

Theme Session on the Incorporation of External Factors in Marine Resource Surveys

**Evaluation of the incorporation of external information using GAM on the  
catch-at-age index estimation for North Sea plaice and sole**

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**Abstract**

External variables are used to improve the indices provided by the BTS survey for the stock assessment of plaice and sole. These external variables consist of data collected during the survey together with data present in other databases and are incorporated using Generalized Additive Models (GAM's). Three methods are studied that use GAM's to calculate the catches of four age-groups (1 - 4+) of plaice and sole: (1) a basic model involving the external variables Depth, Sediment grain-size, Latitude, Longitude, Time of day, Day of year and water temperature was used adding a factor for the effect of the difference between years. (2) The basic model was expanded with three Principal Components describing the catches of fish species other than the two target species. (3) The basic model was applied to a regular grid covering a slightly expanded index area.

The results are validated using two criteria: one is that of internal consistency, the other compares the estimates with the results of the stock assessments of plaice and sole without the tuning of the BTS index. Both in terms of internal consistency and correlation with the stock assessments all three methods involving GAM's performed better than the observed catches. The mean correlation coefficient ( $R^2$ ) between the indices based on the observed catches and the stock assessments was 0.74. The method applying the basic model to a regular grid performed best of all with  $R^2=0.81$ .

## **Introduction**

Several sources of information are used for the stock assessment of plaice and sole: data from commercial fisheries (UK and Netherlands) as well as two research vessel surveys (e.g. Beam Trawl Survey, BTS and Sole Net Survey, SNS) (ICES 2000). The primary objective of these surveys is to provide indices of the year-class strength of the younger age-groups of plaice and sole. During these surveys not only information on the catches of these two target species are recorded but also information on the catches of other fish species as well as several physical and chemical variables.

In the present study this external information is used to improve the catch-at-age indices provided by the BTS survey for the stock assessment of plaice and sole. These external variables consist of data collected during the survey together with data present in other databases and are incorporated as covariates using Generalized Additive Models (GAM's). The objective is to compare several methods that incorporate external data using GAM and to determine whether this approach helps in improving the indices required for the stock assessments of plaice and sole. For this the catches per haul of four age-groups (1 - 4+) of plaice and sole are estimated using GAM's and the results are evaluated using two criteria: one is that of internal consistency, the other compares the estimates with the results of the stock assessments of plaice and sole without the tuning of the BTS index.

## **Material & methods**

The BTS survey was initiated in 1985 and aims at obtaining abundance estimates of the dominant age-groups of plaice and sole including pre-recruits. The survey is carried out in international cooperation and covers both inshore and offshore areas throughout the North Sea, Channel and western waters of the UK. The survey is conducted during five weeks in the months August and September. The fishing gear used is a pair of 8 m beam trawls rigged with nets of 120 mm and 80 mm stretched mesh in the body and 40 mm stretched mesh cod-ends. A total of 8 tickler chains are used, 4 mounted between the shoes and 4 from the groundrope. The survey was designed to take between 1 and three hauls per ICES rectangle depending on the rectangle. The stations are allocated over the fishable area of the rectangle on a "pseudo-random" basis to ensure that there is a reasonable spread within each rectangle. No attempt is made to return to the same tow positions each year. Towing speed is 4 knots for a tow duration of 30 minutes and fishing occurs during daylight only. At each station all fish species are measured and recorded together with physical/chemical variables such as surface and bottom temperature, depth and position in latitude and longitude. For the present study 1155 hauls within the expanded "Index area" were used (Figure 1). All hauls were conducted by the same research vessel (RV "Isis").

To model the catches of plaice and sole in the BTS, Generalised Additive Models (GAM's) were applied. Because of the high proportion of 0 catches and the skewed distribution of the positive catches of the species-at-age it was necessary to use two-stage models: first the presence/ absence of that species-at-age was modelled using a binomial distribution, then the log-transformed positive catches were modelled using a gaussian model. The same two-stage GAM's were used for all species-at-age. Several approaches were followed in the way these GAM's were applied or in the inclusion of additional external factors.

The following external factors were available on a haul-by-haul basis to include in the GAM's: depth, sediment grain-size, geographical position in latitude and longitude, time of day, day of year and species composition of the catch. The relationship of the catch with the external factors was modelled using a cubic smoothing spline. In order to acquire interpretative relationships with all external factors except for the geographical position, the degrees of freedom were restricted to 3 (grain-size, time of day and day of year) or 5 (depth).

Depth data on positions other than the BTS stations were based on Kriging of the depth data in the ICES hydrographic database. Median grain-size was based on data from the 1986 Benthos survey (Craeymeersch et. al. 1997) complemented with data from the Danish Institute for Fisheries Research in Hirtshals irregularly placed in the central North Sea. The target variable, called "median-phi" was derived from the median diameter of grains in the sediment by a logarithmic transformation ( $\phi = -\log_2(\text{diameter})$ ). Median-phi values range from 0-4 defining four classes: coarse sand (0-1), medium sand (1-2), fine sand (2-3) and very fine sand (3-4).

Three different approaches were studied using the basic GAM's. (1) The following GAM model was used for modelling both the presence/ absence and the log-transformed catches:

$$\text{CATCH} = \text{YEAR} + \text{DEPTH} + \text{GRAIN-SIZE} + \text{TIME} + \text{DAY} + \text{LATITUDE} + \text{LONGITUDE} + \text{PERIOD} * \text{DEPTH} + \text{PERIOD} * \text{GRAIN-SIZE} + \text{PERIOD} * \text{LATITUDE} + \text{PERIOD} * \text{LONGITUDE} + \text{LATITUDE} * \text{LONGITUDE} + \text{STEMP} * \text{DEPTH}$$

YEAR was added as a factor for the effect of the difference between years. More gradual change in modelling the fishes distribution over time was incorporated by distinguishing three five-year periods (i.e. 1985-1989, 1990-1994 and 1995-1999) using a factor PERIOD and an interaction between the yearly surface water temperature (STEMP) and DEPTH. (2) Same as first model but the catches of fish species other than the two target species, represented by three Principal Components (PC's), were used as linear explanatory variables in both the binomial and gaussian part of the model. For the Principal Component Analysis (PCA) all fish species other than the two target species were selected that over the entire sampling period contributed more than 0.1 % to the total catch in numbers. (3) Same as first model but applied to a regular grid (raster 2' longitude x 4' latitude) of 1482 gridpoints covering an index area expanded to the east up to the Danish coastline. At each gridpoint the following data were available: geographical position in latitude and longitude, depth and mean sediment grain-size. The time of day was arbitrarily set at 12 noon, the day of year at the 1<sup>st</sup> of September, surface water temperature was equal to the yearly mean water temperature.

Abundance indices per year of both the observed catches and the output of the basic GAM method and basic GAM method + PC's were calculated according to BTS protocol: mean abundance per species-at-age was first calculated per ICES rectangle after which the arithmetic average per year was determined over all ICES rectangles inside the BTS index area. For the GAM method with grid the arithmetic average over all gridpoints was calculated.

For comparison of the trajectories of the abundance indices of each species-at-age the observed and calculated abundances were normalised by subtracting the average over the whole period and dividing this by the standard deviation.

For validation of the results two possibilities existed: (1) first an internal validation was used where the average catch in numbers (observed and fitted) of species-at-age  $A$  in year  $Y$  was correlated using linear regression with species-at-age  $A+1$  in year  $Y+1$ , species-at-age  $A+2$  in year  $Y+2$  and species-at-age  $A+3$  in year  $Y+3$ , (2) the average yearly catch in numbers (observed and fitted) of each species-at-age was correlated using linear regression with the calculated stock abundance in numbers as derived from the assessments using Extended Survivors Analysis (XSA, Darby and Flatman 1994) excluding the BTS index. This correlation was done for the period (1985-1995) during which the assessment is likely to have converged.

## Results

The basic GAM model used to predict the catches of the species-at-age was based on six variables: depth, time of day, latitude, longitude, day of year, median grain-size and yearly surface water temperature. For the modelling of both the presence/ absence (binomial) and the positive log-transformed catches (gaussian) all variables were included for each species-at-age but only some showed a significant contribution (Table 1). The relationships between the positive catches and the external factors as established using cubic smoothing splines differ markedly between the species-at-age (Figure 2). The abundance of the younger age-groups of plaice and sole decreases with increasing depth which does not apply to the older age-groups. These younger age-groups of plaice and sole in turn differ in their preference of sediment type: sole appears to prefer “medium sand” whereas plaice prefers “fine sand”, “very fine sand” is avoided by both. Catches of most species-at-age are lowest around noon and decrease as sampling takes place later in the third quarter.

For the second approach in which catches of fish species other than the two target species were added to the model, Principal Component Analysis on 19 species revealed three PC's that explained nearly 80% of the variance (Table 2).

Yearly estimates of the catches based on the observed catches and the three different GAM methods are shown for each of the species-at-age (Figure 3). Although minor differences are observed between the trajectories the overall pattern appears robust. The age-group with the largest differences between the trajectories is age-1 Plaice. This age-group shows three strong years e.g. 1986, 1988 and 1997. The abundance index of 1986 is higher according to the observed catches and the GAM method applied to a grid than when based on the basic GAM method with or without PC's. The opposite was observed for the 1997 abundance index. The 1988 abundance index is high in all trajectories. Only the observed catches of age-1 Plaice show a relatively high abundance index in 1992. The main difference between the trajectories of age-2 Plaice lies in the contrast between the observed catches and the fitted catches. In 1987 and 1998 the observed catches give a slightly lower abundance index whereas in 1993 and 1987 the resulting abundance index is higher.

For Sole the main differences between trajectories were observed for ages 1 and 4+. For age-1 Sole mainly the trajectories based on the observed catches and/or that based on the model applied to a grid deviated. For age 4+ it was only the trajectory based on the observed catches. Adding PC's to the basic model hardly affected the trajectories.

For validation of the plaice and sole indices based on various GAM-methods as compared to the original method using observed catches, two approaches were used:

internal consistency and correlation with the stock assessment output. In terms of overall (all age-groups) internal consistency all GAM methods perform better than the observed catches and the model applied to a grid performs best of all GAM methods ( $R^2=0.52$ ) (Table 3). The addition of PC's to the basic model resulted only in a minor improvement.

Correlation with the stock assessments without BTS shows a pattern similar to that based on internal consistency: all GAM methods performed better at providing abundance indices in agreement with the assessments than did the observed catches (Table 4). For both flatfish species the model applied to a grid performed best overall ( $R^2=0.81$ ) (Table 4).

## Discussion

The aim of this study was not only to describe the fishes spatial distribution but to try to provide improved abundance indices using the GAM's. Two methods of validation were used to assess the accuracy of the abundance indices: internal consistency where the abundance of a species at age 1 in a particular year was compared to the abundance of that species at age 2 in the next year etc. and correlation with the assessment (XSA) output without the tuning of the BTS index. The fact that both methods of validation display similar results strongly suggests that the applied methods are appropriate for validating the calculated abundance indices.

The above results of plaice and sole show that GAM's are suitable to provide a means of describing the spatial distributions of plaice and sole using smooth functions of several covariates. Providing the main covariates (depth, latitude and longitude) are included in the GAM the addition of more covariates or change of the degree of smoothing does not appear to affect the abundance indices substantially in spite of the fact that they often do change the outcome of the model (number of species-at-age per haul per year) significantly. Therefore in the GAM only those covariates were incorporated (often with a restriction on the degrees of freedom) for which interpretative and plausible relationships could be expected.

Incorporating the interaction between the 5-year periods and the main external factors that determined the distribution of the species-at-age (depth, latitude and longitude) was necessary to describe a gradual shift in distribution further offshore observed during the sampling period for mainly the younger plaice and sole. The relevance of these periods may be based on the introduction of the "plaice box" a closed area in the south-eastern North Sea and/ or (2) a marked increase in water temperature in the index area during the last decade. The latter was also explicitly incorporated in the GAM by the interaction between surface water temperature and depth.

To reduce the discarding of plaice in the nursery grounds along the continental coast of the North Sea, an area between 53 °N and 57 °N was closed to fishing for trawlers with engine power of more than 300 hp in the second and third quarter since 1989, and for the whole year since 1995. These measures resulted in a marked shift of fishing effort to offshore areas (Pastoors et al. 2000) that has possibly affected the distribution of the fish. The mean surface temperature increased from 16.5 °C in the first 5-year period to 17.0 °C in the second to 18.3 °C in the final 5-year period. The increased surface water temperature has strongest impact on demersal species such as plaice and sole in shallow areas where the bottom temperature resembles surface

temperature (Piet et. al. in press). The increasing temperatures in the past decade possibly caused fish to avoid the shallow areas with highest bottom temperatures. For plaice and sole it was decided to apply the GAM to the whole dataset with a factor added for a year-effect instead of to each year separately. The advantage of this was that this allowed establishing one interpretable relationship between catch-at-age and a particular external variable for the whole dataset. Applying GAM to separate years not only resulted in different relationships per year but often these relationships were difficult to interpret biologically.

## **Literature**

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Table 1 Significance of variables in basic GAM model (Top: binomial, bottom: gaussian) of species-at-age. Bold values are significant at  $p \leq 0.05$ .

Variable	Plaice				Sole			
	1	2	3	4+	1	2	3	4+
Depth	<b>0.02</b>	0.18	0.14	0.66	0.13	<b>0.00</b>	<b>0.02</b>	0.39
Time of day	0.44	0.35	<b>0.05</b>	0.16	0.46	0.10	0.52	0.11
Latitude	<b>0.01</b>	0.35	<b>0.01</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
Longitude	<b>0.02</b>	0.57	0.06	<b>0.00</b>	0.14	0.10	<b>0.00</b>	<b>0.00</b>
Day of year	<b>0.01</b>	0.09	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	0.62	<b>0.05</b>	0.28
Median grain-size	0.69	<b>0.00</b>	<b>0.00</b>	0.12	0.40	0.00	0.07	0.25
Latitude*Longitude	0.41	0.57	0.73	0.54	0.41	0.60	0.23	0.16
Depth*Temperature	0.08	<b>0.04</b>	<b>0.00</b>	0.25	<b>0.04</b>	<b>0.01</b>	0.07	<b>0.03</b>

Variable	Plaice				Sole			
	1	2	3	4+	1	2	3	4+
Depth	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.05</b>	<b>0.00</b>	<b>0.03</b>
Time of day	0.18	<b>0.01</b>	0.12	<b>0.02</b>	<b>0.02</b>	<b>0.01</b>	<b>0.00</b>	<b>0.00</b>
Latitude	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>
Longitude	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.01</b>	<b>0.00</b>	<b>0.01</b>	<b>0.01</b>	0.07
Day of year	<b>0.02</b>	0.39	0.31	<b>0.02</b>	0.11	0.11	0.27	<b>0.01</b>
Median grain-size	<b>0.04</b>	<b>0.00</b>	<b>0.00</b>	0.20	<b>0.02</b>	0.08	0.12	<b>0.01</b>
Latitude*Longitude	<b>0.02</b>	<b>0.00</b>	<b>0.01</b>	0.09	0.26	<b>0.05</b>	<b>0.02</b>	0.19
Depth*Temperature	<b>0.00</b>	<b>0.00</b>	0.30	0.29	<b>0.03</b>	<b>0.00</b>	0.15	0.15

Table 2: Principal component loadings per species and explained variance per principal component. Indicated is also the contribution of each species (%) to the total catch in numbers.

Species	%N	PC 1	PC 2	PC 3
<i>Buglossidium luteum</i>	5.7	0.17	-0.03	0.10
<i>Echiichthys vipera</i>	2.3	0.10	-0.34	-0.01
<i>Callionymidae</i>	5.7	0.10	0.27	0.13
<i>Gobiidae</i>	2.4	0.00	-0.10	0.08
<i>Gadus morhua</i>	0.2	-0.01	0.14	0.22
<i>Agonus cataphractus</i>	2.6	0.08	-0.15	0.04
<i>Hippoglossoides platessoides</i>	0.2	-0.16	0.03	-0.27
<i>Limanda limanda</i>	68.3	0.14	0.49	-0.10
<i>Microstomus kitt</i>	0.2	0.06	0.15	0.11
<i>Merlangius merlangus</i>	4.5	-0.11	-0.03	0.38
<i>Myoxocephalus scorpius</i>	0.2	0.17	0.10	-0.36
<i>Platichthys flesus</i>	0.2	0.21	-0.39	-0.08
<i>Rhinonemus cimbrius</i>	0.2	-0.03	-0.07	0.42
<i>Arnoglossus laterna</i>	3.6	-0.04	-0.10	-0.01
<i>Scophthalmus maximus</i>	0.1	0.21	0.19	0.21
<i>Trigla lucerna</i>	0.3	0.23	0.27	0.20
<i>Trisopterus luscus</i>	0.9	0.07	-0.04	0.35
<i>Trisopterus minutus</i>	0.1	-0.02	0.00	0.06
<i>Eutrigla gurnardus</i>	2.0	-0.24	0.23	0.02
Explained variance (%)		38.3	24.3	16.5



Table 3. Validation through internal consistency of the different methods (Method indicated upper left: OBS= Observed catches, BAS=basic method, PCA=Basic method+PC's, GRID=Basic method applied to a raster grid.). Matrix shows correlation coefficients ( $R^2$ ) between the age-group combinations. Upper right are the coefficients for Plaice, lower left for Sole. Average per age-group are in the right column (Plaice) and the bottom row (Sole). The overall mean correlation of that method is shown in the lower right corner.

OBS	1	2	3	4+	Plaice
1		0.37	0.57	0.27	0.40
2	0.34		0.44	0.22	0.35
3	0.59	0.85		0.70	0.57
4+	0.16	0.20	0.25		0.40
Sole	0.36	0.46	0.56	0.20	0.41

BAS	1	2	3	4+	Plaice
1		0.24	0.50	0.41	0.39
2	0.47		0.80	0.31	0.45
3	0.74	0.73		0.45	0.58
4+	0.12	0.25	0.47		0.39
Sole	0.45	0.48	0.65	0.28	0.46

PCA	1	2	3	4+	Plaice
1		0.31	0.56	0.32	0.40
2	0.53		0.76	0.33	0.46
3	0.79	0.76		0.47	0.60
4+	0.12	0.24	0.42		0.37
Sole	0.48	0.51	0.65	0.26	0.47

GRID	1	2	3	4+	Plaice
1		0.24	0.31	0.68	0.41
2	0.63		0.81	0.45	0.50
3	0.56	0.84		0.69	0.60
4+	0.14	0.32	0.61		0.61
Sole	0.44	0.60	0.67	0.36	0.52

Table 4. Correlation coefficients ( $R^2$ ) between stock assessment output and GAM methods (for abbreviations see Table 3) per species-at-age.

Method	Plaice					Sole					overall
	1	2	3	4+	mean	1	2	3	4+	mean	mean
OBS	0.48	0.79	0.85	0.81	0.73	0.87	0.90	0.85	0.37	0.75	0.74
BAS	0.34	0.91	0.88	0.80	0.73	0.81	0.93	0.82	0.53	0.77	0.75
PCA	0.34	0.89	0.87	0.80	0.73	0.81	0.93	0.83	0.53	0.78	0.75
GRID	0.53	0.88	0.91	0.80	0.78	0.89	0.95	0.85	0.65	0.84	0.81

Figure 1. BTS index area and expansion covered by the grid. Positions of the hauls during the period 1985-1999 that were included in this study are indicated.

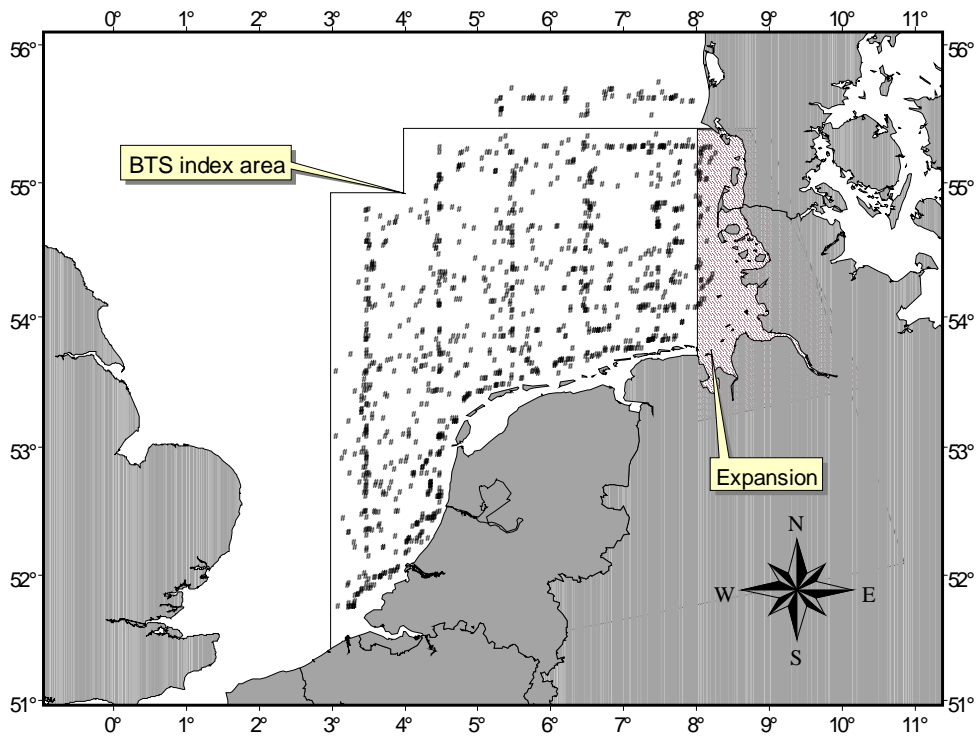


Figure 2. Relationships determined with cubic smoothing splines of catches-at-age of plaice (a) and sole (b) with four covariates used in the GAM models.

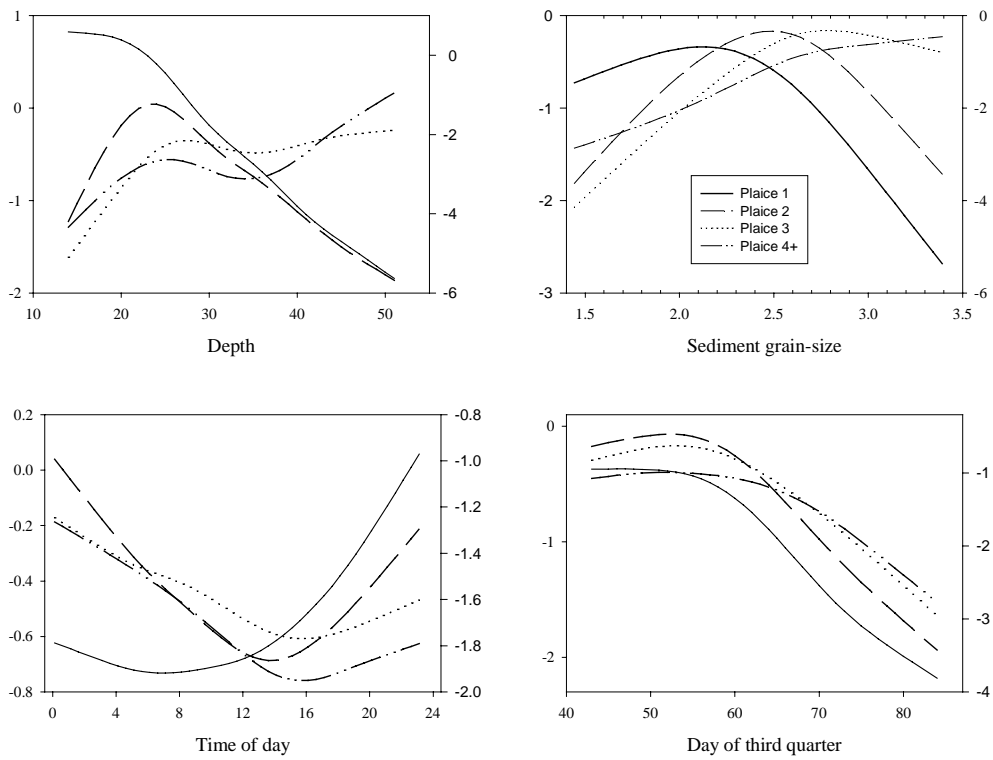


Figure 3. Trajectories of yearly catch-at-age BTS indices of plaice (a) and sole (b) estimated according to four different methods: Observed catches, Basic GAM method, Basic GAM method + three PC's and basic GAM method applied to a grid.

