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Methodology to create a proxy climate index for environmental and *Octopus vulgaris* fishery studies at the Northwest Africa. Analytical and mathematical analyses

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Methodology to create a proxy climate index for environmental and *Octopus vulgaris* fishery studies at the Northwest Africa. Analytical and mathematical analyses

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ABSTRACT

Several proxy indices have been built in local scales attempting to explain fluctuations of other variables, mainly climatological, which have regional interest (Chen, 1982; Trenberth, 1984; Dünkeloh and Jacobeit, 2003; Martín-Vide and López-Bustins, 2006; among others). In order to study the longitudinal low-frequency variability over the North-east Atlantic in the 20º-50ºN and 45ºW-20ºE domain through Sea Level Pressure (SLP) data sets, two methodological approaches are going to be applied. The first one is an analytical procedure; wheras the second is a mathematical one trough a Principal Component Analysis (PCA). Apart from that a review about other climatic indices over the North Atlantic Ocean and about the North-east pressure system have been done. The longitudinal movement of the Azores High is highlighted through an Azores-Liguria Index (ALOi), which has been built in the present study following the analytical method. It has been contrasted with other climatic indices over the North Atlantic Ocean. Then, the obtained climatic proxy indices (ALOi, NAOs and principal components results) were correlated with some fisheries data series to elucidate if the climate variations are the cause of the catches fluctuations in the West

African coast. Significant correlations of the proxy indices have been found with Sea Surface Temperature (SST) and wind stress (W). When correlating octopus catches data with climate variables for the considered domain, significant Pearson correlations were found for the NAO ($0.332 < R > 0.394$) with one lag, ALOi (for annual: R = -0.363 and -0.402; spring: R = -0.312 and -0.310 and summer: R = -0.325 and -0.302, time-scales) with two lags and with the Principal Component 3 (PC3. R = 0.515) with one lag. This fact enhances the importance of the W and SST in the region when considering the fisheries resources.

Key words: Azores-Liguria Index (ALOi), North Atlantic Oscillation (NAO), Western Mediterranean Oscillation (WeMOi), *Octopus vulgaris*.

1.- INTRODUCTION

The high atmospheric pressure centre over Azores seems to be very important to explain many of the environmental and biological events that occur in the North Atlantic Ocean, and particularly at the Northwest Africa area (Naya, 2002; Solari, 2008). It also helps to describe the anomalies of its latitudinal and longitudinal displacements and it could be relevant to explain an important part of the historical commercial catches oscillation in this area. A westward movement in spring and summer of the high over Azores is quoted in Hurrell and van Loon (1997) and for the strong North Atlantic Oscillation (NAO) winters are described by Kapala *et al*. (1998). Previous works have developed proxy indices for different areas with the objective of explaining changes in other variables (sea surface temperature, rainfall, dew point,...), such as those described by Trenberth (1976), Wallace and Gutzler (1981), Chen (1982), Jones *et al*. (1997), Pozo-Vázquez *et al*. (2000), Martín-Vide and López-Bustins (2006), among others. Most of them applied an Eulerian approach to the data sets or, as Mächel *et al*. (1998), a Lagrangian one.

According to the literature based on teleconnections, it is evident how complex these studies are. Several investigators used Sea Level Pressure (SLP) time series at a particular station and correlated them with other atmospheric data series. Some others used SLP between pairs of stations; others used linear combinations of SLP at three or more locations; or using time series of Sea Surface Temperature (SST), geopotential height, etc.. As highlighted by Troup (1965), the use of different stations from season to season is an advantage, since the various centres of action involved in the description of atmospheric features, vary seasonally in position and activity. For instance, for the North Atlantic Oscillation (NAO), while Azores is the southern station during the whole year, during winter the highest correlation with the station over Iceland is found with Gibraltar as the southern location (Pozo-Vázquez *et al*., 2000).

Ten prominent teleconnection patterns can be identified in the North Hemisphere. We can find the North Atlantic Oscillation (NAO) and the Eastern Atlantic Pattern (EA) over the North Atlantic Ocean. The East Atlantic/Western Russia Pattern (EA/WR), the Scandinavian Pattern (SCAND) and the Polar/Eurasian Pattern (POL) over Eurasia. Finally, we find the West Pacific Pattern (WP), the East Pacific-North Pacific Pattern (EP-NP), the Pacific/North American Pattern (PNA), the Tropical/Northern Hemisphere Pattern (TNH) and the Pacific Transition Pattern (PT) over North Pacific-North America. Our interest is focus on some of the mentioned patterns.

The NAO, is the most important one and is present during the whole year. This atmospheric oscillation is characterized by a north-south dipole pressure anomaly, with the low pressure located over Iceland and the high over Azores. The NAO presents two phases, one positive (i. e.: stronger than usual subtropical high pressure centre and a deeper than normal Icelandic low. This fact intensifies the westerlies flow) and a negative one (i. e.: weaker subtropical high and a weaker Icelandic low. This is translated in a decrease in the westerlies flow).

The EA, is the second low-frequency variability in importance in the North Atlantic domain. It is also a north-south dipole anomaly, even though the anomaly centre is displaced south-east regarding to the NAO. This is why this index is more important in the subtropical region than the NAO. It is characterized by three cetres of action, one South-west from the Canary Islands (25ºN/25ºW), another from West Great Britain (55ºN/20ºW) and the last one near the Black Sea (50ºN/40ºE) (Wallace and Gutzler, 1981). The positive phase of the EA pattern is associated with above-average surface temperatures in Europe in all months, and with below-average temperatures over the southern of the United States from January to May and in the north-central of the United States from July to October.

Another local index that we are going to use is the Western Mediterranean Oscillation (WeMOi) described by Martín-Vide and López-Bustins (2006) for the Mediterranean basin. It is defined by means of a dipole composed by the high pressure over Azores and the low pressure over Liguria. This index is the result of the difference of the normalized values in surface atmospheric pressure in San Fernando (Cádiz, Spain) and Padua (Italy). The WeMOi was also built to study local phenomena as the rainfall over the Iberian Peninsula (Martín-Vide and López-Bustins, 2006).

Uncertainties arise with long-periods time series, mostly if they are referred to remote locations. What happens with missing values? Does homogeneity exist for those records? What about the quality and consistency of the recorded values? To solve all these questions, “reanalysis” procedure has been developed since the Tropical Oceans

Global Atmospheric (TOGA) Programme (1985-1994). Reanalysis should be done frequently, at least every 5 or 10 years, taking advantage of the latest state-of-the-art systems (Trenberth, 1995).

The term “oscillation” describes the variability in the spatial-temporal pattern of the dipole formed by a high and a low pressure system. This oscillation is defined applying a Principal Component Analysis (PCA) to the data. This analysis gives several patterns (oscillations), each one associated to a spatial map (loading factors) and a Principal Component (PC) serie which is representative of the phenomenon. This temporal serie is used as an indicator of the oscillation. An “index” is the sign and magnitude that indicates the anomalies of associated elements in the studied region (e. g.: pressures at different stations) at any one time. It gives the intensity of the dipole that describes the oscillation. It may be considered as a dimensionless parameter representing the variations of one particular but unspecified process, with which the variations of the different elements are correlated (Troup, 1965).

The Eastern Central Atlantic, in particular the Northwest Africa domain (21º-26ºN) is the world seventh richest fishing area (FAO, 2004), due to several environmental factors associated to the intense upwelling that take place in the region (Bas, 1993). Cephalopods are characterised by having short life-cycles, and they need an optimal temperature and salinity range (7-33ºC and 32-40%, respectively) (Boyle and Rodhouse, 2005). In this way, Solari (2008) describes the capture oscillations during the last 50 years of *Octopus vulgaris* in the Northwest African upwelling system, and their correspondence with the NAO index variation, he assumed that they are good indicators of climate variability. Therefore, it is essential to understand the effect that environmental factors may have on their habitat and paralarvae mortality rate. In this sense, the ocean is almost homogeneous, but it is subjugated to the climate spatiotemporal variability, which affects directly to the biology of theses species and is reflected on their behaviour and abundance (Boyle, 1987; Hernández-López, 2001). Evidence of this influence does exist. The NAO may be one of the climate variables which are causing fluctuations, however it effect is complex even though if it shows a positive and linear relationship (Hsieh and Ohman, 2006; Solari, 2008).

The aim of this paper is to identify a climate index from the SLP variability over the 20º-50ºN and 45ºW-20ºE region, although the whole domain is amplified northward up to 65ºN (Figure 1). This is going to be done by two different procedures. The first one is an analytical method, considering two areas which can form a pressure dipole (i. e.: the high pressure system over Azores and a low one over the North Mediterranean Sea). Due to the differences between data bases, analysing techniques, approaches between studies and comparisons between results are difficult and non-accurate (Wallace and Gutzler, 1981), we built up a proxy index for the NAO (NAOp, hereafter), to validate the applied methodology, and an Azores-Liguria index (ALOi, hereafter). The other method is a mathematical approach by means of a principal component analysis (PCA), considering a 2.5º x 2.5º grid SLP map and SLP between pairs of stations (Figure 1). All this is done through an Eulerian approach.

The purpose to study this region in detail is to explain the abundance and recruitment fluctuations of some fisheries resources in the African-Canary area. Our interest is focused on the Azores High. For instance, the NAO is considered as an external forcing that may determine the temporal evolution of octopus populations. Catches of octopus are used as a proxy for abundance (see Solari, 2008) and assumed to represent population trend.

2.- MATERIAL AND METHOD

2.1.- Physical data

Monthly Sea Level Pressure (SLP) data were obtained from the CISL Research Data Archives for different locations: Iceland (Ic hereafter; 65º N/20º W), North of Azores (Az hereafter; 40º N/25º W), West of the Mediterranean Sea (WMed hereafter; 40º N/5º E), East Mediterranean Sea (EMed hereafter; 40º N/15º E), Ligurian Sea region (Li hereafter; 45º N/10º E), Portugal waters (Po hereafter; 40º N/10º W), Agadir (Ag hereafter; 30º N/10º W), South-West British Waters (SWUK heretafter; 50º N/5º W) and Gibraltar (Gi hereafter; 35º N/5º W) (Table I), extending from January 1899 to April 2008. These grids have been made-up by Digitized Sky Surveys (DSS) from the grids of various meteorological chart digitization projects and operational analyses; before 1962, there is only one grid per day, but since then there are two grids per day. Before 1946, grids had a 10º resolution and intermediate points were interpolated. Data set were updated regularly.

Data for the PCA and correlations between different parameters were obtained from several grid 2.5º x 2.5º databases from 20º-50ºN/45ºW-20ºE (Figure 1). Monthly SLP and surface zonal wind (W) data were downloaded from NCEP reanalysis from January 1950 to January 2000, were both included. On the other hand, monthly mean SST data were obtained from the NOAA Optimum Interpolation (OI) SST V2 from the National Centers for Environmental Prediction. Data are described in Reynolds *et al.* (2002) from December 1980 to January 2000.

Seasonal cycles have been removed in all the mentioned PCA data sets by subtracting the multiyear monthly time average for such time step.

2.2.- Climatic data

Two NAO data sets were downloaded from the Climate Research Unit (CRU) (NAOcru, hereafter) and from Dr. Jim Hurrell website, from the CGD's Climate Analysis Section (NAOjh, hereafter). Both data sets were compared with our proxy NAO index (NAOp).

Data for the WeMOi were obtained from Martín-Vide and López-Bustins (2006), also for comparison with our ALOi.

EA data set has been obtained from the website, of the NOAA database.

Monthly anomalies presents many short period fluctuations unrelated with the oscillation, which must be considered as noise. Trenberth (1976, 1977) eliminated those fluctuations using seasonal (3-month) values as the shorter period for which an oscillation has a real meaning. The main data used in this investigation are monthly SLP at the quoted stations because of convenience. Indeed, for climate monitoring, monthly data are widely used (Trenberth, 1984).

2.3.- Fisheries data

To evaluate the possible effect of physical parameters on marine populations, as an example, the Common octopus (*Octopus vulgaris*) catches from the Food and Agriculture Organization of the United Nations (FAO), for the Sahara domain (from Morocco to Senegal) from 1950 to 2006 has been evaluated. See Figure 1.

Although the data set starts in 1950, just the period since 1967 was considered in the statistical procedure. This was done because from 1950 to 1967, the increase of catches is due to changes in the fishery effort, not in the cephalopods abundance (Solari, 2008).

2.4.- Statistical Approaches to build an index

2.4.1. – Analytical Method

2.4.1.1.- Data Normalization

All the considered pressure centres must be equally represented in order to be able to make comparisons. This is why values for each station should be normalized before constructing the oscillation and the index. To do this, a normalization period of 30-year was selected, following the experts recommendations to establish a climatic index to avoid interannual and decadal variability (Pozo-Vázquez, pers. comm). Because 1971-2000 is the last completely period available (Pozo-Vázquez, pers. comm) results will be referenced to it after normalizing. Moreover, it is important to take into account that the last decades have been strongly influenced by the climate change, with an accumulation of positive NAO phases during the winters. This could imply that the 1971-2000 interval is not the best one to standardise our time-serie data. For this reason, the 1951-1980 was also evaluated. This procedure took out the seasonality of our SLP series. Normalizing factors differ depending of time scale, however, in this case we used monthly parameters.

2.4.1.2.- Signal-to-Noise Ratio Determination

The Signal-to-Noise ratio (S/N) defined by Trenberth (1984) is $\left(S/N\right)=\left(\frac{1-r_{12}}{1+r_{12}}\right)^{1/2}$, where r_{12} is the correlation coefficient between pairs of stations. The S/N gives the measure of the relative amplitude of the fluctuations in each time serie, this is the performance of the index as an indicator of the oscillation (Pozo-Vázquez, 2000). For that reason, firstly, we calculate the correlation coefficients making all the possible combinations with the selected stations (Table I). The interactions between the atmospheric pressure centres are mostly indicated by the signs of the correlation coefficients (Mächel *et al.*, 1998). Table II shows the correlation coefficients and the associated S/N ratio values for each pair of stations at different time scales. The persistence should be considered and removed when assessing the significance of correlation coefficients (sensus Trenberth, 1976), but this is seldom done, neither in our study. Moreover, the S/N ratio can be regarded as one measure of the effectiveness of an index (Trenberth, 1984). Thus, the highest the S/N ratio, better is the monitorization of the oscillation, because it means that the signal is bigger than the noise. A highly negative correlation indicates a strong out-of-phase relationship between the stations (Pozo-Vázquez *et al*., 2000). The best pair of stations will be used to construct our western-eastern index.

2.4.1.3.- Building the Proxy Index

An index is the pressure difference between the station with the high pressure centre of action and the low one of the selected dipole. The time series used to build it were normalized previously, so the proxy index is deseasonalized. With the same procedure, a seasonal (3-months) index can be built. When building an index it is important to guarantee that the selected stations are representative of the centres of action and to know that other local meteorological phenomena can affect the measures of pressure. The difference between stations remove some, but not all, the in-phase signals, due to those local meteorological phenomena, and enhance the out-of-phase signals. This must been taken into account, especially in relation with monthly and seasonal indices (Pozo-Vázquez *et al.*, 2000).

2.4.2.- Mathematical Method: Singular Value Decomposition and Principal Component Analysis

Singular Value Decomposition (SVD) and Principal Components Analysis (PCA) are techniques for analyses of multivariate data. Different procedures can be applied to do a PCA (see Horel, 1981; Barnston and Livezey, 1982). In this study the SVD during the PCA was used to obtain Principal Components (PC), through a factorization matrix of eigenvalues and eigenvectors (sensus North et al., 1982; Bretherton et al., 1992; Wallace et al., 1992; Cherry, 1997). The eigenvectors are linear combinations of each station data with established weights. These weights can be represented on a map.

The PCA reduces multidimensional data sets to lower dimensions for analysis. A time variation grid-point values of meteorological parameters are used to obtain eigenvectors which are subsequently individually scaled according to the amount of the total data variance they explain. Mathematically, it is an orthogonal linear transformation that convert the data into a new matrices system where the higher explained variance of the original data set is evident in the firsts PCs, which are the eigenvectors of the cross-covariance matrix between grid points (Horel, 1981; Barnston and Livezey, 1982; North *et al.*, 1982).

When the eigenvectors are multiplied by the square root of the principal component eigenvalue, the coefficients obtained are the correlation between the principal component and the original series of pressure data. It is important to have in mind that the principal components depends on the domain used for the analysis, this means that the PC that describes the region under evaluation can not be considered to elucidate what is happening in other place. For meteorological analysis, the first principal component often represents a useful objectively-determined weighted average of the original time series.

2.5.- Statistical treatments to catches data

A standardisation procedure was applied to the data set to make them normal. Afterwards, the trend and seasonality of all the catches data set were analysed and removed through a linear model if it was necessary. This let these series data to be statistically comparable with climatological parameters.

The seasonality of the cephalopod capture data series was evaluated and the trend was removed. The linearization gives us back the residual data, which are the ones of our interest to correlate them with the other variables.

3. RESULTS

3.1.- Selection of the eastern station and construction of the analytical Azores-Liguria Index (ALOi)

The results from the correlations and S/N ratio obtained from the combination between all the stations were used to select the index that best explains the west-east fluctuation of the Azores High (Table II).

Supported by our correlation, S/N ratio (Table II) and literature background, the selected eastern station was located at the north of Italy (Li). Although, the parameters were very similar to the East Mediterranean station (Table II), the Li is the one that shows the most stable negative correlation with the Azores High. This is because the north of Italy used to have a permanent low pressure system in comparison with Azores as it was described previously.

If we evaluate other relationships reported in Table II, it is possible to see how good is the dipole Azores-Iceland (describing the NAOp), that is, the ideal situation to build up an index. The stations of the Western Mediterranean, Portugal, Agadir, South-west Britain and Gibraltar do not show relevant negative correlation with Azores because the constrains explained above, even more, correlations are considerably high and positive, while the S/N is too small.

To construct the monthly ALOi, normalized pressure data of the Ligurian station was subtracted to the Azores one. Figure 2 shows the results of this difference for both normalization periods. There, we can see that the values for the normalizing period 1971-2000 are slightly higher than those for 1951-1980. However, in this study we have used the 1971-2000 because the difference with the other considered 30-year period is not too big and because it is the last 30-year period available.

3.2.- Mathematical description of the atmospheric pattern over the 20º-50ºN/45ºW-20ºE Atlantic region

From the SVD analysis, three PCs were obtained (Figure 3). The three first PC obtained from the principal component analysis explained the 48.35 %, 20.51 % and 13.97 % of the total variance, respectively (Figures 3 and 4), which is a high percentage (82.83 %) of the total variance explained. The remained PCs were considered as noise.

To see the importance of these components of the teleconnection pattern, each of them has been correlated with the SST (Figure 5) and the wind stress (W, Figure 6). From the correlation between the PC1 and SST (Figure 5.1a and b), it can be concluded that the predominant area is from Canary Islands to 20º-30ºN/~40º-10ºW, with small but opposite correlation values . The correlation between the PC2 and the SST (Figure 5.2a and b), makes stand out the south-west of Europe, especially the Portuguese coast, but although it shows a negative and small correlation values with the front over Azores, it is highly significant. From Figure 5.3a two patterns were obtained, (i) small and negative correlations in the west and east boundaries and (ii) small but positive in the remained areas, but the Figure 5.3b highlights only the south, north and eastern edges on the studied region as significant.

The SLP has been correlated with the wind stress (W, Figure 6) and has shown some significant centres of action, where both parameters were well correlated. When using the PC1 for the correlation (Figure 6.a) three regions were highlighted: Azores with a really high correlation, north Mediterranean sea and the Canary region both last with low correlation. This means that as increase the pressure anomaly over Azores more stability in the wind stress pattern at the north Mediterranean Sea and the Canary area. Otherwise, the correlation between PC2 with W (Figure 6.b) shows that when the SLP increase over Azores the wind stress decrease in the same area, but it intensifies in the Canary and West Mediterranean areas. On the other hand, the relationship between PC3 and W (Figure 6.c) shows that as increase the pressure variability in the whole system, less wind stress at the north and south of Azores was found, but more at the centre and West Mediterranean area.

The Azores-Liguria Index is defined analytically by the dipole composed by the Azores High and the Ligurian Low as quoted before. From the Principal Component Analysis (Figure 6.a), an oscillation phenomenon is observed for the PC1 when correlating it with the wind stress (W). This Figure also shows the analytically built ALOi, so this is a mathematical confirmation of the existence of this proxy index. To analyse the importance of the ALOi as a climatic pattern in the studied domain, this proxy index has been correlated through a PCA with the SST (Figure 7) and the W (Figure 8). Again, the Figure 6.b and 7.a shows that the Azores region marks a limit between the eastern and western areas. Moreover, Figure 7.b also puts in evidence this situation where the regions north and southward Azores are not significant in comparison with the previous ones. On this way, Figure 8 draws an east-west pattern that divide the North-east Atlantic in two regions separated by an imaginary diagonal line between the south of UK and beyond Azores.

Figure 9 represents the areas where correlation between SLP and W were significant. It shows almost the same situation, but with opposite sign, than observed in Figure 6.b. When correlating the SLP against W, it can be seen that Azores and the Mediterranean areas have the same behaviour: when SLP increase W decrease and viceversa; the opposite situation was obtained at the Canary region. These three areas are also the most statistically significant ones. Moreover, from the Portuguese coast to the west of the Canary Islands was found a relatively high and positive correlation between both parameters; the same was found over the north and east Mediterranean Sea. Meanwhile, the Azores region presents a highly negative correlation between the ALOi and W. This trend was slightly appreciated when correlating the proxy index with the SST (Figure 7), however it was evident the difference between regions. In the correlations against the wind stress all points were significant.

3.3.- Correlation of ALOi proxy index with North Hemisphere Indices

The correlations between the proxy index of the NAO (NAOp) with the other two NAO considered (NAOcru and NAOjh), using the Spearman approximation, were $R_{NAOp\text{-}NAOcru} = 0.78$ and $R_{NAOp\text{-}NAOjh} = 0.90$. The Pearson correlation was also considerable: $R_{NAOp\text{-}NAOcru} = 0.77$ and $R_{NAOp\text{-}NAOjh} = 0.92$ (all cases were significant at $p < 0.05$). Difference between correlations against NAOcru or NAOjh could be due to the methodology applied to infer the index (Table III, Figure 10).

The correlation coefficients of the relationships between PC1 and NAOcru or NAOjh are shown in Table III. In both cases correlations were highly negative, but significant. In Table III are shown the coefficients of correlations between ALOi and WeMOi. The low correlation in $R_{ALOi\text{-}WeMOi}$ can be due to the spatial scale used in each index. Both figures showed a considerably high similarity in the peaks and in the general tendency. Figure 10 reflects the difference observed between indices.

In order to proof the goodness of the analysis and to elucidate if the local variability observed can be explained by the already used indices such the NAO, EA, among others, or if those fluctuations are explained in an accurate way by local proxy indices, the ALOi was correlated against the EA (Pearson correlation $r = -0.29$; $p < 0.05$; Spearman $R = -0.24$; $p = 0.06$; Table III) indicating that they are not the same index. In fact it has more to do with the PC2 and PC3, because significant correlations were obtained ($R_{Pearson} = 0.29$ and -0.37, respectively; $R_{Spearman} = 0.22$ and -0.23, respectively. Table III).

3.4.- Correlation of ALOi with octopus catches

Figure 11 show the curve of the (a) catches data before applying any treatment, (b) the logarithmic of those catches with the fit superpose and (c) the residual data after applying the linear model to remove the trend.

The residuals show the same curve than the logarithmic data because the data set have no trend. Although the fit-line is not in the X-axis, the statistical parameters obtained with the model (estimation = 0.00417; $p = 0.369$) indicates that the increasing trend is not representative of data evolution.

Figure 12 (a and b) are the results of applying the seasonality analysis. It can be seen that the data set does not present seasonality since there are not any evident cycle in the spectral and density distribution analyses.

Table IV and Figure 13 (a-g) are the Pearson correlation tests between cephalopods and the climate indices. Only the ones that have significant correlations are shown. As highlighted in Solari (2008), significant correlations (Figure 13.a-c) were found with the three NAOs considered, with a lag of 6 years. This was associated with the NAO periodicity and the biological memory of the stock (sensus Solari, 2008). Figure 13.d show that cephalopods catches is correlates with the ALOi in two years lags; the first one is for the first year and the second is for the fifth. Also a seasonal effect of the ALOi was elucidated in cephalopods catches. In this sense, spring (Figures 13.e) and summer (Figures 13.e) indices are shown. Cephalopods captures were significantly correlated with spring ALOi at 0 and 7 years lags. Moreover, it was also correlated with summer ALOi at 2 and 5 years lags. Finally (Figure 13.g), the cephalopods catches against the PC3 gave a significant correlation at lag = 0.

4.- DISCUSSION

Some authors recommend using seasonal data when analysing climatic features (e. g.: Troup, 1965). However, our work was focused on monthly data because of convenience to do correlations with the available fishing data (annual catches). This consideration is supported by Trenberth (1984) where is highlighted that monthly data are widely used when evaluating climate.

All climatic data should be firstly normalized before taken them into account for the analyses. The climatological community considered that a 30-year period is enough to standardise a time serie data. In this sense two 30-year periods were considered, but only the latest one available (1971-2000) was used in the methodology procedure. This was because the difference between 1951-1980 and 1971-2000 periods was too small as shown in Figure 2 for the ALOi. However, it is important to bear in mind that the last decades since the 80’s have been characterised by an accumulation of positive NAOs, mostly during winter, but this have no interference with our results. Dünkeloh and Jacobeit (2003) highlighted that this has also been reflected in the Mediterranean Sea, where an increase in pressure (at surface and upper troposphere) has been detected. This increase has been more evident in the west and central basins than in the east one. Changes are consistent with a weakening and decreasing of cyclones and an increase in anticyclones number during October-March periods of the last decades (Dünkeloh and Jacobeit, 2003). On the other hand, a low pressure system is almost permanent at the north of Italy (Dünkeloh and Jacobeit, 2003; Martín-Vide and López-Bustins, 2006). Even more, Esteban *et al*. (2005) showed, using a clustering procedure, a strong high pressure system over Azores and a low over the Mediterranean basin and they highlighted that this is a frequent situation during the whole year.

All the preceding things leads us to considered Liguria as the eastern station to build up our index through analytical and mathematical procedures. The reason of choosing so many locations as eastern stations was to find, numerically, the best correlation with the western one (Azores). It was desirable that stations represent the centres of action. The best S/N ratio was obtained against Azores with Liguria as shown in Table II in the analytical method, while through the mathematical one. Both techniques have been developed independently, even though they showed similar results in the main proxy index that can be obtained (Figure 6.a). The aim was to try to elucidate if the longitudinal movement of the Azores High was important in local scales to explain the fluctuation in the catches of octopus in the Sahara domain (Tables IV).

From the PCA, only the three first PCs (from 20 PCs obtained) were considered because their sum explained the 82.83% of the total variance. This was our selected criterion and it is important to know that this item depends on the author (Barnston and Livezey, 1982). From this analysis it can be concluded that the Azores atmospheric system control the surrounded regions from a physical point of view. For instance, when the SLP over Azores is intensified, the W in that region is very weak. Meanwhile, with this situation, the W in the Canary area is strong, but also with a high SLP data. These are the trade winds. This situation is translated into an intensified West-African upwelling system which is a physical barrier for some fish migrations (Ramos, 1992), but also a very productive realm. This is also evident when correlating the ALOi against the W; i. e., when the Azores High is in its western position, the wind in Liguria and from the Portuguese coast, south and westward the Canary Islands is really strong.

The ALOi proxy index emphasises the importance of the Azores High in the North-eastern-central Atlantic domain rather than the NAO index, as observed when it was correlated with the SST. A front is clearly evident from 20º-50ºN and going from 10ºW diagonally to 35ºW, approximately.

Using the PCs for correlations with physical parameters, once more, the Azores domain reveals a different behaviour that controls the neighbouring regions. In the first two PCs, the Canary domain has an opposite situation to the one over Azores for SST and W. For the PC3 against SST and W the central region of the studied area, including Azores, has a different behaviour than the remainder areas.

As it was expected, the Azores High *per se* governs the climatic and biological cycles at the Central-east Atlantic Ocean. Obviously, all its atmospheric states have different degrees of influence on the ocean and, indirectly, on marine populations. Previous works (e.g.: Santiago, 1998; Solari, 2008) highlighted that the NAO is reflected in the fluctuations of the fisheries, but it is also known that southward the Canary region it has less accuracy to describe biological and climatic phenomena. The present results demonstrated that for the 20º-50ºN/40ºW-20ºE domain, and southward to the Equator, local indices have to be build. This is supported with the significant correlations that have been obtained for physical and biological parameters.

In this framework, the octopus catches are significantly correlated with the NAO as expected, but also with the ALOi, and its spring and summer variations, and with the PC3. The fact that correlations with ALOi are bigger than those with NAOs is also put into relevance the needed to built local proxy index to explain fluctuations at regional scale in the Central-east Atlantic Ocean.

In the Northwest Africa octopus case, the catches data were linearly treat as a whole showing the already known two catch peaks for the area: (i) from March to June and (ii) from September to October (Guerra and Pérez-Gándaras, 1983; Bravo de Laguna and Balguerías, 1993; Hernández-García et al., 1998). Moreover, both peaks were correlated with the spring and summer ALOi. On the other hand, Figure 11.a shows the presence of three pattern in the capture serie: (i) from 1967 to 1970 the captures were maximal, but (ii) it decreased abruptly from the early 70s to late 80s, to (iii) show strong variations in abundance until 2006. In this way, a linear fit gives the “balanced values” of the fishery, but it does not explain the dynamical process of the stock. Despite this, the analysis is correct. The described dynamic situation is due to the fluctuations of the carry capacity of the system that is reflected in the catches (recruitment to the area/fishery) described by the ALOi. Captures (recruitment) can be considered as an abundance Proxy (sensus Solari 2008).

5.- CONCLUSIONS

From the whole analysis developed in this study it can be concluded that the Azores atmospheric system controls the teleconnection patterns over the 20º-50ºN/45ºW-20ºE area. This is clearly evident in the physical parameters and in the octopus catches data.

Further analyses must be done following this study as a base-point. Looking for other local dipoles southward that may explain other fisheries fluctuations with more significant correlations than the ones quoted before. Also the considered area must be amplified southward to complete the study.

To conclude, the ALOi is a adequately proxy index to explain physical (SST and W) and octopus fisheries parameters variations in a regional scale, at least, when considering the Canary area as the southern edge.

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CISL Research Data Archives: http://dss.ucar.edu/data sets/ds010.1/data/

FAO: http://www.fao.org/fishery/statistics/software/fishstat

NCEP: http://www.cdc.noaa.gov/cdc/reanalysis/reanalysis.shtml

NOAA: http://www.cdc.noaa.gov/ cdc/data.noaa.oisst.v2.html

ftp://ftp.cpc.ncep.noaa. gov/wd52dg/data/indices/tele_index.nh

TABLES

Table I: Summary of the locations of the considered stations:

	Latitude	Longitude
Ic	65º N	20º W
SWUK	50º N	5º W
Li	45º N	10º E
Az	40º N	25º W
W Med	40º N	5º E
E Med	40º N	15º E
Po	40º N	10º W
Gi	35º N	5º W
Ag	30º N	10º W

Table II: Correlation Coefficients (C.C.) and Signal-to-Noise (S/N) ratio between the five stations, for different time scales, independently of the considered period. IIIa shows Az against Iceland, West Mediterranean, East Mediterranean and Liguria. IIIb shows the correlations coefficients and the S/N ratio for Portugal, Agadir, South.west United Kingdom and Gibraltar. Notice that for these tables, the two 30-year periods considered for the standardisation of the data set are not distinguish because, since the apply normalization window is the same, results are the same.

IIIa	Az-Ic		Az-WMed		Az-EMed		Az-Li	
	C.C	S/N	C.C	S/N	C.C	S/N	C.C	S/N
J	**-0.54**	**1.67**	0.38	0.22	0.15	0.37	0.22	0.32
F	**-0.49**	**1.46**	0.44	0.19	0.27	0.29	0.36	0.24
M	**-0.64**	**2.28**	0.48	0.18	0.37	0.23	0.37	0.23
A	**-0.49**	**1.46**	0.18	0.35	0.02	0.48	0.09	0.42
M	**-0.5**	**1.50**	0.1	0.41	**-0.05**	**0.55**	0.01	0.49
J	**-0.53**	**1.63**	0.29	0.28	0.23	0.31	0.17	0.35
J	**-0.34**	**1.02**	0.24	0.31	0.08	0.43	**-0.04**	**0.54**
A	**-0.47**	**1.39**	0.05	0.45	**-0.13**	**0.65**	**-0.09**	**0.60**
S	**-0.46**	**1.35**	0.09	0.42	0.07	0.43	**-0.05**	**0.55**
O	**-0.45**	**1.32**	0.01	0.49	**-0.18**	**0.72**	**-0.18**	**0.72**
N	**-0.32**	**0.97**	0.15	0.37	0.09	0.42	0.05	0.45
D	**-0.44**	**1.29**	0.2	0.33	**-0.01**	**0.51**	0.11	0.40

IIIb	Az-Po		Az-Ag		Az-SWUK		Az-Gi	
	C.C	S/N	C.C	S/N	C.C	S/N	C.C	S/N
J	0.82	0.05	0.61	0.12	0.38	0.22	0.62	0.12
F	0.81	0.05	0.48	0.18	0.47	0.18	0.59	0.13

M	0.77	0.06	0.44	0.19	0.41	0.21	0.58	0.13
A	0.59	0.13	0.28	0.28	0.24	0.31	0.29	0.28
M	0.59	0.13	0.21	0.33	0.28	0.28	0.25	0.30
J	0.52	0.16	0.35	0.24	0.35	0.24	0.31	0.26
J	0.47	0.18	-0.13	0.65	0.14	0.38	0.15	0.37
A	0.22	0.32	0.02	0.48	0.08	0.43	-0.07	0.58
S	0.49	0.17	0.11	0.40	**-0.01**	**0.51**	0.15	0.37
O	0.6	0.13	0.33	0.25	0.07	0.43	0.25	0.30
N	0.61	0.12	0.37	0.23	0.19	0.34	0.38	0.22
D	0.73	0.08	0.33	0.25	0.46	0.18	0.4	0.21

Table III: Summary of the Spearman and Pearson correlation analyses between indices.

Buried on mind that proxy indices are referred to the 1971-2000 normalization period.

	$R_{Spearman}$	p-value	$R_{Pearson}$	p-value
NAOp/NAOcru	0.78	0.0000000	0.77	< 0.05
NAOp/NAOjh	0.90	0.0000000	0.92	< 0.05
PC1/NAOcru	-0.58	0.0000000	-0.54	< 0.05
PC1/NAOjh	-0.41	0.0000000	-0.44	< 0.05
ALOi/WeMOi	0.46	$1\cdot 10^{-6}$	0.46	< 0.05
ALOi/EA	-0.24	0.06	-0.29	< 0.05
PC2/EA	0.22	0.0000000	0.29	< 0.05
PC3/EA	-0.23	0.0000000	-0.37	< 0.05

Table IV: Annual Correlations results between cephalopods catches and climate data. Bear in mind that proxy indices are referred to the 1971-2000 normalization period.

Variables	Lag with significant value	$R_{Pearson}$
Cephal./NAOcru	6	**0.341**
Cephal./NAOjh	6	**0.394**
Cephal./NAOp	6	**0.332**
Cephal./ALOi	1	**-0.363**
Cephal./ALOi	5	**-0.402**
Cephal./ALOi_spring	0	**-0.312**
Cephal./ALOi_spring	7	**-0.310**
Cephal./ALOi_summer	2	**-0.325**
Cephal./ALOi_summer	5	**-0.302**
Cephal./PC3	0	**0.515**

FIGURES

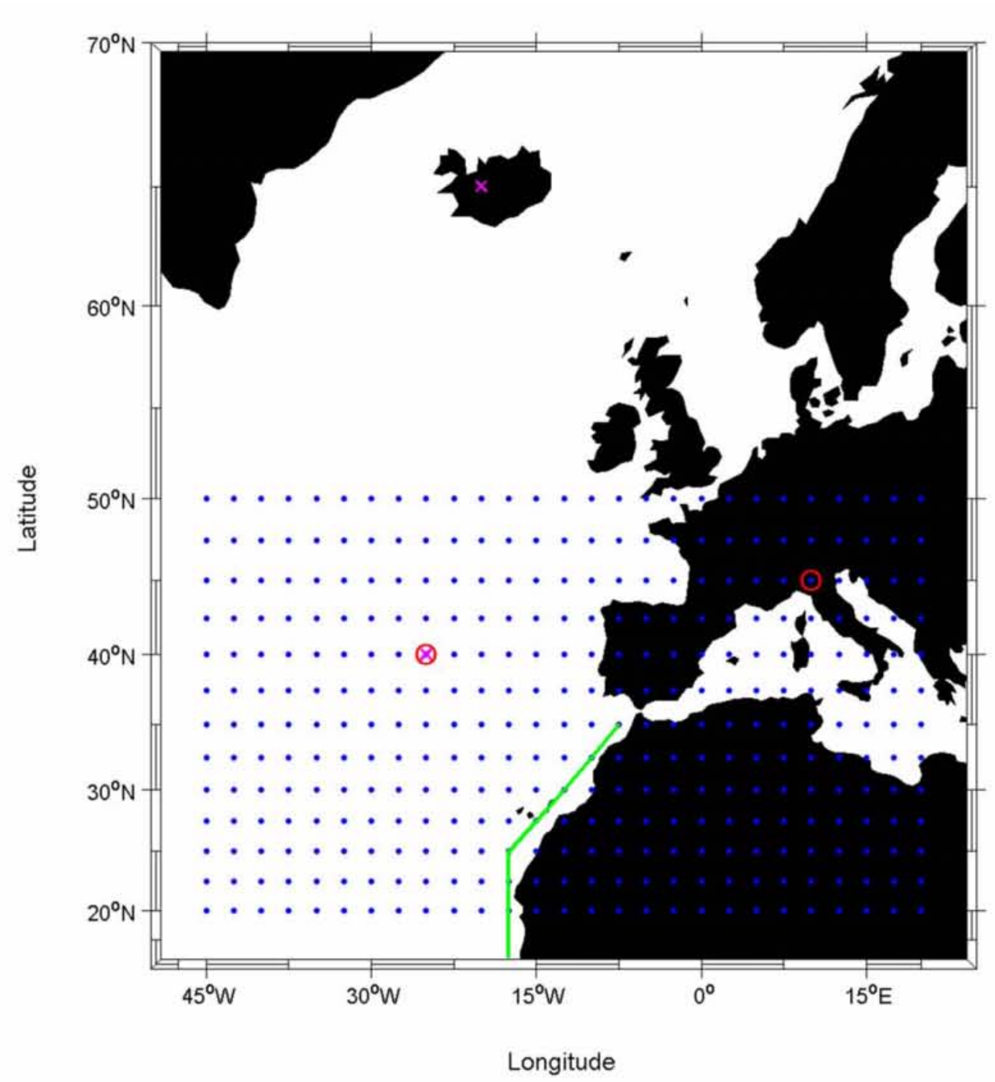

Figure 1: Locations of the stations considered in the present study. Red circles are the finally selected stations to create the ALOi and the pink cross are the ones used to build up the NAOp. Blue dots are the 2.5º x 2.5º grid for the PCA. The green line indicates approximately the catches area.

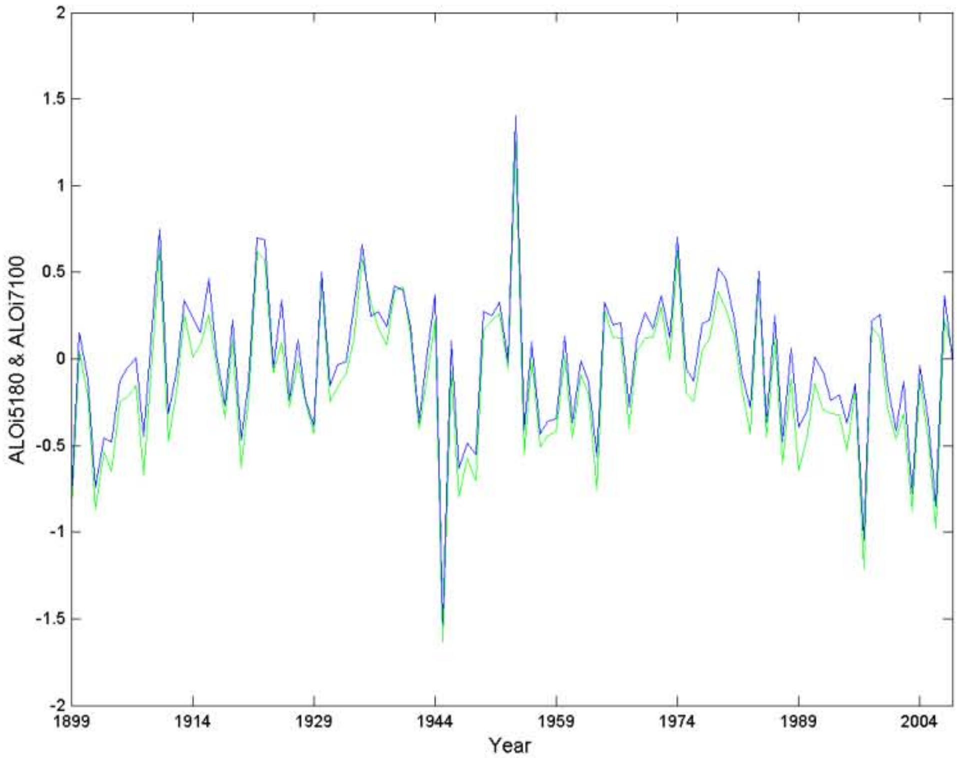

Figure 2: ALOi for both normalizing periods. Green line represents the 1951-1980 normalization period and the blue one is the 1971-2000 30-year period.

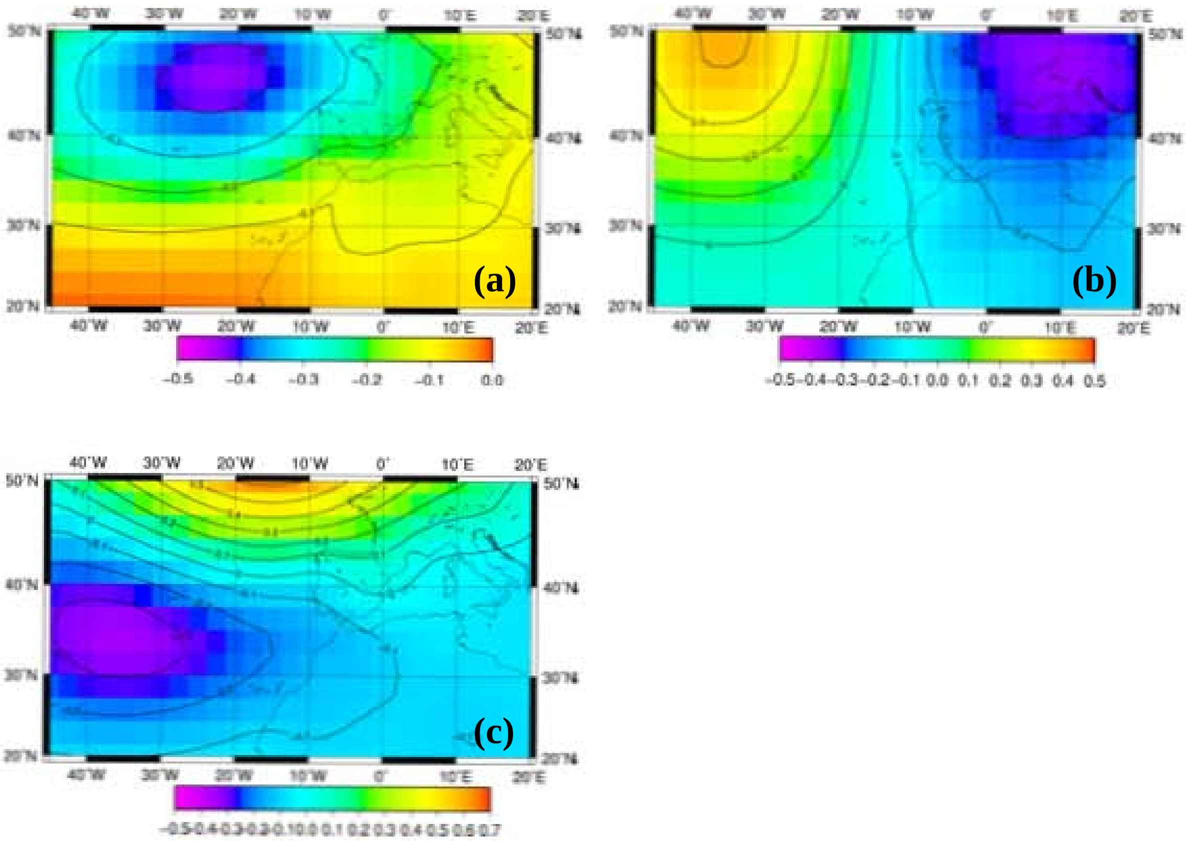

Figure 3: The three PC obtained from a SVD in the PCA are shown. (a) is the first PC, (b) is the second and (c) is the third one.

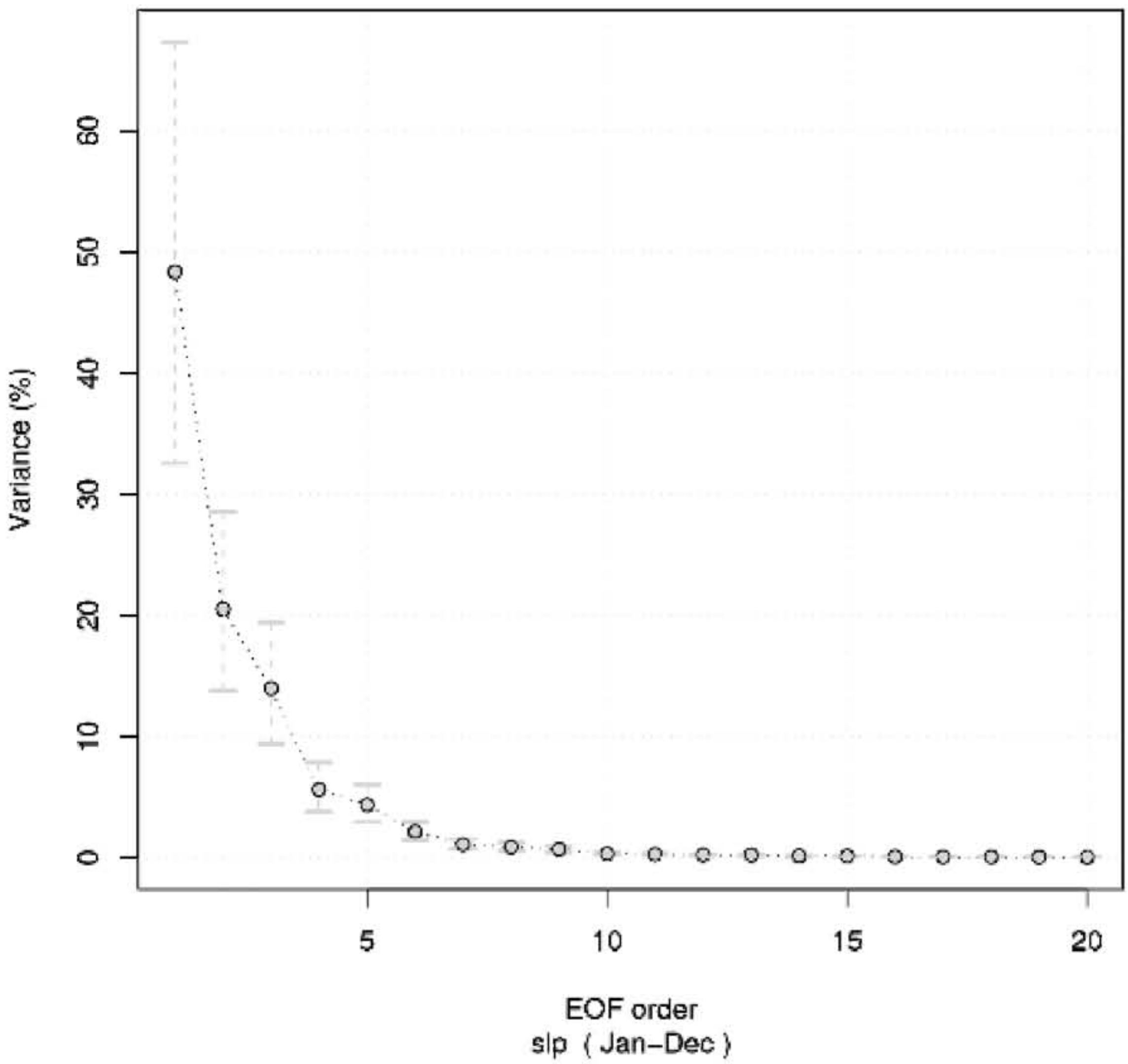

Figure 4: Total variance explained by the Principal Component Analysis. Is relevant the high percentage explained by the three first PC (48.35 %, 20.51 % and 13.97 %, respectively).

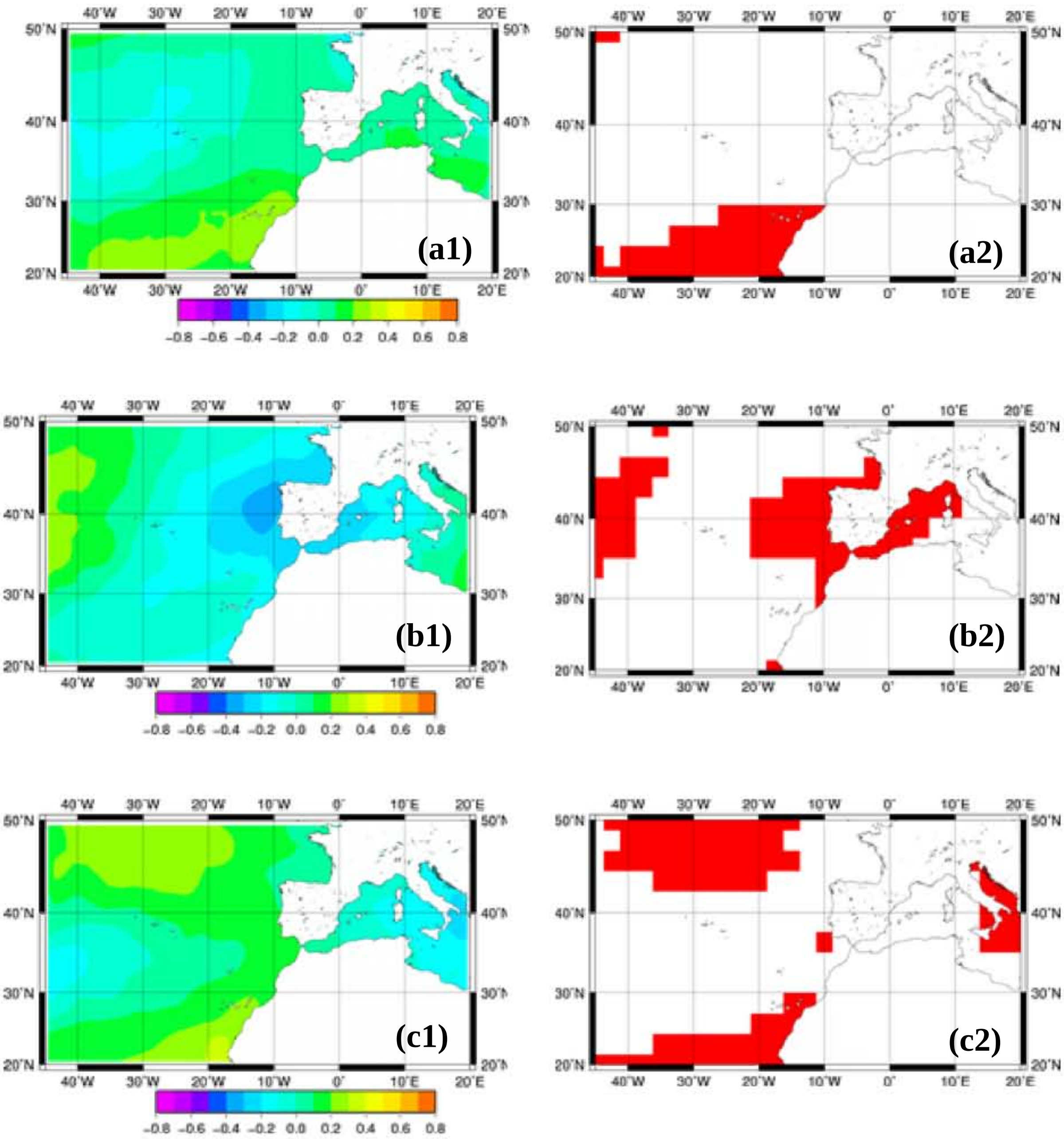

Figure 5: Correlation (a1, b1, c1) and significance (a2, b2, c2) of the three PC with the SST.

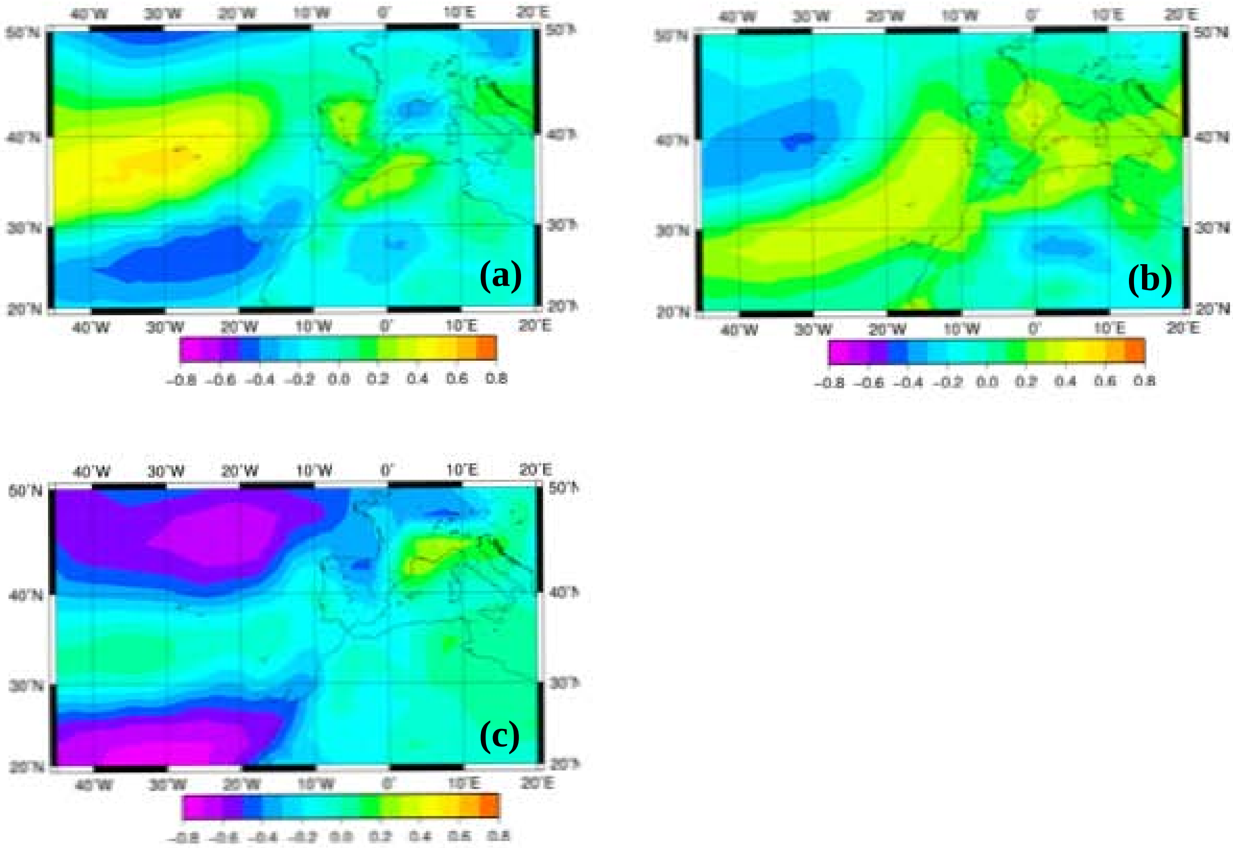

Figure 6: PCA correlating each of the three (a to c) main PC and the wind stress (W). In (a) it is evident the presence of the dipole which describes the Azores-Liguria Index built in the present study.

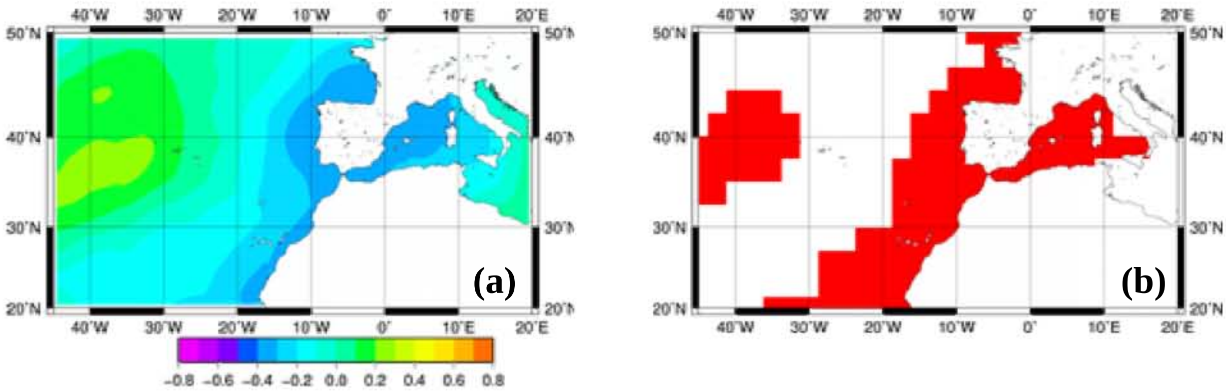

Figure 7: (a) Correlation between the ALOi and the SST. (b) Significance of the correlation between the ALOi and the SST.

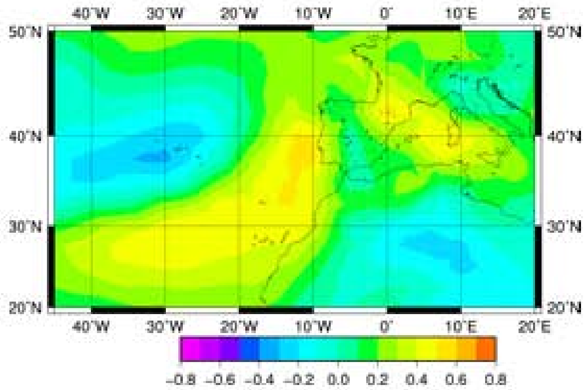

Figure 8: Correlation between the ALOi and the W.

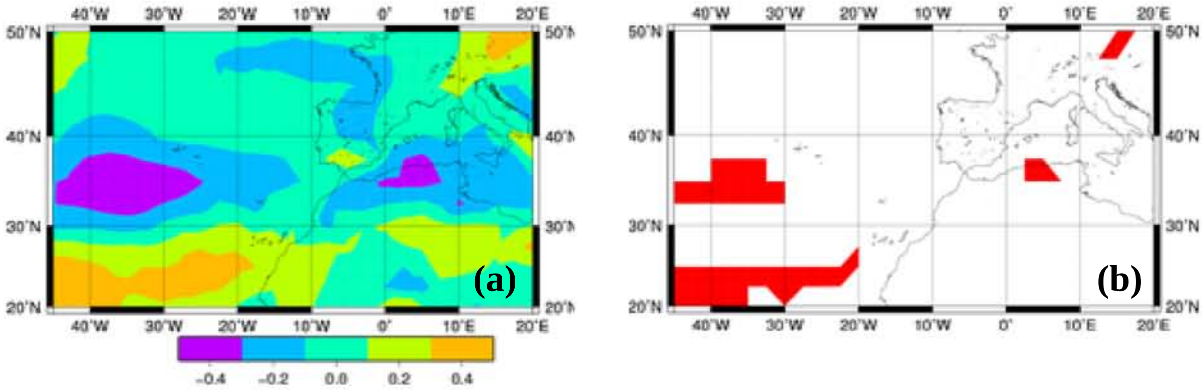

Figure 9: Correlation (a) and significance (b) between the SLP and the W.

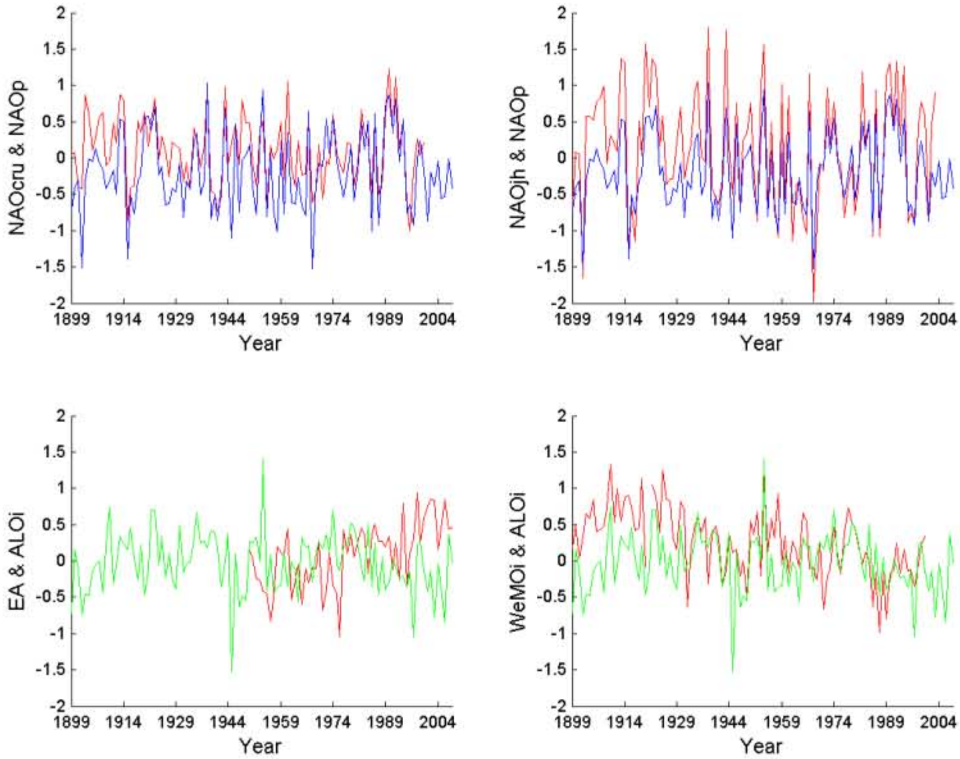

Figure 10: Correlations between climate indices (red) and the proxy indices of the current study (NAOp in blue and ALOi in green). The upside-left represent the NAOcru versus NAOp. The upside-right represent the NAOjh versus NAOp. The downside-left represent the EA versus ALOi. The downside-left represent the WeMOi versus ALOi. Buried on mind that proxy indices are referred to the 1971-2000 normalization period.

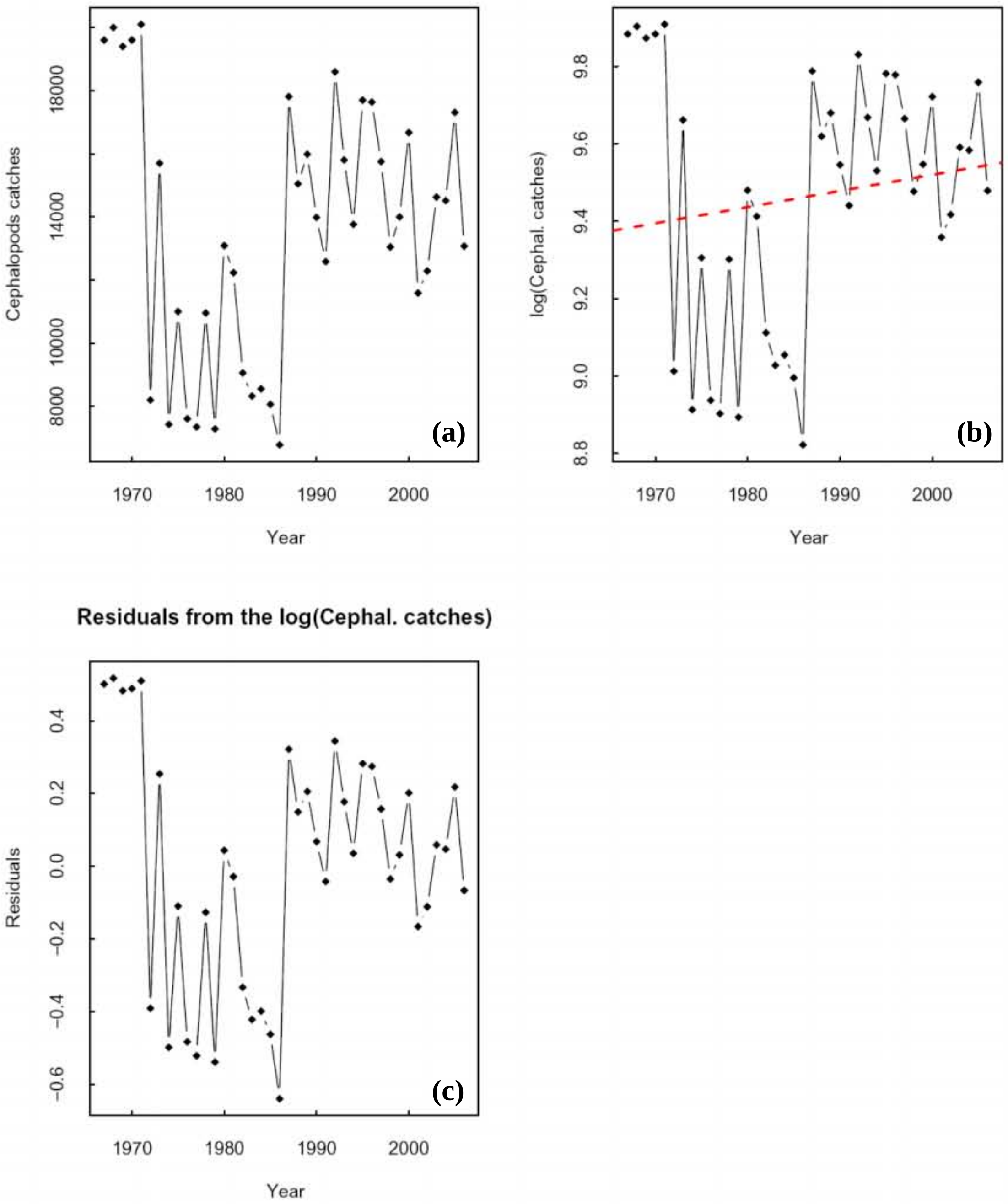

Figure 11: (a) Catches data without any statistical treatment. (b) Logarithmic of the catches data. The red line represent the linear fit, which has a estimation value of 0.00417 and a probability of 0.369. (c) Residuals of the catches data after applying a linear model.

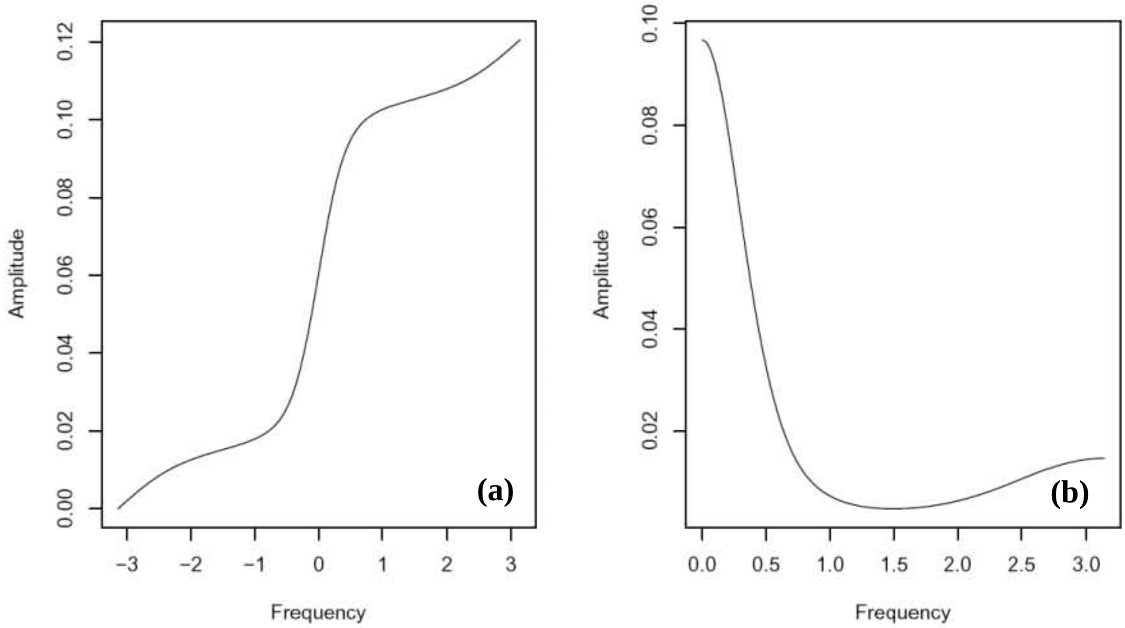

Figure 12: Seasonality analysis results. (a) Spectral distribution analysis. (b) Density distribution analysis. No seasonality is present in the cephalopods data set.

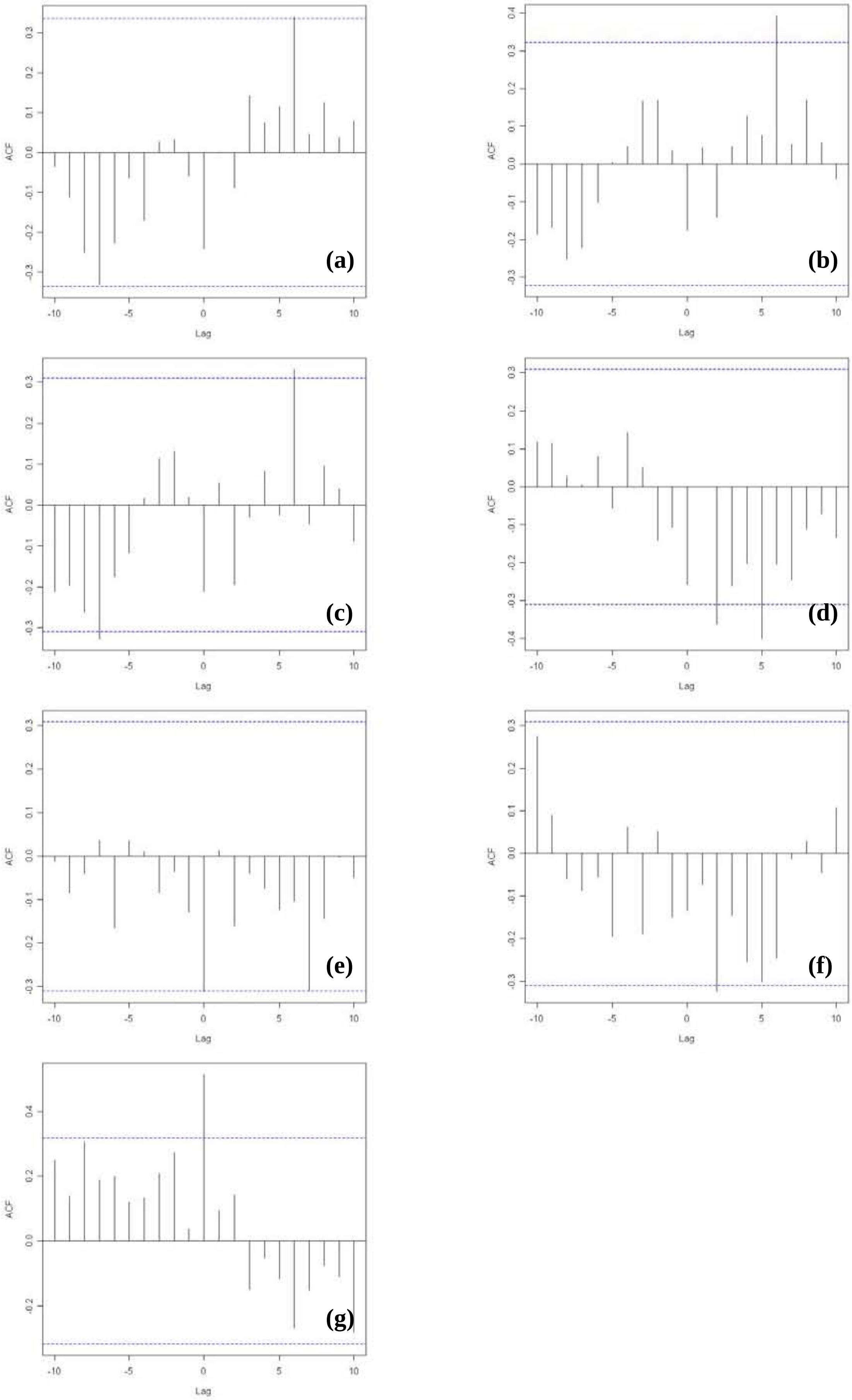
(a)
(b)
(c)
(d)
(e)
(f)
(g)
ACF
Lag

Figure 13: Correlations between the cephalopods catches and the indices. Only the ones that have a significant value (ACF > ± 0.3) are shown. (a) Cephalopods vs. NAOcru. (b) Cephalopods vs. NAOjh. (c) Cephalopods vs. NAOp. (d) Cephalopods vs. ALOi. (e) Cephalopods vs. ALOi_spring. (f) Cephalopods vs. ALOi_summer. (g) Cephalopods vs. PC3.