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Comprehensive indicator-based diagnostics of fish stocks using fishery-independent survey data: the FISBOAT report on case studies

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Research fisheries surveys are now implemented as monitoring programs of fish stocks and provide a large set of measurements on the evolution of their state. Here we show how fishery-independent diagnostics of fish stocks can be achieved using a comprehensive set of indices and analysis procedures inspired from environmental monitoring.

We present fish stock indices, analysis procedures and diagnostics results for nine stocks in European waters. The set of indices considered comprises two population abundance indices, four indices for population vital traits and nine indices for spatial organisation by age. The indices are combined and selected using multivariate techniques that maximise correlation between variables and also continuity in time. Trend detection and quality control techniques are then applied on the time series of the combined and selected indices. Based on these analyses diagnostic tables are filled, leading to comprehensive indicator-based diagnostics of fish stocks.

Similar analysis procedures are applied to all case studies and results are reported using standardised templates. The application to a wide range of fish stocks in different health conditions with different behaviours and past histories demonstrates the potential of the tools and indices for delivering diagnostics in operational mode. The paper is intended to be a manual summarising the results of the EU-project Fisboat (Fishery-independent survey-based operational assessment tools) for general use outside the project.

Key words: Fishery-independent assessment, indicators, quality control, spatial statistics, vital traits, anchovy, hake, cod, herring, red mullet.

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1. Introduction

Can survey data by their own be used to make diagnostics on fish stock health? If so, with which methods? The UE project FISBOAT (Fishery Independent Survey-based Operational Assessment Tools, 2004-2007 ; http://www.ifremer.fr/drvecohal/fisboat/) was set up to answer these questions. The project investigated two approaches. One was the simulation evaluation of traditional stock assessment analytical models (Kell et al., 2007) using abundance survey indices at age. The question was: given that survey abundance indices are non absolute and given the uncertainty in the estimates, what harvest control rule can be set to manage stock abundance levels? The other approach, which is our interest in this paper, was the development of a comprehensive indicator-based monitoring methodology making full use of all the biological information (not just the abundance at age indices) available in survey data. Metrics characterising fish stock attributes (here after termed indicators) were developed and estimated from survey data, resulting in the construction of time series of a variety of indicators of stock attributes. Such indicators were used as control variables with which the state of the stock was monitored. Methods for analysing the time series of indicators were developed as well as methods for making diagnostics based on the analysis of the indicator time series. Indicators and their methods are documented in a companion paper (Cotter et al., 2007). The project methodological developments resulted in the set up of statistical monitoring procedures of fish stock status using a comprehensive list of indicators of stock attributes. In this paper we summarise the results obtained by applying the methods to the indicators on the project case studies.

The project case studies scanned nine different stocks across European waters in the demersal and pelagic domains with different vital traits and stock histories and survey methodologies. The case studies were: cod in the Barents sea the Baltic and the North Sea, hake in the Bay of Biscay, the Ionnian sea and the Aegean sea, herring in the North Sea, anchovy in the Bay of Biscay and red mullet in the Thyrhenean sea. Case study individual reports followed the same template and these have been the basis for the present compilation. Individual reports are available on Fisboat website at http://www.ifremer.fr/drvecohal/fisboat/. Three major steps were followed. First, indicators of population attributes were calculated and time series of indicators were produced. Then, the time series of indicators were statistically analysed to detect changes. Last, results of the previous step for the variety of indicators were combined in diagnostic tables to formulate a diagnostic.

The statistical identification of changes in the time series relied on the definition of a reference period to which compare the indicator values for years outside that period. The reference period was defined as that in which the stock status was thought to be acceptable, based on historical knowledge. Such strategy is similar to that in statistical process control, where two phases are distinguished (e.g., Montgomery, 2005). Phase I is where the process is sampled to acurately define the ‘in-control’ state of the indicators. Phase II is the monitoring phase where statistical procedures are applied to detect any departure from the ‘in-control’ state. Phase I was here replaced by the definition of a reference period. We shall not discuss the definition of the reference period for each stock. We shall be concerned only by the monitoring of the stock relatively to the reference defined. The diagnostic is then relative to a reference and not absolute.

The population indicators were raw indicators estimated from the survey data (e.g., mean length in the population or gravity center in the spatial distribution) as well as multivariate combined indicators derived from the raw indicators (e.g., principal components or departure from a reference domain in factorial space). The time series were analysed to detect trends and changes in trends between different sets of years (e.g., trend over all years as compared to trend in the recent years only). Also the Cusum statistical control scheme was used to detect changes in the mean along the series. The Cusum procedure led to the construction of a traffic light type diagnostic table were departures from reference values triggered alarm signals with set risks of false alarm and non alarm. The trend analysis procedure led to the construction of a cause-effects diagnostic table were trends of different indicators were combined and interpreted using background biological knowledge. In all, changes were detected and were assigned causes when possible. The comprehensive indicator-based monitoring system developed produced coherent results which should complement the traditional assessment and thus increase the reliability of diagnostics on fish stocks.

2. Methods

In this section we summarise the procedures applied to the case study fish populations (Table 1) in order to explicit the monitoring system of population status that was set up based on fisheries research surveys only. For each of the indices and methods used below, documented computer code in R is available on Fisboat website at http://www.ifremer.fr/drvecohal/fisboat/.

How were populations described ?

The evolution of the state of populations was characterised by time series of a variety of indicators.

Raw indices. These were estimated directly from the survey data. Two groups of indices were considered: biological (non spatial) and spatial indices (Tables 2 and 3). Biological indices were estimates at population level to characterise abundance, recruitment, length structure, maturity and mortality. Spatial indices characterised the different aspects of a map: location, dispersion, patchiness, occupation, correlation, aggregation. Spatial indices were estimated by age to characterise the spatial distribution in each age and thus characterise the spatial organisation of the life cycle. The biological and spatial indices are fully described in Cotter et al. (2007) and in Woillez et al. (2007a).

Multivariate indices. These were derived from the raw indices and were (composite) multivariate summaries of the many raw indices considered. They were defined as multivariate distances to the gravity center of the reference period. Principal Components Analysis (PCA) was used for constructing a multivariate biological index and Multiple Factorial Analysis (MFA) was used for constructing a multivariate spatial index as the spatial information was 3D (indices, ages and years). PCA and MFA allowed to evidence the linear correlations existing between the indicators. For the biological indices the PCA-based index was the distance in the first factorial plane between the position of the gravity center of the reference period and that of the current year. For the spatial indices the MFA-based index was the sum over all ages of age-specific distances. Each age-specific distance was calculated in the first factorial plane between the position of the age-specific gravity center for the reference period and that of the current year. The multivariate indices are fully described with their methods in Cotter et al. (2007) and Woillez et al. (2007a).

Selection of raw indices. The MAF method (Min/Max Autocorrelation Factors) was used as an automated procedure to select those indices that best summarised the multivariate information with highest continuity in time. The MAF method allowed to construct pincipal components (factors), the autocorrelation of which decreases from the first factors to the last ones. The very first factors (MAFs) extracted the part of the multivariate information which was the most continuous in time. Therefore the loadings of the indices on the two first MAFs were used to select those indices that showed highest continuity in time as well as carrying the most of the multivariate information. The MAF method is fully documented in Cotter et al. (2007) and in Woillez et al. (2007b).

How were changes identified in the indicators time series ?

Change in population status was identfied by analysing the indicator time series. The detection of linear trends and changes in trends were considered. Another anlysis was the detection of shifts in the mean value of the indicator relatively to that in the reference period using the Cusum control charts as in industrial quality control.

Trend plots. Linear trends were estimated and their significance tested using the p-value that measures the risk of type-I (risk of identifying a trend when non exists). The linear trend in the last years of the series were also tested so as to detect change in the slope between the long-term trend and that in the last years of the series. A method based on the value of the second derivative was used to identify change points and detect change in slope for the last years. The derivative's method is fully documented in Cotter et al. (2007).

DI-Cusum plots. Here, we are interested in detecting shifts in indicator mean level relatively to that in the reference period, irrespective of the type of change, whether linear or not. The decision interval form of the Cusum was used. Values outside the interval were considered significantly different than those in the reference period (in-control) and therefore out-of-control. The in-control interval was statistically defined with set risks of false alarm and no-alarm rates. The DI-Cusum procedure is fully documented in Cotter et al. (2007) and in statistcal quality control litterature (e.g., Montgomery, 2005).

How were diagnostics made and interpreted ?

Results of the analyses of the many indicator time series were combined in diagnostic tables to elaborate a diagnostic of the state of the populations. Each method (trend and di-cusum) led to a particular diagnostic table (full documentation in Cotter et al., 2007).

Trend analysis: interpretation using cause-effects tables. A particular cause inducing variation in biological indices can be translated into an expected combination of trends in the indices, e.g., an increase in fishing mortality is expected to translate into an increase in Z, a decrease in Lbar and a decrease in Ln-Ntot. The cause-effects table (Table 4) provided a list of causes with their expected resulting combination of trends in the indicators, thus helped identify potential causes to the observed trends in the indicators (Trenkel et al., 2007).

Di-Cusum analysis: interpretation using traffic light tables of out-of-control signals. The application of the Di-Cusum to each indicator resulted in an array of out-of-control deviations from the reference mean vector. This was the Cusum diagnostic table. Each column of the array corresponded to each indicator time series of deviations. Setting the non-alerting deviations to zero, the diagnostic Cusum table provided the quantitative values of the deviations from the reference means with a + or – sign which triggered alarm signals. Cells in the table may be coloured red, orange, or green, as for traffic lights, to show at a glance the perceived seriousness of the state indicated.

Summary sheet and case study reporting. The results for each case study were reported in a summary sheet with a defined format. The sheet documented the survey time series, the indicators were used (raw, multivariate), the reference period, the methods were used to analyse the indicator time series, the resulting diagnostic on the stock. A template for reporting case study results was defined which comprised the following items: Data, Looking for change, Interpretation, What has been learned, Summary sheet, Comparison with traditional assessment, Formulation of advice. The template is annexed.

3. Results from the case studies

Indices characterising population status

The different indicators (raw and multivariate) that were computed in each case study were compiled in Table 5. PCA applied on the raw biological indices revealed a strong correlation structure between the indices. Across the different case studies, the correlation structure showed some consistency as can be seen from the loadings of the indices in the principle components (Table 6). The first principal component was always made of the length indices, which are much correlated to each other. Depending on the case study, the second component was correlated either to abundance, recruits or Z. For most stocks, only the first 2 components could be interpreted with high enough loadings of particular indices. For 3 stocks only, the third component was well related to one index, either Z or Recruits. The fact that length indices, abundance indices and Z did not always show a correlation structure easily interpretable (e.g., opposition) was perhaps due to the fact that no time lag was considered in the analysis. The multivariate biological index was a measure of inter-annual departures from the correlation structure as observed in the reference period.

MFA applied on the spatial indices also revealed marked and progressive changes in the spatial distributions with age (Tables 8a-b; Figs. 1a-c), which characterised the life cycle spatial pattern in each case study. Across all case studies, the area indices, inertia and gravity center were the spatial indices that were mostly invilved in explaining best the principal components.

For cod in the Barents Sea, the different ages were progressively aligned along the first component. Spatial distributions of young ages were less dispersed, more to the East and occupied less area than for older ages. Spreading area decreased slightly in the mid-ages (A4-7).

For cod in the North Sea, young (A1) and old ages (A5-6) differred on the first component from intermediate ages (A2-4). Spatial distributions of young and old ages were more to the East, less dispersed, occupied smaller area, and were more uneven (higher microstructure or nugget effect) than for intermediate ages. Age 1 and Ages 5-6 differed on the second component by the location of their centre of gravity and anisotropy. The spatial distribution of old ages was more to the north, more anisotropic, and occupied a smaller area than that of the age 1 fish.

For cod in the Baltic, young (A1-2) differred from old ages (A3-5) on the first component. Spatial distributions of young ages were more to the South, less dispersed and less anisotropic than old ages. Spatial distributions of ages A1-2 and A5 differred from that of other ages on the second component by positive area occupied. Ages A1-2 and A5 occupied a smaller less area than ages A3-4.

For herring in the North Sea, young (A1-2) differred on the first component from old ages (A7-9). Spatial distributions of young (immature) ages were more to the East and South, less dispersed and less spread than older ages (A4-9). The acquisition of maturity marked a clear difference in the spatial distribution for ages A2-3 as the distribution of mature A2-3 were more alike than that of older ages A4-7. Spatial distributions of mature ages A2-A9 occupied larger positive areas with age, which was visible on the second component.

For hake in Biscay, young (A0-3) differred on the first component from old ages (A4-5). Spatial distributions of the old A4-5 were more to the West occupying a larger area with more spread. Ages A0-1 differred on the second component from the other ages as their spatial distribution was more anisotropic.

For hake in the Ionian Sea, young (A0-3) differred on the first component from old ages (A4-5). Spatial distribution of the old A4-5 were more to the South and West, occupying a smaller area and were more uneven (larger microstructure index). Age A0 differred on the second component from the other ages as its spatial distribution was more anisotropic.

For hake in the Aegan Sea, ages A0 and A5 differred on the first component from ages A2-3. Their spatial distributions were more to the North and West and were less dispersed with smaller spreading and equivalent areas. The second component distinguished the spatial distribution of ages A0-1 from that of A4-5 as the young ages A0-1 occupied a larger positive area.

For anchovy in Biscay (acoustic surveys), the spatial distribution of ages A1-3 had similar characteristics, though A1 was slightly more dispersed and anisotropic. The spatial distribution of the anchovy eggs shared similarities to that of the adults but was also different (Table 8b). Both adult fish and egg distributions showed the same opposition on the first component between the area indices and the longitude of the gravity centre. The microstructure index (uneveness in the distribution) was characteristic of the egg distributions (component 2) which was less important in characterising the distribution of the adult fish. The anisotropy index characterised the adult fish distribution (component 2) but did less so for the egg distributions as that index corrrelated to component 3 of the egg distributions.

For red mullet in the Thyrrhrenian Sea, the characterisation of the spatial distributions have been separated in two sub region with marked different orientations, GS10a (western coast of mainland Italy) and GS10b (northern coast of Sicily). In GS10a, Ages A1 and A2 differred on the first and second components. Age A1 was more distributed to the SE and more uneven but occupying a larger

positive area. In GS10b, age A1 differred from A3 on the first component. Age A1 was distributed more to the East with larger equivalent and spreading areas and less uneven than A3.
The multivariate spatial index was a measure of inter-annual departures from the average spatial patterns as observed in the reference period.

Identification of changes and formulation of diagnostics

Table 9 compiles what methods were applied on what indicators in each case study. We now summarise the results obtained in each case study.

Cod in the Barents Sea (Fig.2). Time series of raw indices were visually inspected. The time series of Ln.Ntot, Ln.Rec and Z showed clear troughs at the begining of the series (90-94). This particular situation made it difficult for the trend methods to capture the signals due to scale and position of the changes in the time series. In constrast, the Cusum method was able to detect these changes (note that the reference period was at the end of the time series). The multivariate indices with the Cusum analysis allowed to achieve a diagnostic. Both spatial and abundance indices triggered alarms at the beginning of the 90s. The series of survey Z compared well with that of the ICES VPA esitmate. The survey coverage may be hampered by the presence of sea ice in the eastern Barents Sea, limiting the use of the survey indicators.

Cod in the North Sea (Fig.3a-b). In constrast to Barents Sea cod, North Sea cod showed clear trends in many indices, either long term or in the recent years since 2000. Trend and Cusum methods agreed and raw indices and multivariate indices were in agreement as well. The MAF selection of raw indices selected the following indices as carrying the variability in the stock: L50.matu, Ln.Ntot.matures, PA.matures, xcg.matures, ycg.matures, MI.recruits, MI.immatures, ycg.recruits, Anisotropy.recruits, ycg.immatures. Length at maturity has been decreasing all along the survey time series, total abundance and recruits decreased seriously since 2000 and so did the spatial indices of area and location with more northerly distribution of old fish but also recruits. Out-of-control alarm signals were confidently trigerred with the Cusum diagnostic table since 2003 as all indices have been out-of-control since that year. An alarm could be trigerred as early as 2000, if less weigth was given in the analysis to the length indices. Recent trends in were estimated for the last 5 years using the derivatives methods. The cause-effects table and the trend results table suggested that the closest cause to the recent trends identified was an increase in fishing mortality.

Cod in the Baltic Sea (Fig.4). The survey series began in the mid-90s at a time when the stock was already at a low abundance level. Therefore the survey series could not trace the historical evolution of the stock but its recent evolution within a degraded state. The index L50.matu was unreliable because of the seasonal timing of the survey. Visual inspection of the raw indices suggested that abundance at age A5 and Positive area of A5 showed obvious long-term decreasing trends. The other indices contained much variability. Recent trends were estimated for the last 5 years using the derivatives methods. Comparison of the cause-effects table with the trend results table suggested that the closest cause to the recent trends identified was an increase in fishing mortality. Based on age A5 series, the Cusum traffic light diagnostic table suggested to signal alarms since 2000. Results were in agreement with ICES assessment.

Hake in the Bay of Biscay (Fig.5). The time series in the different indices were variable enough to make visual inspection difficult. Trend analysis revealed no long-term trend but the derivatives method identified recent trends in length indices, Z and some spatial indices. It is noteworthy that the derivatives method identified changes where a linear approach did not. The recent increase in the length indices together with an a recent increase in Z were inconsistent with the cause-effects table and therefore difficult to interpret. The Cusum also diagnosed increase in Z and L25 indices in the recent years. Therefore that increase was considered real. The selection of indices using the MAF procedure resulted in selecting the area indices for the older fish: SA.A4, EA.A5, SA.A5, PA.A5, and xcg.A3. The Cusum procedure identified changes for these indices when the trend method did not, supposedly because of the type of variability in the time series. The old ages A4-5 showed decreased abundance, decreasing area indices and the age A3 a shift of its gravity centre to the West. The multivariate spatial index gave similar results with the Cusum as the MAF selected indices. Departure of the multivariate biological index from its reference domain had different causes that can be assigned based on the PCA loadings of the indices and the Cusum diagnostic table of the raw indices: in 98 total abundance A1-5 is low, in 99 and 2003 L25 has increased, in 2004, recruitment (A0) has increased. In all, though some amelioration of recruitment occurred in 2004, deterioration of abundance and spatial indices for old ages justified signaling alarms since 2000.

Hake in the Ionian Sea (Fig. 6). The survey series was short (1994-2003) and all indicator time series had high variability. Trend and Cusum methods did not agree in the fluctuations that could be identified, due to the variability in the series. The derivatives trend method identified declines in the last 5 years for the Length indices while the Cusum detected no out-of-control fluctuation in these indices. The trends identified in the biological indices could not be interpreted using the cause-effects table as the combination of trends was inconsistent with any of the causes suggested in the table. The multivariate biological index was declared out of control by the Cusum analysis for years in which the recruitment index was high (1995, 2003). The multivariate spatial index was declared out of control for years within the reference period. Given the intrinsic variability in the time series, a longer series seemed necessary to formulate any diagnostic.

Hake in the Aegean Sea (Fig.7). As for Ionian hake, the survey series was short (1994-2003) and all indicator time series had high variability. Trend and Cusum methods did not agree in the fluctuations that could be identified, due to the way in which the variability is disposed in the series. Here the trends method identified no trend while the Cusum identified poor abundance until 1997 as well as positive and negative alarms in L25, L50 and L75 until 1997. At the beginning of the series (1994), the abundance is low and is progressively increasing until 1997. The out-of-control alarms on the length indices could have resulted from the poor abundance, in coherence with the cause-effects table. The Cusum analysis triggered out-of-control signals for the multivariate biological index in 1994-95 as a result of low abundance and increase in length indices. Until 1997, the multivariate spatial index is identified to be out-of-control by the cusum analysis. The diagnostic is thus an alarm signal at the beginning of the series in the years 1994-97: poor abundance, decrease in length, departure in the spatial distribution.

Herring in the North Sea (Fig.8a-c). This case study has been analysed using multivariate methods and Cusum analysis only. Similarly to Barents Sea cod, the time series of abundance showed a clear trough in the middle of the series, peaking low in 1994, the increasing in the recent years until 2002. The selection of indices using the MAF procedure resulted in selecting those raw indices that carried the major signals. Amongst these, 6 indices were selected by visual inspection: Ln-N.matures, Ln-imatures, xcg.matures, ycg.matures, I.matures, SA.matures. The mature fish decreased in abundance reached a low in 1994 and increased again in 2000-02. During the low abundance period, the fish was less northerly distributed but came back latitude of the gravity center came back to previous values with increasing abundance. It is noteworthy that some spatial indices did not came back to their previous values of before the abundance low. In particular the spreading area, the equivalent area and the inertia have stayed low even after the abundance rebuild. Also the longitude of the gavity centre stayed to the West and did not came back to previous values. The abundance of imatures has increased in recent years, rebuilding the population. The Cusum analysis of the multivariate spatial index revealed out-of-control values during the years of low abundance. But the multivariate biological index was not so much influenced by the decrease in the old fish in the mid-90s probably because of the small response of other biological indices (length indices). In contrast, the multivariate biological index responded to the increase in young fish after the mid-90s. Its Cusum analysis identified out-of-control values for the recent period that revealed increase in abundance. In the Cusum diagnostic table, the multivariate spatial index revealed the period of alarm while the multivariate biological index that of recovery. The choice of reference period (1989-93) perhaps influenced the sign of the out-of-control signals for the multivariate biological index.

Anchovy in the Bay of Biscay (Fig.9). The anchovy population in the Bay of Biscay is monitored by two independent surveys in spring, an acoustic survey and an egg survey. Here, the acoustic survey provided the biological indices and the spatial indices at age and the egg survey provided the spatial indices for the eggs. In the last last years of the survey series, total abundance and recruitment droped to extremely low values. Length indices increased. The spatial distributions in the egg and the adult fish were more coastal and anisotropic. The Cusum analysis and the trends method provided similar results as they both identified the important changes in the last years of the series. The Cusum diagnostic table allowed to trigger alarm signals in 2004 and 2005. ICES recommended closure of the fishery in 2005 only. Early warnings seemed possible with the present indicator-based monitoring.

Red mullet in the Thyrrhenian Sea (Fig. 10). As for eastern mediterranean hake, the survey time series was short and variability in the indices high. The derivatives trend method identified significant recent (5 last years) changes in some indices while the Cusum did not. The reference period was defined as the second half of the series because of higher and more stable abundance levels. The choice of the reference period may have generated mismatch between the search for recent trends and the identification of departures from a reference with Cusum. 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. Highest values for Z were reached in the last years (2001-02) of the series whereas the survey index, Lbar and L75 were all, although not significantly, decreasing in 2003. 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 the survey and recruit indices increased, remaining almost stable since then. Spatial indices, especially those regarding location in subunit 10a, displayed a long-term trend and a tendency to change in recent years. But this was not identified using the Cusum analysis which considered that variability was such that no out-of-control value was reached. Di-cusum analysis allowed the triggering of alert signal for the survey index in 1997, when it reached the lowest level. An alert signal was also obtained for the multivariate spatial indices in the years 1995-1996 in the subunit 10b, probably as result of change in location and occupation indices. Older ages were more dispersed westwards and slightly offshore. The retained diagnostic was the following: recent increase in Z, low abundance reached in 1997 and change in spatial distribution in 10b in 1995-96.

4. Discussion

Research survey series have been systematically undertaken since 20 years in the most favourable cases and since 10 years otherwise. These series captured stock fluctuations at a time when stocks were already in a degraded situation. Short series with high variability in the indices resulted in statistical difficulty in detecting change. In the worst case, the derivatives method would detect recent trends and the Cusum no signal.

Assigning one particular cause to a combination of trends using the cause-effects table was not always easy as many causes may occur jointly thus providing signals that are difficult to interpret. Surprisingly, variations in length indices have not always been straightforward to interpret and in some cases have been conflicting with the variation in other indices. The result was that diagnostics have always relied more on abundance and spatial indices and in some cases only on length indices.

Refinements of the procedures in the application of the methods is indeed to welcome. For the Cusum analysis these are anticipated to be the definition of the reference period and the accepted risks of false and no alarm with which to trigger an out-of-control signal. For the trends method, the scale at which to identify short-term trends along the series has been a difficulty in those case studies where the change in slope was not at the end of the series. The interest in the Cusum procedure has the potential advantage of suggesting reference values for the indicators.

In all, the methods have shown potential across the case studies to monitor population status using fishery-independent survey-based indices of population biological and spatial attributes. The system was intended to be a monitoring system of the state of fish stocks. As such, it is hoped that it complements the traditional assessment, providing comprehensive biological and spatial information on the evolution of the stocks. Procedures can now be applied in operational mode to provide results to assessment working groups for any stock that is monitored with research surveys.

Indicator-based diagnostics, because they are based on spatial indices as well as abundance and length indices can justify alternative management strategies to TAC such as the protection of juveniles or closed areas.

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Table 1: Fish stocks case studies of the Fisboat project on which the indicator-based monitoring methodology was applied.

Stock	Behaviour	Life span	Survey Type	Survey time series used	Reference period used	Age range in survey data
Barents Sea Cod	Demersal	Long	Botttom trawl	1989-2004	1996-2004	1-10
North Sea Cod	Demersal	Long	Bottom trawl	1985-2005	1985-1994	1-6
Baltic Sea Cod	Demersal	Long	Bottom trawl	1994-2004	1994-1999 [excluding 97]	1-5
Biscay Hake	Demersal	Long	Bottom trawl	1987-2004 [excluding: 91,93,96]	1987-1997	0-5
Ionian Sea Hake	Demersal	Long	Bottom trawl	1994-2003 [exclusing: 02]	1998-2001	0-5
Aegean Sea Hake	Demersal	Long	Bottom trawl	1994-2003 [exclusing: 02]	1998-2001	0-5
North Sea Herring	Pelagic	Long	Acoustics	1989-2002	1989-1993	0-9
Biscay Anchovy	Pelagic	Short	Acoustics Eggs	1989-2005 [excluding: 91-93,95,96,99] 1989-2005 [excluding: 93,96,99-00]	1990-2001 1990-2001	1-3 -
Thyrrhenian Sea Red mullet (GS10)	Demersal	Short	Bottom trawl	1994-2003	1999-2003	1-3

Table 2 : Raw biological (non spatial) indices used in the study. All Fisboat biological indices are fully described in Cotter et al. (2007).

Population attribute	Index name	Index symbol	Index description
Total abundance	Abundance	Ln-Ntot	Natural logarithm (total surveyed fish numbers all ages pooled +1)
Recruit abundance	Recruit abundance	Ln-Rec	Natural logarithm (fish numbers at recruiting age +1)
Length structure	Mean length	Lbar	Mean length of the fish length histogram
Length structure	First quartile of length	L25	25^{th} percentile of the fish length histogram
Length structure	Last quartile of length	L75	75^{th} percentile of the fish length histogram
Reproductive capability	Length at 50% maturity	L50matu	Length at which 50% of the individuals have reached reproductive maturity
Total mortality	Mortality Z	Z	Mortality rate between years $t-1$ and t of all individuals aged $a_{\min}$ to $a_{\max-1}$

Table 3 : Raw spatial indices used in the study. All Fisboat spatial indices are fully described in Cotter et al. (2007) and in Woillez et al. (2007).

Population attribute	Index name	Index symbol	Index description
Location	Longitude gravity center	Xcg	Weighted average of sample longitudinal positions
Location	Latitude gravity center	Ycg	Weighted average of sample latitudinal positions
Patchiness	Number of Patches	NbPatch	Concentration of abundance in patches with spatially distant local gravity centers
Dispersion	Inertia	I	Weighted variance of sample positions around a gravity centre
Dispersion	Anisotropy	A	Ratio of inertia for directions carrying minimal and maximal inertia
Occupation	PositiveArea	PA	Area of non null values
Correlation	Microstructure	MI	Decrease of correlation at short distance on the relative covariogram
Correlation	EquivalentArea	EA	Integral range of the relative covariogram
Aggregation	SpreadingArea	SA	Concentration of abundance relative to the homogeneous distribution

Table 4 : Cause-effects table linking one cause (first column) to a combination of expected trends in biological indicators. (after Trenkel et al., 2007). 0: no trend; -1: decreasing trend; 1: increasing trend.

Cause	Z	ln-Ntot	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

Table 5: Indices calculated in each case study

	Cod			Hake			Herring	Anchovy		Red mullet	
	Barents sea	Baltic sea	North Sea	Bay of Biscay	Ionian sea	Aegean sea	North Sea	Bay of Biscay	Bay of Biscay	Thyrhenian sea GS10a	Thyrhenian sea GS10b
Survey	BT	BT	BT	BT	BT	BT	AC	AC	EG	BT	BT
Age groups	1-10	1-5	1-6	0-5	0-5	0-5	1-9	1-3	-	1-2	1-3
Biological Indicators											
Ln-Ntot	x	x	x	x	x	x	x	x	x	x	
Ln-Rec	x	x	x	x	x	x	x	x	x	x	
Lbar	x	x	x	x	x	x	x	x		x	
L25	x	x	x	x	x	x	x	x		x	
L75	x	x	x	x	x	x	x	x		x	
L50matu	x	x	x	x	x	x	x	x		x	
Z	x	x	x	x	x	x	x	x	x	x	
PCA-based	x	x	x	x	x	x	x	x		x	
Spatial indicators by age											
PositiveArea	x	x	x	x	x	x	x	x	x	x	x
Inertia	x	x	x	x	x	x	x	x	x	x	x
Anisotropy	x	x	x	x	x	x	x	x	x	x	x
Xcg	x	x	x	x	x	x	x	x	x	x	x
Ycg	x	x	x	x	x	x	x	x	x	x	x
NbPatches	x	x	x	x	x	x	x	x	x	x	x
Microstructure	x	x	x	x	x	x	x	x	x	x	x
EquivalentArea	x	x	x	x	x	x	x	x	x	x	x
SpreadingArea	x	x	x	x	x	x	x	x	x	x	x
MFA-based	x	x	x	x	x	x	x	x	x	x	x
MAF-based									x	x	x

Table 7: Loadings of the biological indices on their Principal Components for each case study. Asbolute values greater than 0.6 are in bold characters.

Case study	Index	Comp1	Comp2	Comp3	Case study	Index	Comp1	Comp2	Comp3
Cod	Ln.Ntot	0.376	**-0.761**	-0.248	Hake	Ln.Ntot	**0.832**	0.353	0.180
Barents Sea	Ln.Nrec	**-0.636**	0.050	**-0.616**	Biscay	Ln.Nrec	**0.876**	0.267	0.115
	Lbar	**0.912**	0.205	-0.020		Lbar	**-0.749**	0.520	0.152
	L25	**0.747**	0.354	-0.065		L25	-0.452	**0.762**	-0.259
	L75	**0.878**	0.187	-0.015		L75	**-0.869**	0.145	0.273
	L50.matu	-0.023	**-0.757**	0.441		L50.matu			
	Z	-0.567	0.557	0.369		Z	-0.590	-0.564	0.027
Cod	Ln.Ntot	0.241	**-0.834**	-0.197	Hake	Ln.Ntot	**0.851**	0.157	-0.040
North Sea	Ln.Nrec	0.558	-0.527	0.550	Ionnian Sea	Ln.Nrec	0.568	**-0.641**	-0.143
	Lbar	**0.831**	0.429	0.129		Lbar	**-0.844**	-0.197	-0.007
	L25	**0.845**	-0.157	0.365		L25	**-0.771**	-0.366	0.147
	L75	0.594	**0.671**	-0.144		L75	**-0.853**	0.139	-0.061
	L50.matu	**0.813**	-0.039	-0.406		L50.matu			
	Z	-0.345	0.277	**0.751**		Z	**-0.833**	0.120	-0.205
Cod	Ln.Ntot	0.104	**-0.842**	-0.183	Hake	Ln.Ntot	**0.759**	0.387	0.160
Baltic Sea	Ln.Nrec	**-0.690**	-0.565	0.036	Aegean Sea	Ln.Nrec	**0.857**	0.118	0.025
	Lbar	**-0.823**	0.227	-0.263		Lbar	**-0.828**	0.260	-0.018
	L25	**-0.853**	0.172	-0.165		L25	-0.410	**-0.652**	0.409
	L75	**-0.841**	0.123	-0.257		L75	**-0.739**	0.448	-0.072
	L50.matu	**-0.620**	-0.527	0.322		L50.matu			
	Z	**0.639**	-0.301	-0.516		Z	0.146	**-0.800**	-0.298
Herring	Ln.Ntot	**-0.66**	**0.60**	0.00	Red Mullet	Ln.Ntot	0.356	**0.799**	0.184
North Sea	Ln.Nrec	-0.48	0.41	-0.62	Thyrhenian	Ln.Nrec	**0.888**	-0.082	0.050
	Lbar	**1.00**	0.54	-0.03	Sea	Lbar	**0.890**	0.053	-0.020
	L25	0.39	**0.77**	0.04		L25	**0.823**	-0.266	-0.208
	L75	**1.00**	-0.14	-0.11		L75	**0.869**	0.150	-0.138
	L50.matu					L50.matu	**0.878**	0.038	-0.165
	Z	0.27	-0.38	**-0.60**		Z	**-0.642**	0.317	-0.537
Anchovy	Ln.Ntot	0.177	**0.908**	-0.014					
Biscay	Ln.Nrec	-0.172	**0.907**	-0.070					
	Lbar	**0.874**	-0.179	-0.195					
	L25	**0.841**	-0.058	-0.352					
	L75	**0.815**	-0.126	0.383					
	L50.matu								
	Z	**-0.795**	-0.381	-0.182					

Table 8a: Interpretation of the principal components (PCs) resulting from applying MFA on the spatial indicators at age. The table shows the number of times that each index has shown a correlation greater than +0.5 or lower than –0.5 whith the PCs along the data series. Values in bold character signal a number of times greater than half the number of years.

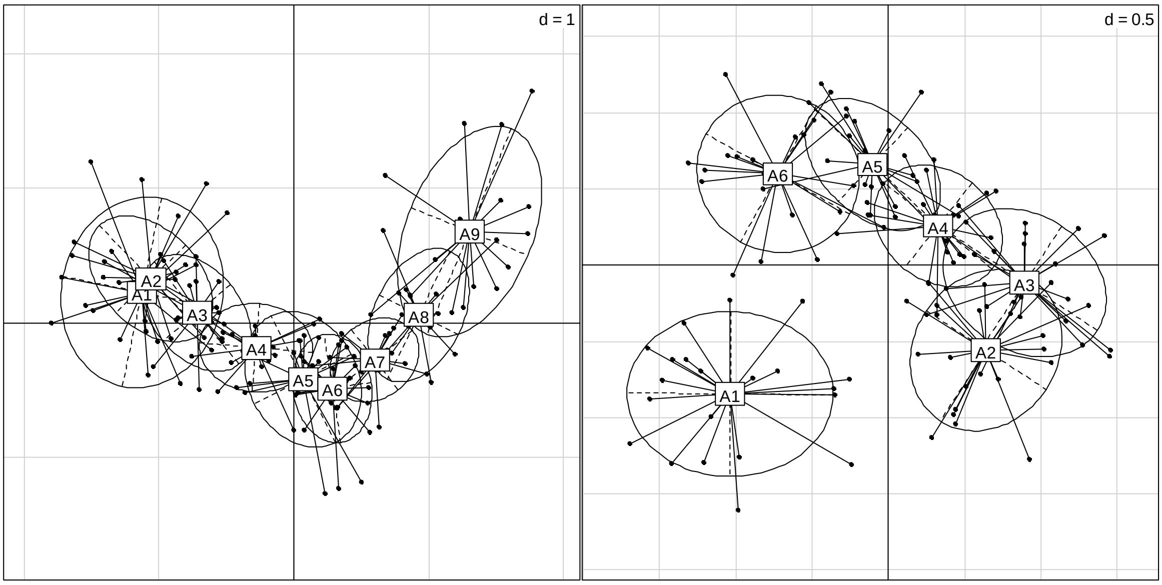
Case study	Index	Comp1	Comp2	Comp3	Case study	Index	Comp1	Comp2	Comp3
Cod	PositiveArea	**0+|16-**	0+|3-	0+|0-	Hake	PositiveArea	**0+|13-**	1+|0-	0+|0-
Barents Sea	Inertia	**1+|12-**	1+|0-	2+|0-	Biscay	Inertia	**9+|0-**	0+|6-	0+|1-
	Anisotropy	**1+|9-**	1+|0-	7+|0-		Anisotropy	7+|0-	**10+|0-**	1+|1-
	xcg	**0+|16-**	0+|0-	1+|0-		xcg	**1+|9-**	2+|3-	1+|1-
	ycg	1+|7-	0+|5-	0+|1-		ycg	7+|2-	4+|1-	2+|0-
	MicrostructureIndex	5+|2-	4+|0-	4+|1-		MicrostructureIndex	4+|0-	2+|4-	2+|2-
	EquivalentArea	1+|3-	0+|6-	2+|7-		EquivalentArea	**0+|12-**	0+|1-	2+|0-
	SpreadingArea	1+|5-	**0+|12-**	1+|3-		SpreadingArea	**0+|11-**	0+|7-	2+|0-
Cod	PositiveArea	**12+|0-**	**0+|16-**	0+|0-	Hake	PositiveArea	**0+|7-**	0+|1-	1+|1-
North Sea	Inertia	**12+|2-**	1+|2-	2+|5-	Ionnian Sea	Inertia	**4+|2-**	2+|0-	2+|1-
	Anisotropy	0+|2-	**15+|0-**	3+|0-		Anisotropy	2+|1-	3+|0-	1+|3-
	xcg	**0+|17-**	4+|4-	2+|0-		xcg	**7+|0-**	2+|0-	1+|0-
	ycg	**13+|0-**	**15+|0-**	0+|0-		ycg	**1+|6-**	2+|2-	0+|1-
	MicrostructureIndex	**1+|11-**	3+|3-	1+|5-		MicrostructureIndex	**5+|0-**	3+|0-	1+|1-
	EquivalentArea	**12+|0-**	1+|2-	2+|4-		EquivalentArea	**2+|5-**	0+|3-	1+|1-
	SpreadingArea	**18+|0-**	0+|7-	1+|0-		SpreadingArea	**1+|5-**	0+|3-	2+|0-
Cod	PositiveArea	3+|0-	**0+|7-**	0+|1-	Hake	PositiveArea	3+|0-	**9+|0-**	0+|0-
Baltic Sea	Inertia	**1+|7-**	0+|3-	2+|2-	Aegean Sea	Inertia	**5+|0-**	**0+|5-**	1+|1-
	Anisotropy	**1+|6-**	3+|1-	5+|0-		Anisotropy	0+|2-	1+|4-	1+|1-
	xcg	2+|3-	3+|0-	1+|2-		xcg	**7+|0-**	0+|4-	0+|0-
	ycg	**9+|0-**	1+|0-	0+|3-		ycg	**2+|6-**	1+|2-	0+|0-
	MicrostructureIndex	1+|3-	1+|1-	2+|1-		MicrostructureIndex	**0+|5-**	1+|1-	0+|1-
	EquivalentArea	**6+|0-**	2+|5-	2+|0-		EquivalentArea	**7+|0-**	0+|1-	3+|0-
	SpreadingArea	**8+|0-**	0+|2-	2+|1-		SpreadingArea	**8+|0-**	0+|0-	2+|0-
Herring	PositiveArea	**0+|12-**	**0+|7-**	0+|0-					
North Sea	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-					

Table 8b: Interpretation of the principal components (PCs) resulting from applying PCA to the spatial indicators at age. PCA was applied instead of MFA when the stock has too few age classes. Values are the loadings of the indices on the PCs. Values in bold character signal a correlation greater than 0.6 in absolute value.

Case study	Index	Comp1	Comp2	Comp3	Case study	Index	Comp1	Comp2	Comp3
Anchovy	PositiveArea	**-0.799**	0.244	-0.291	Red Mullet	PositiveArea	0.38	**0.867**	-0.088
Biscay	Inertia	-0.185	**-0.807**	-0.291	GS10a	Inertia	**0.62**	**0.654**	-0.255
AC	Anisotropy	0.276	**-0.722**	0.416		Anisotropy			
	xcg	**0.595**	-0.032	0.135		xcg	**-0.795**	0.382	0.457
	ycg	-0.56	-0.504	-0.382		ycg	**0.816**	-0.355	-0.439
	MicrostructureIndex	0.593	0.328	-0.383		MicrostructureIndex	**-0.84**	0.312	-0.393
	EquivalentArea	**-0.745**	0.119	0.582		EquivalentArea	**0.932**	-0.02	0.338
	SpreadingArea	**-0.952**	0.13	0.036		SpreadingArea	**0.937**	0.148	0.285
Anchovy	PositiveArea	**0.914**	-0.225	0.131	Red Mullet	PositiveArea	0.586	-0.48	0.585
Biscay	Inertia	**0.711**	**0.649**	0.194	GS10b	Inertia	0.374	**-0.657**	-0.543
EG	Anisotropy	-0.598	-0.17	**0.725**		Anisotropy			
	xcg	**-0.617**	**-0.619**	0.183		xcg	**0.892**	0.378	0.087
	ycg	**0.871**	0.128	0.238		ycg	**0.762**	0.506	0.104
	MicrostructureIndex	-0.469	**0.743**	0.196		MicrostructureIndex	**-0.642**	-0.534	0.346
	EquivalentArea	**0.903**	-0.354	-0.008		EquivalentArea	**0.897**	-0.281	-0.083
	SpreadingArea	**0.924**	-0.197	0.196		SpreadingArea	**0.909**	-0.315	0

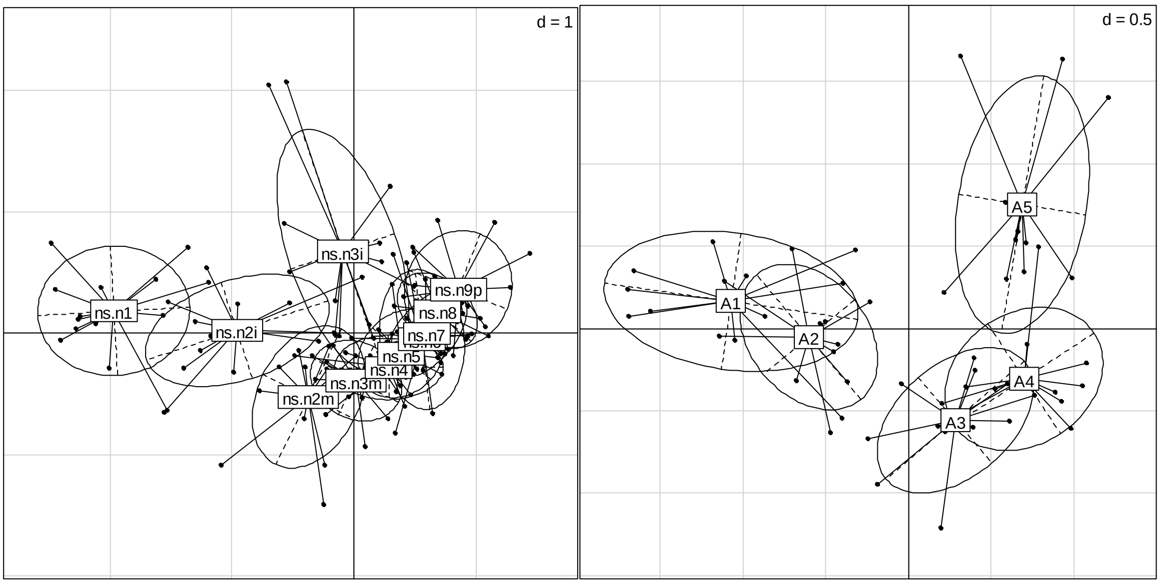
Table 9: Analysis methods applied to detect changes in the time series of raw and multivariate indices by case study

	Cod			Hake			Herring	Anchovy		Red mullet	
	Barents sea	Baltic sea	North Sea	Bay of Biscay	Ionnian sea	Aegean sea	North Sea	Bay of Biscay	Bay of Biscay	Thyrhenian sea GS10a	Thyrhenian sea GS10b
Survey type	BT	BT	BT	BT	BT	BT	AC	AC	EG	BT	BT
Biological Indices : raw											
Trend	x	x	x	x	x	x		x	x	x	
Di-Cusum		x	x	x	x	x			x	x	
Biological Indices : multivariate PCA-based											
Trend			x		x	x					
Di-Cusum	x	x	x	x	x		x	x		x	
Spatial Indices : raw											
Trend		x	x	x	x	x			x	x	x
Di-Cusum		x		x					x		
Spatial Indices : multivariate MFA-based											
Trend			x		x	x			x		
Di-Cusum	x	x	x	x	x	x	x	x	x	x	x
Selection of raw indices											
MAF selection		x		x			x	x			



Cod Barents Sea

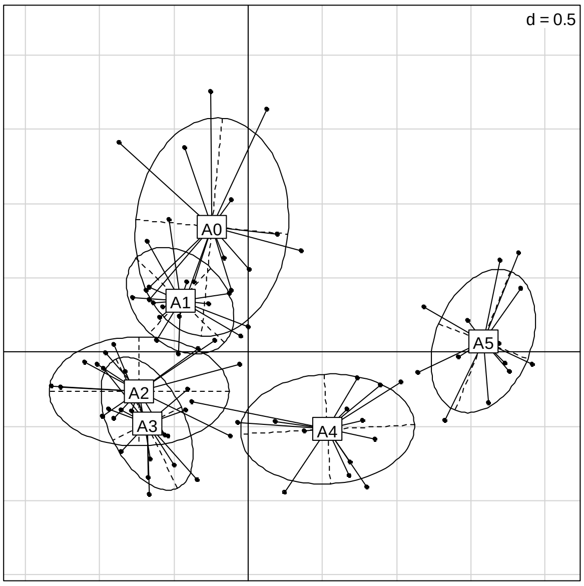
Cod North Sea



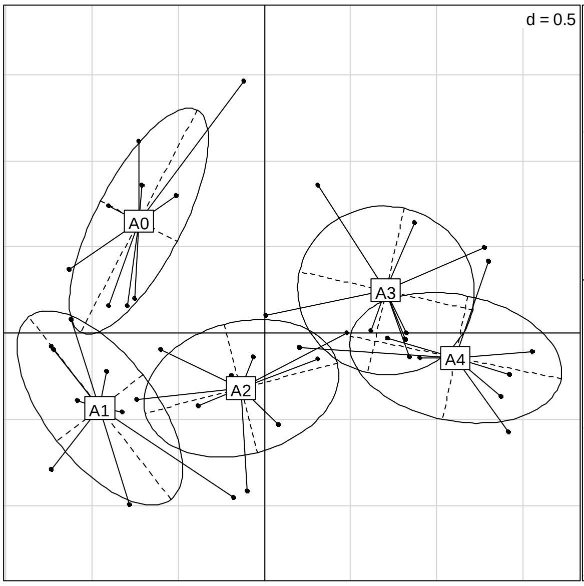
Herring North Sea

Cod Baltic Sea

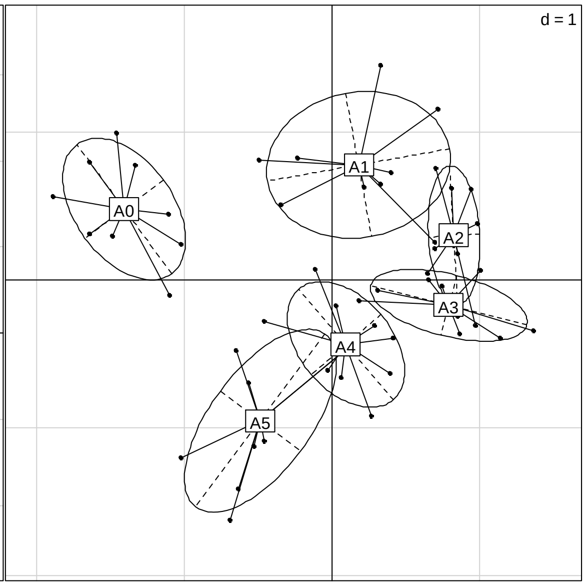
Figure 1a: Representation of the life cycle spatial pattern and its inter-annual variations in the first factorial plane of the MFA applied on the spatial indicators at age. Each point represents the position of each age in each year. The gravity center of each age is labelled. Representations for cod and herring.



Hake Biscay

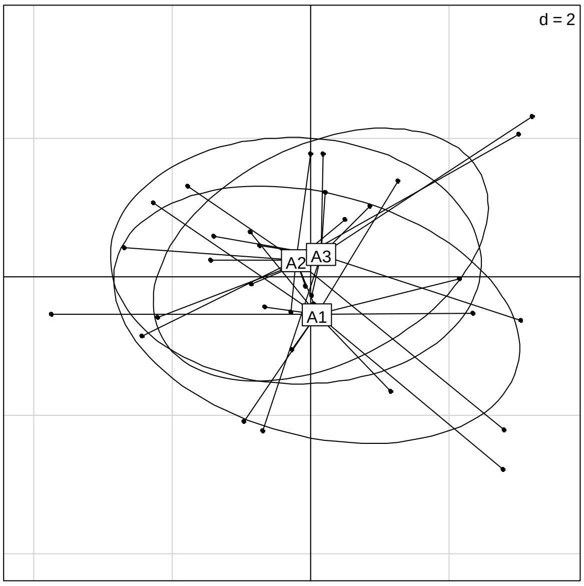


Hake Ionnian Sea

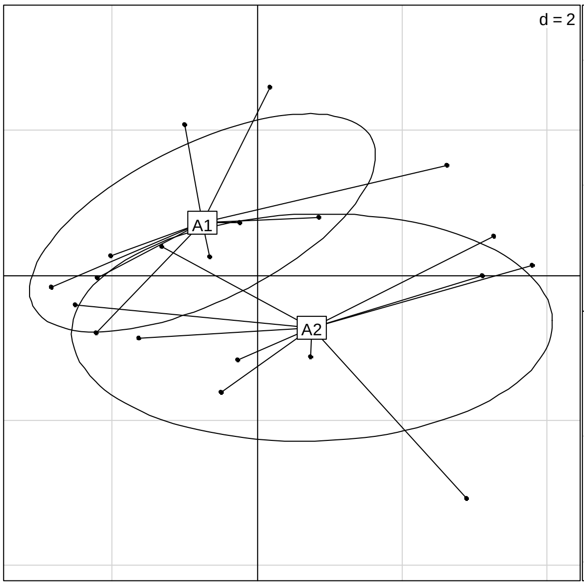


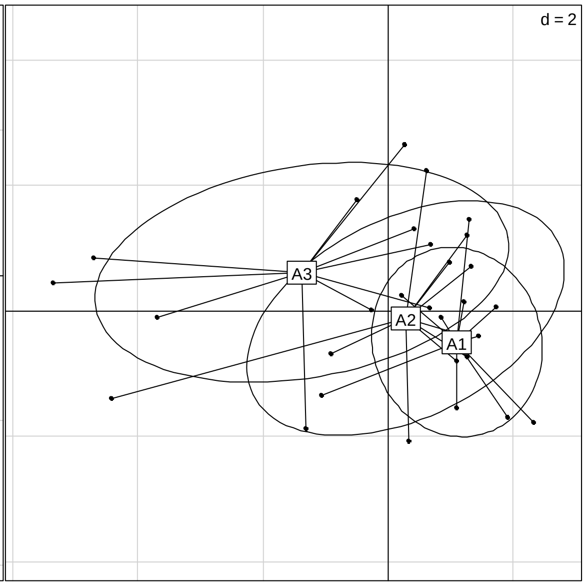
Hake Aegean Sea

Figure 1b: Representation of the life cycle spatial pattern and its inter-annual variations in the first factorial plane of the MFA applied on the spatial indicators at age. Each point represents the position of each age in each year. The gravity center of each age is labelled. Representations for hake.



anchovy Biscay AC





Red Mullet GS10a

Red Mullet GS10b

Figure 1c: Representation of the life cycle spatial pattern and its inter-annual variations in the first factorial plane of the PCA applied on the spatial indicators at age. Each point represents the position of each age in each year. The gravity center of each age is labelled. Representations for Anchovy and Red Mullet.

BS COD		CUSUM diagnostics table							
Years	**MFA_spatial**	**PCA_biological**	**Ln_Ntot**	**Ln_Rec**	**Lbar**	**L25**	**L75**	**Z**	**diagnostic**
1989	0	**3.4**	0	**-0.8**	**1.7**	**4.0**	0		
1990	**1.5**	**3.7**	**-1.6**	**-2.7**	**1.8**	0	**1.5**	0	alarm
1991	**1.1**	**3.4**	**-4.6**	**-4.0**	0	0	0	0	alarm
1992	**2.7**	**3.9**	**-6.9**	**-2.8**	0	0	0	0	alarm
1993	0	**1.0**	**-4.9**	0	0	0	0	**-1.1**	
1994	0	0	0	0	0	0	0	**-1.0**	
1995	0	0	0	0	0	0	0	0	
1996	0	0	0	0	0	0	0	0	ref
1997	0	0	0	0	0	0	**-1.1**	0	ref
1998	0	0	0	0	0	0	0	0	ref
1999	1	0	0	0	0	0	0	0	ref
2000	0	0	0	0	0	0	0	0	ref
2001	0	0	0	0	0	0	0	0	ref
2002	0	0	0	0	0	0	0	0	ref
2003	0	0	0	0	0	0	0	0	ref
2004	0	0	0	0	0	0	0	0	ref

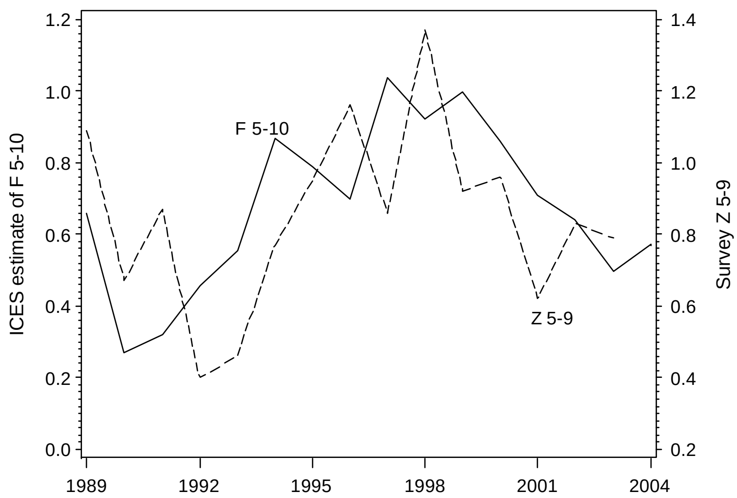


Fig. 2: Barents sea cod. Cusum diagnostic table for multivariate indices and raw biological indices (above). Comparison of survey Z estimate with ICES estimate (below), showing the low in the beginning of the 90s.

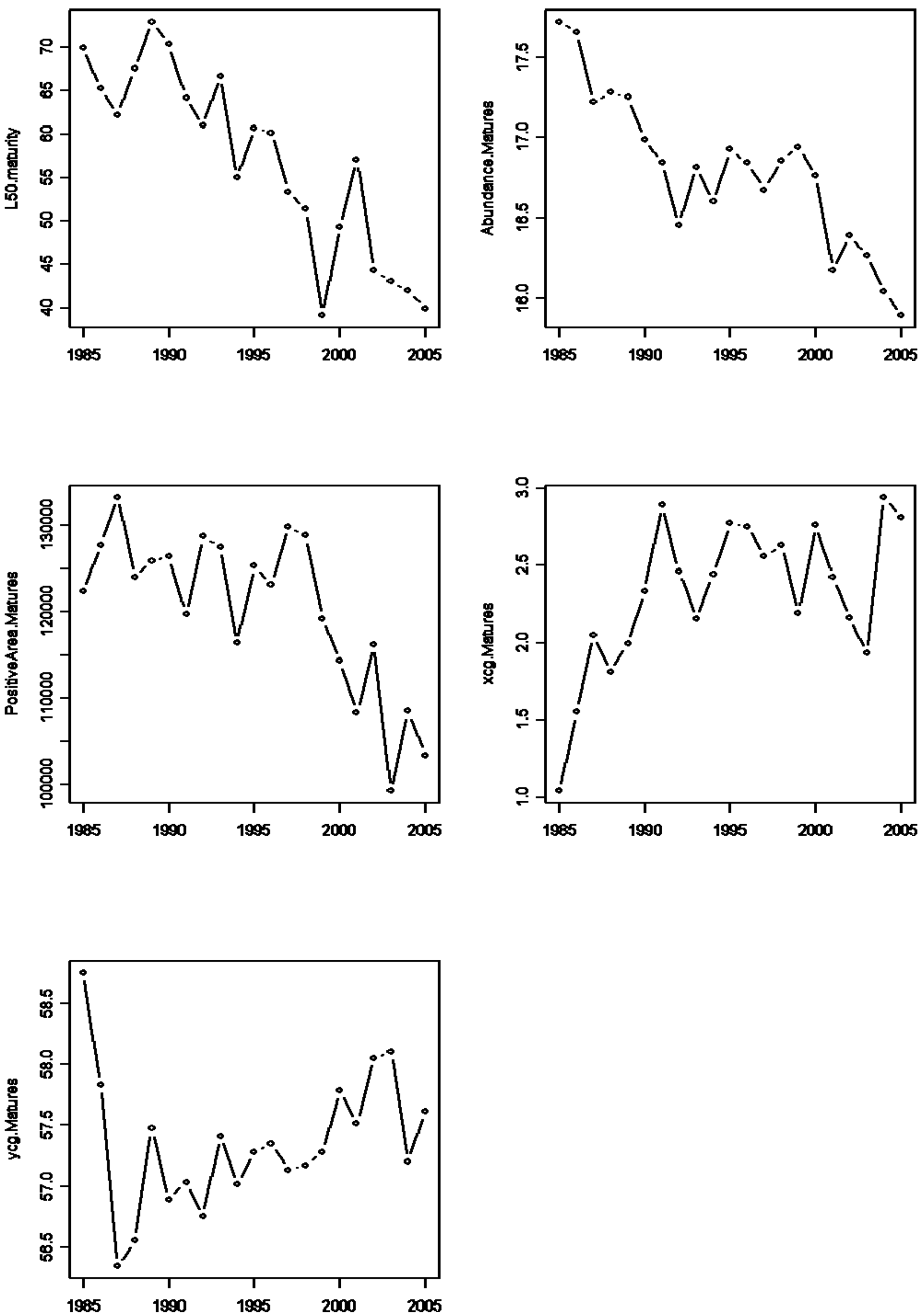


Fig.3a : Example of MAF selected raw indices that express the trend variation in biological and spatial indices

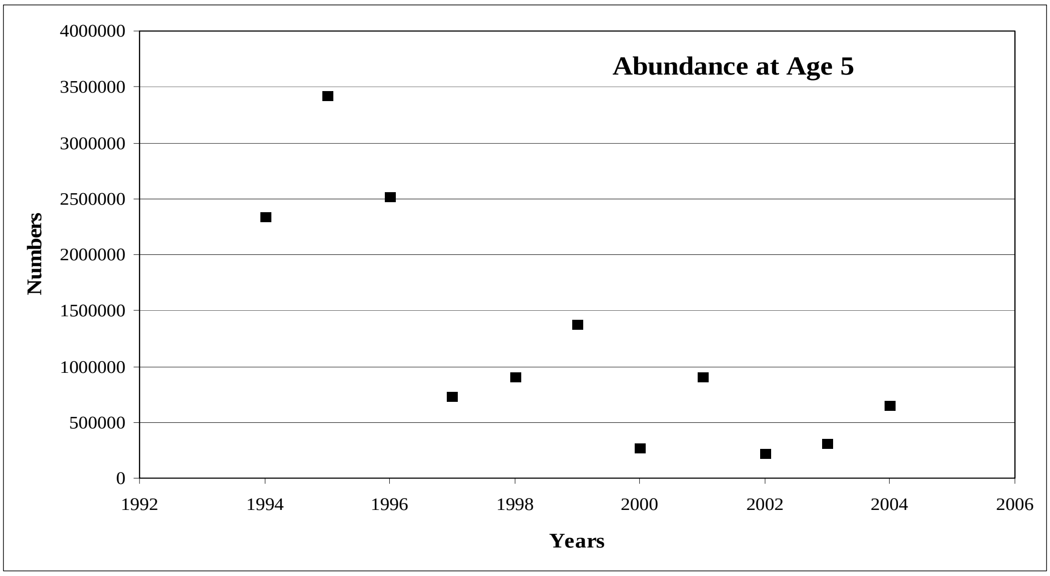
Trend method result table: 1/-1 indicates linear (+/-) trend, 1*/-1* indicates recent change only. recent is from 2001 to 2005 (5 last years).

Non-spatial indices	**all**	**recent**										
Ln_Survey.index	-1	-1										
Ln_Abundance (recruits)	-1	-1										
L25	0	1*										
Lbar	0	1*										
L75	0	1*										
L50.maturity	-1	-1										
Z	0	-1*										
md	1	0										
	Age 1		**Age 2**		**Age 3**		**Age 4**		**Age 5**		**Age 6**	
Spatial indices	**all**	**recent**	**all**	**Recent**	**all**	**recent**	**all**	**recent**	**all**	**recent**	**all**	**recent**
xcg	0	0	0	0	1	0	1	0	0	0	0	-1
ycg	1	0	0	0	0	0	0	0	1	1	0	1
Inertia	0	1*	-1	0	0	0	0	0	-1	0	0	0
Anisotropy	1	0	0	-1	-1	0	0	0	0	0	0	1
Positive area	0	-1*	-1	-1*	0	-1*	-1	-1*	-1	-1	-1	0
Equivalent area	0	-1*	0	-1*	1	1	0	0	0	-1	0	0
Spreading area	0	-1*	0	0	0	-1*	0	0	-1	-1	-1	0
Microstructure	0	0	-1	0	0	0	0	0	0	0	0	0
No. of patches	0	1*	0	0	0	0	0	0	0	0	0	-1
dmul (all ages)	1	1										

cod NS **Cusum diagnostic table**

Year	**MFA_spatial**	**PCA_biological**	**Ln_Ntot**	**Ln_Rec**	**Lbar**	**L25**	**L75**	**L50.matu**	**Z**	**diaqnostic**
1985	0	0	0	0	0	0	0	0		ref
1986	0	0	0	0	0	0	0	0	0	ref
1987	0	0	0	0	0	0	0	0	0	ref
1988	0	0	0	0	0	0	0	0	0	ref
1989	0	0	0	0	0	0	0	0	0	ref
1990	0	0	0	0	0	0	0	0	0	ref
1991	0	0	0	0	0	0	0	0	0	ref
1992	0	0	0	0	0	0	0	0	0	ref
1993	0	0	0	0	0	0	0	0	0	ref
1994	0	0	0	0	0	0	0	0	0	ref
1995	**1.4**	0	0	0	0	0	0	0	0	
1996	0	0	0	0	0	0	0	0	0	
1997	0	**3.4**	0	0	**-1.8**	**-1.0**	**-2.2**	**-1.8**	0	
1998	0	0	0	0	0	0	**-2.0**	**-3.4**	0	
1999	0	**1.3**	**-1.3**	**-1.3**	0	0	0	**-7.4**	0	
2000	**1.8**	0	**-1.7**	0	0	0	0	**-9.3**	0	alarm
2001	**2.7**	0	**-3.0**	0	0	0	0	**-9.8**	0	alarm
2002	**2.0**	0	**-4.0**	0	0	0	0	**-12.8**	0	alarm
2003	**1.7**	**2.5**	**-7.5**	0	0	0	0	**-16.0**	0	alarm
2004	**2.4**	**5.3**	**-10.5**	**-1.2**	0	0	0	**-19.3**	0	alarm
2005	**2.9**	**9.3**	**-15.0**	**-2.0**	0	0	**1.2**	**-23.1**	0	alarm

Fig. 3b: Trend result table (above) and Cusum diagnostic table (below) for North Sea cod.



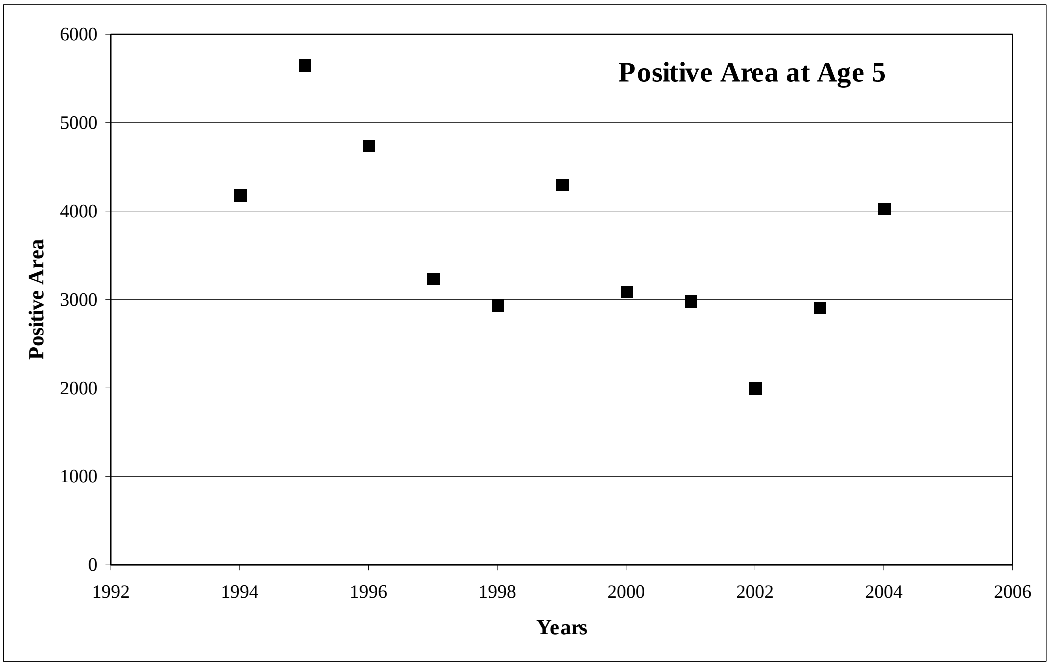


Fig.4a: Time series of the indices that convey the major signal in the evolution of Baltic Sea cod. Indices are Abundance at age 5 and Positive area at age 5.

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

cod BA **Cusum diagnostic table**

Year	Ln.Nb.A5	PositiveArea.A5	Ln_Ntot	Ln_Rec	Lbar	L25	L75	Z	diagnostic
1994	0	0	0	0	0	0	0	0	ref
1995	0	0	0	0	0	0	0	0	ref
1996	0	0	0	0	0	0	0	0	ref
1997	0	0	**-6.19**	**-2.2**	0	0	**3.9**	0	
1998	0	0	**-4.44**	0	**2.3**	0	**4**	0	ref
1999	0	0	0	0	0	0	**3**	0	ref
2000	**-2.24**	0	0	0	0	0	0	0	
2001	**-2.23**	0	0	0	0	0	**1.2**	0	alarm
2002	**-4.88**	**-3.4**	0	0	0	0	0	0	alarm
2003	**-6.86**	**-4.1**	0	0	0	0	0	0	alarm
2004	**-7.47**	**-3.4**	0	0	0	0	**-1.4**	0	alarm

Fig. 4b: trend results table (above) and Cusum diagnostic table (below) for Baltic Sea cod.

Nonparametric derivatives 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

Hake Bay of Biscay			CUSUM diagnostics table												
Years	MFA_spatial	PCA_biological	Ln_N_A0	Ln_N_A1-5	L25	Lbar	L75	Z	EA.A5	SA.A5	PA.A5	EA.A4	SA.A4	xcg.A3	Diagnostic
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	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	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	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	ref
1991															
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	ref
1993															
1994	0.0	0.0	0.0	0.0	0.0	**-1.0**	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	ref
1996															
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	ref
1998	0.0	**1.5**	**-1.1**	**-4.1**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**-1.8**	
1999	0.0	**1.4**	**-1.1**	**-2.6**	**2.0**	0.0	0.0	0.0	0.0	**-2.0**	**-1.2**	0.0	**-1.1**	**-3.0**	
2000	**1.5**	0.0	0.0	**-4.3**	**1.7**	0.0	0.0	0.0	0.0	**-2.4**	**-1.8**	**-1.6**	**-1.7**	**-3.0**	alarm
2001	**3.3**	0.0	0.0	**-3.2**	**2.6**	0.0	0.0	0.0	**-1.4**	**-2.3**	0.0	**-2.8**	**-2.3**	**-3.1**	alarm
2002	**4.3**	0.0	0.0	**-2.2**	**1.5**	0.0	0.0	1.5	**-1.6**	**-2.7**	0.0	**-4.3**	**-4.1**	**-3.3**	alarm
2003	**2.6**	**1.1**	0.0	**-2.3**	**2.8**	**1.1**	**1.1**	**1.2**	**-1.3**	**-2.7**	0.0	**-5.2**	**-5.3**	**-3.2**	alarm
2004	**3.5**	**1.1**	**1.2**	0.0	**3.9**	0.0	0.0	**1.5**	**-1.3**	**-2.6**	0.0	**-6.0**	**-6.8**	**-3.9**	alarm

Fig. 5: Trend results table (above) and Cusum diagnostic table for Bay of Biscay hake.

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

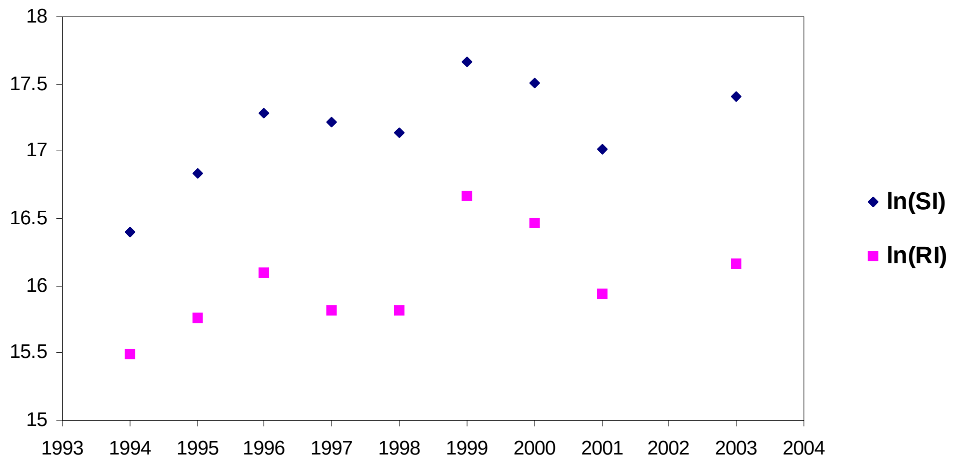
diagnostic No clear diagnostic can be deduced.

a) The senario of increased recruitment is not supported by the 0 trend of ln_rec and by the recent decreasing trend of L75.

b) The senario of slower growth is not supported by the increasing trend of abundance and the recent decreasing trend of L25.

Hake Ionian			**CUSUM traffic light diagnostic table**										
Year	**MFA_Spatial**	**PCA_biological**	**ln_Not**	**ln_Rec**	**Lbar**	**L25**	**L75**	**ln_Matures**	**ln_A2**	**ln_A3**	**ln_A4**	**ln_A5**	**diagnostic**
1994	0	0	**-1.8**	**-1.9**	0	0	0	0	0	0	0	0	
1995	0	**1.6**	0	**1.5**	0	0	0	0	0	0	0	0	
1996	0	0	0	0	0	0	0	0	0	0	0	0	
1997	**4.0**	0	0	0	0	0	0	0	0	0	0	0	
1998	**1.9**	0	0	0	0	0	0	0	0	0	0	0	ref
1999	**2.1**	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	ref
2001	0	0	0	0	0	0	0	0	0	0	0	0	ref
2002													
2003	**2.0**	**2.6**	0	**2.0**	0	0	0	0	0	0	0	0	

Fig. 6: Trend results table (above) and Cusum diagnostic table (below) for Ionian hake.



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.

Hake Aegean Sea **CUSUM diagnostics table**

Year	MFA_spatial	PCA_biological	Ln_Ntot	Ln_Rec	Lbar	L25	L75	Z	Ln_Matures	diagnostics
1994	0	**10.8**	**-2.1**	0	**2.9**	**5.4**	**1.5**	0	0	alarm
1995	**3.2**	**6.8**	**-2.7**	0	0	**3.3**	0	0	**-2.5**	alarm
1996	**3.6**	0	**-1.9**	0	**-2.4**	0	**-1.7**	0	**-2.6**	alarm
1997	**1.2**	0	**-1.3**	0	0	**-2.1**	0	0	0	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	**2.9**	0.0	0	0	0	0	0	0	0	

Fig. 7: Time series of the survey index (SI=Ln_Ntot) and the recruit index (RI=Ln_rec), Trend results table (centre) and Cusum diagnostic table (below) for Aegean hake.

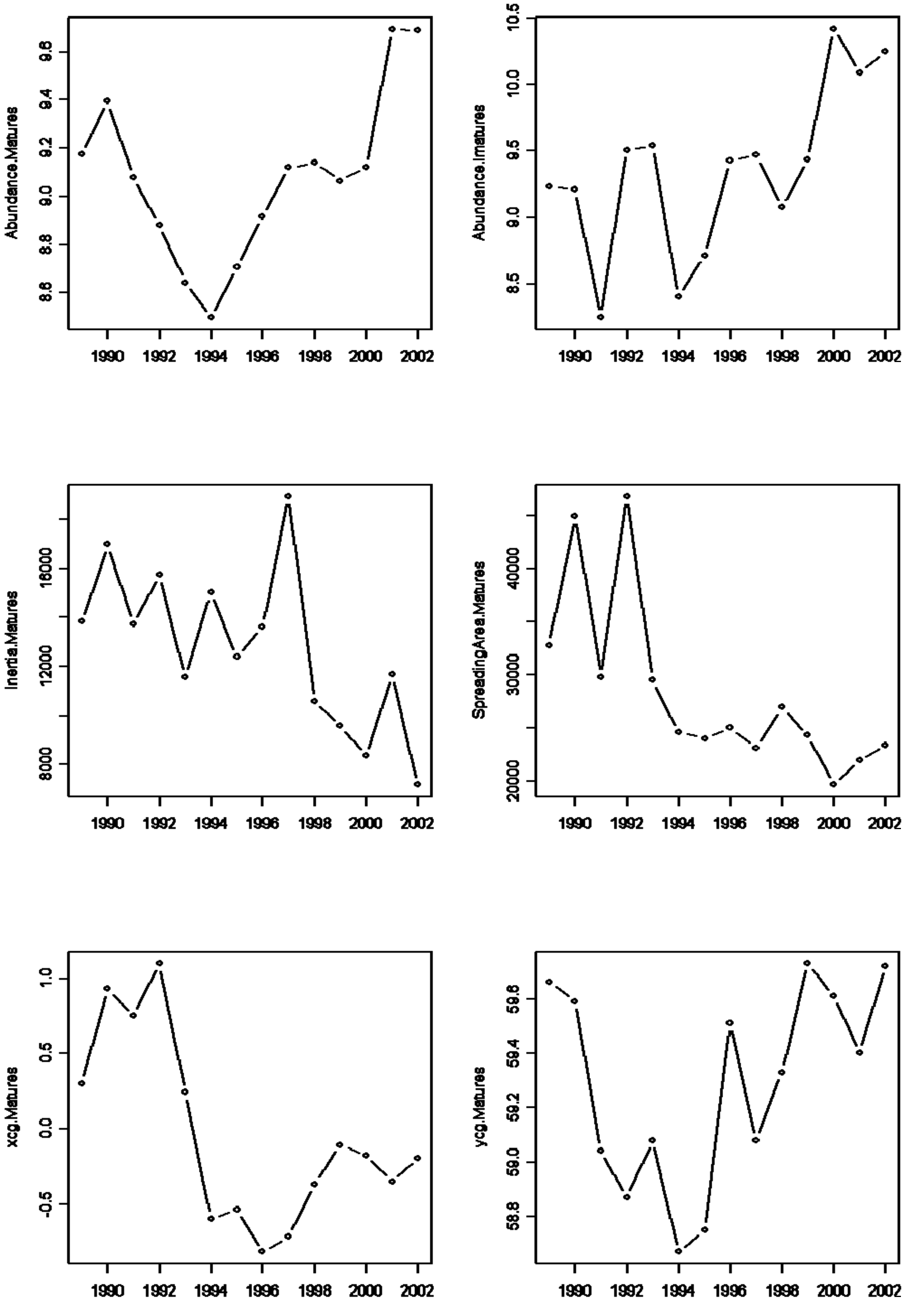


Fig. 8a: North Sea herring raw indices selected using the MAF procedure then visually chosen to evidence the major changes

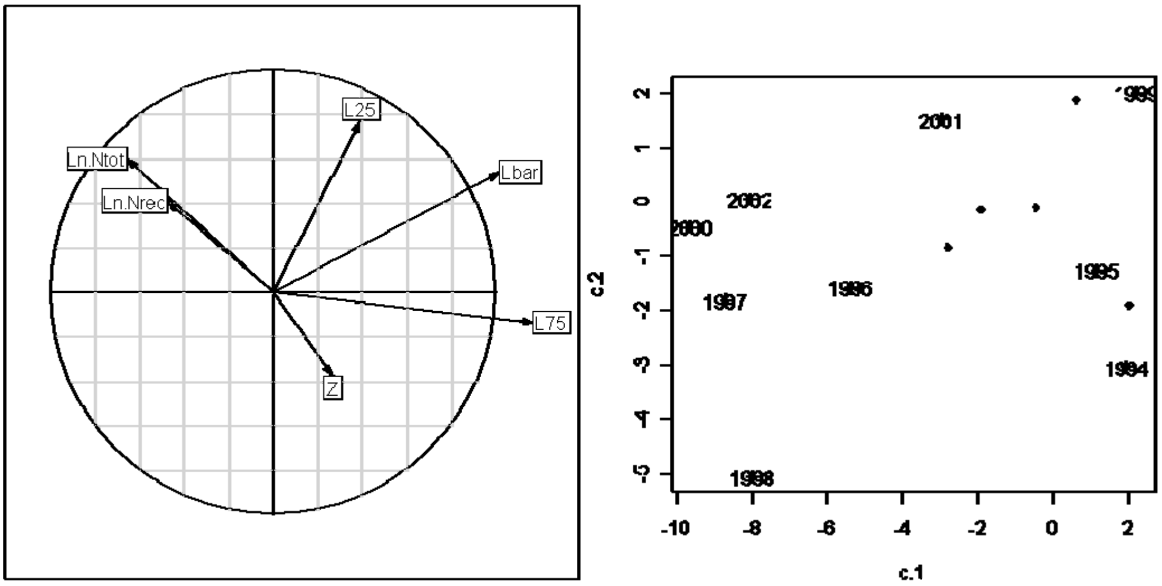


Fig. 8b : North Sea herring multivariate representation of the biological (non spatial) indices (left) and the years (right), in the first plane of the PCA. The reference years of represented by black dots.

North Sea herring		**CUSUM traffic light diagnostic table**	
Years	**MFA_Spatial**	**PCA_biological**	**diagnostic**
1989	0	0	ref
1990	0	0	ref
1991	0	0	ref
1992	0	0	ref
1993	0	0	ref
1994	**1.2**	0	alarm
1995	**4.6**	0	alarm
1996	**2.2**	**1.1**	alarm
1997	0	**5.1**	
1998	0	**9.6**	
1999	0	**9.4**	
2000	0	**14.1**	
2001	0	**13.5**	
2002	0	**16.8**	

Fig. 8c: North Sea herring Cusum diagnostic table for the multivariate indices

Anchovy Bay of Biscay	CUSUM diagnostics table			
Years	**PCA_spatial_AC**	**PCA_biological_AC**	**PCA_spatial_EG**	**diagnostic**
1989	0	**5.9**	0	
1990	0	0	0	ref
1994	0	0	0	ref
1997	0	0	0	ref
1998	0	0	0	ref
2000	0	0	0	ref
2001	0	0	0	ref
2002	0	**9.0**	0	
2003	0	**21.3**	0	alert
2004	**3.0**	**16.7**	0	alarm
2005	**6.5**	**48.1**	0	alarm

Fig. 9: Bay of Biscay anchovy

Biological 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				
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

mul TS				**CUSUM diagnostics table**							
Year	**PCA_spatial_10a**	**PCA_spatial_10b**	**PCA_biological**	**Ln_Ntot**	**Ln_Rec**	**Lbar**	**L25**	**L75**	**L50.matu**	**Z**	**alert**
1994	0		0	0	0	0	0	0	0	0	
1995	0	**1.2**	0	0	0	0	0	0	0	0	
1996	0	**1.2**	0	0	0	0	0	0	**1.7**	0	
1997	0	0	0	**-2.0**	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

Fig. 10: Trend results table (above) and Cusum diagnostic table (below) for the Red mullet in the Thyrrhenian Sea

Annex 1: Template for reporting case studies indicator-based diagnostics

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 : interpretation using cause-effects table as guide line
- cusum analysis :
- interpretation using cusum table of selected indices
- interpretation using cause-effects table as guide line

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 ?)