International Council for
the Exploration of the Sea

2002 ICES Annual Science Conference
Theme Session O : 26
Pelagic Fish responses to climate variability

Environmental variability in the North Atlantic and Iberian waters and its influence on pelagic fish: the cases of horse mackerel and albacore.

A. Lavín[1], X. Moreno-Ventas[2], V. Ortiz de Zárate[1], P. Abaunza[1], and J. M. Cabanas[3]

[1]Instituto Español de Oceanografía. C.O. Santander. Apdo. 240, 39080 Santander, Spain
[2]Dpto. de Ciencias y Técnicas del Agua y del Medio Ambiente. E.U.I.T Minera e Ingeniería Ambiental, 39316 - Tanos (Torrelavega) Spain.
[3]Instituto Español de Oceanografía. C.O. Vigo. Apdo 1552, 36280 Vigo, Spain
alicia.lavin@st.ieo.es;

Time series of environmental variables that characterizes the atmospheric and oceanic variability, such as the North Atlantic Oscillation (NAO) index, the oceanic transport given by differences in Potential Energy anomaly (PEA), the position of the Gulf Stream index (GSI) and local variables as air and sea surface temperature, precipitation, wind, mean sea level and Ekman transport in the western and northern Iberia have been analysed. The system dynamics was characterized using a factorial Principal Component Analysis (PCA) of all variables.

PCA of the abiotic parameters from 1966 to 2000 shows the first component as a thermal axis, setting up air and sea surface temperatures (positive semi-axis) against intensity of spring/summer upwelling (negative semi-axis), explaining around 19% of variability. The second component relates to the oceanic transport indices as PEA and GSI, explaining around 12%, and the third relates to sea level and NAO. The following components are related to the annual and autumn Ekman transport, and wind components. Total explained variability is 64%. Periods of different hydro-climatic conditions have been characterised as well as strong shifts. PCA has also been related to two cases of pelagic fishes: horse mackerel (coastal) and albacore (oceanic). In this context, horse mackerel recruitment is found correlated with the thermal/upwelling first component (r=.78).

A Multiple Regression analysis has been effectuated for both pelagic fishes, Sea Surface Temperature (SST), Upwelling index and 2-year lag NAO index explain 67% of the horse mackerel recruitment variance and the PEA index and the NAO index explain the 47% of the albacore age 3 catches variance.

Keywords: albacore, Atlantic Iberian waters, environmental conditions, horse mackerel recruitment

1 Introduction

Natural and anthropogenic variability in the North Atlantic waters are of great importance on economic and social activities as well as for the fisheries management. All meteorological and oceanic parameters display different variability scales. This variability potentially influences the living oceanic resources of different trophic levels and ecosystems.

To include most of the variability in the ecosystem we are considering the atmospheric part, the oceanic and some biological component represented in this case for two pelagic species: one coastal as the horse mackerel (*Thachurus trachurus* (L.)) recruitment around the Iberian Atlantic coast and the other of oceanic behaviour as the albacore (*Thunnus alalunga* (B.)) fishery.

Variability in the atmosphere and the ocean has been broadly studied. The North Atlantic Oscillation (NAO) index is cited as accounting for the higher part of the atmospheric variability in the North Atlantic (Hurrell, 1995). NAO has large impacts on weather and climate in the North Atlantic region and surrounding continents and is a dominant exogenous factor in many biological systems.

Interannual to interdecadal variability of the circulation intensities of the North Atlantic subtropical and subpolar gyres was indicated by the pentadal comparisons used by Levitus (1989a, 1989b). This variability in the northern part is related with periods of strong and weak convective mixing (Dickson et al, 1996) and the NAO index.

Periods of different oceanographic conditions has been found. Kushnir (1994) studying the ocean surface warming in 1925-1940 and cooling 1960-1975 found opposite signs in wind direction from climatology: Sea Surface Temperature (SST) warming is associated with both a southward displacement of the belt of westerlies and a cyclonic wind anomaly cell centred in 45ºN. Reverdin et al., (1997) suggest that a weakened westerlies at 55ºN and over the central and eastern North Atlantic is associated with high salinity and warm water.

Observational evidence for this variability was presented by Curry and McCartney (2001). They presented an oceanic analogue to the NAO pattern manifested in the North Atlantic dynamic height and potential energy anomaly (PEA) distributions, which provide information regarding the magnitude and geography of geostrophic velocities and mass transports. The amplitude of the PEA index, calculated as the differences between PEA in Labrador and Bermuda, changes from its minimum circa 1970 to its maximum in the mid-1990s is 15-20 MTs-1: for a mean transport of approximately 60 MT s-1, this change amounts to a range of about 25% to 33% over 25 years.

Taylor and Stephens (1998) used satellite-based SST and XBT observations to construct an index of mean annual Gulf Stream position Index (GSI)(65º-79ºW) for the period spanning 1968-98. Joyce et al. (2000) extended the time series back to 1954 based in an alternate index. Both showed significant covariance with the transport index. In the first one a lag of 2-3 year with respect to the NAO index was showed, whereas the second found a 0-1 year lag.

Later eighties and the 1990's have been cited as the warmer period in the Century, the NAO index got the higher values at the beginning of the 1990's. The years 1997/1998 mark the higher mean sea level in the Atlantic (Levitus et al, 2000). Update time series is important due to the strong changes occurred in the last decade.

Previous analysis on environmental parameters indicated a statistically significant relationship between NAO and air temperature in Santander and in Vigo (Lavín et al, 2002). Air temperature, SST and turbulence in Vigo were significantly correlated with the annual Gulf Stream Index.

The effects of different environmental conditions on fish population and fisheries have been studied profusely (see for example: Beamish and McFarlane, 1989; Beamish, 1995; Cushing, 1995; Reid, 2001 and the references there in). The commonest effect of climatic factors regarding fish stocks is to augment or diminish the magnitude of recruitment over a period of time (Cushing, 1995). It is precisely the problem of predicting recruitment, which remains central to fisheries science (Mertz and Myers, 1995). There are some references that take in consideration the influence of environmental factors on aspects related with the horse mackerel recruitment, i.e.: on spawning commencement date (Barenbeim, 1974), on development and hatching of eggs (Pipe and Walker, 1987), and on seasonal occurrence of pelagic eggs at sea (Sola et al., 1990). More recently Santos et al. (2001) analysed the influence of upwelling processes along the Portuguese coast in the southern horse mackerel stock recruitment, concluding that the upwelling events observed off Portugal during winter months affected negatively to the strength of recruitment of those years. These works took in consideration mainly temperature and variables related with coastal dynamics.

In the North Atlantic immature albacore ages 1 to 5, begins to migrate in May from the central Atlantic area around Azores islands towards the feeding grounds in the Bay of Biscay and the south western coast of Ireland. This seasonal trophic migration of albacore is associated with the warming of surface and subsurface waters in those latitudes, ranging from 16 º C - 21º C (Havard Duclos, 1973; Leroy, 1990) that reach northward areas during summer, where imature albacore forage in waters < 100 m. This author also described the different spatio-temporal distribution of immature albacore by size thus age related to sea surface temperature when migrating. This annual migratory behaviour for immature albacore was first described by Aloncle et Delaporte (1976;1979) based on the results of several tagging experiences that took place in the 1960´s and it has been corroborated (Ortiz de Zárate and Cort, 1998) based on the tagging results from the 1990´s. The temporarily presence of immature albacore in those areas has been the base for a surface fishery operated by different fleets along the years (Anon., 2001).

The analyses of the state of the north Atlantic albacore stock (Anon. 2001) has shown a continuous increase of exploitation rate. The lack of information relating this species with the oceanographic conditions might be affecting the estimation of population dynamic parameters. Changes in the distribution of fish forced by environmental conditions represented by the Gulf Stream index (GSI) (Taylor, 1996) might affect the movements of immature albacore thus its distribution and therefore changes in the availability to the diverse surface fleets exploiting this resource and hence the perception of the production (Ortiz de Zárate et al. 1997). Large year to year fluctuations of oceanic phenomena associated with the NAO and GSI Indices where positive correlated with catches of albacore ages 2 and 3 (Lavín et al., 1999).

The purpose of this paper is to present new updated analyses of the variability in the oceanic and coastal conditions by means of Principal Component Analysis and relates it with some fisheries and fish population indices such as catches and recruitment. A predicting regression model taking into account those variables will be designed for horse mackerel recruitment and albacore fishery. Some oceanographic variables, associated with the albacore catches of age two and three for 1975-1999 period are explored in an attempt to understand the broad oceanographic processes that influence the distribution of immature albacore in the north eastern Atlantic waters. Furthermore its consequence on the availability thus catchability of distinct surface fleets operating in those fishing grounds.

2 Material and methods

Meteorological and Oceanographic Data

For this study we have taken some time-series of physical and biological indices. We have tried to cover a representative set of environmental indicators. Our region of interest (Figure 1) is the eastern North Atlantic, mainly the Subtropical Gyre and the temperate area around the Iberian Peninsula, thus, we have selected time series that represent this geographical range. The period studied for the abiotic series extend from 1966 to 2000.

The abiotic large-scale time series includes the atmospheric (NAO) and oceanic transport (PEA and GSI). Even when the NAO is evident throughout the year, during the boreal winter, the atmosphere is more active and from December to March (DJFM) the NAO explains one third of the total Sea Level pressure (SLP) variability over the North Atlantic, more than any other variability pattern (Barnston and Livezey, 1987; Rogers 1990). To cover all the possible variability in the mode, annual, seasonal, DJFM as well as the NAO with a year gap (NAO-1) and two years gap (NAO-2) were used in this work.

The following index used is an oceanic index: the Potential Energy Anomaly (PEA). Update PEA data (Curry and McCartney, 2001) were provided by R. Curry (WHOI), since there were two small gaps on them, a cubic splines interpolation was performed to get the continuous time series of annual values. GSI index was taken from Taylor (1996) annual, seasonal values and values for December, January, February and March are given. The time series associated to the NAO index are 7 and 5 the associated to the GSI. Figure 2 presents the annual value of PEA index and the December to March values of NAO and GSI.

On the other hand, a series of more local variables as SST, air temperature, sea level and winds in a pair of locations around the Atlantic Iberian area have also been considered (Figure 1). In table 1 a list of variables is presented.

In the temperate areas two main seasonal regimes are found the spring/summer of upper stratificated waters and the autumn/winter of mixed waters. This has been clearly stated in the coastal area (Lavín et al., 1998, Cabanas et al., 2002) and periods of upwelling/downweling are also coincident with that (Blanton et al, 1994). To include this variability the April-September, the winter/autumn and previous autumn and winter values were used.

We have chosen two representative points of the area of Western and Northern Iberia: 43ºN, 11ºW and 45ºN, 3ºW, following the results on variability in the area given by Cabanas et al (2002). Our source of data is the Comprehensive Ocean Atmosphere Data Set (COADS) (Woodruff, et al., 1993) and given in http://www.cdc.noaa.gov/coads/coads1a.html. Data included are Sea Surface temperature (SST), air temperature and winds given by the U (East/West) and V (North/South) component and turbulence (given by the cubed of the scalar wind: W). COADS data is restricted to 1997, an extension of the data for the period 1990-2000 in 2ºx 2º is now presented. We have interpolated the data to our location. A comparison of the common period has been performed, and correlation was high (>0.9) in temperatures and less in winds data. Those three years data have been incorporated to our data series. Data are given in a monthly basis. Seasonal means of the five parameters are also included. Total time series are 20 for each location and U in 45º N, 11ºW in autumn. Figure 3 presents the SST annual time-series at 43ºN, 11ºW and 45ºN, 3ºW.

Sea level was used from 3 IEO tide gauge stations located in Santander, La Coruña and Vigo (García, 1998). Seasonal effects in the sea level in the area were signalled by Lavín and García (1992), then seasonal values, as well as annual, were also included. Gaps in the sampling in the tide gauges of Vigo during 1978 and Santander during 1992 have prevented to use those years in the total analysis. The time series are 4 in each of the three locations.

Meteorological data of air temperature and precipitation from the Santander Station of the Instituto Nacional de Meteorología (INM) were also included. Air temperature is given by monthly means. Precipitation is given as monthly accumulated values. Seasonal and annual values were analysed being a total of 8 time series.

Ekman transport based in wind forcing (Bakun, 1973) was calculated by sea surface pressure maps. Note that changing the sign of the Ekman transport in spring/summer gives an idea of the upwelling in the area (Upwelling index = offshore Ekman transport = - Ekman transport). Three daily maps were analysed for these calculations (Lavín et al, 1991, 2000). From the monthly data, the quarterly and seasonally mean values were calculated. Also values for December, January, February and March were added to be coherent with the NAO and GSI time series of these periods. The total time series relative to the Ekman transport are 9. The total number of analysed abiotic time series were 83. Figure 4 present the spring/summer Upwelling Index, autumn/winter Ekman transport and annual Ekman transport time series.

Biological Data

The estimates of the historical series of southern horse mackerel recruitment come from the application of an age structured model on time series of fisheries related data. The model applied is the XSA (Extended Survivor Analysis, Shepherd, J.G. (1999)), (see ICES, 2001). In figure 3 the horse mackerel recruitment values are also presented. The available period is from 1986 to 1999. The recruitment in year 2000 is not considered because the estimates of the model are not reliable for the most recent year.

Although the albacore surface fishery has a long history of catches in the eastern North Atlantic ocean since1920 (Bard and Santiago, 1999) for assessment purposes only the period from 1975 to 1999 has been considered suitable for dynamic population parameter estimates regarding the accuracy of the catch at size distribution for the overall catch reported (Anon. 1996).

The catch-at-age estimates for the northern Albacore stock for the period 1975-1999 from the corrected catch at size data provided by the ICCAT (International Commission for the Atlantic Tuna Conservation) was estimated by Santiago and Arrizabalaga (2001). In figure 5a, total annual age composition of catches of North Atlantic stock are presented, as shown most of the catches correspond to immature albacore of ages 1 to 4.

The largest proportion of those catches are taken by the surface fishery which operates in the study area being the longline catches share minor and targeting the adult population (> 5 age group) on fishing ground of the central Atlantic waters. The surface fleets don´t target the age 1 group although could be interpreted as a proxy of “relative” abundance. The age 2 is more abundant in the Bay of Biscay area, thus more targeted by fleets operating in those fishing grounds, the age 3 group is targeted by all the surface fleets: baitboat and mid-water pelagic trawlers mainly in the Bay of Biscay area and driftneters and trollers in the adjacent eastern North Atlantic waters, thus representing the largest geographical area (figure 1), while the age 4 group is quite variable between years and spatial temporal strata. Therefore we have used the added total annual catch-at-age of age 2 and 3 groups for our study. We have not included the adult albacore population due to different geographical distribution of spawners in the westward waters of the North Atlantic where they migrate to spawn. The total catch in number of immature albacore age groups 1 to 4 landed by the surface fleets: troll, baitboat, driftneters and midwater pair pelagic trawlers for the studied period is described in Figure 5b.

In table 1 the chosen variables are listed. None of the time series has been smoothed in any fashion except for that which occurs in the computation of seasonal or annual mean.

Statistics

Statistics has followed Sierra Bravo (1994) and SPSS (v 11.0) software. Previously to the study of each of the parameters (either physical and biological), a normality test of Kolmogorov-Smirnov was used. All variables were statistically normal.

Principal Components Analysis

We analysed the environmental data using two statistical methods. The first was Principal Components Analysis (PCA) which was used to isolate the most important modes of variability in the data. PCA has been widely used in climatology, a good set of them is given in Hare and Mantua (2000). The main objective of the PCA is to concentrate most of the variance of a large dataset into a small number of physically interpretable patterns of variability. The varimax strategy of rotation maximizes the variance on the new axes. The considered number of eigenvalues were determined using the observed communalities and the eigenvalue scree plot. The mean value of the variables variance of the PCA was taken to be more than 50% and the initial eigenvalues have to be higher than 5%.

Multiple regression analysis

Relationship between abiotic (independent) and biotic (dependent) variables were analysed by multiple regression analysis. The significance levels were $P < 0.05$. Multicolinearity and autocorrelation were checked before use the variables for the regression analysis; analysis was done looking at correlations with different temporal gaps and the Durbin-Watson test. In the colinearity case, correlation between variables and tolerance were checked. A first-difference method (Thompson and Page 1989) was used to correct the cases when autocorrelation was found. Following this method a new variable containing the first difference between correlative pairs of original values was used instead of the previous variable.

The analysed variables were the same than the used in the PCA but without sea-level, air temperature and wind components, due to autocorrelation, and biological interpretation problems, when there are other variables more directly related with the species habitat.

Two methods were simultaneously used to determine the sequence of abiotic variables that best fit the model and were biological meaningful. The first method was including all the abiotic variables as a block with the aim to determine which was the best mathematical fit for the dependent variable and eliminate the low significant variables for the model. The second method was the sequential inclusion of independent variables (forward stepwise) taking an 'F' value of <=0.05 for inclusion and F >= 0.10 for elimination. The 'a priori' tolerance level was 0.0001, then a variable with lower tolerance or that other used variable reduce its tolerance level under this rate, was not used in the model.

After applying both methods, the best sequence of abiotic variables was included in the model following two conditions: first the abiotic variables included had clear biological meaning and second the model explains the highest variability (R^2).

3 Results

Principal Components Analysis

Environmental factors

We have used PCA to separate objectively the most important patterns of common variability from the 83 abiotic selected time series. After the eigenvalue analysis by communalities and the eigenvalue scree plot, the first six principal components have been selected as meaningful. The statistics are presented in table 2. Positive or negative correlations for the six principal components are presented in annex I. Values considered significant ($|r| > 0.7$) are marked.

The six PCs account for 64% of the total variance. Once the components are rotated to get the maximum variance, the PCs are as follows: the first component is positively related to air and sea surface temperature in the western Iberia (43ºN, 11ºW) for most of the periods (annual and the three seasonal ones), in lesser amount to the annual SST and spring/summer air temperature in 45ºN, 3ºW and with the INM temperatures of

Santander. This component is also negatively related to intensity of the spring/summer upwelling and explains 18.6% of the total variability. Local sea surface temperature and air temperature accounts for the highest variability of the system.

The second component is related to the oceanic transport indices as PEA and annual and winter GSI. This component has a marked oceanic character and explains approximately the 12% of the system variance.

The third principal component (9.4% of the system variance) is related to the winter and annual sea level in La Coruña, the most oceanic point of our tide-gauges stations, with positive correlation, and with negative correlation to DJFM NAO index. This third component is more related with atmospheric sea level pressure that affects sea level as well as the NAO index.

The four component (explains 8.5% of the system variance) is related to winter Ekman transport with the higher correlation for the DJFM Ekman transport. The fifth component is related to winter winds in northern and western Iberian and finally the last one with annual turbulence in Northern Iberia with similar correlation to the fifth component. Total explained variability is around 64%.

The distribution of the time-series (years) as a function of the first and second components are presented graphically in Figure 6.

Considering the first principal component, the thermal one, low values were presented at the beginning and some shifts could be found during the 1966-2000 period. After some temperate conditions, a cold shift occurs from 1971 to 1972, being the later the colder year in the studied period. After some warming the tendency keeps cold until 1977/1978 when a shift toward warmer temperatures occurs. After some intermediate conditions during the 1980's, 1988/1989 marks a new shift, this one of warmer nature. Cooling 1990/1991, warming again in 1996/1997 and some cooling for the following pair of years 1998/1999 in the final period.

The oceanic component also presents some regimes separated by shifts mostly coincident to the thermal ones. From low values of the component as the minimum in 1971, a strong shift occurs in 1972, after most of the seventies, another shift happened between 1977/1978 with an important reduction in oceanic transport. Following intermediate to low values in early eighties, a shift appears again between 1988/1989 beginning the strongest values of the early nineties with a maximum in 1995. A shift is presented from 1996/1997 toward low values that seems to begin to recover in year 2000.

Both principal components seem to present similar regimes and strong shifts located in 1972/3, 1977/8, 1988/9, 1996/7 and some small ones only represented in the thermal component. Those changes correspond to important periods, the first one to the low oceanic transport regime (minimum PEA) and NAO index in the North Atlantic, the second one corresponds to the lower temperature and maximum upwelling regime, the third one corresponds to the strong transport (maximum PEA) and also maximum NAO index and finally an increase in temperature, and reduced upwelling in the final part of the time series.

Environmental factors and Horse mackerel recruitment

The analysis of first principal component, the thermic one, versus the southern horse mackerel stock recruitment, shows a significant correlation of r = - 0.86 (see Figure 7). Years with lower mean air and sea surface temperatures favour the success of horse mackerel recruitment as occurred in 1986 and 1991. There is no a clear temporal pattern in the recruitment strength in the time series, but the lower values were found during the last three years coinciding with the higher values of first principal component.

The multiple regression analysis selected 3 variables: Sea surface temperature at 43ºN 11ºw in spring and summer, NAO index with a time lag of two years and summer upwelling index. With these three variables the model explains the 67.1 % of the recruitment variability in the time series (Table 3 and Figure 8).

Environmental factors and Albacore catches

For albacore, the regression analysis were done for age 2 and age 3 catches including as predictor variable PEA index in model 1 and PEA and NAO indices in model 2. The regression model fit for age 2, is not significant. The regression model fit for age 3 catches was significant, explaining the 37% of the variance when considering model 1 with only PEA index as independent variable and a better fit was obtained with model 2 that includes two independent variables: PEA index and NAO index ($r^2 = 0.47$) as is shown in table 4. The distribution of albacore age 3 catches as function of the PEA is presented in Figure 9.

4. Discussion

The regimen shifts presented in this work is coherent with the ones presented in different papers. In the Pacific, Hare and Mantua (2000) in a detailed analysis with 100 variables, found two main regimes shifts in 1977 and 1989. Changes in both years can be found in the analysis presented here in the North Atlantic. In the North Sea, Reid et al (2001) found changes in 1988 related to horse mackerel and Holliday and Reid (2001) changes in the North Sea in 1989 and 1998. Both time periods are coherent with our results. In the Eastern North Atlantic, changes seems occur in 1997.

During autumn/winter a warmer poleward current sporadically develops in the western Iberia and southern Bay of Biscay (Pingree and Le Cann, 1990). Pingree (1994) gave 1983/1984, 1989/1990 as years of high intensity poleward current. Strong events were also detected in the Bay of Biscay by Díaz del Rio et al (1996) in winter 1995/1996. Those events are not coincident with the described shifts.

Cabanas et al, (2002) described a strong shift in winds in the last decades with an important reduction in upwelling from the 1970s to the 1980s and 1990s. A weaker upwelling in spring-summer since the strong period in the 1970’s with periods of low upwelling at the beginning of the 1980’s and late 1990’s. Observing the Upwelling Index, Ekman transport data (figure 4), we can appreciate in 1977, in the annual mean, a strong shift from positive (Upwelling favourable due to high spring summer contribution) to negative values (Inshore Ekman transport or downwelling due to autumn and winter favourable winds).

The Principal Components plot (Figure 6) gives an interesting idea of the system changes. The two periods of extreme values of PEA: low values (1965-1974) and high values (1990-1997) appears well separated. Low transport index corresponds to the negative values of first and second PCs and high transport index (the 1990's) to positive values of both components.

The area of study (Figure 1) is located in the intergyre region between the subpolar gyre (North Atlantic current), the subtropical gyre (Azores Current), and the European shelf. In this area, the mean circulation is very weak (Maillard, 1996). The pattern of SST variability associated with the winter NAO consists of a tripolar structure marked, in the positive NAO phase, by warm anomalies extending from cape Hatteras in the west Atlantic to Biscay in the east and poleward along the North Sea and the Norwegian coast and cold subtropical anomalies (Hurrell and Dickson, 2001; Rodwell et al, 1999; Dickson, 1997). The PC1 or thermal axis represents the local pattern on the Biscay area.

The second PC represents the oceanic transport variability. The comparison of low and high transport periods done by Curry and McCartney (2001) of PEA fields at 200 db relative to 2000db reflects strong transport of the 1990s, uplift in all the entire subtropical dome west of 40ºW and deepened of the subpolar bowl. In addition to the north-south dipole, changes in the east-west circulation indicateopposite sign. The eastern subtropics are characterized by lower PEA while the eastern subpolar region (west of Ireland and south of Iceland) by higher. In the eastern subtropics they conclude that this change is not reflecting strong mode of ocean variability but instead small thermocline displacements. In the subpolar area, changes in vertical density structure of the central subpolar gyre are primarily thermally driven but punctuated by occasional passages of low-salinity Great Salinity Anomalies through the region.

The third PC is related with the sea level and NAO index. This PC seems indicate atmospheric influence and its direct consequence over the ocean. In relation with the influence of sea level in the system variability, Lavín and García (1992), in a study of the monthly sea level measurements in the same locations of the NW Spanish coast (Santander, La Coruña and Vigo) of the 1980's decade, found a different response of the three time series to atmospheric forcing. In La Coruña and Santander it depends more on atmospheric pressure than in Vigo, but the power spectrum of sea level of La Coruña and Vigo were similar but differs somewhat in Santander. La Coruña was the location where mean sea level was highly correlated to atmospheric pressure (r = -0.8), the other values are lower, (r =-0.73 in Santander and r =–0.58 in Vigo). La Coruña sea level was more related to SLP and the NAO is calculated as a SLP difference. Cabanas et al (2002) found correlation of the mean sea level in this area with the NAO index. These justify the system variability associated to this component.

Some work has been done related to the sea level influence in fisheries. Robles et al (1992) give good agreement in the 1980s between sardine recruitment and sea level anomaly in Vigo mainly in the two high recruitment years 1983 and 1987.

The four PC is related to winter Ekman transport. This behaviour is related with the upwelling time series variation previously described. The fifth and sixth PCs are related with winds components, (U and V) in the first case and turbulence in the PC 6.

All those factors related to wind have been studied in relation to fisheries behaviour. Intrinsic high variability on wind parameters is difficult to use. The study of storm tracks presents better results. Lasker (1978) first presented a hypothesis for stability in relation to physical process affecting food chain characteristics in the ocean. Further Cury and Roy (1989) presented optimal environmental windows for moderate winds. In this Iberian area, Borja et al. (1996) used upwelling and turbulence to try to describe Bay of Biscay anchovy behaviour. Dickson et al., (1996) presented the storm activity over the North Atlantic and relate it with the shifting atmospheric circulation on the ocean.

In the same way, the NAO index has been used in a wide way to provide direct information on fisheries management. Different patterns of correlation are found from early ones that relate Sea Surface and air temperature over the northern North Atlantic, or inverse with precipitation in northern and southern Spain (Pérez et al., 2000; Rodrigo et al, 2001) or northern Morocco (Lamb et al, 1997). Also a number of species have presented correlation with the value from long time extended series as in Alheit and Hagen (1997).

It is likely that major processes determining recruitment take place during larvae life. Indeed this is really the only justification for any dependence of recruitment on climatic factors (Cushing, 1995). Temperature is a pasive factor because its direct incidence on the development of eggs and larvae (Pipe and Walker, 1987) and it constitutes a proxy for other changes in physical factors, such us upwelling processes. In this sense the high correlation between the first principal component, the thermal one, and horse mackerel recruitment has biological sense.

It is remarkable the high proportion of the recruitment variability (more than 67%) that the regression model explains with three environmental variables. Similar values were also obtained in the study of Svendsen et al. (1995) with various fish species from the North Sea. This means that forecasts of horse mackerel recruitment could be made taking in consideration environmental indices, thus helping significantly in the resolution of central problem in fisheries: the predictability of recruitment (Mertz and Myers, 1995). Although we can obtain the total explanation of recruitment variability adding without limits the different environmental variables, that has very difficult biological interpretation, due mainly to spurious correlations. Without knowing the mechanistic connections between the variables being correlated, we cannot have confidence that the correlations will continue (Gargett et al., 2001). Above all we can not forget that the time series is not long and that the predicting model will improve as the time series expand.

Years with cooler temperatures at coastal sea surface during spring and summer seem to be favourable for good horse mackerel recruitment. Cooler temperatures are also in the range of greatest survival for the development of horse mackerel eggs, which are pelagic, through to hatching: 12.2º – 15.8 ºC (Pipe and Walker, 1987). Horse mackerel has a very long spawning season over the Iberian shelf, covering the first eight months of the year, and being the peak of spawning mainly in winter and spring in Portuguese coast and in spring-summer in the North of Spain (Sola et al., 1990; Borges and Gordo, 1991; Abaunza et al., 1995). The cooler temperatures may be an indication of upwelling processes and less stormy weather, precisely when the pelagic eggs and larvae are more abundant at sea. In this way the food supply for larvae are secure and the survival in some fish species could be favoured (Cushing, 1995). However, Santos et al. (2001) found that the horse mackerel recruitment was negatively correlated with the upwelling events in winter period, when the spawning in the Portuguese area is produced. They consider that the consequent offshore transport increase the mortality of horse mackerel larvae. This result is open to argument at stock level because the major part of the stock is probably located in the Northwest and the North of Spain (ICES, 2001), in where the peak of spawning is later (spring and summer) than in Portuguese coast. In fact, we have found a positive correlation with the summer Upwelling index. The horse mackerel recruitment is produced along the entire area of distribution (Sola et al., 1990; Villamor et al., 1997).

More difficult is to explain the mechanistic processes for the correlation between the NAO with two years lag and the horse mackerel recruitment. By the moment we can describe the fact. As we have said above major oceanographic processes influence in some degree also the coastal oceanographic dynamics and the ecosystem functioning (Cushing, 1995; Dippner, 1997). Consequently NAO related processes could influence the recruitment of horse mackerel. The relationships in the system are complex and further research is needed to explain the reason for this correlation.

We tried to explore the impact of the large scale, low frequency climatic changes in the North Atlantic and its effect on albacore catches of the surface fishery. These results showing a significant correlation (r^2 = .37) found between the PEA index and the catch of age 3 albacore and an increase on the significant correlation (r^2 = 0.47) when regressing the albacore catches of age 3 with both the PEA index and the autumn/winter NAO index. This means that a relationship exists between the increase of the east-ward transport limited by boundaries of the subpolar gyre and the subtropical gyre and the abundance of albacore found in the North eastern Atlantic ocean. Moreover the horizontal gradient of this index is concentrated in the Gulf Stream–North Atlantic current and it represents the oceanic response to the climatic decadal shift variation expressed by the atmospheric NAO index. However, no significant correlation was found when regressing the age 2 albacore catch and the oceanic variables neither the more local variables represented by the first PC in the analyses of the abiotic variables**.**

Albacore spawn in the west Atlantic during the spring-summer months in an area located in the Sargassum sea in tropical waters (Ueyanagi, 1971; Shiohama, 1971; Uozumi, 1996). As juvenile shows a fast growth during the first months, reaching a size of 30 cm at 6 months old and soon begins to migrate eastwards to approach the feeding grounds in the eastern North Atlantic as one year-class when is recruited to the fishery in the following year.

The decadal PEA index with higher values in the 1990´s might imply a more northward distribution of albacore age 3 in the eastern Atlantic waters. Also it could intervene changing the migratory patterns on annual bases. The entry movements towards the bay of Biscay seems to follow the tripole pattern associated, during positive NAO phase, to warm anomalies from the west Atlantic to Biscay (Hurrell and Dickson, 2001) as cited previously. This pattern could facilitate the transport toward those habitats according to NAO index on a positive phase, as has been the case in the 1990´s. The warm anomalies during the summer months could act as a limiting distribution factor concerning more suitable sea surface temperature range for immature albacore. Leroy and Binet (1987) found that temperature anomalies influenced the abundance of albacore age three in the eastern Atlantic summer fishery and it was correlated with recruitment abundance in the west Atlantic. Else Bard and Santiago (1999) found positive correlations between the winter NAO index and the sea surface temperature anomalies for the period of June to August from 1986 to 1993 in the eastern North Atlantic including the Bay of Biscay area.

Likewise in the Pacific ocean, the migration patterns of albacore were described as been wider in El Niño years than non-El Niño years which area associated with the presence of a cold water region in the central and south western North Pacific (Kimura et al., 1997).

Nevertheless both temperature and forage density play a key role in the distribution of albacore, being an opportunistic feeder, its concentrates in areas where preys are abundant and visibility conditions are good enough as happens to be a visual predator. It is known that gradients of temperature are conditioning the movements and distribution of albacore. Fiedler and Bernard (1987) found in the east Pacific, the immature albacore migrating in summer associated with thermal fronts.

Also in the Pacific ocean horizontal movements of immature albacore migration to the east coast of California (USA) during summer and aggregation of fish with sea surface temperature as been described by Laurs and Lynn (1991). They found that within years with strong temperature fronts albacore were more concentrated than the opposite situation when not very clear temperature fronts were apparent, being more disperse the fish and less available to the fleet, thus thermal gradients being important to form albacore concentrations.

The highest values of PEA index found in the 1990´s in phase with positive anomalies of the North Atlantic oscillation index that affect the sea surface temperature distribution in the European waters might have imply a shift in habitat conditions of the immature albacore in its spring-summer migration to the fishing grounds in the eastern North Atlantic thus a change of its distribution expanding northward.

5. Concluding Remarks

The attempt to correlate albacore catch and oceanographic conditions expressed by the above detailed oceanic transport PEA index and climatic NAO index and the significant correlation found in this study shows that the variability of the system is explained (r^2 = 0.47) partially by climatic and oceanic processes that control the behaviour of this species in the North Atlantic ocean. The interaction between the NAO and PEA processes is difficult to understand as explanatory variables for the changes in albacore catches. Those results do not imply that the relationship holds as a predictive correlation. Moreover the data have been collected separated and pooled in a broad annual scale. Nevertheless it represents an hypothesis to further study and try to define the variables that can explain the inter-annual mechanism in the immature albacore ecosystem; and make the relationship reliable as predictive tool of albacore likely distribution in the eastern North Atlantic.

The use of some oceanic transport indices, as the PEA, that reflects the cumulative nature of the ocean and integrate atmospheric and thermal effects, seems to be more justified that the use of only individual variables when searching for environmental indices related to fisheries, especially for species of oceanic behaviour, as the albacore.

The determination of the main modes of the system variability could be a useful tool for exploratory correlations, as it has been presented with the first and second mode and their correlation with fisheries.

Those main variability modes have also provided interesting information about ecosystem shifts and what are the main changes that have induced the shifts.

To better understand the relationship between oceanographic conditions and albacore catch distribution direct observations at the same temporal spatial grid would be required, it means to carry field observations on environmental variables and fishing effort at the same time to have a comprehensive image of the interactions in the whole ecosystem. Thus more accurate parameters estimates could be achieved for assessment purposes of North Atlantic albacore stock.

However, a lack in the lower trophic levels series is also detected, future work will also include some planktonic series and running confirmatory analysis when new data be available.

The recruitment of horse mackerel, a species distributed in the shelf and coastal waters, is clearly influenced by the variables represented in the first principal component (the thermic/upwelling component). More research is needed to explain the link between NAO and the horse mackerel recruitment.

Acknowledgements

We wish to thank R. Curry (WHOI) for the Potential Energy Anomaly data, J. Hurrell and B. Dickson for the NAO index, A. Taylor for the latitude of the Gulf Stream index, the Centro Meteorológico Zonal de Asturias y Cantabria del Instituto Nacional de Meteorología for the data-series on meteorological variables, M. J. García from the Instituto Español de Oceanografía for the sea-level time-series, The Comprehensive Ocean-Atmosphere Data Set (COADS) and J. Carranza and E. Gallo for his help.

References

Abaunza, P., Fariña, A.C., Carrera, P. 1995. Geographic variations in sexual maturity of the horse mackerel, *Trachurus trachurus*, in the Galician and Cantabrian shelf. Sci. Mar., 59(3-4): 211-222.

Alheit J., and Hagen E., 1997. Long-term climate forcing of European herring and sardine populations. Fish. Oceanogr. 6 :2, 130-139

Aloncle, H. et Delaporte, F. 1976. Marquages de germons par l'ISTPM, 1967-74. SCRS/75/20. Col. Doc. Cientific. Vol. V(2).

Aloncle, H. et Delaporte, F. 1979. Nouvelles remarques sur la structure du stock de germons (*T. alalunga*) dans le nord-est Atlantique. SCRS/78/34. Col. Doc. Cientific. Vol.VIII (2).

Anon. 1996. Inf. Reunión final PSG de atún blanco (junio 1994). ICCAT, Colec. Doc. Cient. Vol, XLIII.

Anon. 2001. Report of ICCAT SCRS Albacore stock Assessment Session(Madrid, Spain, October 9 tp 15, 200). ICCAT, Col.Doc, Cient. Vol. LII. XDET/00/ALB, 1283-1390.

Bakun, A. 1973, Coastal upwelling indices, west coast of North America, 1946-1971. NOAA Tech. Rep. NMFS SSRF-671 US. Dep. Commerce, 103 pp.

Bard, F.X. and Santiago, J. 1999. Review of albacore (*T. alalunga*) historical surface fisheries data (1920-1975) for possible relationships with the North Atlantic Oscillation. SCRS/98/106, 12p.

Barenbeim, D. Ya. 1974. On regularities in the variability of the spawning terms of horse mackerel (*Trachurus trachurus* Linne) within the spawning area. ICES C.M. 1974/J:14.

Barnston M.A. and Livezey, R.E. 1987: Clasification, seasonality and persistence of low-frequency atmospheric circulation patterns. Monthly Weather Review. 115, 1083-1126.

Beamish, R.J. and McFarlane, G.A. (Editors).1989. Effects of ocean variability on recruitment and an evaluation of parameters used in sotock assessment models. Canadian Special Publication of Fisheries and Aquatic Sciences- 108: 379 pp.

Beamish, R.J. (Editor). 1995. Climatic change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences 121: 739 pp.

Blanton J.O., Tenore, K.R. Castillejo, F.F. Atkinson, L.P. Schwing, F.B. and Lavín. A. 1994. The relationship of upwelling to mussels production in the rias on western coast of Spain. Journal of Marine Research, 45, 497-511.

Borges, M. F. , Gordo, L. S. (1991). Spatial distribution by season and some biological parameters of horse mackerel (*Trachurus trachurus* L.) in the Portuguese continental waters (Division IXa). *ICES C.M.* 1991 / H: 54 .

Borja A., Uriarte, A., Valencia, V., Motos L. and Uriarte A., 1996. Relationships between anchovy (Engraulis encrasicolus L.) recruitment and the environment in the Bay of Biscay. Scietia Marina, 60 (Supl 2): 179-192.

Cabanas, J. M., Lavín, A. García, M. J. González-Pola, C. and Tel, E. 2002. Oceanographic variability in the northern shelf of the Iberian peninsula (southern bay of Biscay). 1990-1999. ICES Marine Science Symposium. (in press)

Curry, R. G. and McCartney, M. S. 2001. Ocean gyre circulation changes associated with the North Atlantic Oscillation. Journal of Physical Oceanography, 31, 3374-3400.

Cury P., and Roy C. 1989. Optimal environmental Window and pelagic fish recritment success in upwelling areas. Can. J. Fish. Aquat. Sci, 46, 670-680.

Cushing, D. 1995. Population production and the regulation in the sea. A fisheries perspective. Cambridge University Press, Cambridge, 354 pp.

Díaz del Río, G., Lavín, A., Alonso, J., Cabanas, J. M. and Moreno-Ventas, X., 1996. Hydrographic variability in Bay of Biscay shelf and slope waters in spring 1994, 1995 and 1996 and relation to biological drifting material. ICES C.M. 1996/S:18, 8 p.

Dickson R., Lazier, J., Meincke, J., Rhines, P. and Swift, J., 1996. Long-term coordinated changes in the convective activity of the North Atlantic. Prog. Oceanogr. 38, 241-295.

Dickson R. R. 1997 From the Labrador Sea to global change. Nature 386, 649-650

Dippner, J.W. 1997. SST anomalies in the North Sea in relation to the North Atlantic Oscillation and the influence on the theoretical spawning time of fish. *German Journal of Hidrography*, 49 (2/3): 267-275

Fiedler, P.C. and Bernard, H. J., 1987. Tuna aggregation and feeding near fronts observed in satellite imagery. Cont. Shelf Res. 7, 8, 871-881.

García M. J. 1997. Red Mareográfica IEO. Boletín Anual 1996. Instituto Español de Oceanografía. Madrid. 56p.

Gargett, A.E., Li, M., and Brown, R. (2001). Testing mechanistic explanations between environmental factors and marine fisheries. *Can. J. Fish. Aquat. Sci*., 58, 208-219.

Hare, S. R. and Mantua, N. J.. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography, 47, 103-145.

Havard Duclos, F. 1973. La pêche au germon (*Thunnus alalunga*) dans le Golfe de Gascogne. Influence de la tèmperature sue le déplacement des mattes. ICCAT Rec.Doc.Sci. 1:341-370.

Holliday N. P. and Reid, P. C. 2001. Is there a connection between high transport of water through the Rockall Trough and ecological changes in the North Sea?. ICES Journal of Marine Science, 58, 270-274.

Hurrell J.W. 1995. Decadal trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. Science, 269, 676-679.

Hurrell J.W. and Dickson R.R. 2002. Climate Variability over the North Atlantic. On Ecological effects of climatic variations in the North Atlantic. N.C. Stenseth, G. Ottersen, J.W. Hurrell, A. Belgrano and B. Planque, Eds. Oxford University Press, in press.

ICES 2001. Report of the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy. ICES CM 2001/ACFM: 6, 251 pp.

Joyce, T. M., Deser, C., and Spall, M. A., 2000. the relation between decadal variability of subtropical mode water and the North Atlantic Oscillation. Journal of Climate, 13, 2550-2569.

Kimura, S., Nakai, M. and Sugimoto, T.. 1997. Migration of albacore, *Thunnus alalunga,* in the North Pacific Ocean in relation to large oceanic phenomena. Fish.Oceanogr.6: 2; 51-57.

Kushnir, K., 1994. Interdecadal variations in the North Atlantic sea surface temperature and associated atmospheric conditions. J. Climate, 7, 141-157

Lamb, P-J., El Hamly, M., and Portis, D.H. 1997. North Atlantic Oscillation. Geo Observateur, 7, 103-113.

Lasker R. 1978. The relation between oceanographic conditions and larval anchovy food in California current: identification of factors contributing to recruitment failure. Rapp. P-v Reun, Cons, Int. Expor. Mer. 178, 375-387.

Laurs, R.M. and Lynn, R.J. 1991. North Pacific albacore ecology and oceanography. NOAA Technical Report NMFS105, biology, oceanography and fishery.

Lavín, A., Díaz del Río, G. Cabanas J. M. and Casas, G. 1991. Afloramiento en el noroeste de la península Ibérica. Índices de afloramiento para el punto 43º N 11º W. Periodo 1966-1989. Informes Técnicos del Instituto Español de Oceanografía 91, 40 pp.

Lavín, A. and García, M. J. 1992. Mean Sea Level along the North Atlantic coast 1980-1989. ICES mar. Sci.Sym, 195,187-192.

Lavín A., Valdés, L., Gil, J., and Moral, M. 1998. Seasonal and interannual variability in properties of surface water off Santander (Bay of Biscay)(1991-1995). Oceanolog. Acta 21 (2):179-190.

Lavín A., J. M. Cabanas, X. Moreno-Ventas, V. Ortiz de Zárate, C. Porteiro and P. Abaunza. 1999. Variability of the Environmental Conditions and Fish Communities in the Atlantic Iberian Waters and its Relationship to the NAO. NAO Chapman Conference on NAO. Orense (Spain). November 1999.

Lavín, A., G. Díaz del Río, J. M. Cabanas and G. Casas. 2000. Afloramiento en el noroeste de la península Ibérica. Índices de afloramiento para el punto 43º N 11º W. Periodo 1990-1999. Datos y resúmenes Instituto Español de Oceanografía. Nº 15, 25 pp.

Lavín A., Moreno-Ventas X., Abaunza, P. and Cabanas J. M., 2002. Environmental variability in the Atlantic Iberian Waters and its influence on horse mackerel recruitment. ICES Marine Science Symposium. (in press)

Leroy, C., et Binet, D., 1987. Anomalies thermiques dans l'Atlantique tropical-consequences possibles sur le recrutement du germon (Thunnus alalunga). SCRS/86/46. Col. Doc. Cientific. Vol. XXVI (2).

Leroy, C., 1990. Teledeteccion satellitaire et pêche du germon *Thunnus alalunga* dans le NE atlantique. SCRS/89/59.

Levitus, S., 1989a . Interpentadal variability of salinity in the upper 150m of the North Atlantic Ocean, 1970-1974 versus 1955-1959. J. Geophys Res. 94, 9679-9685.

Levitus, S., 1989b. Interpentadal variability of salinity at intermediate depths of the North Atlantic Ocean, 1970-1974 versus 1955-1959. J. Geophys Res. 94, 6091-6131.

Levitus, S., Antonov, J.I., Boyer, T.P. and Stephens, C. 2000. Warming of the world ocean. Science, 287: 2225-2229.

Maillard C., 1996. Atlas Hydrologyque de l'Atlantique Nord-Est. IFREMER. Brest. 260p.

Mertz, G. and Myers, R.A. 1995. Estimating the predictability of recruitment. Fishery Bulletin, 93, 657-665.

Ortiz de Zárate, V., Lavín A. and Moreno –Ventas X.. 1997. Is there a relationship between environmental variables and the surface catch of albacore *thunnus alalunga* (Bonnaterre, 1788) in the North Atlantic? . ICCAT Col. Doc. Sci. Vol. XLIII (3): 250-252.

Ortiz de Zárate, V., and Cort. J.L. 1998. Albacore stock structure in the Atlantic ocean as inferred from distribution and migration patterns . Actes Symposium ICCAT Sao Miguel, Juin 1996, J.Beckett Ed, 251-260.

Pérez F.F., Pollard, R.P.. Read J.F., Valencia, V. Cabanas J.M. and Rios. A. 2000. Climatological coupling of the thermohaline decadal changes in Central Water of the Eastern North Atlantic. Scientia Marina 64 (3), 347-353.

Pipe, R.K., and Walker, P. 1987. The effect of temperature on development and hatching of scad, *Trachurus trachurus* L., eggs. *J. Fish Biol*., 31, 675-682.

Pingree, R.D. and Le Cann, B. 1990. Structure, strength, and seasonality of the slope current in the Bay of Biscay region. Journal of Marine Biological Association of the United Kingdom, 70, 857-885.

Pingree, R .D., 1994. Winter Warming in the Southern Bay of Biscay and Lagrangian eddy kinematic from a deep-drogued Argos Buoy. Journal of Marine Biological Association of the United Kingdom. 74(1), 106-128.

Reid, D.G. (Editor). 2001. Shelf edge fisheries and oceanography studies (SEFOS). Fisheries Research 50 (1-2), 204 pp.

Reverdin G., Cayan, D. and Kushnir Y. 1997. Decadal variability of hydrography in the upper northern North Atlantic in 1948-1990. journal of geophysical research, 102 C4, 8505-8531.

Robles, R, Porteiro, C. and Cabanas, J.M.. 1992. The stock of Atlanto-Iberian sardine: possible causes of variability, ICES Mar. Sci. Symp. 195, 418:423.

Rodrigo F.S., Pozo-Vazquez, D., Esteban, M.J. and Castro-Díez Y. 2001. A reconstruction of the winter North Atlantic Oscillation index back to A. D. 1501 using documentary data in Southern Spain. Journal of Geophysical research, 106, D14. 14805-14818.

Rodwell M.J., Rodwell, D.P. and Folland C.K. 1999. Oceanic forcing of the winter North Atlantic Oscillation and European climate. Nature, 398, 320-323.

Rogers, J. C., 1990. Patterns of low frequency monthly sea level pressure variability (1899-1986) and associated wave cyclone frequencies. Journal of Climate, 3, 1364-1379.

Sierra Bravo R., 1994. Análisis estadístico multivariable. Ed. Paraninfo, S.A. Madrid.

Santiago, J., and Arrizabalaga, H. 2001. (Rev.) North Atlantic albacore catch-at-age estimates for the period 1975-1999 (updated). . ICCAT Col. Doc. Sci. Vol. LII (3): 1475-1480.

Santos, A. M. P., Borges, M. F. and Groom S., 2001. Sardine and horse mackerel recruitment off Portugal. ICES Journal of Marine science, 58: 589:596.

Shepherd, J.G. 1999. Extended survivors analysis: an improved method for the analysis of catch-at-age data and abundance indices. *ICES Journal of Marine Science*, 56: 584-591.

Shiohama, T. 1971. Studies on measuring changes in the character of the fishing effort of the tuna longline fishery. Concentrations of the fishing effort to particular areas and species in the Japanese Atlantic fishery. Bull.Far Seas Fish.Lab., (5);107-130.

Solá, A., Motos, L., Franco, C., Lago-de-Lanzós, A. (1990). Seasonal occurence of pelagic fish eggs and larvae in the Cantabrian Sea (VIIIc) and Galicia (Ixa) from 1987 to 1989. ICES C.M. 1990/H:26.

Svendsen, E., Aglen, A., Iversen, S.A., Skagen, D.W., Smestad, O. 1995. Influence of climate on recruitment and migration of fish stocks in the North Sea. In: R.J. Beamish (Ed.). Climate change and northern fish populations. *Can. Spec. Publ. Fish. Aquat. Sci.* 121, pages: 641-653.

Taylor A. H. 1996 North-South shifts of the Gulf Stream : Ocean-Atmosphere interactions in the North Atlantic. International Journal of Climatology. Vol 16, 559-583.

Taylor A. H. and Stephens, J. A. 1998. The North Atlantic Oscillation and the latitude of the Gulf Stream. Tellus, 50A, 134-142.

Thompson K. R. and Page F. H. 1989. Detecting synchrony of recruitment using short, autocorrelated time series. Canadian Journal of Fisheries and Aquatic Sciences 46, 1831-1838

Ueyanagi, S. 1971. Larval distribution of tunas and billfishes in the Atlantic Ocean. FAO, Fish. .Rep., 71 (2), 297-305.

Uozumi, Y. 1996. An historical review of Japanese longline fishery and albacore catch in the Atlantic Ocean. ICCAT, Rec. Doc. Sci. Vol. (43), 163-170.

Villamor, B., Abaunza, P., Lucio, P., Porteiro, C. 1997. Distribution and age structure of mackerel (*Scomber scombrus*, L.) and horse mackerel (*Trachurus trachurus*, L.) in the northern coast of Spain, 1989-1994. *Sci. Mar*., 61(3), 345-366.

Woodruff, S.D., Lubker, S.J. Wolter, K. Worley, S.J. and Elms, J.D. 1993: Comprehensive Ocean-Atmosphere Data Set (COADS) Release 1a: 1980-92. Earth System Monitor, 4, No. 1, 1-8.

Tables

Table 1. List and acronym of the variables used in the analysis.

SST4311_23	Sea Surface Temperature at 43º N, 11ºW in spring and summer.
SST4311_14	Sea Surface Temperature at 43º N, 11ºW in winter and autumn of same year
SST4311_1234	Sea Surface Temperature at 43º N, 11ºW, annual mean value
SST4311_4(-1)1	Sea Surface Temperature at 43º N, 11ºW winter and previous autumn.
AT4311_23	Air Temperature at 43º N, 11ºW in spring and summer.
AT4311_14	Air Temperature at 43º N, 11ºW in winter and autumn of same year
AT4311_1234	Air Temperature at 43º N, 11ºW, annual mean value
AT4311_4(-1)1	Air Temperature at 43º N, 11ºW winter and previous autumn.
U4311_4º	East-West component of the wind (U) at 43º N, 11ºW in autumn.
U4311_23	East-West component of the wind (U) at 43º N, 11ºW in spring and summer.
U4311_14	East-West component of the wind (U) at 43º N, 11ºW in winter and autumn of same year
U4311_1234	East-West component of the wind (U) at 43º N, 11ºW, annual value
U4311_4(-1)1	East-West component of the wind (U) at 43º N, 11ºW winter and previous autumn.
V4311_23	North-South component of the wind (V) at 43º N, 11ºW in spring and summer.
V4311_14	North-South component of the wind (V) at 43º N, 11ºW in winter and autumn of same year
V4311_1234	North-South component of the wind (V) at 43º N, 11ºW, annual value
V4311_4(-1)1	North-South component of the wind (V) at 43º N, 11ºW winter and previous autumn.
W4311_23	Turbulence of the wind (W) at 43º N, 11ºW in spring and summer.
W4311_14	Turbulence of the wind (W) of the wind at 43º N, 11ºW in winter and autumn of same year
W4311_1234	Turbulence of the wind (W) of the wind at 43º N, 11ºW, annual value
W4311_4(-1)1	Turbulence of the wind (W) of the wind at 43º N, 11ºW winter and previous autumn.
SST4503_23	Sea Surface Temperature at 45º N, 3ºW in spring and summer.
SST4503_14	Sea Surface Temperature at 45º N, 3ºW in winter and autumn of same year
SST4503_1234	Sea Surface Temperature at 45º N, 3ºW, annual mean value
SST4503_4(-1)1	Sea Surface Temperature at 45º N, 3ºW winter and previous autumn.
AT4503_23	Air Temperature at 45º N, 3ºW in spring and summer.
AT4503_14	Air Temperature at 45º N, 3ºW in winter and autumn of same year
AT4503_1234	Air Temperature at 45º N, 3ºW, annual mean value
AT4503_4(-1)1	Air Temperature at 45º N, 3ºW winter and previous autumn.
U4503_23	East-West component of the wind (U) at 45º N, 3ºW in spring and summer.
U4503_14	East-West component of the wind (U) at 45º N, 3ºW in winter and autumn of same year
U4503_1234	East-West component of the wind (U) at 45º N, 3ºW, annual value
U4503_4(-1)1	East-West component of the wind (U) at 45º N, 3ºW winter and previous autumn.
V4503_23	North-South component of the wind (V) at 45º N, 3ºW in spring and summer.
V4503_14	North-South component of the wind (V) at 45º N, 3ºW in winter and autumn of same year
V4503_1234	North-South component of the wind (V) at 45º N, 3ºW, annual value
V4503_4(-1)1	North-South component of the wind (V) at 45º N, 3ºW winter and previous autumn.
W4503_23	Turbulence of the wind (W) at 45º N, 3ºW in spring and summer.
W4503_14	Turbulence of the wind (W) at 45º N, 3ºW in winter and autumn of same year
W4503_1234	Turbulence of the wind (W) at 45º N, 3ºW, annual mean value
W4503_4(-1)1	Turbulence of the wind (W) at 45º N, 3ºW winter and previous autumn.
NAO_23	North-Atlantic Oscillation Index in spring and summer.
NAO_14	North-Atlantic Oscillation Index in winter and autumn of same year
NAO_1234	North-Atlantic Oscillation Index, annual mean value
NAO_4(-1)1	North-Atlantic Oscillation Index winter and previous autumn.

Table 1 Cont.

GSI_23	Position of the Gulf Stream (GSI) Index in spring and summer.
GSI_14	Position of the Gulf Stream (GSI) Index in winter and autumn of same year
GSI_1234	Position of the Gulf Stream (GSI) Index, annual mean value
GSI_4(-1)1	Nor Position of the Gulf Stream (GSI) Index winter and previous autumn.
SLSant_23	Sea level in Santander in spring and summer.
SLSant_14	Sea level in Santander in winter and autumn of same year
SLSant_1234	Sea level in Santander annual value
SLSant_4(-1)1	N Sea level in Santander winter and previous autumn.
SLCor_23	Sea level in La Coruña in spring and summer.
SLCor_14	Sea level in La Coruña in winter and autumn of same year
SLCor_1234	Sea level in La Coruña annual value
SLCor_4(-1)1	Sea level in La Coruña winter and previous autumn.
SLVigo_23	Sea level in Vigo in spring and summer.
SLVigo_14	Sea level in Vigo in winter and autumn of same year
SLVigo_1234	Sea level in Santander annual value
SLVigo_4(-1)1	N Sea level in Vigo winter and previous autumn.
TempSant_23	Air temperature in Santander in spring and summer.
TempSant_14	Air temperature in Santander in winter and autumn of same year
TempSant_1234	Air temperature in Santander annual value
TempSant_4(-1)1	Air temperature in Santander winter and previous autumn.
PrecSant_23	Precipitation in Santander in spring and summer.
PrecSant_14	Precipitation in Santander in winter and autumn of same year
PrecSant_1234	Precipitation in Santander annual value
PrecSant_4(-1)1	Precipitation in Santander winter and previous autumn.
PEA	Transport Index derived from the difference of Potential Energy Anomaly at Labrador and Bermuda.
GSI_DJFM	Position of the Gulf Stream (GSI) Index December to March.
NAO_DJFM	North-Atlantic Oscillation Index, December to March.
NAO-1	North-Atlantic Oscillation Index, December to March with a year lag
NAO-2	North-Atlantic Oscillation Index, December to March with two years lag
Qx4311_2º	Ekman Transport at 43º N, 11ºW in spring
Qx4311_3º	Ekman Transport at 43º N, 11ºW in summer.
Qx4311_1º	Ekman Transport at 43º N, 11ºW in winter.
Qx4311_4º	Ekman Transport at 43º N, 11ºW in autumn
Qx4311_23	Ekman Transport at 43º N, 11ºW in spring and summer.
Qx4311_14	Ekman Transport at 43º N, 11ºW in winter and autumn of same year
Qx4311_1234	Ekman Transport at 43º N, 11ºW, annual value
Qx4311_4(-1)1	Ekman Transport at 43º N, 11ºW winter and previous autumn.
Qx_DEFM	Ekman Transport at 43º N, 11ºW December to March
H. Mackerel Recruit.	Horse Mackerel recruitment
H. Mackerel -SSB	Spawning Stock Biomass of Horse Mackerel
H. Mackerel -stock	Horse Mackerel Stock
H. Mackerel-landing	Horse Mackerel landings
Albacore Recruit.	Albacore recruitment
Albacore Catch age 2	Catches of age 2 Albacore
Albacore Catch age 3	Catches of age 3 Albacore
Albac. Cat-surf age 3	Catches in surface of age 3 Albacore

Table 2. Statistics of the Principal Component Analysis

	Total Variance					
	Eigenvalues initials			Varimax rotation		
Component	Total	% variance	% accumulate	Total	% variance	% accumulate
1	21.14	25.47	25.47	15.45	18.61	18.61
2	8.75	10.54	36.01	10.09	12.16	30.77
3	8.19	9.87	45.88	7.80	9.40	40.17
4	6.10	7.35	53.23	7.07	8.51	48.68
5	5.16	6.22	59.45	6.60	7.95	56.63
6	3.74	4.51	63.96	6.08	7.33	63.96

Table 3: Horse Mackerel Recruitment Regression model based in three variables: The multiple regression analysis selected 3 variables: Sea surface temperature at 43ºN 11ºW in spring and summer, NAO index with a time lag of two years and summer upwelling index. and ANOVA analysis

Multiple Regression Results: Dependent variable Horse Mackerel Recruitment

Model	**Variables**
1	Qx4311_3º, NAO-2, SST4311_23

Results of model

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard error of estimate**
1	0.86	0.74	0.67	303187.42

ANOVA

Modelo		**Sums of Squares**	**df**	**Mean Squares**	**F**	**Sig.**
1	**Regression**	2906373116070.88	3.00	968791038690.29	10.54	0.00
	Residual	1011148723928.72	11.00	91922611266.25		
	Total	3917521839999.60	14.00			

Coefficients

Model		**B**	**ST error**	**Beta**	**t**	**Sig**
1	**(Intercpt)**	14277528.79	3469078.09		4.12	0.00
	SST4311_23	-795106.38	200468.51	-0.67	-3.97	0.00
	NAO-2	163082.33	61532.53	0.42	2.65	0.02
	Qx4311_3º	-608.40	705.99	-0.15	-0.86	0.41

Table 4.: Albacore Catches age 3 Regression model 1 (PEA) and model 2 (PEA and NAO) and ANOVA analysis

Multiple Regression Results: Dependent variable Albacore Catches age 3

Model	**Variables**
1	**PEA**
2	**NAO_4(-1)1**

Results of model

Model	**Multiple R**	**R^2**	**Adjusted R^2**	**Standard error of estimate**
1	0.63	0.39	0.37	285358.23
2	0.71	0.51	0.47	262529.37

ANOVA

Model		**Sums of Squares**	**df**	**Mean Squares**	**F**	**Sig.**
1	**Regression**	1219578776390.92	1.00	1219578776390.92	14.98	0.00
	Residual	1872874359037.73	23.00	81429319958.16		
	Total	3092453135428.64	24.00			
2	**Regression**	1576176371443.97	2.00	788088185721.99	11.43	0.00
	Residual	1516276763984.67	22.00	68921671090.21		
	Total	3092453135428.64	24.00			

Coefficients

Model		**B**	**ST error**	**Beta**	**t**	**Sig**
1	**(Intercpt)**	3740845.17	690820.73		5.42	0.00
	PEA	-44185.07	11417.24	-0.63	-3.87	0.00
2	**(Intercpt)**	4074856.92	643814.93		6.33	0.00
	PEA	-46984.30	10575.69	-0.67	-4.44	0.00
	NAO_4(-1)1	153174.14	67340.16	0.34	2.27	0.03

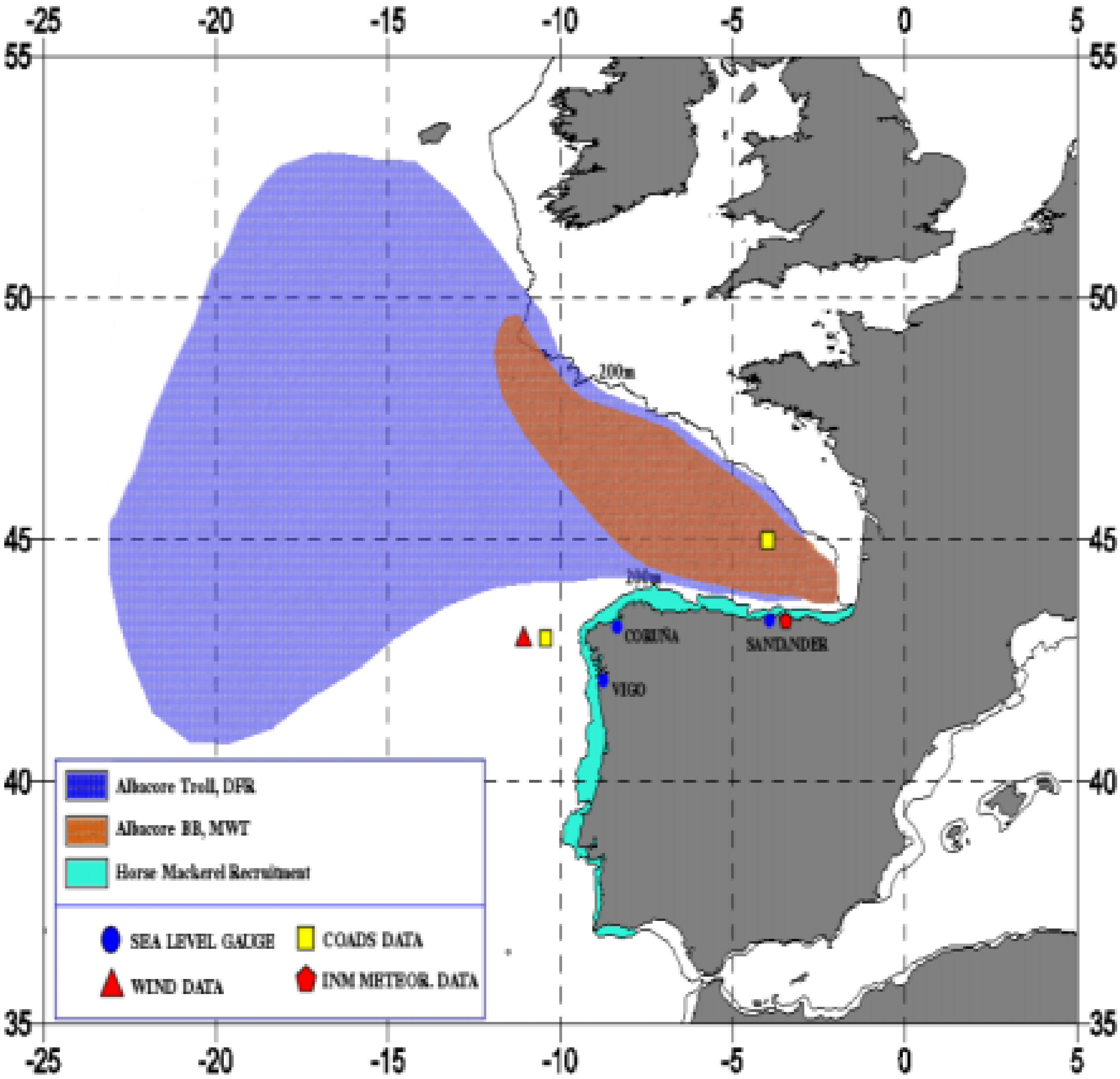

Figure 1. Area of study, location of environmental measurements (Sea level gauges, Wind data, INM Meteorological data and COADS data) and albacore fishing areas by gears (Troll, DFR: driftneters, BB: baitboat, MWT: mid water pelagic trawlers), and horse mackerel recruitment area.

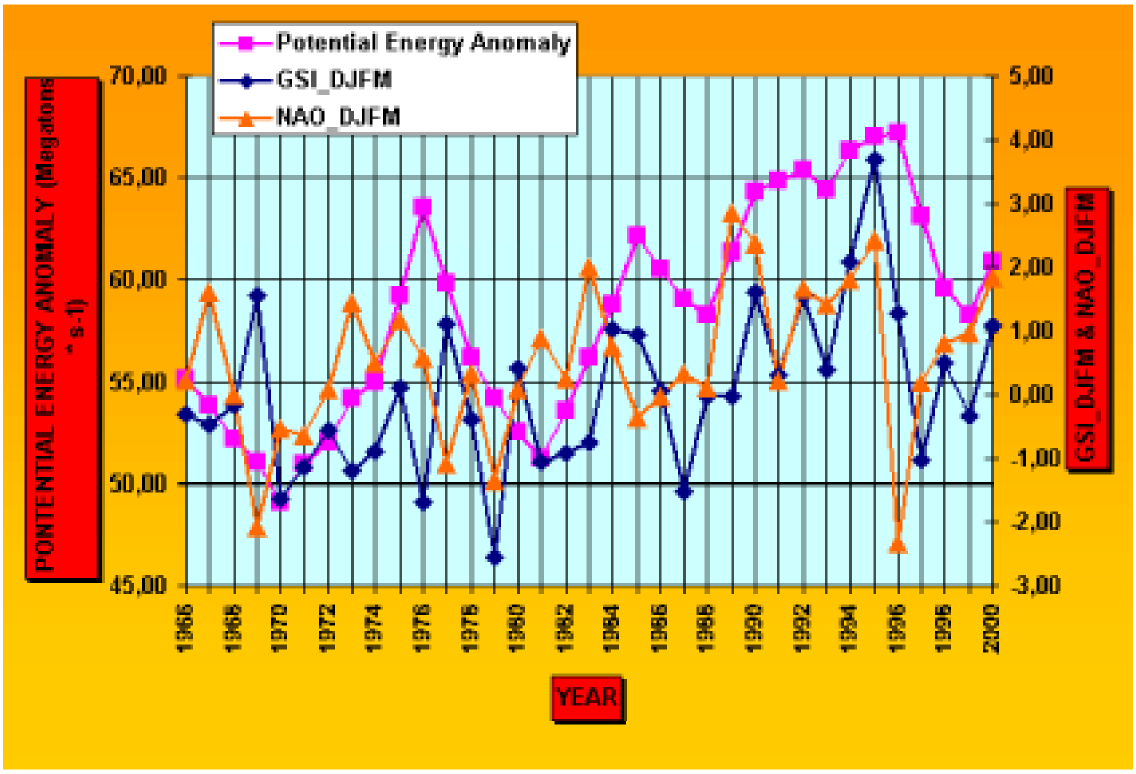

Figure 2: Time series of North Atlantic Oscillation (NAO) Index (Hurrell, 1995), Gulf Stream Index (GSI) (Taylor, 1996) and Transport Index (Curry and McCartney, 2001) from differences in Potential Energy Anomaly (PEA) between Labrador and Bermuda.

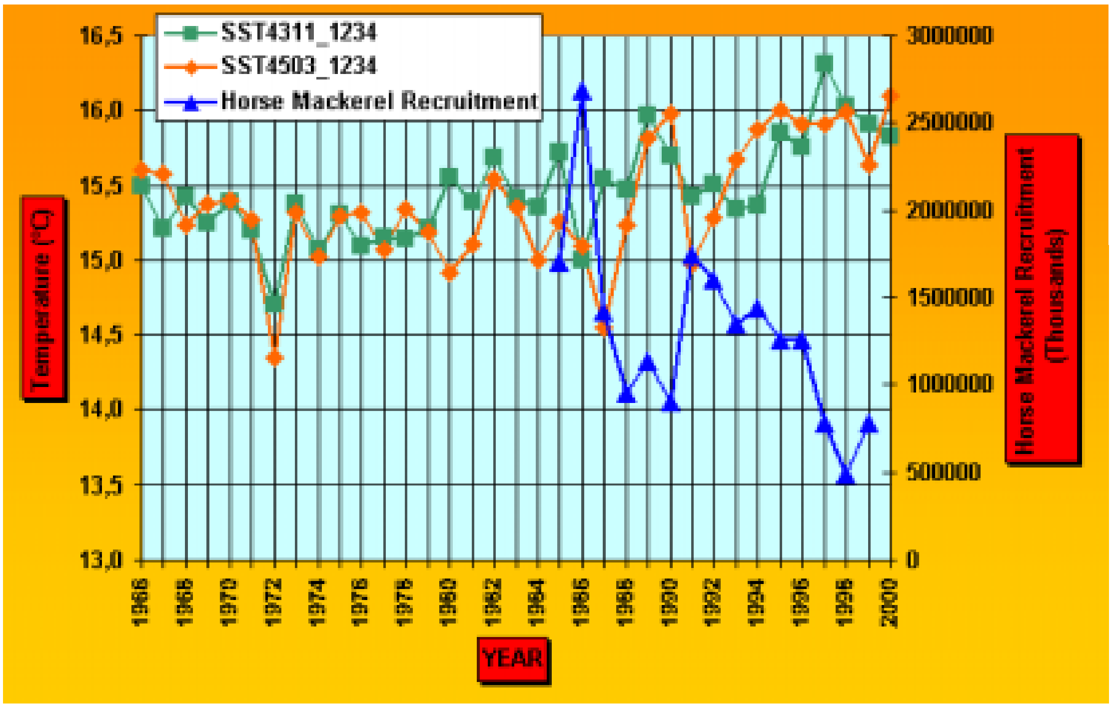

Figure 3: Time series of Sea Surface Temperature at 43°N 11°W and at 45°N 3°W (from COADS) and horse mackerel recruitment (ICES, 2001).

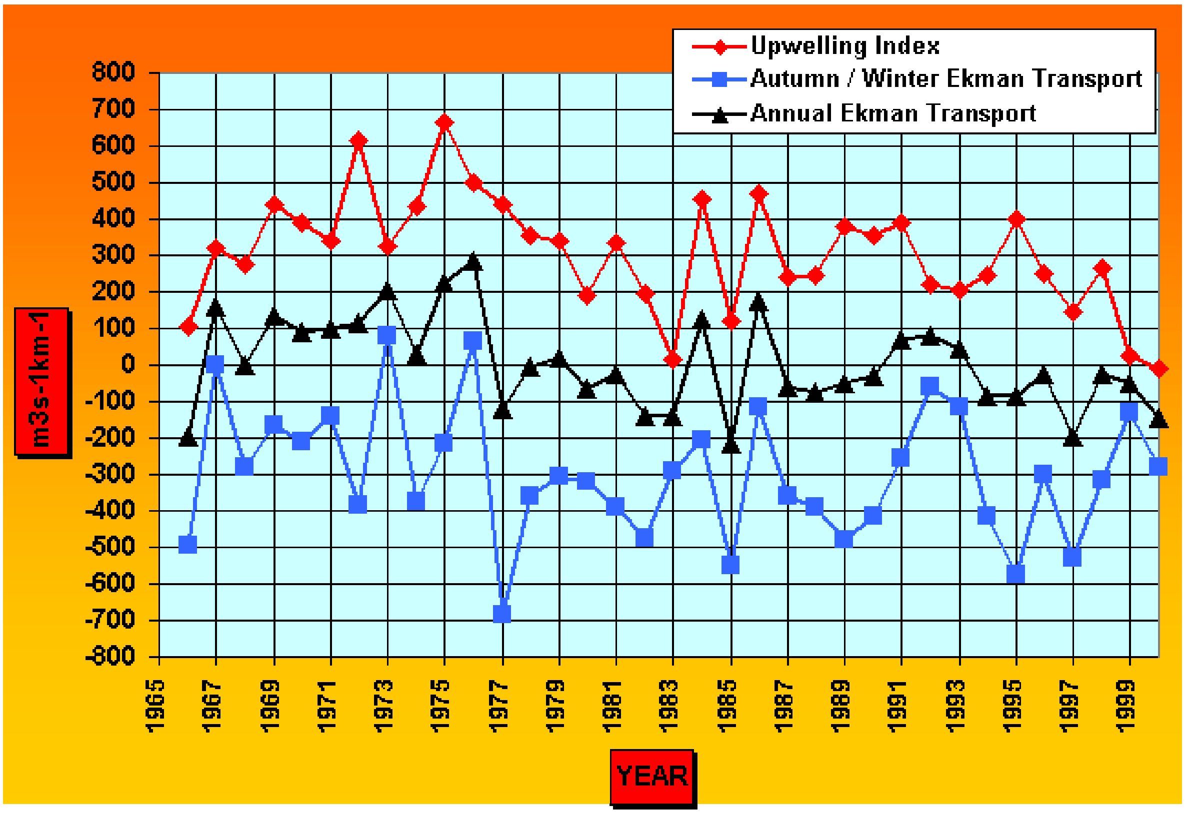

Figure 4: Time series of spring / summer upwelling Index, autumn / winter Ekman Transport and annual Ekman transport at 43°N, 11°W (from Lavín et al, 1991, 2000).

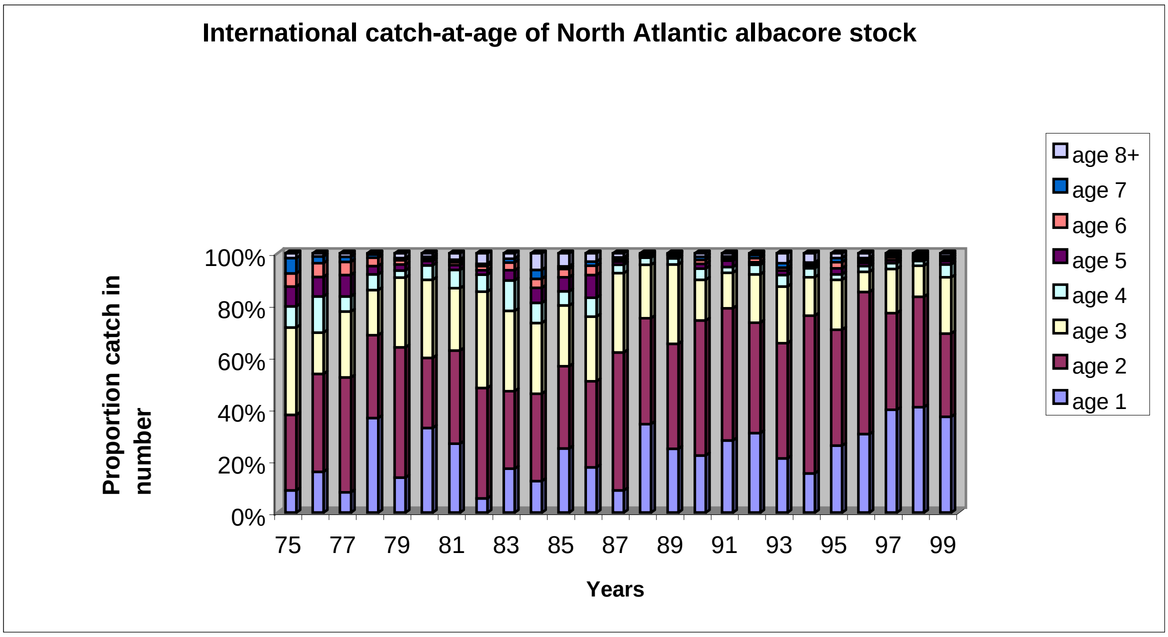

Figure 5a. Proportion of catch in number for North Atlantic albacore by age

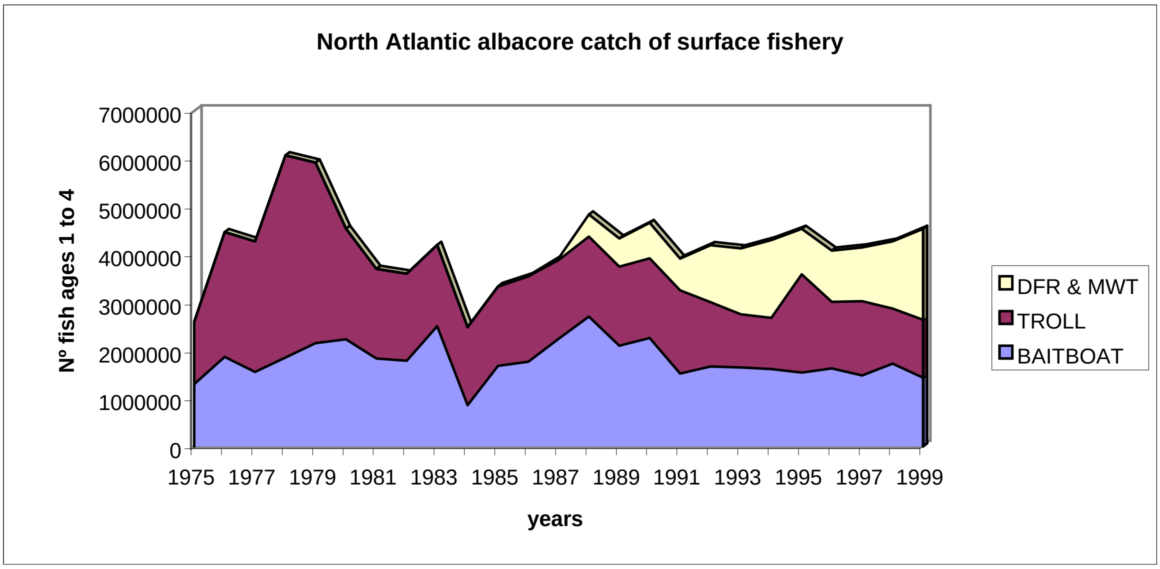

Figure 5.b. Catch in number of albacore by gear of the surface fishery in the eastern North Atlantic, 1975-1999

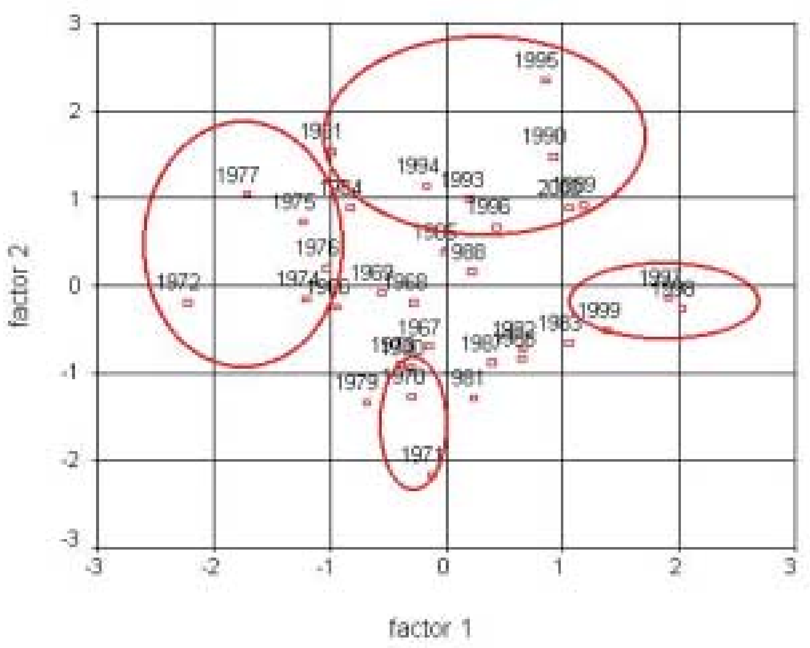

Figure 6: Distribution of time-series (years) as a function of the first and second components from the PCA.

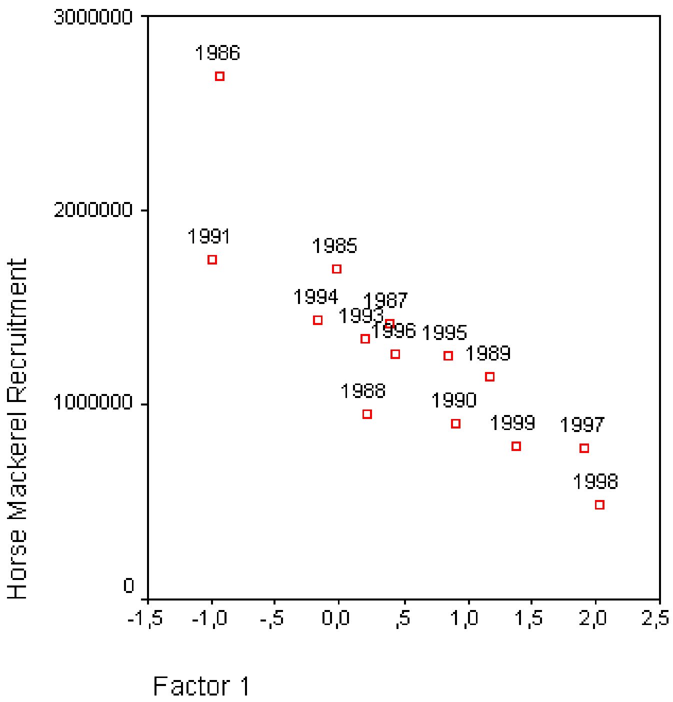

Figure 7: Distribution of Horse Mackerel Recruitment as function of the Principal component 1 (correlation of -0.86)

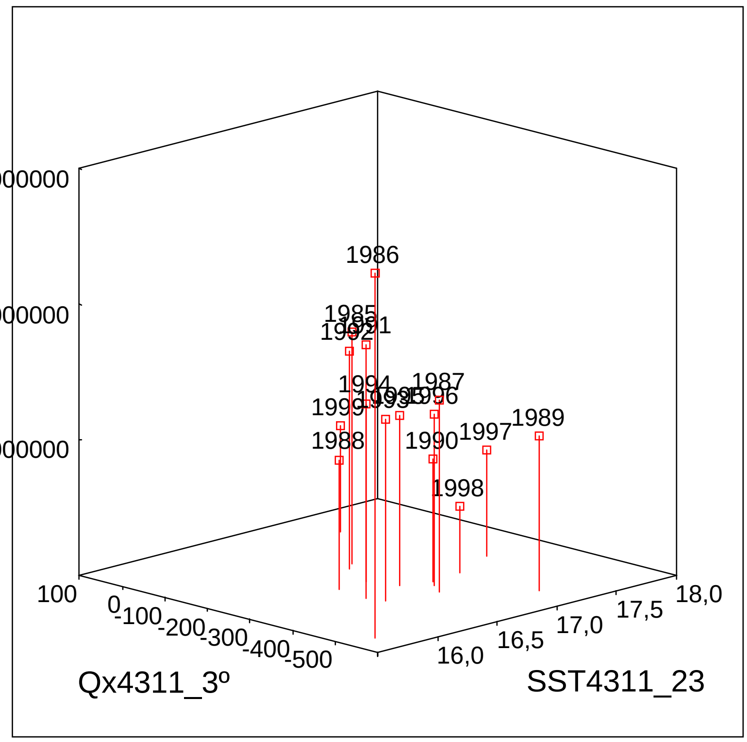

Figure 8: Distribution of Horse Mackerel Recruitment as function of the summer upwelling and spring/summer Sea Surface temperature at 43ºN, 11ºW.

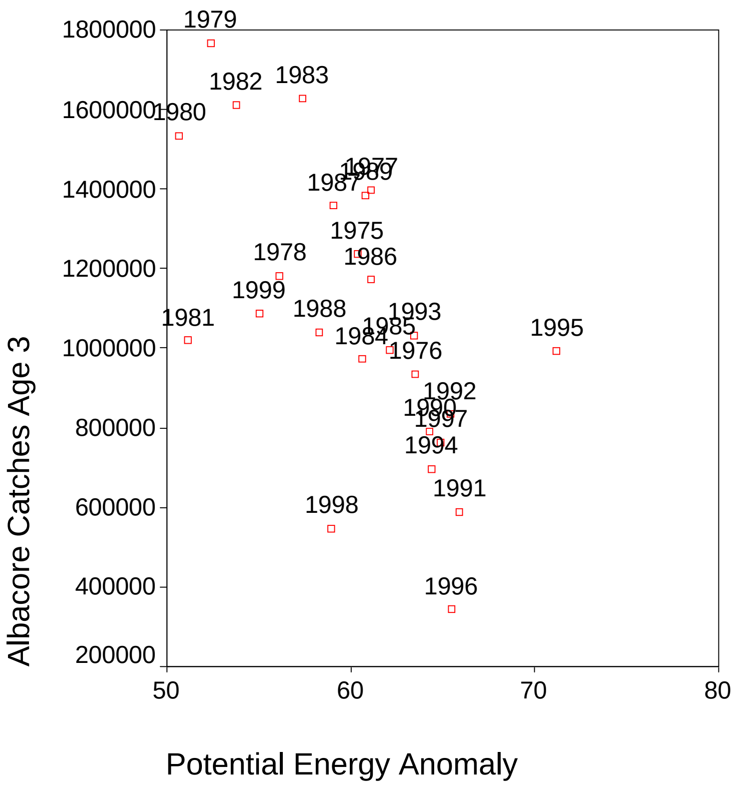

Figure 9. Distribution of albacore age 3 catches as function of the potential energy anomaly (PEA).

Annex I. Contribution of each variable to the six Principal Components. Values considered significant (|r|> 0.7) are marked.

Factor Loadings (Varimax raw)						
	Principal	Component				
	1	2	3	4	5	6
SST4311_23	**0.74**	0.23	0.03	-0.01	0.00	-0.26
SST4311_14	**0.82**	0.15	0.26	0.03	0.06	0.24
SST4311_1234	**0.88**	0.22	0.15	0.01	0.03	-0.05
SST4311_4(-1)1	0.62	0.10	0.37	0.24	-0.13	0.01
AT4311_23	**0.75**	0.27	0.12	0.04	0.01	-0.23
AT4311_14	**0.78**	0.17	0.04	0.06	0.36	0.29
AT4311_1234	**0.87**	0.25	0.09	0.06	0.21	0.03
AT4311_4(-1)1	**0.74**	0.17	0.16	0.38	-0.03	-0.01
U4311_4º	0.12	-0.10	-0.09	-0.24	0.66	-0.31
U4311_23	0.10	0.04	0.14	0.12	-0.05	-0.09
U4311_14	0.05	-0.11	-0.14	-0.03	**0.75**	0.00
U4311_1234	0.11	-0.07	-0.03	0.05	0.65	-0.07
U4311_4(-1)1	-0.03	0.02	-0.01	0.59	0.21	0.56
V4311_23	0.52	-0.35	-0.09	0.02	0.14	0.36
V4311_14	0.03	0.23	0.11	0.11	0.68	0.21
V4311_1234	0.31	0.00	0.05	0.11	0.66	0.38
V4311_4(-1)1	0.23	0.21	0.26	0.65	0.14	0.12
W4311_23	0.27	0.25	0.03	-0.32	-0.09	0.29
W4311_14	0.09	0.57	0.26	0.17	0.22	-0.06
W4311_1234	0.27	0.63	0.22	-0.11	0.10	0.17
W4311_4(-1)1	-0.02	0.41	0.21	0.46	-0.28	0.12
SST4503_23	0.68	0.11	0.13	0.05	-0.20	-0.44
SST4503_14	0.49	0.50	-0.20	0.27	-0.03	0.14
SST4503_1234	**0.72**	0.35	-0.03	0.18	-0.15	-0.22
SST4503_4(-1)1	0.33	0.38	0.12	0.37	-0.02	-0.27
AT4503_23	**0.71**	0.07	0.04	-0.10	0.07	-0.41
AT4503_14	0.27	0.55	-0.21	0.32	0.21	0.15
AT4503_1234	0.64	0.41	-0.11	0.15	0.19	-0.17
AT4503_4(-1)1	0.32	0.47	-0.01	0.47	0.03	-0.01
U4503_23	-0.54	-0.04	-0.17	0.40	-0.05	0.21
U4503_14	-0.26	0.38	-0.30	0.15	0.09	0.50
U4503_1234	-0.48	0.24	-0.30	0.33	0.03	0.47
U4503_4(-1)1	-0.06	0.33	-0.19	0.18	0.23	0.66
V4503_23	0.06	-0.19	0.06	-0.14	-0.01	0.57
V4503_14	-0.14	0.07	0.32	0.09	**0.76**	-0.14
V4503_1234	-0.08	-0.06	0.31	-0.01	0.65	0.24
V4503_4(-1)1	-0.02	0.21	0.38	0.44	0.33	0.28
W4503_23	-0.08	0.06	0.10	0.09	0.22	0.45
W4503_14	0.05	0.40	0.03	0.04	-0.17	**0.70**
W4503_1234	0.00	0.34	0.07	0.07	-0.03	**0.75**
W4503_4(-1)1	0.18	0.33	0.10	0.19	-0.03	0.69
NAO_23	-0.28	-0.10	-0.17	0.45	0.06	-0.30
NAO_14	0.21	0.21	-0.63	-0.03	-0.09	0.08
NAO_1234	0.03	0.13	-0.64	0.22	-0.05	-0.09
NAO_4(-1)1	0.33	0.25	-0.64	-0.39	0.11	-0.03
GSI_23	0.18	0.67	-0.28	0.05	0.06	0.23
GSI_14	0.23	**0.78**	-0.09	-0.03	-0.02	0.21
GSI_1234	0.23	**0.80**	-0.20	0.01	0.02	0.24

GSI_4(-1)1	0.14	**0.75**	0.16	0.18	-0.05	0.15
SLSant_23	0.64	-0.16	0.19	-0.06	0.29	-0.03
SLSant_14	0.34	0.04	0.50	0.16	0.53	0.01
SLSant_1234	0.51	-0.04	0.41	0.08	0.47	-0.01
SLSant_4(-1)1	0.29	0.02	0.46	0.52	0.18	0.14
SLCor_23	0.57	0.11	0.57	-0.13	-0.16	0.15
SLCor_14	0.27	0.17	**0.77**	0.06	0.39	0.01
SLCor_1234	0.43	0.16	**0.77**	-0.02	0.19	0.07
SLCor_4(-1)1	0.21	0.05	**0.75**	0.49	-0.05	0.01
SLVigo_23	0.44	0.10	0.38	-0.49	-0.02	0.05
SLVigo_14	0.11	0.44	0.67	-0.13	0.34	-0.05
SLVigo_1234	0.29	0.33	0.61	-0.33	0.20	0.00
SLVigo_4(-1)1	0.17	0.35	0.68	0.28	-0.06	0.00
TempSant_23	**0.76**	0.25	-0.24	-0.10	-0.01	0.01
TempSant_14	0.60	0.50	0.02	0.08	0.48	0.22
TempSant_1234	**0.77**	0.44	-0.12	-0.01	0.28	0.14
TempSant_4(-1)1	0.58	0.47	0.18	0.50	0.09	0.01
PrecSantr_23	-0.52	0.00	0.14	-0.13	-0.04	-0.20
PrecSantr_14	-0.37	-0.34	0.00	0.48	-0.18	-0.13
PrecSantr_1234	-0.59	-0.31	0.07	0.37	-0.19	-0.21
PrecSantr_4(-1)1	-0.46	-0.32	-0.24	-0.29	0.10	0.25
PEA	0.18	**0.85**	0.03	-0.15	0.05	0.04
GSI_DJFM	0.12	**0.78**	0.16	0.17	-0.11	0.09
NAO_DJFM	0.37	0.35	**-0.70**	-0.23	-0.01	0.00
NAO-1	-0.07	0.65	-0.13	0.01	-0.29	-0.09
NAO-2	-0.09	0.64	0.19	-0.14	0.10	0.08
Qx4311_2º	0.66	-0.24	0.13	0.06	0.22	0.27
Qx4311_3º	0.35	0.06	-0.26	-0.25	-0.18	0.06
Qx4311_1º	-0.09	0.02	-0.06	**0.74**	0.13	0.06
Qx4311_4º	0.31	0.33	0.22	-0.24	0.53	0.36
Qx4311_23	**0.71**	-0.17	-0.02	-0.07	0.10	0.25
Qx4311_14	0.20	0.31	0.14	0.37	0.57	0.36
Qx4311_1234	0.58	0.11	0.09	0.21	0.45	0.41
Qx4311_4(-1)1	0.34	0.08	0.13	**0.78**	-0.08	0.13
Qx_DJFM	0.13	0.03	0.06	**0.81**	0.02	0.22