quartile of fish length, xcg: Longitude of the gravity centre, A1: age 1, A2p: ages 2 and 3.

Looking for changes and interpretation

- **visual inspection**

Visual inspection was coherent with the selection of raw indices performed above.

- **trend plots of selected indices**

Diagnostic Cause-effect table was filled based on the visual inspection of the time series of the biological indices selected by the MAF procedure (Fig.14): L75, RecruitIndex and SurveyIndex. Other indices not selected by the MAF procedure were considered not enough continuous in time and therefore not used.

Anchovy Bay of Biscay **cause-effects diagnostics table**

survey period	1989-2005
ref.period	1990-2001
ref status	

Results of trend analysis

	all period	recent
Z	0	0
Ln_Abdnce	-1	-1
Lbar	0	0
L25	0	0
L75	1	1
Ln_Recruit	-1	-1

diagnostic Recruit decrease and / or F increase

Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0

- **di-cusum plots of selected indices**

A Decision-Cusum monitoring scheme was applied to the multivariate spatial and non spatial distances in order to detect those years in which the stock departed from its reference. The analysis above showed which indices were responsible for the change. We are here interested in detecting the out-of-control years. Reference years were 1990-2001 : a period where the stock abundance was average to high with no drop in abundance.

The ARL(0)s are large, meaning that the risk of false alarm is low. The ARL(2k) (out of control) is small (2 years and lower) meaning that a significant change is rapidly detected. Biological indices started to give an out-of-control signal in 2003 while the spatial indices did one year later. Since 2004, the stock is out-of-control in its biological and spatial indices.

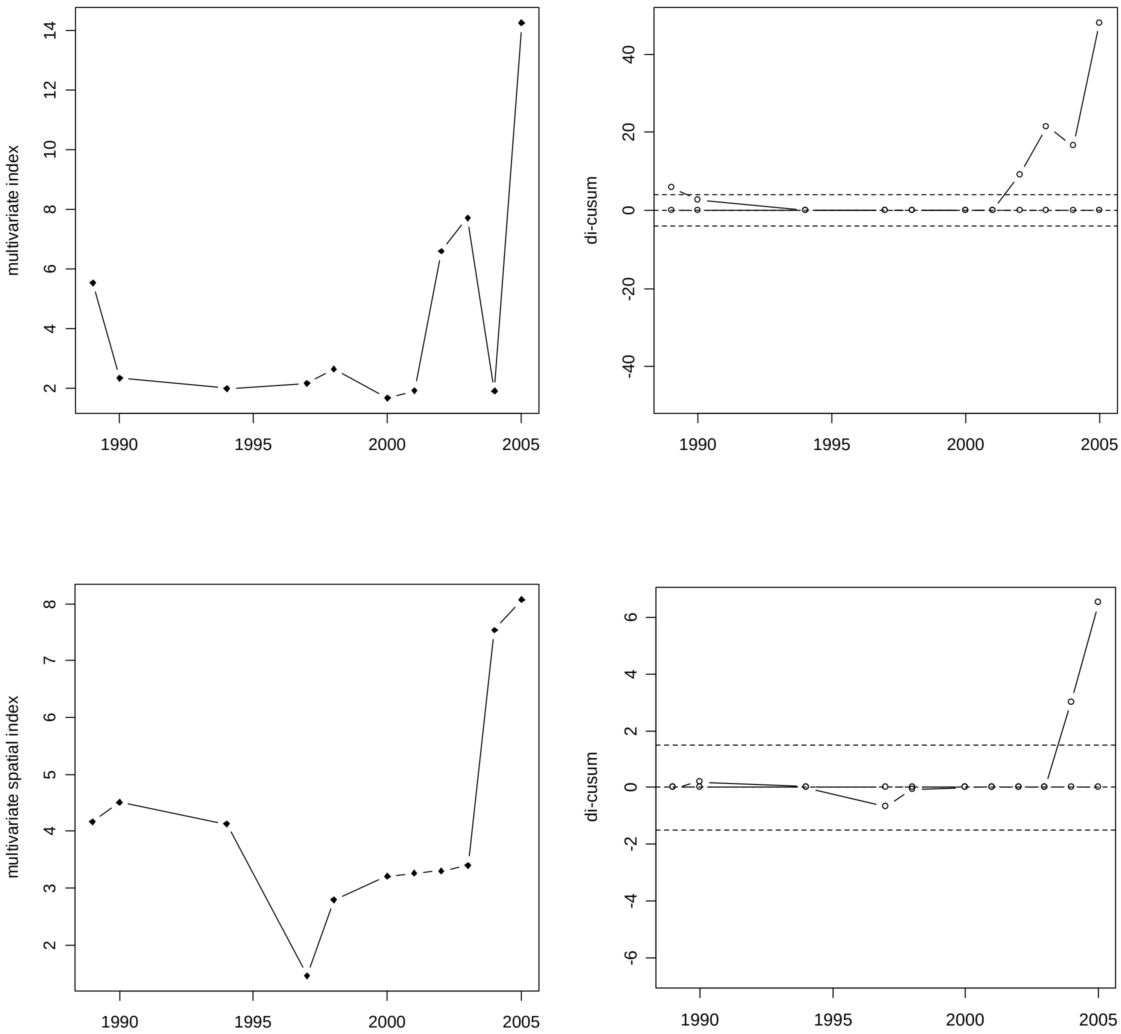


Fig. 15 : Time series of the multivariate indices (left) and their corresponding decision-cusum charts (right) for the biological non spatial indices (above) and the spatial indices (bottom). Reference years are 1990-2001.

Anchovy Bay of Biscay		CUSUM diagnostics table	
ref.period	1990-2001	1990-2001	
m in ref.period	3.22	2.12	
sd in ref.period	1.07	0.34	
k	1	2	
h	1.5	2	
ARL InControl	93.8	24471.1	
ARL OutControl	2.2	1.6	
Years	**PCA_Spatial**	**PCA_Biological**	**diagnostic**
1989	0.00	5.93	
1990	0.00	0.00	ref
1994	0.00	0.00	ref
1997	0.00	0.00	ref
1998	0.00	0.00	ref
2000	0.00	0.00	ref
2001	0.00	0.00	ref
2002	0.00	9.05	
2003	0.00	21.34	alert
2004	3.02	16.70	alarm
2005	6.53	48.09	alarm

Compare approaches (cusum/trends)

The decision interval Cusum is a statistical monitoring scheme used to detect changes if any from a reference period with set risks of false alarm and no alarm. The scheme makes no assumption on the type of change in time, which can be a trend or any other type. The Cause-effects diagnostic table interpreted trends where as the Cusum dignostic table estimated those years where change occurred. The two approaches are complementary.

For anchovy the impact of low recruitment on the total abundance is immediate because the species is short-lived (3 year classes) and because the recruits are a major part of the total stock. Therefore the good correlation between L75 and Ln-abundance with no time lag. The signal is supposedly so strong that it dominates allowing a clear interpretation with the Cause-effects table. The interpretation of combined causes could be more problematic.

What have you learned ?

Anchovy spatial distribution and abundance indicators are well correlated, which is biologically meaningful and provides a clear diagnostic of alarm signal.

When recruitment goes down, total abundance does as well and the proportion of large fish increases. Response in the different indicators is almost immediate at the scale of the year. The offshore component of the stock is depleted and the centre of gravity of the distribution is more coastal. The distribution is then aligned to the coast (anisotropy and inertia change). The occupied area is also reduced. The fact that it is the Equivalent area index that reponds the most (within the pool of area indices) is thought meaningful and perhaps coherent with the so called Basin model (ideal free distribution). The Equivalent area being the integral range of the stock (area covered by a population with constant density equal to the mean density per individual) anchovy shows a strong relationship between area occupied and local density, which would be interesting to investigate further. The biological multivariate index has signalled one year earlier than the spatial one, meaning perhaps that there is an ordered sequence relating biological characteristics and their spatial distribution.

The methods used constituted a multivariate monitoring system of fish stock and were efficient in detecting change and selecting those indices that guided those changes. Depending on the capability to interpret variability in the indicator time series, it may be worthwhile looking at more MAFs than just the first or the two first ones. There is no (little) lag delay in the response of different indicators for anchovy and this may have been a good situation for the methods used.

Summary sheet

- Survey series : 1989 – 2005 / Spring / Acoustic surveys

- Biological (non-spatial) indices

(which index been analysed ? what method for change? change detected ?)

Survey index, Recruitment index
Lbar, L75, L25, L50.maturity
Z by year

L50.maturity not applicable as all ages are mature in spring. All other indices used in the biological multivariate combined index (PCA). Length and abundance indices were anti-correlated. L75, Recruit and Survey indices were selected (using MAF) among those indices that expressed best the multivariate structure with the most continuous time series. A significant departure from the reference period was detected since 2003 (using CUSUM).

- Spatial indices

(which index analysed ? by age or stage ? what method ? change detected ?)

Positive Area, Spreading area, Equivalent area
Centre of gravity, Inertia, Anisotropy
Microstructure

All indices were used in the the spatial multivariate combined index (PCA). Area indices were anti-correlated with the Longitude of the gravity centre. Inertia and Anisotropy were correlated together and non correlated to other indices. Microstructure varied with Longitude of gravity centre. Longitude of gravity centre for ages 2+, Equivalent area for ages 1 and 2+, Inertia for age 1 were selected (using MAF) among those indices that expressed best the multivariate structure with the most continuous time series. A significant departure from the reference period was detected since 2004 (using CUSUM).

- Composite (derived) indices

(method ? index used ? components 1 & 2 dominated by which raw indices ? change detected ?)

Ones multivariate index for biological indicators and one for spatial indicators were constructed based on PCA analyses. MAF were used on all indices (that had a variogram lower than unity at lag 1) to select those indices which guided the multivariate changes in the stock, also facilitating interpretation.

- Reference period

(which years ? choice of period ?)

Reference period was 1990-2001. It was chosen based on the time series of the Survey index : population abundance was seen more stable with no drops during that period. The survey time series is recent. The long term evolution of the stock since the 60s as characterised with fishery catches has shown a long-term decrease.

- Summary of results on the stock

(comments on data series, ref period, changes evidenced, which method support summary)

One multivariate combined index for the biological indicators and one for the spatial indicators were used to characterise the evolution of the stock in time. The MAF procedure was used to select those indicators that best guided the multivariate changes in the stock, which allowed for interpretation of the changes. The CUSUM monitoring scheme was used to detect change and whether to trigger an alarm signal. The Cause-effect table was used to assign a possible cause to the detected changes.

The stock has experienced since 2004 a drop in abundance and recruitment, larger length, higher inertia in the spatial distribution of recruits, gravity centre of older fish spatial distribution more to the coast with higher inertia in the recruits and smaller occupied areas in the recruits and older fish.

Comparison with traditional assessment of stock status

Traditional advice is here taken to be the scientific diagnostic delivered by the relevant ICES expert group (Working group on the assessment of mackerel, horse mackerel, sardine and anchovy, WGMHSA). Did the indicator-based procedures allowed to trigger alert signals for similar years than WGMHSA? has an early warning been possible using indicators ? what did we gain with all indicators in comparision to abundance only ?

ICES WGMHSA has considered that recruitment was repeatedly low since 2002. The closure of the fishery was recommended in 2004 and 2005. This is remarquably consistent with the CUSUM diagnostic table. It should be noted that survey indices have a great impact on the assessment of WGMHSA. The indicator based approach could have re-enforced the diagnostic of WGMHSA in 2004 given the fact that spatial indices also triggered an alarm. The decision to close the fishery was taken in 2005 only.

For anchovy scientific advice for the management relies on assumptions about future recruitments. At present there are no reliable tools for predicting recruitment and therefore a precautionary approach has been set : an annaul TAC is suggested with a low/medium recruitment option which is then updated in mid-year depending on the spring survey-based evaluation and fishery catches in the first semestre.

In summary, the monitoring scheme using both biological and spatial indicators complemented well the traditional analytical assessment (already influenced by survey abundance indices) and is thought to increase the reliability of the assessment in general because coherence in the multivariate signals about the stock is increased.

Formulation of advice

Since 2003 the stock has shown recruitment and abundance values significantly lower than ever recorded in the time series. This drop in recruitment is well correlated with fish length in the population which has increased. Since 2004 the stock has also shown significant change in its spatial distribution since 2004 with a more coastal distribution, more aligned along the coast and occupying less area. Abundance, length and spatial indicators show coherent and significant alarm signals since 2004. The stock has only 3 year classes and 2005 is the second year of alarm signal. A recovery plan is needed. Restoration will be evaluated using biological and spatial distribution indicators.

Indicator Based Assessment

Anchovy Bay of Biscay (egg surveys)

L. Ibaibariaga (AZTI)

DATA

Map of all survey stations overlaid showing polygon used

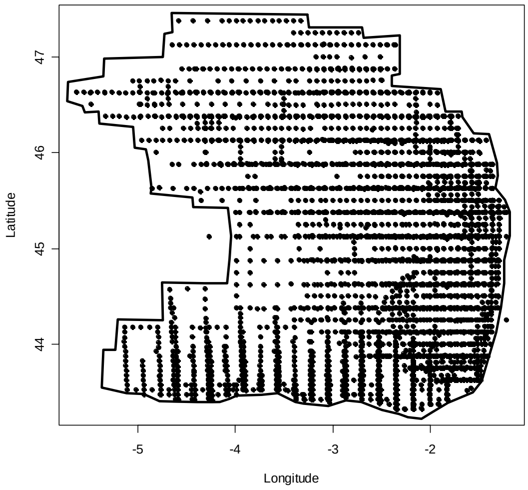


Fig 1: Survey stations from the egg surveys for the Bay of Biscay anchovy in 1989-2005 (except in 1993 that there was no survey). The outer line represents the polygon chosen for the computation of spatial indices.

For spatial indices: 2 maps of gravity centres across years for selected ages in immature and mature stages

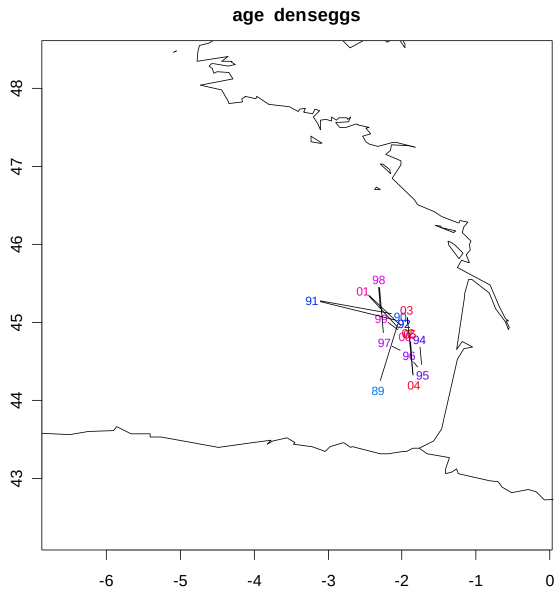


Fig 2: Map of gravity centres of the Bay of Biscay anchovy egg abundances in 1989-2005 (except in 1993)

Input parameters for spatial indices: function infl(), function NBPatches(), function Microstructure()

Input parameters for function infl( ): ndisc=200, dlim=15
Input parameters for function f.spatialpatches( ): Lim.D=50, B.li=0.1
Input parameters for function f.covario( ): num.dir=3, h0=10

Raw indices: Tables of spatial and non-spatial indices (wp2a tables 1 and 2)

Table 1: Spatial indices for the Bay of Biscay anchovy egg abundances

Year	Abundance	PosArea	Inertia	Anisotropy	Xcg	Ycg	NPatches	Microstruct	EquivArea	SpreadArea
1989	44.263	4225	2387	2.605	-2.33	44.15	32	0.811	1560	1740
1990	115.333	12494	3499	1.991	-2.02	45.09	10	0.708	3130	4320
1991	93.439	10561	5126	1.468	-3.22	45.30	15	0.698	2560	3680
1992	142.837	11444	3341	2.022	-1.97	45.00	22	0.708	1970	2970
1993	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1994	184.795	12147	1735	2.038	-1.76	44.80	9	0.56	2690	3040
1995	190.065	8648	1431	2.451	-1.72	44.34	6	0.633	2000	2640
1996	164.346	9315	2071	2.275	-1.91	44.59	4	0.712	2010	3020
1997	117.080	12877	3229	1.699	-2.24	44.75	12	0.683	3850	4840
1998	166.139	19851	3223	1.671	-2.32	45.57	10	0.501	5660	6490
1999	165.154	15246	3584	2.086	-2.29	45.07	10	0.529	5160	6740
2000	129.202	10970	3134	3.676	-1.96	44.84	16	0.795	1830	3920
2001	141.913	19196	4285	2.598	-2.53	45.43	22	0.67	4820	6710
2002	121.986	9773	2653	3.508	-1.92	44.88	7	0.56	2870	3290
2003	60.711	11029	3616	2.353	-1.94	45.18	8	0.857	1540	3200
2004	54.389	5752	2080	3.577	-1.84	44.21	6	0.703	1170	1980
2005	21.278	6050	2611	3.314	-1.90	44.87	17	0.652	2010	2680

Table 2: Non-spatial indices for the Bay of Biscay anchovy DEPM surveys

Year	Survey.index	Recruit.index	Z
1987	656	1129	0.93
1988	2349	2675	2.09
1989	347	663	0.60
1990	5613	5843	2.96
1991	671	966	1.16
1992	5571	5797	NA
1993	NA	NA	NA
1994	2030	2954	1.82
1995	2257	2644	NA
1996	NA	NA	NA
1997	3243	3738	1.45
1998	5467	6283	NA
1999	NA	NA	NA
2000	NA	NA	NA
2001	4362	6048	1.89
2002	284	1039	0.46
2003	1042	1296	2.2
2004	837	980	1.49
2005	95	292	NA

<u>Combined indices: retain the 2 first principal axes, fig of factorial representation, table of indices values</u>

1) Min/Max Autocorrelation Factors (MAF)

Table3: Time series of the first and second MAFs

Year	MAF1	MAF2
1989	0.813	-1.101
1990	0.168	-0.625
1991	0.826	-1.660
1992	1.175	-0.048
1994	1.460	1.708
1995	1.035	1.713
1996	0.647	0.873
1997	0.526	-0.611
1998	-0.092	0.001
1999	-0.589	-0.441
2000	-1.796	0.140
2001	-1.649	-0.976
2002	-1.145	0.706
2003	-0.202	-0.608
2004	-0.551	1.235
2005	-0.627	-0.306

Table 4: Contribution of each of the raw spatial indicators to the first and second MAF components

	MAF1	MAF2
PositiveArea	0.134	0.667
Inertia	-0.082	-0.295
Anisotropy	-0.921	0.060
xcg	0.077	-0.019
ycg	-0.201	-0.252
NumberOfPatches	0.146	-0.117
MicrostructureIndex	-0.325	-0.415
EquivalentArea	-0.459	-0.839
SpreadingArea	-0.314	0.118

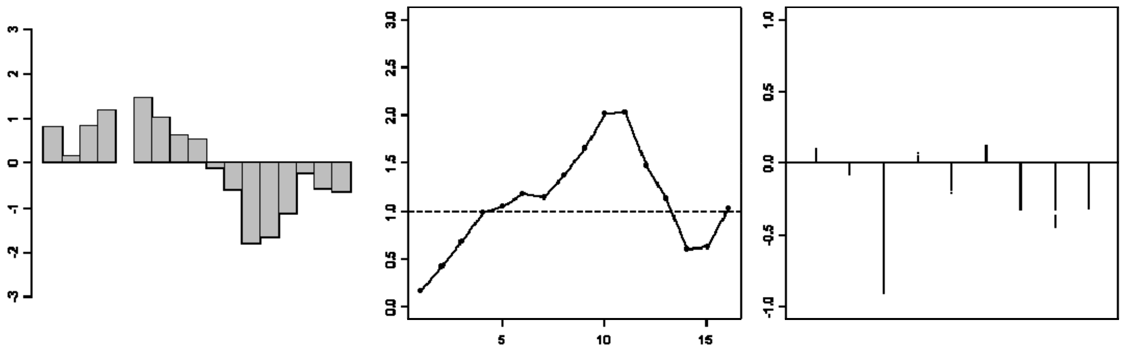


Figure 3: From left to right time series, variogram and contribution of each spatial indicator to the median of the first MAF component

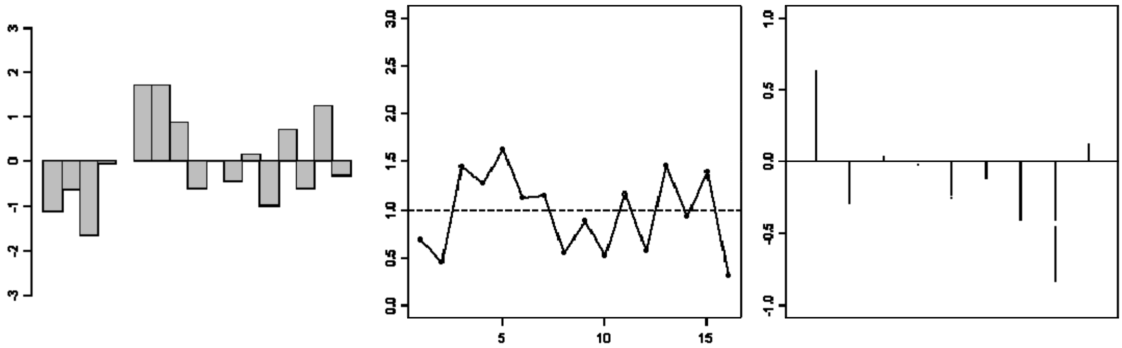


Figure 4: From left to right time series, variogram and contribution of each spatial indicator to the median of the second MAF component

2) PCA (In the case of the BoB anchovy, PCA (principal component analysis) instead of MFA (multi-factorial analysis) since there is only 1 stage (egg abundance))

Table 5: Time series of the distance in the factorial space of the PCA to the reference gravity centre

Year	Dmul
1989	3.910
1990	0.422
1991	3.563
1992	1.261
1994	2.133
1995	3.241
1996	2.287
1997	0.322
1998	3.601
1999	2.364
2000	2.104
2001	2.711
2002	1.921
2003	2.224
2004	4.130
2005	2.529

Table 6: Contribution of each of the raw spatial indicators to the first two components of the PCA

	C1	C2
PositiveArea	0.914	-0.225
Inertia	0.711	0.649
Anisotropy	-0.598	-0.17
xcg	-0.617	-0.619
ycg	0.871	0.128
Microstructure	-0.469	0.743
EquivalentArea	0.903	-0.354
SpreadingArea	0.924	-0.197

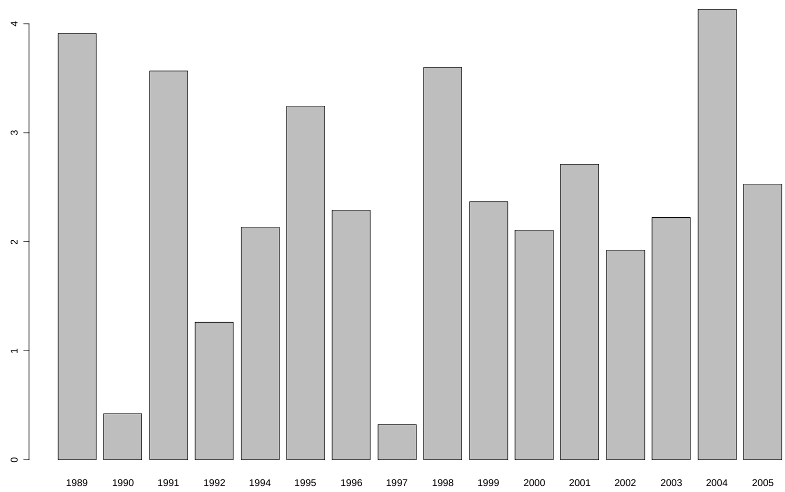


Figure 5: Time series of the distance in the factorial space of the PCA to the reference gravity centre

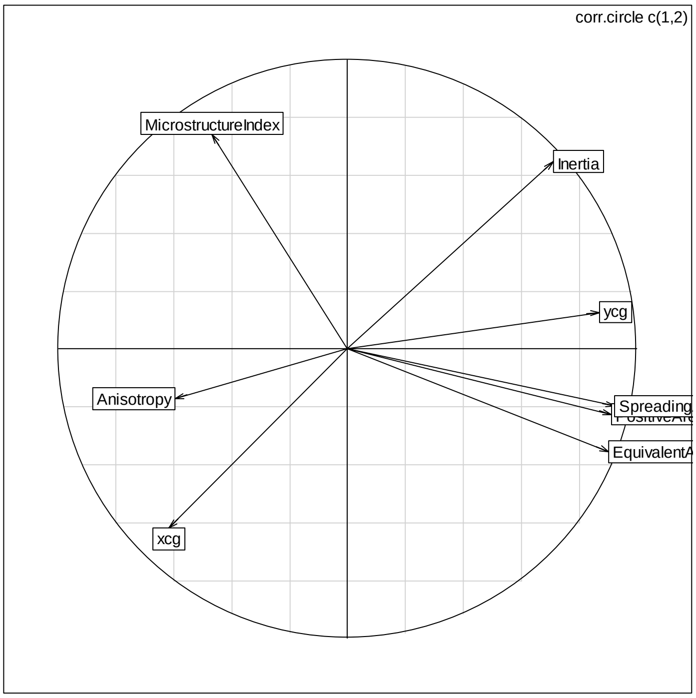


Figure 6: Graphical representation of the contribution of each of the row spatial indicators to the first two components of the PCA.

LOOKING FOR CHANGES

1) Visual inspection: plots of selected indices (raw and combined, expert or MAF-based)

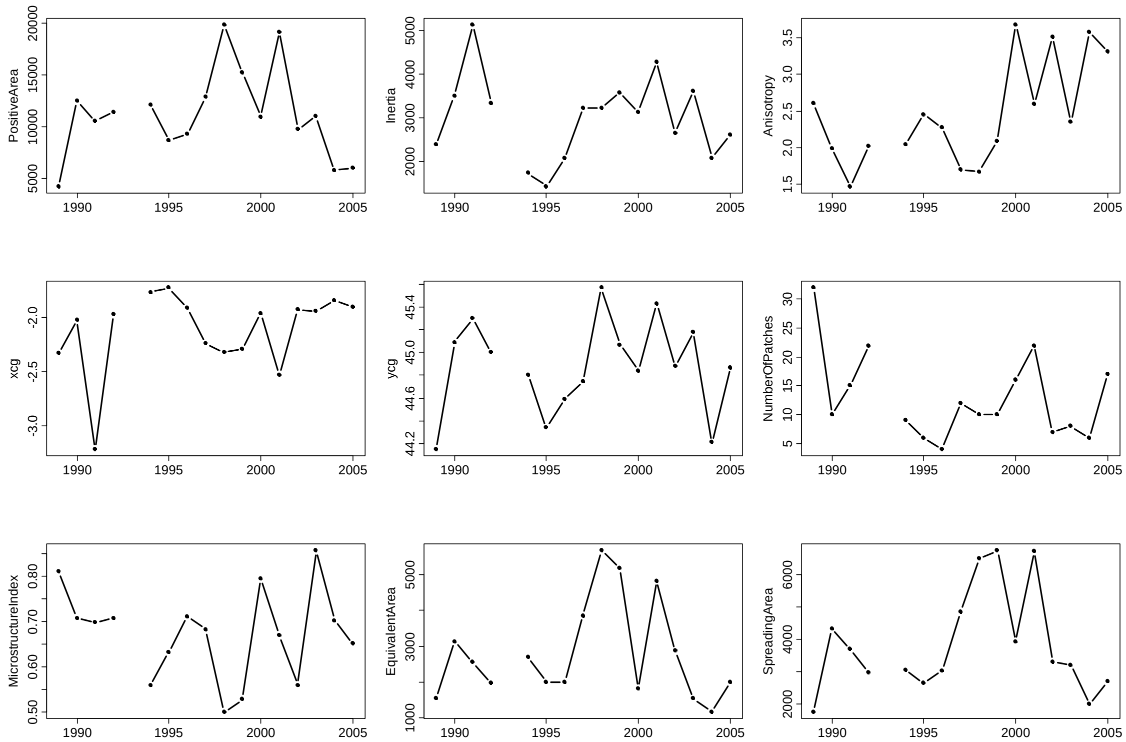


Figure 7: Time series of the row spatial indicators for the Bay of Biscay anchovy egg abundances. From left to right and from top to bottom, positive area, inertia, anisotropy, xcg, ycg, number of patches, microstructure, equivalent area and spreading area.

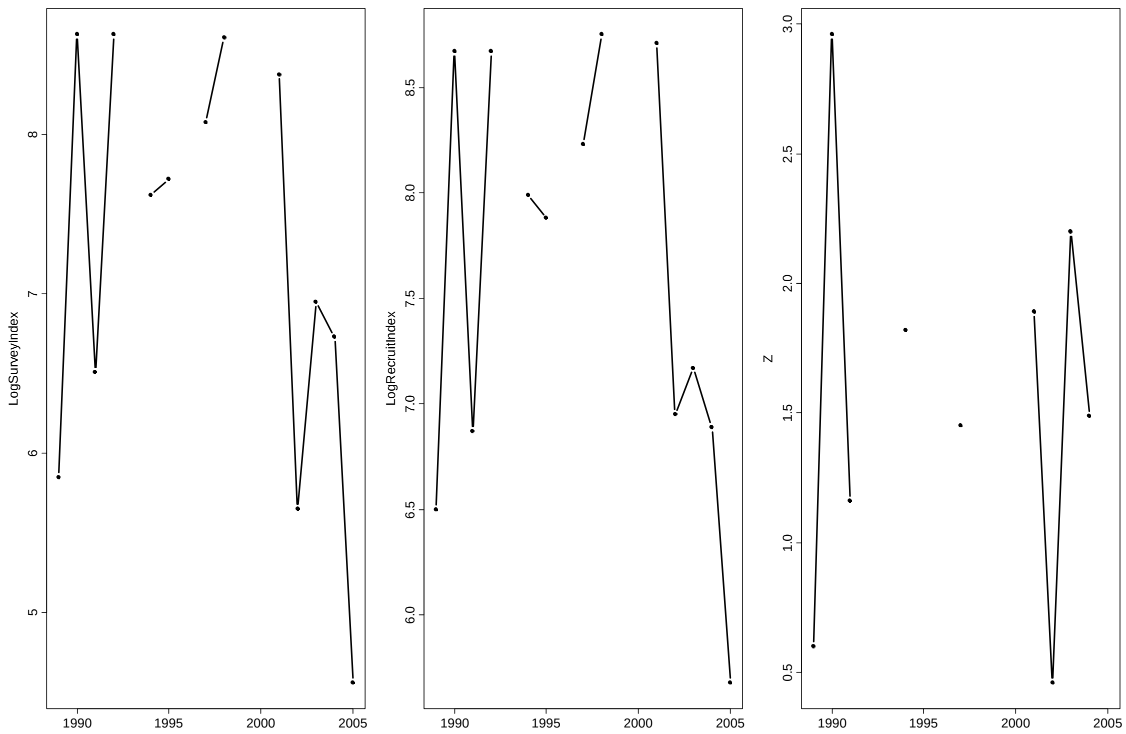


Figure 8: From left to right time series of natural logarithm of the survey index, of natural logarithm of the recruitment index and of total mortality from the Bay of Biscay anchovy DEPM surveys.

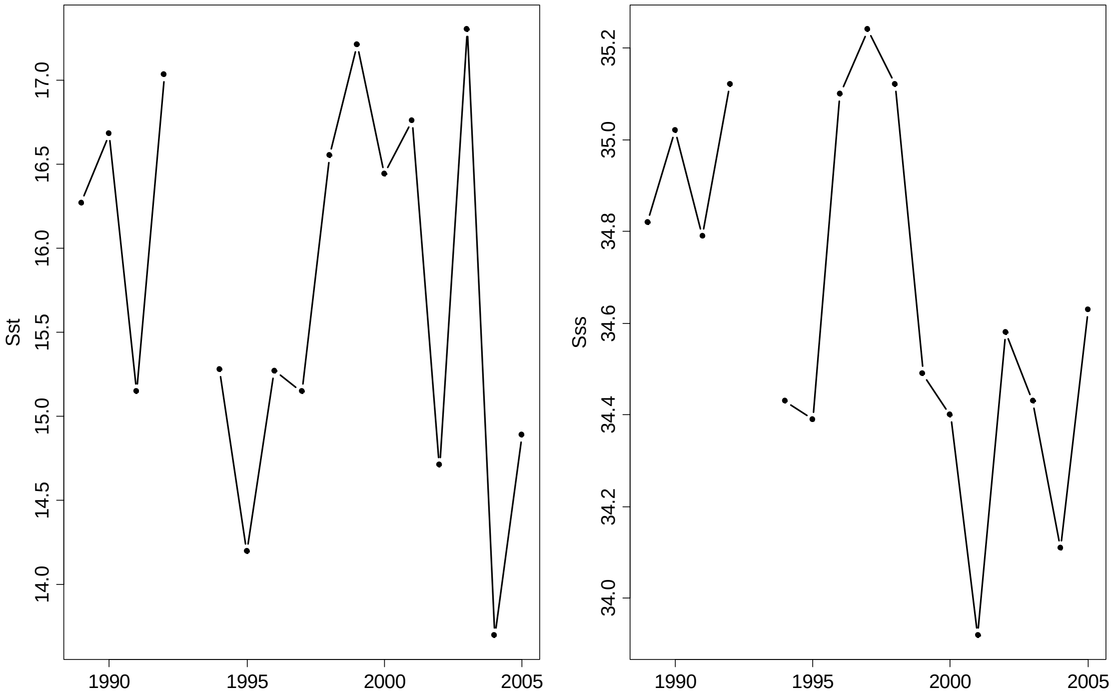


Figure 9: From left to right time series of sea surface temperature and salinity from the Bay of Biscay anchovy DEPM surveys.

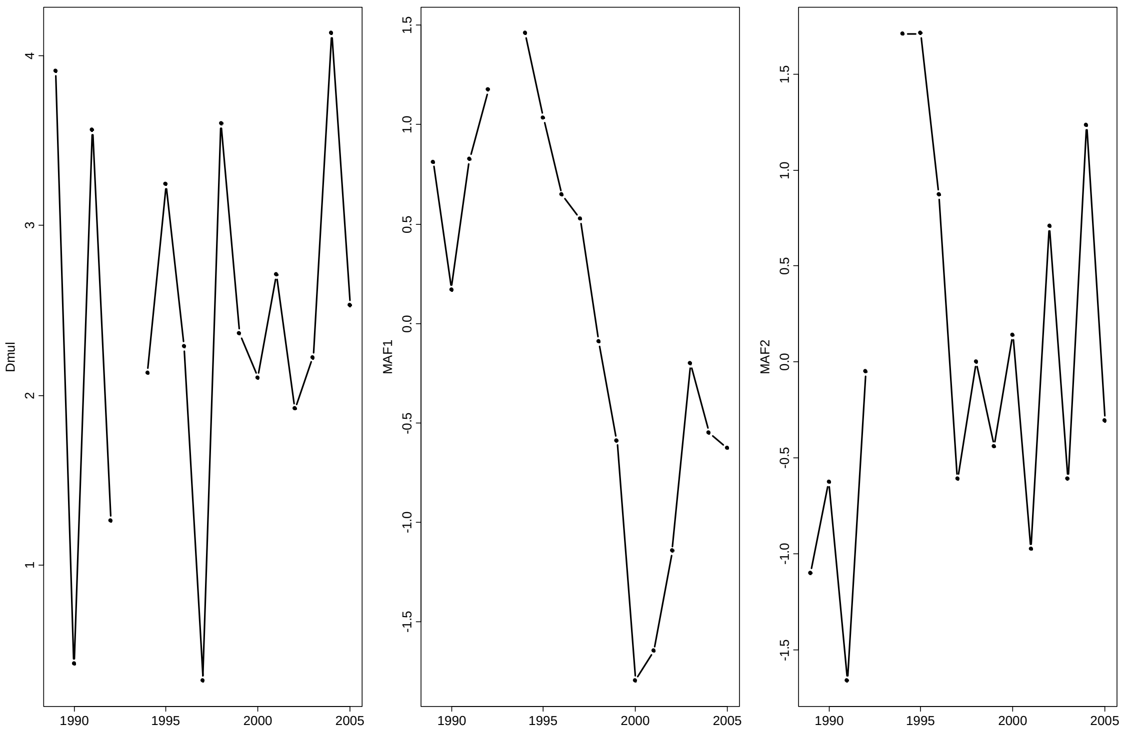


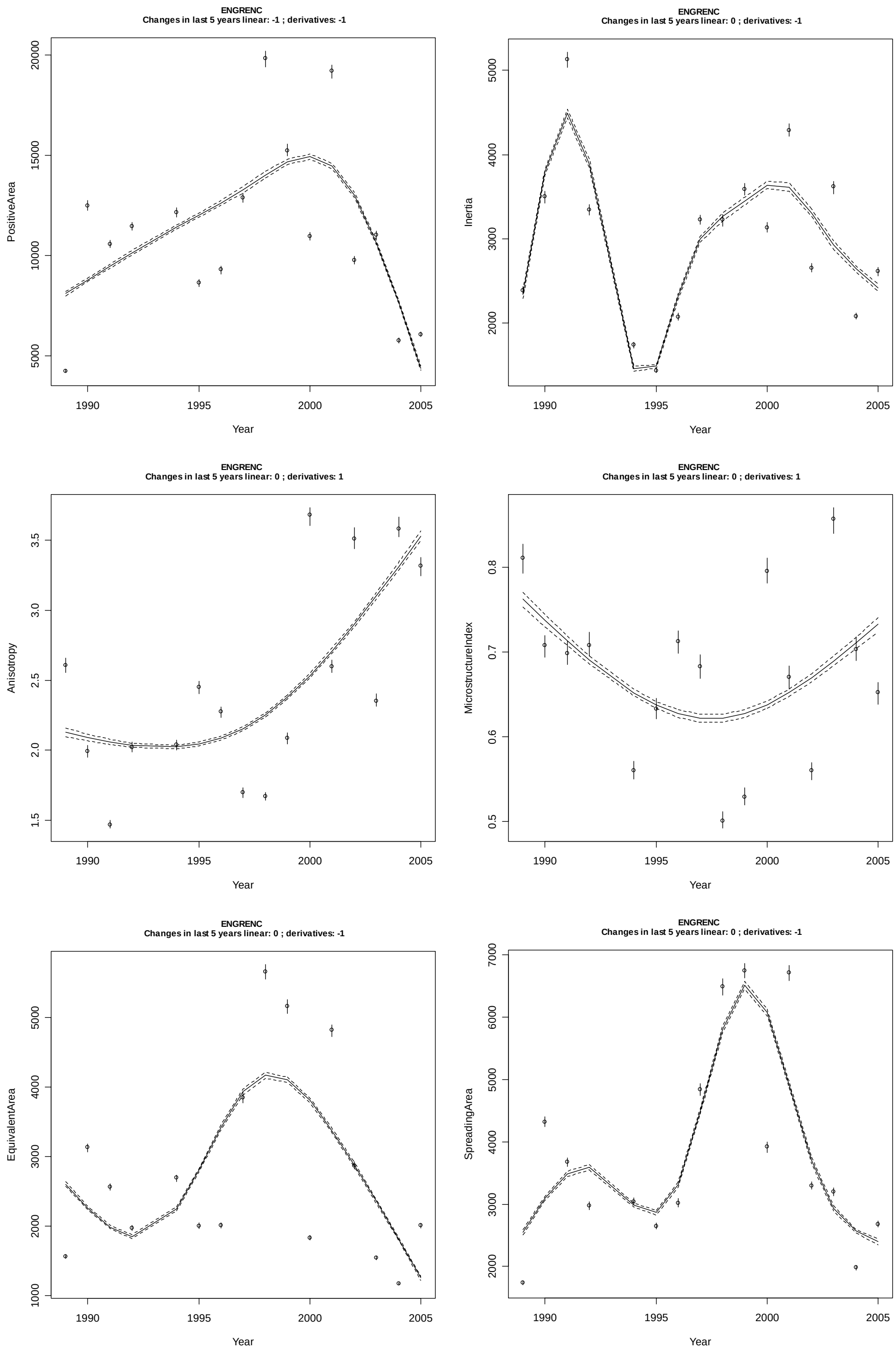
Figure 10: Time series of combined spatial indices from the Bay of Biscay anchovy DEPM surveys. From left to right distance in the factorial space of the PCA to the reference gravity centre and first two MAF components.

2) Trend plots of selected indices (provide plots, specify trend method used, fill trend diagnostic table)

Both the power and the nonparametric trend method were applied to all the indices. However, as none of the indices showed a linear trend the nonparametric method was considered more appropriate. In this section results from this method are summarised.

Table 7: Results from the nonparametric trend method for the different indicators.

Indicator	LinSlope	PvalueLinSlope	LinSlope5	PvalueL5	DiagnosL5	DiagnosRec
PositiveArea	35.676	0.876	-3031.300	0.049	-1	-1
Inertia	-14.955	0.769	-392.100	0.188	0	-1
Anisotropy	0.086	0.011	0.150	0.475	0	1
xcg	0.023	0.245	0.134	0.148	0	0
ycg	0.008	0.721	-0.179	0.265	0	0
NumberOfPatches	-0.495	0.200	-1.100	0.692	0	0
MicrostructureIndex	-0.002	0.694	0.011	0.802	0	1
EquivalentArea	9.520	0.897	-732.000	0.107	0	-1
SpreadingArea	40.141	0.636	-937.000	0.097	0	-1
Sst	-0.041	0.493	-0.475	0.392	0	-1
Sss	-0.040	0.037	0.095	0.404	0	0
Z	-0.005	0.927	0.054	0.908	0	-1
LogSurveyIndex	-0.085	0.223	-0.656	0.169	0	-1
LogRecruitIndex	-0.058	0.277	-0.612	0.040	-1	-1
Dmul	0.028	0.642	0.185	0.573	0	1
MAF1	-0.140	0.002	0.264	0.156	0	0
MAF2	0.040	0.447	0.187	0.601	0	0


ENGRENC
Changes in last 5 years linear: -1 ; derivatives: -1
PositiveArea
Year
ENGRENC
Changes in last 5 years linear: 0 ; derivatives: -1
Inertia
Year
ENGRENC
Changes in last 5 years linear: 0 ; derivatives: 1
Anisotropy
Year
ENGRENC
Changes in last 5 years linear: 0 ; derivatives: 1
MicrostructureIndex
Year
ENGRENC
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Year
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SpreadingArea
Year

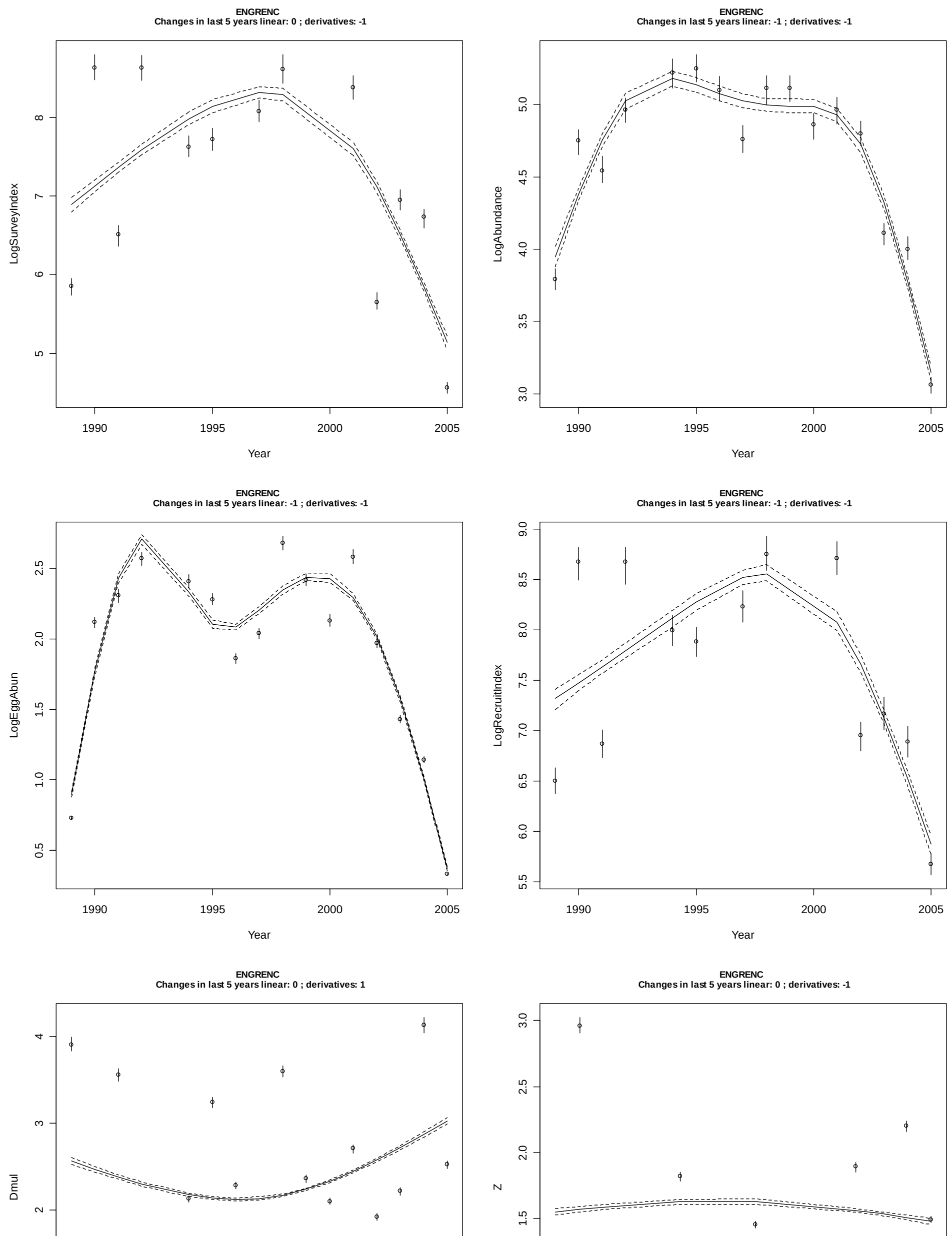


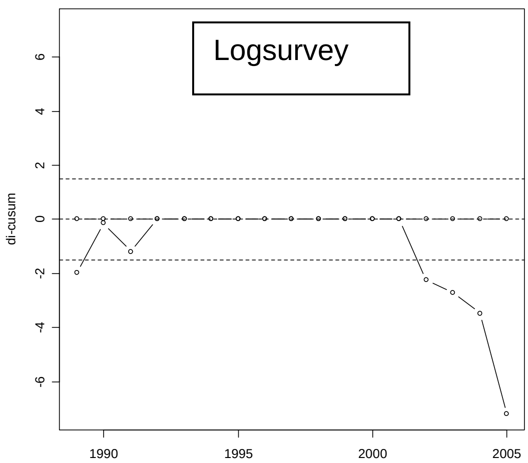
Figure 11: Nonparametric model fitting of the indicators that showed some trend in the last 5 years.

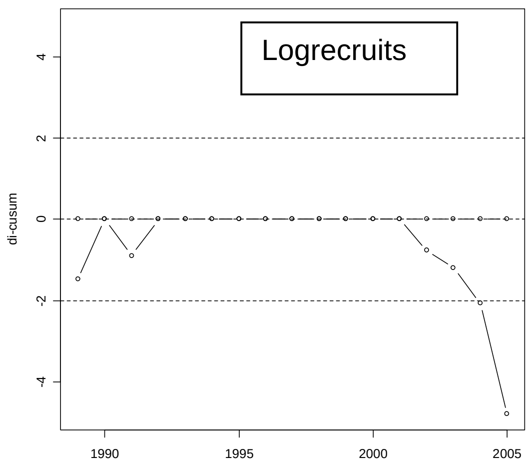
3) Di-cusum plots of selected indices (provide plots, fill cusum diagnostic table)

The selected reference period was: 1990-2001

Table 8: Summary table of the cusum analysis. The first 8 row contain the cusum parameters and below the alarm time series of each indicator are given.

m in ref.period	8.02	8.22	1.86	12977.18	3150.73	2.18	-2.18	44.98	12.36	0.65	3243.64	4397.27	2.18	0.16	0.01
sd in ref.period	0.73	0.65	0.68	3692.89	1080.40	0.60	0.43	0.37	5.87	0.09	1408.53	1581.93	1.13	1.10	1.06
k	1.00	1.20	0.60	0.80	0.50	0.70	0.50	0.50	0.70	0.60	0.60	0.60	0.50	0.50	0.60
h	1.50	2.00	1.50	1.30	1.50	1.50	1.80	1.50	1.50	1.50	1.00	1.50	1.50	1.50	1.50
ARL InControl	93.80	613.80	27.60	35.40	21.10	36.70	30.40	21.10	36.70	27.60	13.80	27.60	21.10	21.10	27.60
ARL IC P25	27.00	177.00	8.00	10.00	6.00	11.00	9.00	6.00	11.00	8.00	4.00	8.00	6.00	6.00	8.00
Shift	2.00	2.40	1.20	1.60	1.00	1.40	1.00	1.00	1.40	1.20	1.20	1.20	1.00	1.00	1.20
ARL OutControl	2.20	2.40	3.10	2.40	3.50	2.90	4.10	3.50	2.90	3.10	2.40	3.10	3.50	3.50	3.10
Years	**Ln_Survey**	**Ln_Recruits**	**Z**	**PositiveAr**	**Inertia**	**Anisotropy**	**xcg**	**ycg**	**NumberOf**	**Microstruc**	**Equivalent**	**Spreading**	**Dmul**	**MAF1**	**MAF2**
1989	-1.97	0.00	0.00	-1.57	0.00	0.00	0.00	-1.77	2.65	0.00	0.00	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00	-1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.23	0.00	0.00	0.00	0.00	0.00	0.00
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1995	0.00	0.00	0.00	0.00	-1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
1996	0.00	0.00	0.00	0.00	-2.40	0.00	0.00	-1.81	0.00	0.00	0.00	0.00	0.00	0.00	2.22
1997	0.00	0.00	0.00	0.00	-1.83	0.00	0.00	-1.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.91	1.88	1.60	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	1.80	0.00	0.00	0.00	0.00	0.00	1.56	0.00	-2.60	0.00
2002	-2.24	0.00	0.00	0.00	0.00	3.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.29	0.00
2003	-2.70	0.00	0.00	0.00	0.00	2.91	0.00	0.00	0.00	1.66	0.00	0.00	0.00	-3.12	0.00
2004	-3.47	-2.06	0.00	0.00	0.00	4.54	0.00	-1.60	0.00	1.60	-1.48	0.00	0.00	-3.26	0.00
2005	-7.20	-4.80	0.00	-2.23	0.00	5.74	0.00	0.00	0.00	0.00	-1.76	-1.67	0.00	-3.48	0.00





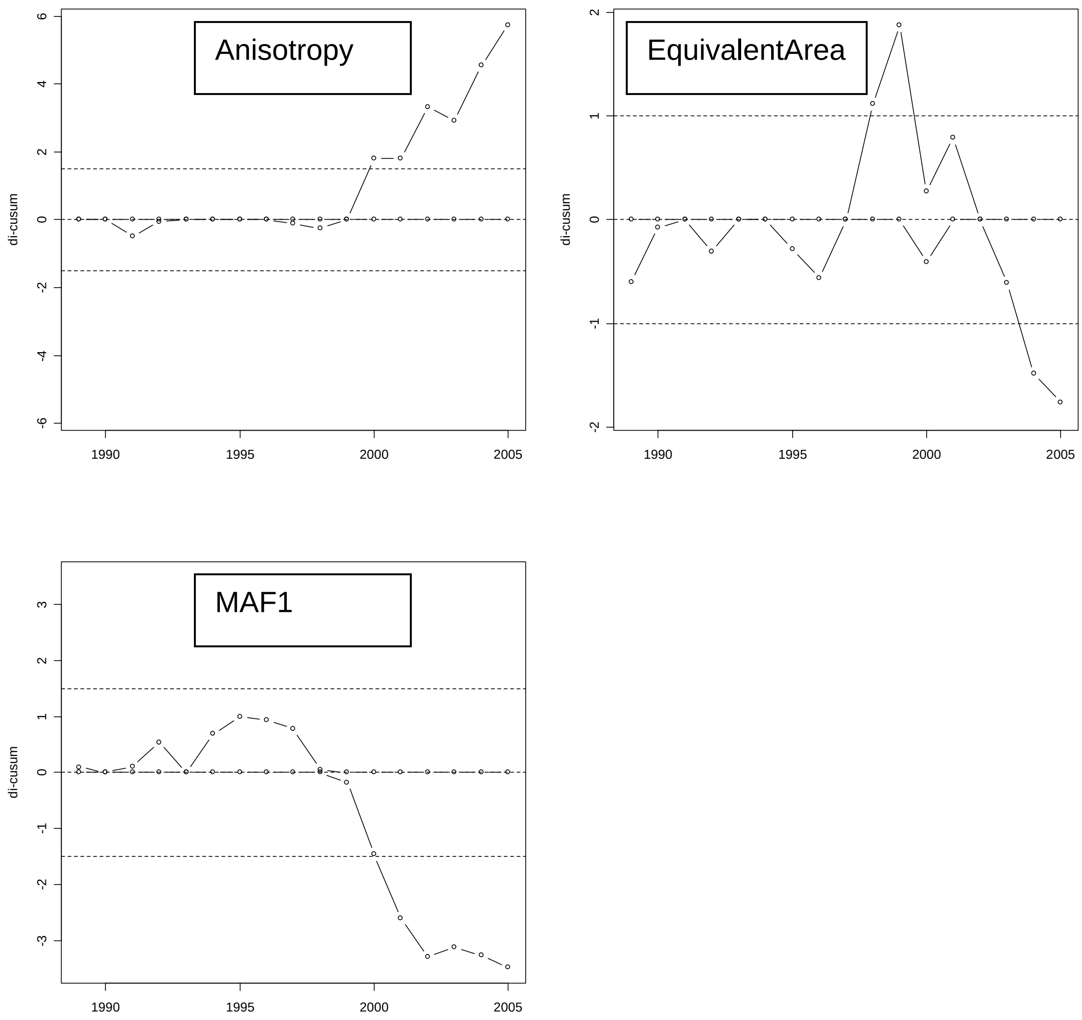


Figure 12: Di-cusum plots for the indicators that indicated some alarm in the last years (out of the reference period).

INTERPRETATION

From the trend diagnostic table (see file indic_diagno_tables_nantes_ancBB_eg.xls):

- The vital trait indicators point out that there has been a consecutive recruitment failure in the last years
- The raw spatial indicators suggests that in the last years, in which the population level has been very low, the area occupied has decreased and the spatial distribution has been more elongated and closer to the coast (Decrease in PositiveArea, SpreadingArea and EquivalentArea, decrease in inertia and increase in anisotropy.
- From the combined indices, only distance in the factorial space of the PCA shows a positive trend in the last years. This can be due to the correspondence between the first PCA component with the raw spatial indices (see table 6). So, it would indicate the same trend as the one detected by the individual raw spatial indices (positive area, spreading area, equivalent area, inertia and anisotropy).

In addition, a retrospective analysis was performed applying the nonparametric trend method from 1989 to 1999 and then, adding a year sequentially until 2005 (Table 9). Clearly, some of the indices started to point out trends since 2002 in agreement with the low population level in the last years.

Table 9: Restrospective analysis of the nonparametric trend method applied to Bay of Biscay anchovy DEPM surveys indicators.

	1989-1999		1989-2000		1989-2001		1989-2002		1989-2003		1989-2004		1989-2005	
Indicator	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear
PositiveArea	0	0	0	0	0	0	0	0	0	-1	0	0	-1	-1
Inertia	1	0	0	0	0	0	0	0	0	0	0	0	0	-1
Anisotropy	0	0	0	0	0	0	0	1	0	0	0	1	0	1
xcg	-1	-1	0	-1	0	-1	0	-1	0	-1	0	0	0	0
ycg	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NumberOfPatches	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MicrostructureIndex	0	0	0	0	0	0	0	0	0	0	0	1	0	1
EquivalentArea	1	0	0	0	0	0	0	0	0	0	0	-1	0	-1
SpreadingArea	1	0	0	0	0	0	0	0	0	0	0	-1	0	-1
Sst	1	0	0	1	0	1	0	0	0	1	0	0	0	-1
Sss	0	0	0	0	-1	0	0	0	0	0	0	0	0	0
Z	0	-1	0	-1	0	0	0	-1	0	-1	0	-1	0	-1
LogSurveyIndex	1	0	1	0	0	0	0	-1	0	-1	0	-1	0	-1
LogRecruitIndex	0	0	0	0	0	0	0	-1	0	-1	0	-1	-1	-1
Dmul	0	1	0	1	0	1	0	1	0	1	0	1	0	1
MAF1	-1	-1	-1	-1	-1	-1	0	0	0	0	1	0	0	0
MAF2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

From the di-cusum diagnostic table (see file indic_diagno_tables_nantes_ancBB_eg.xls):

- Log abundance indices from the survey (total and recruitment) triggered the alarm in the last years
- From the spatial raw indicators, positive area, spreading area and equivalent area detected some decreasing change in the last year or couple of years, whereas anisotropy showed a positive trend in the last 5 years.
- From the combined indices, only the first MAF component triggered an alarm in the last years. This first MAF component is mainly composed by anisotropy, that also triggered an alarm in those years.

The reference period selected for this species is long in comparison with the length of the whole time series. So, changes can only be detected in the last years. Care must be taken in interpreting the results as in these last years the population has entered into a low productivity situation. For comparison purposes it would be desirable to have some additional years in which the population was considered to be at acceptable levels but that wouldn't be part of the reference period.

COMPARE APPROACHES (CUSUM/TRENDS)

Both cusum and nonparametric trend method had detected some change for abundance related variables: natural logarithm of Survey and Recruitment indices in the last years, for area related spatial indicators (equivalent area, positive area and spreading area) and for anisotropy. This might be due to decrease of area occupation and more coastal and elongated distribution when population abundance is low.

The changes detected in the combined indices are difficult to interpret. On the one hand, they combine changes in different raw indicators, so that the final trend cannot be easily understood.

WHAT HAVE YOU LEARNED

We have confirmed that:

- The population is dominated by recruitment. Thus, recruitment indices from the surveys are important
- Positive relationship between area occupation and abundance.
- Anisotropy inversely related to abundance.
- Combined indices difficult to interpret and not always useful

SUMMARY SHEET

Survey series (period/seasons/type): Daily Egg Production Method survey (ichthyoplankton and adult sampling) conducted at the spawning peak (May) in the Bay of Biscay

Vital Traits

Lbar, L25, L50, L75	NA
L50.maturity	NA
Z at age	Done, no signal
Age structure	NA

Abundance

Abundance	Done, decreasing in last years
Recruitment index	Done, decreasing in last years

Spatial

Positive Area	Done, decreasing in last years
Spreading area	Done, decreasing in last years
Equivalent area	Done, decreasing in last years
Inertia	Done, decreasing in last years
Anisotropy	Done, increasing trend (all years)
Microstructure	Done, slightly increasing last years
Centre of gravity	Done, no signal detected
Number of patches	Done, no signal detected
PCA	Done, no signal detected.
MAF	Done, no clear signal detected

Reference period

1990-2001

Methods applied

MFA/PCA	Done
MAF	Done
Nonparametric	NA
Trends table (Verena)	Done, signals in abundance, recruitment and some of the spatial indices
Power analysis	Done, no signal
Cusum	Done, signals in abundance, recruitment and some of the spatial indices

COMPARISON WITH TRADITIONAL ASSESSMENT OF STOCK STATUS

Anchovy is a short-lived species, so the level of the population is mainly determined by yearly incoming recruitment. Consequently the population is very fluctuating from one year to the next. In the last five years there has been a succession of recruitment failures and the population has attained the lowest level of the historical series. These low levels of the population have been detected by the ICES working group on the assessment of anchovy (WGMHSA) based on the integrated assessment of the stock using information from the surveys and the commenercial catches. Spatial indicators related to the area occupied and the shape of the distribution, have shown to be correlated with the level of the population. So, they have corroborated the alerts triggered by the working group.

FORMULATION OF ADVICE

For this case study, some of the indicators support the diagnostics from the population abundance indices in the last 5 years. However, it is difficult to ascertain up to which point it is possible to trigger an alarm only from the indicators. In the last five years, the population level has been very low, and the danger of stock collapse has been very high. For a complete analysis, a longer time series, with the population at different levels (not only very poor situation), would be desirable.

Case Study Name	ancBB_eg	cause-effects diagnostics table
survey period	1989-2005	
ref.period	1990-2001	
ref status	acceptable	

Results of trend analysis for non-spatial indices

	all period	recent	
Z	0	-1	Not very clear pattern in Z
Ln_Abdnce	0	-1	
Lbar	NA	NA	
L25	NA	NA	
L75	NA	NA	
Ln_Recruit	0	-1	
DIAGNOSTIC	Recruitment failure in the last years		

Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
Larger fish caught (or change in fishing area, stock distribution or gear)	-1	1	1	0	1	0
Smaller fish caught (or change in fishing area, stock distribution or gear)	1	-1	-1	-1	0	0

Results of trend analysis for raw spatial indices and combined indices (Dmul from PCA and Maf1 and Maf2 from MAF)

	all period	recent
PositiveArea	0	-1
Inertia	0	-1
Anisotropy	1	1
xcg	0	0
ycg	0	0
NumberPatches	0	0
Microstructure	0	1
EquivalentArea	0	-1
SpreadingArea	0	-1
Dmul	0	1
Maf1	-1	0
Maf2	0	0
Sst	0	-1
Sss	-1	0

diagnostic

In the last years, when the recruitment has failed, there is a decrease in all area related indices (PositiveArea, SpreadingArea and EquivalentArea)
In addition there is a decrease in inertia and an increase in anisotropy. All this can indicate that when the population is at low levels,
the area occupied by the species is reduced and its shape is more elongated all along the coast.
In the combined indices, only Dmul shows a positive trend in the last years.

CASE STUDY NAME	ancBB_eg	CUSUM diagnostics table														
ref.period	1990-2001															
m in ref.period	8.023	8.221	1.856	12977.182	3150.727	2.180	-2.176	44.980	12.364	0.654	3243.636	4397.273	2.183	0.156	0.007	
sd in ref.period	0.732	0.646	0.684	3692.886	1080.402	0.599	0.426	0.366	5.870	0.090	1408.533	1581.930	1.130	1.097	1.063	
k	1.000	1.200	0.600	0.800	0.500	0.700	0.500	0.500	0.700	0.600	0.600	0.600	0.500	0.500	0.600	
h	1.500	2.000	1.500	1.300	1.500	1.500	1.800	1.500	1.500	1.500	1.000	1.500	1.500	1.500	1.500	
ARL InControl	93.800	613.800	27.600	35.400	21.100	36.700	30.400	21.100	36.700	27.600	13.800	27.600	21.100	21.100	27.600	
ARL InControl P25	27.000	177.000	8.000	10.000	6.000	11.000	9.000	6.000	11.000	8.000	4.000	8.000	6.000	6.000	8.000	
Shift	2.000	2.400	1.200	1.600	1.000	1.400	1.000	1.000	1.400	1.200	1.200	1.200	1.000	1.000	1.200	
ARL OutControl	2.200	2.400	3.100	2.400	3.500	2.900	4.100	3.500	2.900	3.100	2.400	3.100	3.500	3.500	3.100	
Years	**Ln_Survey**	**Ln_Recruits**	**Z**	**Pos.Area**	**Inertia**	**Aniso**	**xcg**	**ycg**	**NB.patch**	**Mic.Struc**	**Eq.Area**	**Spread.Area**	**Dmul**	**MAF1**	**MAF2**	**alert**
1989	**-1.966**	0.000	0.000	**-1.570**	0.000	0.000	0.000	**-1.767**	**2.645**	0.000	0.000	0.000	0.000	0.000	0.000	
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**1.543**	0.000	0.000	0.000	0.000	0.000	0.000	ref
1991	0.000	0.000	0.000	0.000	0.000	0.000	**-1.947**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ref
1992	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**2.233**	0.000	0.000	0.000	0.000	0.000	0.000	ref
1993	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ref
1994	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ref
1995	0.000	0.000	0.000	0.000	**-1.902**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**2.005**	ref
1996	0.000	0.000	0.000	0.000	**-2.401**	0.000	0.000	**-1.814**	0.000	0.000	0.000	0.000	0.000	0.000	**2.220**	ref
1997	0.000	0.000	0.000	0.000	**-1.829**	0.000	0.000	**-1.942**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ref
1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**1.116**	0.000	0.000	0.000	0.000	ref
1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**-1.906**	**1.876**	**1.604**	0.000	0.000	0.000	ref
2000	0.000	0.000	0.000	0.000	0.000	**1.800**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	ref
2001	0.000	0.000	0.000	0.000	0.000	**1.799**	0.000	0.000	0.000	0.000	0.000	**1.564**	0.000	**-2.605**	0.000	ref
2002	**-2.239**	0.000	0.000	0.000	0.000	**3.319**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**-3.291**	0.000	
2003	**-2.703**	0.000	0.000	0.000	0.000	**2.909**	0.000	0.000	0.000	**1.661**	0.000	0.000	0.000	**-3.117**	0.000	
2004	**-3.468**	**-2.060**	0.000	0.000	0.000	**4.544**	0.000	**-1.603**	0.000	**1.604**	**-1.482**	0.000	0.000	**-3.262**	0.000	
2005	**-7.195**	**-4.797**	0.000	**-2.232**	0.000	**5.739**	0.000	0.000	0.000	0.000	**-1.758**	**-1.670**	0.000	**-3.476**	0.000	

Indicator Based Assessment

Hake Bay of Biscay

J.C. Poulard (IFREMER)

Data

Survey area and polygon

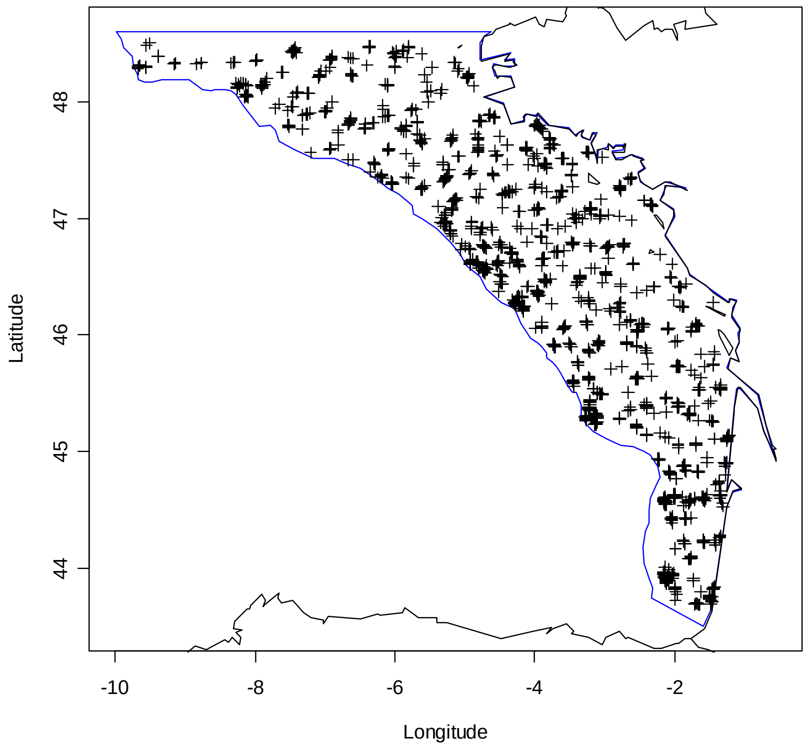


Figure 1. Map of all survey stations occupied (+) during the EVHOE surveys carried out from 1987 to 2004. The polygon used is the blue line.

Spatial indices

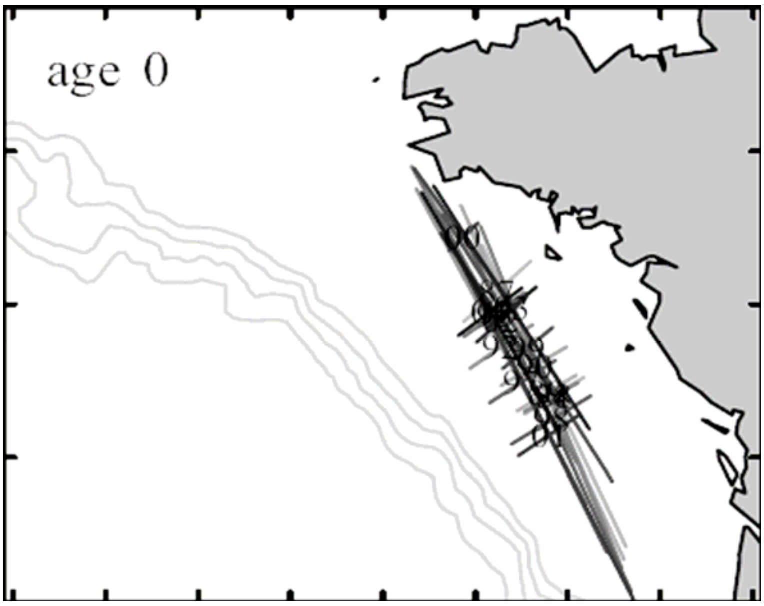


Figure 2. Map of the gravity centres across years of he hake age group 0 (immature fish).

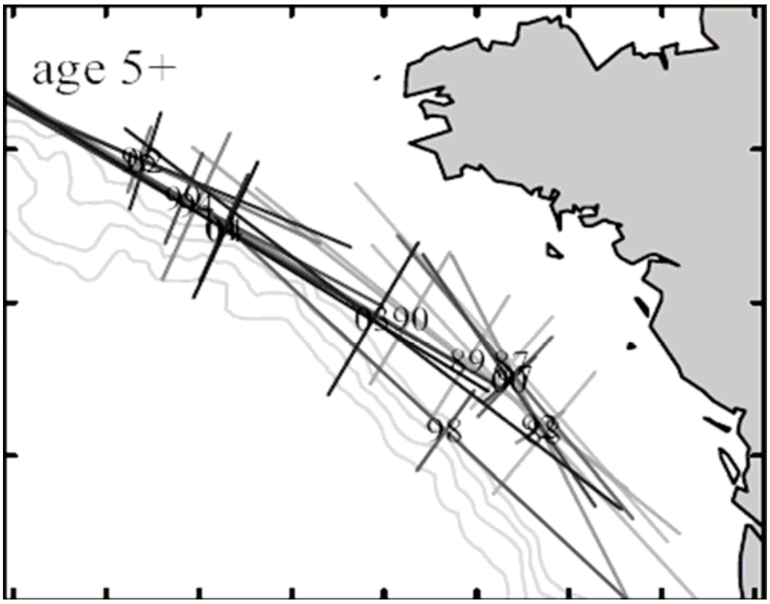


Figure 3. Map of the gravity centres across years of he hake age group 5+ (mature hake).

Input parameters for spatial indices

a) Function infl()
The limit distance of influence (in nautical mile) of a sample (dlim) is 25.

b) Function NBPatches()
The minimum distance (in nautical mile) between a sample and a patch centre (Lim.D) must be 100, otherwise a new patch is identified. The minimal abundance gathered by a patch must be equal to at least 10 % of the total abundance to validate the patch.

c) Function Microstrucure()

The mean lag (h0) between samples has been set to 10 nautical miles. Discretization of the data area has been performed using a mesh side of 3.333 nm along latitude and longitude.

Raw indices

Table 1. Table of spatial indices (hakBB_tab1_wp2a).

hakeBB	Area	Species	Age	Year	Abundance	Positive Area	Inertia	Anisotropy	xcg	ycg	Microstructure Index	EquivalentArea	SpreadingArea	Number of Patches
Biscay	BT	MERLMER	A0	1987	67990000	22333	2799	2.58	-3.77	47.08	0.424	4781	5678	1
Biscay	BT	MERLMER	A0	1988	129665000	22200	4751	4.39	-3.15	46.40	0.330	6300	6666	2
Biscay	BT	MERLMER	A0	1989	97632000	20089	5671	4.89	-3.23	46.42	0.385	6416	6521	3
Biscay	BT	MERLMER	A0	1990	209357000	24689	5311	4.28	-3.37	46.60	0.433	5717	6856	2
Biscay	BT	MERLMER	A0	1992	50809000	19822	5536	4.39	-3.72	46.72	0.377	7148	7348	2
Biscay	BT	MERLMER	A0	1994	262270000	20244	5669	5.60	-3.18	46.39	0.584	2800	4357	2
Biscay	BT	MERLMER	A0	1995	96899000	23767	4997	4.25	-3.80	46.93	0.439	4179	5304	2
Biscay	BT	MERLMER	A0	1997	125287000	20400	6158	4.52	-3.49	46.50	0.327	7007	6713	2
Biscay	BT	MERLMER	A0	1998	36493000	19467	6202	3.79	-3.18	46.24	0.330	9716	9364	2
Biscay	BT	MERLMER	A0	1999	67673000	17200	4357	4.64	-3.44	46.72	0.343	6038	5817	2
Biscay	BT	MERLMER	A0	2000	139999000	18533	1268	4.08	-4.13	47.44	0.401	2310	2991	1
Biscay	BT	MERLMER	A0	2001	149514000	23633	6716	4.98	-3.20	46.15	0.383	7662	8036	2
Biscay	BT	MERLMER	A0	2002	227789000	21722	2083	3.04	-3.72	46.90	0.214	6728	6415	1
Biscay	BT	MERLMER	A0	2003	47216000	15078	3682	4.26	-3.61	46.98	0.365	5082	5298	2
Biscay	BT	MERLMER	A0	2004	379237000	26911	3415	3.27	-3.84	46.95	0.317	4842	7380	2
Biscay	BT	MERLMER	A1	1987	15419000	19844	4481	2.71	-3.34	46.73	0.400	8649	8937	3
Biscay	BT	MERLMER	A1	1988	21342000	20156	4067	2.56	-3.19	46.86	0.484	5212	6475	2
Biscay	BT	MERLMER	A1	1989	14326000	20889	6192	3.77	-3.02	46.16	0.333	11178	10930	2
Biscay	BT	MERLMER	A1	1990	16436000	21133	4729	2.69	-3.52	46.73	0.345	10842	10383	2
Biscay	BT	MERLMER	A1	1992	12920000	18178	5861	4.76	-3.37	46.48	0.348	7645	7662	2
Biscay	BT	MERLMER	A1	1994	7408000	16022	5629	2.85	-3.32	46.78	0.612	5647	7013	2
Biscay	BT	MERLMER	A1	1995	24734000	21222	7198	4.23	-3.73	46.99	0.460	4448	7217	2
Biscay	BT	MERLMER	A1	1997	18102000	20333	4528	3.06	-3.80	46.97	0.401	4994	6577	3
Biscay	BT	MERLMER	A1	1998	3407000	13700	3543	2.78	-2.96	46.59	0.351	7451	7153	1
Biscay	BT	MERLMER	A1	1999	28121000	18144	5462	4.36	-3.29	46.63	0.288	7217	7222	2
Biscay	BT	MERLMER	A1	2000	6555000	15644	3347	4.55	-3.59	47.07	0.326	5490	6041	2
Biscay	BT	MERLMER	A1	2001	23843000	20956	5834	4.61	-3.21	46.47	0.371	7694	7597	3
Biscay	BT	MERLMER	A1	2002	14760000	18422	3883	4.21	-3.56	47.19	0.595	2125	4690	2
Biscay	BT	MERLMER	A1	2003	16970000	18256	2420	2.92	-3.51	47.02	0.317	5514	5878	1
Biscay	BT	MERLMER	A1	2004	32961000	23133	3117	2.43	-3.48	47.02	0.335	6187	6682	2
Biscay	BT	MERLMER	A2	1987	6826000	18878	4941	2.59	-2.90	46.68	0.426	7399	8379	2
Biscay	BT	MERLMER	A2	1988	9528000	22644	7127	2.93	-3.55	46.74	0.470	9471	10248	2
Biscay	BT	MERLMER	A2	1989	11490000	25689	7264	3.15	-2.84	46.10	0.437	11040	12640	3
Biscay	BT	MERLMER	A2	1990	11541000	24711	7136	2.86	-3.25	46.46	0.410	11796	12498	3
Biscay	BT	MERLMER	A2	1992	4558000	20311	9220	4.33	-3.02	46.17	0.437	8781	10150	2
Biscay	BT	MERLMER	A2	1994	13089000	24689	8278	2.64	-3.48	46.71	0.396	11298	11555	5
Biscay	BT	MERLMER	A2	1995	11349000	23711	8299	3.23	-3.28	46.47	0.381	10605	10520	2
Biscay	BT	MERLMER	A2	1997	11768000	24044	4213	2.56	-3.76	46.88	0.311	10492	10713	2
Biscay	BT	MERLMER	A2	1998	1939000	14544	8888	3.09	-3.60	46.48	0.377	7282	7984	2
Biscay	BT	MERLMER	A2	1999	9102000	21867	7579	3.36	-3.29	46.34	0.359	11287	10771	3
Biscay	BT	MERLMER	A2	2000	4431000	16656	3793	2.75	-3.56	46.73	0.455	3552	6668	2
Biscay	BT	MERLMER	A2	2001	4490000	17444	4744	3.53	-4.03	46.97	0.416	5292	6722	2
Biscay	BT	MERLMER	A2	2002	7618000	20978	4969	3.00	-3.09	46.20	0.561	5564	9521	2
Biscay	BT	MERLMER	A2	2003	4937000	22867	8737	2.65	-4.17	46.96	0.270	11506	11187	3

hakeBB	Area	Species	Age	Year	Abundance	Positive Area	Inertia	Anisotropy	xcg	ycg	Microstructure Index	EquivalentArea	SpreadingArea	Number of Patches
Biscay	BT	MERLMER	A2	2004	6053000	20867	5954	2.48	-3.41	46.58	0.344	7771	9035	2
Biscay	BT	MERLMER	A3	1987	4376000	15367	4415	2.22	-2.48	46.37	0.444	6616	7719	3
Biscay	BT	MERLMER	A3	1988	12579000	27089	7704	2.59	-3.29	46.67	0.467	10267	11751	2
Biscay	BT	MERLMER	A3	1989	7131000	21911	7158	2.69	-2.65	46.20	0.463	9686	10485	2
Biscay	BT	MERLMER	A3	1990	7238000	24678	8604	2.40	-3.00	46.06	0.467	10826	11930	2
Biscay	BT	MERLMER	A3	1992	2350000	16100	7892	2.77	-2.85	46.03	0.517	8918	9423	3
Biscay	BT	MERLMER	A3	1994	6966000	28811	8155	2.47	-3.78	46.85	0.320	12114	14181	3
Biscay	BT	MERLMER	A3	1995	7961000	23778	8685	2.58	-2.71	46.09	0.487	8924	10739	2
Biscay	BT	MERLMER	A3	1997	4252000	22867	10618	2.74	-3.80	46.75	0.508	6744	11379	4
Biscay	BT	MERLMER	A3	1998	1778000	18778	11061	3.13	-4.27	46.75	0.350	12877	12759	3
Biscay	BT	MERLMER	A3	1999	2673000	19811	10384	3.73	-4.17	46.61	0.434	8497	10874	3
Biscay	BT	MERLMER	A3	2000	3661000	17267	4686	2.34	-3.59	46.60	0.503	5419	7515	2
Biscay	BT	MERLMER	A3	2001	4846000	20233	8832	2.63	-3.64	46.39	0.419	10868	10580	4
Biscay	BT	MERLMER	A3	2002	8772000	24878	11718	2.86	-3.65	46.44	0.462	10853	12265	3
Biscay	BT	MERLMER	A3	2003	2511000	16378	12065	3.14	-3.51	46.12	0.450	10039	9774	3
Biscay	BT	MERLMER	A3	2004	2791000	21089	8679	2.80	-3.96	46.69	0.490	9970	10699	3
Biscay	BT	MERLMER	A4	1987	1163000	12756	6836	2.56	-3.24	46.35	0.505	8541	8681	2
Biscay	BT	MERLMER	A4	1988	3469000	19922	11508	2.97	-3.77	46.75	0.590	6923	10319	3
Biscay	BT	MERLMER	A4	1989	1539000	13467	6193	2.41	-2.86	46.38	0.514	8137	8406	2
Biscay	BT	MERLMER	A4	1990	1679000	14667	14679	2.99	-4.01	46.47	0.534	8736	9139	3
Biscay	BT	MERLMER	A4	1992	611000	7378	9240	2.97	-3.19	45.97	0.796	2856	4787	3
Biscay	BT	MERLMER	A4	1994	3510000	20333	9479	2.47	-3.32	46.45	0.407	10226	10707	2
Biscay	BT	MERLMER	A4	1995	2724000	16778	13271	2.67	-3.28	46.47	0.555	7368	8455	3
Biscay	BT	MERLMER	A4	1997	802000	11633	9707	3.00	-3.20	46.27	0.447	8730	8981	3
Biscay	BT	MERLMER	A4	1998	739000	9822	16856	3.62	-4.99	47.07	0.483	7750	7432	3
Biscay	BT	MERLMER	A4	1999	717000	7900	15633	4.94	-4.91	46.80	0.674	4280	5047	3
Biscay	BT	MERLMER	A4	2000	1306000	11600	6391	2.19	-3.55	46.69	0.524	4150	6134	2
Biscay	BT	MERLMER	A4	2001	1503000	12533	18841	3.35	-5.05	46.89	0.806	3301	5975	4
Biscay	BT	MERLMER	A4	2002	2474000	12156	17153	4.53	-6.58	47.53	0.490	2572	3892	2
Biscay	BT	MERLMER	A4	2003	721000	9811	13511	3.35	-3.63	45.84	0.686	4013	4874	2
Biscay	BT	MERLMER	A4	2004	463000	8178	19928	3.84	-5.56	46.89	0.604	4206	4374	3
Biscay	BT	MERLMER	A5P	1987	1292000	13911	10437	3.85	-3.62	46.61	0.490	8814	9079	3
Biscay	BT	MERLMER	A5P	1988	1371000	13467	12449	3.22	-3.27	46.15	0.503	8657	8732	4
Biscay	BT	MERLMER	A5P	1989	1186000	11256	14532	3.69	-4.10	46.62	0.502	7167	7148	3
Biscay	BT	MERLMER	A5P	1990	1843000	13278	14932	3.74	-4.72	46.90	0.504	6043	7045	3
Biscay	BT	MERLMER	A5P	1992	81000	1611	6236	6.38	-3.32	46.19	0.661	1611	1611	2
Biscay	BT	MERLMER	A5P	1994	1139000	8789	18827	4.12	-7.02	47.63	0.711	1930	4121	3
Biscay	BT	MERLMER	A5P	1995	3538000	8511	7758	6.28	-7.64	47.93	0.844	403	1441	2
Biscay	BT	MERLMER	A5P	1997	424000	5933	6353	3.32	-3.59	46.52	0.461	4889	4715	1
Biscay	BT	MERLMER	A5P	1998	258000	3244	19773	6.81	-4.34	46.16	0.644	2777	2564	3
Biscay	BT	MERLMER	A5P	1999	331000	2944	10036	5.04	-7.16	47.68	0.778	1528	1683	2
Biscay	BT	MERLMER	A5P	2000	250000	3333	4143	4.22	-3.65	46.49	0.531	2764	2591	2
Biscay	BT	MERLMER	A5P	2001	639000	9367	19418	5.87	-6.72	47.49	0.910	681	3895	3
Biscay	BT	MERLMER	A5P	2002	1763000	6667	9958	4.85	-7.57	47.92	0.484	1964	2457	2
Biscay	BT	MERLMER	A5P	2003	481000	5756	19131	3.70	-5.12	46.89	0.676	3435	3788	3
Biscay	BT	MERLMER	A5P	2004	772000	7689	18676	4.39	-6.71	47.48	0.610	2890	4148	3

Table 2. Table of non-spatial indices (hakBB_tab2_wp2a).

Species	Year	Survey.index	Recruit.index	Lbar	L25	L75	L50.maturity	Z	StdLbar	StdL25	StdL75	SdL50.maturity	StdZ
MERLMER	1987	97066000	67990000	16.4	9.6	17.7	NA	0.10	7.45E-07	6.33E-08	1.05E-07	NA	NA
MERLMER	1988	177954000	129665000	17.2	10.3	16.7	NA	1.91	4.17E-07	1.34E-07	1.83E-08	NA	NA
MERLMER	1989	133304000	97632000	15.5	7.8	18.1	NA	1.20	6.42E-07	3.58E-06	1.18E-06	NA	NA
MERLMER	1990	248094000	209357000	13.9	8.5	12.5	NA	NA	2.30E-07	1.58E-06	4.08E-09	NA	NA
MERLMER	1992	71329000	50809000	15.0	8.0	17.0	NA	NA	9.70E-07	1.77E-06	7.52E-07	NA	NA
MERLMER	1994	294382000	262270000	12.1	7.1	10.8	NA	0.56	1.70E-07	1.62E-07	2.50E-09	NA	NA
MERLMER	1995	147205000	96899000	17.5	9.1	19.1	NA	NA	8.40E-07	2.52E-08	2.83E-07	NA	NA
MERLMER	1997	160635000	125287000	15.3	10.0	14.4	NA	1.62	3.04E-07	2.36E-07	4.75E-09	NA	NA
MERLMER	1998	44614000	36493000	15.9	10.1	14.8	NA	0.78	1.44E-06	5.05E-07	2.95E-08	NA	NA
MERLMER	1999	108617000	67673000	17.6	11.3	19.6	NA	0.81	4.87E-07	4.54E-07	8.71E-08	NA	NA
MERLMER	2000	156202000	139999000	14.3	9.4	13.2	NA	0.36	4.43E-07	5.83E-08	6.99E-09	NA	NA
MERLMER	2001	184835000	149514000	15.6	10.7	14.5	NA	1.19	2.82E-07	3.61E-07	9.49E-09	NA	NA
MERLMER	2002	263176000	227789000	13.9	8.5	12.8	NA	2.38	1.95E-07	5.67E-05	4.31E-09	NA	NA
MERLMER	2003	72836000	47216000	18.8	11.2	21.2	NA	1.37	1.15E-06	4.59E-07	1.91E-07	NA	NA
MERLMER	2004	422277000	379237000	15.2	10.9	15.3	NA	1.76	4.95E-08	2.55E-07	3.40E-09	NA	NA

Combined indices

The multiple factor analysis (MFA)

The multivariate approach gives an overview of the relationship between the different spatial indices and allow to assess their persistence through time. The components of the hake population (age groups 0 to 5+) being characterized with the spatial indices are analysed together.

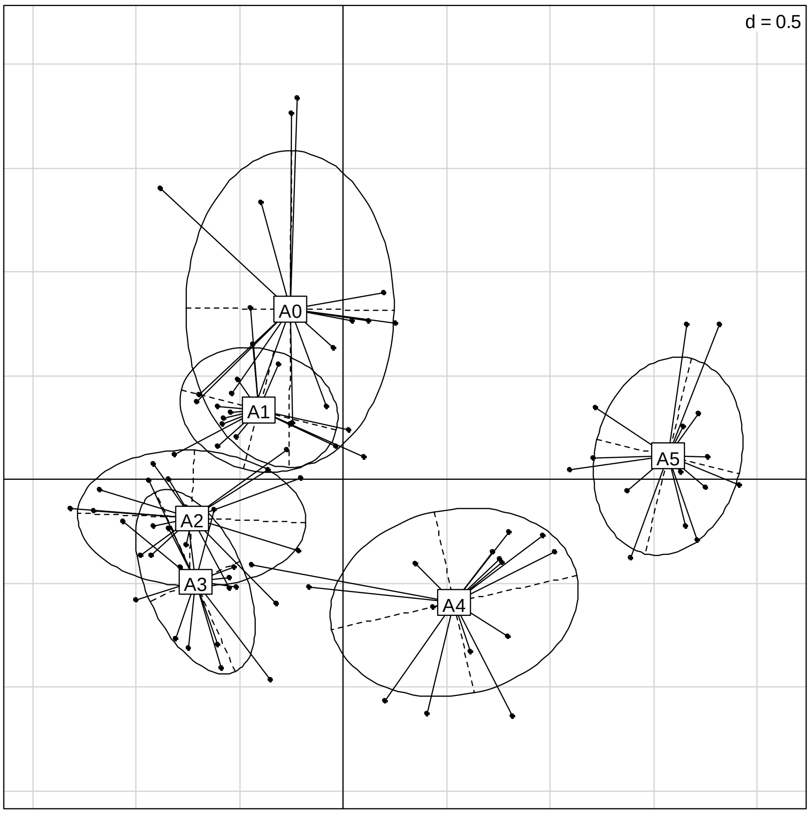


Figure 4. Graphical depiction of the projections of age groups on the principal Multiple Factor Analysis (MFA) plane. Labelled squares represent the centres of gravity of age groups observed during 15 surveys. Points indicate the position of the each age group for a given year.

The first two axes of the MFA account for 77% (Fig. 4) of the total variance of the data. The high value (12.3) recorded for the first eigenvalue shows that the first MFA factor corresponds to an important direction of variance for each of the years. These two components provide a good representation of the main spatial distribution changes occurring during the hake life. The correlation between the indices and the axes are summarized in Table 3. It will be noticed that no index is enough correlated with axis 3 to appear in the Table 3. The main spatial features of the age groups are summarized figure 4.

Table 3. Multiple factor analysis (MFA) of 8 spatial indices describing six components (age groups 0 to 5+) of the hake population of the eastern continental shelf of the Bay of Biscay. along 15 surveyed years. Summary of correlations between variables and the first two MFA factors: number of correlated surveys (- correlation<-0.4, + correlation>0.4) among the 15 considered.

Spatial indices	PCA component	
	1	2
PositiveArea	0+|15-	1+|0-
Inertia	9+|0-	0+|9-
Anisotropy	8+|0-	10+|0-
xcg	0+|10-	2+|3-
ycg	8+|2-	5+|1-
MicrostructureIndex	11+|0-	1+|6-
EquivalentArea	0+|11-	0+|3-
SpreadingArea	0+|13-	0+|6-

From left to right on axis 1 (see Table 3), microstructure index (evenness of the spatial distribution), inertia (dispersion of the fish), anisotropy (spatial distribution not homogeneous in all directions) and latitude increase while the indices referring to occupied area (i.e. positive area, spreading area, equivalent area) and longitude decrease.
From top to bottom on axis 2, latitude and anisotropy decrease while inertia, microstructure index and spreading area increase. Anisotropy and latitude are positively correlated with both axes 1 and 2, while spreading area are negatively correlated with them; inertia and microstructure index are positively correlated to axis 1 and negatively to axis 2. The other three indices are more specifically correlated to one axis only.
Two groups can be identified from their scores on axis 1: the younger ages, 0 to 3, and on the other hand the oldest ages, 4 and 5+. With respect to the age groups 0 to 3, older ages have a more northwards and westwards distribution, they are more scattered over the study area with irregular density values , but they are present over a smaller area. The distributional area is maximal for age 3 which corresponds to maximal spreading area (axes 1 and 2), as well as minimal anisotropy (axes 1 and 2). It will be noticed that the year to year variability decreases from age 0 to 3 and increases again for ages 4 and 5+ (Fig. 4).

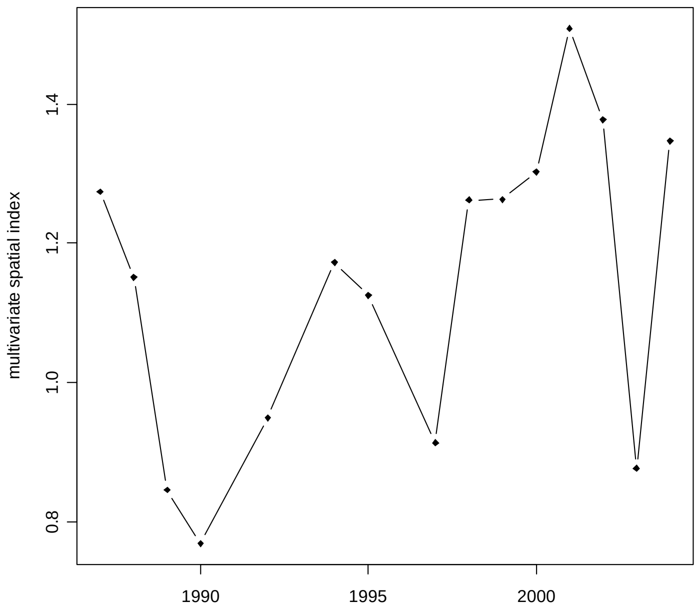


Figure 5. Multivariate distance (dmul) characterising the inter-annual variation around the average spatial pattern of the life cycle.

Except in 2003, dmul is on average higher and less variable in the years after 1997 than for reference years (1987-1990, 1992, 1994, 1995, 1997).

PCA of non spatial indices

Previous analysis have shown that total abundance index is strongly driven by the recruitment component of the population. Sum of the abundance of age groups 1 to 5 have been used instead of the total abundance in the PCA.

Table 4. Eigenvalues of PCA on non spatial indices

Component	Eigenvalue	Cumulated percentage
1	2.649	50
2	1.698	82
2	0.4845	91
4	0.4176	99

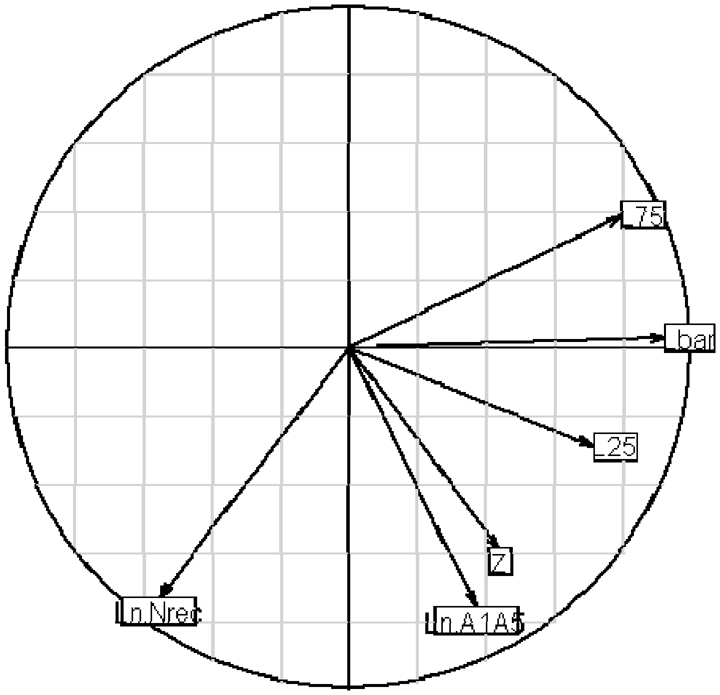


Figure 6. Projection of the variables on the first plane (82% of the data variability) of the principal component analysis.
All length indices are positively correlated with the first axis. Recruitment index is negatively correlated with the both axes while age groups 1 to 5 index and Z are negatively correlated with the axis 2.

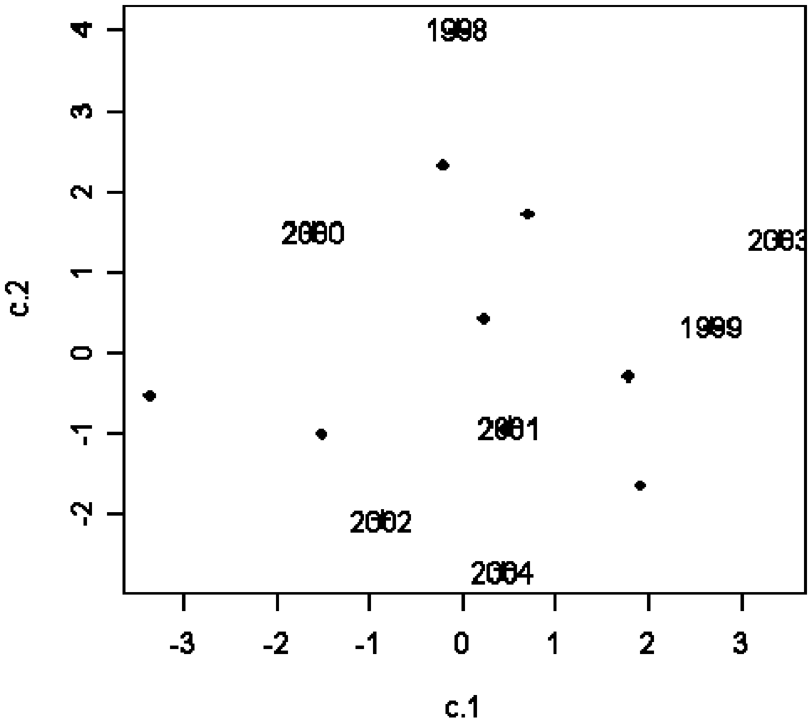


Figure 7. Projection of the years (rows) on the first PCA plane. Reference years are indicated by solid diamonds.

In figure 7, many recent years are outside the area delineated by the positions of the reference years. In most of the case the strength of the recruitment is negatively correlated with the length indices, except in 1998 and 2004. In 1998, both the recruitment and the abundance of age groups 1 to 5+ were low while in 2004 both the recruitment and the abundance of age groups 1 to 5+ were high.

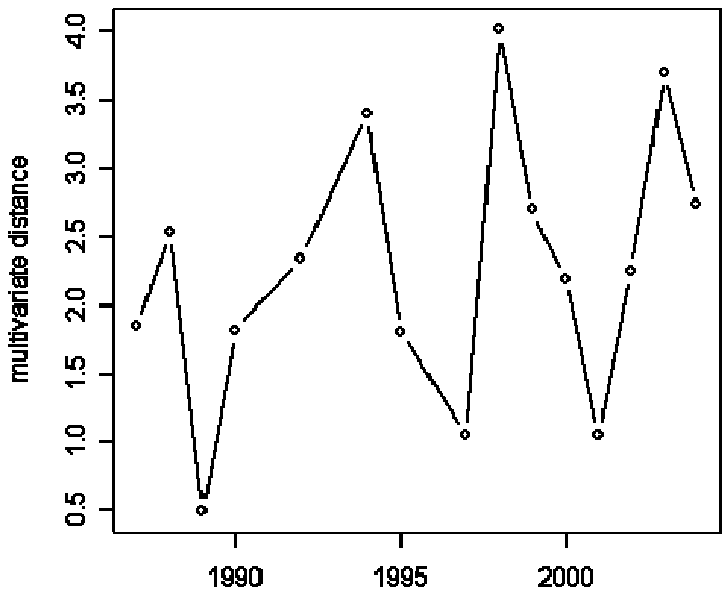


Figure 8. Multivariate distance derived from pca of non-spatial indices (mdpop).

The mdpop is strongly variable from one year to the next.

MAF (min/max autocorrelation factor)

Fifty four indices were considered in this case study, i.e. 48 spatial indices (number of patches being excluded) and 6 biological parameters (L50 maturity was not available). To reduce the number of variables to use in MAF analysis, the values of variograms at lag 1 were first computed and ranked (Fig. 9).

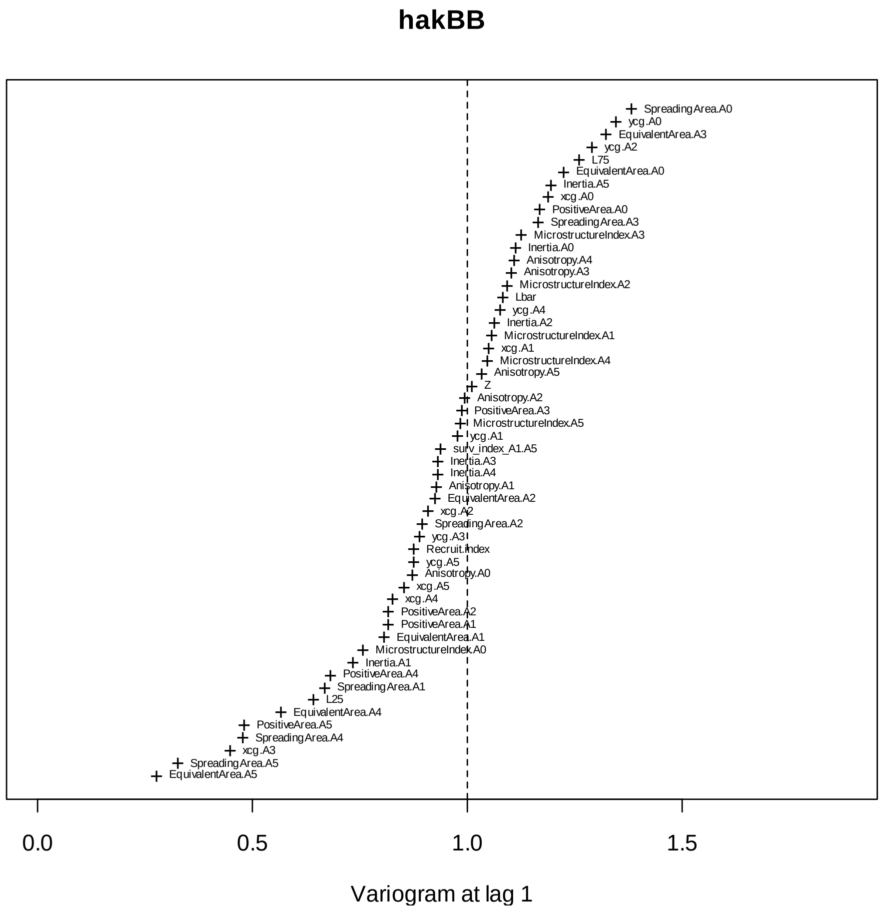


Figure 9. The 54 indices (48 spatial and 6 biological indices) ranked following the values of their variogram at lag 1.

The first 15 indices (Table 5) were used as input MAF analysis. The values of the variogram at lag 1 were respectively 0.0931 and 0.1156 for the first and the second MAF.

Table 5. MAF analysis, loadings of the 15 selected indices on MAF1 and MAF2.

Indices	MAF1	MAF2
L25	-0.1264	-0.0414
EquivalentArea.A1	0.1223	0.0468
EquivalentArea.A4	-0.0611	-0.3391
EquivalentArea.A5	0.4808	0.2347
Inertia.A1	0.3976	-0.3050
MicrostructureIndex.A0	0.0071	0.2505
PositiveArea.A1	-0.1476	0.0981
PositiveArea.A2	0.0579	0.0988
PositiveArea.A4	-0.0612	0.1333
PositiveArea.A5	-0.2821	0.3339
SpreadingArea.A1	-0.1007	-0.1349
SpreadingArea.A4	0.5183	-0.6887
SpreadingArea.A5	0.1289	0.4850
xcg.A3	0.3088	0.1732
xcg.A4	-0.1599	-0.1309

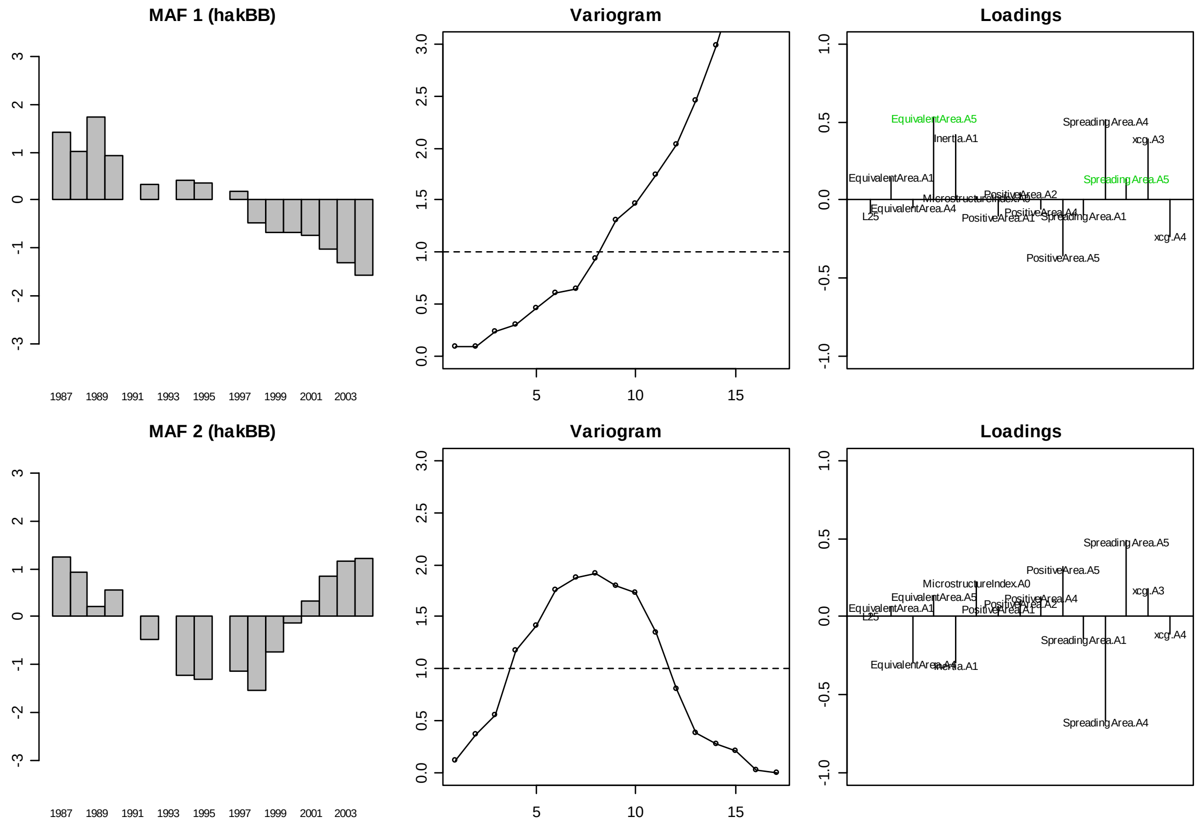


Figure 10. MAF 1 and 2, variogram and loadings.

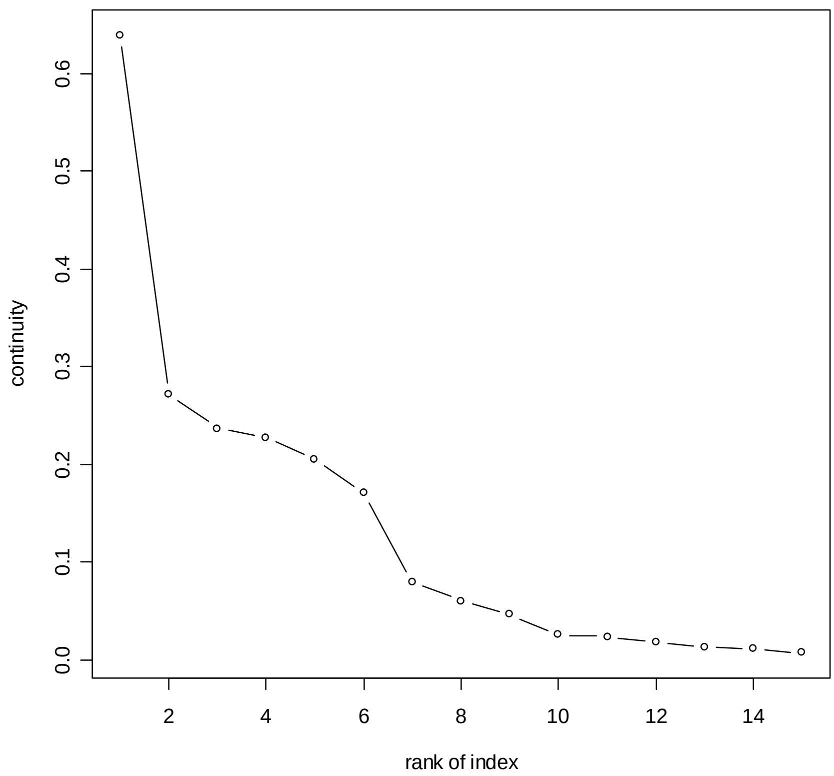


Figure 11. The spatial and biological indices are ranked according to their continuity on MAF 1 and 2.

Then we used the continuity of the indices on MAF 1 and 2 and selected the first 6 more continuous indices on MAF 1 and 2 as indicators of the main change occurring over the whole period. Indices presenting an high continuity (i.e. a low value at lag 1) are easier to follow in time.

Table 6. List of the 6 more continuous indices on MAF 1 and 2.

Index	Continuity
SpreadingArea.A4	0.64
EquivalentArea.A5	0.27
Inertia.A1	0.24
SpreadingArea.A5	0.23
PositiveArea.A5	0.20
xcg.A3	0.17

Looking for trends in indices

The non parametric method has been used to look for trends in all biological and spatial indices used (Table 7 and Fig. 10):
- long term linear trend over the whole period of observation;
- recent trends, both linear and non linear, over the last 7 years (i.e. years beyond the period of reference).

Table 7. Nonparametric method for determining recent trends in indicator time series. For diagnostic recent (7 last years) trends: 1=increase, –1=decrease and 0=no change.

Indicator	LinearSlope	PvalueAll	LinSlopeLastYears	PvalueLast	7 last years diagnostic	
					Linear	Non Linear
L25	0.11	0.06	0.35	0.41	0	**1**
Lbar	0.02	0.83	0.50	0.49	0	**1**
L75	-0.03	0.86	1.09	0.38	0	**1**
ln_recruit_index	0.02	0.56	0.08	0.78	0	0
ln_survey_index_a1a5	-0.01	0.59	0.16	0.21	0	0
Z	0.04	0.22	0.30	0.25	0	**1**
Anisotropy.A0	-0.01	0.75	-0.12	0.42	0	0
Anisotropy.A1	0.03	0.43	-0.15	0.44	0	0
Anisotropy.A2	-0.01	0.65	-0.11	0.15	0	**-1**
Anisotropy.A3	0.03	0.07	-0.06	0.53	0	0
Anisotropy.A4	0.08	**0.03**	-0.01	0.98	0	**1**
Anisotropy.A5	0.05	0.35	-0.33	0.09	0	**-1**
EquivalentArea.A0	3.40	0.97	-432.71	0.37	0	**-1**
EquivalentArea.A1	-219.04	**0.04**	-377.25	0.34	0	0
EquivalentArea.A2	-163.07	0.19	139.89	0.83	0	0
EquivalentArea.A3	33.86	0.74	-7.25	0.99	0	0
EquivalentArea.A4	-280.06	**0.01**	-455.14	0.15	0	0
EquivalentArea.A5	-337.58	**0.00**	119.75	0.55	0	0
Inertia.A0	-72.08	0.36	-317.71	0.45	0	**-1**
Inertia.A1	-101.26	0.10	-243.79	0.35	0	0
Inertia.A2	-61.37	0.49	-189.64	0.66	0	0
Inertia.A3	219.90	**0.03**	116.00	0.83	0	0
Inertia.A4	495.50	**0.01**	561.93	0.56	0	**1**
Inertia.A5	198.69	0.46	739.79	0.58	0	**1**
MicrostructureIndex.A0	-0.01	0.14	-0.01	0.62	0	**-1**
MicrostructureIndex.A1	0.00	0.67	0.01	0.65	0	0
MicrostructureIndex.A2	0.00	0.30	-0.01	0.76	0	0
MicrostructureIndex.A3	0.00	0.96	0.02	0.13	0	**1**
MicrostructureIndex.A4	0.01	0.43	0.01	0.62	0	**1**
MicrostructureIndex.A5	0.01	0.20	-0.01	0.69	0	**-1**
PositiveArea.A0	-77.87	0.60	759.89	0.36	0	**1**
PositiveArea.A1	-59.05	0.63	1117.89	0.04	**1**	**1**
PositiveArea.A2	-190.58	0.23	903.25	0.13	0	0
PositiveArea.A3	-128.10	0.53	274.21	0.65	0	**-1**
PositiveArea.A4	-351.11	0.06	-19.79	0.96	0	0
PositiveArea.A5	-424.21	**0.02**	796.18	0.09	0	0
SpreadingArea.A0	2.96	0.97	-127.36	0.78	0	**1**
SpreadingArea.A1	-193.72	**0.01**	-194.71	0.35	0	0
SpreadingArea.A2	-127.92	0.15	244.21	0.53	0	0
SpreadingArea.A3	12.39	0.89	-129.64	0.73	0	**-1**
SpreadingArea.A4	-286.57	**0.00**	-420.07	0.05	0	**-1**
SpreadingArea.A5	-300.03	**0.01**	315.29	0.06	0	0
xcg.A0	0.02	0.26	0.07	0.34	0	**1**
xcg.A1	0.01	0.30	0.07	0.11	0	0
xcg.A2	0.04	**0.03**	0.03	0.76	0	0
xcg.A3	0.07	**0.00**	-0.08	0.20	0	0
xcg.A4	0.12	**0.01**	0.08	0.73	0	**1**
xcg.A5	0.16	**0.04**	0.25	0.44	0	0
ycg.A0	0.01	0.44	0.08	0.42	0	0
ycg.A1	0.02	0.08	0.08	0.16	0	0
ycg.A2	0.01	0.36	0.04	0.57	0	0
ycg.A3	0.01	0.38	-0.05	0.28	0	0
ycg.A4	0.03	0.20	-0.06	0.60	0	0
ycg.A5	0.05	0.09	0.14	0.31	0	0

No significant linear trends were identified over the whole period or during the seven last years for the biological indices. A non linear increasing trend has been identified for the length and Z indices during the last 7 years (Table 7 and figure 10) while recruitment and abundance of age groups 1 to 5+ did not exhibit significant trend. These results are inconsistent and do not allow to give a diagnostic on what happened in recent years.
For spatial indices per age group, significant trends have been identified as follows:
- 7 increasing long-term linear trends regarding longitude, inertia and anisotropy (Table 7);
- 7 decreasing long-term linear trends regarding mostly area indices for old age groups;
- 1 increasing recent years linear trend (positive area age 1);
- 10 increasing recent years non linear trends which were scattered on several indices and age groups;
- 9 decreasing recent years non linear trends which were also scattered on several indices and age groups.

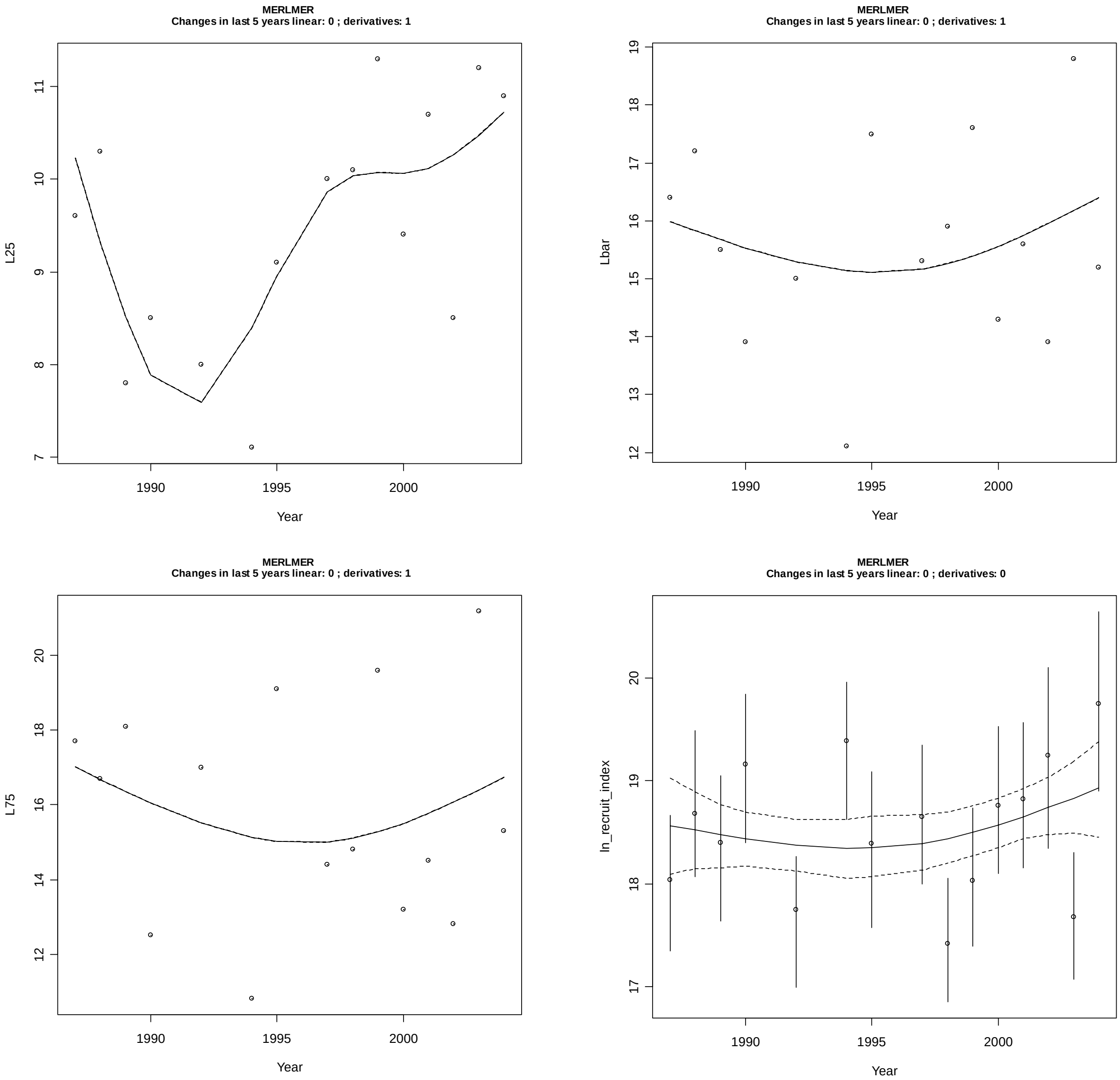


Figure 10. Biological and spatial indicator time series of hake in the Bay of Biscay with cubic spine model. Assessment of recent direction of changes in figure headers using method and linear trend estimation for the final seven years.

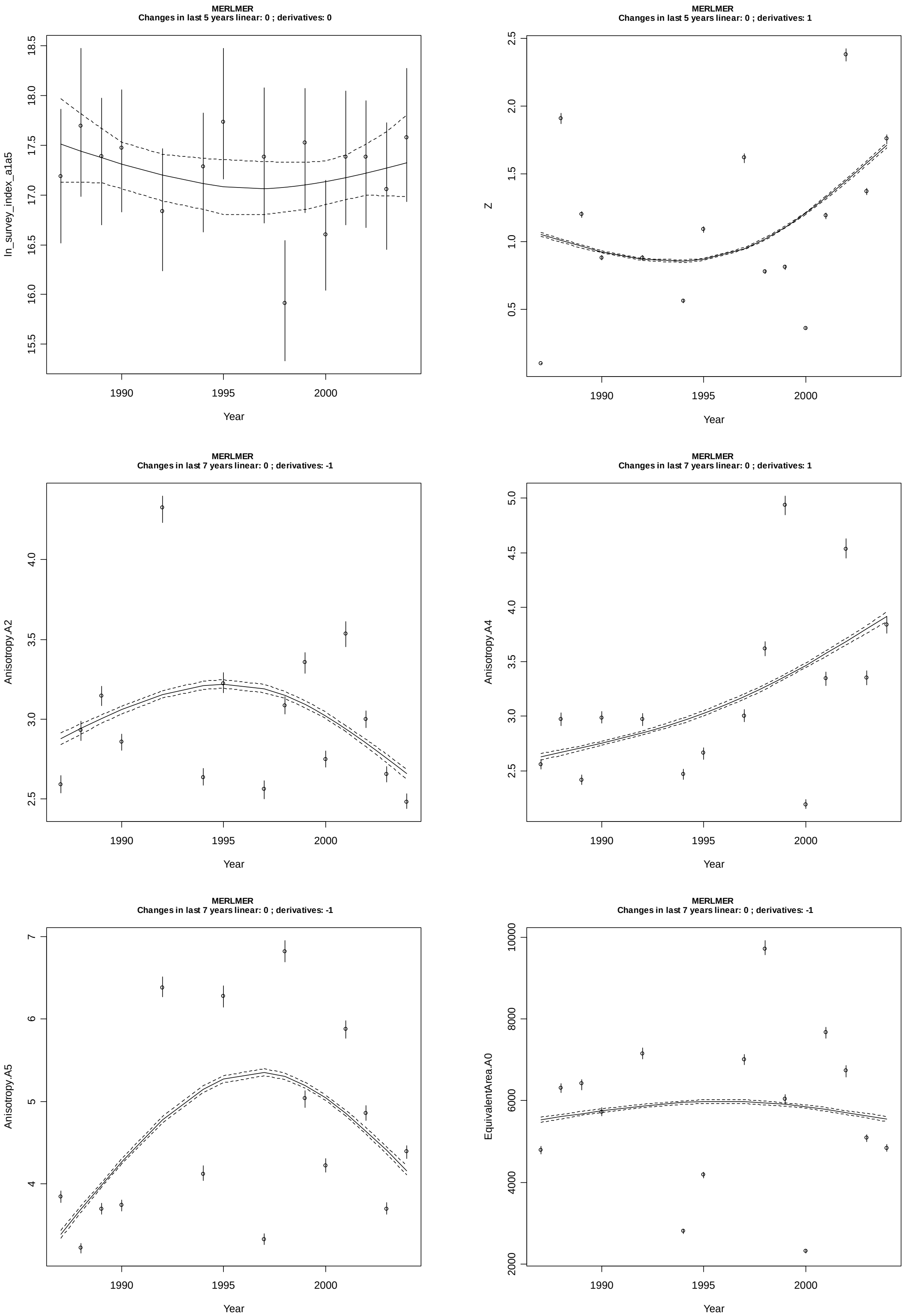


Figure 10 (continued)

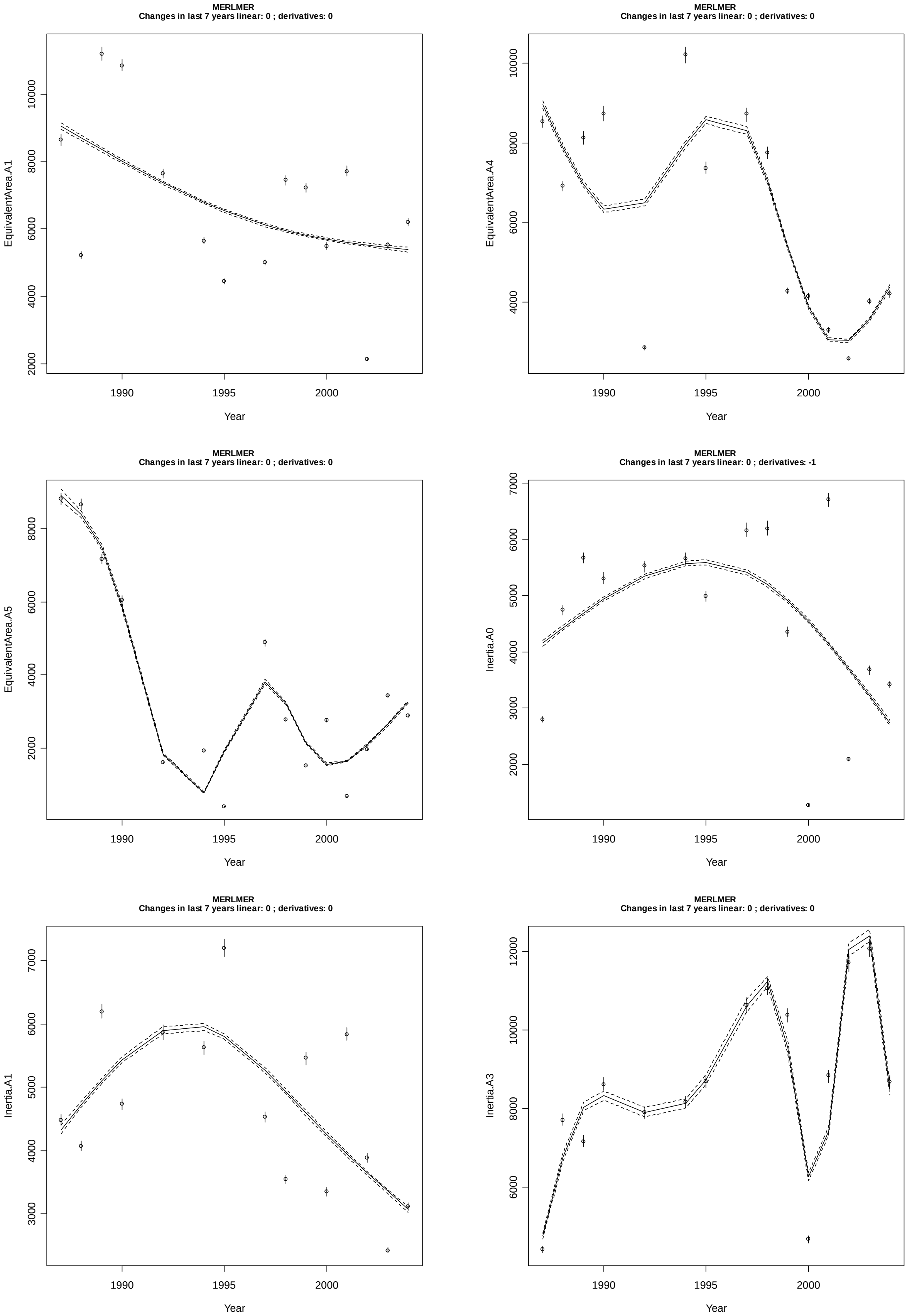


Figure 10 (continued)

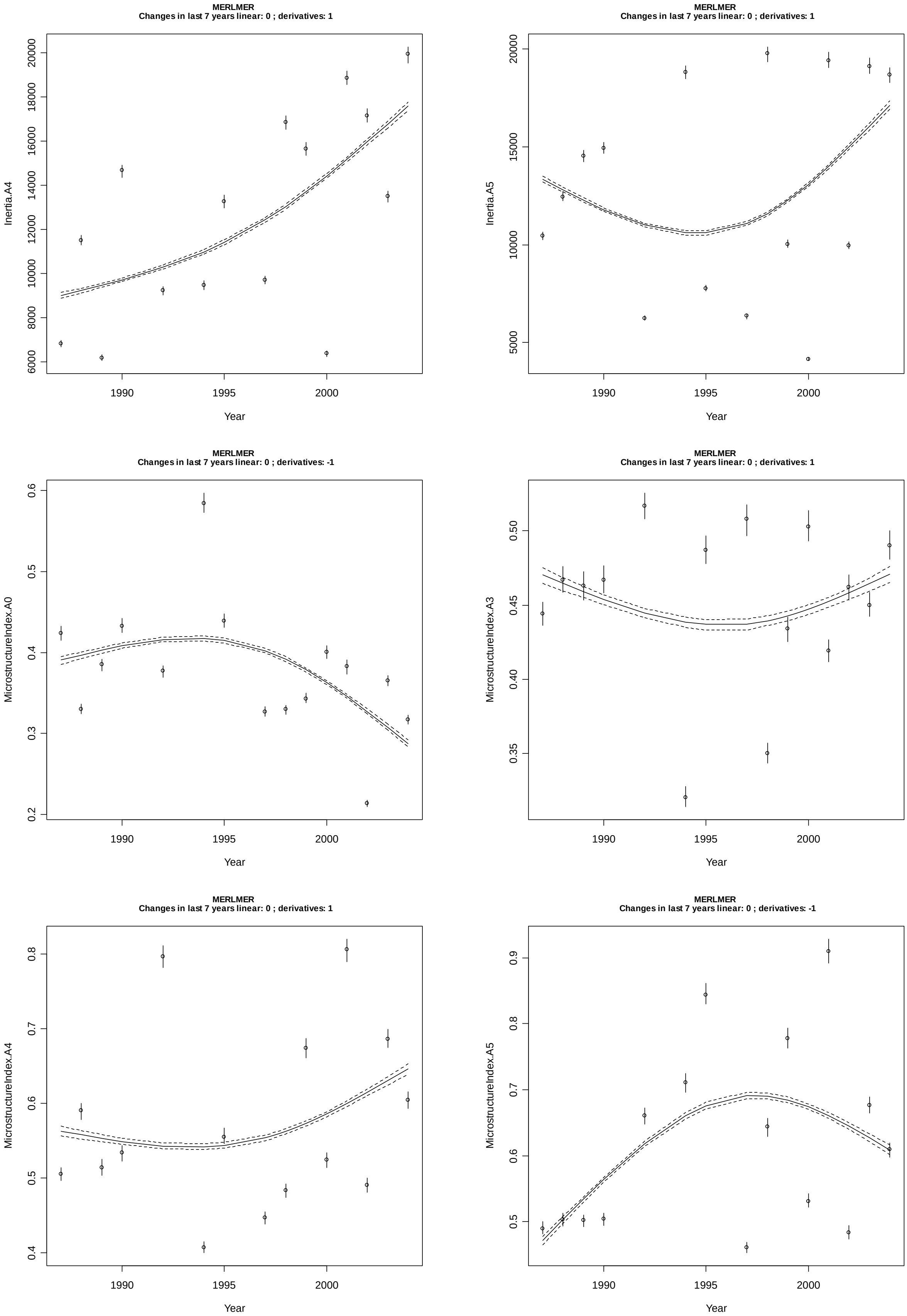


Figure 10 (continued)

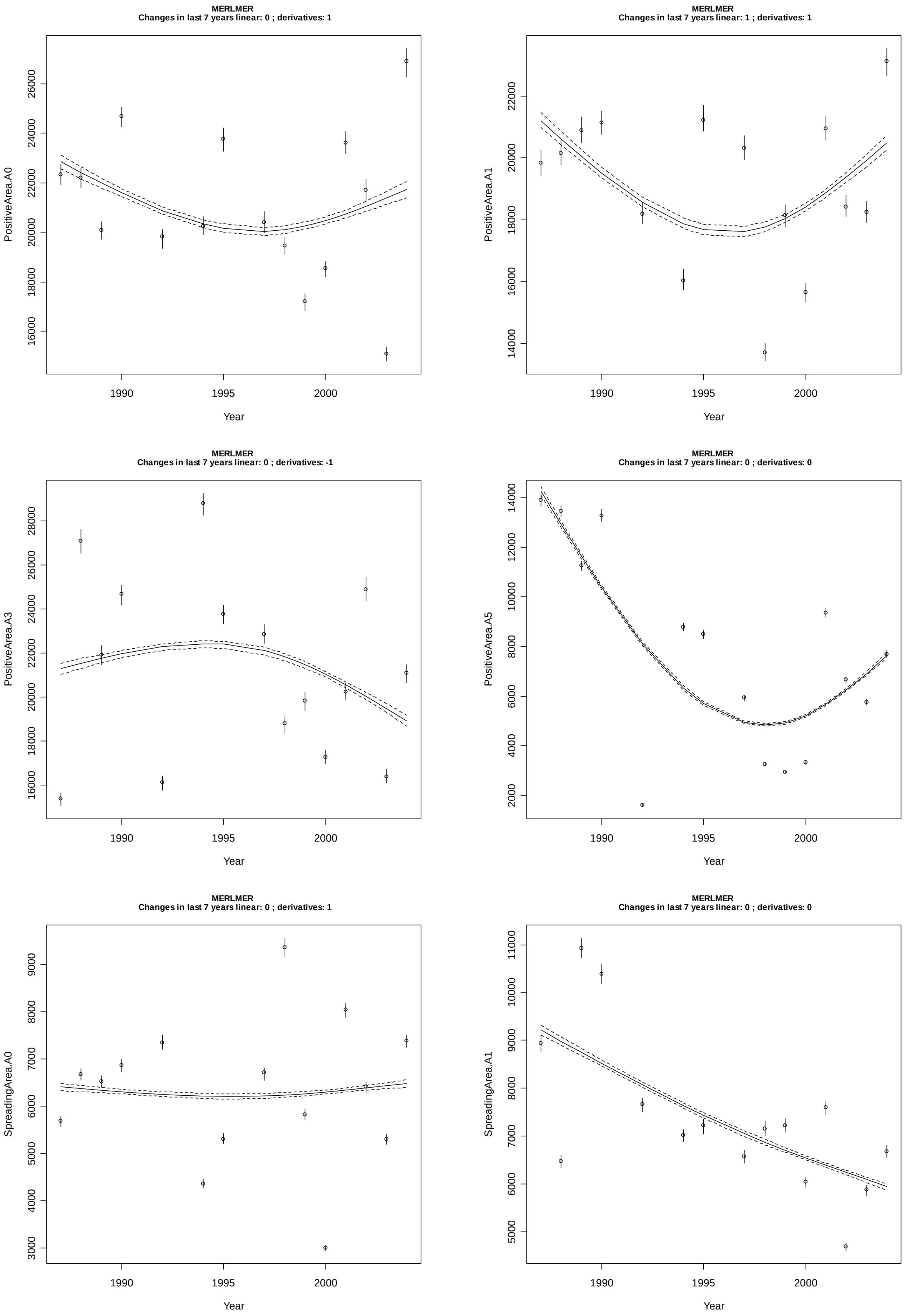


Figure 10 (continued)

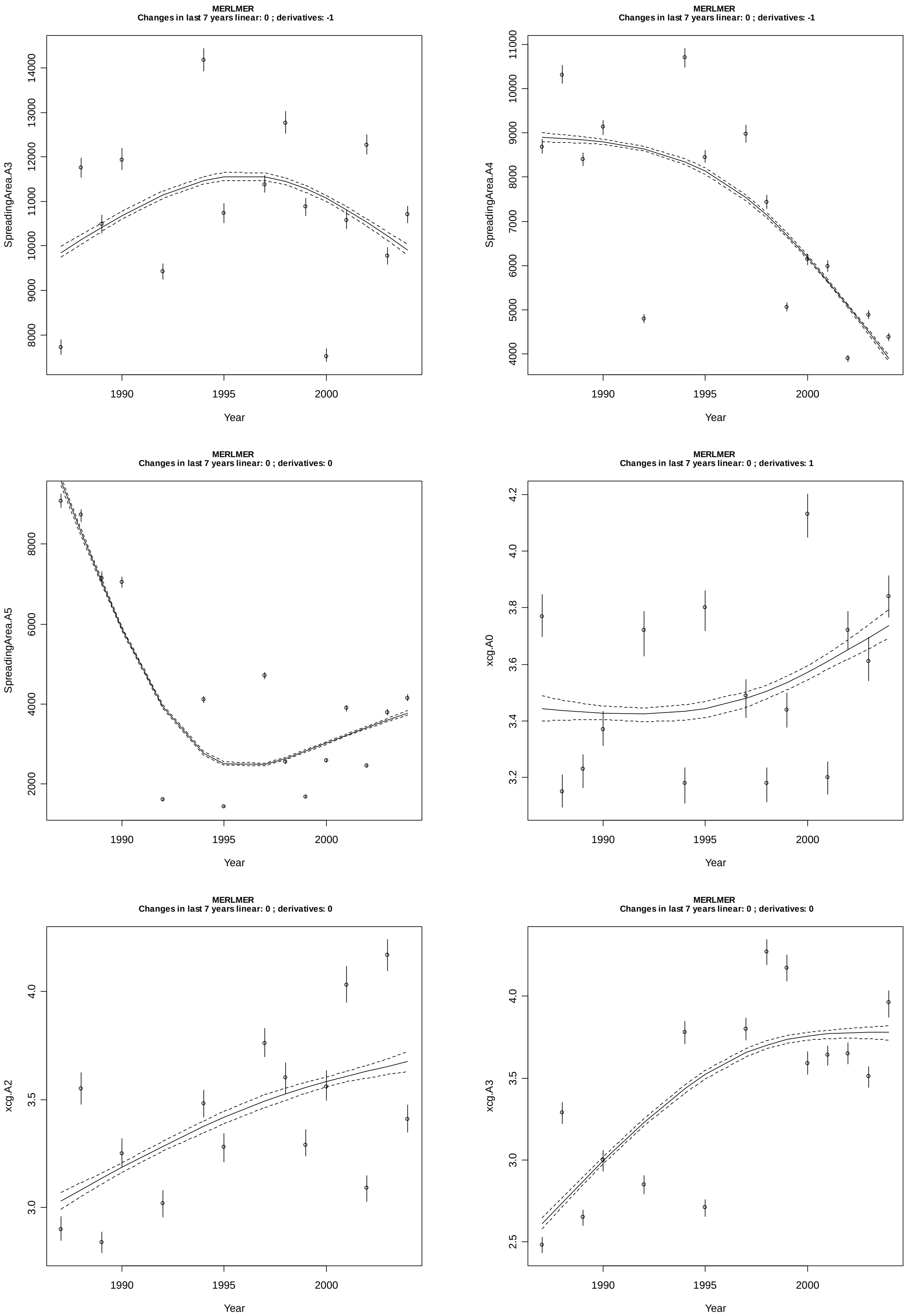


Figure 10 (continued)

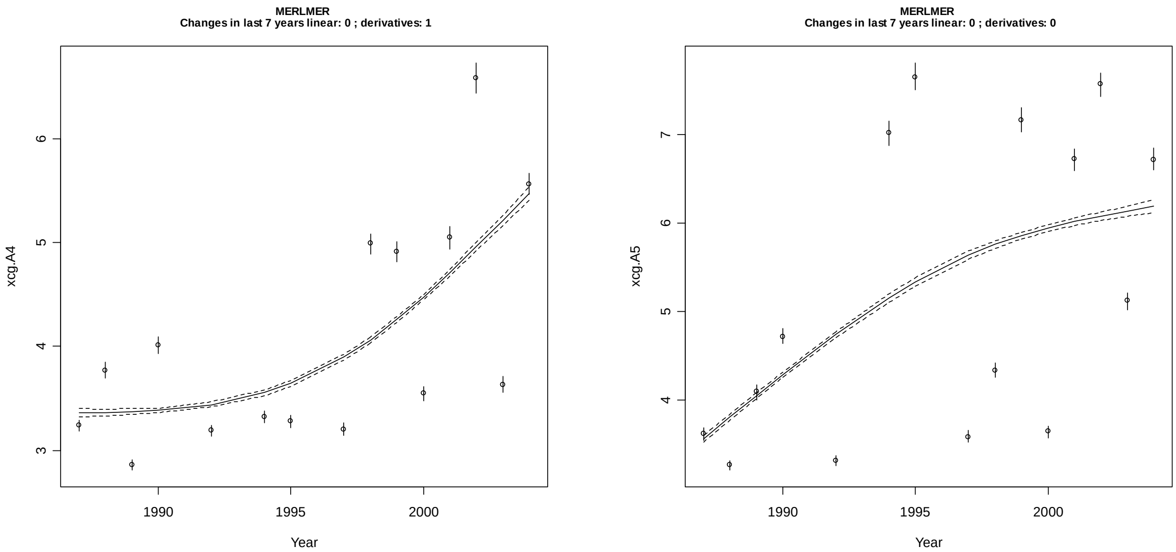
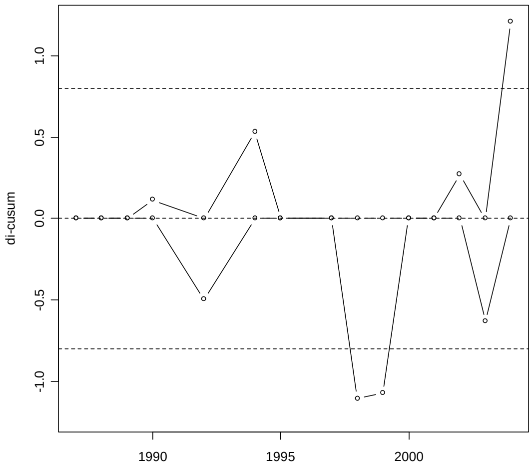


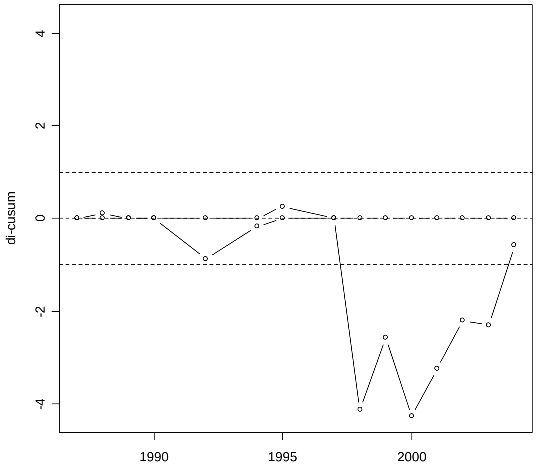
Figure 10 (continued)

Di-cusum plots

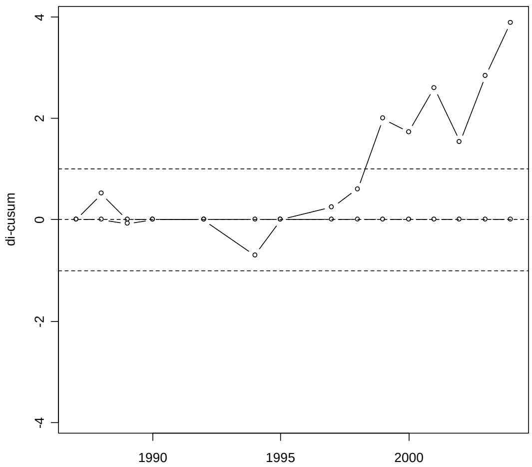
Recruit index



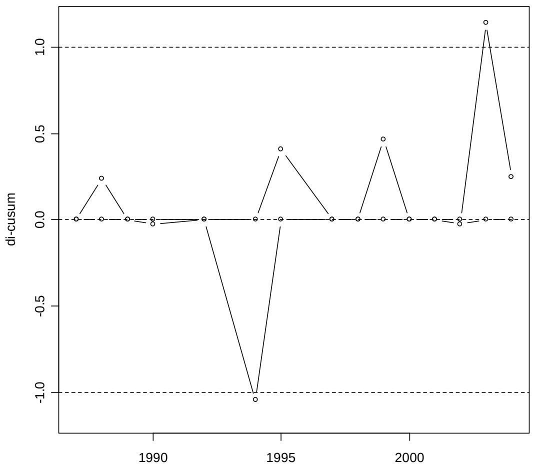
Abundance age groups 1 to 5+



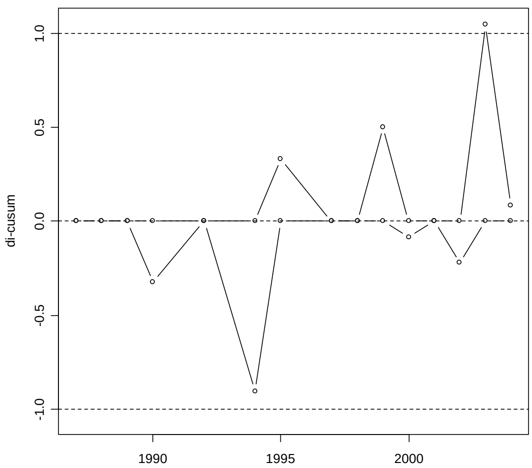
L25



Lbar



L75



Z

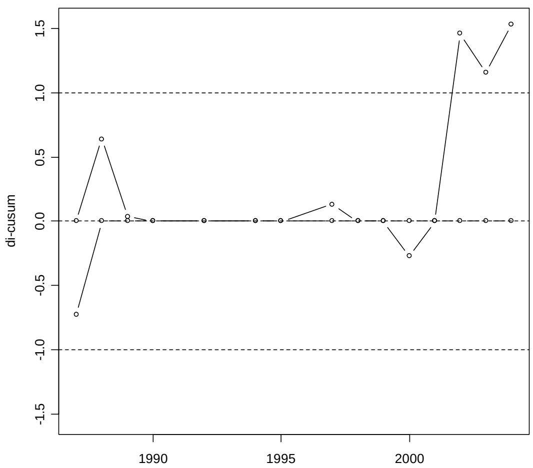
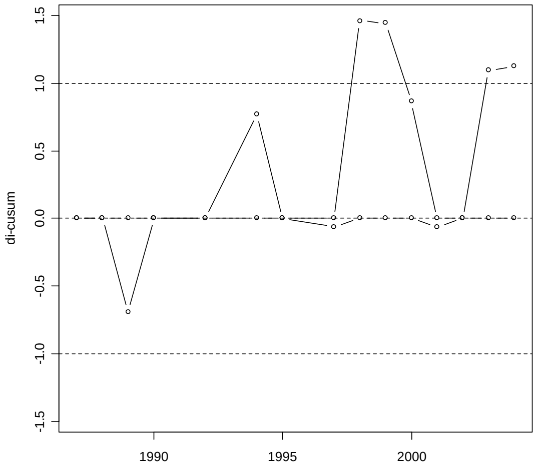


Figure 11. Di-cusum plots for the six biological indices.

mdpopA1A5



dmul

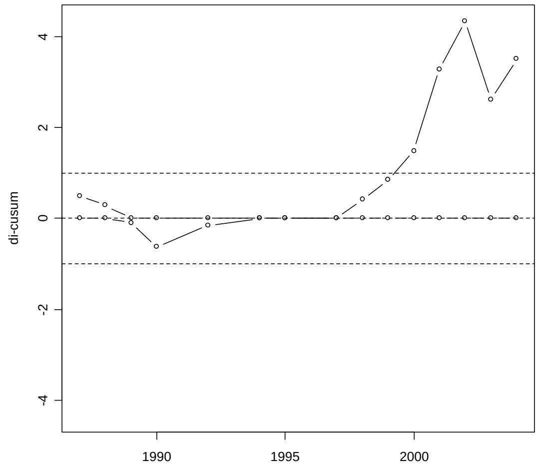
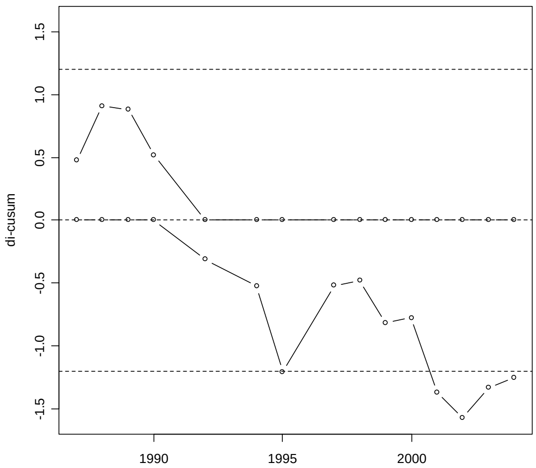
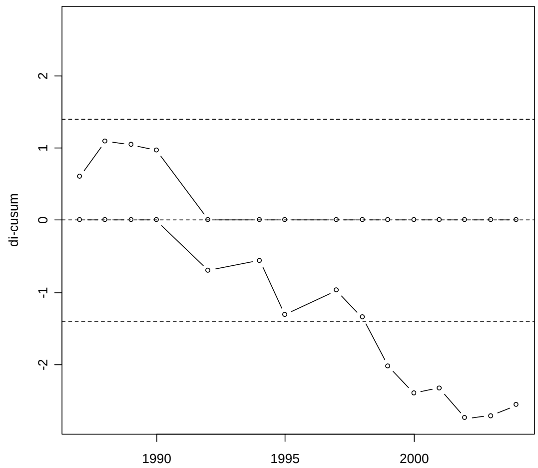


Figure 12. Di-cusum plots for the two combined indices.

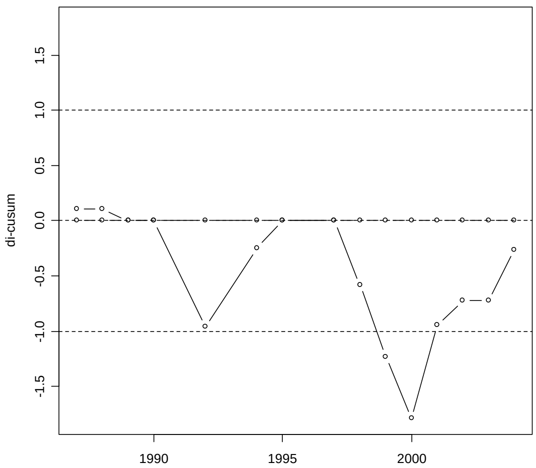
Equivalent Area A5



Spreading Area A5



Positive Area A5



Equivalent Area A4

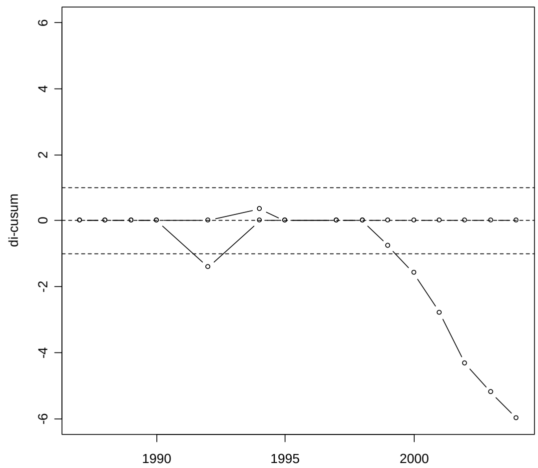
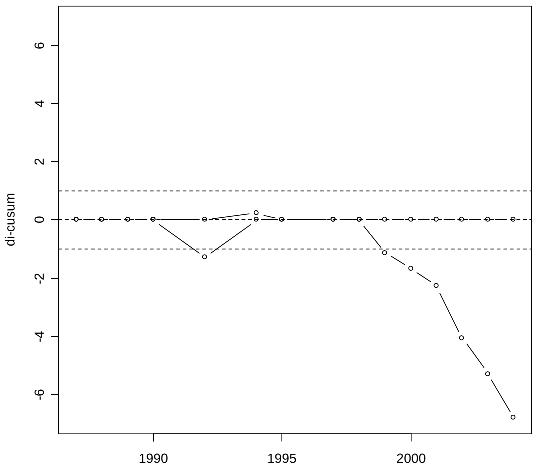
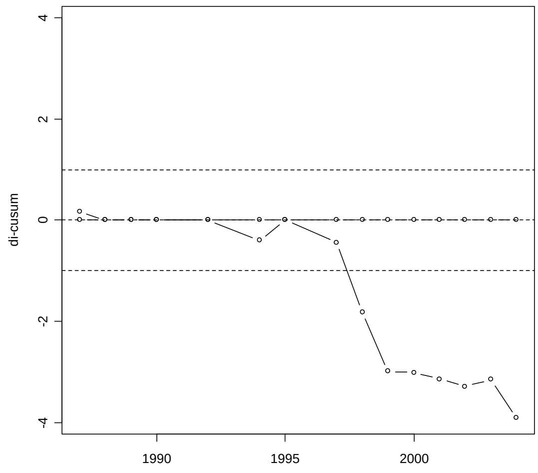


Figure 13. Di-cusum plots for 10 selected spatial indices.

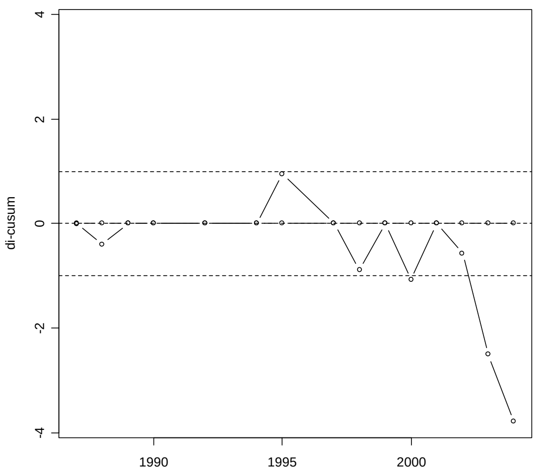
Spreading AreaA4



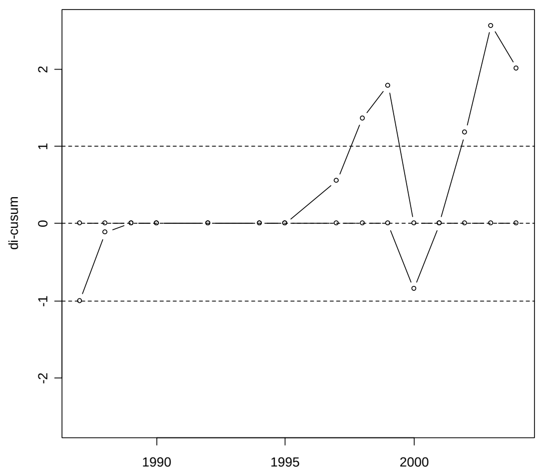
xcg A3



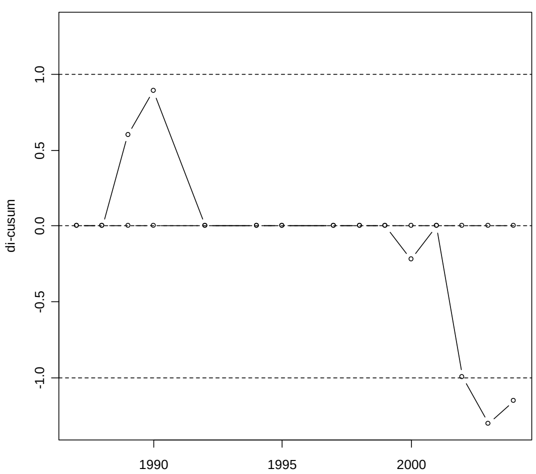
Inertia A1



Inertia A3



Spreading Area A1



Spreading Area A2

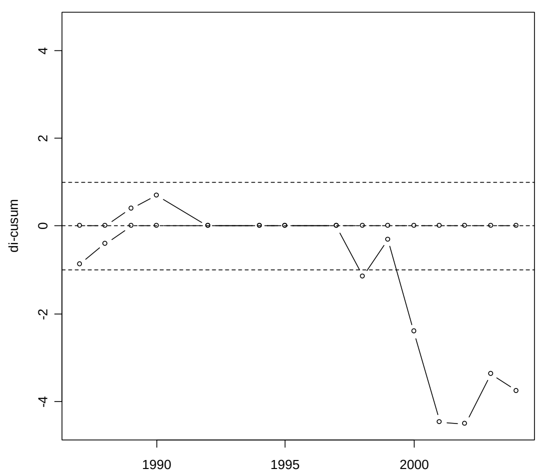


Figure 13 (continued)

Interpretation

Trends analysis

For biological indices, no trends have been identified for the whole period. During the 7 recent years positive trend have been identified for Z and all length indices (L25, Lbar and L75). The observed increase of Z in recent years is inconsistent with the increase of length indices (Table 7 and Fig. 10).
For spatial indices, it seems that a westwards shift of the center of gravity and some decreases in area indices occurred mainly for the oldest age.
It will be noticed that the interannual variability of the indices is generally high. A good improvement of the diagnostic would be achieved by computing their associated standard error values.

Cusum analysis

	Variable	Direction of change	Years
Length indices	L25	+	1999 - 2004
	Lbar	+	2003
	L75	+	2003
Abundance	Recruitment	-	1998-1999
		+	2004
	Sum A1-A5	-	1998-2003
Mortality	Z	+	2002-2004
Combined index	MdpopA1A5	+	1998-1999; 2003-2004
	Dmul	+	2000-2004

The changes observed in dmul may be explained by the changes occurring in spatial indices (Fig. 13) of old age groups/adults (age groups 3, 4, 5+). Di-cusum have been plotted for spatial indices selected using MAF (see Fisboat_Nantes_indic_diagno_tables_hake_bob.xls).

Compare approaches (cusum/trends)

No exhaustive comparison of the two methods have been done. However, it can be noticed that cusum method detect some changes in the abundance of the age group 1 to 5+ (Fig. 11, see Fisboat_Nantes_indic_diagno_tables_hake_bob.xls) while no trend has been identified. The same observation can be made for the spreading area of age group 2. Sometimes very similar diagnostic can be made by the two methods: see inertia of age 3 and spreading area of age 1.

Summary sheet

Survey series

Data were collected during 15 groundfish surveys carried out by IFREMER from October to December between 1987 and 2004 (EVHOE series with gaps in 1991, 1993 and 1996), on the eastern continental shelf of the Bay of Biscay (ICES, 1997; Poulard et al., 2003; Poulard and Blanchard, 2005). The study area was situated between 48º30'N and 43º30'N and depth ranged from 15 to 600 m. The sampling design was stratified according to latitude and depth. The number of hauls per survey varied from 70 to 139.
A 36/47 GOV (Grande Ouverture Verticale) trawl was used with a 20 mm mesh codend liner. Haul duration was 30 minutes at a towing speed of 4 knots. Fishing was mainly restricted to daylight hours. Catch weights and catch numbers were recorded for all species.
Hake sex and total length were recorded, and otoliths were extracted and examined in the laboratory to build age-length keys (ALKs) by sex. These keys were used to transform the length distribution frequencies observed at each trawl station into age distribution frequencies.
Hake densities were disaggregated by age groups (0 to 5+) and are expressed in numbers of fish caught per hour trawled (N/h). To calculate the index of abundance, it is assumed that the area swept in 30 min of trawling was 0.02 square nautical miles.

Non-spatial indices

Except L50.maturity, these indices (i.e. sum of the abundance for age groups 1 to 5, Recruitment index, Lbar, L75, L25 and Z by year) have been analysed using nonparametric method for determining recent trends in indicator time series, power method (results not show) and cusum method.
Power method has shown that generally the power of the detected trends are very low due to the strong variability in time of the different indices. Derivatives method has detected significant trends for all the length indices and Z during the five recent years. Some changes have been identified with regard to reference period by cusum method. Main features are: lower abundance for age groups 1 to 5 abundance, higher L25 values, exceptional low (1998 and 1999) or high (2004) values for recruitment, increase of Z in 2002-2004.

Spatial indices

Most of the selected indices by MAF correspond to the older age groups (3,4 an 5+). The power and the cusum methods have been used to analyze the 10 selected indices.
About power method the same remark as for non spatial indices can be made: the strong variability of the indices in the time generate low power.
Cusum method has shown that:
- for age groups 4 and 5+, equivalent and spreading areas decreased in recent years;
- for age group 3: a westward drift of the CG have been observed while at the same time inertia tended to increase;
- for age group 2: spreading area tended to decrease.

Composite indices

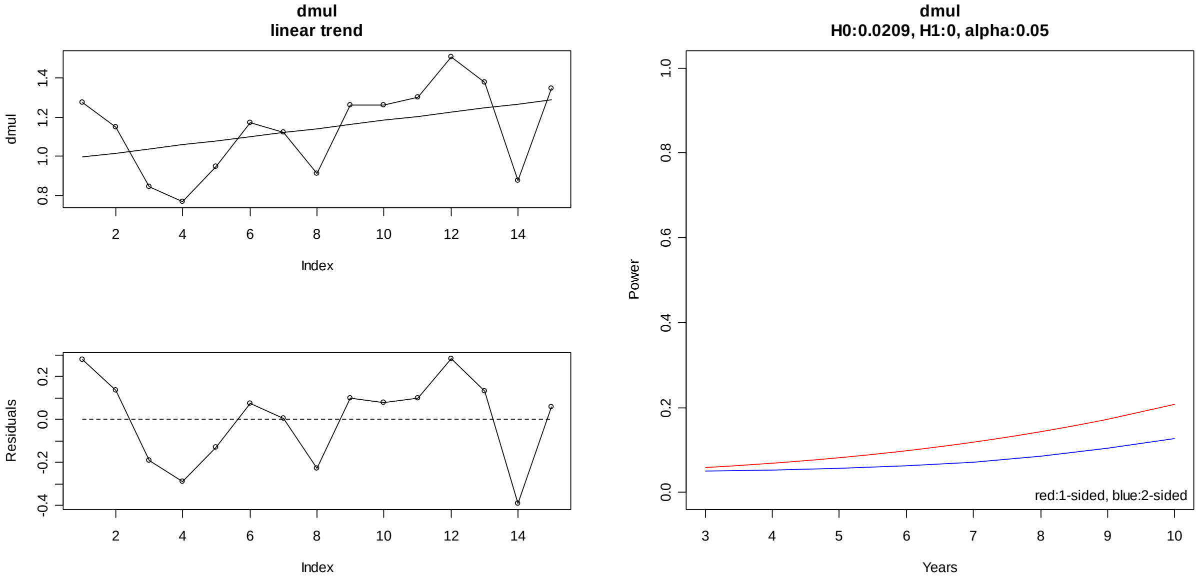


Figure 14. Dmul (distances provide by MFA on spatial indices) evolution over the observed period and power of the tests.

Dmul exhibits an increasing trend but the power method indicates that it has low confidence. Cusum method indicates that changes occurred from 2000 to 2004.It seems from the analysis of the single index (see selection of spatial indices using MAF) that must of the changes can be imputed to spatial indices of the oldest age groups (3 to 5+). Both cusum and PCA analysis indicate an increase of Z in the recent years (2002-2004).

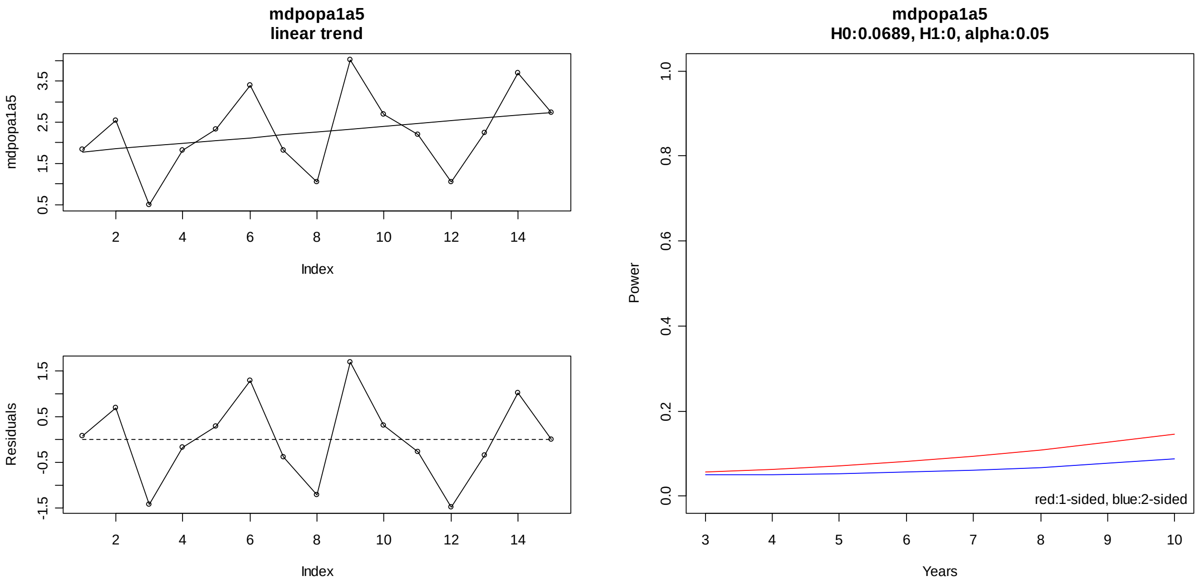


Figure 15. Mdpopa1a5 (distances provides by PCA on non spatial indices) evolution over the observed period and power of the tests.

The mdpopa1a5 is strongly variable from one year to the next. Cusum method indicates changes in 1998-1999 and 2003-2004. The recruitment was rather low in 1998, 1999 and 2003 but there was no special changes in length indices in 1998 while these indices increased in 1999 and 2003. In 1998, both the recruitment and the abundance of older age groups were low. In 2004, a high level of recruitment had no effect on the length indices.

Reference period

During seven of the height years of reference (1987 to 1997, with gaps in 1991, 1993 and 1996), the EVHOE surveys have been carried out using the old Thalassa. Given the interannual high variability of the indices, it seems difficult to use a shorter period of reference for the cusum method.

Summary of results on the stock

The results are not consistent for non spatial indices: we observed significant increases for Z and for length indices in the five recent years. Analysis of spatial indices has shown some change in recent years mostly in the characteristics of the spatial distribution of the older age groups while their abundance tended to decrease. There was no significant trend in the recruitment but low values have been observed in 1998 and 1999 and high ones in 2004.

Comparison with traditional assessment of stock status

Based on the most recent estimates of SSB and fishing mortality ICES classifies the stock as being at full reproductive capacity and being harvested sustainably.

Spawning biomass in relation to precautionary limits	Fishing mortality in relation to precautionary limits	Fishing mortality in relation to highest yield	Fishing mortality in relation to agreed target (=0.25)
Full reproductive capacity	Harvested sustainably	Overexploited	F is around agreed target

ICES assessment points to improvement of the recruitment and spawning stock biomass in recent years. There are some discrepancies between ICES assessment and EVHOE results in the timing and the range of variation of recruitment. It must be noticed that EVHOE surveys provide information on the hake population of the eastern continental shelf and shelf edge of the Bay of Biscay while the stock considered in ICES assessment extends from the south of Bay of Biscay until the Norwegian coasts. It has been observed during EVHOE surveys that low recruitment in Bay of Biscay like in 1998 can be balanced by higher indices in Celtic sea.

Formulation of advice

Knowing the worrying state of the stock at the beginning of the EVHOE surveys and as no improvement occurred in recent years, on contrary some deteriorations of the indices for older age groups, it seems necessary to reduce the fishing mortality.

References

ICES. 1997. Report of the Working Group on Nephrops stocks CM 1997/ Assess : 9.

Poulard, J.-C., Blanchard, F., Boucher, J., and Souissi, S. 2003. Variability in the demersal fish assemblages of the Bay of Biscay during the 1990s. ICES Marine Science Symposia 219: 411-414.

Poulard, J.-C., and Trenkel, V. 2005. Relationship between survey abundance and weight indices, survey design and wind conditions: the French groundfish survey in Bay of Biscay. ICES CM 2005/Z: 02: 17.

Hake Biscay **CUSUM diagnostics table**

	Rec.index	Abundance A1.to.5+	L25	Lbar	L75	Z	mdpop a1a5	dmul	Eq.A. A5	Spread.A. A5	Pos.A. A5	Eq.A. A4	Spread.A. A4	xcg A3	Inert. A1	Inert. A3	Spread.A. A1	Spread.A. A2
ref.period	1987, 1988, 1989, 1990, 1992, 1994, 1995, 1997											1987, 1988, 1989, 1990, 1992, 1994, 1995, 1997						
m ref.period	18.6	17.4	8.8	15.4	15.8	1.0	1.9	1.0	4939.3	5486.5	9594.5	7689.6	8684.4	-3.1	5335.6	7903.9	8149.3	10837.9
sd ref.period	0.5	0.3	1.1	1.8	2.9	0.6	0.9	0.2	3289.1	2987.5	4291.6	2190.6	1787.9	0.5	1064.0	1744.3	1732.7	1388.8
k	1.0	1.0	0.8	0.8	0.8	0.9	0.9	0.9	0.7	0.6	0.9	0.8	0.9	1.0	0.8	1.0	1.0	0.9
h	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ARL InControl	24.3	35.3	21.6	21.6	21.6	27.5	27.5	27.5	23.2	24.0	27.5	21.6	27.5	35.3	21.6	35.3	35.3	27.5
ARL OutControl	1.6	1.8	2.0	2.0	2.0	1.9	1.9	1.9	2.5	3.0	1.9	2.0	1.9	1.8	2.0	1.8	1.8	1.9

Years	Rec.index	Abundance A1.to.5+	L25	Lbar	L75	Z	mdpop a1a5	dmul	Eq.A. A5	Spread.A. A5	Pos.A. A5	Eq.A. A4	Spread.A. A4	xcg A3	Inert. A1	Inert. A3	Spread.A. A1	Spread.A. A2	
1987	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	ref
1988	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1989	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1991	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1992	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.4	-1.3	0.0	0.0	0.0	0.0	0.0	ref
1993	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1994	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1996	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1998	-1.1	-4.1	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	-1.8	0.0	1.4	0.0	-1.2	
1999	-1.1	-2.6	2.0	0.0	0.0	0.0	1.4	0.0	0.0	-2.0	-1.2	0.0	-1.1	-3.0	0.0	1.8	0.0	0.0	
2000	0.0	-4.3	1.7	0.0	0.0	0.0	0.0	1.5	0.0	-2.4	-1.8	-1.6	-1.7	-3.0	-1.1	0.0	0.0	-2.4	
2001	0.0	-3.2	2.6	0.0	0.0	0.0	0.0	3.3	-1.4	-2.3	0.0	-2.8	-2.3	-3.1	0.0	0.0	0.0	-4.5	
2002	0.0	-2.2	1.5	0.0	0.0	1.5	0.0	4.3	-1.6	-2.7	0.0	-4.3	-4.1	-3.3	0.0	1.2	0.0	-4.5	
2003	0.0	-2.3	2.8	1.1	1.1	1.2	1.1	2.6	-1.3	-2.7	0.0	-5.2	-5.3	-3.2	-2.5	2.6	-1.3	-3.4	
2004	1.2	0.0	3.9	0.0	0.0	1.5	1.1	3.5	-1.3	-2.6	0.0	-6.0	-6.8	-3.9	-3.8	2.0	-1.2	-3.8	

Results of trend analysis

	all period	recent
Z	0	1
Ln_Abdnce	0	0
Lbar	0	1
L25	0	1
L75	0	1
Ln_Recruit	0	0

diagnostic 0 inconsistent results for Z and L75: increase or decrease of F?
Faster growth ? Larger fish caught ?

Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
Larger fish caught (or change in fishing area, stock distribution or gear)	-1	1	1	0	1	0
Smaller fish caught (or change in fishing area, stock distribution or gear)	1	-1	-1	-1	0	0
	1	0	1	1	1	0

Indicator Based Assessment
Hake Aegean Sea

C.-Y. Politou (HCMR)

Data

Survey area and polygon

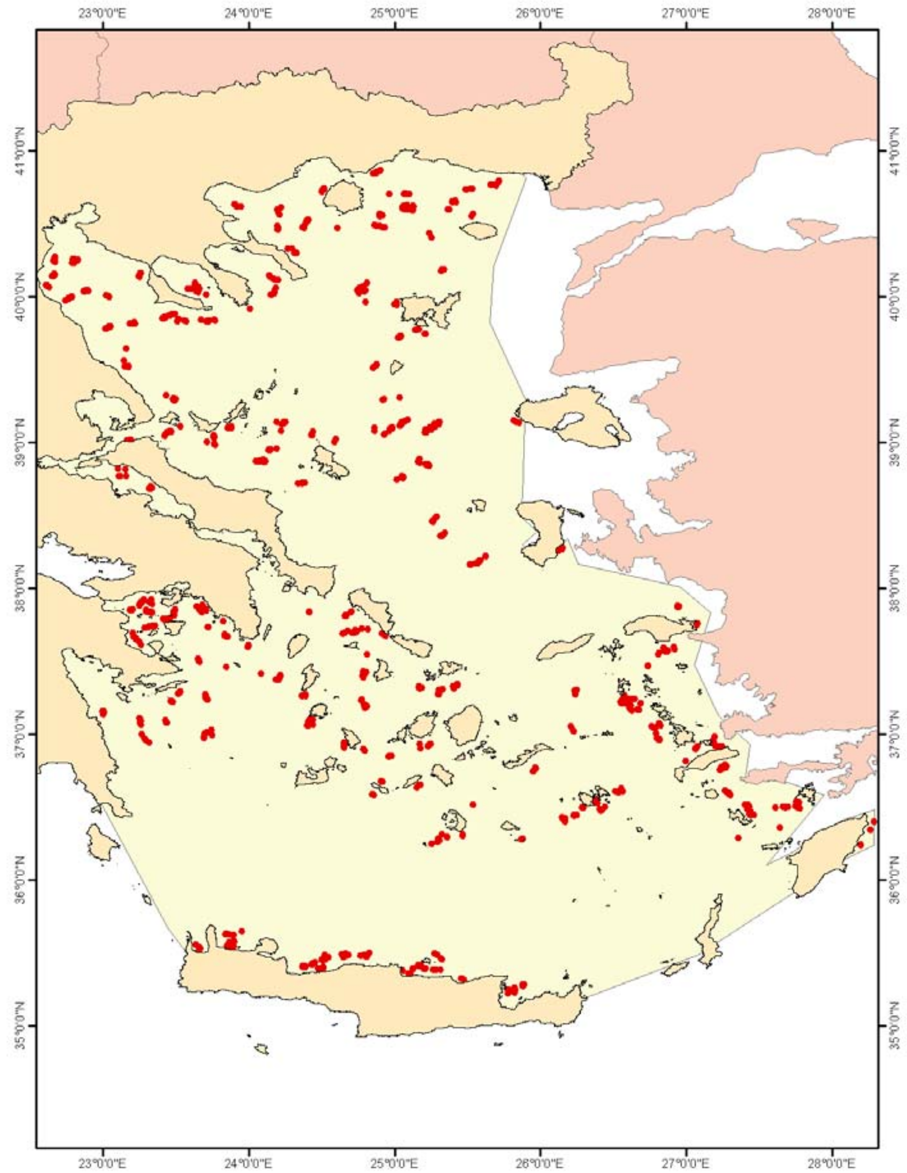


Fig. 1. Map of the survey area of MEDITS in the Aegean Sea (1994-2003) showing the sampling stations.

Maps of spatial indices

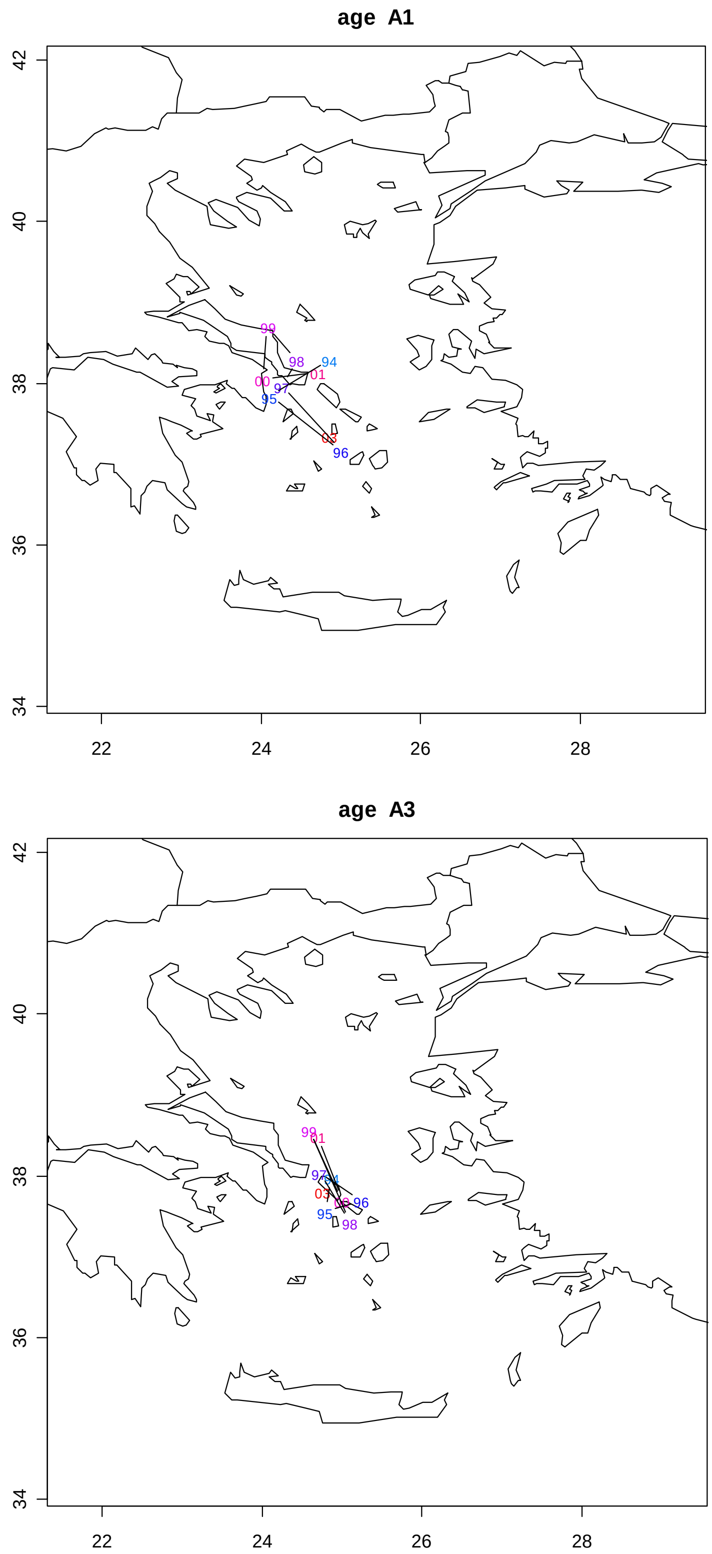


Fig. 2. Maps of the gravity centers across years of ages 1+ and 3+ of hake in the Aegean Sea.

Input parameters for spatial indices

The input parameters for spatial indices in the Aegean Sea were the following:
function infl(dlim =15, ndisc=400)
function NBPatches(Lim.D=100, A.li=10)
function microstructure(h0=10, ndisc=400)

Raw indices

Table 1. Table of spatial indices (hakeAE_tab1_wp2a).

Area	SurveyType	Species	Age	Year	Abundance	Posit.Area	Inertia	Anisotropy	xcg	ycg	Microstr.Index	Equiv.Area	Spread.Area	NP
Aegean Sea	BT	Hake	A0	1994	2889000	9021	6034	1.755	24.43	37.69	0.648	1600	2547	2
Aegean Sea	BT	Hake	A0	1995	10231000	14314	8541	2.092	24.19	37.38	0.637	995	2100	3
Aegean Sea	BT	Hake	A0	1996	15291000	13614	5327	1.646	23.86	38.19	0.673	1048	2839	4
Aegean Sea	BT	Hake	A0	1997	10339000	14882	7081	1.876	23.83	38.82	0.526	2744	3975	3
Aegean Sea	BT	Hake	A0	1998	8119000	13874	6857	3.179	23.9	38.66	0.639	2168	3007	2
Aegean Sea	BT	Hake	A0	1999	20938000	15119	7490	2.4	23.66	39.1	0.632	1824	2964	2
Aegean Sea	BT	Hake	A0	2000	14030000	15295	5654	1.792	23.72	38.7	0.548	1710	3054	3
Aegean Sea	BT	Hake	A0	2001	9403000	13982	7804	2.184	23.96	38.62	0.616	1239	2544	2
Aegean Sea	BT	Hake	A0	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aegean Sea	BT	Hake	A0	2003	15531000	19583	14046	2.721	24.31	38.4	0.658	4462	5834	5
Aegean Sea	BT	Hake	A1	1994	5306000	14488	8816	2.106	24.86	38.29	0.512	5931	6199	3
Aegean Sea	BT	Hake	A1	1995	7053000	16264	7438	1.657	24.11	37.84	0.68	1181	4234	4
Aegean Sea	BT	Hake	A1	1996	9597000	14986	11670	2.052	25	37.17	0.782	1151	2990	4
Aegean Sea	BT	Hake	A1	1997	7438000	15607	7897	1.52	24.26	37.97	0.531	2185	3818	4
Aegean Sea	BT	Hake	A1	1998	7357000	20855	7037	1.583	24.45	38.29	0.602	5119	7574	3
Aegean Sea	BT	Hake	A1	1999	17275000	18562	10798	1.72	24.08	38.71	0.632	2008	3906	3
Aegean Sea	BT	Hake	A1	2000	14315000	17984	6241	1.304	24.02	38.05	0.523	1527	3468	3
Aegean Sea	BT	Hake	A1	2001	8376000	21310	8971	1.498	24.71	38.14	0.586	3561	6935	3
Aegean Sea	BT	Hake	A1	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aegean Sea	BT	Hake	A1	2003	10446000	21635	17790	3.028	24.86	37.35	0.559	2487	5399	4
Aegean Sea	BT	Hake	A2	1994	2912000	14704	9245	2.226	24.86	38.33	0.557	5370	6667	3
Aegean Sea	BT	Hake	A2	1995	1769000	13364	11894	1.97	24.73	37.76	0.735	2699	5299	5
Aegean Sea	BT	Hake	A2	1996	3947000	17515	9654	1.778	24.86	38.07	0.653	3775	6010	4
Aegean Sea	BT	Hake	A2	1997	6643000	17745	7612	1.123	24.5	38.08	0.589	4484	5623	3
Aegean Sea	BT	Hake	A2	1998	6119000	22520	10076	1.909	24.81	37.98	0.585	8175	8684	3
Aegean Sea	BT	Hake	A2	1999	5237000	19123	11057	1.899	24.71	38.52	0.605	6439	7838	4
Aegean Sea	BT	Hake	A2	2000	7600000	18816	9660	1.743	24.69	37.88	0.561	4793	6635	3
Aegean Sea	BT	Hake	A2	2001	4311000	19757	8801	1.777	24.72	38.23	0.509	8355	8540	3
Aegean Sea	BT	Hake	A2	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aegean Sea	BT	Hake	A2	2003	4657000	19602	13066	2.174	25.02	37.65	0.57	5058	7120	5
Aegean Sea	BT	Hake	A3	1994	1431000	13876	12236	2.157	24.87	37.98	0.594	5583	6665	3
Aegean Sea	BT	Hake	A3	1995	615000	8111	11150	1.862	24.79	37.56	0.755	1455	3101	3
Aegean Sea	BT	Hake	A3	1996	1735000	13309	15179	2.265	25.24	37.69	0.923	860	4759	4
Aegean Sea	BT	Hake	A3	1997	3818000	17848	9677	1.385	24.72	38.04	0.636	5507	6888	4
Aegean Sea	BT	Hake	A3	1998	3748000	19272	12460	2.108	25.1	37.43	0.59	6200	8005	4
Aegean Sea	BT	Hake	A3	1999	2357000	17409	12417	2.161	24.59	38.57	0.613	6828	7788	3
Aegean Sea	BT	Hake	A3	2000	2813000	17107	13737	2.345	25	37.7	0.561	6080	6957	5
Aegean Sea	BT	Hake	A3	2001	1681000	15007	9934	1.803	24.7	38.49	0.534	7625	7652	3
Aegean Sea	BT	Hake	A3	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aegean Sea	BT	Hake	A3	2003	2741000	16898	12165	2.616	24.76	37.8	0.563	5576	6737	4
Aegean Sea	BT	Hake	A4	1994	471000	7999	10870	2.243	24.64	38.08	0.697	3169	4323	3
Aegean Sea	BT	Hake	A4	1995	408000	7863	8158	1.627	24.8	37.64	0.663	2570	3672	2

Aegean Sea	BT	Hake	A4	1996	839000	7638	13367	1.895	24.95	38.53	0.776	1831	3083	3
Aegean Sea	BT	Hake	A4	1997	1242000	13960	9483	1.62	24.75	38.45	0.678	5177	6767	3
Aegean Sea	BT	Hake	A4	1998	1772000	17071	12964	1.863	25.49	37.43	0.659	3505	6245	3
Aegean Sea	BT	Hake	A4	1999	932000	11019	11670	1.831	24.42	38.6	0.617	3911	4816	3
Aegean Sea	BT	Hake	A4	2000	1225000	11201	11538	2.006	25.13	38.21	0.768	1616	4410	3
Aegean Sea	BT	Hake	A4	2001	679000	11396	10264	1.869	24.79	38.66	0.501	6824	6785	3
Aegean Sea	BT	Hake	A4	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aegean Sea	BT	Hake	A4	2003	1682000	12127	15847	2.704	24.66	38.03	0.597	3825	4813	3
Aegean Sea	BT	Hake	A5	1994	229000	6720	9020	2.679	24.96	38.02	0.578	5109	4774	2
Aegean Sea	BT	Hake	A5	1995	318000	4249	10284	2.373	25.05	37.63	0.642	1980	2002	3
Aegean Sea	BT	Hake	A5	1996	189000	4850	11529	2.515	24.34	39.03	0.748	2205	2911	3
Aegean Sea	BT	Hake	A5	1997	558000	8589	9615	1.697	24.93	38.43	0.733	2932	4324	4
Aegean Sea	BT	Hake	A5	1998	645000	10272	10767	1.974	25.52	37.78	0.671	3723	5191	3
Aegean Sea	BT	Hake	A5	1999	365000	8526	11118	1.949	24.67	38.68	0.639	5186	5376	3
Aegean Sea	BT	Hake	A5	2000	445000	7578	8120	2.009	24.41	38.92	0.547	2497	3638	3
Aegean Sea	BT	Hake	A5	2001	220000	6187	9571	2.287	24.89	39.22	0.611	3045	3931	3
Aegean Sea	BT	Hake	A5	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Aegean Sea	BT	Hake	A5	2003	691000	10846	13109	1.935	24.75	38.41	0.586	6353	6456	5

Table 2. Table of non-spatial indices (hakeAE_tab2_wp2a).

Area	SurveyType	Species	Year	Survey.index	Recruit.index	Lbar	L25	L75	L50.matur.	Z	StdLbar	StdL25	StdL75	SdL50.m	StdZ
AegeanSea	BT	MERLMER	1994	13238000	5306000	21.8	16.5	25.6	NA	0.47188	0.05131	0.15639	0.08246	NA	NA
AegeanSea	BT	MERLMER	1995	20394000	7053000	15.6	11.4	17.4	NA	0.48691	0.0138	0.02138	0.01162	NA	NA
AegeanSea	BT	MERLMER	1996	31598000	9597000	14.2	10.3	14.7	NA	0.75232	0.00849	0.00673	0.00281	NA	NA
AegeanSea	BT	MERLMER	1997	30038000	7438000	17.6	10.1	22.7	NA	0.70134	0.02931	0.00721	0.0821	NA	NA
AegeanSea	BT	MERLMER	1998	27760000	7357000	18.9	12.1	23.1	NA	0.34234	0.03129	0.01552	0.0704	NA	NA
AegeanSea	BT	MERLMER	1999	47104000	17275000	16.1	12	17.6	NA	0.62282	0.0069	0.01131	0.0066	NA	NA
AegeanSea	BT	MERLMER	2000	40428000	14315000	17	10.9	20.1	NA	0.78560	0.01465	0.00638	0.0210	NA	NA
AegeanSea	BT	MERLMER	2001	24670000	8376000	17.3	12.5	19.3	NA	NA	0.01951	0.01245	0.0424	NA	NA
AegeanSea	BT	MERLMER	2003	35748000	10446000	17.3	11	20.2	NA	NA	0.02476	0.01058	0.0449	NA	NA

Combined indices

a) MFA of spatial indices

The first two axes of the MFA explain 88% of the total variance of the data. The first axis is highly positively correlated with xcg and spreading area and also with inertia and equivalent area, while it is negatively correlated with ycg (Table 4). The second axis is highly positively correlated with the positive area. Following Fig. 5, the 0+ age group is clearly differentiated from the older groups in axis 1. The location of this age in the factorial space corresponds to a more westwards and northwards distribution with lower spreading area, inertia and equivalent area in comparison to the older groups. The A1 group displays the highest positive area and this area decreases with age (minimum in A5), while the positive area of A0 is closer to that of A2 (axis 2).

Table 3. Variation of the distance of the multivariate spatial index through the years.

Year	dmul
1994	1.07050838444455
1995	1.71816214455620
1996	1.42923404945998
1997	0.656367610171896
1998	0.456509850765206
1999	0.86698480852423
2000	1.10786233533099
2001	0.968584709405437
2003	1.61906925787725

Table 4. PCA loadings for the first two axes of MFA.

Spatial index	"comp.1"	"comp.2"
"PositiveArea"	2+|0-	9+|0-
"Inertia"	7+|0-	0+|3-
"Anisotropy"	0+|4-	1+|4-
"xcg"	8+|0-	0+|3-
"ycg"	2+|5-	1+|3-
"EquivalentArea"	7+|0-	0+|1-
"SpreadingArea"	8+|0-	1+|0-
"NumberOfPatches"	4+|0-	2+|0-

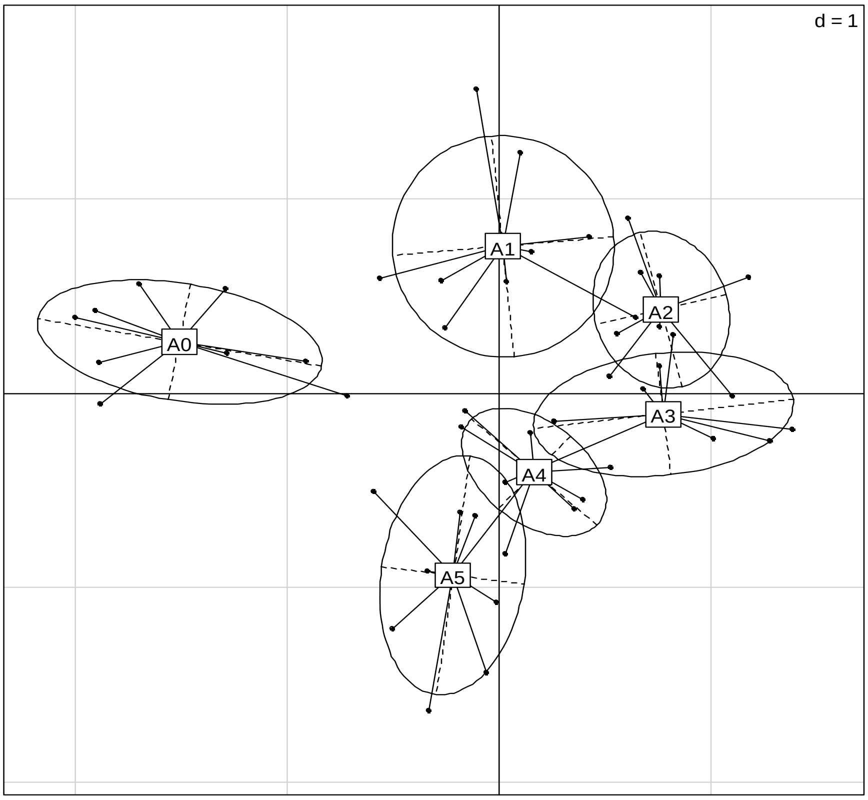


Fig. 5. Graphical representation of the hake age groups in the factorial space using MFA.

b) PCA of non spatial indices

Table 5. Inter-annual variation of the multivariate distance derived from PCA of non-spatial indices.

year	md
1994	7.3208432677882
1995	2.02157973661438
1996	2.57427186582508
1997	2.72313074699466
1998	2.50803760612078
1999	1.94579258397664
2000	1.64898279490931
2001	2.01689333320041
2003	1.71112511858312

Table 6. PCA loadings for the first two axes of the non-spatial indices.

Index	Comp.1	Comp.2
"Ln.Ntot"	0.75879047097662	0.386801334189362
"Ln.Nrec"	0.856654188084862	0.11792779723126
"Lbar"	-0.82782234862231	0.259578012512945
"L25"	-0.410359116336871	-0.652130517108992
"L75"	-0.738619556172251	0.447922788854624
"Z"	0.145538162433765	-0.799812209058387

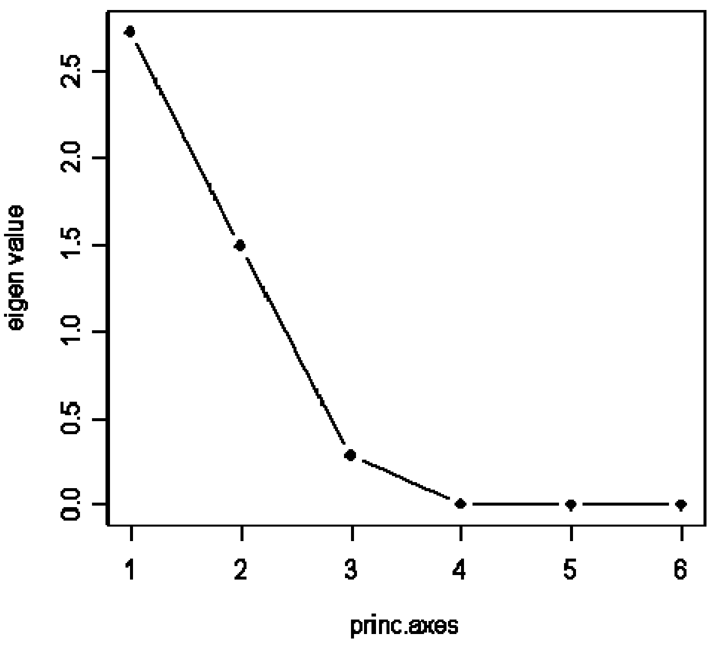


Fig. 6. Eigen values of the PCA components.

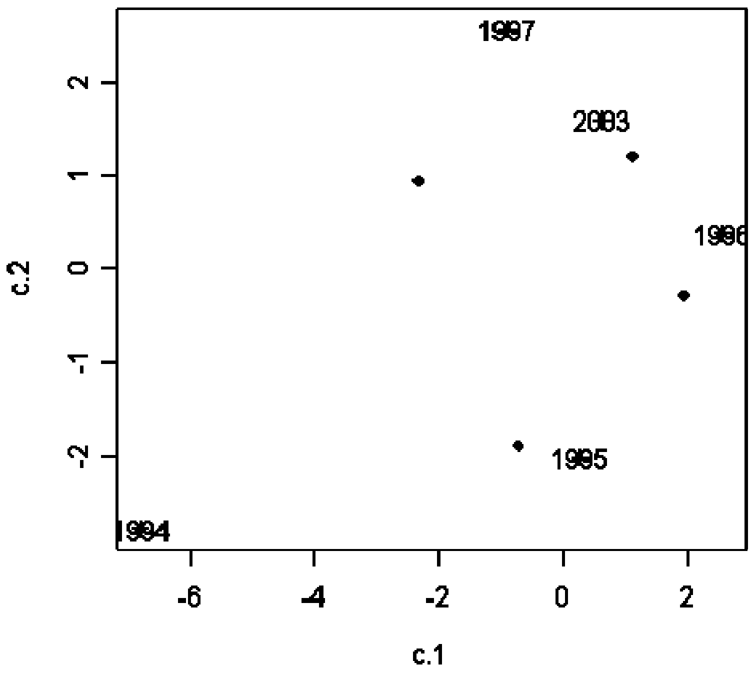


Fig. 7. Projection of the years on the first PCA plane. Reference years are shown as solid diamonds.

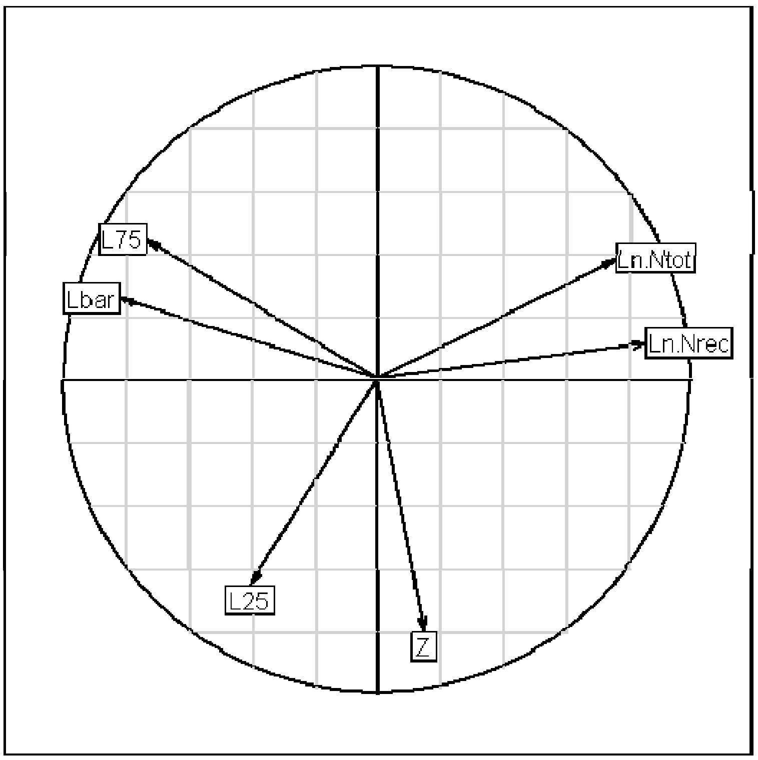


Fig. 8. Projection of the non-spatial indices on the first PCA plane.

According to the eigen values of the PCA of the non-spatial indices the first 2 axes explain the greatest part of the data variability (Fig. 6). The first axis is highly positively correlated to the recruitment index and the total abundance, whereas it is highly negatively correlated to Lbar, L75 and less to L25 (Table 6, Fig. 8). The second axis is mainly negatively correlated with Z and L25 and also positively correlated to L75 and total abundance. The year 1994 shows the highest multivariate distance (Table 5) and in Fig. 7, it is the most distant year from the area determined by the reference years. This is due mainly to the very high L25 obtained this year accompanied also by high Lbar and L75 (Table 2).

Looking for changes

Visual inspection

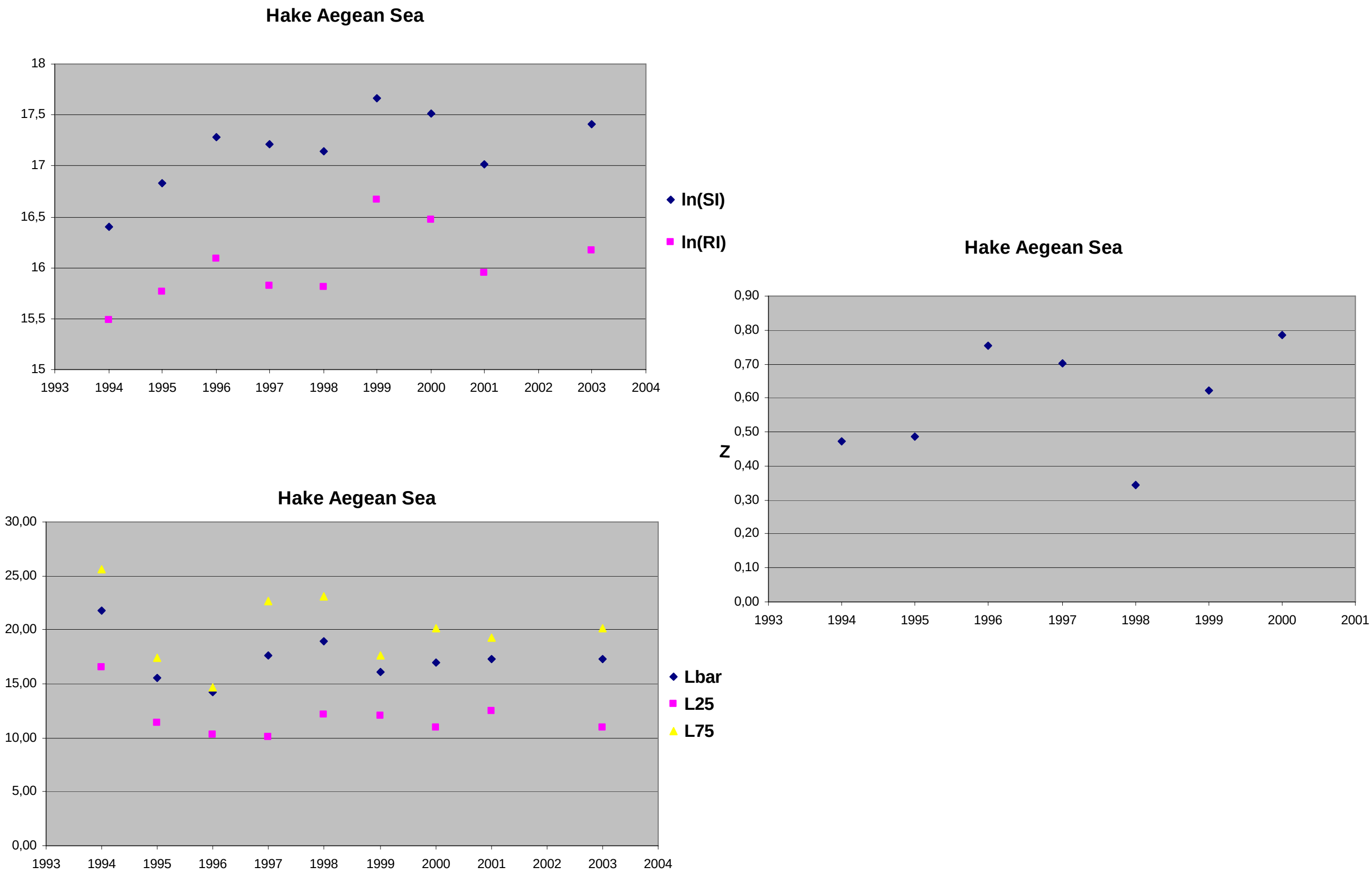


Fig. 9. Time series of biological indices (Survey Index, Recruitment Index , Length Indices and Z) of hake in the Aegean Sea.

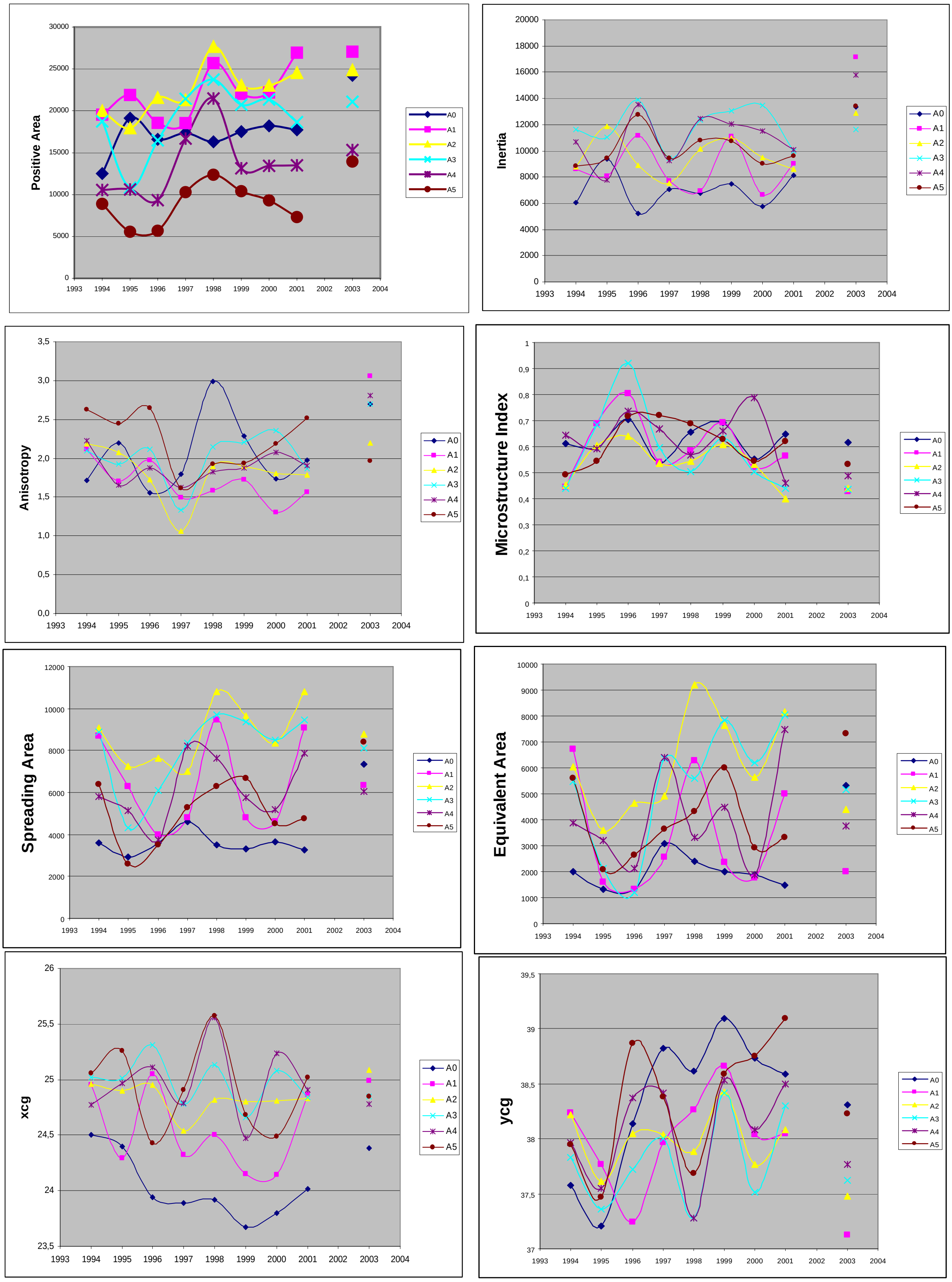
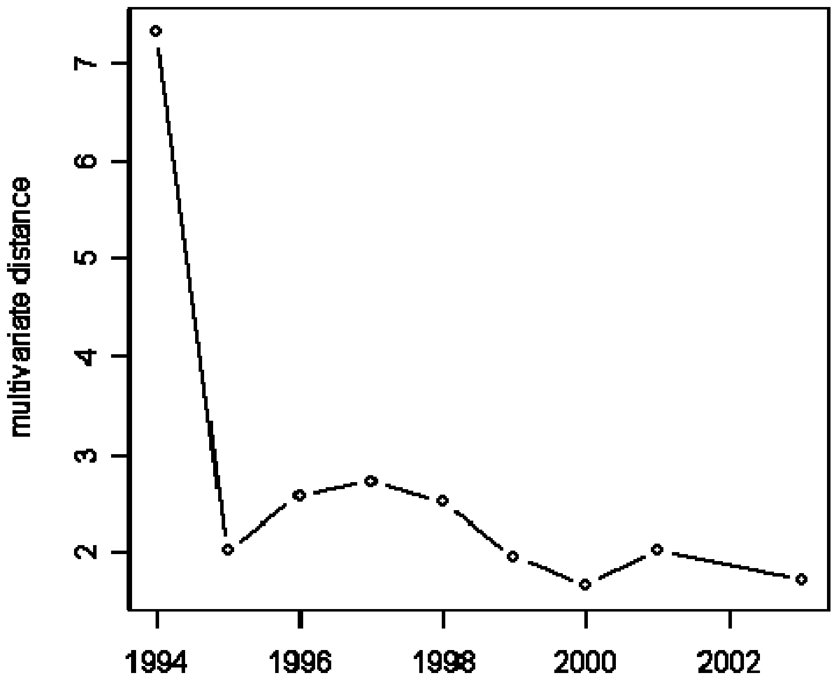


Fig. 10. Time series of spatial indices for hake in the Aegean Sea.



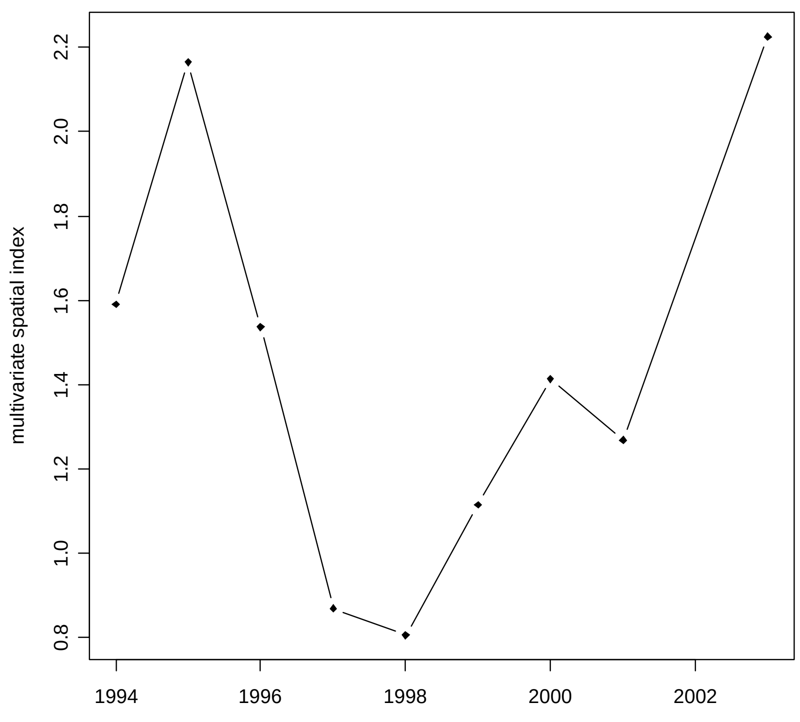


Fig. 11. Time series of the biological multivariate index (above) and of the spatial multivariate index (below).

Trends of selected indices

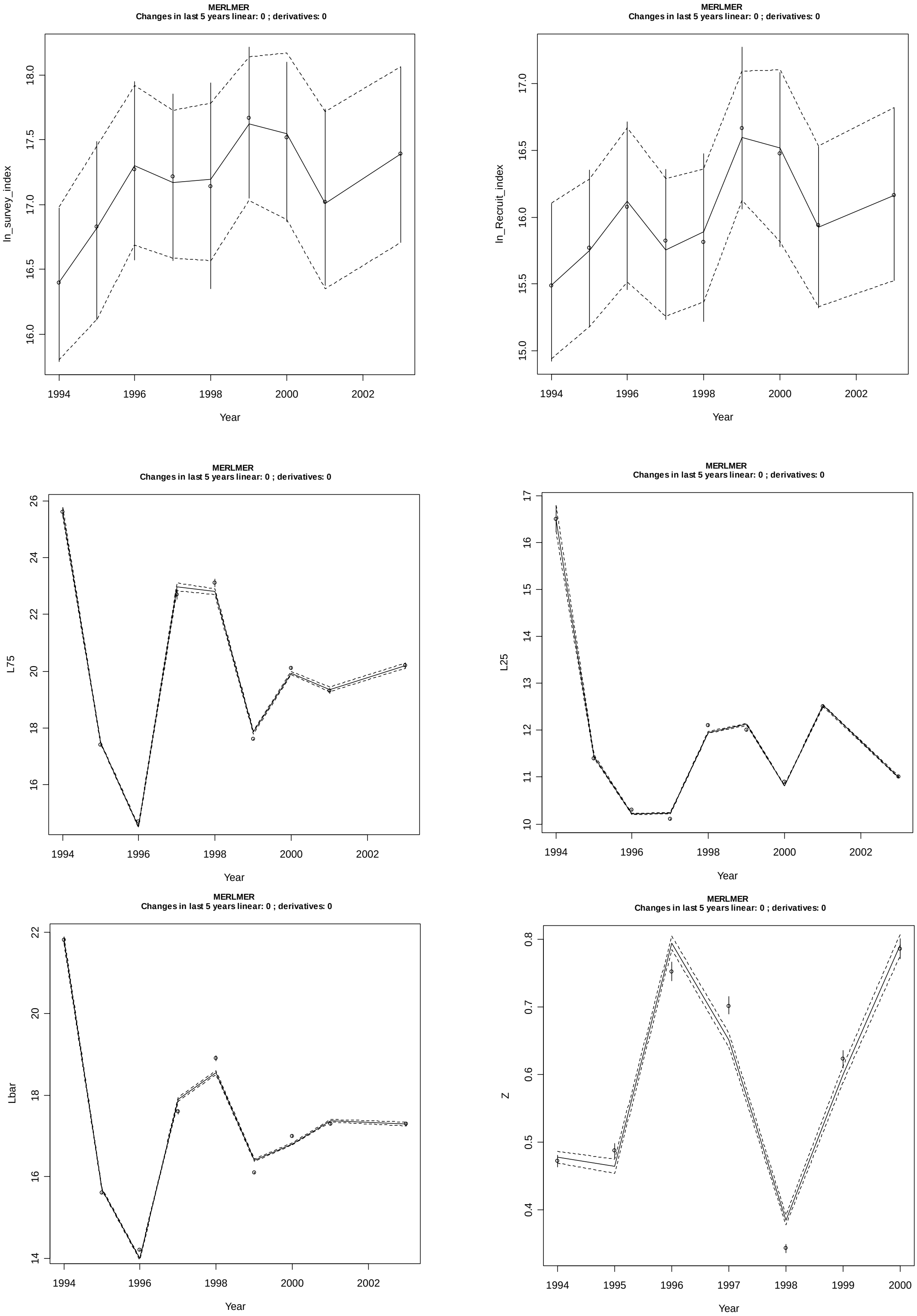
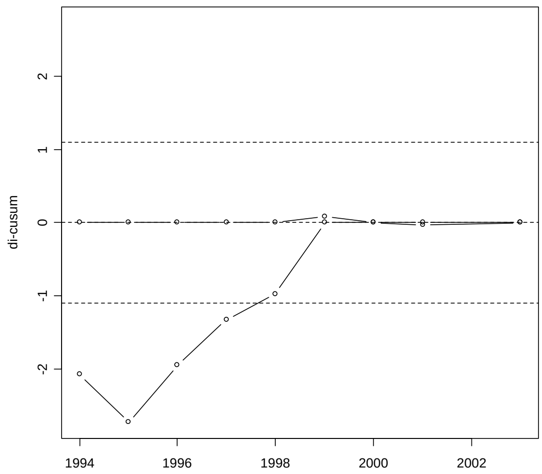


Fig. 12. Trends of the biological indices using the linear and derivatives methods.

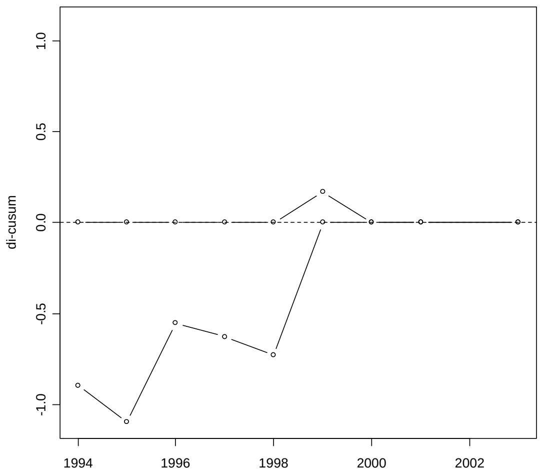
Area	Species	Indicator	LinearSlope	PvalueAll	LinSlopeLast5Years	PvalueLast	DiagnosLinearRecent	DiagnosNonLinearRecent
AegeanSea	MERLMER	PositiveAreaA0	726.165	**0.01156**	1.100.314	0.23672	0	0
AegeanSea	MERLMER	InertiaA0	541.419	0.08263	1.852.171	0.13497	0	1
AegeanSea	MERLMER	AnisotropyA0	0.08	0.21089	0.128	0.43724	0	0
AegeanSea	MERLMER	MicrostructureIndexA0	-0.002	0.77819	0.013	0.51176	0	1
AegeanSea	MERLMER	EquivalentAreaA0	218.748	0.09313	671.4	0.21337	0	0
AegeanSea	MERLMER	SpreadingAreaA0	239.892	0.06647	718.286	0.18572	0	0
AegeanSea	MERLMER	xcgA0	-0.019	0.59353	0.171	0.01252	1	0
AegeanSea	MERLMER	ycgA0	0.114	0.08496	-0.159	0.06847	0	0
AegeanSea	MERLMER	PositiveAreaA1	817.931	**0.00317**	918.257	0.16001	0	0
AegeanSea	MERLMER	InertiaA1	590.797	0.17824	2.136.343	0.25986	0	0
AegeanSea	MERLMER	AnisotropyA1	0.045	0.50612	0.366	0.19846	0	0
AegeanSea	MERLMER	MicrostructureIndexA1	-0.008	0.48234	-0.011	0.60059	0	-1
AegeanSea	MERLMER	EquivalentAreaA1	-92.445	0.68628	208.771	0.59022	0	0
AegeanSea	MERLMER	SpreadingAreaA1	92.889	0.66905	508	0.44857	0	0
AegeanSea	MERLMER	xcgA1	0.001	0.99168	0.224	0.11033	0	0
AegeanSea	MERLMER	ycgA1	-0.014	0.82165	-0.309	0.05244	0	0
AegeanSea	MERLMER	PositiveAreaA2	641.985	**0.04177**	167.6	0.33941	0	0
AegeanSea	MERLMER	InertiaA2	180.14	0.40233	571.886	0.47548	0	0
AegeanSea	MERLMER	AnisotropyA2	0.004	0.93253	0.081	0.29646	0	0
AegeanSea	MERLMER	MicrostructureIndexA2	-0.012	0.13577	-0.008	0.65681	0	0
AegeanSea	MERLMER	EquivalentAreaA2	280.279	0.24323	-159.286	0.8332	0	0
AegeanSea	MERLMER	SpreadingAreaA2	220.426	0.14187	-61.457	0.87407	0	0
AegeanSea	MERLMER	xcgA2	0.011	0.57658	0.082	0.11204	0	0
AegeanSea	MERLMER	ycgA2	-0.024	0.5074	-0.177	0.21058	0	0
AegeanSea	MERLMER	PositiveAreaA3	601.035	0.14633	-174.143	0.72613	0	0
AegeanSea	MERLMER	InertiaA3	-58.313	0.79986	-248.886	0.73064	0	-1
AegeanSea	MERLMER	MicrostructureIndexA3	-0.023	0.12016	-0.011	0.44743	0	0
AegeanSea	MERLMER	EquivalentAreaA3	446.221	0.11522	-235.057	0.55122	0	0
AegeanSea	MERLMER	SpreadingAreaA3	282.603	0.15047	-202.914	0.32706	0	0
AegeanSea	MERLMER	xcgA3	-0.021	0.45238	0.012	0.88454	0	0
AegeanSea	MERLMER	ycgA3	0.036	0.48302	-0.126	0.52643	0	0
AegeanSea	MERLMER	PositiveAreaA4	468.602	0.23231	280.086	0.01549	1	0
AegeanSea	MERLMER	InertiaA4	421.382	0.13187	1.045.229	0.26511	0	1
AegeanSea	MERLMER	AnisotropyA4	0.054	0.19587	0.211	0.11854	0	1
AegeanSea	MERLMER	MicrostructureIndexA4	-0.015	0.15629	-0.021	0.66912	0	-1
AegeanSea	MERLMER	EquivalentAreaA4	201.947	0.33731	257.829	0.79387	0	0
AegeanSea	MERLMER	SpreadingAreaA4	171.647	0.31522	90.286	0.85587	0	0
AegeanSea	MERLMER	xcgA4	-0.002	0.97004	0.011	0.93408	0	0
AegeanSea	MERLMER	ycgA4	0.032	0.57124	-0.111	0.37497	0	0
AegeanSea	MERLMER	PositiveAreaA5	450.316	0.0991	611	0.46746	0	0
AegeanSea	MERLMER	InertiaA5	169.3	0.37912	724.743	0.42111	0	0
AegeanSea	MERLMER	AnisotropyA5	-0.061	0.11707	0.001	0.99051	0	0
AegeanSea	MERLMER	MicrostructureIndexA5	-0.009	0.31353	-0.007	0.71385	0	0
AegeanSea	MERLMER	EquivalentAreaA5	198.755	0.3136	469.4	0.55696	0	0
AegeanSea	MERLMER	SpreadingAreaA5	249.5	0.13187	385.4	0.49859	0	0
AegeanSea	MERLMER	xcgA5	-0.022	0.63649	0.049	0.58382	0	0
AegeanSea	MERLMER	ycgA5	0.092	0.19102	-0.075	0.63086	0	0

Table 7. Trends of the spatial indices for the different ages using the linear and derivatives methods.

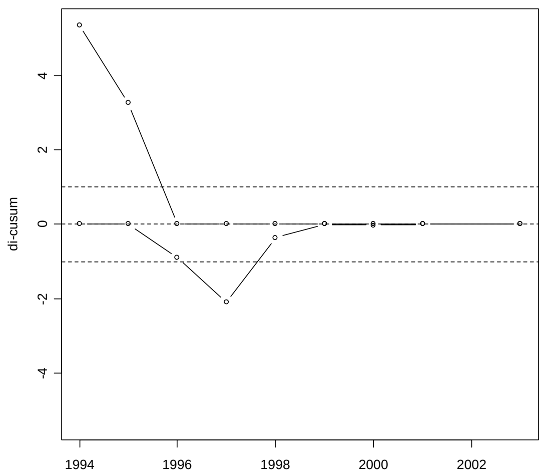
Di-cusum plots of selected indices



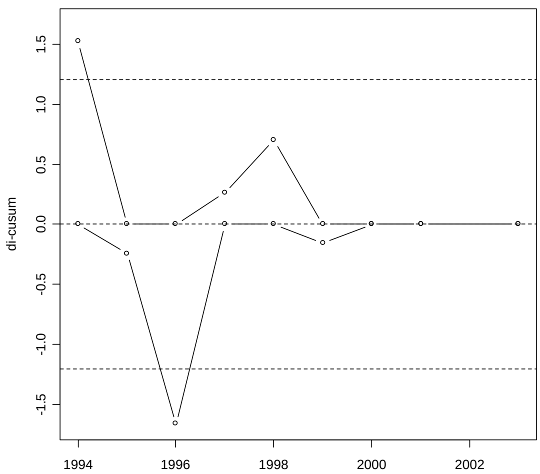
Ln_SI



Ln_RI



L25



L75

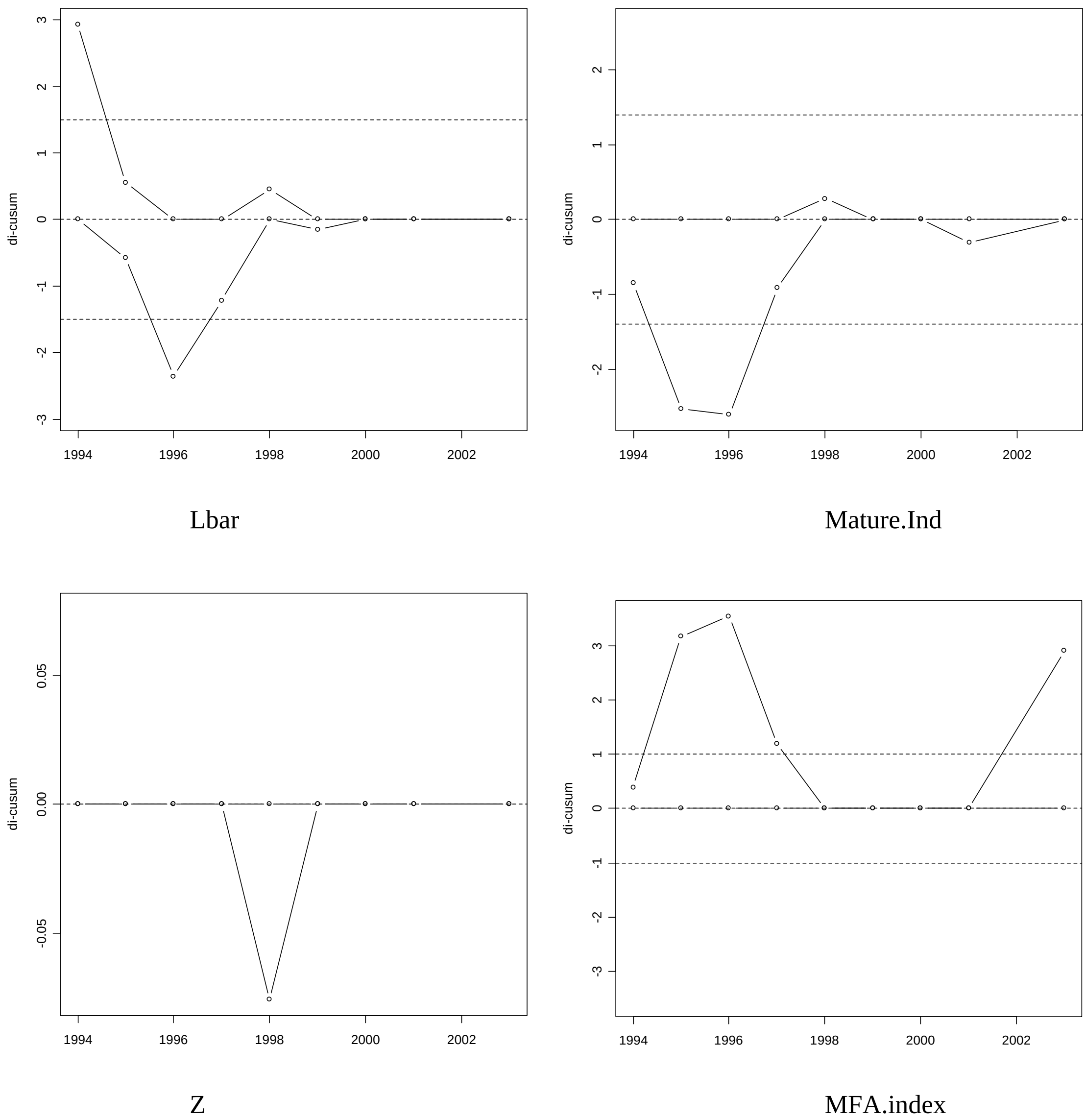


Fig. 13. Di-cusum plots of biological and multivariate indices.

Interpretation

Trend analysis
The trend analysis showed no significant trends for the whole period or the last 5 years of the biological indices of hake in the Aegean Sea. For the spatial indices, there was an increasing trend in the positive area of the smaller age groups (A0, A1 and A2) during the whole period. During the last 5 years, the positive area of A4 and the longitude of A0 increased, according to the linear method. However, most changes in the last 5 years were observed using the derivatives method and they concerned the inertia, the microstucture index and the anisotropy.

Cusum analysis
The cusum analysis of total abundance gave negative signals until 1997. No signals in the abundance of recruits or Z were observed. Cusum analysis also showed positive and then negative signals in the length indices until 1997, which are probably due to the poor abundance of mature individuals signaled in 1995 and 1996 and the poor abundance of immature specimens from 1994 to 1997. Concerning the composite indices, no Cusum analysis could be performed to the biological distance, whereas the spatial index showed positive signals in 1995, 1996 and 2003.

Compare approaches (cusum/trends)

Although the trends method did not show any long term or recent changes in the biological indices, the cusum analysis indicated an amelioration of the abundance after 1997 and a stabilization of the length indices, after positive and negative signals, during the same period.

Summary sheet

Survey series
Data were collected during the MEDITS (International bottom trawl surveys in the Mediterranean) surveys in the Aegean Sea from 1994 to 2003. The surveys were carried out every summer in depths from 10 to 800 m using the stratified sampling design and following the MEDITS protocols. In 2002, no survey was carried out in the area.
In the analyses, hake specimens of age 1 were considered as recruits, specimens of age 2 and 50% of age 3 as immature and the rest of age 3 and older as mature.

Non-spatial indices
The abundance index (SI), the recruitment index (RI), the total mortality (Z) and the length indices (Lbar, L25, L75) were analysed using the trends method (linear for the whole period and for the last 5 years and derivatives for the last 5 years) and the cusum analysis. SI showed no trend for the whole period or the last 5 years, whereas negative signals from 1994 to 1997 were observed using the cusum analysis. RI and Z did not show any trends (linear, derivatives) or signals (cusum). The length indices did not show any trends (linear, derivatives), although negative and then positive signals were obtained until 1997 (cusum).

Spatial indices
Positive area (PA), Spreading area (SA), Equivalent area (EA), Inertia, Anisotropy, Microstructure and Centre of gravity were analysed by age using the trends method (linear

and derivatives). Positive trends of PA for A0, A1 and A2 were detected for the whole period, whereas the following recent changes were observed: PA A4 +1(linear), longitude A0 -1(linear), MI A0 +1 (derivatives), MI A1,A4 -1 (derivatives), Inertia A0,A4 +1 (derivatives), Inertia A3 –1 (derivatives) and Anisotropy A4 +1 (derivatives).

Composite (derived) indices

MFA spatial indices: The component 1 was highly positively correlated with xcg and spreading area and also with inertia and equivalent area, while it was negatively correlated with ycg. The component 2 was highly positively correlated with the positive area.. The cusum analysis of MFA spatial gave positive signals in 1995,1996 and 2003.

PCA biological indices: The component 1 was highly positively correlated to the recruitment index and the total abundance, whereas it was highly negatively correlated to Lbar, L75 and less to L25. The component 2 was mainly negatively correlated with Z and L25 and also positively correlated to L75 and total abundance. No cusum analysis could be applied to the index.

Reference period

The period 1998-2001 was chosen for reference period. During this period, the sampling was more representative comparing to previous years, since the number of stations was increased.

Summary of results on the stock

No significant trends were observed for any of the biological parameters considered using the linear and derivatives methods. However, there is indication of a general increase of abundance the last years, which was poor before 1998 according to the CUSUM analysis. Although there was no signal for the abundance of recruits, there were negative signals in the abundance of immature from 1994 to 1997 and in the abundance of mature in 1995 and 1996, which consequently did not give any signal (CUSUM). Furthermore, the different lengths did not give any signals after 1997 (CUSUM). These results show a stable situation at least after 1997 for the biological indices, however, trends may be observed if more recent years are considered. Concerning the spatial indices increasing trends in the positive area of the younger age groups (A0, A1, A2) was observed for the whole period, whereas some recent trends were found in the distribution characteristics of different ages (mostly A4).

Comparison with traditional assessment of stock status

Such data are not available for hake in the Aegean Sea.

Formulation of advice

Given the fact that hake was considered overexploited in the beginning of the studied period and that after 1994 the fishing effort was reduced gradually until 2005 and a larger cod-end mesh size was imposed recently, it is suggested to continue the enforcement of the existing measures, which may have resulted in an amelioration of abundance. The protection of recruits by expansion of closed seasons in the main nursery grounds is also recommended.

Hake Aegean Sea **CUSUM diagnostics table**

ref.period	1998-2001	1998-2001	1998-2001	1998-2001	1998-2001	1998-2001	1998-2001	1998-2001	1998-2001	
m in ref.period	0.8499854	17.3357767	16.2234083	17.325	11.875	20.025	0.5835898	14.8256804	16.7280469	
sd in ref.period	0.2802846	0.3055701	0.4118194	1.167262	0.6849574	2.299819	0.2242218	0.3790404	0.2872603	
k	1.3	1	0.9	0.9	1.4	0.9	1	0.9	1.2	
h	1	1.1	1.2	1.5	1	1.2	1.1	1.4	1	
ARL InControl	79.3	42.7	39.2	67.8	105.8	39.2	42.7	56.4	60	
ARL OutControl	1.5	1.9	2.1	2.4	1.4	2.1	1.9	2.3	1.6	
Years	**MFA_Spatial**	**Ln_TotAbun**	**Ln_Recruits**	**Lbar**	**L25**	**L75**	**Z**	**Ln_Mature**	**Ln_Immature**	**alert**
1994	0	-2.066971	0	2.933759	5.352245	1.524104	0	0	-1.31574	alarm
1995	1.797483	-2.719703	0	0	3.258771	0	0	-2.526812	-2.555934	alarm
1996	2.564128	-1.939529	0	-2.355023	0	-1.656794	0	-2.605471	-2.206992	alarm
1997	0	-1.325047	0	0	-2.090815	0	0	0	-1.496348	alarm
1998	0	0	0	0	0	0	0	0	0	ref
1999	0	0	0	0	0	0	0	0	0	ref
2000	0	0	0	0	0	0	0	0	0	ref
2001	0	0	0	0	0	0	0	0	0	ref
2002										
2003	1.443939	0	0	0	0	0	0	0	0	

Hake Aegean Sea **cause-effects diagnostics table**

survey period	1994-2003
ref.period	1994
ref status	Overfished

Results of trend analysis

	all period	recent
Z	0	0
Ln_Abdnce	0	0
Lbar	0	0
L25	0	0
L75	0	0
Ln_Recruit	0	0

diagnostic

No apparent trends during the studied period.
However, the CUSUM analysis shows a poor abundance until 1997. CUSUM analysis also gives positive and then negative alarms in L25, L50 and L75 until 1997, which are probably resulted from the poor abundance of immature specimens from1994 to 1997 and of mature individuals signaled in 1995 and 1996.
Nevertheless, no clear scenario can be fitted to these results.

Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
change in fishing area, sto	-1	1	1	0	1	0
change in fishing area, sto	1	-1	-1	-1	0	0

Indicator Based Assessment
Hake Ionian Sea

C.-Y. Politou (HCMR)

Data

Survey area and polygon

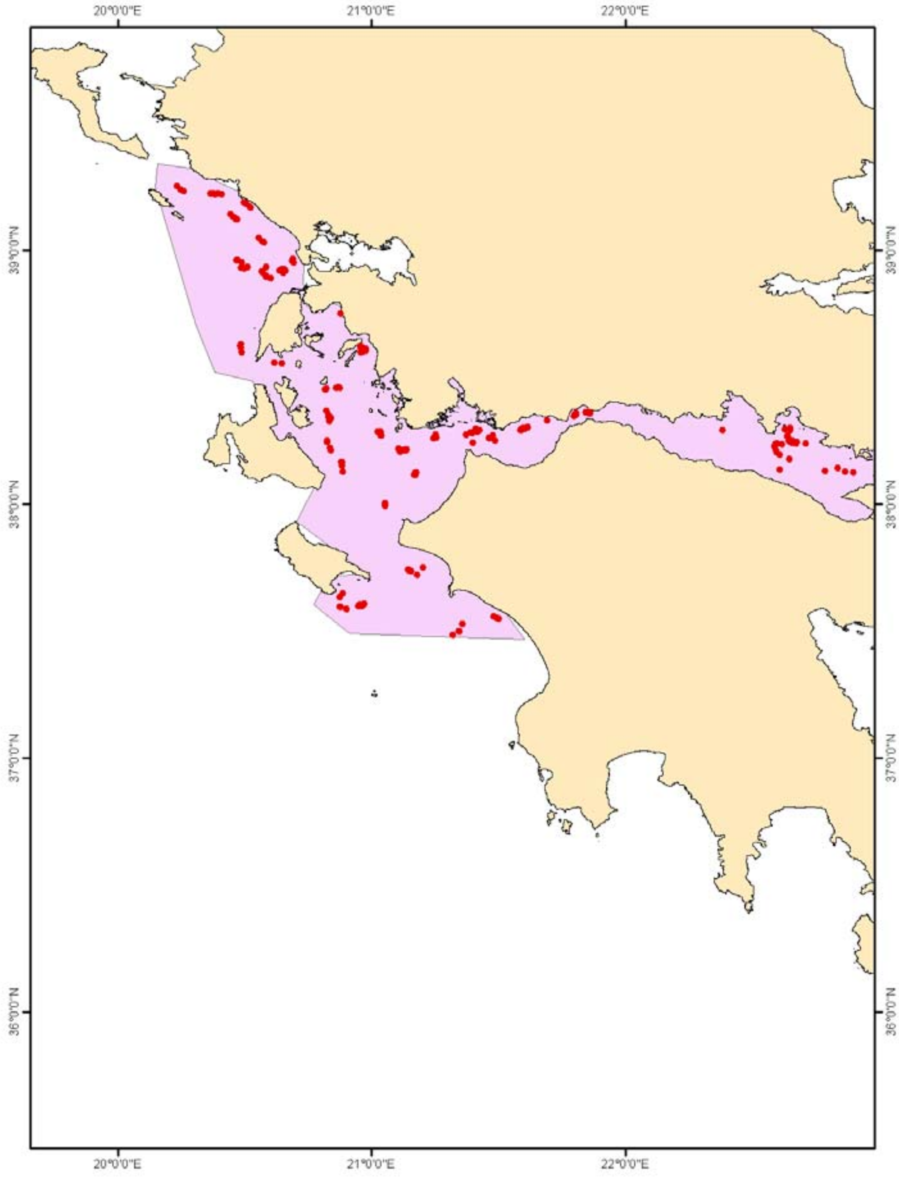


Fig. 1. Map of the survey area of MEDITS in the Ionian Sea (1994-2003) showing the sampling stations.

Maps of spatial indices

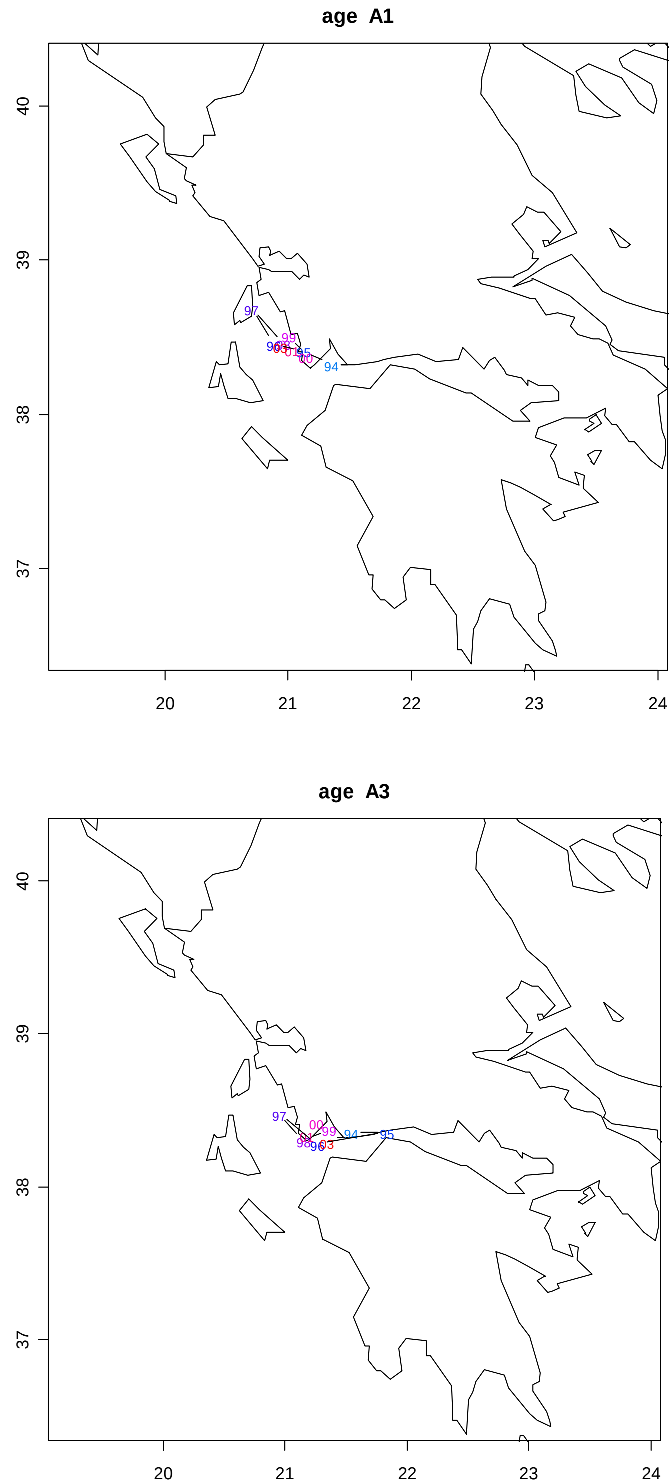


Fig. 2. Maps of the gravity centers across years of ages 1+ and 3+ of hake in the Ionian Sea.

Input parameters for spatial indices

The input parameters for spatial indices in the Ionian Sea were the following:
function infl(dlim =15, ndisc=400)
function NBPatches(Lim.D=50, A.li=10)
function microstructure(h0=10, ndisc=400)

Raw indices

Table 1. Table of spatial indices (hakeIO_tab1_wp2a).

Area	SurveyType	Species	Age	Year	Abundance	Posit.Area	Inertia	Anisotropy	xcg	ycg	Microstr.Index	Equival.Area	Spread.Area	NP
Ionian Sea	BT	Hake	A0	1994	191000	1165	415	2.833	21.49	38.34	0.824	421	546	1
Ionian Sea	BT	Hake	A0	1995	263000	1976	521	3.581	20.87	38.67	0.555	999	976	1
Ionian Sea	BT	Hake	A0	1996	3441000	2299	1353	2.216	21.06	38.22	0.614	1249	1183	2
Ionian Sea	BT	Hake	A0	1997	26000	859	771	3.237	21.04	38.5	0.832	528	627	2
Ionian Sea	BT	Hake	A0	1998	526000	1958	587	4.884	20.75	38.7	0.775	584	656	1
Ionian Sea	BT	Hake	A0	1999	1544000	1506	255	2.407	20.93	38.44	0.759	381	480	1
Ionian Sea	BT	Hake	A0	2000	2300000	1926	974	5.484	20.95	38.64	0.83	459	511	2
Ionian Sea	BT	Hake	A0	2001	2256000	2018	699	3.593	21.07	38.48	0.865	407	584	2
Ionian Sea	BT	Hake	A0	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ionian Sea	BT	Hake	A0	2003	3330000	2506	887	2.405	21.01	38.39	0.868	585	996	2
Ionian Sea	BT	Hake	A1	1994	238000	1539	244	2.344	21.35	38.33	0.719	474	634	1
Ionian Sea	BT	Hake	A1	1995	1107000	2134	422	2.139	21.12	38.41	0.604	1015	996	1
Ionian Sea	BT	Hake	A1	1996	489000	2437	896	3.042	20.89	38.46	0.537	1751	1578	2
Ionian Sea	BT	Hake	A1	1997	345000	1689	510	2.922	20.7	38.69	0.603	917	880	1
Ionian Sea	BT	Hake	A1	1998	535000	1960	304	2.212	20.96	38.46	0.643	730	901	1
Ionian Sea	BT	Hake	A1	1999	371000	1610	241	2.369	21.01	38.51	0.83	273	373	1
Ionian Sea	BT	Hake	A1	2000	715000	2134	521	2.14	21.15	38.38	0.795	604	932	2
Ionian Sea	BT	Hake	A1	2001	604000	2312	612	1.911	21.03	38.42	0.605	1351	1260	1
Ionian Sea	BT	Hake	A1	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ionian Sea	BT	Hake	A1	2003	1271000	2074	685	2.345	20.94	38.44	0.731	1032	1087	2
Ionian Sea	BT	Hake	A2	1994	80000	886	627	66.271	21.29	38.32	0.678	783	718	1
Ionian Sea	BT	Hake	A2	1995	516000	1779	1101	4.907	21.63	38.3	0.813	588	831	2
Ionian Sea	BT	Hake	A2	1996	433000	2301	835	1.73	21.09	38.33	0.643	1449	1419	2
Ionian Sea	BT	Hake	A2	1997	402000	1867	589	2.813	20.87	38.52	0.537	1464	1310	1
Ionian Sea	BT	Hake	A2	1998	155000	1860	679	1.971	21.09	38.46	0.842	691	1002	1
Ionian Sea	BT	Hake	A2	1999	166000	1275	607	1.67	21.14	38.42	0.808	596	591	1
Ionian Sea	BT	Hake	A2	2000	449000	1764	846	2.501	21.12	38.47	0.833	622	844	2
Ionian Sea	BT	Hake	A2	2001	606000	2231	514	2.252	21.12	38.39	0.676	970	1075	1
Ionian Sea	BT	Hake	A2	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ionian Sea	BT	Hake	A2	2003	1128000	2128	357	2.02	21.28	38.3	0.92	184	536	1
Ionian Sea	BT	Hake	A3	1994	42000	935	841	4.895	21.54	38.36	0.822	519	558	1
Ionian Sea	BT	Hake	A3	1995	182000	1361	1395	4.227	21.84	38.36	0.84	459	562	3
Ionian Sea	BT	Hake	A3	1996	106000	1227	419	4.142	21.27	38.28	0.806	497	657	1
Ionian Sea	BT	Hake	A3	1997	128000	1677	639	2.658	20.95	38.48	0.647	1266	1256	2
Ionian Sea	BT	Hake	A3	1998	73000	1480	927	2.098	21.15	38.3	0.855	553	786	2
Ionian Sea	BT	Hake	A3	1999	56000	1122	955	2.226	21.36	38.38	0.779	934	843	3
Ionian Sea	BT	Hake	A3	2000	241000	1345	813	2.744	21.26	38.42	0.898	256	436	2
Ionian Sea	BT	Hake	A3	2001	190000	1476	429	2.133	21.18	38.34	0.809	538	699	1
Ionian Sea	BT	Hake	A3	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ionian Sea	BT	Hake	A3	2003	372000	1812	340	1.968	21.35	38.29	0.931	127	337	1
Ionian Sea	BT	Hake	A4	1994	30000	1220	1169	5.012	21.51	38.38	0.73	861	808	2
Ionian Sea	BT	Hake	A4	1995	92000	1147	1175	5.402	22.1	38.31	0.825	390	454	2

Ionian Sea	BT	Hake	A4	1996	45000	1087	628	3.237	20.92	38.51	0.793	673	841	1
Ionian Sea	BT	Hake	A4	1997	38000	893	664	4.891	20.72	38.68	0.671	716	660	2
Ionian Sea	BT	Hake	A4	1998	10000	479	585	1.412	21.16	37.98	0.886	439	416	1
Ionian Sea	BT	Hake	A4	1999	27000	827	1598	1.877	21.57	38.33	0.876	665	619	3
Ionian Sea	BT	Hake	A4	2000	20000	633	367	5.742	21.32	38.29	0.833	482	472	1
Ionian Sea	BT	Hake	A4	2001	64000	882	363	2.874	21.16	38.33	0.866	343	464	1
Ionian Sea	BT	Hake	A4	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ionian Sea	BT	Hake	A4	2003	43000	992	776	2.207	21.31	38.24	0.903	332	543	1
Ionian Sea	BT	Hake	A5	1994	20000	758	295	71.448	21.02	38.32	0.658	524	495	1
Ionian Sea	BT	Hake	A5	1995	53000	756	1023	164.429	22.25	38.28	0.833	276	312	2
Ionian Sea	BT	Hake	A5	1996	7000	380	624	NA	20.61	38.91	0.672	366	368	2
Ionian Sea	BT	Hake	A5	1997	24000	600	1304	3.222	20.81	38.73	0.717	556	517	2
Ionian Sea	BT	Hake	A5	1998	6000	246	695	1.116	21.1	38.29	0.914	227	220	2
Ionian Sea	BT	Hake	A5	1999	20000	533	1385	2.612	22.13	38.12	0.825	416	395	2
Ionian Sea	BT	Hake	A5	2000	22000	398	316	1.746	21.16	38.26	0.915	212	222	1
Ionian Sea	BT	Hake	A5	2001	42000	759	926	4.125	21.26	38.29	0.802	519	492	2
Ionian Sea	BT	Hake	A5	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ionian Sea	BT	Hake	A5	2003	17000	543	826	6.396	20.86	38.02	0.739	487	446	2

Table 2. Table of non-spatial indices (hakeIO_tab2_wp2a).

Area	SurveyType	Species	Year	SurveyIndex	Recruit.Ind.	Lbar	L25	L75	L50.maturity	Z	StdLbar	StdL25	StdL75	StdL50m	StdZ
IonianSea	BT	MERLMER	1994	601000	238000	19.9	12.4	21.8	NA	-0.73	0.102	0.0701	0.3056	NA	NA
IonianSea	BT	MERLMER	1995	2213000	1107000	22.2	17.8	24.1	NA	-0.40	0.0212	0.039	0.0517	NA	NA
IonianSea	BT	MERLMER	1996	4521000	489000	16	10.3	20.5	NA	0.55	0.033	0.0094	0.793	NA	NA
IonianSea	BT	MERLMER	1997	963000	345000	27.1	21.9	29.1	NA	-0.19	0.1062	0.1137	0.0894	NA	NA
IonianSea	BT	MERLMER	1998	1305000	535000	25.2	18.4	29.9	NA	-0.29	0.0286	0.0377	0.2155	NA	NA
IonianSea	BT	MERLMER	1999	2184000	371000	20.9	12.6	28.4	NA	-0.31	0.0249	0.0179	0.6004	NA	NA
IonianSea	BT	MERLMER	2000	3747000	715000	17.3	10.8	21.5	NA	-0.07	0.0191	0.0077	0.4124	NA	NA
IonianSea	BT	MERLMER	2001	3762000	604000	17.5	8.4	23.8	NA	-0.29	0.0355	0.0067	0.0259	NA	NA
IonianSea	BT	MERLMER	2003	6161000	1271000	16.2	10	18.4	NA	NA	0.0143	0.0023	0.1359	NA	NA

Combined indices

a) MFA of spatial indices

The first axis of the MFA explains most of the variance of the data (72%), and it is highly positively correlated with xcg and highly negatively correlated with the positive area, spreading area and ycg (Table 4). Following Fig. 5, the younger groups (A0, A1 and A2) are found more westwards and northwards and occupy a higher area than the older groups (axis 1). The A2 group shows the highest spreading area and the lowest anisotropy inversely to the A0 group (axis 2). During the reference period (1998-2001) dmul takes the lowest values, whereas during the other years it is higher with highest value in 1997 (Table 3).

Table 3. Variation of the distance of the multivariate spatial index through the years.

Year	dmul
1994	1.13039876040228
1995	1.12492526055813
1996	1.02763331966354
1997	2.19611892565279
1998	0.296819129061229
1999	0.915013638063722
2000	0.69184007635617
2001	0.725947146892640
2003	1.48143841227623

Table 4. PCA loadings for the first two axes of MFA.

Spatial index	"comp.1"	"comp.2"
"PositiveArea"	"0+|7-"	"0+|1-"
"Inertia"	"4+|2-"	"2+|0-"
"Anisotropy"	"2+|2-"	"4+|1-"
"xcg"	"7+|0-"	"1+|1-"
"ycg"	"1+|6-"	"1+|0-"
"EquivalentArea"	"2+|5-"	"0+|3-"
"SpreadingArea"	"1+|6-"	"0+|4-"
"NumberOfPatches"	"3+|3-"	"2+|0-"

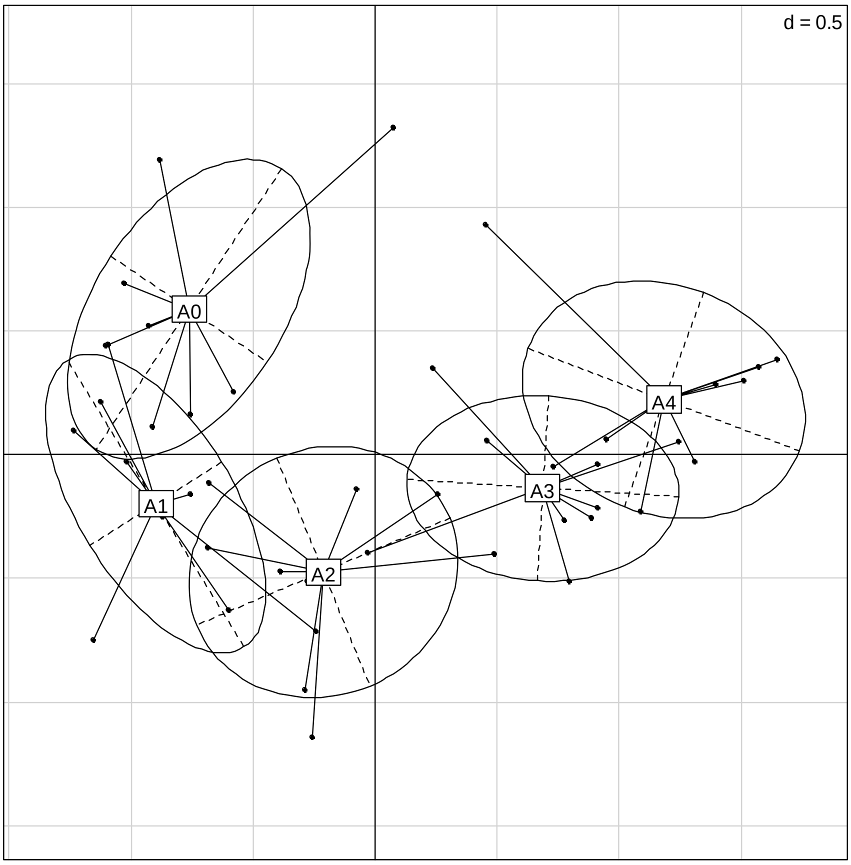


Fig. 5. Graphical representation of the hake age groups in the factorial space using MFA.

b) PCA of non spatial indices

Table 5. Inter-annual variation of the multivariate distance derived from PCA of non-spatial indices.

year	md
1994	1.87580556377500
1995	3.61018652551796
1996	1.93722668215972
1997	2.98848700382574
1998	2.74568645264121
1999	1.59657208698428
2000	2.25343683669686
2001	1.57553552529749
2003	4.17968090690033

Table 6. PCA loadings for the first two axes of the non-spatial indices.

Index	Comp.1	Comp.2
"Ln.Ntot"	0.851386826847731	0.157198464946645
"Ln.Nrec"	0.567978656225676	-0.641228283814367
"Lbar"	-0.843515538783428	-0.197125322031005
"L25"	-0.771359124401298	-0.365642420818452
"L75"	-0.852707328763112	0.138763287446127
"Z"	-0.832994861742054	0.119602347476527

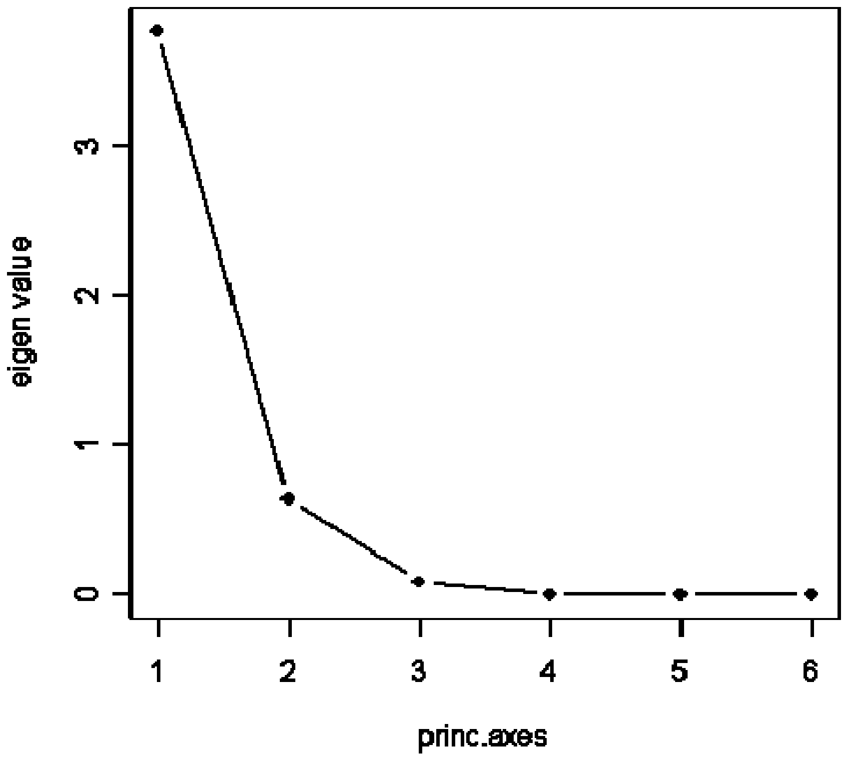


Fig. 6. Eigen values of the PCA components.

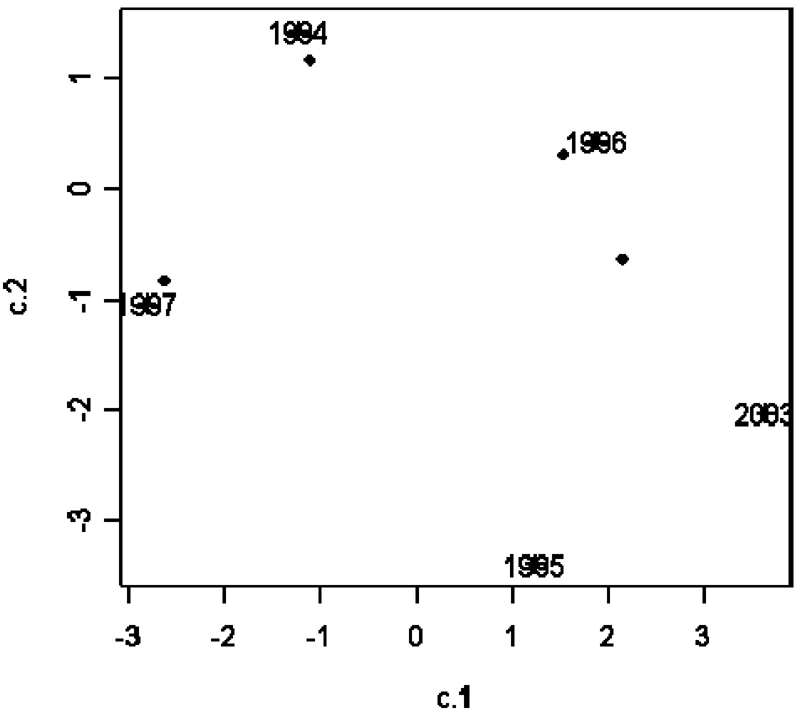


Fig. 7. Projection of the years on the first PCA plane. Reference years are shown as solid diamonds.

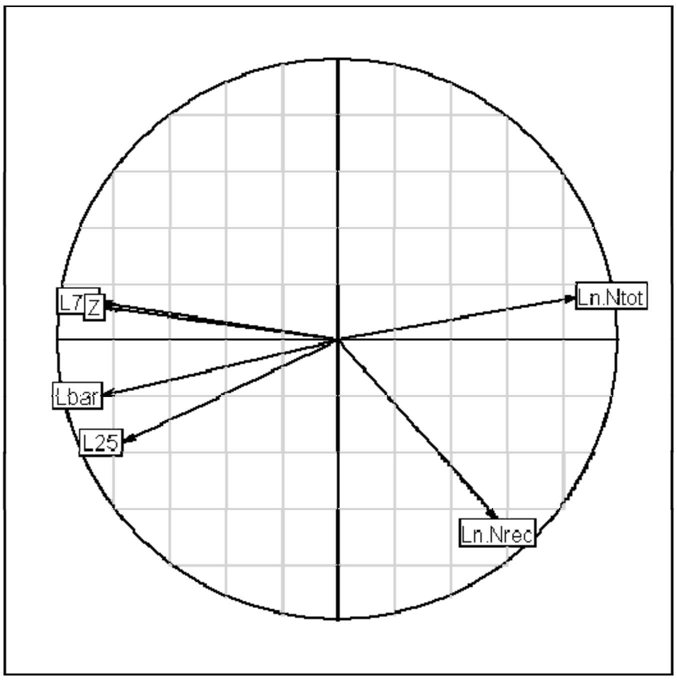


Fig. 8. Projection of the non-spatial indices on the first PCA plane.

According to the eigen values of the PCA of the non-spatial indices the first 2 axes explain the greatest part of the data variability (Fig. 6). The first axis is highly positively correlated to the total abundance and less to the recruitment index, whereas it is highly negatively correlated to all the other indices (Table 6, Fig. 8). The second axis is mainly negatively correlated with the recruitment index. The years 2003 and 1995 show the highest multivariate distance (Table 5) and in Fig. 7, they are the most distant years from the area determined by the reference years. It is clear that the position of these years is driven by their recruitment indices, which are the highest of all years considered (see also Table 2).

Looking for changes

Visual inspection

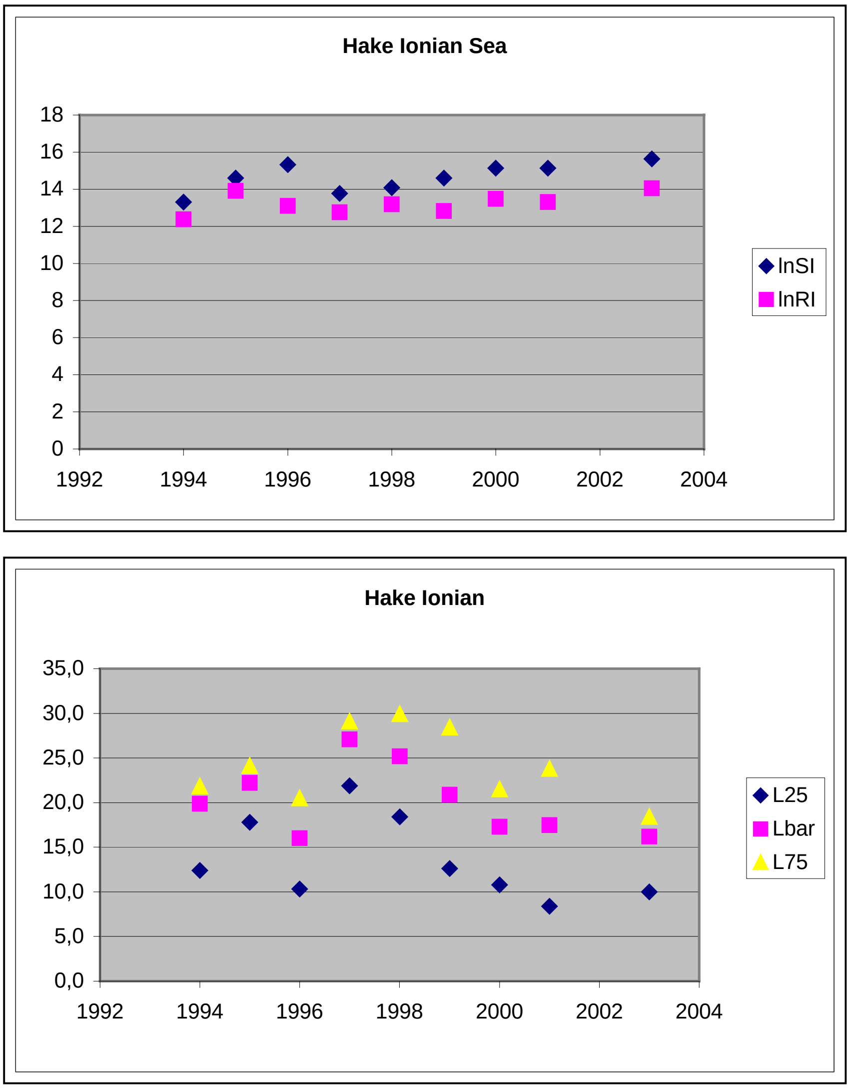


Fig. 9. Time series of biological indices (Survey Index, Recruitment Index and Length Indices) of hake in the Ionian Sea.

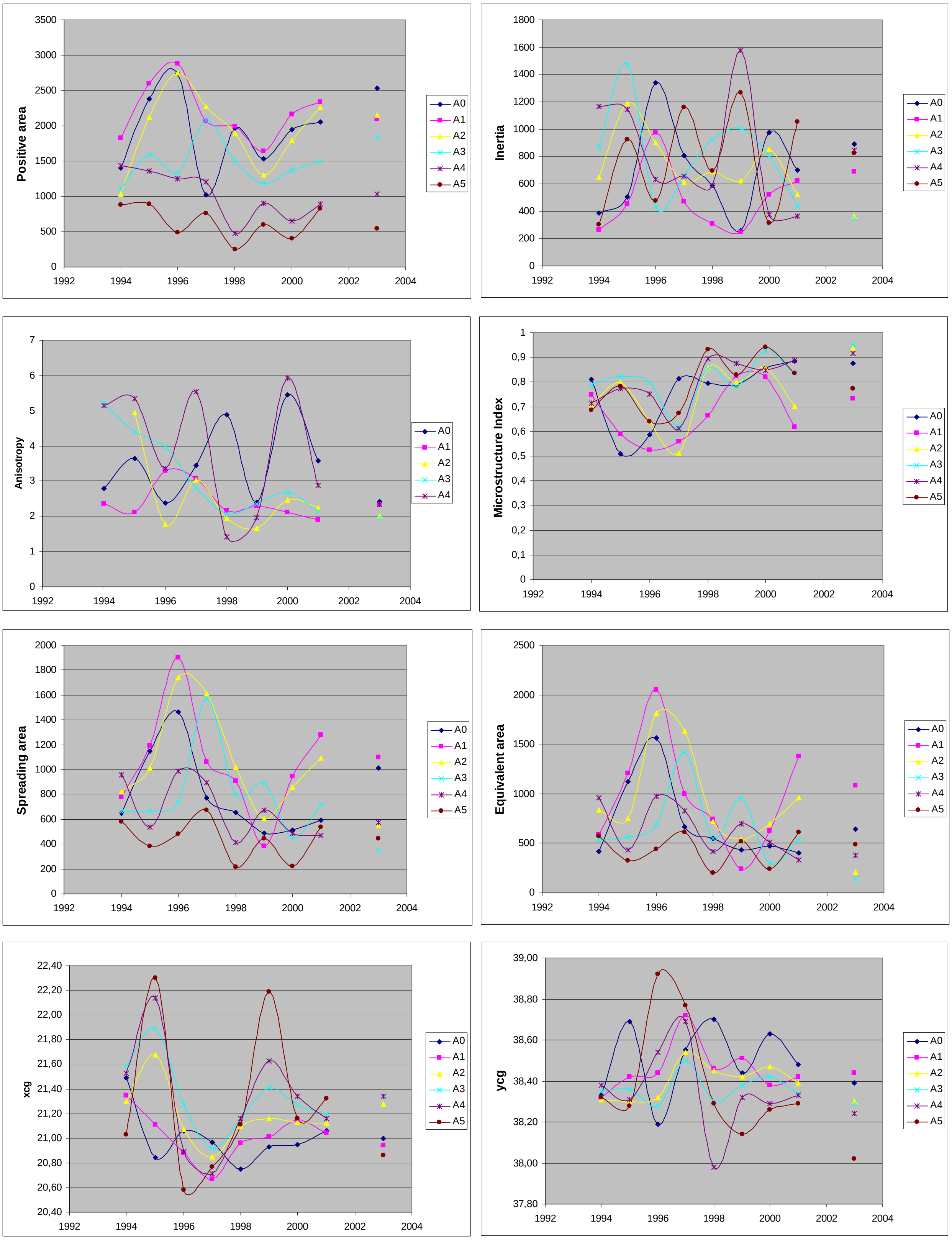
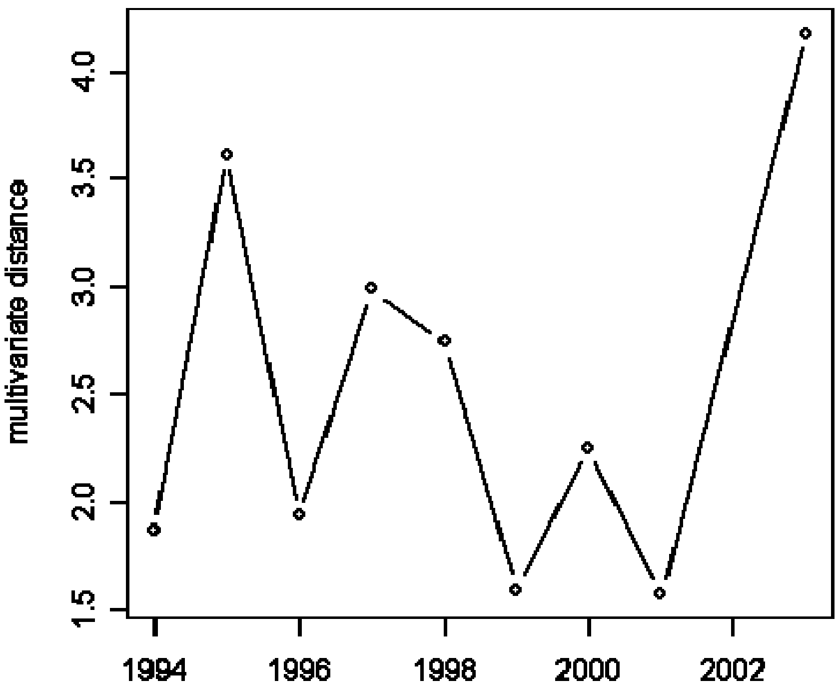


Fig. 10. Time series of spatial indices for hake in the Ionian Sea.



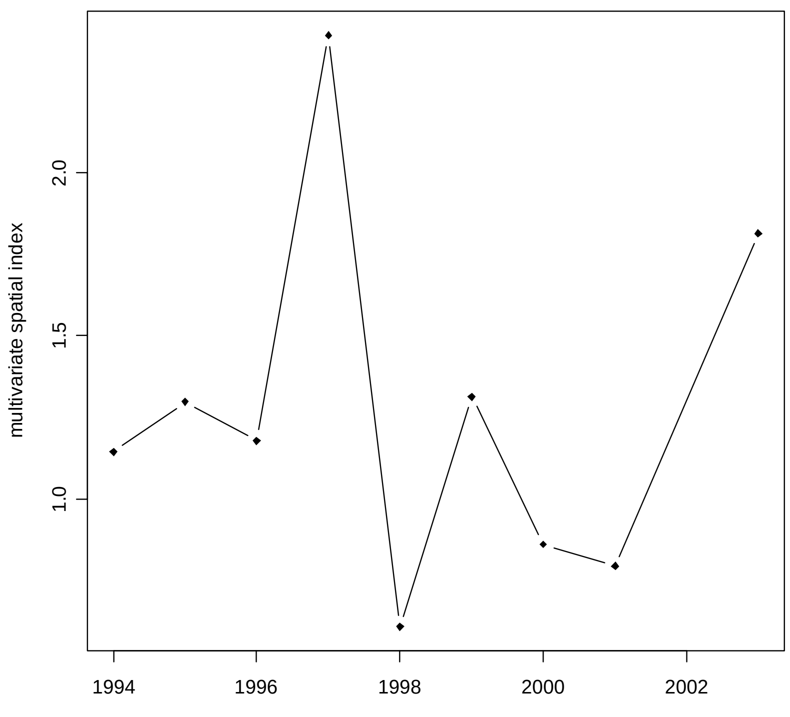
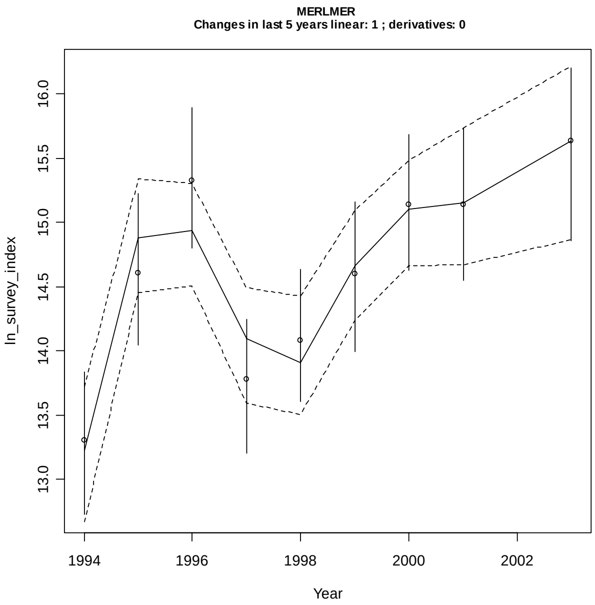
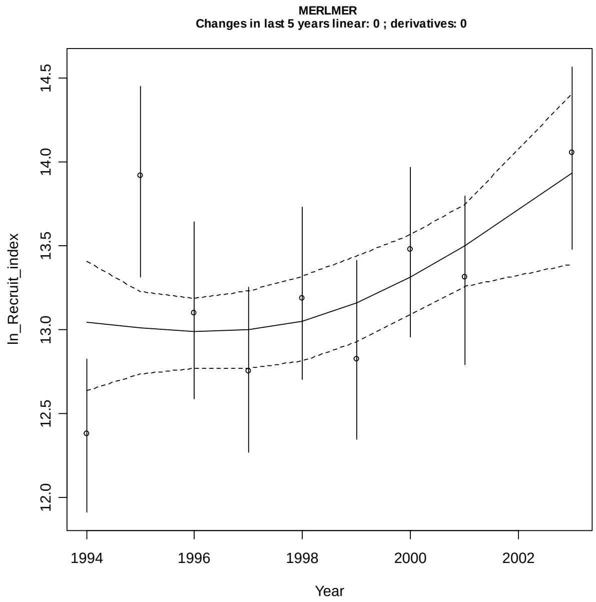
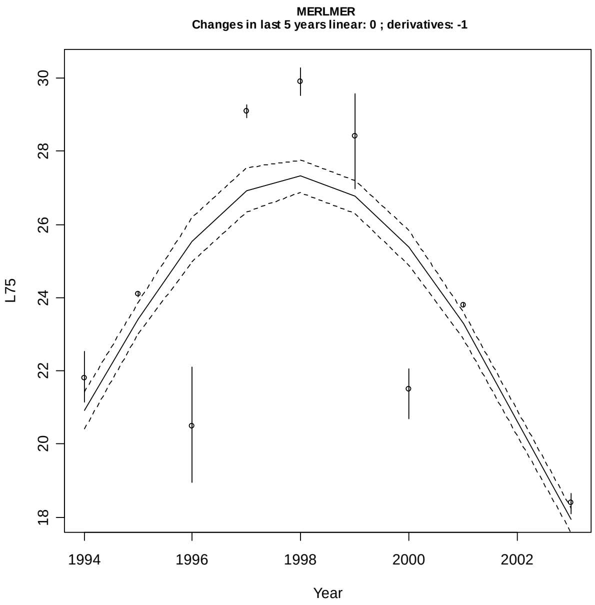


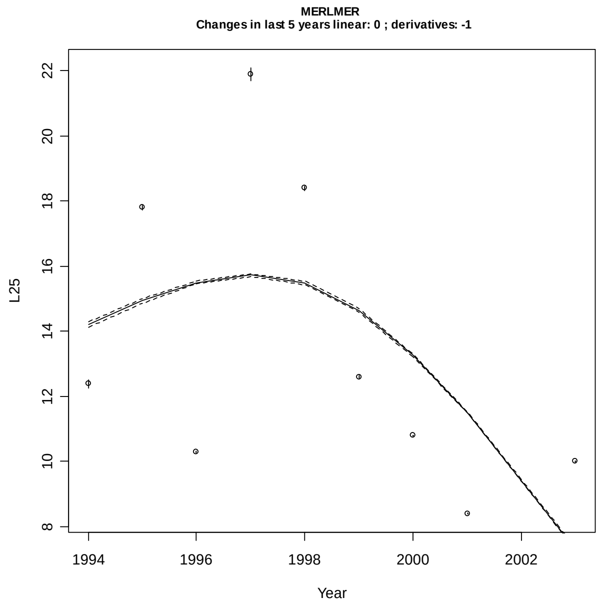
Fig. 11. Time series of the biological multivariate index (above) and of the spatial multivariate index (below).

Trends of selected indices









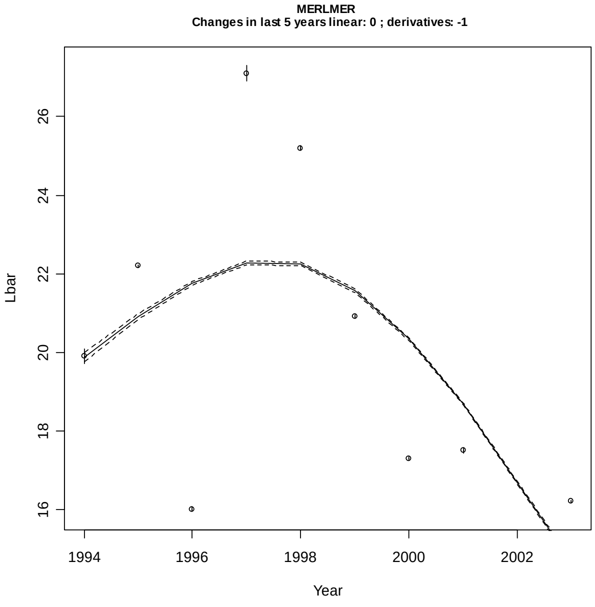


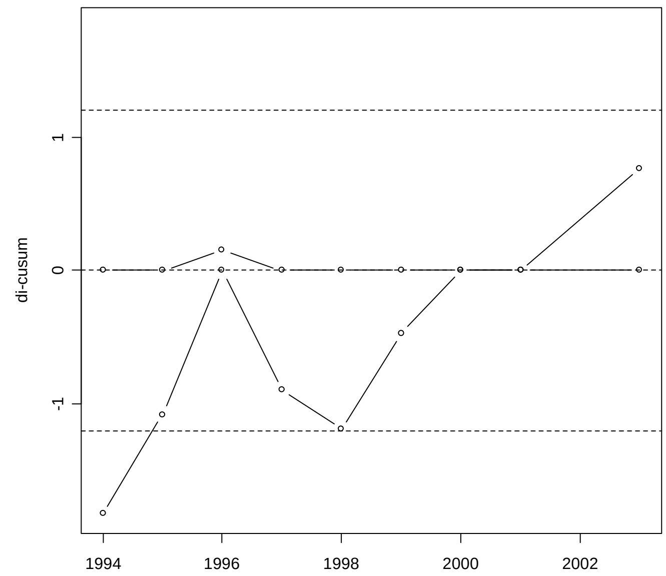
Fig. 12. Trends of the biological indices using the linear and derivatives methods.

Table 7. Trends of the spatial indices for the different ages using the linear and derivatives methods.

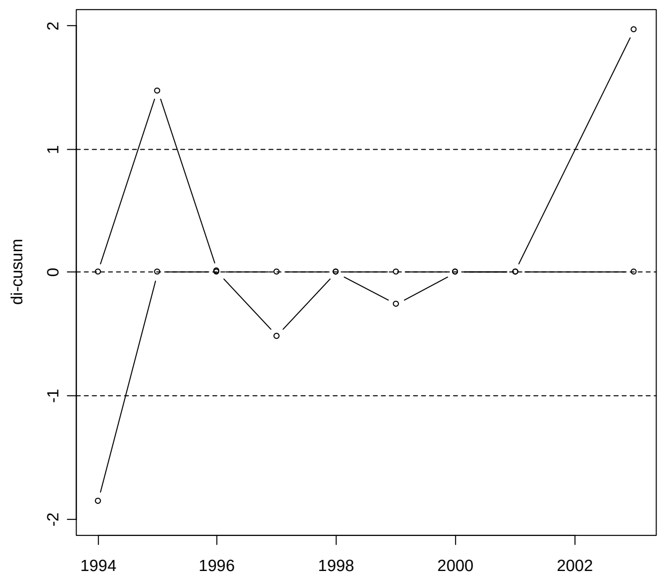
Indicator	LinearSlope	PvalueAll	LinSlopeLast5Years	PvalueLast	DiagnosLinearRecent	DiagnosNonLinearRecent
PositiveAreaA0	88.484	0.18006	235.771	0.01897	1	1
InertiaA0	19.118	0.66032	113.571	0.39468	0	0
AnisotropyA0	0.044	0.77116	-0.23	0.72927	0	-1
MicrostructureIndexA0	0.023	0.08979	0.025	0.1587	0	0
EquivalentAreaA0	-41.889	0.27275	46.514	0.12382	0	0
SpreadingAreaA0	-8.706	0.7972	133	0.05161	0	0
XcgA0	-0.024	0.36188	0.023	0.38279	0	0
YcgA0	0.005	0.83193	-0.029	0.54422	0	0
PositiveAreaA1	30.126	0.46374	94.457	0.46093	0	0
InertiaA1	21.879	0.44208	100.771	0.11489	0	0
AnisotropyA1	-0.045	0.35115	0	0.99703	0	0
MicrostructureIndexA1	0.012	0.33343	-0.029	0.50193	0	0
EquivalentAreaA1	6.224	0.91817	197.6	0.28733	0	0
SpreadingAreaA1	13.527	0.76801	161.029	0.28406	0	0
XcgA1	-0.017	0.48126	-0.029	0.42444	0	0
YcgA1	0.002	0.9027	-0.009	0.70395	0	0
PositiveAreaA2	72.553	0.20519	204.743	0.19102	0	0
InertiaA2	-45.405	0.07872	-87.429	0.27017	0	0
AnisotropyA2	-3.95	0.12951	0.035	0.82894	0	0
MicrostructureIndexA2	0.02	0.18976	0.023	0.61292	0	1
EquivalentAreaA2	-63.934	0.22569	-97.486	0.4823	0	0
SpreadingAreaA2	-32.721	0.4085	-22	0.8487	0	0
XcgA2	-0.017	0.54481	0.037	0.17879	0	0
YcgA2	0.004	0.70888	-0.036	0.13908	0	0
PositiveAreaA3	57.547	0.07177	168.429	0.00321	1	0
InertiaA3	-61.097	0.13677	-161	0.07231	0	0
MicrostructureIndexA3	0.011	0.27749	0.03	0.29366	0	1
EquivalentAreaA3	-37.598	0.39651	-160.714	0.23204	0	-1
SpreadingAreaA3	-24.279	0.49004	-99.343	0.27238	0	0
XcgA3	-0.034	0.29846	0.001	0.9827	0	0
YcgA3	-0.003	0.70205	-0.028	0.14876	0	0
PositiveAreaA4	-37.679	0.21195	60.629	0.31082	0	0
InertiaA4	-52.75	0.32421	-141.143	0.58529	0	0
AnisotropyA4	-0.265	0.20181	-0.218	0.78862	0	0
MicrostructureIndexA4	0.017	0.0569	0.01	0.38921	0	0
EquivalentAreaA4	-42.134	0.05566	-79.143	0.13055	0	-1
SpreadingAreaA4	-26.889	0.16759	-11.371	0.73145	0	0
XcgA4	-0.029	0.58796	-0.057	0.42561	0	0
YcgA4	-0.02	0.41512	-0.02	0.21188	0	0
PositiveAreaA5	-12.942	0.5981	20.6	0.76432	0	1
InertiaA5	18.906	0.71191	-65.229	0.74599	0	-1
AnisotropyA5	-12.955	0.07072	1.09	0.08578	0	0
MicrostructureIndexA5	0.011	0.36168	-0.03	0.28562	0	0
EquivalentAreaA5	3.221	0.85681	38.686	0.52086	0	1
SpreadingAreaA5	-0.134	0.99299	30.714	0.55553	0	1
XcgA5	-0.023	0.76366	-0.268	0.16005	0	0
YcgA5	-0.05	0.15635	-0.033	0.55393	0	0

Di-cusum plots of selected indices

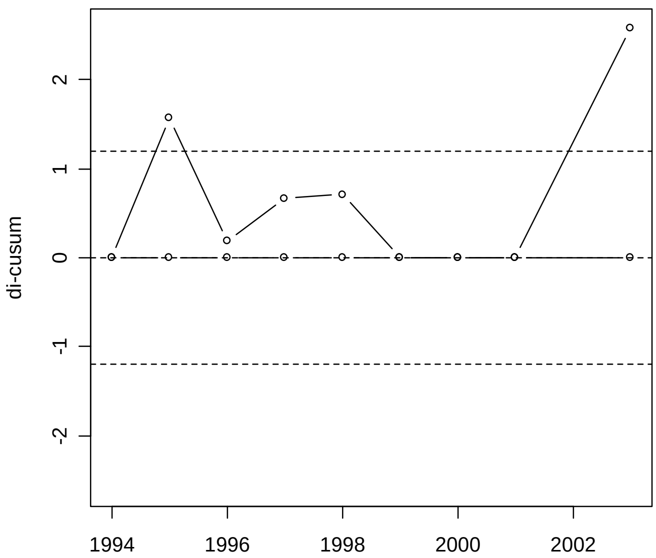
Ln SI



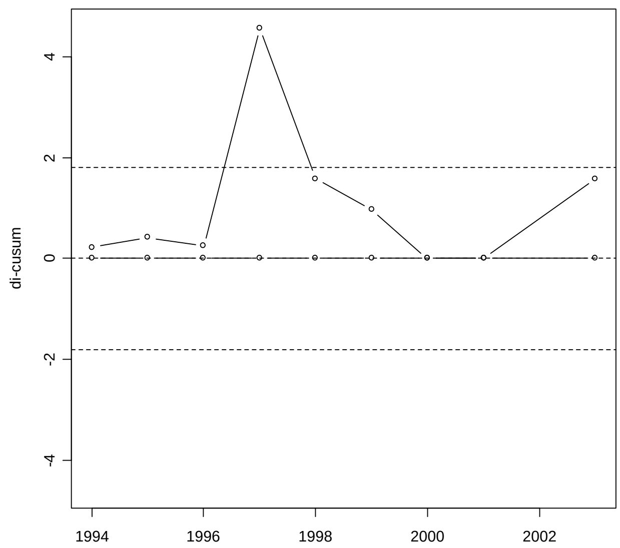
Ln RI

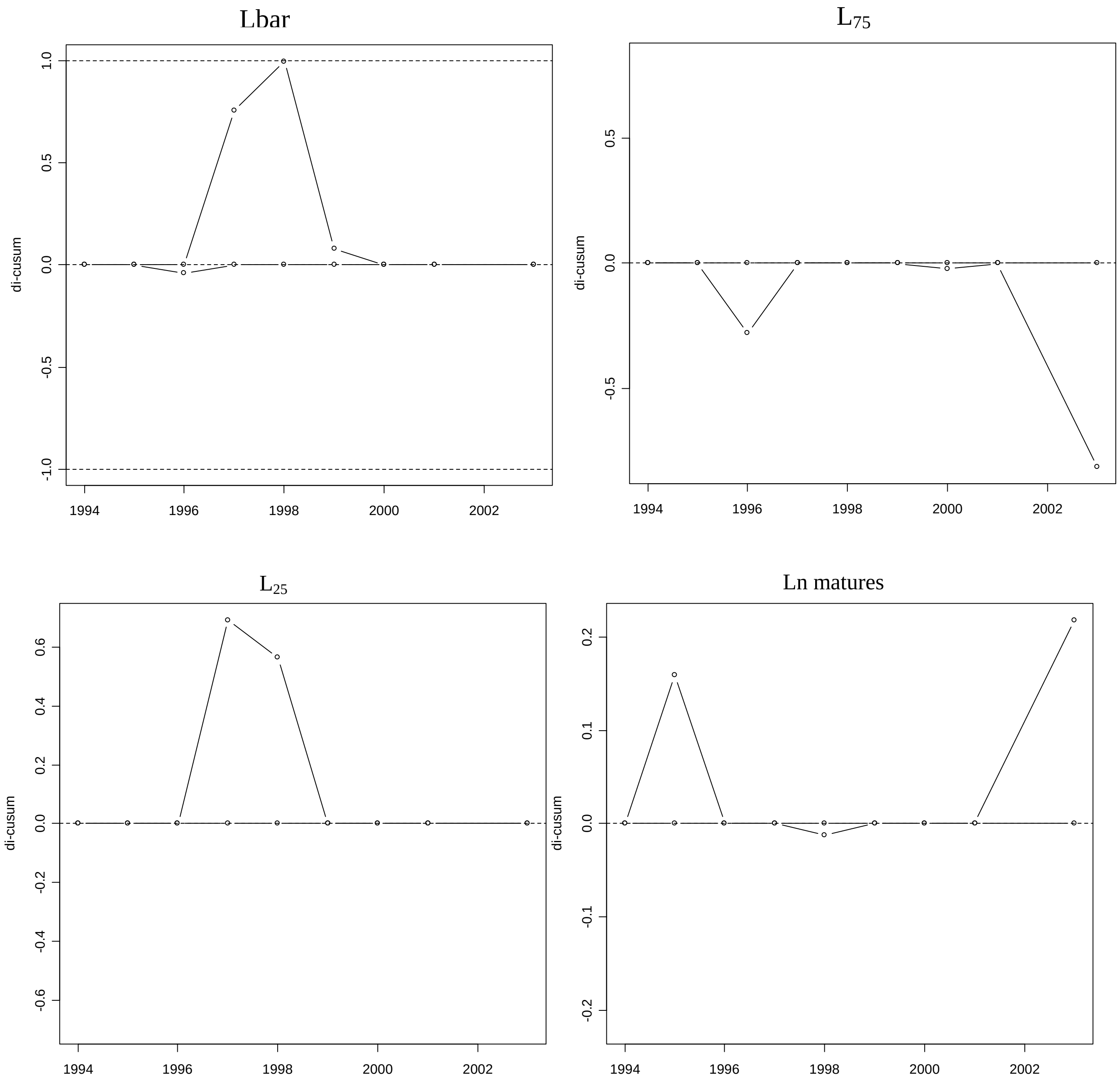


mdbio



MFA spatial




Lbar
L75
L25
Ln matures
di-cusum
1994
1996
1998
2000
2002

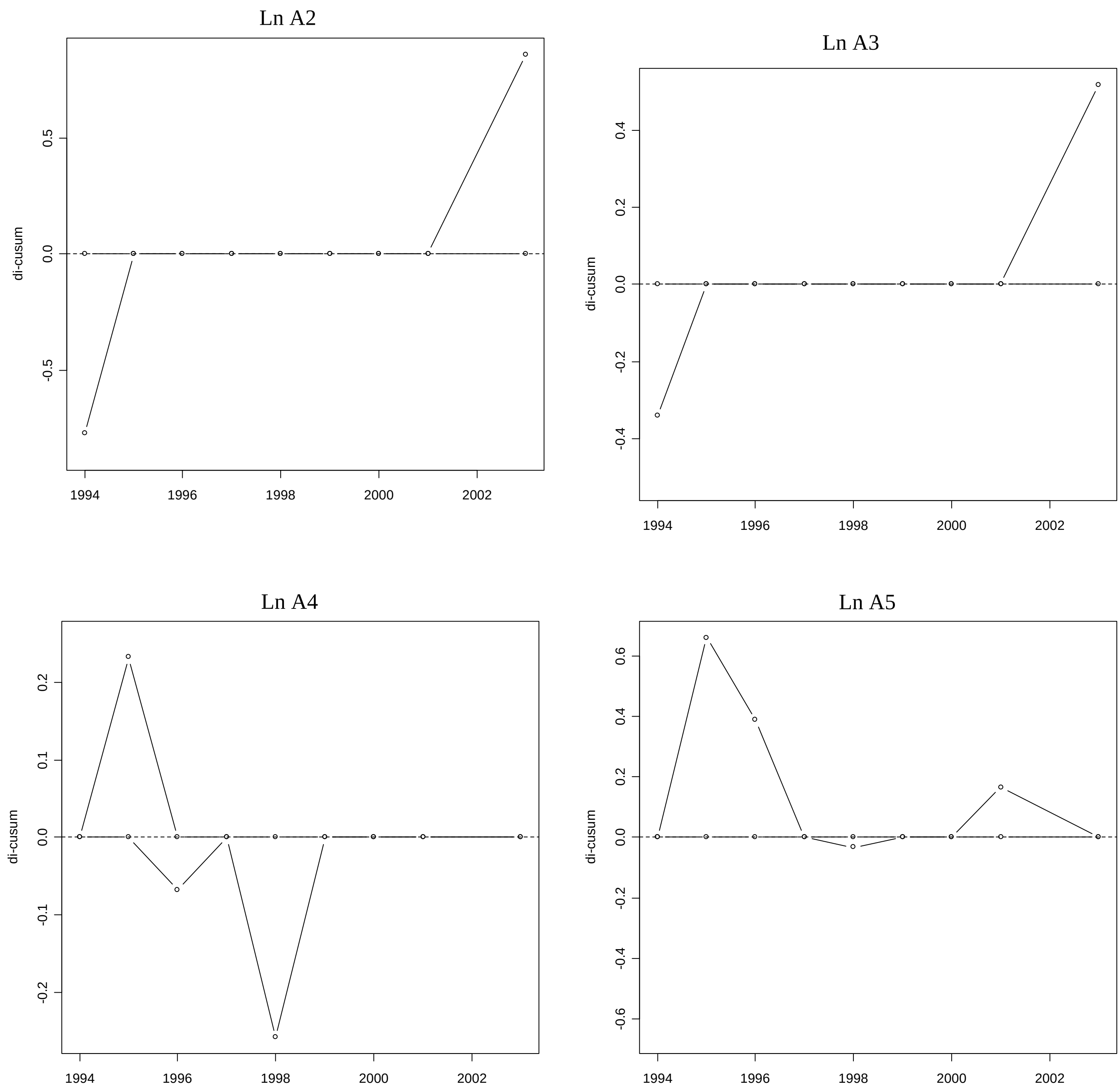


Fig. 13. Di-cusum plots of biological and multivariate indices.

Interpretation

Trend analysis

The trend analysis showed a significantly increasing total abundance of hake in the Ionian Sea for the whole period and for the last 5 years (linear). There was also a significant decreasing trend of all the length indices during the last 5 years (non linear). No trends were obtained for the recruitment index, while the Z values were not good to be analysed.

For the spatial indices, there was no trend during the whole period. However, some trends were obtained during the last 5 years, mainly using the derivatives method. In 4 cases the spatial indices showed a decreasing trend and in 6 an increasing trend mostly for old ages and age 0+.

Cusum analysis

The Cusum analysis did not show any changes in the length indices or in the abundance indices of ages 2 to 5. However, there were signals in the total abundance (negative for the first year), the recruitment index (negative for the first year and positive for the second and last year). Concerning the composite indices, the biological distance showed a positive sign during the second and the last year (1995, 2003), which can be explained by the increased recruitment index. The spatial index showed a positive signal in 1997.

Compare approaches (cusum/trends)

Both methods, more or less, depict a positive change in the total abundance comparing to the beginning of the survey. Although no trends were observed in the recruitment index, the cusum analysis showed a positive change comparing to the first year. On the other hand, the trends observed during the last 5 years in the length indices did not give any changes in the cusum analysis. Furthermore, the recent trends obtained in some spatial indices were not reflected in the cusum analysis of the relevant composite index.

Summary sheet

Survey series

Data were collected during the MEDITS (International bottom trawl surveys in the Mediterranean) surveys in the Greek Ionian Sea from 1994 to 2003. The surveys were carried out every summer in depths from 10 to 800 m using the stratified sampling design and following the MEDITS protocols. In 2002, no survey was carried out in the area.

In the analyses, hake specimens of age 1 were considered as recruits, specimens of age 2 and 50% of age 3 as immature and the rest of age 3 and older as mature.

Non-spatial indices

The abundance index (SI), the recruitment index (RI) and the length indices (Lbar, L25, L75) were analysed using the trends method (linear for the whole period and for the last 5 years and derivatives for the last 5 years) and the cusum analysis. SI showed a positive trend for the whole period and the last 5 years (linear) and a negative signal in 1994 (cusum). RI did not show any trends (linear, derivatives), but it showed a negative signal in 1994 and positive signals in 1995 and 2003 (cusum). The length indices did not show any signals (cusum), although negative trends were obtained for all of them in the last 5 years (derivatives).

Spatial indices

Positive area (PA), Spreading area (SA), Equivalent area (EA), Inertia, Anisotropy, Microstructure and Centre of gravity were analysed by age using the trends method (linear and derivatives). No trends were detected for the whole period, whereas the following recent changes were observed: PAA0 +1(linear, derivatives), Anisotropy

A0 -1(derivatives), MIA2 +1 (derivatives), PAA3 +1 (linear), MIA3 +1 (derivatives), EAA3 –1 (derivatives), EAA4 –1 (derivatives), PAA5 +1 (derivatives), Inertia A5 –1 (derivatives), EAA5 +1 (derivatives) and SAA5 +1 (derivatives).

Composite (derived) indices

MFA spatial indices: The component 1 was highly positively correlated with xcg and highly negatively correlated with the positive area, spreading area and ycg. The component 2 was mostly correlated with anisotropy (positively) and spreading area (negatively). The cusum analysis of MFA spatial gave a positive signal in 1997.

PCA biological indices: The component 1 was highly positively correlated to the total abundance and less to the recruitment index, whereas it was highly negatively correlated to all the other indices. The component 2 was mainly negatively correlated with the recruitment index. The cusum analysis of the multivariate biological index showed positive signals in 1995 and 2003, years with the highest recruitment index.

Reference period

The period 1998-2001 was chosen for reference period. During this period, the sampling was more representative comparing to previous years, since the number of stations was increased.

Summary of results on the stock

There is an increasing trend in abundance during the studied period (linear). This result in combination with the decreasing trend of L25 and Lbar obtained for the recent years (derivatives) could be showing an increasing trend in the recruitment. However, this scenario was not confirmed by the trend of the RI (not significant), although there was indication of increased recruitment in the last year (CUSUM). The simultaneous decreasing trend of L75 (derivatives) could show a slower growth rate. However, this scenario was not supported by the increasing trend of abundance and the decreasing trend of L25. Furthermore, the CUSUM analysis did not give any alarm for the different lengths. Additionally, the CUSUM analysis did not give any signal for the abundance of the different ages with the exception of recruits and the mdbio showed to be driven only by the positive alarms of the recruitment index (1995, 2003).

The results are not clear and perhaps this is due to the short data series (1994-2003). The consideration of more recent years in the analysis is suggested in order to obtain a clearer image.

Comparison with traditional assessment of stock status

Such data are not available for hake in the Greek Ionian Sea.

Formulation of advice

Given the fact that hake was considered overexploited in the beginning of the studied period and that after 1994 the fishing effort was reduced gradually until 2005 and a larger cod-end mesh size was imposed recently, it is suggested to continue the enforcement of the existing measures, which may have resulted in an amelioration of recruitment. The consideration of more recent years in the analysis is suggested before imposing new measures.

Hake Ionian			CUSUM traffic light diagnostic table										
ref.period	1998 - 2001	1998 - 2001	1998 - 2001	1998 - 2001	1998 - 2001	1998 - 2001	1998 - 2001	1998 - 2001	1998 - 200	1998 - 2001	1998 - 200	1998 - 2001	
m in ref.period	2.0	0.7	14.7	13.2	20.2	12.6	25.9	11.6	12.6	11.7	10.1	9.8	
sd in ref.period	0.6	0.3	0.5	0.3	3.7	4.3	3.9	0.6	0.7	0.7	0.8	0.8	
k	1.2	1.6	1.0	1.1	1.1	1.5	1.1	1.1	1.1	1.1	1.1	1.1	
h	1.2	1.8	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
ARL InControl	93.3	2003.0	51.8	45.8	45.8	142.2	45.8	45.8	45.8	45.8	45.8	45.8	
ARL OutControl	1.7	1.8	2.0	1.7	1.7	1.4	1.7	1.7	1.7	1.7	1.7	1.7	
Years	**mdbio**	**MFA_Spatial**	**ln_TotAbd**	**ln_Rec**	**Lbar**	**L25**	**L75**	**ln_Matures**	**ln_A2**	**ln_A3**	**ln_A4**	**ln_A5**	**diagnostic**
1994	0.0	0.0	-1.8	-1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	alarm
1995	1.6	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	alarm
1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1997	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	ref
2002													
2003	2.6	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	alarm

Hake Ionian **Scenario based Diagnostic table (scenarios by combining trends)**

survey period	1994-2003
ref.period	1994
ref status	overfished

Results of trend analysis

	all period	recent
Z	NA	NA
Ln_Abdnce	1	1 (linear)
Lbar	0	-1
L25	0	-1
L75	0	-1
Ln_Recruit	0	0

diagnostic No clear diagnostic can be deduced. a) The senario of increased recruitment is not supported by the 0 trend of ln_recruit and by the recent decreasing trend of L75.
However, according to the cusum analysis there is a positive signal of the recruitment in the last year and there is no signal for L.
b) The senario of slower growth is not supported by the increasing trend of abundance and the recent decreasing trend of L25.

Explanatory scenarios of combined trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
ange in fishing area, s	-1	1	1	0	1	0
ange in fishing area,	1	-1	-1	-1	0	0

Indicator Based Assessment

red mullet Thyrrhenian Sea (GSA10)

M.-T. Spedicato, G. Lembo (SIBM)

Data

Data used in the analyses are of the Medits trawl-surveys in the GSA10 (central-southern Tyrrhenian sea) from 1994 to 2003. Map of the bubble plot of the survey indices (Fig. 1.wp5GSA10; all years, index of total abundance in the whole area including 0 values) indicates a higher abundance of the population in the southernmost part of the area, along the mainland and the north Sicily coasts. In the analysis of the gravity centres age 0 has not been further considered, because its occurrence depended on the shift in the survey calendar. Age A1 represented immature or recruits while ages A2 and A3 adults or fully mature. Maps of the GCs across years (Fig. 2.wp5GSA10) highlight a less changing spatial location of the younger age (A1) compared to the older ones (A2 and A3) that are more dispersed in both the geographical sub-units 10a (mainland coasts) and 10b (north Sicily coasts).

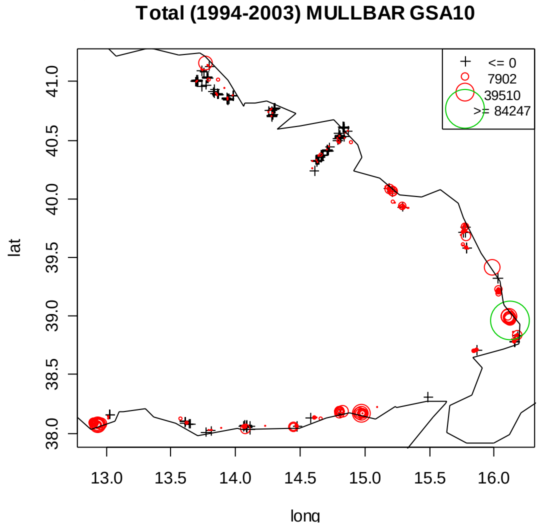


Fig. 1.wp5GSA10. Map of the bubble plot of the survey indices.

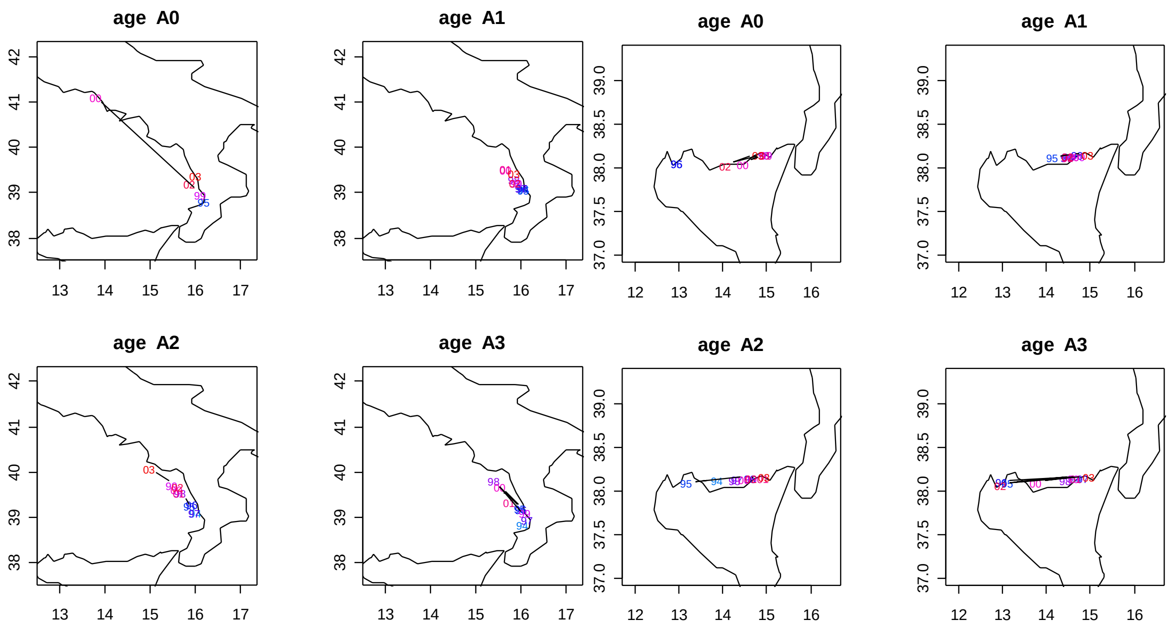


Fig. 2.wp5GSA10. Maps of the gravity centres in the subunit 10a (mainland coasts, left) and 10b (North Sicily, right).

The input parameters for spatial indices were as follows:

10a function infl(db = db.fish, pol=polcgi.fish10a.dg, dlim=40, ndisc=200)
10b function infl(db = db.fish, pol=polcgi.fish10b.dg, dlim=30, ndisc=200)
10a function NBPatches(db=db.fish, vz=c("A1","A2","A3"), Lim.D=40, B.li=0.1, nplot=c(1,1))
10b function NBPatches(db=db.fish, vz=c("A1","A2","A3"), Lim.D=30, B.li=0.1, nplot=c(1,1))
10a f.microstructure(db=db.fish, vz="A1", h0=10, pol= pol.FishData10a.dg, dlim=40, ndisc=200)
10b f.microstructure(db=db.fish, vz="A1", h0=3, pol=pol.FishData10b.dg, dlim=30, ndisc=200)
(same function parameters for each age).

The raw spatial indices, related to the subunits 10a and 10b are respectively reported in Tab. 1.wp2aGSA10a and in the Tab. 2 wp2aGSA10b, while the raw non-spatial indices are in Tab. 3. wp2a10a&b. The age 0 group has been excluded in the estimates of Lbar, L25, L75 and L50.maturity.

Tab. 1.wp2aGSA10a. Spatial indices (age 0 has been excluded)

Year	Age	Abundance	Pos.Area	Inertia	Anisotropy	xcg	ycg	N.P.	Microst.	Equiv.Area	Spre.Area
1994	A1	4913000	1036	333	6.328	16.05	39.12	2	0.786	389	410
1995	A1	2922000	1277	349	6.848	16.06	39.07	2	0.864	274	359
1996	A1	3224000	1617	456	4.906	16.02	39.14	2	0.836	344	499
1997	A1	2791000	1262	662	7.221	16	39.14	2	0.834	311	376
1998	A1	9351000	2760	1435	6.286	15.85	39.33	2	0.819	480	703
1999	A1	5266000	2342	1307	8.581	15.9	39.24	2	0.858	310	503
2000	A1	4141000	2017	1264	9.902	15.67	39.53	2	0.77	699	689
2001	A1	4656000	2310	1507	5.836	15.65	39.55	2	0.741	1180	1130
2002	A1	4614000	1505	1372	10.389	15.89	39.24	2	0.753	563	601
2003	A1	1537000	1668	831	5.133	15.84	39.45	2	0.827	490	586
1994	A2	704000	1036	373	3.687	16.01	39.11	1	0.746	516	512
1995	A2	419000	1354	1042	5.049	15.88	39.27	2	0.863	431	513
1996	A2	742000	1022	473	5.039	15.92	39.31	1	0.697	782	695
1997	A2	335000	929	672	4.352	15.98	39.12	2	0.859	288	352
1998	A2	699000	2038	1046	4.142	15.66	39.57	2	0.577	1530	1320
1999	A2	424000	1732	1869	6.727	15.46	39.75	2	0.695	1170	1010
2000	A2	638000	1233	885	8.754	15.57	39.65	2	0.727	708	609
2001	A2	638000	1637	1299	3.848	15.61	39.58	2	0.647	1380	1160
2002	A2	300000	971	676	9.939	15.58	39.72	1	0.8	377	417
2003	A2	95000	994	583	10.562	14.99	40.1	2	0.664	900	828
1994	A3	30000	391	105	NA	16.01	38.87	1	0.687	411	376
1995	A3	48000	447	424	58.211	16	39.2	2	0.847	430	342
1996	A3	72000	664	277	26.571	16.01	39.21	1	0.773	495	491
1997	A3	33000	137	0	NA	16.13	38.98	1	0.894	142	137
1998	A3	77000	804	1417	10.704	15.38	39.85	2	0.749	780	670
1999	A3	29000	382	48	NA	16.07	39.13	1	0.725	398	381
2000	A3	155000	611	792	62.123	15.53	39.71	2	0.766	571	479
2001	A3	31000	436	1059	3.733	15.74	39.37	2	0.819	475	436
2002	A3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NaN
2003	A3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NaN

Tab. 2 wp2aGSA10b. Spatial indices (age 0 has been excluded)

Year	Age	Abundance	Pos.Area	Inertia	Anisotropy	xcg	ycg	N.P.	Microst.	Equiv.Area	Spre.Area
1994	A1	919000	203	1659	46.6	14.42	38.15	2	0.611	144	128
1995	A1	766000	438	1489	20.328	14.16	38.14	3	0.732	85.5	101
1996	A1	1377000	278	1273	61.02	14.63	38.15	2	0.599	178	164
1997	A1	791000	303	1707	20.26	14.34	38.13	2	0.629	262	217
1998	A1	2571000	355	1734	35.554	14.39	38.14	2	0.67	198	180
1999	A1	1616000	370	807	16.702	14.72	38.15	1	0.598	191	184
2000	A1	3235000	430	1295	89.343	14.63	38.15	2	0.606	171	156
2001	A1	4673000	451	1311	17.873	14.49	38.13	3	0.624	251	223
2002	A1	1751000	211	1638	143.308	14.49	38.15	2	0.619	176	160
2003	A1	1699000	409	53	13.356	14.94	38.17	1	0.594	145	138
1994	A2	133000	176	2249	49.655	13.79	38.13	2	0.619	128	109
1995	A2	178000	236	620	37.83	13.16	38.1	2	0.8	46.2	66.3
1996	A2	146000	226	1077	42.248	14.66	38.16	2	0.59	176	171
1997	A2	73000	226	2062	59.83	14.29	38.14	2	0.603	197	174
1998	A2	239000	288	2124	36.77	14.09	38.12	2	0.672	200	168
1999	A2	337000	329	1449	34.012	14.55	38.15	2	0.619	179	166
2000	A2	344000	308	1576	127.384	14.48	38.14	2	0.616	193	178
2001	A2	829000	350	219	13.035	14.9	38.16	1	0.592	161	151
2002	A2	438000	193	1165	103.846	14.66	38.16	2	0.602	174	153
2003	A2	232000	212	30	NA	14.94	38.17	1	0.595	139	129
1994	A3	72000	105	1423	261.49	14.61	38.15	2	0.557	92.2	86.2
1995	A3	21000	137	195	13.177	13.13	38.11	2	0.715	77.7	83.7
1996	A3	8000	62	7	3.38	12.95	38.09	1	0.641	38.8	45.3
1997	A3	62000	159	1052	201.263	14.73	38.16	2	0.6	139	132
1998	A3	82000	288	1274	26.355	14.31	38.12	2	0.534	155	161
1999	A3	59000	159	1703	182.029	14.51	38.15	2	0.667	137	124
2000	A3	131000	308	2105	161.09	13.78	38.11	2	0.678	102	127
2001	A3	272000	156	1132	NA	14.69	38.16	2	0.602	160	144
2002	A3	57000	35	0	NA	12.96	38.08	1	0.689	37.3	35.1
2003	A3	38000	124	0	NA	14.96	38.17	1	0.595	132	124

Tab. 3. wp2a10a&b. Non spatial indices GSA10 (age 0 has been excluded in the estimates of Lbar, L25, L75 and L50.maturity).

Year	Survey index	Recruit.index	Lbar	L25	L75	L50.maturity	Z	StdLbar	StdL25	StdL75	SdL50.maturity
1994	6984000	6002000	15.06	13.00	15.80	14.10	1.77	0.012	0.024	0.069	0.033
1995	4447000	3768000	15.36	13.30	16.50	14.80	2.09	0.015	0.044	0.080	0.156
1996	5662000	4647000	15.19	13.10	16.20	14.50	2.44	0.016	0.051	0.116	0.190
1997	4052000	3537000	14.83	12.90	15.50	14.00	1.32	0.018	0.028	0.107	0.108
1998	13202000	12037000	14.75	12.90	15.50	13.80	2.65	0.006	0.013	0.025	0.019
1999	7854000	6958000	15.13	13.20	16.00	14.40	2.08	0.009	0.031	0.117	0.050
2000	9271000	7332000	15.17	13.10	15.90	14.30	1.71	0.011	0.020	0.038	0.040
2001	12156000	9278000	15.24	13.20	16.00	14.40	2.73	0.008	0.020	0.065	0.023
2002	30901000	6283000	15.12	13.00	16.00	14.30	3.01	0.014	0.025	0.183	0.079
2003	6781000	3048000	14.44	12.80	14.90	13.70		0.019	0.045	0.259	0.080

The combined non-spatial population indices are reported in the Tab.4. wp5_red mullet_GSA10a&b. The plot in Fig. 3.wp5GSA10 display the relationship between the principal components and the eigen value, that rapidly decrease, thus the first two components provide a reasonable summary of the data. The PC loadings reveal that the first component explains almost all the data variability and is highly positively correlated with all the length-related indices as well as with the recruit index, while it is negatively correlated with the total mortality. The second component is positively well correlated with the survey index, while it shows a very low correlation with the other indices, except for total mortality that is, however, poorly correlated (~0.32). This is also represented in the correlation circle in the Fig. 4.wp5GSA10.
The diagram of the first two PCs (Fig. 3.wp5GSA10) shows that the pattern in terms of time (years) on the first component axis is more associated with the length-related indices (positively) and mortality (negatively), while the second component axis should mainly benefits of survey index (positively).
The year 2003 shows the highest multivariate distance from the gravity centre within the reference period followed by 1997, outside the reference period. In the latter all the population indices were low, including total mortality, while in the former the length and abundance indices (both survey and recruit) were low but total mortality was at the highest level.

Tab.4. wp5_red mullet_GSA10a&b. PCA results. Multivariate non spatial indices by year

Non spatial Indices	PCs loadings			PCs multivariate distance index	
	Comp1	Comp2		year	md
Ln.Ntot	0.356091	**0.79854**		1994	0.75948
Ln.Nrec	**0.887619**	-0.08248		1995	2.151838
Lbar	**0.88978**	0.053305		1996	1.624576
L25	**0.823143**	-0.2659		1997	2.387907
L75	**0.868604**	0.149741		1998	0.523856
L50.matu	**0.878409**	0.037966		1999	0.882524
Z	**-0.6415**	0.31662		2000	1.090799
				2001	1.972025
				2002	1.881551
				2003	4.053707

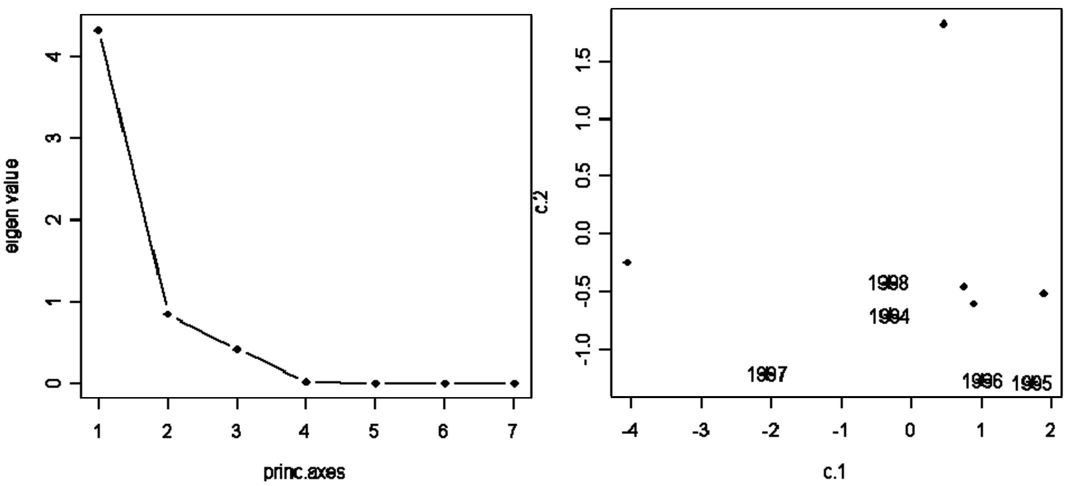


Fig. 3.wp5GSA10. Relationship between the first components and the eigen values (left); PC of axes 1 and 2 (right).

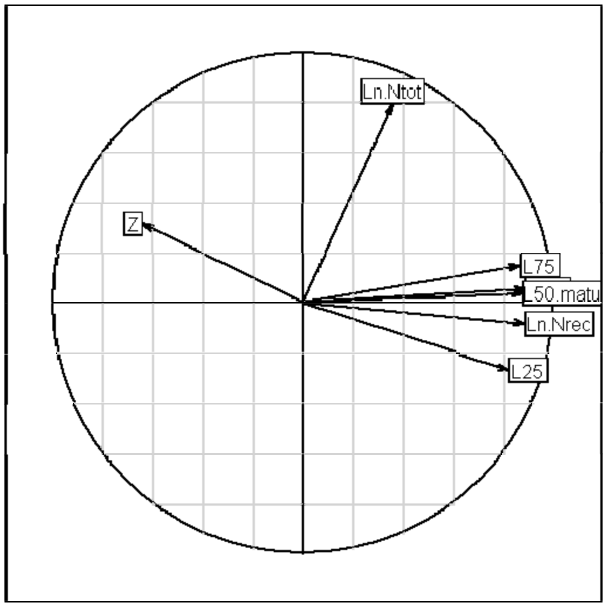


Fig. 4.wp5GSA10. Correlation circle from PCA of non-spatial indices

The combined spatial population indices are reported in the Tab.5. wp5_red mullet_GSA10a&b. The plots in Fig. 5.wp5GSA10a&b show the age groups in the factorial space. The two age groups of the subunit 10a occupy rather distinct portion of the factorial space, while those of the subunit 10b are more overlapped, with the first two ages close each other, but rather separated from the oldest group (age 3). The PCs loadings reveal that in the subunit 10a the first component explains most of the variability and is highly positively correlated with the spreading and equivalent area and the ycg, while it is negatively correlated with the microstructure index and the xcg. The second component is highly positively correlated with the positive area. Both the components are almost equally correlated with inertia. In the subunit 10b, the first component explains less variability compared to the subunit 10a and it is highly positively correlated with the spreading and equivalent area, the xcg, the ycg and the positive area, while it is negatively correlated with the microstructure index. The second component is positively correlated with the ycg and negatively correlated with inertia and microstructure indices. This is also represented in the correlation circles in fig. 6.wp5GSA10a&b. In general, the loadings more effecting the analysis seem to be primarily the occupation and then the location indices in both the geographical subunits.
In the subunit 10a, the year 2001 shows the highest multivariate distance from the gravity centre of the factorial space within the reference period, followed by 1998 outside the reference period. In the subunit 10b, the year 2002 shows the highest multivariate distance from the gravity centre of the factorial space within the reference period, while outside the reference period the higher value was observed in 1996.

Tab. 5. wp5_red mullet_GSA10a&b. PCA loadings by component and subunit 10a and 10b of the GSA10. Multivariate spatial indices by year and subunit.

Spatial Indices	**PCs loadings by subunit 10a and 10b**					**PCA dmul index by subunit 10a and 10b**		
	Comp1 10a	Comp2 10a	Comp1 10b	Comp2 10b		year	dmul 10a	dmul 10b
PositiveArea	0.38	**0.867**	**0.586**	-0.48		1994	2.642965	3.284793
Inertia	**0.62**	**0.654**	0.374	**-0.657**		1995	2.678753	7.215753
xcg	**-0.795**	0.382	**0.892**	0.378		1996	1.044853	5.128001
ycg	**0.816**	-0.355	**0.762**	**0.506**		1997	3.194324	1.433489
MicrostructureIndex	**-0.84**	0.312	**-0.642**	**-0.534**		1998	4.303184	1.945616
EquivalentArea	**0.932**	-0.02	**0.897**	-0.281		1999	3.453014	1.198815
SpreadingArea	**0.937**	0.148	**0.909**	-0.315		2000	2.393162	2.522977
						2001	5.030488	2.325563
						2002	1.812827	5.696466
						2003	3.397546	4.592594

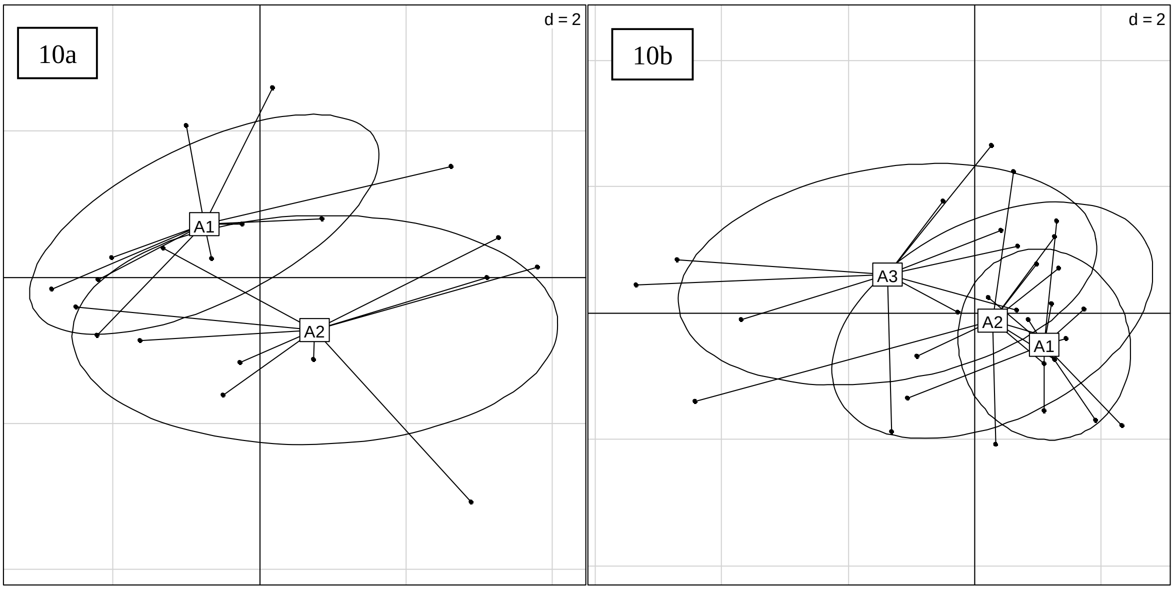


Fig. 5.wp5GSA10. Age groups in the factorial space for the subunits 10a and 10b of GSA10.

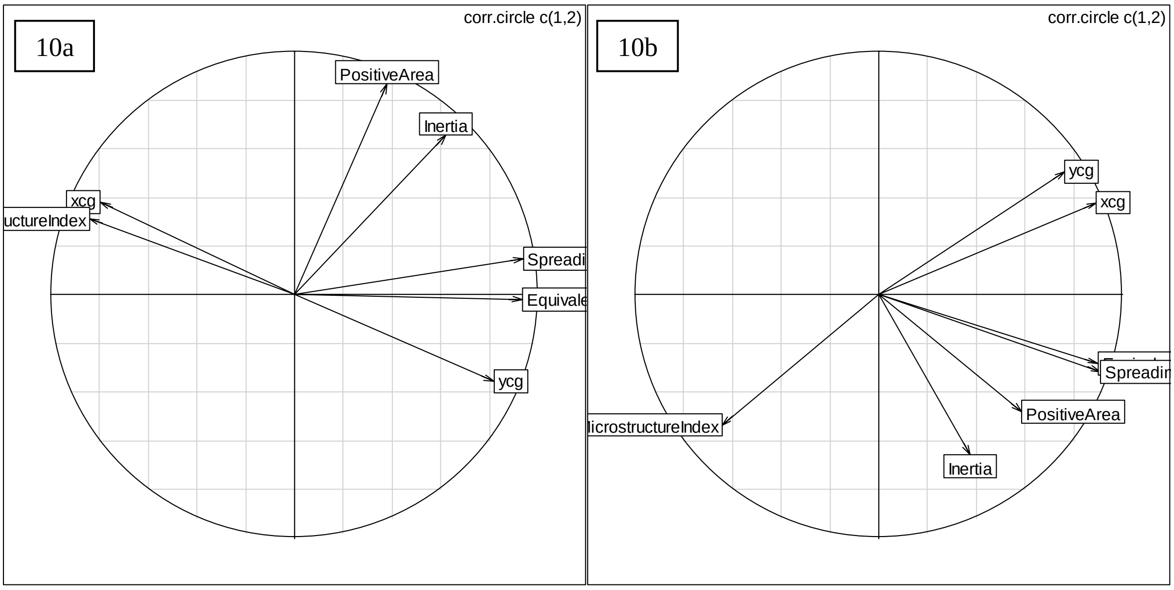


Fig. 6.wp5GSA10a&b. Correlation circles from PCAs of spatial indices of the subunits 10a and 10b of GSA10.

Looking for changes

1. Visual inspection. Plots of selected indices (raw & combined)
Plots of non-spatial univariate indices show the increasing of the survey index (total abundance, all ages) in 1998 and 2002, while a decreasing occurred in 2003, reaching an intermediate value in the range of the observations in 1994-1997 and 1999-2001. Similar pattern is observed for the recruit index (abundance of the age 1 group), that reached a very low value in 2003. The length indicators (age 0 excluded) show a decreasing from 1995 to 1998, an increasing in 1999 and stable values up to 2002, while a decreasing was observed again in 2003. The total mortality was rather varying with lower values in 1997 and 2000, while it increased more in 2001 and especially in 2002. Globally, indices of length structure and recruit abundance were decreasing in the last two years, while total mortality was increasing. A similar pattern was observed in 1997, but in this year the total mortality index was considerably lower.
The plot of the non-spatial multivariate index shows the higher distance from the gravity centre in 2003 and the lower in 1998, the former likely as effect of the changes in many univariate indices (decreasing of recruits and length indices, increasing of total mortality) the latter when a decrease of length indices occurred. The multivariate distance index seems more affected by the loadings based on demography indices (lengths) and recruitment index.

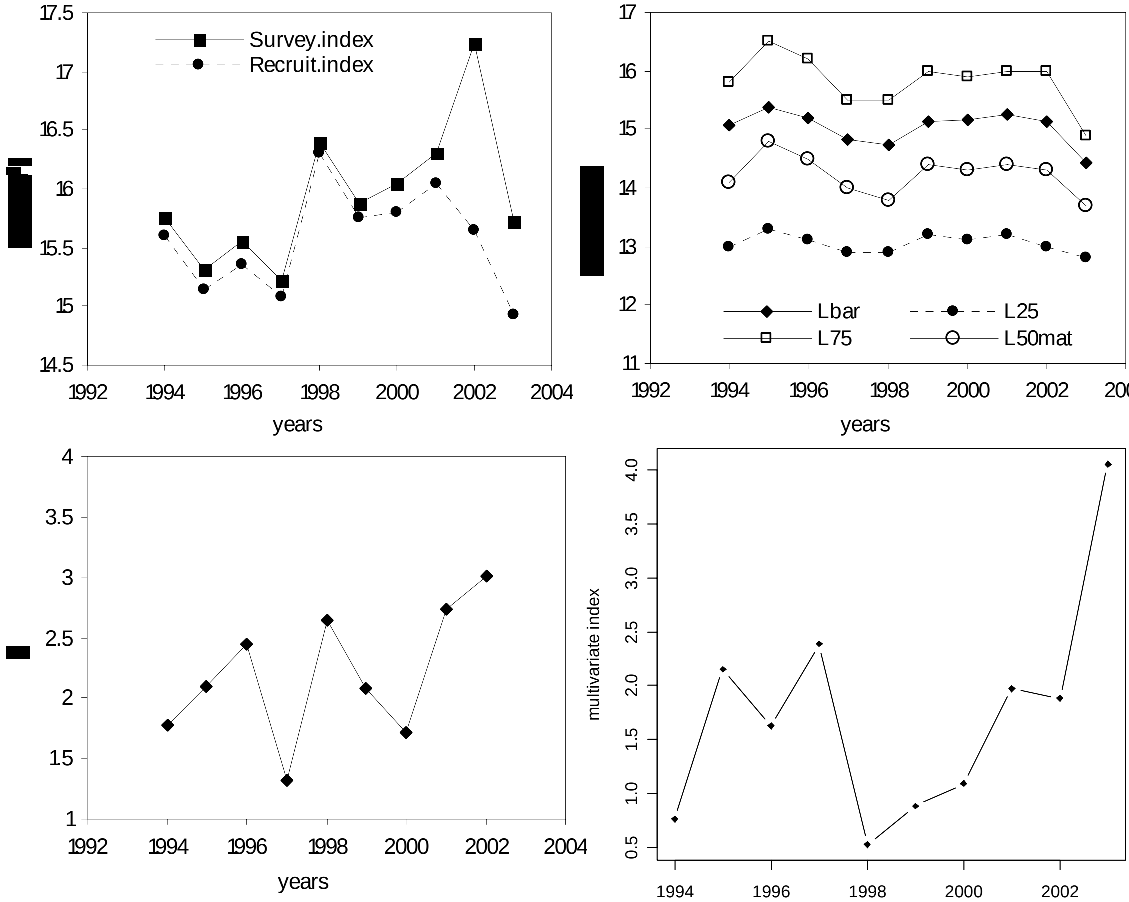
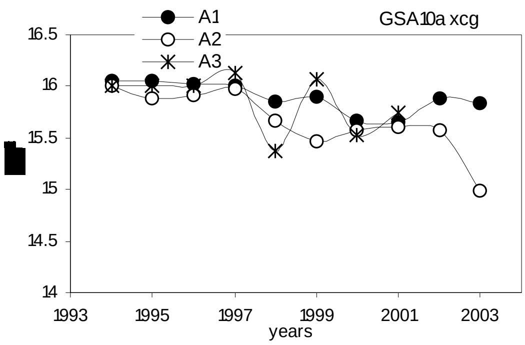
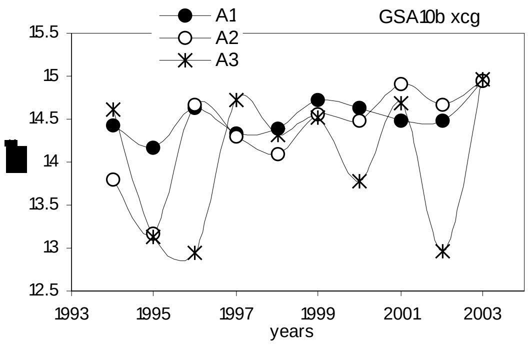


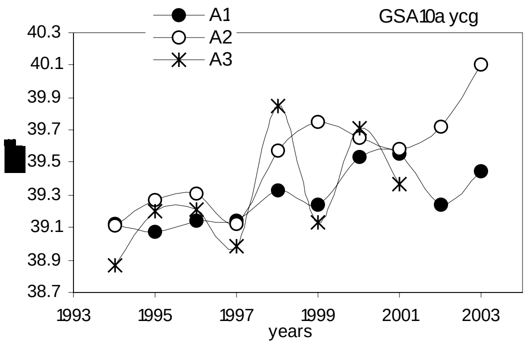
Fig. 7.wp5GSA10. Raw univariate non spatial indices (survey index, recruit index, lengths indices and Z) and multivariate index (lower right)

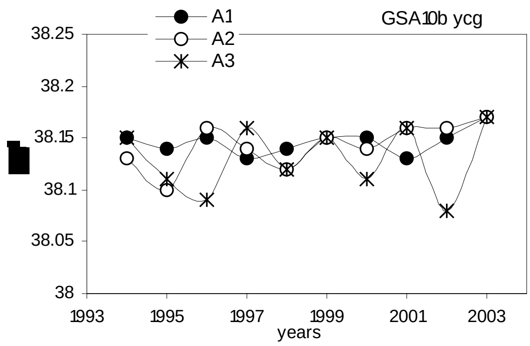
In the sub-area 10a plots of univariate spatial indices highlight that the occupation indices such as positive, equivalent and spreading areas are varying considerably for all the three age groups without any apparent tendency. Location indices, conversely, evidenced temporal changes, in particular xcg was decreasing for all the age groups, while ycg and inertia of the age group 1were increasing, as well as the anisotropy of the age group 2, all these indicating a shift of the population age groups offshore and towards the northern side of the area, associated with a higher spatial dispersion. These aspects might be related to the seasonal movements of the species, to inshore for spawning (May-June-July) and then offshore, the latter displacement likely more intercepted in the surveys of 2002 and 2003. The microstructure was decreasing, but only for the age 3 group. What is, in addition, remarkable is that the age group 3 disappeared from the experimental catches of the last 2

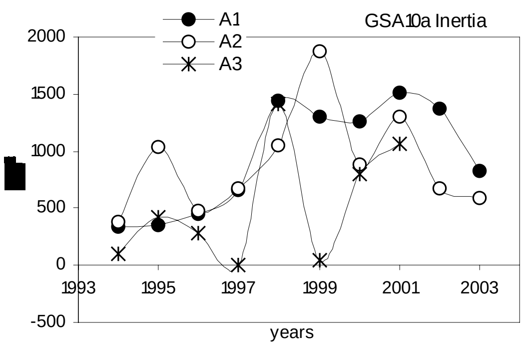
years (2002-2003). Effects of an increased fishing pressure on the reduction of the older groups in the population might thus be considered.
In the sub-unit 10a, the multivariate spatial index was higher in 1998 and 2001, probably as consequence of high equivalent and spreading areas in those years, while in the sub-unit 10b it increased considerably in 1995-1996 and in 2002, that were more distant from the other years for several spatial indices.
On average, the multivariate distance was higher in the subunit 10b (~3.5) compared to the 10a (~3.0), highlighting a higher variability in the multivariate spatial pattern or a lower stability in the correlation among spatial indices in the former subunit.

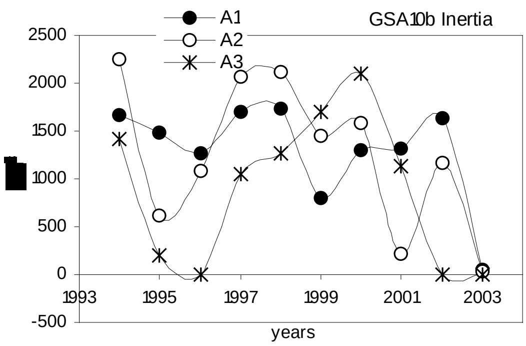


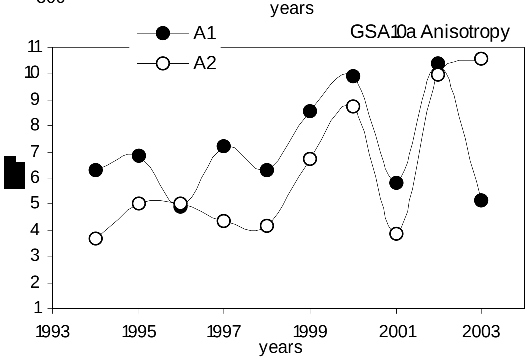


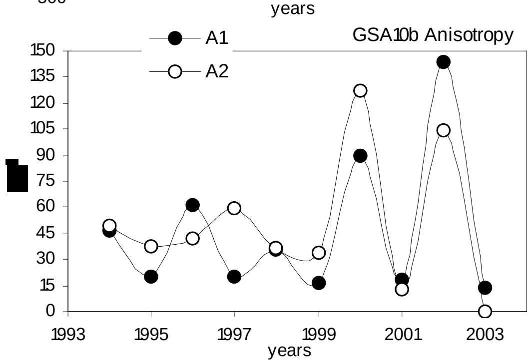












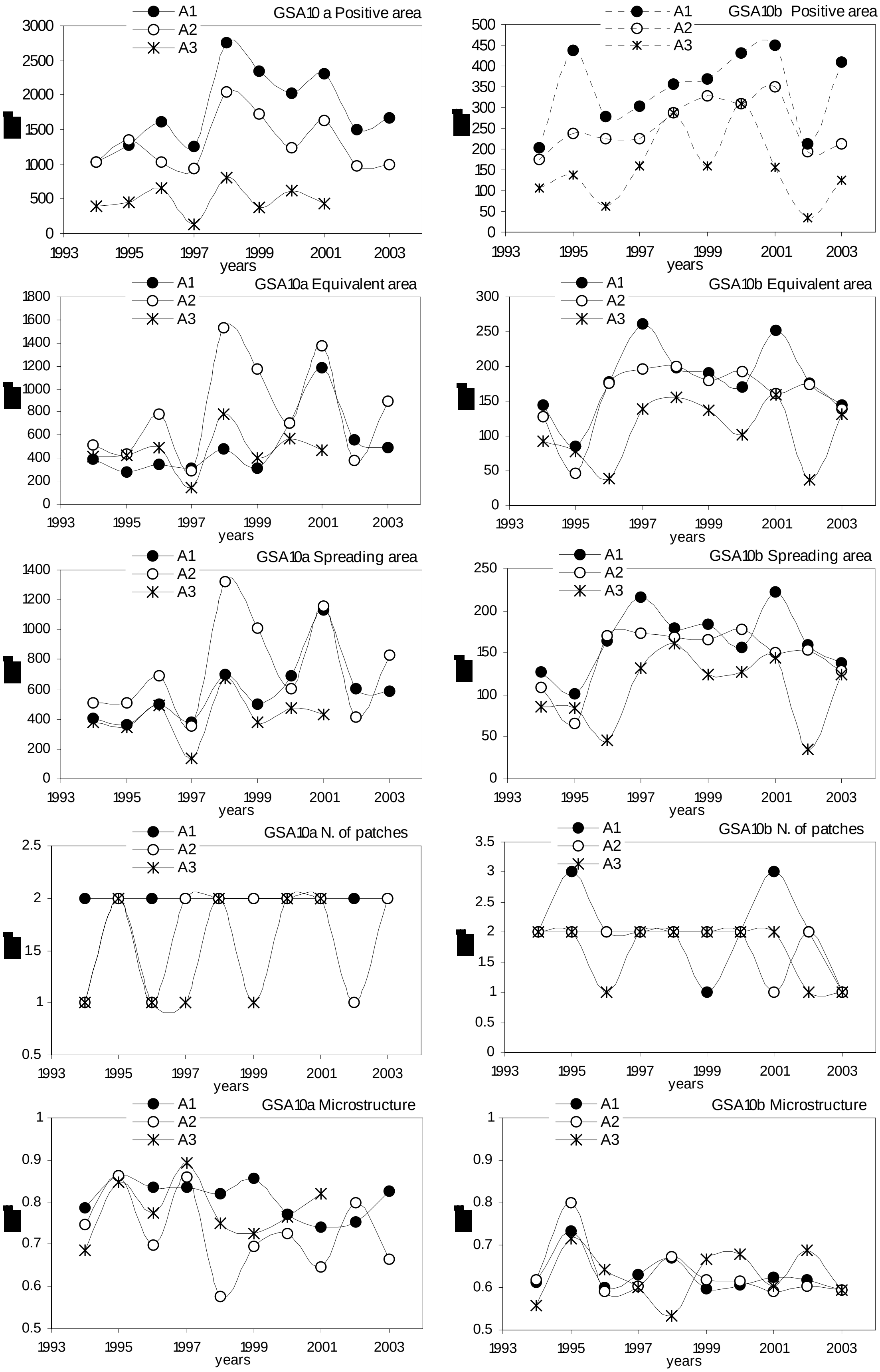


Fig. 8.wp5GSA10. Raw spatial indices of GSA10a (left) and GSA10b (right).

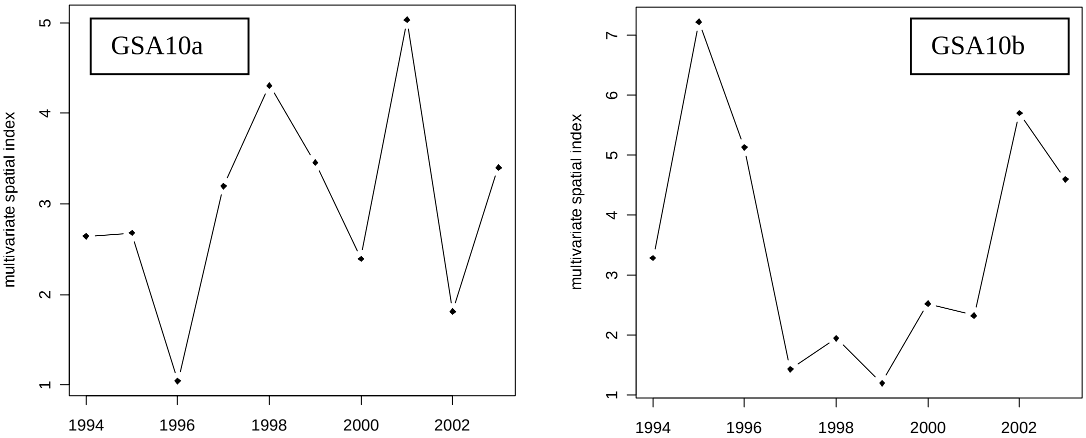
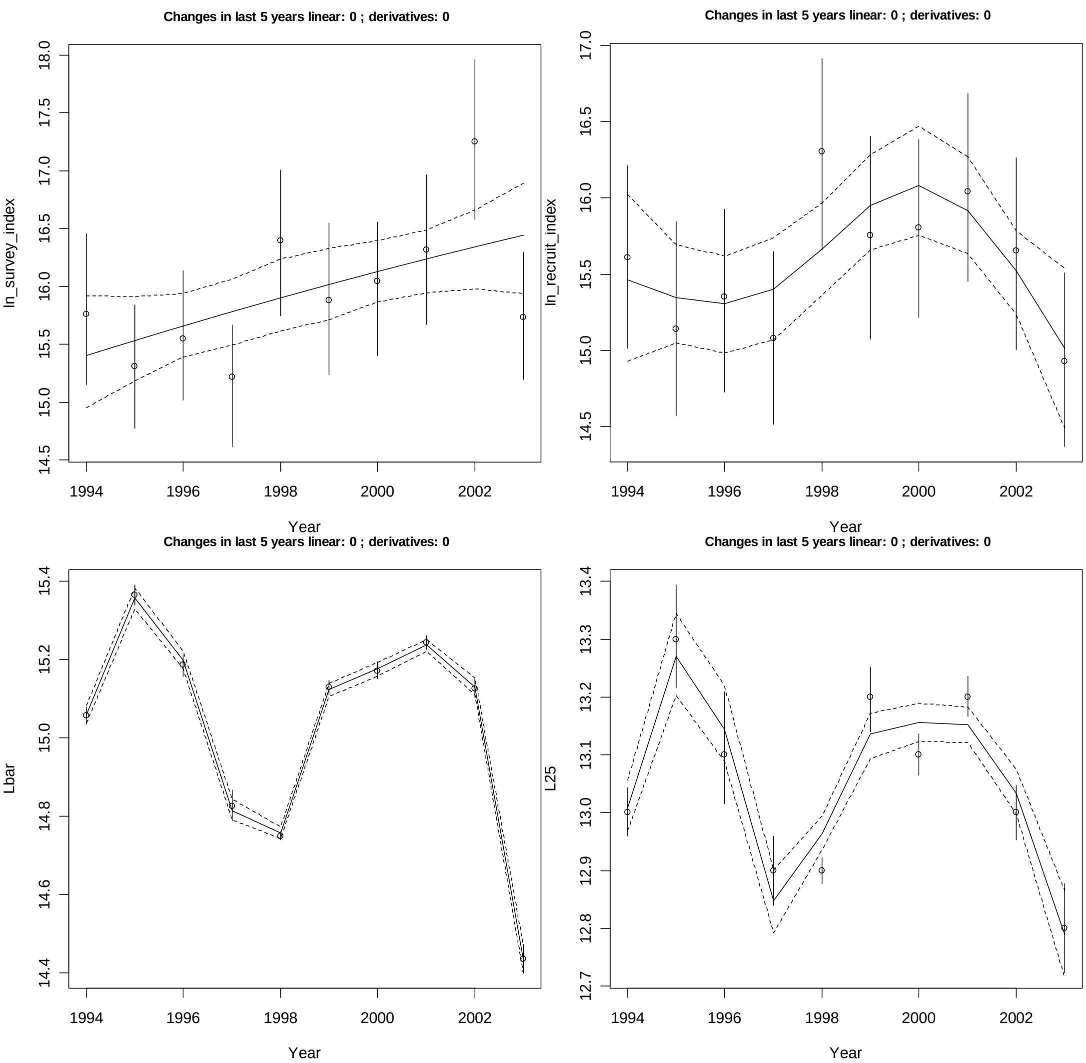


Fig. 9.wp5GSA10. Multivariate spatial indices in the GSA10a (left) and GSA10b (right).

2. Trend plots of selected indices

Trend analysis results (Tab. 6. wp5_red mullet_GSA10a&b) of non-spatial indices are based on linear and non-linear (derivative on a GAM smoothed series) methods, the former applied for both all and recent periods, the latter only for recent years. Reference period for detecting recent changes was based on the last five years (1999-2003). The non spatial population indices did not show any significant trend in all period and changes were not detected also in recent years, except for the total mortality that shows a recent positive increasing, although interannual variations seem rather high, especially considering 1997 and 2000 values (Fig. 10.wp5.GSA10). Also multivariate non spatial index showed a change in the recent years as detected through linear slope.



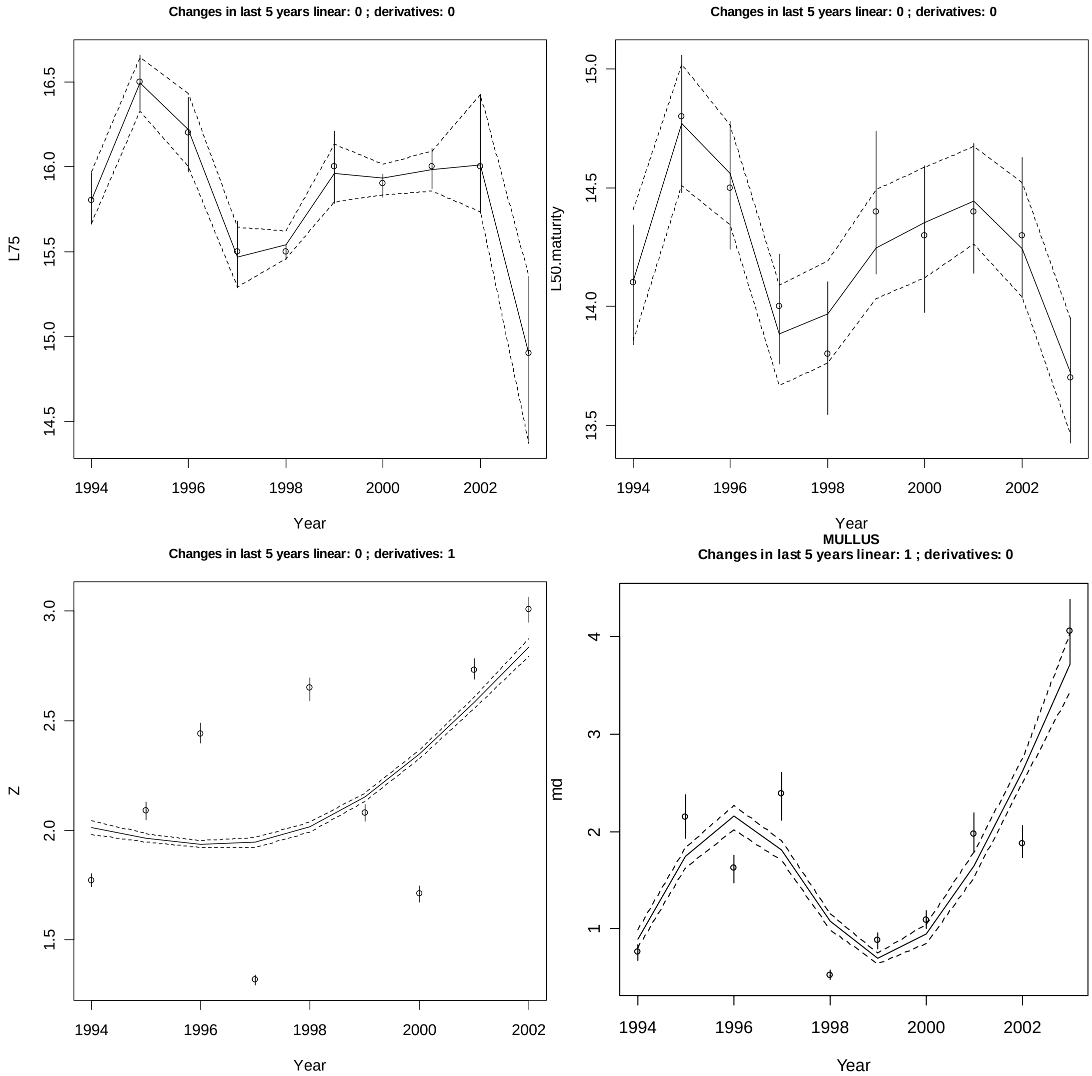


Fig. 10.wp5.GSA10. Plots of the trend analysis using derivative method.

Linear regression and non-parametric trends (Kendall's Thau, Spearman's rho) were used for analysing univariate spatial indices in all period. Results were considered significant when at least 2 of the three methods applied were consistent. The occurrence of changes in the recent years (1999-2003) was analysed using linear and non linear (derivative) methods, but only the latter was retained for diagnostic purposes. Results are reported in tab. 6. wp5_red mullet_GSA10a&b.

In all the period and in the sub-unit 10a, xcg was significantly decreasing for all the age groups, while microstructure was diminishing for the age 3 group alone. Ycg, inertia and spreading area of the age group 1 were significantly increasing, as well as anisotropy of the age 2 group. In the sub-unit 10b, the spatial indices seem more stable across time, with only xcg of the first two age groups and ycg of the age 2 significantly increasing. The analysis on recent years (Tab. 6. wp5_red mullet_GSA10a&b) shows that xcg of age 3 group, inertia and positive area of age 2 group were all decreasing in the subunit 10a (population stages located more offshore, and less dispersed), while in the subunit 10b inertia of age 2 group and positive area of age 3 group were decreasing (lower spatial dispersion).

MAF method was also used for analysing multivariate statistics of spatial indices. Figure 11.wp5GSA10 shows the variogram at lag 1 in the subunit 10a and 10b. In the sub-unit 10 a, inertia (age 1) and xcg (age 2) were the most continuous indices, the former positively and the latter negatively contributing to the observed trend of the MAF1 and MAF 2 respectively (Fig. 12.wp5GSA10a). These results are consistent with the observed positive increasing of inertia and decreasing of xcg observed in the plots of indices and the outcomes from PCA.

In the sub-unit 10b, the most continuous indices contributing respectively to the observed trend of MAF1 and MAF 2 were xcg (age 2) and spreading area (age 2), both acting as negative loadings of the MAFs (Fig. 13.wp5GSA10b). This result seems instead contrasting with the outcomes of PCA and plots of indices.

Tab. 6. wp5_red mullet_GSA10a&b. trend diagnostic table

Non-spatial and spatial indices	all period 10a&b	recent 10a&b	all period 10a	all period 10b	recent 10a	recent 10b
Z	0	1				
Ln_Abdnce	0	0				
Lbar	0	0				
L25	0	0				
L75	0	0				
L50mat	0	0				
Ln_Recruit	0	0				
md	0	1*				
xcg (age1)			-1	1	0	0
xcg (age2)			-1	1	0	0
xcg (age3)			-1	0	-1	0
ycg (age1)			1	0	0	0
ycg (age2)			1	1	0	0
ycg (age3)			1	0	NA	NA
Inertia (age1)			1	0	0	0
Inertia (age2)			0	0	-1	-1
Inertia (age3)			0	0	1	0
Anisotropy (age1)			0	0	ND	ND
Anisotropy (age2)			1	0	ND	ND
Anisotropy (age3)			0	0	ND	ND
Positive area (age1)			0	0	0	0
Positive area (age 2)			0	0	-1	0
Positive area (age 3)			0	0	0	-1
Equivalent area (age1)			0	0	0	0
Equivalent area (age2)			0	0	0	0
Equivalent area (age3)			0	0	0	0
Spreading area (age1)			1	0	0	0
Spreading area (age2)			0	0	0	0
Spreading area (age3)			0	0	0	0
Microstructure (age1)			0	0	ND	ND
Microstructure (age2)			0	0	ND	ND
Microstructure (age3)			-1	0	ND	ND

*linear

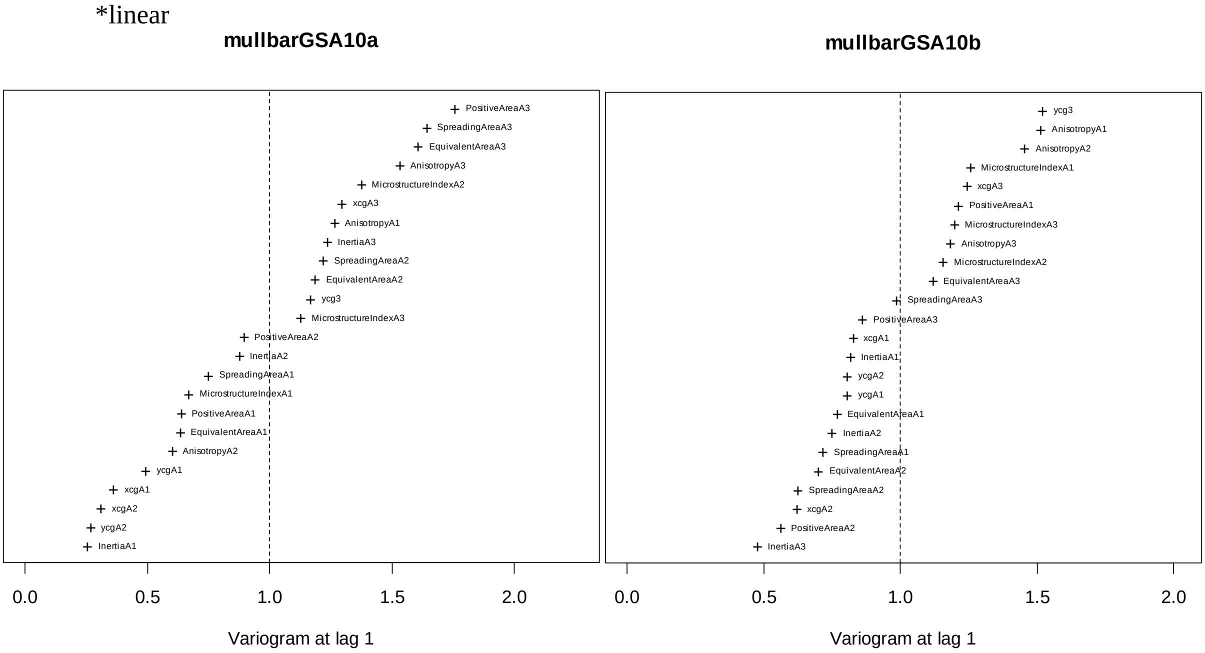


Fig. 11.wp5GSA10. Variogram at lag 1 in the subunit 10a (left) and 10b (right).

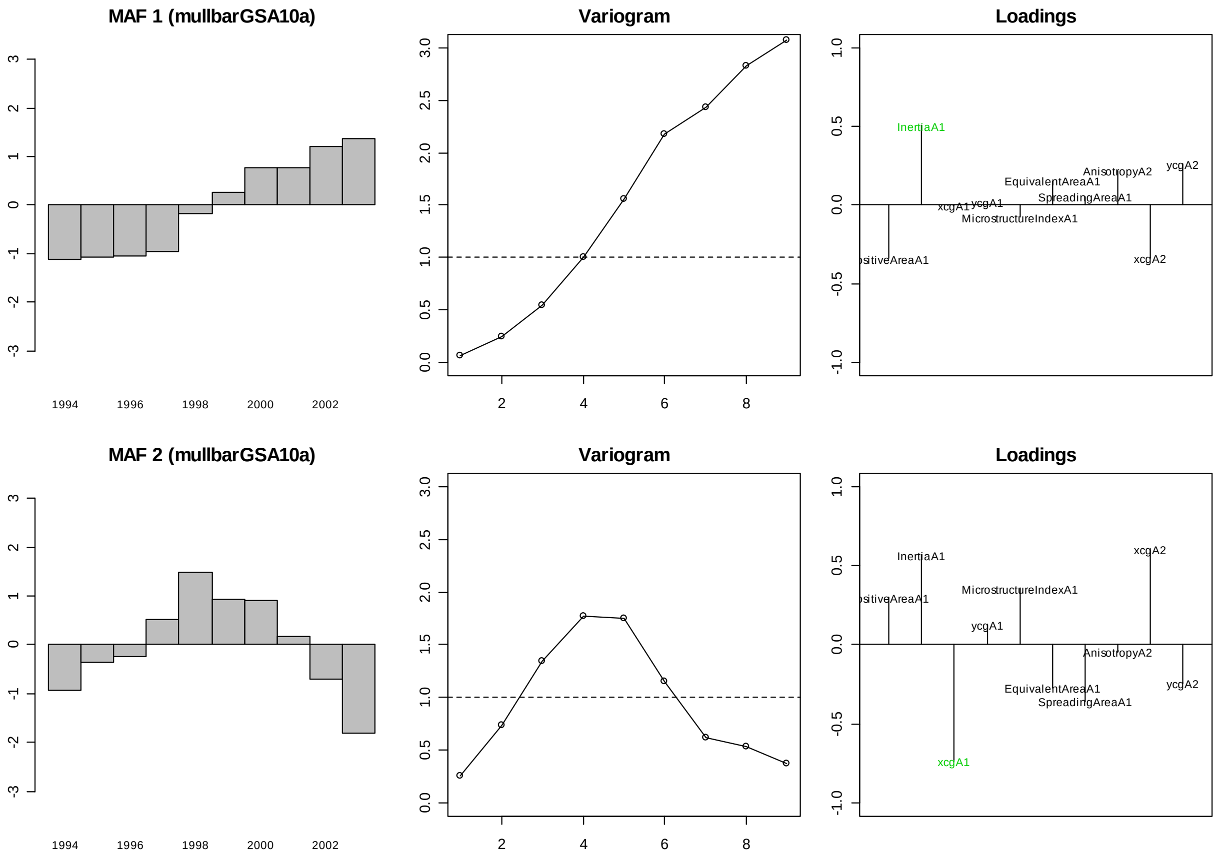


Fig. 12.wp5GSA10a. Results of MAF1 and MAF2 in the subunit 10a.

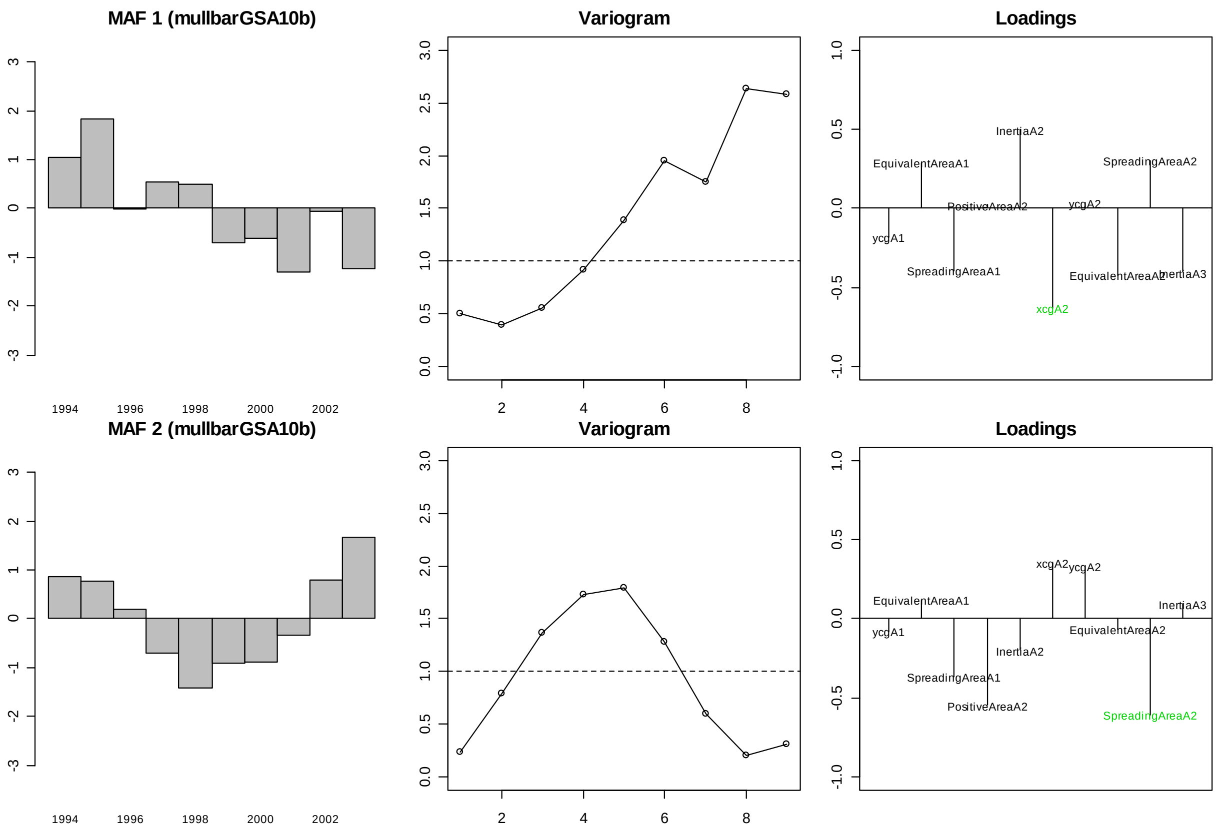
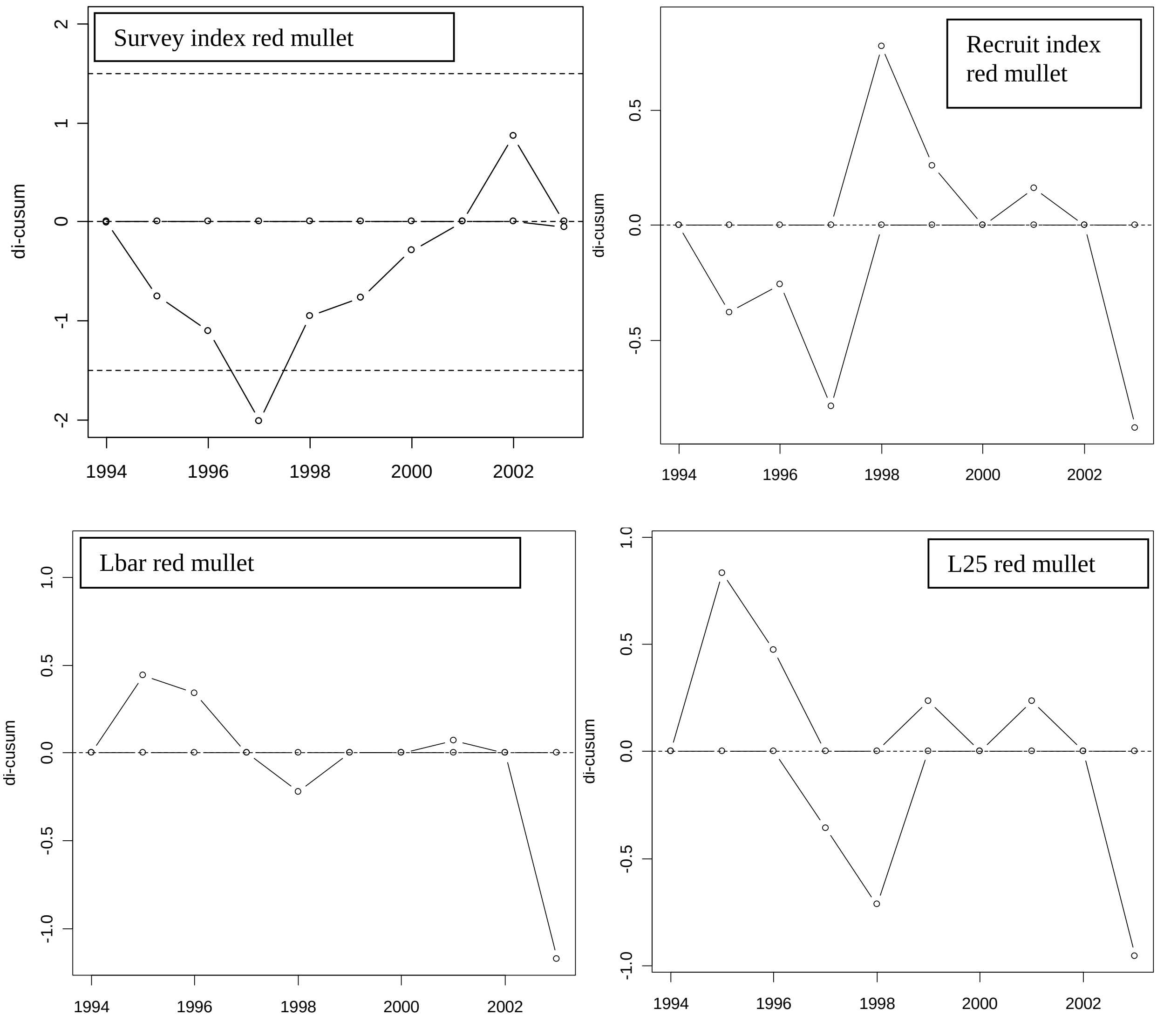


Fig. 13.wp5GSA10b. Results of MAF1 and MAF2 in the subunit 10b.

3. di-cusum plots of selected indices

di-cusum analysis was performed for the non spatial univariate and multivariate population indices and for spatial multivariate indices. The reference period for all the di-cusum analysed indices was 1999-2003. We tried to accommodate h and k parameters in order to reduce the possibility of false alarm, but probably this resulted in a reduced sensitivity of the estimates. Results of non-spatial di-cusum analysis are reported in Fig. 14.wp5GSA10, and those of multivariate spatial indices in Fig. 15.wp5GSA10a&b. In Tab. 7a. wp5_red mullet_GSA10a&b are reported the di-cusum parametrs of the analysed indices, while diagnostic table is in Tab. 7b. wp5_red mullet_GSA10a&b.

A triggering alert signal was obtained for the survey index in 1997, when it reached the lowest level. A signal was also detected for the L50maturity in 1996, but in this case it was higher than in the reference period, and for the type of indicator it should be considered positive. A signal was also obtained for the multivariate spatial indices in the years 1995 and 1996 for the subunit 10b. Indeed, in these years the higher multivariate spatial indices were observed, likely as a result of the lower location indices (plots of indices), and of occupation indices, namely spreading and equivalent areas. Possible implications for population dynamics are not straightforward, although changes in the spatial pattern can be viewed as a response of the population to environmental or exploitation pressure.



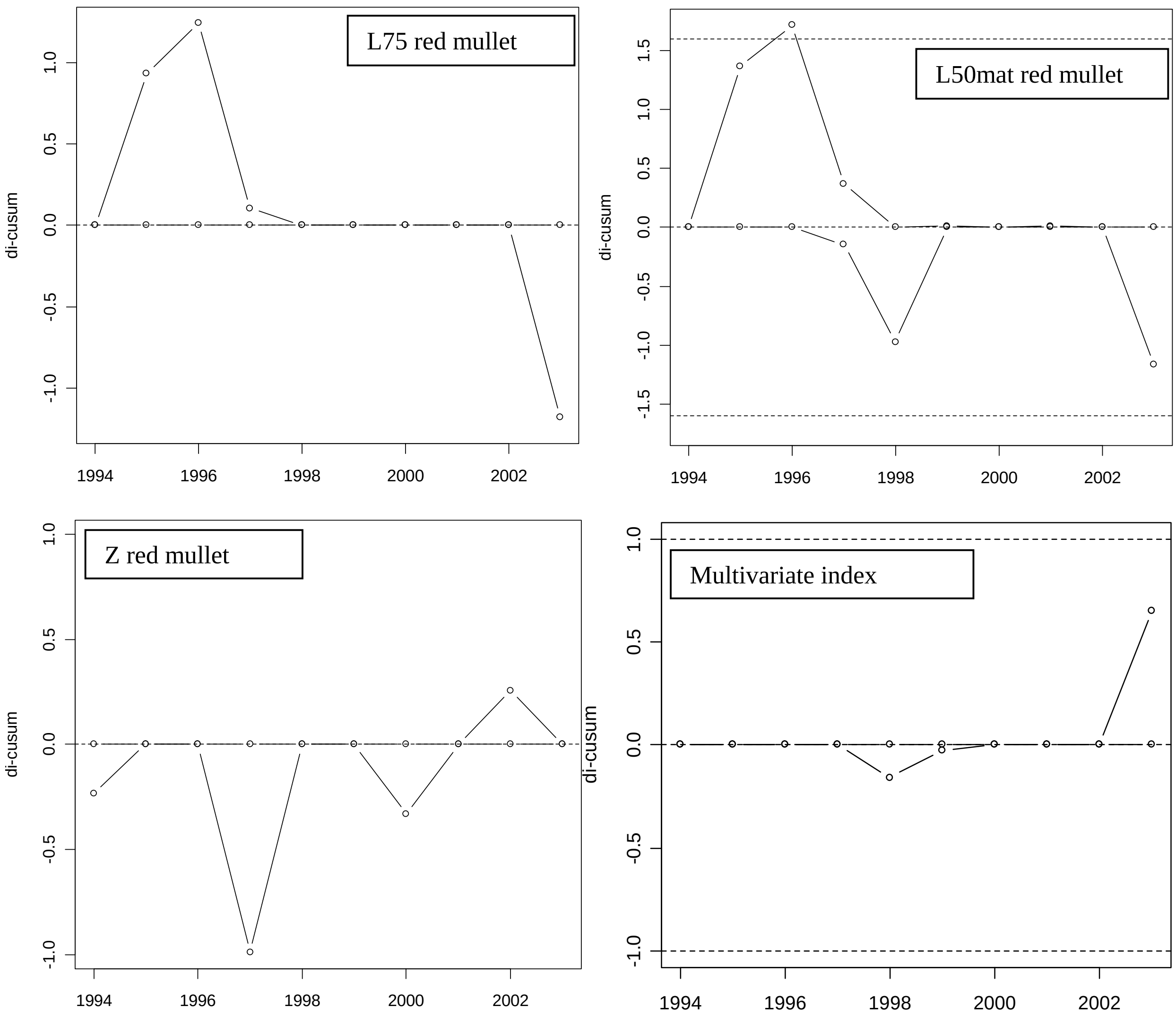


Fig. 14.wp5GSA10. Di-cusum plots of non spatial univariate indices and multivariate index (lower right).

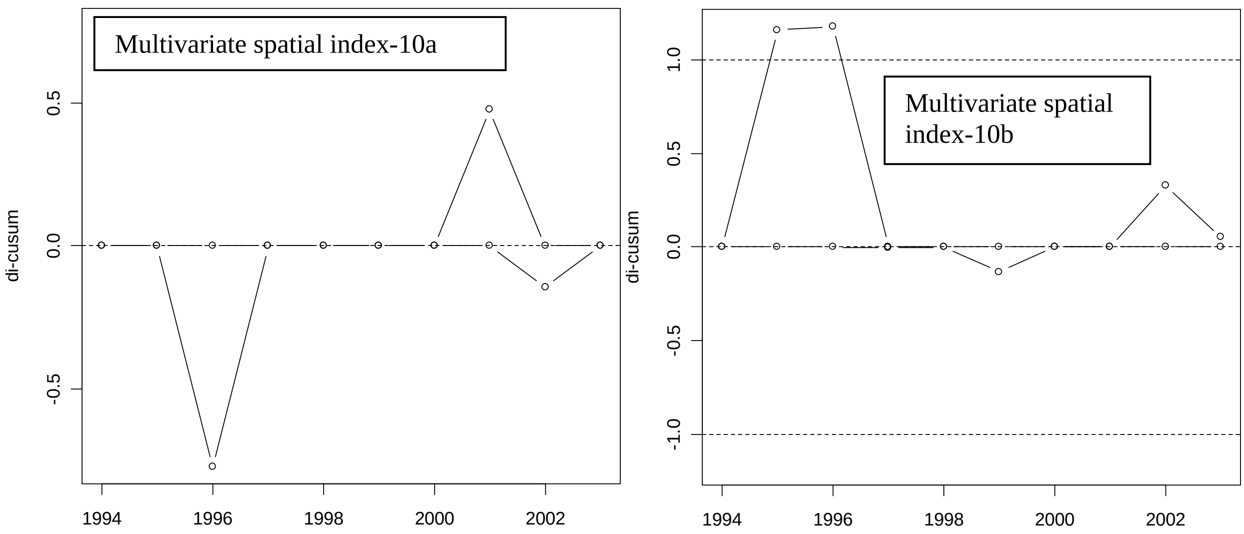


Fig. 15.wp5GSA10a&b. Di-cusum plots of multivariate spatial indices in the GSA10a (left) and GSA10b (right).

Tab. 7a. wp5_red mullet_GSA10a&b. di-cusum parameters

Cusum parameters							
	ref.period	**m in ref.period**	**sd in ref.period**	**k**	**h**	**ARL In Control**	**ARL Out Control**
md	1999-2003	1.98	1.255	1	1	35.3	1.8
dmul-10a	1999-2003	3.22	1.228	1	1	35.3	1.8
dmul-10b	1999-2003	3.27	1.829	1	1	35.3	1.8
Ln_Tot Abun	1999-2003	16.24	0.602	0.8	1.5	49.5	2.6
Ln_ Recruits	1999-2003	15.64	0.421	0.8	1.5	49.5	2.6
Lbar	1999-2003	15.02	0.331	0.6	1.6	31.7	3.3
L25	1999-2003	13.06	0.167	0.6	1.6	31.7	3.3
L75	1999-2003	15.76	0.483	0.6	1.6	31.7	3.3
Lmat	1999-2003	14.22	0.295	0.6	1.6	31.7	3.3
Z	1999-2003	2.38	0.594	0.8	1.3	35.4	2.4

Tab. 7b. wp5_red mullet_GSA10a&b. di-cusum diagnostic table.

CUSUM diagnostics table											
Years	**md**	**dmul-10a**	**dmul-10b**	**Ln_Tot Abun**	**Ln_ Recruits**	**Lbar**	**L25**	**L75**	**Lmat**	**Z**	**alert**
1994	0	0		0	0	0	0	0	0	0	
1995	0	0	1.159	0	0	0	0	0	0	0	
1996	0	0	1.177	0	0	0	0	0	1.716	0	
1997	0	0	0	-2.009	0	0	0	0	0	0	alert
1998	0	0	0	0	0	0	0	0	0	0	
1999	0	0	0	0	0	0	0	0	0	0	ref
2000	0	0	0	0	0	0	0	0	0	0	ref
2001	0	0	0	0	0	0	0	0	0	0	ref
2002	0	0	0	0	0	0	0	0	0	0	ref
2003	0	0	0	0	0	0	0	0	0	0	ref

<u>Interpretation</u>

The trend analysis in all period did not show significant trend for the non spatial indices. However recent change significantly occurred for total mortality, that in 2001 and 2002 reached the highest levels, whereas the survey index, Lbar and L75 were all, although not significantly, decreasing in 2003. These can be interpreted as warning signs of deterioration likely due to fishing mortality increase or to the catch of smaller fish, or change in fishing area and/or stock distribution. In 2003 also recruit index was decreasing. A decline in length indicators was also observed from 1995 to 1998, but in that period the total mortality was lower and, in addition, in 1998 survey index and recruit index increased, remaining almost stable up to 2001. Spatial indices, especially those regarding location in subunit 10a, displayed a trend in all period and a tendency to change in recent years, although it is difficult to establish cause-effect link with driving factors such as localised fishing pressure. This is because other causes, for example those environmentally driven might be evocated. Probably, a longer time series might help this interpretation. It is also worth to note that in 2003 also the multivariate non spatial index was the most distant in the time series, highlighting a different overall condition. The recent trend analysis (linear) also confirmed significant recent trend (increasing) in the multivariate non spatial index.

In the di-cusum analysis h and k parameters were tuned to avoid the occurrence of false alarms. A triggering alert signal was detected for the survey index in 1997, when it reached the lowest level. No other deterioration signals were detected in the non spatial indices and, thus, it is difficult to ascribe this change to the decrease, for example, of recruits that indeed in 1997 were as low as in 2003.

A signal was also obtained for the multivariate spatial indices in the years 1995-1996 in the subunit 10b, probably as result of lower location and occupation indices. Population, especially older ages, was more dispersed westwards and slightly offshore, probably as result of reduced density, although it is not easy to link these signals with possible deterioration effects due to exploitation.

<u>Compare approaches (cusum/trends)</u>

Looking at the di-cusum analysis, averages of survey index in the reference period (1999-2003) was higher than outside the reference period, thus allowing to trigger an alert in 1997. Conversely, the total mortality, that recent trend analysis revealed significantly increasing in the last five years, was on average higher in the reference period than in the first 5 years of the time series. In both cases the other population non spatial indicators did not show significant changes. Also trend analysis of multivariate non spatial distance showed a recent change that was likely not sufficient to be evidenced by the di-cusum analysis. The combination of the two approaches indicates that the red mullet population dynamics is affected by impacts that influence demography and production probably with cyclical phases, although the most recent condition displays more clear signs of an increased exploitation pattern.

What have you learned ?
The trend analysis using the linear approach was useful for detecting tendency in the time series, while non-linear approach through derivative revealed to be helpful in identifying recent trends, as for total mortality. The combination of di-cusum and trend analysis make the evaluation more robust. Trend analysis, using tools as derivative, gives the signal of changes and thus enables for the evaluation on the current state, accounting for the past information. Di-cusum adds the advantage of triggering alert signals suggesting reference values for a given indicator, based on the time series and the selected reference period. This is a key factor in the analysis and can be viewed as a reference time related to a better status of the population to compare with, or as a recent time, when changes are occurring, to be contrasted retrospectively with a previous time lag.
The multivariate approach is useful for deriving synthetic indices and identifying the most influencing factors in a complex framework including many correlated indicators. Di-cusum approach applied to the multivariate indices should allow to avoid the occurrence of false alarms, although the analysis on univariate key indicators has the power of explaining relationships in the dynamics.
Despite difficult to interpret in a cause-effect scheme, changes in the spatial pattern as revealed by the PCA applied to the spatial indices can be viewed as a response of the population to environmental or exploitation pressure factors.

Summary sheet
The survey time series is related to the Medits bottom trawl surveys from 1994 to 2003. Surveys at sea were conducted in late spring-early summer (May-August). In the performed analyses individuals at age 1 were considered as recruits, and those of age 2 and 3 as adults (all the latter are spawners considering the size/age at first maturity of the female population).

Non-spatial indices
Abundance index, recruitment index, Lbar, L75, L25, L50.maturity and Z by year have been analysed using linear regression, non parametric trends and derivative methods. Linear and non-linear (derivative) methods were used for detecting recent changes (last 5 years) of the indices. The latter method gave significant (p=0.05) change for Z, that showed an increasing pattern. Di-cusum method was also applied and alert detected for survey index (total abundance decreasing) in 1997.

Spatial indices
Positive Area, Spreading area, Equivalent area, Centre of gravity, Inertia, Anisotropy and Microstructure were analysed by age (age groups 1, 2 and 3 that were fully represented in the samples). Linear regression, Kendall's Thau, Spearman's rho were used for detecting trends in all period. Linear and non-linear (derivative) methods were used for detecting recent changes (last 5 years) of the indices, but only the latter was retained for diagnosis. In all period trends were mainly detected for location indices (xcg decreasing, ycg increasing of all the age groups, inertia and anisotropy of age 1 increasing) ant to a less extent for occupation indices (spreading area of age 2 increasing) in the 10a subunit, while spatial structure in the geographical sub-unit 10b seems more stable along time, except for xcg of age group 1 (increasing) and xcg and ycg of age group 2 (increasing). In the geographical sub-unit 10a recent changes were occurring for location (xcg decreasing, inertia) and occupation (positive area, decreasing) indices of age groups 2 and 3. In the subunit 10b recent changes (decreasing) regarded inertia and positive area of age group 2 and 3 respectively.

Composite (derived) indices
PCA was applied for deriving non spatial and spatial multivariate indices. The first component of non spatial PCA was highly positively correlated especially with recruit index and Lbar, followed by L50.maturity, L75 and L25 and negatively correlated with Z, while the second component was positively correlated with the survey index. The multivariate index was more distant in 2003 in the reference period, and in 1997 outside the reference period. The di-cusum analysis applied to the multivariate index did not trigger any alert.
The PCA analysis applied to the spatial indices reveals that, in general, the loadings more effecting the analysis seem to be primarily the occupation and then the location indices in both the geographical subunits. In the subunit 10a, the year 2001 shows the highest multivariate distance from the gravity centre of the factorial space within the reference period, followed by 1998 outside the reference period. In the subunit 10b, the year 2002 shows the highest multivariate distance from the gravity centre of the factorial space within the reference period, while outside the reference period the higher value was observed in 1996.

The di-cusum analysis applied to the multivariate spatial indices revealed a signal for the subunit 10b in the years 1995 and 1996. Indeed, in these years the higher multivariate spatial indices were observed, likely as a result of the lower location indices, namely spreading and equivalent areas. Possible implications for population dynamics are not straightforward, although changes in the spatial pattern can be viewed as a response of the population to environmental or exploitation pressure.

Reference period
The more recent period (1999-2003) was chosen as reference in the time series whose length is 10 years. Compared to the first 5 years (all the population indices at lower level, excluding the length-related ones) the recent period had higher survey and recruit indices and higher total mortality, in addition the last year was displaying most changes in the time series. Thus it was considered as a new state to be contrasted retrospectively with the previous time lag.

Summary of results on the stock
Higher abundance of the population is located in the southernmost part of the studied area, along the mainland coasts and the north Sicily coasts. Maps of the GCs across years highlight that the younger age (A1) shows a less changing spatial location compared to the older ages (A2 and A3) that are more dispersed in both the geographical sub-units.
Age group 3 disappeared from the experimental catches of the last 2 years (2002-2003) in the sub-unit 10a and a decrease of indices of length structure and recruit abundance, referred to the whole area, was occurring in the last two years.
The trend analysis in all period did not show significant trend for the non spatial indices. However recent change significantly occurred for total mortality, that in 2001 and 2002 reached the highest levels, whereas the survey index, Lbar and L75 were all, although not significantly, decreasing in 2003. These can be interpreted as warning signs of deterioration likely due to fishing mortality increase or to the catch of smaller fish, or change in fishing area and/or stock distribution. In 2003 also recruit index was decreasing. A decline in length indicators was also observed from 1995 to 1998, but in that period the total mortality was lower and, in addition, in 1998 survey index and recruit index increased, remaining almost stable up to 2001. Spatial indices, especially those regarding location in subunit 10a, displayed a trend in all period and a tendency to change in recent years, although it is difficult to establish cause-effect link with driving factors such as localised fishing pressure.
Di-cusum analysis allowed the triggering of alert signal for the survey index in 1997, when it reached the lowest level. No other deterioration signals were detected in the non spatial indices and, thus, it is difficult to ascribe this change to the decrease, for example, of recruits that indeed in 1997 were as low as in 2003.
A signal was also obtained for the multivariate spatial indices in the years 1995-1996 in the subunit 10b, probably as result of lower location and occupation indices. Population, especially older ages, was more dispersed westwards and slightly offshore, probably as result of reduced density, although it is not easy to link these signals with possible deterioration effects due to exploitation.

Comparison with traditional assessment of stock status
Assessment of red mullet in the area are from results presented to the SCSA (Sub-Committee Stock Assessment) of the SAC (Scientific Advisory Committee) of GFCM in 2002 and subsequently in 2003. In 2002 the geographical boundary of the geographical sub-areas were different (all the Tyrrhenian sea, north and south, and northern Sicily were two distinct GSAs). Evaluation were based on the total mortality and linear regression analysis of abundance indices on the shelf. The Z value was estimated as twofold the natural mortality (constant value adopted) and the abundance indices were showing an increasing trend. The diagnostic was of fully exploitation. In 2003 the assessment was based on linear regression analysis of abundance indices (number and weight, 1994-2001) and on the results of a simulation model under equilibrium assumption. Diagnosis was of growth overfishing, and a reduction of the mortality was recommended.

The use of more indicators enables to construct a more robust and comprehensive evaluation, especially when recent changes are detectable and reference value and alert can be set or signalled using tool such as di-cusum. Abundance only cannot be as robust as a multi-indicators approach, because other metrics help in the diagnosis of cause-effects. Model-based outcomes can add further information to the indicator framework, especially for the estimation of reference values of indicators and/or reference points.

Formulation of advice
Fishing pressure in space and/or time should be reduced and recruitment phase protected.

Case Study Name	red mullet GSA 10	cause-effects diagnostics table
survey period	1994-2003	
ref.period	1999-2003	
ref status	fully exploited	

Results of trend analysis global interpretation is based on linear regression and non parametric trend for all period and on derivative method for the recent period

	all period 10a&b	recent 10a&b	all period 10a	all period 10b	recent 10a	recent 10b
Z	0	1				
Ln_Abdnce	0	0				
Lbar	0	0				
L25	0	0				
L75	0	0				
L50mat	0	0				
Ln_Recruit	0	0				

diagnostic Signs of deterioration likely as a consequence of F increases
total mortality significantly increasing in recent years, survey index and length-related metrics decreasing although not significantly

Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
Larger fish caught (or change in fishing area, stock distribution or gear)	-1	1	1	0	1	0
Smaller fish caught (or change in fishing area, stock distribution or gear)	1	-1	-1	-1	0	0

Results of trend analysis global interpretation is based on linear regression and non parametric trend for all period and on derivative method for the recent period

Results of trend analysis global interpretation is based on linear regression and non parametric trend for all period and on derivative method for the recent period

	all period 10a&b	recent 10a&b	all period 10a	all period 10b	recent 10a	recent 10b
md	0	1 (linear)				
xcg (age1)			-1	1	0	0
xcg (age2)			-1	1	0	0
xcg (age3)			-1	0	-1	0
ycg (age1)			1	0	0	0
ycg (age2)			1	1	0	0
ycg (age3)			1	0	NA	NA
Inertia (age1)			1	0	0	0
Inertia (age2)			0	0	-1	-1
Inertia (age3)			0	0	1	0
Anisotropy (age1)			0	0	ND	ND
Anisotropy (age2)			1	0	ND	ND
Anisotropy (age3)			0	0	ND	ND
Positive area (age1)			0	0	0	0
Positive area (age 2)			0	0	-1	0
Positive area (age 3)			0	0	0	-1
Equivalent area (age1)			0	0	0	0
Equivalent area (age2)			0	0	0	0
Equivalent area (age3)			0	0	0	0
Spreading area (age1)			1	0	0	0
Spreading area (age2)			0	0	0	0
Spreading area (age3)			0	0	0	0
Microstructure (age1)			0	0	ND	ND
Microstructure (age2)			0	0	ND	ND
Microstructure (age3)			-1	0	ND	ND

ND: not determined

CASE STUDY NAME	red mullet GSA 10			CUSUM diagnostics table							
ref.period	1999-2003	1999-2003	1999-2003	1999-2003	1999-2003	1999-2003	1999-2003	1999-2003	1999-2003	1999-2003	
m in ref.period	1.976121	3.217407	3.267283	16.2416406	15.6379345	15.02035	13.06	15.76	14.22	2.3825	
sd in ref.period	1.255495	1.227543	1.828713	0.602002376	0.42079049	0.330562	0.167332	0.482701	0.294958	0.593935	
k	1	1	1	0.8	0.8	0.6	0.6	0.6	0.6	0.8	
h	1	1	1	1.5	1.5	1.6	1.6	1.6	1.6	1.3	
ARL InControl	35.3	35.3	35.3	49.5	49.5	31.7	31.7	31.7	31.7	35.4	
ARL OutControl	1.8	1.8	1.8	2.6	2.6	3.3	3.3	3.3	3.3	2.4	
Years	**md**	**dmul-10a**	**dmul-10b**	**Ln_TotAbun**	**Ln_Recruits**	**Lbar**	**L25**	**L75**	**Lmat**	**Z**	**alert**
1994	0	0		0	0	0	0	0	0	0	
1995	0	0	1.159152	0	0	0	0	0	0	0	
1996	0	0	1.176653	0	0	0	0	0	1.715673	0	
1997	0	0	0	-2.00875164	0	0	0	0	0	0	alert
1998	0	0	0	0	0	0	0	0	0	0	
1999	0	0	0	0	0	0	0	0	0	0	ref
2000	0	0	0	0	0	0	0	0	0	0	ref
2001	0	0	0	0	0	0	0	0	0	0	ref
2002	0	0	0	0	0	0	0	0	0	0	ref
2003	0	0	0	0	0	0	0	0	0	0	ref

Indicator Based Assessment
herring North Sea

P. Fernandes (FRS), P. Petitgas (IFREMER)

Data

- **Map of all survey stations and polygon used**

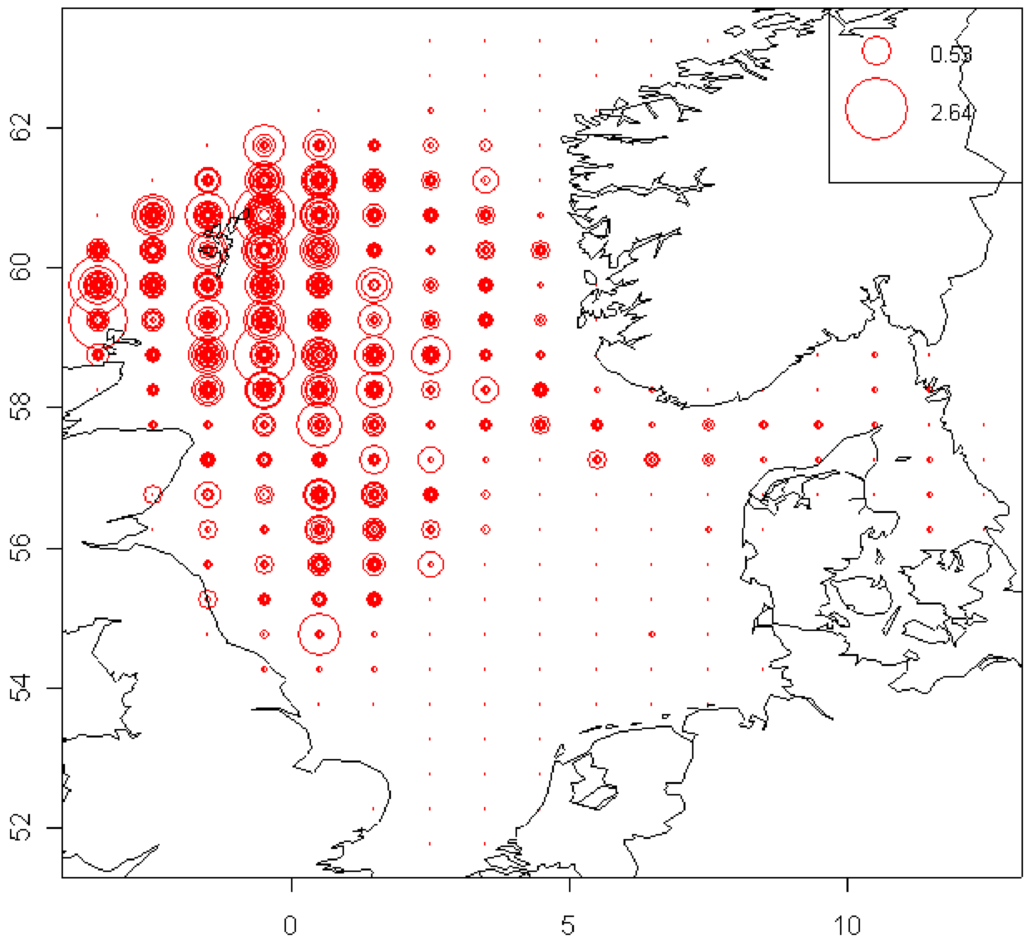


Fig. 1.0.1 : Map of the North Sea showing the abundance of mature North Sea herring (circle size proportional to abundance) from all the surveys from 1989-2006. The data are aggregated by ICES rectangle, so each sample point is representative of a similar area; a rectangle of approximately 30 nm x 30nm, hence there is no need for a polygon and there would be also no need of areas of influence as all of them are equal.

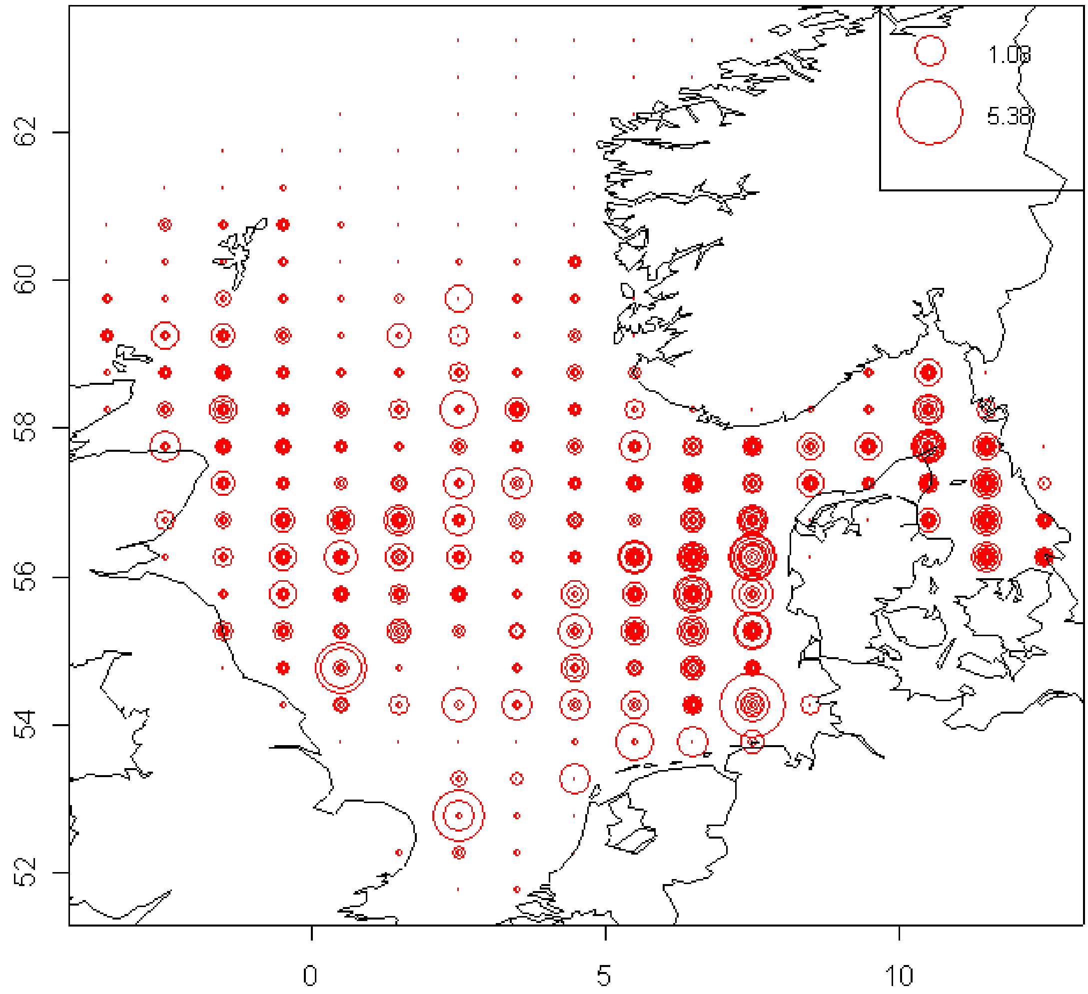
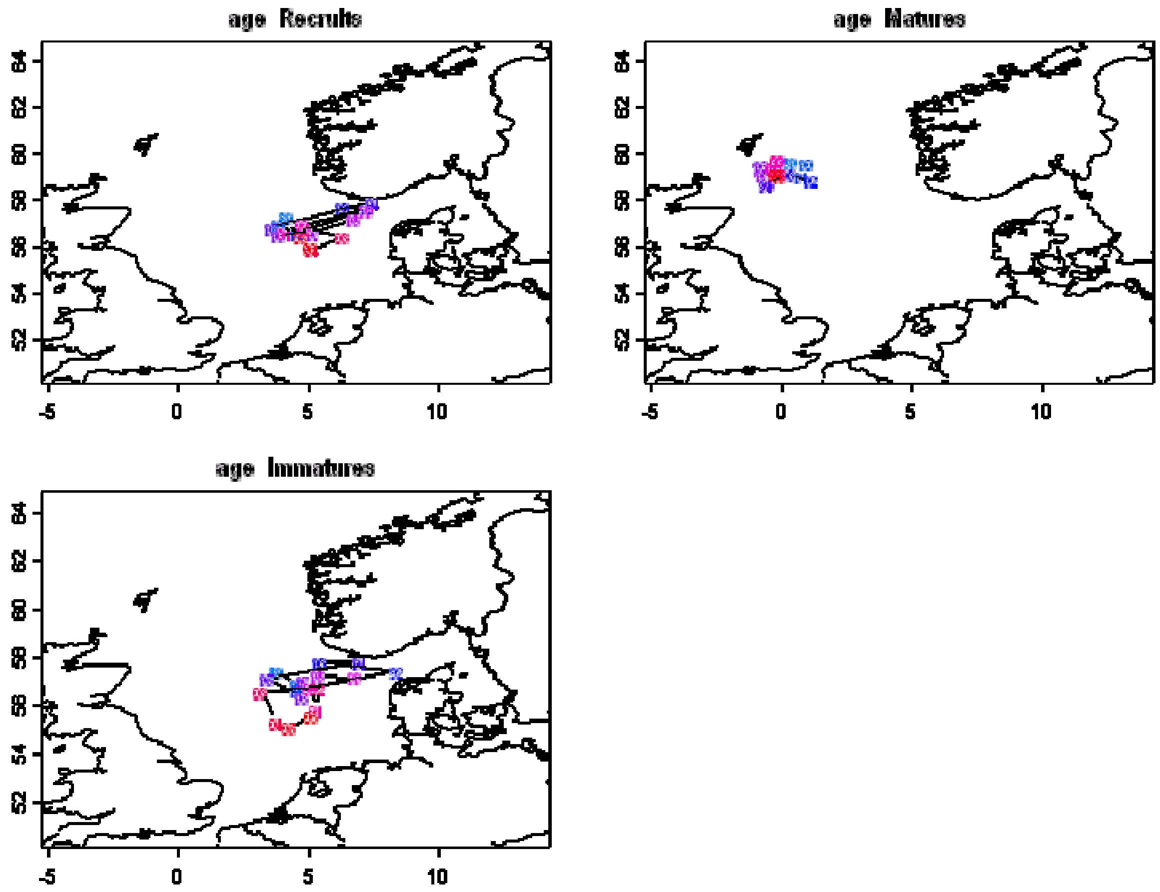


Fig. 1.0.2 : Map of the North Sea showing the abundance of immature North Sea herring (circle size proportional to abundance) from all the surveys from 1989-2006. The data are aggregated by ICES rectangle, so each sample point is representative of a similar area; a rectangle of approximately 30 nm x 30nm, hence there is no need for a polygon and there would be also no need of areas of influence as all of them are equal.

- **Maps of gravity centres across years for selected ages**



- **Input parameters for spatial indices :**

Spatial indices were calculated using functions in RGeoS (geostatistical library in R developed at Ecole des Mines Centre de Géostatistique). Some of the functions in RGeoS need input parameters which are now given.

Function infl() : dlim= 16.5nmi x 15nmi, ndisc=200 (But see legend Figure 1)

Function f.spatialpatches() : Lim.D = 250 nmi, A.li = 10%.

Function f.covario() : num.dir=, h0=30 nmi

- **Raw indices**

Fisboat wp2a Table 1: Spatial indices

Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	MicrostructureIndex	EquivalentArea	SpreadingArea	NumberOfPatches
n0	1989	3152	50871	40164	2.62	4.13	57.14	0.848	6865	11113	2
n0	1990	2584	43184	2795	1.665	7.03	56.26	0.623	5411	5906	1
n0	1991	883	12430	3521	1.777	5.81	56.05	0.816	5036	4793	1
n0	1992	5128	23430	2946	1.652	11.02	57.02	0.528	9414	8990	1
n0	1993	149	2996	590	NA	10.5	58.43	0.832	2325	2227	1
n0	1994	386	15365	620	1.481	10.44	58.07	0.795	2262	2218	1
n0	1995	33	14362	2753	2.254	9.56	57.93	0.749	4576	6049	1
n0	1996	4763	35712	6058	2.09	7.38	55.73	0.864	5179	6941	1
n0	1997	1219	24387	6940	2.725	10.15	56.67	0.605	9994	9133	1
n0	1998	1946	25005	8269	3.454	7.56	55.8	0.871	3136	7039	1
n0	1999	6031	16467	11326	4.059	7.53	56.46	0.694	6852	6943	1
n0	2000	7571	36055	2155	1.841	6.81	55.88	0.625	6093	6282	1
n0	2001	14053	35506	4066	1.444	6.94	54.91	0.831	5670	7050	1
n0	2002	3982	43184	7902	1.6	8.71	56.3	0.809	8812	10848	1
n0	2003	2590	50406	26177	2.222	2.75	55.12	0.883	5924	8027	2
n0	2004	10652	39254	10270	2.382	4.29	54.2	0.89	6947	8071	1
n0	2005	5010	41248	7967	2.555	4.4	54.06	0.798	7233	7546	1
n0	2006	4622	37281	2094	1.686	6.45	53.99	0.8	3455	3718	1
ns.n1	1989	6070	130113	42065	1.905	4.04	57.33	0.645	32106	37681	3
ns.n1	1990	6985	128591	17208	1.726	3.85	56.97	0.505	31198	30848	2
ns.n1	1991	2542	90893	11718	1.274	4.49	56.56	0.778	13220	18939	1
ns.n1	1992	6463	100284	22956	3.456	7.18	57.66	0.544	26964	28029	2
ns.n1	1993	11498	109744	24395	2.595	6.2	57.77	0.586	28129	27462	2
ns.n1	1994	3188	64738	20349	3.363	7.54	57.88	0.769	6413	11921	2
ns.n1	1995	4701	73421	25305	2.694	3.62	56.85	0.787	10563	12841	2
ns.n1	1996	5861	92265	31464	2.348	3.85	56.51	0.67	27889	28972	2
ns.n1	1997	9376	119108	16253	1.847	5.18	56.62	0.694	21804	32068	2
ns.n1	1998	4449	89292	21727	2.05	6.71	57.15	0.621	29828	32160	2
ns.n1	1999	5087	105982	18439	2.192	7.28	57.59	0.623	18460	20953	2
ns.n1	2000	24736	124779	27214	1.93	4.68	56.97	0.736	28220	37225	2
ns.n1	2001	6837	111318	20158	1.425	4.06	56.62	0.659	39725	39520	1
ns.n1	2002	23182	130510	17889	1.481	4.88	56.75	0.55	40613	42421	1
ns.n1	2003	9829	109546	23604	2.377	6.2	56.45	0.724	22396	25983	1
ns.n1	2004	5168	88445	14528	2.623	5.03	55.87	0.626	16522	18094	1
ns.n1	2005	2925	109176	14775	2.031	4.68	56.45	0.891	6068	15826	2
ns.n1	2006	6906	109752	18690	1.413	5.07	55.97	0.802	16429	25842	2

Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	MicrostructureIndex	EquivalentArea	SpreadingArea	NumberOfPatches
ns.n2	1989	4089	113400	17093	1.896	0.34	59.21	0.639	25694	32344	2
ns.n2	1990	3307	134349	18803	1.136	1.74	58.16	0.65	38667	42270	2
ns.n2	1991	2634	100092	13086	1.293	1.5	58.08	0.632	20166	26161	1
ns.n2	1992	3638	115463	23706	2.249	3.72	58.06	0.567	39431	42208	2
ns.n2	1993	2984	90646	10690	1.671	0.5	58.2	0.7	14202	23421	1
ns.n2	1994	3185	78366	22353	1.419	0.31	58.09	0.636	20704	28787	2
ns.n2	1995	3849	80028	17252	2.027	0.51	58.5	0.638	18660	28572	2
ns.n2	1996	4497	103625	24954	1.501	0.08	58.56	0.602	33841	36790	2
ns.n2	1997	5960	111115	20564	1.656	-0.19	58.62	0.845	12021	27685	2
ns.n2	1998	5747	104035	12899	1.392	0.52	58.43	0.622	22518	28650	1
ns.n2	1999	3078	99290	14559	1.728	1.04	58.79	0.573	25953	29288	1
ns.n2	2000	2923	101516	14136	1.364	0.65	58.4	0.52	29891	33656	1
ns.n2	2001	12290	116116	13463	2.028	-0.2	58.94	0.623	18036	20876	2
ns.n2	2002	5009	112277	10549	1.515	0.18	59.2	0.608	16394	26343	1
ns.n2	2003	18949	136628	15410	1.998	0.25	57.51	0.627	23324	28730	1
ns.n2	2004	3426	109059	16891	1.501	1.66	57.63	0.644	22621	29159	2
ns.n2	2005	1876	115516	6091	1.552	0.13	58.31	0.586	11666	17209	1
ns.n2	2006	3800	135183	12073	1.823	0.21	58.7	0.526	26554	29821	1
ns.n3	1989	3903	100768	12477	1.574	0.09	59.68	0.606	24324	30986	1
ns.n3	1990	3529	108439	14657	1.727	0.39	59.71	0.5	35482	38014	2
ns.n3	1991	1704	85641	11359	1.466	0.73	58.75	0.614	19490	24641	1
ns.n3	1992	1483	114466	14292	1.054	1.17	58.57	0.528	36427	40514	1
ns.n3	1993	1637	80073	10728	1.812	0.47	58.72	0.661	19074	23898	1
ns.n3	1994	839	55964	14006	1.63	-0.47	58.91	0.72	18050	21259	1
ns.n3	1995	2041	73486	11969	1.407	-0.53	58.86	0.645	18044	21083	1
ns.n3	1996	2824	85162	10121	1.54	-1.13	59.51	0.655	18594	20953	1
ns.n3	1997	2935	100638	20374	1.458	-0.4	59.03	0.792	13759	24663	2
ns.n3	1998	2520	100954	9100	1.202	-0.47	59.71	0.54	19924	24514	1
ns.n3	1999	4725	82721	6542	1.302	-0.33	60	0.611	14974	19653	1
ns.n3	2000	2156	79491	9226	1.995	-0.22	59.27	0.535	19091	21022	1
ns.n3	2001	3083	87327	14128	1.957	0.06	59.25	0.588	17974	23976	2
ns.n3	2002	8299	98842	7469	1.437	-0.14	59.73	0.426	22694	23459	1
ns.n3	2003	3081	95373	10936	1.686	-0.03	59.84	0.508	29111	29791	1
ns.n3	2004	9167	102689	13388	1.674	0.17	58.3	0.65	26169	30262	1
ns.n3	2005	3454	104877	3902	1.222	-0.31	58.95	0.673	8166	13770	1
ns.n3	2006	2000	110202	6555	1.625	-0.31	58.9	0.591	16967	21067	1

Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	MicrostructureIndex	EquivalentArea	SpreadingArea	NumberOfPatches
ns.n4	1989	1633	93038	9135	1.211	0.57	60.06	0.554	25516	28505	1
ns.n4	1990	3424	95963	10442	1.287	0.76	60.15	0.515	31652	34299	1
ns.n4	1991	1959	86604	10043	1.654	0.3	59.65	0.611	22510	23867	1
ns.n4	1992	1111	93031	12888	1.466	0.6	58.9	0.523	41721	40931	1
ns.n4	1993	902	101410	13924	1.405	1.25	59.06	0.551	31716	34865	1
ns.n4	1994	399	54117	14039	1.566	0.04	58.5	0.817	12076	20046	1
ns.n4	1995	672	67719	10710	1.55	-0.78	58.79	0.684	15969	18335	1
ns.n4	1996	1087	75446	9176	1.464	-1.19	59.88	0.68	14333	17293	1
ns.n4	1997	1441	80337	8154	1.102	-1.34	60.1	0.722	9697	13150	1
ns.n4	1998	1625	88502	5967	1.171	-0.77	60	0.616	13129	16582	1
ns.n4	1999	1116	79907	7128	1.346	-0.3	60.04	0.629	13223	18828	1
ns.n4	2000	3140	75419	4650	1.279	-0.34	60.04	0.563	13041	13469	1
ns.n4	2001	1462	78690	10737	1.866	-0.09	59.83	0.524	17324	22358	2
ns.n4	2002	1390	86367	8150	1.42	0.31	59.83	0.422	22929	24223	1
ns.n4	2003	4189	95373	10827	1.875	0	60.06	0.569	23312	26254	1
ns.n4	2004	2166	99787	10396	1.339	-0.75	59.67	0.777	11917	21163	1
ns.n4	2005	5640	108687	4874	1.272	-0.27	59.04	0.584	13693	17981	1
ns.n4	2006	2097	70332	6647	1.742	-0.08	58.9	0.567	16192	18988	1
ns.n5	1989	492	75668	8225	1.139	0.72	60.23	0.616	18555	24465	1
ns.n5	1990	1372	86367	8943	1.173	0.82	60.55	0.578	21599	27663	1
ns.n5	1991	1849	94318	10845	1.672	0.7	59.64	0.594	22773	25372	1
ns.n5	1992	1116	93031	11406	1.378	0.3	59.53	0.515	34853	36429	1
ns.n5	1993	741	76356	10015	1.626	0.37	59.25	0.618	24592	25075	1
ns.n5	1994	381	67455	22620	1.519	0.74	58.57	0.772	17372	24177	2
ns.n5	1995	299	61637	23142	1.26	-0.24	57.71	0.819	10694	19198	3
ns.n5	1996	311	72444	11798	1.525	-0.74	59.76	0.676	18045	22195	1
ns.n5	1997	601	72437	15672	1.297	-1.07	59.82	0.736	9878	13803	1
ns.n5	1998	982	68933	4953	1.341	-0.87	60.1	0.628	11728	13676	1
ns.n5	1999	506	67479	10196	1.435	-0.11	59.98	0.63	14391	19954	1
ns.n5	2000	1007	51430	7741	1.978	-0.23	59.83	0.594	14818	15195	1
ns.n5	2001	1676	69094	7661	1.466	-0.36	60.2	0.518	16310	18577	1
ns.n5	2002	790	73892	8825	1.398	-0.07	60.1	0.478	17522	20757	1
ns.n5	2003	675	88737	18840	2.093	0.47	59.43	0.633	26236	27664	2
ns.n5	2004	2590	100569	8420	1.125	-1.09	59.98	0.796	8907	16433	1
ns.n5	2005	1211	86618	5375	1.262	-0.16	59.71	0.618	17041	19567	1
ns.n5	2006	4175	79095	5833	1.588	0	59.06	0.543	18244	19440	1

Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	MicrostructureIndex	EquivalentArea	SpreadingArea	NumberOfPatches
ns.n6	1989	283	78577	6263	1.048	0.97	60.51	0.667	12591	18226	1
ns.n6	1990	394	77730	7380	1.228	0.96	60.79	0.592	18189	22397	1
ns.n6	1991	644	88410	12703	1.861	0.45	59.64	0.553	26762	27380	1
ns.n6	1992	1099	107734	16787	1.223	0.97	59.39	0.52	41088	43498	2
ns.n6	1993	777	79099	7003	1.332	-0.29	59.85	0.633	19207	21577	1
ns.n6	1994	321	47197	13040	2.369	-0.16	59.04	0.82	8856	14044	1
ns.n6	1995	203	63611	24208	1.229	0.03	57.74	0.836	9864	16410	3
ns.n6	1996	99	63769	9258	1.604	-0.99	59.86	0.684	14955	17120	1
ns.n6	1997	215	64631	26732	1.456	-0.31	59.16	0.745	13106	18528	2
ns.n6	1998	445	48581	4534	1.573	-0.97	60.12	0.67	9929	11598	1
ns.n6	1999	314	56014	11153	1.814	-0.51	59.87	0.635	13932	17131	1
ns.n6	2000	483	49511	8183	2.07	-0.19	59.98	0.64	12375	13824	1
ns.n6	2001	450	71013	8482	1.458	-0.23	60.09	0.507	19110	20877	1
ns.n6	2002	1020	65255	6167	1.386	-0.43	60.34	0.514	13416	15401	1
ns.n6	2003	495	74890	21935	3.238	-0.04	59.61	0.707	14874	19392	2
ns.n6	2004	317	66365	9446	1.181	-0.3	59.99	0.721	14170	19379	1
ns.n6	2005	1173	75627	4618	1.375	-0.11	59.85	0.564	16508	18443	1
ns.n6	2006	618	65330	6132	1.435	-0.04	59.33	0.581	19041	20203	1
ns.n7	1989	120	66957	5817	1.37	1.23	60.5	0.713	8979	16666	1
ns.n7	1990	211	58538	6668	1.483	0.82	60.95	0.6	15545	18636	1
ns.n7	1991	228	83714	14199	1.984	0.7	59.59	0.603	20836	24621	2
ns.n7	1992	372	91036	13386	1.68	0.28	59.17	0.539	38155	38662	1
ns.n7	1993	551	73435	8002	1.576	-0.19	59.62	0.621	21099	22647	1
ns.n7	1994	326	46071	8735	1.808	-1.12	59.72	0.669	12949	13669	1
ns.n7	1995	138	64466	20921	1.361	-0.14	58.98	0.749	16202	20562	3
ns.n7	1996	83	61874	10172	1.168	-1.13	60.01	0.69	13720	15928	1
ns.n7	1997	46	53227	15039	2.025	-0.23	60.01	0.736	11623	14403	1
ns.n7	1998	170	36272	5932	2.138	-0.64	60.28	0.713	10272	11190	1
ns.n7	1999	139	58760	17012	1.566	-0.2	59.53	0.637	16327	19937	2
ns.n7	2000	266	39787	6381	1.812	-0.14	60.3	0.696	8840	10586	1
ns.n7	2001	170	60457	13633	1.851	-0.35	59.89	0.58	17666	19301	2
ns.n7	2002	243	61417	5625	1.175	-0.39	60.32	0.507	15063	16805	1
ns.n7	2003	568	48485	10293	1.974	-0.08	60.56	0.7	10941	15089	1
ns.n7	2004	327	66365	10020	1.246	-0.75	59.93	0.758	11447	17586	1
ns.n7	2005	138	66854	6640	1.598	0.96	59.67	0.541	19570	19741	1
ns.n7	2006	562	62643	6210	1.517	-0.06	59.36	0.63	16873	18252	1

Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	MicrostructureIndex	EquivalentArea	SpreadingArea	NumberOfPatches
ns.n8	1989	45	58313	8233	1.102	0.58	60.14	0.669	20107	25010	1
ns.n8	1990	134	54699	10644	1.553	1.46	60.91	0.675	9760	13162	1
ns.n8	1991	94	49487	25648	2.994	0.2	58.96	0.571	22055	20766	2
ns.n8	1992	108	92200	11724	1.391	0.33	60.04	0.553	23184	28347	1
ns.n8	1993	180	66565	9386	1.439	0	59.66	0.64	22225	23921	1
ns.n8	1994	219	47152	10800	2.041	-0.77	59.55	0.695	13342	14427	1
ns.n8	1995	119	57594	14162	2.164	-0.41	59.55	0.758	11445	16100	2
ns.n8	1996	133	40308	6107	1.417	-1.02	60.19	0.686	14235	15171	1
ns.n8	1997	78	52200	18091	1.351	-0.76	59.79	0.749	9779	11462	1
ns.n8	1998	45	38491	15743	1.961	0.27	60.08	0.716	11977	13699	1
ns.n8	1999	54	40677	23918	3.134	-0.49	58.28	0.633	15515	16417	2
ns.n8	2000	120	40958	14551	2.814	-0.06	59.72	0.717	10635	13338	2
ns.n8	2001	98	51820	11632	1.719	-0.55	60.12	0.593	15127	15664	1
ns.n8	2002	119	37426	4139	1.62	-0.62	60.51	0.549	11353	12225	1
ns.n8	2003	146	57590	8217	1.685	0.01	60.67	0.698	10957	15434	1
ns.n8	2004	342	57192	6156	1.51	-1.39	60.25	0.802	7294	12567	1
ns.n8	2005	125	60298	5064	1.298	0.3	59.85	0.53	16900	18773	1
ns.n8	2006	84	55335	6712	1.355	0.36	59.44	0.581	21430	21961	1
ns.n9p	1989	22	45681	4771	1.501	1.31	60.81	0.812	4464	10246	1
ns.n9p	1990	43	36466	5511	1.835	1.39	61.15	0.639	11109	12636	1
ns.n9p	1991	51	47761	9464	1.87	0.17	60.03	0.64	17193	17436	1
ns.n9p	1992	114	88044	10879	1.223	0.25	59.71	0.575	29418	32533	1
ns.n9p	1993	116	68390	6411	1.158	-0.28	60.06	0.643	18184	20900	1
ns.n9p	1994	131	30866	9970	2.067	-0.91	59.61	0.691	12729	13518	1
ns.n9p	1995	93	48753	15639	2.607	-0.53	59.86	0.773	8052	11701	2
ns.n9p	1996	206	49263	7713	1.411	-0.67	60.23	0.69	14787	15002	1
ns.n9p	1997	159	24330	4719	3.485	-1.92	60.29	0.764	6238	6417	1
ns.n9p	1998	121	34377	4428	1.621	-0.99	60.12	0.675	9693	11152	1
ns.n9p	1999	87	47066	23074	3.242	-0.43	58.52	0.631	16681	18006	2
ns.n9p	2000	97	44033	22537	3.551	-0.04	58.66	0.722	13778	14274	2
ns.n9p	2001	59	47022	17114	2.391	-0.63	59.87	0.662	12237	12648	2
ns.n9p	2002	149	47022	5366	1.216	-0.39	60.2	0.465	16969	16856	1
ns.n9p	2003	178	33087	18752	3.092	-0.26	60.14	0.76	9093	10893	2
ns.n9p	2004	186	58735	7383	1.166	-1.88	60.02	0.871	4084	11337	1
ns.n9p	2005	107	44051	3793	1.612	0.26	59.99	0.512	14425	16316	1
ns.n9p	2006	70	50519	6570	1.438	0.01	59.69	0.696	15164	17538	1

Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	MicrostructureIndex	EquivalentArea	SpreadingArea	NumberOfPatches
Matures	1989	9621	113400	13852	1.567	0.3	59.66	0.596	27522	32840	1
Matures	1990	12010	134349	17003	1.496	0.93	59.59	0.524	41337	45075	2
Matures	1991	8764	105036	13729	1.657	0.75	59.04	0.603	25578	29828	1
Matures	1992	7188	115463	15763	1.187	1.1	58.87	0.52	47433	46958	1
Matures	1993	5661	111841	11569	1.574	0.24	59.08	0.619	25477	29588	1
Matures	1994	4895	78366	15032	1.357	-0.6	58.67	0.668	21820	24670	1
Matures	1995	6046	82082	12401	1.317	-0.54	58.75	0.622	20320	24043	1
Matures	1996	7437	94778	13624	1.598	-0.81	59.51	0.634	20615	25046	1
Matures	1997	9128	113169	18974	1.457	-0.72	59.08	0.81	11474	23160	2
Matures	1998	9298	104983	10564	1.503	-0.37	59.33	0.535	24614	26984	1
Matures	1999	8632	98239	9594	1.417	-0.11	59.73	0.608	18162	24344	1
Matures	2000	9140	92789	8359	1.562	-0.18	59.61	0.543	17845	19669	1
Matures	2001	16196	98842	11665	2.402	-0.35	59.4	0.579	17679	21959	2
Matures	2002	16085	110358	7171	1.562	-0.2	59.72	0.438	22663	23408	1
Matures	2003	17277	133872	17562	2.388	-0.05	59.1	0.546	35848	35891	2
Matures	2004	14256	112713	14456	1.533	-0.19	59.09	0.742	18983	29467	1
Matures	2005	13157	111648	4957	1.199	-0.24	59.13	0.599	14025	19289	1
Matures	2006	11868	123655	6334	1.524	-0.14	59.02	0.528	20054	21473	1
Immatures	1989	10187	134019	41093	1.98	3.74	57.45	0.747	22881	39781	2
Immatures	1990	9973	136268	17002	1.69	4.57	56.88	0.511	30141	32568	2
Immatures	1991	3823	112522	12250	1.386	4.58	56.66	0.789	12235	19753	1
Immatures	1992	13444	102279	21131	3.274	8.37	57.45	0.511	22062	24681	2
Immatures	1993	13872	111841	26101	2.383	5.4	57.84	0.586	31824	32492	2
Immatures	1994	4479	76409	24121	3.618	6.97	57.84	0.764	7399	15209	2
Immatures	1995	6100	82082	26279	2.194	3.41	57.12	0.766	14713	18744	2
Immatures	1996	12426	104638	27983	1.904	4.75	56.37	0.716	23898	32351	2
Immatures	1997	12903	120990	24945	1.86	4.82	57.01	0.68	31336	41745	2
Immatures	1998	8752	115309	27839	1.833	5.37	57.24	0.677	29656	41198	2
Immatures	1999	12506	110748	20659	1.432	6.76	57.18	0.635	17872	23077	2
Immatures	2000	33358	124779	23099	1.791	5.06	56.73	0.674	29873	37538	2
Immatures	2001	23981	133389	20213	1.725	5.33	55.82	0.811	13855	31375	2
Immatures	2002	28097	140107	19181	1.488	5.36	56.75	0.529	46529	46133	1
Immatures	2003	23423	153232	27416	1.576	3.15	56.6	0.676	31441	40042	2
Immatures	2004	20086	138055	19644	1.14	3.79	55.29	0.822	19071	29294	2
Immatures	2005	8501	143761	17071	1.208	4.28	55.12	0.809	14299	20966	3
Immatures	2006	13068	146662	22130	1.332	5.09	55.55	0.758	17770	29072	2

Fisboat wp2a Table 2 : Biological non-spatial indices

Year	Survey.ind	Recruit.ind	Lbar	L25	L75	L50.matu.f	L50.matu.r	Z	StdLbar	StdL25	StdL75	SdL50.mat	SdL50.mat	StdZ
1989	23343000	7592000	NA	NA	NA	NA	NA	0.180346	NA	NA	NA	NA	NA	NA
1990	23346000	7094000	19.54669	16.75	22.75	NA	NA	0.305582	NA	NA	NA	NA	NA	NA
1991	14789000	3488000	18.97551	14.25	24.25	23.74491	23.2657	0.149749	NA	NA	NA	0.244424	0.215212	NA
1992	23696000	7687000	17.94527	14.25	21.75	22.67792	22.49832	0.350652	NA	NA	NA	0.173123	0.165465	NA
1993	21100000	13187000	18.58999	14.75	22.75	23.64829	23.45323	0.547162	NA	NA	NA	0.147521	0.140949	NA
1994	10552000	4085000	18.82026	14.75	22.75	22.96017	22.8035	0.132514	NA	NA	NA	0.15573	0.149406	NA
1995	12830000	5549000	19.01454	14.25	23.25	24.35672	23.89047	0.085331	NA	NA	NA	0.123536	0.122255	NA
1996	24601000	7053000	16.15267	12.75	19.25	23.44936	23.38466	0.162858	NA	NA	NA	0.127994	0.124061	NA
1997	25024000	11403000	15.01624	12.75	15.75	22.9454	22.16367	0.302402	NA	NA	NA	0.132039	0.123856	NA
1998	19287000	5331000	14.20366	10.75	16.75	23.5042	22.83689	0.191699	NA	NA	NA	0.122549	0.116682	NA
1999	26233000	7287000	20.46292	15.75	24.75	23.20611	22.53009	0.260231	NA	NA	NA	0.112172	0.113728	NA
2000	44334000	25756000	14.74365	12.75	16.75	NA	NA	0.266216	NA	NA	NA	NA	NA	NA
2001	45629000	7658000	18.16931	14.75	21.25	NA	NA	0.207255	NA	NA	NA	NA	NA	NA
2002	46277000	24736000	15.81444	12.25	18.25	NA	NA		NA	NA	NA	NA	NA	NA

- **Multivariate combined indices**

Reference period 1989 - 1993

MFA-based combination of spatial indices at age

The first principal component is made of the opposition between ycg (Latitude of gravity centre) with xcg (longitude of gravity centre), Area indices and Inertia. Principal component 2 is made by the Area indices only. The adults (age 5 and older) are more to the North and West with smaller inertia and occupying smaller area. In comparison, the young (age 1 and 2 imature) are more to the South and East with larger inertia and covering larger areas. The position of age 3 imature is particular : central in its gravity centre and inertia but occupying less are than all other ages. The imatures and the matures are aligned on two different curves in the plance. The matures show a consistent trend with age to have a more Northwesternly distribution with les inertia and area occupied. There is marked difference in the imature and mature spatial characteristics at age 2 and 3.

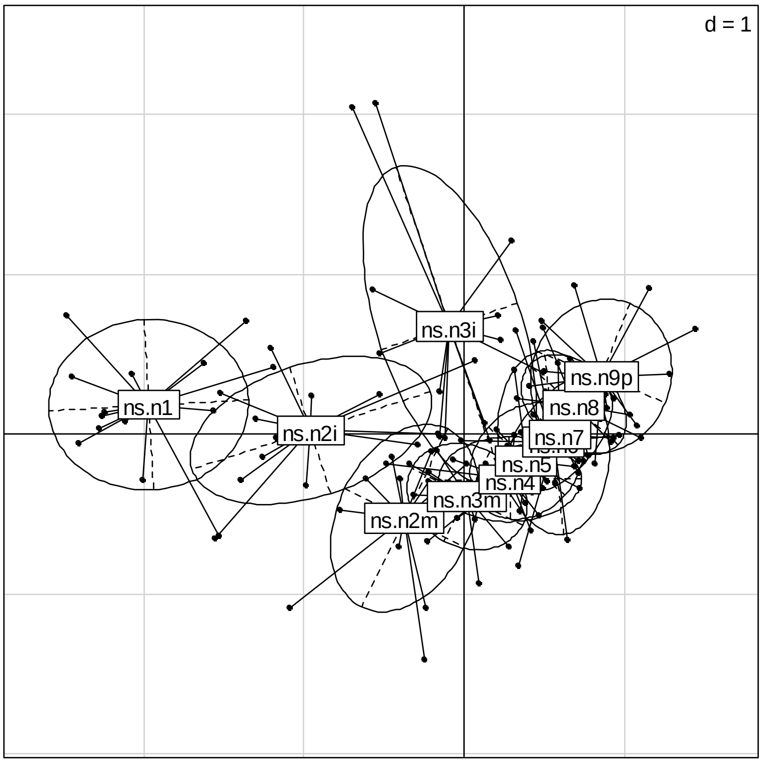


Fig. 3 : Position of each age in each year (point) in the factorial space of the spatial indices. Gravity centre for each age are labelled. Reference years are 1989 - 1993. Lines represent departure from the reference.

Table 3 : correlation between each spatial index and the first three principal components. Numbers indicate the number of times (years) in the data series where the index was correlated to the principal component with a correlation greater than 0.5 in absolute value. Signal +/- indicates the sign of that correlation

	comp.1	Comp.2	comp.3
PositiveArea	**0+|12-**	**0+|7-**	0+|0-
Inertia	**0+|10-**	2+|0-	0+|0-
Anisotropy	0+|3-	3+|0-	3+|0-
xcg	**0+|14-**	0+|0-	0+|1-
ycg	**14+|0-**	0+|1-	0+|0-
MicrostructureIndex	2+|2-	2+|1-	4+|0-
EquivalentArea	**0+|8-**	**0+|5-**	0+|4-
SpreadingArea	**0+|8-**	**0+|5-**	1+|0-

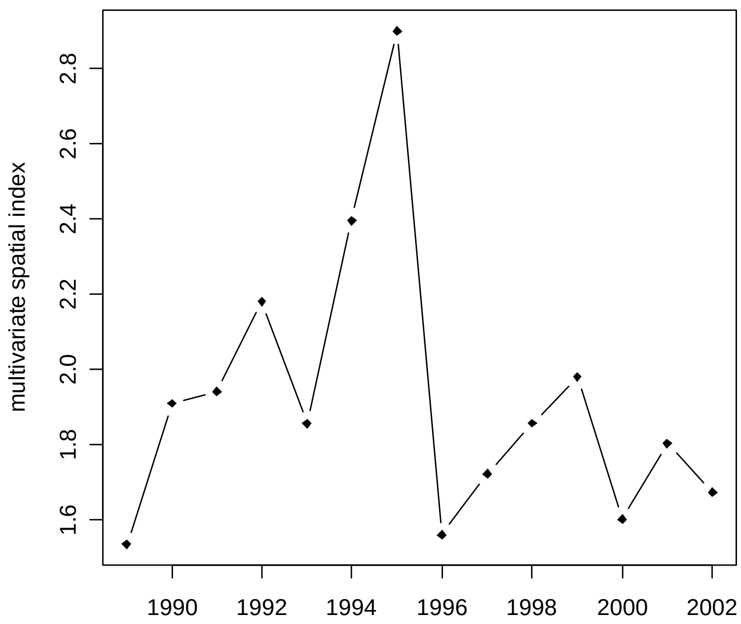


Fig. 5 : Multivariate distance (dmul) characterising the evolution of the population spatial distribution relative to the reference period 1989-1993.

Table 4 : Time series of the multivariate distance (dmul) characterising the evolution of the population spatial distribution

year	dmul
1989	1.533
1990	1.908
1991	1.939
1992	2.180
1993	1.855
1994	2.396
1995	2.900
1996	1.558
1997	1.721
1998	1.856
1999	1.979
2000	1.599
2001	1.802
2002	1.672

PCA-based combination of biological (non spatial) indices

Indices are those in Fisboat Table 2. The first 3 eigen values and factorial axes resume the variability in Table 2. The first principal represents the length index L25 and its partial opposition with the abundance indices. The opposition between Abundance indices and Length indices occurs in the plane (1,2). The third component is that of Z and Ln-Rec, which show variability that is non correlated with the other indices. The deviation in the plance (1,2) from the reference period for the years 1996-98 and 2000-02 is then mainly explained by an increase in abundance with the year 98 showing very low length indices.

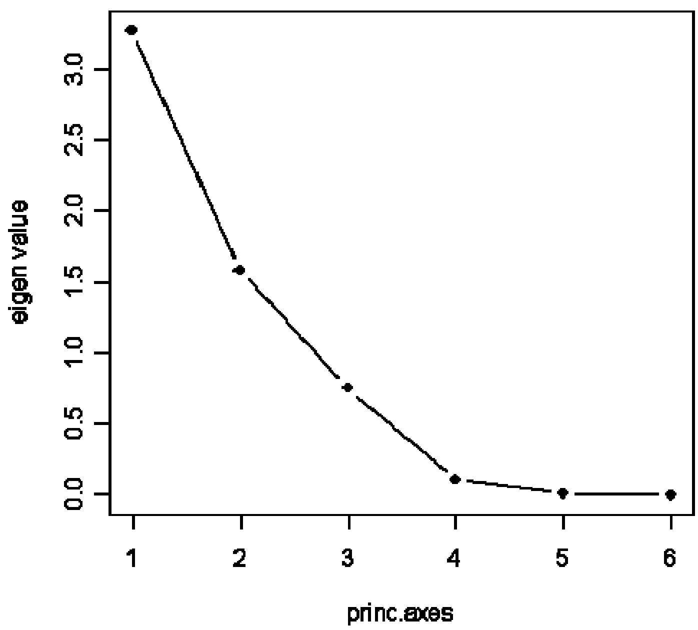


Fig. 6 : Decrease in the eigen values associated with the principal components for the PCA on the biological indices

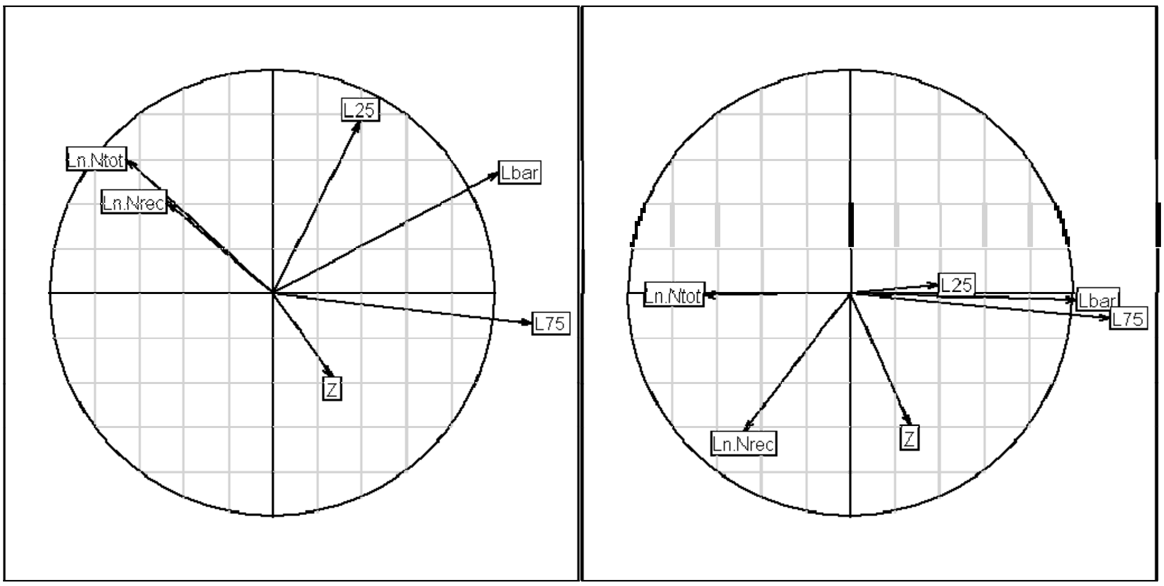


Fig. 7 : Correlation circle of the biological indices in the factorial plane of the principal axes 1 and 2 (left) and in that of axes 1 and 3 (right)

Table 5 : Correlation between each biological (non spatial) index and the first three principal components

	Comp1	Comp2	Comp3
Ln.Ntot	**-0.659**	**0.602**	-0.003
Ln.Nrec	**-0.478**	0.412	**-0.621**
Lbar	**1.015**	**0.542**	-0.025
L25	0.391	**0.773**	0.040
L75	**1.167**	-0.136	-0.112
Z	0.266	-0.377	**-0.596**

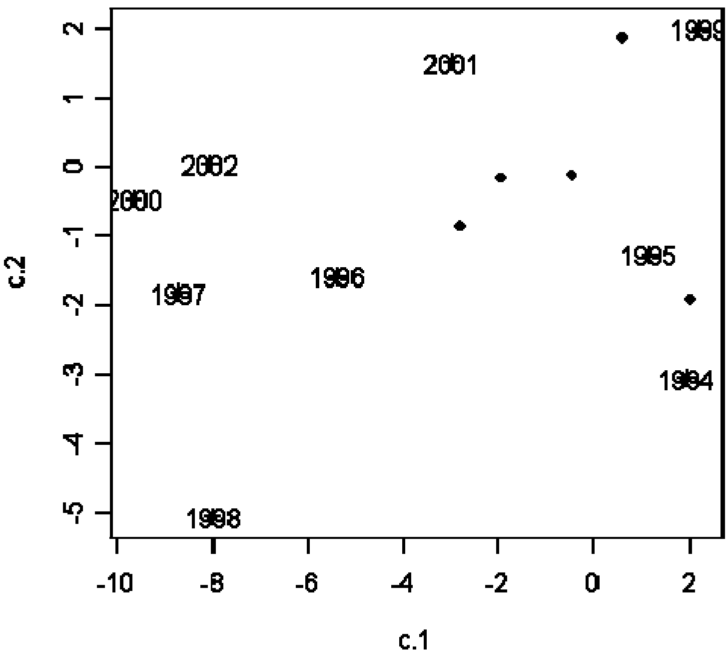


Fig. 8 : Monitoring North Sea herring in the factorial sub-space of the two first principal axes using the biological non spatial indicators (Fisboat Table 2). Representation of years in the factorial sub-space (the black diamonds are the reference years); right: the time series of the multivariate distance representing the deviation of the stock from its reference status.

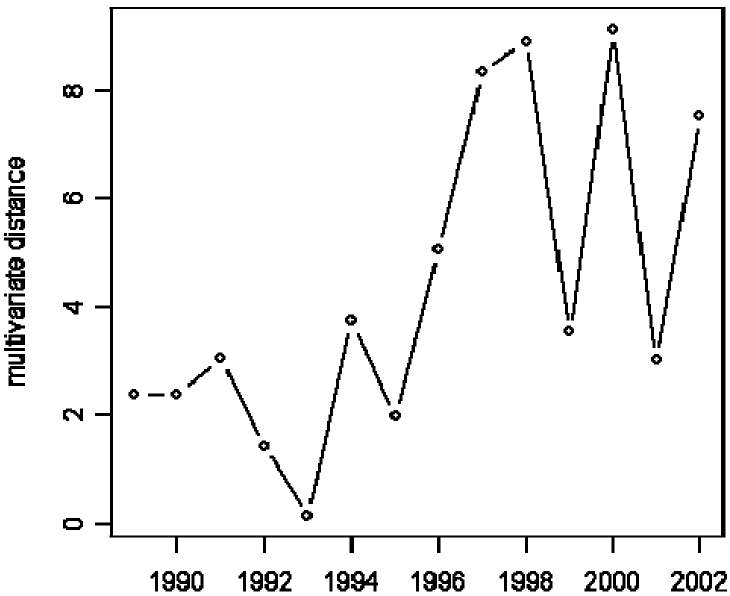


Fig. 9 : Multivariate distance (mdbio) characterising the evolution of the population biological non spatial indices, relative to the reference period 1989-1993.

Table 6 : Time series of the multivariate distance (mdbio) characterising the evolution of the population biological non spatial indices.

year	mdbio
1989	2.364
1990	2.379
1991	3.044
1992	1.421
1993	0.127
1994	3.733
1995	1.975
1996	5.050
1997	8.333
1998	8.903
1999	3.527
2000	9.133
2001	3.017
2002	7.533

- **Selection of informative raw indices using MAF**

37 indices in all. L50.matu deleted because of too many NA values. 35 indices. 29 have variogram at lag 1 < unity and are retained. MAFs computed with adding noise and estimating the median over 600 realisations. Several runs made of 600 realisations to ensure that results are stable.

MAF1 is formed by a large number of indices but none are well correlated to that MAF, meaning that a large trend exists in a large number of indices but is not the major signal in their time series. In contrast, MAFs 2 and 3 are supported by fewer indices well correlated to these MAFs. The signal in MAF2 is a change in the early-mid 90s that concerns abundance, inertia and xcg. MAF3 also shows an additional change in the late 90s. Biological indices are well correlated the MAF3 only.

In the years 1993-95, the abundance of matures has decreased with a lowest value being in 1994. Spatial distribution indices show correlated bethaviour in their time series: latitude and longitude of the gravity centre of matures (ycg.matures, xcg.matures) show a drop in the period 1993-95 and the Area indices as well, meaning that the matures were less abundant, occupying less area in more southern and central areas of the North Sea. In 1998, L25 shows a very low value (unexplained). From 1998 onwards up to 2002, abundance has recovered reaching the highest values in the series. But some indices in the spatial distribution have not recovered their values of beginning of the series : xcg has stayed low, as well as inertia, spreading area and equivalent area. In the last period (in particular 2000-02) in comparison to the first period (1989-93) abundance is higher, but xcg switched to the West, inertia is lower and areas of high density are smaller and more homogeneous.

Abundance droped to a low in 1994 but has recovered since 1998 and reached high values 2000-02. But the changes that occurred in 1994 in the spatial distribution of matures have not recovered.

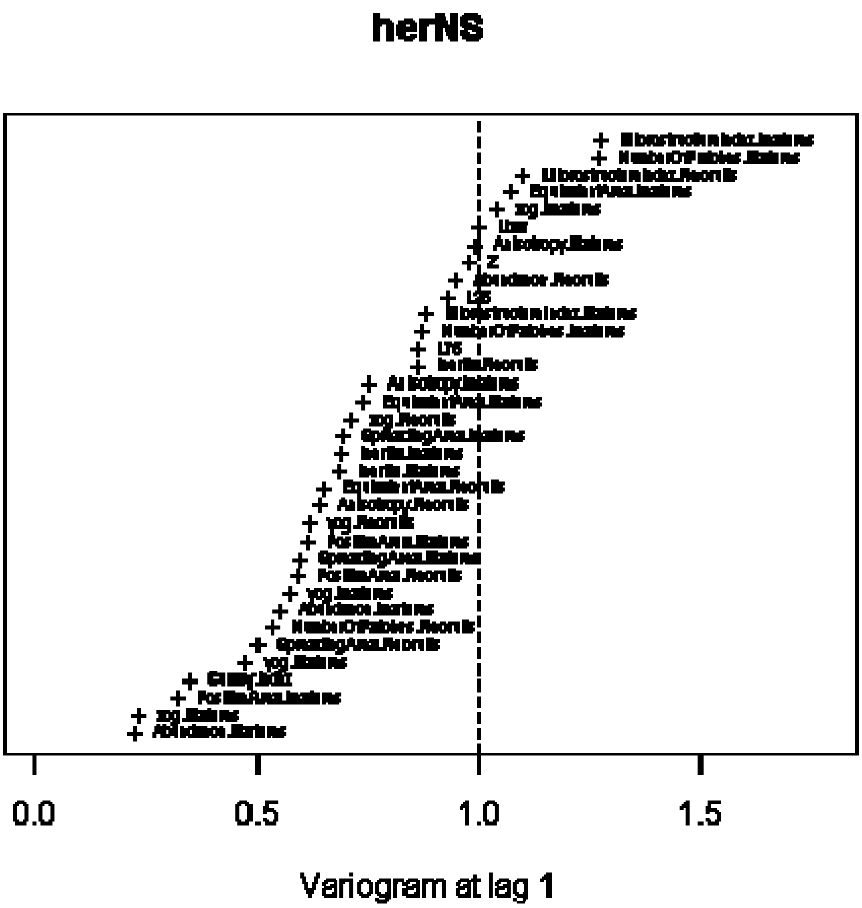


Fig. 10 : Variogram at lag 1 year for the indicators ranked. Indices with variogram value lower than 1 are selected.

Table 7 : Variogram at lag 1 year for the first 3 MAFs

	MAF1	MAF2	MAF3
Variogram value	0.095	0.152	0.312

Table 8 : Loadings of the indices on the first 3 MAFs

	MAF1	MAF2	MAF3
ycg.Matures	-0.10	0.05	**-0.24**
Anisotropy.Imatures	0.09	0.01	**0.23**
Abundance.Imatures	**-0.12**	**0.11**	**0.16**
Survey.index	**-0.15**	0.10	**0.11**
Anisotropy.Matures	0.00	0.05	**0.22**
Inertia.Imatures	-0.05	**-0.19**	0.02
Inertia.Matures	**0.15**	-0.08	-0.09
xcg.Matures	**0.13**	**0.14**	0.01
Abundance.Matures	**-0.13**	**0.13**	-0.01
NumberOfPatches.Recruits	-0.02	-0.09	**-0.18**
PositiveArea.Matures	0.11	0.01	**-0.15**
Inertia.Recruits	0.05	**-0.14**	**0.11**
MicrostructureIndex.Matures	-0.03	**-0.17**	-0.03
xcg.Recruits	**-0.16**	0.05	-0.04
Z	**0.11**	-0.03	**0.14**
SpreadingArea.Matures	**0.15**	0.04	-0.07
NumberOfPatches.Imatures	**-0.15**	-0.06	0.03
EquivalentArea.Matures	**0.15**	0.07	-0.02
L25	0.07	0.09	**0.13**
Abundance.Recruits	0.03	0.10	**0.13**
L75	0.06	0.03	**0.13**
SpreadingArea.Imatures	-0.02	-0.04	**-0.14**
ycg.Recruits	-0.03	0.06	**0.12**
PositiveArea.Imatures	-0.01	0.10	-0.08
Anisotropy.Recruits	-0.01	-0.07	**0.11**
PositiveArea.Recruits	-0.01	0.08	-0.06
ycg.Imatures	0.07	-0.02	0.04
SpreadingArea.Recruits	-0.04	0.05	0.01
EquivalentArea.Recruits	-0.01	0.01	0.04

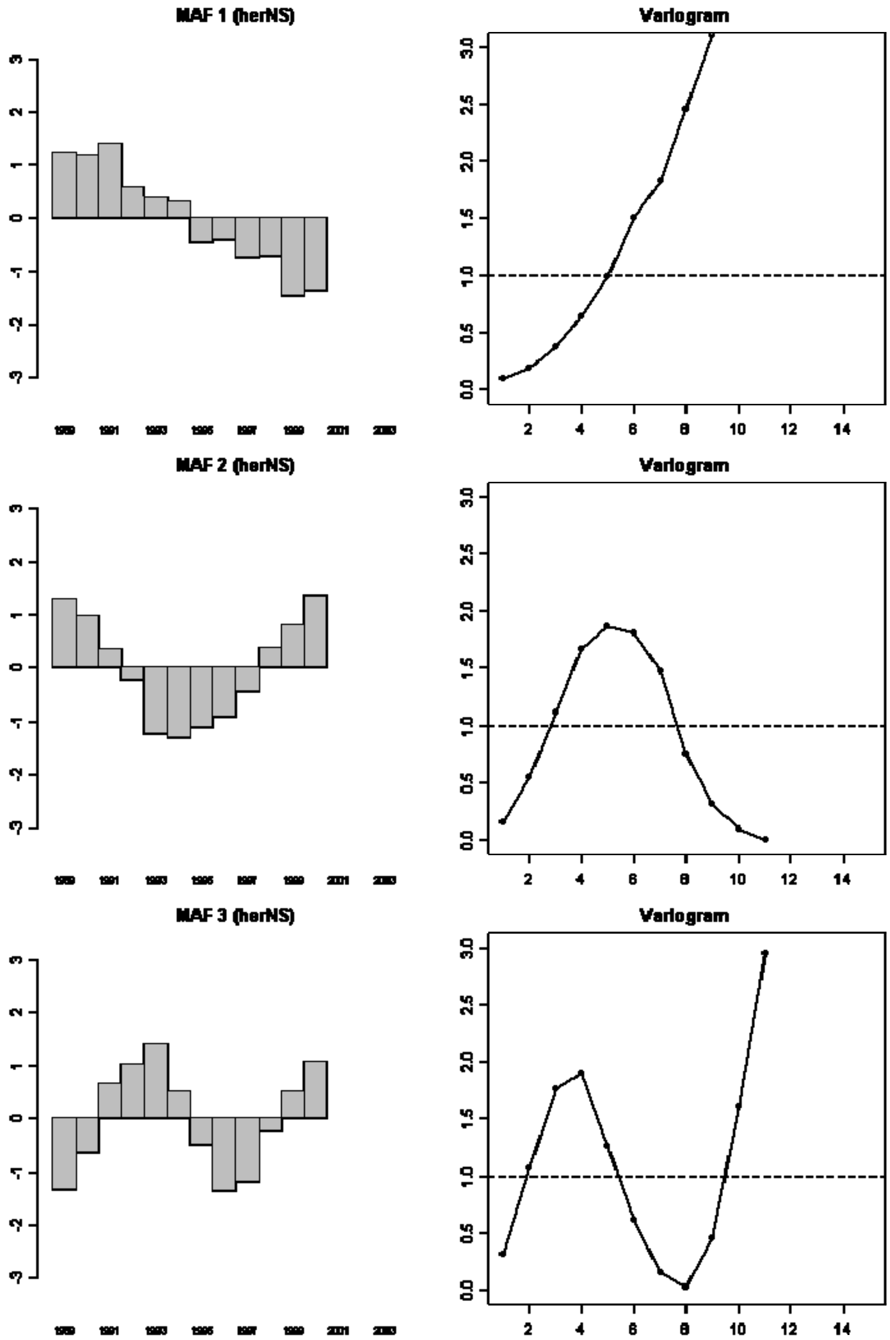


Fig. 11 : MAFs 1 (top) , 2 (centre) and 3 (bottom): time series (left), variogram (right).

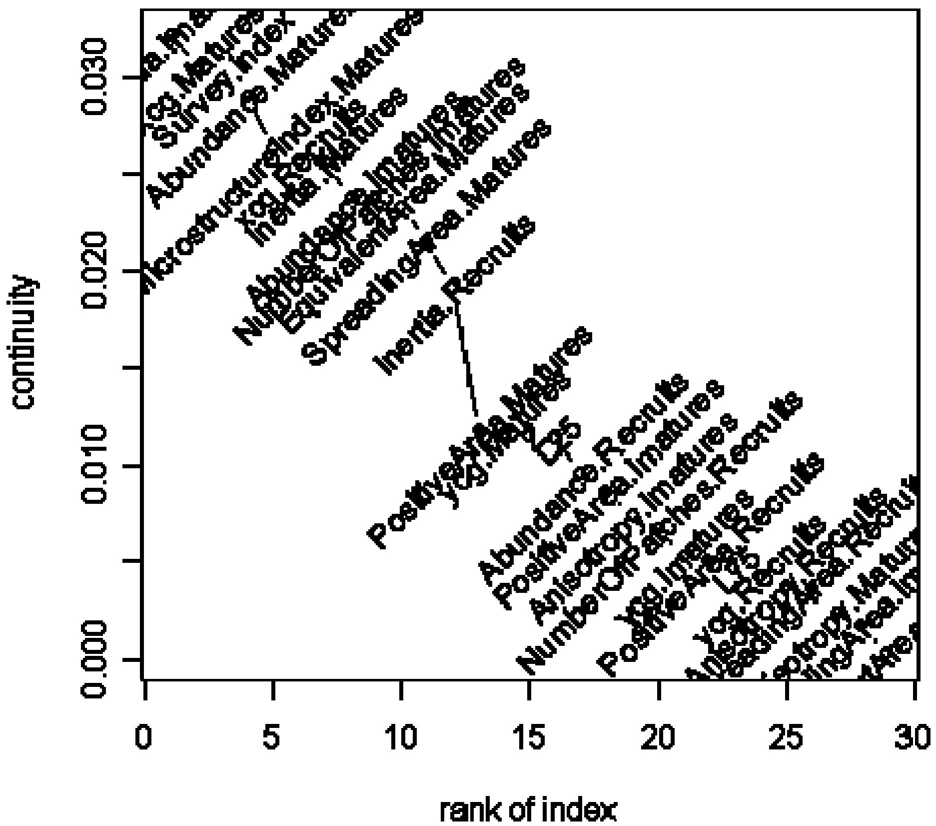


Fig. 12 : Continuity on the first 2 MAFs of indicators ranked. 9 raw indices are selected that support the changes. First index at the top left is Inertia.Imatures.

Selected indices for interpreting the multivariate diagnostic are the first 16 indices :
Inertia.Imatures, xcg.Matures, Survey.index, Abundance.Matures, MicrostructureIndex.Matures, xcg.Recruits, Inertia.Matures, Abundance.Imatures, NumberOfPatches.Imatures, EquivalentArea.Matures, SpreadingArea.Matures, Inertia.Recruits, PositiveArea.Matures, ycg.Matures, Z, L25

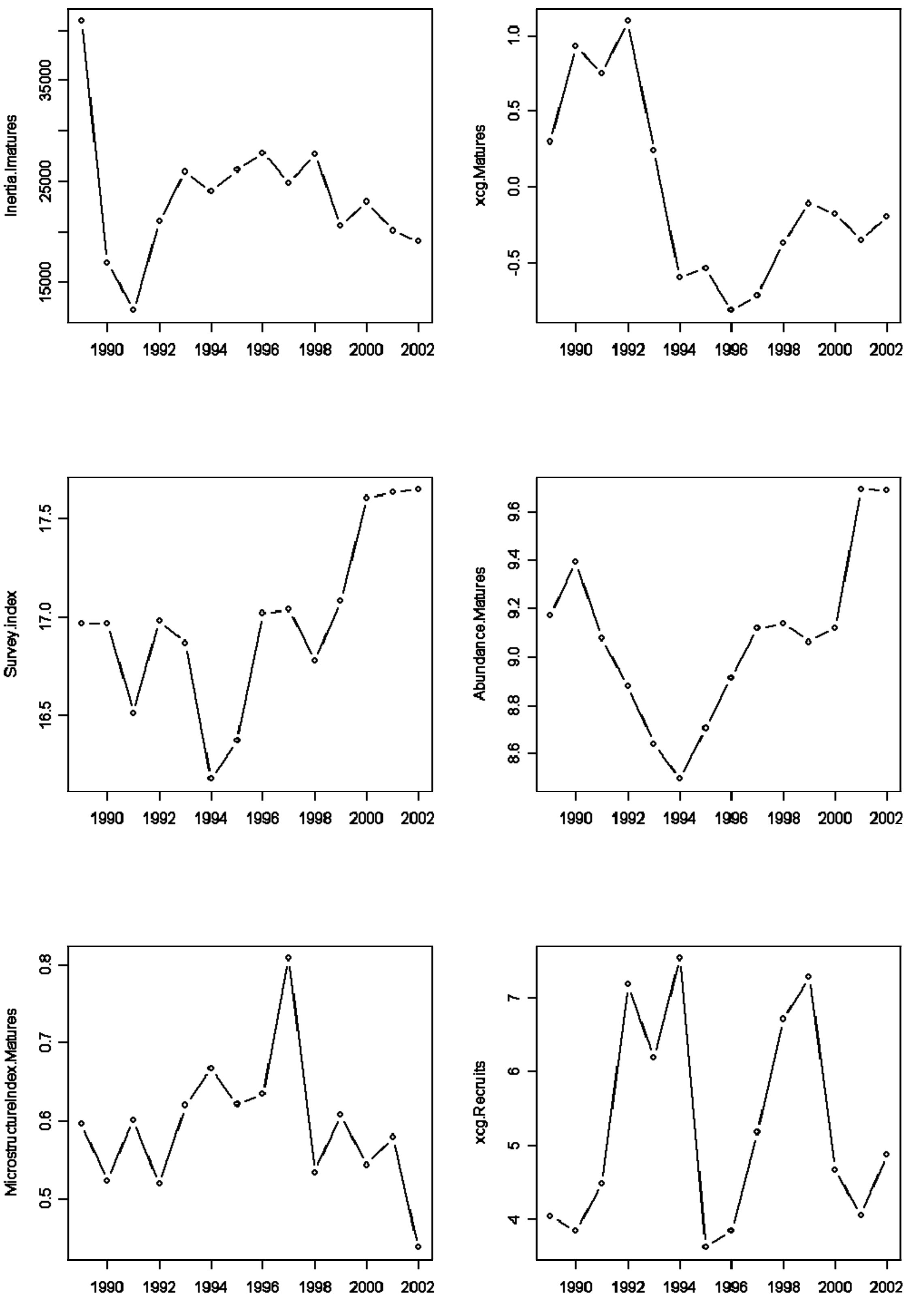


Fig. 14a: Time series of the 16 selected indices using MAFs.

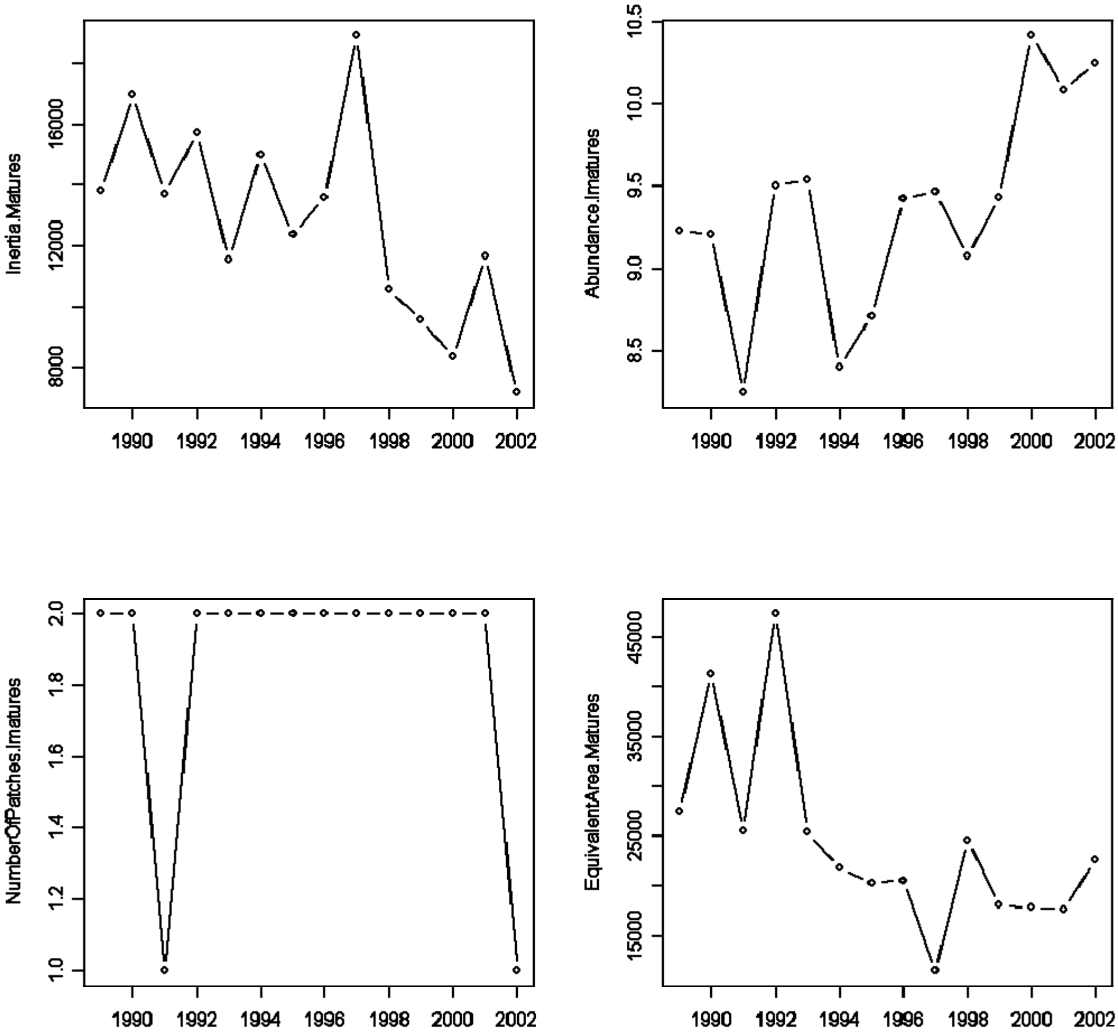


Fig. 14b: Time series of the 16 selected indices using MAFs.

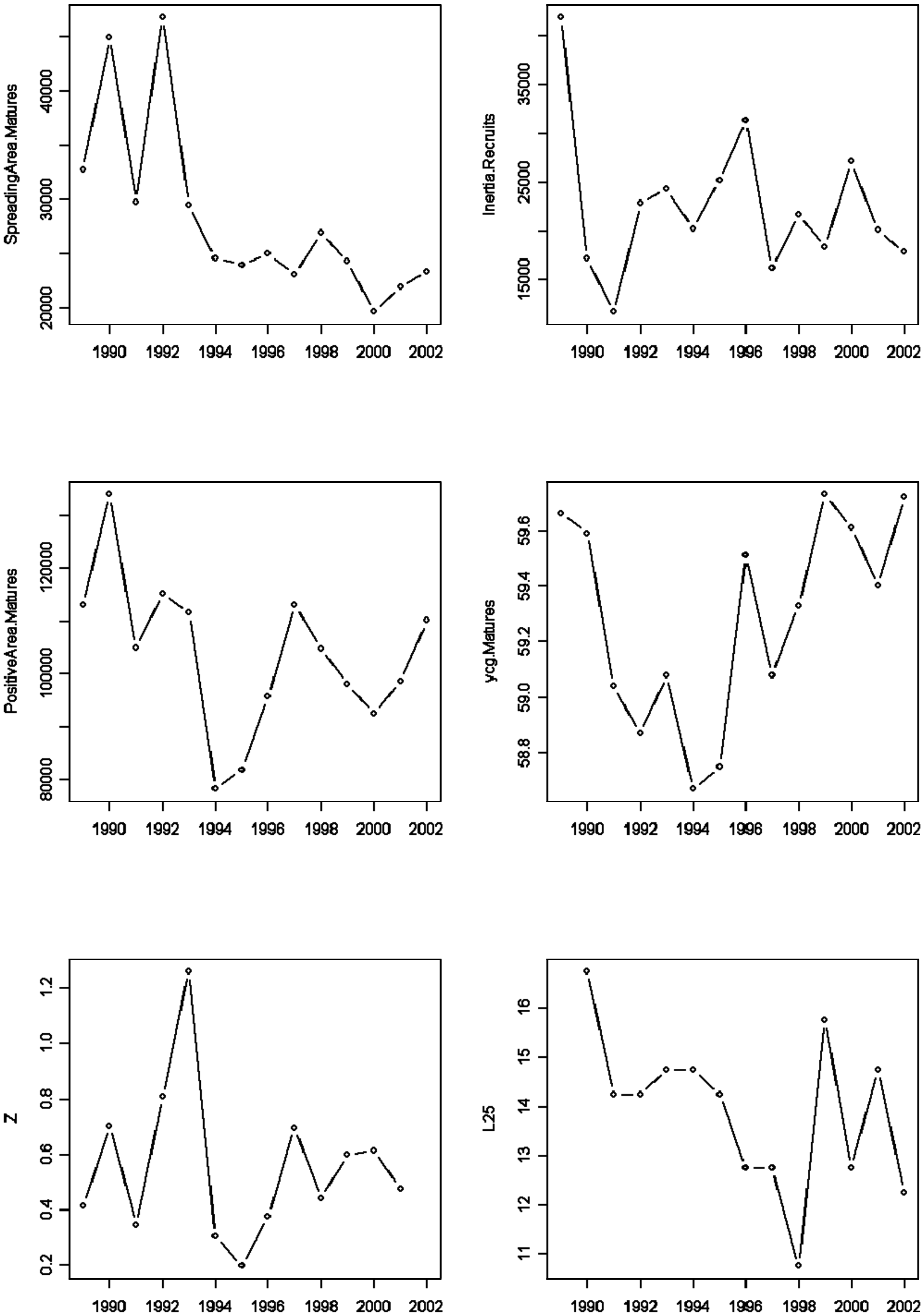


Fig. 14c: Time series of the 16 selected indices using MAFs.

Looking for changes and interpretation

- **di-cusum plots of selected indices**

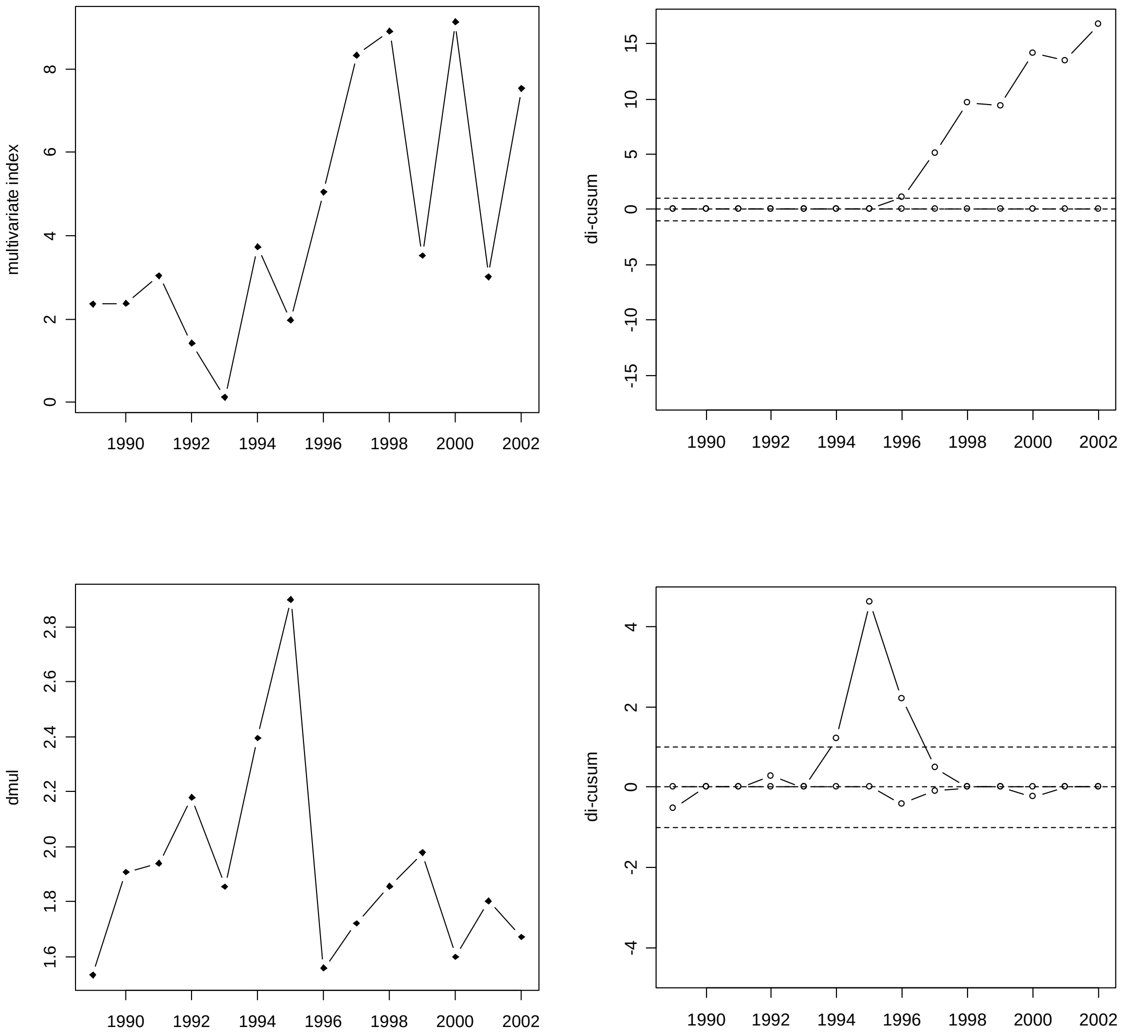


Fig. 15 : Time series of the multivariate indices (left) and their corresponding decision-cusum charts (right) for the biological non spatial indices (above) and the spatial indices (bottom). Reference years are 1989-1993.

North Sea herring		CUSUM traffic light diagnostic table	
ref.period	1989, 1990, 1991, 1992, 1993		
m in ref.period	1.88	1.87	
sd in ref.period	0.23	1.13	
k	1.0	1.7	
h	1.0	1	
ARL InControl	35.3	263.1	
ARL OutControl	1.8	1.3	
Years	**MFA_Spatial**	**PCA_biological**	**diagnostic**
1989	0.00	0.00	ref
1990	0.00	0.00	ref
1991	0.00	0.00	ref
1992	0.00	0.00	ref
1993	0.00	0.00	ref
1994	1.21	0.00	
1995	4.60	0.00	
1996	2.20	1.11	
1997	0.00	5.13	
1998	0.00	9.65	
1999	0.00	9.41	
2000	0.00	14.14	
2001	0.00	13.45	
2002	0.00	16.76	

The multivariate biological index does not capture the low in the mid90s, while the multivariate spatial index does capture de changes in the spatial distribution. The multivariate biological index captures the increase in abundance since 1996, significant in comparison to the reference period. The years of bad stock status were 1994-1996, as evidenced by the spatial and abundance indices. The departure from the reference in the biological indices from 1996 onwards is to the better! The multivariate spatial index has been been sensitive to the persistent changes in some spatial indices of the matures after 1996.

Indicator Based Assessment

Cod Barents Sea

K. Korsbrekke (IMR)

The survey data and information of basic biology

The demersal trawl survey series used in this study is from the period 1989 to 2004. There have been some changes made to the survey during this period. The most important of these changes is an increase in the survey area (1993). But the yearly coverage after the increase has also been varying due to other factors. Adverse weather conditions is one, varying ice coverage is a second while not getting access to Russian EEZ a third (1997 and 1998).

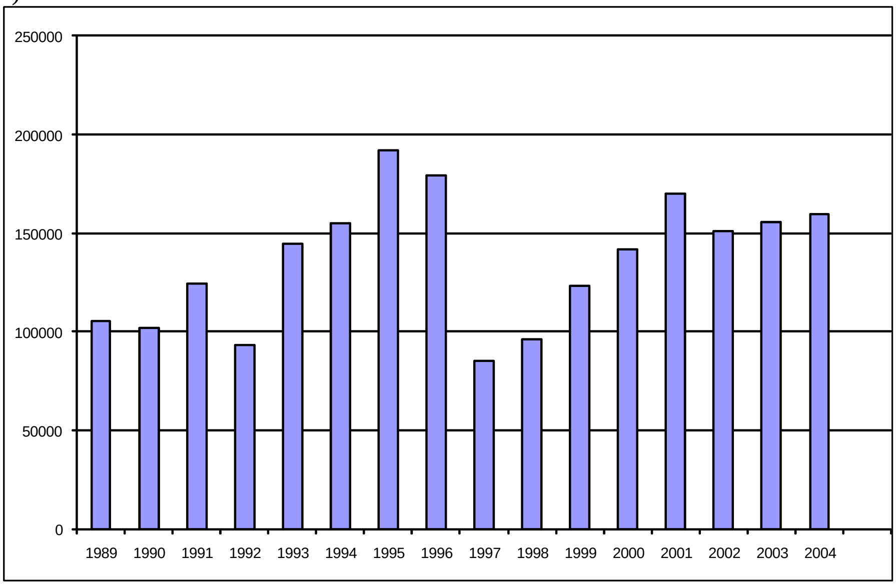


Figure 1 Survey coverage (area in nm2) in different years.

The spawning take place along the Norwegian coast (outside the survey area) over a two month period with a peak around 1. April. The egg and larvae drift freely in the coastal current and into the Barents Sea where in August 0-group fish can be found relatively close to the surface over a very large area (larger than the survey area). The 0-group fish settles at the bottom in September-November and is heavily predated on. The spatial structure in this predation influences the distributional pattern of 1- and 2-group observed in the survey. Higher survival in the eastern part of the survey area is the factor causing the easterly distributions of centre of gravity for 1- and 2-group. The cod starts feeding migrations at approximately age 3 and the most attractive areas for feeding (at the time of the survey) is around Bear Island, at the coast of Finnmark and at an area north east of the Kola Peninsula. The cod matures at age 6 to 8 and a varying proportion of mature fish will have left the survey area at the time of the survey. These are the basic processes influencing the spatial properties of the stock and these processes are also influenced by strong environmental variation.

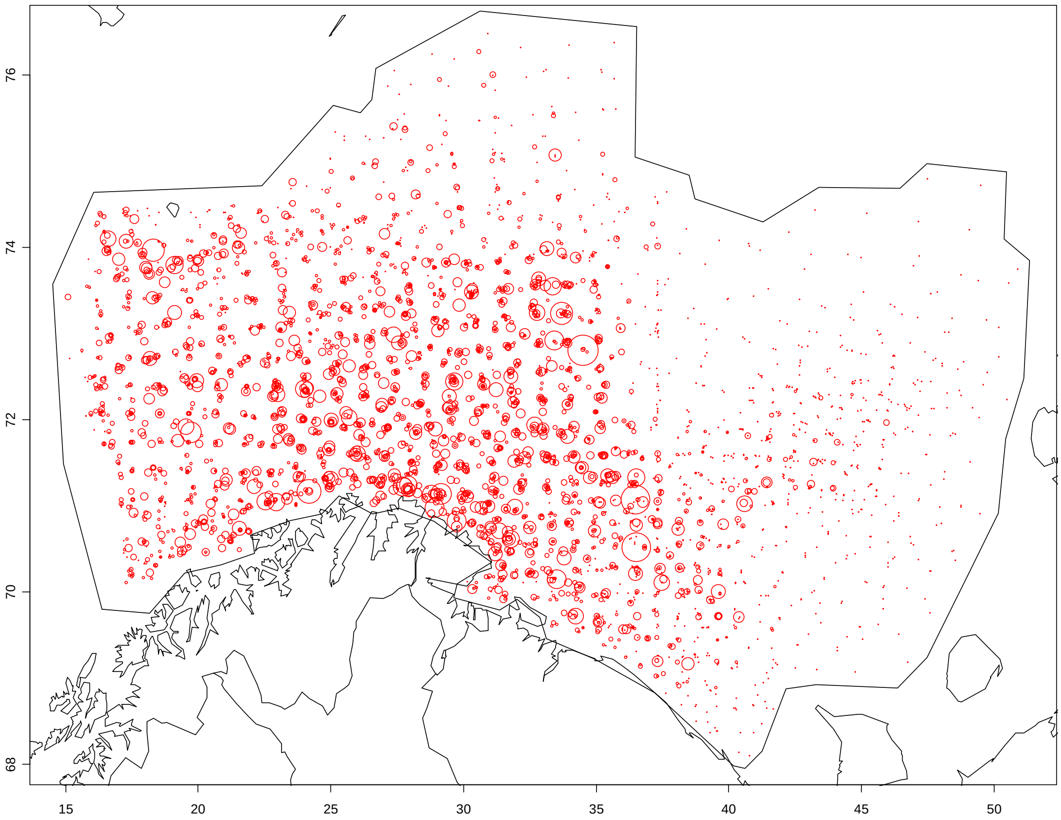


Figure 2 Map of all survey stations overlaid showing polygon used. Please note that the area covered varies between years.

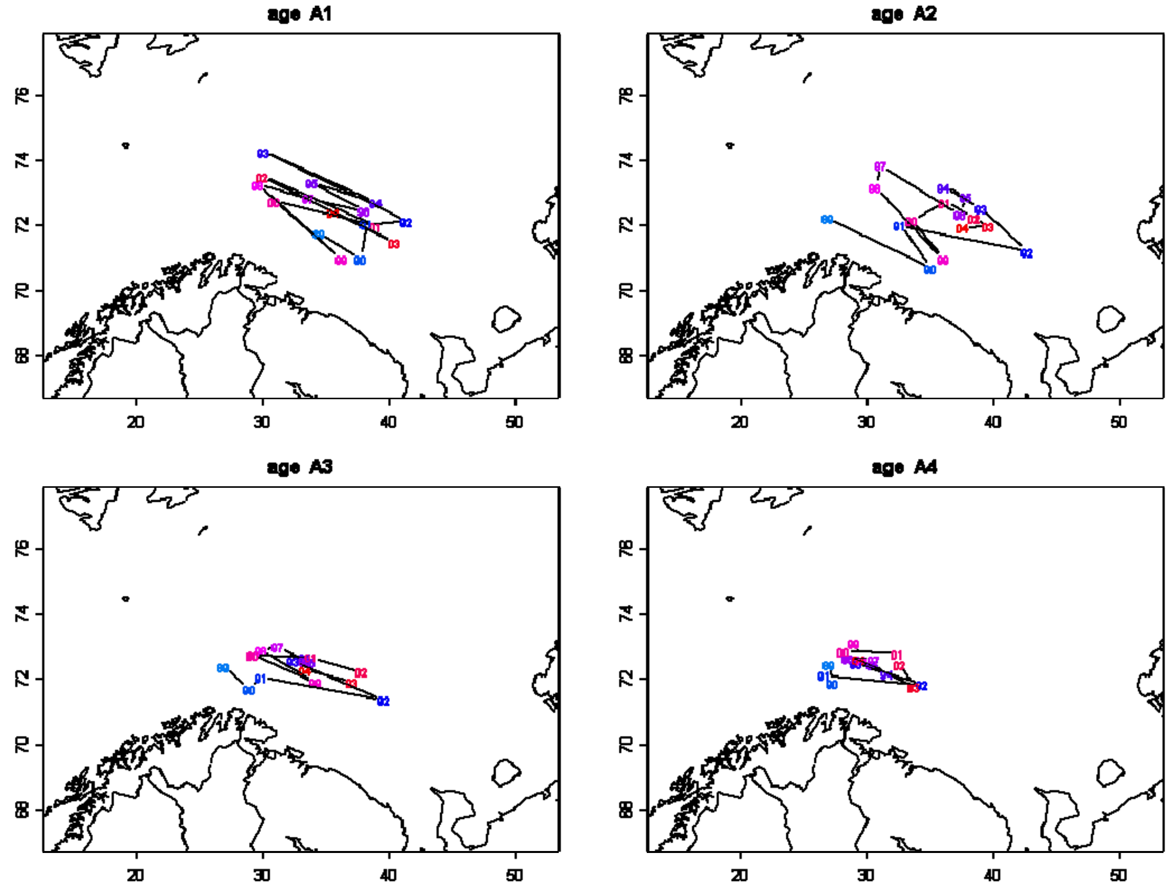


Figure 3 Maps of gravity centres across years for age 1-4 (immature fish).

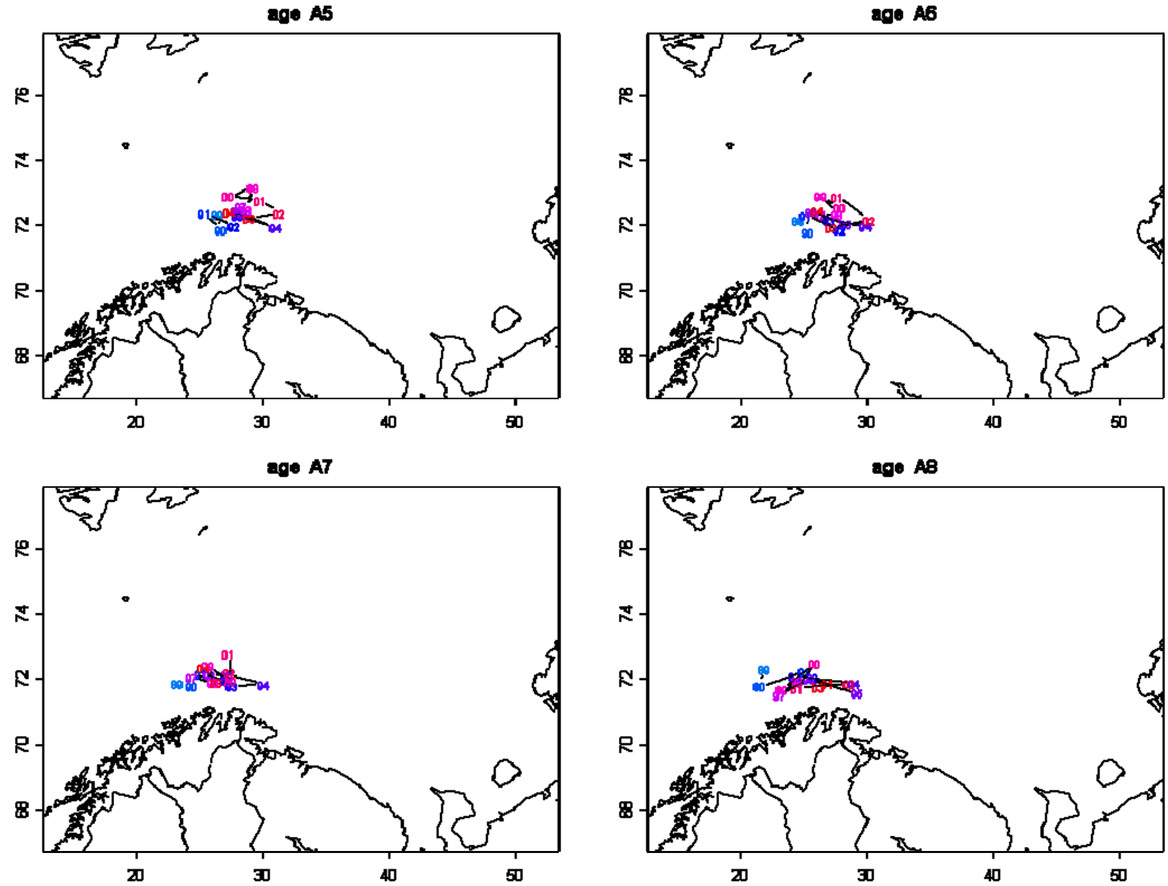


Figure 4 Maps of gravity centres across years for agea 5-8 (most fish of 7 and 8 are mature).

Input parameters for spatial indices: function infl() , function NBPatches() , function Microstructure()

Infl	dlim = 40	Ndisc = 200	
f.spatialpatches	Lim.D = 200	B.li = 0.1	
microstructure	dlim = 40	Ndisc = 200	H0 = 10

Table WP2A1

Area	Survey Type	Species	Age	Year	Abundance	Positive Area	Inertia	Anisotropy	xcg	ycg	Num. Of Patches	Micro-structure Index	Eq. Area	Spreading Area
BarentsSea	BT	Cod	A1	1989	176000	90780	18645	1.505	34.42	71.77	1	0.424	44400	42600
BarentsSea	BT	Cod	A1	1990	2482000	115480	13352	1.262	37.74	70.95	2	0.391	24600	35100
BarentsSea	BT	Cod	A1	1991	8276000	138166	29525	2.407	38.22	72.05	2	0.307	27000	32600
BarentsSea	BT	Cod	A1	1992	4995000	134186	21511	3.151	41.4	72.13	2	0.252	53400	35100
BarentsSea	BT	Cod	A1	1993	8045000	173619	20999	2.012	30.05	74.27	1	0.241	24900	40200
BarentsSea	BT	Cod	A1	1994	13322000	194457	36964	1.892	38.91	72.7	3	0.267	65500	61300
BarentsSea	BT	Cod	A1	1995	67885000	204775	34663	2.21	33.86	73.32	3	0.248	50100	63500
BarentsSea	BT	Cod	A1	1996	65226000	197726	32664	1.946	38.04	72.44	3	0.255	57300	70400
BarentsSea	BT	Cod	A1	1997	29151000	110072	7643	1.281	33.65	72.84	1	0.412	10000	25100
BarentsSea	BT	Cod	A1	1998	14539000	129476	18980	1.367	29.63	73.25	2	0.225	64000	51700
BarentsSea	BT	Cod	A1	1999	8028000	136552	16707	2.142	36.23	70.97	2	0.44	16800	24600
BarentsSea	BT	Cod	A1	2000	2274000	174067	45582	1.98	30.9	72.75	4	0.295	64200	52800
BarentsSea	BT	Cod	A1	2001	10019000	185451	32663	1.865	38.94	71.99	3	0.361	53300	65300
BarentsSea	BT	Cod	A1	2002	506000	127110	37482	2.239	29.95	73.5	4	0.401	12500	43800
BarentsSea	BT	Cod	A1	2003	28773000	168992	20256	1.872	40.42	71.47	2	0.408	12600	47200
BarentsSea	BT	Cod	A1	2004	3190000	164112	40986	2.264	35.54	72.43	4	0.34	31000	59800

BarentsSea	BT	Cod	A2	1989	338000	102569	24170	2.623	26.84	72.22	2	0.424	22400	31400
BarentsSea	BT	Cod	A2	1990	1340000	120435	12963	2.194	35.04	70.69	2	0.425	11800	29300
BarentsSea	BT	Cod	A2	1991	3748000	145748	29940	2.966	32.57	72	3	0.438	18600	36100
BarentsSea	BT	Cod	A2	1992	20039000	136655	6517	1.271	42.65	71.2	1	0.37	14600	18600
BarentsSea	BT	Cod	A2	1993	8408000	182418	43322	3.087	39.01	72.53	3	0.264	40400	52200
BarentsSea	BT	Cod	A2	1994	10512000	194071	33457	1.94	36.06	73.17	3	0.321	52300	56600
BarentsSea	BT	Cod	A2	1995	8259000	203087	25735	1.953	37.78	72.89	2	0.306	40800	55400
BarentsSea	BT	Cod	A2	1996	11162000	181344	24422	1.755	37.3	72.34	2	0.298	48700	58000
BarentsSea	BT	Cod	A2	1997	12503000	115826	8463	1.458	31.08	73.85	1	0.31	29100	23800
BarentsSea	BT	Cod	A2	1998	6628000	127861	20980	1.725	30.65	73.16	2	0.258	48500	41500
BarentsSea	BT	Cod	A2	1999	6043000	144877	18408	2.388	36.01	70.96	2	0.392	18200	29100
BarentsSea	BT	Cod	A2	2000	3852000	171865	51484	2.881	33.55	72.17	2	0.345	31200	37400
BarentsSea	BT	Cod	A2	2001	1293000	147561	38340	2.03	36.14	72.72	2	0.341	42800	49200
BarentsSea	BT	Cod	A2	2002	4317000	165249	31722	2.194	38.46	72.22	3	0.297	56600	51700
BarentsSea	BT	Cod	A2	2003	1467000	131687	33831	2.492	39.61	71.97	2	0.413	15200	27800
BarentsSea	BT	Cod	A2	2004	3719000	166487	34405	2.574	37.53	71.94	3	0.443	20400	52800
BarentsSea	BT	Cod	A3	1989	867000	110447	25157	3.076	26.89	72.39	2	0.482	15200	24100
BarentsSea	BT	Cod	A3	1990	523000	86142	10155	1.779	28.93	71.7	2	0.345	17100	29800
BarentsSea	BT	Cod	A3	1991	1050000	109251	23968	2.48	29.84	72.06	2	0.349	28100	35800
BarentsSea	BT	Cod	A3	1992	5587000	135440	16361	2.371	39.54	71.36	2	0.306	21000	30500
BarentsSea	BT	Cod	A3	1993	5398000	173726	32855	2.243	32.38	72.55	2	0.241	84800	78000
BarentsSea	BT	Cod	A3	1994	4465000	167156	29674	2.368	33.29	72.67	2	0.325	33600	44600
BarentsSea	BT	Cod	A3	1995	3892000	178914	21857	2.093	33.72	72.51	2	0.388	28000	43100
BarentsSea	BT	Cod	A3	1996	3190000	158306	32756	2.908	33.35	72.55	3	0.281	42600	48000
BarentsSea	BT	Cod	A3	1997	2286000	112144	13914	1.868	31.22	72.99	2	0.34	28400	33100
BarentsSea	BT	Cod	A3	1998	4899000	123910	22577	2.417	29.83	72.88	2	0.312	32100	40000
BarentsSea	BT	Cod	A3	1999	3616000	149578	21271	2.315	34.15	71.9	2	0.412	17900	35700
BarentsSea	BT	Cod	A3	2000	4522000	164965	45690	2.894	29.19	72.75	3	0.297	46800	39600
BarentsSea	BT	Cod	A3	2001	2874000	162704	33117	2.281	33.81	72.67	2	0.379	24800	42100
BarentsSea	BT	Cod	A3	2002	1982000	172743	27082	2.382	37.8	72.22	2	0.258	66500	57600
BarentsSea	BT	Cod	A3	2003	5528000	156318	31926	2.853	37.03	71.91	2	0.52	10100	37700
BarentsSea	BT	Cod	A3	2004	1432000	133811	32704	3.436	33.33	72.28	2	0.482	11600	28700
BarentsSea	BT	Cod	A4	1989	1429000	110632	22940	2.898	27.01	72.44	2	0.474	17300	27500
BarentsSea	BT	Cod	A4	1990	597000	81618	10342	1.982	27.26	71.86	2	0.406	12600	29600
BarentsSea	BT	Cod	A4	1991	486000	95815	17184	1.615	26.58	72.11	2	0.392	23100	35700
BarentsSea	BT	Cod	A4	1992	1766000	127387	24002	2.46	34.35	71.82	2	0.286	47700	49100
BarentsSea	BT	Cod	A4	1993	3298000	167333	24661	1.916	29.16	72.47	2	0.299	74500	75100
BarentsSea	BT	Cod	A4	1994	4185000	145510	25577	2.029	31.56	72.17	3	0.304	47000	59100
BarentsSea	BT	Cod	A4	1995	3828000	120122	16686	1.766	30.43	72.45	2	0.335	25200	42300
BarentsSea	BT	Cod	A4	1996	2779000	137702	27555	3.05	28.44	72.63	2	0.292	41500	45100
BarentsSea	BT	Cod	A4	1997	1221000	107069	14441	2.147	30.49	72.61	2	0.311	21400	32000
BarentsSea	BT	Cod	A4	1998	3693000	115374	23028	2.611	29.47	72.6	2	0.31	32500	38200
BarentsSea	BT	Cod	A4	1999	3158000	131526	20724	1.66	28.98	73.09	2	0.337	33700	52700
BarentsSea	BT	Cod	A4	2000	2713000	142842	34122	2.937	28.14	72.84	3	0.264	55000	46800
BarentsSea	BT	Cod	A4	2001	3105000	159556	30193	2.084	32.39	72.79	3	0.36	28800	45600
BarentsSea	BT	Cod	A4	2002	2375000	163843	30445	2.267	32.61	72.46	4	0.289	64900	70000
BarentsSea	BT	Cod	A4	2003	2090000	145066	29100	2.579	33.67	71.75	3	0.353	29600	47900
BarentsSea	BT	Cod	A4	2004	2649000	126652	33908	3.399	29.35	72.6	3	0.484	16000	32800
BarentsSea	BT	Cod	A5	1989	1004000	108621	16748	2.075	26.42	72.32	2	0.363	32900	41500
BarentsSea	BT	Cod	A5	1990	597000	84977	10912	2.071	26.69	71.85	2	0.399	13300	30400
BarentsSea	BT	Cod	A5	1991	587000	106225	18485	1.821	25.39	72.37	3	0.426	16100	34500
BarentsSea	BT	Cod	A5	1992	473000	115880	15252	1.749	27.69	71.98	3	0.275	43800	51200
BarentsSea	BT	Cod	A5	1993	1826000	144718	19488	1.691	27.99	72.29	2	0.323	54100	68300
BarentsSea	BT	Cod	A5	1994	3207000	139120	21521	1.733	31.01	71.93	2	0.26	54100	60400

BarentsSea	BT	Cod	A5	1995	4004000	109155	16560	1.653	28.51	72.32	2	0.345	33200	50100
BarentsSea	BT	Cod	A5	1996	2705000	121993	25387	2.558	27.91	72.43	2	0.317	46600	49700
BarentsSea	BT	Cod	A5	1997	1007000	106278	16957	2.119	28.31	72.6	2	0.309	27700	40300
BarentsSea	BT	Cod	A5	1998	899000	113766	21977	1.994	28.65	72.47	2	0.286	54300	46700
BarentsSea	BT	Cod	A5	1999	1440000	124218	18430	1.302	29.24	73.16	3	0.285	54800	59400
BarentsSea	BT	Cod	A5	2000	1852000	138391	21380	2.201	27.23	72.9	2	0.313	34800	53400
BarentsSea	BT	Cod	A5	2001	1808000	153924	26651	1.647	29.74	72.79	2	0.305	45300	59700
BarentsSea	BT	Cod	A5	2002	2313000	164316	29814	2.122	31.3	72.38	3	0.324	61700	72900
BarentsSea	BT	Cod	A5	2003	1656000	135260	25905	1.996	28.96	72.22	2	0.271	60500	65500
BarentsSea	BT	Cod	A5	2004	1134000	121927	27816	2.545	27.32	72.42	2	0.494	22200	46000
BarentsSea	BT	Cod	A6	1989	1358000	109432	12684	1.738	24.58	72.14	2	0.269	40900	45600
BarentsSea	BT	Cod	A6	1990	460000	80394	11449	2.062	25.25	71.81	2	0.373	20200	33100
BarentsSea	BT	Cod	A6	1991	444000	106518	17053	1.524	25.11	72.31	3	0.375	27900	44200
BarentsSea	BT	Cod	A6	1992	323000	116348	16943	1.798	27.78	71.86	3	0.277	46900	55800
BarentsSea	BT	Cod	A6	1993	508000	133704	18604	1.505	27.01	72.14	2	0.252	63700	65100
BarentsSea	BT	Cod	A6	1994	1404000	134973	19502	1.699	29.85	71.97	3	0.227	57800	60200
BarentsSea	BT	Cod	A6	1995	2183000	104103	15205	1.56	28.25	72.06	2	0.33	36700	48100
BarentsSea	BT	Cod	A6	1996	2668000	121112	23193	2.059	25.54	72.41	2	0.335	49800	52200
BarentsSea	BT	Cod	A6	1997	946000	106187	17428	1.785	26.23	72.32	2	0.311	38800	45900
BarentsSea	BT	Cod	A6	1998	650000	114218	21477	1.843	27.61	72.34	2	0.317	48400	49200
BarentsSea	BT	Cod	A6	1999	383000	118962	19553	1.369	26.36	72.9	3	0.295	51400	61000
BarentsSea	BT	Cod	A6	2000	536000	130632	18301	1.392	27.78	72.55	2	0.298	54300	61500
BarentsSea	BT	Cod	A6	2001	838000	144635	22792	1.149	27.62	72.89	3	0.343	44100	64300
BarentsSea	BT	Cod	A6	2002	1100000	156941	26712	1.831	30.18	72.16	4	0.329	65100	74000
BarentsSea	BT	Cod	A6	2003	1385000	130217	21695	1.811	27.17	71.95	3	0.335	41900	60400
BarentsSea	BT	Cod	A6	2004	943000	121088	25836	2.124	26	72.43	2	0.487	23800	47700
BarentsSea	BT	Cod	A7	1989	328000	82579	10327	1.803	23.22	71.85	2	0.254	34800	38100
BarentsSea	BT	Cod	A7	1990	570000	77300	11766	2.099	24.33	71.81	2	0.37	23800	33600
BarentsSea	BT	Cod	A7	1991	306000	104570	15862	1.432	25.13	72.15	2	0.295	40000	47000
BarentsSea	BT	Cod	A7	1992	186000	112017	16585	1.801	27.09	71.98	3	0.288	51300	57100
BarentsSea	BT	Cod	A7	1993	166000	119349	20038	1.545	27.49	71.78	2	0.292	50200	56700
BarentsSea	BT	Cod	A7	1994	260000	120721	15774	1.405	30.02	71.83	2	0.206	50800	53600
BarentsSea	BT	Cod	A7	1995	521000	95250	16448	1.564	27.16	72.13	2	0.309	39800	46600
BarentsSea	BT	Cod	A7	1996	795000	115826	23039	1.857	25.74	72.13	3	0.364	49700	54700
BarentsSea	BT	Cod	A7	1997	595000	106761	15068	1.59	24.34	72.06	2	0.3	41600	45900
BarentsSea	BT	Cod	A7	1998	397000	108874	18424	1.649	26.07	71.9	2	0.313	42800	49600
BarentsSea	BT	Cod	A7	1999	151000	105782	21203	1.594	25.64	72.41	3	0.369	39200	51000
BarentsSea	BT	Cod	A7	2000	99000	104788	18290	1.294	27.4	71.93	2	0.372	33900	49800
BarentsSea	BT	Cod	A7	2001	257000	129779	22156	1.335	27.28	72.77	3	0.37	33800	54700
BarentsSea	BT	Cod	A7	2002	413000	140064	23295	1.589	27.37	72.18	3	0.312	60600	66900
BarentsSea	BT	Cod	A7	2003	476000	123594	19867	1.499	26.32	71.9	3	0.36	27100	54400
BarentsSea	BT	Cod	A7	2004	634000	119469	22951	1.842	25.31	72.32	2	0.43	29300	45900
BarentsSea	BT	Cod	A8	1989	26000	40985	12102	1.301	21.83	72.3	2	0.293	27300	25400
BarentsSea	BT	Cod	A8	1990	81000	54827	8175	1.661	21.44	71.78	1	0.284	28900	27600
BarentsSea	BT	Cod	A8	1991	273000	104612	15668	1.394	25.05	72.21	3	0.281	45500	49400
BarentsSea	BT	Cod	A8	1992	98000	104432	14787	1.745	25.68	72.05	2	0.296	47600	50800
BarentsSea	BT	Cod	A8	1993	121000	112585	19616	1.332	24.31	72.09	3	0.31	49200	47800
BarentsSea	BT	Cod	A8	1994	66000	87287	18235	1.649	28.94	71.86	3	0.283	34500	44300
BarentsSea	BT	Cod	A8	1995	84000	76471	11462	1.447	29.18	71.56	2	0.39	15500	27500
BarentsSea	BT	Cod	A8	1996	90000	100643	23047	1.741	25.43	72.01	2	0.367	47400	52400
BarentsSea	BT	Cod	A8	1997	141000	87400	13714	1.648	23.02	71.52	2	0.321	20800	32600
BarentsSea	BT	Cod	A8	1998	209000	106141	15362	1.556	24.47	71.92	2	0.291	41800	47000
BarentsSea	BT	Cod	A8	1999	92000	87260	16408	1.503	23.25	71.68	2	0.491	11400	35500
BarentsSea	BT	Cod	A8	2000	60000	93073	19180	1.116	25.82	72.47	3	0.395	30900	46900

BarentsSea	BT	Cod	A8	2001	44000	76603	15525	1.282	24.43	71.73	3	0.454	9050	27900
BarentsSea	BT	Cod	A8	2002	85000	111049	20459	1.547	28.57	71.85	4	0.335	42500	49500
BarentsSea	BT	Cod	A8	2003	118000	106351	18541	1.348	26.17	71.77	3	0.35	17900	44000
BarentsSea	BT	Cod	A8	2004	182000	110691	22833	2.118	26.75	71.87	2	0.428	24900	42300
BarentsSea	BT	Cod	A9	1989	4000	6024	6814	3.058	20.08	70.87	2	0.386	6280	4580
BarentsSea	BT	Cod	A9	1990	6000	10546	19621	4.161	24.73	71.83	2	0.534	7840	7420
BarentsSea	BT	Cod	A9	1991	18000	54196	14981	1.234	23.17	72.05	2	0.381	28300	29000
BarentsSea	BT	Cod	A9	1992	82000	100281	15109	1.694	26.47	71.9	2	0.324	36000	44400
BarentsSea	BT	Cod	A9	1993	83000	94819	18890	1.512	26.07	71.82	2	0.349	30200	39900
BarentsSea	BT	Cod	A9	1994	52000	78362	18436	1.459	30.7	71.75	2	0.265	37900	39100
BarentsSea	BT	Cod	A9	1995	21000	49238	13123	1.348	23.03	72.42	3	0.259	26000	26400
BarentsSea	BT	Cod	A9	1996	13000	58115	22027	2.194	26.47	72.1	2	0.34	32400	33500
BarentsSea	BT	Cod	A9	1997	22000	50987	18078	1.75	24.26	71.41	2	0.345	15400	25100
BarentsSea	BT	Cod	A9	1998	32000	73466	16038	1.761	27.08	71.5	2	0.335	36000	34600
BarentsSea	BT	Cod	A9	1999	23000	52771	17337	1.722	25.24	71.55	2	0.506	12000	21500
BarentsSea	BT	Cod	A9	2000	24000	40550	15042	1.889	22.56	72.46	2	0.433	22600	19000
BarentsSea	BT	Cod	A9	2001	14000	44292	21118	1.344	26.76	71.81	3	0.512	9830	18900
BarentsSea	BT	Cod	A9	2002	8000	37867	29401	1.09	29.23	72.21	3	0.412	16200	16200
BarentsSea	BT	Cod	A9	2003	27000	83919	17253	1.536	25.62	71.75	2	0.335	18900	32600
BarentsSea	BT	Cod	A9	2004	34000	69669	19781	2.12	26.59	71.85	3	0.445	19600	24400
BarentsSea	BT	Cod	A10	1989	3000	9262	15403	1.683	21.89	71.04	2	0.413	6970	5730
BarentsSea	BT	Cod	A10	1990	0	411	0	NA	28.2	71.83	1	0.61	411	411
BarentsSea	BT	Cod	A10	1991	1000	1843	624	1.253	27.97	71.54	1	0.531	1890	1840
BarentsSea	BT	Cod	A10	1992	5000	27295	12706	2.336	27.53	71.41	2	0.531	7520	14400
BarentsSea	BT	Cod	A10	1993	52000	86115	17901	2.033	27.44	71.44	2	0.342	33300	40000
BarentsSea	BT	Cod	A10	1994	13000	43258	19484	1.326	26.02	73.34	2	0.357	26400	22300
BarentsSea	BT	Cod	A10	1995	12000	23102	11247	2.308	22.66	71.39	2	0.319	13700	12500
BarentsSea	BT	Cod	A10	1996	4000	22512	7648	1.723	33.62	70.96	1	0.478	11000	13300
BarentsSea	BT	Cod	A10	1997	6000	22448	11274	2.936	22.34	70.93	2	0.322	7620	9660
BarentsSea	BT	Cod	A10	1998	5000	12785	13568	1.674	26.87	71.58	2	0.588	4800	7370
BarentsSea	BT	Cod	A10	1999	7000	14915	16458	6.448	25.21	70.92	2	0.583	3500	6270
BarentsSea	BT	Cod	A10	2000	6000	18591	13592	2.199	25.39	71.4	2	0.387	12600	11700
BarentsSea	BT	Cod	A10	2001	5000	8009	17811	1.64	23.57	71.61	3	0.554	3220	3810
BarentsSea	BT	Cod	A10	2002	3000	16227	27096	2.695	28.04	72.27	2	0.448	6670	10500
BarentsSea	BT	Cod	A10	2003	5000	17340	9265	1.776	23.29	71.41	1	0.378	6060	7900
BarentsSea	BT	Cod	A10	2004	6000	30674	14984	2.35	27.62	71.12	2	0.461	9880	12500

Table WP2A2 (transposed)

YEAR	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
TOT_SURV_N	233975	119458	89033	102983	246410	526646	592843	396405	203723	321228	259352	250679	310229	356022	304709
R3	53345	29016	38460	159512	269688	297489	273177	179735	158001	333235	216175	246244	189746	80949	364476
L25	33.4	11.3	10	18.3	10.9	10	9	9	8.2	8.8	10.8	17.9	9.7	19.7	9
L75	50.8	45.2	26.1	32.4	35.3	31.8	12.2	12	12.2	25.6	29.3	34.5	35	48.5	12.2
L1	12.5	14.4	13.6	13.2	11.3	12.0	12.7	12.6	11.4	10.9	12.1	13.0	12.0	12.2	12.0
L2	25.4	27.9	27.2	23.9	20.3	18.3	18.7	19.6	18.8	17.4	18.8	21.0	22.5	19.9	21.2
L3	34.7	39.4	41.6	41.3	35.9	30.5	29.9	28.1	28.0	28.7	29.0	28.7	33.1	30.1	29.1
L4	39.9	47.1	51.7	49.9	50.8	44.7	42.0	41.0	40.4	40.0	40.6	39.7	41.6	43.6	39.2
L5	46.8	53.8	59.5	60.2	59.0	55.4	54.1	49.3	49.9	50.5	50.6	51.5	52.2	52.2	53.3
L6	56.2	60.6	67.1	68.4	68.2	64.3	64.1	61.4	59.3	58.9	59.9	61.6	63.1	61.7	61.6
L7	67.0	68.2	72.3	76.1	76.8	73.5	74.8	72.2	69.1	67.5	70.3	70.5	71.2	71.6	70.3
L8	83.3	79.2	77.6	82.8	85.8	82.4	80.6	85.3	80.6	76.3	78.0	75.7	79.2	79.1	80.7
L9	101.1	97.3	88.5	83.5	77.7	77.4	85.8	91.1	88.7	83.0	87.1	84.1	84.3	90.6	86.4
L10	89.5	103.0	111.7	93.2	86.0	96.1	98.4	90.7	79.1	100.9	81.4	80.4	97.0	91.1	89.0
L50mat	66.5	70.3	70.0	70.8	72.0	73.0	70.8	74.7	72.3	70.8	72.9	65.1	73.4	75.8	74.9
A50mat	6.76	6.89	6.65	7.11	6.63	7.07	7.23	7.55	7.59	7.71	7.33	7.27	7.54	7.37	7.28
Z5-9	1.09	0.67	0.87	0.4	0.46	0.77	0.95	1.16	0.86	1.37	0.92	0.96	0.62	0.83	0.79
Z1	-1.55	-0.3	-0.09	-1.08	0.03	0.84	2.14	2.41	2.53	1.57	0.49	0.58	1.03	-0.87	2.59
Z2	-0.43	0.39	0.5	0.74	0.23	0.55	0.9	1.36	0.46	0.03	0.17	0.45	-0.12	-0.43	-0.19
Z3	0.4	0.25	-0.4	0.12	-0.15	0.21	0.82	1.17	-0.31	0.65	0.6	0.33	0.23	-0.44	0.74
Z4	0.93	0.41	0.23	-0.25	-0.04	0.22	0.54	0.67	0.26	1.3	0.57	0.36	0.28	0.52	0.79
Z5	0.78	0.6	0.6	0.11	0.37	0.67	0.84	1.04	0.7	1.15	0.8	0.91	0.51	0.71	0.69
Z6	1.22	0.62	0.96	0.7	0.56	1.04	1.17	1.3	0.86	1.53	1.16	1.11	0.8	1.01	0.9
Z7	1.92	0.82	0.94	0.63	1.02	1.33	1.79	1.39	1.16	1.42	1.21	1.22	0.93	1.31	0.87
Z8	1.36	0.83	1.49	0.67	1.05	1.51	1.8	0.87	1.29	2.07	1.81	1.39	1.19	1.21	1.06
Z9	1.94	1.74	1.38	0.26	1.41	1.03	1.16	1.1	1.83	2.17	1.57	1.45	1.43	1	1.74

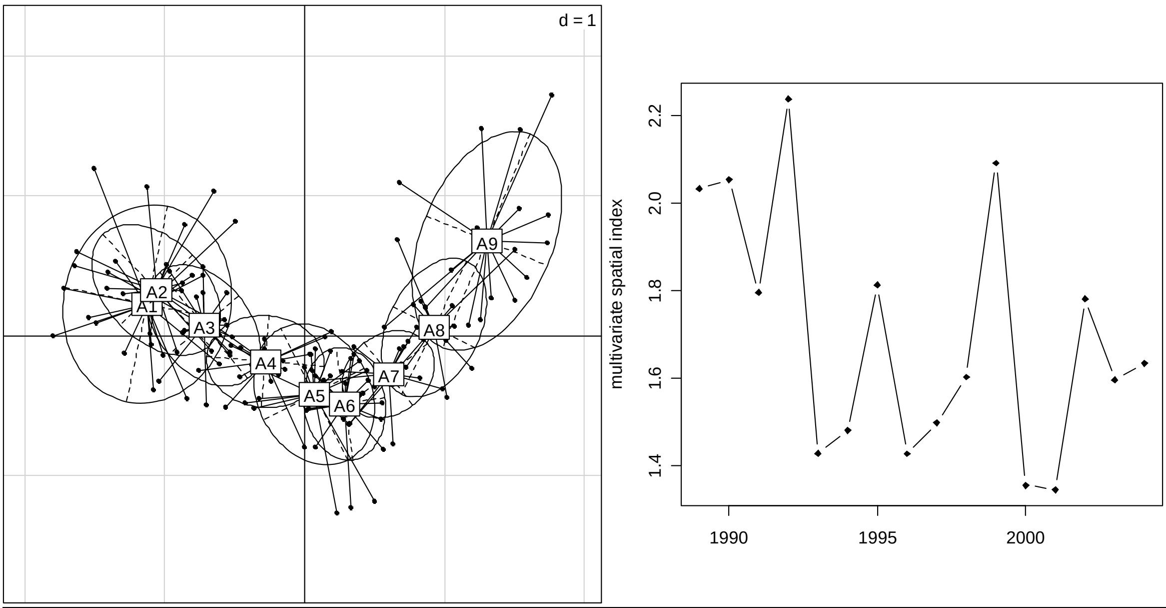


Figure 5 Multivariate MFA-based analysis. Gravity centers (left) and yearly distance from the gravity centers (right)

Looking for changes:

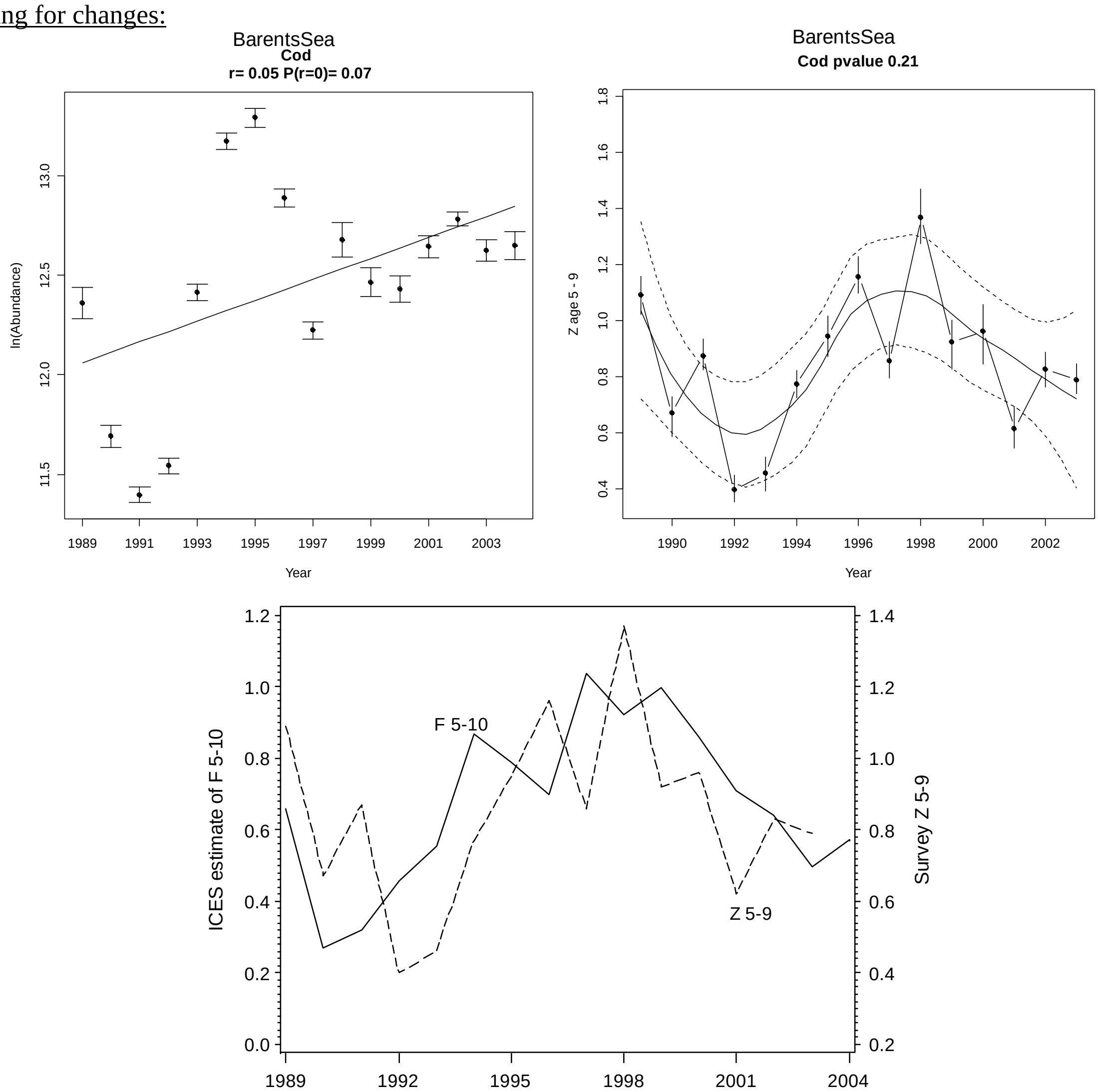


Figure 6 Ln(abundance) indices (upper left), raw and smoothed estimates of total mortality (upper right) and a comparison of raw survey Z with the ICES estimate of fishing mortality.

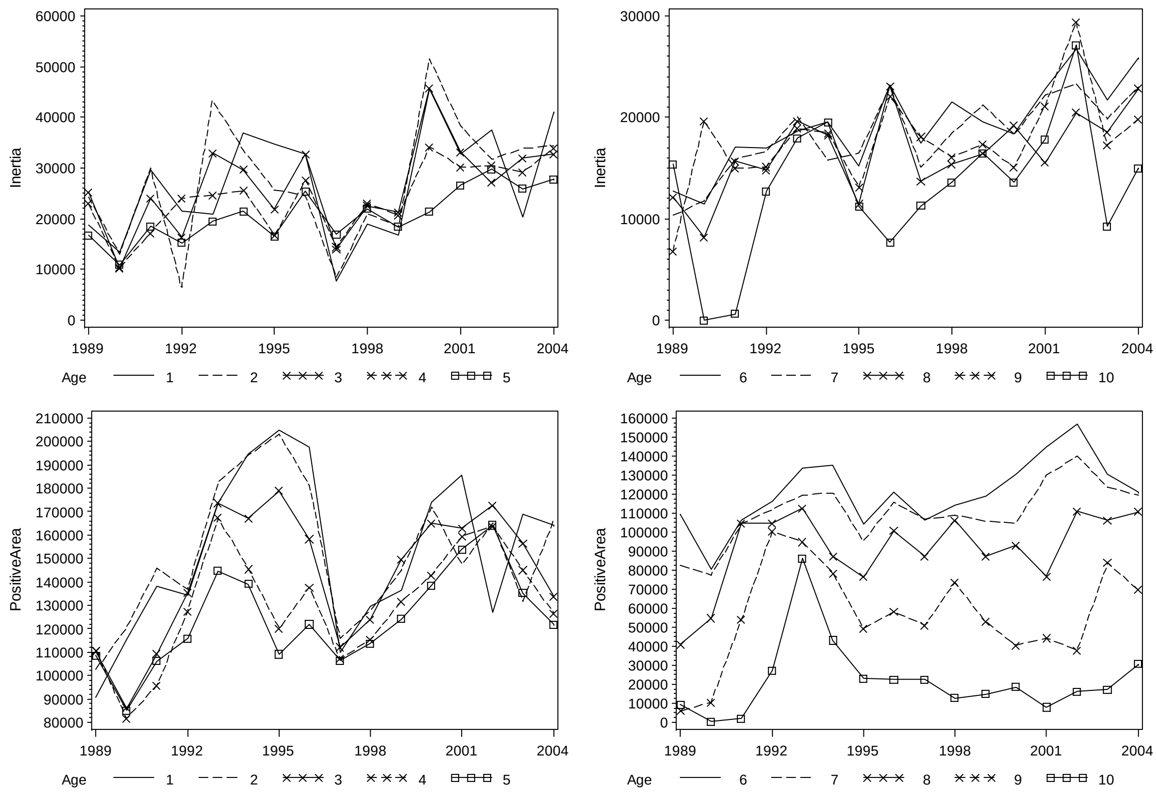


Figure 7 Plot of inertia (top) and Positive Area (bottom) for agegroups 1 to 5 (left) and agegroups 6 to 10 (right).

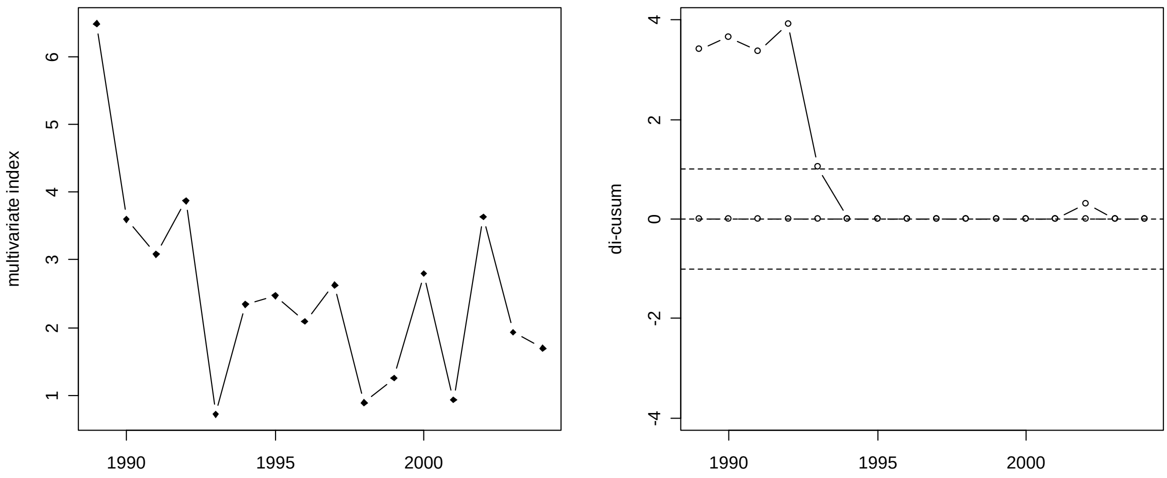


Figure 8 Di-cusum plot for the non-spatial indices (right) and the distance to the gravity centre of the reference period 1996-2004 (left).

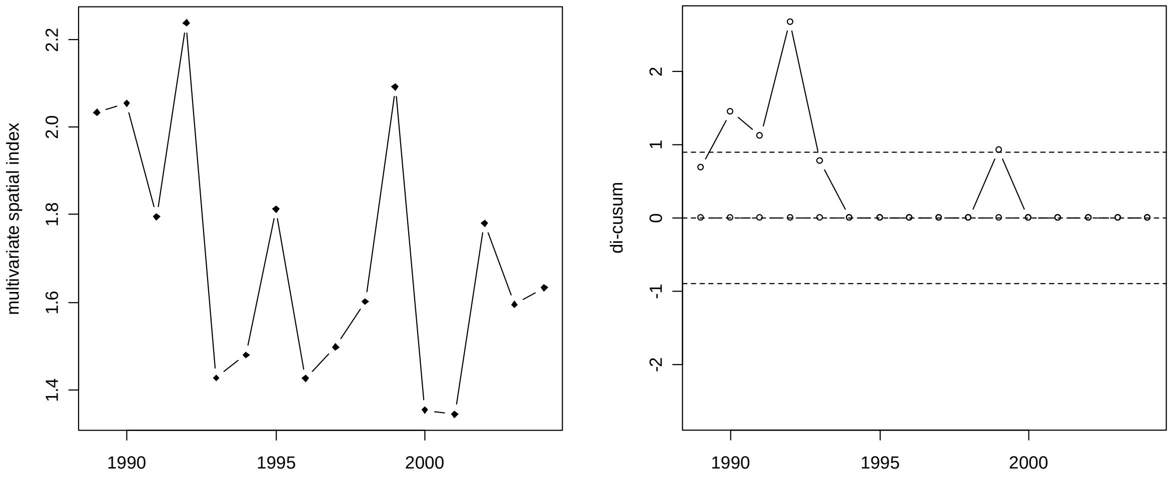


Figure 9 Di-cusum plot for the spatial indices (right) and the distance to the gravity centre of the reference period 1996-2004 (left).

<u>Interpretation</u> :
comment diagnostics tables results

- trend analysis : interpretation using cause-effects table as guide line
  The trend analysis was not conclusive for the Barents Sea Cod case study. The factor coming closest to being significant was the Ln(abundance). The reason for not being significant is that even there is large and rapid variations there is no obvious trend over the whole time series and the most recent part of the series are from a period which is much more stable than the situation in the 1990's. The most remarkable finding is really how well the estimated survey Z's compare with ICES estimates of fishing mortality (Figure 6 bottom panel). The XSA based estimates of fishing mortality is from the converged part of the time series and is as such independent of the survey results.
- cusum analysis :
  - interpretation using cusum table of selected indices

  The cusum analysis performs much better than the trend analysis. But both the biological and spatial analysis is influenced by some of the "practical" problems associated with the coverage of the survey. The problem can be illustrated by comparing Figures 1 and 7. Figure 1 is showing the variation in area coverage (in nm2) from year to year. The increase in area coverage in 1993 and the lack of coverage in the Russian EEZ in 1997 and 1998 is of course showing up in the PostiveArea index especially for the youngest agegroups. This complicates any interpretation of the spatial analysis because it is difficult to disentangle changes in the population from changes induced by the survey changes. The area coverage issue should be almost non-existent for the oldest agegroups, but they also show some kind of "event" happening around 1993 possibly linked to the very strong 1983 yearclass.

  The deviations in the non-spatial di-cusum analysis (Figure 8) is mostly caused by the variation in the Ln(abundance) index and the Ln(Recruitment) index. Please note that the period of "alert" coincides with the period before the expansion of the survey area.

  The deviations in the spatial di-cusum plot in Figure 9 is also from the period before 1993 and again this makes interpretation difficult. The deviation in 1999 seems to be caused by an "outlier" in the Anisotropy index for age 10 in 1999.

- interpretation using cause-effects table as guide line

	comp.1	comp.2	comp.3
PositiveArea	0+ | 16-	0+ | 3-	0+ | 0-
Inertia	1+ | 12-	1+ | 0-	2+ | 0-
Anisotropy	1+ | 9-	1+ | 0-	7+ | 0-
xcg	0+ | 16-	0+ | 0-	1+ | 0-
ycg	1+ | 7-	0+ | 5-	0+ | 1-
MicrostructureIndex	5+ | 2-	4+ | 0-	4+ | 1-
EquivalentArea	1+ | 3-	0+ | 6-	2+ | 7-
SpreadingArea	1+ | 5-	0+ | 12-	1+ | 3-

The table shows that both PositiveArea and the longitude gravity centre (xcg) has a strong negative correlation with the first PC for all survey years. Inertia is also showing strong negative correlation with the first PC (9 years) while the SpreadingArea has a strong negative correlation with the second PC in 12 of the survey years. Again the "event" or transition around 1993 seems to represent quite a lot of the variation in the material.

Compare approaches (cusum/trends)
It seems from this case study that the "cusum" approach is more useful, but that is only relative to the problems one is facing. The Barents Sea cod stock has historically seen drastic changes in recruitment, growth and overall productivity. In such cases will the ability to detect sudden changes be more useful than detecting changes over longer time periods (trends).

What have you learned ?
1. The raw and smoothed survey Z's will be very useful.
2. The usefulness of the spatial indices is hampered by the lack of proper survey coverage. (The Institute of Marine Research was denied access to the Russian EEZ in the Barents Sea again in 2007.)
3. The "traffic light" approach in the cusum analysis seems to be very promising. Some more work/experience is needed to decide what indices to include (causality links etc.) together with a more detailed look into potential cohort effects.

Summary sheet
- Survey series (Periods / Seasons / Type)
  Barents Sea cod, 1989-2004, 1st quarter, bottom trawl
- Non-spatial indices

Abundance index, Recruitment index: No trends detected, cusum analysis detected "alerts" for a period before 1993 (problems with survey coverage)
Lbar, L75, L25: No trends, fluctuations caused by fluctuations in recruitment
L50.maturity: No trends, cusum analysis gave an "alert" for 1 year (possibly an outlier)
Z by year: No overall or recent trends, but fluctuations compare extremely well with VPA based estimates of fishing mortality (visual inspection)
- Spatial indices (a few words : index analysed ? by age or stage ? what method ? change detected ?)

Positive Area: Visual, fluctuations, large differences between agegroups
Spreading area: Visual, some fluctuation, differences between agegroups
Equivalent area: Visual, some change around 1993 for most agegroups
Centre of gravity: Visual, very strong age effect, influenced by varying survey coverage
Inertia: Visual, increasing trend for all agegroups
Anisotropy: Visual, nothing
Microstructure: Visual, nothing

- Composite (derived) indices:

MAF: NA
MFA: Strong age dependent structure, fits very well with knowledge on life history, components 1 dominated by PositiveArea, xcg and inertia, component 2 influenced by SpreadingArea
PCA: NA
- Reference period:
  1996-2004, relatively long apparently stable period

- Summary of results on the stock:
  "Best" information gained by looking at logarithmic abundance indices and recruitment together with an "impressive" series of survey Z. The reference period used (1996-2004) is quite unique in being far more stable than VPA based information indicates for the period 1945-1995.This "stability" makes it difficult to interpret the information from the spatial indices.

<u>Comparison with traditional assessment of stock status</u> :
NA

<u>Formulation of advice</u>
NA

BS COD **cause-effects diagnostics table**

survey period	1989-2004
ref.period	1996-2004
ref status	NA

Results of trend analysis

	all period	recent
Z	0	0
Ln_Abdnce	0 (1)	0
Lbar	0	0
L25	0	0
L75	0	0
Ln_Recruit	0	0

diagnostic

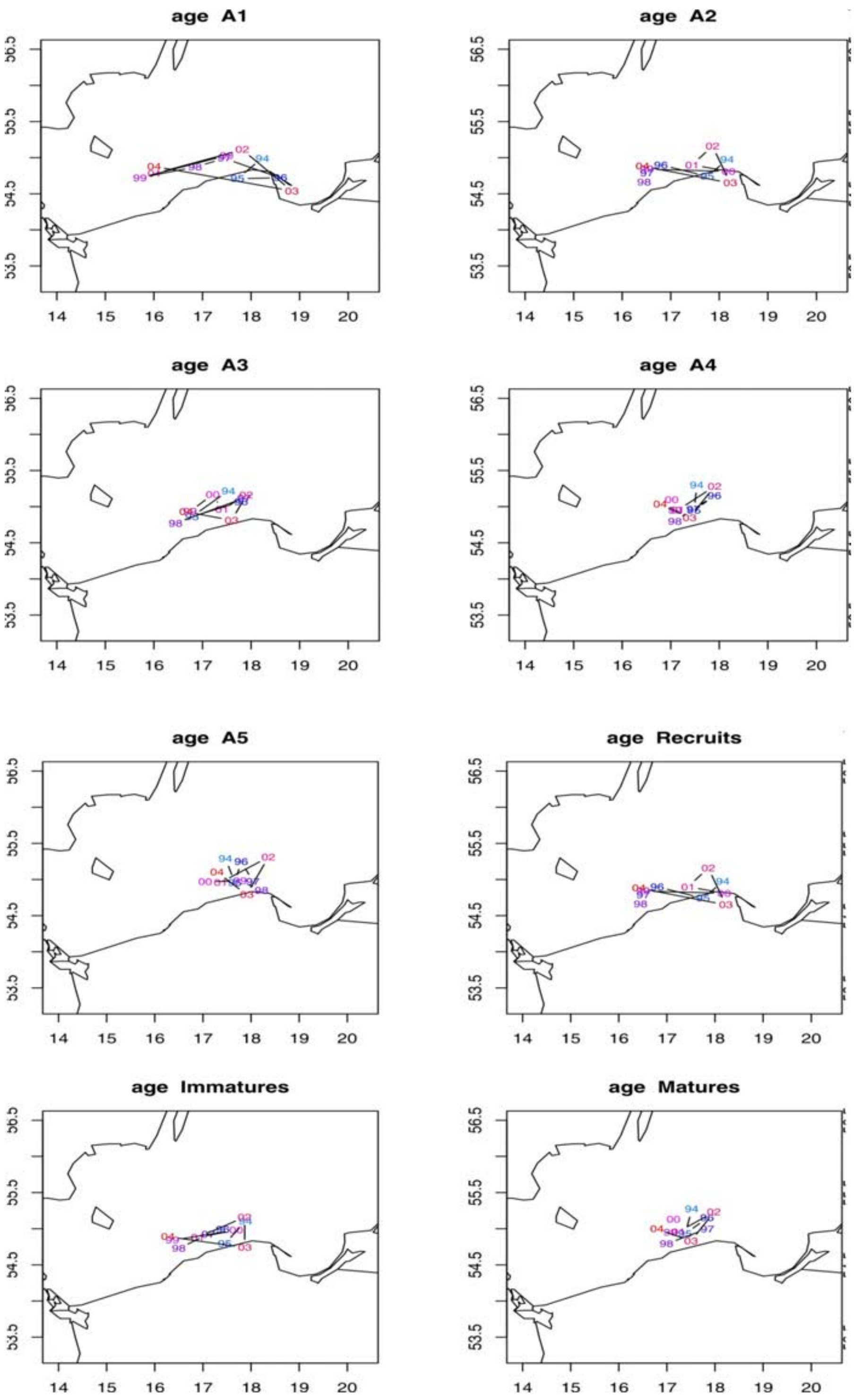
Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
Larger fish caught (or change in fishing area, stock distribution or gear)	-1	1	1	0	1	0
Smaller fish caught (or change in fishing area, stock distribution or gear)	1	-1	-1	-1	0	0

BS COD	CUSUM diagnostics table							
ref.period								
m in ref.period								
sd in ref.period								
k								
h								
ARL InControl								
ARL OutControl								
Years	**MFA_Spatial**	**Ln_TotAbun**	**Ln_Recruits**	**Lbar**	**L25**	**L75**	**Z**	**alert**
1989		0	-0.8	1.7	4.0	0		
1990		-1.6	-2.7	1.8	0	1.5	0	alert
1991		-4.6	-4.0	0	0	0	0	alert
1992		-6.9	-2.8	0	0	0	0	alert
1993		-4.9	0	0	0	0	-1.1	alert
1994		0	0	0	0	0	-1.0	
1995		0	0	0	0	0	0	
1996		0	0	0	0	0	0	ref
1997		0	0	0	0	-1.1	0	ref
1998		0	0	0	0	0	0	ref
1999		0	0	0	0	0	0	ref
2000		0	0	0	0	0	0	ref
2001		0	0	0	0	0	0	ref
2002		0	0	0	0	0	0	ref
2003		0	0	0	0	0	0	ref
2004		0	0	0	0	0	0	ref

Indicator Based Assessment
Cod Baltic Sea
K. Radtke (SFI)

Data



Gravity centres of spatial distributions

Table. codBA_tab1_wp2a

Area	SurveyType	Species	Age	Year	Abundance	PositiveArea	Inertia	Anisotropy	xcg	ycg	NumberOfPatches	MicrostructureIndex	EquivalentArea	SpreadingArea
BalticSea	BT	GADUMOR	A1	1994	3558000	4999	1244	6.889	18.04	55.05	2	0.948	290	982
BalticSea	BT	GADUMOR	A1	1995	4575000	3695	2354	3.355	17.79	54.7	2	0.673	1470	1540
BalticSea	BT	GADUMOR	A1	1996	1188000	3688	2228	2.722	18.41	54.7	3	0.575	642	1500
BalticSea	BT	GADUMOR	A1	1997	612000	2344	2726	3.392	17.32	54.9	2	0.757	681	975
BalticSea	BT	GADUMOR	A1	1998	858000	2993	2518	2.979	16.96	54.87	3	0.782	835	1340
BalticSea	BT	GADUMOR	A1	1999	11159000	5105	1672	4.588	15.9	54.71	2	0.52	270	982
BalticSea	BT	GADUMOR	A1	2000	1619000	2827	2014	2.354	17.89	54.9	3	0.436	729	1460
BalticSea	BT	GADUMOR	A1	2001	7594000	3178	2932	3.265	16.26	54.77	3	0.457	246	995
BalticSea	BT	GADUMOR	A1	2002	1633000	5510	1123	1.638	17.73	54.98	2	0.489	1730	3260
BalticSea	BT	GADUMOR	A1	2003	1352000	2384	498	2.66	18.82	54.54	1	0.819	187	408
BalticSea	BT	GADUMOR	A1	2004	16671000	4007	966	2.782	16.06	54.85	1	0.431	190	816
BalticSea	BT	GADUMOR	A2	1994	3875000	5125	817	6.875	17.45	55.17	2	0.736	6680	2160
BalticSea	BT	GADUMOR	A2	1995	14857000	4823	1990	3.229	17.79	54.73	2	0.626	1810	1900
BalticSea	BT	GADUMOR	A2	1996	13462000	5277	2891	3.085	16.61	54.81	3	0.441	1990	2670
BalticSea	BT	GADUMOR	A2	1997	2113000	2245	2104	4.529	16.56	54.77	2	0.842	685	788
BalticSea	BT	GADUMOR	A2	1998	9953000	4610	1855	3.917	16.51	54.66	2	0.799	610	1210
BalticSea	BT	GADUMOR	A2	1999	8387000	4341	2636	3.618	16.49	54.81	2	0.625	1120	1390
BalticSea	BT	GADUMOR	A2	2000	11620000	4247	1335	2.137	18.33	54.76	3	0.823	505	996
BalticSea	BT	GADUMOR	A2	2001	6610000	3501	2788	3.839	17.63	54.88	2	0.569	493	1310
BalticSea	BT	GADUMOR	A2	2002	17234000	6024	1166	2.213	17.82	55.09	2	0.651	1060	1810
BalticSea	BT	GADUMOR	A2	2003	4766000	3941	2060	2.876	18.18	54.65	3	0.678	531	989
BalticSea	BT	GADUMOR	A2	2004	13800000	4289	2114	3.241	16.69	54.84	2	0.447	308	1230
BalticSea	BT	GADUMOR	A3	1994	14752000	5102	158	3.378	17.18	55.26	1	0.655	7770	1980
BalticSea	BT	GADUMOR	A3	1995	10469000	5091	2417	3.351	16.94	54.82	3	0.616	2740	1910
BalticSea	BT	GADUMOR	A3	1996	15007000	5391	2373	2.331	17.71	54.97	3	0.665	1140	2710
BalticSea	BT	GADUMOR	A3	1997	1025000	3160	2428	2.447	17.69	55	2	0.419	760	1550
BalticSea	BT	GADUMOR	A3	1998	13718000	5150	1217	2.965	16.44	54.73	2	0.586	953	1660
BalticSea	BT	GADUMOR	A3	1999	17433000	5475	1975	3.294	16.63	54.89	3	0.493	2240	2360
BalticSea	BT	GADUMOR	A3	2000	7817000	4198	1760	1.821	17.48	55.04	4	0.313	632	1880
BalticSea	BT	GADUMOR	A3	2001	10997000	3862	2359	3.255	17.48	54.95	3	0.599	633	1350
BalticSea	BT	GADUMOR	A3	2002	5224000	5804	1096	1.419	17.69	55.07	2	0.514	2310	3020
BalticSea	BT	GADUMOR	A3	2003	7189000	4374	2389	2.547	17.38	54.81	3	0.566	1590	1930
BalticSea	BT	GADUMOR	A3	2004	7631000	3924	2129	3.001	16.92	54.92	2	0.463	334	1700
BalticSea	BT	GADUMOR	A4	1994	5398000	5135	134	2.292	17.23	55.27	1	0.456	6860	2670
BalticSea	BT	GADUMOR	A4	1995	8953000	5959	1872	3.919	17.77	54.92	2	0.67	1340	1470
BalticSea	BT	GADUMOR	A4	1996	5383000	6298	1645	2.106	17.89	55.07	2	0.491	1160	2820
BalticSea	BT	GADUMOR	A4	1997	659000	3460	2575	2.996	17.21	54.9	3	0.657	909	1530
BalticSea	BT	GADUMOR	A4	1998	1955000	4681	1684	2.61	16.81	54.79	3	0.629	833	1650
BalticSea	BT	GADUMOR	A4	1999	5765000	5803	1749	3.041	16.93	54.92	3	0.457	1780	2610
BalticSea	BT	GADUMOR	A4	2000	1549000	4260	1343	1.918	17.08	55.03	3	0.347	1530	2330
BalticSea	BT	GADUMOR	A4	2001	8323000	4683	2182	3.32	17.11	54.93	3	0.62	998	1460
BalticSea	BT	GADUMOR	A4	2002	1373000	5265	927	1.313	17.58	55.13	1	0.298	2060	3410
BalticSea	BT	GADUMOR	A4	2003	3862000	4701	1910	2.931	16.96	54.85	3	0.452	1660	1980
BalticSea	BT	GADUMOR	A4	2004	2942000	4489	1261	3.246	16.93	55.06	2	0.489	515	1590
BalticSea	BT	GADUMOR	A5	1994	2343000	4176	119	2.149	17.24	55.26	1	0.377	6570	3010
BalticSea	BT	GADUMOR	A5	1995	3429000	5646	1583	3.749	17.89	54.93	2	0.65	1360	1680
BalticSea	BT	GADUMOR	A5	1996	2518000	4749	924	2.736	17.83	55.18	2	0.468	756	2300
BalticSea	BT	GADUMOR	A5	1997	731000	3235	2574	2.77	17.83	54.89	3	0.681	621	1180
BalticSea	BT	GADUMOR	A5	1998	904000	2946	1800	2.186	17.73	54.97	3	0.843	147	878
BalticSea	BT	GADUMOR	A5	1999	1372000	4310	2079	2.792	17.56	54.97	3	0.578	913	1900
BalticSea	BT	GADUMOR	A5	2000	276000	3086	1411	2.122	16.98	54.94	3	0.493	2070	2230
BalticSea	BT	GADUMOR	A5	2001	909000	2983	2371	3.877	17.27	54.95	3	0.684	844	1320
BalticSea	BT	GADUMOR	A5	2002	221000	1994	520	1.888	18.3	55.26	1	0.316	396	1250
BalticSea	BT	GADUMOR	A5	2003	316000	2906	2742	5.522	17.31	54.73	2	0.431	1340	1810
BalticSea	BT	GADUMOR	A5	2004	655000	4034	1256	2.434	17.42	55.13	2	0.381	1220	2130

Table.codBA_tab2_wp2a

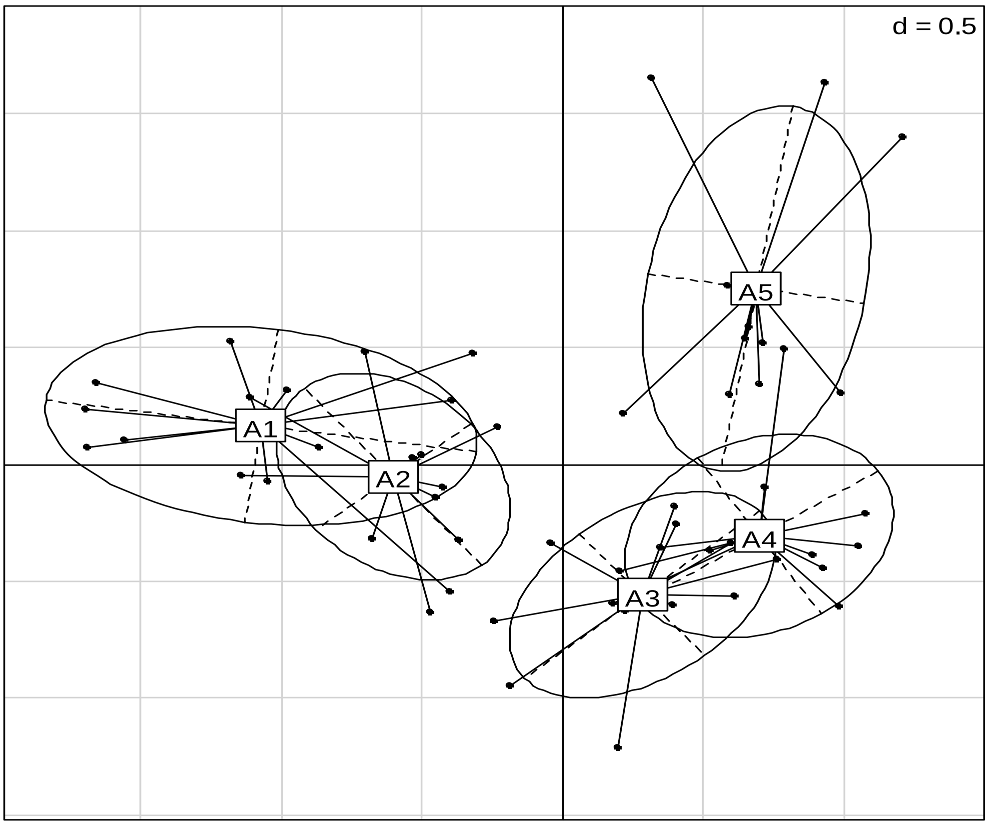
Area	SurveyType	Species	Year	Survey.index	Recruit.index	Lbar	L25	L75	L50.maturity	Z	StdLbar	StdL25	StdL75	SdL50.maturity	StdZ
BalticSea	BT	GADUMOR	1994	29926000	3875000	19.70888383	8.1	26.1	40.57880297	0.6	0.001619825	0.000141312	0.001056303	0.613811435	0.08
BalticSea	BT	GADUMOR	1995	42283000	14857000	22.04027356	13.9	28.5	55.92919425	0.82	0.000349282	0.000109001	0.001233243	1.041144709	0.07
BalticSea	BT	GADUMOR	1996	37558000	13462000	30.09164557	24.4	33	50.28519572	1.1	0.000327328	0.000230202	0.000464229	0.620436661	0.06
BalticSea	BT	GADUMOR	1997	5140000	2113000	35.0952381	25.7	44.8	57.71948705	3.65	0.00149142	0.002864453	0.002009146	0.795785531	0.07
BalticSea	BT	GADUMOR	1998	27388000	9953000	30.90516206	25.2	33.4	50.21569199	0.85	0.001673724	0.002035076	0.000914785	0.816018367	0.07
BalticSea	BT	GADUMOR	1999	44116000	8387000	23.78701847	11.8	29.8	45.58198255	4.17	0.000364765	0.000121858	0.000411245	0.892514997	0.06
BalticSea	BT	GADUMOR	2000	22881000	11620000	23.98648943	18.8	26.9	36.66542306	0.82	0.00032493	0.000523857	0.000307275	1.181713731	0.05
BalticSea	BT	GADUMOR	2001	34433000	6610000	25.20112295	12	33.5	52.77466592	3.04	0.000510753	0.000234362	0.001010072	1.3326597	0.09
BalticSea	BT	GADUMOR	2002	25685000	17234000	24.33532678	20.1	27	53.01261137	1.23	0.000247131	0.000207166	0.000155337	1.790926731	0.1
BalticSea	BT	GADUMOR	2003	17485000	4766000	28.12724494	22.4	34.9	56.95849366	1.23	0.000975271	0.002990568	0.001783032	1.51951874	0.07
BalticSea	BT	GADUMOR	2004	41699000	13800000	19.10763454	11.8	23.1	64.46806011		0.000362838	0.000325425	0.005877986	2.175531053	

Combined indices

MFA spatial

year	dmul
1994	1.25213840124764
1995	1.09909332758386
1996	1.34194237414125
1997	1.75105465980008
1998	1.61346232815646
1999	1.16569264060841
2000	1.11629820765472
2001	1.15206198129703
2002	1.75903143537341
2003	1.18656542548907
2004	1.33519391353396

	comp.1	comp.2
PositiveArea	3+|0-	0+|7-
Inertia	1+|7-	0+|3-
Anisotropy	1+|6-	3+|1-
xcg	2+|3-	3+|0-
ycg	9+|0-	1+|0-
MicrostructureIndex	1+|3-	1+|1-
EquivalentArea	6+|0-	2+|5-
SpreadingArea	8+|0-	0+|2-

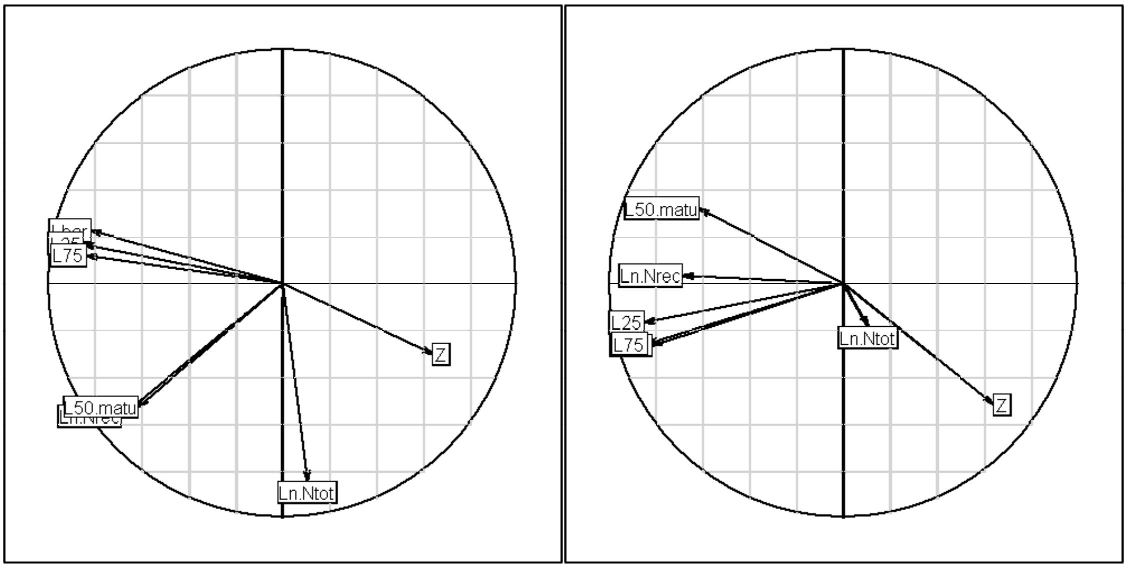


PCA biological

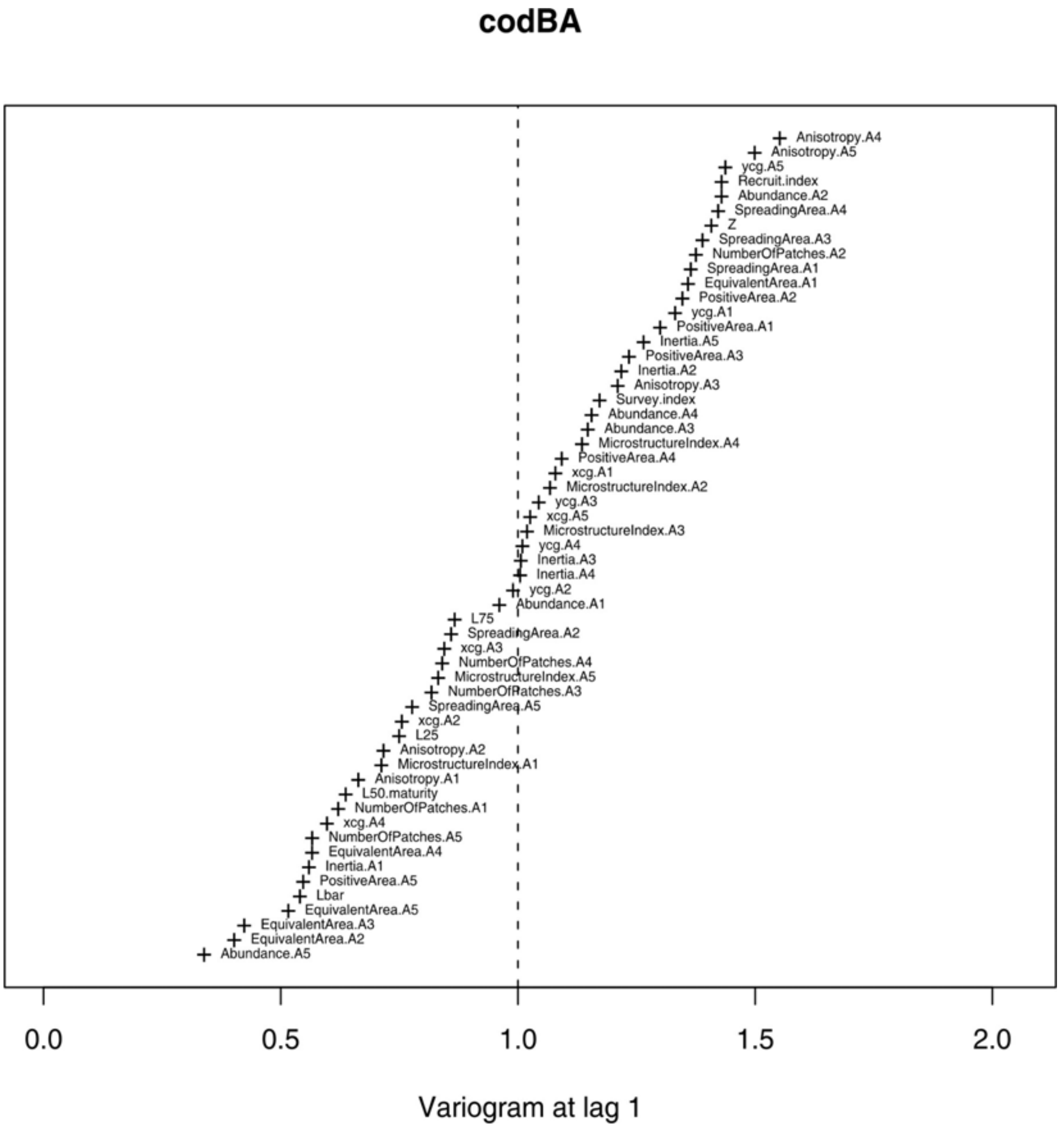
	cmu	csd
Ln.Ntot	17.3886958932181	0.210579188324514
Ln.Nrec	16.0309994780273	0.533131886699591
Lbar	25.306596698	4.96369320681268
L25	16.68	7.70305134346124
L75	30.16	3.07944800248356
L50.matu	48.518173496	5.75721258106496
Z	0.410931140722545	0.650537208449744

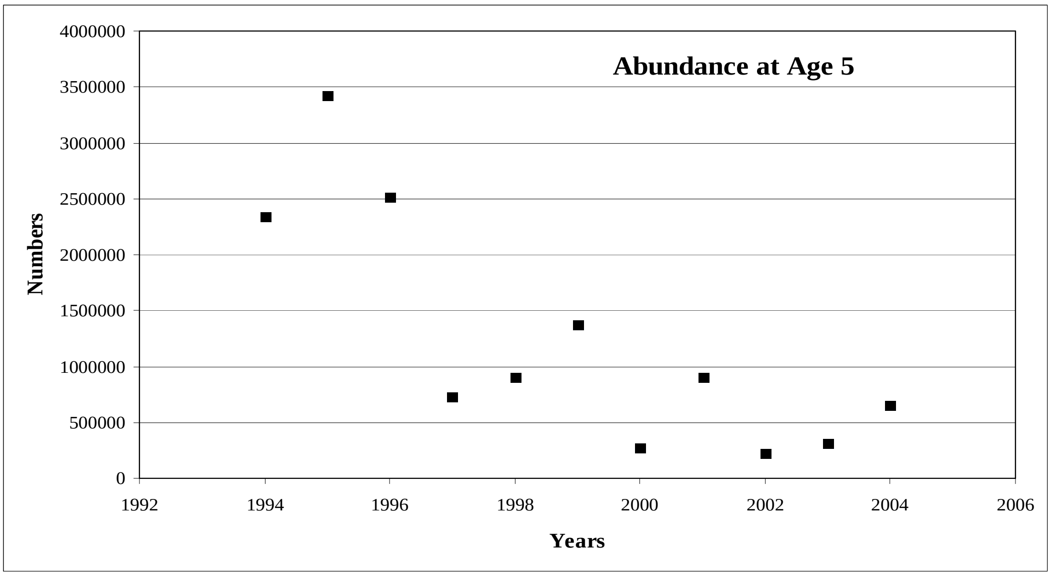
	Comp1	Comp2
Ln.Ntot	0.104082705151607	-0.842439028929846
Ln.Nrec	-0.689720761700632	-0.565193165845870
Lbar	-0.823108234913754	0.227316467201867
L25	-0.852739975865506	0.17172378852688
L75	-0.841443844949335	0.122531944320277
L50.matu	-0.620167122436702	-0.526858722422502
Z	0.639154160974953	-0.300767876710408

year	md
1994	3.17486625987780
1995	1.73930228133922
1996	1.53046715693373
1997	7.54165471371644
1998	2.76782238473592
1999	1.11230440265449
2000	2.31897965776742
2001	0.597445335617933
2002	0.863999426401413
2003	3.09515051803004
2004	3.01335354980897

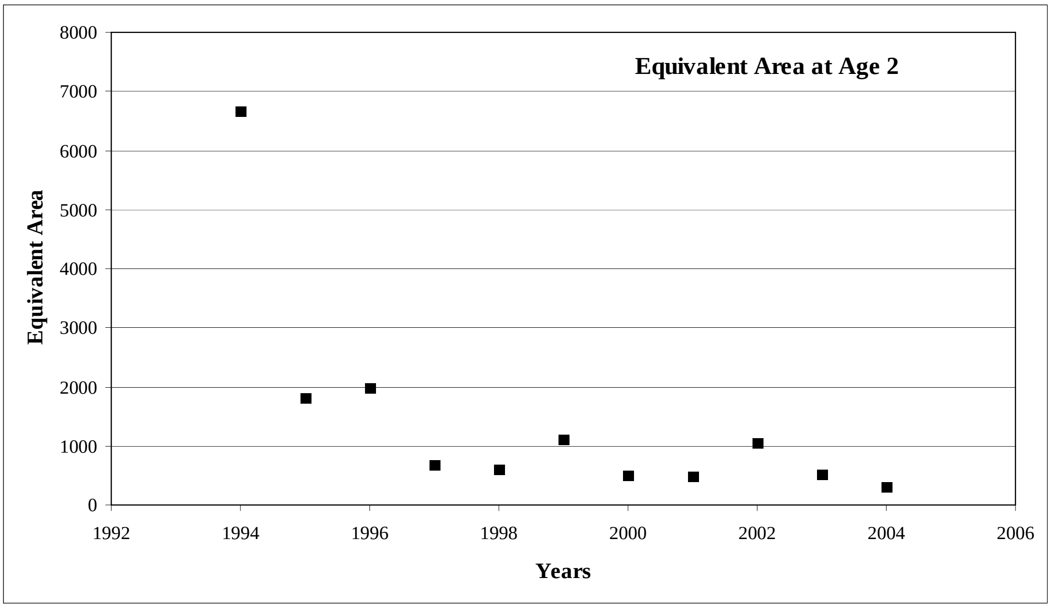


VISUAL INSPECTION
MAF based selection of indices

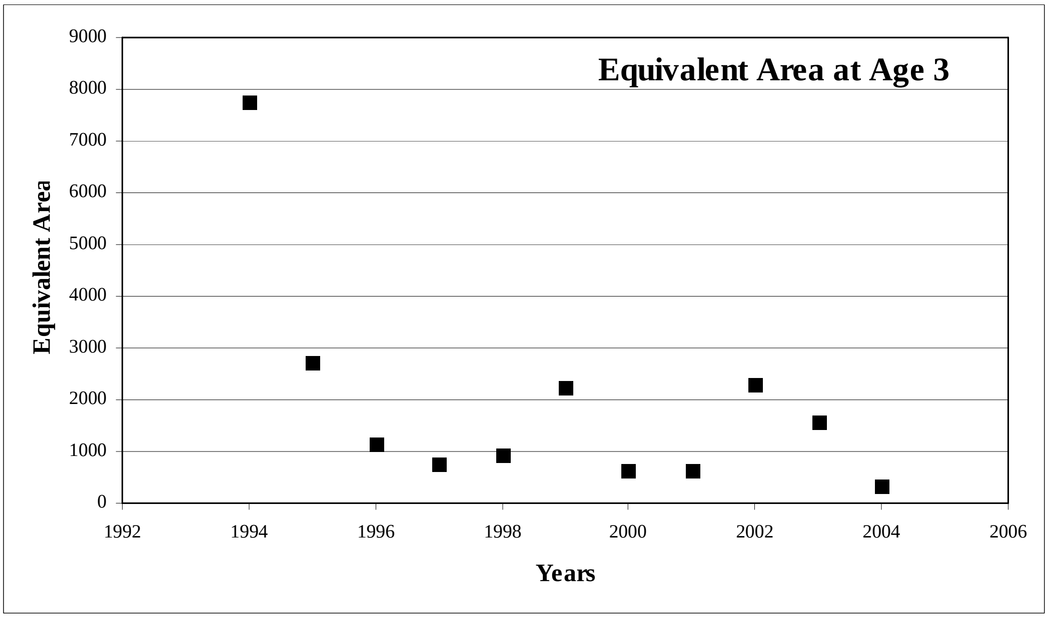




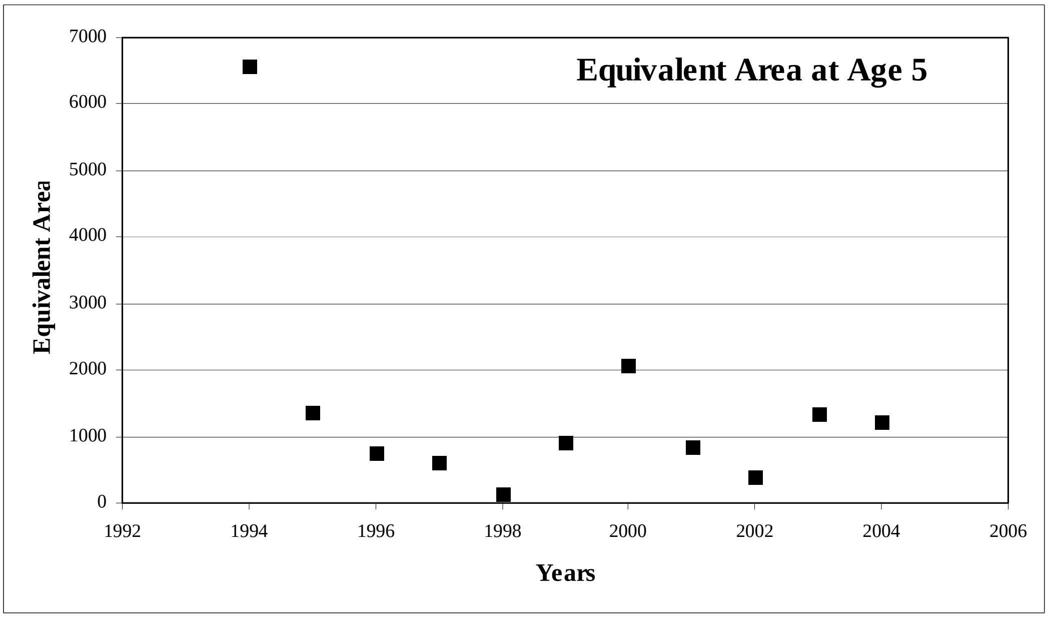
Abundance at Age 5
Numbers
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
1992
1994
1996
1998
2000
2002
2004
2006
Years



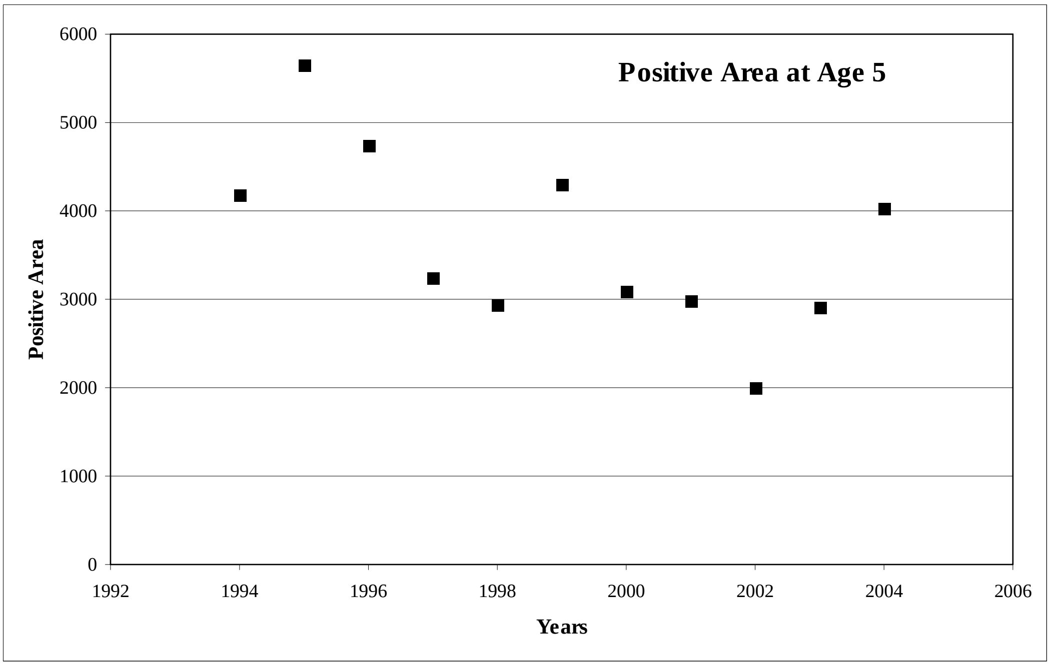
Equivalent Area at Age 2
Equivalent Area
8000
7000
6000
5000
4000
3000
2000
1000
0
1992
1994
1996
1998
2000
2002
2004
2006
Years



Equivalent Area at Age 3
Equivalent Area
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1992
1994
1996
1998
2000
2002
2004
2006
Years

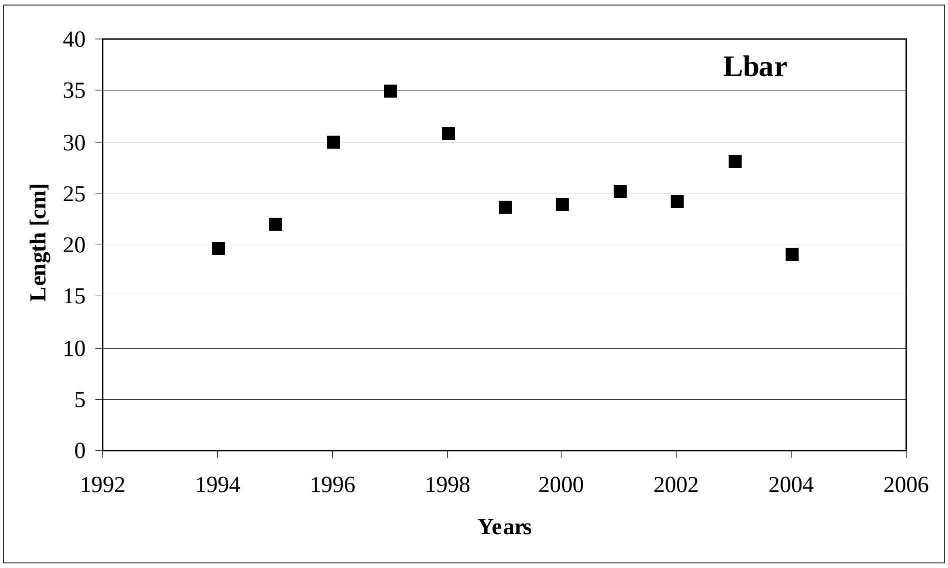


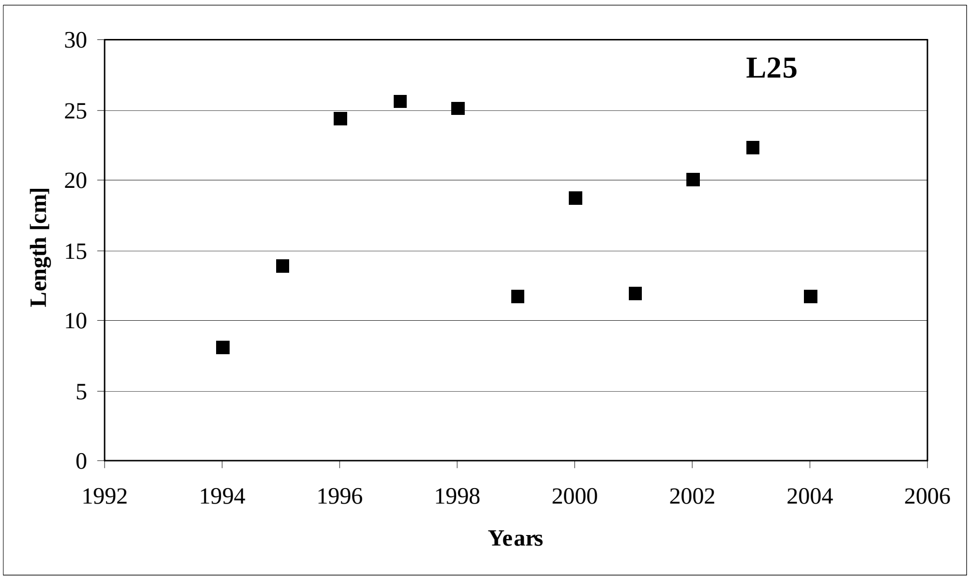
Equivalent Area at Age 5
Equivalent Area
Years
0
1000
2000
3000
4000
5000
6000
7000
1992
1994
1996
1998
2000
2002
2004
2006

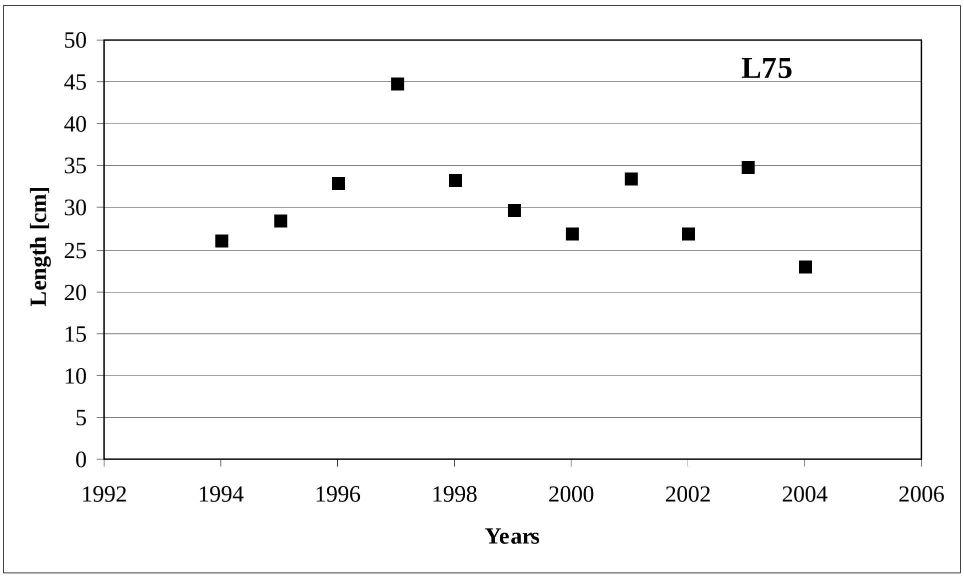


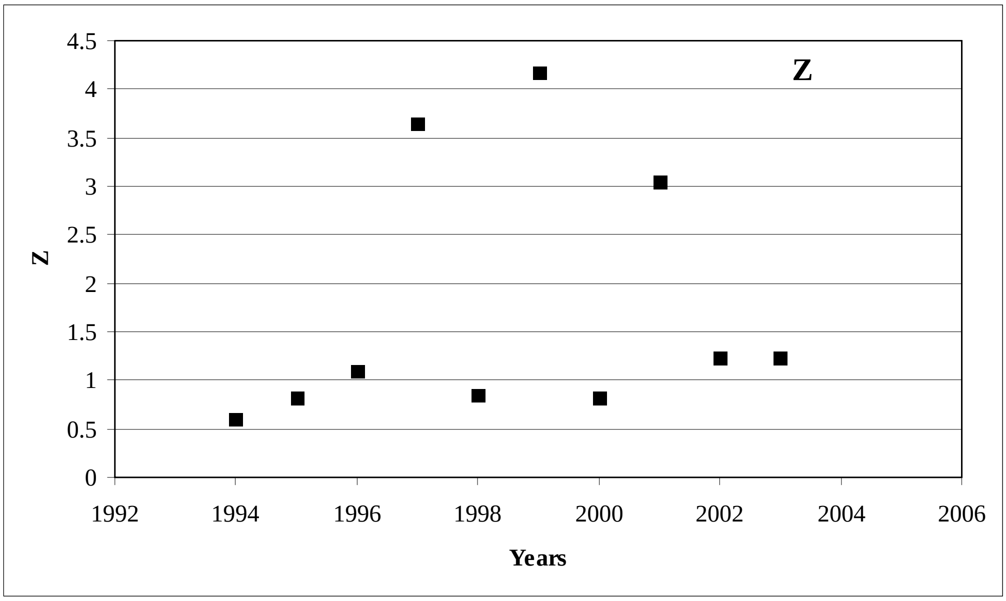
Positive Area at Age 5
Positive Area
Years
0
1000
2000
3000
4000
5000
6000
1992
1994
1996
1998
2000
2002
2004
2006

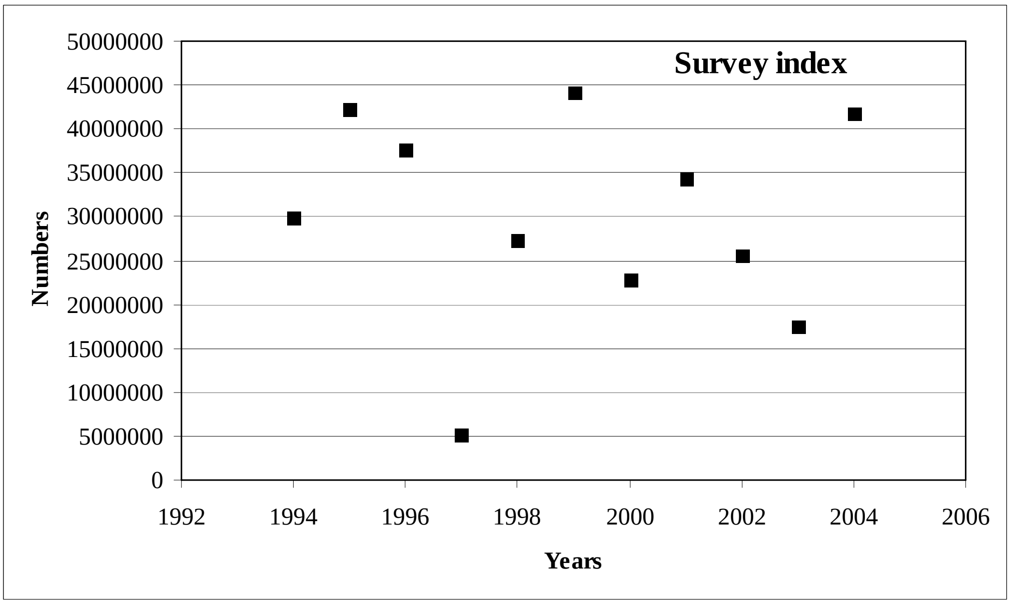
VISUAL INSPECTION (other vital indices - not MAF based ranking order)

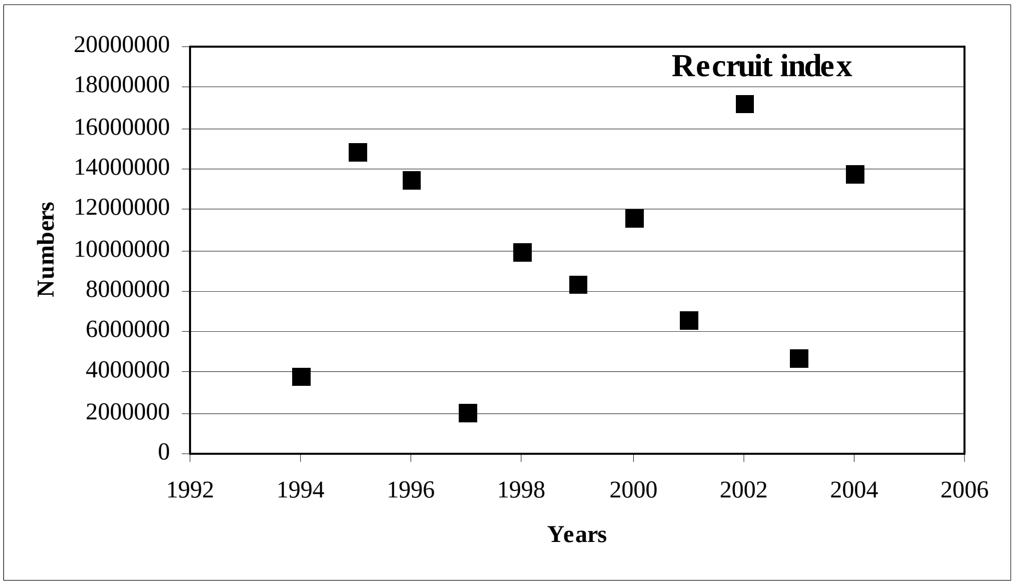







Z
Z
Years


Survey index
Numbers
Years


Recruit index
Numbers
Years

TREND PLOTS
Abundance A5

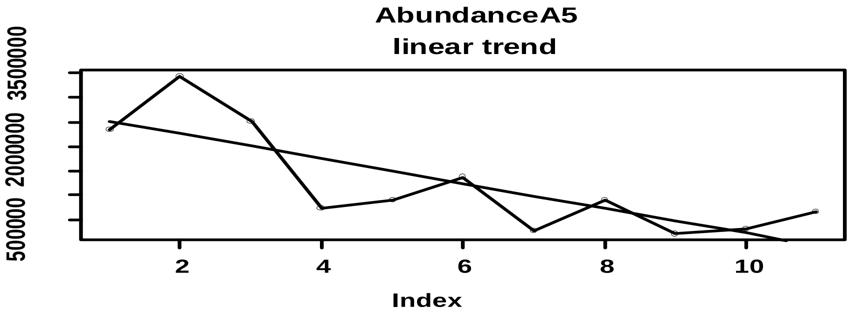


Fig.1. Abundance A5 - Linear regression

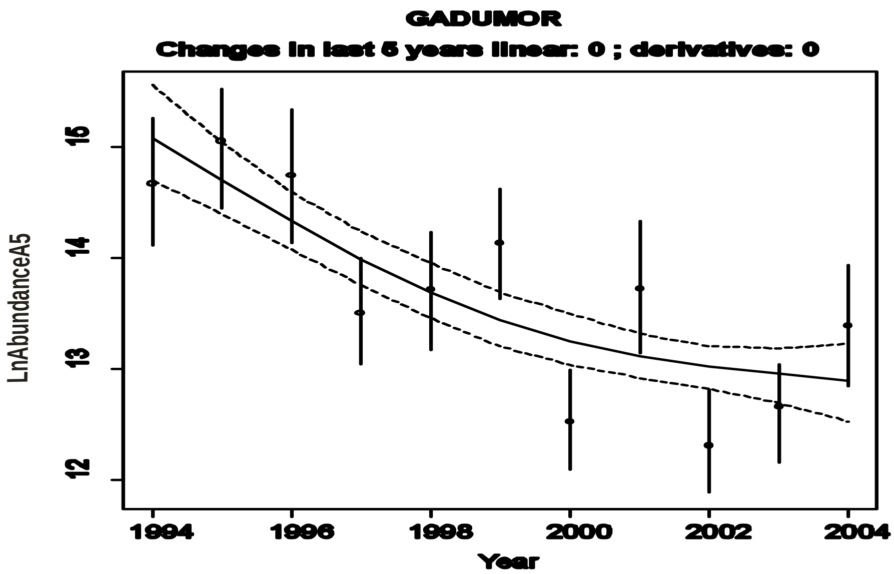


Fig.2. Abundance A5 – Derivatives method

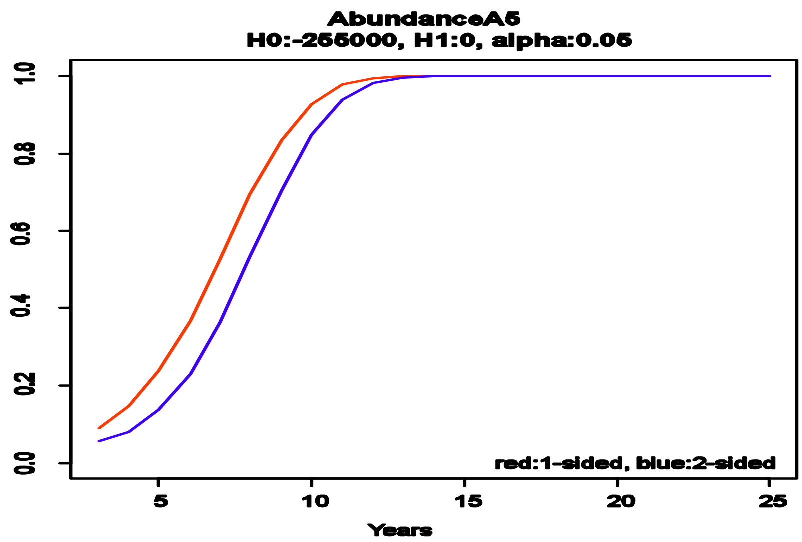


Fig.3. Abundance A5 – Power method

Equivalent Area A2

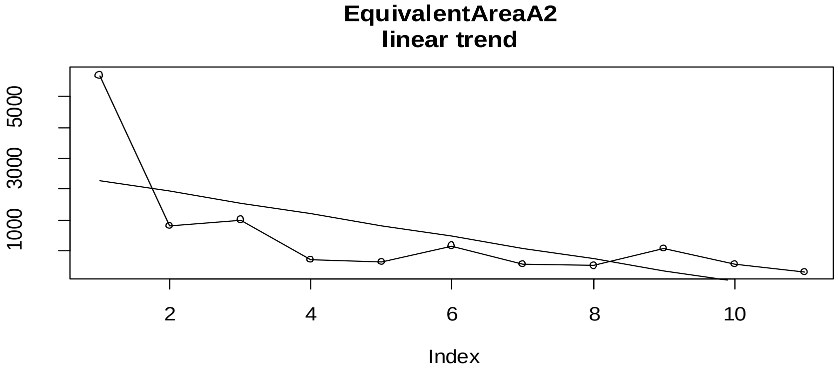


Fig.4. Equivalent Area A2 – Linear regression

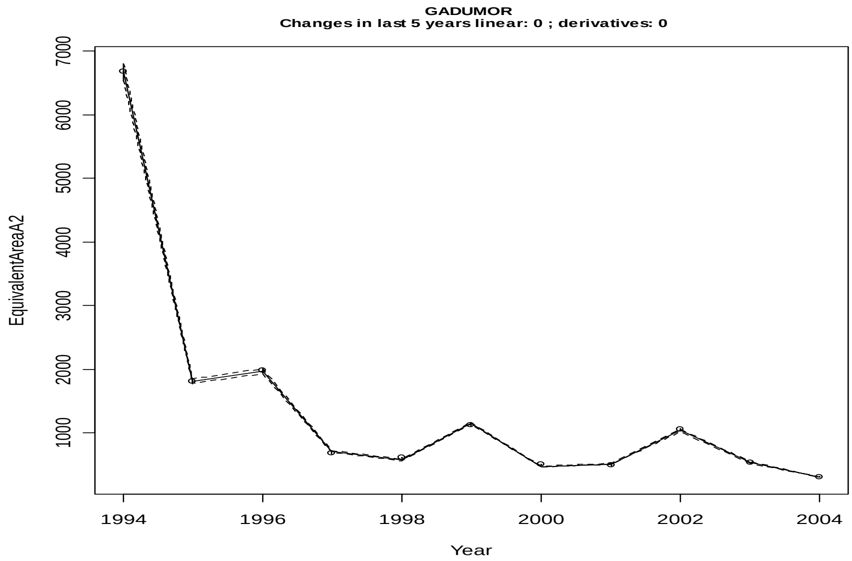


Fig.5. Equivalent Area A2 – Derivatives method

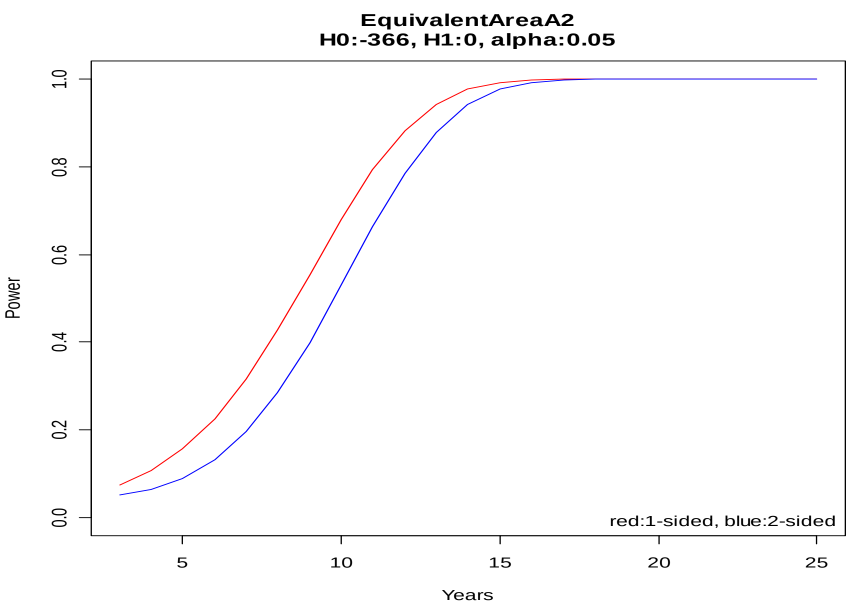


Fig.6. Equivalent Area A2 – Power method

Equivalent Area A3

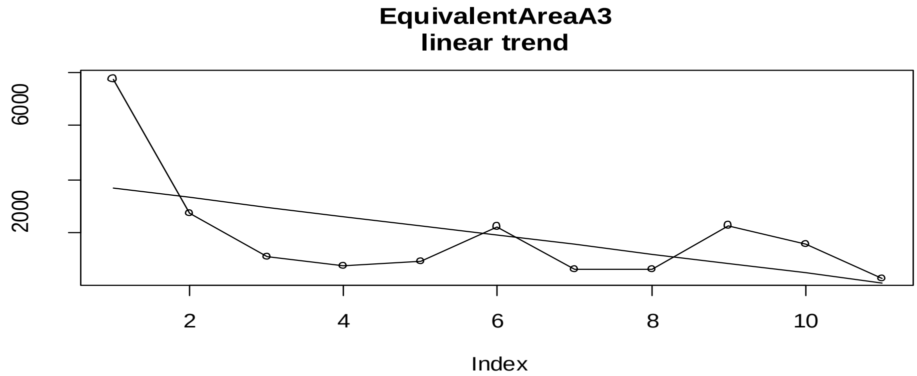


Fig.7. Equivalent Area A3 – Linear regression

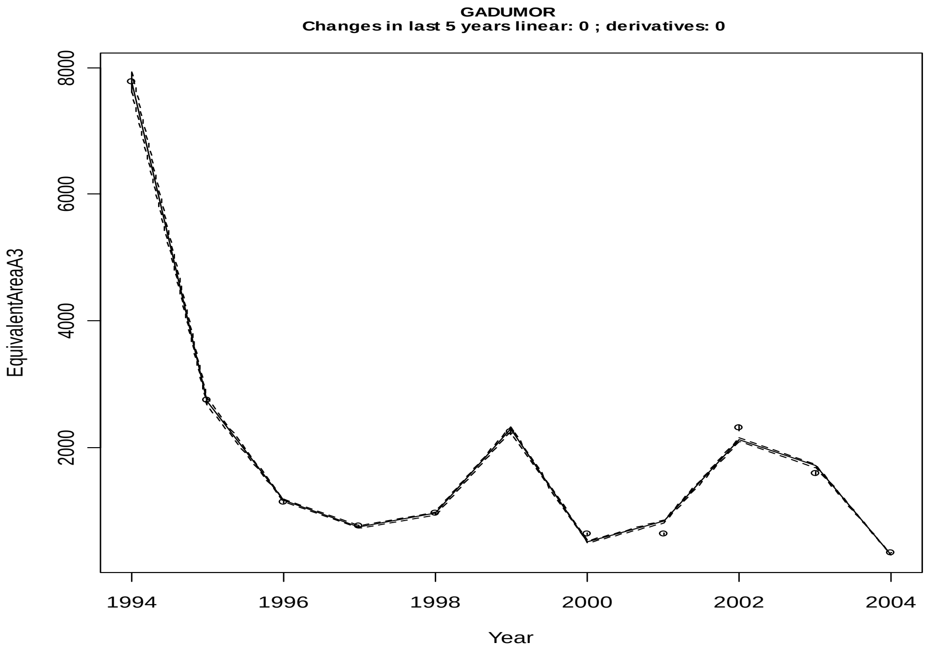


Fig.8. Equivalent Area A3 – Derivatives method

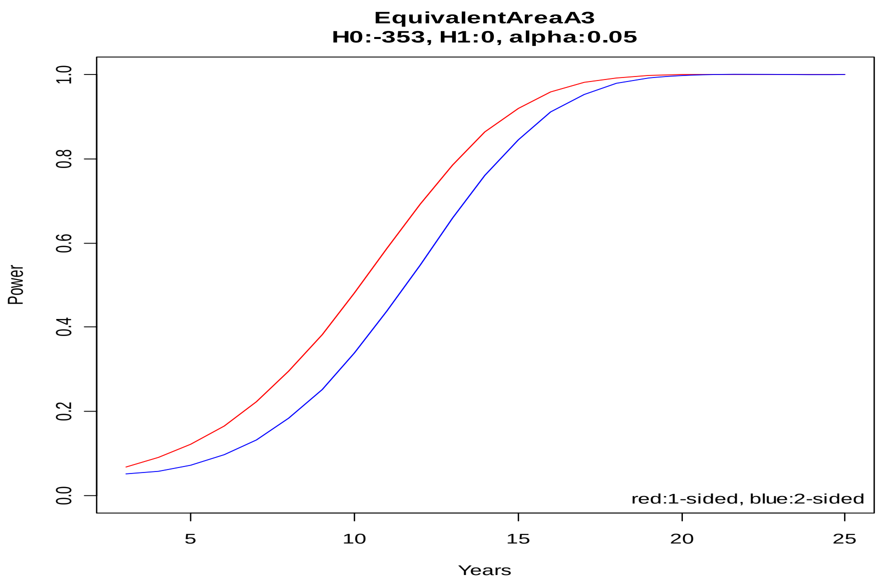


Fig.9. Equivalent Area A3 – Power method

Equivalent Area A5

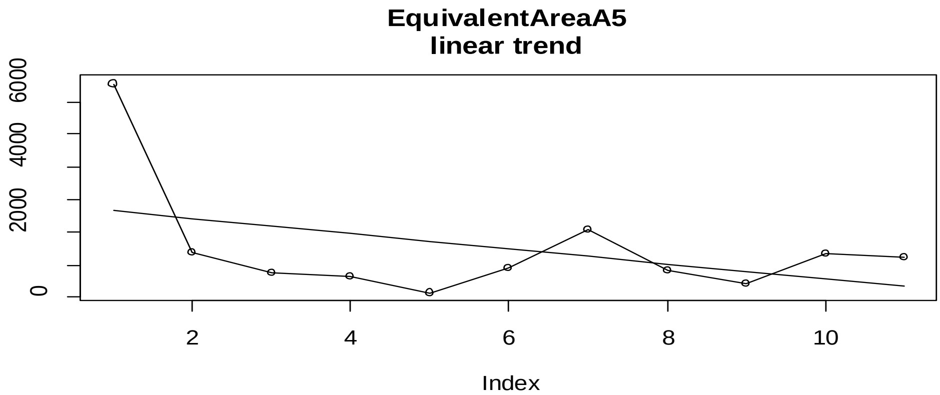


Fig.10. Equivalent Area A5 – Linear regression

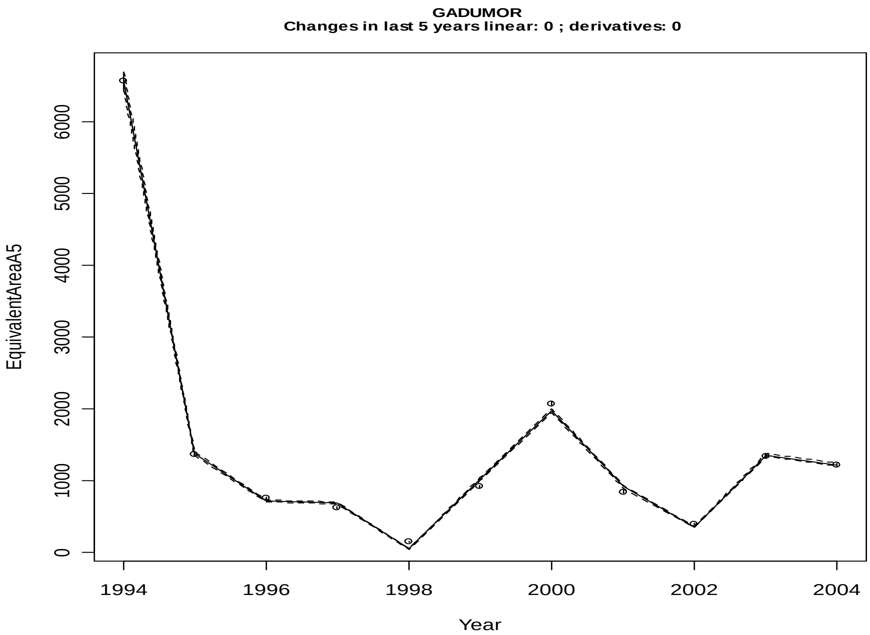


Fig.11. Equivalent Area A5 – Derivatives method

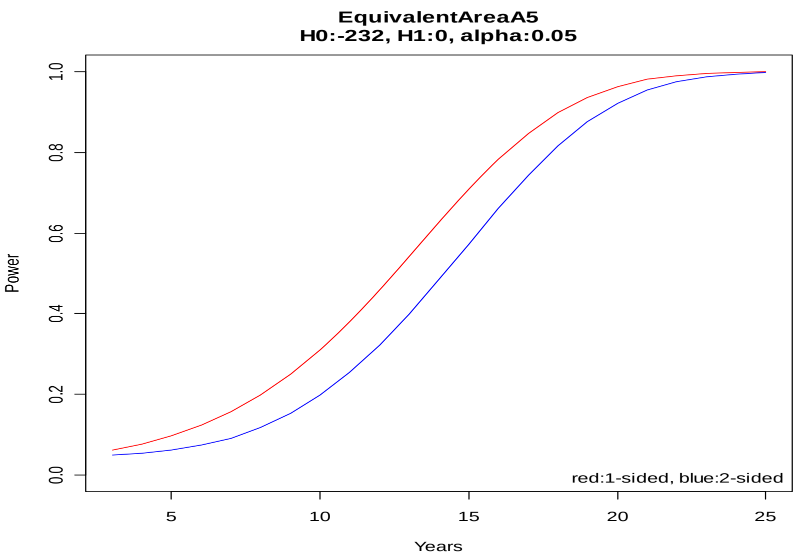


Fig.12. Equivalent Area A5 – Power method

Positive Area A5

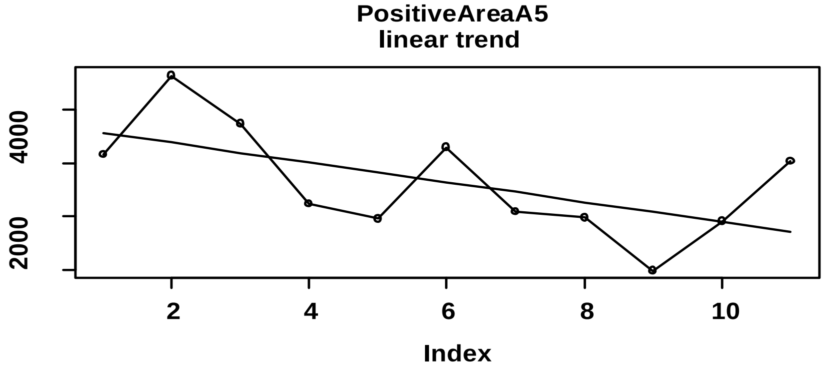


Fig.13. Positive Area A5 – Linear regression

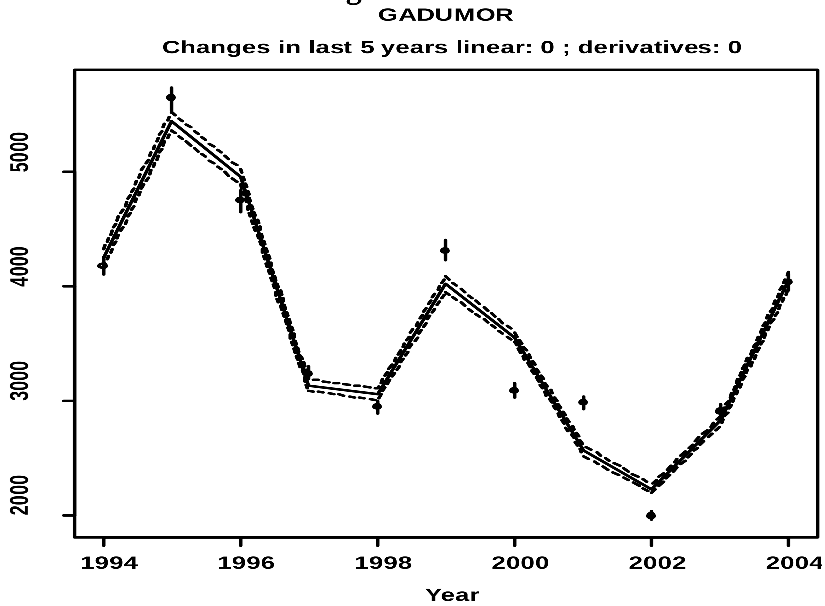


Fig.14. Positive Area A5 – Derivatives method

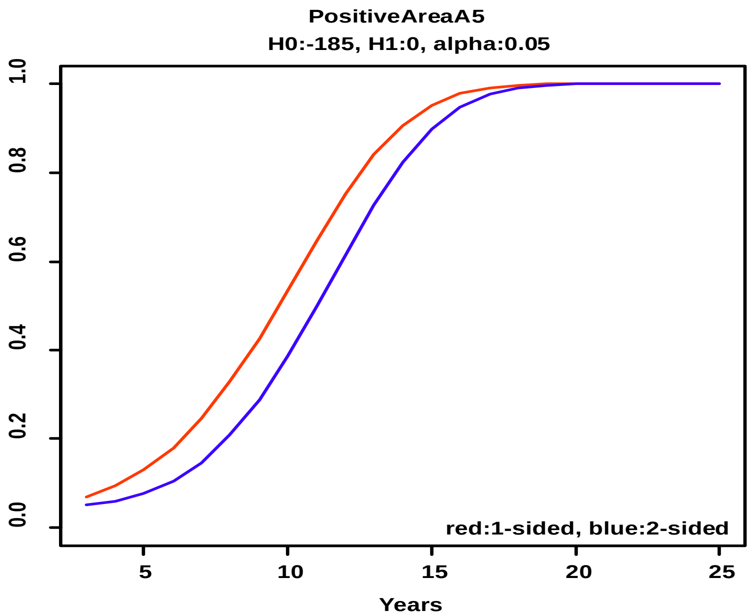


Fig.15. Positive Area A5 – Power method

Lbar

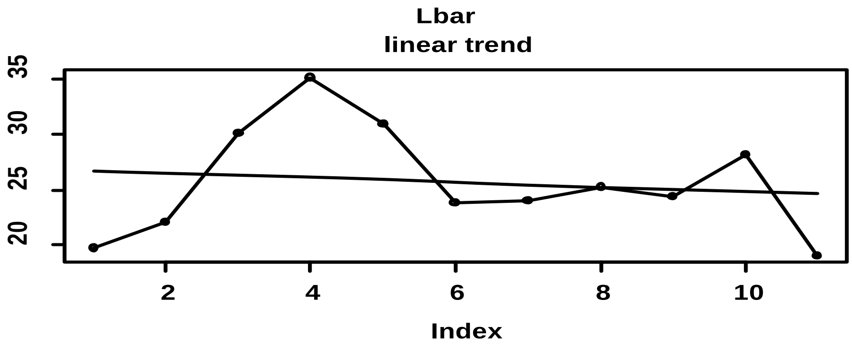


Fig.16. Lbar – Linear regression

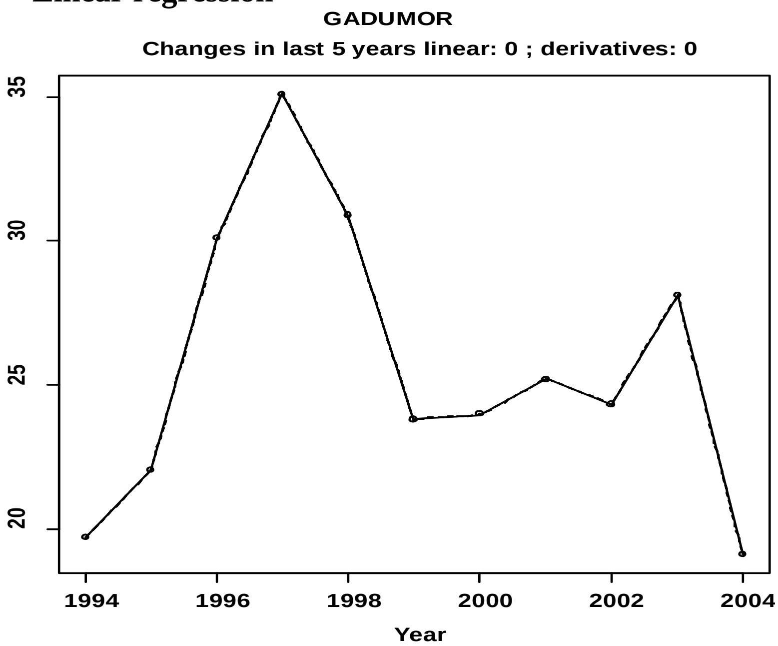


Fig.17. Lbar – Derivatives method

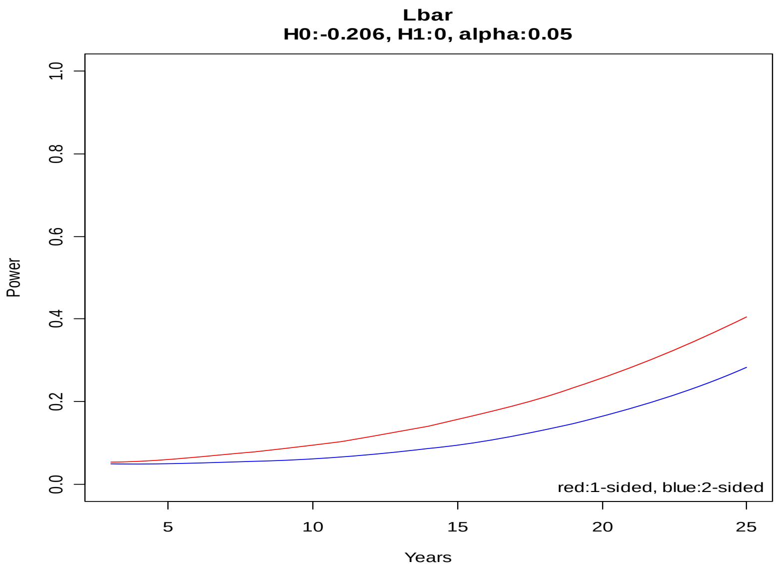


Fig.18. Lbar – Power method

L25

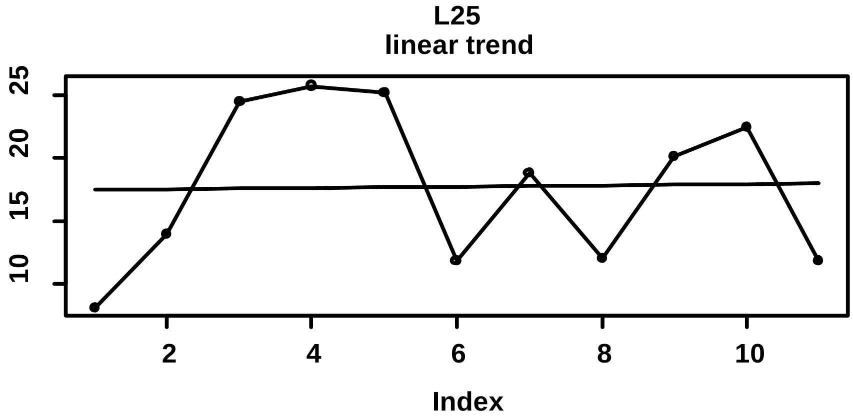


Fig.19. L25 – Linear regression

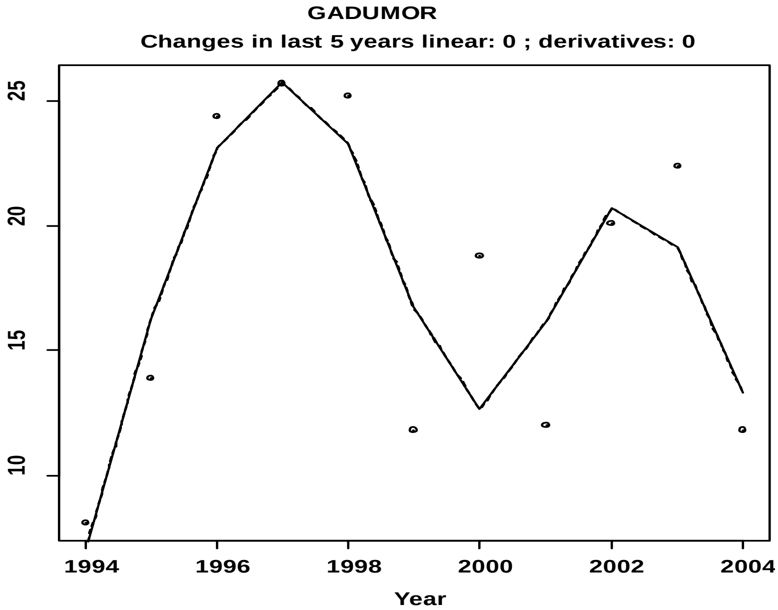


Fig.20. L25 – Derivatives method

L75

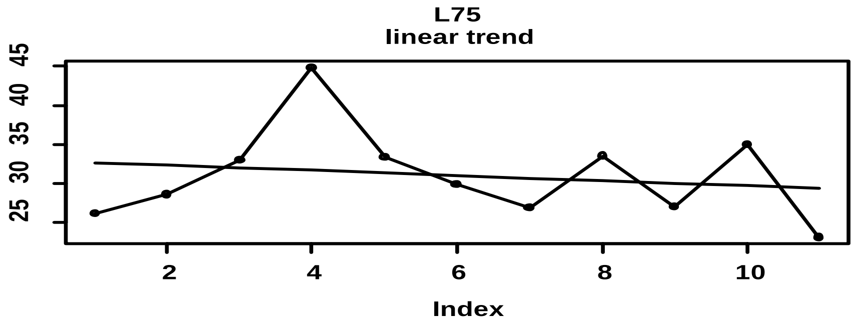


Fig.21. L75 – Linear regression

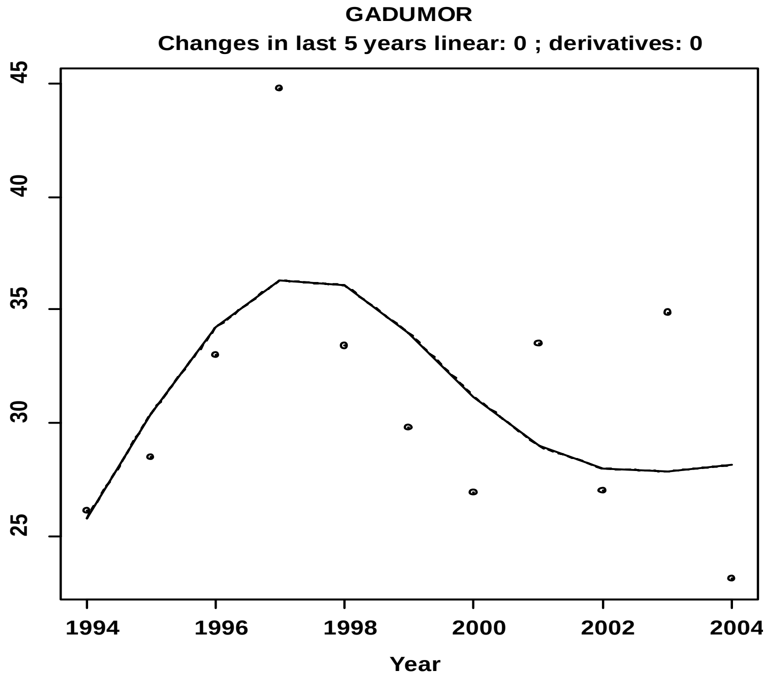


Fig.22. L75 – Derivatives method

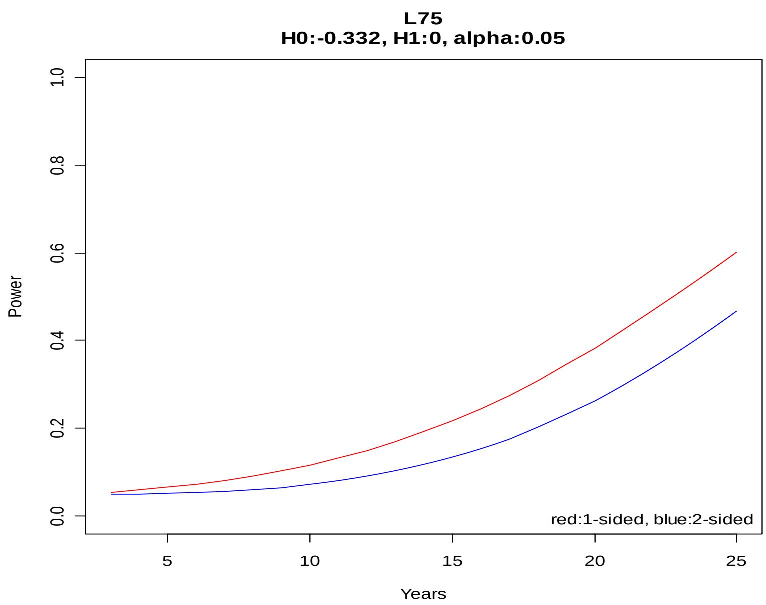


Fig.23. L75 – Power method

Z

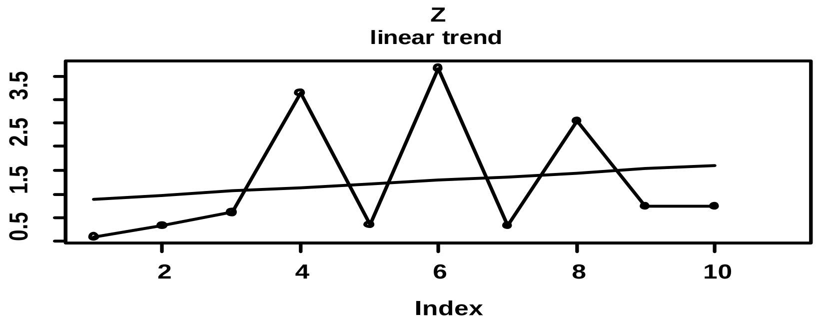


Fig.24. Z – Linear regression

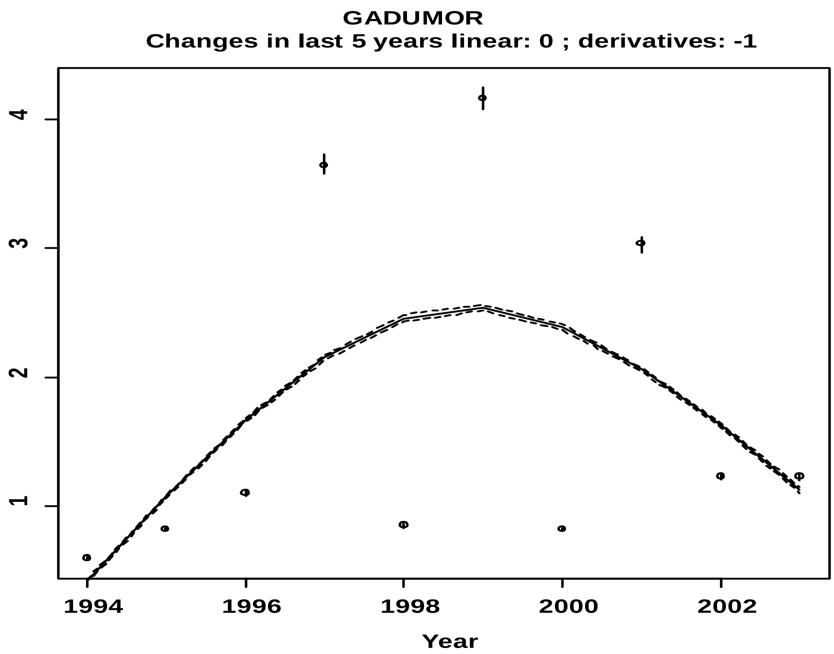


Fig.25. Z – Derivatives method

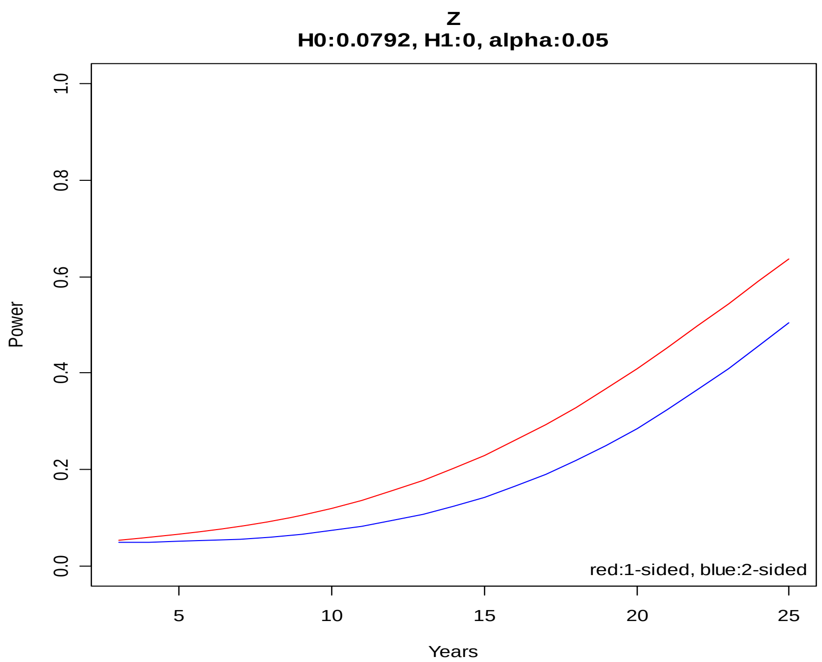


Fig.26. Z – Power method

Survey index

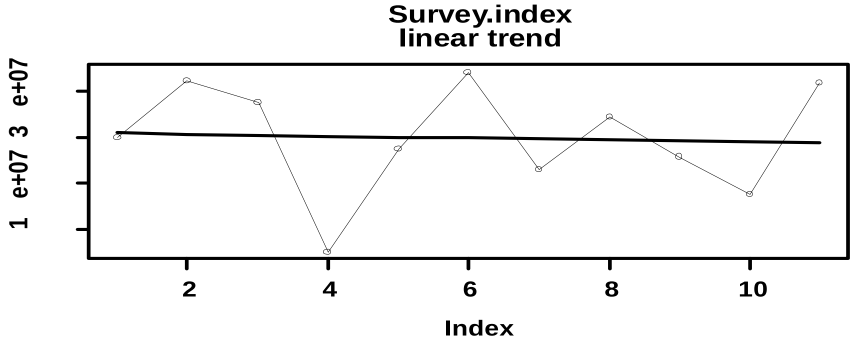


Fig.27. Survey index – Linear regression

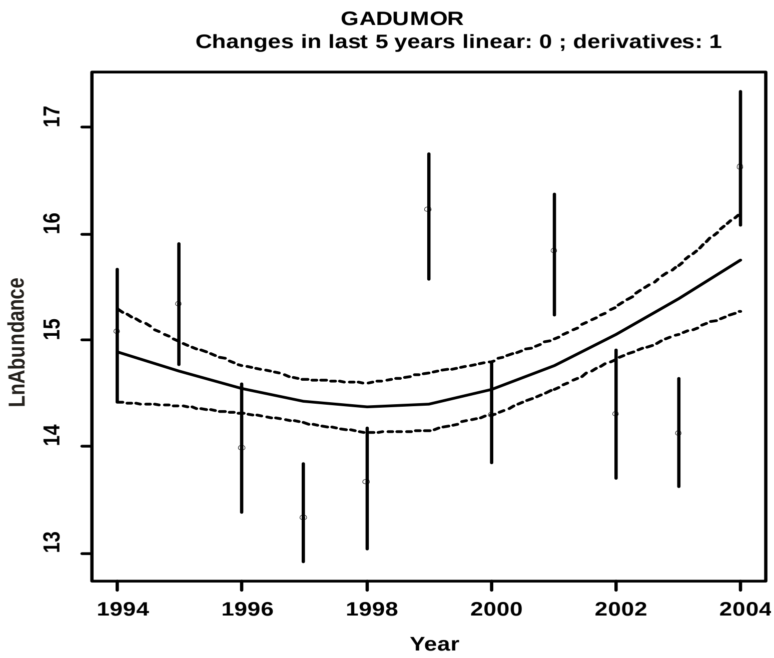


Fig.28. Survey index – Derivatives method

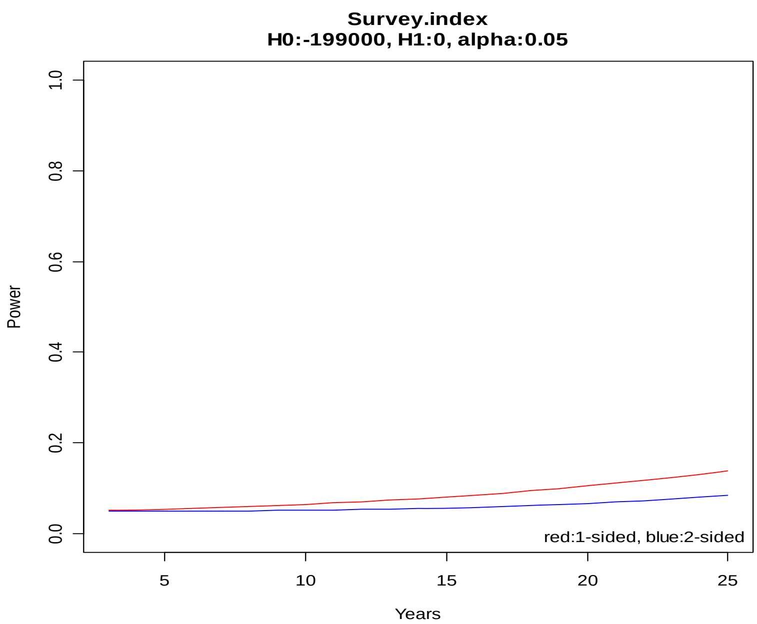


Fig.29. Survey index – Power method

Recruit index

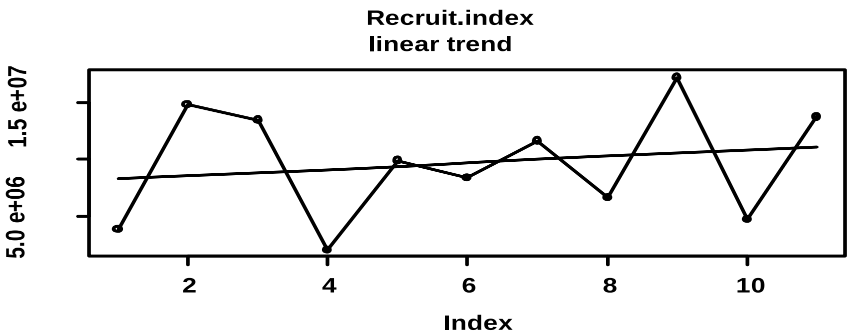


Fig.30. Recruit index – Linear regression

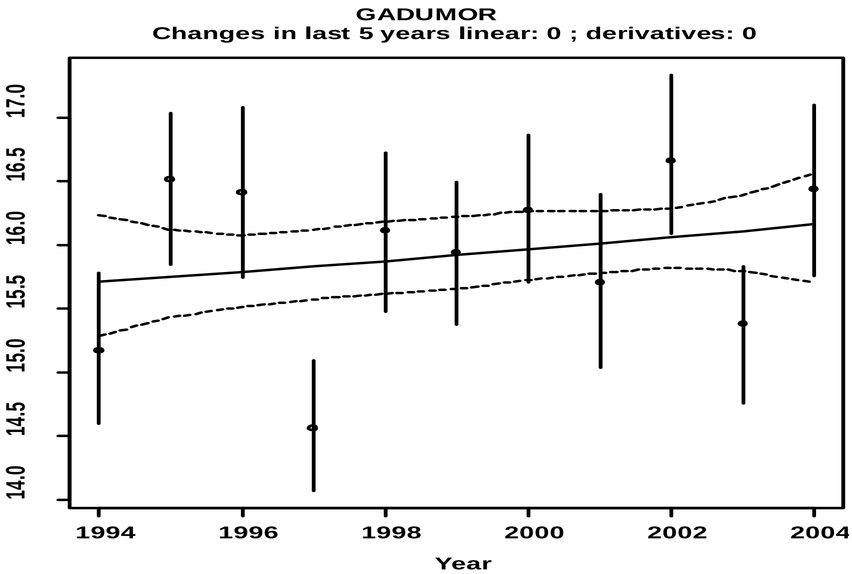


Fig.31. Recruit index – Derivatives method

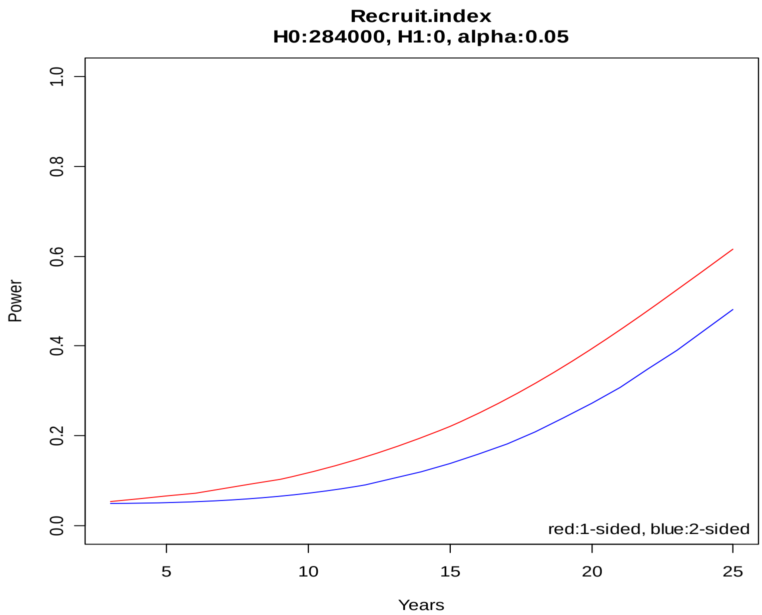


Fig.32. Recruit index – Power method

DICUSUM PLOTS

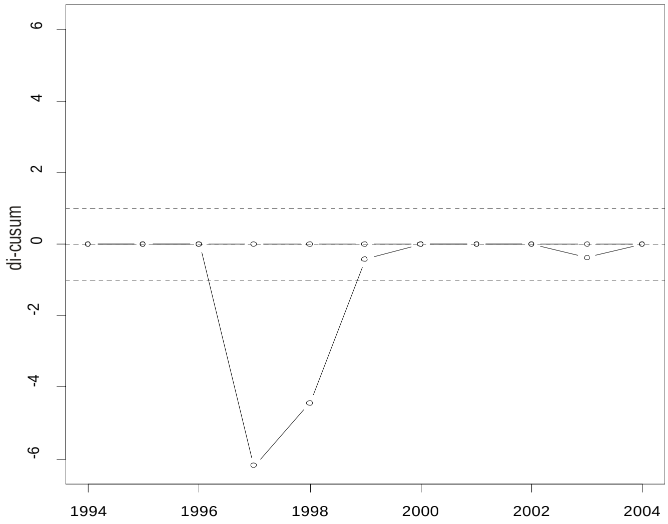


Fig.1. Total abundance

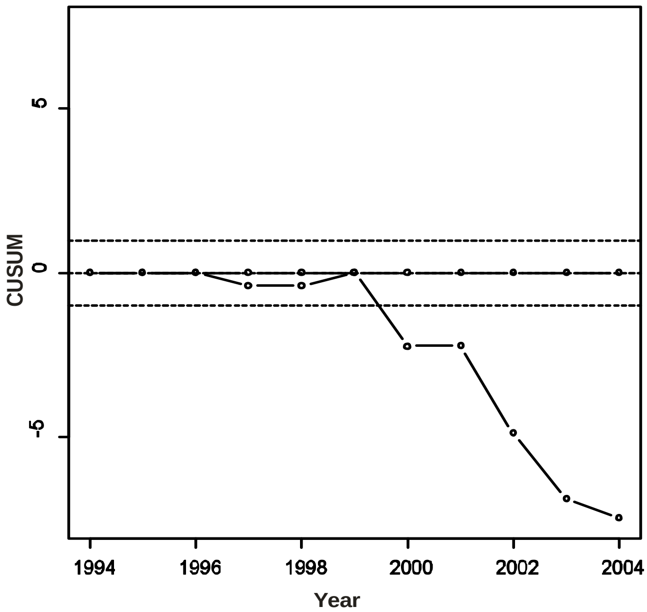


Fig.2. Abundance A5

Fig.3. Positive area A5

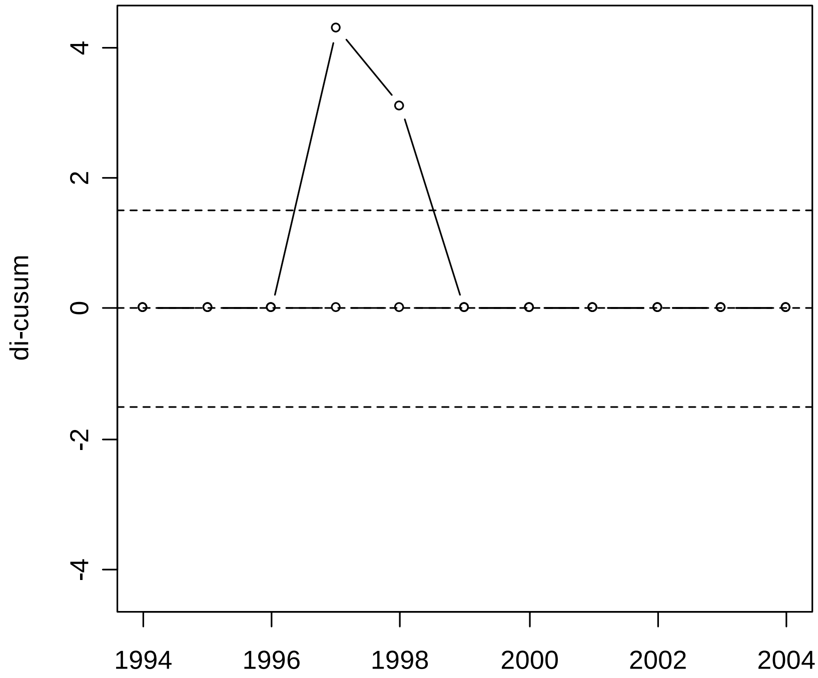


Fig.4. Index md

Interpretation

Trend analysis using cause-effects table

The trend analysis results indicate that the increase in fishing mortality seems to be the most influencing cause of changes in the stock. Although only 4 of 6 of observed "all period" trend direction of indices is in compliance with trends in cause-effects table it is however the highest match among all the options (causes) represented in that table. It is also worth to notice that in the case of two miss-match trends (ln-N and ln-Rec) their directions are not opposite to trend directions presented in the cause-effects table. Decrease in Z for recent 5 years is most probably the result of implementation of fishing regulatory measures (extended closed seasons and areas) which have reduced fishing mortality. Recent increase in total abundance might be the result of both fishing reduction (as mentioned above) as well as increase in recruitment. Since the stock consists mainly of young fish therefore total abundance is sensitive to pulse of recruitment

Cusum analysis

The most evident deviation of cumulative sum of observations from the mean is represented by abundance of fish Age 5. The negative direction of change is detected immediately following the reference period and the negative trend is continued till the last year of observations. Abundance Age 5 negative change is also accompanied by positive area for that age. For the other cusumed indices there is not a continued change detected or no deviation detected. Findings of cusum abundance Age 5 support the conclusions of cause-effects diagnostic table described in the proceeding subchapter indicating on significant fishing mortality pressure on the stock. Since fish Age 5 and older contribute the most to the reproduction of the stock their considerable decrease justifies triggering the alert (as marked in the CUSUM diagnostics table).

Compare approaches (cusum/trends)

Cumulative sum as an early warning monitoring system detecting trends in time-series requires at best a reference period characterized by good state of the stock, reflected by its parameters (indices). In that particular case of Baltic cod however the stock was in a good condition in the middle of eighties. The survey data considered in FISBOAT project cover the years with very low level of the biomass. Going back in time with survey results means deteriorating the quality of source data and its consistency with the data available for the present study. The chosen reference period represents relatively stable stock with relatively high survey total numbers and is the most adequate within the survey data available. Nevertheless it may result in failing of detecting "long-term" changing in trends in most of the indices investigated. It was possible to detect the most dramatic change which is observed for fish abundance Age 5.

What have you learned about the stock

The stock is mainly young fish, therefore its dynamics strongly depends on the abundance of recruitment. The PCA analysis indicate that biological indices most correlated with component one are L25(-0.85), L75(-0.84), Lbar (-0.82). These indices are also the most correlated in both components. Total abundance is most correlated in component two. Lbar, L25, L75, and survey index are more trustworthy than L50.maturity and Z. Spatial indices most correlated with mfa components tend to be location (ycg – 9 of 11 observations) and area (Spreading Area – 8 and Equivalent Area 6). The multivariate MFA analysis revealed the

gravity centres of fish Age 1 and 2 to large extend overlap in a factorial space. Occupation of almost the same area might be explained by the fact that fish Age 1 are immature and Age 2 is matured only in approximately 15%. Similarly is explained the distribution of fish Age 3 and 4 in factorial space. These ages constitute of fish matured in 36% and 62% respectively, while fish Age 5 and older that are almost fully matured are the most distant from the other ages. For some of the observations the distance between each single year of Age 5 and the gravity centre is very distant as compared with the other ages.
The summary analysis of stock behaviour in spatial indices context resulting from R.Geos package analysis confirms existing differences between immature fish (Age 1 and 2) and mature fish (Age 3 and older). Centre of gravities along x axis is narrower for Ages 4-5 as compared to younger fish, while centre of gravities along y axis are considerably higher for fish Age 3-5 in comparison with younger fish which means that the latter ones are located closer to the coast on shallower waters. Inertia is quite stable by age except for Age 1 which is bigger. Anisotropy is higher for Age 2 what may be related to maturity diversification of that age. Considering Microstructure Index it is evident that fish Age 1 and 2 are considerably less regular in space and also these ages are less expanded (Equivalent Area) as well as less evenly distributed (Spreading Area). Young fish are also more concentrated (positive Area).

Summary sheet: Baltic Cod

Bottom trawl surveys 1994-2004, I quarter (February-March)

Non-spatial indices

Total abundance	methods: linear regr., power, cusum : no signal detected; derivatives method : increase in recent 5 years;
Abundance at age	Age 5 : strong decrease (methods: visual, linear regr., cusum, power); Age1 : increase (methods: visual, linear regr., derivatives, power)
Recruitment index (Age 2)	methods: linear regr., visual : increase; methods: power, derivatives, cusum : no signal detected
Lbar	methods: linear regr., visual : decrease; methods: derivarives, power, cusum : no signal detected,
L75	methods: linear regr., visual : decrease; methods: power, derivatives : no signal detected;
L25	methods: linear regr., power, derivatives, cusum : no signal detected
L50.maturity	signal seen but probably artifact of survey dates and maturity staging;
Z	methods: linear regr., visual : increase; methods: power, cusum : no signal detected; method: derivatives : decrease in recent 5 years

Spatial indices (indices analysed by age, if change has been detected then index with particular age is described)

Positive Area	Age 5 : decrease (methods: visual, liner regr., cusum, power), methods: derivatives – no signal detected;

Spreading area	Ages 5, 2 – decrease (methods: visual, linear regr.) methods: derivatives, cusum - no signal detected
Equivalent area	Ages 5, 4, 3, 2 : decrease (methods: visual, linear regr.); Age 1 : decrease in recent 5 years (method: derivatives)
Centre of gravity	ycg of Ages 5, 3 : decrease (methods: visual, linear regr.); methods: derivatives, power : no signal detected
Inertia	Age5 : increase (methods: visual, linear regr.); decrease in recent 5 years (method: derivatives)
Anisotropy	Age5 : increase (methods: visual,linear regr., derivatives); method : power: no signal detected
Microstructure	Ages 5, 4 : decrease (methods: visual, linear regr.); Age 4 : decrease in recent 5 years (method: derivatives); Age 2 : decrease (methods: visual, linear regr.,); decrease in recent 5 years – method: derivatives.

Composite indices

MFA

component 1 is positively correlated with: ycg (9+), Spreading Area (8+), Equivalent Area (6+) and negatively correlated with: Inertia (7-), Anisotropy (6-)

component 2 is positively correlated with: Anisotropy (3+), xcg (3+) and negatively correlated with: Positive Area (7-), Equivalent Area (5-)

MAF

MAF1: Age 1 : Inertia (0.76), Spreading Area (-0.75)
Age 2 : Spreading Area (-1.08), Microstructure Index (-0.58)
Age 3 : xcg (0.86), Anisotropy (0.81)
Age 4 : Equivalent Area (-0.68), xcg (-0.61)
Age 5 : Spreading Area (0.95), xcg (0.86)

PCA

component 1 is dominated by length indices (L25=-0.85, L75=-0.84, Lbar=0.82)

component 2 is dominated by abundance (Ln.Ntot=-0.84)

Reference period

1994-1999 excluding 1997

Comments: relatively stable period with relatively high survey total numbers (except for 1997)

Summary of results on the stock

Data series relatively short (11 years). Data series covers the period with very low and stable level of SSB (below Blim) and poor and stable (not fluctuating) recruitment. These may result in a failure of detecting significant signals in population biology indices indicating that the stock is still in a very low level. However abundance indices indicate rapid decrease of fish Age5 and older and slower decrease of fish Age4. Although there is an increase observed in immature fish Age1 the overall abundance has not indicated change in “all period” trend. In recent 5 years there has been observed positive change in trend in total abundance.

Comparison with traditional assessment of stock status

Since the late of eighties until now the stock is in a poor state, below Bpa and quite often (since 1997) below Flim. Fishing mortality usually exceeded 1. For the years covered by survey data considered in the present study since 1995 a reduction in fishing effort or fishing mortality was proposed. In 2003 and2004 70% and 90% reduction in fishing mortality was recommended while for 2002 and as well as for 2005-2007 no fishing was advised. The proposed fishing regime is proposed mainly due to low recruitment and fishing pressure on the stock that reduce significantly the number of fish that can reproduce. The fact of significant reduction of fish Age 5 and older was also evidenced by CUSUM analysis in 2000 year for which the alert has been triggered. The CUSUM alert coincided in time with the advice of fishing termination. CUSUMed Positive area for fish Age 5 indicated decrease in 2002 outside the limits of reference period, what also justified triggering the alert. However in case of population biology indices there was not a clear signal of alarming changes. Only L75 - which is the attribute of larger fish decrease - in the last year of observation was negative. Trend analysis has shown that in "all period" trend, L75 and Lbar were declining.

Formulation of advice

The results of the present study indicate that fishing mortality is still too high, playing a key role in reduction of the reproductive capacity of the Eastern Baltic cod stock. Taking into account strong dependence of that stock on inflows of more saline waters from the North Sea it seems crucial to protect the reproductive part of the stock. It shall therefore be the highest priority to reduce further the fishing pressure on that stock.

codBA		CUSUM diagnostics table										
ref.period	1994:1996,1998:1999											
m in ref.period		17.3886959	16.0	25.3	16.7	30.2	1.5	14.5	2.064952497	8.36	
sd in ref.period		0.2105792	0.5	5.0	7.7	3.1	1.5	0.5	0.869654482	0.24	
k		3	0.6	0.6	0.9	0.9	0.9	1.4	2	0.9	
h		1	1.7	1.8	1.2	1.1	1.1	1	1.5	1.1	
ARL InControl		31428.6	36.3	41.5	39.2	32.8	32.8	105.8	3790.5	32.8	
ARL OutControl		1	3.5	3.6	2.1	2	2	1.4	1.3	2	
Years	**MFA_Spatial**	**Ln_TotAbun**	**Ln_Recruits**	**Lbar**	**L25**	**L75**	**Z**	**Abundance A5**	**md**	**PositiveArea A5**	**alert**
1994	NA	0	0	0	0	0	0	0	0	0	ref
1995	NA	0	0	0	0	0	0	0	0	0	ref
1996	NA	0	0	0	0	0	0	0	0	0	ref
1997	NA	-6.194319	-2.2	0	0	3.9	0	0	4.297561076	0	
1998	NA	-4.443637	0	2.3	0	4.0	0	0	3.10577848	0	ref
1999	NA	0	0	0	0	3.0	0	0	0	0	ref
2000	NA	0	0	0	0	0	0	-2.235464	0	0	alert
2001	NA	0	0	0	0	1.2	0	-2.227868	0	0	alert
2002	NA	0	0	0	0	0	0	-4.881551	0	-3.4	alert
2003	NA	0	0	0	0	0	0	-6.862323	0	-4.1	alert
2004	NA	0	0	0	0	-1.4	0	-7.471428	0	-3.4	alert

codBA **cause-effects diagnostics table**

survey period	1994-2004
ref.period	1994:1996;1998:1999
ref status	"outside safe biological limits"

Results of trend analysis

	all period	recent
Z	1	-1
Ln_Abdnce	0	1
Lbar	-1	0
L25	0	0
L75	-1	0
Ln_Recruit	1	0

diagnostic ***increse in fishing mortality over the period investigated***

Explanatory cause-effects table for combining trends

Cause	Z	ln-N	Lbar	L25	L75	ln-Rec
F: increase	1	-1	-1	0	-1	0
F: decrease	-1	1	1	0	1	0
Recruit: increase	0	1	-1	-1	0	1
Recruit: decrease	0	-1	1	1	0	-1
Faster growth	0	0	1	0	1	0
Slower growth	0	0	-1	0	-1	0
Larger fish caught (or change in fishing area, stock distribution or gear)	-1	1	1	0	1	0
Smaller fish caught (or change in fishing area, stock distribution or gear)	1	-1	-1	-1	0	0

Indicator Based Assessment
Cod North Sea

C. Deerenberg (IMARES)

<u>Data</u>

The data used in the analyses are collected in North Sea area IV during the International Bottom Trawl Survey (IBTS) from 1985 to 2005. A map showing indices of the total abundance of Cod (Fig. 1. catch rate during IBTS, quarter 1 including 0-values) indicates that Cod is widespread over the North Sea and the highest numbers are found in the Skagerrak and Kattegat. It is suspected that this is due to a ‘spill-over’ of the population in the Baltic Sea. There has been a reduction in numbers caught in the German Bight since the late 1980s. Age A1 are recruits, ages A2-A3 represent immature individuals, whereas of ages A4 and up individuals are 60-100% mature.

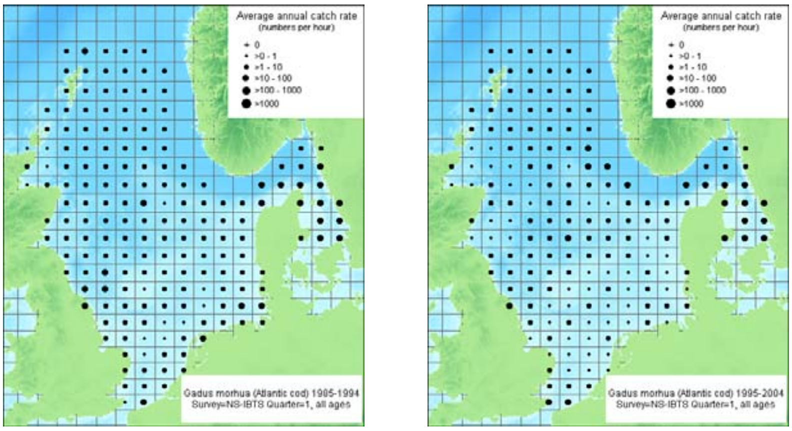


Fig. 1. Average annual catch rate (numbers per hour). Left panel: 1995-1994, Right panel: 1995-2004.

Maps of the gravity centres (GCs) across years (Fig. 2.) show that all age groups have a similar degree of dispersion. In the last ten years (1995-2005), the spatial location of the recruits (age A1) has changed in a westerly direction, from north of the Dutch part of the Wadden Sea to the centre of the North Sea, relative to the previous ten years (1998-1994). This supports the observation of reduced numbers in the German Bight (Fig. 1.).

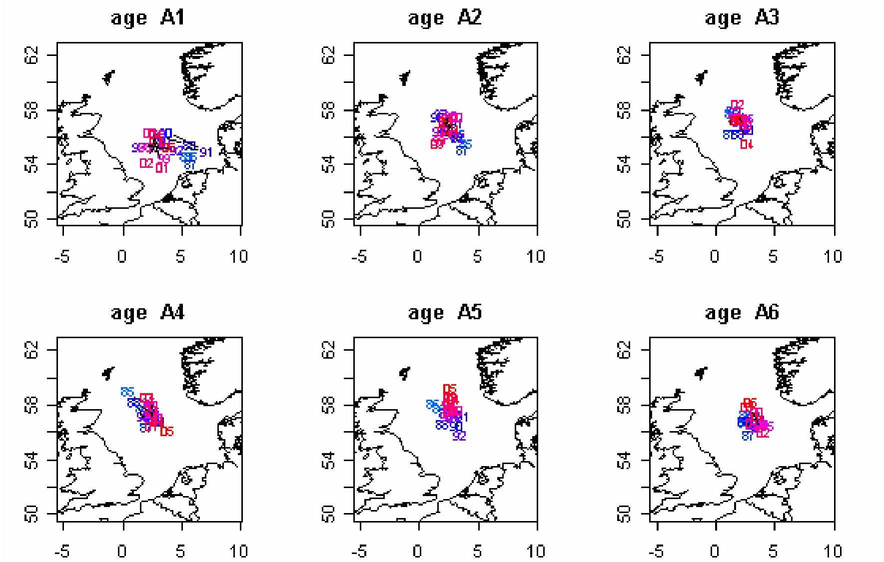


Fig. 2. Maps of the gravity centres of the six age classes for the years 1985-1994 (blue) and 1995-2005 (red).

Univariate indices

The raw spatial indices are reported in Tab. 1. and the raw non-spatial indices are in Tab. 2. The combined non-spatial indices are reported in Tab.3.

Tab. 1. Spatial indices

Year	Age	Abundance	Pos.Area	Inertia	Anisotropy	xcg	ycg	N.P.	Microst.	Equiv.Area	Spre.Area
1985	A1	5902000	25276	19537	1.391	4.77	54.87	5	0.578	6420	10700
1986	A1	119798000	77492	19072	1.107	4.35	55	3	0.851	4930	26500
1987	A1	87602000	85735	18908	1.382	5.08	54.35	2	0.645	5170	18200
1988	A1	31560000	62863	19909	1.775	5.32	55.17	3	0.466	9270	18800
1989	A1	102528000	98756	19865	1.285	2.16	56.17	4	0.446	23900	32500
1990	A1	23516000	50431	16269	1.314	4.21	56.37	3	0.459	8480	17000
1991	A1	74198000	51283	11141	1.5	7.39	54.94	2	0.513	1860	7020
1992	A1	97453000	98414	32694	1.537	3.49	55.61	7	0.441	24000	36100
1993	A1	49402000	60519	8608	1.599	1.46	55.51	2	0.49	4780	12600
1994	A1	77380000	79065	15794	1.205	3.89	55.57	4	0.31	26900	29400
1995	A1	56536000	87128	33944	1.865	3.26	56.13	4	0.389	26600	31000
1996	A1	18748000	50417	15090	1.566	3.51	55.46	4	0.298	23900	24900
1997	A1	257983000	101454	13699	1.548	2.9	55.78	3	0.643	4670	18400
1998	A1	14508000	61206	14889	1.363	2	55.68	3	0.475	15300	24400
1999	A1	17160000	44228	33702	2.315	3.94	55.11	4	0.498	8750	17100
2000	A1	50244000	73025	30463	1.824	1.06	57.44	4	0.481	17000	22500
2001	A1	13381000	31655	35192	2.399	4.44	55.45	4	0.698	3060	9580
2002	A1	35113000	57260	38279	1.611	1.63	56.1	6	0.618	11000	18800
2003	A1	4571000	23188	15067	2.041	3.59	56.09	3	0.491	12000	13300
2004	A1	26430000	44637	17707	1.777	3.66	56.64	3	0.458	5600	14700
2005	A1	11590000	43052	22505	1.171	4.05	55.43	5	0.416	20700	23600
1985	A2	116871000	117170	25244	1.622	2.33	56.43	4	0.501	23600	40800
1986	A2	23607000	85917	30484	1.757	1.91	57.18	6	0.8	9890	35700
1987	A2	218540000	124752	32470	1.774	2.22	55.8	5	0.819	8290	34000
1988	A2	56631000	99409	46522	2.74	1.92	56.08	6	0.349	25300	38300
1989	A2	43457000	92876	32766	2.263	2.4	56.91	7	0.629	13800	34000
1990	A2	133757000	113470	21318	1.55	1.39	57.66	7	0.428	31700	38100
1991	A2	37022000	87969	27228	1.495	3.1	57.22	5	0.4	22100	35900
1992	A2	42569000	103436	41590	2.128	2.42	56.17	7	0.441	21700	37600
1993	A2	154371000	111831	28587	2.136	1.56	57.86	7	0.357	43600	45200
1994	A2	32346000	75720	21094	1.694	1.99	56.7	5	0.4	20300	29200
1995	A2	214982000	110941	19006	1.629	2.84	57.89	5	0.357	13600	29300
1996	A2	69718000	97923	35356	2.231	2.47	57.25	4	0.454	22800	36100
1997	A2	43126000	80192	18542	2.021	2.37	57.45	3	0.462	12900	26000
1998	A2	178606000	123451	27108	2.127	2.58	57.1	7	0.463	24200	38600
1999	A2	12223000	61621	25378	2.116	1.78	55.92	4	0.412	19100	27700
2000	A2	46273000	86984	18965	1.445	3.34	57.8	2	0.273	11600	27100
2001	A2	66116000	95923	20643	1.843	2.6	58.07	4	0.299	29400	36800
2002	A2	34929000	86114	26379	1.642	0.84	57.85	5	0.404	23500	23900
2003	A2	26795000	79210	29741	1.881	1.62	56.47	7	0.437	26500	36800
2004	A2	16660000	70810	19980	1.168	3.55	56.91	2	0.436	13100	30400
2005	A2	17381000	69189	21703	1.592	2.25	57.75	5	0.387	24100	34900
1985	A3	28764000	75167	29630	2.728	0.94	58.88	2	0.542	6450	26700
1986	A3	70550000	96132	20001	1.848	0.71	58.28	3	0.572	8800	29000
1987	A3	12068000	63955	32076	1.949	0.69	57.1	6	0.528	21300	29400
1988	A3	62527000	97251	45655	2.499	1.34	56.36	5	0.308	30500	37400
1989	A3	48184000	92582	30437	2.213	0.81	58.38	7	0.369	32400	34500
1990	A3	17136000	80162	43059	2.257	2.28	56.76	7	0.409	40500	42200
1991	A3	30600000	86304	30204	1.956	1.56	57.9	5	0.467	24400	38200
1992	A3	9165000	51584	33345	1.751	2.17	56.84	7	0.489	24500	28900
1993	A3	17812000	72454	28890	1.799	1.08	58.24	7	0.419	33100	35900
1994	A3	21261000	80722	28785	1.927	1.95	57.54	7	0.402	34800	39600
1995	A3	24701000	85371	27627	1.652	2.53	57.57	5	0.344	23200	35700
1996	A3	40791000	87020	25623	1.782	2.54	57.61	3	0.727	4390	30700

1997	A3	16982000	67716	28795	2.12	1.71	57.85	5	0.41	24700	32000
1998	A3	13672000	70000	24600	1.779	1.77	57.9	5	0.435	25000	33400
1999	A3	59639000	109574	24729	2.204	1.79	57.57	4	0.389	41400	48100
2000	A3	6667000	51951	35377	1.812	2.65	57.25	3	0.486	25700	29500
2001	A3	12381000	62801	31112	2.198	2.12	58.06	4	0.4	29000	33400
2002	A3	34620000	88563	18599	1.727	1.63	58.71	6	0.347	31500	38400
2003	A3	10182000	55932	27939	1.712	1.33	58.11	4	0.365	33800	30600
2004	A3	12166000	65970	31898	1.818	2.98	56.11	5	0.427	35400	36900
2005	A3	5035000	44902	26860	1.641	2.1	57.61	7	0.448	37000	33100
1985	A4	26913000	55332	24165	3.417	0.43	59.62	3	0.569	1620	13300
1986	A4	26776000	65781	22886	2.169	1.05	58.31	3	0.597	4590	20400
1987	A4	12896000	66965	35195	2.597	1.68	57.13	7	0.581	20500	35300
1988	A4	5268000	45950	25227	1.85	0.53	58.37	3	0.41	23000	26500
1989	A4	19522000	82733	32950	2.127	1.54	57.92	8	0.465	32500	39700
1990	A4	8387000	58817	40519	2.615	2.1	57.51	4	0.458	29800	32200
1991	A4	8205000	51670	35129	1.96	2.61	57.69	4	0.437	13200	24800
1992	A4	6349000	45017	31918	2.163	1.72	57.57	7	0.547	14100	24900
1993	A4	5978000	48883	29740	2.03	1.89	57.83	10	0.414	30000	30200
1994	A4	5937000	47818	22884	1.356	2.55	57.48	7	0.407	28100	29600
1995	A4	10276000	57361	29935	2.168	2.59	57.86	5	0.384	16100	29400
1996	A4	5579000	40970	22719	1.852	2.07	58.47	8	0.501	19300	22900
1997	A4	7787000	55660	28487	1.918	2.58	57.6	5	0.461	22200	29700
1998	A4	7691000	47538	30416	2.13	2.97	57.6	7	0.382	21000	27000
1999	A4	6011000	46633	28877	1.862	2.37	57.96	6	0.406	31900	30100
2000	A4	17576000	70603	30513	2.264	2.45	58.35	4	0.533	21100	33300
2001	A4	2096000	22401	43765	2.516	1.85	57.25	7	0.570	16200	16600
2002	A4	4917000	33394	29021	2.167	2.65	58.17	2	0.437	12100	17200
2003	A4	10194000	50544	24781	1.957	1.43	58.88	4	0.468	23300	27000
2004	A4	3000000	28922	33783	2.285	2.91	57.56	7	0.441	17400	18400
2005	A4	4734000	46429	35501	2.014	3.47	56.76	6	0.471	32000	32500
1985	A5	5906000	35065	30979	2.956	1.00	58.71	4	0.573	2550	13300
1986	A5	11878000	51075	19594	2.351	1.40	58.08	5	0.581	5990	20500
1987	A5	4876000	42056	26948	2.787	1.89	58.18	5	0.436	26400	26600
1988	A5	6444000	48906	24944	2.426	1.96	56.8	4	0.372	30300	30300
1989	A5	3165000	38456	23764	1.837	1.75	57.97	7	0.466	29100	27700
1990	A5	7195000	61631	33502	2.372	2.78	56.65	7	0.420	42400	40000
1991	A5	3405000	33118	29054	2.382	3.53	57.64	7	0.440	12500	20700
1992	A5	2284000	22613	36941	2.755	3.09	56.16	6	0.557	11500	13800
1993	A5	4342000	38956	19127	2.308	2.77	57.39	6	0.351	26500	25900
1994	A5	3162000	29981	14786	1.829	2.90	57.42	4	0.490	10600	17300
1995	A5	1994000	26076	20003	1.611	2.56	57.49	5	0.491	18500	19400
1996	A5	4945000	36870	27294	2.174	2.38	58.14	4	0.398	23800	22600
1997	A5	3243000	31189	22067	2.249	2.82	57.65	4	0.459	20900	21000
1998	A5	4088000	36248	19612	1.735	3.08	57.87	5	0.373	20900	22800
1999	A5	3012000	32379	23795	2.416	2.29	58.7	4	0.370	22000	21400
2000	A5	3759000	35511	31748	2.395	3.18	58	4	0.396	20600	22300
2001	A5	3106000	30247	27576	1.848	2.23	58.09	6	0.443	24200	22900
2002	A5	932000	8991	17838	2.475	2.79	58.56	3	0.458	6590	6250
2003	A5	3239000	25183	20143	2.611	2.45	58.72	7	0.542	10200	14100
2004	A5	4827000	27607	17325	2.280	2.78	58.71	4	0.436	6630	13100
2005	A5	1602000	15124	10830	2.152	2.07	59.77	5	0.418	12100	10700
1985	A6	9957000	33568	33837	3.099	2.25	57.53	4	0.553	6700	13000
1986	A6	7997000	38599	22979	2.093	2.23	57.61	7	0.496	14200	19400
1987	A6	6028000	39813	17262	2.015	2.87	56.02	4	0.437	20600	23900
1988	A6	8287000	47251	20986	2.930	2.5	57.03	4	0.332	20700	24500
1989	A6	6546000	39485	17996	2.672	3.04	56.95	4	0.439	17900	21300
1990	A6	4411000	37794	17675	1.916	3.04	56.61	2	0.484	21900	24300
1991	A6	5855000	43791	21883	2.047	3.51	56.64	7	0.407	23300	27100
1992	A6	3278000	25436	29946	3.479	2.96	57.29	5	0.485	11800	16000
1993	A6	2614000	25461	21656	3.377	3.56	57.13	4	0.468	17500	17800

1994	A6	3967000	33114	18588	3.061	2.86	56.99	8	0.379	15000	19000
1995	A6	2661000	21075	14682	1.837	4.42	56.64	3	0.516	7230	13300
1996	A6	3029000	21807	17671	2.280	3.93	56.76	2	0.407	11600	13100
1997	A6	3273000	24052	16207	2.508	3.75	57.05	8	0.477	11600	13900
1998	A6	2940000	23739	18098	2.097	4.26	56.64	4	0.485	14100	14800
1999	A6	4295000	32761	25475	2.584	3.43	56.65	5	0.459	17500	20500
2000	A6	4694000	33419	25869	2.536	3.64	57.79	5	0.440	13200	21200
2001	A6	2059000	20125	31018	2.543	2.97	57.04	7	0.511	15800	14800
2002	A6	1709000	17981	29806	2.619	3.69	56.92	7	0.529	13700	13300
2003	A6	1554000	15151	24589	2.954	2.31	58.41	4	0.526	11200	11400
2004	A6	1400000	14521	18309	2.752	3.77	57.36	3	0.477	11300	11700
2005	A6	3498000	21996	29967	2.796	2.61	58.74	3	0.410	15400	14200

Tab. 2. Non-spatial indices

Year	**Survey index**	**Recruit.index**	**Lbar**	**L25**	**L75**	**L50.maturity**	**Z**	**StdLbar**	**StdL25**	**StdL75**	**SdL50.m**
1985	194313000	116871000	41.37	27.7	47.3	69.86	0.183	0.0236	0.0175	0.0823	1.1
1986	260606000	23607000	29.45	14.9	38.1	65.20	0.569	0.0193	0.0028	0.1678	1.5
1987	342010000	218540000	31.86	22.8	35.3	62.18	0.479	0.0077	0.0058	0.0044	1.8
1988	170717000	56631000	40.99	23.7	52.8	67.45	0.228	0.0635	0.0551	0.1948	0.0
1989	223402000	43457000	35.26	18.1	44.8	72.86	0.488	0.0452	0.0082	0.0812	2.7
1990	194402000	133757000	38.28	26.8	40.8	70.29	0.540	0.0526	0.0197	0.0786	1.5
1991	159285000	37022000	37.85	18.5	49	64.15	0.575	0.0768	0.0231	0.1515	1.3
1992	161098000	42569000	28.11	15.8	33.2	60.89	0.293	0.0481	0.0098	0.3087	1.7
1993	234519000	154371000	34.40	25.1	38	66.62	0.726	0.0309	0.0589	0.0325	1.6
1994	144053000	32346000	30.08	13.5	37.7	54.91	0.199	0.0826	0.0075	0.2538	1.5
1995	311150000	214982000	32.28	24.7	35.1	60.64	0.666	0.0178	0.0429	0.0120	1.4
1996	142810000	69718000	39.93	28.3	47.3	60.10	0.588	0.0557	0.0395	0.0454	1.5
1997	332394000	43126000	20.17	10.7	22.3	53.36	0.399	0.0152	0.0012	0.0243	1.4
1998	221505000	178606000	34.11	24.3	37.9	51.32	0.447	0.0188	0.0048	0.0369	1.3
1999	102340000	12223000	40.84	29.9	46	39.11	0.393	0.0834	0.0439	0.2744	1.2
2000	129213000	46273000	36.04	17.8	45.7	49.32	0.578	0.1047	0.0478	0.7758	1.3
2001	99139000	66116000	35.03	25.2	37.9	57.04	0.298	0.0525	0.0229	0.0821	1.6
2002	112220000	34929000	34.43	20.5	42.2	44.28	0.476	0.0751	0.0232	0.2873	1.3
2003	56535000	26795000	43.09	28.8	52.1	43.03	0.372	0.1543	0.0404	1.0298	1.5
2004	64483000	16660000	35.48	17.6	47.5	41.97	0.392	0.2306	0.0388	1.9008	1.7
2005	43840000	17381000	39.48	21.2	48.9	39.91	n.a.	0.4022	0.7038	1.1292	1.7

Multivariate indices

1. PCA of biological, non-spatial indices

The plot in Fig. 3 displays the relationship between the principal components and the eigen value, that decrease fairly rapidly: the first three components provide a reasonable summary of the data. The PC loadings (Tab. 3, Fig. 4) reveal that the first component is highly and positively correlated with all the length-related indices. The second component is highly and negatively correlated with the survey index (total abundance) and the antagonism between survey index and length at the third quantile (L75). The third component is highly and positively correlated with total mortality (Z). All three components are equally correlated with the recruit index, component 1 and 3 positively and component 2 negatively. Overall, length indices and abundance indices are correlated.

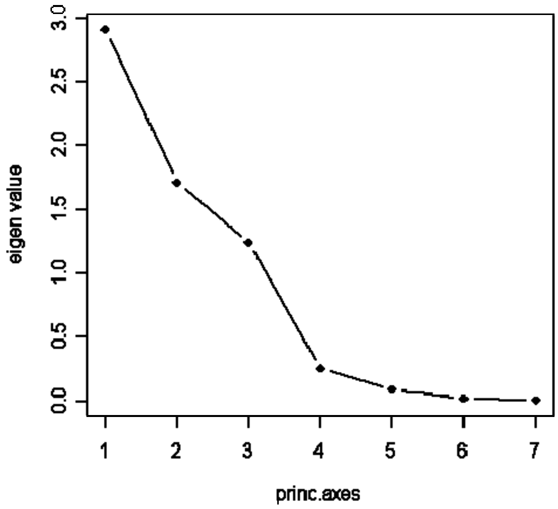


Fig. 3. Relationship between the first components and the eigen values.

Tab.3. PCA results for non-spatial population indices: correlation of indices with components.

	PC loadings		
	Comp1	Comp2	Comp3
Ln.Ntot	0.2411	**-0.8337**	-0.1972
Ln.Nrec	*0.5578*	*-0.5266*	*0.5496*
Lbar	**0.8314**	0.4288	0.1291
L25	**0.8449**	-0.1568	0.3649
L75	0.5936	**0.6706**	-0.1445
L50.maturity	**0.8125**	-0.0392	-0.4060
Z	-0.3451	0.2769	**0.7505**

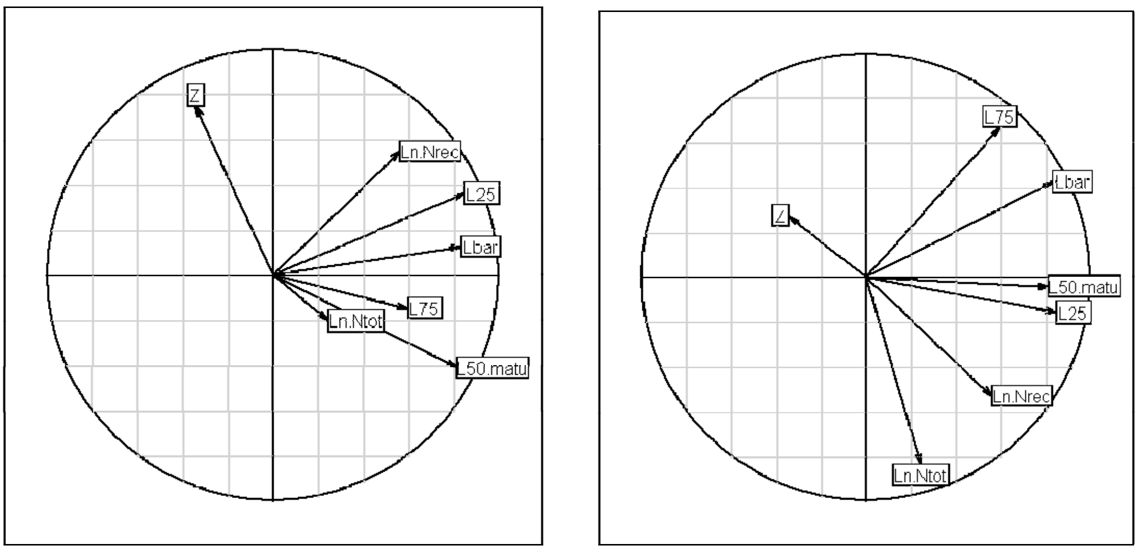


Fig. 4 (left). Correlation circle of PCA with non-spatial indices. C1 on horizontal axis, C2 (left panel) and C3 (right panel) on vertical axes.

Fig. 5 (below) illustrates the multivariate monitoring approach. The overall pattern shows a shift from reference years to other (i.e. later) years towards negative values on the c1 axis, that is driven by changes in length at 50% maturity. More specifically, the years 1997, 1999 and 2003-2005 are outside the domain defined by the reference years, which indicates that they depart from the reference status. The direction of the departure (low on the c1 axis) indicates that for 1997 this is mainly the result of the low values for the length indices (see Fig. 7), whereas the total abundance is within normal limits. The direction of the departure for the other years (high on the c2 axis) is due to changes in abundance.

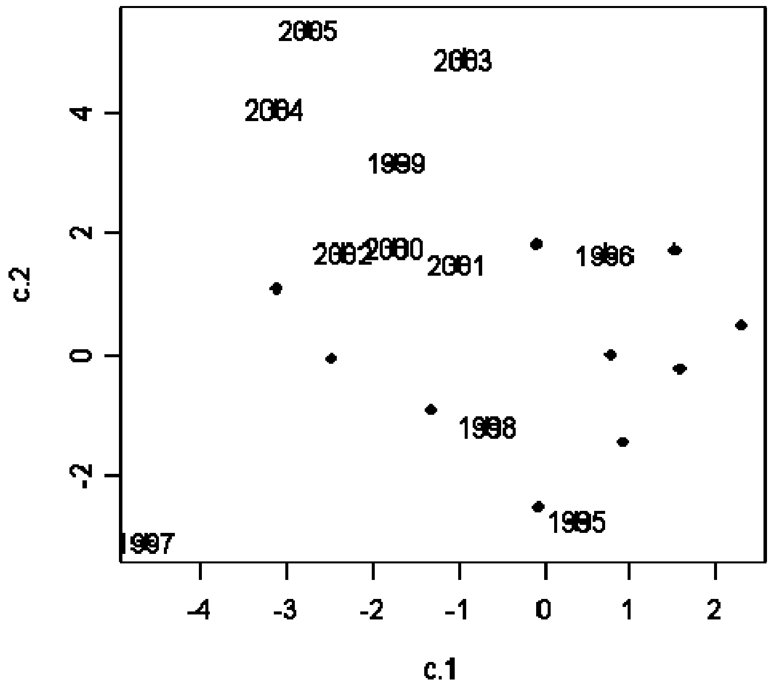


Fig 5. Position of the years in the factorial plane (two first principal axes)

2. MFA of spatial indices

Table 4 gives a summary of the correlation structure in the spatial indicators. Both location and aggregation indices seem to contribute to the components similarly. The first component is determined by having a larger area occupied (positive, equivalent and spreading area), a centre of gravity more to the north (ycg) and west (xcg), higher dispersion (inertia), and a lower nugget effect (microstructure index). The second component is determined by having a centre of gravity more to the north (ycg), higher anisotropy and a smaller positive area.

Tab. 4. MFA results for spatial indices: correlation of indices with components.

Spatial Indices	**Number of correlations (+ or -) > 0.5 with pc**			
	Comp1		Comp2	
	+	–	+	–
PositiveArea	**12**	0	0	**16**
Inertia	**12**	2	1	2
Anisotropy	0	2	**15**	0
xcg	0	**17**	4	4
ycg	**13**	0	**15**	0
MicrostructureIndex	1	**11**	3	3
EquivalentArea	**12**	0	1	2
SpreadingArea	**18**	0	0	7

The plot in Figure 6 shows the age groups in the factorial space, which characterises the life cycle spatial pattern of North Sea cod. The six age groups show a moving occupation of the factorial space with the first age group completely separated from the other age groups. The transition from recruits (age1) to ages 2-3 shows a positive shift along the first axis and is represents a movement to the west, a higher degree of dispersion and thus occupation of a larger area and with smoother correlation (a smaller nugget effect). The transition to older ages 3-6 shows a shift in spatial distribution that is characterised by being more to the north, more anisotropic and occupying a smaller area compared to the younger ages (axis c1). From age 4 onwards, this is accompanied by a shift towards the north-west, a higher degree of dispersion and thus a larger area occupied, and again a smoother correlation (smaller nugget effect, lower microstructure index).

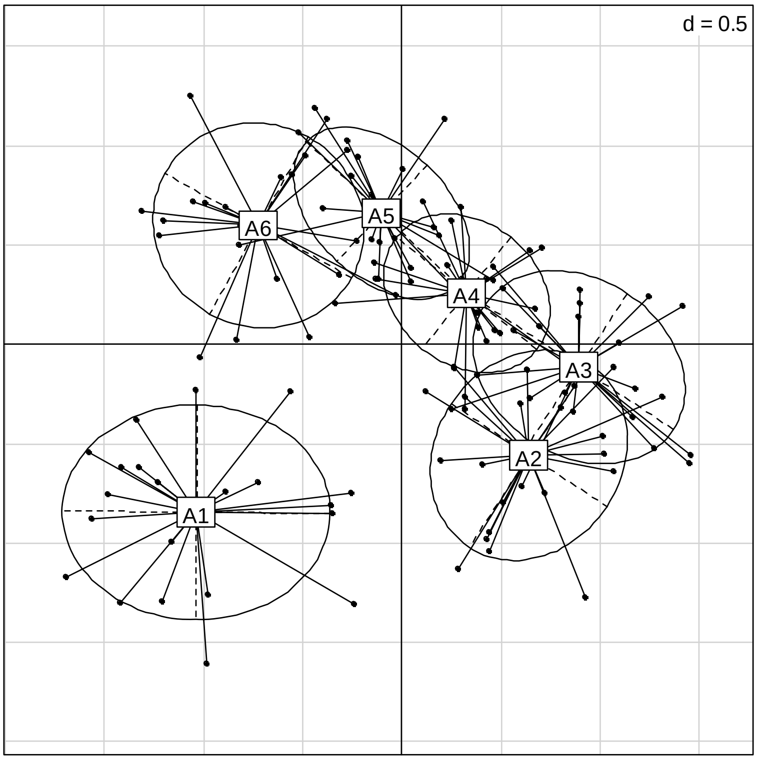


Fig. 6. Age groups in the factorial space. C1 on horizontal axis, C2 on vertical axis.

3. MAF of all indices
The multivariate indices that resulted from the PC analysis on non-spatial indices and the MF analysis on spatial indices showed changes in the population that indicate whether indices fluctuated together, in opposition or without relationship. To describe changes in the population in time, continuity is an important aspect. We therefore applied the Min/Max Autocorrelation Factors (MAF) method to construct principal components with decreasing degrees of autocorrelation: the first factors (MAFs) are the most continuous in time.

The abundance indices were Ln-transformed. MAFs are sensitive to the number of indices compared to the number of years in the time series. The number of years was 21, which was well below the number of indices (37). We reduced the number of indices by retaining the most continuous ones. To this end, the indices were ranked in ascending order of their variogram value at lag 1 year and those indices with a value of less than 0.6 were retained (Fig. 7). The MAFs were constructed after centring and normalising each of the 13 retained indices by its mean and standard deviation along the series. MAFs were calculated 600 times on the 600 realisations of indices and the median MAF was then estimated.

The first two MAFs had highest continuity (Tab. 5a). Table 5b gives the correlation of the univariate indices to the first two MAFs. By construction, the indices that are most continuous in time are also the most correlated to the multivariate structure of all indicators. The fist MAF is mainly determined by the abundance of mature fish in the survey and the length at 50% maturity, two non-spatial population indices and also by the latitudinal distribution of mature fish. The second MAF is mainly determined by the spatial indices microstructure index of the immature fish, the antagonism between anisotropy and positive area of the mature fish, and also by length at 50% maturity. For a multivariate monitoring approach, we select the first two MAFs and the six most continuous indices to represent the evolution in time of the population.

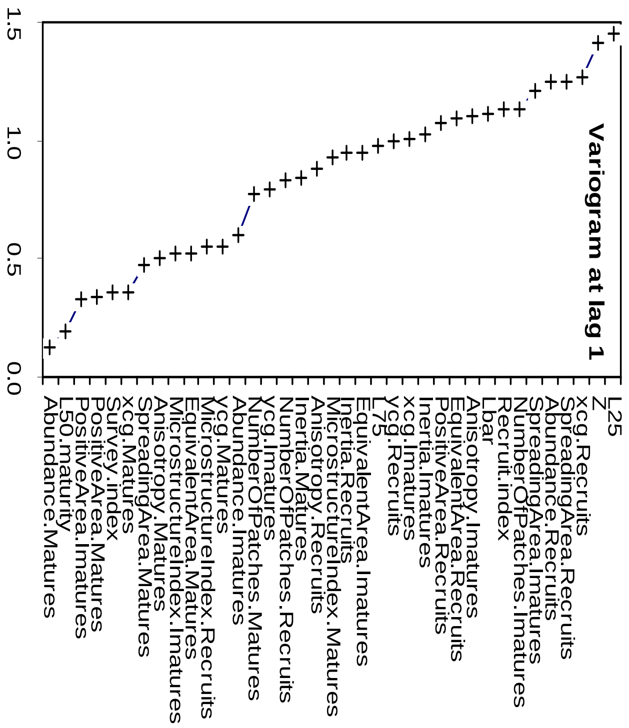


Fig. 7. Variogram at lag 1 of all 37 univariate indices.

Tab 5. a. Variogram values at lag 1 for the first five MAFs. b. Correlations of 13 most continuous population indices to first two MAFs.

a. MAF	**Variogram value at lag 1**
1	0.031
2	0.162
3	0.430
4	0.483
5	0.709

b.	**MAF loadings**	
	MAF1	MAF2
Abundance.Matures	**0.453**	0.270
L50.maturity	*0.371*	*-0.385*
MicrostructureIndex.Immatures	-0.060	**0.504**
Anisotropy.Matures	0.010	**0.493**
ycg.Matures	*-0.338*	0.074
PositiveArea.Matures	0.075	*-0.323*
EquivalentArea.Matures	0.026	0.204
MicrostructureIndex.Recruits	0.141	0.137
xcg.Matures	-0.172	0.056
Abundance.Immatures	0.087	-0.156
Survey.index	-0.082	0.149
SpreadingArea.Matures	-0.138	-0.088
PositiveArea.Immatures	0.006	-0.099

<u>Looking for changes</u>

1. Visual inspection. Plots of indices (raw & combined)

Plots of non-spatial univariate indices (Fig. 8) show a decrease of the survey index (total abundance, all ages) from the late 1990s onwards. A similar pattern is observed for the recruitment index (abundance of the age 2 group), but with a later start of the decrease: since the early 2000s. When the number of fish is split into mature and immature fish (the latter including the recruits at age 2), we notice that the decline in immature fish is largely similar to that of the survey index. However, the number of mature fishes started to decrease already in the third year of the time series (1987) by about 30%. This was followed by another reduction of about 30% around 1990. A final reduction in the number of mature Cod of about 50% occurred in 2001. Of the length indicators, only the length at 50% maturity shows a decrease: from the early 1990s onwards. During the first decade of the time series (reference period), total mortality (Z) was rather variable, and this variability decreased markedly during the second decade. The plot of the non-spatial multivariate index shows an increased variance towards higher values (i.e., larger distances from the gravity centre) with peaks in 1994, 1997, 1999 and after 2002.

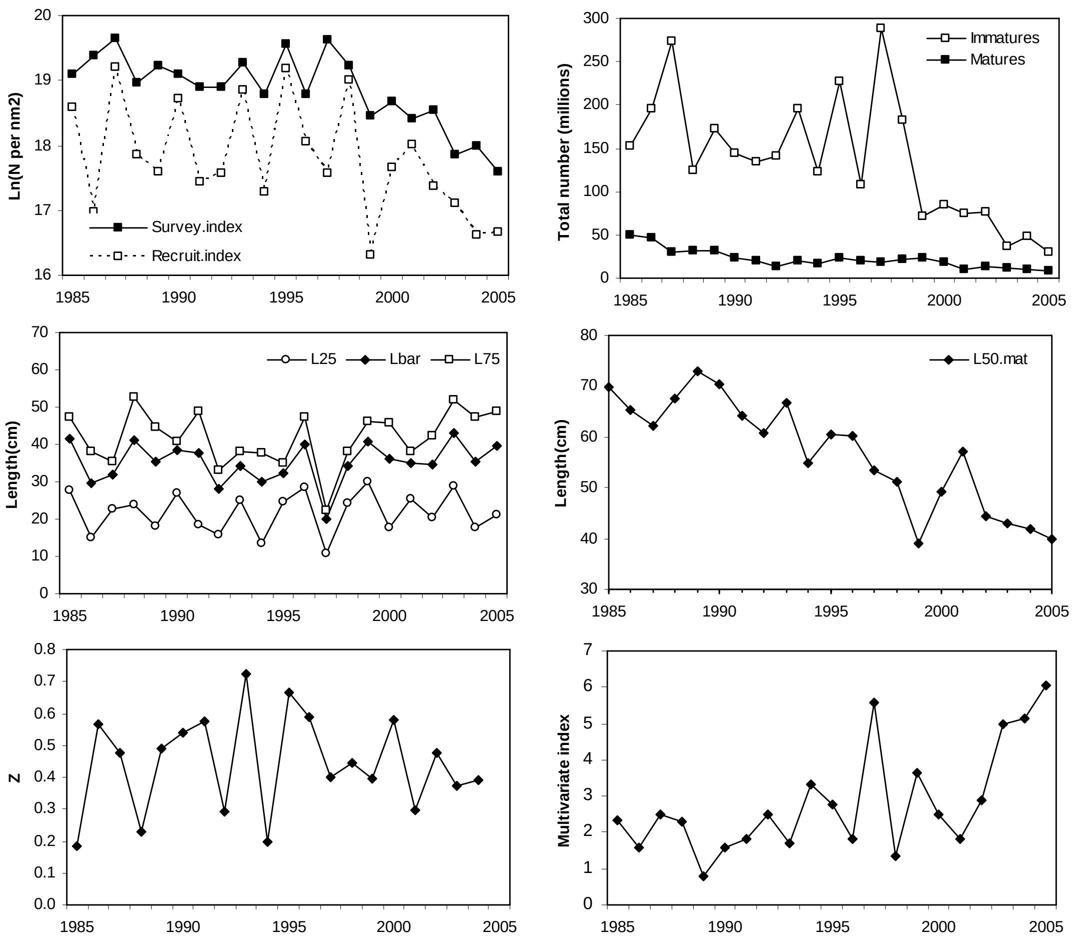


Fig. 8. Raw univariate non-spatial indices (survey and recruit index, total numbers, lengths indices and Z) and multivariate index (lower right)

Plots of the univariate spatial indices (Fig. 9) highlight that most occupation and location indices show a considerably inter-annual variation. The period of the variation of especially the younger age groups (recruits and immatures) is two to three years for ycg, anisotropy and positive area, whereas it is a regular four years for inertia. In both inertia and positive area, the regular pattern disappears in the last decade of the time series. Ycg shows a positive trend, inertia and positive area of the recruits show a negative trend. Positive area has also a negative trend for both mature and mature fish, that is limited to the last decade of the time series. Temporal change is further apparent in the microstructure, that shows higher values in the first three years, after which it remains at a lower level, except in 1989 for recruits and in 1997-1998 for immature and mature fish. The plot of the multivariate spatial index shows an overall increase in time, with isolated high values in 1990, 1992 and 1995, and after 2000.

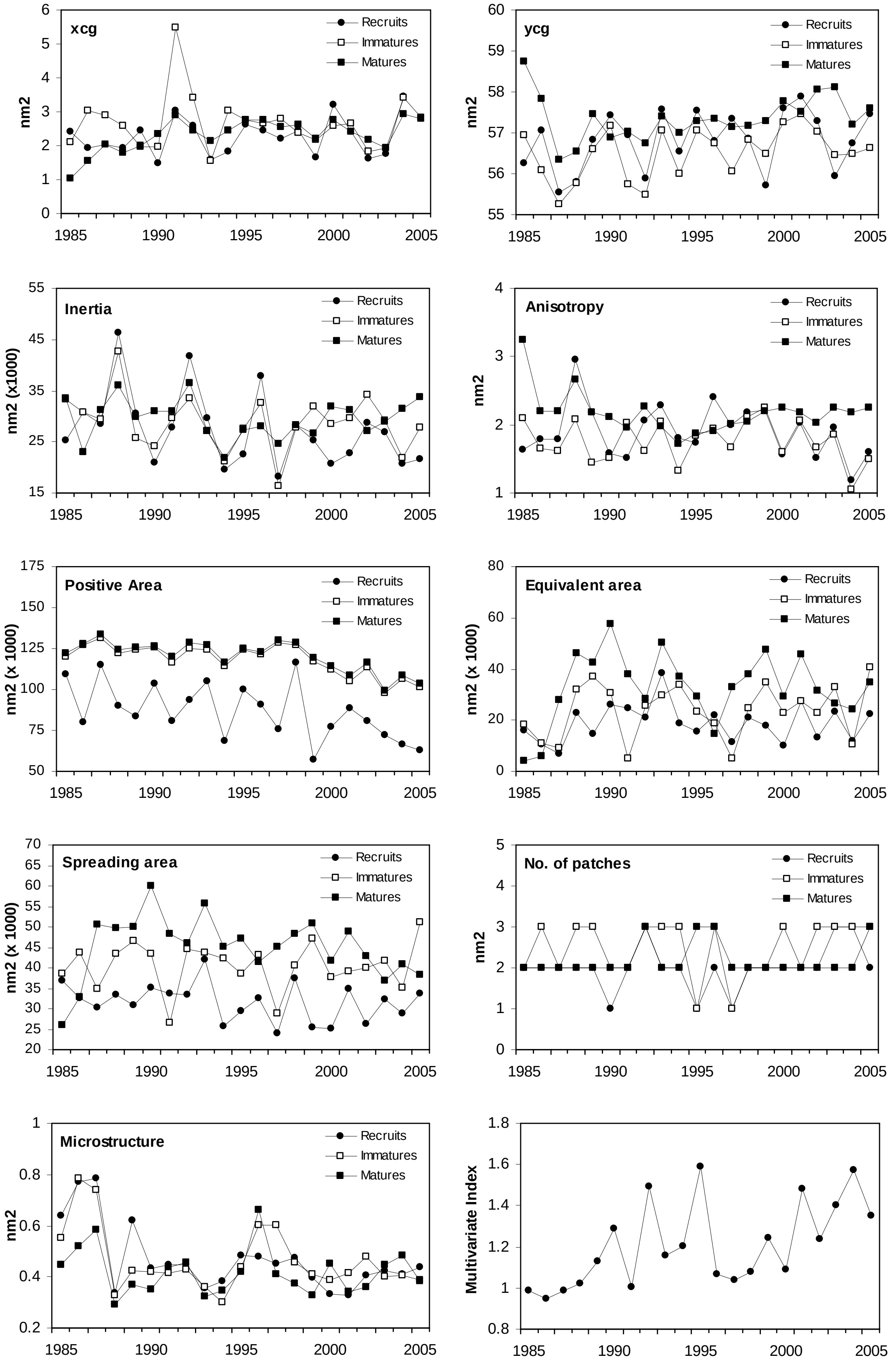


Fig. 9. Raw spatial indices for three age groups separately (recruits = age 2, immature (including age 2) and mature fish) and multivariate spatial index (bottom right) for all ages combined.

The changes occurring in the time series of MAFs 1 and 2 can be described by three phases of 5, 10 and 5 years, respectively. MAF1 shows a decrease in the first phase, followed by a phase of relative stability, and again a decrease in the third phase. MAF2 shows an increase in the first phase, a change from increase to decrease in the second phase, and a further decrease in the third phase (Fig. 10).

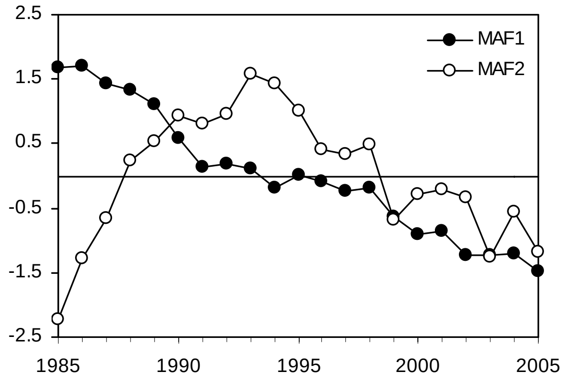


Fig. 10. Time series of MAFs 1 and 2: the two most continuous factors based on the 13 most continuous univariate indices.

3. Trend analysis of indices

Trend analysis results (Tab. 6) of non-spatial indices are based on linear and non-linear methods (derivative on a GAM smoothed series), the former applied to both all years and recent years (1996-2005), the latter only for recent years. The period for detecting recent changes was based on the last ten years. All non-spatial population indices generated significant trends or changes. The recruitment index, the survey index and length at 50% maturity showed negative linear trends during the whole period and the latter two also over the last ten years. Survey index and length at 50% maturity did not show any changes in the last ten years. Changes did occur during the last ten years of the recruitment index and all other non-spatial indices: the length indices (L25, Lbar, L75) had a positive change, whereas recruitment index and total mortality Z changed negatively (Fig. 11).

Univariate spatial indices were analysed for linear trends during all years of the time series and during the last ten years. In addition, the occurrence of changes in the recent years (1996-2005) was analysed using linear and non-linear (derivative) methods (see above). Results are reported in Tab. 6 and Fig. 12. Positive area showed a significant linear decrease during both the whole period and the last decade for all age groups. The positive area of recruits and mature fish also showed a significant negative change during the last decade. For recruits, negative trends over the whole or in the recent period occurred also in inertia, anisotropy, equivalent area and microstructure. In addition, equivalent area of recruits showed a recent change. For immatures, xcg showed a long-term negative trend and recent change, whereas microstructure decreased and spreading area changed in the recent period. In mature fish, in contrast to the negative trends in positive area, positive trends were observed in xcg (whole period), inertia and anisotropy (recent period).

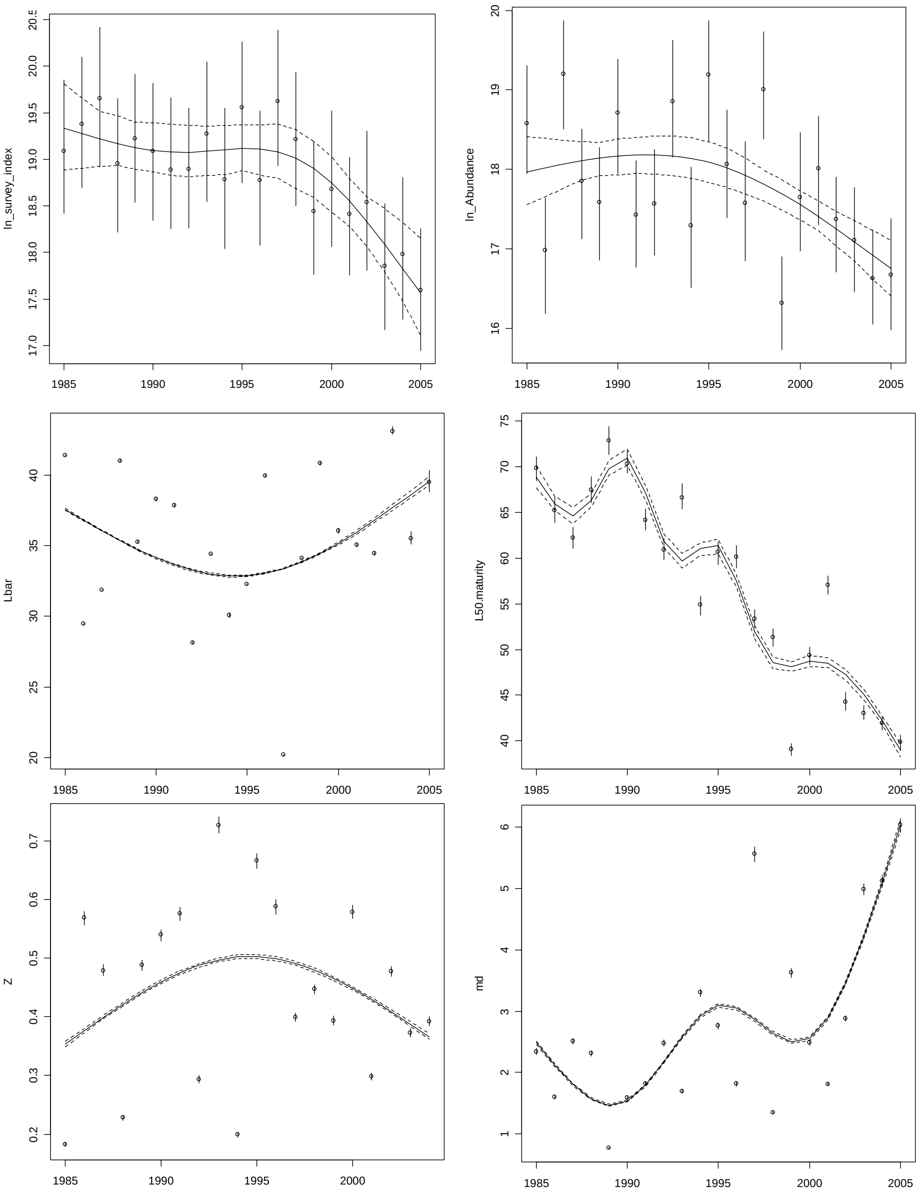


Fig. 11. Plots of the trend analysis using derivative method for non-spatial population indices.

Tab. 6. Trends diagnostic table: 1/-1 indicates linear trend,1* indicates recent change

Non-spatial indices	**all**	**recent**				
Ln_Survey.index	-1	-1				
Ln_Recruit.index (Age2)	-1	-1				
Ln_Abundance Immatures	-1	-1				
Ln_Abundance Matures	-1	-1				
L25	0	1*				
Lbar	0	1*				
L75	0	1*				
L50.maturity	-1	-1				
Z	0	-1*				
md	1	0				
	Recruits (Age 2)		**Immatures**		**Matures**	
Spatial indices	**all**	**recent**	**all**	**recent**	**all**	**recent**
xcg	0	0	-1	0*	1	0
ycg	0	0	0	0	0	0
Inertia	-1	0	0	0	0	1
Anisotropy	0	-1	0	0	0	1
Positive area	-1	-1*	-1	-1	-1	-1*
Equivalent area	0	-1*	0	0	0	0
Spreading area	0	0	0	0*	0	0
Microstructure	-1	0	0	-1	0	0
No. of patches	0	0	n.a.	n.a.	n.a.	n.a.
dmul (all ages)	1	1				

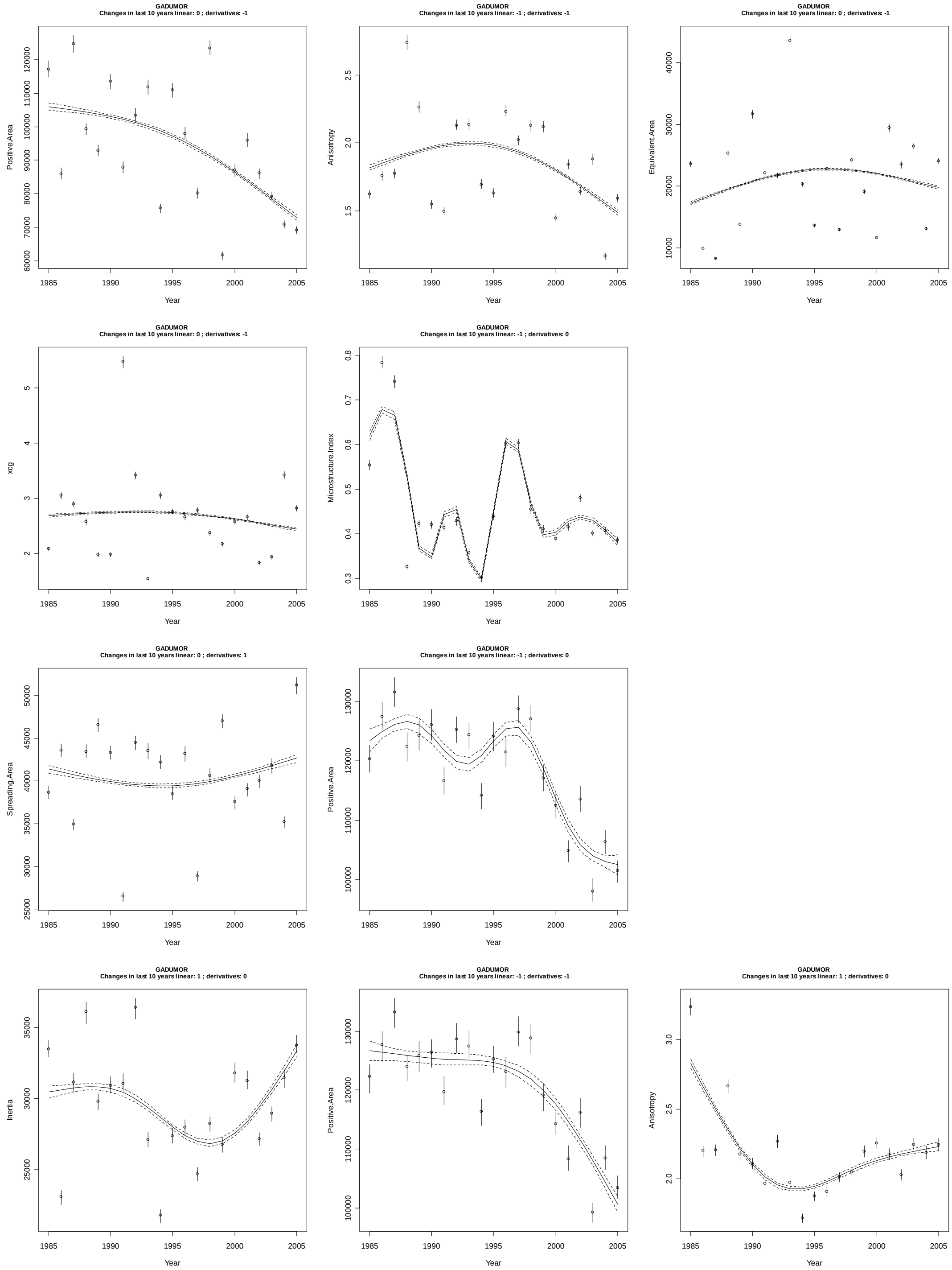


Fig. 12. Plots of the trend analysis using derivative method for selected spatial population indices.

4. Di-cusum plots of selected indices

Di-cusum analysis was performed for the non-spatial univariate and multivariate population indices and for the spatial multivariate index. The reference period for all the di-cusum analysed indices was 1985-1994. We accommodated h and k parameters in order to reduce the possibility of false alarm, but this may have resulted in a reduced sensitivity of the estimates. In Tab. 7 the di-cusum parameters of the analysed indices are reported. Results of di-cusum analysis for non-spatial indices are shown in Fig. 13, and those for the multivariate spatial index in Fig. 14. Diagnostics of the population based on the di-cusum analysis are given in Tab. 8a and b.

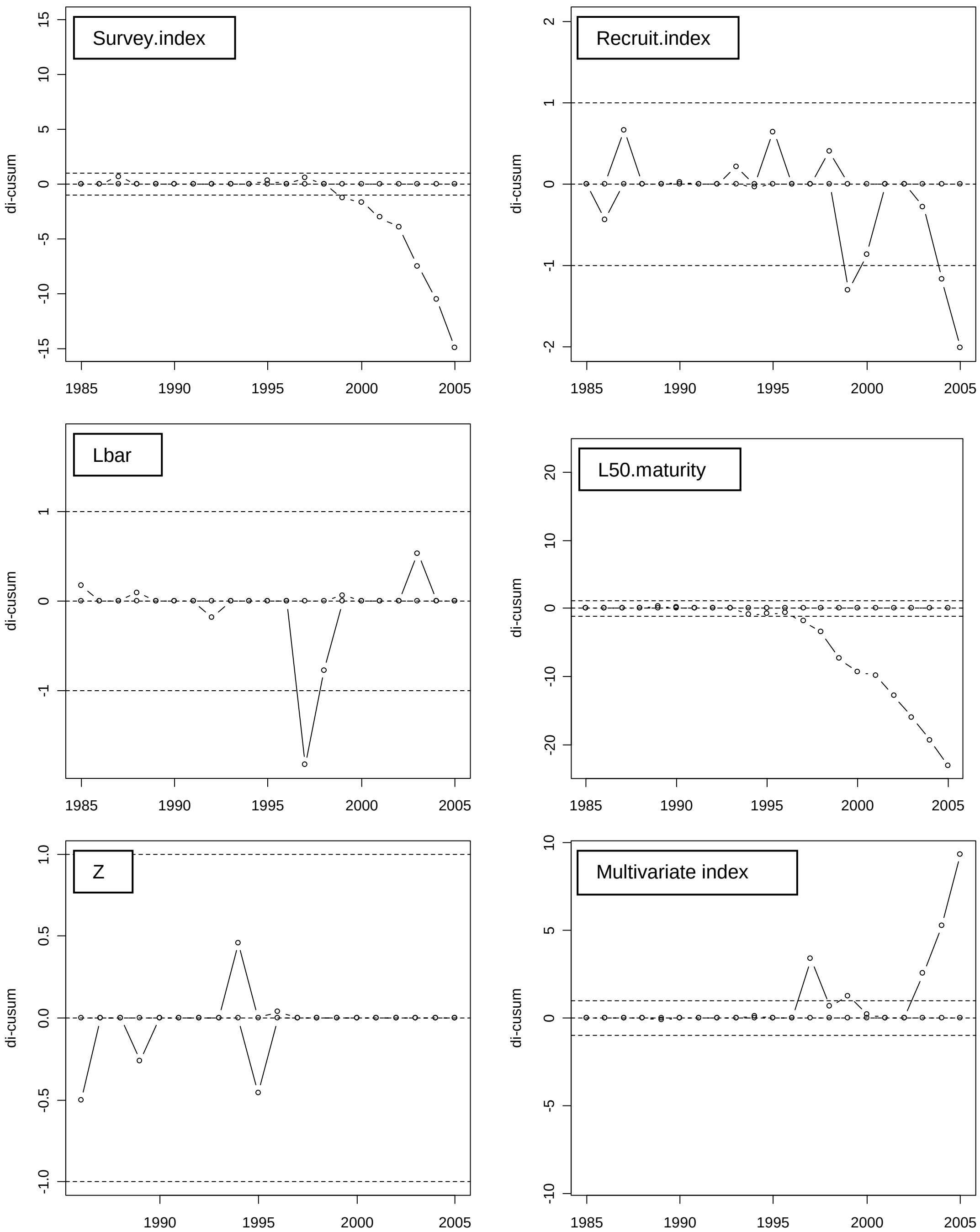


Fig. 13. Di-cusum plots of non spatial univariate indices and multivariate index (lower right).

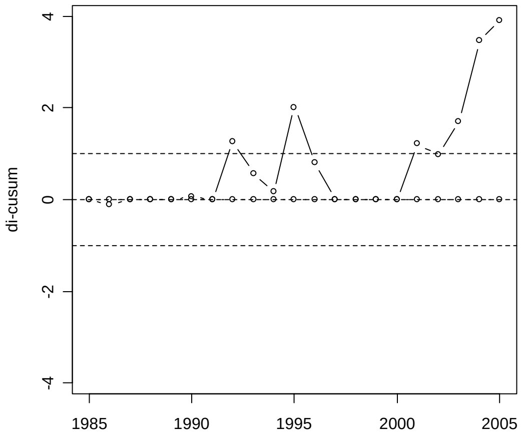


Fig. 14. Di-cusum plot of multivariate spatial index for all ages together.

Tab. 7. Di-cusum parameters

	Parameters						
	ref.period	m in ref.period	sd in ref.period	k	h	ARL In Control	ARL Out Control
Ln_Tot Abun	1985-1994	19.1	0.3	1.3	1.0	79.3	1.5
Ln_ Recruits	1985-1994	18.0	0.8	0.9	1.0	27.5	1.9
Lbar	1985-1994	34.8	4.8	1.2	1.0	60.0	1.6
L25	1985-1994	20.7	5.2	0.9	1.0	27.5	1.9
L75	1985-1994	41.7	6.4	0.8	1.2	30.0	2.3
L50.mat	1985-1994	65.4	5.2	1.1	1.1	56.2	1.8
Z	1986-1994	1.1	0.4	1.0	1.0	35.3	1.8
***md**	1985-1994	2.0	0.7	1.7	1.0	263.1	1.3
***dmul**	1985-1994	1.3	0.2	0.9	1.2	39.2	2.1

A triggering alert signal was obtained for all length indices in 1997. Length at 50% maturity continued to signal with increasing strength in the subsequent years, whereas the other length indices returned to within reference limits. In 1999, additional alert signals appeared for recruitment and survey indices. While the recruitment index returned to within reference limits in the subsequent years, the total abundance of the fish caught in the survey continued to trigger an alert signal with increasing strength. The recruitment index triggered an alert again in 2004 and 2005. A positive signal was obtained in 2005 from the L75 length index.

Tab. 8a. Di-cusum diagnostic table for univariate non-spatial indices.

Years	Tot Abun	Recruits	Lbar	L25	L75	L50.mat	Z	alert
1985	0	0	0	0	0	0		ref
1986	0	0	0	0	0	0	0	ref
1987	0	0	0	0	0	0	0	ref
1988	0	0	0	0	0	0	0	ref
1989	0	0	0	0	0	0	0	ref
1990	0	0	0	0	0	0	0	ref
1991	0	0	0	0	0	0	0	ref
1992	0	0	0	0	0	0	0	ref
1993	0	0	0	0	0	0	0	ref
1994	0	0	0	0	0	0	0	ref
1995	0	0	0	0	0	0	0	
1996	0	0	0	0	0	0	0	
1997	0	0	-1.84	-1.03	-2.21	-1.85	0	alert
1998	0	0	0	0	-2.00	-3.44	0	alert
1999	-1.27	-1.30	0	0	0	-7.36	0	alarm
2000	-1.65	0	0	0	0	-9.34	0	alarm
2001	-3.04	0	0	0	0	-9.84	0	alarm
2002	-3.96	0	0	0	0	-12.78	0	alarm
2003	-7.48	0	0	0	0	-15.95	0	alarm
2004	-10.50	-1.18	0	0	0	-19.33	0	alarm
2005	-14.97	-2.02	0	0	1.23	-23.10	0	alarm

Tab. 8b. Di-cusum diagnostic table for multivariate non-spatial and spatial indices.

Years	non-spatial	spatial	alert
1985	0	0	ref
1986	0	0	ref
1987	0	0	ref
1988	0	0	ref
1989	0	0	ref
1990	0	0	ref
1991	0	0	ref
1992	0	(+)0	ref
1993	0	0	ref
1994	0	0	ref
1995	0	1.40	alert
1996	0	0	
1997	3.38	0	alert
1998	0	0	
1999	1.26	0	alert
2000	0	1.77	alert
2001	0	2.66	alert
2002	0	2.00	alert
2003	2.53	1.69	alarm
2004	5.28	2.42	alarm
2005	9.34	2.85	alarm

Comparison of approaches (principal components/trends/di-cusum)

To compare the results of the various analyses, they were collated in Table 9. The first three columns list for each index whether it contributed to the principal components. PCA was applied to non-spatial indices only, MFA was applied to age-group specific spatial indices only, and MAF to all indices. The 'recent trend' and 'recent change' columns list the results of the derivatives analysis, that was applied to all indices. The last column list the results for the di-cusum analysis, that was applied to non-spatial indices and multivariate indices. All non-spatial indices except the recruit.index contributed to the principal components, and all indices showed a trend in the last 11 years of the study (1995-2005).The MAF- and di-cusum methods were more selective, because they took into account continuity and (low) variance, respectively, of the indices. The abundance indices survey.index triggered a di-cusum alert and abundance.matures was a major contributor to the first MAF. The length at 50% maturity did both.

The selectivity of the methods applied to the spatial indices was intermediate: four or five out of the eight spatial indices contributed to a principal component (MFA or MAF) or showed a recent trend or change, but the selection varied with type of analysis. Positive area signalled in all analyses, and anisotropy and ycg (mainly of the mature fish) contributed to the principal components of both MFA and MAF. The results of the other spatial indices were less consistent.

Both non-spatial and spatial multivariate indices triggered an alarm in the di-cusum method, but only the spatial multivariate index also showed a recent trend.

Tab. 9. Comparison of analytical results of all indices.

Index	PCA[1]	MFA[1]	MAF[1]	Recent trend	Recent change	Cusum[2]
Survey.index	2			1		1
Recruits.index				1		
Abundance.Immatures	--			1		
Abundance.Matures	--		1	1		
L25	1			1	1	
Lbar	1			1	1	
L75	2			1	1	
L50.maturity	1		1,2	1		1
Z	3			1	1	
non-spatial multivariate	--		--			1
xcg		1			1 (immatures)	--
ycg		2	1 (matures)			--
inertia				1 (matures)		--
anisotropy		2	2 (matures)	1 (recruits, matures)		--
positive.area		2	2 (matures)	1 (all)	1 (recruits, matures)	--
equivalent.area				1 (recruits)	1 (recruits)	--
spreading.area		1			1 (immatures)	--
microstructure.index			2 (immatures)	1 (immatures)		--
spatial multivariate		--	--	1		1

[1] Number indicates principal component (1, 2, or 3) to which index contributes importantly
[2] Occurrence of a significant trend or change is indicated by 1
[3] A ‘1’ indicates that the index yielded a warning signal (alarm)
-- Not included in analysis

Interpretation

It has long been know that the stock of Cod in the North Sea area is in decline. The annual stock assessment carried out by ICES dates back to at least 1963 and shows a temporary increase of the stock in the 1960s, followed by a decline that was initially variable and almost steady after 1982, except for an apparent short-term recovery of the stock around 1995 (Fig. 15). The data used in this study cover the period from 1985 to 2005. The data start when the fishing mortality F(2-4) had been above Flim for already a decade, and the spawning stock (SSB) was on an almost continuous downward slope, already below the precautionary level (Bpa) and sinking below the save limit (SSBlim) in 1999. Based on SSB, the years 1990 to 1996 represent a period of relative stability, when the downward trend comes to a temporary standstill and even a slight increase. For part of our analysis (derivatives method and di-cusum), we used the first decade of our data (1985-1994) as the reference period, based on the relative stability of the survey abundance data during the first 10-15 years of our study period (see Fig. 9). To reduce subjectivity of the selection of start and end dates of the reference period, it was limited to ten years. It is obvious from the ICES data that this reference period does not represent a period when the stock was in a relatively stable state. Rather the contrary: the stock was in decline. Thus, when this study observes changes, they indicate either an higher or a lower rate of decline.

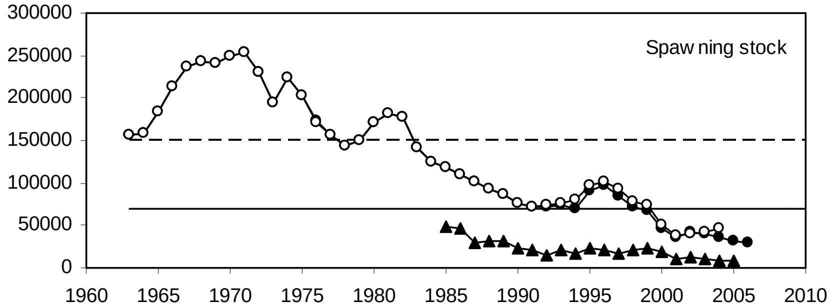


Fig. 15. Spawning stock biomass (tonnes) from ICES stock assessments 2004 (open circles) and 2007 (closed circles) and abundance of mature fish (thousands, closed triangles) from this study.

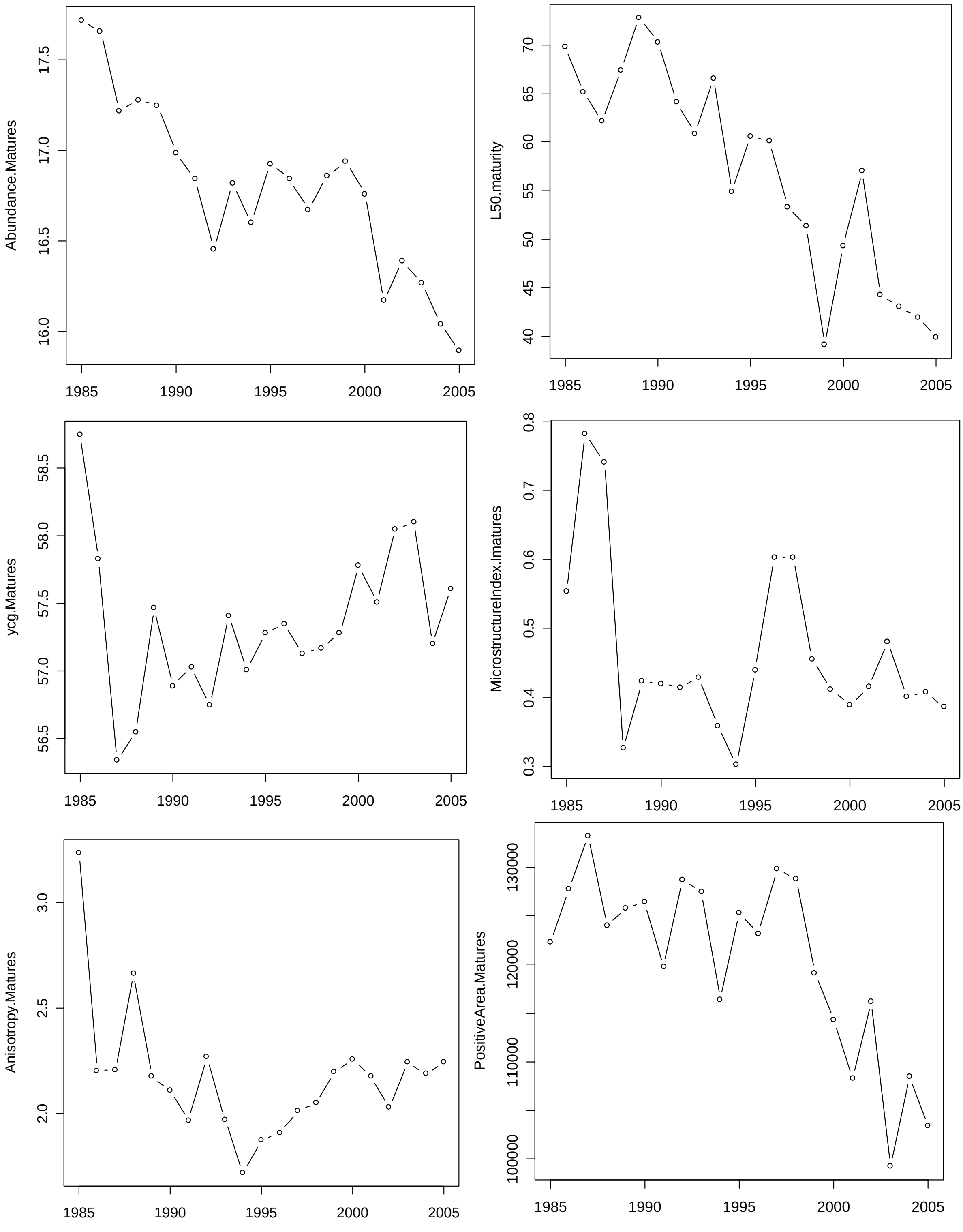


Figure 16. Time series of six selected univariate indices.

The reduction in positive area predates the final observed decline in abundance of mature fish that occurred after 2000. Unfortunately, the time series do not date back long enough to examine whether the decline in abundance of mature fish after 1986 was also predated by a reduction in positive area. The high anisotropy of the mature fish in the first years of the study may be related to their more southerly extended distribution in the same years. This confirms the observations of ICES scientists that there has been a northerly shift in the mean latitudinal distribution of the stock. They argue that cod in the North Sea are composed of a complex of more or less isolated sub-stocks and that the southern units, i.e. in the German Bight, have been subjected to disproportionately high rates of fishing mortality (ICES, 2007). A similar shift in distribution occurred in northern cod, that was thought to have resulted from a combination of abiotic (climate) and biotic environmental changes and cumulative long-term fisheries effects on cod behavior (Rose et al. 2000).

The decline in length at 50% maturity is a well-known effect of (high) fishing pressure, that is also observed in other species (e.g. Grift et al. 2003, Ernande & Dieckmann 2004, Hutchings 2005, De Roos et al. 2006), rift 2003?, Kraak et al?, Olsen et al. 2005, Andersen et al. 2007). However, it is striking that this negative trend still continues. In combination with the reduced numbers of mature cod, the small length at maturity adds to the impaired reproductive capacity of the stock. The di-cusum analysis reveals that the out-of-range values started in 1997, but this is strongly dependent on the reference period chosen. A shorter or reference period, e.g. 1985-1990, may yield earlier out-of-range values for this index. Again, unfortunately, the time series do not date back long enough to assess when this index really started to decrease. De Roos et al. (2006) and Swain et al. (2007) show that exploitation of late-maturing populations – like the cod – can induce an irreversible evolutionary regime shift to smaller maturation sizes associated with stepwise, 1-year decreases in age at first reproduction. De Roos et al. (2007) further state that belated or partial closure of fisheries may accelerate or even instigate further evolution to smaller sizes at maturation. They thus give scientific support to the suggestion that decreases in maturation (size or) age can be used as an early warning of upcoming evolutionary changes, and should inspire timely restrictions of fisheries.

What have you learned ?

The multivariate approach is useful for deriving synthetic indices from many factors (PCA and MFA) and for identifying the most influencing factors in a complex framework including many correlated indicators (MAF). In this case study of Cod in the North Sea, the multivariate indices do not take preference over selected univariate indices. To select indices, the MAF-analysis proved very useful. It helps to identifying the most influencing factors in a complex framework comprising many correlated indices, of which many show more or less conspicuous trends or changes. This applies especially to the selection of spatial indices for Cod in the North Sea.

To evaluate time series of univariate or multivariate indices, the trend analysis using the linear approach was useful for detecting tendency in the whole time series. The non-linear approach using derivatives may be helpful in identifying in which part of the analysed time series trends or changes occurred. For the Cod in the North Sea, with so many factors changing in a population that started to decline well before the currently analysed time-series, one would need to play with timing of the 'recent' period to explore to early warning potential of this method. The di-cusum analysis has the advantage over the trend analysis of triggering alert signals, based on out-of-range signals, for specific years relative to the variation observed in reference years. However, the tuning of the chart parameters is not straightforward and thus liable to producing different results dependent on the choices made. In principle, this method allows annual evaluation of the situation, provided a reliable reference period and resulting reference values have been established. This is a key factor in the analysis of the current status of a population.

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Summary sheet

The survey time series is based on the International Bottom Trawl Survey data from 1985 to 2005. The IBTS is coordinated by ICES. The surveys at sea were conducted in February and August/September, but only the data from the February surveys were used. The individuals caught in the survey were classified into six age groups, the last age groups comprising ages six and older. Individuals at age 1 are recruits (born in the previous summer). However, in the analyses performed, individuals of age 2 were considered as recruits, because

Non-spatial indices
Abundance index, recruitment index, Lbar, L75, L25, L50.maturity and Z by year have been analysed using linear regression and derivative methods. Linear and non-linear (derivative) methods were applied to detect long-term trends and recent (last 10 years) trends and changes in the indices, respectively. The linear method yielded significant (p=0.05) and negative recent trends for abundance and length indices and Z, and significant and positive recent trends for the length indices. The non-linear method indicates recent changes for the length indices except length at 50% maturity, and Z. The di-cusum method was applied to all indices and they all triggered an alert in one or more years. Length at 50% maturity and survey index triggered alerts of increasing strength (both indices decreasing) in successive years from 1997 and 1999 onwards, respectively.

Spatial indices
Positive Area, Spreading area, Equivalent area, Inertia, Anisotropy, Microstructure and Centre of Gravity (xcg, ycg) were analyzed by age or age groups (recruits, immatures and matures). Linear and non-linear (derivative) methods were applied to detect long-term trends and recent (last 10 years) trends and changes in the age-grouped indices, respectively. Most obvious were the long-term and recent negative trends in the occupation index positive area of all age groups, and recent changes in the same index for recruits and matures. For the recruits, also equivalent area and the location index anisotropy had negative recent trends, and the former showed a recent change. For the immatures, also microstructure index had a negative recent trend, whereas spreading area and the location index xcg showed a recent change. For the mature fish, also both the location indices inertia and anisotropy had positive recent trends.

Composite (derived) indices
PCA was applied for deriving non-spatial and spatial multivariate indices. The first component of the non-spatial PCA was positively correlated to Lbar, L25 and L50.maturity. The second component was negatively correlated with the survey index and positively correlated with L75, and the third component was positively correlated to Z. The di-cusum analysis applied to the multivariate index triggered alerts in 1997, 1999 and from 2003 onwards, the last one with increasing strength. In 1997, this was due to out-of-range values for all length indices, in 1999 to out-of-range values for L50.maturity, total abundance and abundance of recruits, and from 2003 onwards as a result of the increasing out-of-range values of L50.maturity and total abundance.

The PCA (MFA) analysis applied to the spatial indices revealed that all indices except anisotropy contributed to the first component, whereas the location indices anisotropy (positively), together with ycg (positively) and the occupation index positive area (negatively) contributed to the second component. The di-cusum analysis applied to the multivariate spatial indices resulted in alert signals in the years 1995 and 2000-2005. These out-of-range values most likely resulted from the shift to the north and the reduction in positive area, both observed in mature fish. Given that the German Bight used to be an important spawning area, this is the third factor (in addition to reduced abundance of mature fish and reduced length at maturity) contributing to reduced productive capacity.

Reference period
The first decade of the time series (1985-1994) was chosen as the reference period, because the total numbers in the survey were relatively stable during that time and a few years afterwards and we wanted to limit the reference period to a maximum length of ten years.

Summary of results on the stock
Two indices show a continuous decline, the non-spatial factor length at 50% maturity and the spatial factor ycg, representing a shift to the north of the mature fish, the latter except in the first two years of the study. Abundance of the mature fish represents the decline in three phases (decline, relative stability and decline, respectively) that are retained in the first MAF, which is strengthened in the first years by the decline in nugget effect (microstructure) of the immature fish and a reduction in the unequal distribution of the mature fish around their centre of gravity (anisotropy). The reduction in positive area of the mature fish strengthens the decline in the second decade of the study period.

Comparison with traditional assessment of stock status

Assessment of cod in the North Sea is done annually by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (e.g. ICES 2007). Evaluation of the status of the stock is based on a precautionary approach with set levels of precautionary (pa) and conservation (lim) limits for the spawning stock and the fishery mortality (SSBpa, SSBlim, Fpa and Flim, respectively). The assessment of the stock is currently done by applying an age-based assessment model (B-ADAPT), that uses landings and discards, and that is calibrated with two survey indices (from the IBTS quarter 1 and quarter 3 surveys). The stock is diagnosed as overexploited with F above the target, at risk of being harvested unsustainably and of reduced reproductive capacity (ICES 2007).

A major problem with the VPA-based assessments as done by ICES WGs, is the incomplete information about recent years. When one compares estimates of SSB of North Sea cod from earlier years with the most recent assessment (in which information about those earlier years is complete) a striking pattern emerges: almost always is the assessment of the stock in the last year of the series higher than the assessment for the same year made in a later year (with complete information). This may be a characteristic of assessments of stocks in decline only. The result will be that suggested management actions are insufficient, because they assume a better status of the stock than the 'true' status assessed in later years.

The indices calculated in this study do not change over time with new information gathered. Although they do show annual variation (and more so than the VPA-assessed factors), they do not have the inherent (false-) positive value for the most recent year. It is therefore interesting to examine the behaviour of the multivariate and selected univariate indicators during the decade 1991-2000, when the stock, F and catches appeared relatively stable. Both the non-spatial and spatial multivariate indicators showed increased variation towards higher values during this period, the spatial dmul in the early 1990s, the non-spatial dmul in the late 1990s (Figs. 8 and 9). The first component of the MAF is more or less constant, but the second MAF shows a strong change from increase to decrease in the middle of this period (Fig. 10). Of the six selected univariate indicators, only L50.maturity expresses a trend (negative) during this period of apparent stability of the stock. Indeed, this indicator triggers an – annual! – alarm in the di-cusum method, even though the selection of the reference period is inappropriate given the known history and status of the stock. This may have alarmed both biologists and managers a few years earlier than 2000 (first advice for 2001 of lowest possible or zero catch).

Simulation Evaluation with FLR

Herring North Sea

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1. Introduction

Herring (*Clupea harengus*) is one the most important commercial species taken in the North East Atlantic. While the fishery dates back at least to the middle ages, it expanded in the 19th century to respond to the need of industrialised cities. During the 20th century, the rapid development of the industrial fishing of herring led to a collapse in the 1970s (Figure 1), with recovery made more difficult by juvenile bycatch by the sprat industry.

Following the two severe declines (up to 1977 and up to 1997), the North Sea herring became the first stock in the North Sea managed through the implementation of the precautionary approach. ICES classifies the stock *as "being at risk of having reduced reproductive capacity and at risk of being harvested unsustainably".* The lower biomass reference point (B_{lim}), below which there is an aggravated risk of low recruitment, is set at 800 000 tonnes and triggers an emergency plan until the upper reference point – B_{pa}, set at 1 300 000 tonnes – is reached (Appendix 1).

Current fisheries assessment methods and management are mainly based on fisheries landings (catches) and models of population demography (cohort analysis). But such data may not exist (area closure), be difficult to access (if landing points are scattered) or their reliability might be questionable (miss-reporting or non-accounted discards). Collapse of important fish stocks in the past have revealed that fisheries based demographic indices suffer from a number of limitations. Probably the most serious limitation is that the indication of population collapse is only perceived very late with such indices. Furthermore, fishery dependent data can be particularly biased due to black-landings, by-catch, ageing error process or misreporting. The use of fishery independent data could potentially improve the quality of the advice in fishery management as it eliminates important sources of bias from fishery dependent data.

2. The simulation evaluation loop

The simulation evaluation platform developed in this work is made up of four model components: an operating model, an observation error model, an assessment model and a harvest control rules model which are going to be developed in the four following sections.

2.1.Parameterisation of the operating model

The operating model implemented is a population dynamics model and more specifically an "age-structured production model" (McAllister, Pikitch et al. 1994; Punt, Smith et al. 2002) and has been developed in the FISBOAT Manual on simulation evaluation tools.

The biological operating model includes several components. The population is structured into 10 age groups (0 to 9+, 9+ being an age plus group). Also, the model is single stock and single area, following Fisboat project guidelines. The natural mortality rate at age is based on existing ICES Working Group estimates derived from North Sea MSVPA (Pope 1991), decreases with age and is constant over years. Finally, the fraction mature at age is variable over time. Between 1960 and 1971 (last year before the first survey), the maturity at age was equal to zero for ages 0 and 1 and equal to 1 for all other ages. In 1972, the first MLAI larval SSB survey made a change in the quality of data. From 1972, precision of maturity-at-age values has been improved and an average maturity curve (1972-2006) can been seen on Figure 2.

While North Sea herring data contain all the relevant biological information, the biological operating model has to be seeded. It requires selectivity information to run, and to do this, the fishing mortality information from this dataset is used to estimate a logistic selectivity ogive. As the selectivity values are the same for the last 5 years, only the final year’s data are used to fit the logistic selectivity curve (Figure 3).

The next stage in parameterising the operating model is to select a suitable stock-recruit relationship. To do this, a Beverton Holt, a Ricker and a hockey stick (also called segmented regression) model are fitted individually to the stock-recruit data using a maximum likelihood estimation method. For all stock recruit functions, the Akaike Information Criterion (AIC) was calculated. The model which minimises this AIC value is the best statistical fit to the data. AIC for Beverton Holt, Ricker and Hockey stick stock recruit functions are equal to 94.87, 79.03 and 76.22

respectively. The third value is the smallest AIC, suggesting that the Hockey stick model is the best model fit to these data, but not by very much compared with the Ricker's one. To test the robustness of the models, we are using both the segmented regression and the Ricker stock-recruit functions (Figure 4 and Figure 5).

Recruitment occurs when herrings are aged 0 and there is evidence of autocorrelation in the recruit values which is reduced but not removed by fitting the stock recruit relationship. For the purposes of the simulations the autocorrelation in the recruitment was estimated and used directly or as double the value. The use of a doubled autocorrelation in recruitment is interesting to examine the robustness of management in cases such as important decline in the recruitment during several consecutive years.

The maximum initial fishing mortality F equates to a harvest rate H and this value and the selectivity ogive are used to set the initial exploitation regime. The initial recruitment value is always defined by the initial recruitment value set by ICA (Integrated Catch at Age, Patterson and Melvin 1996) values.

ICA results and ICES working group settings are used to define the past (1960-2006). It starts in 1960 as data provided by FRS Aberdeen begin in 1960. Those data contain stock numbers at age, fishing mortality and biological information required by the operating model. The population dynamics model starts in 1960 and runs to 2006.

2.2. Observation error (description of surveys)

The aim of the observation error model is to describe how observations are sampled from the operating model and it simulates the data utilised in the assessment model.

The observation error model simulates an acoustic survey between 1989 and 2006. It is based on an age aggregated or age non-aggregated relative abundance index:

$$I_{a,y} = q_a N_{a,y} b_y e_{a,y} \tag{1}$$

The relative abundance indices considered are age-aggregated or age non-aggregated depending on which harvest control rule is applied in the simulation evaluation platform. It will be age non-aggregated for the harvest control rules based on Z (total mortality rate equal to fishing mortality rate added to natural mortality rate) (displayed further down) as the calculation of the TAC distinguishes two age groups: 0-1 year old and 2-6 years old.

In this work, we assume that bias in surveys is equal to 1 which means that there is no bias since we do not have any estimate of potential bias in the survey indices at present.
The error term considered in this work incorporates ageing error variability. A sigma variance-covariance error matrix has been provided by FRS Aberdeen as a result of the ICES Study Group on methodology for the assessment of North Sea herring SGEHAP (ICES 2001) and the EU EVARES project. The age is the covariate used in the simulation error model. The method used to incorporate the ageing error process was developed in SGEHAP.

2.3. Assessment methods

Assessment methods translate catch and survey data to stock numbers and mortalities in the past. In the frame of the FISBOAT project, a year-catch-curve (YCC) assessment method has been implemented (Cotter et *al*. 2004). To run the assessment, outputs of the operating model and the observation error model are needed.
As the ageing of fish is not a perfect science, an ageing error process has been included in the calculation of catch-at-age data that are used in the assessment. This ageing error process Catch-at-age data are in the form of proportions so it can be assumed that if a logit transformation is applied to these proportion data then the residuals around these data can be assumed to be normally distributed:

$$\log it(prop) = \ln\left(\frac{prop}{1-prop}\right) \qquad (2)$$

This normality in the logit-residuals allows the introduction of an ageing error process into the system.

2.4. Harvest control rules

A relatively simple harvest control rule model has been implemented that incorporates already existing harvest control rules (Bell, Stefansson et al. 1998 Cooke, 1999; Stefánsson 1998) and has been developed in the FISBOAT Manual on simulation evaluation tools.

Two types of HCRs are considered in this project: model-free and model-based. The first one is based directly on survey data and is relatively simple to understand and to simulate compared to model-based ones. The latter is based on the results of a stock assessment and provides a smoothing effect by fitting a model to data, which lowers variability when evaluating management controls. Four harvest control rules are implemented in this work.

The first model-free harvest control rule implemented in this work is based on observation index:

$$TAC_{y+1} = TAC_y \left(\frac{I_y}{I_{y-1}} \right) \tag{3}$$

The observation index is the output of the observation error model and the value of the TAC in the next year will depend on the TAC of the current year and the ratio of the observation index of the current year and the observation index of the previous year. If the ratio is larger than one this means there is an increase in the observation index which can be interpreted as an increase in the SSB of the stock so catches can be raised proportionally.

The second model-free harvest control rule implemented in this work is based on relative SSB trend from the acoustic survey data:

$$TAC_{y+1} = TAC_y \left(\frac{\overline{SSB}_y}{\overline{SSB}_{y-1}} \right) \tag{4}$$

Relative SSB trends are calculated for all years from the beginning of the simulated survey (1990 in this study) until the current year of the simulation:

$$\overline{SSB}_y = \sum_{a=1}^{9} \left(I_{a,y} m_{a,y} w_{a,y} e^{-Mspwan_y M_{a,y}} \left(1 - Hspawn_y H_{a,y} \right) \right) \tag{5}$$

The index used in the calculation is the output of the observation error model, the same as the one used in the first harvest control rule. Changes in the TAC of the subsequent year will be proportional to the ratio of the apparent relative SSB trend in the current year and the one of the preceding year.

The third harvest control rule is a model-based one. It is for this harvest control rule we need an age non-aggregated index as 2 age groups (0 to 1 and 2 to 6) are distinguished in the calculation of the TAC:

$$TAC_{y+1} = TAC_y * \min \left(\frac{Z_{[0,1]}^{PA}}{Z_{y-1,[0,1]}}, \frac{Z_{[2,6]}^{PA}}{Z_{y-1,[2,6]}} \right) \tag{6}$$

The variation of the TAC of next year will be inversely proportional to the changes in total mortality estimated along cohorts from the survey.
Values of the total mortality rate at age at precautionary level (Z_{PA}) for each age group derive from other parameter values defined by ICES. The total mortality rate, Z, corresponds to the sum of the natural mortality M and the fishing mortality F. For the group 0-1 year old, F_{PA}, defined by ICES, is

equal to 0.12 (Appendix 1) and M is estimated as 1 by ICES North Sea MSVPA (Pope 1991). The combination of both of them gives a value of 1.12 for $Z_{[0,1]}^{PA}$. For the group of ages 2 to 6, F_{PA} has been fixed at 0.25 by ICES experts and the natural mortality rate is equal to 0.3, 0.2 and 0.1 for ages 2, 3 and 4 and plus respectively. The mean of the natural mortality rate at age plus F_{PA} give a value of 0.4 for the $Z_{[2,6]}^{PA}$. For each year, both ratios are calculated and the minimum value is used to calculate the TAC for the following year.

The last harvest control rule implemented is model-based as it uses outputs of the YCC assessment.

$$TAC_{y+1} = TAC_y * \min\left(\frac{Z_{[0,1]}^{PA}}{Z_{y-1,[0,1]}^{YCC}}, \frac{Z_{[2,6]}^{PA}}{Z_{y-1,[2,6]}^{YCC}} \right) \tag{7}$$

It is quite similar to the previous one. The major difference is that the harvest rate is estimated by the assessment and not directly from the survey. It is again a harvest control rule that prioritises the precautionary approach as the variation in the TAC will depend on the smaller of the two ratios.

For all harvest control rules implemented, a potential bias in catches has been included in equations:

$$TAC = TAC * bc \tag{8}$$

A random increment between 0 and 5% has been decided upon based on reasonable guess. It corresponds to potential misreporting and/or error of implementation of the TAC by fishermen. Simulations have been run with and without this bias in catch data to see what is the impact of integrating such a bias in catch data on the SSB at the end of the projection.

2.5. Other (projection time, number of iterations…)

The models have been applied to a set of data for North Sea herring for the period 1960-2006 for ages 0 to 9+, 9 being an age plus-group. These data consist of:

- Catch at age (landings) in numbers.
- Catch (landings) in tonnes.
- Proportion mature at age.
- Proportion of fishing mortality (F) and natural mortality (M) at age before spawning.
- Natural mortality at age.
- Mean weight at age in catches.
- Mean weight at age in stock.

Data are collected from different sources. Fisheries Research Services (FRS Marine Laboratory, Aberdeen, UK) own a database for the North Sea herring which contains national catches of herring (catch at age and catch weight at age) and associated biological data but also data from acoustic surveys (in the form of survey index at age plus maturity at age and weight at age. The available data from surveys are:

- Acoustic survey index at age:
  - Values from 1989 to 2006 for ages 1 to 9.
  - No values for age 1 from 1989 to 1996.

Incomplete time series of catches of herring were filled in using data coming from the Herring Assessment Working Group reports (Kienzle 2003).

The stock has already crashed (a major crash occurred in the late 1970s and a minor one in the middle 1990s) and recovered twice in just over 40 years. Also, based on biological information, 10 years covers one generation of North Sea herring. Based on these observations, it is assumed that 10 years can be considered as a medium term simulation. In order to provide a reflexive material and a strong base for advice provision, the simulations will cover a twenty year period and thus encompass two generations. That will provide a relevant perspective of the evolution of the stock and the fishery at a realist time scale.

In order to have a large number of observations per year, a Monte Carlo iteration is included in the simulation of the observation index. The number of iterations has been fixed at 100.

The software used for this project is FLR (Fisheries Library in R). For further explanation about FLR, please refer to Kell et al. (2007).

3. Simulation strategies

In order to test our model, we have started by running deterministic simulations. The first one was without catch to check if the SSB would increase immediately. We then tested the simulation evaluation framework with constant TAC. It allows seeing if the actual TAC is not too high for the actual state of the stock. Our last test was to run our model without any error to test the performance of the HCRs.

After deterministic runs, stochasticity was included in the model in order to evaluate the performance of the HCRs. Performance criteria calculated are:

- probability SSB < Blim at least once in the projection.
- probability SSB < B_{PA} at least once in the projection.
- probability SSB < Blim in final year.
- probability SSB < B_{PA} in final year.
- CV in the TAC in final year.

Sensitivity was tested by changing the level of noise in the survey, including a potential under-reporting and using several stock-recruit functions.

All simulations are listed in Table 1.

4. Results

4.1. Deterministic runs

Simulations without catch and with constant TAC have been run for 50 years to make sure scenarios are stable over time. The ones without errors have been run for 20 years for the reasons explained above.

The simulation without catch has been run for 50 years to check the effect of the stock-recuit function on the SSB. It can be seen on the Figure 6 a very rapid increases of the SSB in the first 20 years to reach a plateau after 40 years. In 20 years, the SSB has been multiplied by circa 770% (1230.10^3 tonnes in 2006 vs. 9458.10^3 tonnes in 2026) and by circa 940% in 2056 (11584.10^3 tonnes). The recruitment reaches in the first years of the projection a plateau due to the stock-recruit relationship as the SSB increases very quickly. The mean of the recruitment between 2007 and 2056 is equal to 46903.10^3 herring.
For the same simulation but with a Ricker stock recruit function (Figure 7), the SSB increases quickly between 2007 and 2015 (4066.10^3 tonnes) and then decreases until 2024 (3449.10^3 tonnes) and then reaches a plateau with an averaged value of 3557.10^3 tonnes. The recruitment increases in 2007 and 2008 (27777.10^3 herring in 2006 and 41930.10^3 in 2008) to then decreases to 7926.10^3 in 2015. Within approximately 10 years, the recruitment reaches a plateau with an averaged value of 14490.10^3 herring.
With both stock-recruit functions, the fact of doubling the autocorrelation in the recruitment did not make an important difference.

The following test was to keep TAC constant over years and equal to the one in 2006 (512.10^3 tonnes). In all cases (both stock-recruit functions and both autocorrelation in recruitment), the SSB increased from the first year of the projection and either stabilises with a segmented regression stock-recruit function to a value of 5713.10^3 tonnes in 2056 (Figure 8) or decreases for a couple of years with a Ricker stock-recruit function to then reach a plateau with a value of 2194.10^3 tonnes in 2056.

The use of the acoustic survey without error has been tested with the three first harvest control rules (Figure 9, Figure 10, Figure 11 and Table 2). With the two HCRs based on SSB, the SSB increases in the first 10 years and then reaches a plateau (2554.10^3 tonnes for the first HCR and 2456.10^3 tonnes for the SSB trend based). The Z-based HCR shows a different shape in the projection. The SSB increases in the first 15 years until a value of 3761.10^3 tonnes in 2018 and then decreases to 2320.10^3 tonnes in 2026.

In terms of probability of being below reference values, with the two HCRs based on SSB, the probability of being below Blim at least once in the projection is null. It is smaller than 0.05 with the Z-based one. The probability of being below B_{PA} is more important with a Ricker stock-recruit function, independently to the HCR. The coefficient of variation (CV) in the TAC in the final year for the three HCRs is equal to 0.225, 0.218 and 0.279 respectively.

The change in the autocorrelation in the recruitment does not make any major difference.

4.2. Survey-based HCRs: SSB-based

For the acoustic survey, the error taken into consideration is an ageing error process. The sigma variance-covariance error matrix has been estimated in the frame of another project and is used in this simulation. Projections have been run over 20 years.

With both SSB-based HCRs, the SSB increases to reach a plateau in 2015 or 2016 (Figure 12, Figure 13). The average SSB is then 2609.10^3 tonnes and 2404.10^3 tonnes for the first and the second HCRs respectively, both values being well above the biomass at precautionary approach level (1300.10^3 tonnes). Over the 100 iterations, the probability of being below Blim at least once in the projection is null for both HCRs. It is equal to 1 for being below B_{PA} at least once but null in the final year (Table 2).

Catch for those two simulations decrease for the first two or three years and then increase and stabilise. For the first HCR, catch fell to 325.10^3 tonnes in 2008 and then stabilized at 758.10^3 tonnes. The CV in the TAC in the final year is equal to 0.264. For the second HCR, catch decrease to 378.10^3 tonnes in 2009 and then reach a plateau with an averaged value of 778.10^3 tonnes. The CV in the TAC in the final year is equal to 0.269.

The change in the autocorrelation in the recruitment did not make any difference in terms of probability of being below Blim or B_{PA}, either at least once in the projection or in final year. That neither made a difference in the final year in the CV in the TAC, the SSB or the catch.

The change of the stock-recruit function (Ricker instead of a segmented regression) induced a very small increase in the probability of being below reference points (e.g. 0.01 instead of 0). The CV in the TAC in final year has been slightly increased (0.264 vs. 0.269 and 0.269 vs. 0.271 for each HCR). Finally, the SSB in final year is smaller with a Ricker stock recruit function due to the nature of the function (2572.10^3 tonnes vs. 2037.10^3 tonnes and 2300.10^3 tonnes vs. 2019.10^3 tonnes). As the TAC is related to the SSB, values are smaller with the second stock-recruit function in final year (753.10^3 tonnes vs. 608.10^3 tonnes and 747.10^3 tonnes vs. 614.10^3 tonnes).

A random under-reporting varying between 0 and 5% has been included as a test. With both HCRs, the SSB increases between 2007 and 2015 (2154.10^3 tonnes and 2047.10^3 tonnes) and then decreases until the final year of the projection (1554.10^3 tonnes and 1496.10^3 tonnes) to reach values smaller than without the under-reporting (2572.10^3 tonnes vs. 1554.10^3 tonnes and 2300.10^3 tonnes vs. 1496.10^3 tonnes). Both final values are above the reference points but the probability of being below those values is not negligible (Table 2) and can reach 0.35 for the probability of being below B_{PA} in final year for the second HCR.
Catch are higher with under-reporting and the CV in the TAC in final year has increased.

4.3.Model-free HCR: Z-based

Like for the previous section, simulations have been run for 20 years with an ageing error process in the acoustic survey.
The SSB starts by decreasing in 2007 and then increases continuously until the final year of the projection (6845.10^3 tonnes) and tend to stabilize but that could only be confirmed by a projection of more than 20 years (Figure 14). The probability of being below Blim at least once in the projection is null and to be below B_{PA} in the final year as well (Table 2).
Catch decrease from 2007 until 2012 (217.10^3 tonnes) to then increase slowly until final year to reach a value of 355.10^3 tonnes, which is still smaller than the one in 2006. The coefficient of variation in the TAC in final year is quite high: 0.714

The change in the autocorrelation in the recruitment tends to increases the SSB in final year (6845.10^3 tonnes vs. 7007.10^3 tonnes) but to decreases the catch in final year (355.10^3 tonnes vs.

318.10^3 tonnes) and also the CV in TAC (0.714 vs. 0.661). Only the probability of being below Blim at least once in the 10 years of projection is different. It is equal to 0.02 when it was null when a segmented regression stock-recruit function was used.

Using a Ricker instead of a segmented regression as stock-recruit function shows important differences in the results, particularly in the final SSB. With the first SR, the final SSB is equal to 6845.10^3 tonnes and with the second one, equal to 2682.10^3 tonnes. The probability of being below Blim at least once is increased from 0 to 0.02 and the probability of being below B_{PA} in final year from 0 to 0.02 as well. Catch are also smaller with the second SR function but the ratio between the two SR functions is smaller than for the SSB (1.3 for the catch vs. 2.5 for the SSB). Contrary to previously, the CV in the TAC decreases when a Ricker SR function is used instead of a segmented regression one.

Again, a random potential under-reporting has been included. With this scenario, the final SSB is smaller than without the under-reporting while the catch is higher. The CV in the TAC is decreased and probabilities of being below reference points are still equal to zero.

4.4. Model-based HCR: YCC

The last model tested is the model-based using YCC as an assessment method.
For the 20 years of the projection, the SSB increases intensely to reach in 2026 an SSB of 9319.10^3 tonnes (Figure 15). The probability of being below Blim at least once in the projection is null.
Catch reduce drastically to end up at a level of 416 tonnes in 2026. The CV is similar to the one obtained with the first HCR using the observed index (Table 2).

The change in the autocorrelation in the recruitment tends to increase even more the final SSB to 9804.10^3 tonnes and catch are even smaller (409 tonnes). The coefficient of variation in the TAC is slightly larger.

As for the previous HCR, the fact of using a Ricker stock-recruit function makes important changes in the outputs and particularly in the SSB in the final year. With a segmented regression, the final SSB is equal to 9319.10^3 tonnes and with a Ricker one, 3484.10^3 tonnes in 2026. Like in most scenarios, probabilities of being below reference points are equal to 0. Differences between final TAC and CV in TAC are not unduly high between scenarios using the two stock-recruit functions.

Finally, a random under-reporting has been included in some scenarios. In terms of SSB, there are no noticeable changes but the catch in final year is largely improved (416 tonnes without under-reporting vs. 702 tonnes with under-reporting) without real change in the CV.

5. Discussion

First part of this work shows that catch in 2006 are sustainable if kept constant over time. In fact, the SSB increases continuously and the recruitment stays constant at a level equivalent to the averaged one since the closure of the fishery in 1977.

HCRs based on SSB index tend to be better options than the one based on Z as the SSB and the catch increase and then stabilize with the first set of HCRs while with Z-based one, catch tend to decrease in the first years due to the conservative aspect of the HCR.

In the simulations run in this work, the change of autocorrelation in the recruitment did not induce distinguishable changes in the statistics calculated. It could be interesting to test the implication of such a change in the recruitment by forcing the model to start the projection by few years of very low recruitment or/and very low SSB and see how long it takes to recover.

The introduction of noise in the acoustic survey does not make noticeable changes in the outputs of scenarios using SSB-based harvest control rules contrary to those based on Z. In fact, for the SSB-based HCRs, the shape of the curve of the SSB and the averaged value of the SSB in the final years are similar. With a HCR based on Z, the noise modifies significantly the shape of the SSB curve: dome-shaped without noise and continuous increase with noise. Also, catch increases very quickly without noise while they start by decreasing when noise is taken into consideration. SSB-based HCRs seem to be more robust to noise in the acoustic survey.

Due to the nature of the two stock-recruit functions used in this work, noticeable changes can be observed but they are linked with the HCR used and the taking or not into account of noise. Again, changed are more important with Z-based HCRs.

In the present work, only one type of survey is considered. Other survey data are available (IBTS, MIK and MLAI indices) and new HCRs have to be developed to take them into consideration as indices coming from those surveys are not all of them biomass indices. Furthermore, those indices do not cover the same age classes and the same years. All surveys did not start the same year and do not focus on the same age classes (IBTS: ages 1 to 5, MIK: age 0 and MLAI: SSB index).

As a conclusion, it is possible to manage the North Sea herring stock using only fishery independent data with noise in the survey. It is important to choose adequately the HCR and the stock-recruit function but also the assessment method. The latter does not seem to be adapted to this specific stock and others could be tested.

6. References

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7. Appendix

Appendix 1: Agreed Harvest control rule for North Sea herring.

According to the EU-Norway agreement (November 2004):

1. *Every effort shall be made to maintain a level of Spawning Stock Biomass (SSB) greater than the 800,000 tonnes (B_{lim}).*
2. *Where the SSB is estimated to be above 1.3 million tonnes the Parties agree to set quotas for the directed fishery and for by-catches in other fisheries , reflecting a fishing mortality rate of no more than 0.25 for 2 ringers and older and no more than 0.12 for 0-1 ringers.*
3. *Where the SSB is estimated to be below 1.3 million tonnes but above 800,000 tonnes, the Parties agree to set quotas for the direct fishery and for by-catches in other fisheries, reflecting a fishing mortality rate equal to: 0.25 (0.15*(1,300,000-SSB)/500,000) for 2 ringers and older, and 0.12 (0.08*(1,300,000-SSB)/500,000) for 0-1 ringers.*

4. *Where the SSB is estimated to be below 800,000 tonnes the Parties agree to set quotas for the directed fishery and for by-catches in other fisheries, reflecting a fishing mortality rate of less than 0.1 for 2 ringers and older and less than 0.04 for 0-1 ringers.*
5. *Where the rules in paragraphs 2 and 3 would lead to a TAC which deviates by more than 15% from the TAC of the preceding year the Parties shall fix a TAC that is no more than 15% greater or 15% less than the TAC of the preceding year.*
6. *Not withstanding paragraph 5 the Parties may, where considered appropriate, reduce the TAC by more than 15% compared to the TAC of the preceding year.*
7. *By-catches of herring may only be landed in ports where adequate sampling schemes to effectively monitor the landings have been set up. All catches landed shall be deducted from the respective quotas set, and the fisheries shall be stopped immediately in the event that the quotas are exhausted.*
8. *The allocation of TAC for the directed fishery for herring shall be 29% to Norway and 71% to the Community. The by-catch quota for herring shall be allocated to the Community.*
9. *A review of this arrangement shall take place no later than 31 December 2007.*

8. Outputs

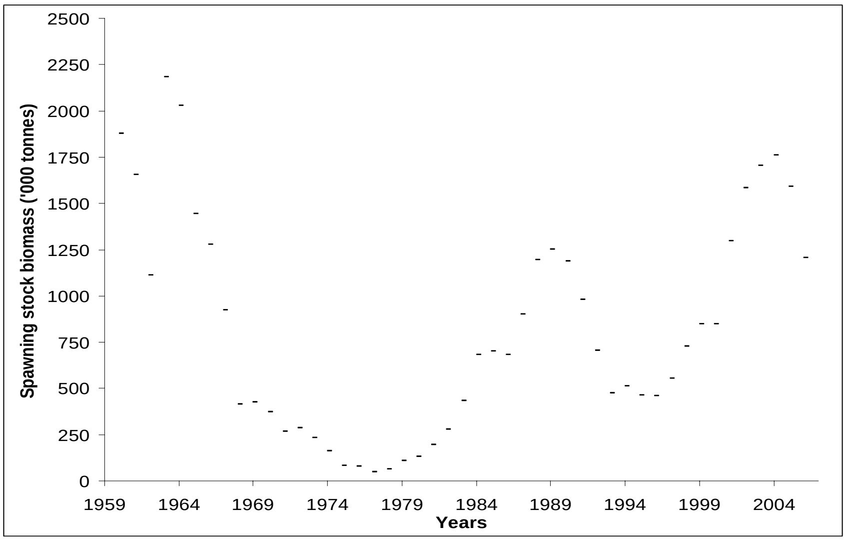

Figure 1: Total spawning stock biomass over years estimated from ICA between 1960 and 2006 (ICES 2007).

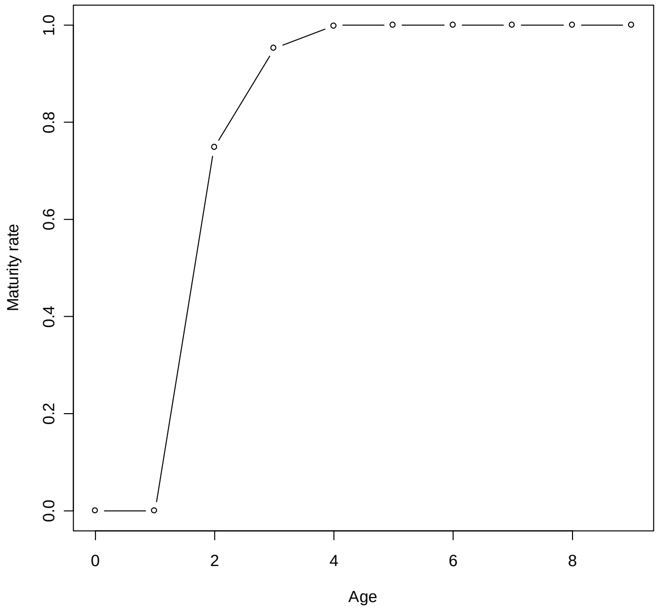

Figure 2: Maturity-at-age averaged between 1972 and 2006.

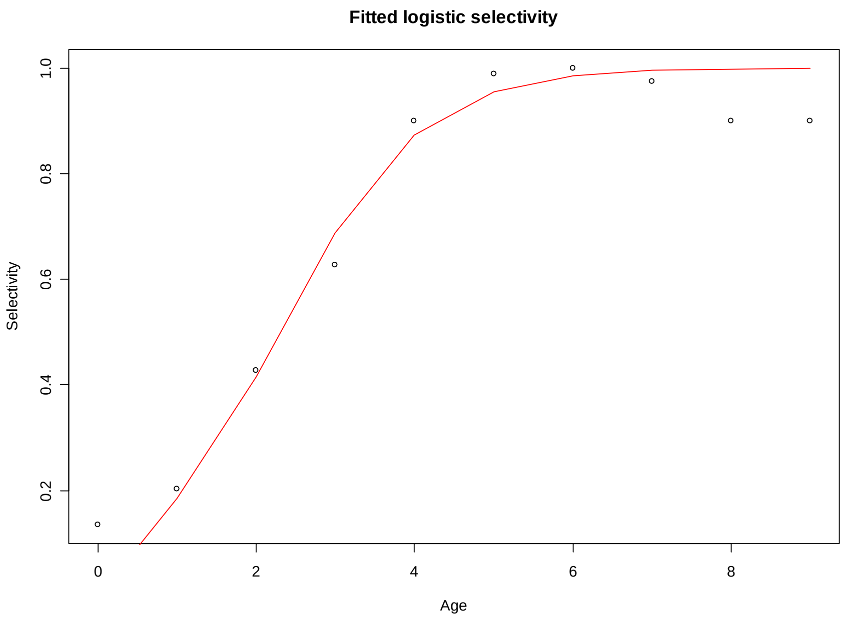

Figure 3: Fitted logistic selectivity on 2006 year's data.

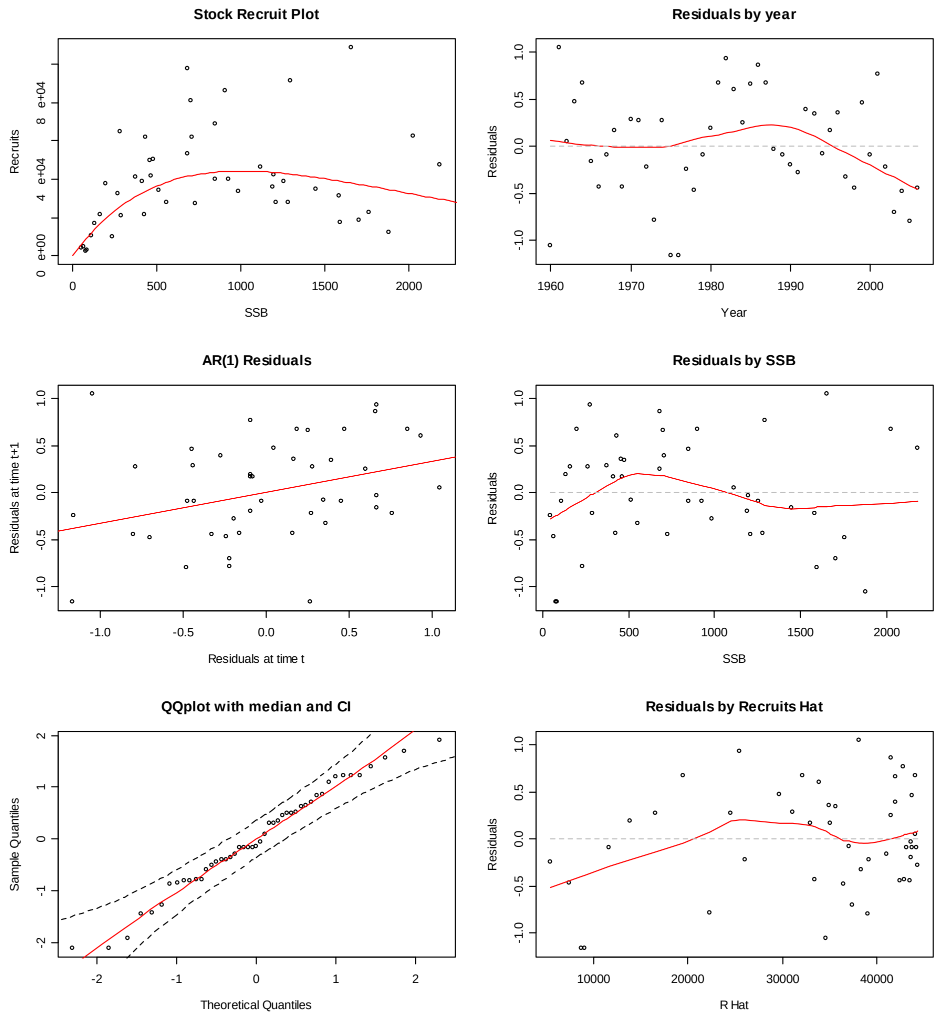

Figure 4: Ricker stock-recruit function

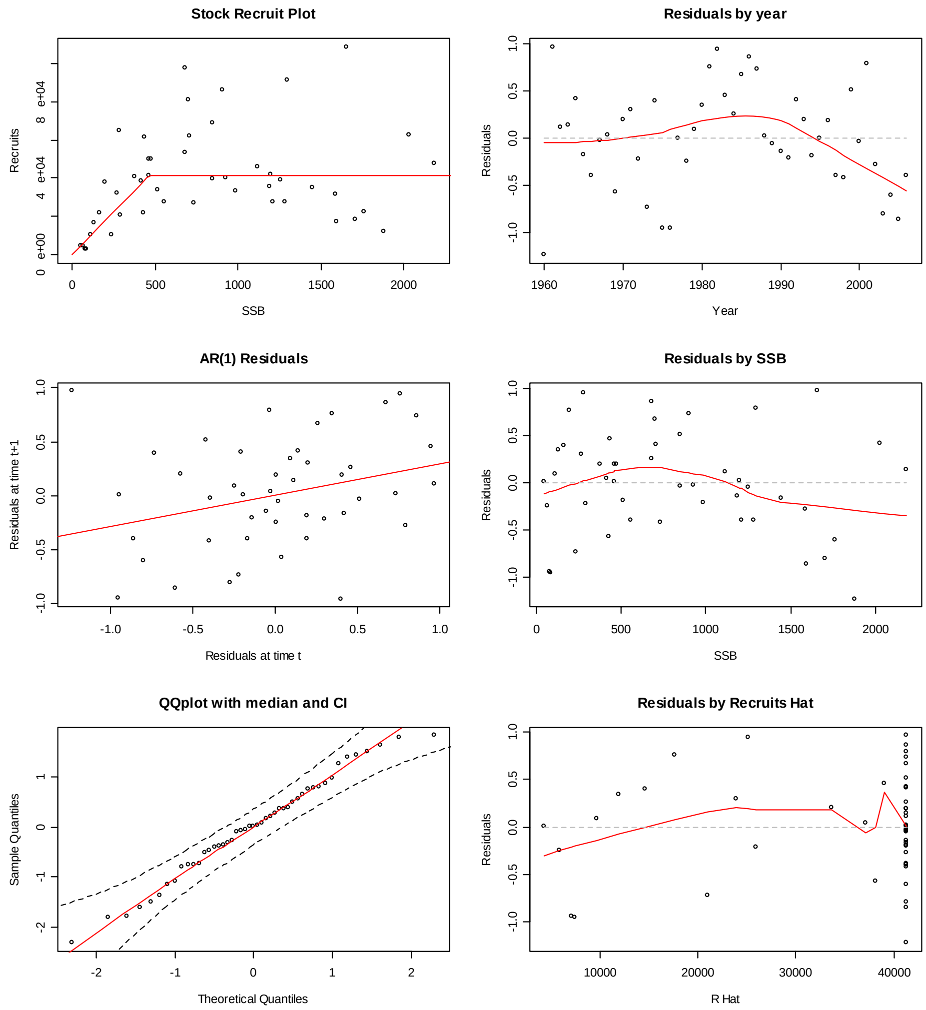

Figure 5: Hockey-stick stock-recruit function.

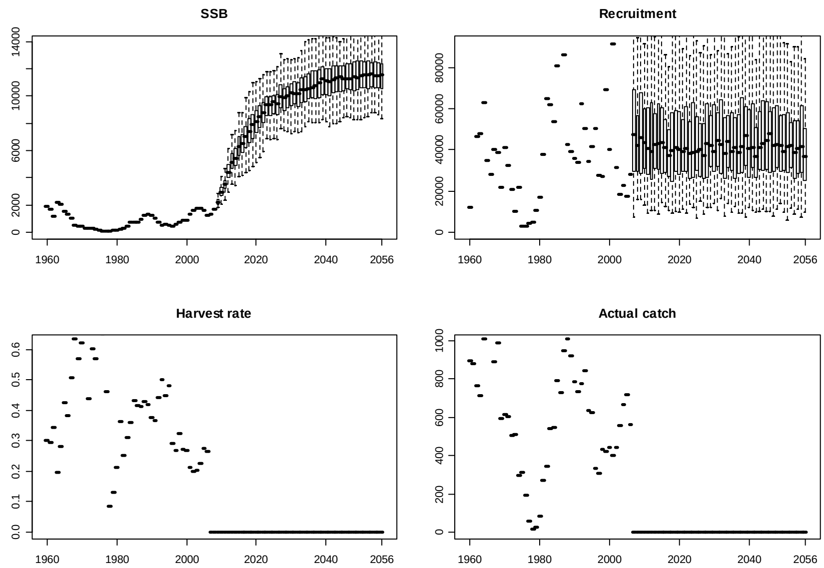

Figure 6: Projection over 50 years of the North Sea herring stock without catch. SR: Segmented regression. Top left: SSB (10^3 tonnes); top right: recruitment (10^3 tonnes); bottom left: harvest rate; bottom right: catch (10^3 tonnes).

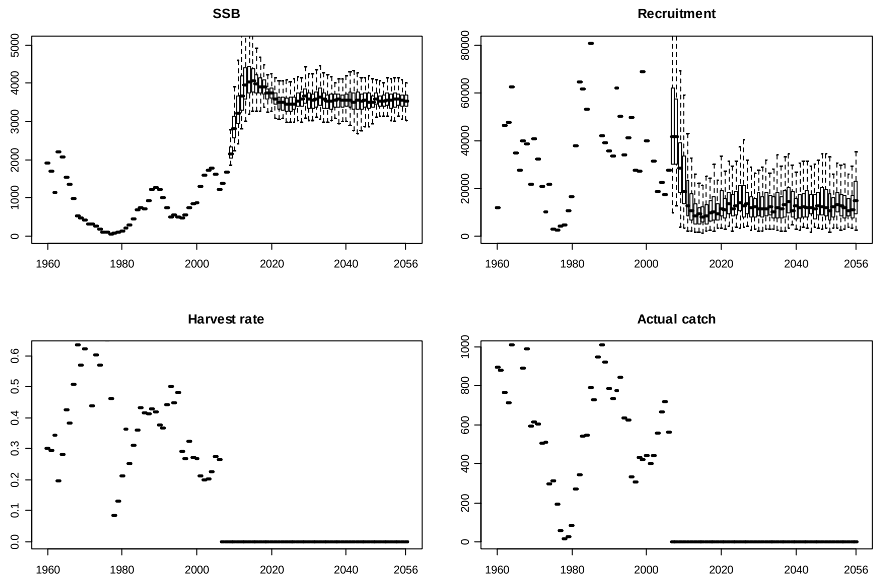

Figure 7: Projection over 50 years of the North Sea herring stock without catch. SR: Ricker. Top left: SSB (10^3 tonnes); top right: recruitment (10^3 tonnes); bottom left: harvest rate; bottom right: catch (10^3 tonnes).

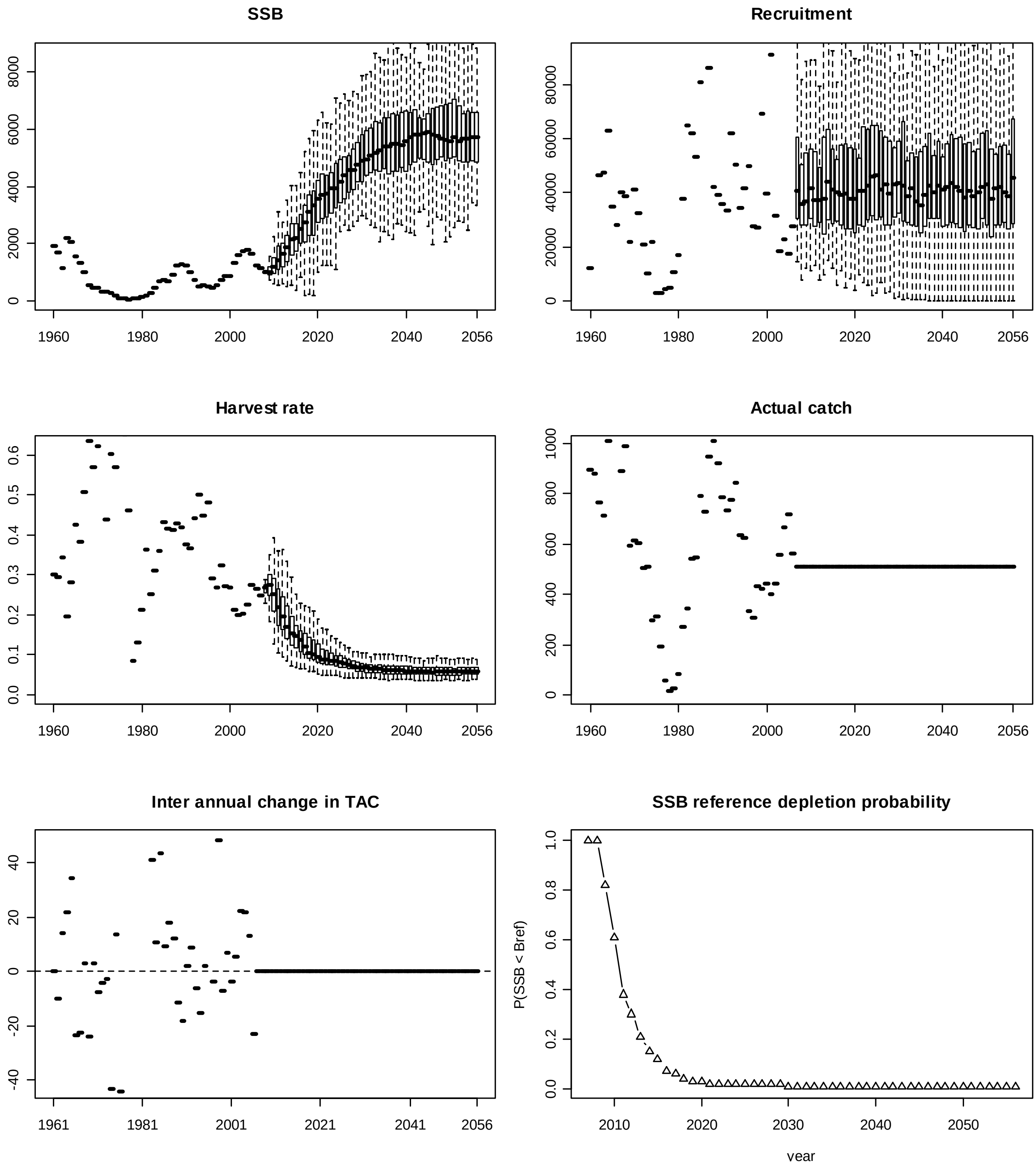

Figure 8: Projection over 50 years of the North Sea herring stock with constant catch. SR: Segmented regression.

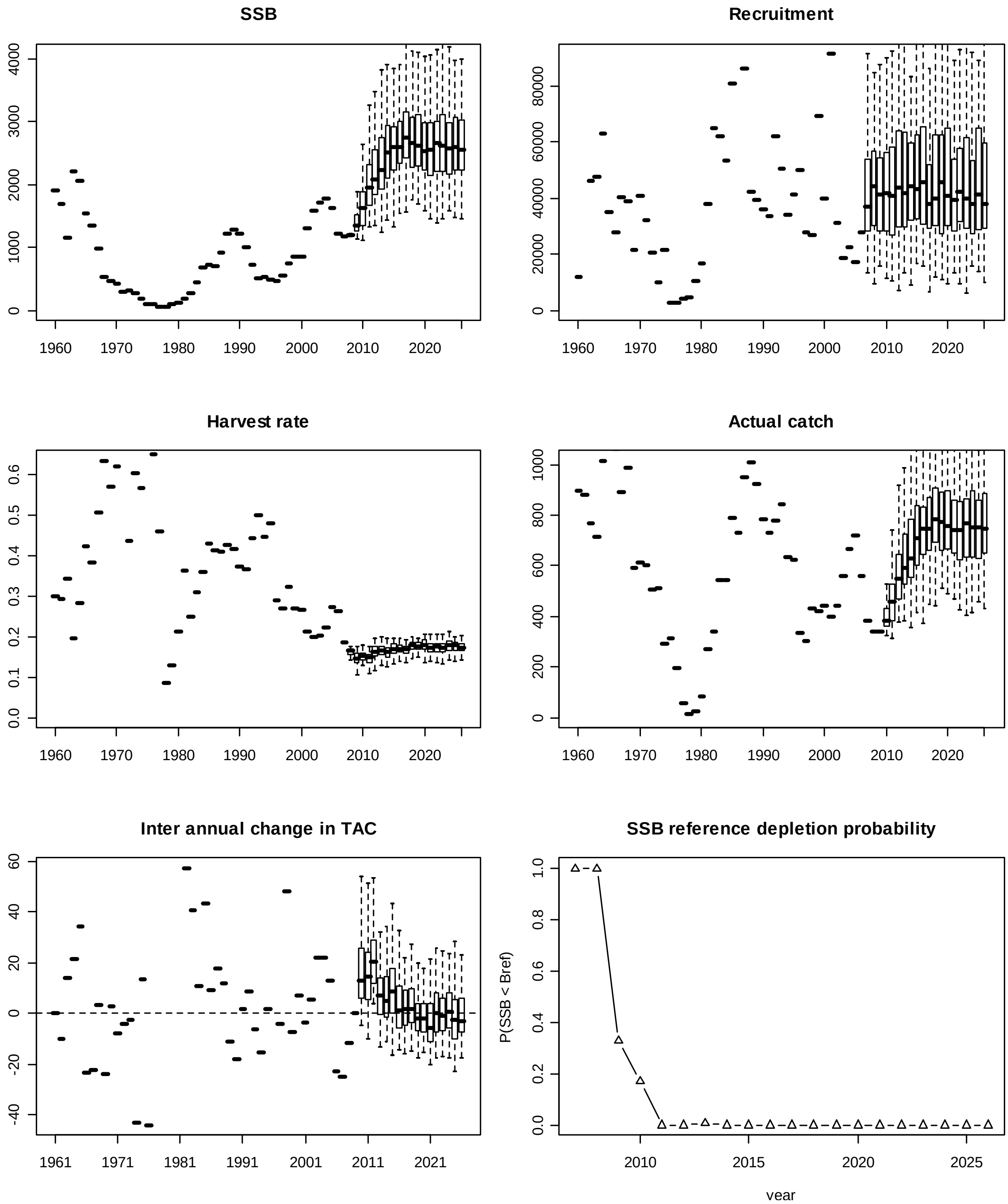

Figure 9: Projection over 20 year of the North Sea herring stock without error. HCR: Observed index. SR: Segmented regression.

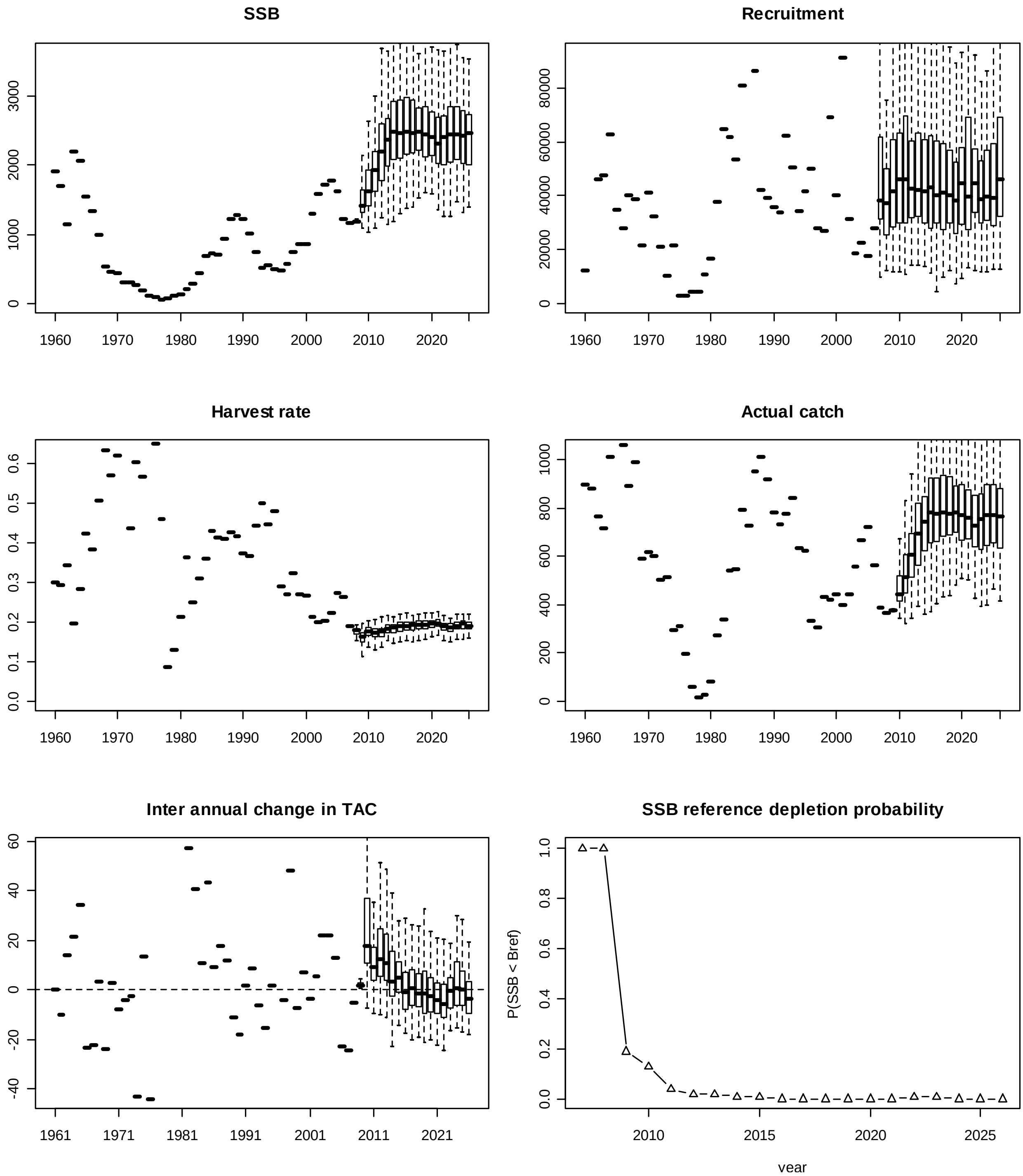

Figure 10: Projection over 20 year of the North Sea herring stock without error. HCR: Single SSB trend. SR: Segmented regression.

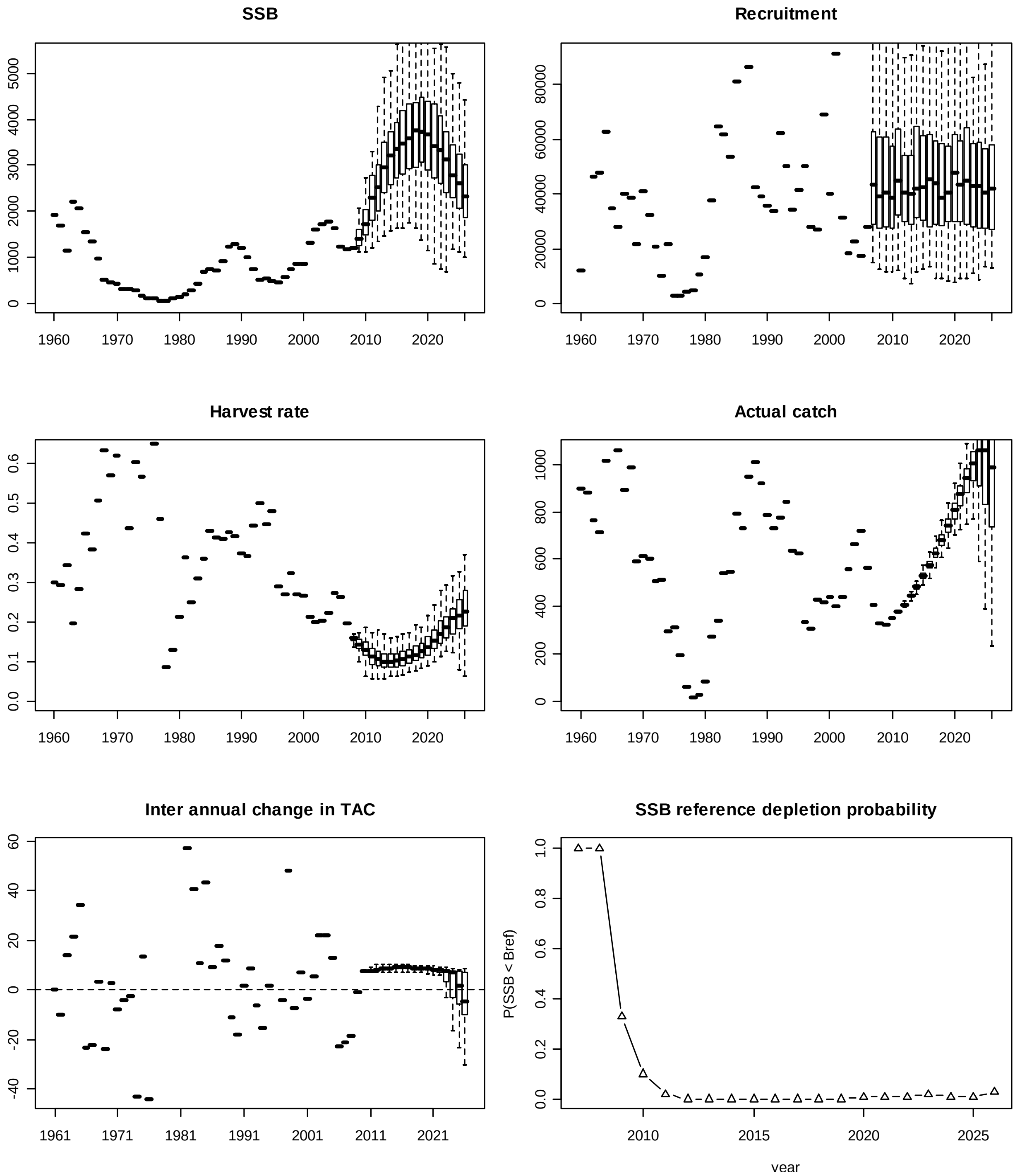

Figure 11: Projection over 20 year of the North Sea herring stock without error. HCR: Z-based. SR: Segmented regression.

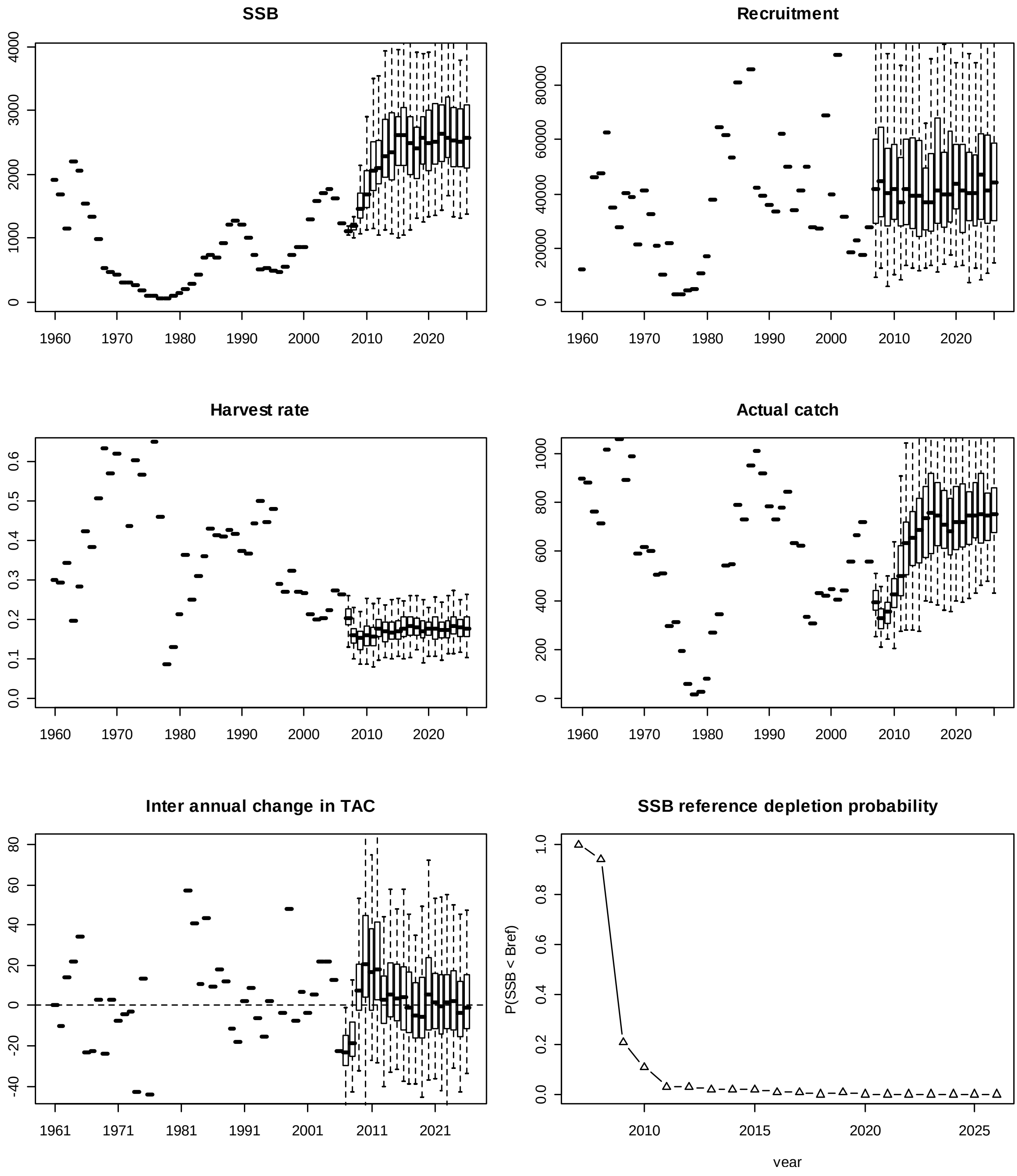

Figure 12: Projection over 20 year of the North Sea herring stock with error. HCR: Observed index. SR: Segmented regression.

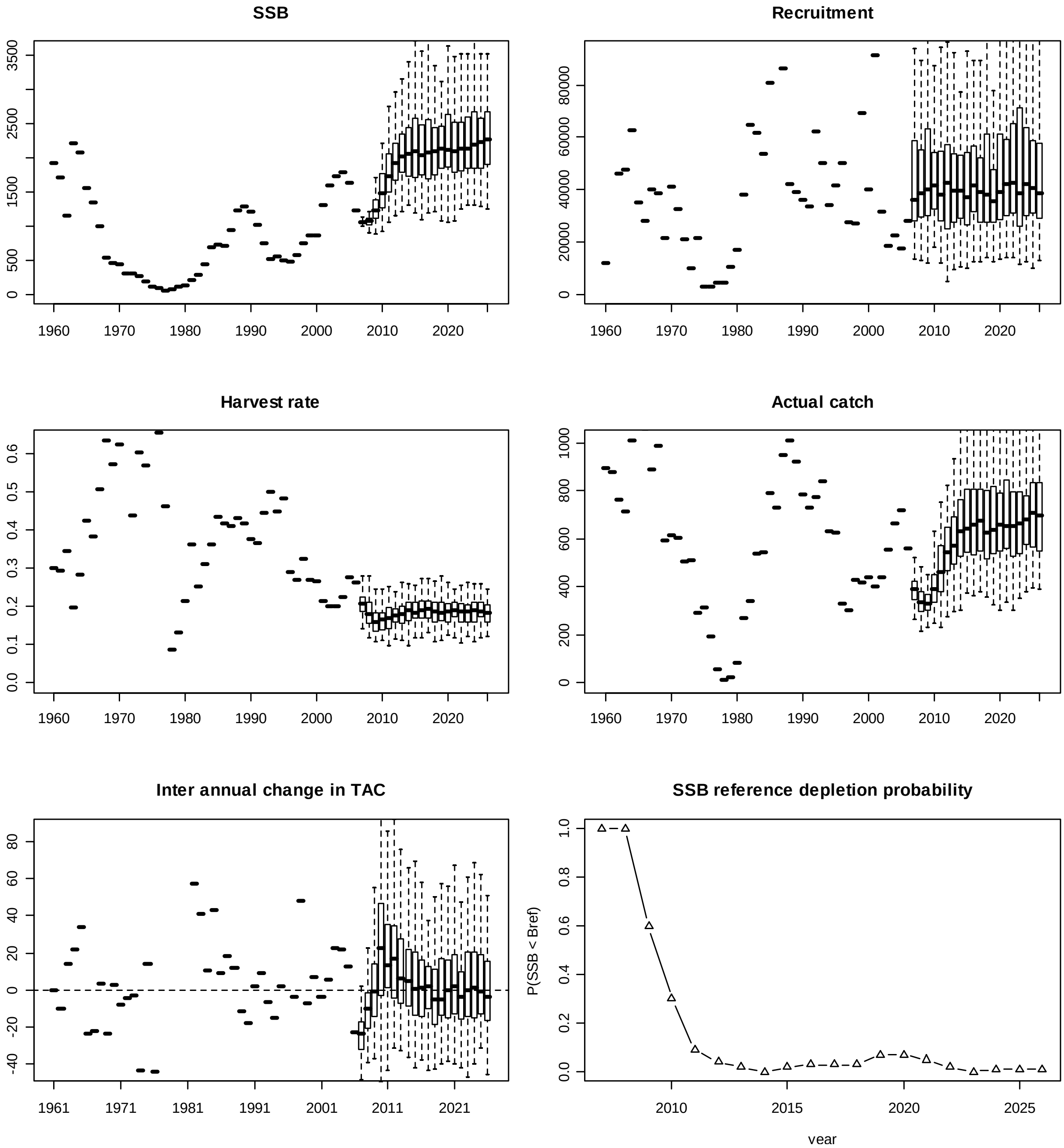

Figure 13: Projection over 20 year of the North Sea herring stock with error. HCR: Single SSB trend. SR: Segmented regression.

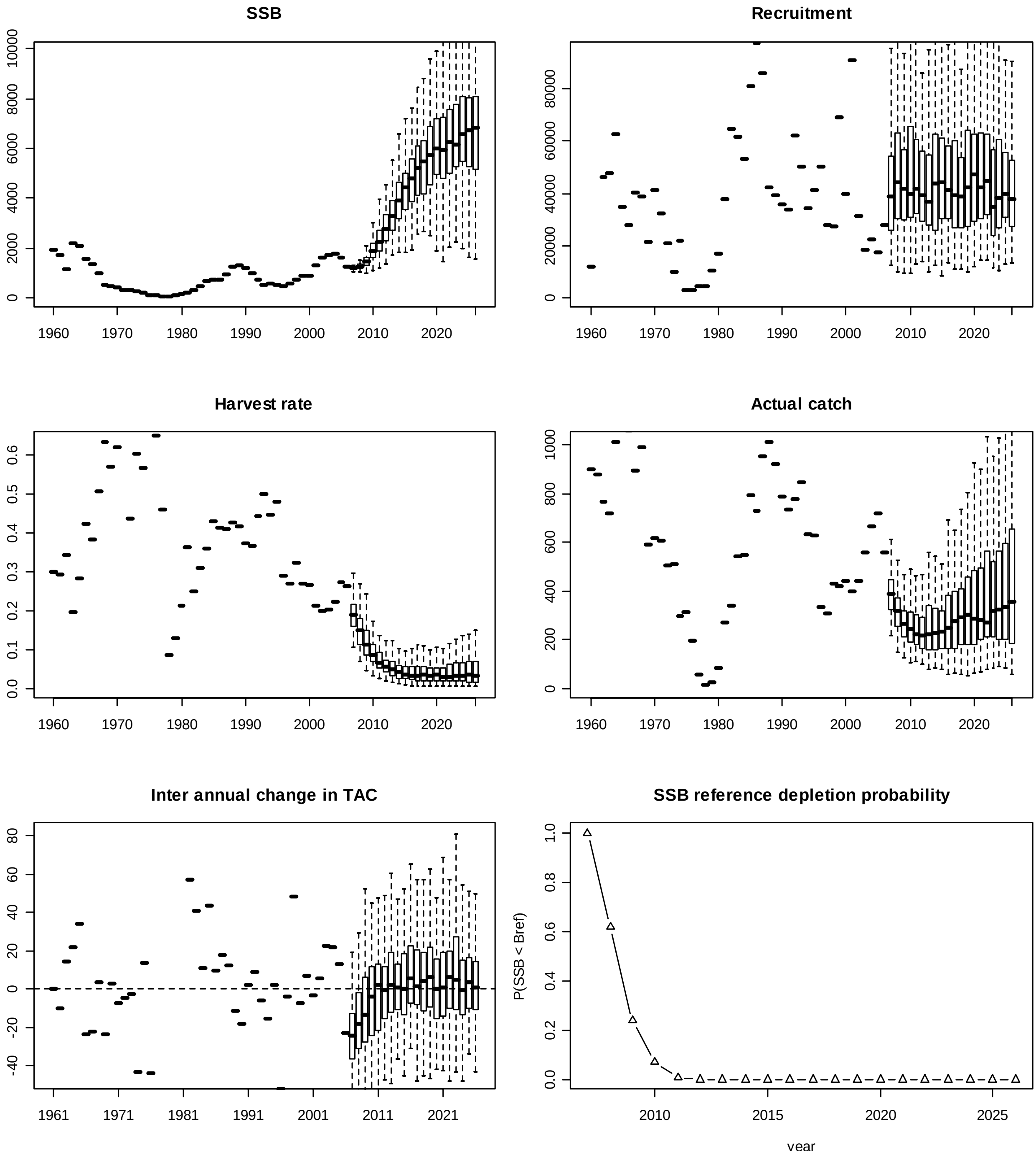

Figure 14: Projection over 20 year of the North Sea herring stock with error. HCR: Z-based. SR: Segmented regression.

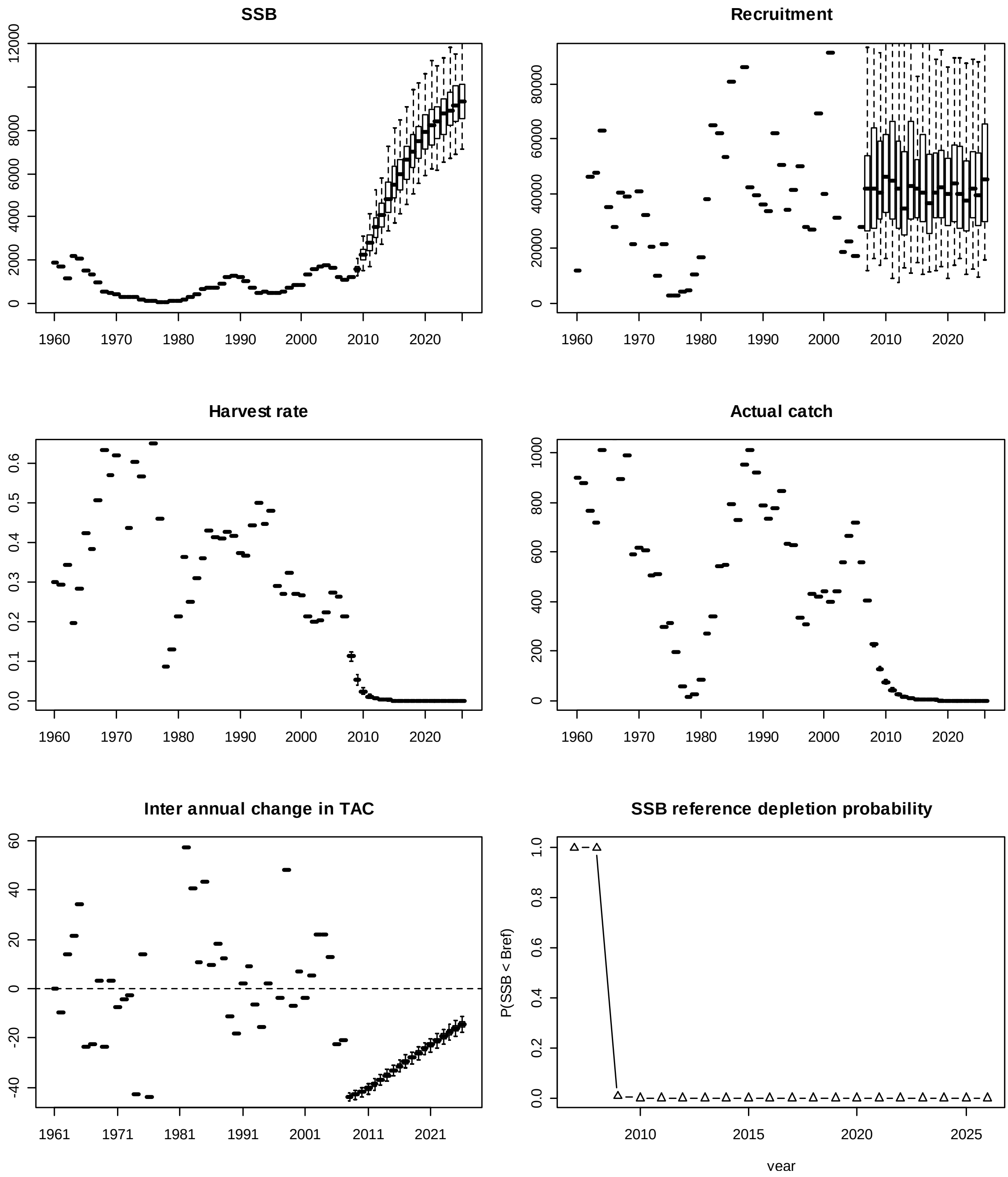

Figure 15: Projection over 20 year of the North Sea herring stock with YCC. HCR: Z-based. SR: Segmented regression.

Table 1: List of simulations

	HCR						Survey			SR		Autocorr		UR	
	No	Fix	Obs Ind	SSB trend	Z	YCC	no	No error	Acoust	SG	R	estim	dbl	N	Y
1	√						√			√		√		√	
2	√						√			√			√	√	
3	√						√				√	√		√	
4	√						√				√		√	√	
5		√					√			√		√		√	
6		√					√			√			√	√	
7		√					√				√	√		√	
8		√					√				√		√	√	
9			√					√		√		√		√	
10			√					√		√			√	√	
11			√					√			√	√		√	
12			√					√			√		√	√	
13				√				√		√		√		√	
14				√				√		√			√	√	
15				√				√			√	√		√	
16				√				√			√		√	√	
17					√			√		√		√		√	
18					√			√		√			√	√	
19					√			√			√	√		√	
20					√			√			√		√	√	
21			√						√	√		√		√	
22			√						√	√			√	√	
23			√						√		√	√		√	
24			√						√		√		√	√	
25				√					√	√		√		√	
26				√					√	√			√	√	
27				√					√		√	√		√	
28				√					√		√		√	√	
29					√				√	√		√		√	
30					√				√	√			√	√	
31					√				√		√	√		√	
32					√				√		√		√	√	
33			√						√	√		√			√
34			√						√	√			√		√
35			√						√		√	√			√
36			√						√		√		√		√
37				√					√	√		√			√
38				√					√	√			√		√
39				√					√		√	√			√
40				√					√		√		√		√

41					√				√	√		√			√
42					√				√	√			√		√
43					√				√		√	√			√
44					√				√		√		√		√
45						√			√	√		√		√	
46						√			√	√			√	√	
47						√			√		√	√		√	
48						√			√		√		√	√	
49						√			√	√		√			√
50						√			√	√			√		√
51						√			√		√	√			√
52						√			√		√		√		√

SR: stock-recruit function.
SG: segmented regression
R: Ricker
Autocorr: autocorrelation in recruitment
Estim: estimated
Dbl: doubled
Survey:
No: no survey
No error: acoustic survey without error
Acoust: acoustic survey with ageing error process
HCR: harvest control rule
No: no harvest control rule
Fix: fixed TAC
Obs Ind: based on observed index (Equation)
SSB trend: based on relative SSB trend (Equation)
Z: based on Z
YCC: based on YCC index
UR: potential under-reporting
N: no
Y: yes

Table 2: Performance metrics

	Once in 20 years prob:		Final year prob:		Final year		
	SSB<Blim	SSB<B_{PA}	SSB<Blim	SSB<B_{PA}	CV in TAC	SSB	Catch
1	0	0	0	0	NA	11584	0
2	0	0	0	0	NA	11584	0
3	0	0	0	0	NA	3525	0
4	0	0	0	0	NA	3612	0
5	0.15	1	0.01	0.01	0	5713	512
6	0.07	1	0	0	0	5909	512
7	0.05	1	0	0.01	0	2194	512
8	0.1	1	0	0.01	0	2203	512
9	0	1	0	0	0.225	2554	749
10	0	1	0	0	0.212	2675	769
11	0	1	0	0	0.187	2087	595
12	0	1	0	0.02	0.191	1994	552
13	0	1	0	0	0.218	2456	767
14	0	1	0	0	0.21	2441	757
15	0	1	0	0.01	0.203	1809	579
16	0	1	0	0.03	0.187	1921	606
17	0.01	1	0	0.03	0.279	2320	986
18	0	1	0	0.04	0.255	2342	1025
19	0.04	1	0.01	0.07	0.293	2064	481
20	0.02	1	0	0.07	0.277	2082	504
21	0	1	0	0	0.264	2572	753
22	0	1	0	0	0.226	2482	750
23	0.01	1	0	0.03	0.269	2037	608
24	0	1	0	0.03	0.236	1953	575
25	0	1	0	0	0.269	2300	747
26	0	1	0	0.01	0.270	2407	772
27	0.01	1	0	0.01	0.271	2019	614
28	0	1	0	0.01	0.231	1864	617
29	0	1	0	0	0.714	6845	355
30	0.02	1	0	0	0.661	7007	318
31	0.02	1	0	0.02	0.558	2682	269
32	0.02	1	0	0.01	0.522	2879	304
33	0.09	1	0.04	0.29	0.277	1554	828
34	0.21	1	0.03	0.31	0.299	1633	862
35	0.2	1	0.05	0.4	0.35	1418	789
36	0.17	1	0.09	0.43	0.328	1414	765
37	0.05	1	0.01	0.35	0.338	1496	806
38	0.08	1	0.01	0.23	0.327	1522	827
39	0.08	1	0.01	0.26	0.302	1500	792
40	0.08	1	0.01	0.42	0.305	1352	711

41	0	1	0	0	0.635	5779	400
42	0.01	1	0	0.01	0.624	6489	430
43	0.04	1	0	0.01	0.505	2741	276
44	0.09	1	0	0.02	4.18	2712	264
45	0	1	0	0	0.287	9319	0.416
46	0	1	0	0	0.313	9804	0.409
47	0	1	0	0	0.291	3484	0.469
48	0	1	0	0	0.302	3358	0.444
49	0	1	0	0	0.296	9408	0.702
50	0	1	0	0	0.309	9273	0.702
51	0	1	0	0	0.303	3425	0.703
52	0	1	0	0	0.314	3450	0.719

SIMULATION EVALUATION WITH FLR

COD NORTH SEA

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1. Introduction

Since the 1970s the stock of North Sea (NS) cod (*Gadus morhua*) has been decreasing, which is reflected in the dramatic decline in catches since 1980 (Fig. 1). ICES classifies the stock as “being at risk of being harvested unsustainably” (ACFM 2007). Since the late 1990s, several cod recovery plans have been adopted with the aim to increase the spawning stock biomass (SSB) of NS cod above the precautionary limit (Bpa) of 150×10^3 tonnes (t). However, stock assessment models have estimated a continuing decline since, SSB being well under the 70×10^3 t limit (Blim) below which the stock is expected to suffer reduced reproductive capacity. The 1999-2004 year classes are all estimated to have been well below average, while fishing mortality is estimated to have declined only slightly since the late 1990s (WGNSSK 2006).

Although official catches (reported landings and estimated discards) are at an all-time low of around 35×10^3 t in the past years, surveys indicate that year classes are depleted faster than one would expect from these catches. This points to unaccounted removals, which are assumed to originate mostly from illegal fishing activities. In recent years, recorded landings have fluctuated between 35% and 65% of total removals, indicating that the management system does not control the catches effectively (ACFM 2007).

Management of NS cod traditionally rests on harvest control rules (HCRs) that target fishing mortality. While survey data are used to calibrate VPA-type assessment models, estimates of fishing mortality are still dominated by official catch figures. Consequently, estimated trends may be misleading whenever official catches are not representative of the true catches, a situation that readily applies to NS cod. The objective of this simulation study is to assess fishery-independent management possibilities for NS cod. Specifically, we aim to identify HCRs that are entirely based on information derived from surveys.

2. Methods

All simulations were run under R 2.4.1.We used simulation tools that have been developed within the FLR framework (Kell et al. 2007). The basic packages used are specified in the Acknowledgments and are described in the FISBOAT manual on simulation evaluation tools. Simulations comprised an operating model, describing the population dynamics of NS cod given certain catch levels, and an observation model, describing observations made on the stock by research vessel surveys. In the jargon of control theory, the observation model is the state-output map of the cod-fishery system and we are looking for a sensible way to modulate this system by an output-to-control feedback (see FISBOAT manual on simulation evaluation tools).

2.1 Population dynamics

The mathematical specifics of the operating model are described in the FISBOAT manual on simulation evaluation tools. Briefly, in deterministic fashion the dynamics of the cod-fishery system are governed by the following equations,

$$[1] \qquad \begin{cases} N_{1,y} = \Phi(\theta, SSB_{y-1}) \\ N_{2,y} = N_{1,y-1}\left(1-\kappa_1 H_{y-1}\right)\exp(-M_1) \\ \vdots \\ N_{6,y} = N_{5,y-1}\left(1-\kappa_5 H_{y-1}\right)\exp(-M_5) \\ N_{7,y} = N_{6,y-1}\left(1-\kappa_6 H_{y-1}\right)\exp(-M_6) + N_{7,y-1}\left(1-\kappa_7 H_{y-1}\right)\exp(-M_7) \end{cases}$$

Here, N denotes stock numbers at age in a particular year, Φ is the particular stock-recruitment (SR) function with parameters θ that depends on SSB in the previous year, M is the natural mortality at age, H is the ratio of catch to total exploitable stock biomass and κ is the selectivity at age. The plusgroup is set at age seven. In stochastic simulations, the deterministic recruitment term is multiplied by a stochastic recruitment multiplier.

The observation model takes the stock numbers at age from the operating model and transforms these to numbers at age as observed in a survey. The transformation we consider here only takes account of catchability at age and has a lognormal error structure.

2.2 Parameterization of the model

The operating model was parameterized using ICES WG estimates as of 2006 (data for 1963-2005, plusgroup at age seven). To estimate selectivity, F was transformed to a harvesting rate and scaled to unity by year. As the last decade supported a sigmoidal ogive, a logistic function was fitted to data for 1996-2005 (Fig. 2).

Three SR relations were fitted to the historical SSB and recruitment estimates, of which the "hockey-stick" (obtained by segmented regression) yielded the best fit according AIC (Fig. 3). This relation was used as the default for further simulations. To study robustness of model outcomes, we also used a Ricker-type function, as well as a "hockey-stick" fitted to recruitment data for 1998-2005 only, when recruitment was low.

To investigate fisheries-independent HCRs, the operating model was supplemented with an observation model in which we mimicked the international bottom trawl survey carried out at the beginning of the year (IBTS-Q1). Catchability at age one was set equal to a ballpark estimate of fishing effort times a selectivity of 0.3 (Cook 1997). Catchability at higher age was scaled according to the ratio of survey catch to stock (in numbers) relative to age one (data for 1983-2005, plusgroup at age five). The scaled catchability ratios for ages one to five (treated as a plusgroup) are 1 : 3 : 3.1 : 4 : 5.9. As our operating model used seven age classes, we set catchability at ages six and seven equal to catchability at age five. Standard deviation of the lognormal error distribution was set to 0.25, an approximation of the average variability in the ratio of survey catch to stock (in numbers). We noticed decreased variability at higher age, but the observation model did not allow for age-dependent error distributions. Simulations show that some discrepancy exists between numbers observed in the survey and numbers obtained by observation model runs (Fig. 4), but the agreement was considered good enough for the purpose of this study.

2.3 Harvest control rules

We tested various HCRs based on the following general form,

$$[2] \qquad \begin{cases} TAC_{y+1} = \exp\{u_y\}\, TAC_y \\ u_y = K_P\, e_y + K_I \sum_{z=y-\delta}^{y} e_z + K_D\left(e_y - e_{y-1}\right) \end{cases}$$

Here, u denotes the control signal that is used for TAC adjustment from one year to the next. The control signal is calculated from the divergence of an index relative to a reference point. The desired closed-loop behavior is obtained by tuning the three parameters K_P, K_I and K_D with δ denoting the history that is considered in calculating the control signal. We set δ arbitrarily at five years in all simulations.

We set out to evaluate three survey-based indices: survey SSB, overall mortality Z (averaged over ages 2-7), and linear trend in Z using year-class curves (Cotter et al. 2007). The latter is a model-based index, whereas the first two are model-free indices. As reference points we considered the index in the previous year (a moving target) and for the Z-based HCRs, we also considered fixed targets. However, we could not obtain any sensible tuning for the model-free Z-based HCR, neither with a moving target nor with a fixed target. This index was therefore dropped from further investigation. In the model-based HCR, we aimed to stabilize TAC by incorporating the absence of a linear trend in Z (implying stable mortality) as a fixed target. In all simulations, the linear trend in Z is calculated from the ten most recent years of survey data.

2.4 Simulation strategy

To find sensible control parameters, we applied Ziegler-Nichols tuning to deterministic model runs (see FISBOAT manual on simulation evaluation tools). If needed, the Ziegler-Nichols settings were fine-tuned in order to obtain a smooth response in the control signal. A "smooth tune" decreases the possibility of TAC overshoot while safeguarding high catches. Deterministic simulations were run for as long as needed to assess convergence or periodicity due to control parameter settings.

Next, stochasticity was added to both the operating model and the observation model in order to assess the performance of HCRs in light of empirically defined variability. Performance criteria included (i) the risk of stock collapse: Prob{TAC > exploitable stock biomass (ESB)}, (ii) the time until stock recovery (SSB > Bpa), (iii) median SSB at the end of the simulation period, (iv) average annual catch and (v) mean inter-annual catch variability (ICV, cf. Roel & De Oliveira 2007). In stochastic simulations, the simulation period was fixed at 30 years (similar to the one used in the North East Arctic cod case study, corresponding to approximately five generations). Performance statistics were calculated on the basis of 100 stochastic model runs.

Sensitivity was tested to (i) different starting conditions, (ii) increased noise in the survey, (iii) under-reporting up to 25% and (iv) structural overfishing, implemented as knowingly increasing TAC. This is in contrast to reporting bias, where catches are increased but the official TAC remains the basis for future adjustment. Finally, we tested the robustness of HCRs to alternative SR relations.

3. Results

As a preliminary to the evaluation of HCRs, we set a baseline scenario wherein TAC was kept constant and set equal to the catch observed in 2005 (Fig. 5). The results show that, conditional on the parameterization of the model, the current official catch level (reported landings and estimated discards) is sustainable if compliance can be enforced. Half the runs achieved SSB>Bpa as of 2010 (95% as of 2011). At the end of the simulation period, i.e. in 2035, median SSB was 7277×10^3 t. Because TAC was not adjusted in response to increasing SSB, harvest rate declined to almost zero.

3.1 HCR based on survey SSB

Tuning the control signal based on a survey SSB index did not present any difficulty (Fig. 6). In stochastic simulations, the standard Ziegler-Nichols PID setting frequently resulted in stock collapse: Prob{TAC>ESB}=0.60 for the next 30 yrs (Fig. 7). In contrast, the fine-tuned PID controller hardly ever resulted in stock collapse: Prob{TAC>ESB}=0.02. Half the runs achieved SSB>Bpa as of 2009 (95% as of 2012). The average annual catch over the next 30 years was 394 (SE 68) $\times 10^3$ t, with an ICV of 0.36 (SE 0.08). In 2035, median SSB was 2841×10^3 t (Fig. 8).

Sensitivity to starting conditions was tested by temporarily closing the fisheries for three years, and applying the HCR with the TAC in 2009 being modified from the catch in 2005. The time to stock recovery was shortened (95% of runs achieved SSB>Bpa as of 2009) and none of the simulations resulted in stock collapse. The average annual catch was significantly lower: 261 (SE 41) $\times 10^3$ t, with a similar ICV of 0.36 (SE 0.06). In 2035, median SSB was 5191×10^3 t (Fig. 9).

Increasing survey noise from 25% to 35% gave Prob{TAC>ESB}=0.07. The average annual catch was not affected: 386 (SE 86) $\times 10^3$ t, but inter-annual variability increased, as reflected in an ICV of 0.46 (SE 0.14). A survey noise of 50% gave Prob{TAC>ESB}=0.12 and reduced expected catch to 344 (SE 126) $\times 10^3$ t, with ICV at 0.68 (SE 0.18) denoting a high inter-annual variability in catch. In 2035, median SSB was 2379×10^3 t (Fig. 10).

Introducing a reporting bias of 5%, 10% or 25% gave probabilities of stock collapse of 0.02, 0.01 and 0.02, respectively. In all these simulations, half the runs achieved SSB>Bpa as of 2010, whereas 95% did so in 2013, 2013 and 2014, respectively. Average annual catches were 399 (SE 70), 421 (SE 81) and 419 (SE 75) $\times 10^3$ t, respectively. ICV was around 0.36 in all these simulations. Results are shown for a reporting bias of 25% (Fig. 11). In 2035, median SSB was 2123×10^3 t.

Sensitivity to structural overfishing was investigated to assess the robustness of the HCR with respect to (economic, political) decision-making. At a rate of 1% the risk of stock collapse was not increased, Prob{TAC>ESB}=0.01 for the next 30 years. At a rate of 5%, however, nearly all runs experienced stock collapse (Fig. 12). From this we conclude that the HCR is not robust to cumulative upwards TAC adjustments.

Using a "hockey-stick" SR function fitted to recruitment data for 1998-2005 only, or a Ricker-type SR function, both resulted in an increased risk of stock collapse. The low-level "hockey-stick" SR function gave Prob{TAC>ESB}=0.03 (Fig. 13), while the Ricker-type SR function gave Prob{TAC>ESB}=0.20 (Fig. 14). Both simulations had significantly reduced catches: 132 (SE 22) and 298 (SE 59) $\times 10^3$ t, respectively, with corresponding ICVs of 0.32 (se 0.07) and 0.41 (se 0.11). It goes without saying that the lower level of recruitment in the alternative "hockey-stick" SR function significantly increased the time to stock recovery (95% as of 2014).

To study robustness of a "less greedy tune" we assessed the performance of a conservative proportional controller, i.e. $K_P = 0.5 \times K_C$ and other control parameters set to zero. It appeared that, although the catches were much lower as compared to the fine-tuned PID controller, none of the runs resulted in stock collapse, neither those with a "hockey-stick" nor those with a Ricker-type SR function. In the latter case, the average annual catch was 146 (SE 11) $\times 10^3$ t, with an ICV of 0.13 (SE 0.02). Half the runs achieved SSB>Bpa as of 2010 (95% as of 2011). In 2035, median SSB was 2768×10^3 t (Fig. 15). Note that the oscillatory behavior of the controller in case of the Ricker-type SR function is due to the phenomenon of overcompensation at higher stock sizes. Simulated recruitment according to the Ricker-type SR function is plotted together with the historical estimates of recruitment (Fig. 16).

3.2 HCR based on year-class curves (YCC)

In this model-based HCR, we estimated the linear trend in Z from the ten most recent years of survey data according to the following model (in R notation):

[3] log(cpue) ~ -1 + as.factor(yrclass) + year:age

The interaction term in this equation allows for a linearly changing slope of a set of year class curves over time; this we refer to as the linear trend in Z. Because the effort of the survey in our model is the same from year to year, we simply used the output of the observation model as the input for YCC analysis.

First, we used a fixed target of zero, i.e. the magnitude of the interaction term was taken as the input for tuning. The absence of a linear trend in Z implies a constant slope of year-class curves over time, hence would signal a stable exploitation rate. The Ziegler-Nichols approach however did not lead to a sensible tuning, because we never obtained a periodic response in the control signal (Fig. 17). Somehow the HCR is not possible to stabilize the control signal at zero, which would stabilize TAC. Instead, TAC is drastically lowered initially (the higher K_P, the stronger the initial TAC reduction) and increases only marginally when SSB reaches a plateau due to self-limitation in the SR function. Estimating the linear trend in Z from the 5 most recent years of survey data does not provide a better tuning (data not shown).

Next, we used a moving target, i.e. the input for tuning was this year's estimate minus last year's estimate of the interaction term. This way we were able to find a smooth tune, but only by using PI control. Neither standard Ziegler-Nichols settings nor fine-tuned PID settings gave a smooth response in the control signal (Fig. 18). Using the standard PI controller never resulted in stock collapse over the 30-year simulation period. Half the runs achieved SSB>Bpa as of 2010 (95% as of 2011). The average annual catch over the next 30 years was 194 (SE 8) $\times 10^3$ t, with an ICV of 0.05 (SE 0.002). In 2035, median SSB was 5349×10^3 t (Fig. 19).

Application of this HCR after temporary closure of the fisheries shortened the time to stock recovery and none of the simulations resulted in stock collapse. The average annual catch was 153 (SE 6) $\times 10^3$ t with an ICV of 0.05 (SE 0.02). In 2035, median SSB was 6645×10^3 t (Fig. 20). Doubling the survey noise to 50% never resulted in stock collapse and did not affect the catch: annually 195 (SE 14) $\times 10^3$ t; nor the inter-annual catch variability: ICV 0.06 (SE 0.003). In 2035, median SSB was 5575×10^3 t (Fig. 21). Results were very sensitive to reporting bias. The risk of stock collapse was already large at a level of only 5%: Prob{TAC>ESB}=0.32. The average annual catch over the next 30 years was of 425 (SE 53) $\times 10^3$ t, with ICV at 0.09 (SE 0.03). In 2035, median SSB was 996×10^3 t (Fig. 22). Similar results were obtained by introducing an overfishing rate of 5%, which gave Prob{TAC>ESB}=0.26 for the next 30 years. The average annual catch was 425 (SE 69) $\times 10^3$ t, with ICV at 0.08 (SE 0.04). In 2035, median SSB was 748×10^3 t (Fig. 23).

Using a "hockey-stick" SR function fitted to recruitment data for 1998-2005 only, when recruitment was low, resulted in a high risk of stock collapse: Prob{TAC>ESB}=0.24 (Fig. 24). Using a Ricker-type SR function resulted in an even higher risk of stock collapse: Prob{TAC>ESB}=0.42 (Fig. 25). Because of this, we applied the standard Ziegler-Nichols settings for a strictly proportional controller, i.e. $K_P = 0.5 \times K_C$ and other control parameters set to zero. This reduced the occurrence of stock collapse over the 30-year simulation period, but the probability was still significant; Prob{TAC>ESB}=0.14 (Fig. 26). Only with a very conservative proportional controller ($K_P = 0.25 \times K_C$, $K_I = 0$ and $K_D = 0$) did the stock not collapse. In this case, the average annual catch was 82 (SE 6) $\times 10^3$ t, with an ICV of 0.05 (SE 0.01). Half the runs achieved SSB>Bpa as of 2010 (95% as of 2012). In 2035, median SSB was 2940×10^3 t (Fig. 27).

4. Discussion

Of the three survey-based indices considered in this case study, we found that model-free estimates of Z could not serve as the basis for a sensible HCR. Using the linear trend in Z (estimated by YCC) as the basis for control only provided a sensible HCR when using a moving target, i.e. taking the index in the previous year rather than a fixed target as the reference point. From an optimization point of view, the best tuning could be obtained with HCRs based on survey SSB, as these yielded the highest average annual catches. In stochastic simulations, however, the inter-annual catch variability was considerably higher as compared to the more conservative HCRs based on YCC. Also, the latter appear more robust to changes in the survey measurement error.

This simulation study shows that, in principle, it is possible to obtain excellently performing HCRs based on survey-derived information only. However, results were highly sensitive to changes in the SR function assumed for simulations. Specifically, the optimality of control settings strongly depends on the use of a “hockey-stick” or Ricker-type SR relation. Because we used the “hockey-stick” SR function as the default in all simulations, the Ricker-type SR function was only considered in sensitivity analyses. Had we used a Ricker-type SR function to start with, we would have used a very different (likely more conservative) tuning. Preliminary investigations suggest that it is not possible to obtain a smooth tune for the system with a Ricker-type SR function. This relates to the fact that PID controllers are linear, and their performance in non-linear systems (such as the operating model considered in this case study) greatly depends on the adequacy of a linear approximation. The additional complexity introduced by overcompensation in stock-recruitment is that the equilibrium may become unstable, which has profound effects on harvest policies (Clark 1990). Under these conditions, PID controllers are often enhanced through methods such as fuzzy logic or neural networks (Yeap & Ahmed 1994) but that is outside the scope here.

Sensitivity to starting conditions was investigated by modeling the temporary closure of cod fisheries for three years in a row. Application of HCRs with the TAC in 2009 being modified from the catch in 2005 resulted in significantly reduced catches, in simulations with HCRs based on survey SSB as well as YCC. This follows logically from the adaptive nature of the HCR used in this case study; if the stock would be allowed to attain carrying capacity before reopening the fisheries, TAC would remain close to the value that is used as the basis for TAC adjustment. This is clearly one of the drawbacks of HCRs that attempt to manage stocks in an adaptive way. Indicators cannot be used to manage stocks in an absolute way, in contrast to TACs that correspond to levels of fishing mortality.

As survey-based HCRs take an input that is irrespective of official catch figures, one could assume that they are comparatively robust to misreportings. This is indeed the case for the HCRs based on survey SSB, as evidenced by inclusion of reporting biases up to 25%. However, the HCRs based on YCC were less robust to reporting bias; the risk of stock collapse was already large at 5% underreporting. The difference in sensitivity to reporting bias is perhaps explained by the fact that the YCC model focuses on gradual changes in the stock, whereas survey SSB can cope with sudden changes in the stock. This would also explain the higher sensitivity of HCRs based on survey SSB to increased survey noise. All results were very sensitive to structural overfishing, which we included as knowingly increasing TAC by a few percent each year. This demonstrates that sustainability of survey-based stock management is only safeguarded if biological advice is accepted as given and is not to be negotiated.

NS cod catches were at an historic low as of 2006. Perhaps even more alarming is the suggestion that catches are not controlled effectively by the management system (ACFM 2007). If true, this situation seriously hampers the possibilities for sustainable management of the NS cod stock. This applies to management strategies that depend on fishery-dependent information as well as those that are dependent on survey-derived information only. In principle, the latter should be less prone to mismanagement because catch misreportings need not influence the setting of next year's TAC. Still, other biases may become important and the validity of our results relies on the extent to which our modeling approach captures the intricacies of a biological survey. On a more fundamental level, the validity of the model rests on an adequate description of the dynamics of the cod-fishery system.

The results of our baseline scenario suggest that keeping a constant TAC, equal to the official catch figure for 2005, would allow NS cod to recover and eventually allow SSB to grow to a level that is over ten times the maximum historical estimate of SSB. The tendency of SSB growing to unprecedented levels is also witnessed in other simulations, wherein TAC is allowed to be adjusted upwardly in response to positive signals coming through surveys. As the proposition of historically unprecedented stock sizes cannot be backed with evidence in any way, the conclusions drawn from this study may only be applicable to the model stock.

The tendency of SSB growing to unprecedented levels should come as no surprise: in all simulations relating to sustainable management, the HCR settles on a harvesting rate that is significantly reduced compared to historical estimates. As a consequence, the model stock depends primarily on the SR function for regulation of stock size. Uncertainty in the SR relation clearly limits the validity of any analysis of the cod-fishery system, be it analytical or otherwise. Nonetheless, given the data available and assuming applicability of a "hockey-stick" function over the entire range of modeled SSB levels, it can be deduced that fishing mortality historically has been too high from the MSY point of view. Indeed, our HCR based on survey SSB with a modified Ziegler-Nichols PID setting fixes the harvesting rate at 0.16, which is close to the optimum value of 0.20 obtained by analytical analysis (Fig. 28).

The potential for NS cod recovery currently rests on adequate implementation and control of agreed TACs more than on the development of a fishery-independent management device. Instead of aiming to maximize catches based on very specific modeling assumptions, it is better to strive for a conservative harvesting regime that performs reasonably well given the uncertainties in the biology of NS cod.

Acknowledgments

We acknowledge the use of the following FLR packages and thank those responsible for coding them and making them publicly available. FLCore 1.99-rc1; FLEDA 1.4-2 FLOgive 0.1-1; FLAssess 1.3-2; FLFisboat 1.0-3; FLOE 0.2-3; FLYCC 0.2

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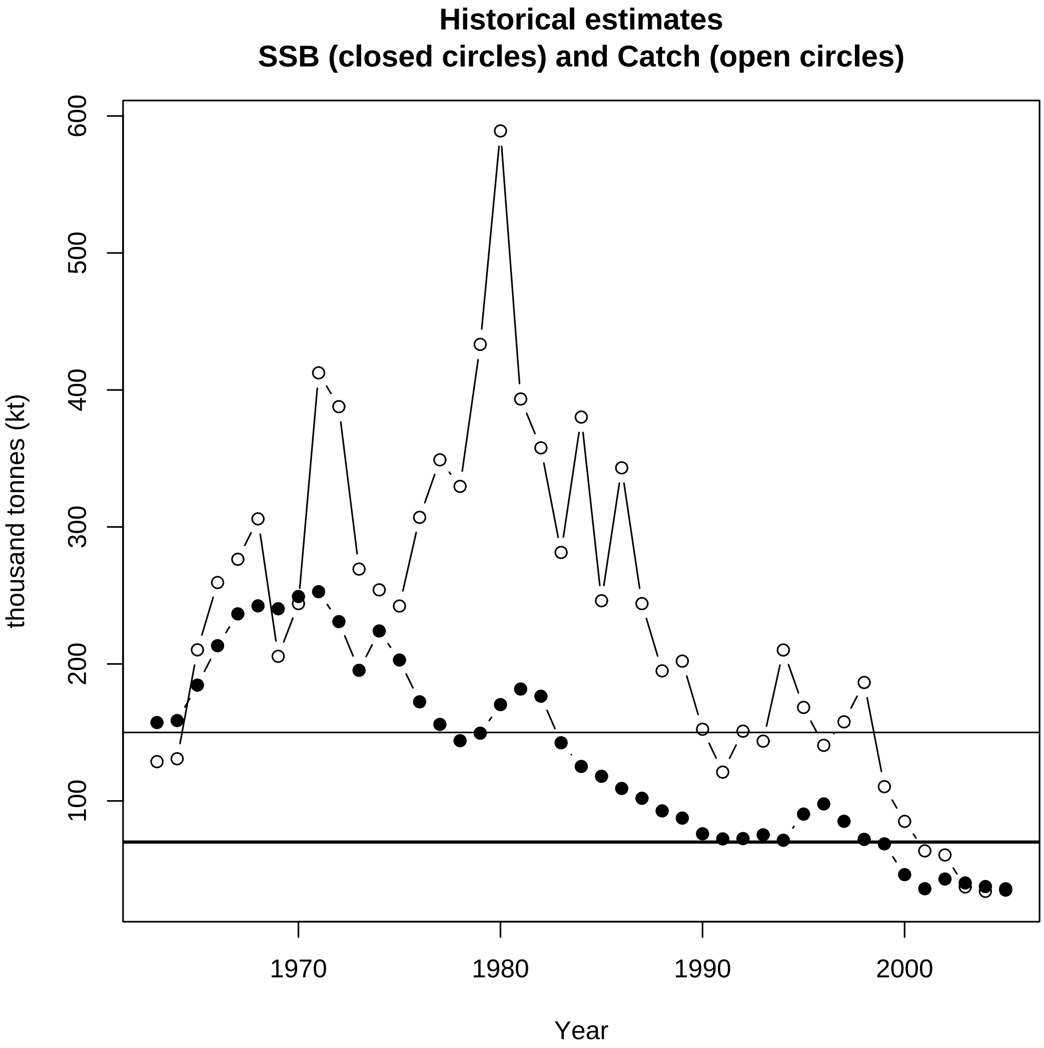

Figure 1. Historical catches and total spawning stock biomass (SSB) as estimated by ICES working groups over the period 1963-2005. The thin line gives Bpa, the thick line gives Blim.

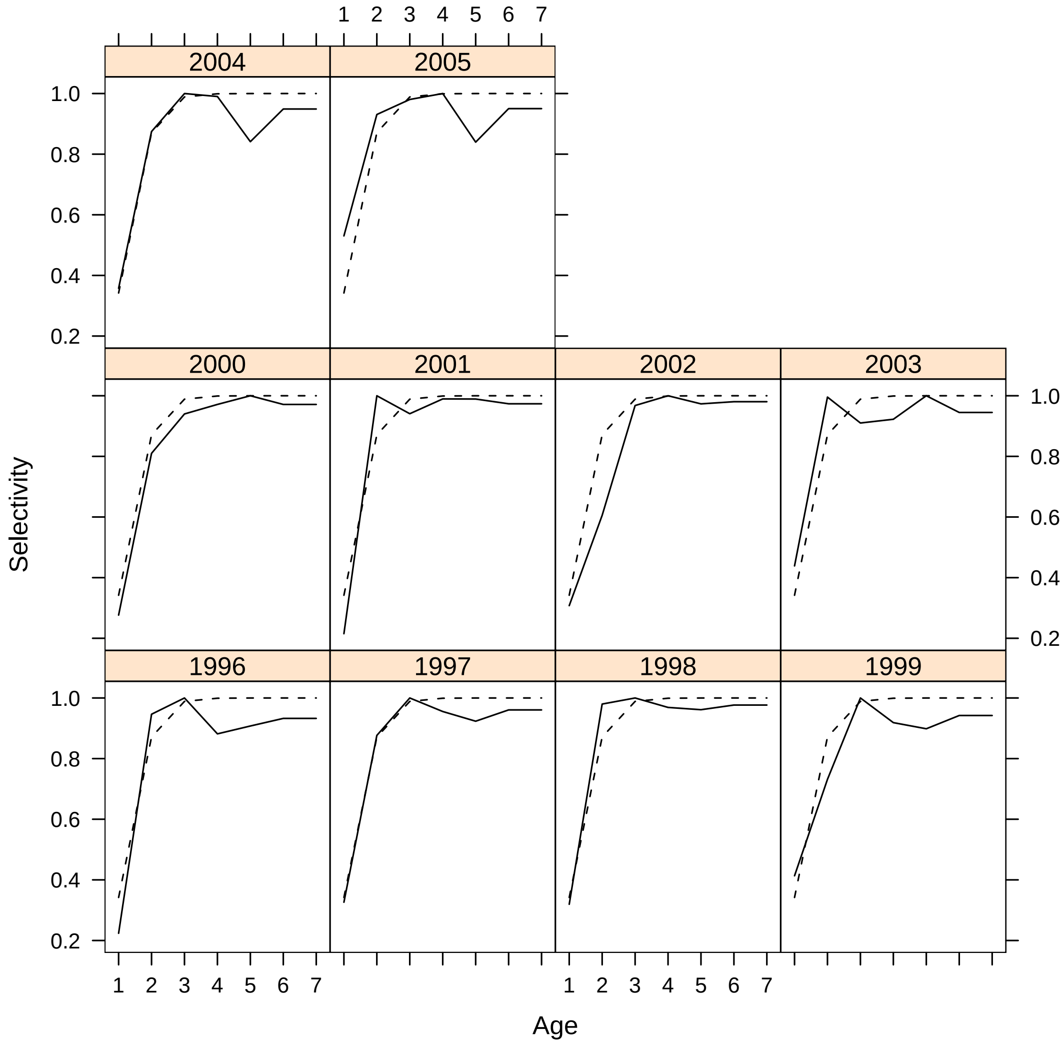

Figure 2. Scaled estimates of fishing mortality at age for 1996-2005 (solid lines) and the logistic selectivity function fitted to these data (dotted line).

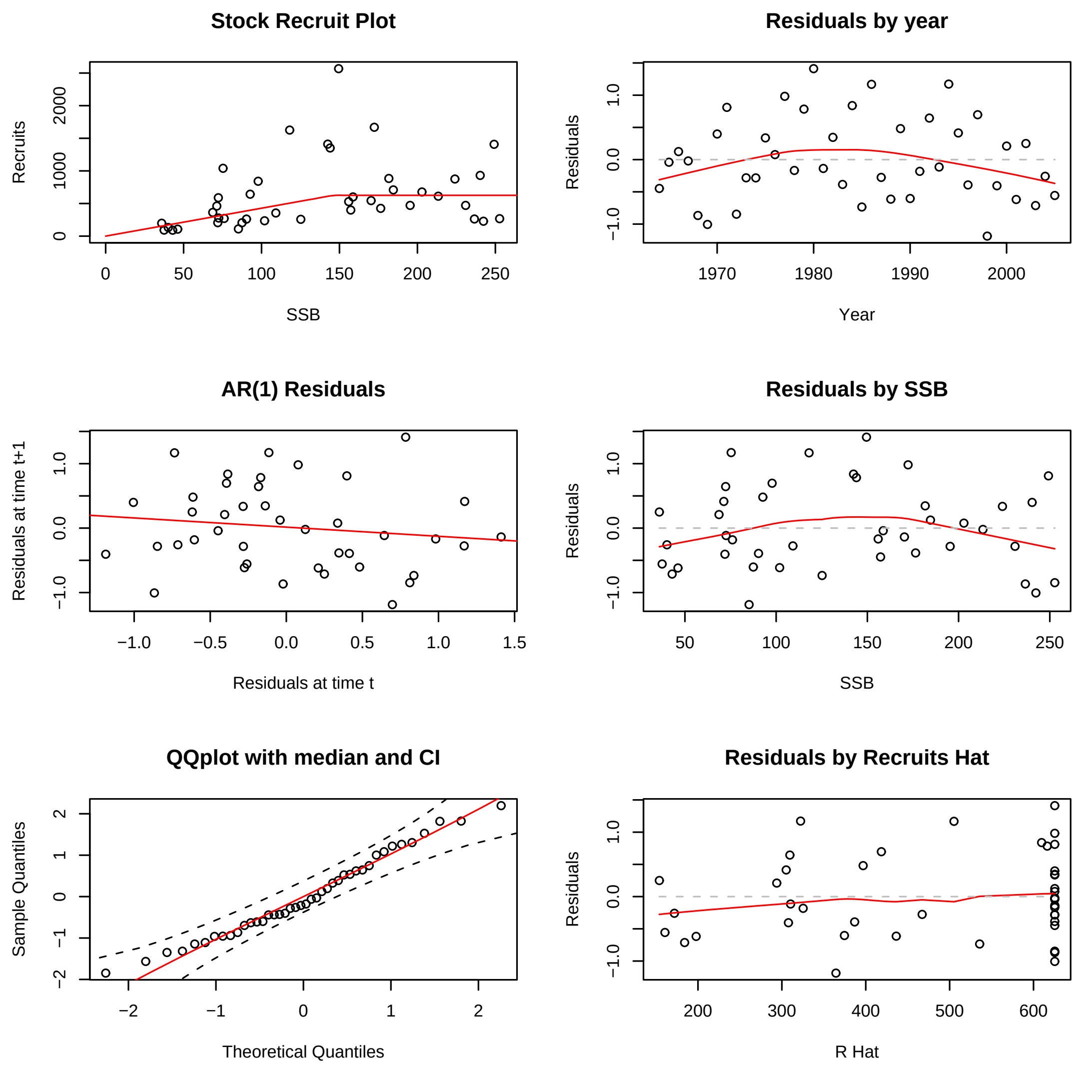

Figure 3. Stock-recruitment relation obtained by segmented regression on historical estimates of SSB and recruitment.

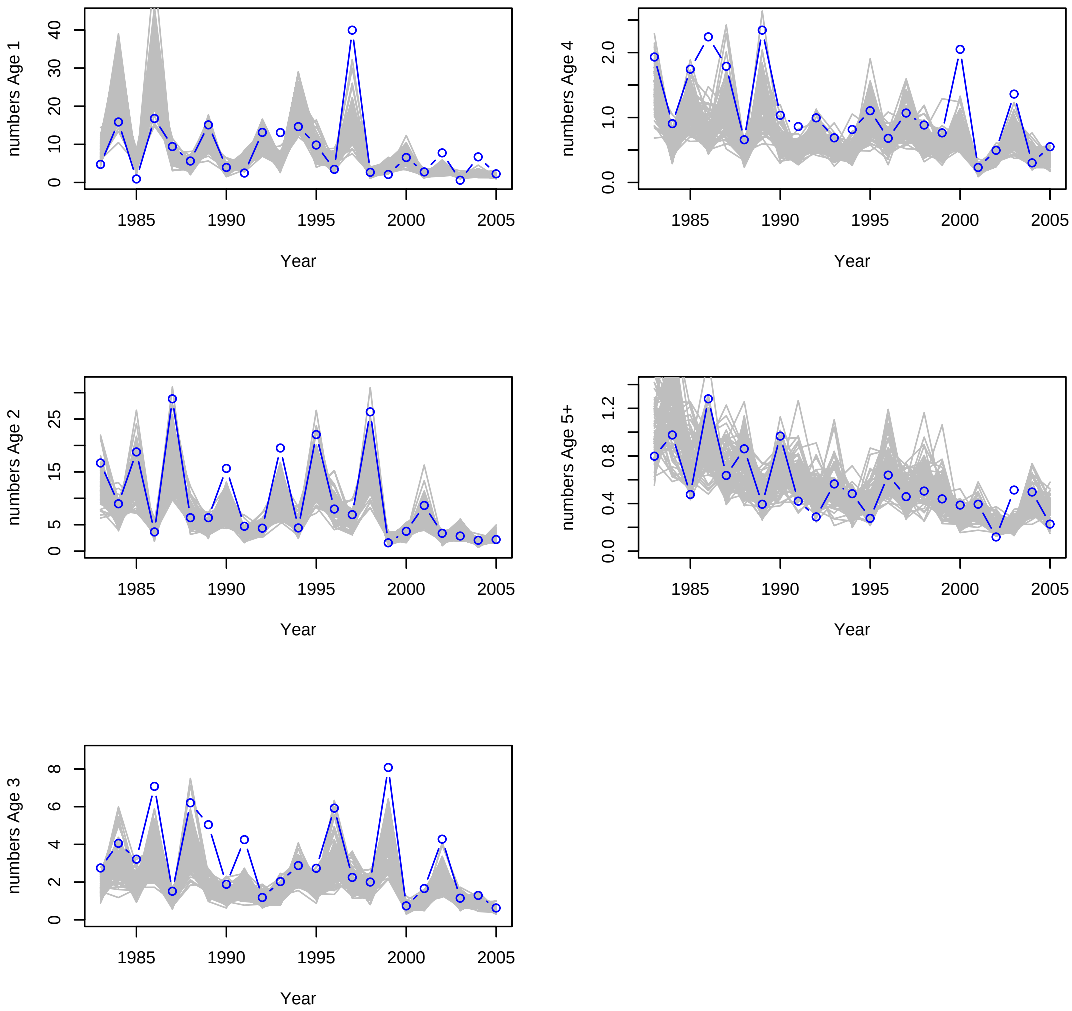

Figure 4. Survey catch numbers at age (points) with simulated observations from ICES stock estimates (grey lines) over the period 1983-2005 (100 model runs).

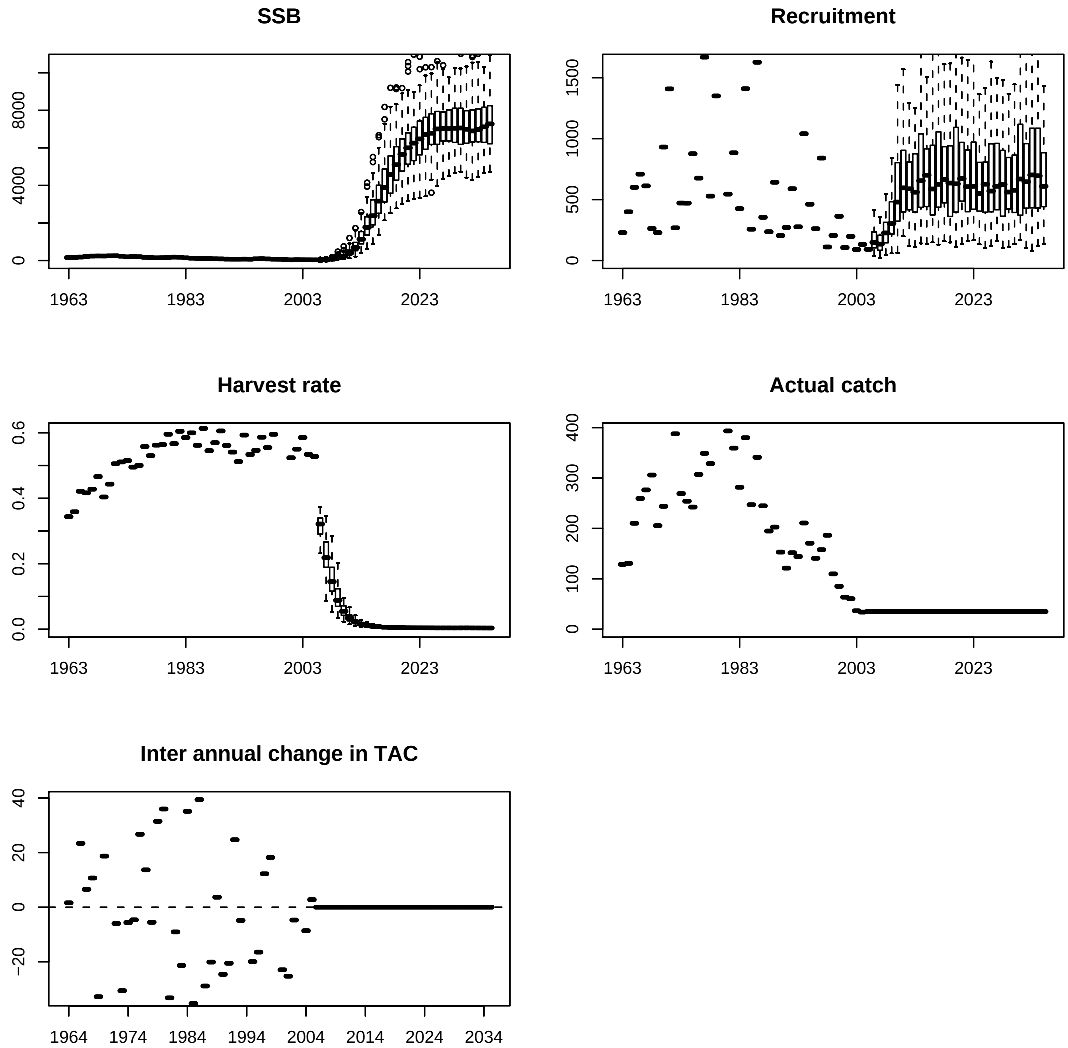

Figure 5. Results from the baseline scenario, wherein the official catch of 2005 is carried forward for the entire simulation period. Median SSB in 2035 is 7277×10^{3} t.

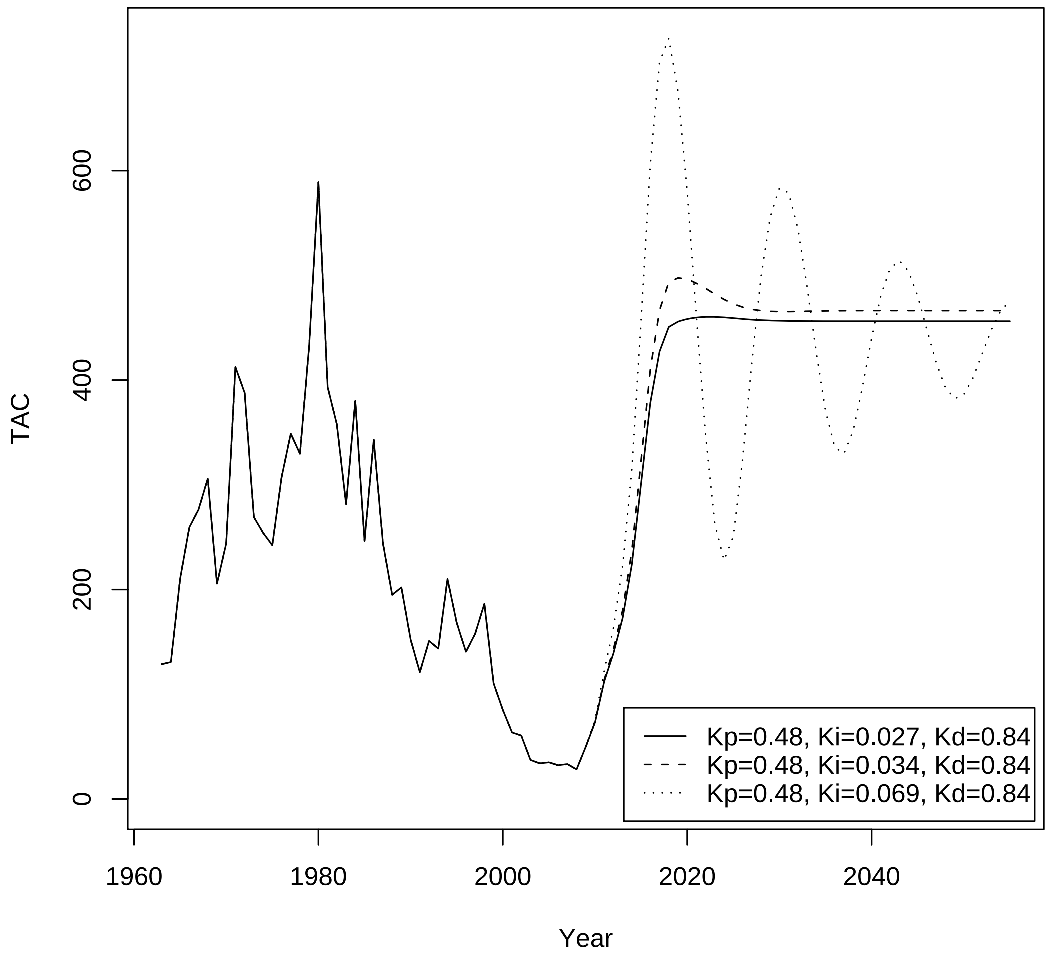

Figure 6. Deterministic model runs according to different control parameter settings for the HCR based on survey SSB. The settings corresponding to a smooth tune were subsequently evaluated in stochastic simulations, referred to as using a modified Ziegler-Nichols PID setting.

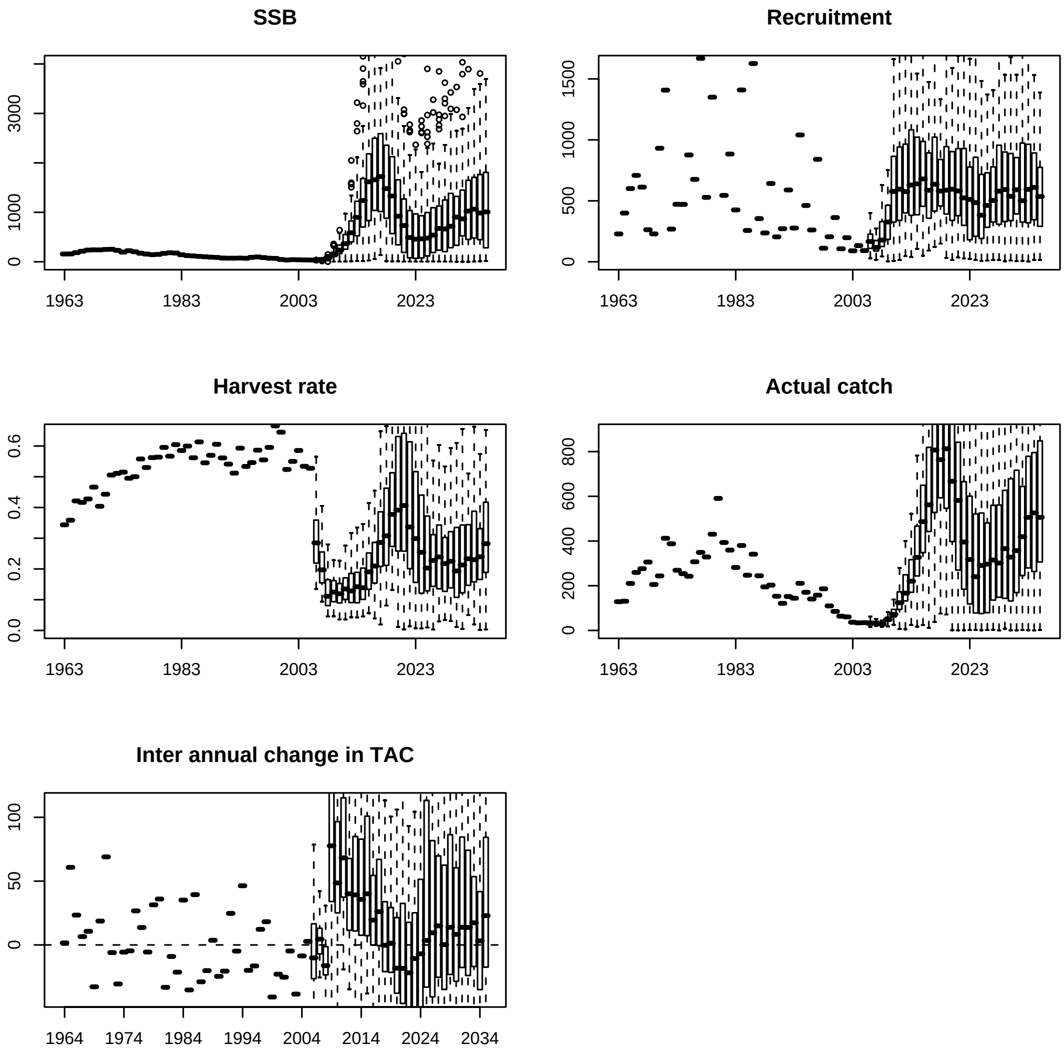

Figure 7. Results from the HCR based on survey SSB, using the standard Ziegler-Nichols PID setting: K_P=0.48, K_I=0.069, K_D=0.84 (see Fig. 6).

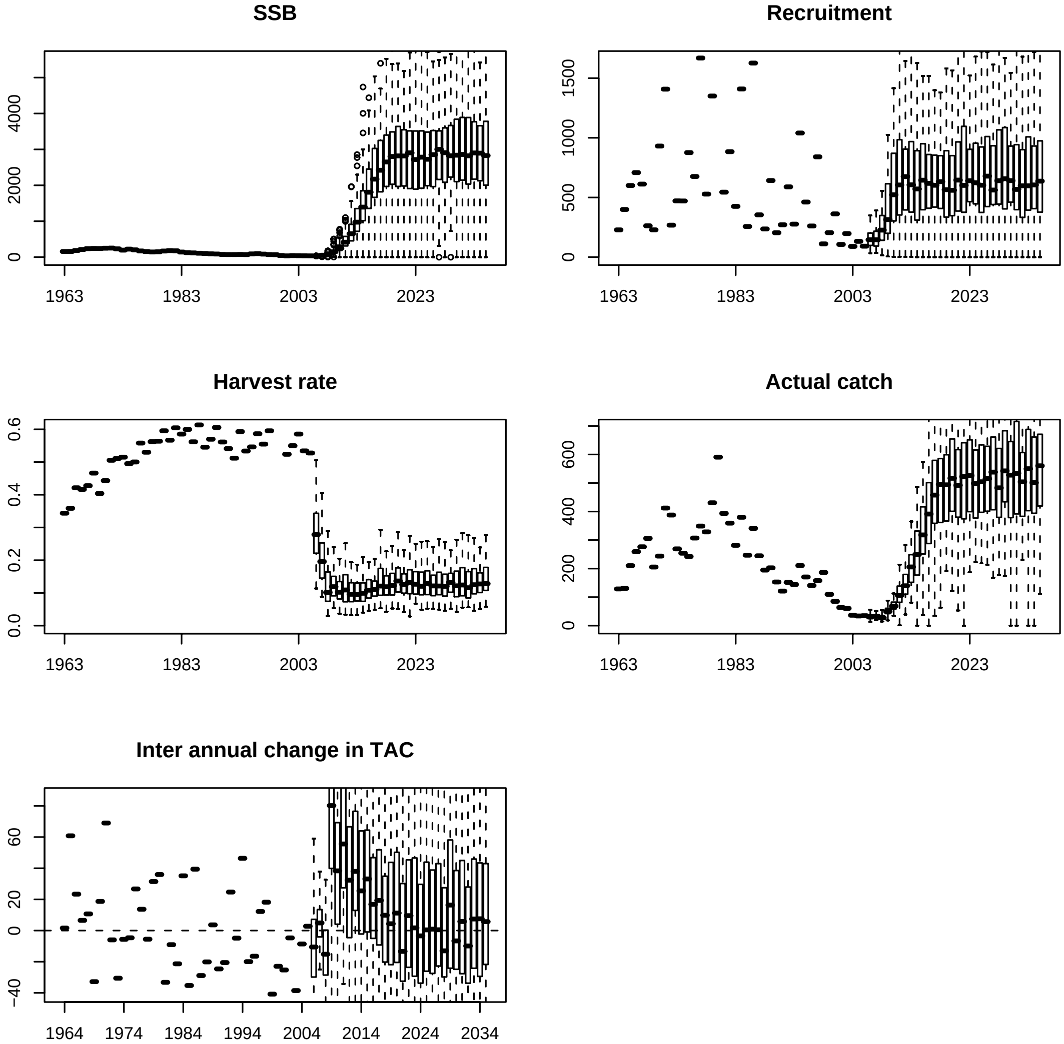

Figure 8. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting: K_P=0.48, K_I=0.027, K_D=0.84 (see Fig. 6).

Figure 9. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting and allowing for a temporary closure of cod fisheries.

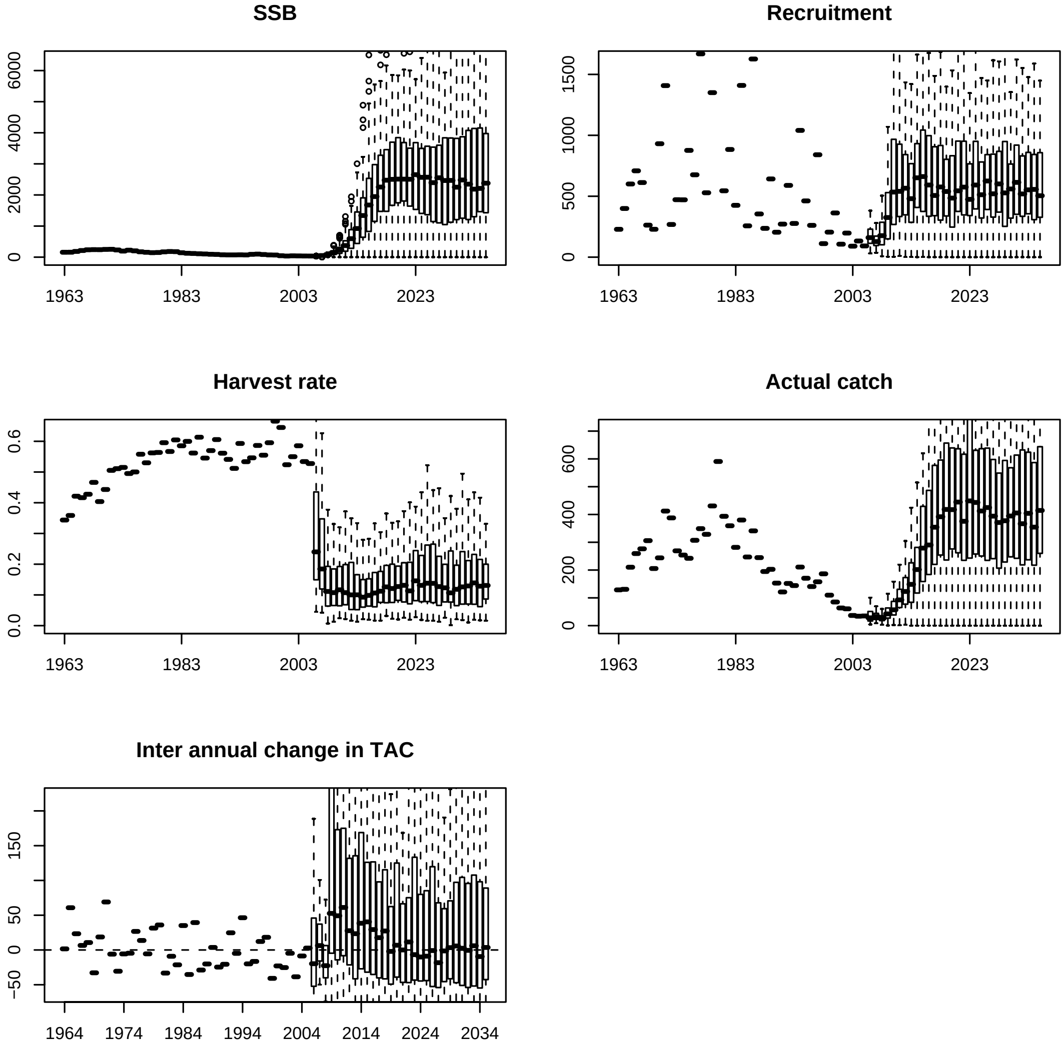

Figure 10. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting and increased noise in the survey (double the default value).

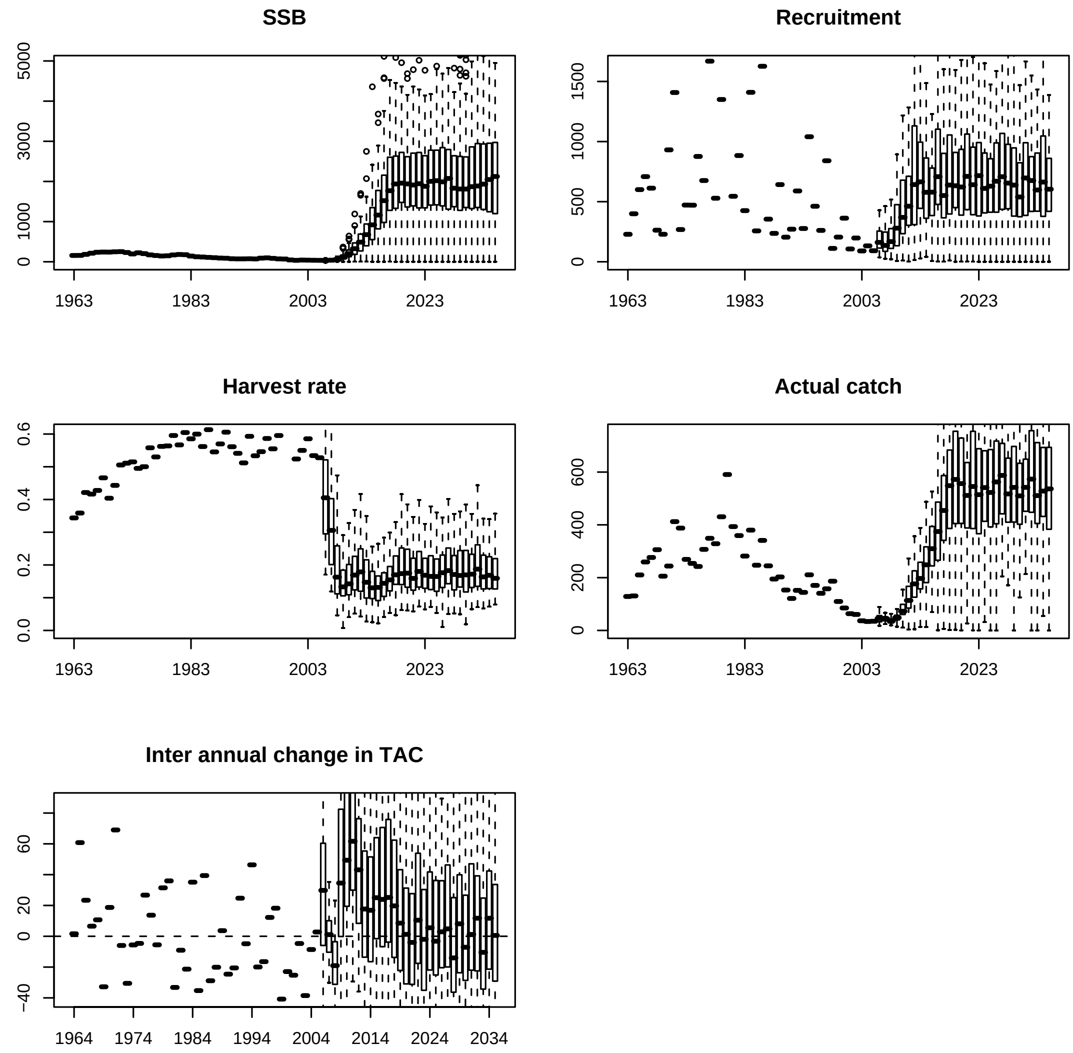

Figure 11. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting and a reporting bias of 25%.

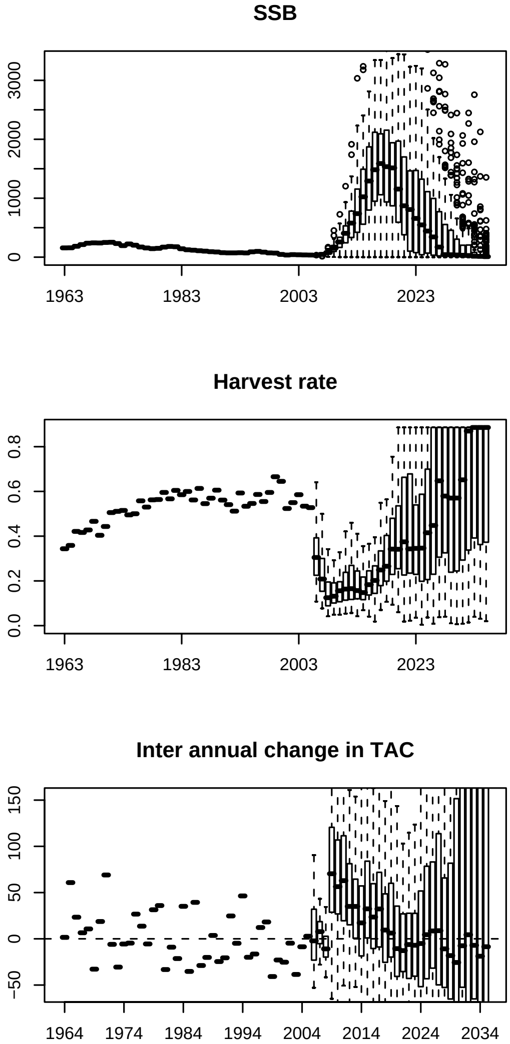

Figure 12. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting and structural overfishing of 5%.

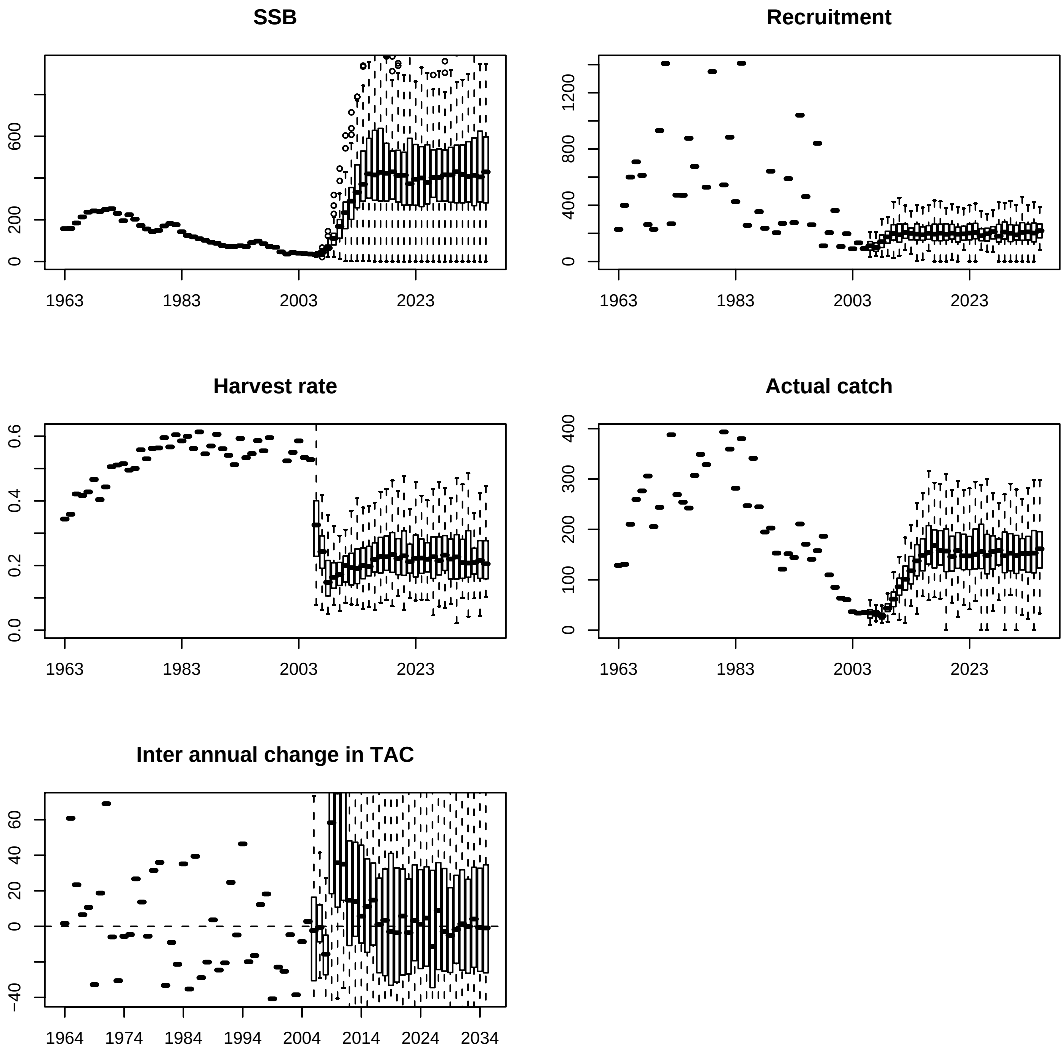

Figure 13. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting and a “hockey-stick” SR function fitted to recruitment data for 1998-2005 only, when recruitment was low.

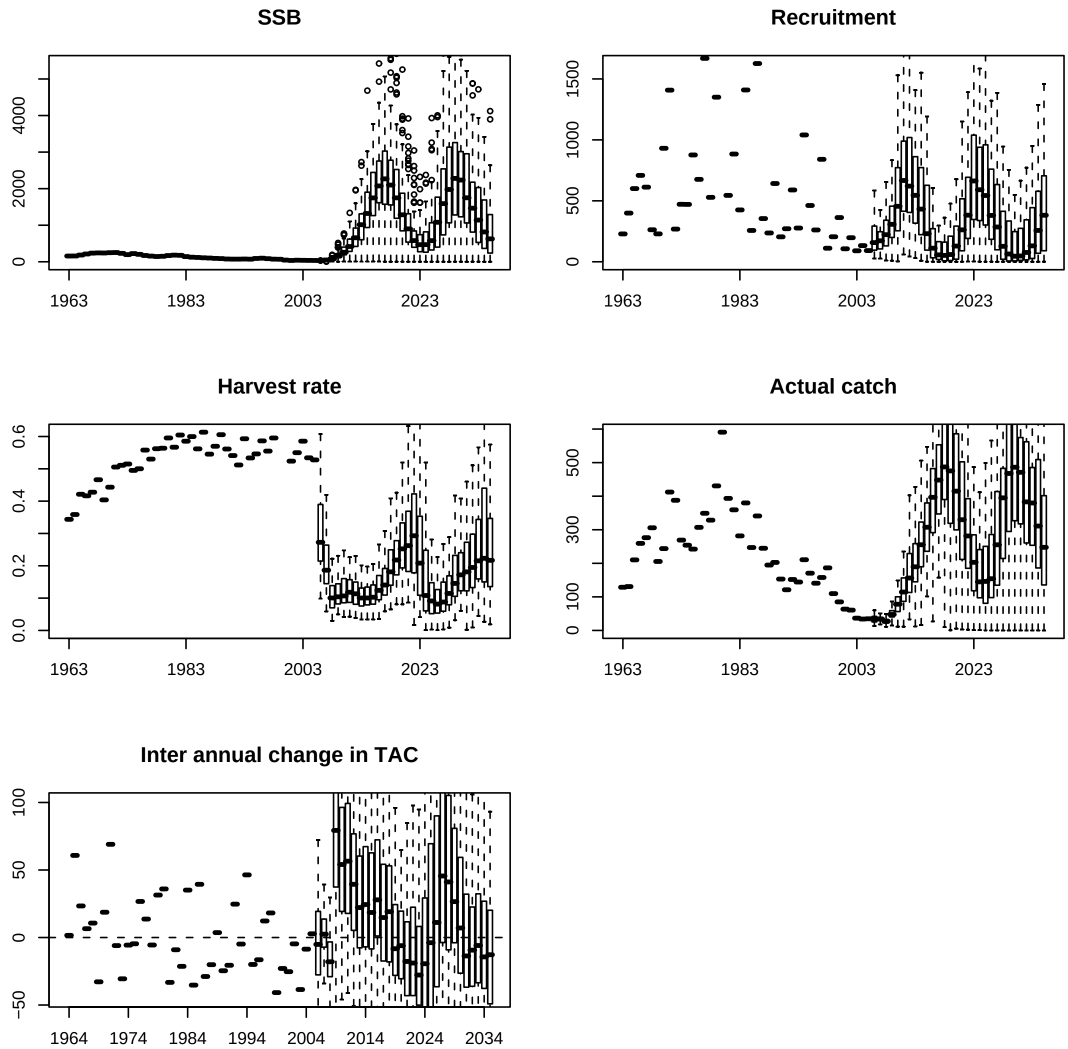

Figure 14. Results from the HCR based on survey SSB, using a modified Ziegler-Nichols PID setting and a Ricker-type SR function.

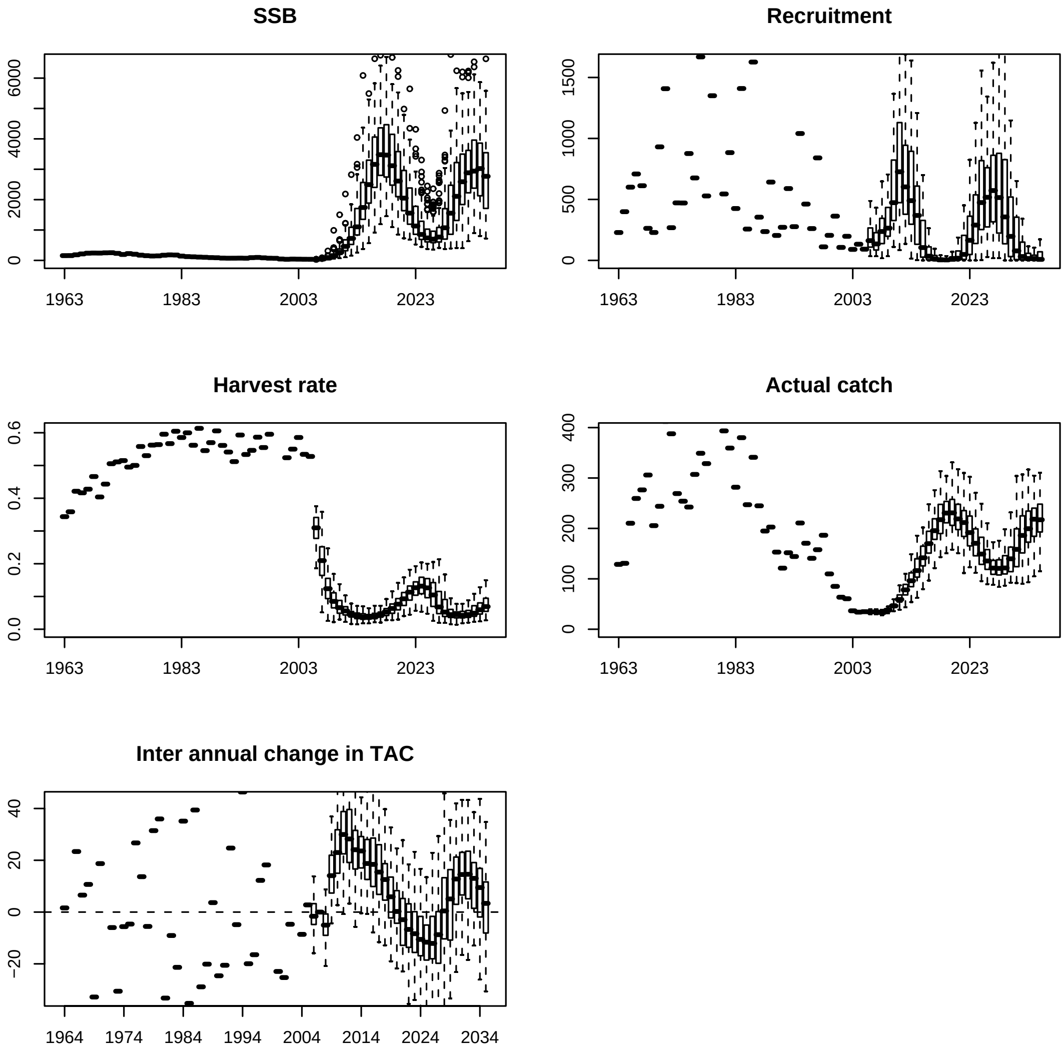

Figure 15. Results from the HCR based on survey SSB, using the standard Ziegler-Nichols setting for a strictly proportional controller and a Ricker-type SR function.

Figure 16. Simulated (grey) and historical (black) recruitment resulting from the HCR based on survey SSB, using the standard Ziegler-Nichols setting for a strictly proportional controller and a Ricker-type SR function.

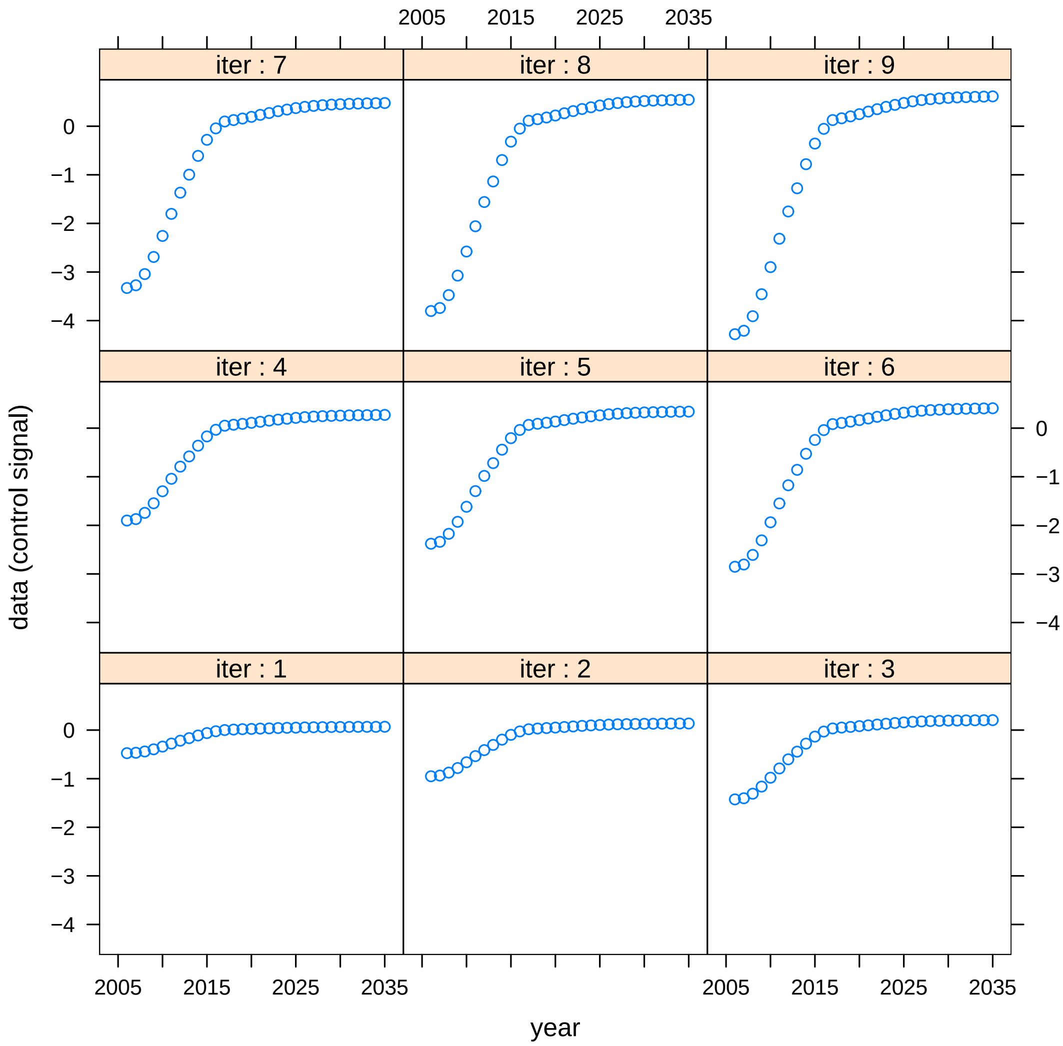

Figure 17. Control signal from applying the Ziegler-Nichols approach to tuning the HCR based on YCC with a fixed zero target for the linear trend in Z. The control parameter K_P is increased from 0.1 to 0.9 from iteration 1 to iteration 9. Because no critical gain parameter could be identified, the HCR with a fixed target was omitted from further investigation.

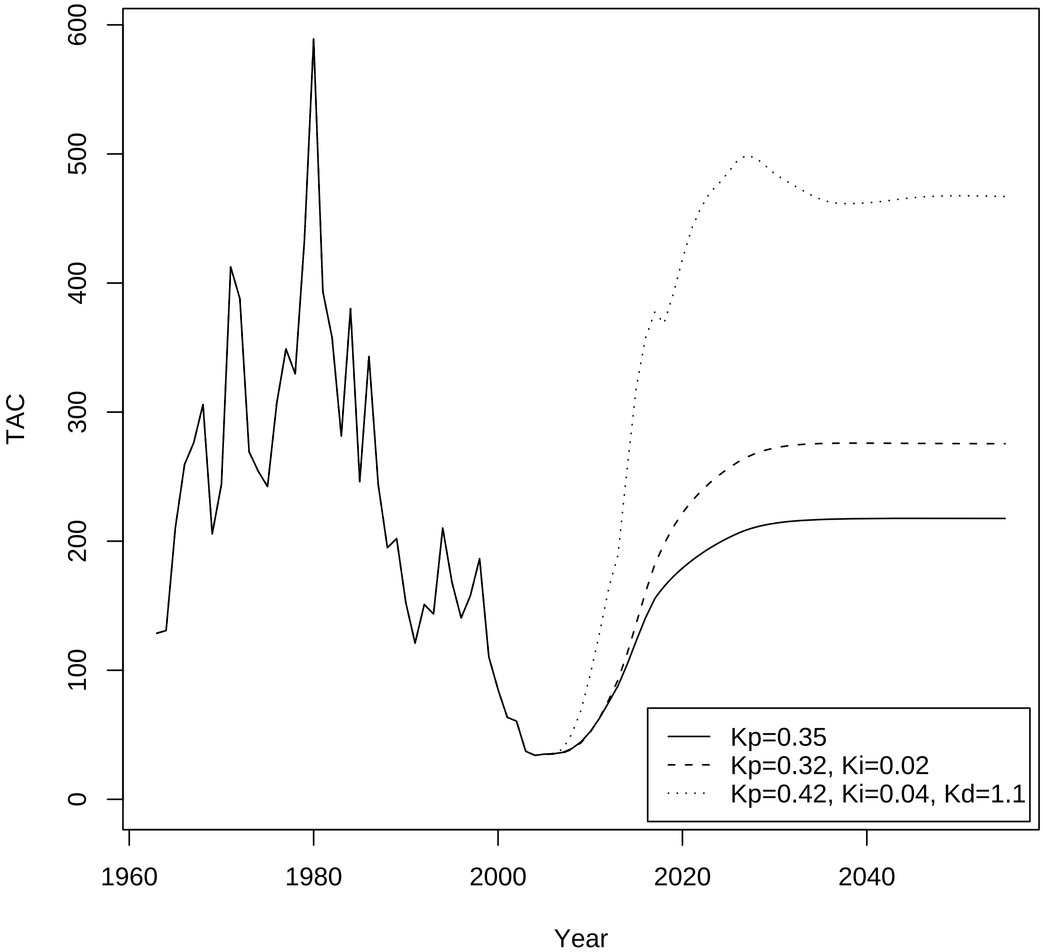

Figure 18. Deterministic model runs according to different control parameter settings for the HCR based on YCC using a moving target. Standard Ziegler-Nichols settings are shown; the ones corresponding to PI control were subsequently evaluated in stochastic simulations.

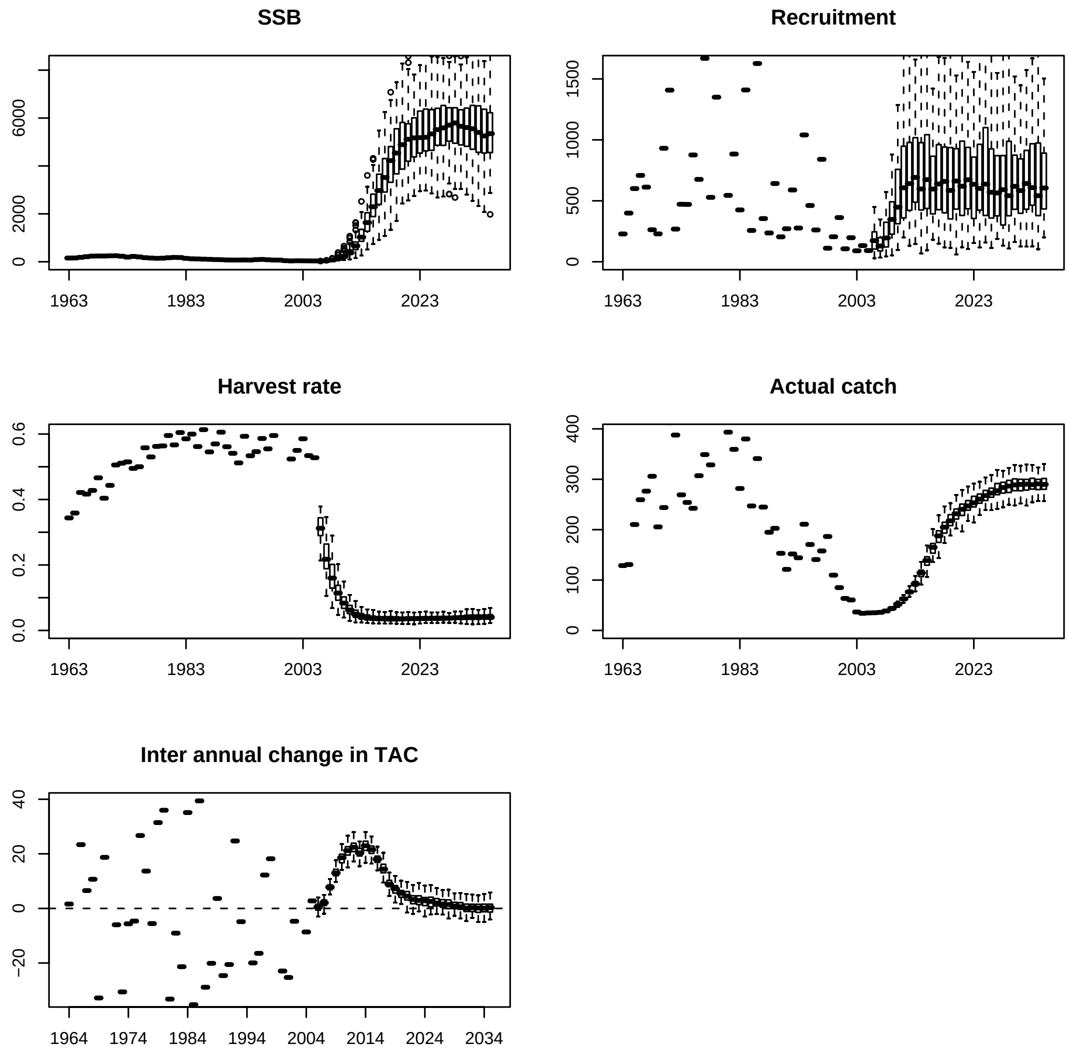

Figure 19. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting: K_P=0.32, K_I=0.02, K_D=0 (see Fig. 18).

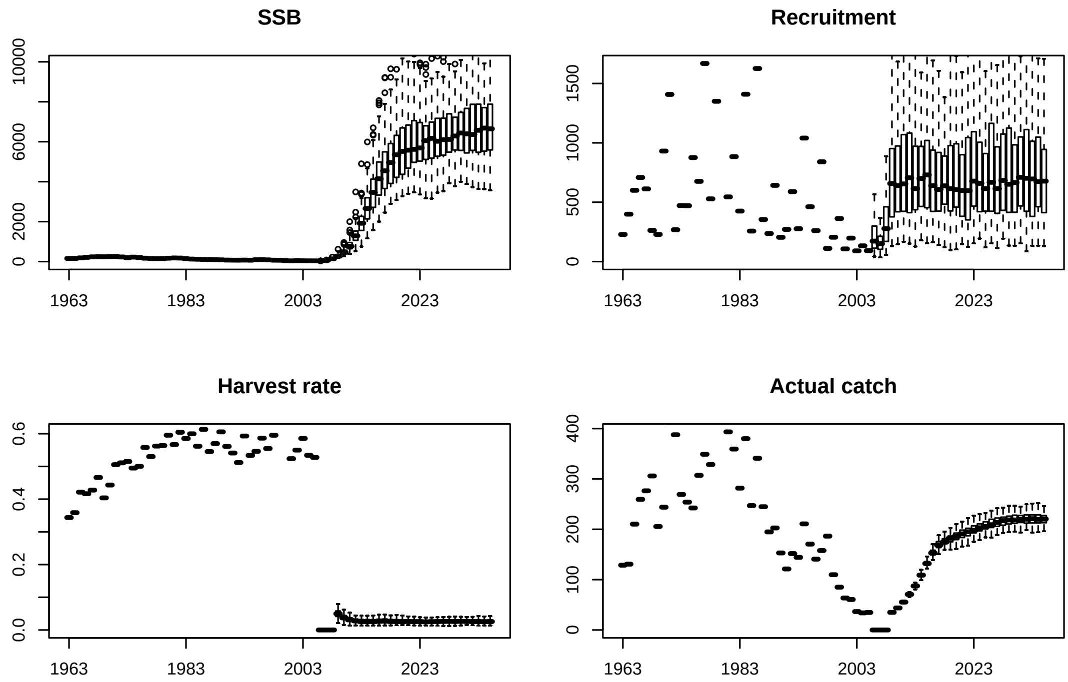

Figure 20. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting and allowing for a temporary closure of cod fisheries.

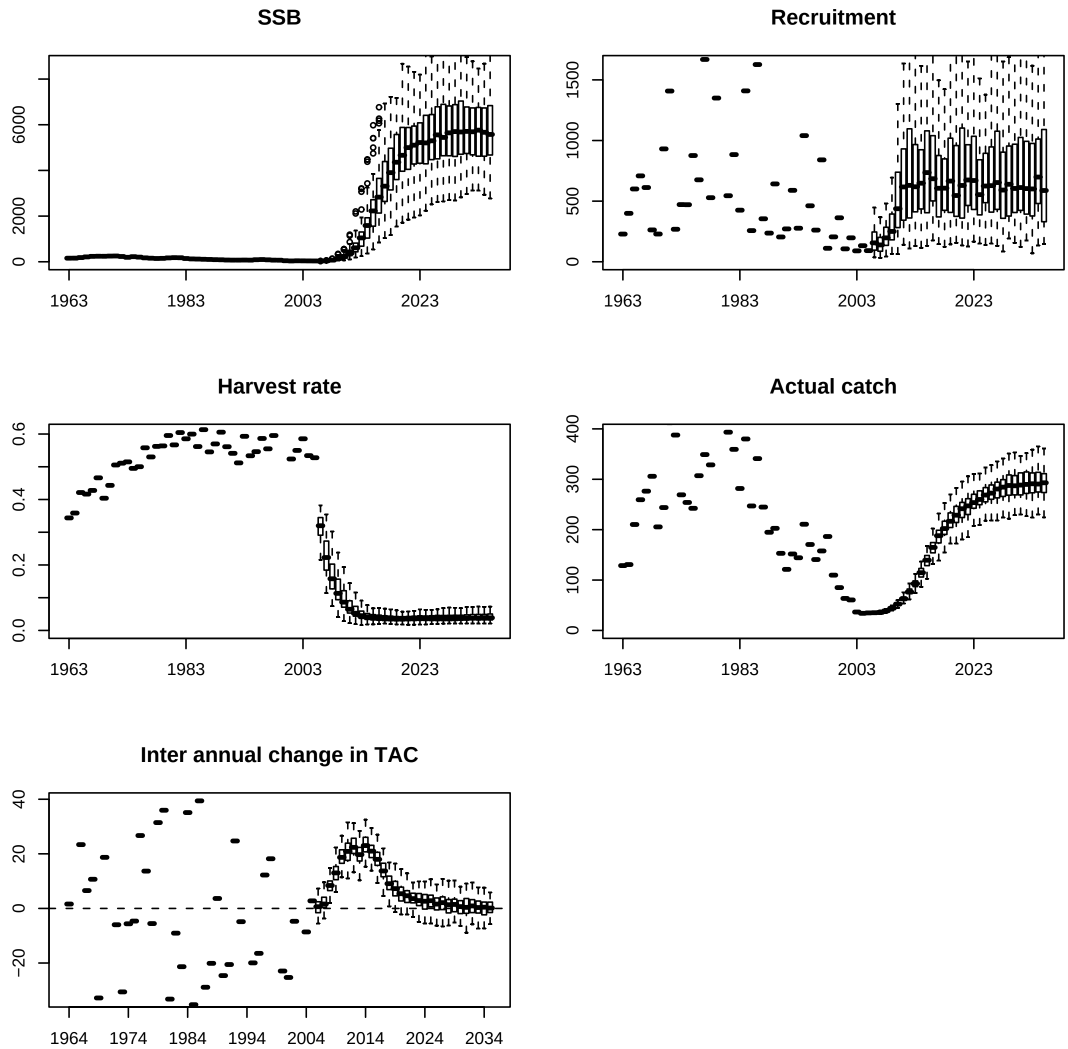

Figure 21. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting and increased noise in the survey (double the default value).

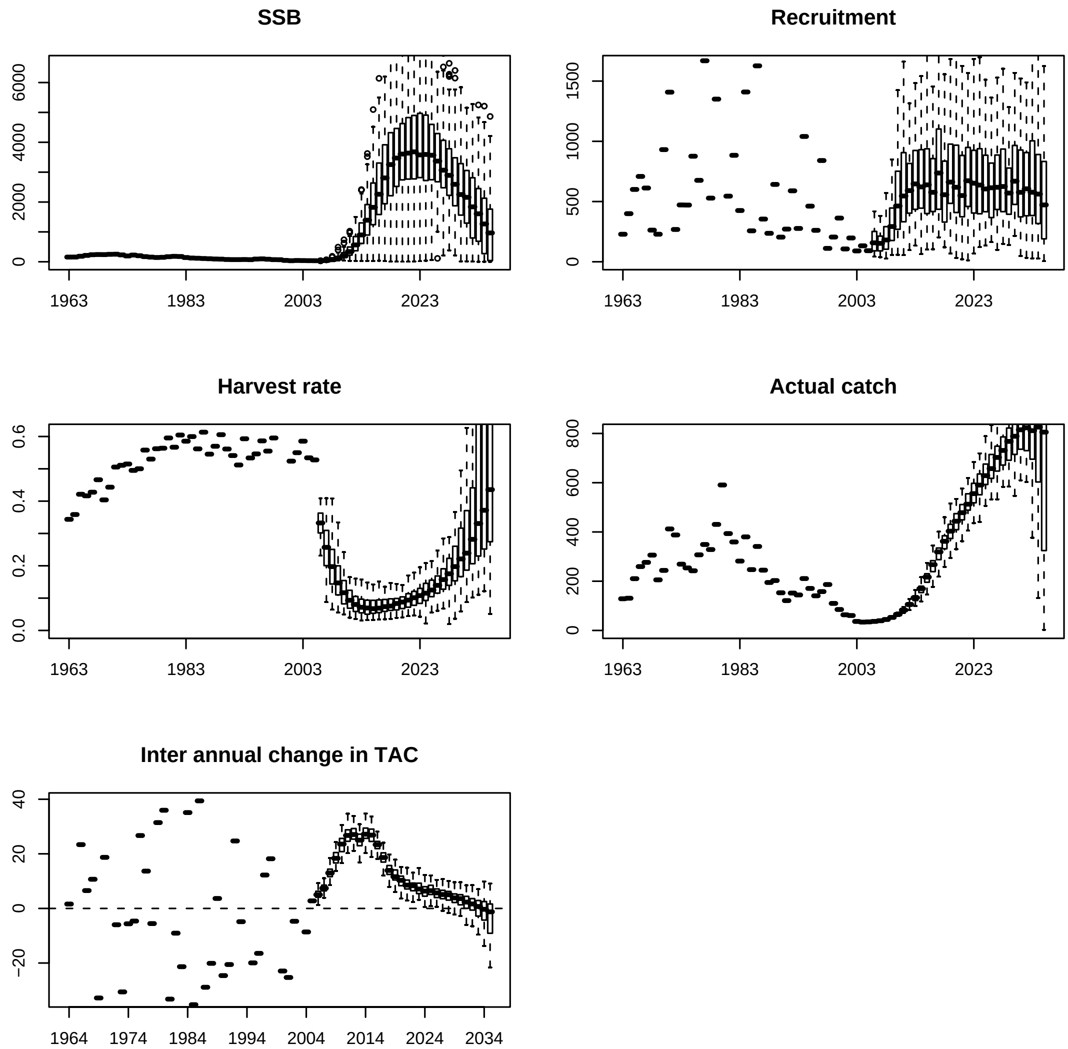

Figure 22. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting and a reporting bias of 5%.

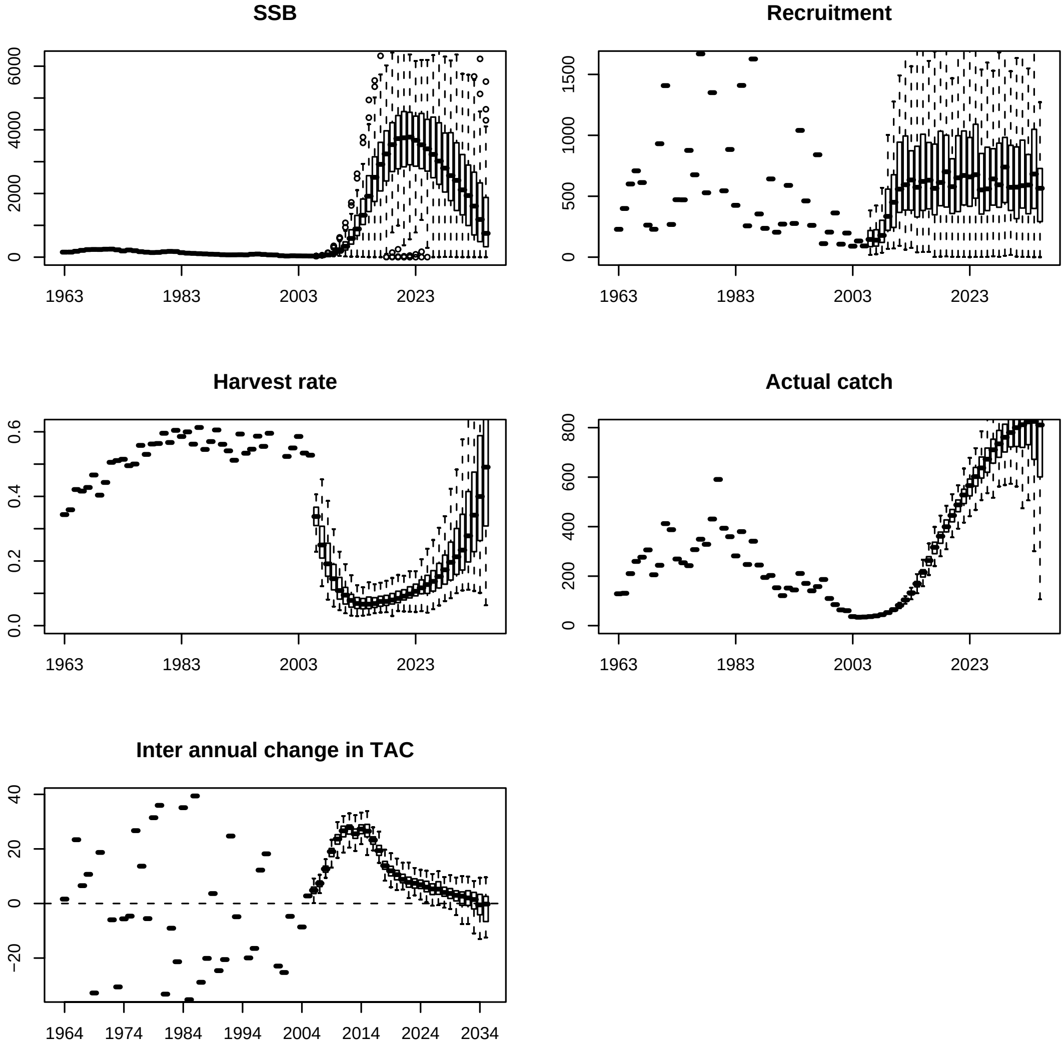

Figure 23. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting and structural overfishing of 5%.

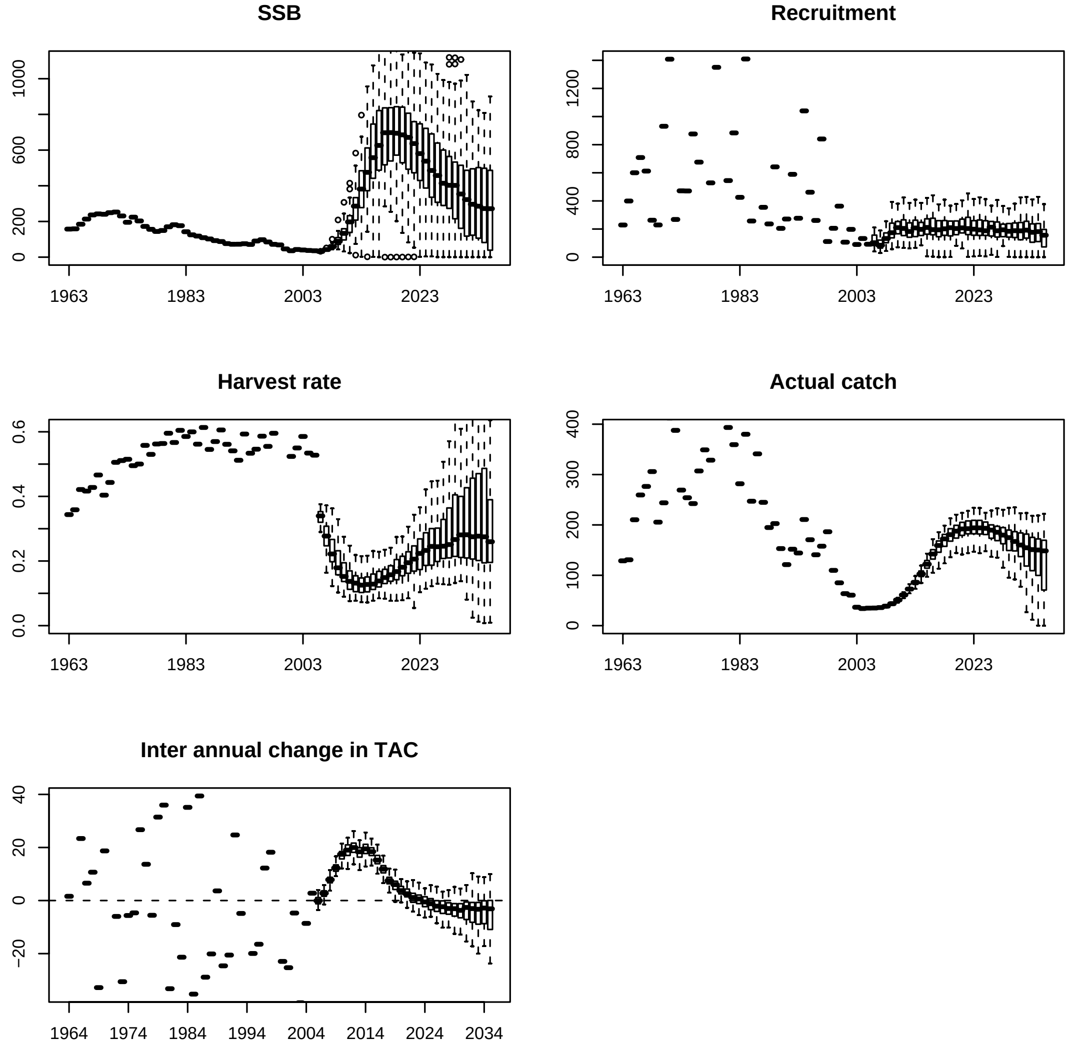

Figure 24. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting and a “hockey-stick” SR function fitted to recruitment data for 1998-2005 only, when recruitment was low.

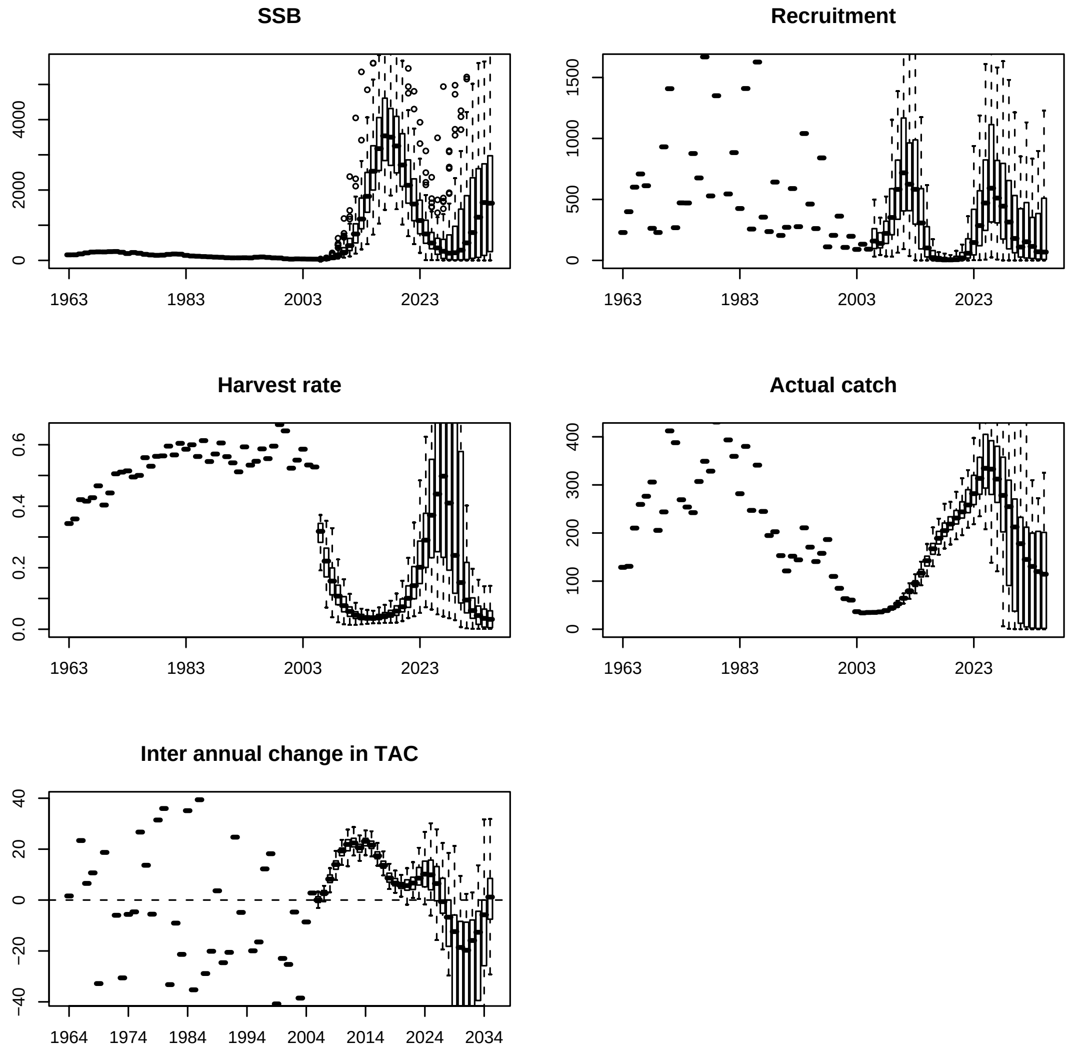

Figure 25. Results from the HCR based on YCC, using the standard Ziegler-Nichols PI setting and a Ricker-type SR function.

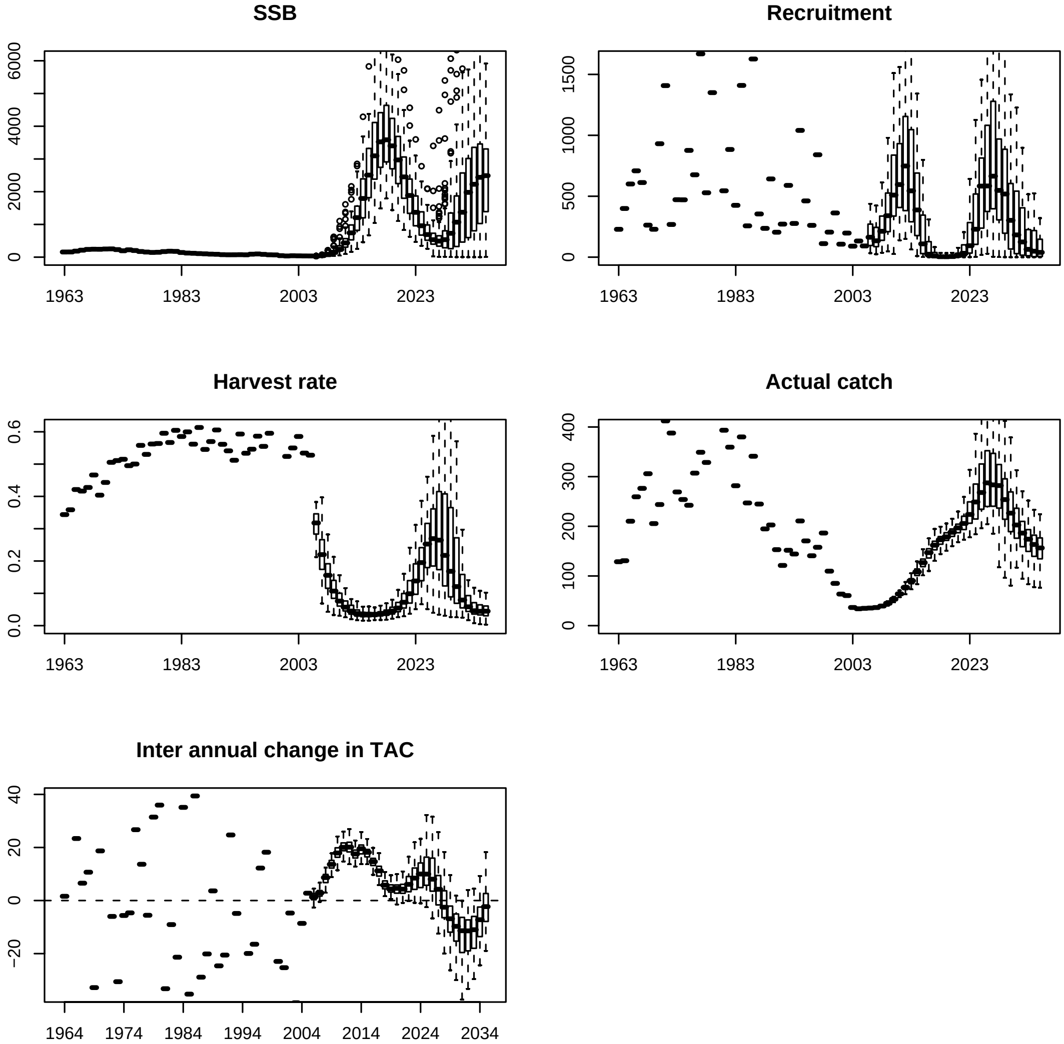

Figure 26. Results from the HCR based on YCC, using the standard Ziegler-Nichols setting for a strictly proportional controller and a Ricker-type SR function.

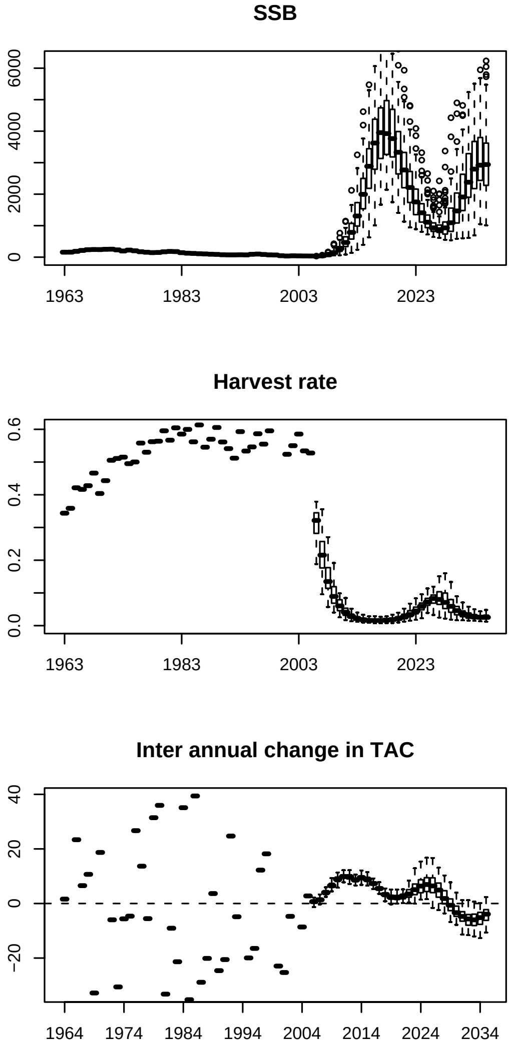

Figure 27. Results from the HCR based on YCC, using a very conservative proportional controller ($K_P = 0.175$) and a Ricker-type SR function.

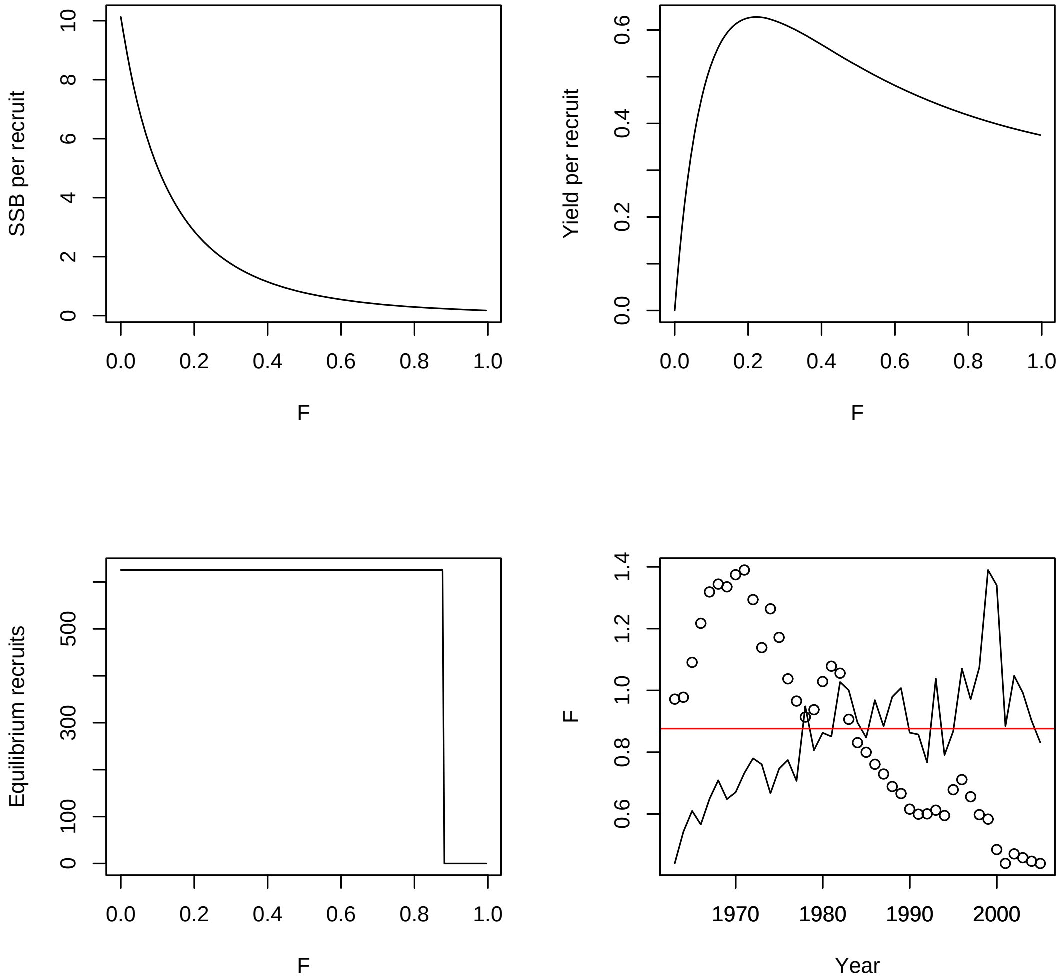

Figure 28. Analytical results from the model with a “hockey-stick” SR function. SSB per recruit diminishes with increasing fishing mortality (upper left). The fishing mortality corresponding to a maximum yield is 0.22 (upper right), whereas the SR function allows a maximum fishing mortality of 0.87 (lower left). This limit is plotted as a reference line in the historical estimates of fishing mortality (lower right; SSB estimates plotted as circles). Since the 1960s, fishing pressure has been above the level implicated by MSY; since the late 1970s, fishing pressure has been unsustainably high.

Simulation Evaluation with FLR

North East Artic Cod

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The objective of this simulation study is to look at the performance of different harvest-control-rules (HCR) operating without fishery data under different level of survey-based information and different level of noise.

1.1 *Description of the species*

The NEA cod is economically important for several countries, e. q. Norway and Russia. The stock is an important predator in the Barents Sea ecosystem. There have been observed large variation in growth rate, mean weight at age, maturity and degree of cannibalism. These fluctuations have been linked to water temperature, food supply and abundance of cod and capelin. (Annon 2006)
ICES describe the stock as overexploited in terms of fishing mortalities in relation to highest yield and agreed target. Further ICES describe the harvest as unsustainably in terms of fishing mortalities in relation to precautionary limits and management plan (Annon 2006).
Historical spawning stock biomass (SSB) is shown in Figure 1. The SSB have been increasing since 2000 until 2004 and decreased in 2005. The catches have increased since 2000 until 2005 as shown in Figure 2.

1.2 *Parameterisation of the model*

We have conditioned our model using historical data from ICES form the period of 1984 to 2005. The model contains ages 1-11, where the last age group is a plus group. Selectivity, maturity and weight at age are fixed as averages over three last years. Due to cannibalism we have high mortality values for the younger ones. There is big fluctuation in the degree of cannibalism, without any clear pattern; therefore mortality is bootstrapped for age 1-3 and fixed at 0.2 for older fish. The last year with historical data is 2005, so the simulation starts in 2006.

The first part of the parameterisation of the model is the stock-recruitment (S-R) function. We have tried different models, but ended up with a hockey-stick function.
We modelled the recruitment at age 1. Many model for this stock model the recruitment at age three to smooth the effect of cannibalism and varying recruitment. In the mid nineteen's there was some very high recruitments. These "outliers" make it difficult to estimate the parameters in the S-R function.

First we tried to set these parameters manually. After removing the five highest recruitments in the mid nineteen's the hockey-stick function fit the data very well, but the residuals are too small. It is possible to construct a more complex S-R function with two levels of recruitments and a binominal distribution between the two levels. However a function of this type is not easy to implement within the framework of the FLR/Fisboat software.
The chosen recruitment function overlaid historical data is shown in Figure 3 together with different diagnostic plots.
Looking at the S-R plot of the full dataset, a Ricker function may fit the data better. The noise in the S-R function is limited to be within (0.1, 2) of the predicted values of the model.

Selectivity at age is estimated from normalized Z-values. A selectivity curve averaged over year 2003 to 2005 is shown in Figure 4, together with an average maturity curve.

The main parameter describing the parameterization of the operating model is summarized in Table 1.

Analyzing the first year with simulated data, using a average mortality based on the three last year's, we find a maximum sustainable harvest rate HR_{msy} = 0.222 equivalent to a fishing rate F_{msy} = 0.25. A stock in equilibrium will give a maximum sustainable yield (MSY) around 493 * 103 tones and a total stock biomass (TSB) around 2 735 * 103 tones based on an average recruitment on 2 672 * 106 individuals. The highest observed TSB is around 4.2 million tons in 1946, due to a period with low fishing pressure during the war. Relative maximum sustainable yield (MSY) is shown in Figure 5. Note that the MSY highly depends on the mortality rate used in the analyses.

From now on when referring to the stock we implicit means the simulated or virtual stock. We will not discuss in which degree this virtual stock reflects any properties of the true stock. Any conclusions in this paper may only be valid for the virtual stock.

1.2.1 Signal from the stock

We mimic a bottom trawl survey which gives us number at age with different level of error added. We use fixed selectivity equal to one for all year-classes for the survey which gives us an unbiased index. We will use signal in the biomass and the total mortalities for different year-groups.

1.2.2 Other constrains

The fleet is only allowed to take 90% of the TSB. We consider this as a realistic property of the fleet. This rule will not affect the probabilities of economic extermination of the stock. A catch equal to 90% of TSB will give a harvest rate very close to one because of the selectivity.

1.3 *Harvest control rule (HCR)*

A HCR respond on the signal (the stock index or the signal form the assessment) by adjusting the total allowable catch (TAC), based on last year's TAC and the signal form the stock. Here we will only look at a linear response. We will try to use the HCR on the raw signal form the index, but we will also try to smooth the signal with assessment tools. The first one is often called model free. The HCR is limited to adjust the TAC with maximum 80% per year downwards and 200% upwards. The different HCR's are tuned with a deterministic operating model.
We have used a PID-controller as a HCR. PID-controller acting as HCR is described in (Bogaards 2007).

The HCR is of the form:

$$TAC_{y+1} = RT * f(\mu_y) * TAC_y$$

Where

$$RT = \begin{cases} 1, \text{ if signal in biomass (B)} \\ -1, \text{ if signal in mortality (Z)} \end{cases}$$

And the response from the HCR is:

$$f(\mu_y) = \mu_y = K_P e_y + K_I \sum e_t + K_D (e_y - e_{y-1}) + 1$$

And the error is:

$$e_y = (\text{signal}_y - \text{ref.point})/\text{ref.point}$$

1.3.1 Signal in total mortality (Z) - model free

With signal in total mortality (Z) we started with a pure D-controller, this has been referred to as a moving target rule. A gain of K_D=1.5 gave the best result. The big drawback with this rule is that it stabilizes the stock at an arbitrary level, depending on the starting condition of the simulation and the gain. A rule with a moving target and signal in total mortalities will work poorly for a stock out of equilibrium, because it only consider change in Z and don't take into account the state (level/change) of the stock.
We therefore introduce an arbitrary target of Z=0.55 (average Z over age 4 to 9).
In the work plan for this case study we proposed a pure P-controller (equal a fixed target rule) for signal in Z. Even with a very small gain K_P, a PD controller will drive the stock to the defined target. The PD controller gave a high rise time and some overshooting. We therefore decided to use a full PID controller. This was first tuned with a Ziegler-Nichols method and then slightly

modified. K_P=0.6, K_I=0.13 and K_D=1.08 gave a good result with signal in Z. This tuning is shown in Figure 6.
Our signal in Z is an average over different ages. It isn't clear witch age that gives the strongest signal; we therefore tried different set of ages. Some of the ages just smooth the signal. Therefore we ended up with using the age from four to nine.
The model free Z rule with this tuning gave us as yield around 530 * 10^3 tones and a TSB around 1720 * 10^3 tones.

1.3.2 Signal in total mortality - assessment

We have implemented year-catch-curve (YCC) assessment see (Cotter et al. 2007).
We choose to use one qualitative variable describing year-class-strength and individual slope for each year, described in equation (1) in S notation.

(1) log(cpue) ~ -1 + as.factor(yrclass) + as.factor(year):age

We used the ratio between the average predicted Z values from this year's assessment compared to the same value from last year's assessment. We find this signal to be stronger compared to looking at the two last years from the last assessment. We could not find any tuning values with the Ziegler-Nichols method. The manual tuning K_P=0.5, K_I=0.12 and K_D=0.4 seems to stabilize the stock in deterministic runs, seen in Figure 7. This tuning overshoots the target a little bit.
With the target of Z=0.55 and this tuning the stock stabilize at a TSB around 1760 * 10^3 tones and a yield of 540 * 10^3 tones.
Only a small change in the starting condition of the simulation alters the tuning in a radical way. Therefore we conclude that it is not advisable to use signal in Z alone to manage this stock without other information (i.e. fisheries statistics).

1.3.3 Signal in biomass (B) - model free

For signal in biomass we used biomass of age two to eleven as an index. Since our selectivity is equal to one for every age class, our index is therefore identical to the true TSB, except from biomass of the age one and the noise added.
A fixed target rule (or a pure P controller) will work poorly with a signal in biomass. Given a signal above the target and a decreasing stock, the rule will still increase the TAC until the signal is below the target. This will accelerate the decreasing in the stock and often deplete the stock. Therefore we will not consider pure fixed-target rule together with signal in biomass.
A moving target rule (pure D controller), as proposed in our working plan, stabilise the stock at an arbitrary level with a gain around K_D=1.5. This stabilise the stock at a TSB around 1 300 * 10^3 tonnes and a yield around 465 * 10^3 tonnes. Using information only from age two to seven alter the picture. We get

larger fluctuation in the stock and we need longer time to stabilize the stock. And we also need a higher gain parameter.
For signal in biomass (B) we tuned a PID-controller with an arbitrary target of 2000 * 10^3 tonnes total stock biomass (TSB). This is near the maximum observed biomass in our data. We then tested this rule with arbitrary levels of 1600 and 1200 * 10^3 tonnes TSB, the optimum gain was K_P=0.1, K_I=0.01 and K_D=1.4. This tuning is shown in Figure 8. The target of 2000 * 10^3 tonnes TSB gave a yield around 565 * 10^3 tonnes and an average Z of 0.49.
The target of 1600 *10^3 tonnes TSB gave a yield around 515 * 10^3 tonnes and an average Z of 0.58.
The target of 1200 * 10^3 tonnes TSB gave a yield around 410 * 10^3 tonnes and an average Z (age 4:9) of 0.74. This tuning doesn't perform well with this target, another tuning may perform better.

1.4 Simulations

All simulations have been projected for 30 years. Some of the simulation has been run for 60 years to check that they really converge and are stable. Every simulation has 100 iterations each. Each simulation is started with a new seed value. We have defined a set of scenarios and we want to see how well the different HCR perform within these scenarios. The scenarios are summarised in Table 2. The performance is described both graphically and with different performances statistics. The different statistics are described in (Ibaibarriaga 2007). The statistics for the different HCR under the scenarios described in Table 2 are summarized in Table 3.

1.4.1 Deterministic runs

We started with deterministic projection of the data to see how well the different HCR will perform under perfect (data) condition. We project the stock for five year with zero catches using the built-in stock-dynamics in the operating model (OM) as a test. This test shows that the stock will decline in 2006 and then increase thereafter. A fixed TAC equal to the catch in 2005 (641 * 10^3 tonnes) will drive the SSB below both B_{lim} = 220 * 10^3 tonnes and B = 50 * 10^3 tonnes within five year. We can conclude from this that we need a HCR that can reduce the TAC rapidly. This reduction can be achieved with a flexible rule. The catch in 2005 is not sustainable in this model. An alternatively way of starting the simulation is to close the fisheries for some years and let the stock recover and then applying the different HCR's. This approach has only been tested to a low extent. We belief that it will be easier to control the stock in this case.

1.4.2 Signal in total mortalities (Z) - model free

The HCR based on information in Z is very sensitive to noise in the simulation, specially the CV in the survey index, but also the bootstrapped M values for the young age classes. Because of the weak signal in the data, we are not able to stabilise the stock at any equilibrium, and the catches will slowly decrease on average and the stock grow on average. See Figure 9. The stock is growing five to ten times bigger than observed in the past twenty years.

1.4.3 Signal in total mortalities - assessment

Our prior belief was that an assessment model like YCC would perform better than the raw signal from the survey. As seen in Figure 10 we are not able to control the stock in a better way with an assessment tool. There can be many explanations for this; we may have not chosen the best regression model within YCC, or the best signal from the assessment. An assessment tool will smooth your signal. An assessment tool may smooth a weak signal to much and you will not be able to react on any change in trends. Assessments normally involve human interpretation; this is of cause impossible in simulations.

1.4.4 Signal in biomass (B) - model free

We started testing the pure D controller with adding different source and levels of noise to the model. As described in chapter 1.3.3 a gain of 1.5 worked well in a deterministic model. The controller was able to stabilise the stock at an average level within the observed biomass in the period from 1984 to 2005. As shown in Figure 11, even with a CV of 40% in the survey, index the HCR is able to control the stock. The D controller stabilise the stock at a low TSB.

The PID controller described in chapter 1.3.3 was tested with three different targets.

We will not recommend the target of TSB = 1 200 * 10^3, because the probability of SSB being below B_{lim} is very high and the probability of the actual catch being lower than the decided TAC is very high. The last probability is equal to the probability of the TAC being greater than 90% of the total stock!

The D controller perform more or less equal to the PID controller with a target of 1 600 * 10^3. This is little bit surprising, since the D controller stabilise the stock at a level around 1300 * 10^3.

All the tested rules used approximately ten year to stabilise the stock at the given target.

2 Discussion

With only looking at the summary graphics, without the performance metrics, one can conclude that the HCR rule based on biomass are more robust against error and noise than the rule based on information in total mortalities, since they are the only one that stabilise the stock. It is also clear that only a small amount of variation in the recruitment will have a great effect on the stock. If one allows for large inter annual variation in TAC it is possible to manage the stock without data from the fisheries.
Every simulation shows that the stock and the catches will decrease first five years and then increase; given the recruitment in the model. It also shows that the catches of 2005 are not sustainable.

In this work the only density depended regulating mechanism is the stock-recruitment function in terms of recruit per spawner. In nature no stock can grow to infinity. Limitation in habitat, prey and competition from other specie will interact with the stock and one will expect to find density dependent effects elsewhere as well; for example in age at maturity, fecundity and mean weight at age etc. Such mechanism might prevent the stock form growing out of control in some simulations. This is also a signal that could be used in a HCR.
In this paper mean weight at age and maturity at age has been constant; this is of cause not true in nature. Further we have treated the age at known without error.

The signal in B and Z can easily be combined into one signal and may perform better. We have only used one index per year; more indices may provide more information so that we are able to control the stock within the uncertainties in the model.

The bootstrapped natural mortalities values for the young age classes are an important source of noise in the model. We have trimmed the stock-recruitment data used to estimate the S-R function. We think that the combined effect of these error sources together with the error in the survey index varying from CV=10% to CV=40% is realistic. As seen in Figure 9 to Figure 12 the variation in the simulated recruitment span the variation in the observed recruitment, except from the high recruitment in the mid nineteen's.

With only one survey index per year we are only able to control the stock with information from the biomass signal.

There are many way to judge the performance of a HCR. Only looking at one performance metric it is easy to draw the wrong conclusion. For example if you set a fixed TAC equal zero (or very small); the stock will steadily increase. In this case the probabilities of the biomass going under some reference limit will of cause be very small and the inter annual change in TAC will also be zero, but the yield will be very low or zero.

For the HCR with a fixed target or a reference point, the time the rule needs to bring the stock to the target is also of interest and the abilities to keep the stock near the target once there are also of interest.
None of the HCR's responding to signal in total mortalities (Z or YCC) is able to stabilise the stock near the given target.
With only one survey index per year we are only able to control the stock with information from the biomass signal. But we will have a high probability of SSB going below B_{lim}. The probability is varying from 3% to 35% percent on average, depending on controller, target and CV of index. The probability of the same occurrence, happen at least once, is varying from 40% to 100%. Without any auxiliary information we will have a very high probability of the stock going below B_{lim}.
The probability of the actually catch being below the decided TAC is varying from 2% to 24% percent on average, depending on controller, target and CV of index. The probability of the same occurrence, happen at least once, is varying from 33% to 99%. Without any auxiliary information we will have a very high probability of setting a TAC that is too high. From a fisherman and an economics perspective the yield and the inter-annual change in TAC are of most interest. The median yield will vary from 342 to 494 $*10^3$ tonnes and the inter-annual change in TAC will vary from 14% to 35% in both directions. The yield is within the observed value in the historical data.

The objectives of this paper have been to investigate if it's possible to manage a stock like the NEA cod without fishery statistics. We conclude that this is possible if you have at least one scientific survey per year, providing a biomass index.

No statement in this paper should be interpreted as official policy of the EC or the author's employers.

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Ref Type: Unpublished Work

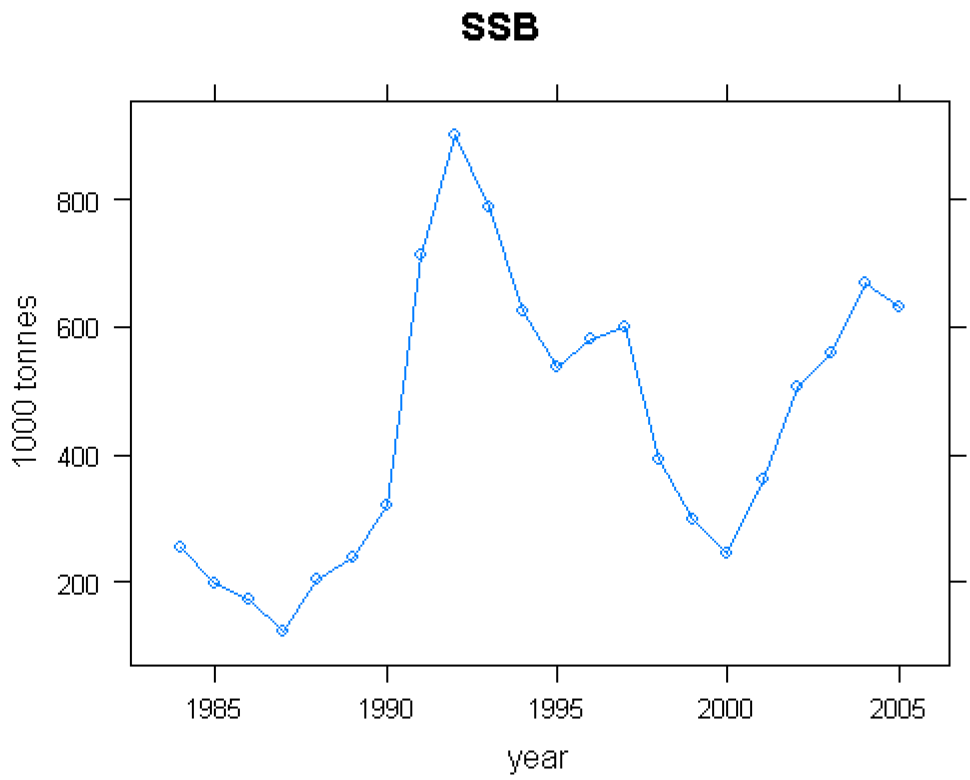


Figure 1 Spawning stock biomass for historical data

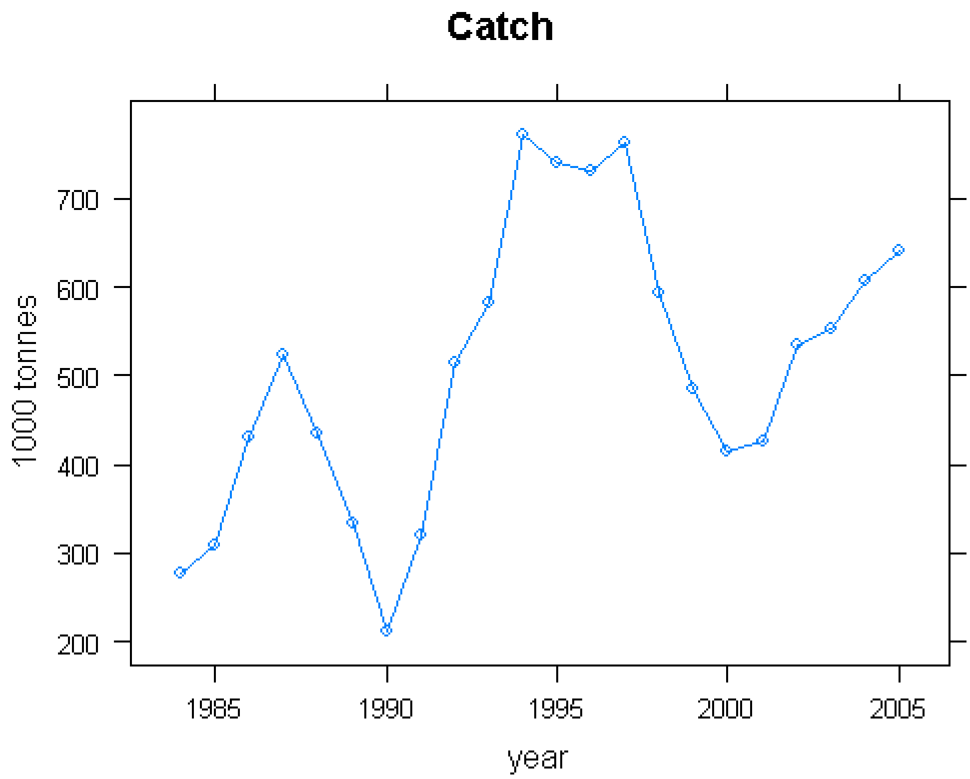
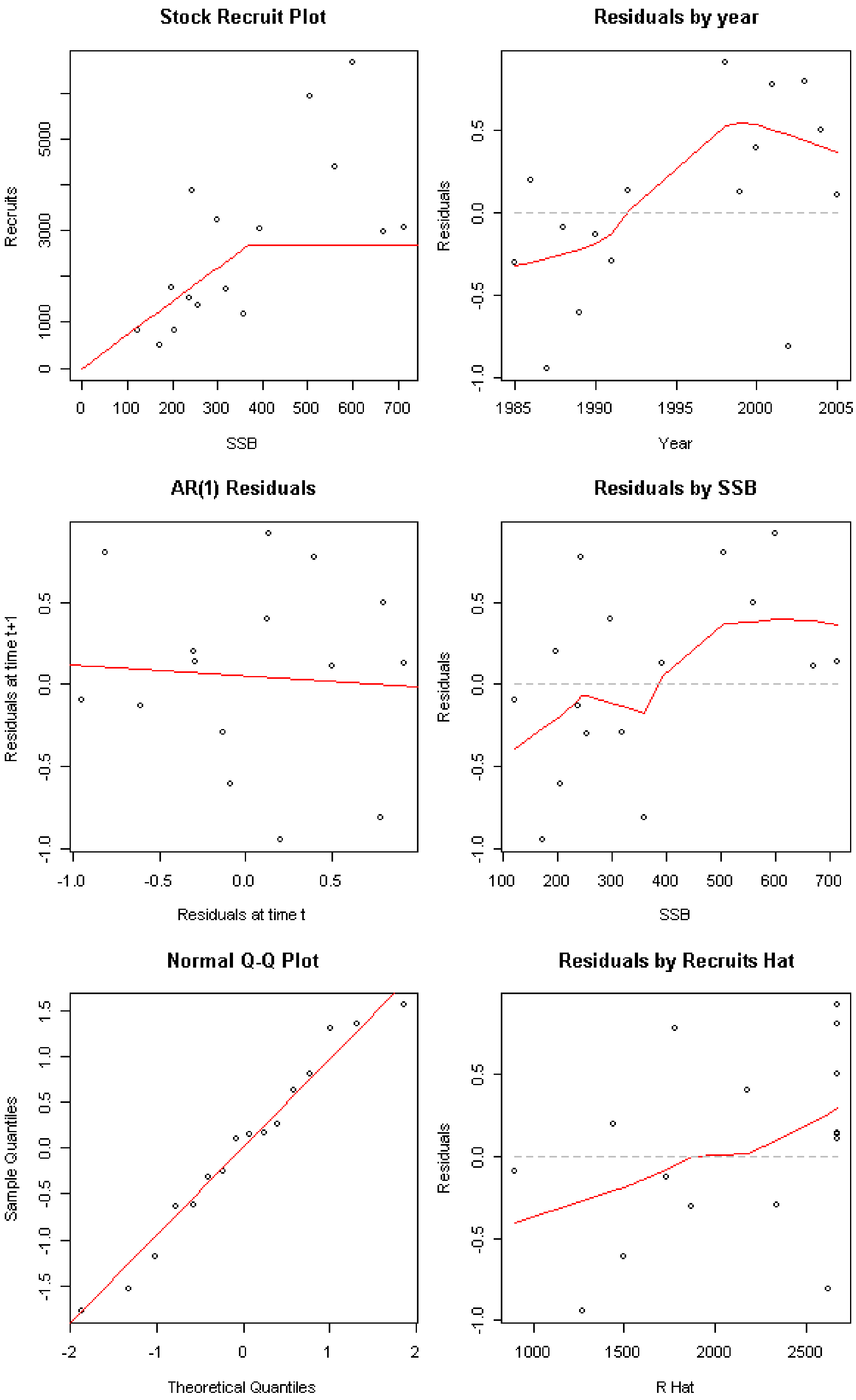


Figure 2 Historical catches



Stock Recruit Plot
Recruits
SSB
Residuals by year
Residuals
Year
AR(1) Residuals
Residuals at time t+1
Residuals at time t
Residuals by SSB
Residuals
SSB
Normal Q-Q Plot
Sample Quantiles
Theoretical Quantiles
Residuals by Recruits Hat
Residuals
R Hat

Figure 3 Stock recruitment function

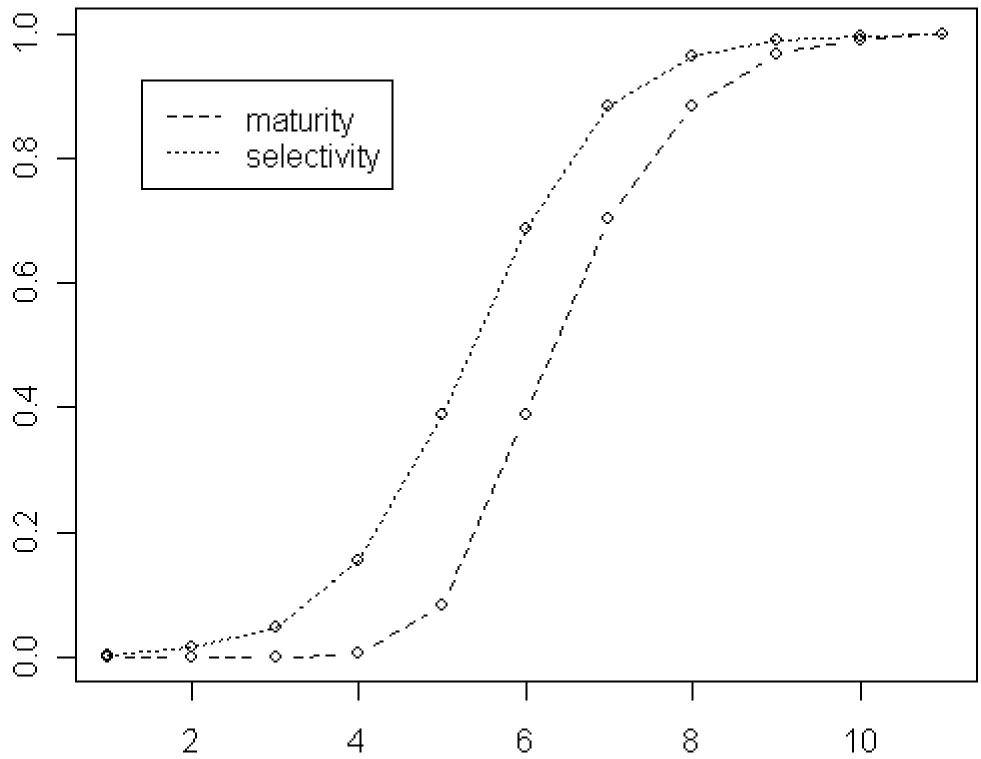


Figure 4 Selectivity and maturity, average over data from 2003 to 2005

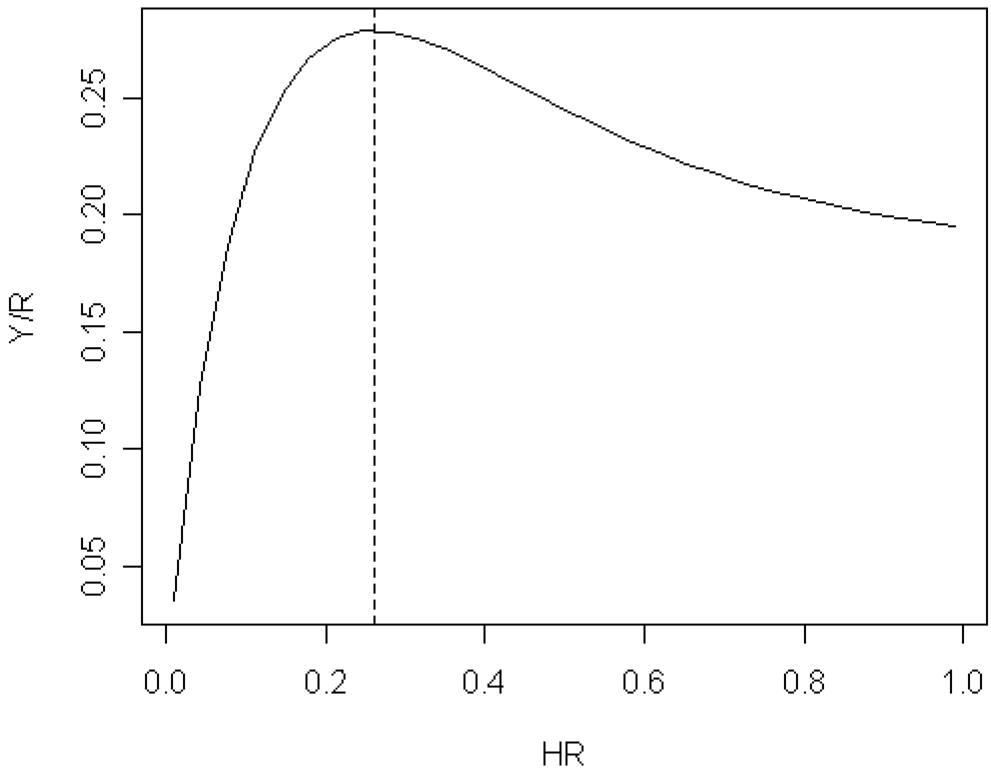


Figure 5 Yield per recruit for 2006

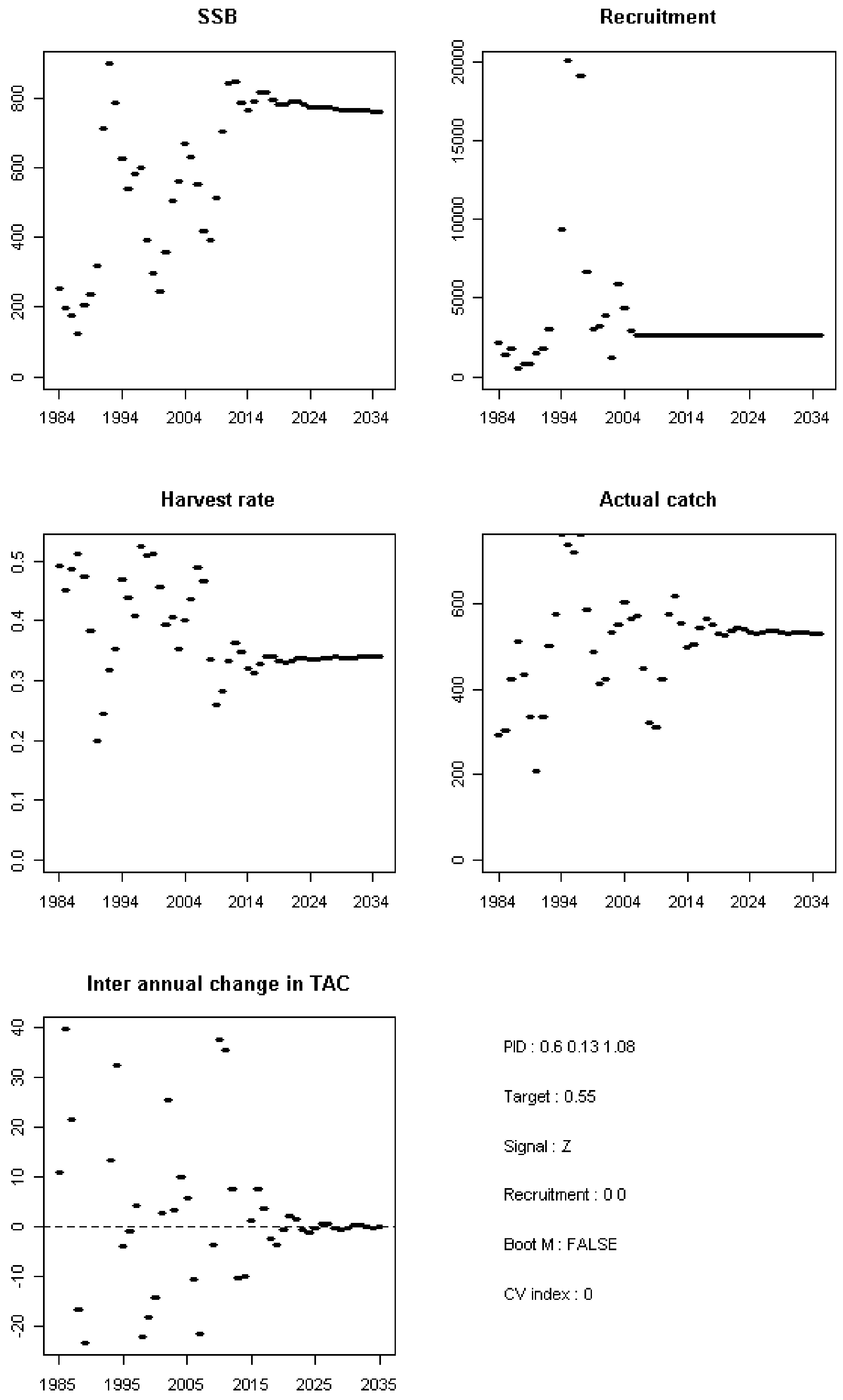


Figure 6 Deterministic run, signal in Z, target Z=0.55

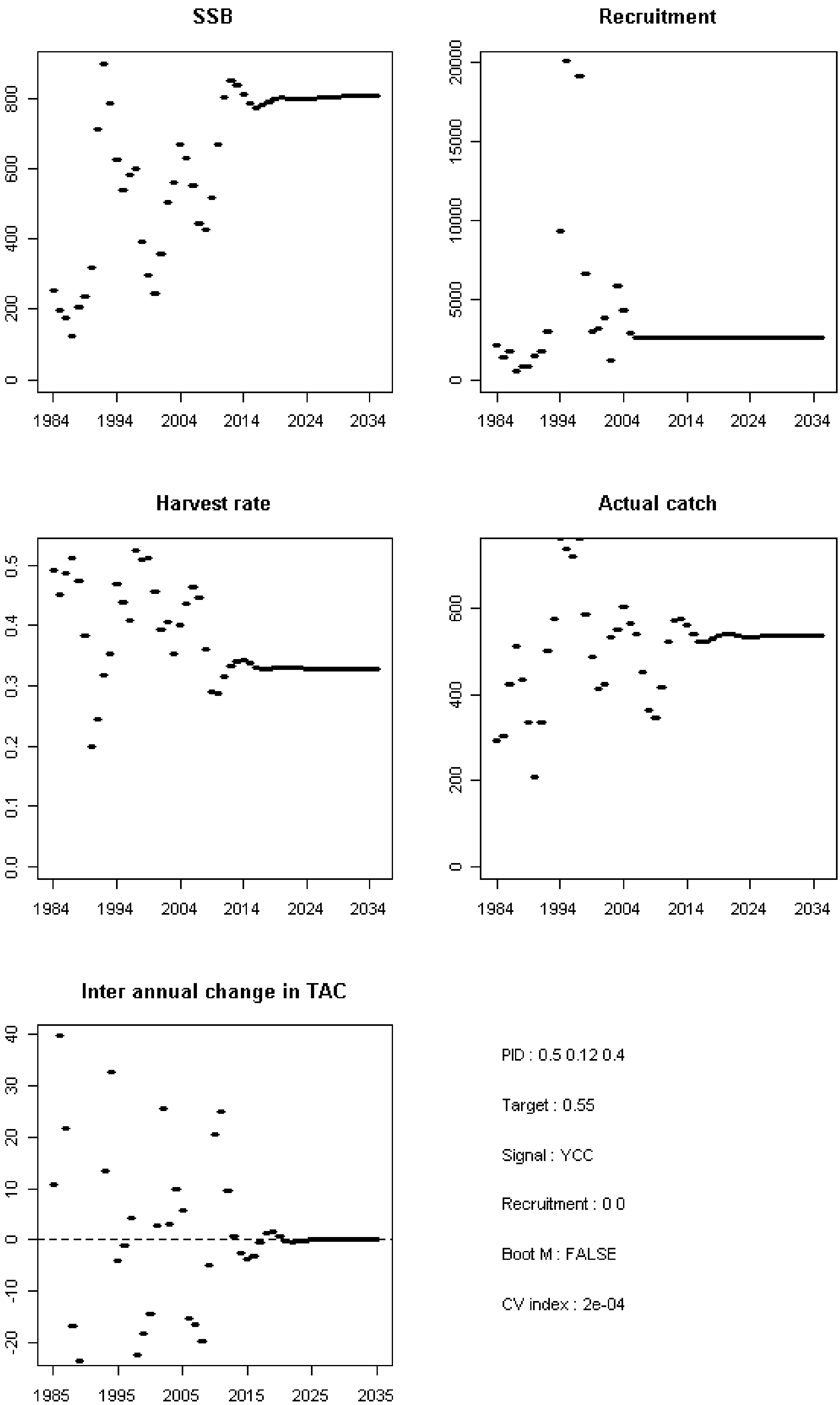


Figure 7 Deterministic run, signal form YCC, target Z=0.55

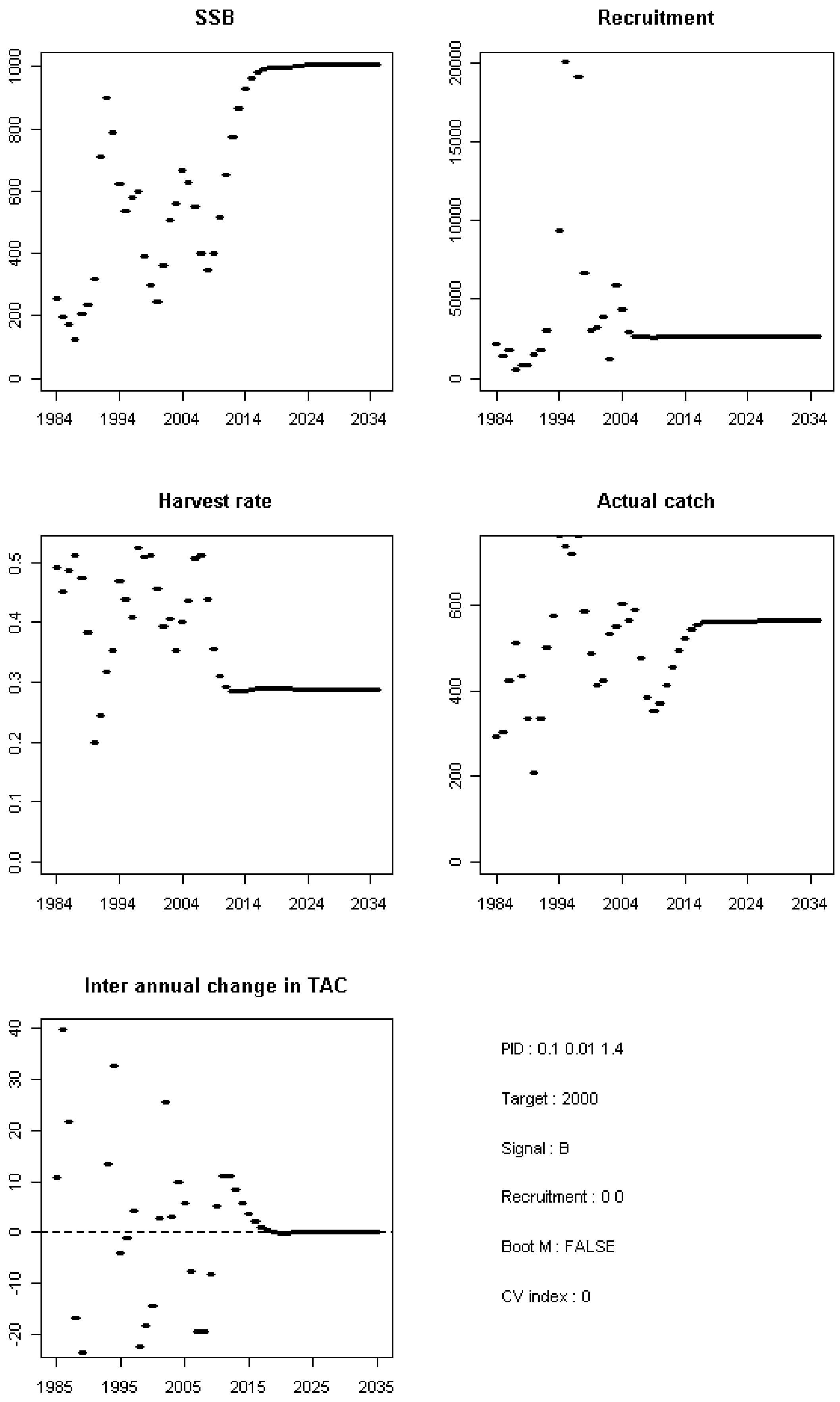


Figure 8 Deterministic run, signal in B, target TSB=2000

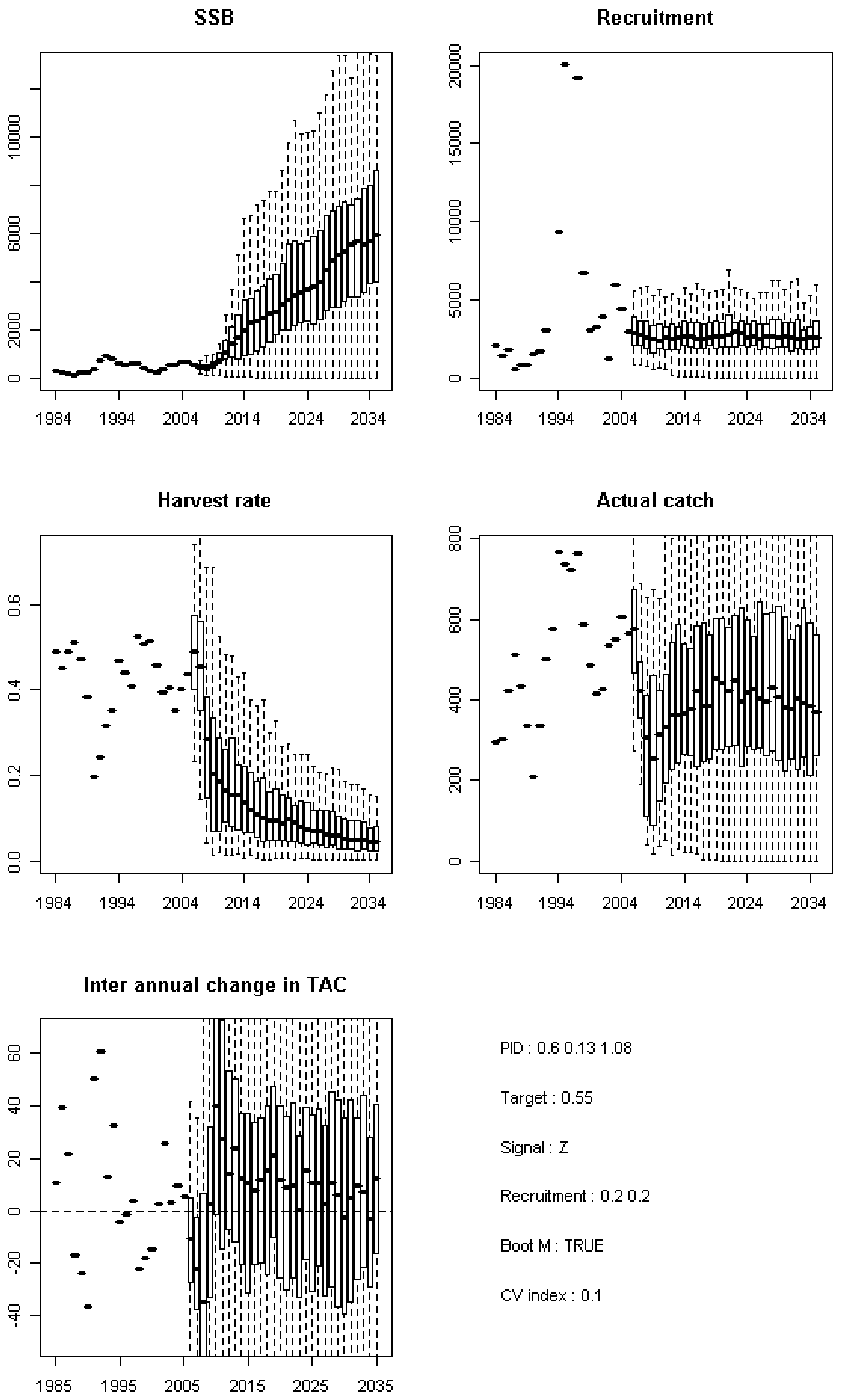


Figure 9 Stochastic run, signal in Z – model free

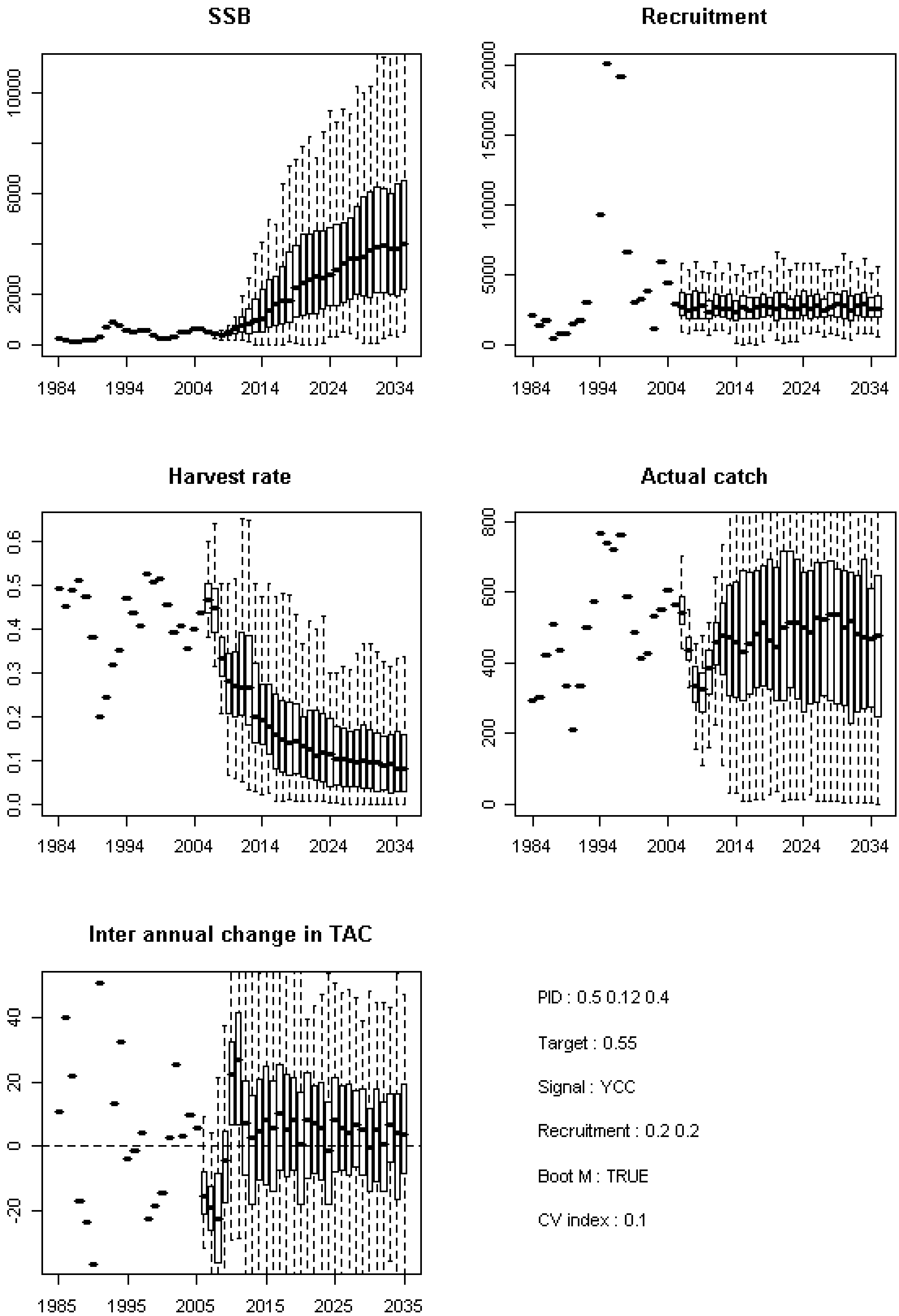


Figure 10 Stochastic run, signal from YCC

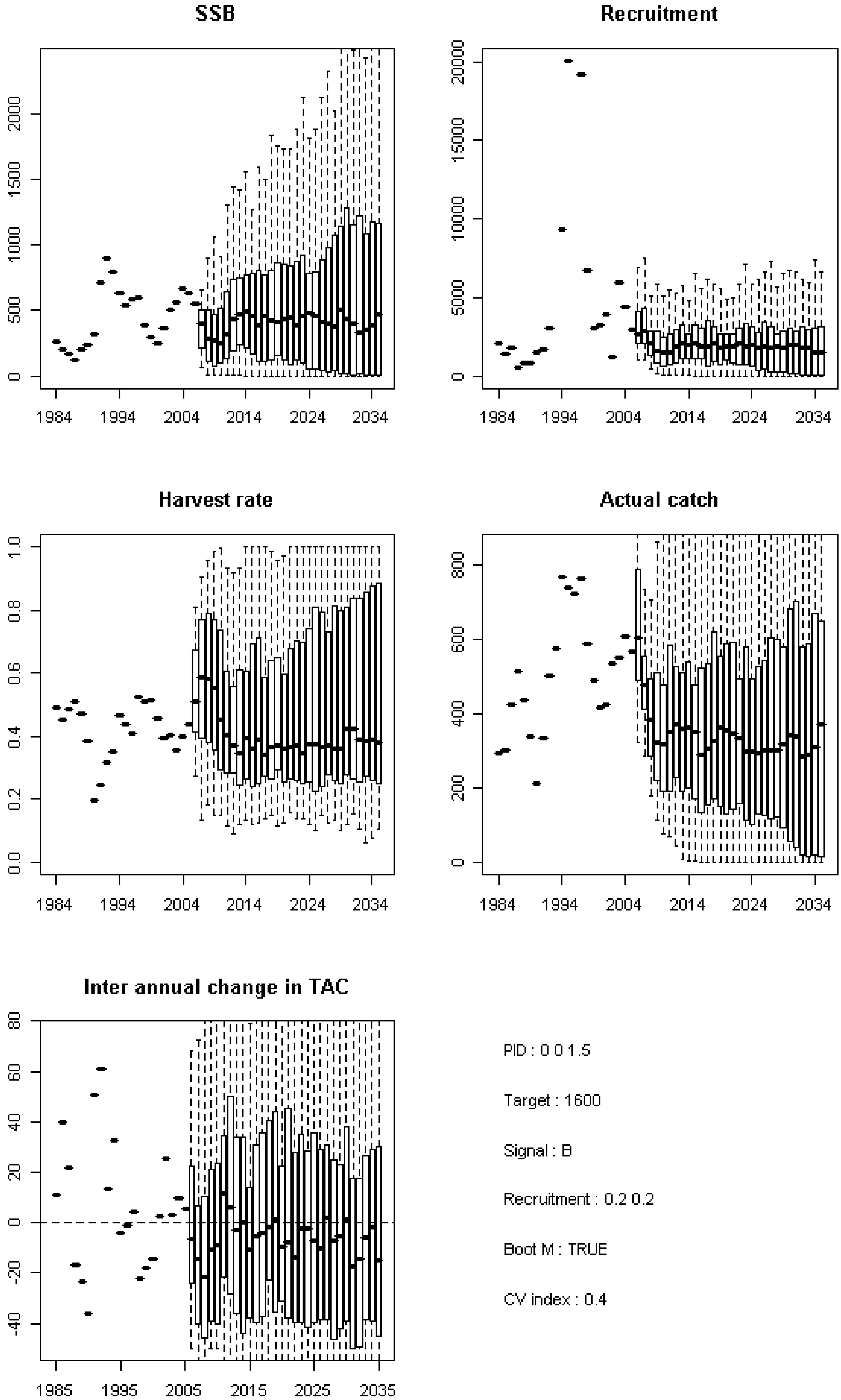


Figure 11 Stochastic run, signal in B – model free, D controller

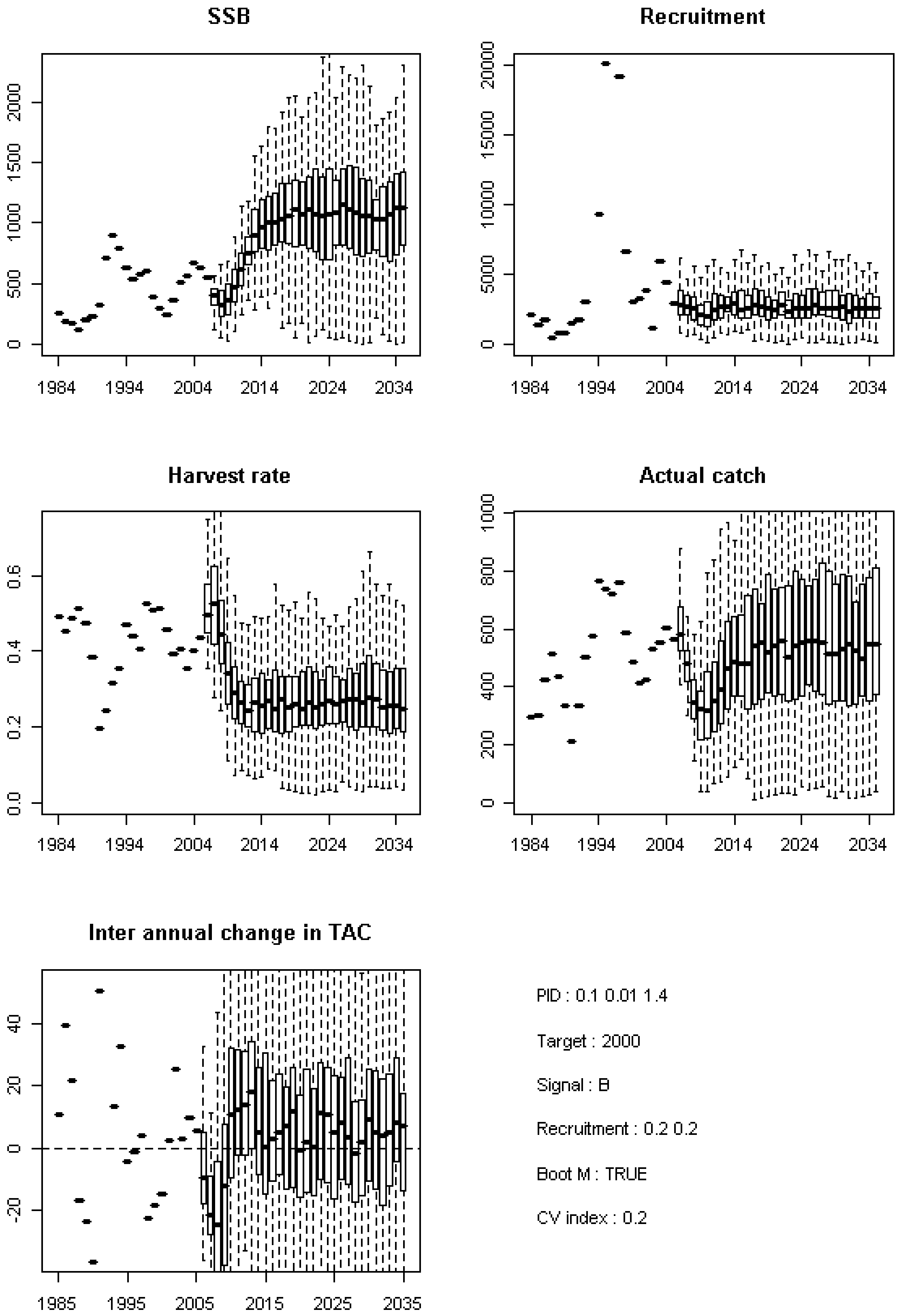


Figure 12 Stochastic run, signal in B - model free, target TSB=2000

Stock-Recruitment Alpha / Beta Var / varacor Error	Hockey-stick 7.3 / 365.9 0.2 / 0.2 Lognormal
Index Error Mu / autocorr CV	 Lognormal 0 / 0 Varying 0-40%

Table 1 Parameters

Scenario	CV index	Target	PID	Signal
10B2000	10%	2000	0.1 0.01 1.4	Biomass
20B2000	20%			
40B2000	40%			
10B1600	10%	1600		
20B1600	20%			
40B1600	40%			
10B1200	10%	1200		
20B1200	20%			
40B1200	40%			
10B	10%	NO	0 0 1.5	
20B	20%			
40B	40%			
10Z0.55	10%	0.55	0.6 0.13 1.08	Total mortalities (Z)
10YCC0.55	10%	0.55	0.5 0.12 0.4	Assessment Z (YCC)

Table 2 Scenarios

Scenario	P(SSB < B_{lim} once)	P(SSB < B_{lim} average)	Median yield	Median inter annual change in TAC	P(catch <TAC once)	P(catch <TAC average)
10B2000	40%	3%	494	14%	33%	2%
20B2000	47%	4%	491	19%	50%	3%
40B2000	70%	9%	450	31%	69%	7%
10B1600	67%	6%	460	16%	63%	5%
20B1600	86%	11%	457	21%	83%	8%
40B1600	93%	15%	418	33%	93%	11%
10B1200	98%	24%	381	19%	94%	15%
20B1200	99%	24%	349	25%	99%	16%
40B1200	100%	27%	342	35%	99%	18%
10B	58%	8%	440	17%	51%	4%
20B	66%	16%	438	21%	66%	9%
40B	77%	35%	354	35%	75%	24%
10Z0.55	26%	1%	207	35%	50%	15%
10YCC0.55	32%	2%	473	16%	15%	1%

Table 3 Summary performance metrics

Simulation evaluation with FLR

Anchovy Bay of Biscay

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1. Introduction

The Bay of Biscay anchovy (*Engraulis encrasicolus*) is an important species for the Spanish and French fleets. Two direct surveys, Acoustics and Daily Egg Production Method (DEPM), are conducted in spring every year to assess the state of the stock. Based on these direct population estimates and on data from the commercial catches, the integral assessment of the stock is conducted by the International Council for the Exploration of the Sea (ICES) in the Working Group on the assessment of Mackerel, Horse mackerel, Sardine and Anchovy (WGMHSA).

Currently the biological reference points for the stock, B_{lim} and B_{pa}, are set at 21 000 and 33 000 t respectively. Although there is no management plan developed, the stock has been traditionally managed by a fixed annual TAC (Total Allowable Catch) of 30 000 or 33 000 t.

Since 2002 the stock is at very low levels, being in 2005 the lowest of the historical series. After the failure of the fishery in spring 2005 the fishery has been closed successively for the second half of 2005 and 2006. In 2007 only experimental fishing with spatio-temporal restrictions has been allowed and the STECF has advised that any fishery reopening should not be considered until June 2008, when the results from the spring surveys become available.

As anchovy is a short lived species, the population is very dependent on the yearly incoming recruitment. Therefore, knowing the recruitment level beforehand can be very helpful for the development of any management plan. Currently, various juvenile surveys aiming at estimating recruitment and better understanding the recruitment process are being conducted. However, it is still soon to use their results for any management advice.

The main objective of the EU project FISBOAT is to improve the stock assessment and management using only fishery independent information. The use of the spring surveys for the assessment and the potential use of the new juvenile surveys for the management of the Bay of Biscay anchovy make this stock an interesting case study for the project.

In particular, one of the tasks within FISBOAT is to build a simulation-testing evaluation framework (Kell *et al.* 2006) in FLR (www.flr-project.org, Kell *et al.* 2007) allowing for full-scale testing and comparing survey-based assessment procedures and management procedures based on them. This document describes how the tool has been applied to the Bay of Biscay anchovy and summarises the main results and conclusions.

2. Methodology

A simulation-testing evaluation framework consists on an operating model, which represents the "true" dynamics of the system, and on a management procedure, which represents the "observed" system including data collection, stock assessment, harvest control rules (HCR) and management implementation.

The specifics of the FISBOAT simulation-testing evaluation framework and the corresponding FLR packages are described in the FISBOAT manual on simulation evaluation tools. In this section, we describe each of the parts of the simulation-testing evaluation framework for the case of the Bay of Biscay anchovy.

2.1. Operating model

The FISBOAT biological operating model consists on a single age-structured stock exploited by a single fleet acting via harvest rates (ratio of catch to total biomass), allowing either for yearly or seasonal time steps. Thus, parameterization of the model requires biological information of the stock, such as natural mortality, stock weight at age, maturity ogive or fraction of the season before spawning, as well as a selectivity ogive and a stock-recruitment function.

The operating model for the Bay of Biscay anchovy has been parameterized based on the results from the Integrated Catch-at Age (ICA, Patterson and Melvin 1996) from the latest WGMHSA (ICES 2006), in which the population is structured in 6 age classes (from 0 to 5+) covering the period from 1987 to 2005.

Four stock-recruitment models have been fitted to the data via maximum likelihood: Ricker, Beverton and Holt, segmented regression and quadratic hockey stick (**Figure 1**). The best model is considered to be that with the lowest Akaike's Information Criteria (AIC). All models provide similar fits to the data in terms of AIC (48.72, 49.05, 49.15 and 49.77, respectively), resulting Ricker to be slightly better than the others. **Figure 2** shows the diagnostic plots for the fitted Ricker model. Residual patterns look acceptable and no autocorrelation is observed.

For the Bay of Biscay anchovy the separable period spans for the last 15 years of the ICA assessment, giving constant selectivity values across these years. A doubled normal selectivity ogive has been fitted to the standardised harvest rates derived from the fishing mortality pattern in the last year 2005 (**Figure 3**).

Therefore, forward projection of the population is based on the past stock from ICA, on the Ricker stock recruitment model with residuals not allowed to be larger than +/- 1 in log scale, and on the fitted double normal selectivity ogive. Stock weight at age is taken to be the average from the historical series, whereas the rest of the biological parameters such as natural mortality or maturity at age that are considered constant are fixed as in ICA.

2.2. Observation model

In FISBOAT the general form of any simulated abundance index $\hat{I}$ is:

$$\hat{I} = q\, b\, I^{\beta}\ (\times \text{ or } +)\ \varepsilon\ ,$$

where q is the catchability, b is the bias in the observations, I is the "true" abundance variable being observed, β is the power coefficient and ε is the error term, which can be additive or multiplicative and allows to include autocorrelation (see the FISBOAT manual on simulation evaluation tools for further details).

As mentioned before, two direct surveys, Acoustics and DEPM, are conducted in spring every year providing estimates of SSB and numbers at age of the Bay of Biscay anchovy. However, for simplicity, a unique spring survey providing spawning stock biomass (SSB) estimates has been simulated in this study. The simulated SSB index is considered to be unbiased with catchability and power coefficients equal to 1 and uncorrelated multiplicative errors (i.e. independent and log normally distributed). Different CVs, ranging from 0 to 1, are considered in order to test the sensitivity of the different HCRs to the survey uncertainty.

In addition, a juvenile survey has been simulated in order to test the additional value of a recruitment index for management purposes. Similarly to the SSB index, the recruitment index is considered to be unbiased with catchability and power coefficients equal to 1, uncorrelated multiplicative errors and different uncertainty levels.

One of the approaches explored in FISBOAT is the extraction of information other than abundance indices from the surveys in order to construct additional indicators and methods and to study their potential use in providing advice. In an attempt to test the value of the indicator approach within the evaluation-testing framework, an alarm-triggering binary index, $\hat{A}$, has been simulated. This index triggers an alarm, independently of the abundance indices observed, modifying the harvest control rule to a more restrictive one. The index has been simulated as follows: When the true population biomass is below $\mathrm{B}_{\mathrm{lim}}$, the probability that an alarm is triggered is of 0.9, i.e.:

$$P(\hat{A}_y = 1 \mid SSB_y < \mathrm{B}_{\mathrm{lim}}) = 0.9\,,$$

and when the true population biomass is above $\mathrm{B}_{\mathrm{lim}}$, the probability that a false alarm is triggered is of 0.05, i.e.

$$P(\hat{A}_y = 1 \mid SSB_y \geq \mathrm{B}_{\mathrm{lim}}) = 0.05\,.$$

2.3. Assessment procedure

No assessment procedure has been applied to the Bay of Biscay case study.

2.4. Decision procedure

Various HCR’s defining the TAC based on fishery independent information have been tested for the Bay of Biscay case study.

The first HCR, referred to in what follows as HCR_0, serves as a reference scenario and corresponds to the case in which no fishing is allowed, i.e.:

HCR_0: $$TAC_{y+1} = 0$$

The next HCR, HCR_1, is the base case for the Bay of Biscay anchovy, as represents the traditional management procedure for the stock, in which the TAC is set constant at 30 000 t.

HCR_1: $$TAC_{y+1} = 30\,000$$

The HCR’s considered within FISBOAT are of the general form of proportional integral derivative (PID) control:

$$TAC_{y+1} = \exp\{u_y\}\, TAC_y\,,$$

where u_y is the control signal which is calculated as

$$u_y = K_P e_y + K_I \sum_{z=y-\delta}^{y} e_z + K_D \left(e_y - e_{y-1}\right),$$

being e_y the divergence from the reference point, which can be either fixed or variant (Bogaards 2007 and references therein).

Within this general form, the rest of the HCRs considered for the Bay of Biscay anchovy are pure P-controllers,

$$TAC_{y+1} = \exp\{K_P\, e_y\}\, TAC_y\,,$$

where the reference point is last year's index (moving target) and divergence is measured in log scale:

$$e_y = \log(I_y) - \log(I_{y-1}) = \log\left(I_y / I_{y-1}\right).$$

As only age-aggregated abundance indices are considered and no assessment procedure is applied for this case study, all the HCRs tested are SSB-based and model-free, i.e., based directly on the SSB observations from the surveys ($I_y = S\hat{S}B_y$). The simplest of this type of HCRs is:

HCR$_2$: $$TAC_{y+1} = \frac{S\hat{S}B_y}{S\hat{S}B_{y-1}} TAC_y\,.$$

A variant of this HCR can be obtained by simply adding a restriction of +/- 20% on the inter-annual variation allowed to the TAC:

HCR$_3$: $$TAC_{y+1} = \min\left\{\max\left\{\frac{S\hat{S}B_y}{S\hat{S}B_{y-1}}, 0.8\right\}, 1.2\right\} TAC_y$$

In order to analyse the potential benefits of including a recruitment index for setting the TAC the following HCR has been considered:

HCR$_4$: $$TAC_{y+1} = \frac{S\hat{S}B_y}{S\hat{S}B_{y-1}} \frac{\hat{R}_y}{\hat{R}_{y-1}} TAC_y$$

Finally, the last HCR considered aims at studying the benefits of reducing automatically the TAC by a fraction α in case the indicator triggers an alarm (i.e. $\hat{A}_y = 1$):

HCR$_5$: $$TAC_{y+1} = \begin{cases} \alpha\ \dfrac{S\hat{S}B_y}{S\hat{S}B_{y-1}} TAC_y & \text{when } \hat{A}_y = 1 \\ \dfrac{S\hat{S}B_y}{S\hat{S}B_{y-1}} TAC_y & \text{when } \hat{A}_y = 0 \end{cases}.$$

2.4. Implementation model

No implementation error has been considered.

2.5. Simulations

All the runs performed are summarised in **Table 1**. In each of the runs the population is projected forward for 10 years and 100 iterations are conducted.

Given the low level of the population in 2005, two starting conditions have been considered: a) start to apply the HCR immediately in 2006 b) start to apply the HCR after a fishery closure for the first two years (2006 and 2007) to let the population recover slightly and an initial TAC of 30 000 t for 2008.

The performance of each of the HCRs under different scenarios has been evaluated graphically and analytically. The standard summary plots consist on:

- Series of SSB
- Series of recruitment
- Series of harvest rates
- Series of actual catch
- Series of inter-annual change in TAC
- Series of probability being below B_{lim}

The performance statistics calculated are:

- Probability of SSB being below B_{lim} at least once in the series
- Average number of years to get SSB > Blim
- Average actual catch
- Average percentage of change in TAC
- Overall probability of actual catch being below TAC
- Overall probability fishery is closed

3. Results

When no fishing is allowed (HCR_0), even if the simulations start from the lowest level of the population observed since 1987, the stock will recover rapidly, getting in four years to the highest SSB in the series (**Figure 4**). The probability of SSB being below B_{lim} at least once in the 10 years of projection is 0.12 with an average of 0.19 years to get the population back above B_{lim} (**Table 2**).

However, when keeping the traditional fixed TAC management (HCR_1) starting from the current situation the stock declines rapidly until the complete collapse around 2010 (**Figure 5**). The probability of SSB being below B_{lim} at least once in the 10 years of projection is 1. These exploitation rates are very high and in around 60 % of the cases the TAC is higher than the exploitable population, with an average actual catch of approximately 20 000 t (**Table 2**). When the simulations start from a fishery closure of two years the stock still shows a downwards trend and an increasing trend in depletion probability (**Figure 6**). But the probability that the SSB is below SSB at least once decreases to 0.5 and the probability that the TAC is higher than the exploitable population decreases to 15% being the average actual catch slightly larger (24 000 t) (**Table 2**).

For the HCR_2, when the CV of the SSB index is 25%, the probability of SSB being below B_{lim} at least once in the 10 years of projection is 0.11 with less than 1 year on average to get the population back above B_{lim} (**Table 2**). Based on the low starting level, this means that the population starts outside the biological limits but recovers rapidly at low exploitation levels (4 000 t) minimizing the depletion probability (**Figure 7**). **Figure 8** shows that the CV of the SSB index does not have an influence in the state of the stock, probably due to the low exploitation levels. However, the larger the CV the larger the TAC and its variability are. Similarly, when HCR_2 is tested but starting the simulations after two years of fishery closure and an initial TAC of 30 000 t, the probability of SSB being below B_{lim} at least once in the 10 years of projection raises to 0.53, needing 2 years on average to get the population back above B_{lim} (**Table 2**). In comparison with the other initial conditions, the average actual catch is larger (approximately 29 000 t) and the inter-annual change in TAC is centred on zero (**Figure 9**). In this case, the effect of the increasing CV of the SSB index leads to increasing number of years to recover from stock depletion and increasing probability of the TAC being larger than the exploitable stock (**Figure 10**).

HCR_3 is the same as HCR_2 but with an additional restriction on the maximum TAC inter-annual variability allowed fixed at 20%. This generally implies lower catch levels and consequently larger population levels for the population (**Figures 11-14**).

Incorporating a recruitment index to the decision rule (HCR_4) allows adjusting the TAC with a better knowledge of the situation of the stock in the next year. In that way, in comparison with HCR_2 and without starting the simulations from a fishery closure, the actual catch is around 25 000 t and keeps the depletion probability below 0.2 (**Figure 15**). The larger the CV of the SSB index the larger the depletion probability, the number of years to recover and the probability that the TAC is not sustainable (**Figure 16**). Similarly, the larger the CV of the recruitment index the larger the depletion probability, the number of years to recover and the variation in the TAC (**Table 2**). In case the simulations are started after a fishery closure of 2 years, the results are similar (**Figures 17 and 18, Table 2**) showing just slightly larger catches and therefore, larger depletion probability (approximately 0.3).

Performance statistics and summary plots of HCR_5 (**Figures 19-22**) show that there is almost no improvement with respect to HCR_2 due to the alarm triggering indicator, except that the probability that the TAC is larger than the exploitable population is reduced to zero. As expected the smaller the reduction factor α the smaller the depletion probability and the smaller the catches (**Table 2**).

4. Conclusions

- As anchovy is a short-lived species, when there is no fishing, the recovery of the species can be very fast (approx. 2 or 3 years). Similarly, overfishing in 1 or 2 years can lead the stock to the collapse.
- Except for HCR_4, the performance of all the HCRs was dependent on the initial conditions.
- The larger the CV of the indices the larger the TAC variability, the probability TAC being lower than the exploitable biomass and the larger the number of years to recover from stock depletion.
- Including a restriction on the maximum inter-annual variability allowed decreases the catch levels and increases the population levels.
- Modulating the TAC with a SSB and a recruitment index keeps the population within safe biological limits at low risk while allowing the catches to be maximal.
- The alarm triggering indicator did not add any significant improvement to the HCR.
- The decision on which HCR is more adequate should be based on the management objectives set for the stock.

5. References

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Table 1: Summary of the simulations conducted for the Bay of Biscay anchovy.

OPERATING MODEL		OBS ERROR			DECISION MAKING		IMPLEMENTATION ERROR
SR MODEL	SEL MODEL	SSB INDEX	CV	OTHER INDICES	ASSESSMENT	HCR	UNDER-REPORTING
Ricker	Double normal	no	no	no	no	HCR0	no
Ricker	Double normal	no	no	no	no	HCR1	no
Ricker	Double normal	yes	from 0 to1	no	no	HCR2	no
Ricker	Double normal	yes	from 0 to1	no	no	HCR3	no
Ricker	Double normal	yes	from 0 to1	Recruitment	no	HCR4	no
Ricker	Double normal	yes	from 0 to1	Alarm indicator	no	HCR5	no

Table 2: Performance statistics for the different HCRs under different starting conditions for the case in which the CV of the SSB index is 25%. For HCR_4 and HCR_5 the other parameters column refer to the CV of the recruitment index and the reduction factor α respectively. From left to right the performance statistics are: (a) probability of SSB being below B_{lim} at least once in the series, (b) average number of years to get SSB > B_{lim}, (c) average actual catch, (d) average percentage of change in TAC, (e) overall probability of actual catch being below TAC, (f) overall probability fishery is closed.

			PERFORMANCE STATISTICS					
HCR	START COND	OTHER PARAMS	a	b	c	d	e	f
HCR_0	normal	NA	0.120	0.190	0.000	0.000	0.000	1.000
HCR_1	normal	NA	1.000	6.955	20.160	0.000	0.572	0.000
	no fishing	NA	0.520	2.135	23.928	0.000	0.150	0.200
HCR_2	normal	NA	0.110	0.120	3.068	0.664	0.000	0.000
	no fishing	NA	0.660	1.965	29.124	0.669	0.070	0.200
HCR_3	normal	NA	0.210	0.255	1.400	0.175	0.000	0.000
	no fishing	NA	0.530	1.850	24.874	0.179	0.091	0.200
HCR_4	normal	0	0.440	0.678	31.680	1.148	0.003	0.000
	normal	0.1	0.510	0.835	33.446	1.243	0.010	0.000
	normal	0.2	0.460	0.780	29.839	1.253	0.008	0.000
	normal	0.3	0.450	0.885	30.257	1.324	0.011	0.000
	normal	0.4	0.510	0.965	31.986	1.561	0.035	0.000
	normal	0.5	0.520	1.032	30.184	1.669	0.038	0.000
	normal	0.6	0.600	1.128	32.533	1.994	0.050	0.000
	normal	0.7	0.620	1.373	33.082	2.458	0.056	0.000
	normal	0.8	0.560	1.200	29.390	2.342	0.043	0.000
	normal	0.9	0.620	1.477	30.248	2.873	0.064	0.001
	no fishing	0	0.640	1.890	30.683	0.943	0.063	0.200
	no fishing	0.1	0.560	1.550	31.049	0.896	0.050	0.200
	no fishing	0.2	0.530	1.693	32.910	1.034	0.067	0.200
	no fishing	0.3	0.550	1.677	34.400	1.134	0.071	0.200
	no fishing	0.4	0.590	1.970	32.275	1.280	0.076	0.200
	no fishing	0.5	0.580	1.988	30.644	1.465	0.096	0.201
	no fishing	0.6	0.640	2.035	33.118	1.526	0.097	0.200
	no fishing	0.7	0.640	2.115	26.531	1.820	0.098	0.201
	no fishing	0.8	0.630	2.070	29.633	2.293	0.101	0.201
	no fishing	0.9	0.630	2.310	28.234	2.228	0.114	0.201
HCR_5	normal	0.25	0.030	0.030	0.829	0.715	0.000	0.000
	normal	0.5	0.080	0.090	1.570	0.653	0.000	0.000
	normal	0.75	0.140	0.170	2.141	0.676	0.000	0.000
	no fishing	0.25	0.570	1.480	23.976	0.716	0.029	0.200
	no fishing	0.5	0.680	1.820	24.879	0.681	0.042	0.200
	no fishing	0.75	0.640	1.710	29.302	0.627	0.039	0.200

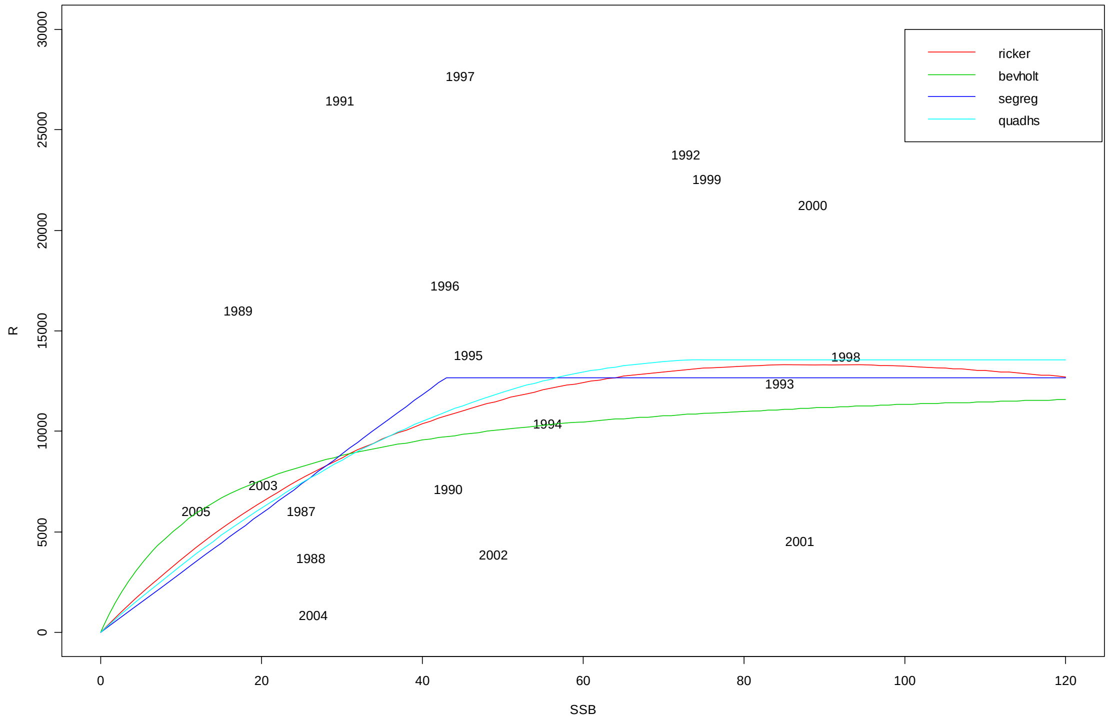

Figure 1: Stock-recruitment models fitted to the Bay of Biscay anchovy data.

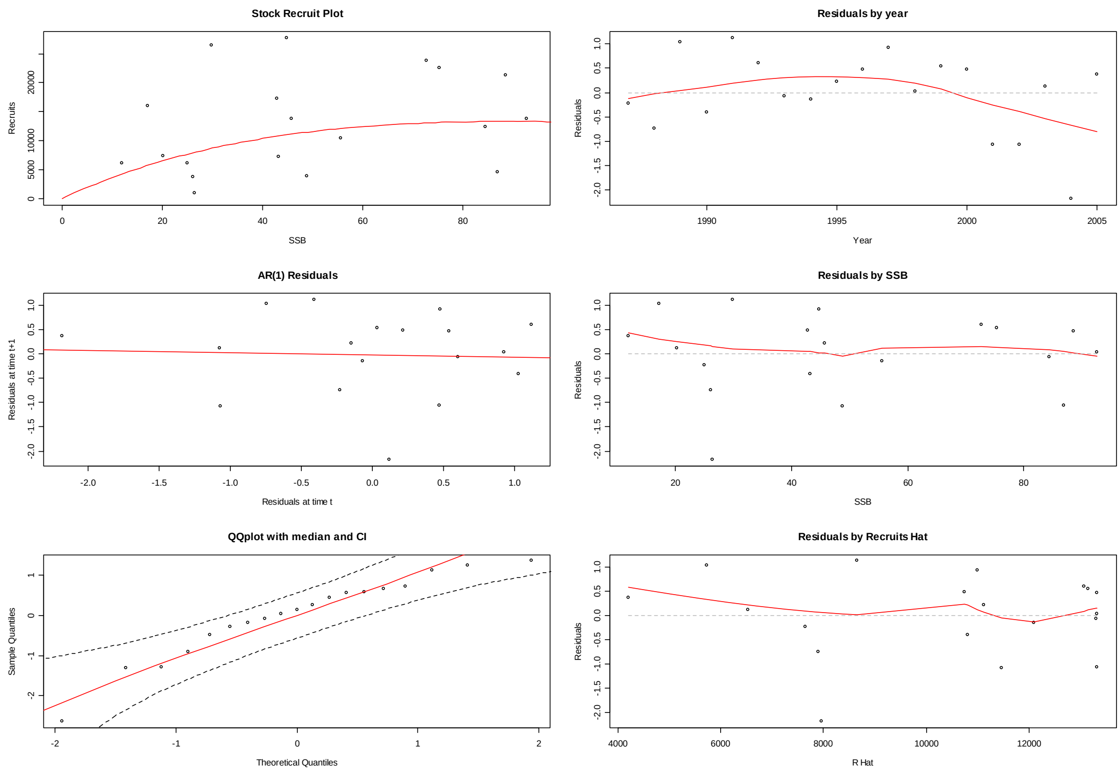

Figure 2: Diagnostic plots of the Ricker stock-recruitment model fitted to the Bay of Biscay anchovy.

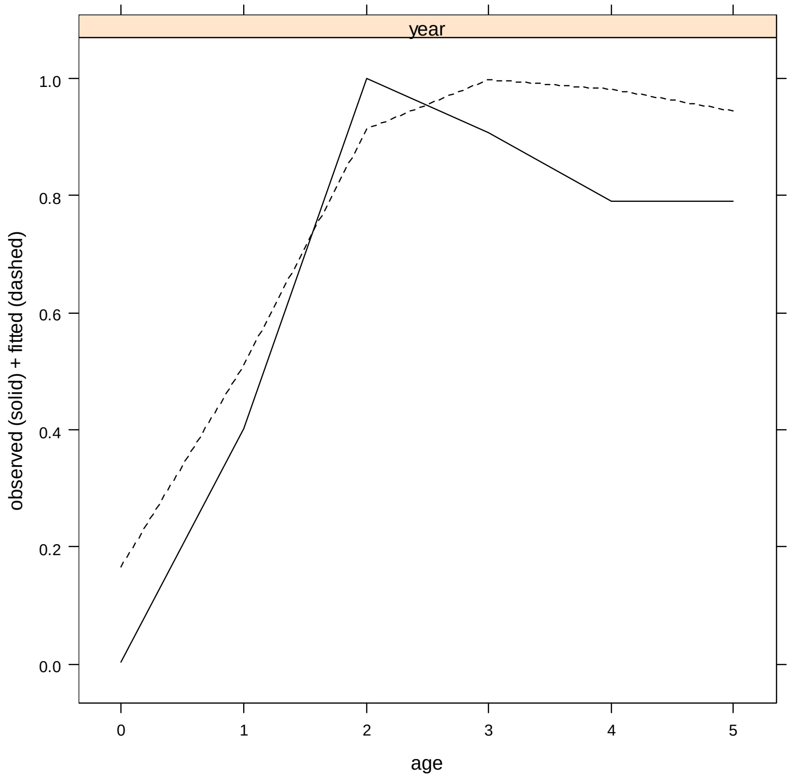

Figure 3: Observed (solid line) and fitted double normal (dashed line) selectivity ogive for the Bay of Biscay anchovy.

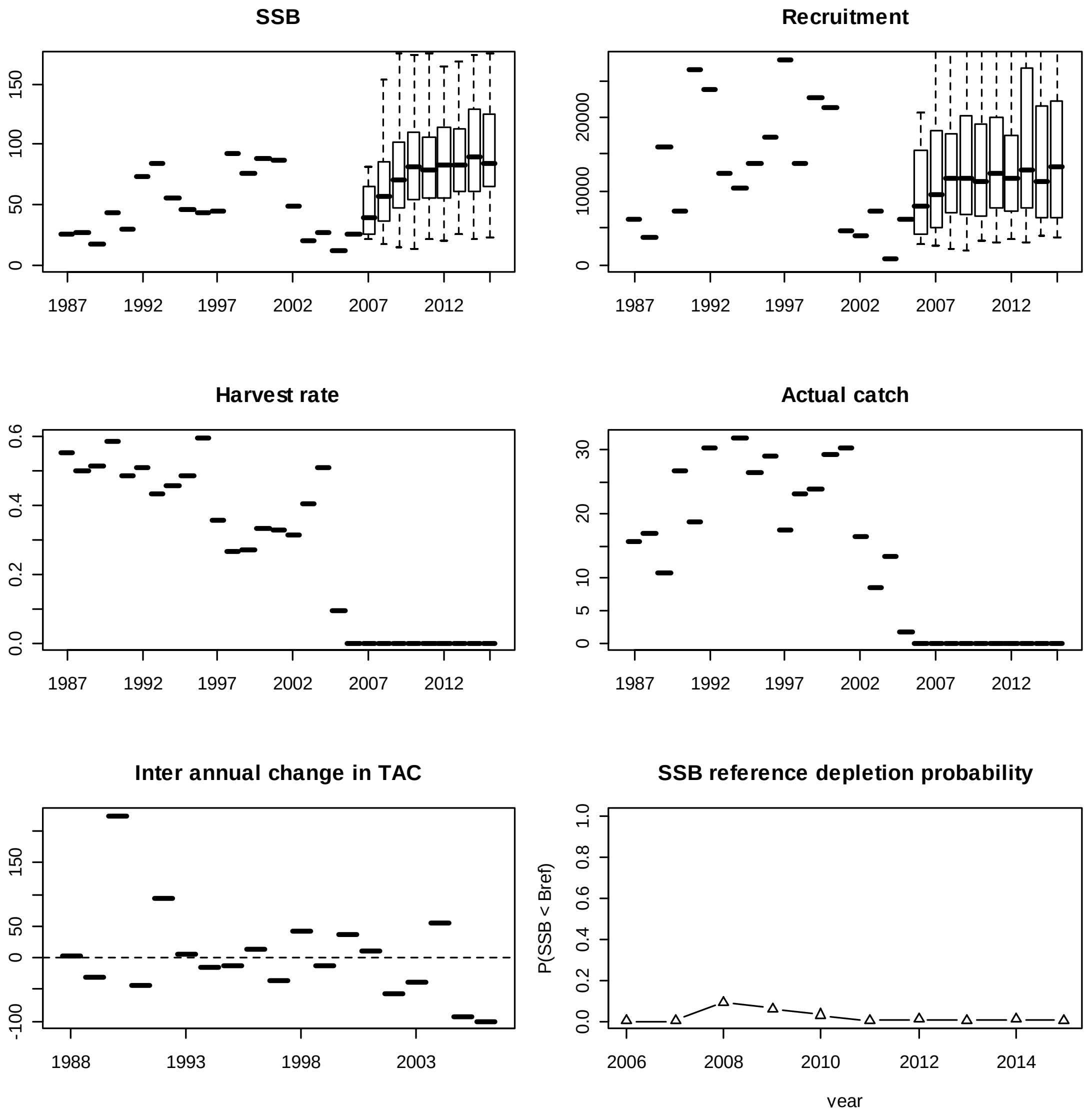

Figure 4: Summary plot of HCR_0 for the Bay of Biscay anchovy.

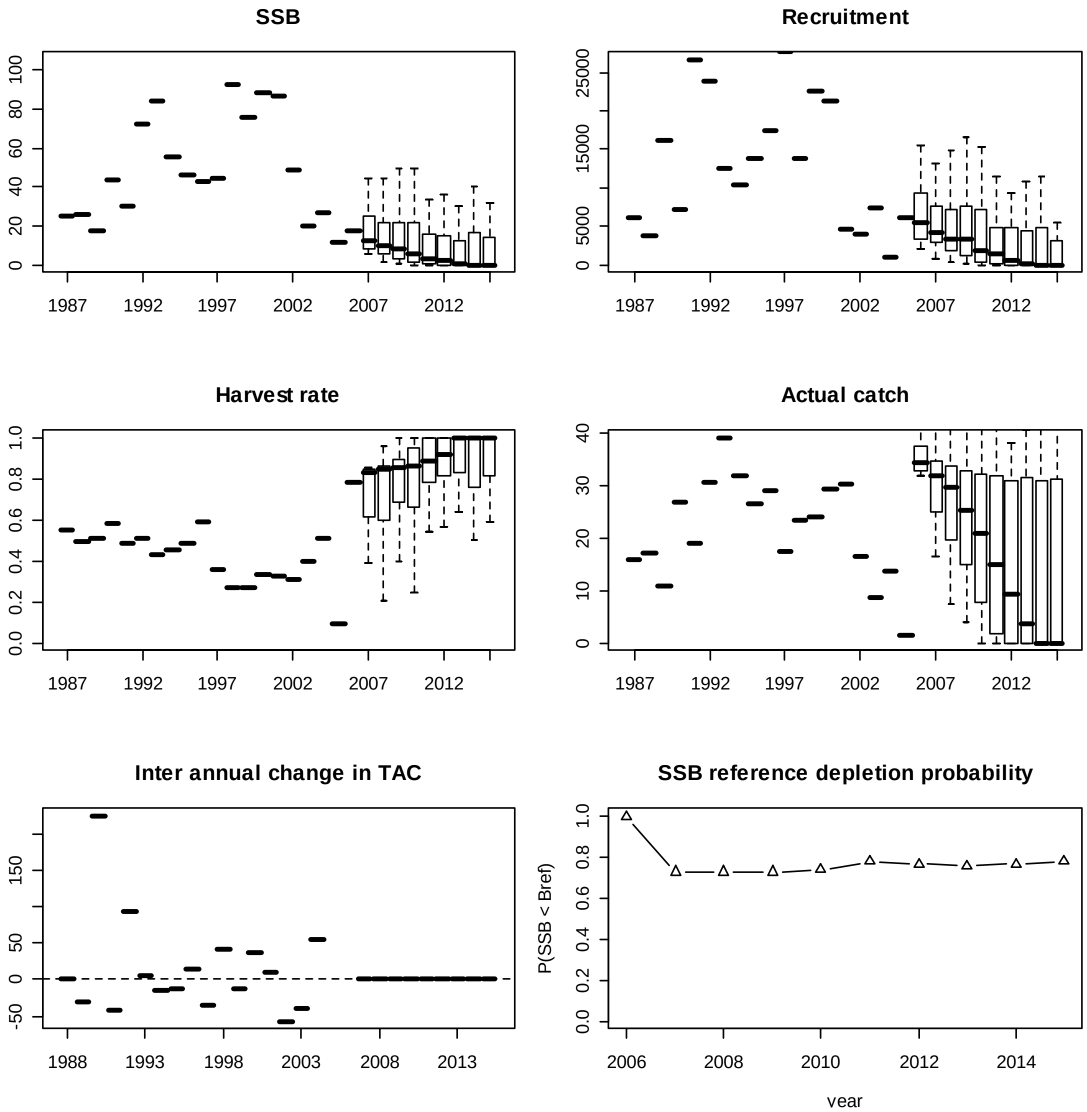

Figure 5: Summary plot for HCR_1 for the Bay of Biscay anchovy.

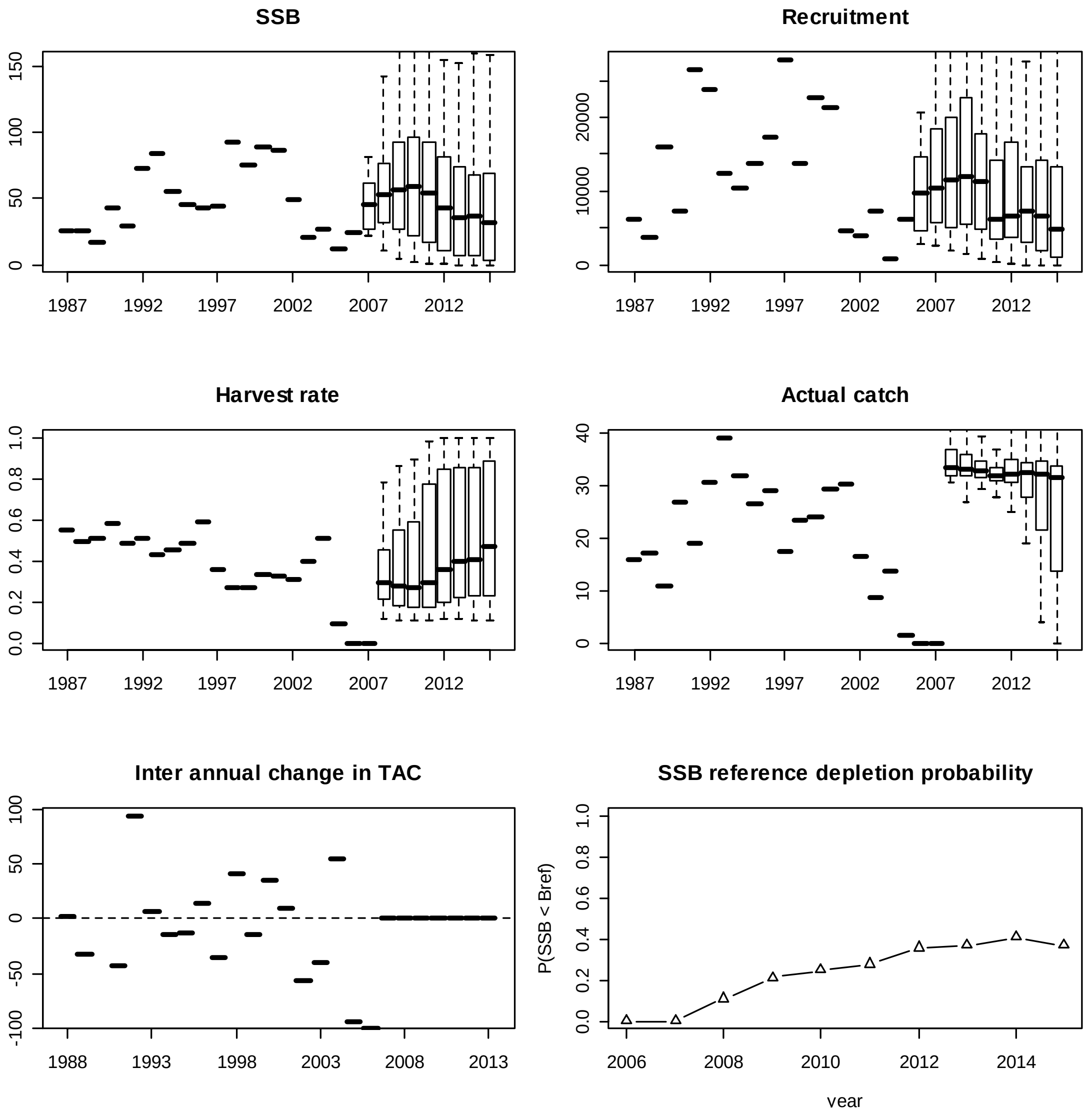

Figure 6: Summary plot for HCR_1 for the Bay of Biscay anchovy starting the simulations with 2 years of fishery closure.

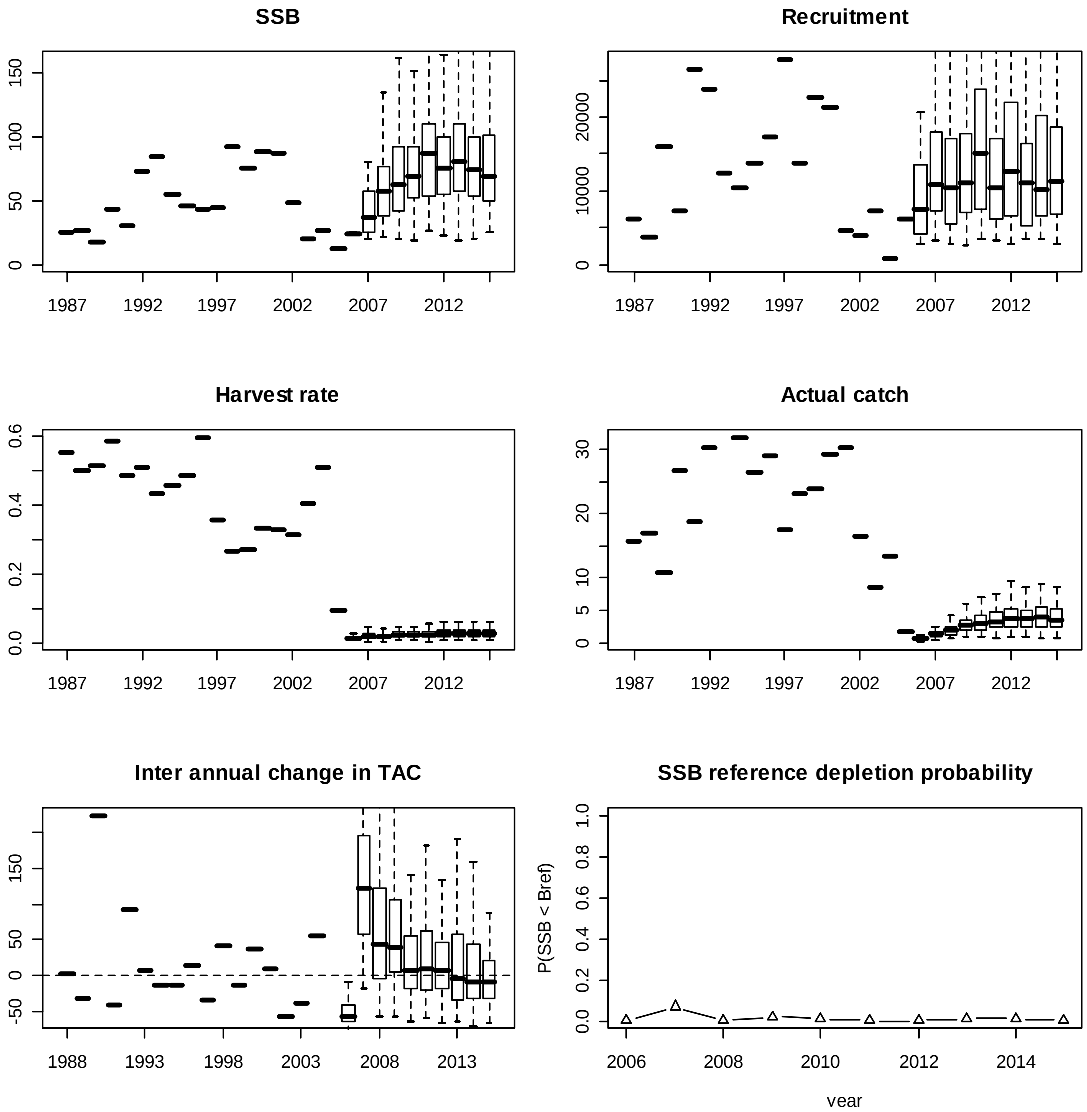

Figure 7: Summary plot for HCR_2 for the Bay of Biscay anchovy when the CV of the SSB index is 25%.

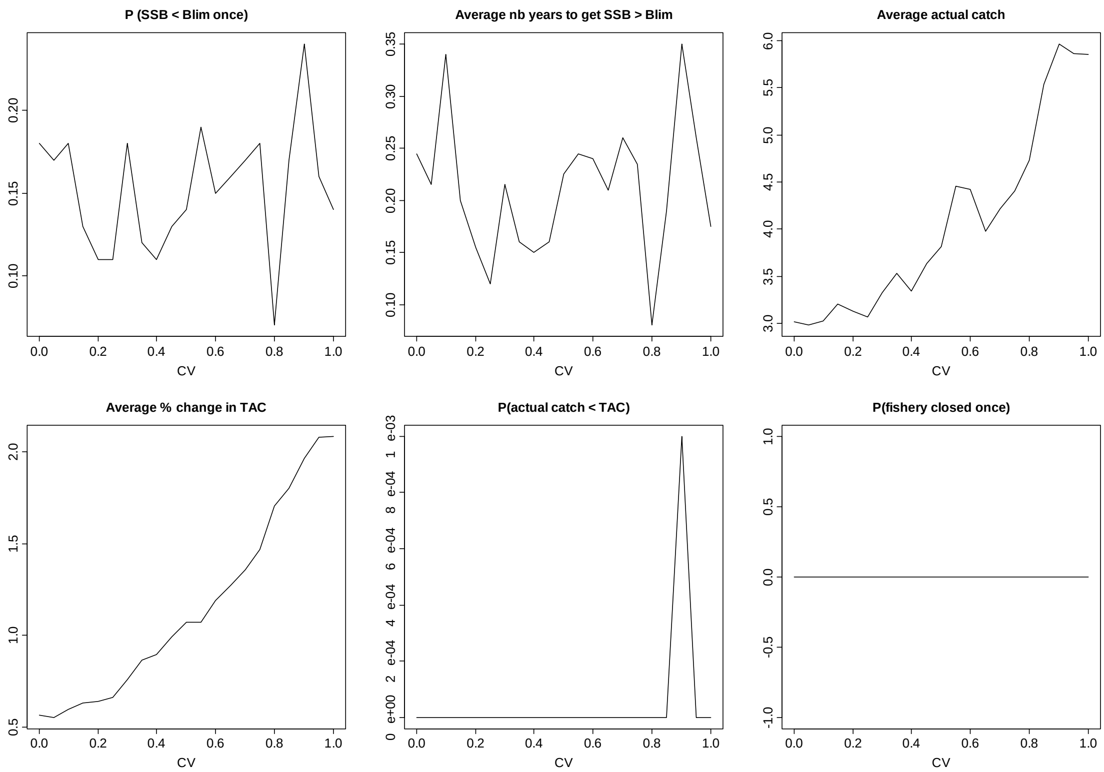

Figure 8: Sensitivity of the performance metrics to the CV of the SSB index for HCR_2.

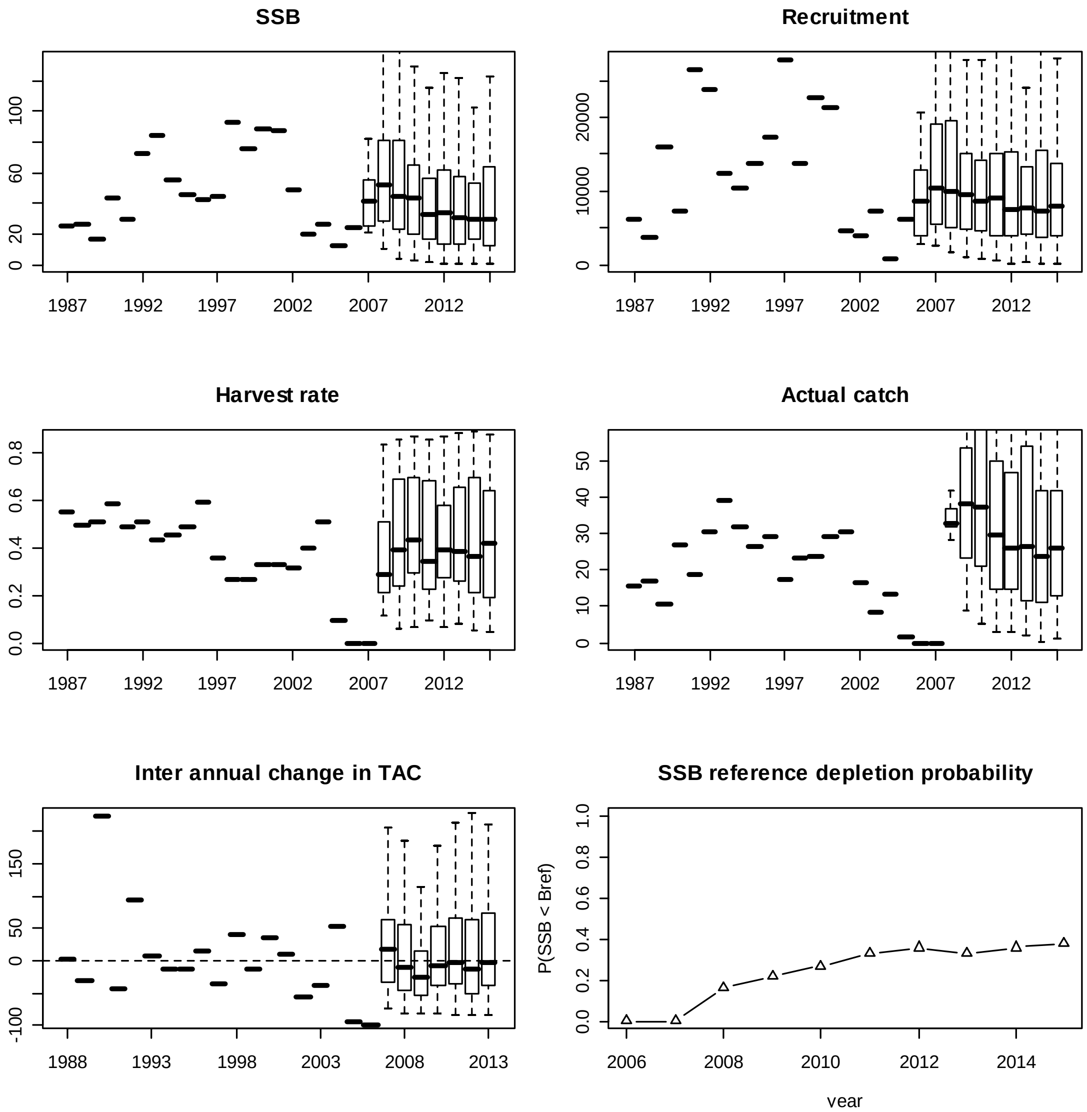

Figure 9: Summary plot for HCR_2 for the Bay of Biscay anchovy when the CV of the SSB index is 25% and the simulations are started with 2 years of fishery closure.

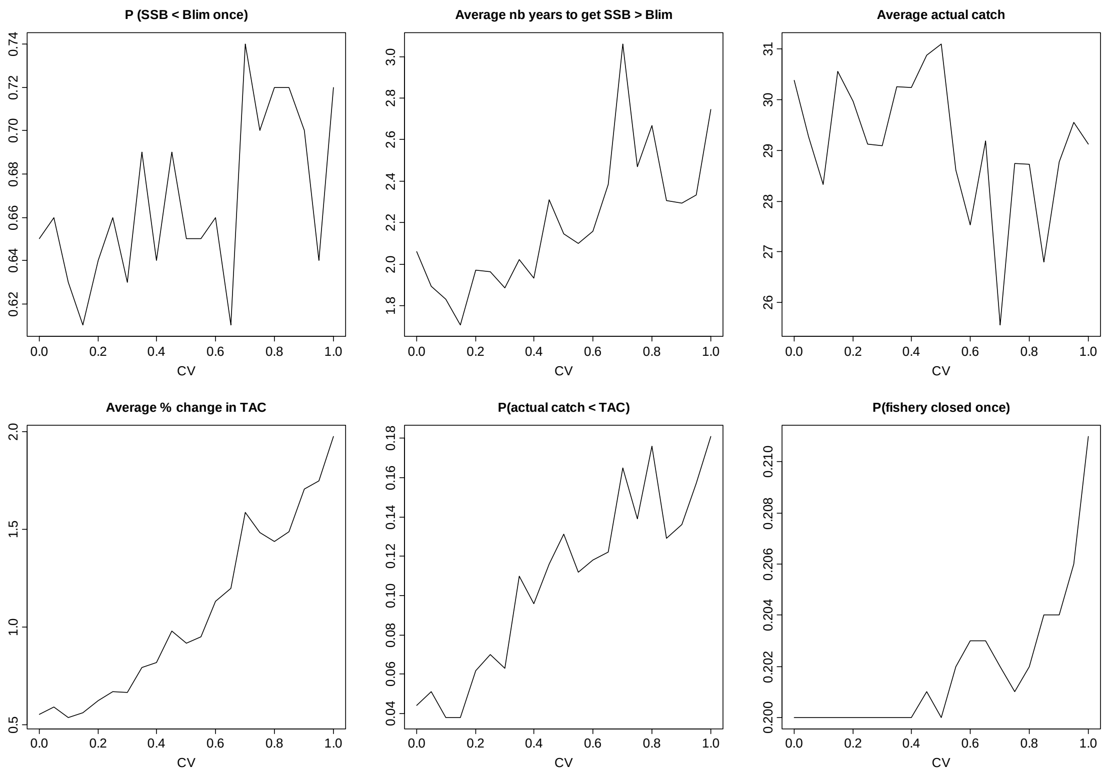

Figure 10: Sensitivity of the performance metrics to the CV of the SSB index for HCR_2 when the simulations are started with 2 years of fishery closure.

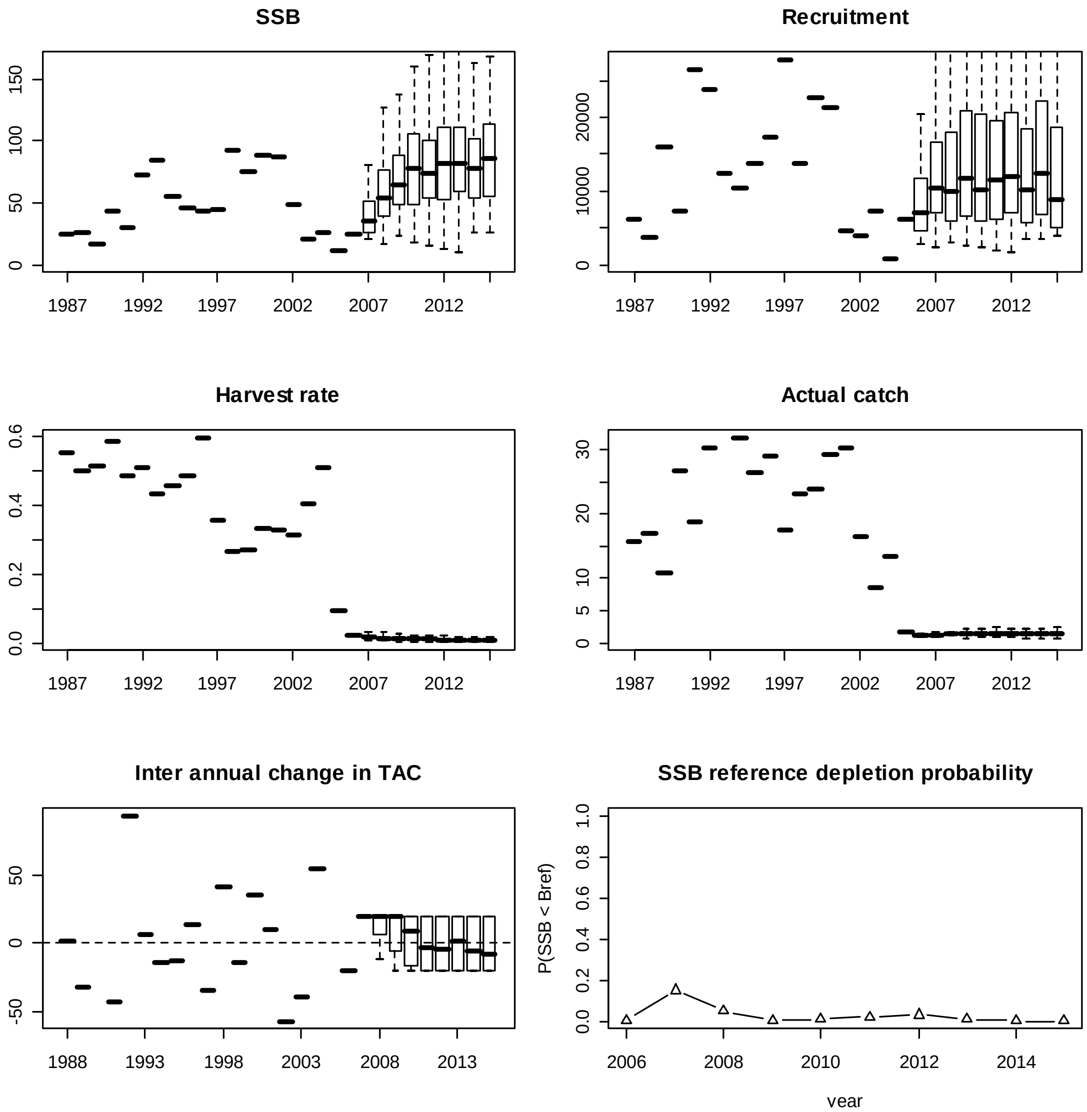

Figure 11: Summary plot for HCR_3 for the Bay of Biscay anchovy when the CV of the SSB index is 25%.

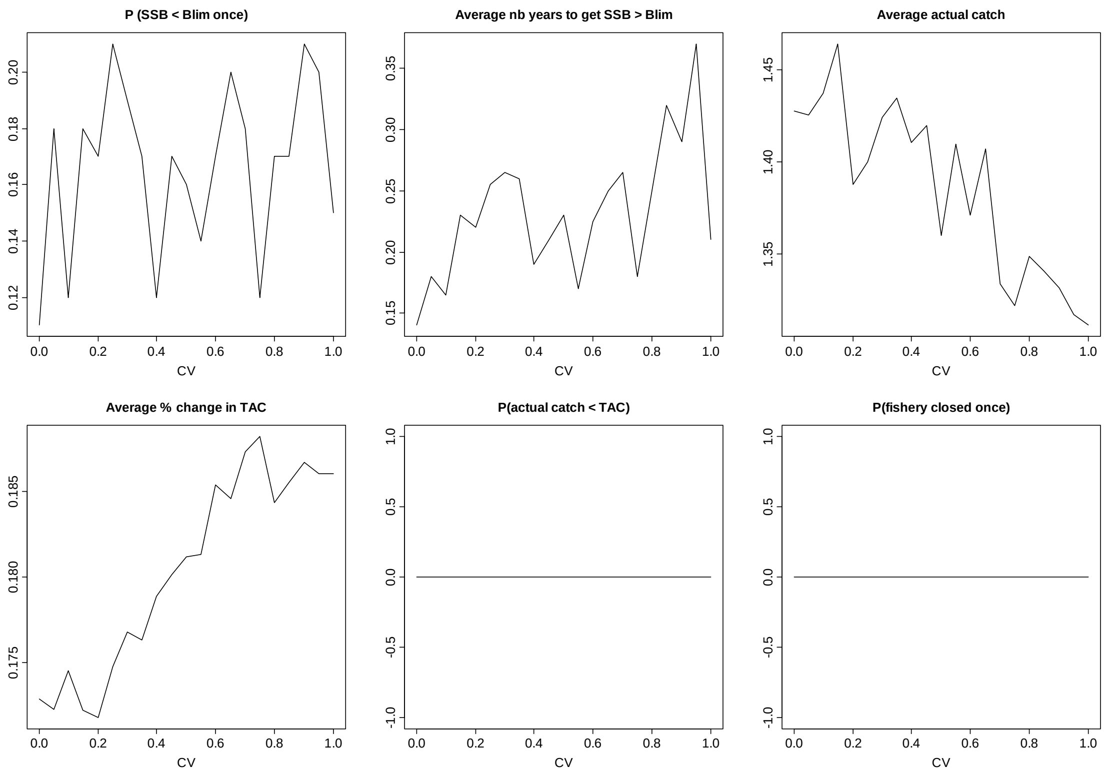

Figure 12: Sensitivity of the performance metrics to the CV of the SSB index for HCR_3.

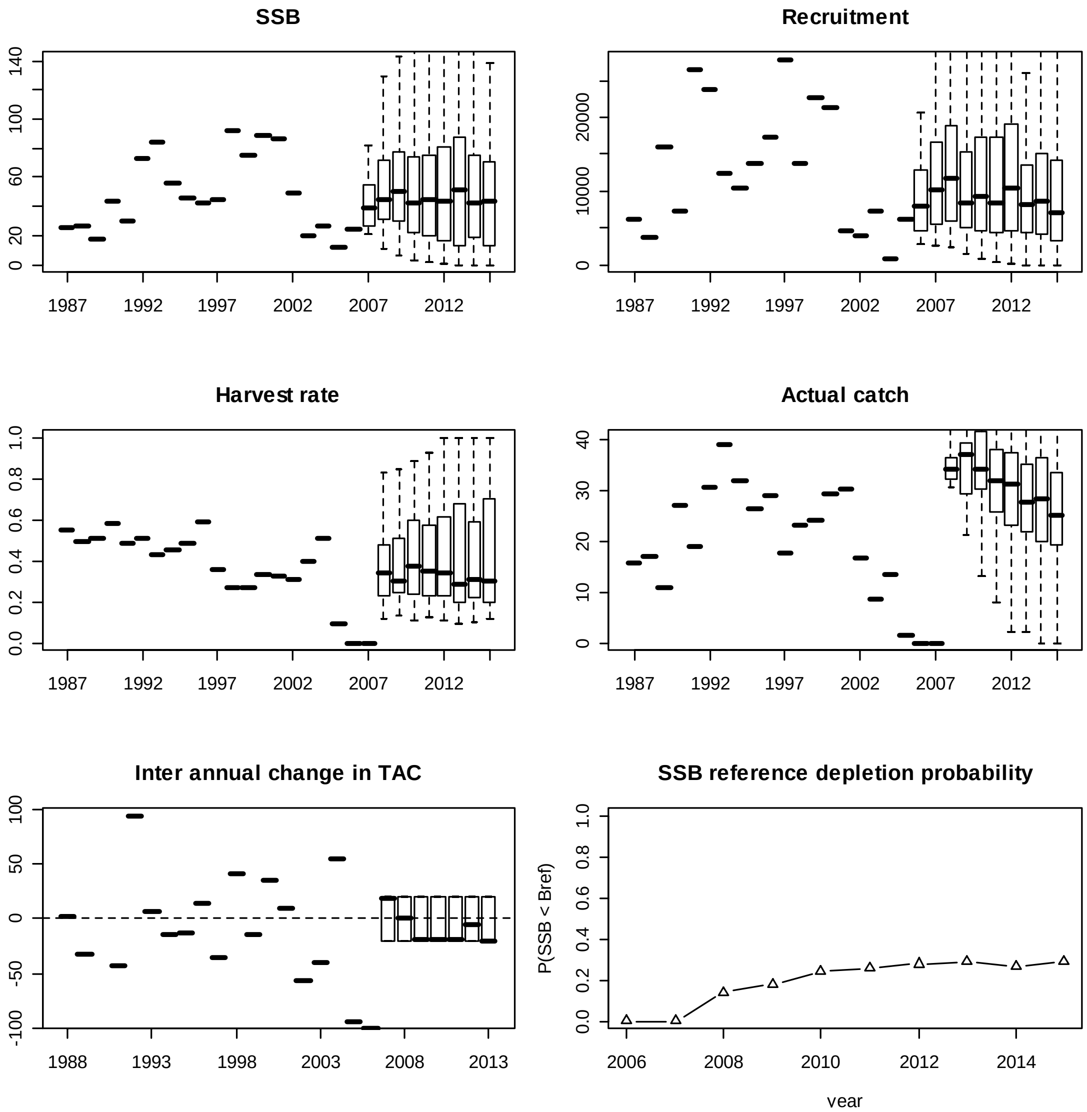

Figure 13: Summary plot for HCR_3 for the Bay of Biscay anchovy when the CV of the SSB index is 25% and the simulations are started with 2 years of fishery closure.

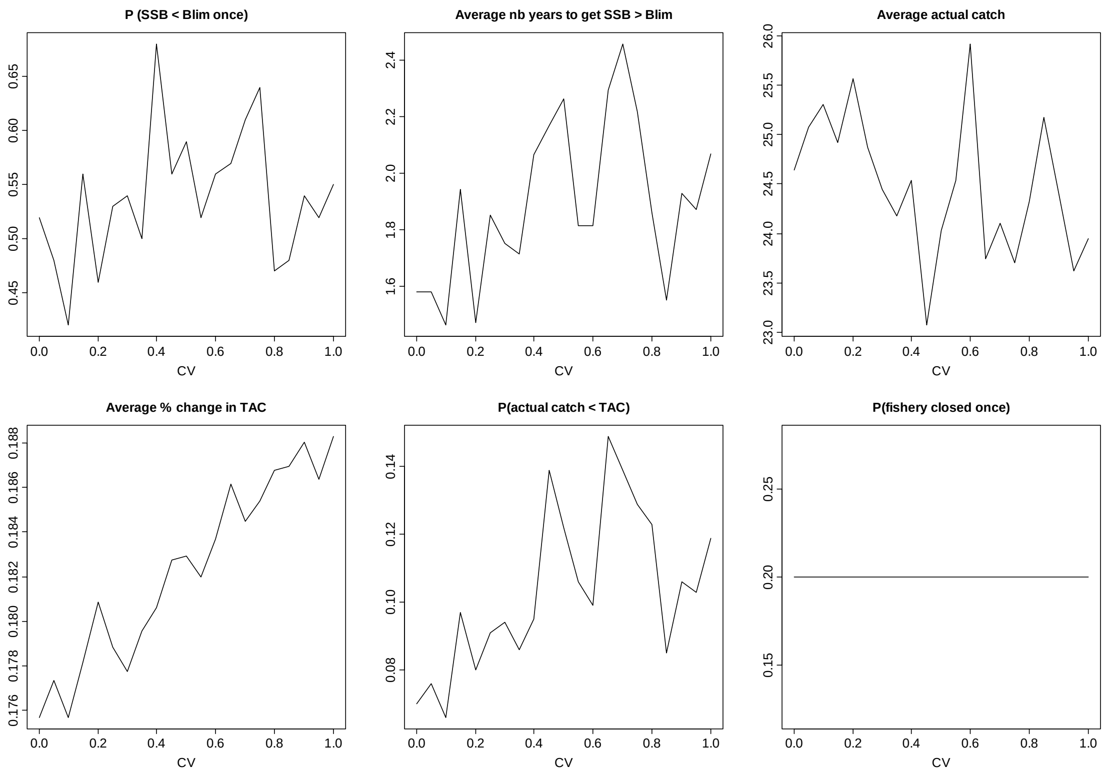

Figure 14: Sensitivity of the performance metrics to the CV of the SSB index for HCR_3 when the simulations are started with 2 years of fishery closure.

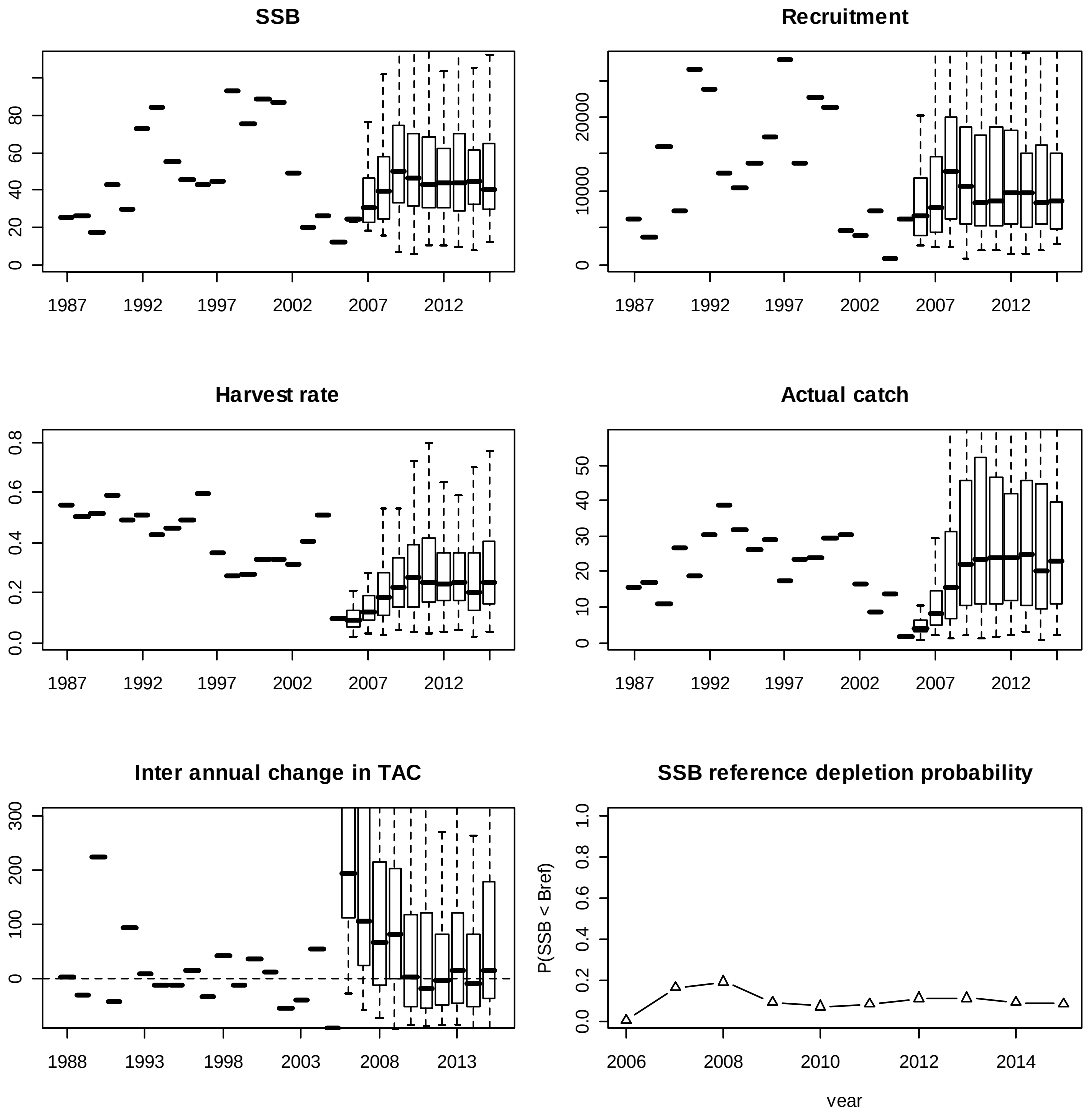

Figure 15: Summary plot for HCR_4 for the Bay of Biscay anchovy when the CVs of the SSB and recruitment indices are 25% and 30% respectively.

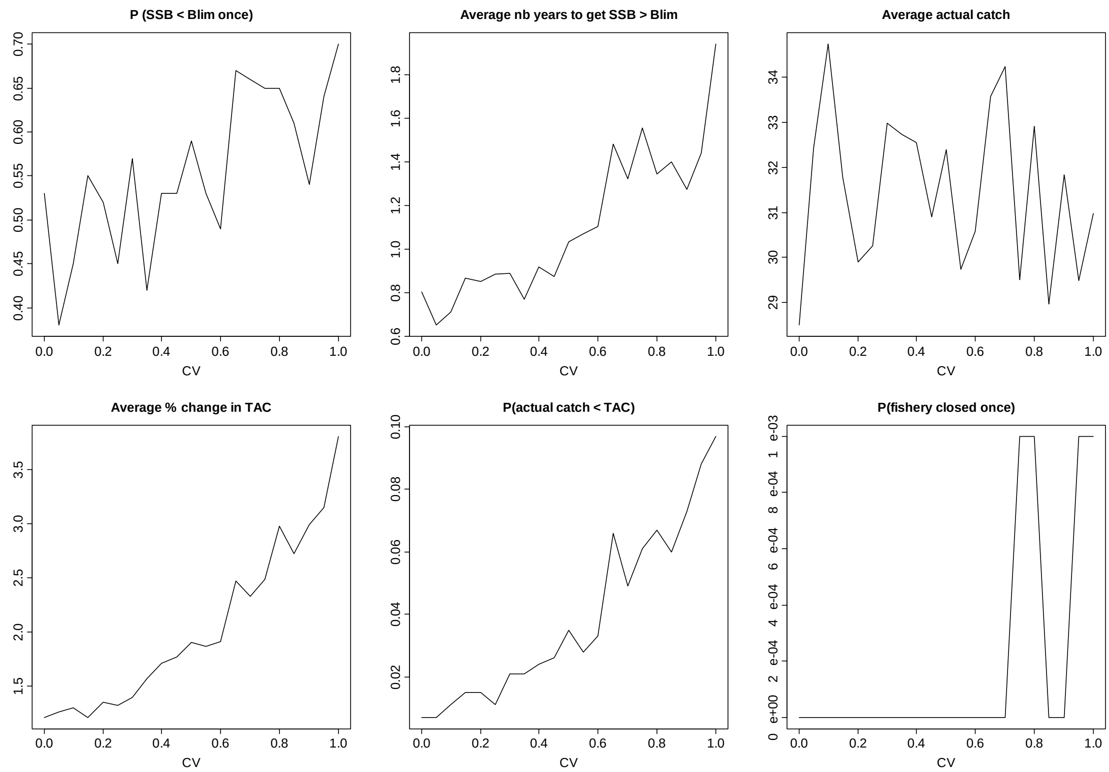

Figure 16: Sensitivity of the performance metrics to the CV of the SSB index for HCR_4 when the CV of the recruitment index is 30%.

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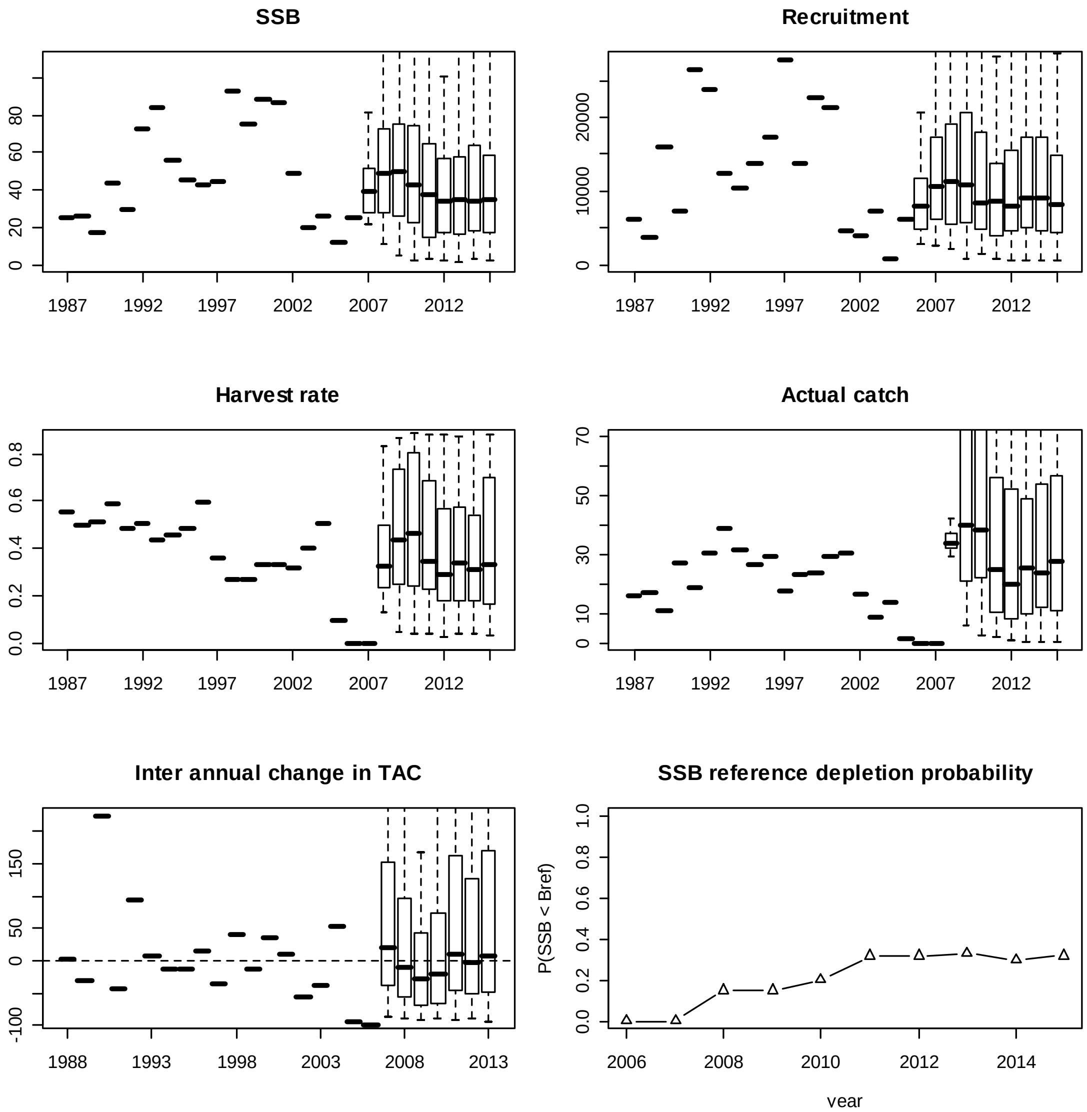

Figure 17: Summary plot for HCR_4 for the Bay of Biscay anchovy when the CVs of the SSB and recruitment indices are 25% and 30% respectively and the simulations are started with 2 years of fishery closure.

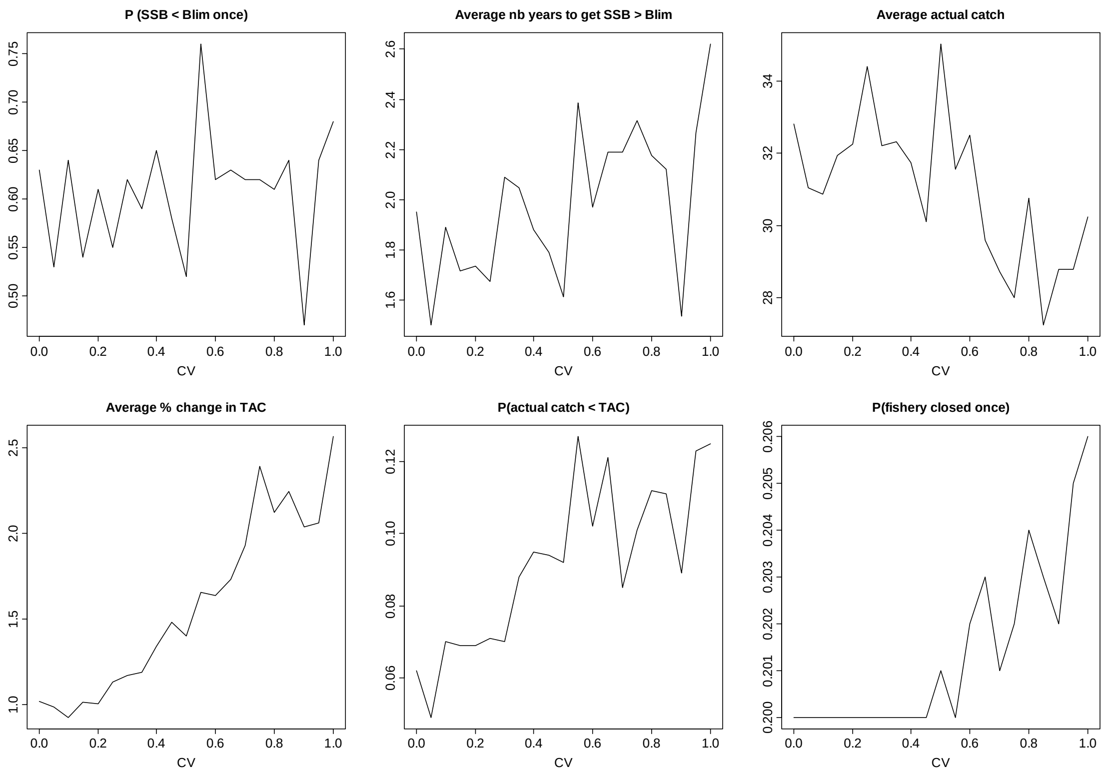

Figure 18: Sensitivity of the performance metrics to the CV of the SSB index for HCR_4 when the CV of the recruitment index is 30% and the simulations are started with 2 years of fishery closure.

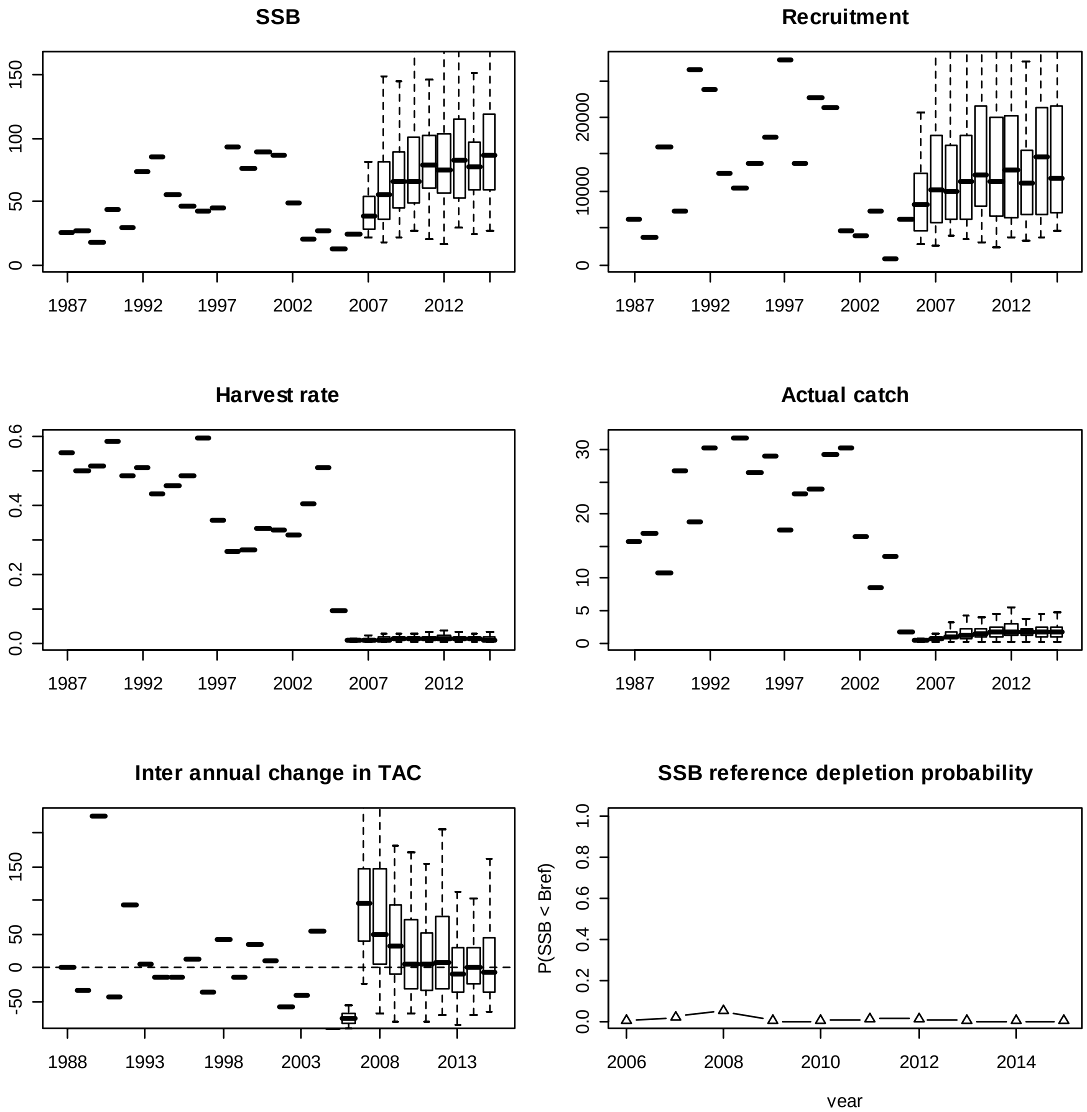

Figure 19: Summary plot for HCR_5 for the Bay of Biscay anchovy when the CV of the SSB index is 25% and the reduction factor is 0..

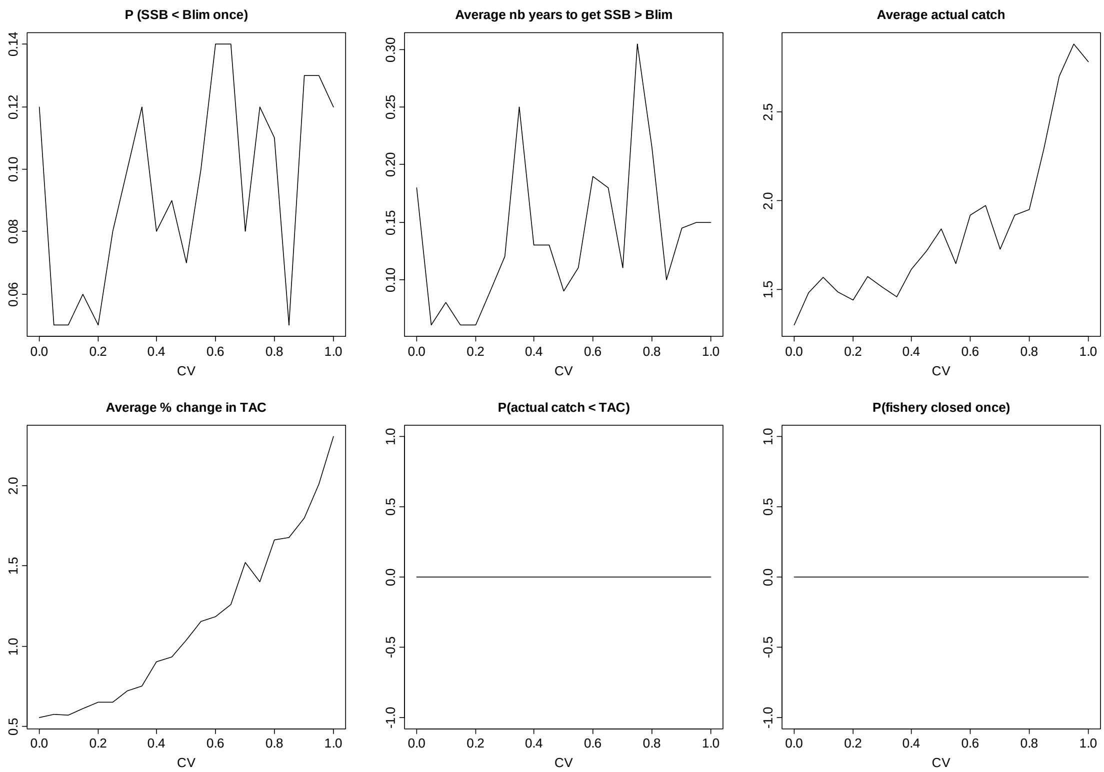

Figure 20: Sensitivity of the performance metrics to the CV of the SSB index for HCR_4 when the reduction factor is 0.5.

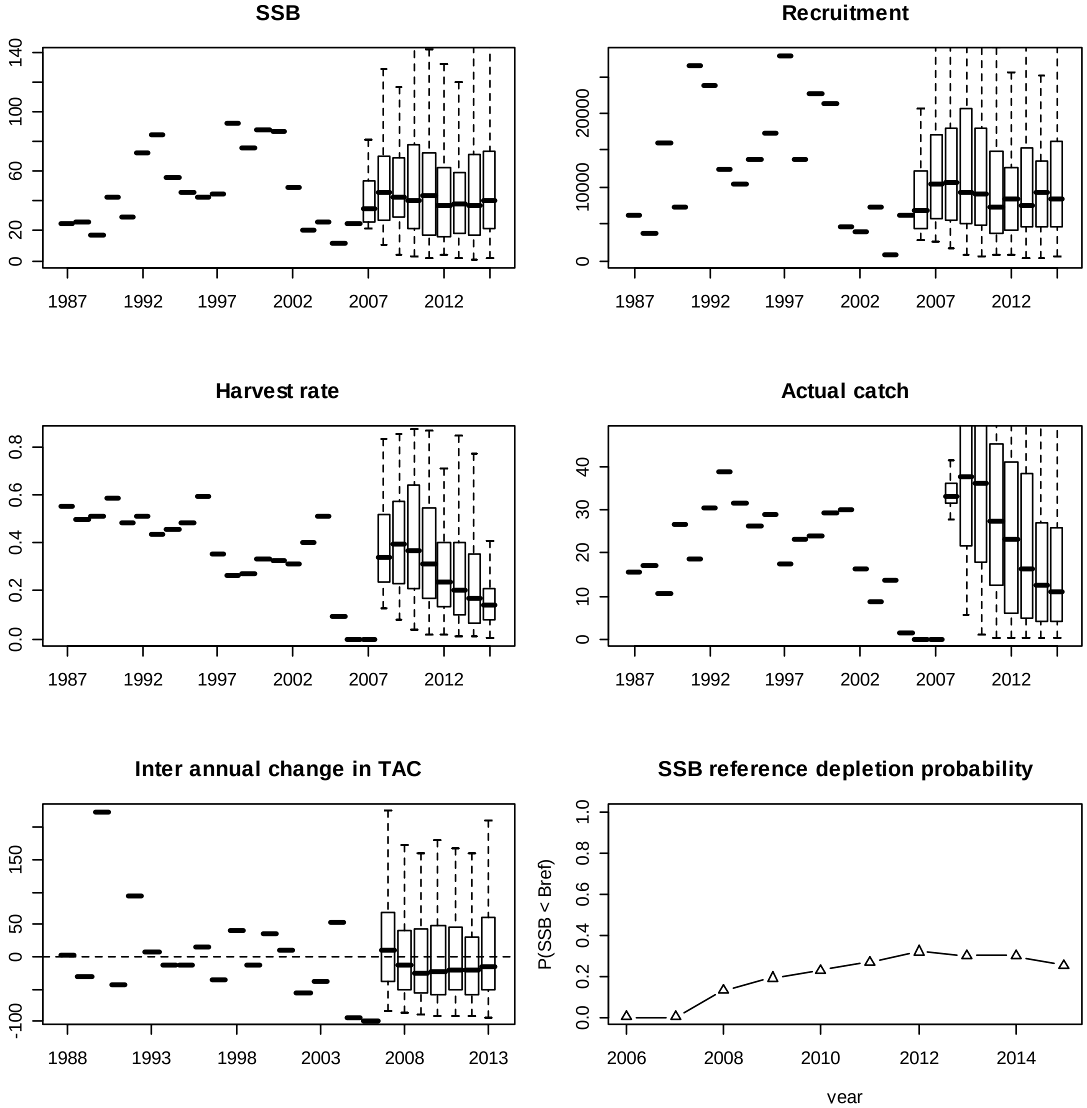

Figure 21: Summary plot for HCR_5 for the Bay of Biscay anchovy when the CV of the SSB index is 25%, the reduction factor is 0.5 and the simulations are started with 2 years of fishery closure.

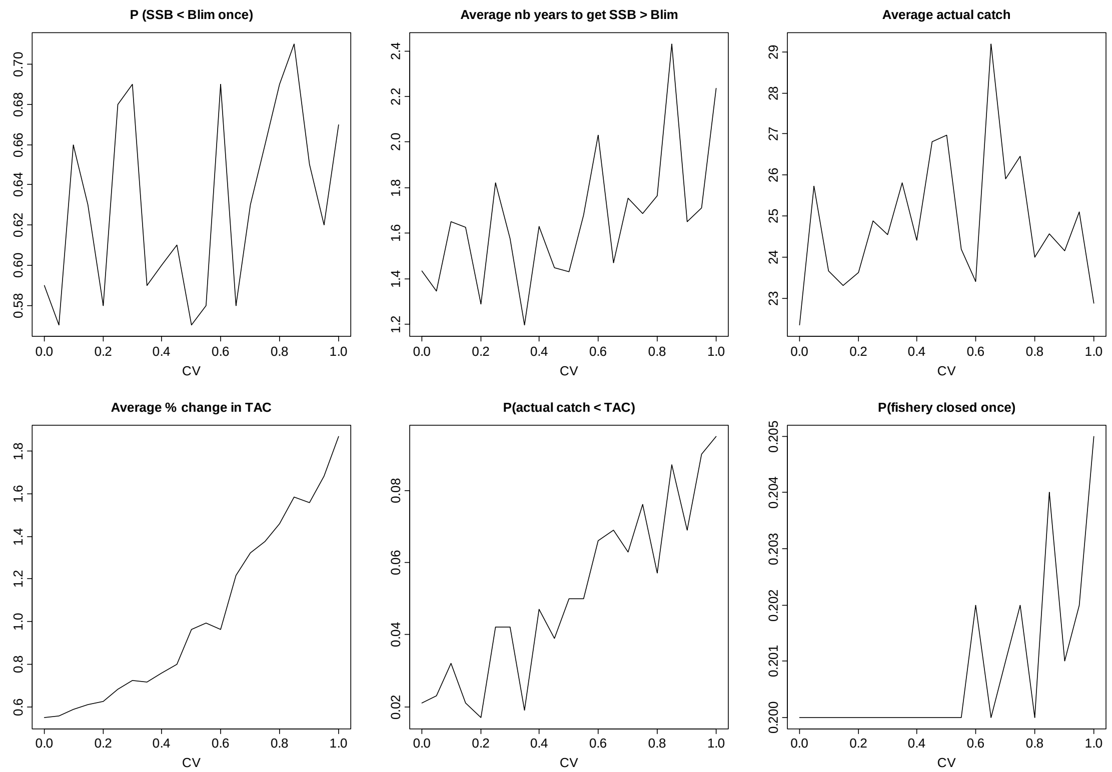

Figure 22: Sensitivity of the performance metrics to the CV of the SSB index for HCR_4 when the reduction factor is 0.5 and the simulations are started with 2 years of fishery closure.

Simulation Evaluation using ALADYM

Red mullet Thyrrhenian Sea (GSA10)

M.T. Spedicato, G. Lembo
(SIBM)

Use of *Aladym* model for assessing the effects of total mortality changes along the time with specific reference to the impact on model-based population indicators and reference points. The case of the red mullet.

Introduction

The age-length based Aladym model has been thought to be useful for assessing, through a simulation process, the consequences of changes of biological (e.g. size at first maturity, growth, recruitment), pressure (e.g. total mortality) and management (e.g. size at first capture, fishing activity) parameters on the fish population dynamics. These effects can be estimated through the expected resulting changes on population metrics derived from the model outputs.
The aim of this exercise was to evaluate along the time the effects of total mortality changes on model-based population indicators, as the total biomass, the spawning stock biomass, the biological production (all deaths removed from the population for natural and fishing causes), and on model-derived vital traits indicators, as the average length of the population and of the spawning population. Consequence of changes on simulated yield were also estimated. Finally, effects on a sustainability indicator as the ratio between exploited and unexploited spawning stock biomass (ESSB/USSB) were assessed. The relationships among the previous mentioned indicators and an additional model-based indices represented by the ratio between the exploited biomass of spawners and exploited biomass (ESSB/EB) were also investigated. Red mullet in the GSA10 (central-southern Tyrrhenian sea) was used as case study.

Materials and methods

Three exercises were conducted. In the first, a Ricker type stock-recruitment relationship with a rather low density-dependent effect was used; in the second exercise all the inputs were the same as in exercise 1, except for the stock-recruitment relationship that was substituted by recruit numbers from a vector (recruitment independent from the parental stock). In the third exercise all the inputs were the same as in the first one, but a Ricker type stock-recruitment relationship with a relatively higher density-dependent effect was used.
Inputs of the model (WP5_ptn_08_tab.01) were only obtained from trawl survey information, except for the size at first capture (L_{50}) and the related selection range (SR) that were derived from selectivity experiments conducted in the area using a commercial trawl net (Lembo et al., 2002). Parameters of the von Bertalanffy growth model and of the length-weight relationship were estimated from the autumn surveys conducted in the area (e.g. Spedicato et al., 2003; 2006). Maturity (140 mm, average value of the time series), total mortality (ranging from 1.77 in 1994 to 3.01 in 2002) and recruits indices were estimated in WP2A and WP2B of Fisboat project. As regards the number of recruits a proxy of fish at earlier stage was obtained projecting backwards the number of fish at age 1, using the total mortality value (age 2-1) estimated in WP2A. Spawning season, months in which spawning peaks are occurring and sex-ratio were from the literature on the species (reviewed in Relini et al., 1999), besides from the trawl survey information (Spedicato et al., 2003). The natural mortality by length/age was estimated inside the model by the Chen and Watanabe model, while a guess estimate of longevity was obtained by the Taylor's approximation and inputed.
In the exercise 1, the number of fish entering in the population in each time step was computed inside the model from a Ricker stock-recruitment relationship ($R=a \cdot S \cdot \exp(-b \cdot S)$), which parameters were updated using previous information in the area (Spedicato et al., 2004) and reported in the table WP5_ptn_08_tab.01.
In the exercise 2, the number of fish entering in the population at each spawning event was from a vector with a range of recruit numbers as reported in table WP5_ptn_08_tab.01.

In the exercise 3, the number of fish entering in the population at each time step was computed inside the model from a Ricker stock-recruitment relationship, which parameters were the follows: a (S_R)=350; b (S_R)=0.00000089.
All the simulations were run for 20 years. The total mortality in the years following those for which the estimates of the rates were available (first 9 years) was assumed to follow the same pattern as in the first time lag.
The tools Aladym-r was used for the three exercises, tuning the parameter QZ (Z proxy) by the tool Aladym-z in the exercise 1, while Aladym-q was used for the exercises 1 and 3 (for more details on Aladym model see Cotter et al., 2007b).

Results
Simulated population metrics are in the figure WP5_ptn_08_fig.01. The evolution of the biomass and spawning stock biomass along time follows a similar pattern as the unexploited biomass and spawning stock biomass, although at different levels. This dynamics seems characterised by cycles, very likely influenced by the life history trait, characterised by an average longevity of about 7 years and a discrete recruitment mode lasting for 5 months. As a consequence of exploitation, however, the peaks of exploited biomass and spawning stock biomass are less conspicuous after 10 years. Impact of a high rate of total mortality is well evidenced in the evolution of the indicator ESSB/USSB that falls down at very low values almost every 5-6 years, when the additive effects of harvesting along cohorts were combined with the characteristic of the life cycle.
Simulated removal metrics (yield and biological production) are in the figure WP5_ptn_08_fig.02 and show a temporal pattern comparable with that of the population metrics. Annual rates of total mortality recomputed by the model for each sex and the rate of fishing mortality (F) calculated by the model for the whole population are also reported (WP5_ptn_08_fig.02). Length-based vital trait indicators as length mean of the exploited and unexploited populations and length mean of the exploited and unexploited spawning populations are in the figure WP5_ptn_08_fig.03. Also these indicators show similar cycles, as the simulated mean length of the catches.
To better understand the evolution of the population dynamics along time, the relationships between pressure parameters and population or removal metrics have been investigated (WP5_ptn_08_fig.04). It is worth mentioning that all the examined indicators and metrics were well correlated with the pressure parameters Z and F, although slightly better correlations were find with F. This is not surprising, given the component of natural mortality that Z incorporates. The best correlation between the two parameters Z and F was found with a delay effect of 1 year: i.e. Z value at the year *i* was better correlated with the F value at the here *i+1*. This might be explained considering a cascade effects along cohorts combined with the growth rate of the species, that requires a time lag to be evidenced. Thus, all the relationships regarding Z and population or removal metrics or vital traits had a delay of 2 years, while those regarding F had a delay of 1 year.
Considering the high level of negative correlation with the pressure parameters, the indicator ESSB/USSB was retained at the end of the analysis to explore pairwise relationships with the length indicators (WP5_ptn_08_fig.05). In addition, also the indicator represented by the ratio between the exploited spawning population and the whole population (ESSB/EB) was considered. It has the advantage to be likely more easy to understand (which proportion should the biomass of spawners represent for a sustainable exploitation?). The investigated pairwise relationships all evidenced a very high level of positive correlation between indicators, thus higher length mean of population, spawning population and catches corresponded to higher levels of both ESSB/USSB and ESSB/EB.
These two indicators were retained for evaluating the effects of a Ricker stock-recruitment relationship on the population dynamics in comparison with a recruitment pattern independent from the parental stock. The results, reported in the figure WP5_ptn_08_fig.06, highlight that the ratio ESSB/USSB, under the hypothesis of independent recruitment, was about 50% of the ESSB/USSB (about 34% in case of stock-recruitment relationship with higher density-dependent effect) when a Ricker stock recruitment relationship was acting. Instead, the ESSB/EB ratio was about 130% (about 85% in case of the exercise 3). This results is expected considering the density dependent effects, hence type and parameters of stock-recruitment relationship should be handled with care.
The figure WP5_ptn_08_fig.07 shows the results from the stochastic Aladym-q simulation model regarding the indicator ESSB/USSB with associated standard deviation. Four peaks were observed in correspondence of the years 2, 7, 12 and 17. The relative probability distributions are reported in figure WP5_ptn_08_fig.08, while the cumulative distributions in the figure WP5_ptn_08_fig.09. Excluding the year 2, that still

incorporates the effect of lower past rate of mortality, for the other years more probable values of the ratio ESSB/USSB were in the range 0.1-0.17. In the years when the minimum values were observed (5, 10, 15 and 20; figures WP5_ptn_08_fig.10 and WP5_ptn_08_fig.11) the more probable values were between 0.06 and 0.10 or between 0.04 and 0.07, depending on the year.
Aladym-q was also used to perform simulations of different pressure scenarios. Assuming a current average rate of total mortality of 2.4 and a stock-recruitment relationship characterised by a higher density-dependent effect, that is plausible according to the knowledge on the species (Levi et al., 2003), we tried to evaluate the effects of changing pressure, from -25% to +25% of the current value. Cumulative distributions after 20-years simulation (all the parameters kept constant along time for each simulation and scenario) are reported in figures WP5_ptn_08_fig.12 and WP5_ptn_08_fig.13. Overall results summarised in WP5_ptn_08_fig.13 highlight an alert and the positive effect of reducing pressure on the population.

Conclusion

The state of the red mullet population in the central-southern Tyrrhenian sea has been evaluated by previous studies carried out within Samed (Anonymous, 2002) and Medits (Tserpes et al., 2002) projects. In the former approach the analysis was based on population model (equilibrium assumptions) and trawl-survey derived indices; in the latter only 'direct' indices were used. In both cases recommendations of reducing pressure and protect recruitment were formulated, although 'direct' indices of abundance did not show any trend, but the time series was short.
The analyses conducted in this study underpin the identification of sign of deterioration in the red mullet population and provide converging evaluation with the comprehensive indicator approach based on 'direct' estimates performed in WP5 of the Fisboat project.
This study supports the usefulness of coupling evaluations aimed at understanding how changes of biological and pressure parameters affect fish population dynamics and which are the consequences on the model-based indicators that can be used as reference points.

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Spedicato M.T., P. Carbonara, T. Silecchia & G. Lembo. 2004. Strategie di gestione basate sulla biomassa di riproduttori. Simulazione di diversi scenari di prelievo della triglia di fango (*Mullus barbatus* Ll., 1758). *Seminario per l'identificazione di Reference Points. MIPAF-SIBM, 28-29 January 2004.*

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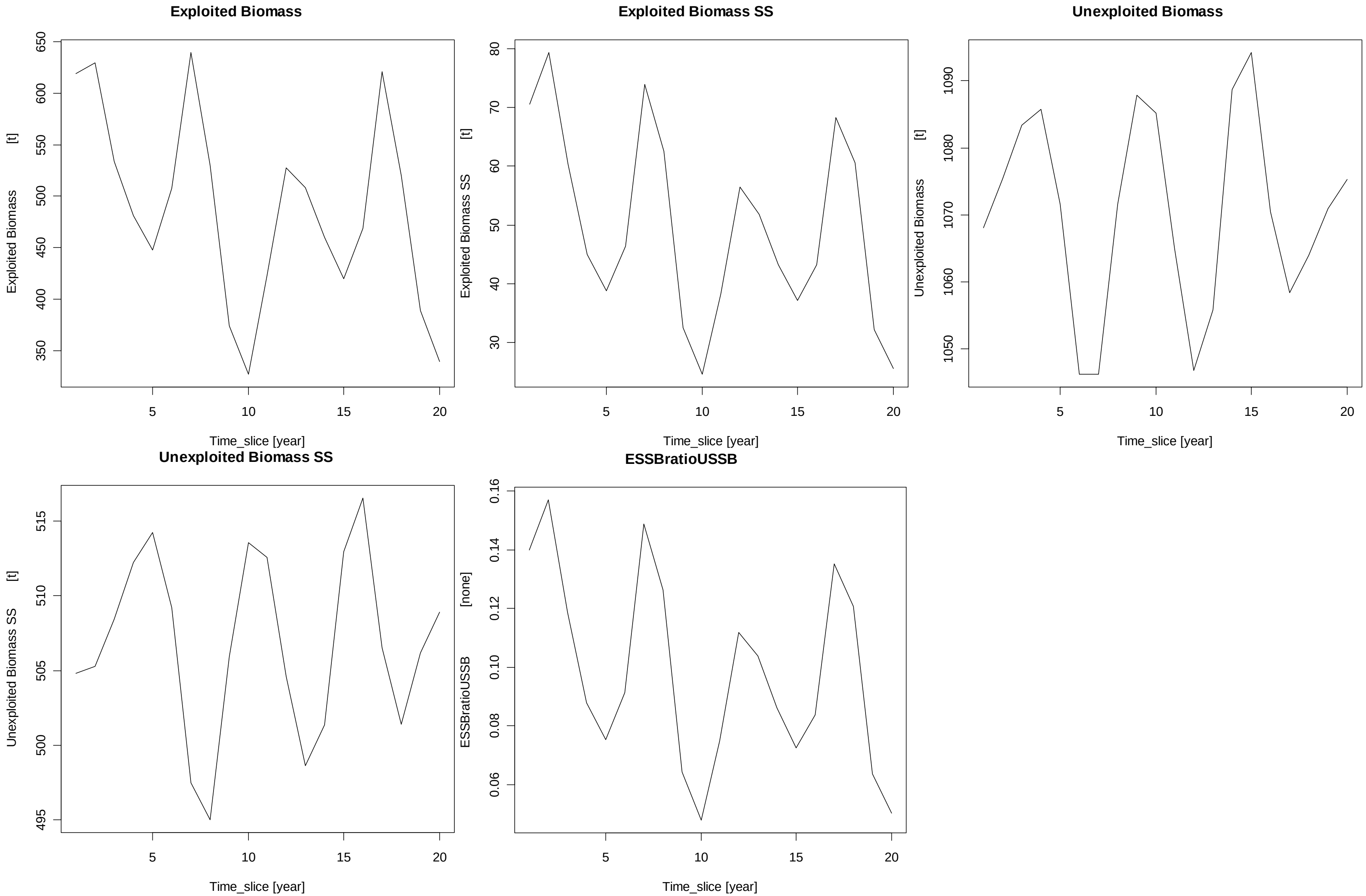
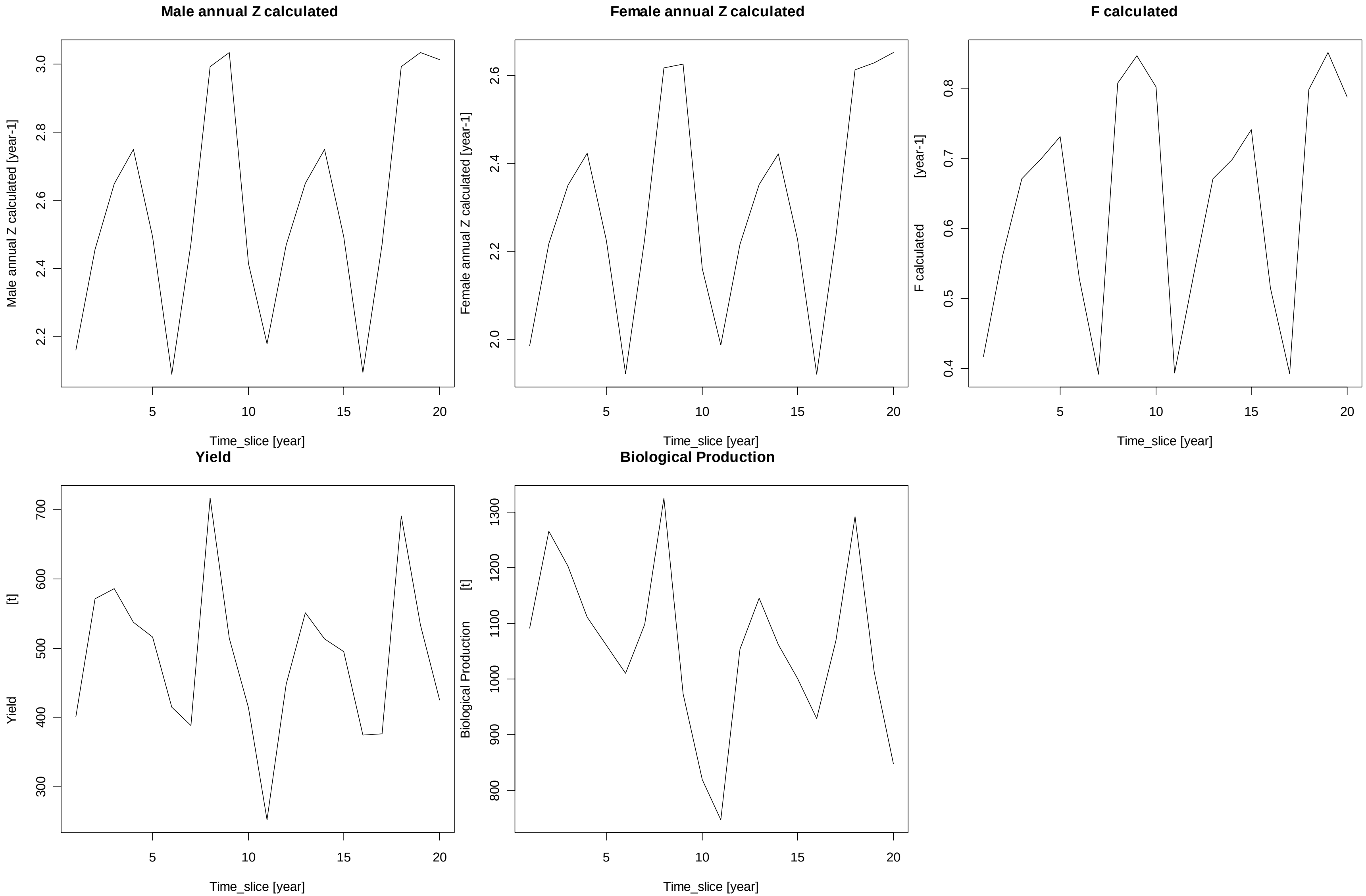
WP5_ptn_08_tab.01 – Summary table of the inputs used in Aladym model for the red mullet case study.

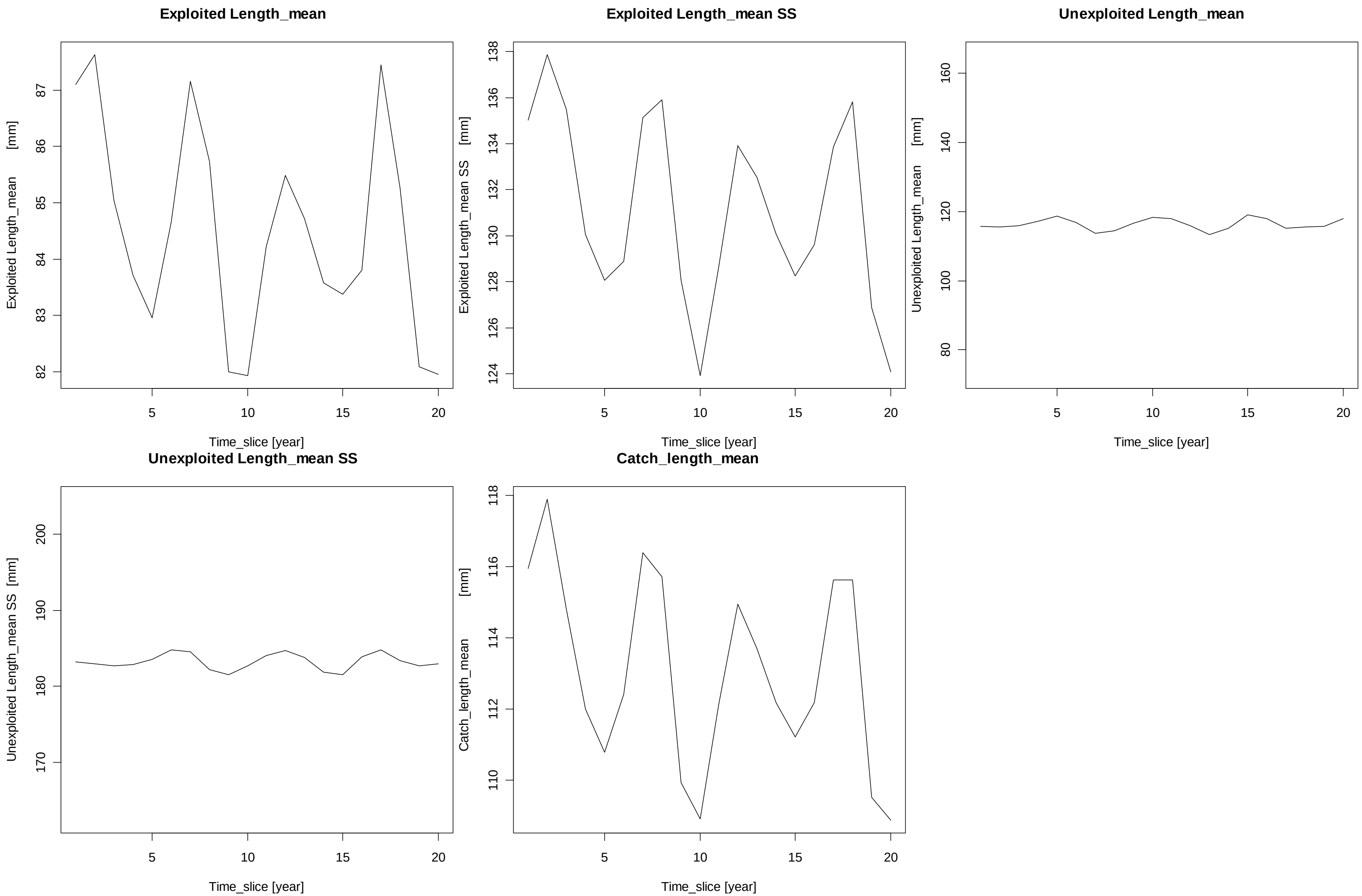
Input description		**females**	**males**
K (year)		0.385±0.03	0.61±0.03
L_∞ (mm)		260 ±10	260 ±10
t_0		0.4 ±0.1	0.3 ±0.1
a		0.00000662033	0.00001037264
b		3.10	3.01
Life span (years)		8	5
M		Variable with age/length	
L_{mat} (mm)		140±10	110±10
Maturity range (L75-L25) (mm)		30	20
L_{50} (mm)		89	
Sex ratio (F/F+M)		0.5	
SR (mm)		18	
Fishing coefficient		1 (all the months)	
Recruits (initial number) and parameters of the log-normal distribution		$83 \cdot 10^6$ (mean ln(R)=17.97; ds ln(R)=0.43)	
a (S_R)		190	
b (S_R)		0.00000049	
Spawning time and spawning peak		From May to September (June-July)	
Number of year to be simulated		20 (pre-simulation 40)	
Z (year)	1994	1.77	
	1995	2.09	
	1996	2.44	
	1997	1.32	
	1998	2.65	
	1999	2.08	
	2000	1.71	
	2001	2.73	
	2002	3.01	



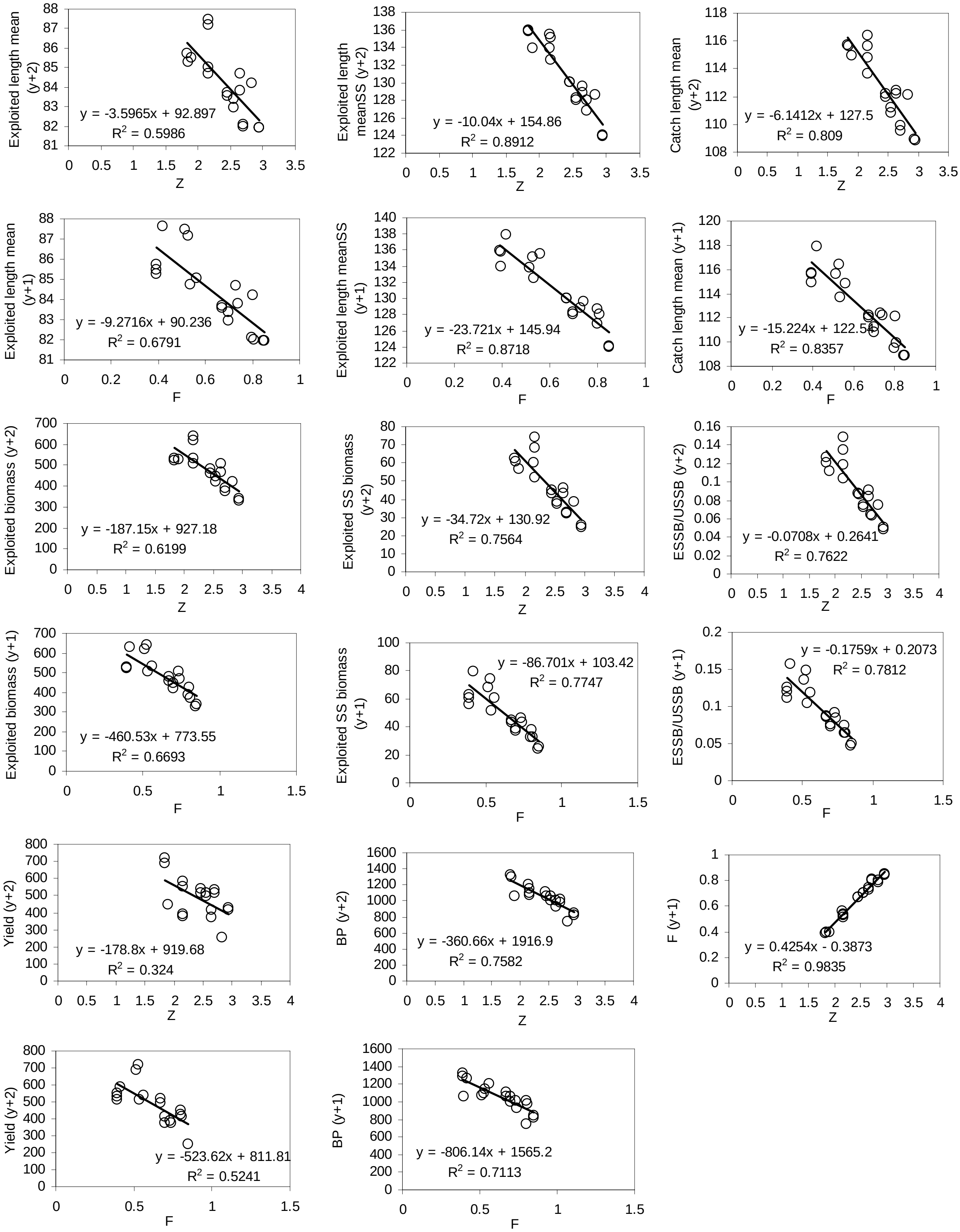
WP5_ptn08_fig01-Outputs of the simulations of the Aladym-r model related to the exploited and unexploited biomass (population at sea) of the whole population (Exploited Biomass and Unexploited Biomass), biomass of female spawners (Exploited Biomass SS and Unexploited Biomass SS), ratio (ESSBratioUSSB) between the exploited spawning stock biomass and the unexploited spawning stock biomass. 20 years simulation results for red mullet in the GSA10.



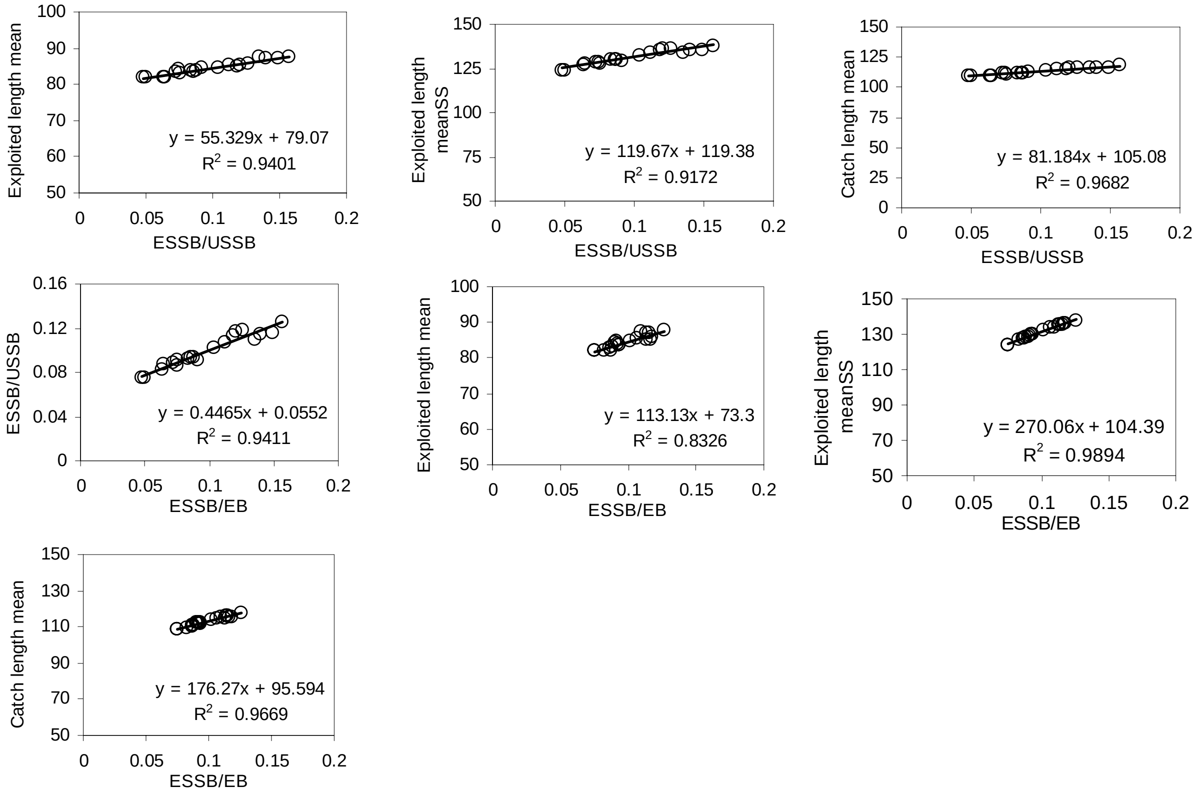
WP5_ptn08_fig02-Outputs of the simulations of the Aladym-r model related to the total mortality of females and males calculated by the model, the fishing mortality F, the Yield, the biological production (all deaths, including fished population). 20 years simulation results for red mullet in the GSA10.



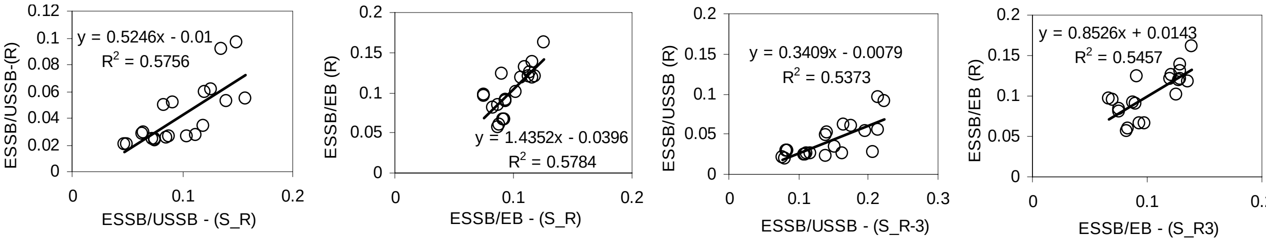
WP5_ptn08_fig03-Outputs of the simulations of the Aladym-r model related to the mean length of: the exploited population, the unexploited population, the exploited spawning population and the unexploited spawning population and the mean length of catches. 20 years simulation results for red mullet in the GSA10.



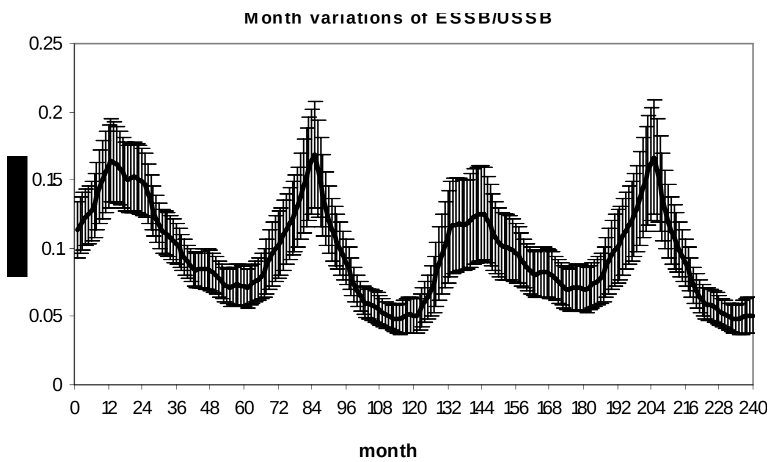
WP5_ptn08_fig04 - Plots of the relationships between the pressure factors and the model-based indicators. 20 years simulation results. The plot of the relationship between the total mortality and the fishing mortality computed by the model are also reported. In each plot the fitted linear model and the regression coefficient are indicated for red mullet in the GSA10.



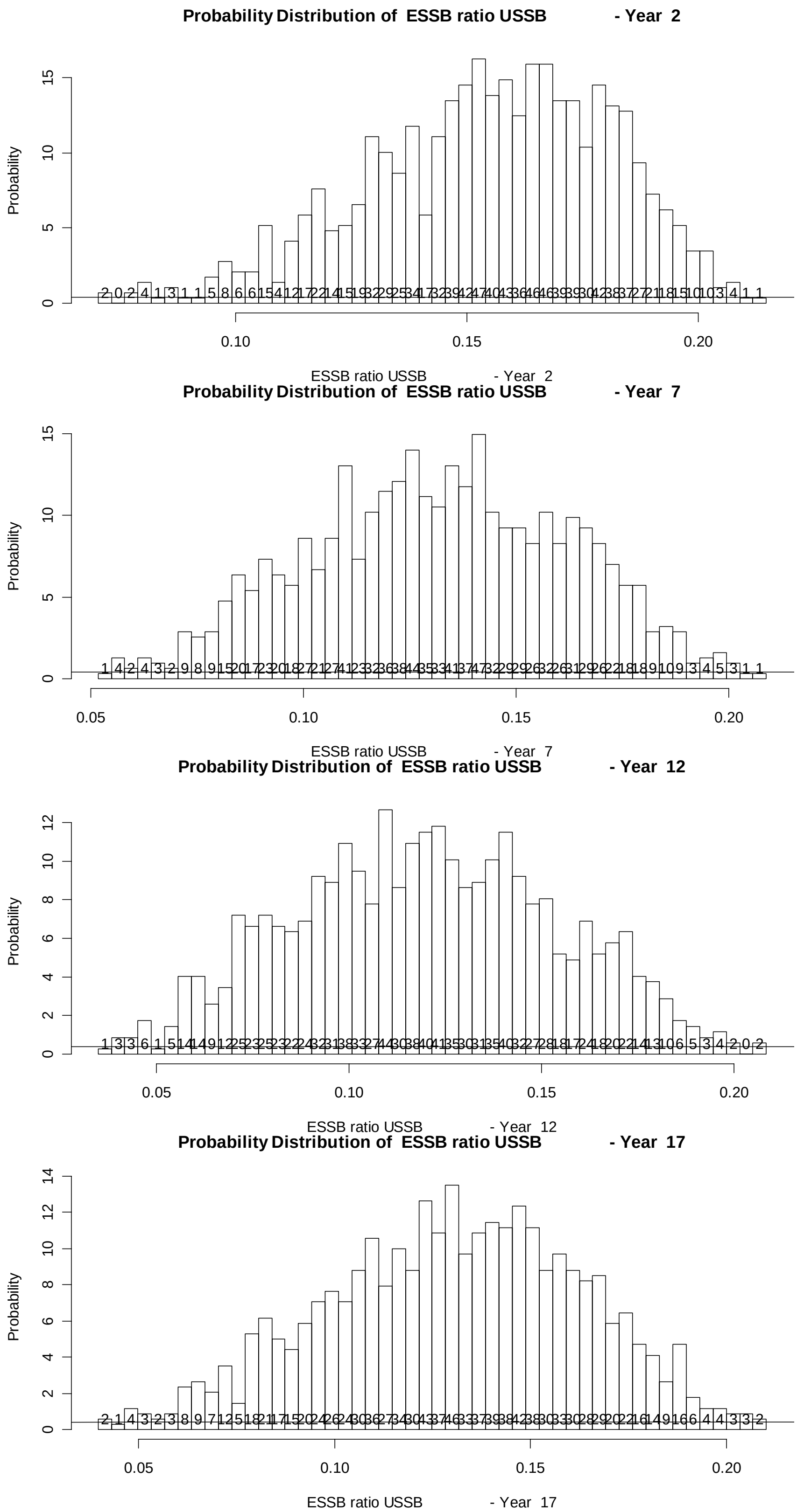
WP5_ptn08_fig05- Plots of the cross relationships between relevant model-based indicators derived from the Aladym-r outputs. 20 years simulation results for red mullet in the GSA10.



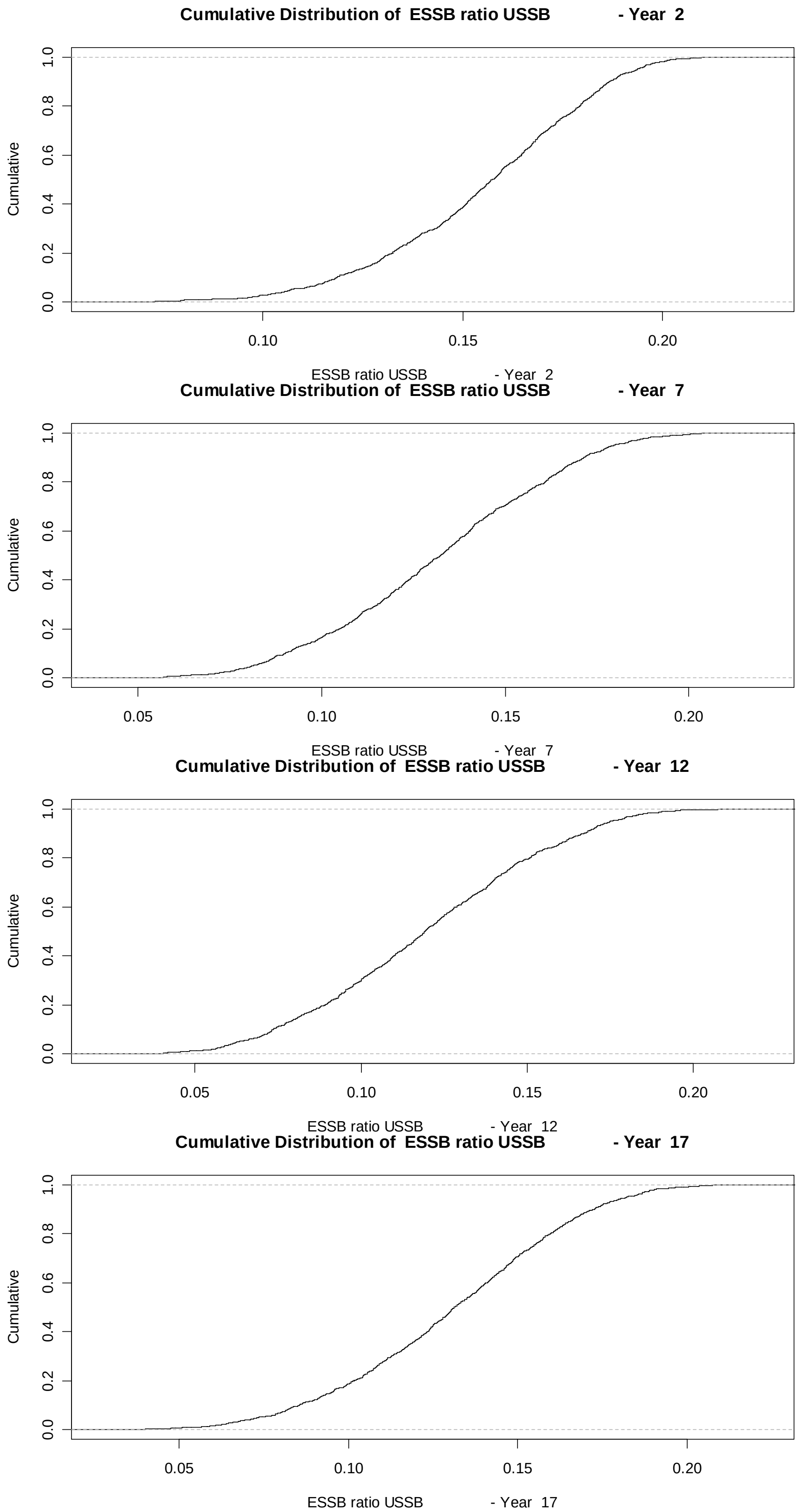
WP5_ptn08_fig06- Relationships between the ratio of the exploited and unexploited spawning stock biomass obtained using a stock recruitment relationship (ESSB/USSB-(S_R) and a vector of recruits (ESSB/USSB-(R)). The same relationship (right side) is also represented for the ratio between the exploited spawning stock biomass and the exploited biomass obtained using a stock recruitment relationship (ESSB/EB-(S_R) and a vector of recruits (ESSB/EB-(R)). The same relationships are also reported for a stock-recruitment relationship with a higher density-dependent effect (ESSB/USSB-(S_R-3); ESSB/EB(S_R-3)). Results from 20 years simulation for red mullet in the GSA10.



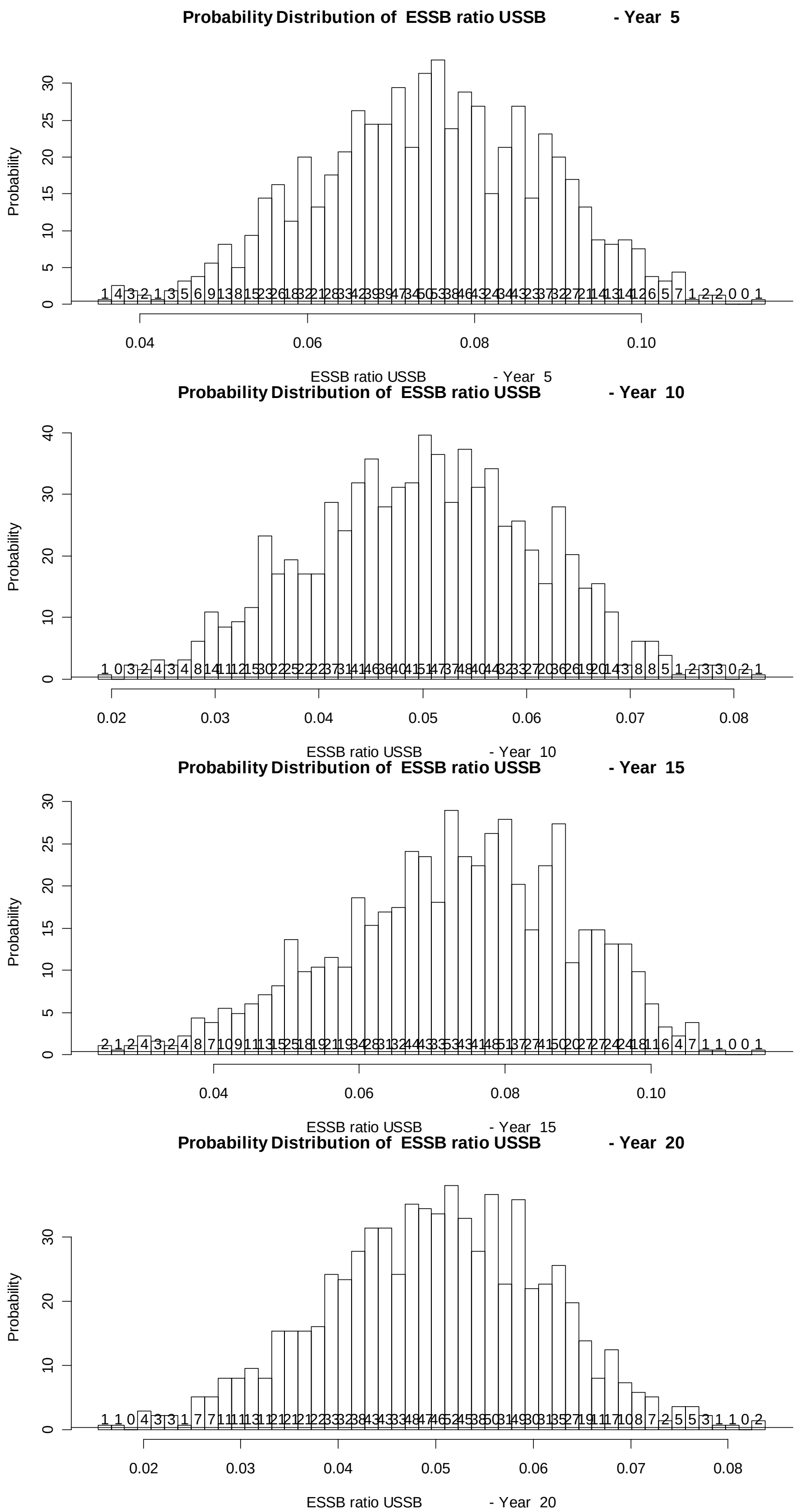
WP5_ptn08_fig07-Month variations of the model-based indicator ESSB/USSB (exploited spawning stock biomass/unexploited spawning stock biomass) with standard deviations. Results from Aladym-q simulations along 20 years (1000 runs) for red mullet in the GSA10.



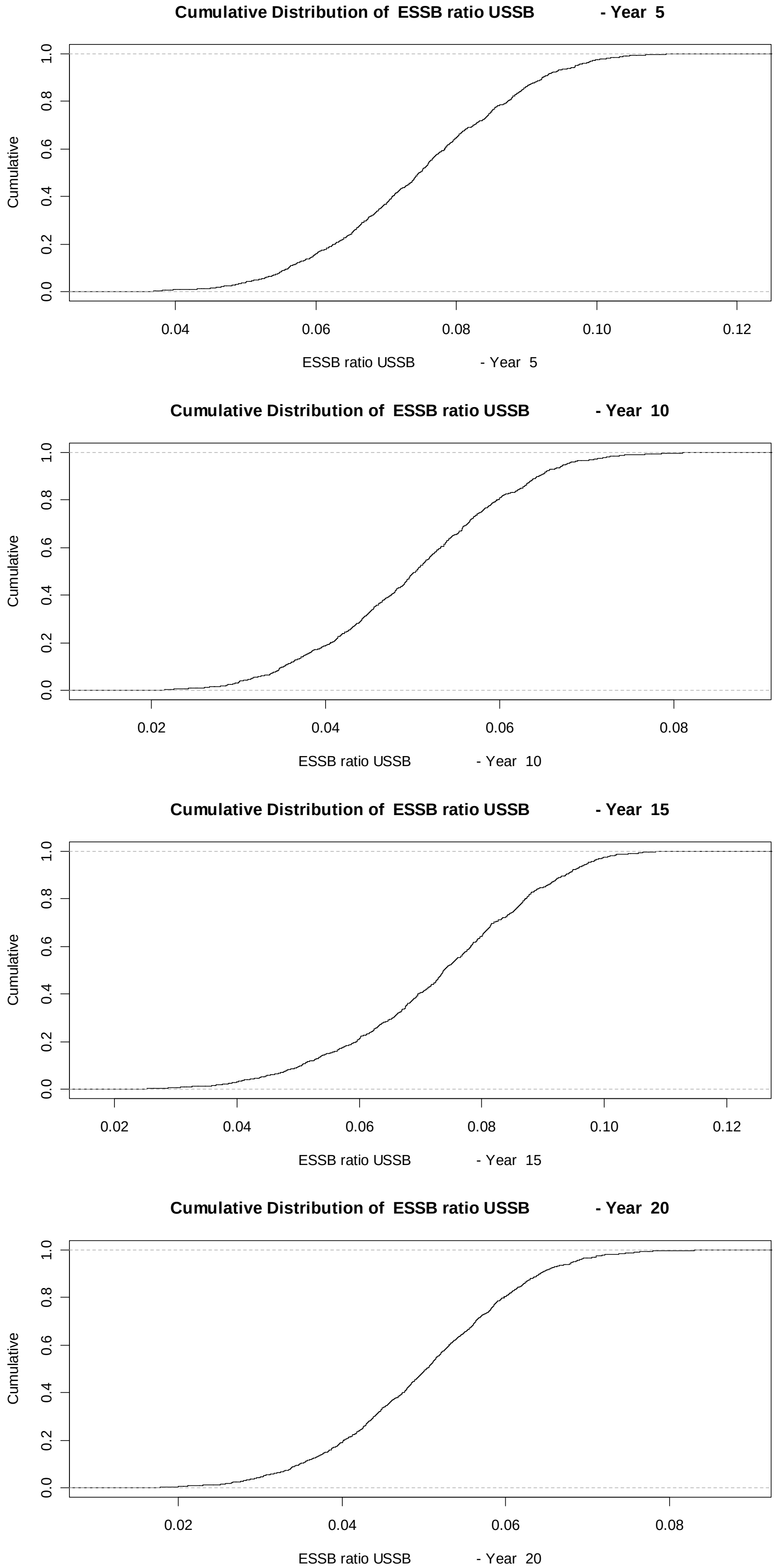
WP5_ptn08_fig08-Probability distributions of the model-based indicators (exploited spawning stock biomass/unexploied spawning stock biomass, ESSB/USSB) in the years where the maximum values were observed. Results from Aladym-q simulations along 20 years for red mullet in the GSA10.



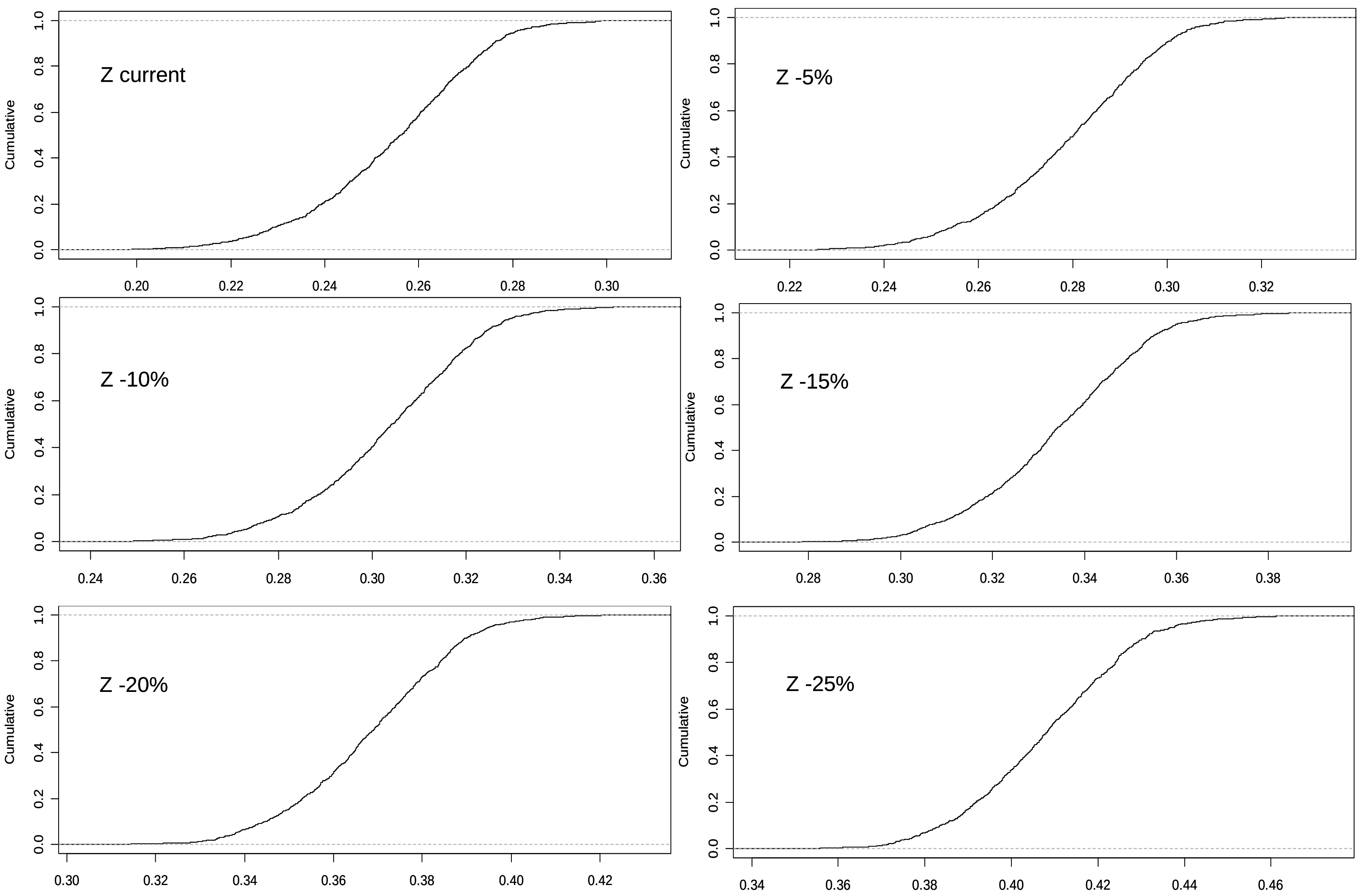
WP5_ptn08_fig09-Cumulative distributions of the model-based indicators (exploited spawning stock biomass/unexploited spawning stock biomass, ESSB/USSB) in the years where the maximum values were observed. Results from Aladym-q simulations along 20 years for red mullet in the GSA10.



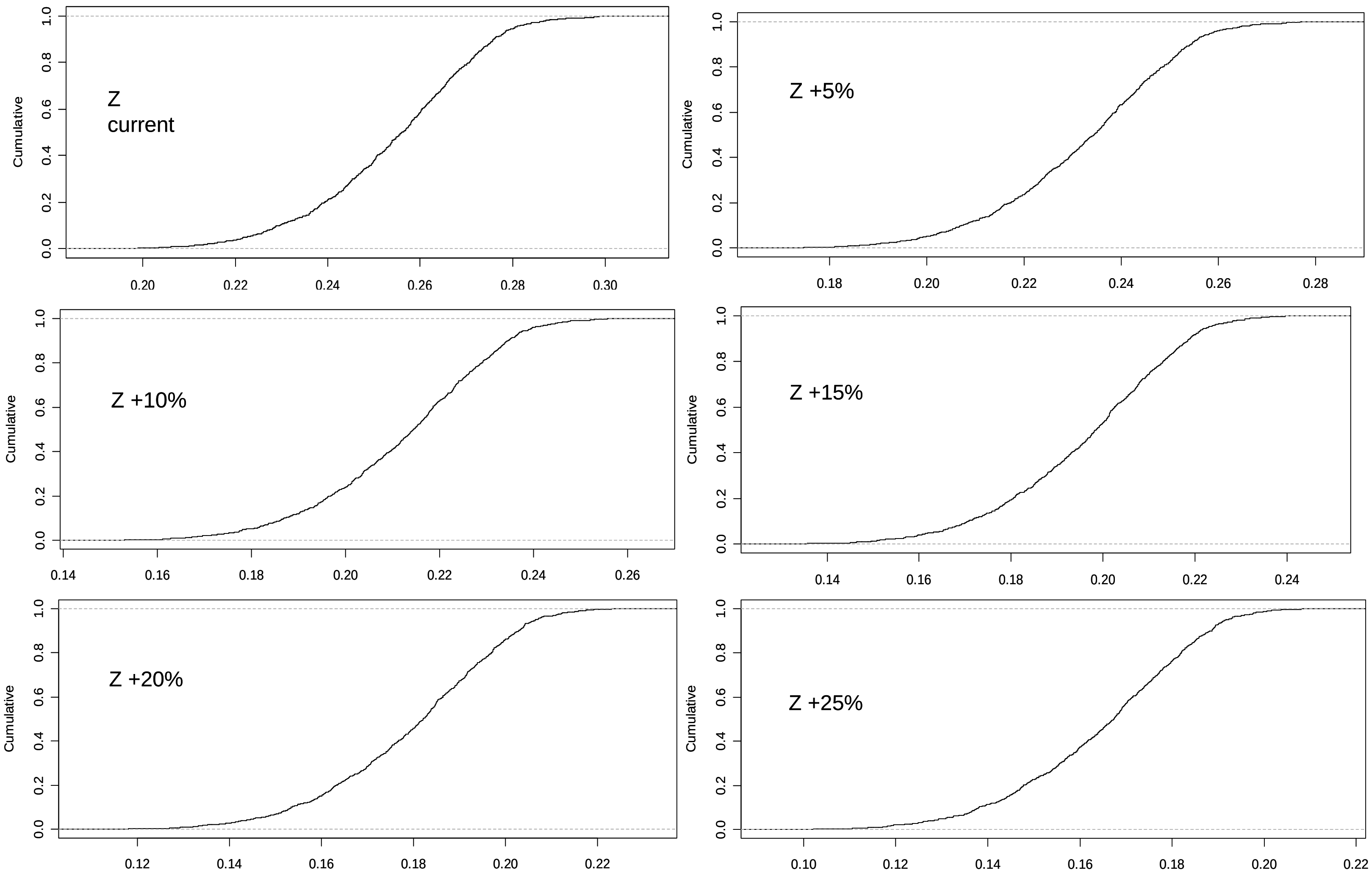
WP5_ptn08_fig10-Probability distributions of the model-based indicators (exploited spawning stock biomass/unexploited spawning stock biomass, ESSB/USSB) in the years where the minimum values were observed. Results from Aladym-q simulations along 20 years for red mullet in the GSA10.



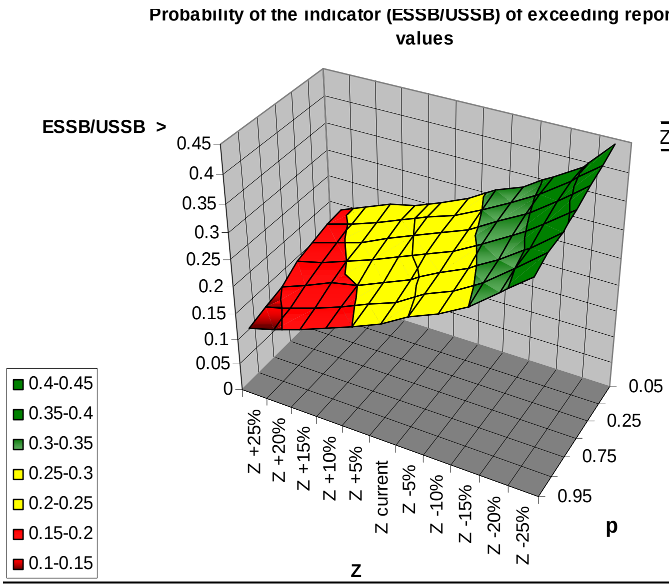
WP5_ptn08_fig11-Cumulative distributions of the model-based indicators (exploited spawning stock biomass/unexploited spawning stock biomass, ESSB/USSB) in the years where the minimum values were observed. Results from Aladym-q simulations along 20 years for red mullet in the GSA10.



WP5_ptn08_fig12 – Cumulative probability of the effects of different pressure scenarios simulating decreasing total mortality on the indicator ESSB/USSB of red mullet in the GSA10. 5 step-reductions were simulated over 20 years with Aladym-q and compared to the ‘current scenario’. The plots are related to the 20th year scenario.



WP5_ptn08_fig13 - Cumulative probability of the effects of different pressure scenarios simulating increasing total mortality on the indicator ESSB/USSB of red mullet in the GSA10. 5 step-augmentations were simulated over 20 years with Aladym-q and compared to the ‘current scenario’. The plots are related to the 20th year scenario.



Z		probability of exceeding reported values						
Z value	Z change	0.05	0.10	0.25	0.50	0.75	0.90	0.95
3.0	Z +25%	0.19	0.19	0.18	0.17	0.15	0.14	0.13
2.9	Z +20%	0.21	0.2	0.2	0.18	0.17	0.16	0.15
2.8	Z +15%	0.23	0.22	0.21	0.2	0.19	0.17	0.16
2.7	Z +10%	0.24	0.24	0.23	0.22	0.2	0.19	0.18
2.6	Z +5%	0.26	0.26	0.25	0.24	0.22	0.21	0.2
2.4	Z current	0.28	0.28	0.27	0.26	0.24	0.23	0.22
2.3	Z -5%	0.31	0.30	0.29	0.28	0.27	0.26	0.25
2.2	Z -10%	0.33	0.33	0.32	0.31	0.29	0.28	0.27
2.1	Z -15%	0.36	0.36	0.35	0.34	0.32	0.31	0.3
1.9	Z -20%	0.39	0.39	0.38	0.37	0.36	0.35	0.34
1.8	Z -25%	0.44	0.43	0.42	0.41	0.40	0.39	0.38

WP5_ptn08_fig14 – Traffic light graph and table of the results obtained from simulations evaluating the effects of changes of pressure scenarios based on total mortality on the indicator ESSB/USSB for the red mullet in the GSA10. The results from Aladym-q are expressed in terms of probability of exceeding reported values of ESSB/USSB.

Simulation Evaluation using ALADYM

Hake Aegean Sea

C.-Y. Politou (HCMR)

Use of *Aladym* model for assessing the effects of total mortality changes along the time with specific reference to the impact on model-based population indicators and reference points. The case of hake in the Aegean Sea.

Introduction

The age-length based Aladym model has been used to test, through a simulation process, the consequences of changes of pressure and management parameters (e.g. total mortality, size at first capture) on the fish population dynamics of hake (*Merluccius merluccius*) in the Aegean Sea. These effects have been estimated along 40 years, analysing the changes of model-based population indicators, as the total biomass, the spawning stock biomass, the biological production (i.e. all deaths removed from the population for natural and fishing causes), and on model-derived vital traits indicators, as the average length of the population and of the spawning population. Consequences of changes on simulated yield and mean length of the catches were also estimated. Finally, effects on a sustainability indicator as the ratio between exploited and unexploited spawning stock biomass (ESSB/USSB) were assessed. The relationships among the previous mentioned indicators and an additional model-based index represented by the ratio between the exploited biomass of spawners and the exploited biomass (ESSB/EB) were also investigated.

Materials and methods

The exercise was conducted modelling the population through total mortality indices estimated within WP2A of the Fisboat project for the first 9 years (years: 1-9, corresponding to the available time series). The value of the last year (year 9) was then projected forward for 11 years (years: 10-20), and for the final 20 years (years: 21-40) a lower value of total mortality was introduced, to simulate long-term effects of a pressure reduction. The resulting input vector of total mortality, tuned by the tool Aladym-z, is reported in figure WP5_ptn_09_fig.01.

The main inputs of the Aladym model are in the WP5_ptn_09_tab.01.

The size at first capture (about 80 mm total length) corresponding to a mesh size of 28 mm was used as input for the first 8 years. In the following years a value (about 108 mm total length) approximately corresponding to a mesh size of 40 mm was applied. Also a de-selection length ($D_{50\%}$) was considered and thus the equation (the product of two logistic curves, cfr. Aladym methods, in Cotter et al. 2007, Manual of Indicators and Methods) accounting for vulnerability/accessibility of the fish to the gear was employed. This choice was driven by the knowledge about the fishing grounds targeted by differently equipped fishing units, accounting for the distribution of adult hakes in the area, which inhabit the deeper waters (Anon., 2006). The input values regarding the selectivity pattern were finally based on the knowledge regarding the harvesting pattern of the gears mainly used in the area and the scientific literature related to the subject (Abella and Serena, 1998; Fiorentino et al., 1998; Petrakis et al., 2004). The fishing activity was set at 1.0, except in the months (June-September) when the fishing ban of trawlers is enforced. During this time the fishing activity coefficient was set at ~0.4 accounting for the prevailing of trawlers compared to the other fishing systems in terms of global catches (data from National Statistical Service of Greece.

Parameters of the von Bertalanffy growth model by sex were set using the estimates obtained in the Samed project (Anonymous, 2002) for the Aegean Sea, while those of the length-weight relationships for females and males were derived from Papaconstantinou et al. (1993). Size at first maturity was from literature data (Mytilineou & Vassilopoulou, 1988). As regards the number of recruits a proxy of fish at earlier stage was obtained projecting backwards the number of fish at age 1, using a total mortality value of 0.8 mean value estimated from WP2A for age 2-1). Recruitment was assumed independent from the parental stock and hence a vector of recruits, randomly changing by time interval, was used as input. Spawning season, months in which spawning peaks are occurring and sex-ratio were from the literature on the species

(Papaconstantinou & Stergiou, 1995; Karlou-Riga & Vrantzas, 2001), besides from the trawl survey information (Papaconstantinou et al., 1993; Papaconstantinou et al., 1994; Papaconstantinou et al., 1998).
The natural mortality was maintained fixed through ages and calculated comparing different methods (e.g. Pauly equation, Alagaraja, Beverthon and Holt life history invariants (Jensen, 1996)) while a guess estimate of longevity (about 20 years) was obtained by the Taylor's approximation.
All the simulations were run for 40 years.
The tools Aladym-r and Aladym-q were used, the latter to account for uncertainty in the process of assessing the effects of changes in model input parameters.

Results
Simulated population metrics are in the figure WP5_ptn_09_fig.02. The evolution of the exploited biomass and spawning stock biomass along the time appears influenced by two main events, the first around years 7-8 as a consequence of lower values of total mortality in the preceding 2-3 years. This effect, of small entity, was afterwards impaired by the new increasing of Z up to year 20, despite the contemporary increase, although small, of the size at first capture. The beneficial results following the decreasing of the total mortality from years 20 onwards becomes evident after the year 20 with a continuous rising phase, due to the cumulative effects along cohorts. At this stage a new and more safe state seems to be reached, as evidenced by the indicator ESSB/USSB that follows a similar evolution. The lower levels of Unexploited Biomass and Spawning Biomass along the years 25 and 30 might be attributed to the occurrence of lower recruitment in the years preceding the completion of the first life cycle.
Simulated removal metrics (yield and biological production) are in the figure WP5_ptn_09_fig.03 and show a temporal pattern with cycles comparable to that of the population metrics. Annual rates of total mortality recomputed by the model for each sex and the rate of fishing mortality (F) calculated by the model for the whole population are also reported (WP5_ptn_09_fig.03). Length-based vital trait indicators as length mean of the exploited and unexploited populations and length mean of the exploited and unexploited spawning populations are in the figure WP5_ptn_09_fig.04. The length-based indicators of the exploited populations show cycles occurring at the same time intervals as those of the exploited population metrics, with a tendency to increase when the mortality decreases. Similar behaviour can be also observed for the catch length mean indicator.
To better understand the evolution of the population dynamics along time, the relationships between pressure parameters and population or removal metrics and indicators have been investigated (WP5_ptn_09_fig.05). The best correlation between the yearly values of the two parameters Z and F (average along the year) was found with a delay effect of 1 year: i.e. Z value at the year i was better correlated with the F value at the year $i+1$. All the relationships regarding Z and population or removal metrics or vital traits had a delay of 3 years, while those regarding F had a delay of 2 years. This might be explained considering a cascade effects along cohorts combined with the growth rate of the species, that requires a time lag to be evidenced. Length-based indicators and population metrics resulted well correlated, except the length mean of the exploited spawning stock versus Z and F and the yield versus Z and F. All the relationships showed negative slopes as expected. The poor correlation level identified for some indicators and metrics might be due to two main factors: 1) the mortality rates were not enough and regularly contrasted along time; 2) the recruitment was assumed independent from the parental stock.
The indicator ESSB/USSB, that represents the ratio between the exploited spawning stock biomass and the level of spawning biomass if only the natural mortality was acting, was retained at the end of the analysis to explore pairwise relationships with the length indicators (WP5_ptn_09_fig.06). In addition, also the indicator represented by the ratio between the exploited spawning population and the whole exploited population (ESSB/EB) was considered. Better correlations among pairwise relationships were evidenced for the length mean of the exploited population versus ESSB/USSB and the length mean of catches versus ESSB/USSB, that was well positively correlated with the ESSB/EB.
The values assumed by ESSB/USSB were about 0.07 at initial time and were gradually growing to 0.17 when the mortality was reduced, a similar pattern showed the ratio ESSB/EB, which values were at level of about 0.4 at beginning and progressively increasing to 0.5, as a result of the beneficial effect on the population of a mortality diminution.
The figure WP5_ptn_09_fig.07 shows the results from the stochastic Aladym-q simulation model regarding the indicator ESSB/USSB with associated standard deviation. A low increase was observed in year 7, as a result of the small increase of the size at first capture. Afterwards, the situation remained almost steady upto the year 20, from which a growing phase was starting up until the years 30-35, when a new stationary phase

was reached that was lasting stable until year 40. The probability distribution of the indicator ESSB/USSB in correspondence of the most significant years: 7, 20 and 40 are reported in figures WP5_ptn_09_fig.08 , while the cumulative distributions in the figure WP5_ptn_09_fig.09. More probable values of the ratio ESSB/USSB were in the range 0.07-0.12, both at the years 7 and 20, while at year 40 the more probable values were between 0.12 and 0.18.

Conclusion

Recommendations from previous studies regarding the state of the hake stock in the Aegean Sea, using a non-equilibrium surplus production model fed with Medits data, have stressed an overexploitation condition and the needing of reducing the fishing pressure (Tserpes et al., 2007).

The analysis conducted in the present study identifies signs of positive changes after the first 7 years (i.e. around 2000) as consequence of mesh increase. A (slight) reduction of fishing pressure on Aegean hake population would produce in the long-term a positive change, increasing of about ~50-60% the current levels of the ESSB/USSB sustainability indicator.

Comparing the above results with those obtained from the indicator approach developed in WP5 for the Aegean hake, they seem to be in a quite good agreement. Although the linear and derivatives method did not depict any significant changes in the indicators used, the CUSUM analysis showed positive changes (mainly in the abundance) after 1998, which then led to a stable situation until 2003. The changes observed were attributed to the fishing pressure's reduction measures imposed after 1994. The application of the Aladym model on the Aegean hake gives the opportunity to explore further long-term effects of the management measures on the population.

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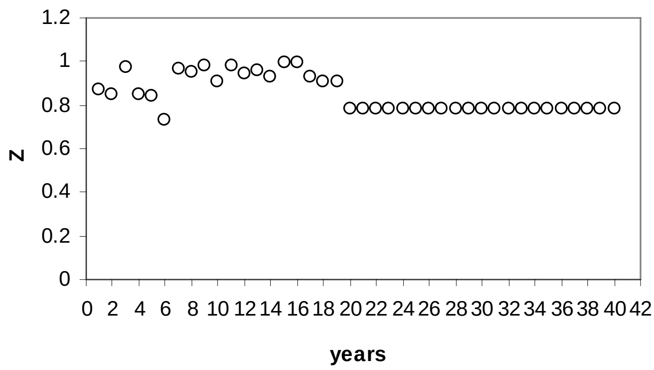
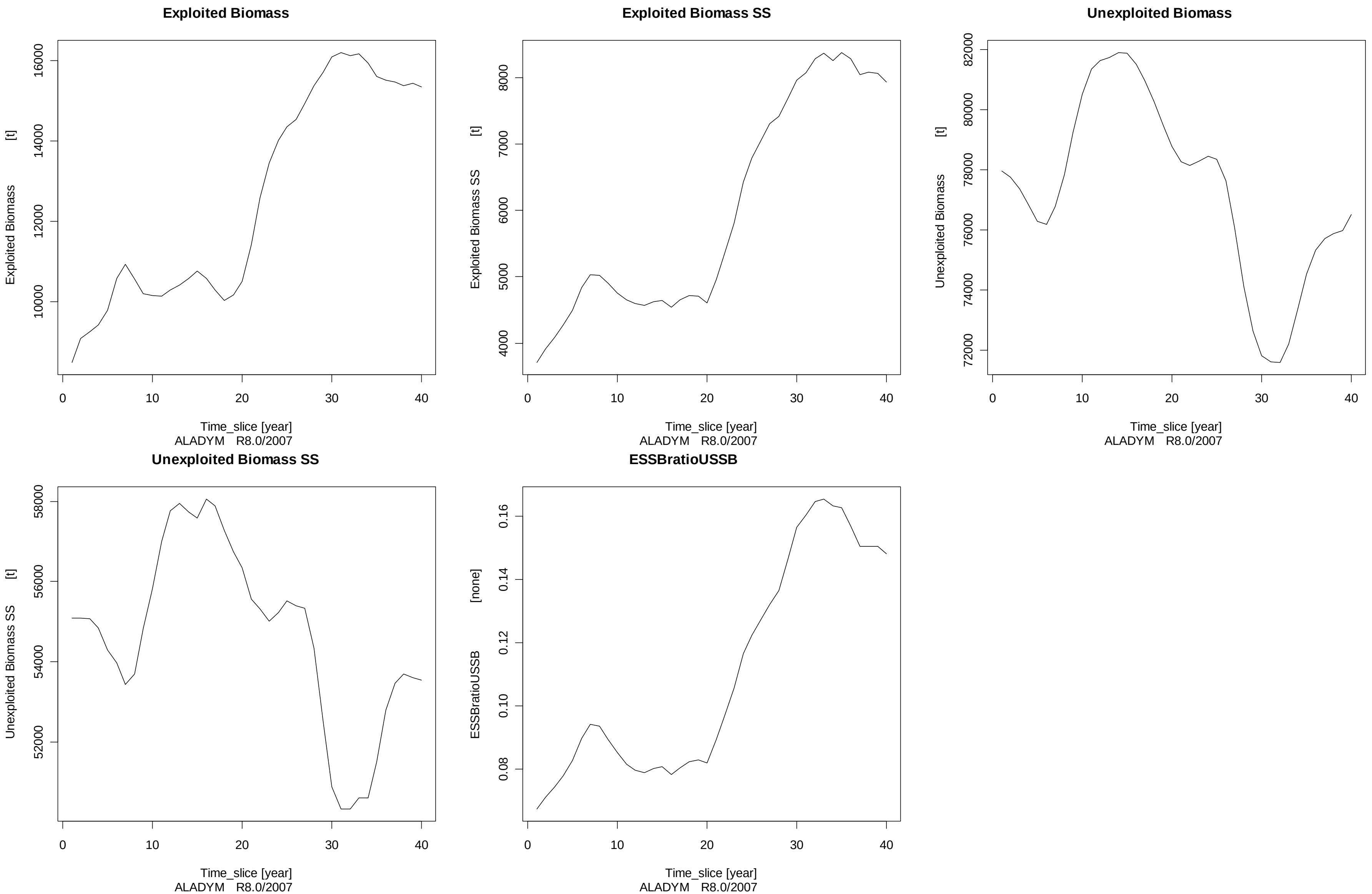
WP5_ptn_09_tab.01 – Summary table of the inputs used in Aladym model for the Aegean hake case study.

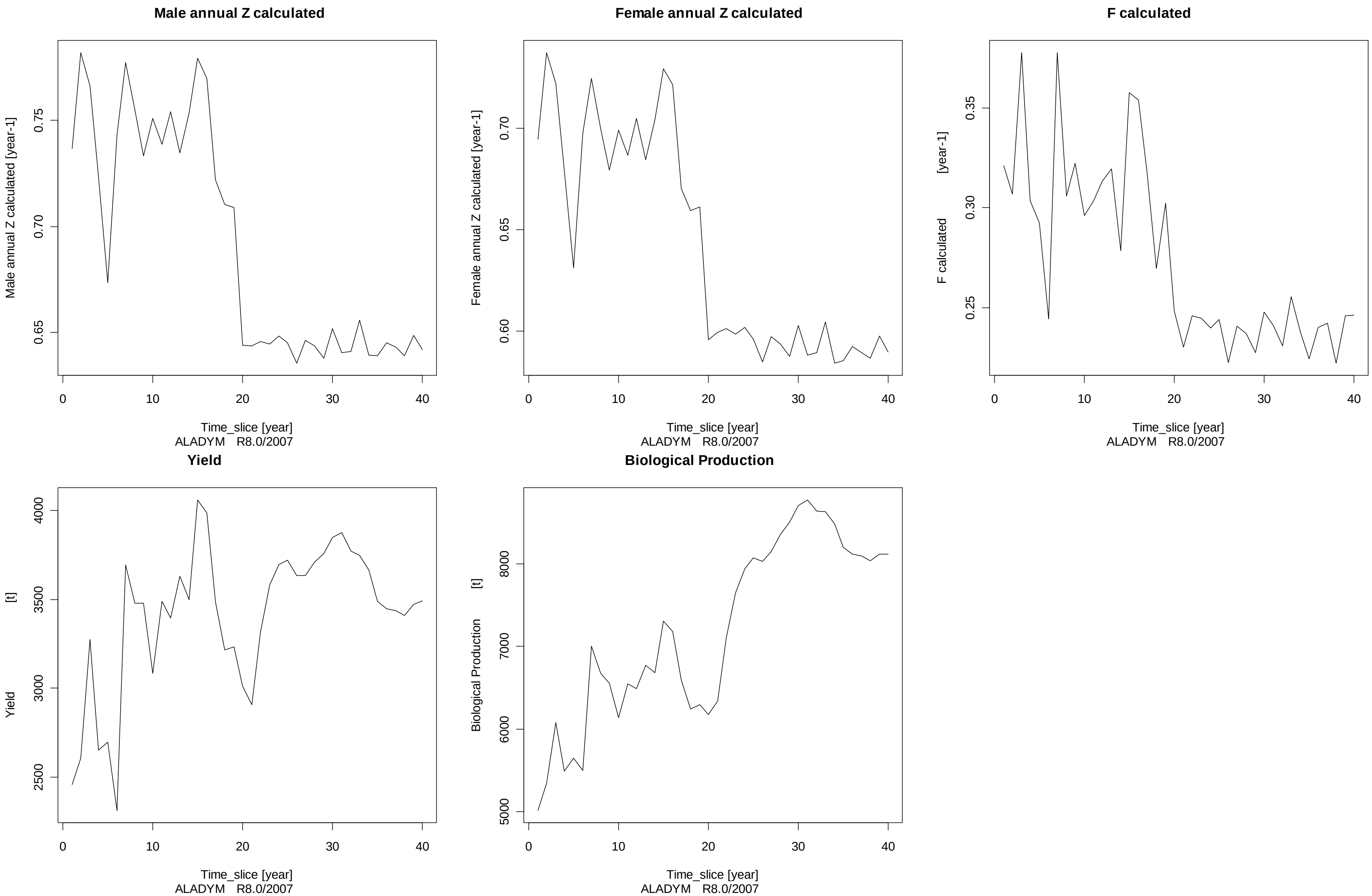
Input description	**females**	**males**
K (year)	0.174±0.0174	0.24±0.024
L_∞ (mm)	746 ±74.6	566 ±56.6
t_0	-0.2 ±0.1	-0.2 ±0.1
a	0.000005	0.000003
b	3.078	3.125
Life span (years)	20	20
M males-females	0.28	0.38
L_{mat} (mm)	342±18	303±16
Maturity range (L75-L25) (mm)	41±2	40±2
L_{50} (mm)	80/108	
SR (mm)	20/57	
Sex ratio (F/F+M)	0.5	
$D_{50\%}$	460/480	
Fishing coefficient	1/0.44	
Recruits (initial number) and parameters of the log-normal distribution	~$80 \cdot 10^6$ (mean ln(R)=18.06; ds ln(R)=0.88)	
Spawning time and spawning peak	From November to August (March-June)	
Number of year to be simulated	40 (pre-simulation 80)	



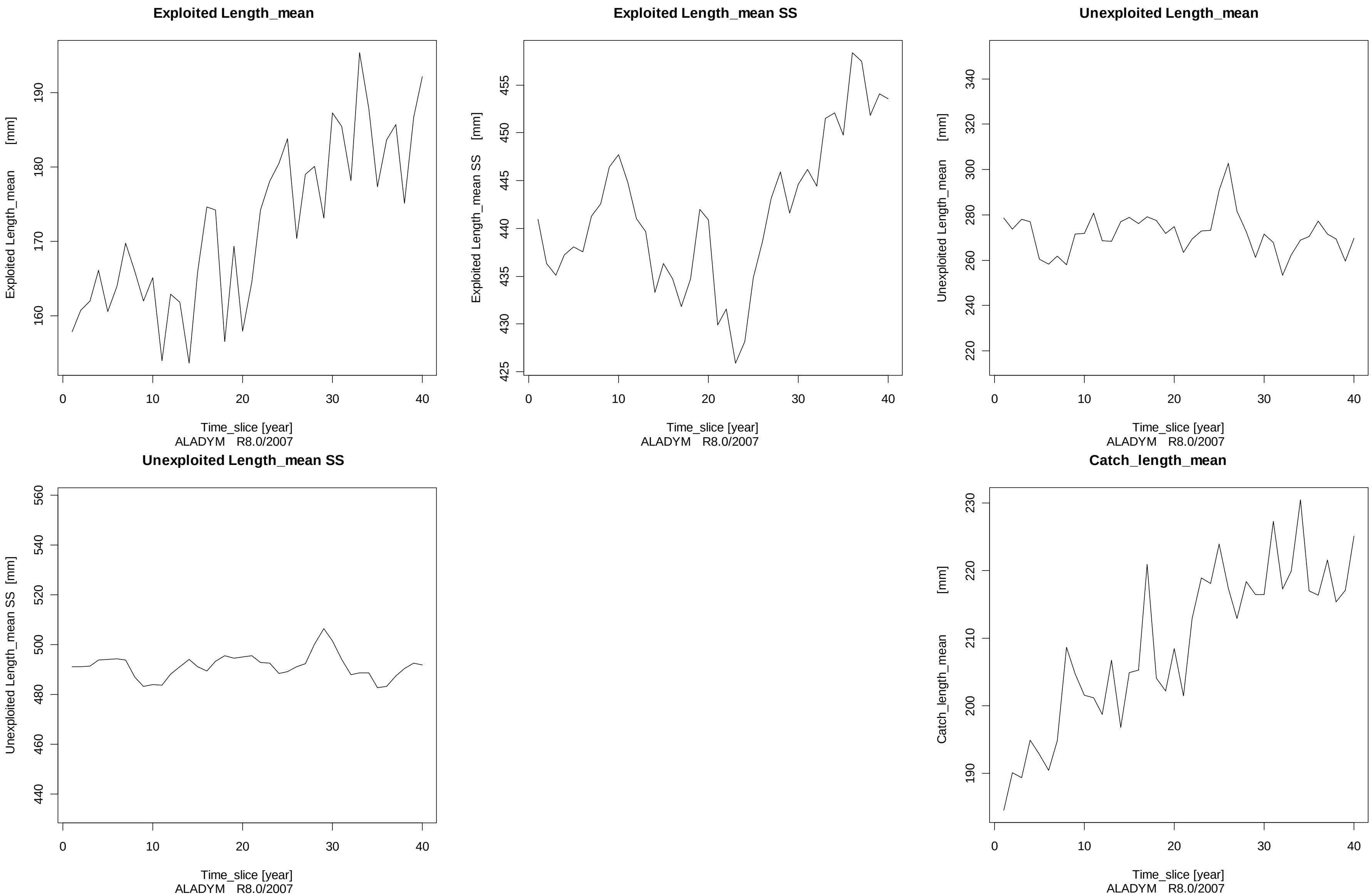
WP5_ptn_09_fig.01. Vector of total mortality used along 40-years simulation for hake in the Aegean Sea.



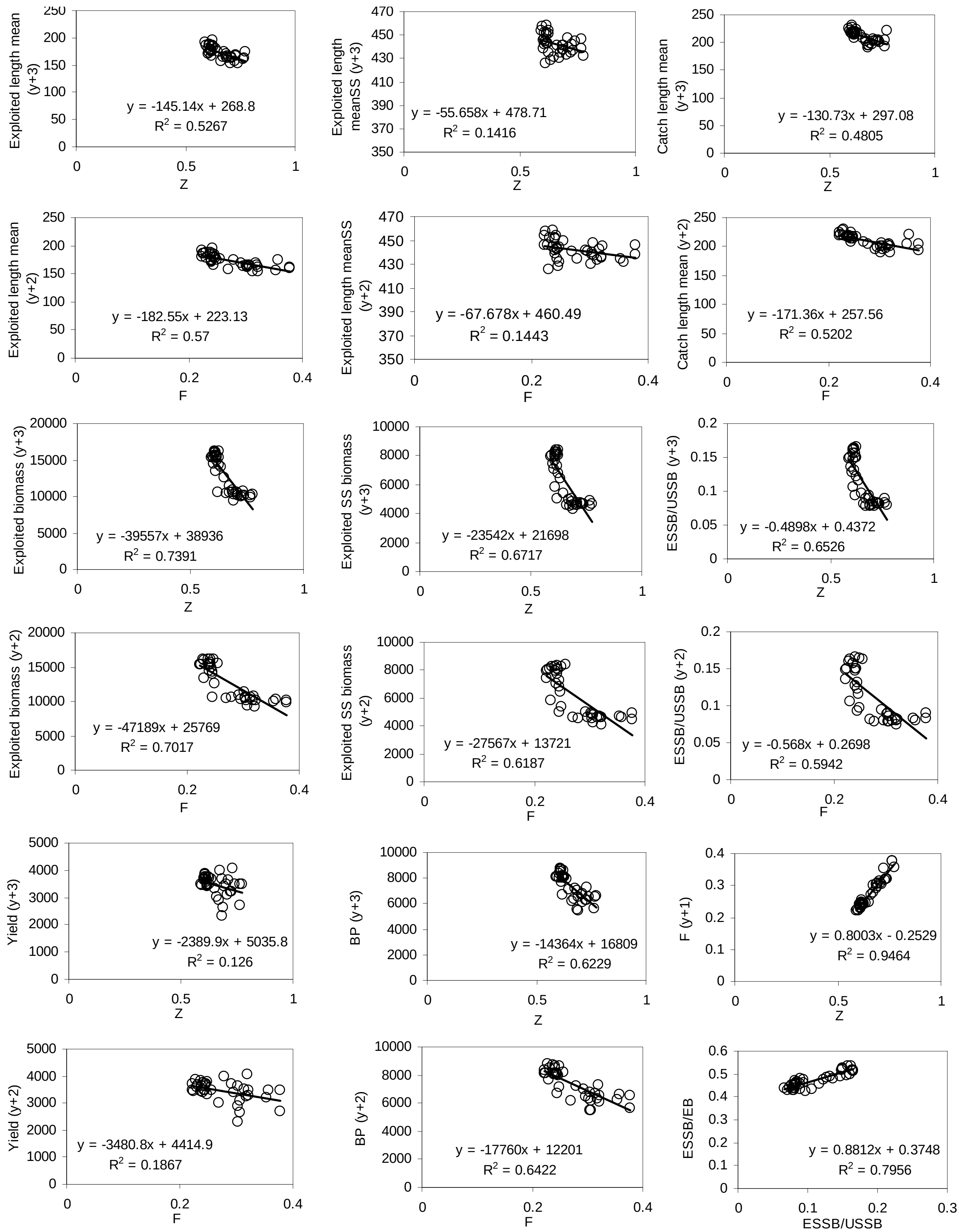
WP5_ptn09_fig02-Outputs of the simulations of the Aladym-r model related to the exploited and unexploited biomass (population at sea) of the whole population (Exploited Biomass and Unexploited Biomass), biomass of female spawners (Exploited Biomass SS and Unexploited Biomass SS), ratio (ESSBratioUSSB) between the exploited spawning stock biomass and the unexploited spawning stock biomass. 20 years simulation results for hake in the Aegean Sea.



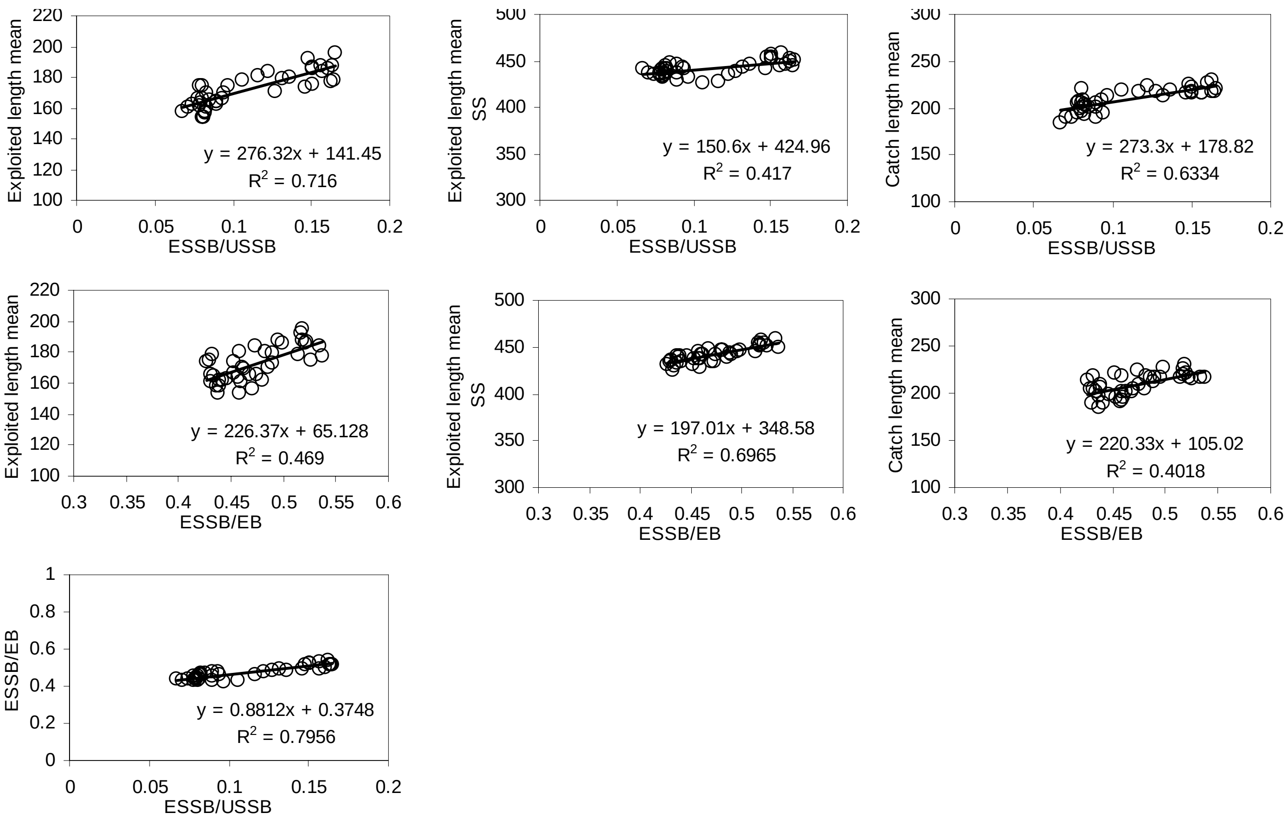
WP5_ptn09_fig03-Outputs of the simulations of the Aladym-r model related to the total mortality of females and males calculated by the model, the fishing mortality F, the Yield, the biological production (all deaths, including fished population). 20 years simulation results for hake in the Aegean Sea.



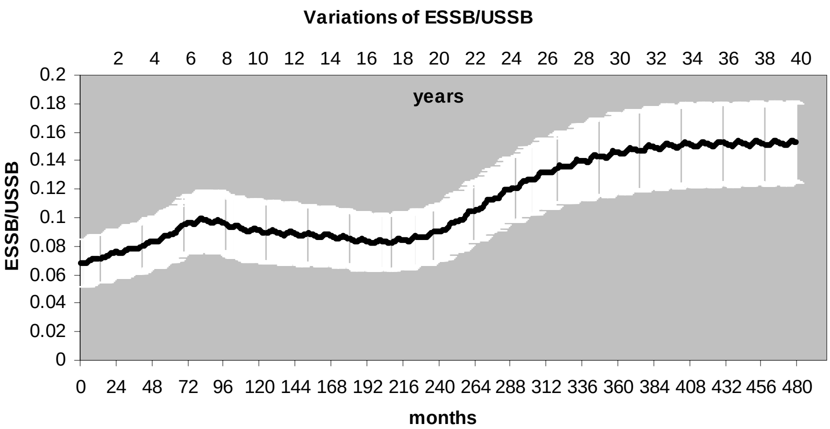
WP5_ptn09_fig04-Outputs of the simulations of the Aladym-r model related to the mean length of: the exploited population, the unexploited population, the exploited spawning population and the unexploited spawning population and the mean length of catches. 20 years simulation results for hake in the Aegean Sea.



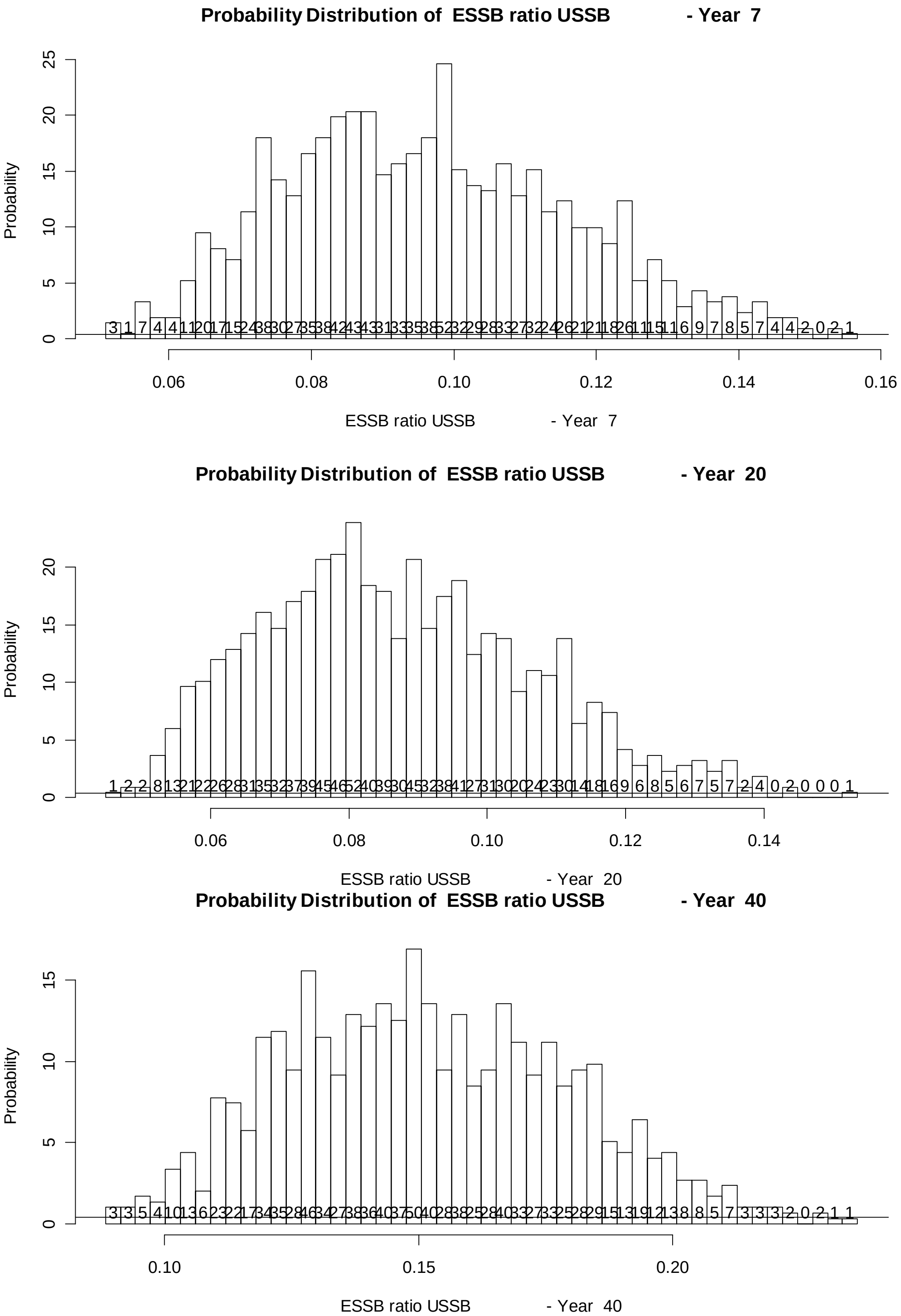
WP5_ptn09_fig05 - Plots of the relationships between the pressure factors and the model-based indicators. 40 years simulation results. The plot of the relationship between the total mortality and the fishing mortality computed by the model are also reported. In each plot the fitted linear model and the regression coefficient are indicated for hake in the Aegean Sea.



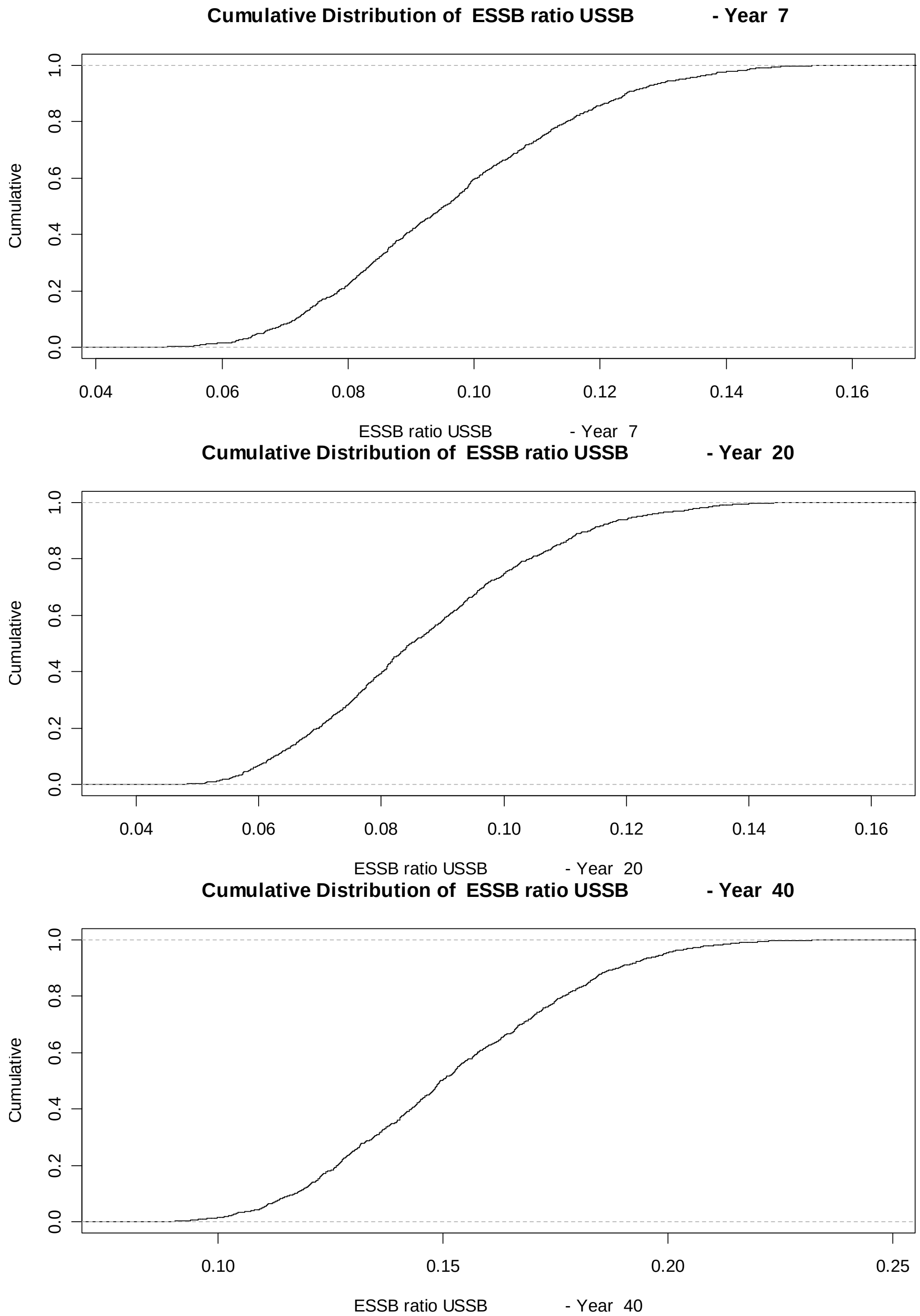
WP5_ptn09_fig06- Plots of the cross relationships between relevant model-based indicators derived from the Aladym-r outputs. 40 years simulation results for hake in the Aegean Sea.



WP5_ptn09_fig07-Month variations of the model-based indicator ESSB/USSB (exploited spawning stock biomass/unexploited spawning stock biomass) with relative standard deviations (white strip). Results from Aladym-q simulations along 40 years (1000 runs) for hake in the Aegean Sea.



WP5_ptn09_fig08-Probability distributions of the model-based indicators (exploited spawning stock biomass/unexploied spawning stock biomass, ESSB/USSB) in the years 7, 20 and 40. Results from Aladym-q simulations along 40 years hake in the Aegean Sea.



WP5_ptn09_fig09-Cumulative distributions of the model-based indicators (exploited spawning stock biomass/unexploited spawning stock biomass, ESSB/USSB) in the years 7, 20 and 40. Results from Aladym-q simulations along 40 years for hake in the Aegean Sea.

Simulation Evaluation using ALADYM

Hake Bay of Biscay

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Use of *Aladym* model for assessing through simulations the long-term effects of total mortality changes on model-based population indicators and reference points. The case of the hake in the Bay of Biscay.

Introduction

The age-length based Aladym model has been used to test, through a simulation process, the consequences of changes of pressure parameters (total mortality) on the fish population dynamics of hake (*Merluccius merluccius*) in the Bay of Biscay. These effects have been estimated along 40-years simulations, analysing the changes of model-based population indicators obtained as model outputs, i.e. the total biomass, the spawning stock biomass, the biological production (all deaths removed from the population for natural and fishing causes). Consequences on model-derived vital traits indicators (i.e. average length of the population and of the spawning population) have been also evaluated, as well as . changes regarding simulated yield and mean length of the catches. Finally, effects on a sustainability indicator as the ratio between exploited and unexploited spawning stock biomass (ESSB/USSB) were assessed. The relationships among the previous mentioned indicators and an additional model-based index represented by the ratio between the exploited biomass of spawners and the exploited biomass (ESSB/EB) were also investigated. Two different scenarios were simulated, the first named ‘mean’ in which a lower lever of total mortality was acting along all the time (40-years) except a change in few years (15-18) and a second named ‘high’ in which the same initial value of total mortality suddenly increased after the year 15.

Materials and methods

The exercises were conducted modelling the population through total mortality indices obtained as a result of the cusum analysis in WP5. In the first exercise (‘mean’) the simulated scenario had a total mortality input constant (~1.04) for all the years, except from years 15 to 18, when a higher value (~1.8) was used. After this time mortality rapidly decreased at its previous level. In the second exercise (‘high’), the simulated scenario had the same total mortality as in the first exercise until the year 15, then Z increased (~1.8) and remained constant until the year 40.

The main inputs of the Aladym model are in the WP5_ptn_01_tab.01.

The size at first capture (about 302 mm total length) was used as input along the whole time span used in the model and the fishing activity was set at 1.0.

Parameters of the von Bertalanffy growth model by sex were set using the estimates given by de Pontual et al. (2006) for the Bay of Biscay, while those of the length-weight relationships for females and males were derived from ICES (1991). Size at first maturity was from Martin (1991). Recruitment was assumed independent from the parental stock. A proxy of the initial number of the fish at earlier stage for the period 1987-2004 was obtained from groundfish surveys carried out in autumn on the eastern continental shelf of the Bay of Biscay. Hence a vector of recruits, generated using a random function for the years projected forward (22 years), was used as input. Spawning season, months in which spawning peaks are occurring and sex-ratio were from the literature on the species (Murua and Motos, 2006; Murua et al., 2006) and/or from ‘direct’ observations.

The natural mortality was maintained fixed through ages and calculated comparing different methods (e.g. Alagaraja, Beverthon and Holt life history invariants (Jensen, 1996)) while a guess estimate of longevity (about 20 years) was obtained by the Taylor’s approximation.

All the simulations were run for 40 years.

The tools Aladym-r and Aladym-q were used, the latter to account for uncertainty in the process of assessing the effects of changes in model input parameters.

Results
Simulated population metrics for the ‘mean’ scenario (WP5_ptn_01_fig.01) evidenced minima for unexploited biomass and spawning biomass at years 16 and 32, while maxima at year 26. This evolution seems related to the number of recruits that entered in the population at least 2 years before. Lower values of exploited biomass and spawning biomass occurred at year 18 and 29, the former being the minimum along the simulation. This should be related with the higher total mortality occurring between year 15 and 18, which added a depressive effect to that of lower recruitments in the preceding years, while the low value of year 29 seems more related to failure of the recruitment events in the years 24-27. Instead, the highest peaks of exploited biomass and spawning biomass were at year 24 and 25, respectively. The indicator ESSB/USSB reached the minimum at the year 18 as a consequence of the Z increase between year 15 and 18.
Simulated removal metrics (yield and biological production) are in the figure WP5_ptn_01_fig.02 and show a temporal pattern with a maximum at year 25 and a minimum at year 30 that appears related with the respective lowest and highest value of biomass. Length-based vital trait indicators as length mean of the exploited and unexploited populations and length mean of the exploited and unexploited spawning populations are in the figure WP5_ptn_01_fig.03. The length-based indicators of the exploited and unexploited populations show cycles occurring similarly as those of the population metrics. Similar behaviour can be also observed for the catch length mean indicator.
If we consider the ‘high’ mortality scenario (figures from WP5_ptn_01_fig.04 to WP5_ptn_01_fig.06), the dramatic effect of the increased total mortality appears as the most relevant for all the examined indicators and metrics only very slightly mitigated by especially favourable recruitment events (years 22-23). Under this scenario the ratio ESSB/USSB dropped down to levels lower than 0.04.
To better understand the evolution of the population dynamics along time, the relationships between pressure parameters and population or removal metrics and indicators have been investigated. Those calculated under the ‘high’ mortality scenario are reported (WP5_ptn_01_fig.07), which presented more contrasted values of Z compared to the ‘mean’ one (very poor correlation), although the analysis was influenced by the presence of two ‘poles’ in the outputs. Better correlations were found with a 2-years delay between the total mortality Z and the population metrics indicators as the exploited biomass and the exploited spawning stock biomass, besides the ratio ESSB/USSB that was also well correlated with the ESSB/EB at the same time step (WP5_ptn_01_fig.08). This indicator assumed values around 0.4 when the ESSB/USSB indicator was between 0.10 and 0.15.
The figure WP5_ptn_01_fig.09 shows the results from the stochastic Aladym-q simulation model regarding the indicator ESSB/USSB with associated standard deviation for the ‘mean’ and ‘high’ scenarios. The ESSB/USSB indicator followed a coincident pattern up to the year 18, after this year the patterns of the two scenarios were divergent. The continuous decrease took place for the ‘high’ scenario, while for the ‘mean’ one only irregular fluctuations were observed. The cumulative distributions of the indicator ESSB/USSB (WP5_ptn_01_fig.10) in correspondence of the most significant years: 3, 10, 18, 25 and 29 of the ‘mean’ scenario highlight in ‘good’ years (10 and 25) more probable values of the indicator ranging between 0.11-0.13 and 0.14-0.16. In the ‘bad’ years (3 and 29) the ratio ESSB/USSB was instead fairly lower and the more probable values were ranging between 0.085-0.095 and 0.05-0.055. The most critical condition was observed at year 18 when after the increasing of total mortality the ratio between ESSB/USSB was the lowest (more probable values: 0.035-0.045). Considering the ‘high’ scenario, simulations gave in years 3, 10 and 18 patterns of ESSB/USSB analogous to that of the ‘mean’ scenario (not reported in the figure), but at the year 40 this ratio was as low as 0.02-0.025.

Conclusion
In 2004, a recovery plan for the hake Northern stock followed up a previous emergency plan. Based on the most recent estimates of SSB and fishing mortality (WGHMM, 2006) ICES classifies the stock as being at full reproductive capacity and being harvested sustainably. SSB appears to have been very close to Bpa over the last 3 years, and F has
been around Fpa since 2001. As the growth rate and thus the age determination and productivity of northern hake stocks
are uncertain, absolute estimates of SSB and F have to be considered with caution.
In the analyses conducted in this study under the hypothesis of a ‘mean’ scenario (Z lower and constant except for three years) signs of negative changes were identified following the period of mortality increase. Alternate positive and negative changes occurred also as consequence of recruitment fluctuations, becoming these effects more severe when coincident with the fishing pressure intensification. Aladym simulation

results confirmed the conclusion of the “Indicator Approach”, i.e. “Knowing the worrying state of the stock at the beginning of the EVHOE surveys and as no improvement occurred in recent years, on contrary some deteriorations of the indices for older age groups, it seems necessary to reduce the fishing mortality”.
In the case of ‘high’ scenario a continuous decrease, with some fluctuations, of the indicator ESSB/USSB was observed and likely the population still survived because the initial hypothesis was based on the independence of recruitment from parental stock.

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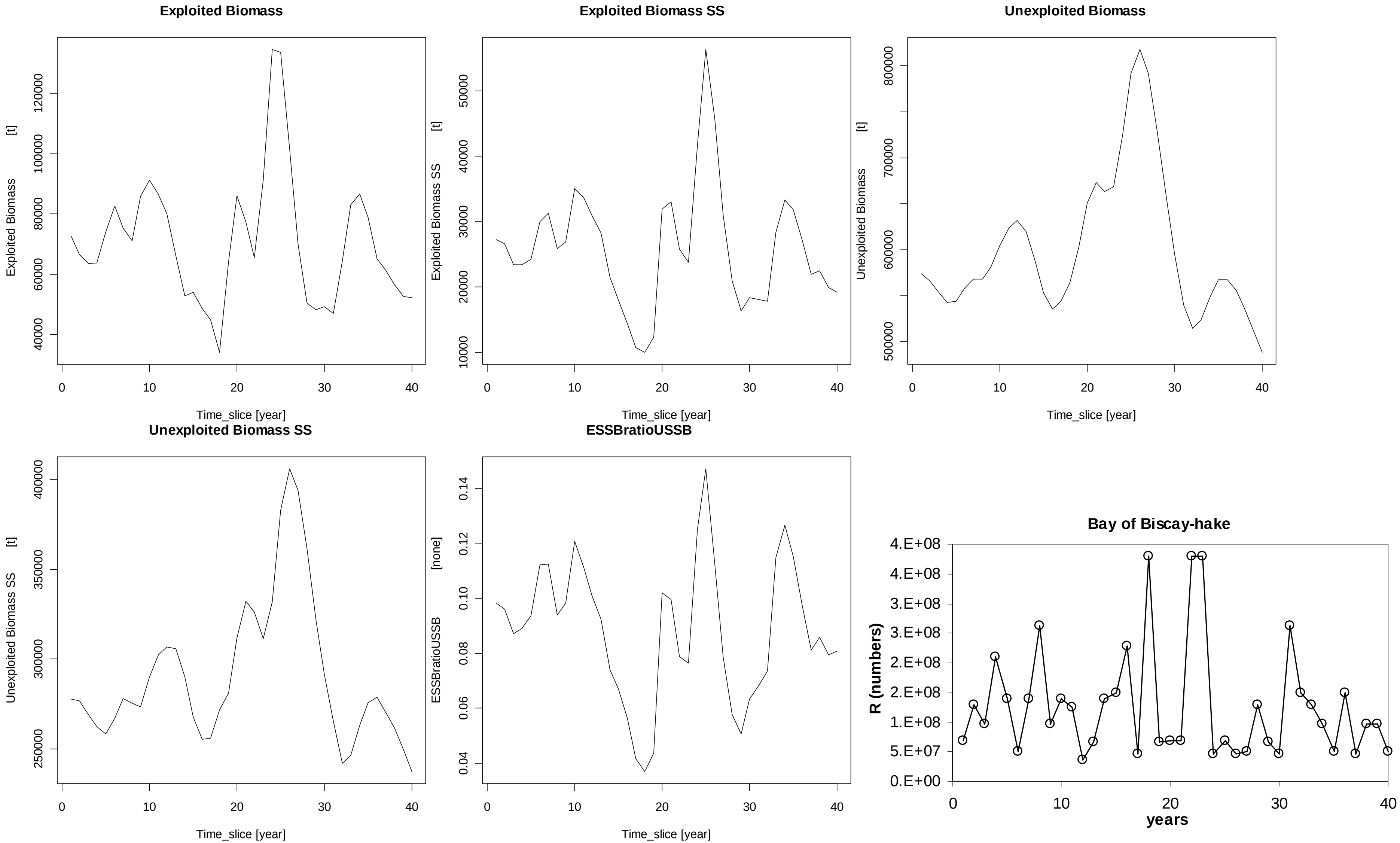
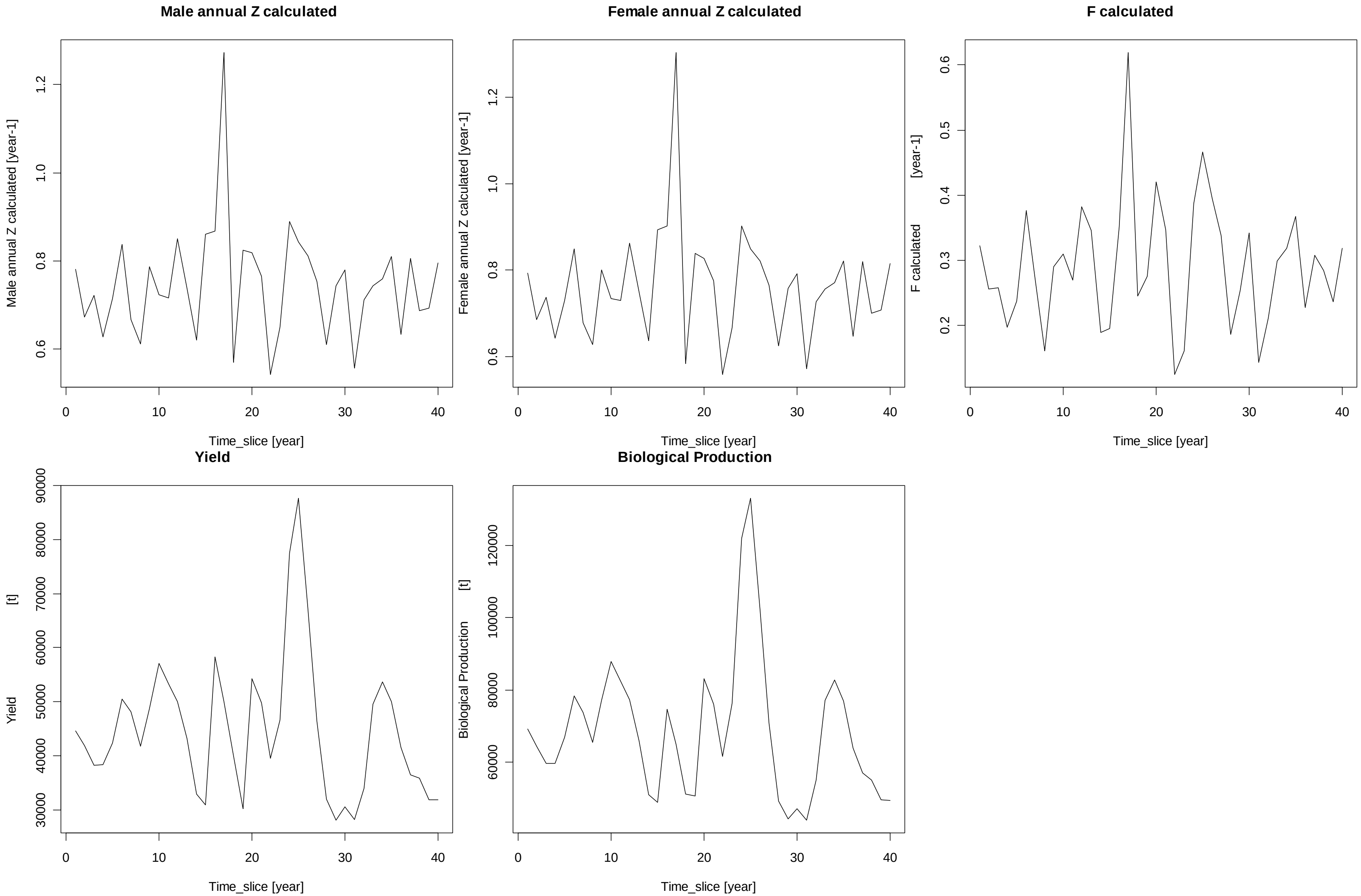
WP5_ptn_01_tab.01 – Summary table of the inputs used in Aladym model for the case study of hake of Bay of Biscay.

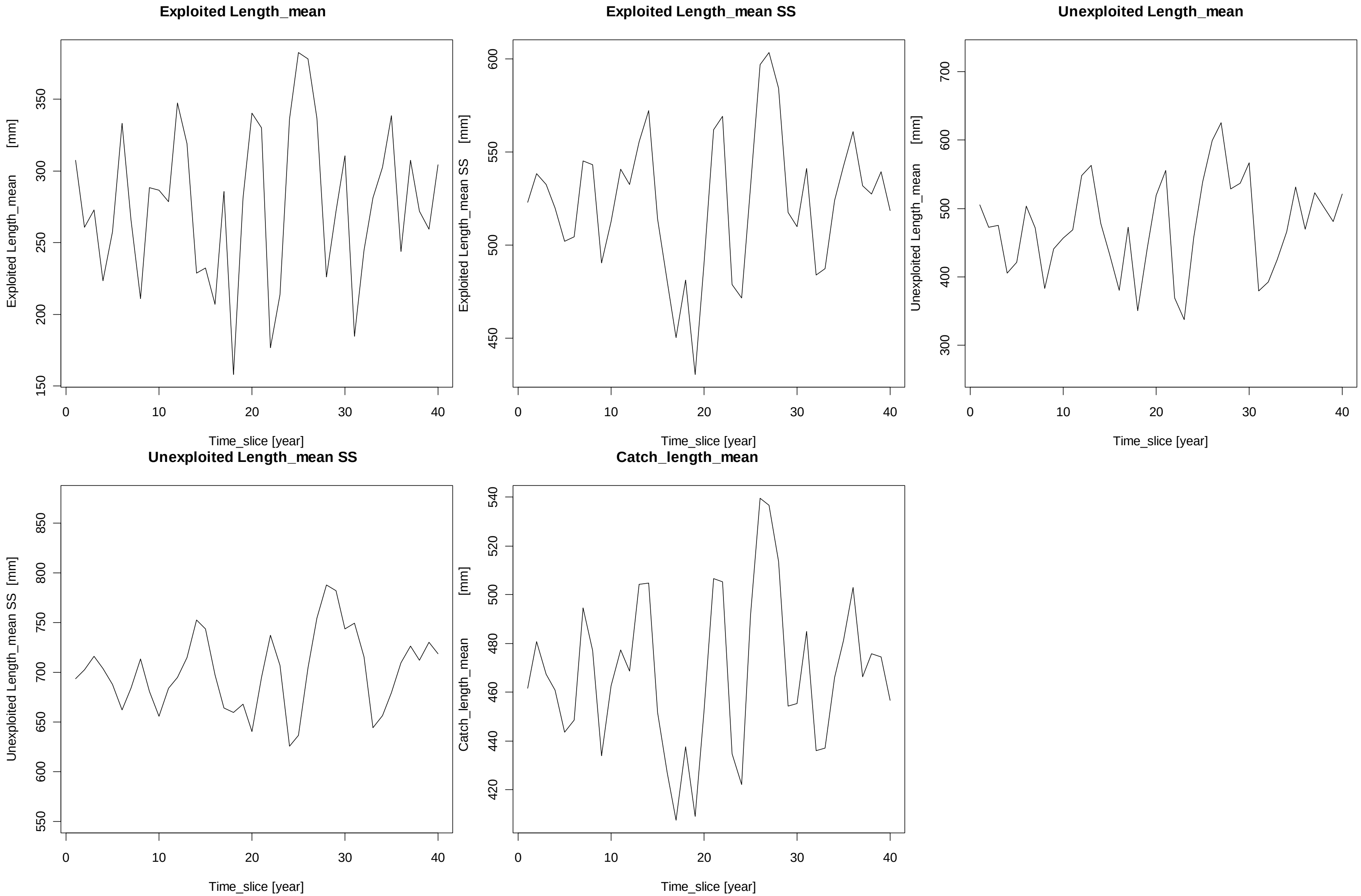
Input description	**Sex combined**
K (year)	0.25±0.05
L_{∞} (mm)	1100 ±60
t_0	-0.000075±-0.000035
a	0.0000043254
b	3.074
Life span (years)	20
M males-females	0.35
L_{mat} (mm)	414±30
Maturity range (L75-L25) (mm)	81±10
L_{50} (mm)	302.4
SR (mm)	3.25
Sex ratio (F/F+M)	0.5
Fishing coefficient	1.0
Recruits (initial number) and parameters of the log-normal distribution	~$208 \cdot 10^6$ (mean ln(R)=18.54; ds ln(R)=0.68)
Spawning time and spawning peak	From December to May (February-March)
Number of year to be simulated	40 (pre-simulation 80)



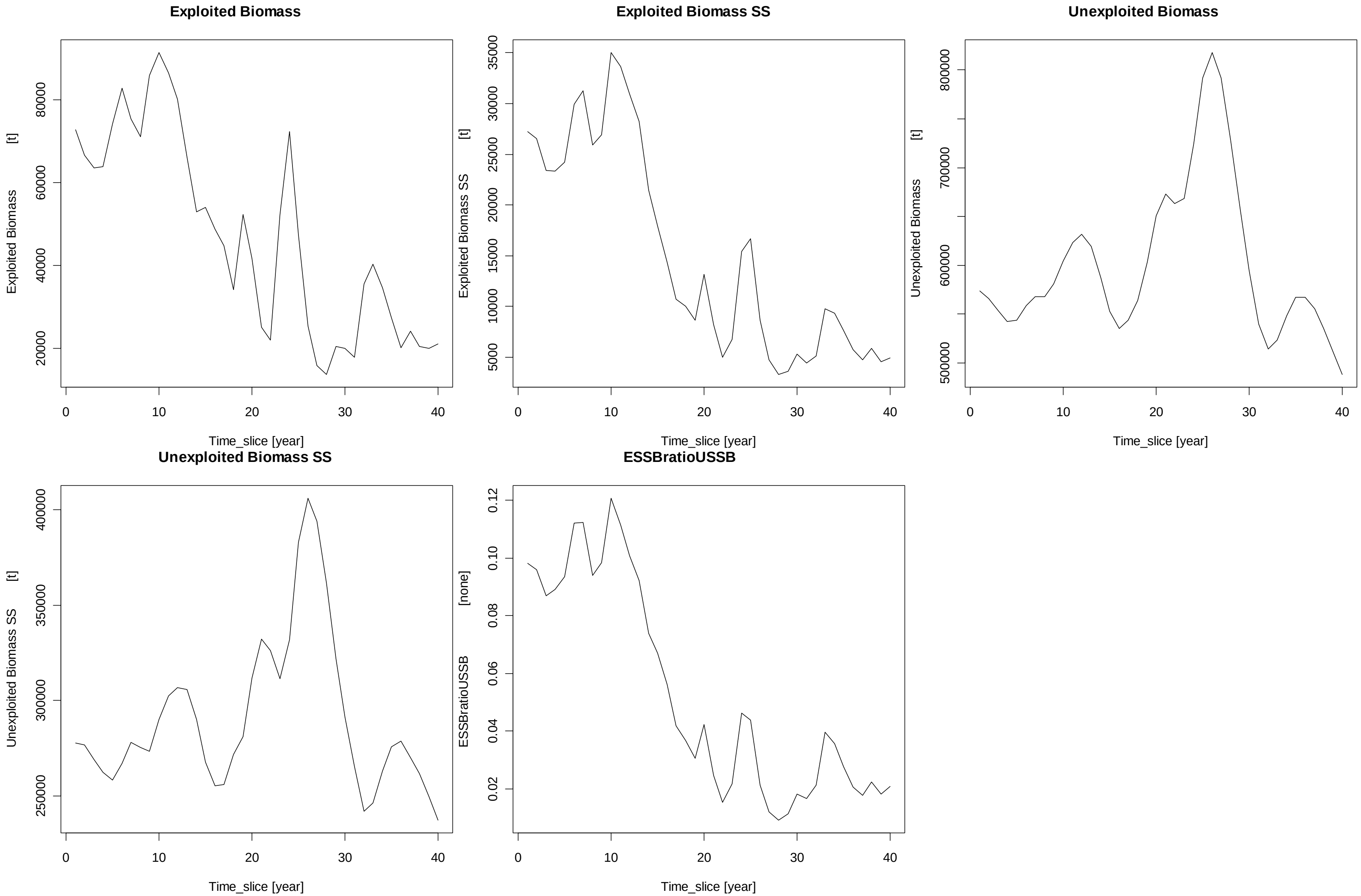
WP5_ptn01_fig01-Outputs of the Aladym-r model simulations related to the whole population (Exploited Biomass and Unexploited Biomass), biomass of female spawners (Exploited Biomass SS and Unexploited Biomass SS), ratio (ESSBratioUSSB) between the exploited spawning stock biomass and the unexploited spawning stock biomass. 40 years simulation results for hake in the Bay of Biscay. Scenario using Z 'mean'. The values of the input recruits by year are also represented.



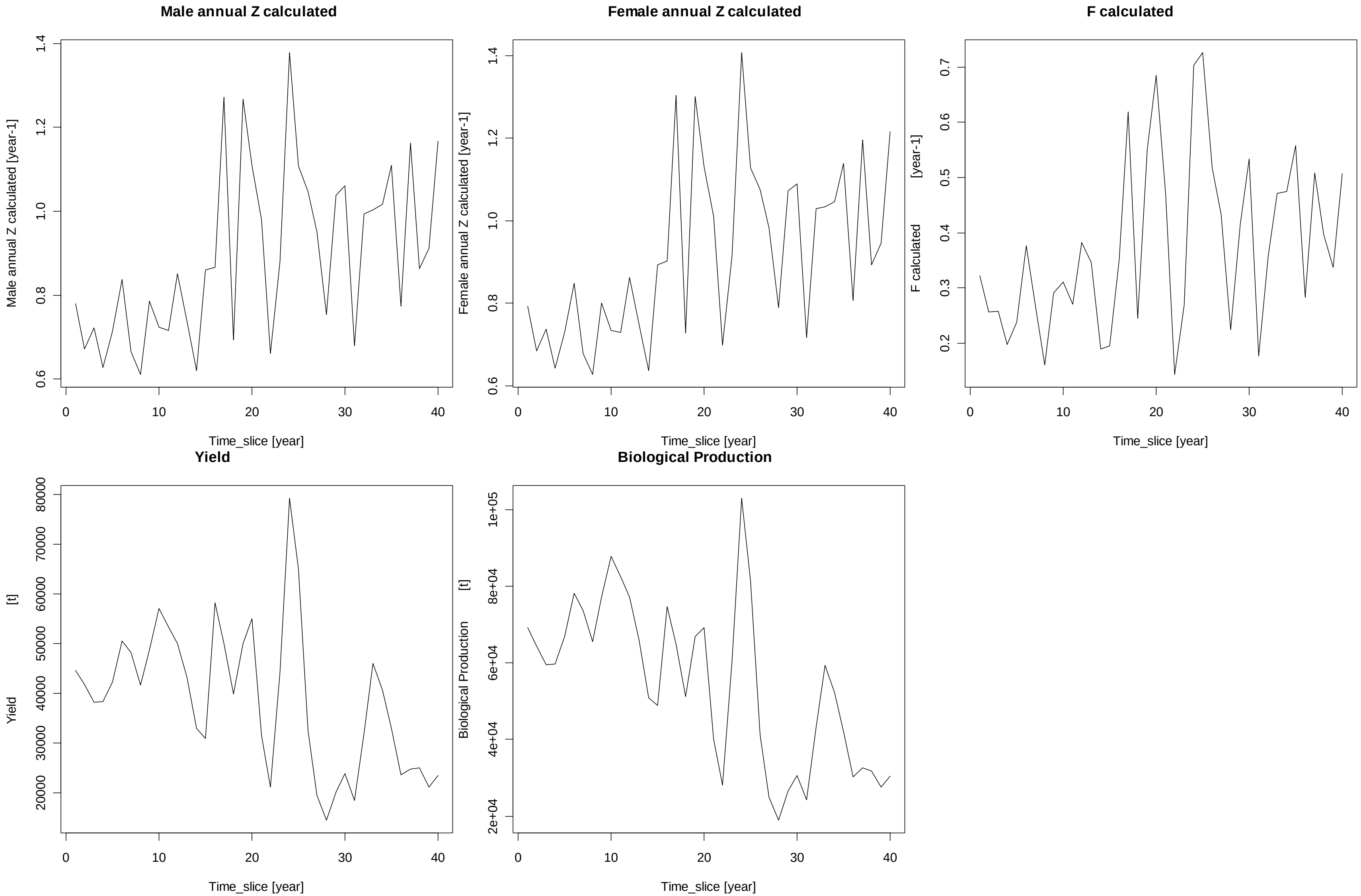
WP5_ptn01_fig02- Outputs of the Aladym-r model simulations related to the total mortality of females and males calculated by the model, the fishing mortality F, the Yield, the biological production (all deaths, including fished population). 40 years simulation results for hake in the Bay of Biscay. Scenario using Z mean.



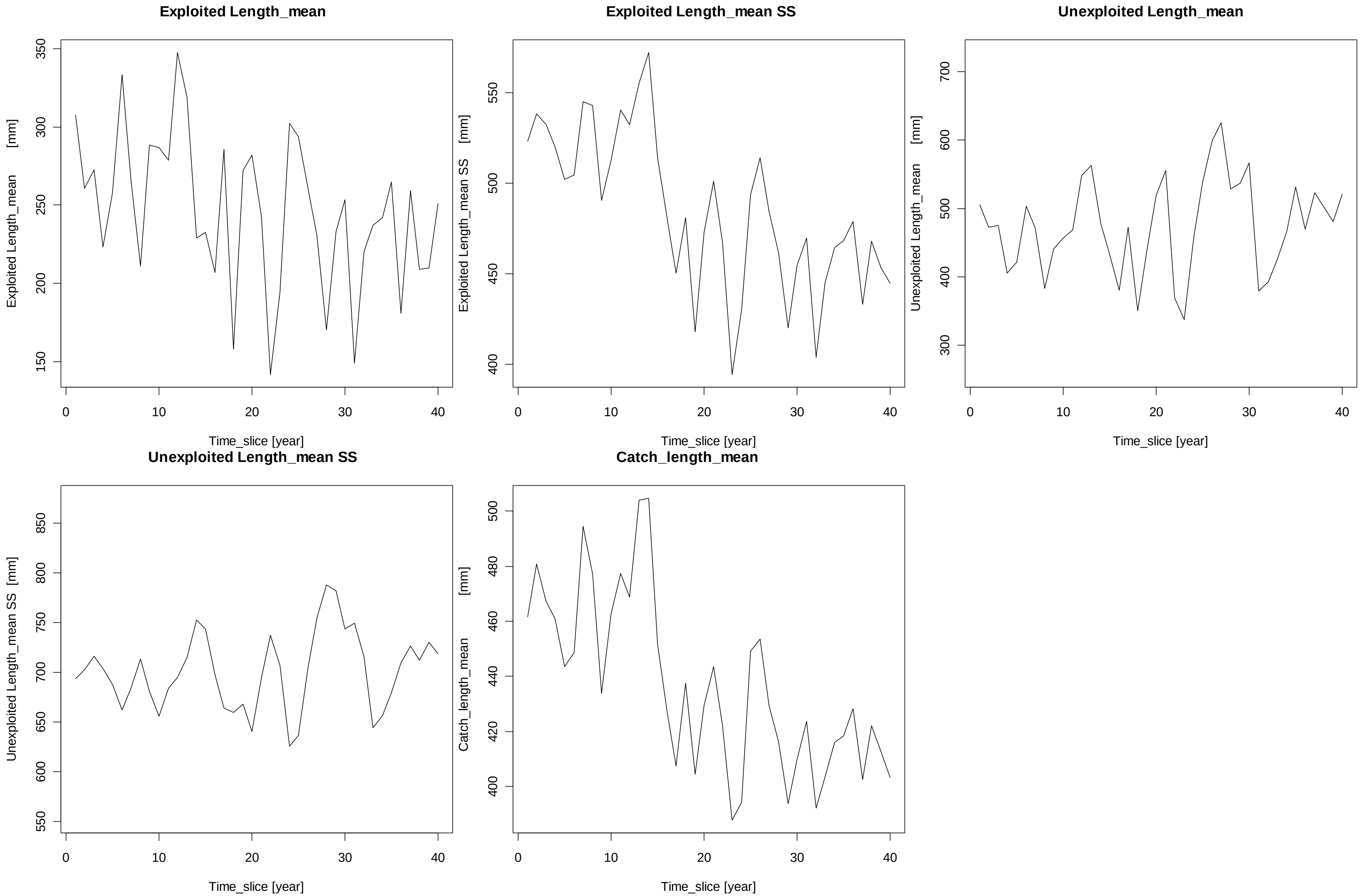
WP5_ptn01_fig03- Outputs of the Aladym-r model simulations related to the mean length of: the exploited population, the unexploited population, the exploited spawning population and the unexploited spawning population and the mean length of catches. 40 years simulation results for hake in the Bay of Biscay. Scenario using Z mean.



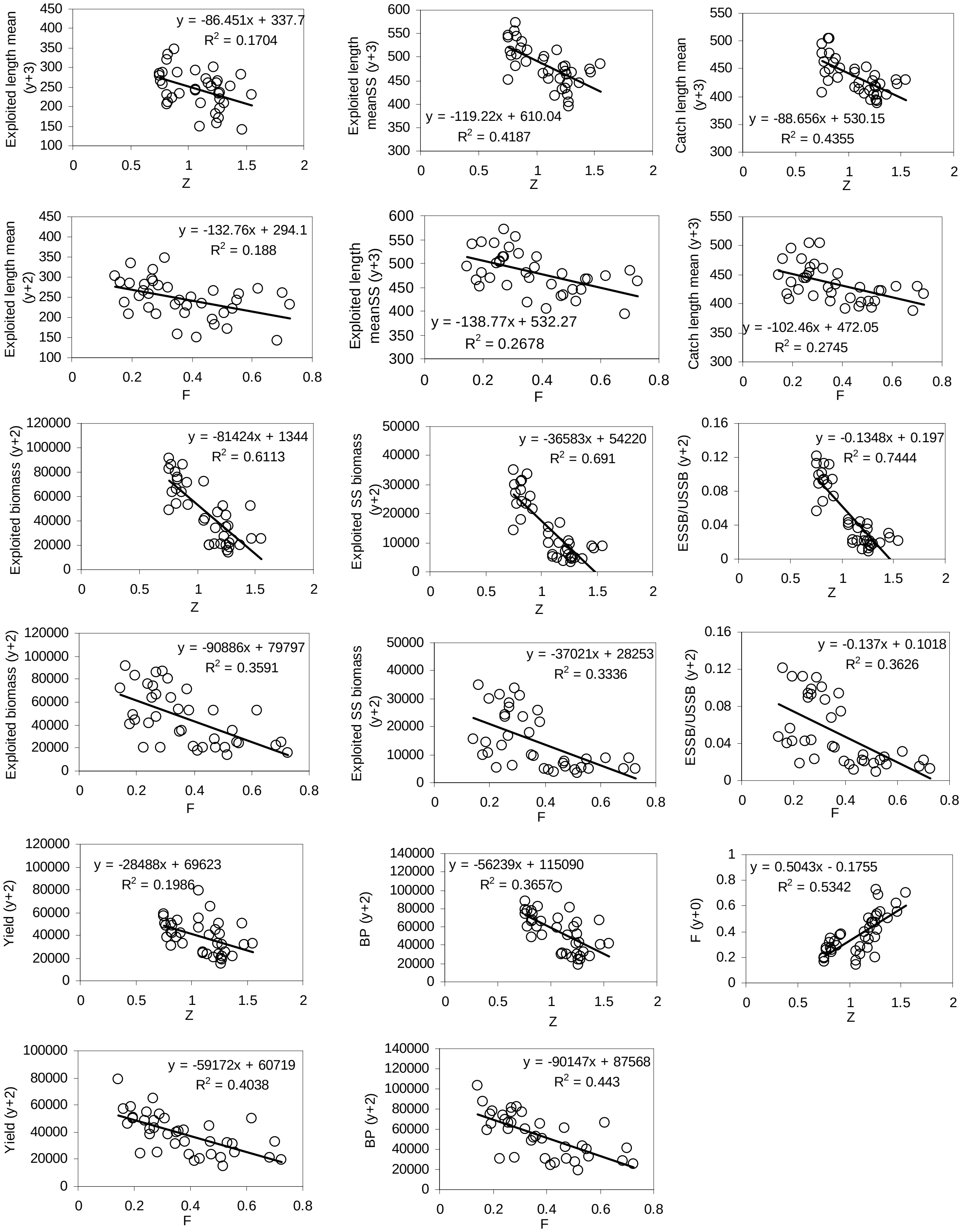
WP5_ptn01_fig04-Outputs of the Aladym-r model simulations related to the whole population (Exploited Biomass and Unexploited Biomass), biomass of female spawners (Exploited Biomass SS and Unexploited Biomass SS), ratio (ESSBratioUSSB) between the exploited spawning stock biomass and the unexploited spawning stock biomass. 40 years simulation results for hake in the Bay of Biscay. Scenario using Z high.



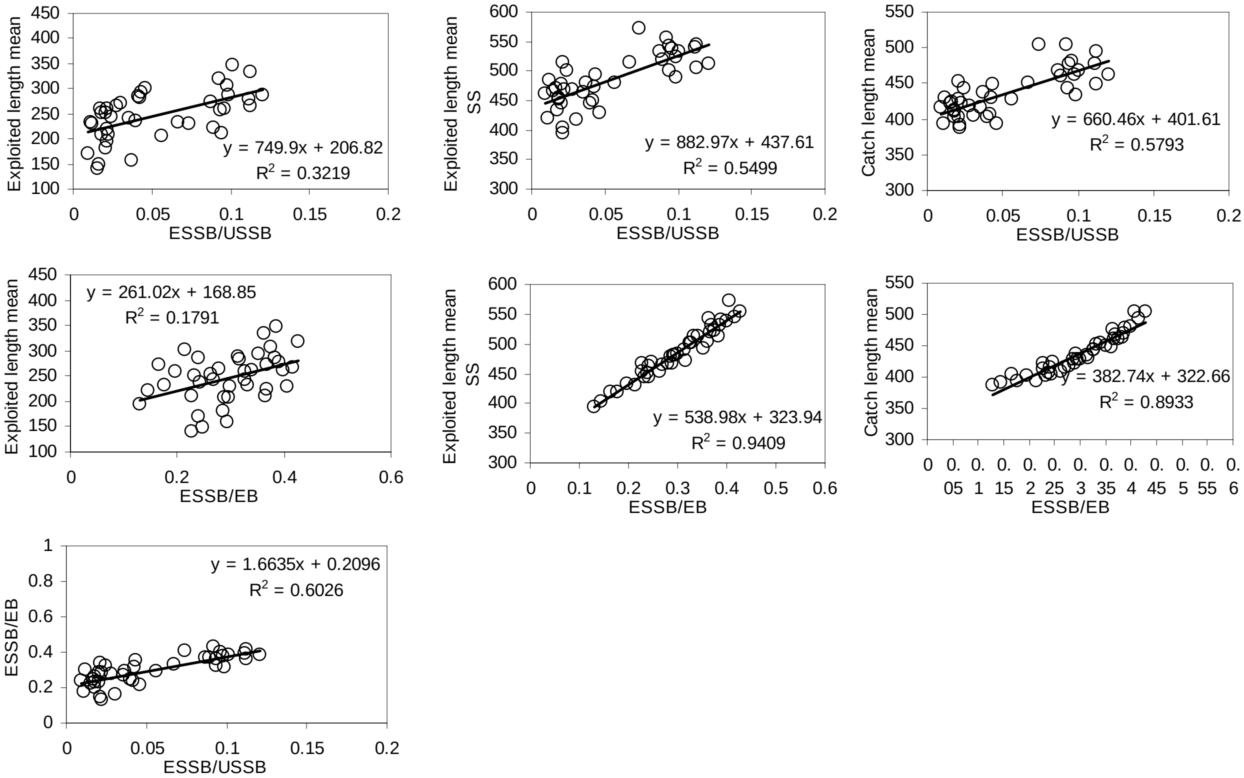
WP5_ptn01_fig05- Outputs of the Aladym-r model simulations related to the total mortality of females and males calculated by the model, the fishing mortality F, the Yield, the biological production (all deaths, including fished population). 40 years simulation results for hake in the Bay of Biscay. Scenario using Z high.



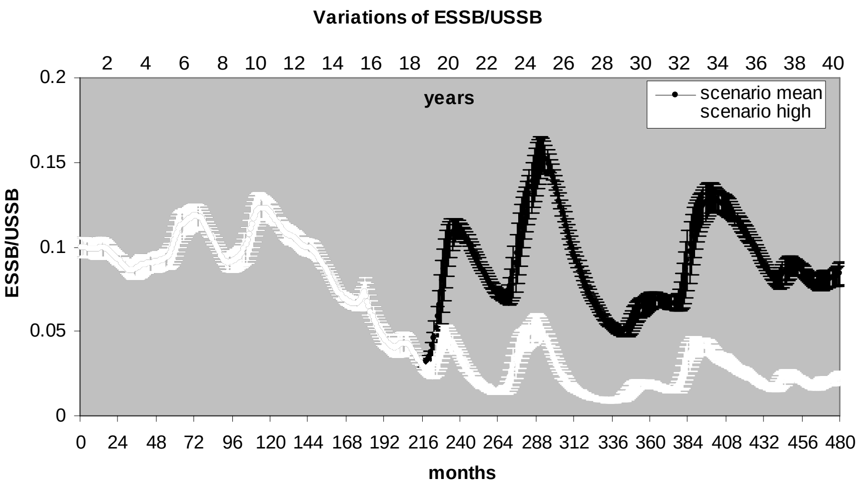
WP5_ptn01_fig06- Outputs of the Aladym-r model simulations related to the mean length of: the exploited population, the unexploited population, the exploited spawning population and the unexploited spawning population and the mean length of catches. 40 years simulation results for hake in the Bay of Biscay. Scenario using Z high.



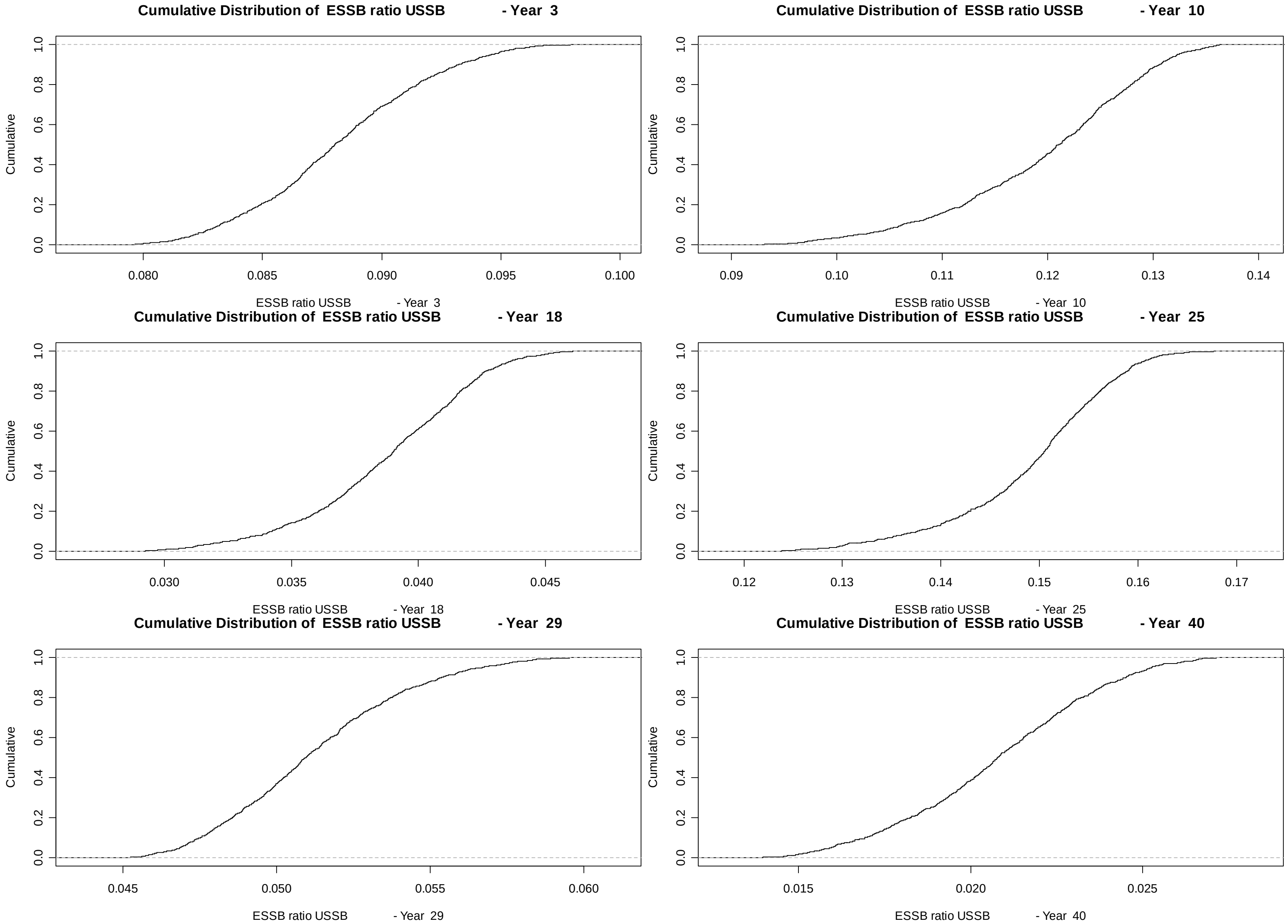
WP5_ptn01_fig07 - Plots of the relationships between the pressure factors and the model-based indicators. 40 years simulation results of the high mortality scenario. The plot of the relationship between the total mortality and the fishing mortality computed by the model are also reported. In each plot the fitted linear model and the regression coefficient are indicated for hake in the Bay of Biscay.



WP5_ptn01_fig08- Plots of the cross relationships between relevant model-based indicators derived from the Aladym-r outputs. 40 years simulation results of the 'high' mortality scenario for hake in the Bay of Biscay.



WP5_ptn01_fig09-Month variations of the model-based indicator ESSB/USSB (exploited spawning stock biomass/unexploited spawning stock biomass) with relative standard deviations (white strip). Results from Aladym-q simulations along 40 years (1000 runs) for the two pressure scenarios for hake in the Bay of Biscay.



WP5_ptn01_fig10-Cumulative distributions of the model-based indicators (exploited spawning stock biomass/unexploited spawning stock biomass, ESSB/USSB) in the years 3, 10, 18, 25, 29 (scenario ‘mean’) and 40 (scenario ‘high’). Results from Aladym-q simulations along 40 years (1000 runs) for hake in the Bay of Biscay.

Simulation Evaluation using ALADYM

Hake Bay of Biscay

J.-C. Poulard (IFREMER), M.-T. Spedicato (SIBM)

Long term effects of Z scenarios for hake in Bay of Biscay as estimated using the Aladym model

Introduction

The age-length based Aladym model was applied to the case of the hake in the Bay of Biscay, to assess through simulations the long-term effects of total mortality changes on model-based population indicators and reference points.

These effects have been estimated along 40-years simulations, analysing the changes of model-based population indicators obtained as model outputs, e.g., the total biomass, the spawning stock biomass, the biological production (i.e., all deaths removed from the population for natural and fishing causes). Consequences on model-derived vital traits indicators (e.g., average length of the population and of the spawning population) have been also evaluated, as well as changes regarding simulated yield and mean length of the catches. Finally, effects on a sustainability indicator as the ratio between exploited and unexploited spawning stock biomass (ESSB/USSB) were assessed. The relationships among the previous mentioned indicators and an additional model-based index represented by the ratio between the exploited biomass of spawners and the exploited biomass (ESSB/EB) were also investigated. Three different scenarios were simulated.

The analysis of population indicators (Petitgas et al., 2007) has showed that Z increased during the last three years of the observation period whereas old ages (ages 4 and 5+) exhibited a decreasing abundance. Hence the importance of simulating scenarios for Z to assess the viability range of the population according to exploitation pressure. The aim was also to get reference values for Z and model-based indicators for a sustainable exploitation (i.e., durable and little variable in time).

Materials and methods

Three exercises were conducted modelling the population through total mortality indices obtained as a result of the cusum analysis in WP5. The study period (1987-2004) was always simulated using a constant total mortality set at ~1.04 for the first 14 years and at a higher value (~1.8) from years 15 (2001) to 18 (2004).

In the first exercise, 'Z high', the total mortality remained at this high value (~1.8) during 22 years. The scenario "Z mean" was run using a total mortality set to ~1.04, i.e., the mortality value observed during the first part of the study period. Finally in the "Z low" scenario, the mortality value was fixed at the three quarters of the mortality used in "Z mean" scenario, i.e., 0.78.

The main inputs of the Aladym model are in the Table 1. The size at first capture (about 302 mm total length) was used as input along the whole time span used in the model and the fishing activity was set at 1.0.

Parameters of the von Bertalanffy growth model by sex were set using the estimates given by de Pontual et al. (2006) for the Bay of Biscay, while those of the length-weight relationships for females and males were derived from ICES (1991). Size at first maturity was from Martin (1991). Recruitment was assumed independent from the parental stock. A proxy of the initial number of the fish at earlier stage for the period 1987-2004 was obtained from groundfish surveys carried out in autumn on the eastern continental shelf of the Bay of Biscay. Recruitment was projected forward for 22 years by random sampling with replacement the passed recruitment values. The same vector of recruitment values was used to simulate the three Z scenarios. On average the recruitment was lower (Table 2) and more variable from one year to another than during the period 1987-2004. Spawning season and sex-ratio were taken from the literature (Murua and Motos, 2006; Murua et al., 2006) and/or from 'direct' observations.

The natural mortality was maintained fixed across ages and calculated comparing different methods (e.g. Alagaraja, Beverthon and Holt life history invariants (Jensen, 1996)) while a guess estimate of longevity (about 20 years) was obtained by the Taylor's approximation.
All the simulations were run for 40 years. The tools Aladym-r and Aladym-q were used, the latter to account for uncertainty in the process of assessing the effects of changes in model input parameters.

Results
From 1987 to 1991, the Bay of Biscay hake Aladym model generated catches which were lower than the hake Northern stock total catches (Fig. 1) but higher than the hake catches recorded for the sub-divisions VIIIab. Afterwards, simulated catches and hake total catches were at similar levels and well above the VIIIab catches. This suggests that the hake recruitment recorded, over the eastern continental shelf of the Bay of Biscay during autumn groundfish surveys, might supply hake fishery beyond the VIIIab area.
The scenario "Z high" describes changes occurring in hake population if the fishing pressure remains at the level observed during the four last years (2001-2004) of the study period. All indicators exhibited long term decreasing trend (Figure 2) although some improvement can be seen some years as a consequence of very good recruitment. Effects of good recruitment were of short duration. All the population production indicators (e.g. yield, biological production, exploited spawning stock biomass, length …) and the ratios ESSB vs EB or ESSB vs USSB were on average the lowest simulated (Table2) and lower than ones of 1987-2004 period.
In the scenario "Z mean" the fishing pressure was maintained to the mean level prevailing during the first 14 years of the study period. This scenario can be considered as the continuation of the exploitation on the same conditions as during the period of study. The results were very close to those of this period (Figure 3 and Table 3) with some more variability induced by more variable recruitment.
The last scenario, "Z low", allowed to increase on average all the population production indicators and the ratios ESSB vs EB and ESSB vs UB (Figure 4 and Table 3). The lowest catch was predicted the first year of the simulated period afterwards catches would be higher and less variable than in any other scenarios.
Figures 5 to 7 show the evolution through time of three indicator candidates: (i) ESSB vs USSB (Figure 5); (ii) ESSB vs EB (Figure 6); (iii) ESSB vs yield (Figure 7). The second and third ratios are probably more informative, as the adult part of the exploited population was compared to total biomass available or yield. The first ratio is more sensitive to changes in recruitment while the second one allows to illustrate the effect of the fishing pressure, making easier the proposition of a management action that would warrant a more stable catch level.

Discussion and conclusion
A general observation is that the CV of Aladym outputs increase when Z increases, i.e., biomass and yield are more variable for higher values of Z. The occurrence (in %) over the 22 simulated years of, for instance, a ratio ESSB/EB <0.35 (mean value of this ratio was 0.36 over the period 1987-2004) is: 95% for the "Z high" scenario, 33% for "Z mean" and 9% for "Z low". A potential option to warrant a sustainable exploitation of the hake population would be to target a value of Z ranging from "Z mean" to "Z low".
It should be noticed that results may partly depend on the recruitment vector used. It could be interesting to simulate the hake population using different recruitment vectors for a set of Z values ranging form "Z mean" to "Z low".
One may question why the catch levels observed and obtained by simulation are so close. Is it fluke or reality ? Our understanding is that the hake recruitment recorded over the eastern continental shelf of the Bay of Biscay during autumn groundfish surveys, might supply the hake fishery beyond the VIIIab area. This would then imply that part of the F assessed by Aladym model is due to hake migration from VIIIab to neighbouring areas. As M is derived from the growth curve in the Aladym model, F would then contain apparent mortality due to migration losses out of VIIIab.

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Table 1. Summary table of the inputs used in Aladym model for the case study of hake of Bay of Biscay.

Input description	Values sex combined
K (year)	0.25±0.05
L_{∞} (mm)	1100 ±60
t_0	-0.000075±-0.000035
a	0.0000043254
b	3.074
Life span (years)	20
M males-females	0.35
L_{mat} (mm)	414±30
Maturity range (L75-L25) (mm)	81±10
L_{50} (mm)	302.4
SR (mm)	3.25
Sex ratio (F/F+M)	0.5
Fishing coefficient	1.0
Recruits (initial number) and parameters of the log-normal distribution	~$208 \cdot 10^6$ (mean ln(R)=18.54; ds ln(R)=0.68)
Spawning time and spawning peak	From December to May (February-March)
Number of year to be simulated	40 (pre-simulation 80)

Table 2. Summary statistics for the input recruitment.

Period	Variable	Recruitment (10^6)
1987-2004	Mean	139
	Min	36
	Max	379
	std	86
	CV	0.62
22 simulated years	Mean	116
	Min	47
	Max	379
	std	99
	CV	0.86

Table 3. Hake Aladym model in Bay of Biscay. Summary statistics for the outputs: during the period observed (1987-2004) by the groundfish surveys and for three scenarios during the 22 following years.

Scenario	Variable	Z	F	Yield (tons)	Biological Production (tons)	Exploited Biomass (EB, tons)	Exploited Spawning Stock Biomass (ESSB, tons)	Mean Length (mm)			ESSB/EB	ESSB/USSB	ESSB/Yield
								Exploited	SS	Catch			
1987-2004	Mean	0.91	0.56	45009	67663	67421	24508	265	519	462	0.36	0.09	0.55
	Min	0.76	0.41	30926	48872	34086	9987	158	450	407	0.24	0.04	0.21
	Max	1.46	1.11	58271	87854	91303	35022	347	572	505	0.43	0.12	0.65
	std	0.20	0.20	7627	11032	15736	7291	48	30	26	0.05	0.02	0.15
	CV	0.21	0.35	0.17	0.16	0.23	0.30	0.18	0.06	0.06	0.14	0.27	0.27
High	Mean	1.24	0.89	33860	43882	30443	7343	232	456	416	0.25	0.02	0.22
	Min	1.06	0.71	14481	18940	13712	3296	142	394	388	0.13	0.01	0.15
	Max	1.55	1.20	79259	102959	72202	16657	302	514	454	0.35	0.05	0.27
	std	0.12	0.12	16713	21457	14927	3685	44	31	18	0.06	0.01	0.03
	CV	0.10	0.13	0.49	0.49	0.49	0.50	0.19	0.07	0.04	0.25	0.44	0.14
Mean	Mean	0.83	0.48	44646	69364	73608	27131	287	527	473	0.37	0.09	0.60
	Min	0.71	0.36	28061	43871	46958	12315	177	430	409	0.19	0.04	0.41
	Max	0.96	0.61	87663	133119	134632	56362	382	603	540	0.45	0.15	0.68
	std	0.06	0.06	16081	24361	24919	10568	57	43	35	0.06	0.03	0.06
	CV	0.08	0.13	0.36	0.35	0.34	0.39	0.20	0.08	0.07	0.17	0.30	0.11
Low	Mean	0.67	0.32	48217	89536	122024	50649	326	565	508	0.41	0.17	1.04
	Min	0.59	0.24	20632	42511	69095	13956	207	435	411	0.20	0.05	0.68
	Max	0.74	0.39	87249	159254	211973	94149	443	653	594	0.47	0.25	1.13
	std	0.04	0.04	15418	27772	36295	17765	64	52	46	0.06	0.04	0.10
	CV	0.06	0.13	0.32	0.31	0.30	0.35	0.20	0.09	0.09	0.15	0.26	0.09

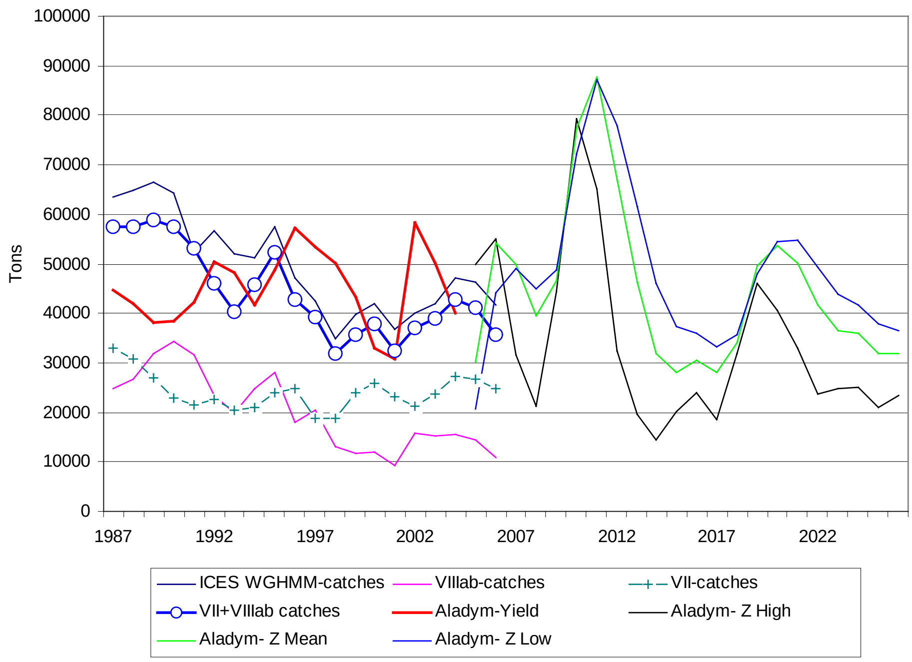
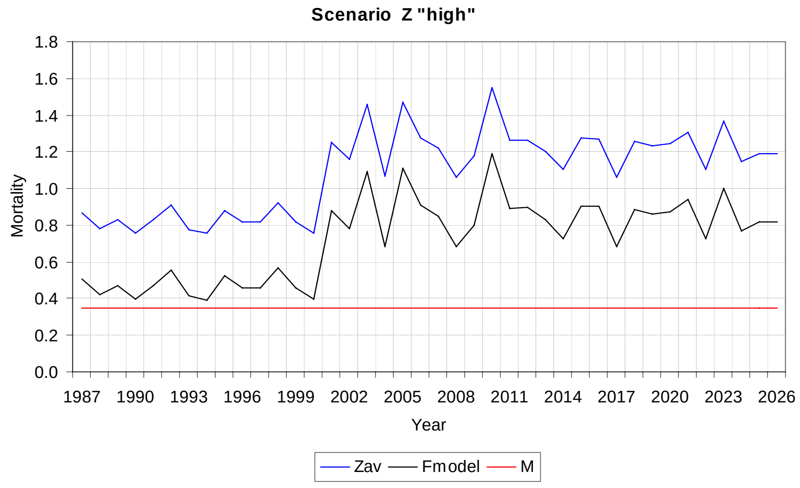
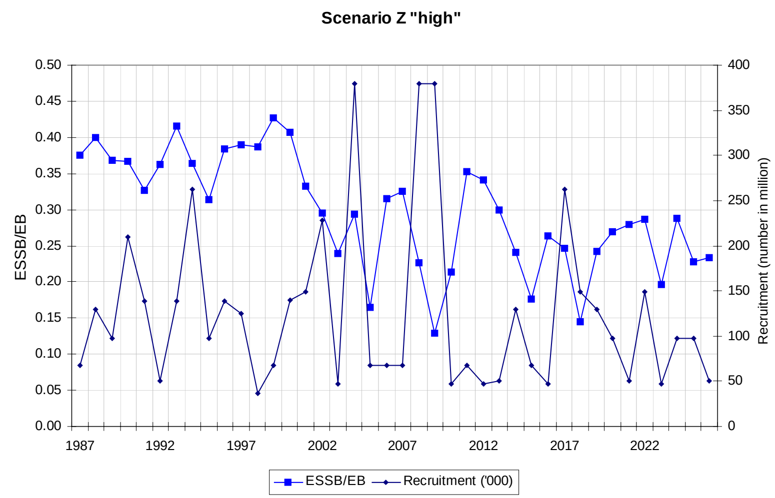
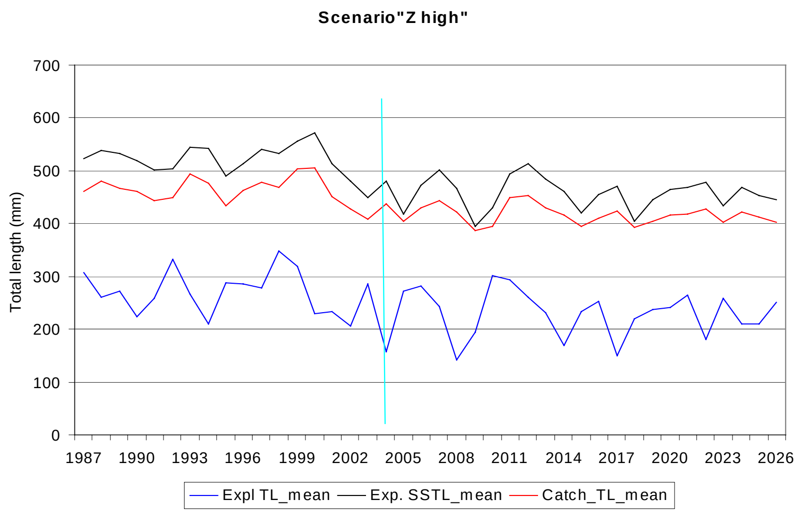


Figure 1. Hake catches and simulations of Aladym hake model for the Bay of Biscay: hake catches used by the ICES WGHMM (total hake Northern stock, in ICES divisions VII, VIIIab) and Aladym simulated yields from 2005 to 2026 for three scenarios of Z.







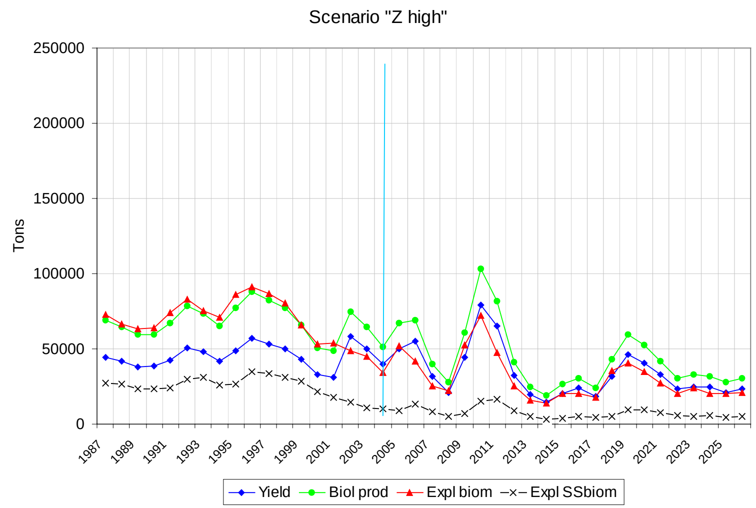


Figure 2. Hake Aladym model in Bay of Biscay: inputs (Z, recruitment) and outputs for the scenario “Z high”.

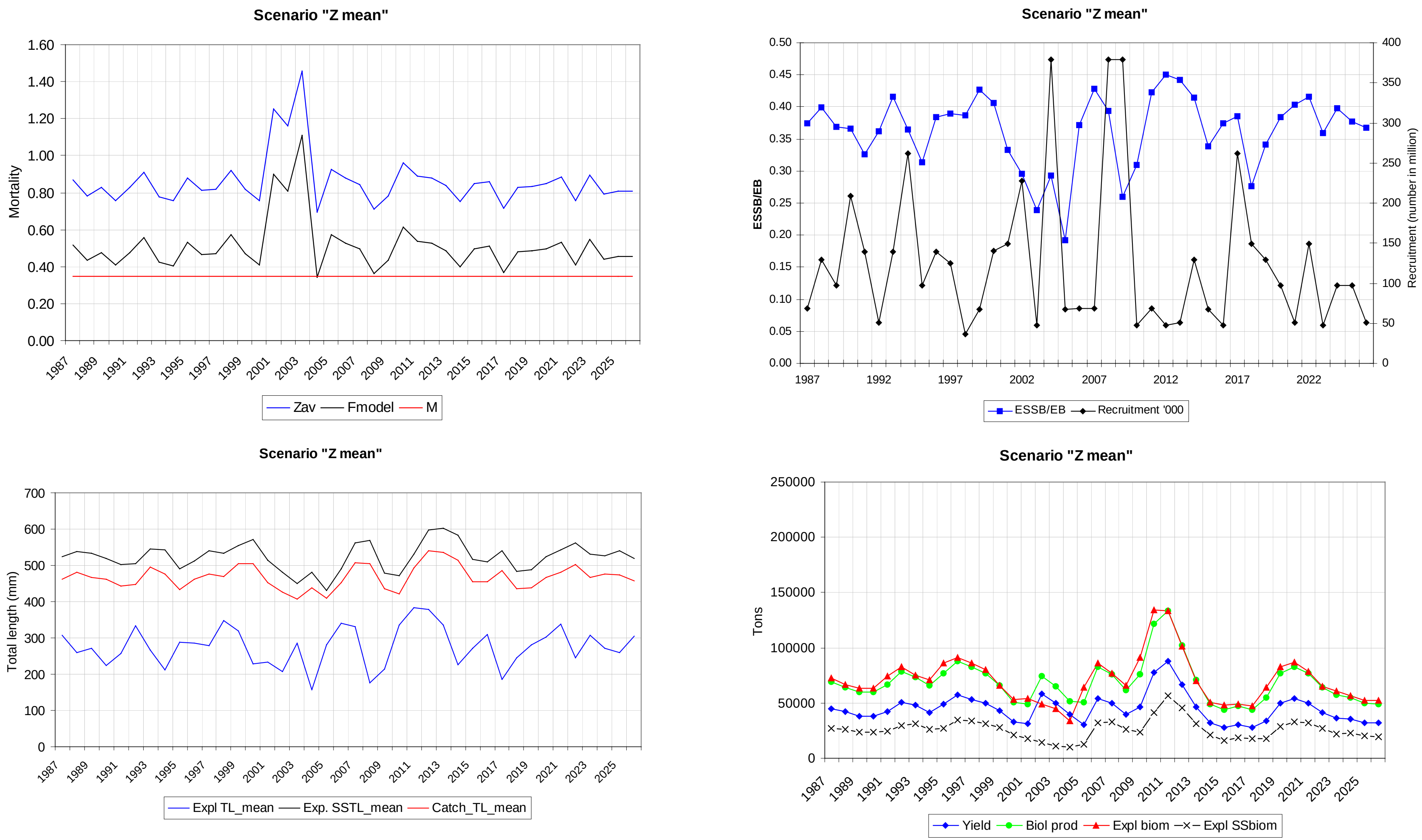


Figure 3. Hake Aladym model in Bay of Biscay: inputs (Z, recruitment) and outputs for the scenario “Z mean”.

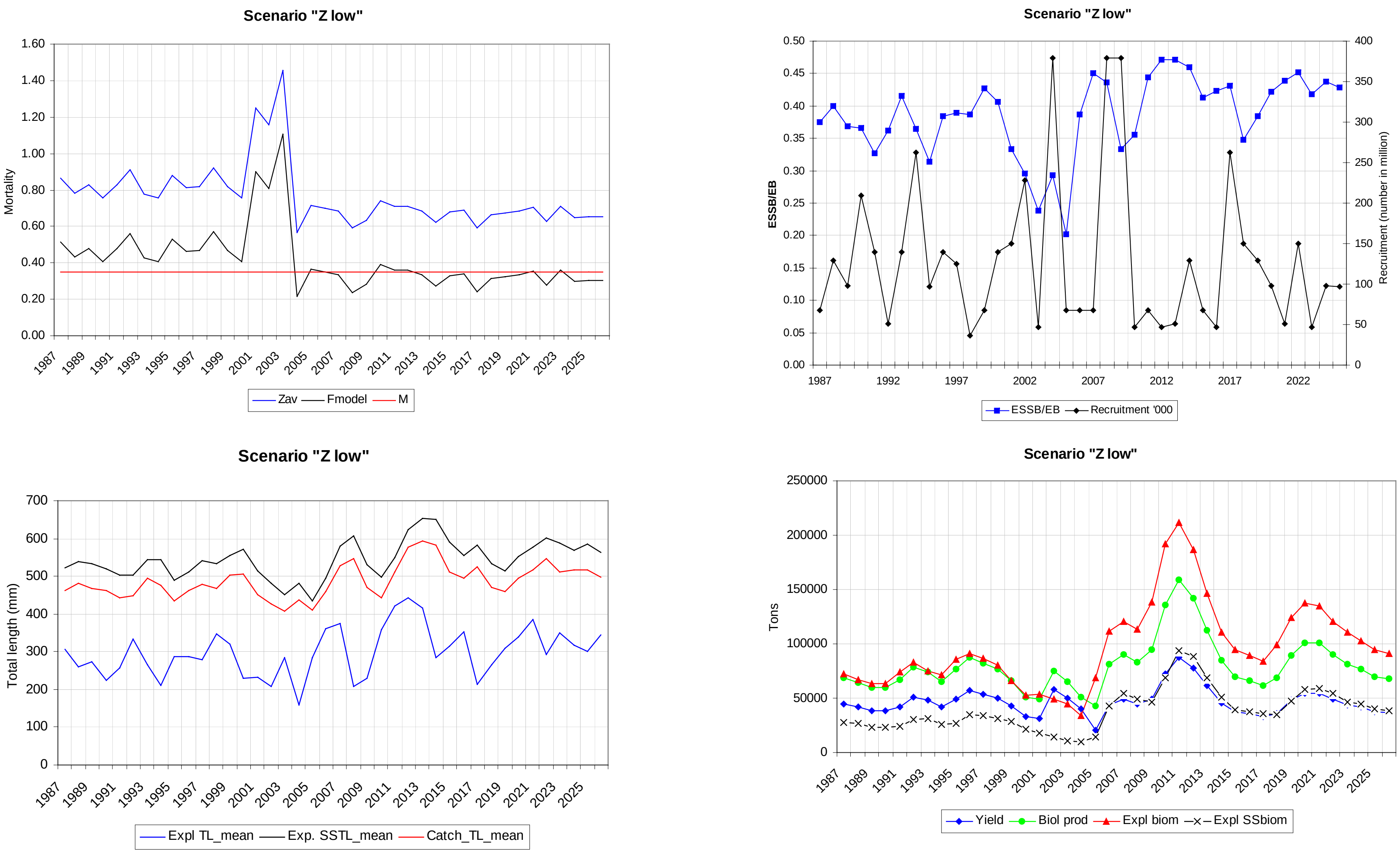


Figure 4. Hake Aladym model in Bay of Biscay: inputs (Z, recruitment) and outputs for the scenario “Z low”.

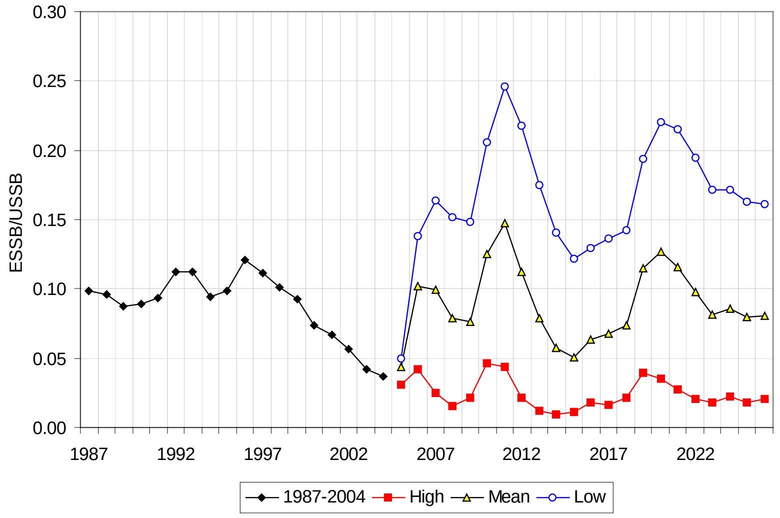


Figure 5. Hake Aladym model in Bay of Biscay: ratio ESSB (Exploited Spawning Stock Biomass) vs USSB (Unexploited Spawning Stock Biomass) for the three scenarios.

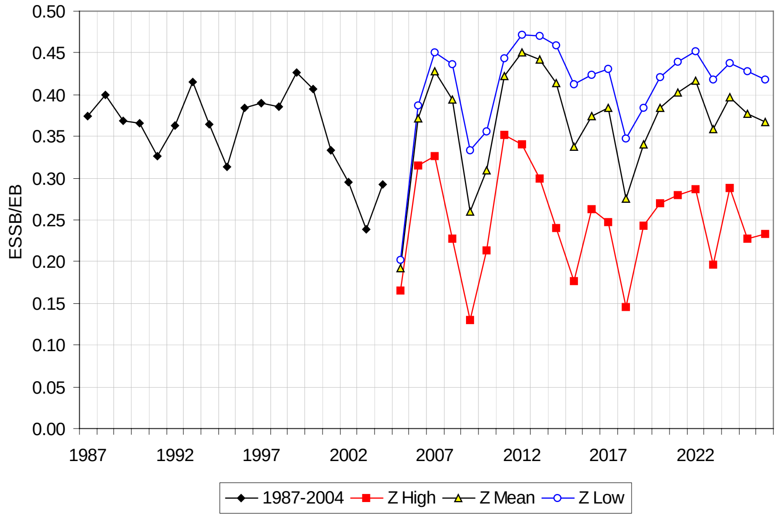


Figure 6. Hake Aladym model in Bay of Biscay: ratio ESSB (Exploited Spawning Stock Biomass) vs EB (Exploited Biomass) for the three scenarios.

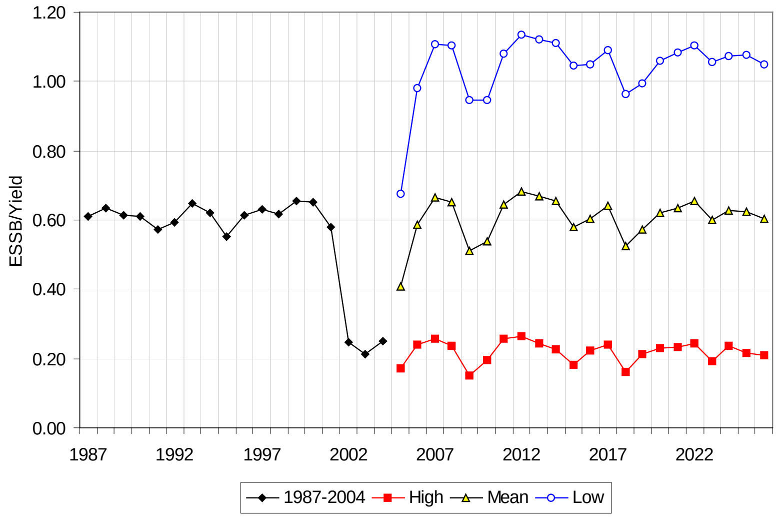


Figure 7. Hake Aladym model in Bay of Biscay: ratio ESSB (Exploited Spawning Stock Biomass) vs yield for the three scenarios.

Simulation Evaluation using ALADYM

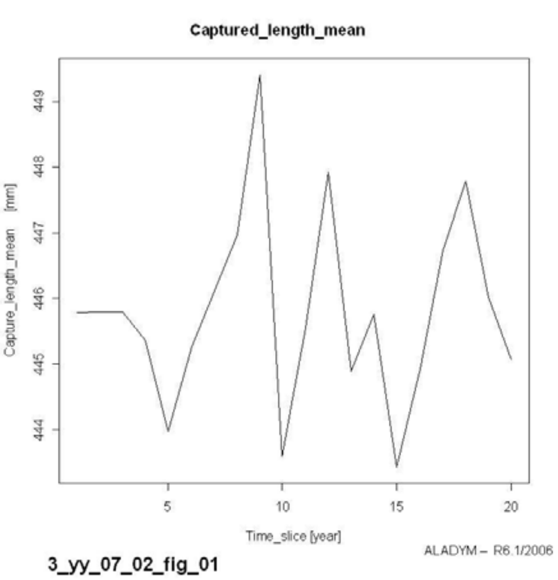
Cod Baltic Sea

K. Radtke, Sea Fisheries Institute, Gdynia, Poland

Application of the ALADYM simulation model to Baltic cod to investigate the long-term sustainability of different scenarios of fishing pressure

The ALADYM simulation model was used to predict the effects of various fishing pressure scenarios. Input values (growth parameters, stock-recruitment relationship etc.) to the model were obtained from surveys. Options implemented in the model were as follows: gear selectivity (commercial fleet -unchanged in the simulation), fishing activity (changed according to fishing scenario considered – total fishing ban, periodical fishing ban etc.), recruitment variability was assumed as +/-20% (on the basis of observed recruitment variations) and total mortality Z (first order approximation equal to the value of Z observed as obtained from research surveys - the outcome from WP2).

In each HCRs scenario considered the sustainability of the Baltic cod (eastern stock) population in the long-term context was analysed. Among the simulations performed the results of a few selected ones are presented in the current report. Exploitation scenario corresponding to the *status quo* fishery, which in fact very closely corresponds to the observed Baltic cod exploitation, resulted in insignificant changes to the population in a 20 years perspective. However, *status quo* scenario does not cause positive changes in the population, what is reflected by low mean captured length (fig. 3_yy_07_02_fig_01) and low mean captured age (fig. 3_yy_07_02_fig_02). It might indicate that the stock is exploited too intensively since it consists mainly of young fish and there were not any significant recruitment pulses which might decrease the mean length and age. Stock consisting of mainly young fish means low spawning stock biomass (SSB) level, which is at present the case of Baltic cod. Following the *status quo* simulation, the SSB (fig. 3_yy_07_02_fig_03) continues to be at a low level as compared to reference points (B_{lim}=160 000 t, B_{pa}=240 000 t) and similarly to captured biomass (fig. 3_yy_07_02_fig_04) tends to decline. Therefore in further simulations options with fishing decrease were studied. The next option examined was *status quo* scenario including two months fishing ban for each year during spawning season (July-August). It resulted in a very slight increase in captured mean length (fig. 3_yy_07_02_fig_05) and captured mean age (fig. 3_yy_07_02_fig_06) as compared to the previous scenario. Although there was an increase in SSB but it did not reach the B_{lim} level (fig. 3_yy_07_02_fig_07). Since ICES for several years has recommended total ban on Baltic cod, therefore in another simulation 2 years total ban was simulated and after that fishing was continued with the intensity as in *status quo* scenario. The results revealed an increase in captured mean length (fig. 3_yy_07_02_fig_08) and captured mean age (fig. 3_yy_07_02_fig_09) but after 5 years both parameters returned to their initial values. SSB exceeded B_{lim} in year 2 and 3 of the simulation but then returned to the value of 80 000 t (fig. 3_yy_07_02_fig_10). Simulation with two years ban and next applying fishing mortality (F) reduced to 0.3 (as recommended by EU in multiannual plan for Baltic cod) gave much better results then in proceeding simulations since captured length increased to 52 cm (fig. 3_yy_07_02_fig_11), captured mean age increased to 4.7 year (fig. 3_yy_07_02_fig_12), and what is important, both parameters were kept on the same level in consecutive years. In addition, that exploitation allowed for SSB to rebuild to B_{pa} (fig. 3_yy_07_02_fig_13) and SSB did not drop below the value of B_{pa}. However, exploitation strategy that assumes total ban on fishing might be hardly accepted by fishermen. Therefore, instead of two years ban, another strategy assuming gradual reduction of F by 10% each year until recommended F=0.3 is reached was examined. ALADYM simulation showed that stepwise F reduction would allow in 10 years perspective obtain SSB equal to B_{pa} (fig. 3_yy_07_02_fig_14) without the necessity of total fishing ban implementation. In addition, captured mean length (fig. 3_yy_07_02_fig_15) and captured mean age (fig. 3_yy_07_02_fig_16) reached values that confirm "positive" changes in the stock. Positive effect of gradual F decrease as compared to strategy implementing 2 years ban was higher average captured biomass (by 5% in 20 years simulation), which would be welcomed by fishermen. The ALADYM series of simulations performed showed that the most adequate value of Z for the Baltic cod recovery should be equal to 0.5. Also it seems that Z=0.5 should assure safe stock exploitation in the future and therefore Z=0.5 could be considered as a reference value.



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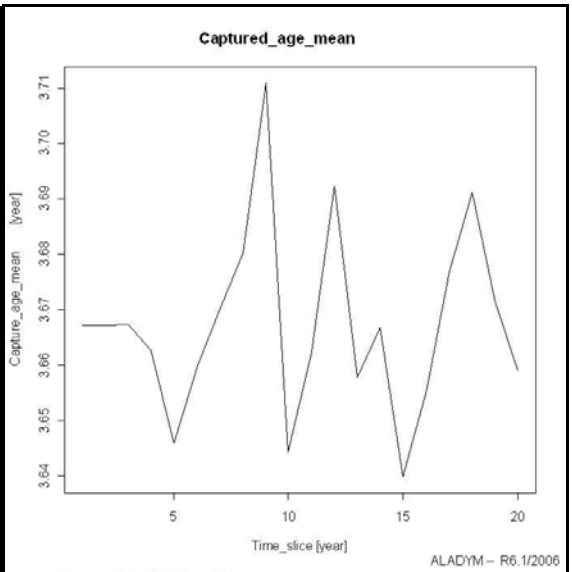

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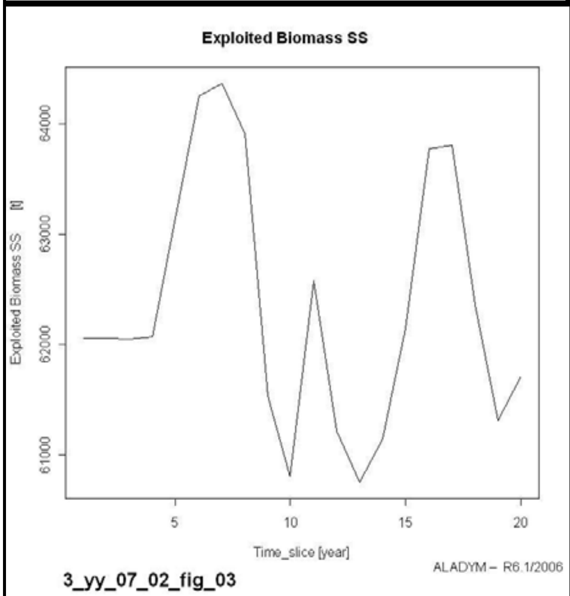

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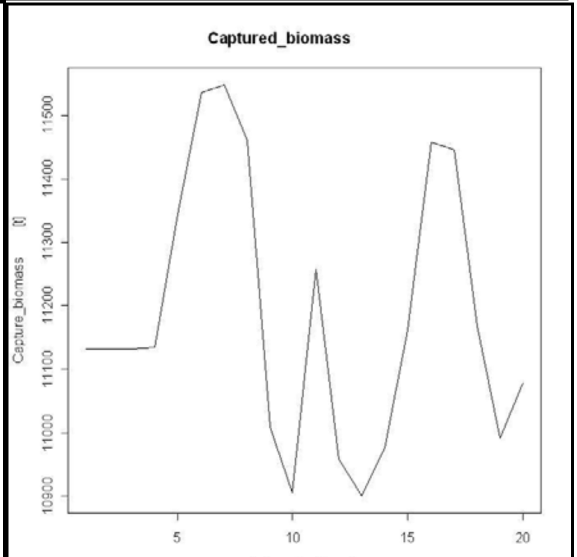

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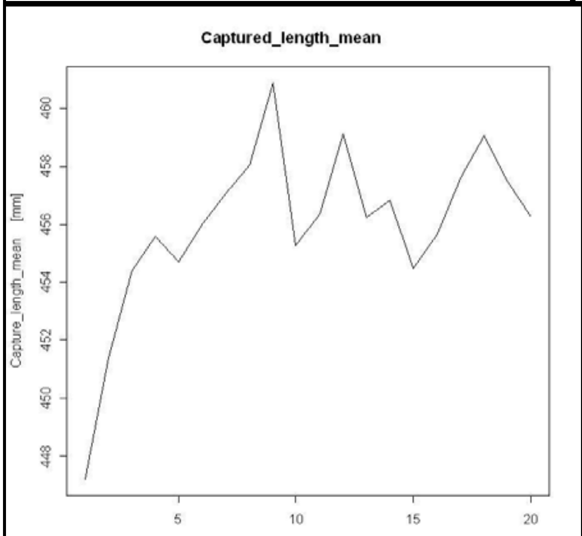
ALADYM – R6.1/2006



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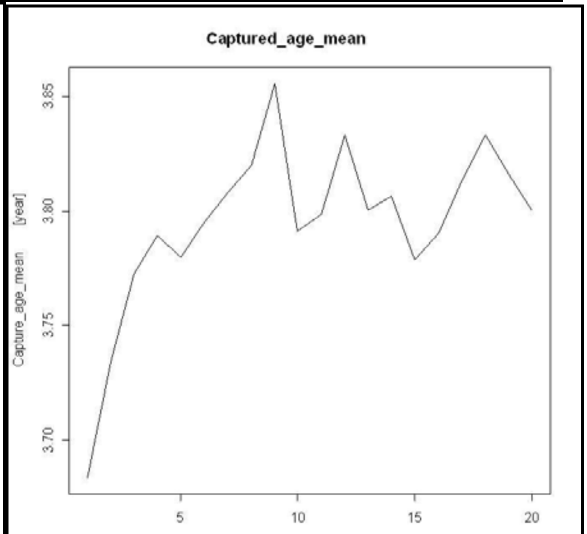

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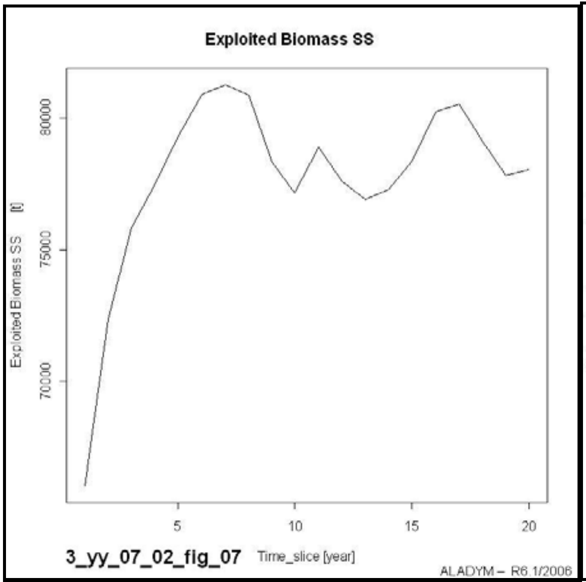
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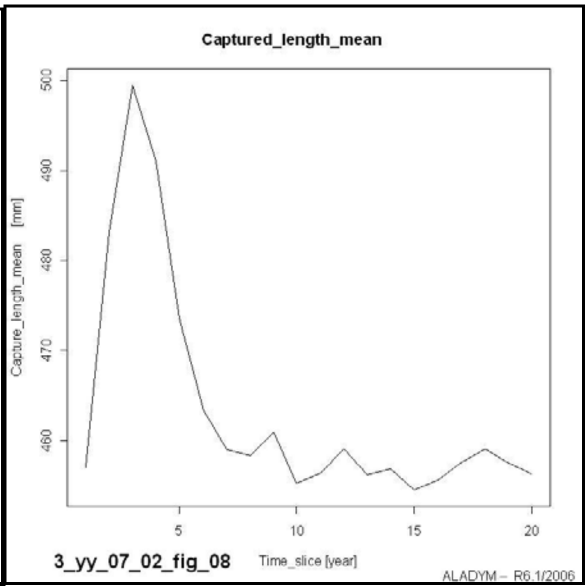
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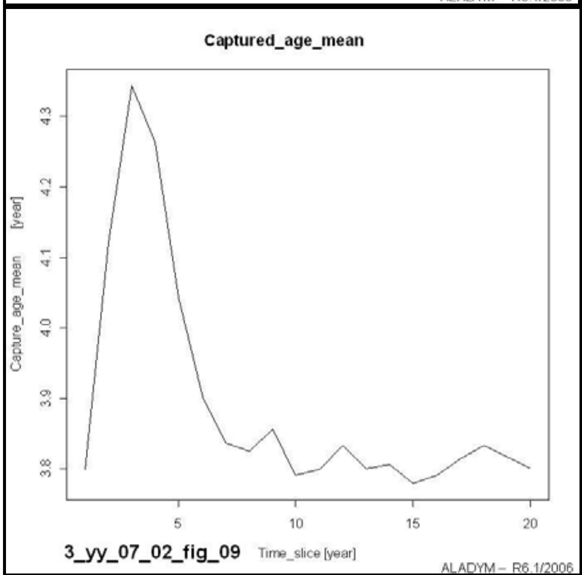
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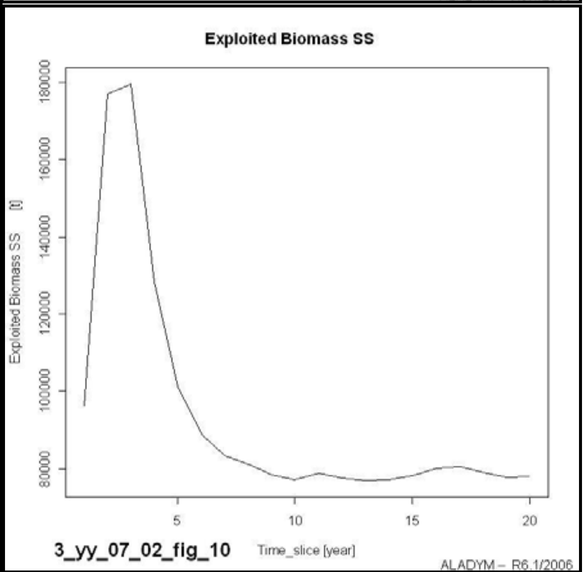
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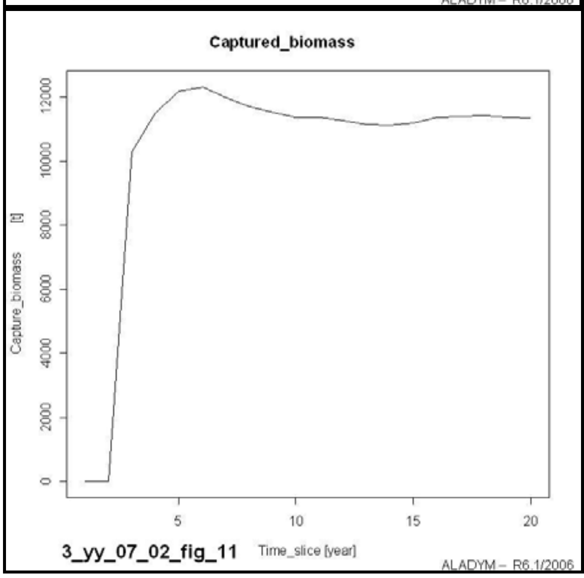
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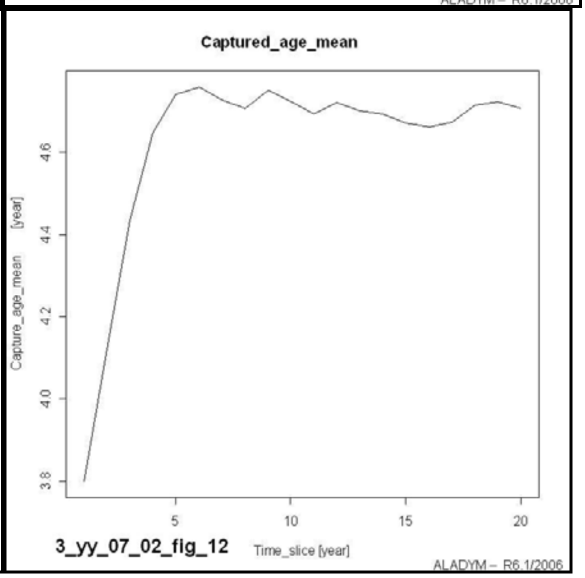
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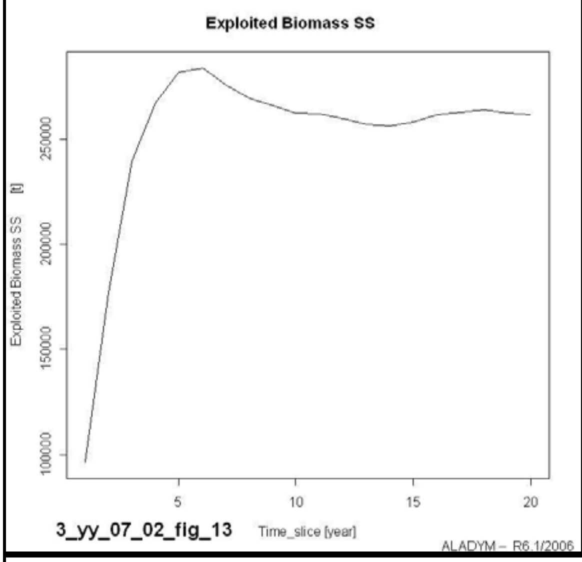
ALADYM – R6.1/2006



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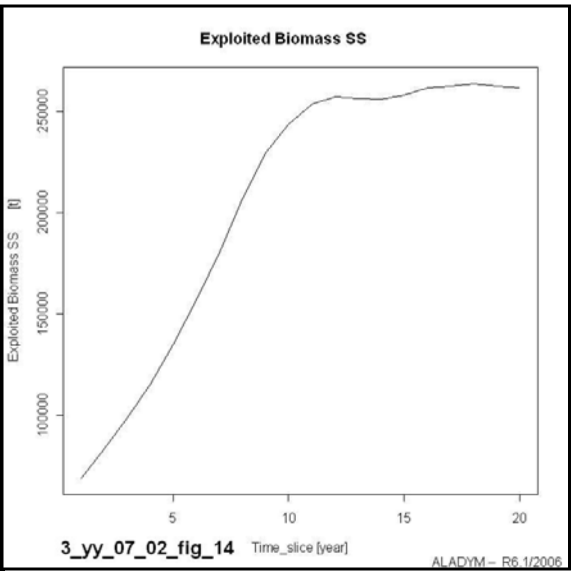

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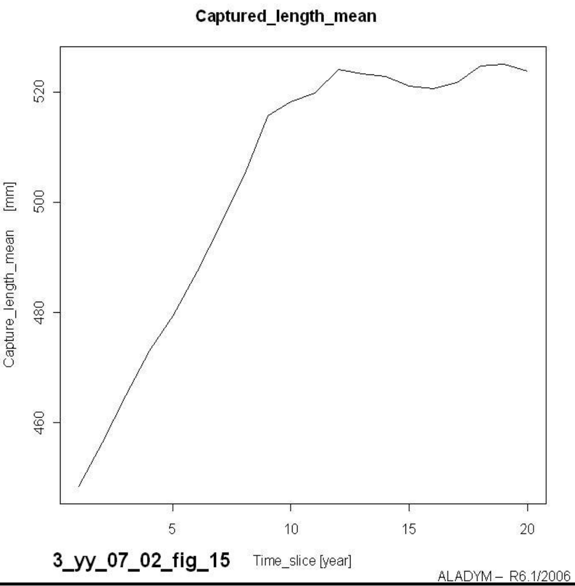

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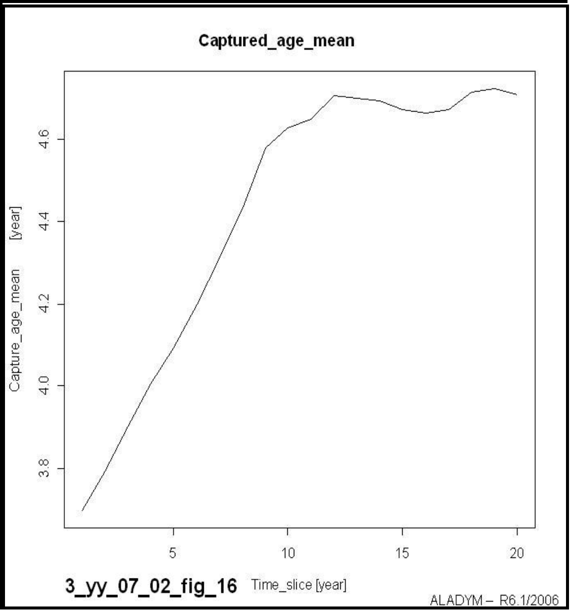

3_yy_07_02_fig_16