Selecting and combining survey based indices of fish stocks using their correlation in time to make diagnostic of their status

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Abstract

Research fisheries monitoring surveys provide an ensemble of measurements on fish stocks and their environment. Presently fish stock diagnostics are based on the evaluation of abundance and the survey data contribution is through abundance indices only. Here we shall consider a large set of survey-based indices that represent a target stock over its time series through its spatial pattern (longitude of the center of gravity, latitude of the center of gravity, inertia, anisotropy, positive area, equivalent area, spreading area, and microstructure index), its vital traits (Lbar, L25, L75, L at 50% maturity, and Z), and its abundance (logarithm of the abundance of the recruits, logarithm of the abundance at age or pooled age, and logarithm of the total abundance). The present work aims at establishing a procedure that analyses these indices in order to diagnose and forecast the state of a stock.

Because the interannual variability in survey based indices is high and because diagnostics on fish stock cannot be based on noise, the first concern is to select and combine those indices that support a reliable diagnostics, thanks to their continuity in time. First, the set of indices is reduced by selecting the ones that present the highest autocorrelation in time. Then Min/max Autocorrelation Factors (MAF) are used to combine the indices into factors that present the maximal continuity in time, and that will be used here to monitor the population status. Finally, the population status forecast to the next year is attempted based on the forecast potential of the MAF method when modelling the time continuity.

The procedure will be applied to North Sea cod and the Bay of Biscay anchovy, two stocks that have experienced a decline and for which survey series exist for more than 10 years. Results are presented and discussed in view of the present ICES assessments, which demonstrates the potential of the proposed fishery independent indicator based diagnostic procedure.

Key words: fish stock diagnosis, time correlation, Min/max Autocorrelation Factors, survey based indices, North Sea cod, Biscay anchovy.

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1. Introduction

Most of analytical models developed for fish stock evaluation and based on virtual population analysis use catch at age data from fisheries and abundance at age index from research surveys. These models are traditionally used by the ICES working groups and present evaluation results as absolute and deterministic values. However there are many questions about their performance and their reliability to provide an advice on a fish population (Punt, 1997). The lack of comprehension and communication about these models with the managers, in particularly with respect to the associated uncertainty is one of the drawbacks that can be cited. The quality of the data is another one. These models require an important amount of data that are often uncertain and unavailable (Kelly and Codling, 2006). In addition, discarding, misreporting, and other actions that distort catch records have increased in fisheries due to inappropriate TAC management (Beare et al., 2005). And the research survey data currently only contribute to abundance indices, whereas they hold potential for other uses. We have to invent alternative approaches to explore the possibility for better management advice.

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A first approach is to develop analytical models based on research survey data only. Although research survey data are generally more variable than catch-at-age data, they have known uncertainty and reliability. This will appreciate the importance of research surveys and their evident need in the marine resource monitoring due to their method of collecting data consistently across years. There are already an important variety of fisheries independent based models that have been developed for that purpose (Beare et al., 2005; Needle, 2003; Fryer, 2002; Trenkel, 2007).

A second approach is to use the research survey data to describe a fish stock status, a fish community or an ecosystem status, and to monitor these data for changes through indicators. A large variety has been developed that characterise a stock, e.g. relative abundance of a stock fraction (e.g. the recruits), fish length, fish age or fish weight spectra, trophic structure, species diversity, etc. They have been used to measure the impacts of fishing or climate change (Bianchi et al., 2000; Rice, 2000; Rochet and Trenkel, 2003; Trenkel and Rochet, 2003; Shin et al., 2005). The question is to know if the system is under control or not, if its status improves or not. The use of a conceptual framework to interpret the combined trends of indicators from ecological theory is a mean to provide a diagnostic of a fish stock or a fish community (Rochet et al., 2005). The use of quality process control (Scandol, 2005) is another mean to interpret the information included in the indicators by triggering alarms on stock status with assigned risks of false alert. More generally, the interest in making use of research survey is that they give a snapshot of an ecosystem, which is quite an actual preoccupation from fisheries scientists ("ecosystem approach to fisheries"). Thus, the signal evaluation of an indicator system should be done according to reference levels or long term objectives, defined in the frame of the precautionary approach.

Finally, more than one indicator would be necessary to allow a management based on unbiased signals. The choice of indicators has to rely on several considerations such as the data availability, the cost of their collect, the reliability of the indicator, the variability of the signal, the stock characteristics described and the need of fisheries dependent or independent data (Kelly and Codling, 2006). The approach proposed in this paper considers the time correlation as a choice criterion. It will allow to select surveys based indicators which are the most continuous in time from a starting set, then to combine them into continuous population indicators using the method of the Min/max Autocorrelation Factors (MAF). A recent application of MAFs in a fishery context was reported by Erzini et al. (2005).They applied the method to catch rate (cpue) time-series of 17 species caught during trawl surveys off Mauritania on the period 1982-2001. Their objective was to detect the main trends in the time series, and to identify correlations between the series, the common structures and the explicative variables by using a dynamic factor analysis (Zuur et al., 2003). The combined indicators (MAFs) allow us to describe the population and make a projection in time by modelling their variogram. The projection may assist us diagnosing the potential change by comparing the forecast (e.g. the projection) and the reality of the year of projection (which will have to be excluded when building the MAFs)

2. Material and methods

2.1 Material

2.1.1 The North Sea cod data

The data used here were collected in the North Sea during the International Bottom Trawl Survey (IBTS) from 1985 to 2005 (Figure 1.a). The coastal countries of the North Sea operate these research surveys according to a common and standardized protocol. The studied area is located between latitudes 50°30'N and 61°30'N, and between longitudes 4°00'W and 9°00'W (ICES area IV, IBTS areas 1-7). Sampled depth interval is between 9 m and 270 m. The sampling design is random stratified, with in average two hauls per ICES square (30' of latitude and 1° longitude). The number of trawl hauls per year varied between 340 and 940, on average 685. A 36/47 Grande Ouverture Verticale (GOV) trawl was used with a codend liner of 10-mm mesh. Haul duration was 30 min at a towing speed of four knots. Catch weights and numbers were recorded for all species. For cod and other commercial species, sex and total length were recorded, and otoliths were collected and examined in the laboratory to construct age–length keys (ALKs) by sex. These keys were used to transform the length frequencies observed at each trawl station into age frequencies. Cod is a long-live species, living until 12 years, and it is sexually mature around age 4 and after. For our purpose, cod densities were disaggregated by age (1-6) and expressed in numbers of fish caught per hour trawled. To calculate the index of abundance, we assumed that the area swept in 30 min of trawling was 0.02 square nautical miles. Representative life stages (recruits, immatures and matures) were used instead of ages. Age 2 represents the recruits, as age 1 is less representative of the recruitment as the survey gear has a low selection with this age. The number of immatures and matures was determined for each trawl station according to a global ogive of maturity (Table 1).

2.1.2 The Bay of Biscay anchovy data

The data are collected in the Bay of Biscay during the French acoustic surveys (currently the PELGAS series) on the period 1989-1990, 1994, 1997-1998, 2000-2005. 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. Prior to 2000, this design was applied only inside a polygon (Figure 1.b) that was thought to be the core distribution area of the anchovy (the continental shelf from 43°50N to 46°30N between the isobath 100m and the coast). In this study we have 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. Anchovy is a short-live species, living no longer than 3-4 years. Anchovy is sexually mature and is reproducing at age 1. Here we have considered 2 groups of age that correspond to recruits (age 1) and matures (age group 2+).

2.2 Methods

For each case study (North Sea cod and Bay of Biscay anchovy) and each representative life stage, we computed time series of survey-based indices. We applied a large set of indices that represent a target stock through its spatial pattern (longitude of the center of gravity, latitude of the center of gravity, inertia, anisotropy, positive area, equivalent area, spreading area, and microstructure index), its vital traits (Lbar, L25, L75, L at 50% maturity, and Z), and its abundance (logarithm of the abundance of the recruits, logarithm of the abundance at age or pooled age, and logarithm of the total abundance). The derivation of the spatial indicators is documented in Woillez et al. (2007). The derivation of the biological indicators (vital traits and abundance indices), together with the spatial indicators, are documented in a manual of indicators (Cotter et al., 2007).

To select and combine indices to develop an indicator-based assessment, we used correlation in time as the major criterion. This will be done by maximizing the time correlation as it is easier to monitor for changes an indicator that is continuous in time than one that is noisy. The time correlation is then measured at the lag of the time series, i.e. at 1 year lag if there is an annual survey, or at variable lag when there are gaps between successive surveys.

2.2.1 Selection of indicators

The first step in the selection process aimed at reducing the number of indicators that describe the system (here the stock). This selection step was based on the time structure of each indicator (normalized to a variance of 1). The time structure of an indicator was described by the experimental variogram calculated along the time series. The experimental variogram is defined classically in intrinsic geostatistics as:

$$\gamma^*(h) = 0.5 \frac{1}{N(h)} \sum_{x_i - x_j \sim h} [z(x_i) - z(x_j)]^2 \quad (1)$$

where $N(h)$ is the number of pairs of points $(x_i ; x_j)$, separated by the distance vector h.

In the case of a time series, the variogram was simplified to a 1D computation. In addition, and by choice, the time structure of the indicators was only described by the first lag of the variogram $\gamma^*(1)$. For each indicator, the half variance between two points separated by a unit lag is thus measured. It allows us to sort the indicator according to their time correlation. The selection will keep only the indicators which have the most important time continuity.

2.2.2 Combination with Min/max Autocorrelation Factors

The Min/max Autocorrelation Factors (MAF) are a multivariate statistical method (Switzer and Green, 1984), having similarities with the classical Principal Components of PCA when analyzing repeated values taken from a set of variables. When applied to a time series, the MAFs decompose the set of initial variables into factors, the autocorrelation of which decreases from the first factors to the last ones (or more generally, the variogram – half variance of increments – of which increases from the first factors to the last ones). Hence the very first factors extract the part of the variables which is the most continuous in time.

Here, a set of indicators has been selected to represent a target population over its time series. The estimated indicators present notable variations in time. These may be due to actual variations but also to various errors. MAFs can be used to extract from the set of indicators the very first factors, that present the maximal continuity in time, and that can be thought to be used for a follow-up of the population in time. The continuity in time is measured here at the lag of the time series: for instance a lag of 1 year.

Derivation
The MAFs, which are linear combinations of the original variables, offer a better factorization of variables distributed in time or space than PCs: in addition to be uncorrelated with each other at the same time (or location), they are uncorrelated with each other for a given time (or space) lag (taken equal to the sampling lag in practice). The MAFs are computed with the aim of: (1) presenting the highest autocorrelation (or smallest variogram) at this lag for the 1st MAF; (2) presenting the second highest autocorrelation at this lag, while being uncorrelated with the 1st MAF, for the 2nd MAF. Etc. Hence, in a time series, the MAFs offer a way to build the combinations of variables which present the maximum continuity in time (as measured at the lag) for the first MAFs, and the minimum continuity for the last MAFs.

The MAFs depend on the chosen computation lag and may be correlated with each other for other lags. The MAFs do not depend on a possible normation of the initial variables and have a variance conventionally set to 1.

Like a PC, a MAF is equivalent to its opposite (= the MAF with changed sign, that would be obtained by changing the sign of each coefficient of its linear combination), because the unit variance and the variogram at the computation lag remains unchanged. A MAF that would be monotonic over a time series can indifferently appear to be increasing or decreasing. Similarly, a MAF with an extreme in the middle of a time series may present indifferently a maximum or a minimum.

The very first MAFs (typically MAF 1 and 2) allow us to extract trends in the multivariate time series of a set of indicators. A trend may correspond to a gradual change, but also to a more sudden change of level. Loadings inform us about the contribution of each index to the observed trends. The very first MAFs can be used to qualify the stock.

Limits for short time series, and robustification
The number of MAFs cannot exceed the number of variables, nor the number of year increments (no. years - 1). If the number of variables tends to be larger than the number of sampled years, the MAF i (i = 1, 2...) tends to have a period equal to (no. years - 1)×2/i. In particular there will be evidence of a high continuity with period (no. years - 1)×2 for MAF 1, (no. years -1) for MAF 2, etc, whatever the data, which may not be significant outside the current time series, e.g. for additional years.

To prevent such an overfitting to the very detailed values of the variables and to increase the significance of the MAFs, we computed them while adding a repeated random noise to the variables. The noise, added to the variables after normalization, was normally distributed with zero mean and with a variance equal per default to 0.1 × (no. indices / (no. years - 1)) vanishing for a long series. The MAFs were calculated for a given number (1000) of realizations with different noises. A final MAF i was obtained by merging the MAFs i from all realizations: first these MAFs i were made consistent by setting their sign to the same value (to avoid that some present a tendency to increase in time, while the others would decrease), then the coefficients for each contributing variable were averaged into their median value (more robust than their mean value). So the final MAFs are obtained from the median profile of the MAFs from all realizations (each of these MAFs being renormalized to a variance of 1).

2.2.3 Forecasting

We forecast the status of a fish stock for one or more following years by using the forecast potential of the MAF method through the factor variogram modelling (e.g. the MAFs variogram modelling). For each factor, the time structure is modelled through the experimental variogram. The forecast for the following year is obtained for each MAF by ordinary kriging. By assuming that the distributions (of the starting indicators) are reasonably close to a gaussian distribution, the uncertainty associated to the kriging estimate is known. Thus, the kriging variance allows us to define the 95% gaussian confidence interval defined by + or – 2 times the kriging standard deviation.

We used this method to compare a posteriori the forecasted year n with the kriging estimate obtained from years $\leq n-1$ to its true, or observed, value obtained from the values of the indicators for year n and the loadings determined by using the years $\leq n-1$. This method measures a posteriori the difference between the forecasted and the observed values. When the difference is high relative to the kriging standard deviation, the considered year n is inadequately described by the established model, identifying a deviation from the previous time series.

Kriging can also be used to re-estimate each year of the series while filtering the nugget effect (purely random components), then smoothing the series, the nugget component giving the 95% confidence interval within which the determined value of the factor should lie.

3. Results
3.1 Selection of indicators

35 indicators have been calculated to represent the North Sea cod population during the period 1985-2005. They present more or less marked variations in time. The selection step maximizes the time correlation of the indicators at the first lag of the variogram on the period 1985-2004 (Figure 2.a). 21 indicators upon 35 show a marked time correlation with a value at the first lag of the variogram below 1. Among these indicators, 12 indicators show a time correlation notably stronger than the others (discontinuity between the values 0.547 and 0.750). These indicators have been retained for the following steps of the process. There are 1 vital trait (L at 50% maturity), 2 indicators of abundance (logarithm of the abundance of the matures and of the immatures) and 9 spatial indicators (the longitude and the latitude of the center of gravity of matures, the anisotropy of the matures, the positive, the equivalent and the spreading areas of the matures, the positive area of the immatures, the microstructure of the immatures and the one of the recruits). Their values at the first lag of the variogram are between 0.167 and 0.547.

For the Bay of Biscay anchovy, 24 indicators have been calculated to represent the population during the period 1989-1990, 1994, 1997-1998, 2000-2005. The selection step maximizes the time correlation of the indicators at the first lag of the variogram on the period 1989-1990, 1994, 1997-1998, 2000-2004 (Figure 2.b). 16 indicators upon 24 show a marked time correlation with a value at the first lag of the variogram below 1. These indicators have been retained for the following steps of the process. There are 3 vital traits (Lbar, L75, L25), 1 indicator of abundance (logarithm of the abundance of the recruits) and 12 spatial indicators (the positive areas of the age 1 and age 2+, the microstructure of the age 1 and age 2+, the equivalent area of the age 2+, the spreading area of the age 2+, the latitude and the longitude of the center of gravity of the age 2+, the inertia of the age 1 and age 2+, the spreading area of age 1, the anisotropy of age 2+). Their values at the first lag of the variogram are between 0.435 and 0.983.

3.2 Combination with Min/max Autocorrelation Factors

The MAF method is now applied on the 12 retained indicators for the North Sea cod and the 16 retained indicators for the Bay of Biscay anchovy in order to combine them into the most continuous factors in time that can be used to follow these populations. The very first MAFs (here the MAF 1 and 2) allow to extract the trends in the multivariate time series from the set of the selected indicators. These MAFs have been obtained from 1000 realizations where a white noise has been added. The figures 3 and 4 present the MAFs time series and the contribution of each indicator to the corresponding MAFs, respectively for the North Sea cod and the Bay of Biscay anchovy.

The North Sea cod shows two first MAFs marked by a stronger continuity in time than the Bay of Biscay anchovy. The first lag of the variogram of the MAFs 1 and 2 are respectively 0.029 and 0.178 for the North Sea cod (Table 2), while the ones of the Bay of Biscay anchovy are 0.094 and 0.183 (Table 3). This could be related to their life cycle and to their sensibility to the environment. Indeed, the life cycle is shorter for the anchovy than for the cod, and anchovy is known to be a resource highly variable in relation to its environment.

The observed trends of the multivariate time series are described through the MAFs. For the North Sea cod, the MAF 1 is globally monotonic, with very small discontinuities, while the MAF 2 increases until 1993-1994, then decreases until 2004, with higher discontinuities between two successive years. MAF 1 can be detailed in three periods. From 1985 to 1990, it increases. From 1991 to 1998, it is close to being flat. And from 1999 to 2004, it increases again. For the MAF 2, one can note a period of higher values between 1988 and 1995, slightly in advance to the flat period of MAF 1.
For the Bay of Biscay anchovy, the MAFs show more irregularity than the ones of the North Sea cod; there are more gaps in the time series but also the discontinuities are more marked. It is another point where differences between the behaviour of the two populations can be seen. The MAF 1 is almost monotonic, except for the last years of the time series (from 2001) which are separated by a marked discontinuity from the others. Concerning the MAF 2, it increases until 2000 and then decreases.

The loadings inform us on the contribution of each indicator in the observed trends. For the North Sea cod, the indicators that contribute the most to MAF 1 are the logarithm of the abundance of the matures (-0.418), the L at 50% maturity (-0.378) , and with an opposite sign, the latitude of the center of gravity (0.383). Then, the indicators that contribute the most to MAF 2 are the microstructure of the immatures (-0.613), the anisotropy of the matures (-0.589) and with an opposite sign, the L at 50% maturity (0.393).
For the Bay of Biscay anchovy, the indicators that contribute the most to MAF 1 are the L75 (-0.339), the inertia at age 1 (-0.335), the microstructure at age 2+ (-0.322) and with an opposite sign, the equivalent area at age 2+ (0.322). Then, the indicators that contribute the most to MAF 2 are the logarithm of the abundance of the recruits

(0.498), the microstructure of the age 1 (0.366), the positive area at age 2+ (0.337) and with an opposite sign, the spreading area of the age 1 (-0.374).

The time series of the indicators contributing the most to the first two MAFs allow us to explain the observed trends. For the North Sea cod, the MAF 1 (the long term trend) is explained by the decrease in two times of the logarithm of the abundance of the matures first for the years 1985-1991 then for years 2000-2004. The stability of the abundance corresponds mostly to the flat period of the MAF 1, however the MAF 1 decreases sooner than the abundance). The MAF 1 is also explained by the shift of the matures towards the North for the years 1987-2004 and the reduction of the L at 50% maturity for the years 1985-2004 (Figure 5). Thus, the status of the North Sea cod stock has declined compared to the beginning of the series. The decrease of the reproductive potential (decrease of the logarithm of the abundance of the matures) due to the impact of the fishing activity (decrease of the L at 50% maturity) have been accompanied by a change in the spatial distribution (shift towards the North for the matures). The microstructure of the immatures, the anisotropy of the matures and the L at 50% maturity are the indicators that contribute the most to MAF 2. This short term trend illustrating the North Sea cod stock presents an increase then a decrease that can be explained by the behaviour of previously listed indicators. In short, the change in the spatial distribution of the matures (modification of the geometry of the distribution), the impact of the fishing activity on the matures (decrease of the L at 50% maturity) as well as the spatial distribution of the immatures (spatial regularity of the densities) are the characteristics of the status of the stock explaining the trend of MAF 2. One can relate values for the MAF 2 between 1988 and 1995 and the flat to the MAF 1 with a period of small microstructure of the immatures (illustrating in a delayed way the goodness of the recruitment) and the stability of the abundance of the mature that appears few years later.
For the Bay of Biscay anchovy, the same analysis can be done on the time series of the most contributing indicators (Figure 6). For the MAF 1, trend is mostly explained by the increase of L75 (low value 1990 opposed to high values in 2002 and 2003), the increase of the inertia at age 1, the decrease of the equivalent area at age 2+ and the increase of the microstructure at age 2+. All indicators show marked changes in the last years of the series. For the MAF 2, the trend is explained by stability of the recruitment index in the middle of the series in opposition to low values in years 1989, 2002-2003, the decrease of the spreading area at age 1, the increase of the microstructure at age 1 on the period, and the increase until 2000, then the decrease until 2004 of the positive area at age 2+. The stock has experienced in the recent years a drop in the recruitment, a larger length, a higher inertia in the spatial distribution of recruits, smaller occupied areas for the recruits and the older fish, and a higher amount of irregularity in their density surface for the mature and the recruit fish. This situation illustrates a decline of the reproductive potential of the anchovy that also affect the reproduction success.

3.3 Forecasting

The population status forecast to the next year is attempted based on the forecast potential of the MAF method, making use of the variogram of the factors. Thus, the experimental variograms of MAF 1 and MAF 2 are modelled respectively for the two populations (Figures 7 and 8). For the North Sea cod, the models with two components are respectively a nugget effect of 0.01 and a 0.015 × power 1.99 model for MAF 1 and a nugget effect of 0.01 and a 0.155 × power 1.15 model for the MAF 2. For the Bay of Biscay anchovy, the models are a model with three components for the MAF 1 – a nugget effect of 0.01, a cubic model with sill 0.5 and range of 8 and a 0.01 × power 1.99 model – and a model with two components for the MAF 2 – a nugget effect of 0.01, a cubic model with sill 1.3 and range of 5.3 –.

The kriging estimates are performed for the two populations according to the models fitted, for the years of the series as well as for 10 years ahead. The assumption on the distributions has been checked to be reasonably close to the gaussian distribution to use the 95% gaussian confidence interval defined by + or – 2 times the kriging standard deviation. For the North Sea cod, the observed MAF values (for MAF 1 and 2) are reasonably lying within the 95% confidence interval defined from the kriging estimates, as well as for the observed MAF values (for MAF 1 and 2) of the Bay of Biscay anchovy. Concerning the forecasted years, for the North Sea cod the year 2005 appears to be in the continuity of the MAF models inferred with the past years, while, for the Bay of Biscay anchovy, the year 2005 is not in the continuity. There is no observed change compared to the forecast concerning the evolution of the North Sea cod status: this is what it was before i.e. not good. For the Bay of Biscay anchovy, there is an observed change compared to the forecast, but it may be an improvement as well as the opposite.

4. Discussion

A procedure is proposed to select and combine a set of survey based indicators that describe the main characteristics of a fish stock. This does not mean however that this choice of indicators and the procedure can not be improved. Currently the idea is rather to see if this procedure is enough demonstrative to make a diagnosis of the status of a fish stocks.

The main problem of an indicator approach is the amount of available information. Many indicators are available to describe a fish stock. The information must be reduced or combined to make a coherent and comprehensive diagnostic. Our selection step retains a certain number of indicators based on a time correlation criterion. The choice of the number of indicators to retain has to be made according to the number of years present in the time series. Indeed, even if the MAF method has been made robust on this point, it does not allow us to handle as many indicators as possible. Its weakness is in the number of indices compared to the size of the time series, since the noise to be added for robustification has to increase with the number of indices. Then, to select a number of indicators below the number of years is reasonable. One can note also that the MAF method is sensitive to the proportion giving the amount of variance for the white noise. Then, when indicators are ordered according to the variogram value at the first lag, clumps can be identified. So selecting as many clumps as possible with a total number of indicators below the number of studied years is the way that has been adopted here, especially for the North Sea cod. For the Bay of Biscay anchovy, it is slightly different as only spatial indicators would have been selected by this way. It has been decided to retain all the indicators that present a variogram at lag 1 below 1, in order to incorporate vital traits and abundance indicators. Indeed, these indicators appeared important as they present high contributions to the MAFs (L75 and the logarithm of the abundance of the recruits) and they help the interpretation. For the North Sea cod it was checked that no other important indicator would have been highlighted by retaining more indicators.

Results are now replaced in the light of the present ICES assessments. The North Sea cod stock is a highly deteriorated stock according to the ICES diagnostic. This stock has a reduced reproductive capacity and its exploitation is qualified to be not sustainable. The fishing mortality compared to the maximal production corresponds to an over fishing. The fishing mortality is above the determined objectives (*Flim*) almost on the whole studied period, it has reached *Flim* around 2004. The spawning stock biomass is under the limit biomass (in the early nineties and since 1999). For the Bay of Biscay anchovy, the ICES WGMHSA (Working group on the assessment of mackerel, horse mackerel, sardine and anchovy) has considered that recruitment was repeatedly low since 2002. The closure of the fishery was recommended in 2004 and 2005. The decision to close the fishery was taken in 2005 only. Note that anchovy scientific advice for the management relies on assumptions about future recruitments, which is not the purpose of this procedure.

However, the MAF method allows us to follow a fish stock in time through the most suited indicators to be followed in time: the MAFs. By looking at the contributing raw indicators, fish stock status can be identified. The North Sea cod shows a progressive evolution of its status towards a general degradation, while the Bay of Biscay anchovy shows a sudden change in the recent years (2000-2001) towards a decline. The observed situation for the forecasted year (2005 for the both series) is in the continuity of the trend for the North Sea cod (i.e. the decline continues), while it is not in the continuity of the trend for the Bay of Biscay anchovy (i.e. the decline accelerates or the situation improves). In fact, time series of indicators show for the Bay of Biscay anchovy that the degradation is more marked in 2005 (e.g. very low abundance of matures and recruits).

Finally, the North Sea cod and the Bay of Biscay anchovy, two stocks that have experienced a severe decline, allow us to demonstrate the potential of the proposed fishery independent indicator based diagnostic procedure by selecting and combining survey based indicators on a time correlation criterion. This time correlation based procedure has also a potential to forecast. The idea is that, if the actual situation deviates too much from the forecast (i.e. the kriging estimate), it means that something abnormal has happened compared to the past: this could correspond to a deteriorated situation or not, and would require an increased monitoring.

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Table 1. Ogive of maturity at age used to determine the representative life stage (immatures and matures) for the North Sea cod.

Age	**Proportion of matures**
1	0.01
2	0.05
3	0.23
4	0.62
5	0.86
6	1.00

Table 2. Values of the variogram at lag 1 for the all MAFs computed for the North Sea cod.

MAFs	**Variogram at lag 1**
1	0.029
2	0.178
3	0.434
4	0.496
5	0.764
6	0.916
7	0.845
8	1.131
9	1.233
10	1.289
11	1.473
12	1.746

Table 3. Values of the variogram at lag 1 for the all MAFs computed for the Bay of Biscay anchovy.

MAFs	Variogram at lag 1
1	0.094
2	0.183
3	0.391
4	1.036
5	1.168
6	1.513
7	1.465
8	1.953
9	1.752

Figure 1. a) Map of the North Sea showing the trawl stations for the survey 2005 with the polygon which has been sampled in all surveys (ICES area IV, IBTS areas 1-7). b) Map of the Bay of Biscay showing the acoustic transects for the survey 2005 with the polygon which has been sampled in all surveys. Prior to 2000, sampling outside this polygon was not done regularly.

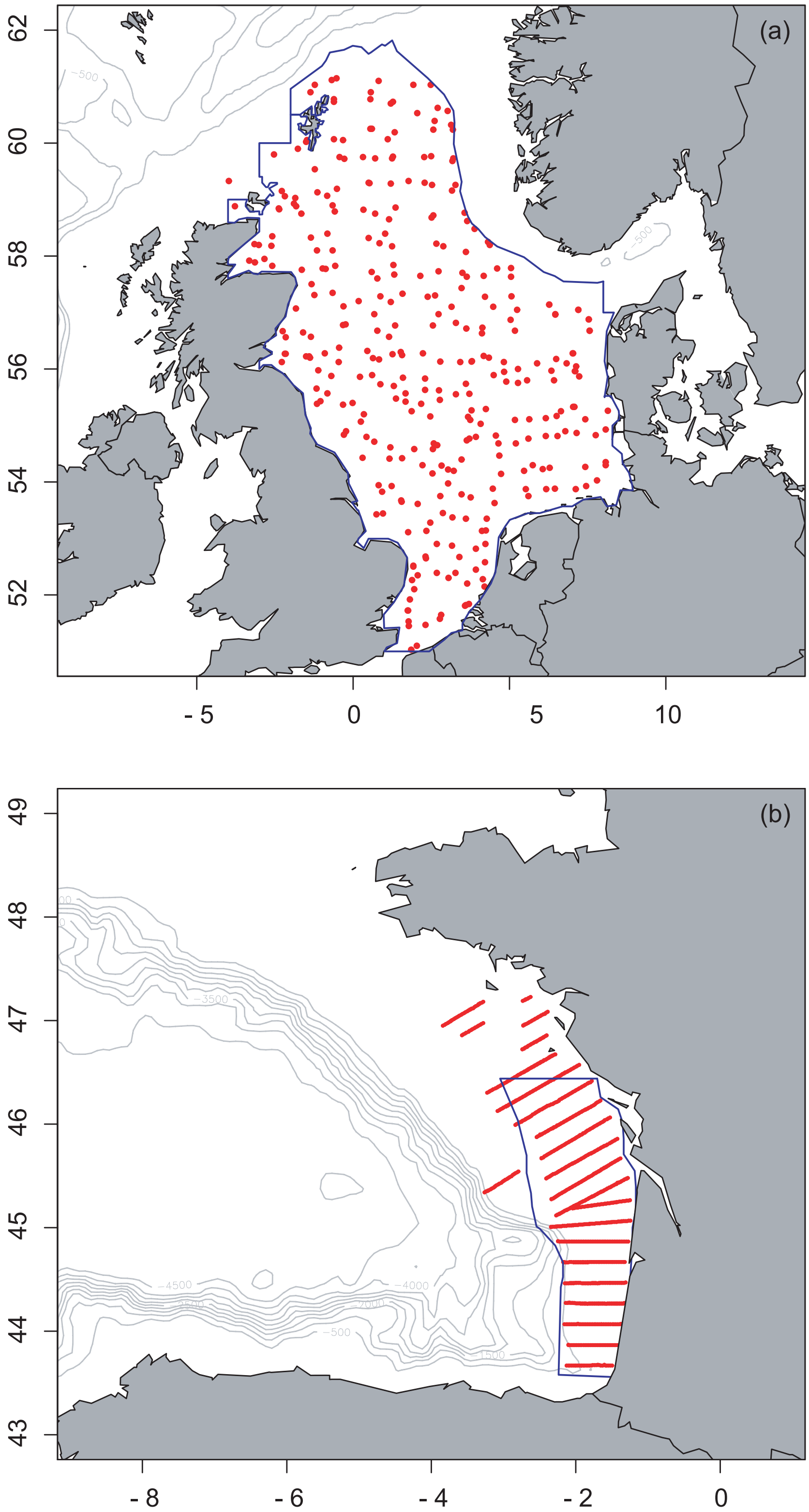

Figure 2. Plot representing the indicators describing the North Sea cod (a) and the Bay if Biscay anchovy (b) that have been ordered according to their time correlation respectively on the period 1985-2004 and on the period 1989-1990, 1994, 1997-1998, 2000-2004. In red, the most continuous indicators in time (i.e. the ones that present the lowest values at the first lag of the variogram) that have been retained at the selection step.

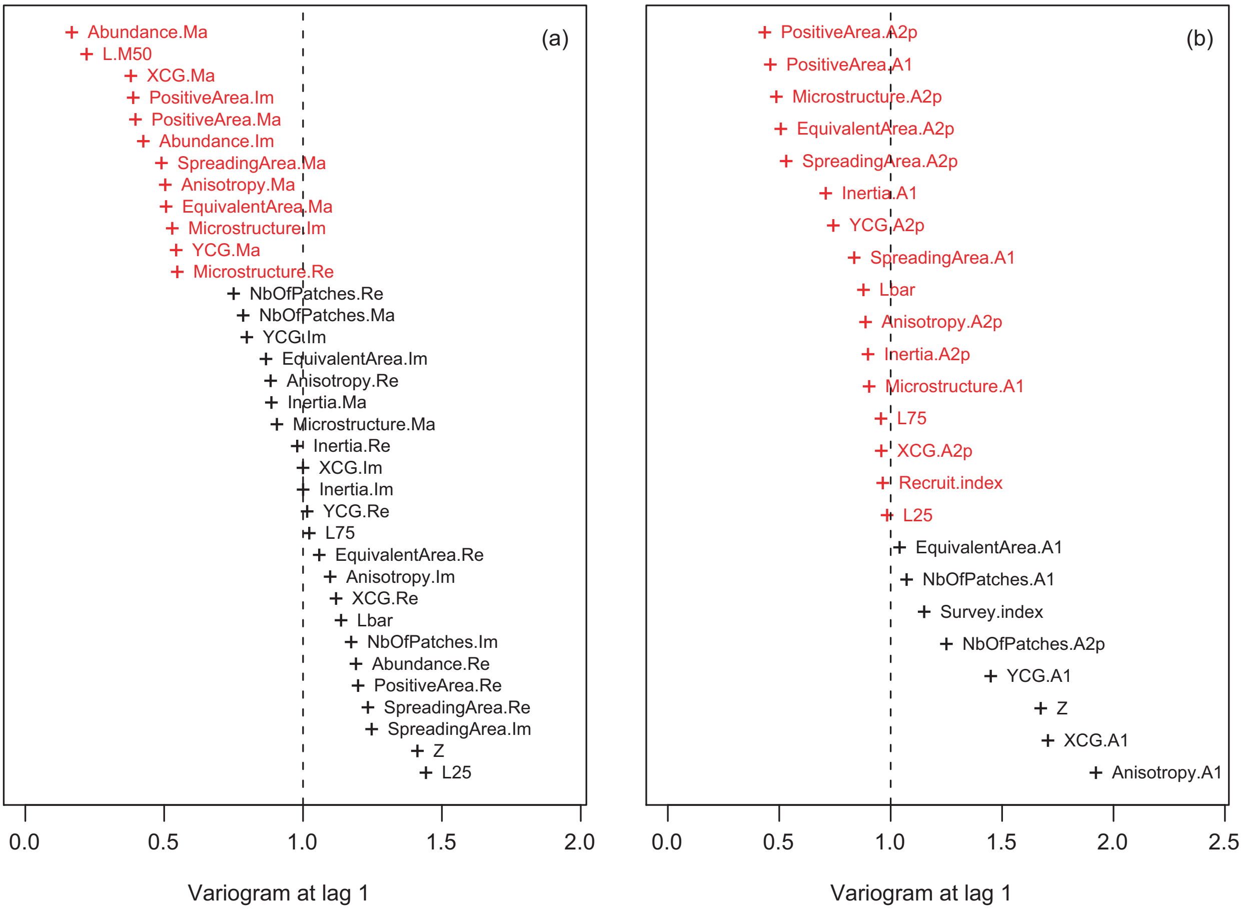

Figure 3. Time series of the two first MAFs and loadings associated to each indicator for the North Sea cod. These are the most continuous MAFs and they have been built from 1000 realizations.

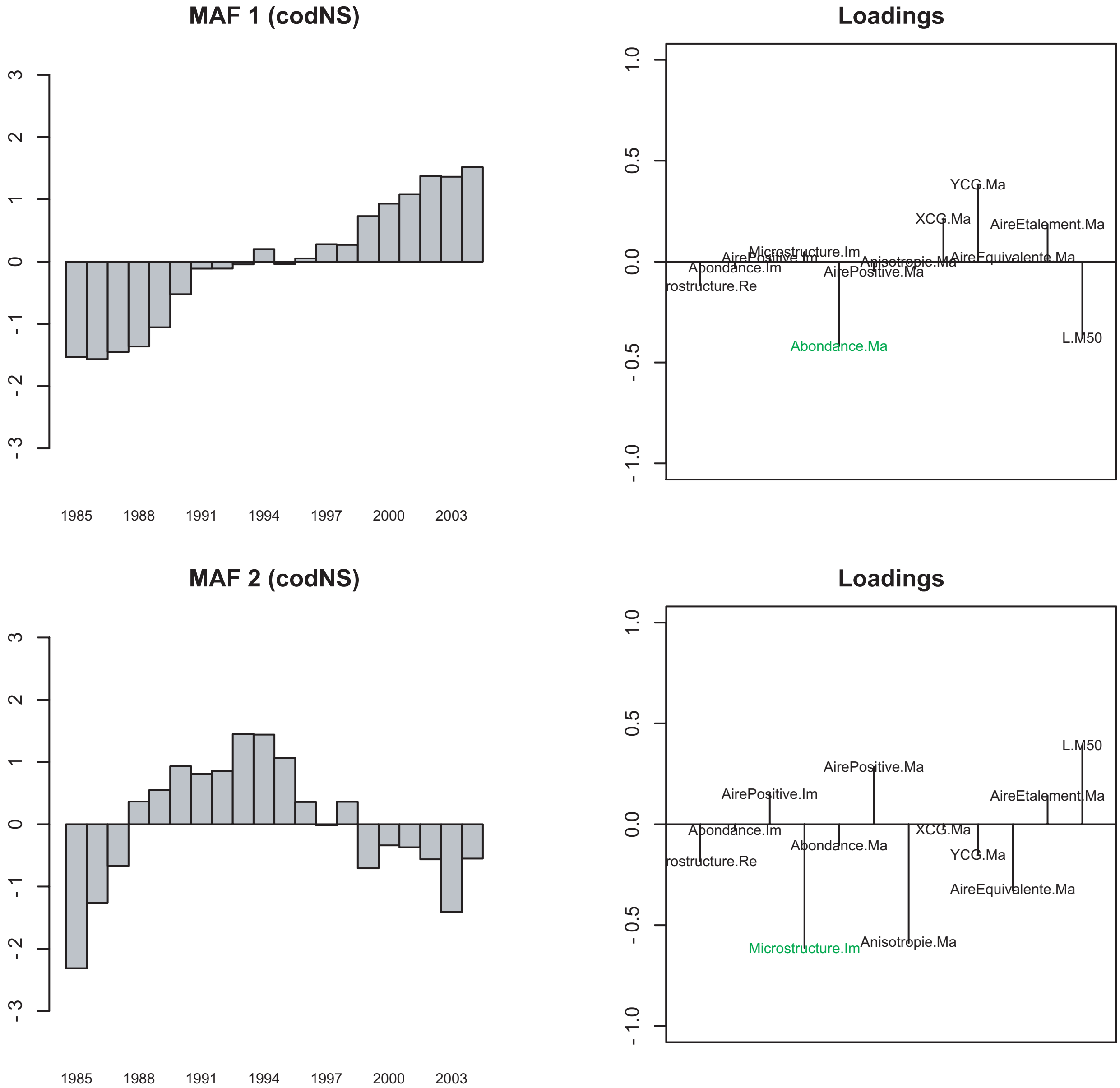

Figure 4. Time series of the two first MAFs and loadings associated to each indicator for the Bay of Biscay anchovy. These are the most continuous MAFs and they have been built from 1000 realizations.

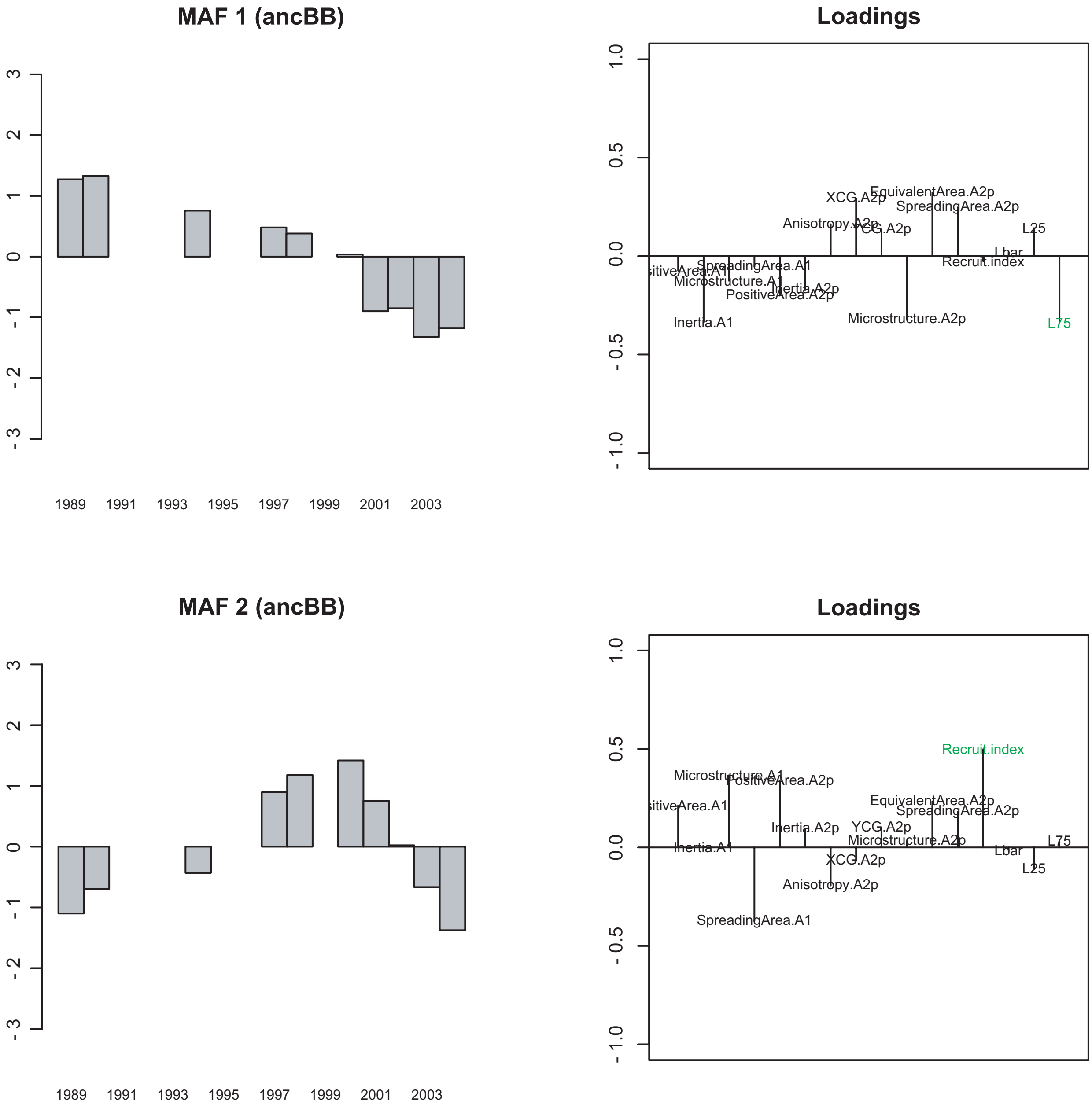

Figure 5. Time series of the indicators contributing the most to the first two MAFs for the North Sea cod. The logarithm of the abundance of the matures (a), the latitude of the center of gravity (b) and the L at 50% maturity (c) for the MAF 1. The microstructure of the immatures (d), the anisotropy of the matures (e) and the L at 50% maturity (c) for the MAF 2.

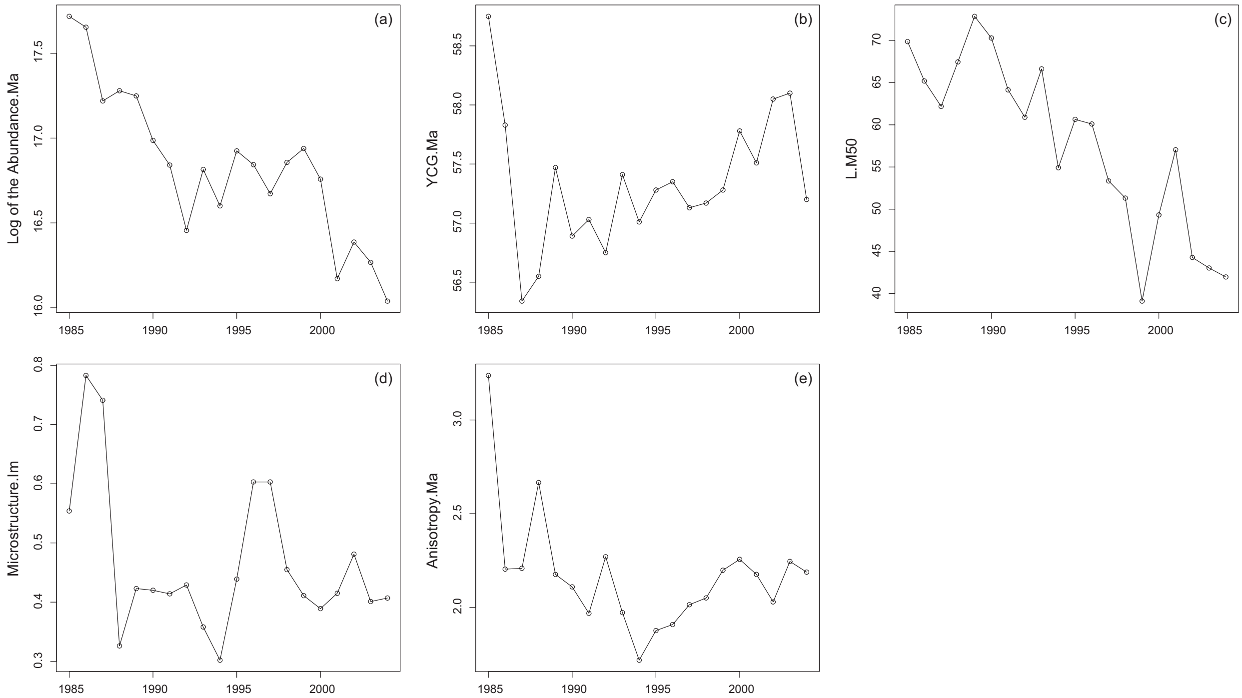

Figure 6. Time series of the indicators contributing the most to the first two MAFs for the Bay of Biscay anchovy. The L75 (a), the inertia at age 1 (b), the equivalent area at age 2+ (c) and the microstructure at age 2+ (d) for the MAF 1. The logarithm of the abundance of the recruits (e), the spreading area at age 1 (f), the microstructure at age 1 (g) and the positive area at age 2+ (h) for the MAF 2.

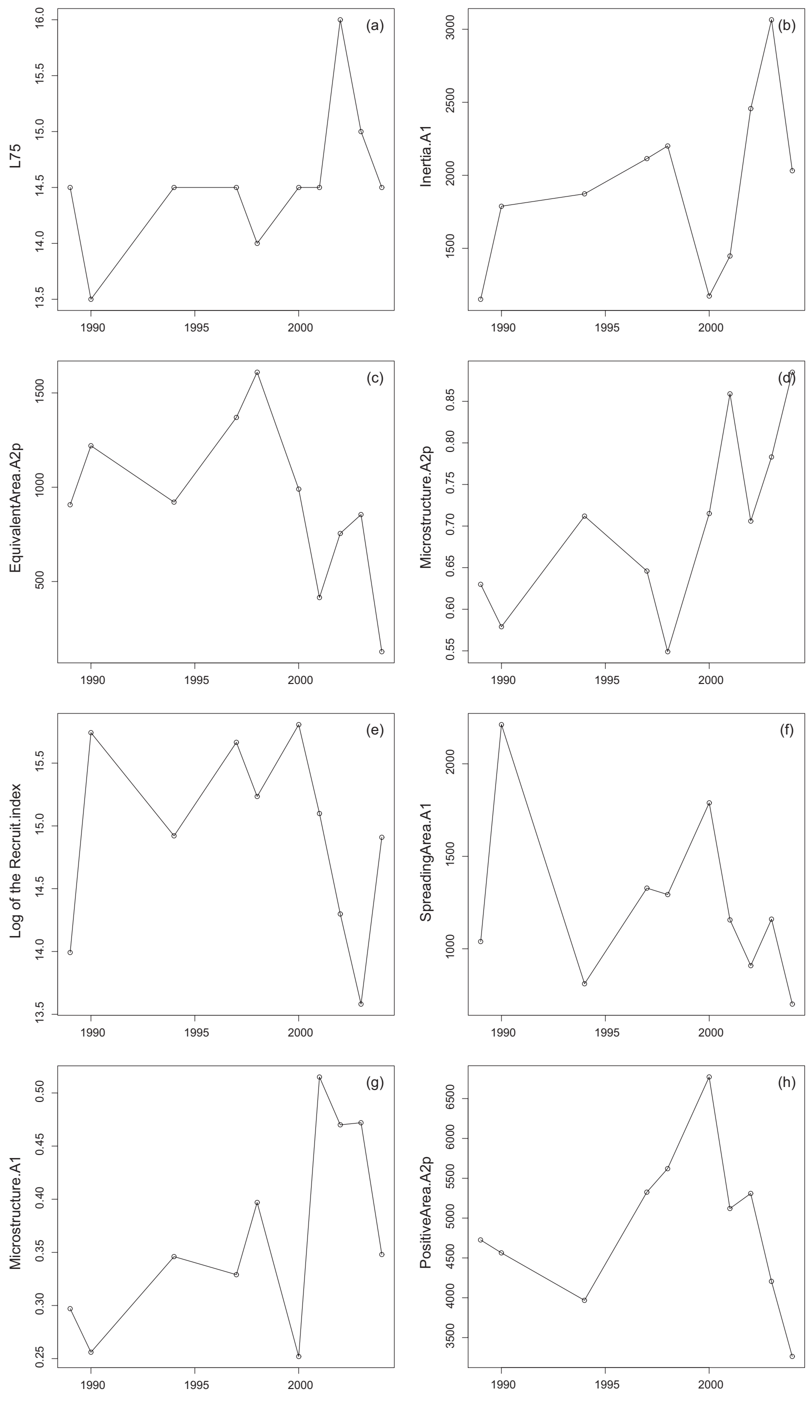

Figure 7. North Sea cod. Left: Experimental variograms of the MAFs 1 and 2 with their models. Right: Kriging estimates and observed values for the MAFs time series (black crosses). The kriging estimates appears for the whole time series as red points with the 95% confidence interval defined by +/- 2 times the kriging standard deviation (red vertical lines). For the forecasted year, the black point is the observed value for the year using the loadings defined from the previous years.

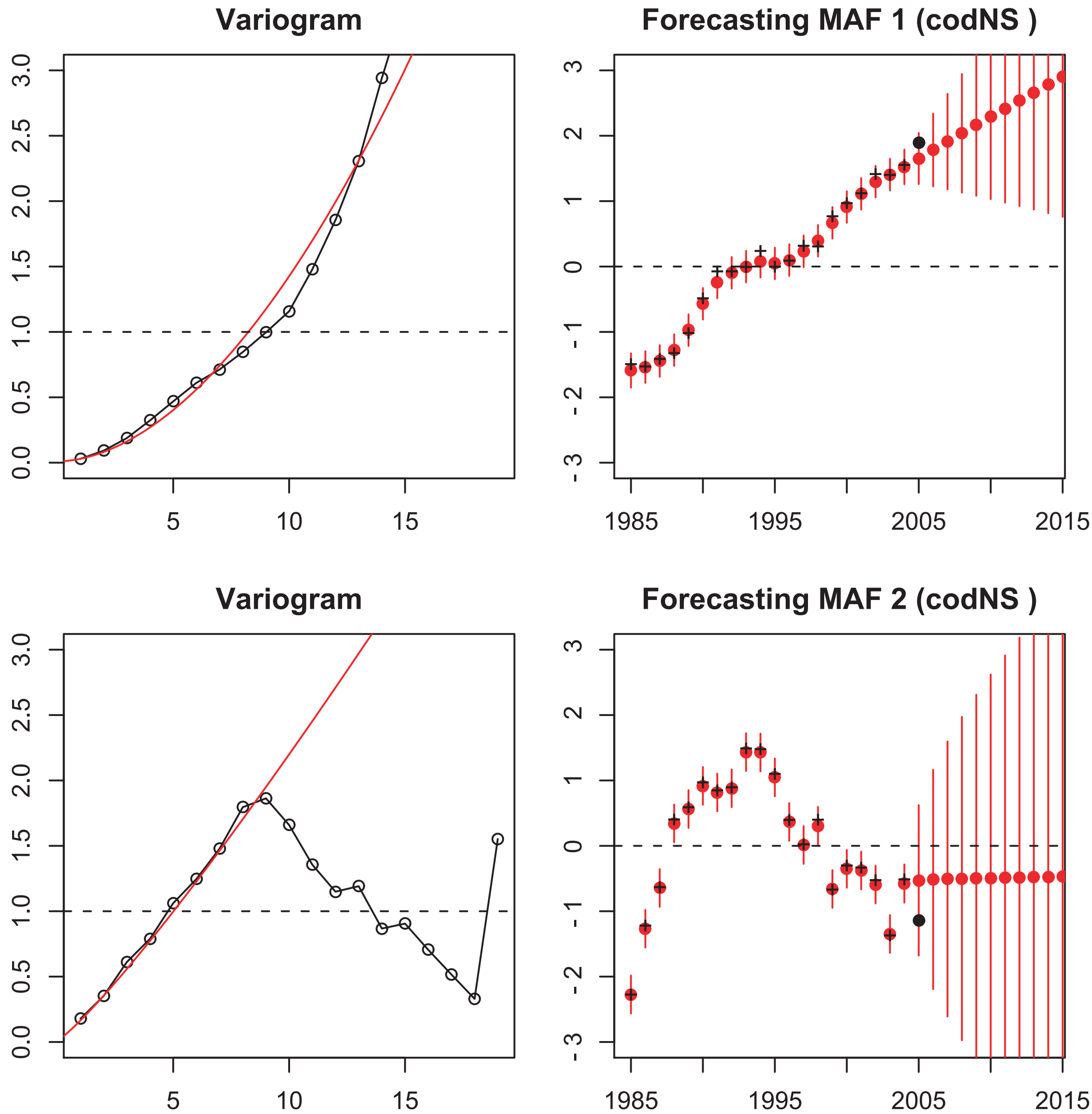

Figure 8. Bay of Biscay anchovy. Left: Experimental variograms of the MAFs 1 and 2 with their models. Right: Kriging estimates and observed values for the MAFs time series (black crosses). The kriging estimates appears for the whole time series as red points with the 95% confidence interval defined by +/- 2 times the kriging standard deviation (red vertical lines). For the forecasted year, the black point is the observed value for the year using the loadings defined from the previous years.