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Common trends in two populations of the European lobster, Homarus gammarus, in Scottish waters

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Abstract

Dynamic factor analysis (DFA), a multivariate time series analysis technique recently applied to fisheries data for the first time, is used to explore common trends, and the effects of sea surface temperature (SST) and wind speed (WS) on short non-stationary multivariate time series of catch rates of the European lobster in Scottish fisheries. Catch rates of undersized and legal lobsters at three locations in the Hebrides and two locations in the Southeast of Scotland, were generally highest in autumn (August-October) with strong seasonal trends during the period 1990-1997, and therefore, de-seasonalised time series were analysed. From the DFA analysis, significant relationships between catch rates (undersized lobsters in one location and legal lobsters in two locations) and SST were observed for the Hebrides. At all locations in the Southeast, catch rates (both undersized and legal size lobsters) were related to SST. The results suggest, by observations on the most important trends, that (i) catch rates in the Hebrides have been steadily decreasing, (ii) those in the Southeast have been increasing during the studied period. DFA identified two common trends not revealed by traditional approaches, and proved to be a robust technique in the study of multivariate time series for the European lobster fishery.

Key words: Dynamic factor analysis, common trends, catch rates, European lobster.

Introduction

The study of factors affecting the capture processes, and the relative abundance of crustacean populations around the world has identified the need to incorporate environmental variables into stock assessment models to acquire a better interpretation, and possible prediction, of fluctuations taking place over time (Fogarty and Murawski, 1986; Krouse, 1989). In lobster fisheries, sea temperature strongly influences the distribution and availability of lobsters around the traps in the short term (McCleese and Wildner, 1958) and also strongly correlates with long time series of catch rates (> 50 yrs of data) on a large spatial scale (Koeller, 1999). In Scotland, lobster fisheries have, traditionally, been an important source of income and employment amongst coastal fishermen (Thomas, 1964; Thomas and Saville, 1972). These fisheries are characterised by a strong seasonality with two main fisheries, peaks in catch rates, in spring and autumn when moulting and recruitment processes are affected by sea temperature (Shelton et al. 1978). Some fishing grounds are strongly influenced by westerly winds (Manley, 1979; Connor, 1991), which affect the length (duration) of the fishing season and hence data availability. Analysis on the effects environment has on the fluctuations of Scottish lobster populations is desired at any spatial scale. Revealing how catch rates behave over time and if these are related, and how, to environmental variables is a priority goal in stock management.

To further elucidate the effects of environmental factors on fishery variables a careful selection of conventional and modern statistical techniques should be considered. Multivariate techniques such as principal components analysis (PCA), redundancy analysis (RDA) and others are potentially applicable tools for the interaction of multiple response and explanatory variables (Zuur et al., 2003a; Erzini, 2005). However, these techniques are not designed to obtain trends or detect changes over time. Identification of common trends between multiple time series of relevant explanatory (environmental) and response (catch rates) variables has not been obtained for the European lobster. In this aspect, it is of relevance to know: (i) if there is a common trend between the time series of catch rates and (ii) the effects of environmental variables. A solution to this question is the use of dynamic factor analysis (DFA). DFA, a dimension reduction technique especially designed for time series data, has been used in econometric (Harvey, 1989), psychological fields

(Molenaar, 1985; Molenaar et al., 1992) and most recently to fisheries (Zuur and Pierce, 2004; Zuur et al., 2003a; Zuur et al, 2003b; Erzini, 2005). In DFA short, non-stationary time series can be modelled in terms of common trends and explanatory variables, and time series of the response variables with missing values, which is the case for most of the fisheries time series data, can be included in the analysis (Zuur et al., 2003a).

In the present investigation DFA is applied for the first time to short, non-stationary monthly time series (with missing values) of the European lobster catch rates, obtained from logbook information, for three locations in the Hebrides and two locations in the Southeast of Scotland over the period 1990-1997. This paper gives account of: (i) the underlying common trends in the time series of catch rates, (ii) and the effects SST and WS.

Materials and Methods

Monthly short time series, with missing values, of the catch rates of undersized (U, <85mm carapace length (CL)) and legal size (L, ≥ 85mm CL) lobsters were obtained from logbooks recorded voluntarily by fishermen and kept by the FRS, Marine Laboratory for the Hebrides (1990-1996) and Southeast (1990-1997) areas of Scotland. The available data included the general location of fishing by rectangles of 0.5º lat x 1º long, from which the Hebrides and the Southeast form part of the ICES fishing ground areas VIa and IVb, respectively. The Hebrides lobster fishery extends over an area of 26,500 km² (56.5-59°N and 6-9°W), containing 8 sub-areas (ICES rectangles of 30' x 60'). The fishery in the Southeast covers an area of approximately 11,500 km² (55.5-56.5°N and 1-4°W) and contains about 3.5 ICES rectangles. SST and WS were obtained for both areas from the Comprehensive Ocean-Atmosphere Data Set (COADS) web site http://www.cdc.noaa.gov/coads/ for the period 1990-97. The spatial coverage of the data was the same as for the fishery data, from 56.5-59°N in the Hebrides and 6-9°W and from 55.5-56.5°N and 1-4°W in the Southeast. Initial inspection of fishery data availability suggested that three locations (HE 1, HE 2, HE 3), of 0.5º x 1º each (Fig. 1), for the Hebrides and two for the Southeast (SE 1 and SE 2) were most suitable to investigate the effects of SST and WS on lobster catch rates, the interactions between response and explanatory variables, and to identify the common trends. The catches were recorded at St. Andrews, St. Monans and Anstruther of SE 1 and West and Newhaven for SE 2. The Hebrides lobster catches were recorded mainly at Barra (HE 1), Castlebay (HE 2) and Stornoway (HE 3). A first visualisation of the time series of the response (outliers present) and explanatory variables showed strong seasonal trends (Figs. 2-3). Catch rates were square root transformed and to eliminate seasonal effects on the data two approaches were followed: 1) both response and explanatory variables were de-seasonalised and monthly mean values obtained, and 2) the interaction of not de-seasonalised monthly values of the response (transformed) and SST (untransformed) data with one common trend (M=1) and noise using a non diagonal matrix were investigated in the multivariate statistical program Brodgar (http://www.brodgar.com) where DFA was applied to both approaches.

Full technical details of the DFA are given in Zuur et al., (2003b) with further details of applications of DFA to Nephrops norvegicus (Zuur et al., 2003a), squid (Zuur and Pierce, 2004) and most recently to a series of mixed fisheries in Portugal (Erzini, 2005). The aforementioned investigations deal with time series on annual basis only. In the present application, the short time series measured on a monthly basis are modelled in terms of (i) a linear combination of common trends, (ii) explanatory variables, (iii) a level parameter, and (iv) a noise component expressed as:

N time series = M common trends + explanatory variables + level parameter + noise

DFA is especially designed to investigate interactions between several time series where a linear combination of M common trends is estimated. The common trend component is a smooth curve, the explanatory variables component is modelled as in linear regression, level parameter is time independent and is the equivalent of the constant in a linear regression model, and the noise components which can be modelled using a diagonal matrix or alternatively using a positive-definite, symmetric or non-diagonal, matrix. The off-diagonal elements given by the matrix used and representing the joint information of the response variables may indicate to what extent the existent relationship between the response variables cannot be solely explained by the other terms involved in the model (i.e. explanatory variables chosen). A matrix containing the vectors N x M give factor loadings that are used to infer on the importance of particular trends which may represent underlying common patterns over time to specific response variables and groups of response variables (Zuur and Pierce, 2004; Zuur et al., 2003a, b; Erzini, 2005).

DFA was applied to: de-seasonalised monthly mean values of response and explanatory variables, using a range of dynamic factor models with different matrices (diagonal and non-diagonal), and to not de-seasonalised data with the model containing one common trend, SST and noise, using a non-diagonal matrix. The optimal models were chosen from the smallest values of the Akaike's information criterion (AIC) and the plots of the fitted values and common trends were obtained. Comparisons between locations were obtained. No attempt was made to compare results between both, the Hebrides and Southeast areas.

Results

Dynamic factor analysis was applied to short time series of catch rates, with missing values, for the first time, on monthly basis, to two European lobster fisheries in Scottish waters, with different area coverage (Fig. 1). Based on the biology of the species and the behaviour of the fisheries two environmental variables were chosen, WS and SST, to inspect if common patterns are present over time and their relationship with particular response variables and groups of response variables. Catch rates and WS and SST showed strong seasonality, hence it was decided to eliminate any seasonality effects as illustrated in figures 2 and 3. For the Hebrides, catch rates, both of the undersized (U) and legal sized (L) lobsters, show a slight and steady decline from 1990, months 1-12, to 1996, months 75-86. Legal lobster catch rates were higher at all times for this area, particularly for location 2 and one annual peak in catches was observed. In the Southeast, the opposite pattern was observed with two annual peaks in catch rates with values for undersized lobsters being the highest, especially for location 2. From 1990 to 1994, months 1-60, catch rates declined steadily and rose afterwards. The resulting patterns of the de-seasonalised and standardised series were consistent with the untransformed series.

For the wind speed and sea temperature series no apparent trends were observed, either for the Hebrides or Southeast. In both areas, SST presented high values in summer coinciding with low values of WS (Fig. 3). Lowest temperatures in winter and highest in summer were observed for the Southeast. Higher estimates of wind speed were obtained, both for low and high peaks, for the Hebrides. Standardised data showed a constant decline in wind speed values from 1990 to 1993, months 1-48, and a steady increase afterwards for the Hebrides. SST presented the opposite pattern. For standardised WS and SST series in the Southeast, irregular patterns were obtained.

In the DFA analysis, the two Scottish fisheries, had within regional differences in regarding the environmental variables SST and WS over a period of 84 (Hebrides from 1990-96) and 96 (Southeast from 1990-97) months. The AIC values indicate that the model containing two common trends (M = 2), SST as explanatory variable and a non-diagonal matrix were the optimal models for both, the Hebrides and Southeast (Table 1). From the optimal models the strength of the relationship was classified as weak when t-values were between 2-3 (in absolute terms) and as strong for those greater than 3 (Table 2). The regression parameters and t-values, of the de-seasonalised data, revealed that for the Southeast SST is strongly related to catch rates of legal, in both locations, and undersized lobsters at location SE 1, and weakly related to undersized lobsters at location SE 2. For the Hebrides, SST was weakly related to catch rates of legal lobsters in locations HE 2 and HE 3, and undersized lobsters in location HE 3 (Table 2).

The plotted common trends of the optimal models can be seen in figures 4 and 5 for the Hebrides and Southeast, respectively. In the Hebrides, the first common trend of the de-seasonalised data showed a steady decrease from 1991-1996 (Fig. 4a). A similar pattern was observed for trend 2 and trend 1 of the not de-seasonalised data (Fig. 4b and c). The standard error bands may indicate that for the years 1994 (months 48-60) and 1996 (months 72-84) the time series data presented too many missing values at all locations for all catch rates time series (Fig. 4a-c). For the Southeast the first common trend of the de-seasonalised data was steadily increasing from 1990-1993, continue constant from autumn 1993-96, and sharply increased from 1996 to 1997 where the highest values were observed, and this was similar for the common trend of the not de-seasonalised data (Fig. 5a and c). The second common trend (de-seasonalised data) was fairly constant from 1990-1994, with a sharp decrease in 1995 and a marked increase in 1996 and finally falling strongly in autumn 1997 (Fig. 5c). As with the Hebrides common trends, the standard error bands for the Southeast showed high variation for the time series in 1994 (months 48-60), which coincides with missing values of the catch rates of, both legal and undersized lobsters at location 1.

In this investigation only two environmental variables were tested with SST being the resulting influential explanatory variable. It was determined that the most important common trend was the first, common trend 1, when M=2. For comparative purposes only, the common trend 1 of the model with not de-seasonalised data was used to corroborate the most important common trend of the model with transformed data. The factor loadings and canonical correlations of the optimal model are included in table 3, and for simplicity, only canonical correlations were plotted (Figs. 6 and 7). Axis 1 and 2 represent the first and second common trends, respectively. In the Hebrides, legal lobsters at location 1 were strongly and positively correlated with common trend 1 and legal and undersized lobsters at locations 2 and 3 were poorly correlated. In contrast, these variables presented a higher correlation with common trend 2 where catch rates of undersized lobsters at location 1 and 3 presented the strongest positive correlation and legal lobsters at location 2 negative correlation (Table 3; Fig. 6). HE 2U and HE 3L were poorly correlated with common trend 1 and moderately with trend 2.

The fitted values of the optimal model for individual data series are included in figures 8-10. The HE 1L data series (Fig. 8) describe a very similar pattern to that observed for the first common trend (Fig. 4). It was also the case for the fitted values of the HE 1U and HE 3U time series (Fig. 8) with the second common trend (Fig. 4). Most of the time series showed a slight and constant decline over time.

For the Southeast, legal lobsters at the two locations were positively correlated with the first common trend and undersized lobsters negatively correlated (Table 3; Fig. 7). Legal lobsters at location 2 were mainly correlated with common trend 1 and canonical correlation values were close to cero in respect to common trend 2. The fitted values for the optimal model for SE 1L and SE 2L showed a steady increase over time and this was similar for the first common trend, when M=1 for transformed data, and M=1 for untransformed (Fig. 4). Undersized lobster catch rates were negatively correlated with common trend 1 (Fig. 7). For the common trend 2, SE U1 showed a high positive correlation and SE U2, with higher correlation values, a negative. The figures of the fitted values for the optimal model showed a constant decrease in the catch rates over time with peaks in the summer months (Fig. 10). No apparent similarities with the plots of the common trends were observed (Fig. 5).

Discussions

This study aimed at inspecting the interactions of catch rates of two different components, discarded and landed lobsters, with two important environmental variables, SST and WS. Emphasis was made on the interactions at the smallest possible spatial scale, squares of 0.5º x 1º which could have implications for stock management at larger spatial scales (Fig. 1). Biological parameters differ between the Hebrides and Southeast (Lizárraga-Cubedo et al., 2003) lobster populations therefore no attempts were made to compare DFA results between areas.

In fisheries with marked seasonality, time series with missing values are not uncommon. The application of DFA has been previously documented as a good technique to analyse common trends in the interaction of multiple response and explanatory variables, which may include missing values (Zuur and Pierce, 2004; Zuur et al., 2003a; Zuur et al, 2003b; Erzini, 2005). In our investigation fishery and environmental data presented strong seasonality and hence data were de-seasonalised (Figs. 2-3). Missing values were present for the Hebrides data for some of the months of 1994 and 1996. For the Southeast, missing values were observed for months of 1992 and 1994 for some catch rate series (Fig. 2). DFA was applied to lobster fishery data and four main models were inspected and the smallest AIC values for both, the Hebrides and Southeast, were obtained for the model with two common trends, SST and noise with a non-diagonal matrix (Table 1). Another approach was simultaneously followed, not de-seasonalised data with one common trend, SST and noise with a non-diagonal matrix, and used to corroborate which of the common trends was the most important. DFA indicates that there are two common trends relating SST and catch rates in both areas. This relationship was more important with the first common trend (Fig. 4a and c, and 5a and c). The common trend showed a steady decrease in the Hebrides and increase in the Southeast for the studied period. For the Hebrides SST was weakly related to the catch rates of legal lobsters in locations HE 2 and HE 3, and undersized lobsters in location HE 3. In the Southeast, SST was strongly related with legal lobsters in locations SE 1 and SE 2 and undersized lobsters in location SE 1, and weakly related to undersized lobsters in location SE 2. The regression parameters and t-values of both approaches showed that catch rate time series present a positive relationship with SST in the Southeast and negative in the Hebrides (Table 2). The factor loadings and canonical correlations indicated that legal and undersized lobsters responded differently to the common trends and their relationship with SST. In the Southeast, landed lobsters of locations 1 and 2, had high correlation with common trend 1. Undersized lobsters of location 1 had strong correlation with common trend

2 and this was positive. At location 2, undersized lobsters showed a weak relationship with SST and weak correlations with both common trends (Table 3; Fig. 7). This may indicate that density-dependent processes mainly regulate undersized lobsters at location 2.

For the Hebrides, the plots of the canonical correlations confirmed that for legal lobsters at location 1 there was a strong positive correlation with trend 1, although this was not statistically significant (Tables 2-3; Fig. 6). This may indicate, by the off diagonal elements of the optimal model, that the existent relationships between the response variables cannot be solely explained by the other terms involved in the model. In addition, common trend 1 may be more important for this size component and that this location may be the most susceptible to the effects of sea temperature and other important oceanographic variables. In figure 2, it can be seen that HE L1 showed a steady declined over the study period and this was similar to the common trend 1 of the optimal model (Fig. 4). It can also be inferred that this declined could be attributed to fishing heavily on this component.

For HE 2L, HE 3L and HE 3U, weak relationships with SST were obtained with higher correlations with common trend 2 (Tables 2-3; Fig. 6). It can be argued that the common trend 2 is the most important trend, although the model with not de-seasonalised data and common trend 1 gave a strong significant relationship with SST. In general, the interaction of SST and de-seasonalised time series, may prove that in effect SST is important at small regional scales and that the capture processes and catch rates may be affected by other factors not considered in the present analysis, as revealed by the use of non-diagonal matrix in the optimal models. Although, it must be taken into account that seasonal effects in the de-seasonalised time series may have not been completely eliminated.

The role that temperature has on the catch rates has been previously reported at different regional scales for the American lobster fishery (Koeller, 1999), and confirmed in the present work for the European lobster fishery.

The fitted curves showed that the monthly time series of catch rates have a reasonable fit, and strong seasonality, to the de-seasonalised data (Fig. 8-10). In most of the cases where the time series of catch rates were significantly related to SST (weakly or strongly), both in the Hebrides and Southeast, the relationship was higher in autumn (August-October) as seen in the fitted values (Fig. 8-10). This confirms Shelton's et al (1978) comments on the European lobster recruitment processes being affected by moulting, occurring in June-July, although this was difficult to observe for the Hebrides area.

The application of DFA to lobster catch rates was for the first time considered in the analysis of multiple response and environmental variables, which in most of the cases due to data availability, missing values are not uncommon. The results allowed an insight of the density-independent processes that affect lobster fisheries at small spatial scales. This is a valuable contribution for lobster stock management.

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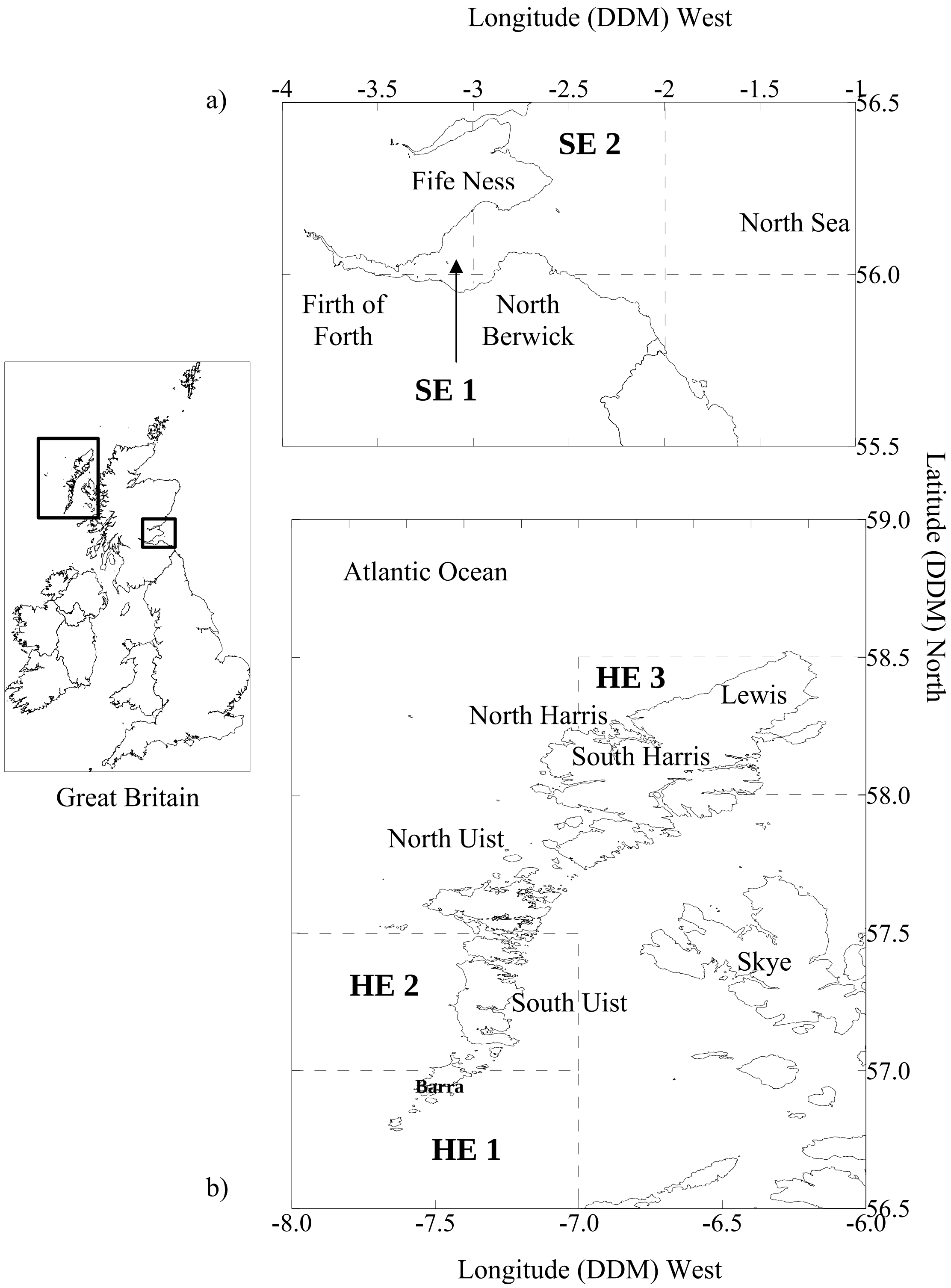

Fig. 1. Map of the study areas for the dynamic factor analysis of time series of the European lobster catch rates in different locations of the Southeast (a) and Hebrides (b), Scotland between 1990-97.

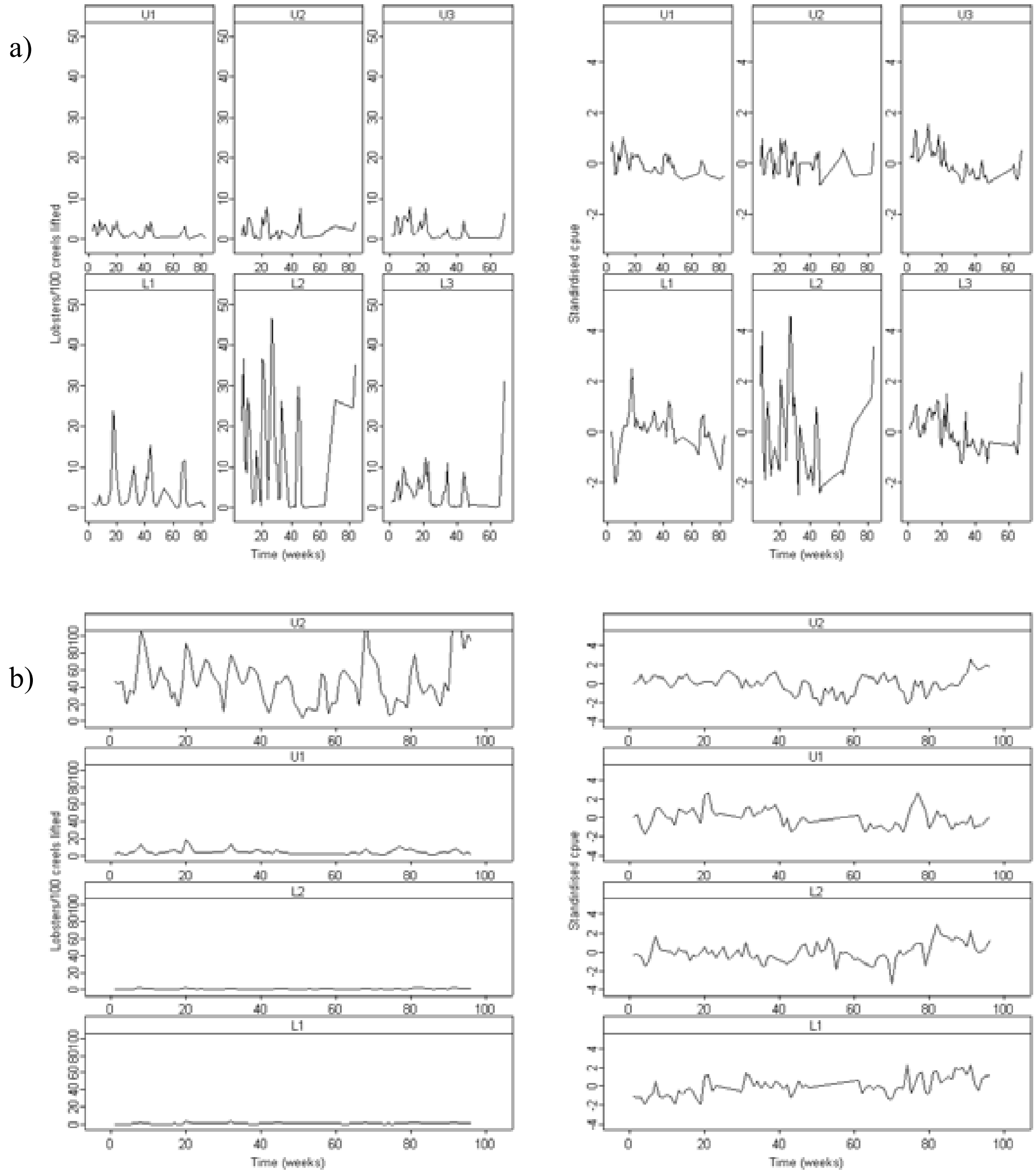

Fig. 2. Untransformed and standardised weekly time series of catch per unit effort at three locations in the Hebrides (a) and two locations in the Southeast (b) of Scotland. Undersized (U) and legal sized (L) lobster data available from 1990-96 for the Hebrides and from 1990-97 for the Southeast. Note that missing values were included in the analyses. NB: Time is given in months.

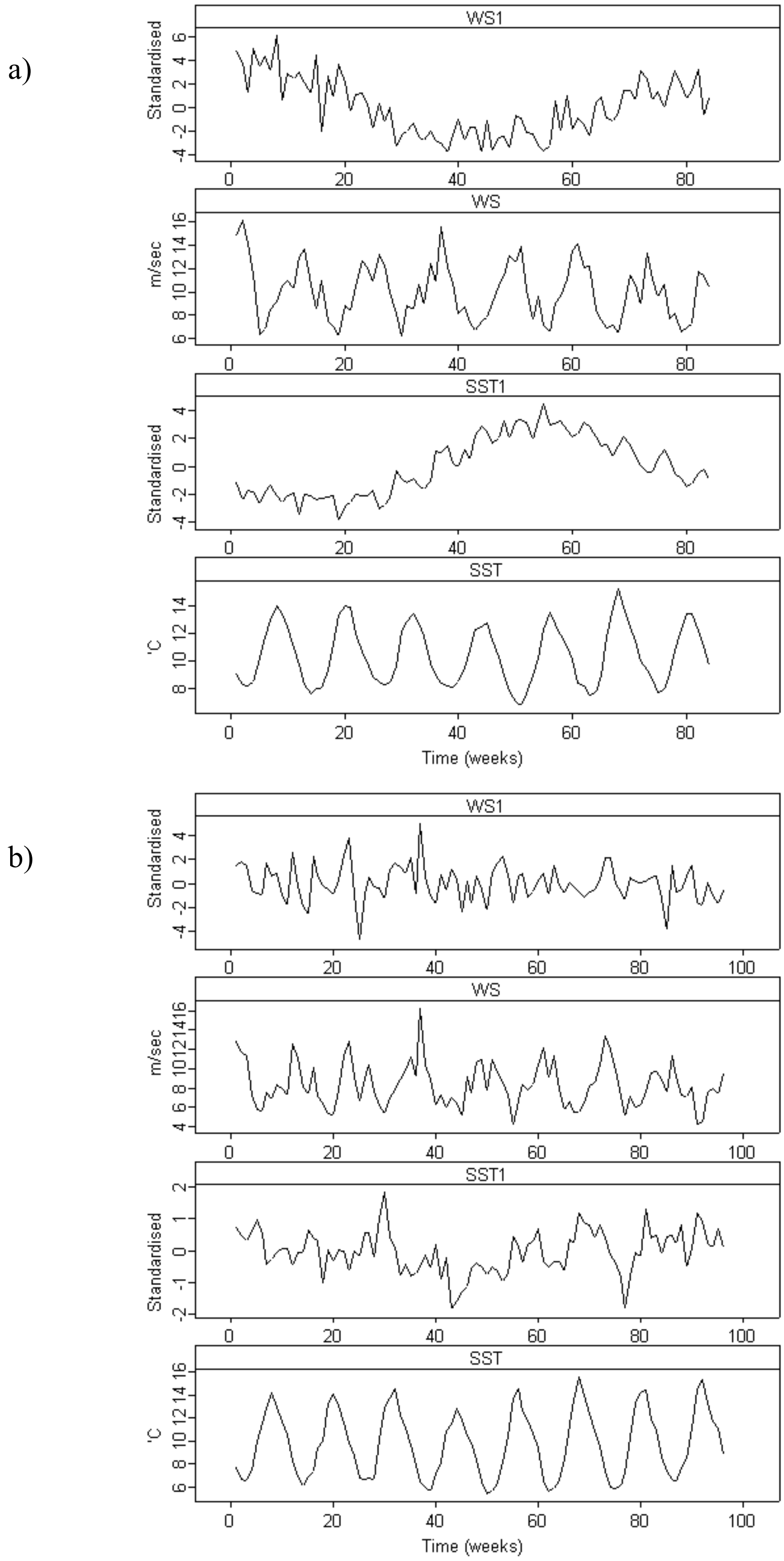

Fig. 3. Untransformed and standardised weekly time series of wind speed (WS) and sea surface temperature (SST) for the Hebrides (a) and Southeast (b) of Scotland. Data available from 1990-96 for the Hebrides and from 1990-97 for the Southeast.

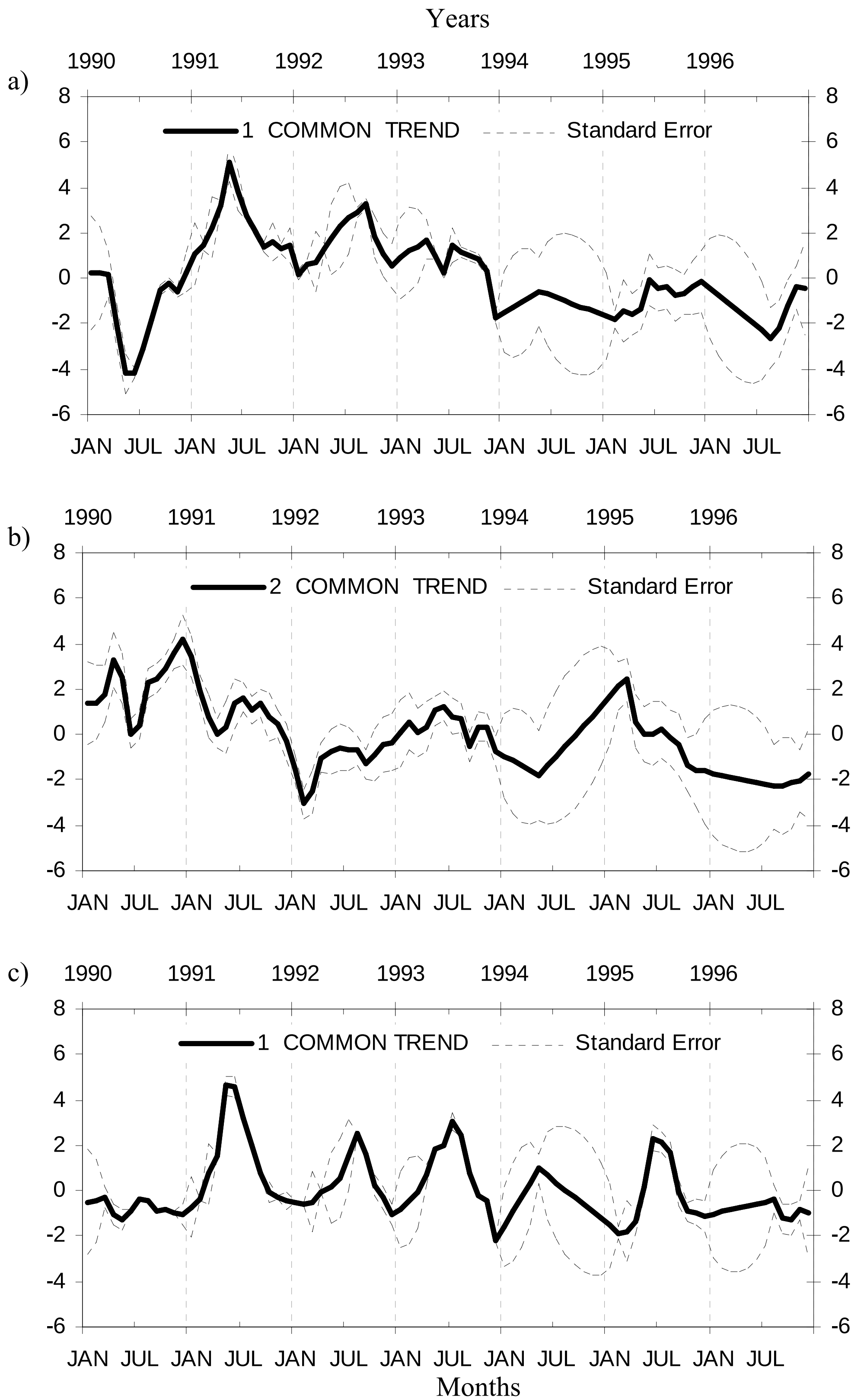

Fig. 4. Common trends for the optimal models for the Hebrides, de-seasonalised (a and b) and untransformed (c) monthly data series from 1990-96. The dashed lines indicate Standard Errors.

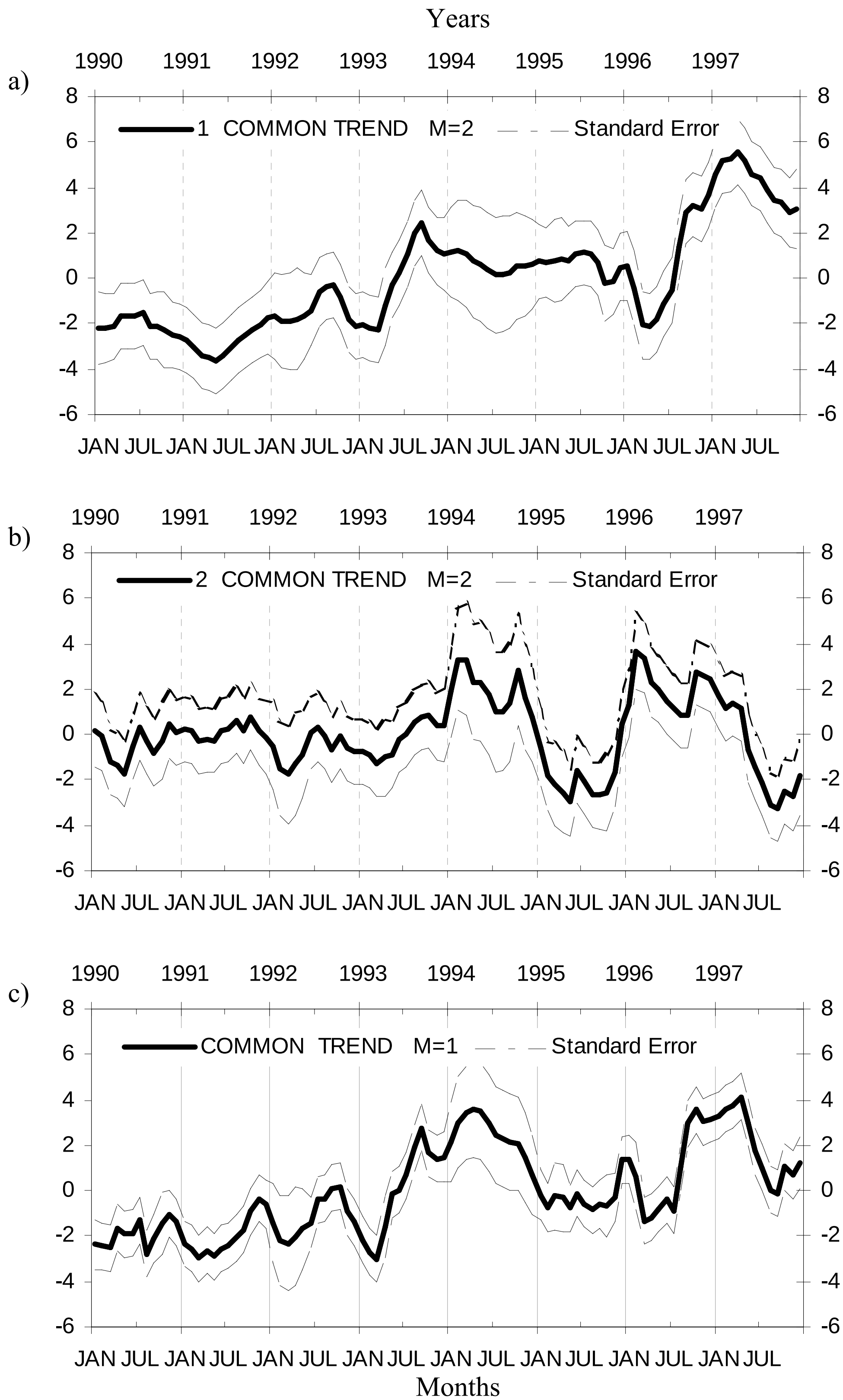

Fig. 5. Common trends for the optimal models for the Southeast, de-seasonalised (a and b) and untransformed (c) monthly data series from 1990-96. The dashed lines indicate Standard Errors.

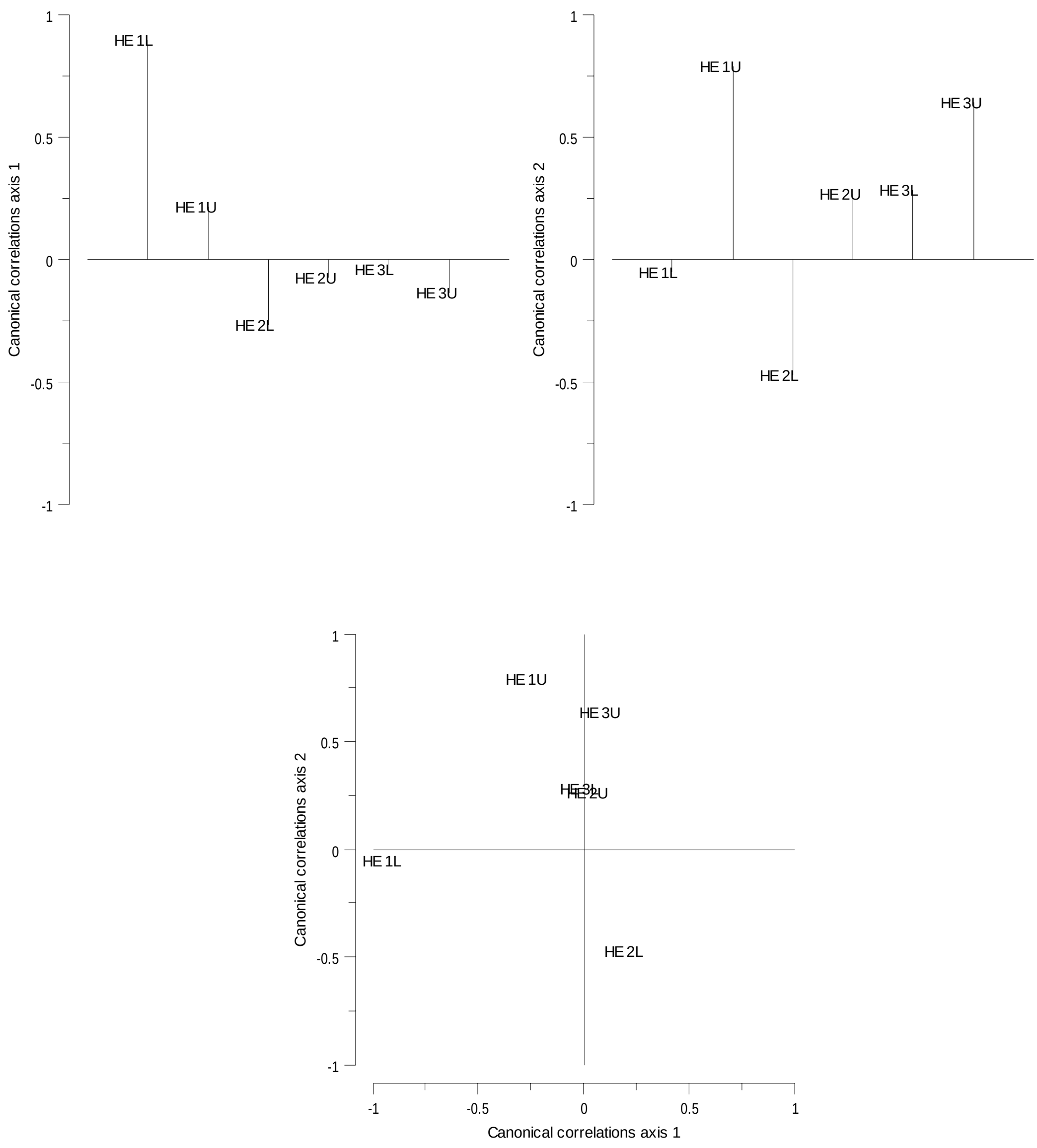

Fig. 6. Canonical correlations for the Hebrides optimum DFA model with two common trends and sea surface temperature (SST) as explanatory variable and a symmetric matrix. Axes represent common trends where axis 1 is common trend 1, top left, and axis 2 is common trend 2, top right. Biplot of the two axes also included, bottom.

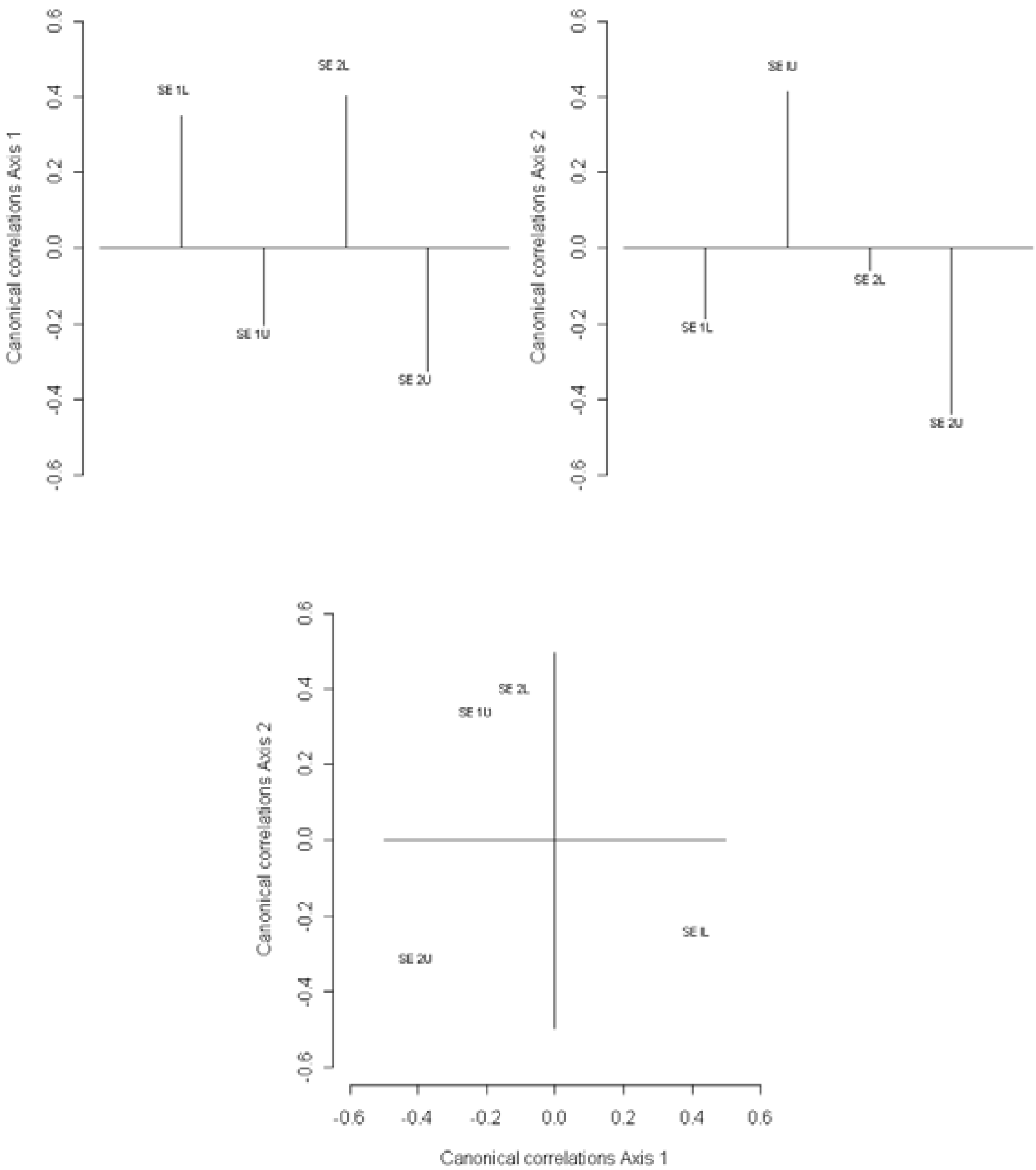

Fig. 7. Canonical correlations for the Southeast optimum DFA model with two common trends and sea surface temperature (SST) as explanatory variable and a symmetric matrix. Axes represent common trends where axis 1 is common trend 1, top left, and axis 2 is common trend 2, top right. Biplot of the two axes also included, bottom.

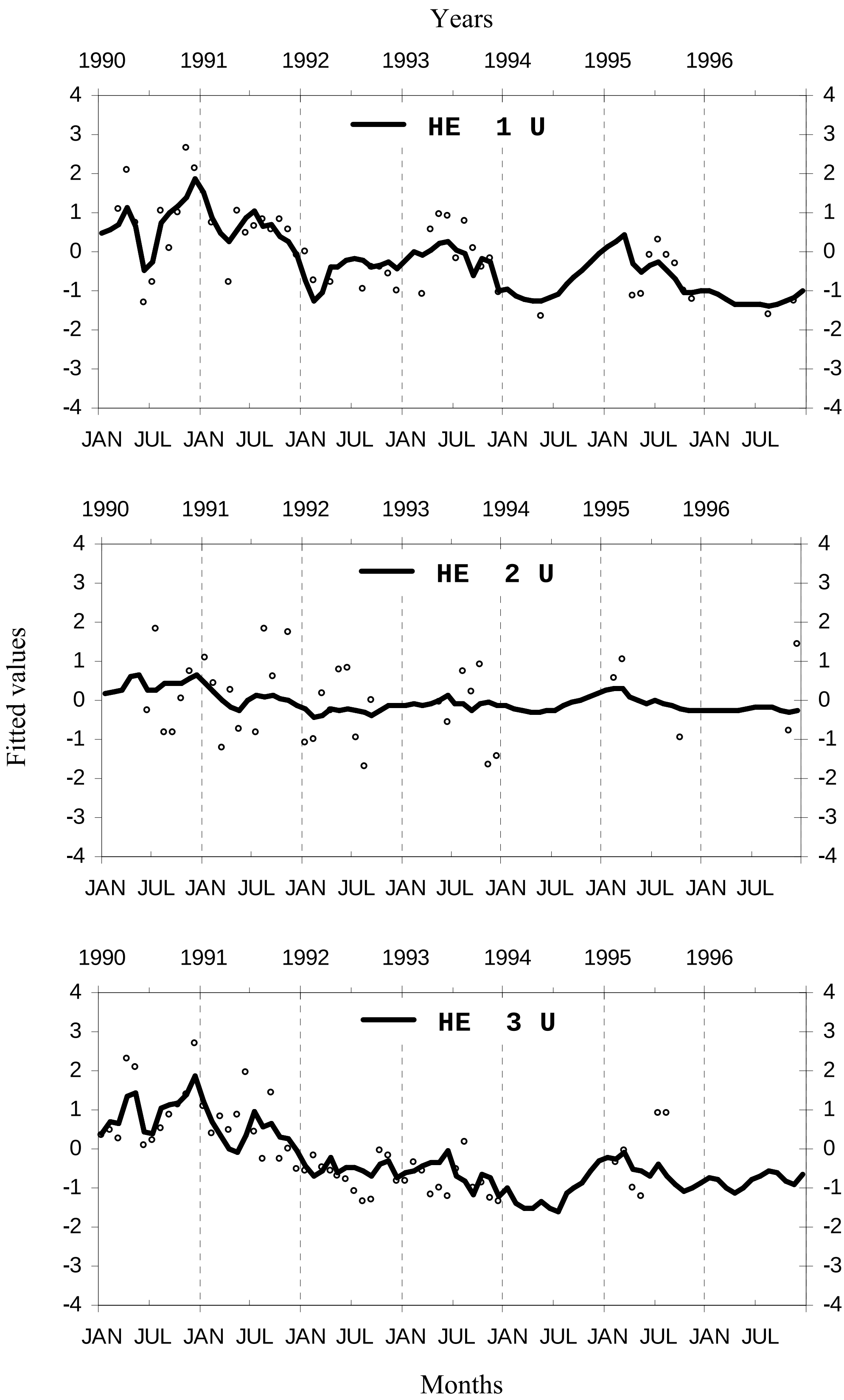

Fig. 8. Fitted values of the best model, for de-seasonalised data, with two common trends and SST as explanatory variables, for monthly time series of catch rates of undersized (U) lobsters in three locations in the Hebrides (HE 1, 2 and 3).

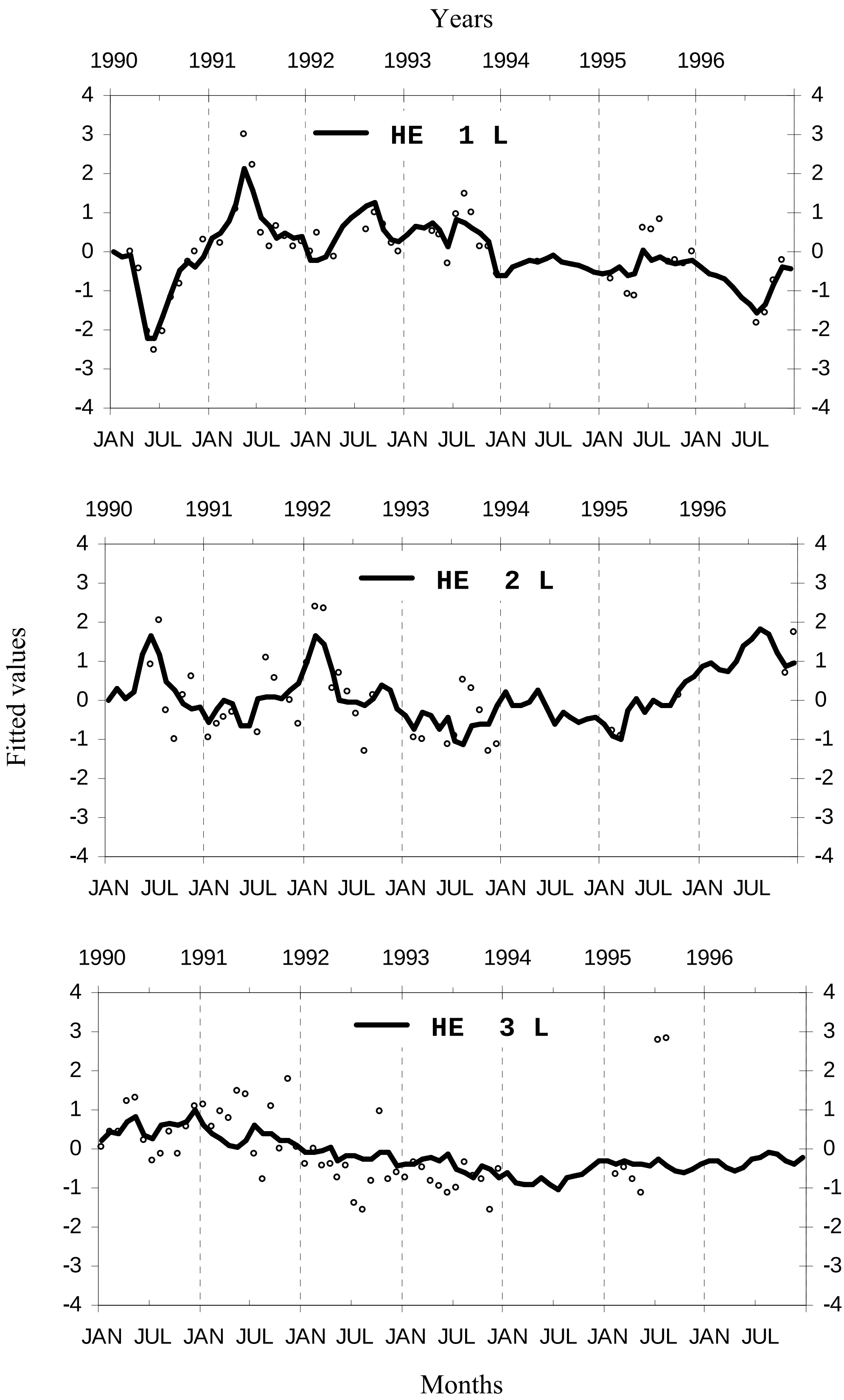

Fig. 9. Fitted values of the best model, for de-seasonalised data, with two common trends and SST as explanatory variables, for monthly time series of catch rates of legal size (L) lobsters in three locations in the Hebrides (HE 1, 2 and 3).

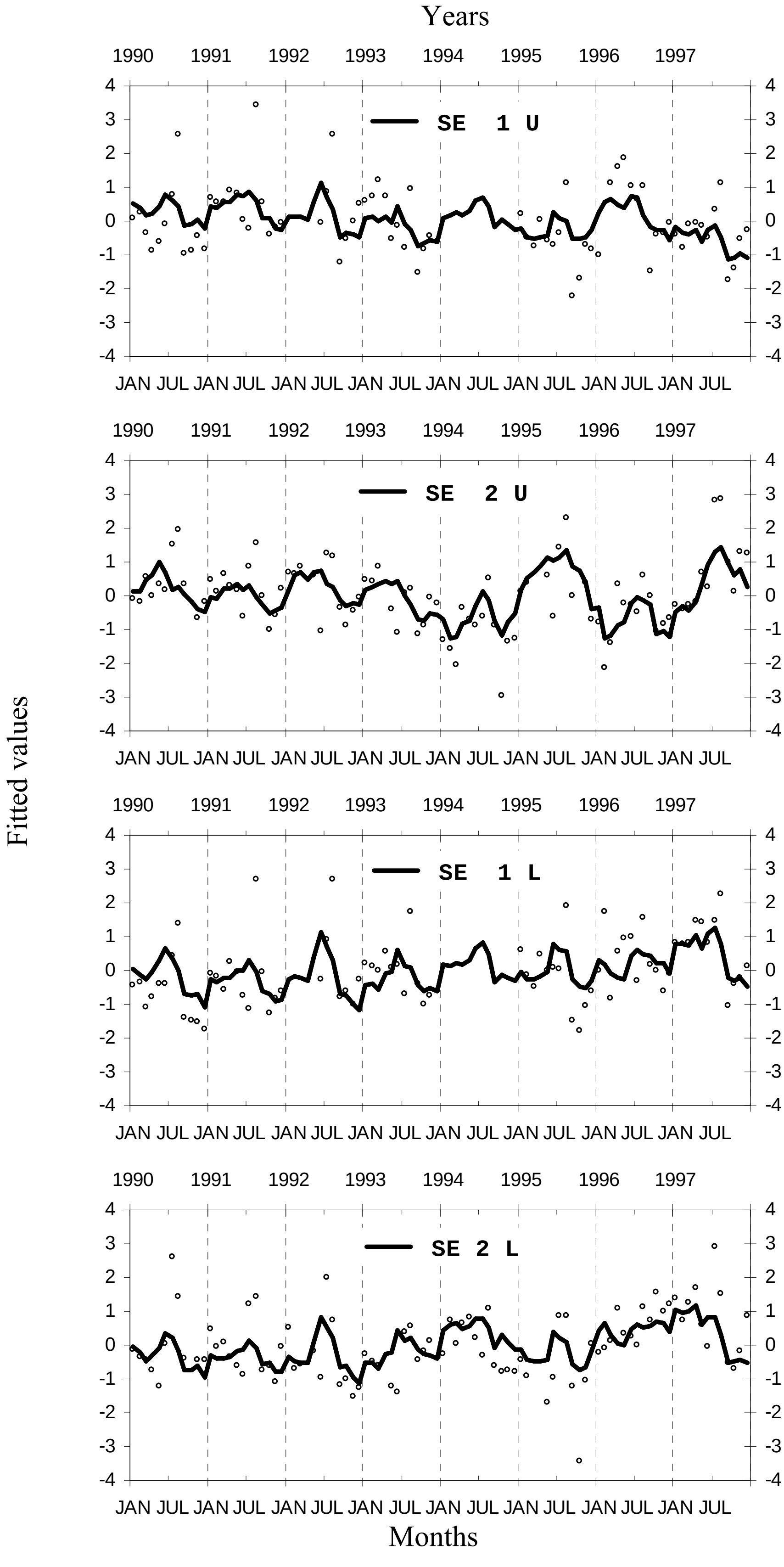

Fig. 10. Fitted values of the best model, for de-seasonalised data, with two common trends and SST as explanatory variables, for monthly time series of catch rates of legal (L) and undersized (U) lobsters in two locations in the Southeast (SE 1 and 2).

Table 1. Akaiken's information criterion (AIC) values for the models used in the dynamic factor analysis for de-seasonalised and not de-seasonalised data, with common trends (M), sea surface temperature (SST) and wind speed (WS), and diagonal ($_{d}$) and symmetric positive-definite or non-diagonal ($_{n\text{-}d}$) matrices. The optimal model of the de-seasonalised time series was obtained by the minimum AIC values, and is indicated in bold letters.

Model	M	De-seasonalised		Not de-seasonalised	
		Hebrides	Southeast	Hebrides	Southeast
data = common trends + noise	1_{d}	736.69	913.18		
	2_{d}	704.04	877.15		
	$1_{n\text{-}d}$	717.46	833.97		
	$2_{n\text{-}d}$	701.21	797.62		
data = common trends + WS + noise	1_{d}	725.17	915.50		
	2_{d}	707.41	879.79		
	$1_{n\text{-}d}$	707.65	832.70		
	$2_{n\text{-}d}$	700.00	797.95		
data = common trends + SST + noise	1_{d}	737.90	904.45		
	2_{d}	703.41	864.22		
	$1_{n\text{-}d}$	705.52	813.31	673.48	731.10
	$2_{n\text{-}d}$	**693.45**	**779.36**		
data = common trends + WS + SST + noise	1_{d}	729.52	908.94		
	2_{d}	707.30	866.82		
	$1_{n\text{-}d}$	706.15	814.48		
	$2_{n\text{-}d}$	697.19	781.07		

Table 2. Estimated parameters and t-values of the SST series and catch rates of undersized (U) and legal sized (L) lobsters from the Hebrides (HE) and Southeast (S. Parameters and t-values in italics are referred to as weak and numbers in bold to as strong series influenced by SST with common trends.

Location	Estimated values	t-value	Estimated values	t-value
	De-seasonalised		Not de-seasonalised	
HE 1 L	0.20	0.99 [ns]	0.03	0.14 [ns]
HE 1 U	-0.17	-0.80 [ns]	-0.24	-1.53 [ns]
HE 2 L	-0.57	*-2.83*	-0.37	*-2.47*
HE 2 U	-0.06	-0.32 [ns]	0.04	0.22 [ns]
HE 3 L	-0.37	*-2.73*	-0.26	-1.80 [ns]
HE 3 U	-0.50	-2.96	**-0.43**	**-3.36**
SE 1 L	**0.47**	**5.19**	**0.71**	**9.70**
SE 1 U	**0.34**	**3.53**	**0.44**	**4.23**
SE 2 L	**0.36**	**3.92**	**0.56**	**6.71**
SE 2 U	0.0.27	*2.97*	**0.40**	**4.18**

[ns] is not significant at the 5 % level.

Table 3. Factor loadings and Canonical correlations for the optimum DFA models for three locations in the Hebrides and two in the Southeast. Explanatory and response data were square rooted transformed and de-seasonalised for the analysis. Axes represent the common trends.

	Factor loadings		Canonical correlations	
Location	Axis 1	Axis 2	Axis 1	Axis 2
HE 1 L	0.90	-0.07	0.47	0.04
HE 1 U	0.22	0.79	0.10	0.44
HE 2 L	-0.27	-0.46	-0.25	-0.29
HE 2 U	-0.08	0.27	-0.06	0.14
HE 3 L	-0.04	0.30	-0.05	0.14
HE 3 U	-0.14	0.64	-0.07	0.33
SE 1 L	0.11	0.09	0.35	-0.19
SE 1 U	-0.13	0.15	-0.21	0.42
SE 2 L	0.13	0.21	0.44	-0.06
SE 2 U	-0.001	-0.34	-0.33	-0.44