ICES WKLTVSWE Report 2007

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Report of the ICES/GLOBEC Workshop on Long-term Variability in SW Europe (WKLTVSWE)

13-16 February 2007

Lisbon, Portugal

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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Executive summary

The WKLTVSWE-Workshop is a joint effort of ICES and GLOBEC and was endorsed by EUR-OCEANS (http://www.eur-oceans.org). In 1997 the SPACC (Small Pelagic Fishes and Climate Change) initiative of GLOBEC held a joint meeting with SCOR Working Group 98 on world-wide large-scale fluctuations of sardine and anchovy populations (Schwartzlose *et al*. 1999). It was decided then to continue this "global" undertaking with a series of regional workshops. Previous meetings focused on the Benguela Current in 2001 (e.g. Cury and Shannon 2004), the Humboldt Current in 2002 (e.g. Alheit and Niquen 2004) and the Japanese waters in 2003. During the annual meeting in 2005 of the former ICES Study Group on Regional Ecology of Small Pelagics (SGRESP), now a permanent ICES Working Group (WGLESP, ICES/GLOBEC Working Group on Life Cycle and Ecology of Small Pelagic Fish), it was recommended to continue this series of workshops with a meeting focusing on the waters surrounding the Iberian peninsula including the western Mediterranean Sea. A synthesis of the hydrography, oceanography and biology of the South Western European waters is presented in section 3.

The goals of this workshop were:

1) to provide a survey of large-scale, long-term changes throughout the ecosystems surrounding the Iberian peninsula; are there signals of regime shifts in the region?
2) to identify apparent synchronies (teleconnection patterns) with other regions of the north Atlantic or northern hemisphere.;
3) to gain insight into the causes and mechanisms underlying the major ecosystem changes, e.g. identifying possible links of those changes in the ecosystems to climate variability.

Testing material are climatic and oceanographic variables, ecosystem indices (Zooplankton and phytoplankton indices) and population indices of small pelagics (catches and recruitment series), in addition to climate forcing indices at local and worldwide scales. The time series compiled during the Workshop were as broad as possible. Seventy three (73) time series data were compiled into an excel table (Section 4) and classified by type of data: global climatic indices, and biological indices. With the objective of identifying and analysing oscillations at a multi-annual scale in the variability of the time series we decided to work on 3 case studies:

Case Study 1 - global region of Atlantic Iberian Peninsula (section 6.1).

Case Study 2 - local -region- Portugal (section 6.2)

Case study 3 - local region Bay of Biscay (section 6.3)

Highlights

The results of the global case study indicated significant inter-annual trends in climatic, oceanographic and ecosystem variables indicative of global warming in the region since ca. 1950. Quasi- decadal scales are characteristic of climatic, oceanographic and fish abundance indices, but plankton indices display shorter periods. Sardine and Anchovy showed synchrony in positive and negative phases up to 1978, they increased and decreased simultaneously. This pattern was broken and moved to asynchrony thereafter, when sardine and anchovy have opposite phases.

The Portuguese case study shows that sardine catches are negatively correlated with north-westerly winds and these are strongly and positively correlated with NAO. Sardine catches showed periods of 20-29 years, and 10 years of cyclic variation (section 6.2.2). The Bay of Biscay case study showed that anchovy recruitment is significantly correlated with local downwelling and upwelling events that can be measured at 45º North and 2ºW and follow a seasonal pattern: During Winter the water column has almost no stratification due to

convergence and downwelling from western poleward currents bringing warmer and saltier water of sub-tropical origin During Summer water column stratification increases when northern winds dominate and mechanisms of divergence and stable stratification prevail, bringing colder and less saline water of sub-polar origin to the Bay of Biscay. This weak upwelling gives a stable stratification that favours good recruitment. Nevertheless if Spring - Summer northern winds induce gales and storms disrupting the stable stratification this is detrimental for anchovy success.

A general mechanism emerges: there is an alternation of periodical quasi decadal dominance of boreal fresher and colder water and sub-tropical warmer and saltier water, and in accordance with the biogeography of the region, this will favour the productivity of each species' life-traits differently.

The Workshop also discussed the necessity of keeping the compiled database updated at ICES to allow for further tests to be carried out. This will serve several ICES Working Groups and permit conceptual work and model validation of regime shifts for ecosystem fisheries management.

1 Opening of the meeting

The Workshop on Long-term Variability in South West Europe (WKLTVSWE) was held at IPIMAR, Lisbon from 13-16 February 2007. The list of participants and contact details are given in Annex 1.

The Workshop members were welcomed by the Workshop co-conveners Maria de Fatima Borges, Jürgen Alheit, Andrés Uriarte and Alicia Lavín. The first day of the Workshop was made up of a series of general presentations, open to the public as well as Workshop members. The Terms of Reference for the Workshop were discussed on the second morning, taking into consideration these presentations, and a plan of work was adopted for the remaining days of the meeting. The Terms of Reference are listed below in section 2.2. The Workshop Agenda and minutes are given in Annex 2.

2 Introduction

2.1 Rationale

Understanding the role of natural variability, occurring over a variety of time scales, is essential if we are to effectively manage marine living resources. Evidence is accumulating that marine ecosystems undergo large-scale, decadal fluctuations which seem to be driven by climate forcing (Stenseth *et al*., 2002), as clearly demonstrated for the North Sea and the Baltic Sea (Beaugrand 2004, Alheit *et al*. 2005), the North Pacific (e.g. Hare and Mantua, 2000) and eastern boundary current systems (e.g. Chavez *et al*., 2003; Alheit and Niquen, 2004). Shifts in climate regimes can reorganize marine communities and trophodynamic relationships and induce changes in the mix of dominating species over decadal time scales.

Respective evidence was gained largely through retrospective studies, i.e., the analyses of historical atmospheric and marine data. In some instances, paleo-records have allowed us to look much further back in time and, most importantly, at periods when human intervention through fishing was not important. The impact of climate variability on marine ecosystems has been the focus of a number of national and international regional projects which have been carried out in local waters through a combination of retrospective investigations, modelling efforts and process studies.

All these GLOBEC workshops were/are concentrating on ecosystems in which small pelagic fishes such as anchovies and sardines are important, as well as horse mackerel which was also mentioned. Reasons are (Hunter and Alheit 1995): Small pelagic fishes such as sardine, anchovy, herring, sprat and others represent about 20 – 25 % of the total annual world fisheries catch. They are widespread and occur in all oceans. They support important fisheries all over the world and the economies of many countries depend on those fisheries. They do respond dramatically and quickly to changes in ocean climate. Most are highly mobile; have short, plankton-based food chains and some even feed directly on phytoplankton. They are short-lived (3-7 years), highly fecund and some can spawn all year-round. These biological characteristics make them highly sensitive to environmental forcing and extremely variable in their abundance (Hunter and Alheit 1995). Thousand-fold changes in abundance over a few decades are characteristic for small pelagics and well-known examples include the Japanese sardine, sardines in the California Current, anchovies in the Humboldt Current, sardines in the Benguela Current or herring in European waters. Their drastic stock fluctuations often caused dramatic consequences for fishing communities, entire regions and even whole countries. Their dynamics have important economic consequences as well as ecological ones. They are the forage for larger fish, seabirds and marine mammals. The collapse of small pelagic fish populations is often accompanied by sharp declines in marine bird and mammal populations that depend on them for food. Major changes in abundance of small pelagic fishes may be accompanied by marked changes in ecosystem structure. They are often accompanied by rigorous changes in abundance and species composition of zooplankton. The great plasticity in the growth, survival and other life-history characteristics of small pelagic fishes is the key to their dynamics and makes them ideal targets for testing the impact of climate variability on marine ecosystems and fish populations and in general marine ecosystems.

Valuable accounts on long-term changes of anchovies and sardines and their respective ecosystems around the Iberian peninsula and the potential impact of climate variability have been published recently (e.g. Borja *et al.* 1998, Allain *et al.* 2001, Uriarte *et al.* 2002, Borges *et al.* 2003, Guisande *et al.*, Bode *et al.* 2006). However, they concentrated on single species or ecosystems and were restricted to regional parts of the European south-western waters.. This workshop is an attempt to analyze long-term time series of physical and biological data from the seas surrounding the Iberian Peninsula in a comparative manner with the main focus on long-term changes of small pelagic fish.

It is expected that this workshop enhance our understanding of the response of marine ecosystems to low-frequency environmental change and improve our knowledge of the impact of climate variability on marine ecosystems. The comparative approach was chosen to elucidate mechanisms controlling the abundance and distributions of marine populations. The improved mechanistic understanding of the coupling between physics and biology will, in turn, improve the reliability of predictions of the future composition of marine communities and provide a new basis for ecosystem and resource management.

2.2 Terms of Reference

The Terms of Reference for the Workshop on Long-term Variability in SW Europe (WKLTVSWE) were to:

a) rescue, collate and jointly analyze decadal-scale; long-term time series of physical, chemical and biological data from ecosystems surrounding the Iberian peninsula with a focus on long-term changes of small pelagic fish;

b) identify possible links to climate variability;

c) look for possible telecommunication patterns with European and other marine ecosystems.

WKLTVSWE will report by 31 March for the attention of the Living Resources Committee.

2.3 Participants

The following scientists attended the Workshop.

Full contact details are given in Annex I.

A. Miguel Santos, Portugal

Aarón Trujillo, Spain

Alicia Lavín, Spain

Andrés Uriarte, Spain

Antonio Bode, Spain

Hugo Mendes, Portugal

Jürgen Alheit, Germany

Louize Hill, Portugal

M. Luz Fernández de Puelles, Spain

Manuel Vargas, Spain

Maria de Fátima Borges, Portugal

Maria Manuel Angélico, Portugal

Omar Ettahiri, Morocco

Raquel Somavilla, Spain

Teresa Moita, Portugal

Víctor Valencia, Spain

The following scientists contributed to the workshop by giving a presentation, providing valuable background information to the workshop:

José Carlos Mendes, Portugal

Ricardo Trigo, Portugal

Yorgos Stratoudakis, Portugal

3 Background – hydrography, oceanography and biology of the SW European waters

3.1 The Atlantic waters

Most of the water masses in the region (Figure 3.1.1.) are of North Atlantic origin, including those that have been transformed after mixing with the Mediterranean water. The region is affected by both the subpolar and subtropical gyres depending on latitude, but the general circulation in the area mainly follows the subtropical anticyclonic gyre in a relatively weak manner (1-2 cm.s-1). The southern part of the Bay of Biscay, along the Northern Spanish coast is known as the Cantabrian Sea and is characterised by a narrow shelf. Further south a narrow shelf continues west off Portugal Lastly, to the south, the Gulf of Cadiz has a wider shelf strongly influenced by the Mediterranean Sea. Within these zones the topographic diversity and the wide range of substrates result in many different types of coastal habitat (OSPAR Commission 2000).

The eastern boundary of the North Atlantic subtropical gyre extends from the northern tip of the Iberian Peninsula at 43º N to south of Senegal at about 10º N, approximately the displacement of the trade wind band. The meriodinal shift of the trade wind system causes seasonal upwelling in the extremes of the band, while in the central region upwelling is relatively continuous all year round (Wooster *et al*. 1976; Arístegui *et al*. 2004). Superimposed on the seasonal variation, short term variability in wind direction and intensity may induce or suppress upwelling affecting the dynamics of the ecosystem. The upwelling region is separated into two distinct areas: the Iberian coast and the Northwest African coast, with apparently little continuity in the flow between them. This is caused by the interruption of the coast line at the Strait of Gibraltar, which allows the exchange of water between the Mediterranean Sea and Atlantic Ocean. Associated with the topography of the shelf large filaments of coastal upwelled water stretch offshore from the numerous capes and promontories, exchanging water and biological properties with the ocean boundary. This exchange is particularly noticeable along the giant filaments of Cape Cuir and Cape Blanc which stretch up to several hundred kilometres into the open ocean transporting rich organic matter waters. (Aristegui, *et al*., 2004).

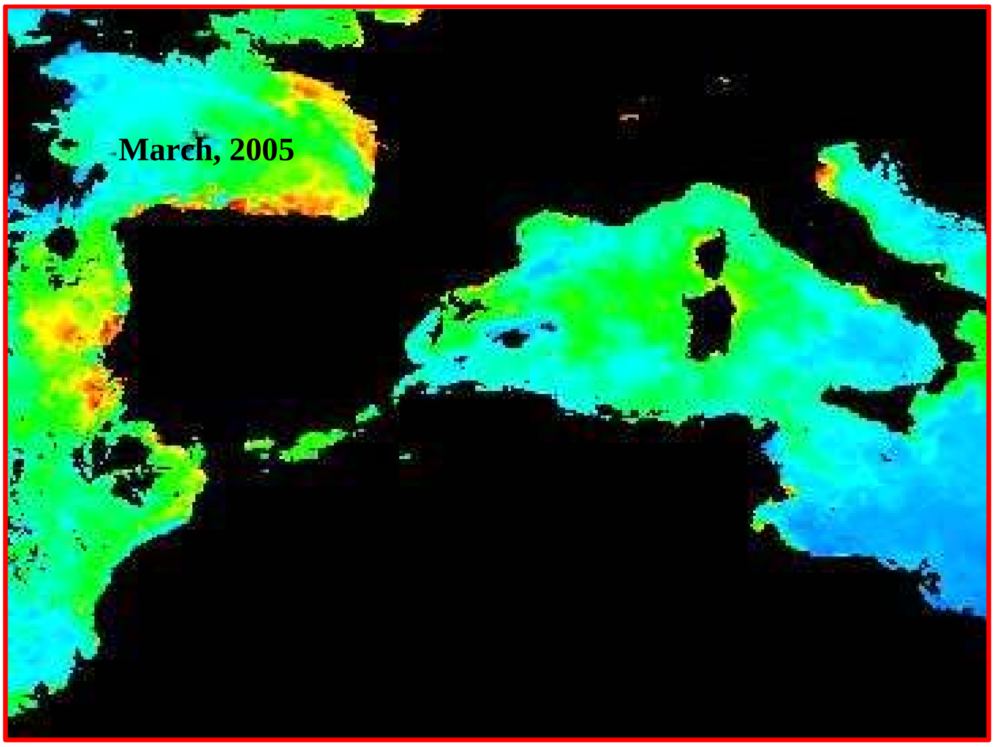


Figure 3.1.1. Map of the SW Europe seas, including the Bay of Biscay, Cantabrian Sea, Portuguese continental waters, gulf of Cadiz and Mediterranean.

In the Cantabrian Sea the surface currents generally flow eastwards during winter and spring and change westwards in the summer following the wind forcing (Lavin *et al*. 2005). These changes in the direction of the currents produce seasonal coastal upwelling. The circulation on the west coast of the Iberian Peninsula is characterized by a complex current system subject to strong seasonality and mesoscale variability, showing reversing patterns between summer and winter in the upper layers of the slope and outer shelf (e.g.: Barton 1998; Peliz *et al*. 2005; Ruiz-Villarreal *et al*. 2006). During spring and summer northerly winds along the coast are dominant causing coastal upwelling and producing a southward flowing at the surface and a northward undercurrent at the slope (Fiúza *et al*. 1982; Haynes and Barton 1990; Peliz *et al*. 2005; Mason *et al*. 2006).

In the autumn and winter, the surface circulation is predominantly northward, partially driven by meridional alongshore density gradients (Peliz *et al*. 2003a; Peliz *et al*. 2003b), and transporting higher salinity and warmer (subtropical) waters over the shelf break (Frouin *et al*. 1990; Haynes and Barton 1990; Pingree and Le Cann 1990) - the Iberian Poleward Current (Peliz *et al*. 2003b). These waters are nutrient poor and contribute to fronts which determine the distribution of plankton, fish eggs and larvae (Fernández *et al*. 1993; González-Quirós *et al*. 2003). Strong subtropical water intrusions in the Cantabrian Sea may be a feature strongly influenced by wind events (Villamor *et al*. 2005). Another important feature of the upper layer is the Western Iberia Buoyant Plume (WIBP) (Peliz *et al*. 2002), which is a low salinity surface water body fed by winter-intensified runoff from several rivers from the northwest coast of Portugal and the Galician Rias. The WIBP could play an important role in the survival of fish larvae (Santos *et al*. 2004).

The intermediate layers are mainly occupied by a poleward flow of Mediterranean Water (MW), which tends to contour the south-western slope of the Iberia (Ambar and Howe 1979), generating mesoscale features called Meddies (e.g.: Serra and Ambar 2002), which can transport salty and warm MW over great distance. The exchange of water masses through the Gibraltar Straits is driven by the deep highly saline (S>37) and warm Mediterranean Outflow Water (MOW) that flows into the Gulf of Cadiz and the less saline, cool water mass of the Atlantic Intermediate Water (AIW) at the surface. Most important features enhancing primary production are coastal upwelling, coastal run-off and river plumes, seasonal currents and internal waves and tidal fronts. Water temperature is highest to the south, where it is influenced by the MW. For example, the yearly mean temperature at 100m depth is 11.2 °C to the North of the region, 48°N, and 15.6 to the South, 36°N (Levitus, 2001).

Upwelling events are a common feature in Portugal, West of Galicia and in a narrow coastal band in western Cantabrian Sea, especially in summer (Fraga 1981; Fiúza *et al*. 1982; Blanton *et al*. 1984; Botas *et al*. 1990; OSPAR Commission 2000).

The climatic and oceanographic features of the inner part of the Bay of Biscay follow the main trends and patterns described above for the Iberian Atlantic coasts at the intergyre region of the north eastern Atlantic Ocean (Valencia *et al*., 2003). The Eastern North Atlantic Central Water (ENACW) is the main water mass in the upper layers of the Bay of Biscay; it occupies almost all the water volume over the continental shelf and the continental slope. However the upper layers of waters suffer some modifications (at regional and seasonal scales) due largely to the close coupling between meteorological and oceanographic data in the inner part of the Bay of Biscay (Pérez *et al*., 1995, Pérez *et al*., 2000; Valencia *et al*., 2003) as for instance the relationships between atmospheric temperature, SST and heat content and salinity, in relation to the precipitation minus evaporation balance and the influences of river flows.

In this region, two varieties of ENACW can be identified: colder and fresher ENACWP, of sub-Polar origin, and warmer and saltier ENACWT of sub-Tropical origin (Ríos *et al*., 1992). The relative occurrence of those water masses in the SE Bay of Biscay, as well as the degree of modification of their characteristics, is related with the main seasonal cycle and with the specific climatic conditions. During autumn and winter, southerly and westerly winds are dominant and a poleward current prevails, with associated mechanisms of convergence, downwelling and vertical mixing. During spring and summer southerly and westerly winds decline, being dominant weaker north and north-easterly wind with associated mechanisms of divergence, upwelling and stable stratification. These regimen increases also the proportion of relatively colder and less saline waters (ENACWP) into SE Bay of Biscay in summer (Valencia *et al*, 2004).

The seasonal interplay of the large scale climatology between the Azores high pressure cell and strengthened and displaced northward during the summer, and the Icelandic low, weakened at that time, governs the set up of favourable upwelling winds (northerlies) off Western Iberia between April and October (Wooster *et al*. 1976; Fiúza *et al*. 1982). During the winter the dominant wind direction changes and poleward flow becomes a conspicuous feature at all levels between the surface and the Mediterranean water at ~ 1500 m, along the Iberian shelf edge and slope. The surface poleward current carries relatively warm and saline water clearly identifiable in sea surface temperature satellite imagery (Frouin *et al*. 1990; Haynes and Barton 1990; Peliz *et al*. 2005) that propagates to locations so far north as the Cantabrian Sea (Pingree and Le Cann 1990) and Goban Spur, northwest of the U.K. in the continental margin (Pingree 1993).

In the case of the North Atlantic system the Canary and Iberian regions form two different subsystems (Barton 1998). The separation is not simply geographical, but a consequence of the discontinuity imposed by the entrance to the Mediterranean Sea, allowing the exchange between to different water masses with a profound impact in the regional circulation (Relvas *et al*. 2006). Recent work suggests that the large scale climatologic patterns are partly obscured by the mesoscale activity (Relvas *et al*. 2006).

The upper waters of the Bay of Biscay have experienced progressive warming during the past and the present century. Mean surface water temperatures increased by 1.48C in the south-eastern Bay of Biscay over the period 1972–1993 (0.68C per decade) and by 1.038C over the past century (Koutsikopoulos et al., 1998; Planque et al., 2003). The increase in heat content stored in the water column appears to be greatest in the 200–300 m layer (González-Pola and Lavín, 2003), and it is in this layer that eastern North Atlantic central waters (ENACW) respond quickly to climate forcing in areas of water mass formation located in the northern Bay of Biscay and adjacent areas. In the southern Bay of Biscay, temperature has increased during the last decade in the ENACW by 0.032ºC y-1 and in the Mediterranean Water around 0.020ºC and 0.005 for salinity (González-Pola et al., 2005).

Koutsikopoulos, C., Beillois, P., Leroy, C., and Taillefer, F. 1998. Temporal trends and spatial structures of the sea surface temperature in the Bay of Biscay. Oceanologica Acta, 21: 335–344.

González-Pola, C., and Lavín, A. 2003. Seasonal cycle and interanual variability of the heat content on a hydrographic section off

Santander (southern Bay of Biscay), 1991–2000. ICES Marine Science Symposia, 219: 343–345.

González-Pola, C., Lavín, A., and Vargas-Yánez, M. 2005. Intense warming and salinity modification of intermediate water masses in the southeastern corner of the Bay of Biscay for the period 1992– 2003. Journal of Geophysical Research, 110: C05020, doi:10.1029/2004JC002367.

Planque, B., Beillois, P., Jégou, A-M., Lazure, P., Petitgas, P., and Puillat, I. 2003. Large-scale hydroclimatic variability in the Bay of Biscay: the 1990s in the context of interdecadal changes. ICES Marine Science Symposia, 219: 61–70.

3.2 The Balearic Sea

The Balearic Islands located in the central area of the Western Mediterranean basin represents a complex topographic barrier separating two subbasins, where different water masses are coming through. The marine region can be considered as a transition zone where water masses of southern and northern origins meet in the surface layer (0-100m). In the northern Western Mediterranean, the Balearic Sea receives the cold and saline waters originating during winter in the Gulf of Leon, where strong winds are frequent and in the south, the Alborán basin, direct receptor of Atlantic waters through Gibraltar receives warmer and less saline waters where weather conditions are milder. Therefore, in the Balearic sea and particularly in their channels, the cool and salty northern waters proceeding northward, encounter warmer, fresher waters of Atlantic origin flowing northwards (Font *et al*., 1988; Garcia *et al*., 1994; Pinot *et al*., 1994). The Mallorca channel is the preferred route of southern waters in their northward spread. Nevertheless, the circulation can be reversed during winter and spring as cool, southward-flowing waters of northern origin (Pinot *et al*., 2002). According to the time of the year and the mesoscale processes in the adjacent areas, it is observing a mixture of these waters but also clear inputs of different water masses, forming frontal systems with more or less intensity and permanence (Lopez-Jurado, 2002). During the period of 1994-2003 high interannual variability has been observed in the hydrography of the islands as main drivers of the zooplankton variability (Fernandez de Puelles *et al*., 2004 b). However, the northern saltier waters southward can usually be observed in winter, during autumn more recent Atlantic waters northward can be found. A permanent mesoscale eddies disturb the area giving very complex circulation characterizing the region. The seasonal and interannual variability of these currents has been investigated during the last decade by oceanographers finding out relation to atmospheric forcing but its implication on planktonic communities is still poorly known (Fernandez de Puelles *et al*., 2004a).

Multidisciplinary projects since 1994 have found that the Mallorca channel is an adequate place for a long term monitoring studies, observing the boundary character of the area where any hydrography change can be reflected by the zooplankton community (Fernandez de Puelles *et al*., 2004b). In addition, it is important to mention that the area is not affected by river discharge or pollutants of terrestrial origin, being more influenced by ocean circulation conditions than by the coastal circulation, such as those at play in shelf areas, where more studies exit (Estrada *et al*., 1985). Considering all of that, this channel could well represent the transitional open sea environment of the Mediterranean pelagic ecosystem.

4 Data

A total of 73 climatic, oceanographic and biological variables were identified and data for each of these variables was compiled into tables during the workshop. The longest available time series were from 1940 to 2005 for variables such as the NAO index, the Global Temperature Anomaly, Portuguese north wind or sardine landings, etc. Shorter time series were available for other variables, the shortest being for anchovy and horse-mackerel recruitment in the Bay of Biscay which were only from 1986 and 1985 respectively until 2005 and 1999. The time series used in the Workshop were as broad as possible and include different types of climatological, oceanographic and biological data to cover most of the variability in the area. The period studied in the long term analyses here was fixed to around 1960 to 2005. Short term data series were also computed to study regional variability. The tables in the following sections summarise the details of the 73 variables, show the period for which data is available and list the data sources. They are organised according to abiotic and biotic data type: global climatic, physical oceanographic and biological indices (Tables 4.1.1.-4.3.1.). Explanations on the background for each of these variables are given in Annex 5.

4.1 Global climatic indices

Table 4.1.1. The 17 available time series of global climatic indices and source of data

No	Variable	Definition	Start	End	Source of data
1	NAO	North Atlantic Oscillation	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
2	EA	Eastern Atlantic Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA of monthly values.
3	WP	Western Pacific Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.

4	EP_NP	Eastern Pacific / North Pacific Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
5	PNA	Pacific North American Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
6	EA_WR	East Atlantic / West Russia Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
7	SCA	Scandinavia Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
8	TNH	Tropical / Northern Hemisphere Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
9	POL	Polar / Eurasia Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
10	PT	Pacific Transition Pattern	1950	2005	PFEL-NOAA. Annual standarized means from PCA monthly values.
11	CLI1	1st. PCA component of climatic indices	1950	2005	PCA of teleconnection indices
12	CLI2	2nd. PCA component of climatic indices	1950	2005	PCA of teleconnection indices
13	CLI3	3rd. PCA component of climatic indices	1950	2005	PCA of teleconnection indices
14	NAO_DM	North Atlantic Oscillation Hurrell (1995) Dec-March	1940	2005	Climate Research Unit (CRU) actual values (not from PCA components)
15	NAO_m	North Atlantic Oscillation Hurrell (1995) annual mean	1940	2005	Climate Research Unit (CRU) actual values(not from PCA components)
16	At_global	Global temperature anomaly (continent-ocean) from mean value between 1880-2000 (ºC)	1940	2005	Climate Research Unit (CRU)
17	At_NH	Northern Hemisphere temperature anomaly (continent-ocean) from mean value between 1880-2000 (ºC)	1940	2005	Climate Research Unit (CRU)

4.2 Physical oceanographic indices

Table 4.2.1. The 29 available time series for local physical oceanographic indices and the source of data.

No	Variable	Definition	Start	End	Source of data
18	AMO	Atlantic Multidecadal Oscillation (sea surface temperature anomaly from detrended mean global warming value)	1940	2005	Climate Data Center (CDC) NOAA
19	SSTP	Mean sea surface temperature Portugal (39.5ºN,9.5ºW, ºC)	1960	2002	ICOADS (reanalysis data) 2ºx2º grid
20	RFG	Mean annual river flow Gironde (Garonne+Dordogne, m3/s)	1952	2005	AZTI from various sources
21	SSTSS	Mean sea surface temperature at San Sebastian Aquarium (ºC)	1947	2005	AZTI from various sources
22	POLE	Poleward index at 43ºN, 11ºW from geostrophic winds (Qy, October-December of preceding yr)	1955	2004	Cabanas, J.M. (1999) PhD Thesis
23	UIs_4311	Upwelling index at 43ºN, 11ºW from geostrophic winds (March-October, m3/(s km))	1966	2005	Lavin *et al.* (1991) Inf Tecn Inst Esp Oceanogr 91:1-40
24	Uim_4311	Upwelling index at 43ºN, 11ºW from geostrophic winds (annual mean, m3/(s km))	1966	2005	Lavin *et al.* (1991) Inf Tecn Inst Esp Oceanogr 91:1-40
25	TPEA	Mean water transport from Potential Energy Anomaly North Atlantic (Mtons/s)	1955	2005	WHOI Ruth Curry

26	SST_450 3	Mean sea surface temperature (45ºN,03ºW, ºC)	195 5	200 5	ICOADS
27	SST_431 1	Mean sea surface temperature (43ºN,11ºW, ºC)	195 5	200 5	R. Somavilla / A. Lavin
28	TAIR_43 11	Mean air temperature (43ºN, 11ºW, ºC)	195 5	200 5	R. Somavilla / A. Lavin
29	U_4503	mean E-W wind (45ºN,03W, m/s)	195 5	200 5	R. Somavilla / A. Lavin
30	V_4503	mean N-S wind (45ºN,03W, m/s)	195 5	200 5	R. Somavilla / A. Lavin
31	U_4311	mean E-W wind (43ºN,11ºW, m/s)	195 5	200 5	R. Somavilla / A. Lavin
32	V_4311	mean N-S wind (43ºN,11ºW, m/s)	195 5	200 5	R. Somavilla / A. Lavin
33	NWPw	North wind Portugal (40ºN,10ºW, Jan-March, m/s)	194 0	200 0	R. Somavilla / A. Lavin
34	NWPs	North wind Portugal (40ºN,10ºW, Jun-Aug, m/s)	194 0	200 0	NCAR reanalysis data (original data from 5ºx5º grid 30-50ºN, 25-5ºW)
35	SOFWE	Significantly offshore favourable wind events Portugal (number of events with >4 favourable days)	194 8	200 3	H. Mendes
36	SUFWE	Significantly upwelling favourable wind events Portugal (number of events with >4 favourable days)	194 8	200 3	H. Mendes
37	HSFWE	hybrid SUFWE-SOFWE events Portugal	194 8	200 3	H. Mendes
38	SONFW E	Significantly onshore favourable wind events Portugal (number of events with >4 favourable days)	194 8	200 3	H. Mendes
39	UILm_45 02	Upwelling index Landes (45ºN, 2ºW, annual mean, m3/(s km))	196 7	200 5	ICOADS (reanalysis data) 2ºx2º grid
40	UIBm_45 02	Upwelling index Basque coast (45ºN, 2ºW, annual mean, m3/(s km))	196 7	200 5	ICOADS (reanalysis data) 2ºx2º grid
41	UIBs_45 02	Upwelling index Basque coast (45ºN, 2ºW, annual mean of positive values, March-July, m3/(s km))	196 7	200 5	V. Valencia / A. Borja
42	TURB_4 502	mean annual turbulence Bay of Biscay (at 45ºN, 2ºW, m3/s3)	196 7	200 5	ICOADS (reanalysis data) 2ºx2º grid
43	SHF_450 3	annual mean sensible heat fluxes Bay of Biscay (45ºN, 3ºW, W/m2)	194 8	200 5	ICOADS (reanalysis data) 2ºx2º grid
44	LHF_450 3	annual mean latent heat fluxes Bay of Biscay (45ºN, 3ºW, W/m2)	194 8	200 5	ICOADS (reanalysis data) 2ºx2º grid
45	ZMF_450 3	annual mean zonal momentum flux Bay of Biscay (45ºN, 3ºW, N/m2)	194 8	200 5	ICOADS (reanalysis data) 2ºx2º grid
46	MMF_45 03	annual mean meridional momentum flux Bay of Biscay (45ºN, 3ºW, N/m2)	194 8	200 5	ICOADS (reanalysis data) 2ºx2º grid

4.3 Biological Indices

In the following table the available biological indices for the Iberian region are listed. These include landings and recruitment data for of sardine, anchovy, and horse mackerel from the different Iberian sub-areas.

Phytoplankton colour index (PCI) time series observed in Galicia-Portugal and in the Bay of Biscay monitored by the Continuous Plankton Recorder (CPR) provided by SAFHOS http://www.sahfos.org/ was available since 1958 to 2004. Meso-zooplankton biomass, and copepod abundance time-series of several local sub-areas were the basis for biological indicators of ecological meaning such as the Phytoplankton-Zooplankton Index.

Table 4.3.1. The 26 available biological time series indices: description, period and source of data.

No	Variable	Definition	Start	End	Source of data
47	sard_PNW	sardine landings (x1000 T) ICES NW Portugal	1940	2005	M.F. Borges
48	sard_PSW	sardine landings (x1000 T) ICES SW Portugal	1940	2005	M.F. Borges
49	sard_PS	sardine landings (x 1000 T) ICES S Portugal	1940	2005	M.F. Borges
50	sard_PW	sardine landings (x1000 T) ICES SW Portugal = sard_PNW+sard_PSW	1940	2005	M.F. Borges
51	sard_P	sardine landings (x1000 T) ICES Portugal = sard_PNW+sard_PSW+sard_PS	1940	2005	M.F. Borges
52	anch_BBI	anchovy landings (x1000 T) ICES area VIIIa,b,c (France+Spain)	1940	2005	ICES; A. Uriartre
53	anch_BBS	anchovy landings (x1000 T) ICES area VIIIb,c (Spain)	1940	2005	ICES; A. Uriartre
54	sardine	sardine landings (x1000 T) ICES areas VIIIc+IXa	1940	2005	ICES; A. Bode
55	anchovy	anchovy landings (x1000 T) ICES areas VIII+IXa	1943	2005	ICES; A. Bode
56	sard_e	sardine landings (standarized, normalized, detrended)	1940	2005	A. Bode
57	anch_e	anchovy landings (standarized, normalized, detrended)	1943	2005	A. Bode
58	RIS	Regime Indicator Series = sard_e - anch_e	1940	2005	A. Bode
59	ARI	anchovy recruitment index (ICES VIII) relative units	1967	2003	ICES;A. Uriartre
60	AR	anchovy recruitment (Bay of Biscay) ICES area VIII (x10^9 indiv.)	1986	2005	ICES;A. Uriartre
61	SR	sardine recruitment (Iberia) ICES areas VIIIc+IXa (x10^9 indiv.)	1978	2004	ICES;A. Uriartre
62	HMRI	horse-mackerel recruitment (Iberia, ICES) (x10^9 indiv.)	1985	1999	ICES;A. Uriartre
63	HMR	horse-mackerel recruitment (European Atlantic, ICES) (x10^9 indiv.)	1982	2004	ICES; A. Lavin; P. Abaunza
64	PCI_F4	Phytoplankton Colour Index (CPR) annual mean area F4 (Galicia-Portugal)	1958	2004	Continuous Plankton Recorder (CPR, SAHFOS)
65	PCI_E4	Phytoplankton Colour Index (CPR) annual mean area E4 (Bay of Biscay)	1958	2004	Continuous Plankton Recorder (CPR, SAHFOS)
66	COP_F4	Copepod abundance from CPR (n/1000) area F4	1958	2004	Continuous Plankton Recorder (CPR, SAHFOS)
67	COP_E4	Copepod abundance from CPR (n/1000) area E4	1958	2004	Continuous Plankton Recorder (CPR, SAHFOS)
68	DWCPR	Mesozooplankton biomass (mg DW/m3) estimated from abundance for E4+F4 CPR areas	1958	2003	A. Lopez-Urrutia (IEO)
69	PCI_m	Phytoplankton Colour Index (CPR) annual mean areas F4-E4	1958	2004	A. Bode

70	COP_m	Copepod abundance from CPR (n/1000) areas F4-E4	195 8	200 4	A. Bode
71	PZI	Phytoplankton-Zooplankton Index (CPR areas F4-E4)	195 8	200 4	A. Bode
72	PZI_F4	Phytoplankton-Zooplankton Index (CPR areas F4-E4)	195 8	200 4	A. Bode
73	PZI_E4	Phytoplankton-Zooplankton Index (CPR areas F4-E4)	195 8	200 4	A. Bode

5 Methods

Principal component analysis (PCA) has been used to objectively identify coherent patterns of variability among the available time-series. This reduces the dimensionality of the data matrix to a smaller number of uncorrelated and possibly meaningful time series (PC scores) and loading vectors (Von Storch & Zwiers 1999). It is particularly useful when investigating regime shifts, in part because it requires no *a-priori* assumptions about candidate regime shift years (Mantua 2004). Additionally time series analysis methods must be used to assess the statistical significance and character of temporal changes in the PC's. Nevertheless accordingly to Mantua (2004) there are well known weaknesses in the use of PCA. First, it is a linear method and therefore cannot identify non linear relationships between different input variables. Second, the resulting loading vectors and PC score pairs are orthogonal. Both characteristics may lead to erroneous interpretations in cases wherein the resulting PC scores and loading vectors fail to reproduce the true characteristics of the input data matrix. So identifying statistically significant shifts in PC scores requires additional time series analysis methods to be subsequently applied.

We inspected different methodologies available in order to analyses fish catches time series and their relationship with environmental conditions. We have addressed the problem of identifying high frequency and low frequency time scales present in the catch time series and how they interact and are affected by environmental forcing.

The variability time scale present in fisheries and climatic time series range from long term trends, represented by linear trends, to low frequency, (typically multi-decadal) oscillations and high frequency variability consisting in inter-annual variability.

The statistical tools described were applied to the regional case study sardine catches in Portuguese waters, to exemplify the methodology to treat the auto-correlation which reflect the memory of the of the time series in the system.

First – Detrending the time -series

Figure 5.1. shows in black catch time series in NW Portugal. In the first place we tested the presence or absence of a long-term linear trend by fitting a straight line using a least squares fit (black straight line in figure 5.1.). The anomalies relative to this linear trend were calculated by subtracting the trend from the mean value, thus obtaining detrending anomalies with a variability containing both the decadal (low-frequency) and the inter-annual (high-frequency).

Second – estimating autocorrelation and correcting for significance

We estimated the autocorrelation of this time series at different time lags (upper left corner in figure 5.1.). We can clearly see that catches in NW Portugal are strongly auto-correlated, as the correlations are positive up to a 10 year delay. This simply reflects the strong memory of the system and the influence of each single data on the following one. From a statistical point of view, it implies that consecutive data points are not statistically independent and each data point does not provide one more degree of freedom. Statistical significance for the linear trend detection took this into account with a loss of 91 degrees of freedom to 18 effective degrees of freedom. This correction is made using the expression:

edof = L/τ, where L is the total length of the time series and τ the integral time scale calculated as:

$$\tau = \int_{0}^{ZERO} \rho(k)dk$$

ρ(k) is the correlation coefficient for lag k, and ZERO denotes the first zero crossing of the auto-correlation function.

Taking into account the loss of degrees of freedom, the decreasing linear trend was not statistically significant at the 95% confidence level.

The following step is to estimate the low-frequency by means of a five year moving average (blue line in figure 5.1.), and once it is subtracted to the original series we get the high-frequency (red line in figure 5.1.).

We performed the same analysis for NAO, north-westerly winds and SST (Sea Surface Temperature) time series and performed a linear regression of the NW catches on each of these variables.

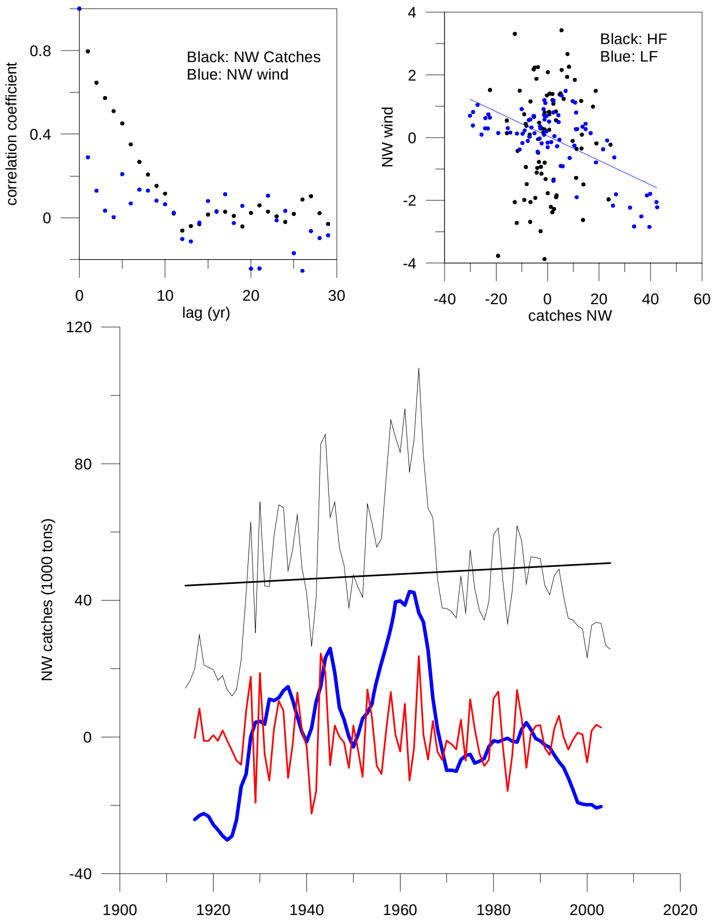


Figure 5.1. – Autocorrelation function for the Northwest catches and Northwest wind (bottom). Adjusted linear trend to the Northwest catches (middle).

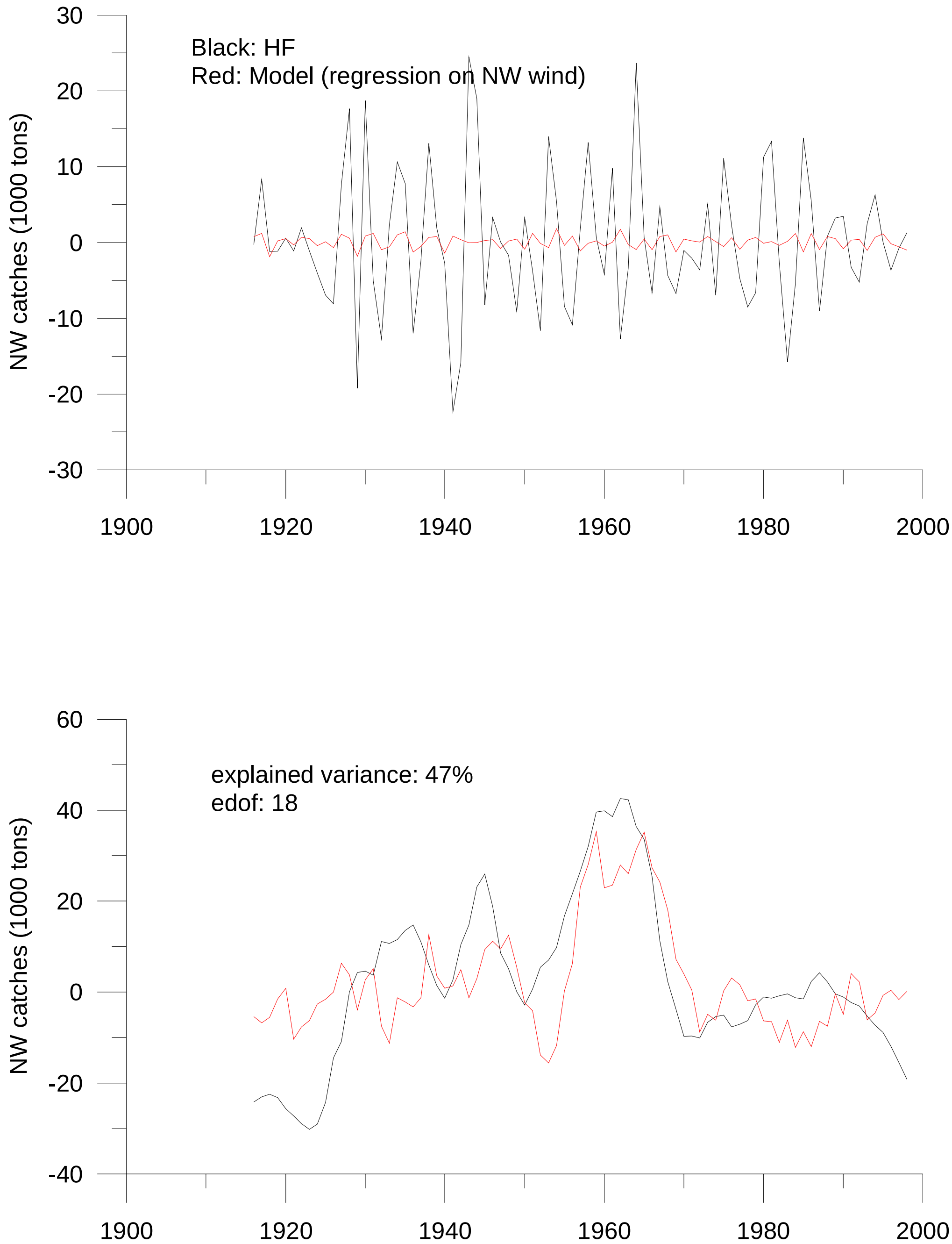


Figure 5.2. – Short-term regression (top) and long-term regression model (bottom) between the Northwest catches and the winter North wind. The Northwest catches (black) and the reconstructed series from the model (red).

The regression of the NW catches on north-westerly winds for the high frequency time series revealed that these two variables are not correlated at this short time scale. The upper panel in figure 5.2. shows the NW catches in black, and the reconstructed time series using the linear model in red. The lower panel in figure 5.2. shows the same analysis for the low-frequency NW catches. Again the black line is the time series and the red one is the reconstructed series from the regression on the Northwest wind. In this case the explained variance is 47%.

Interestingly, the results improve for the inter-annual variability (9% variance explained) when the catches are regressed on the NAO index, but the results are worse for the low frequency. It is important to note a negative relationship between NAO and catches for the decadal variability.

Finally we performed a multiple regression analysis of the NW catches on the NAO and north-westerly winds and for high and low frequency time series

The model was able to explain 11% of the variance for the inter-annual variability being positively correlated with NAO and negatively with north-westerlies. For the low frequency, the explained variance is 52%. Even considering the lost degrees of freedom for this case (dof = 91; edof = 18) the correlation was significant at the 95% confidence level. The model showed that catches are affected negatively by NAO, contrary to what was observed for the high-frequency and also negatively correlated for north-westerly winds

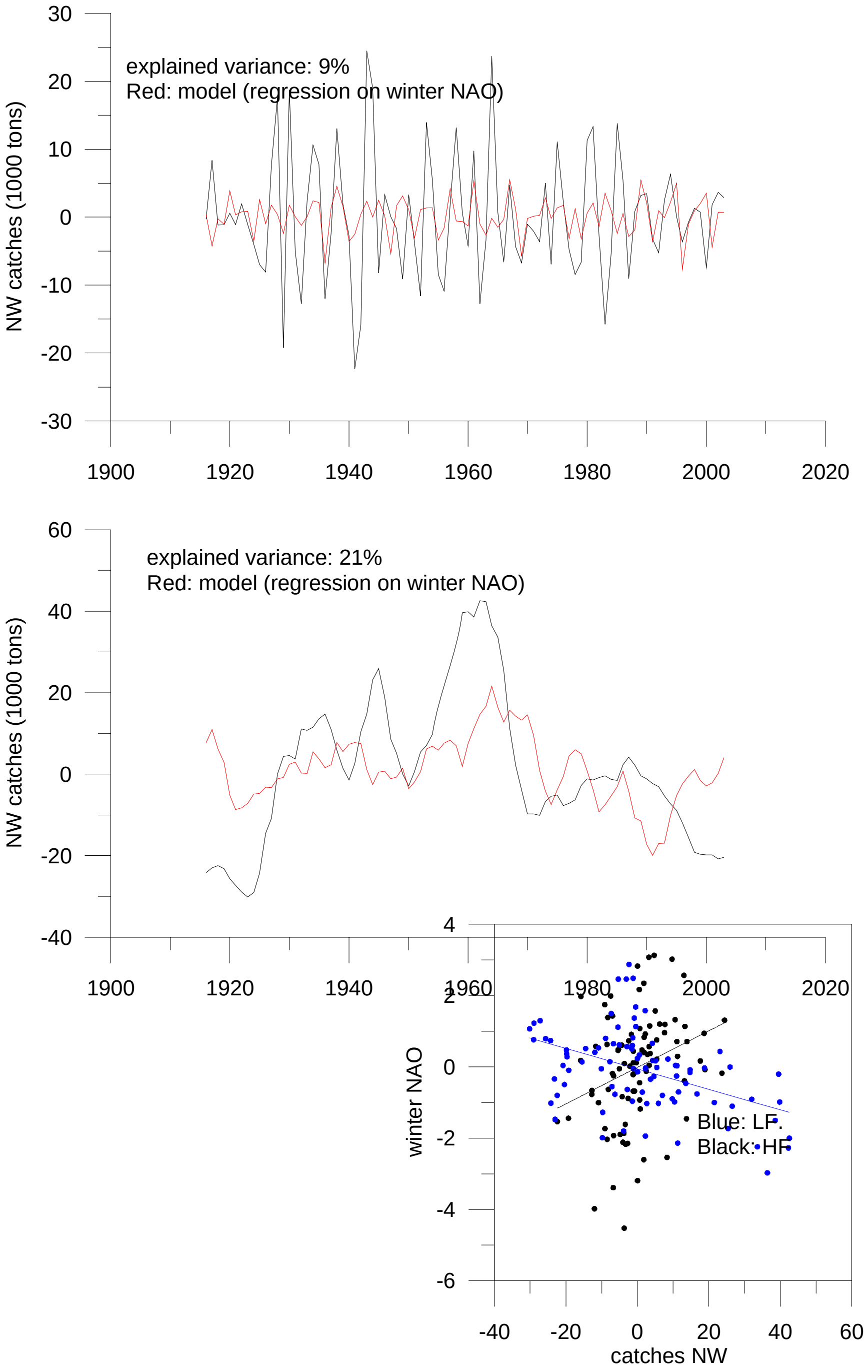
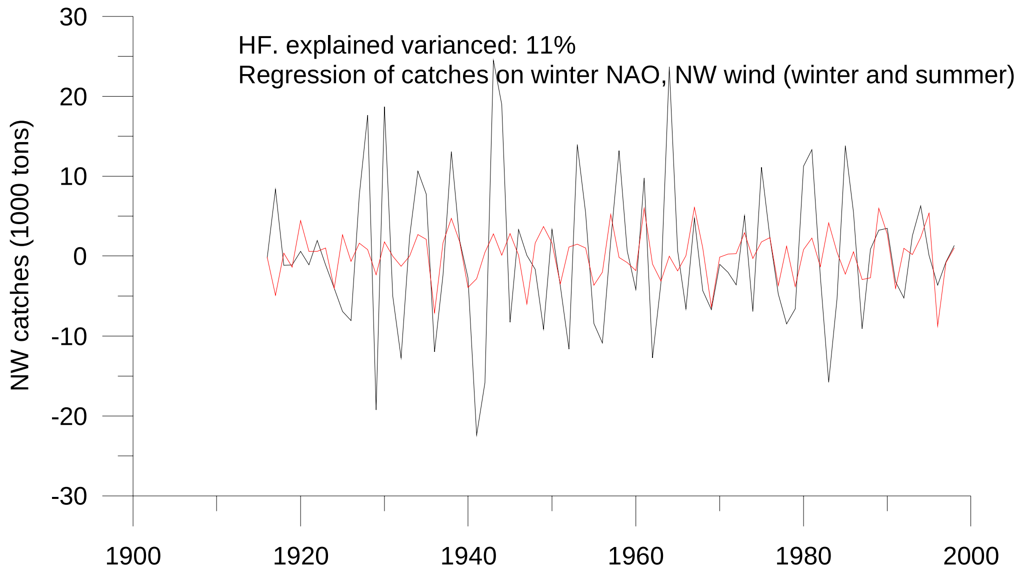


Figure 5.3. – Short-term regression (top) and long-term regression model (middle) between the Northwest catches and the NAO winter. The Northwest catches (black) and the reconstructed series from the model (red). In the bottom the adjusted line to the long-term (blue) and the short-term series (black).



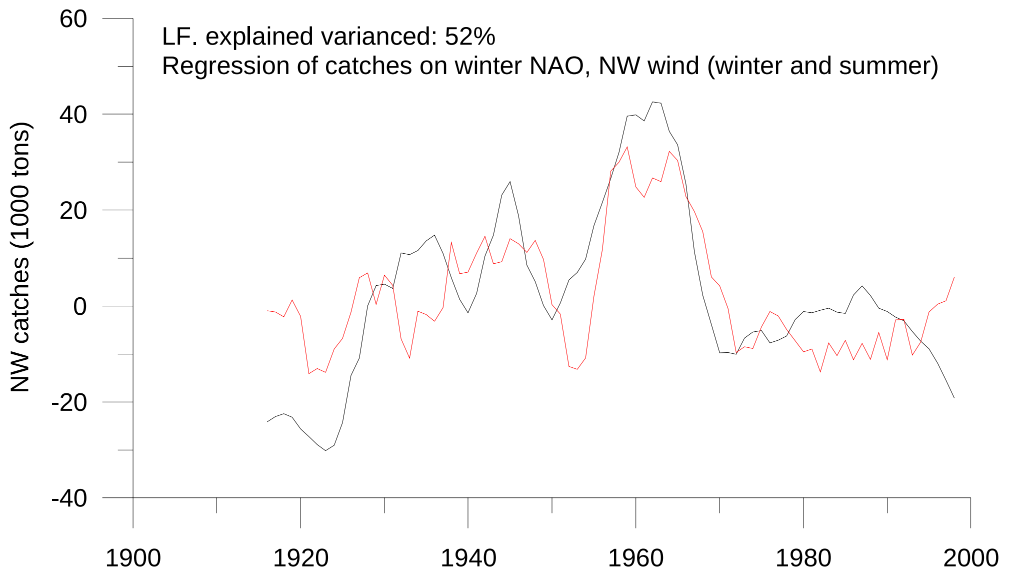


Figure 5.4. – Short-term regression (top) and long-term regression model (bottom) between the Northwest catches and predictors winter NAO index and North wind. The Northwest catches (black) and the reconstructed series from the model (red).

The approach followed up to this moment is based on the time domain. An alternative approach is to study time series on the frequency domain. This approach focuses on investigating periodic properties of the series. Some authors tend to focus on one domain or another. To a large extent, this division arises from the types of question that are being asked of the data. However, combining the approaches can at times give a more thorough understanding of the data.

The estimated spectrum decomposes the movement of the series in various sinusoidal waves of different frequencies and shows the relative strength of each frequency oscillation. The lower frequencies (at left) measure the contribution of long-run oscillations and the high frequencies (at right) measure the contribution of short-run oscillations. Variation in the data at high and low frequencies will correspond to long and short term cyclical variation with period=1/f.

The shortness of the series – in a time series perspective – for this case study is one of the limiting factors in analyzing periodicity, spectrum analysis made through autoregressive modelling as better results in short time series and this method provides a good estimation of the true spectrum of the series.

In figure 5.5. the autoregressive spectral analysis carried out on the Northwest, Southwest and Western catches is shown. It is clear that the series are dominated by long-run movements with strong memory. A common peak occurs in the three regions at a low frequency roughly corresponding to a 20-29 years period. Another low frequency peak is present in both Northwest and Southwest catch series implying a period of about 10 years, corresponding to the memory structure found in the autocorrelation function computed in this study for the Northwest area. The remaining high frequency peaks were dominated by the intra annual variability.

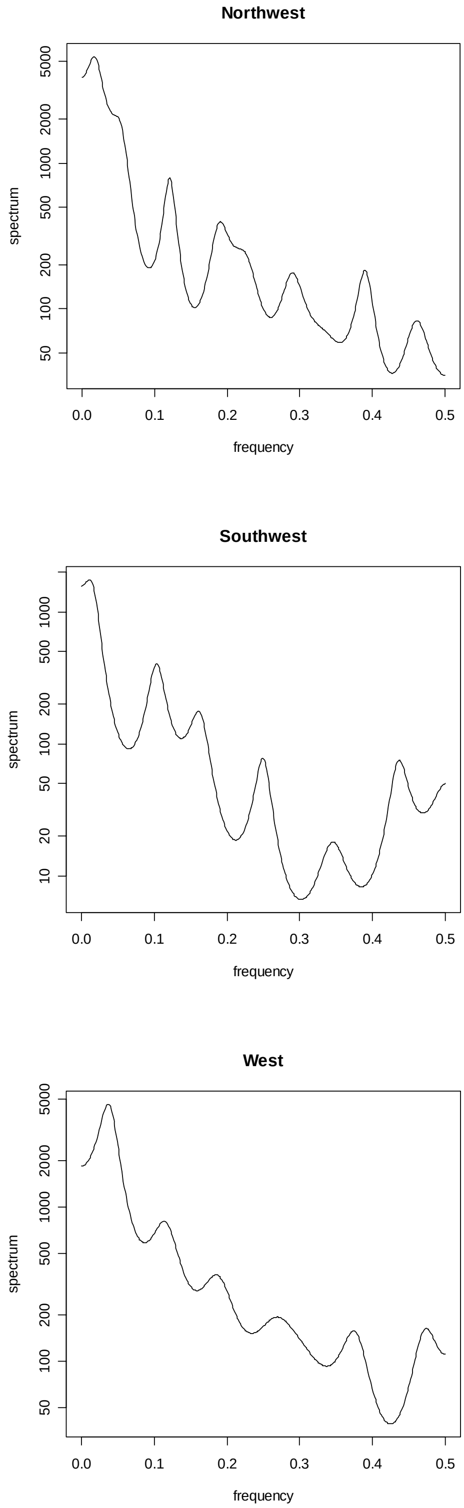


Figure 5.5. – Autoregressive spectral analysis for the sardine Northwest, Southwest and Western catch series.

The statistical time series analysis was performed using autocorrelation analysis. The Autocorrelation Function (ACF) measures the correlation between observations at different distance apart.

6 Case studies

6.1 Case study 1 – global

6.1.1 Introduction

The study of variability in climate, oceanographic factors and key ecosystem components was generally limited by the availability of time-series at long (multiannual) scales (e.g. Bode *et al.* 2006). Therefore in this workshop a large synthetic effort was devoted to the collection and construction of a database including the relevant variables in each of the climatic, oceanographic and ecological subsets. This database should allow the analysis of either regional or subregional patterns. In this section we present the results of the analysis of the whole region of the NE Atlantic near the Iberian Peninsula. For this purpose variable values obtained at local or subregional level were integrated or averaged to provide estimates representative of the whole region. Alternatively, only one variable representing relevant indicators was selected in those cases where measurements were available for several sites or subregions. The complete database is included as an excel file in the Annex.

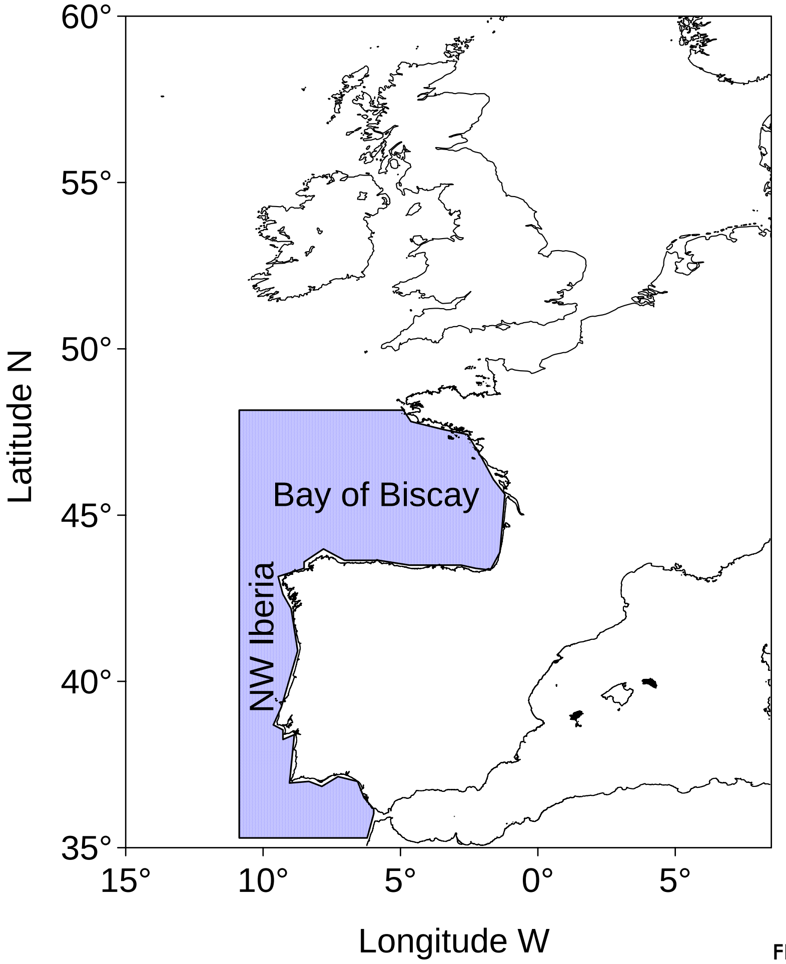


FIGURE 1

Fig. 6.1.1.1. Map of the study region (shaded) in the NE Atlantic.

6.1.2 Objectives

1. To identify and analyze linear trends at multiannual scale
2. To identify and analyze oscillations at multiannual scale

6.1.3 Methods

Variables. Climatic variables were mainly provided by teleconnection indices computed for the northern hemisphere (NOAA Climate Prediction Center). The data used in our analysis were annual standardised means from principal component analysis of monthly values covering the period 1950-2005. Only four indices were employed (Table 6.1.3.1.), as representative of the main drivers of atmospheric circulation over the NE Atlantic (Barnston and Livezey 1987) and taking into account the results of preliminary analysis in the context of the present study (Bode *et al*. 2006). The North Atlantic Oscillation (NAO), computed as the atmospheric pressure anomaly between Iceland and S Europe was associated to dominant climatic conditions over Western Europe (Hurrell and Dickson 2004), while the East Atlantic pattern (EA), which is structurally similar to the NAO, contains a strong subtropical component. Scandinavia (SCA) and Polar/Eurasia (POL) patterns are characterized by atmospheric pressure anomalies in boreal regions affecting the longitudinal circulation of winds and storms.

Table 6.1.3.1. Variables selected for the regional analysis. The period of data covered, along with the interannual linear trend and significance (P) is also indicated. Variable names correspond to those in the original database (see Appendix).

VARIABLE	DEFINITION	START	END	TREND	P
NAO	North Atlantic Oscillation (1)	1950	2005	0.007	0.014
EA	Eastern Atlantic Pattern (1)	1950	2005	0.016	0.000
SCA	Scandinavia Pattern (1)	1950	2005	-0.007	0.021
POL	Polar / Eurasia Pattern (1)	1950	2005	-0.001	0.773
AMO	Atlantic Multidecadal Oscillation (2)	1940	2005	-0.001	0.282
UIm_4311	Mean upwelling index at 43ºN,11ºW (3)	1966	2005	-4.798	0.006
TPEA	Mean water transport from Potential Energy Anomaly North Atlantic (4)	1955	2005	0.104	0.013
SHF_4503	Mean sensible heat fluxes at 45ºN,03ºW (5)	1948	2005	0.265	0.000
ZMF_4503	Mean zonal momentum flux at 45ºN,03ºW (6)	1948	2005	0.000	0.356
sardine	sardine landings (7)	1940	2005	-0.601	0.021
anchovy	anchovy landings (8)	1943	2005	-0.670	0.000
PCI	Phytoplankton Colour Index (9)	1958	2004	0.011	0.000
COP	Copepod abundance (10)	1958	2004	-0.008	0.001
ACA	Acartia abundance (10)	1958	2004	-0.006	0.001
CAL	Calanus abundance (10)	1958	2004	-0.002	0.047

(1) Teleconnection indices. Annual standarized means of PCA values (relative scale units). ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh

(2) Sea surface temperature anomaly from detrended mean global warming value. http://web1.cdc.noaa.gov/Timeseries/AMO/

(3) Offshore water transport estimated from geostrophic winds (Lavin *et al*., 1991, 2001). Annual means (m3 s-1 km-1).

(4) Annual means (Mtons s-1)

(5) Annual means (W m-2) computed from values provided by http://www.cdc.noaa.gov/cdc/data.coads.2deg.html

(6) Annual means (N m-2) computed from values provided by http://www.cdc.noaa.gov/cdc/data.coads.2deg.html

(7) Commercial catches at ICES areas VIIIc and IXa (ktons). http://www.ices.dk

(8) Commercial catches at ICES areas VIIIa,b,c and IXa (ktons). http://www.ices.dk

(9) Continuous Plankton Recorder (CPR) areas F4 and E4. Annual means (relative scale units). http://www.sahfos.org

(10) CPR areas F4 and E4. Annual means (x103 indiv. sample-1). http://www.sahfos.org

The five oceanographic variables variables retained were representative of vertical stability of the upper water column, sea surface temperature and east-west oceanographic gradients (Table 1). The Atlantic Multidecadal Oscillation (AMO) was significantly correlated ($P<0.05$) with all other variables indicating sea surface temperature at various sites in the region, with the advantage over individual site values of providing an integrated value for the entire N Atlantic basin (Kerr 2000). Similarly, sensible (SHF_4503) and zonal (ZMF_4503) heat fluxes were preferred to values of sea temperature or wind because they are related to water column stability and turbulence caused by wind stress, respectively (Curry and Webster 1999, Siedler *et al.* 2001). Heat fluxes were computed from temperature and wind speed values at the sea surface in a 2ºx2º cell centred at 45ºN, 3ºW provided by the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). Transport of water was estimated from the potential energy anomaly (TPEA), a two-point baroclinic pressure difference between the subtropical and subpolar gyre centres derived from hydrographic measurements in the Labrador Basin and at Station S near Bermuda (Curry and McCartney, 2001). This transport index indicates variations in main N Atlantic currents as the Gulf Stream and the North Atlantic Current. The role of upwelling was represented by the data series of the Ekman transport values computed at a 2ºx2º cell centred at 43ºN, 11ºW (Lavin *et al.*, 1991), as this series was significantly correlated with most other indices of upwelling available for the region ($P<0.05$). The annual mean of the upwelling index (UIm_4311) was selected in this case because of the higher correlation of this series with other oceanographic variables, compared with seasonal means, and because the mean value was expected to balance the positive and negative effects of upwelling on pelagic fish (e.g. Guisande *et al.*, 2001, Borges *et al.*, 2003).

Biological variables included plankton abundance and/or biomass values from the Continuous Plankton Recorder (CPR) survey (http://www.sahfos.org/). Data were averaged over the CPR grids F4 (NW Iberian shelf) and E4 (Bay of Biscay) between 1958 and 2004. Phytoplankton biomass was estimated from the Phytoplankton Colour Index (PCI), whereas zooplankton abundance was represented by total copepod abundance (COP). To investigate changes in the plankton community that may be relevant for upper trophic levels, the abundance of small copepods, represented by the genus Acartia (ACA), and large copepods, represented by genus Calanus (CAL), were also analyzed. Planktivorous fish biomass was estimated from the time series of commercial landings of sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) in the ICES Areas VIII (VIIIc for sardine) and IXa (ICES, 2005).

Statistical methods. A preliminary treatment was to complete the missing data in some variables to ensure continuity of the series in the study period. Data were estimated from significant regression functions with related variables (as in the case of CPR data from nearby zones) or autoregression within the series. In all cases the estimated data were <10% of the total in the series. Significance in linear trends in all variables were investigated to reveal interannual change rates. Thereafter, the trends were removed and the variables were normalized and standardised for subsequent analysis of multiannual periods. The main patterns of interannual variability in climate and oceanography were summarized through principal component analysis (PCA) of the selected variables. These analyses were repeated with different combinations of variables to identify the components showing the highest correlations with all other variables (including those not used in the PCA). In the case of biological variables, the analysis of multiannual periods was performed with the original variables and also with several ecosystem indices, the latter aimed to reveal changes in ecosystem structure. These indices were computed by difference of the detrended, normalized and standardized values of paired variables such as the Phytoplankton-Zooplankton index (PZI = PCI-COP), the Acartia-Calanus index (ACI = ACA-CAL) and the Relative Indicator Series (RIS = sardine-anchovy). The computation procedure and rationale are based on those described by Lluch-Cota *et al.* (1997) for the study of alternating species of pelagic fish. Finally, the relationships between interannual changes in the relevant indices were analyzed. In this study we explored the instantaneous link between climate, oceanographic and ecosystem variables, as the latter are referred to components of short life span, as plankton and planktivorous fish, that are able to respond immediately to changes in environmental conditions.

6.1.4 Results

Climate. All selected indices, except POL, show significant linear trends during the period analyzed (Table 6.1.3.1.). NAO and, particularly, EA increase, while SCA decrease between 1950 and 2005. These indices can be considered as independent as they were uncorrelated one to another (P>0.05). The two first PCA components retain 59% of total variance (Table 6.1.4.1.), representing the first component (32%) the effect of northern versus subtropical modes (NAO and EA) while the second component (27%) indicate the variability of boreal modes (SCA and POL). Positive anomalies of CLI1are observed in the periods 1964-1978, and 1989-1997, while negative anomalies dominate in the periods 1950-1963, 1979-1989 and 1998-2005 (Fig 6.1.4.1.a). The duration of each phase is ca. 15 y before 1978 and 9 y thereafter. Such variations correspond mostly with EA, particularly after 1960s. Variability of CLI2 is characterized by alternating positive and negative anomalies every 3 to 10 y, mirroring the variations in SCA after 1960s (Fig. 6.1.4.1.b).

Table 6.1.4.1. Correlations between the original variables and the first (CLI1) and second (CLI2) components of the PCA on climate variables.

VARIABLE	CLI1	CLI2
NAO	0.586	0.162
EA	-0.689	0.155
SCA	0.449	-0.759
POL	0.532	0.663

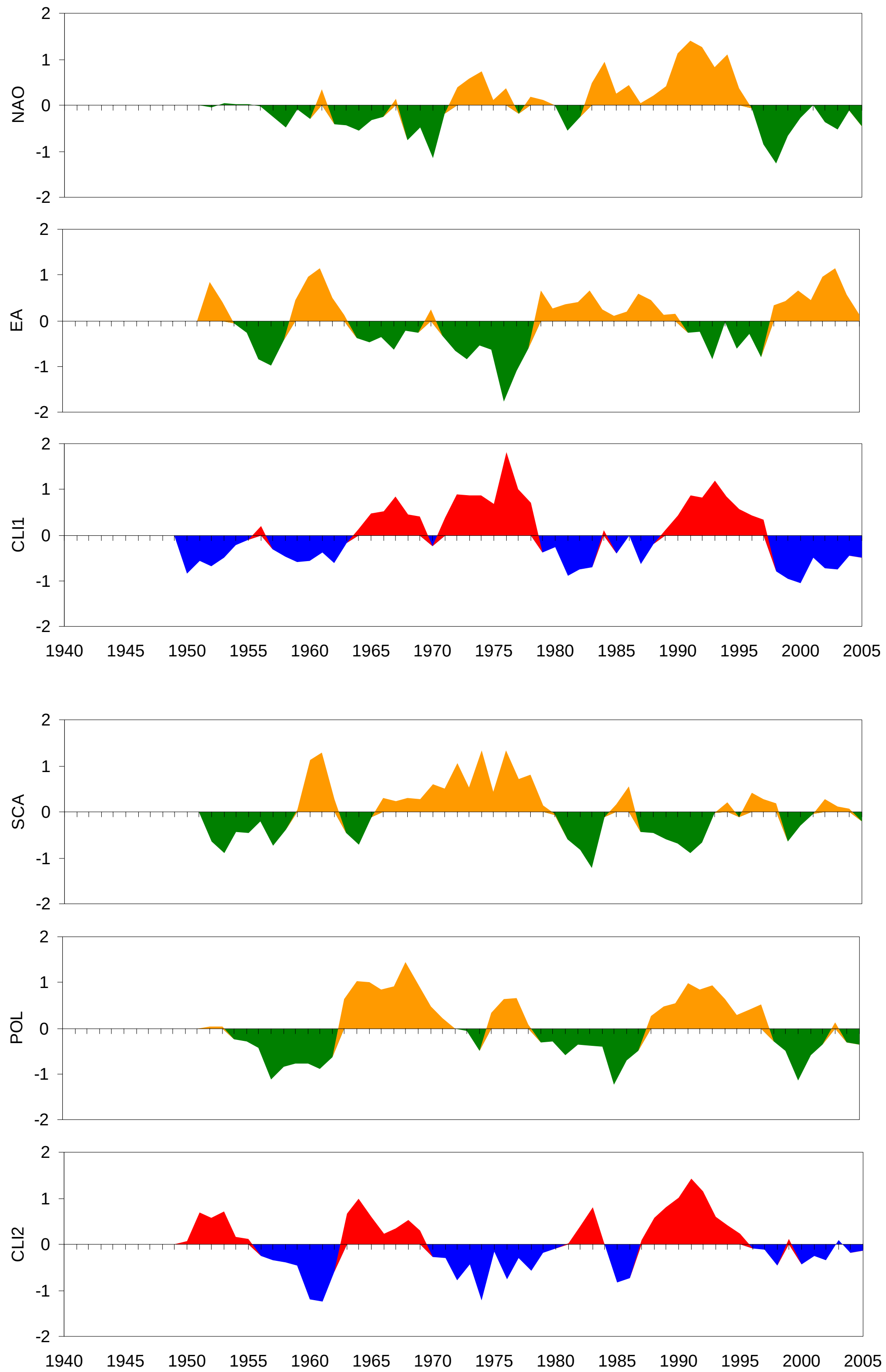


Fig. 6.1.4.1. Anomalies of climatic variables with the long term trend removed contributing to the first (a, CLI1) and second (b, CLI2) components extracted by a principal component analysis. NAO: North Atlantic Oscillation. EA: Eastern Atlantic pattern. SCA: Scandinavia pattern. POL: Polar / Eurasia pattern. All series have been normalized, standardized and smoothed with a 3-year running mean.

Oceanography. No significant linear trends with time were found for AMO and ZMF, while SHF and TPEA increase, and UIm_4311 decrease (Table 6.1.3.1.). These results indicate an increase in the stratification of surface waters as a consequence of the reduction of the upwelling in the eastern Atlantic, along with an intensification in the water transport by the N Atlantic gyre. The PCA analysis performed on these variables, after excluding UIm_4311 because of the lack of values before 1966 and the significant correlation with AMO and ZMF_4503 ($r = -0.330$ and 0.418, respectively, $P<0.05$), produced two main components accounting for 63% of total variance (Table 6.1.4.2.). The first component (OCE1) is mostly related to the variability of SHF_4503 and AMO, as opposed to that of ZMF_4503. This component accounts for 37% of total variance and can be interpreted as an index of stability in the upper water column of the region, with positive values associated to positive anomalies of AMO and SHF_4503 (i.e. high sea surface temperature and heat flux from the sea to the atmosphere), and negative values associated to positive anomalies of wind stress causing turbulence. The second component (OCE2) accounts for 26% of variance and mainly reflects the intensity of water transport by the N Atlantic gyre, as indicated by the high positive correlation with TPEA (Table 6.1.4.2.). This component is also positively related to turbulence.

Table 6.1.4.2. Correlations between the original variables and the first (OCE1) and second (OCE2) components of the PCA on oceanographic variables.

VARIABLE	OCE1	OCE2
AMO	0.614	-0.183
TPEA	0.444	0.788
SHF_4503	0.792	0.107
ZMF_4503	-0.523	0.617

Positive and negative anomalies of OCE1 alternate at a remarkably constant period of 12 y (Fig. 6.1.4.2a), however a discontinuity is apparent after 1978, when the positive anomaly period was extremely short and weak producing two consecutive negative anomalies separated by only 2 y. This apparent shift is related to the coincidence of the long period of negative AMO between 1964 and 1995 with a maximum value of negative anomaly in ZMF_4503 in the late 1970s, which suggests a relaxation of the coupling between wind stress turbulence and sea surface temperature. The shift can be also recognized in OCE2, as the oscillations in this component are nearly identical to those of TPEA in recent years (Fig. 6.1.4.2b), but the pattern differed before 1978, when positive anomalies were of short duration (3-4 y).

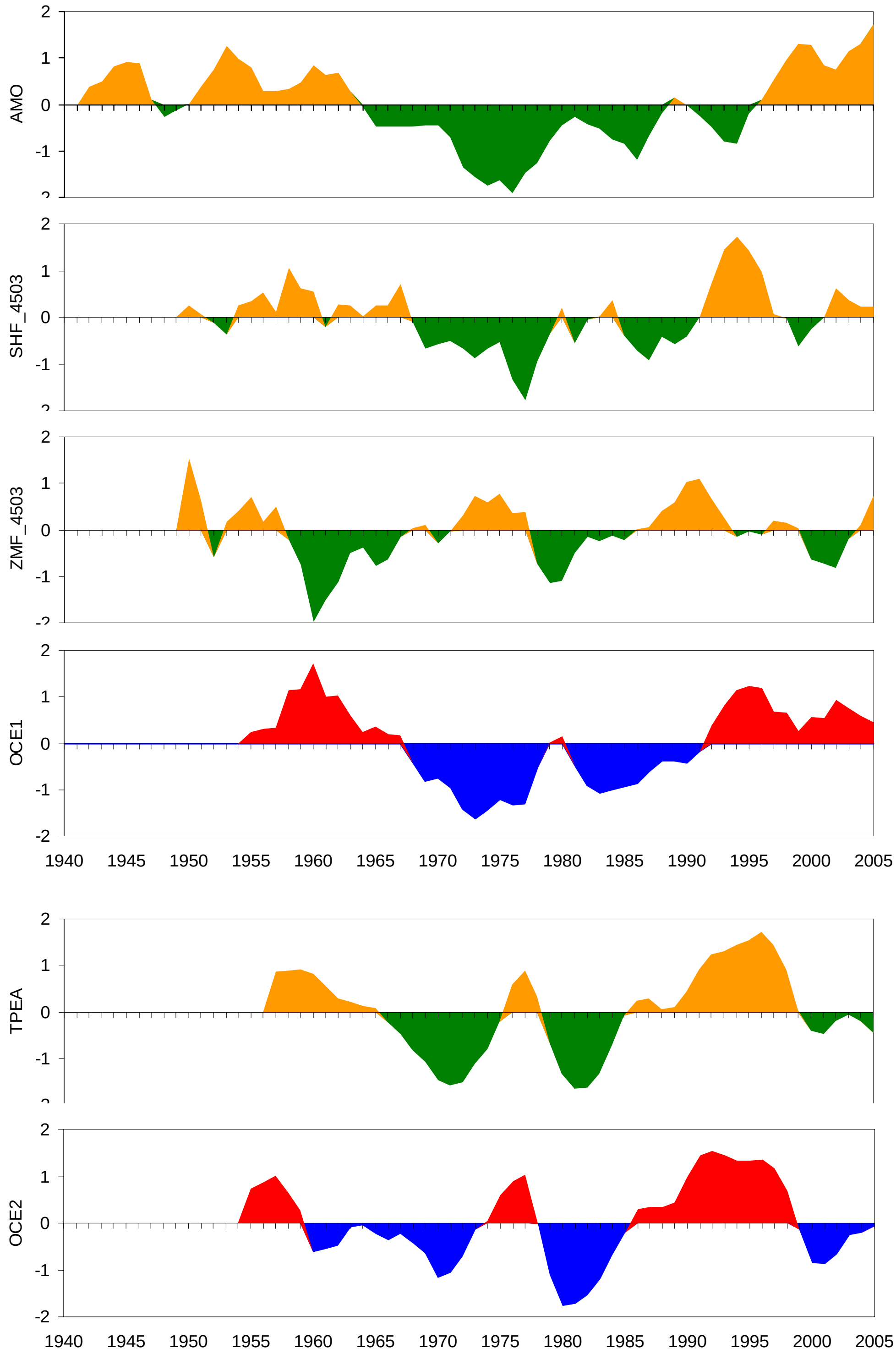


Fig. 6.1.4.2. Anomalies of oceanographic variables with the long term trend removed contributing to the first (a, OCE1) and second (b, OCE2) components extracted by a principal component analysis. AMO: Atlantic Multidecadal Oscillation. SHF_5403: Sensible Heat Flux at 45ºN, 3ºW. ZMF_4503: Zonal Momentum Flux at 45ºN, 3ºW. TPEA: Transport caused by the Potential Energy Anomaly over the N Atlantic. All series have been normalized, standardized and smoothed with a 3-year running mean.

Ecosystem structure. Most biological variables display negative trends during the study period (Table 6.1.3.1.). Only phytoplankton biomass (PCI) shows a mean increase, while copepod abundance and fish biomass decrease for all species considered. Plankton variables are characterized by the succession of relatively short periods (generally <5 y) of positive and negative anomalies but paired variables (e.g. PCI vs. COP or Acartia vs. Calanus) do not show consistent match-mismatch patterns (Fig. 6.1.4.3.). The combined indices, however, have relatively longer periods of ca. 10 y, particularly after late 1970s. In this way, an increase in the relative dominance of phytoplankton over zooplankton is recent years can be traced by the longer and higher positive PZI anomalies compared to those observed before 1970 (Fig. 6.1.4.3.a). Similarly, there is a decrease in the relative dominance of small over large copepods indicated by a reduction in the peaks of both positive and negative anomalies of ACI since 1980 (Fig. 6.1.4.3.b).

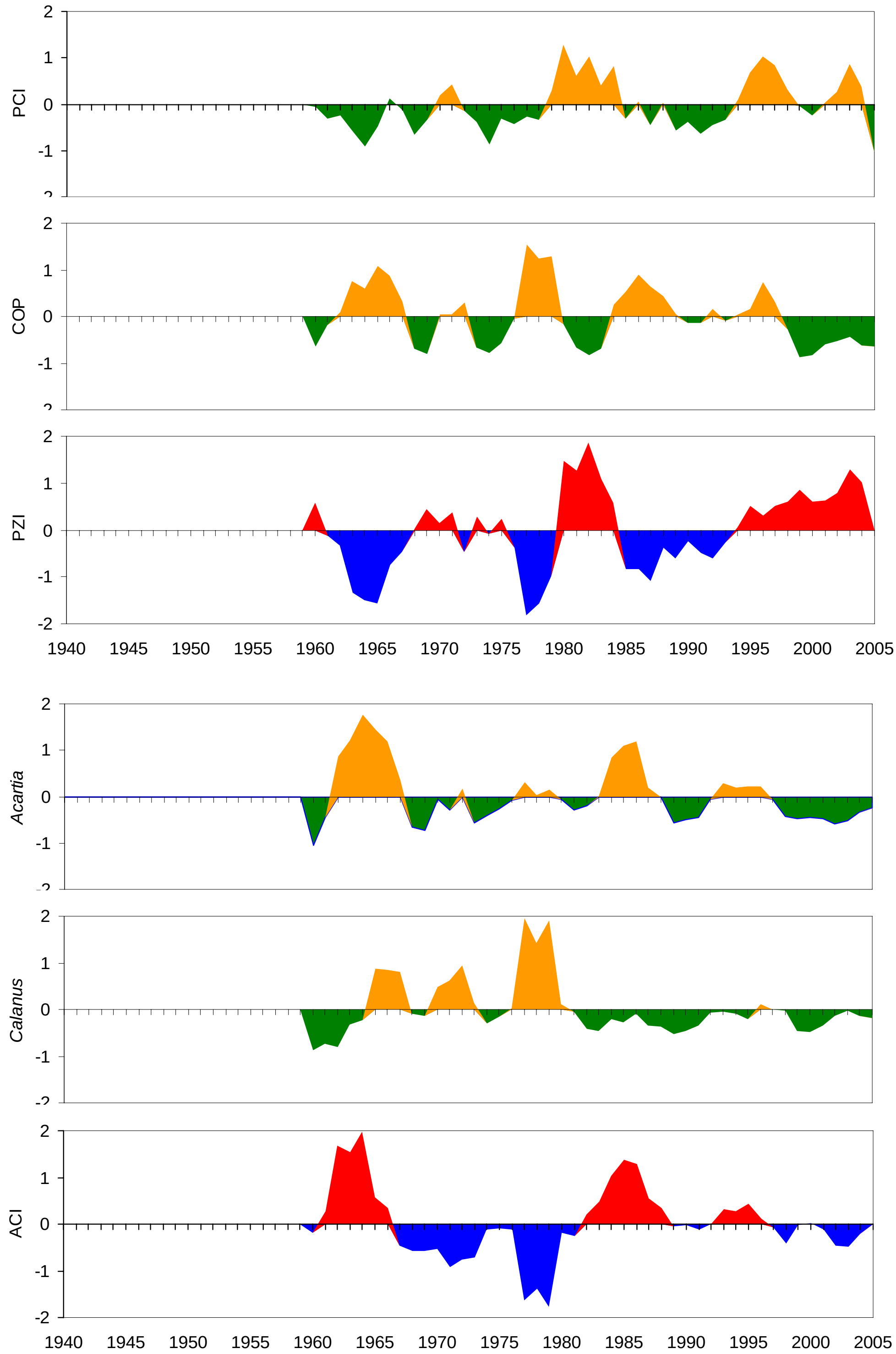


Fig. 6.1.4.3.. Anomalies of biological variables with the long term trend removed contributing to ecosystem indices of plankton structure (a, PZI), zooplankton composition (b, ACI) and planktivorous fish dominance (c, RIS). PCI: Phytoplankton Colour Index. COP: Copepod abundance. Acartia: Abundance of Acartia spp. Calanus: Abundance of Calanus spp. All series have been normalized, standardized and smoothed with a 3-year running mean.

The series of pelagic fish indicates the succession of positive and negative anomaly periods of ca. 10 y for both sardine and anchovy (Fig. 6.1.4.4.). Interestingly, the anomalies are in phase before 1980, when both species increase or decrease simultaneously, but out of phase thereafter. This shift in the succession pattern translates is reflected by RIS anomalies before late 1970s with longer periods and lower amplitude than those observed in recent years. The time of shift can be dated around 1978, when a short period of negative RIS anomaly indicates the start of the mismatch between sardine and anchovy landings.

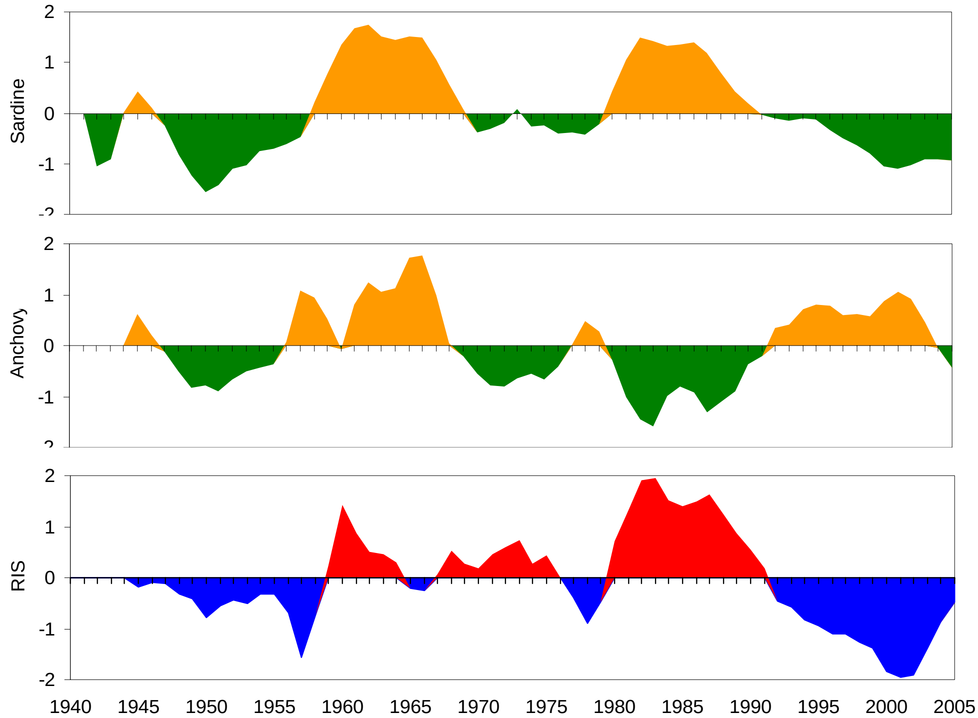


Fig. 6.1.4.4. Anomalies of sardine and anchovy landings with the long term trend removed contributing to the Regime Indicator Series index (RIS). All series have been normalized, standardized and smoothed with a 3-year running mean.

Comparative analysis. The combination of source variables produce integrated indices with less high frequency variability than the original, thus revealing large time scale patterns (Fig. 6.1.4.5.). Interannual variability in climate, ocean and ecosystem properties in the NW Iberian region, summarized using the principal components and indices computed, is characterized mainly by oscillations at decadal time scales. A recurrent feature, however, is the shift in the correspondence between positive and negative anomalies when comparing different indices. As noted with individual variables, after late 1970s anomalies of paired indices changed from phase to out of phase or the converse. For instance, CLI1 and OCE1 anomalies before 1980 are out of phase but those for the period 1980-1995 are in phase. The positive PZI anomaly period since 1990 is related to positive anomalies of OCE1 and negative of CLI1, while in other periods (as in late 1960s and 1970s) the converse association can be observed. More consistent, however, appears the association between positive anomalies in ACI and those in RIS, suggesting a major role of trophic factors linking higher abundances of small copepods to the abundance of sardine, and conversely a relative dominance of large copepods to anchovy abundance.

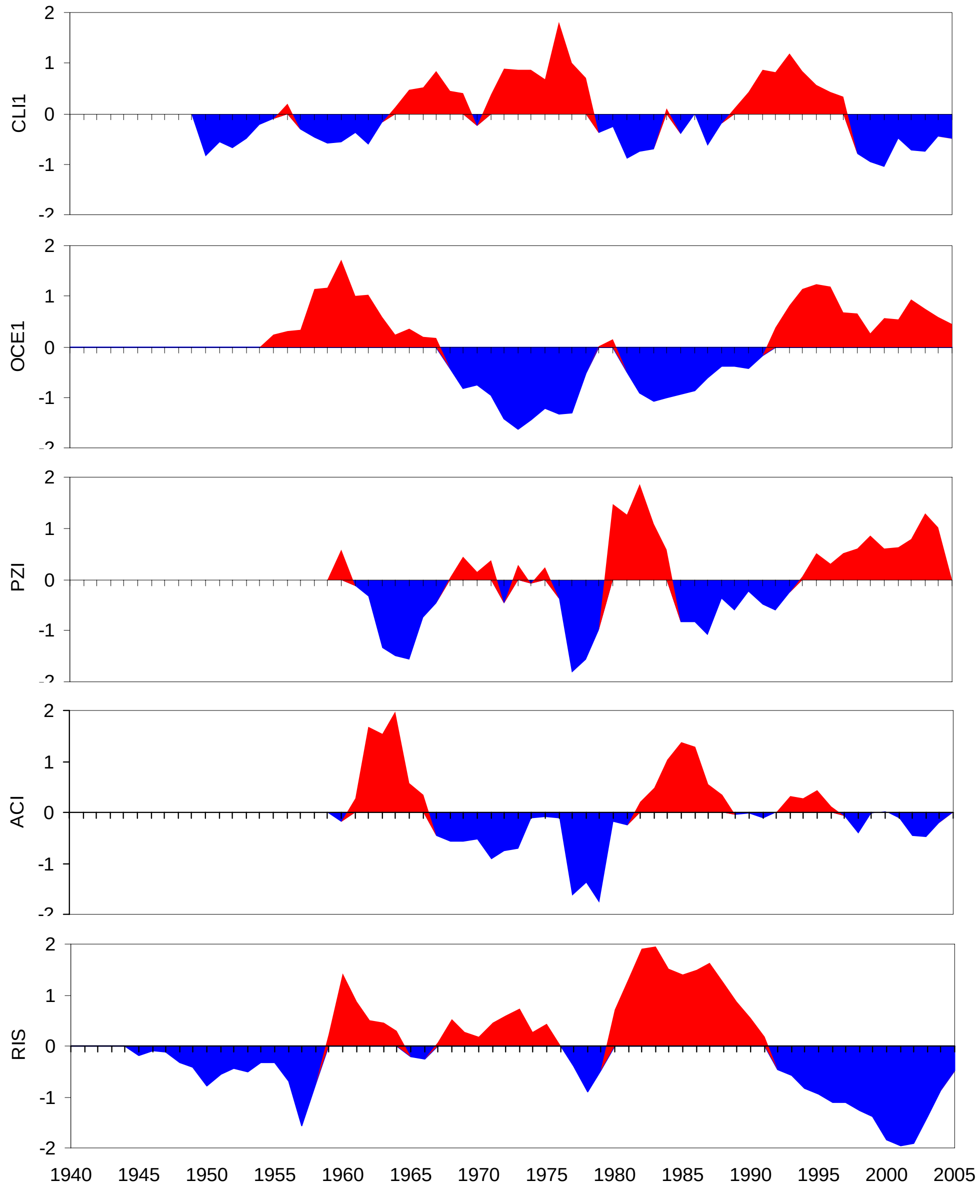


Fig. 6.1.4.5. Comparison of anomalies of the main climatic (CLI1), oceanographic (OCE1) and ecosystem indices (PZI, ACI and RIS) as obtained in Figs. 6.1.4.1., 6.1.4.2., 6.1.4.3. and 6.1.4.4.. The dashed line identifies a major shift in the pattern of succession of the positive and negative anomalies.

Because of the shift in the correspondence of anomalies, the average functional relationships between indices for the whole study period are low. However, selected linear relationships suggested possible links between climate and ocean factors affecting ecosystem structure (Fig. 6.1.4.6.). Oceanographic variability, as summarized by OCE1, is negatively correlated to the main climatic component (CLI1). This is consistent with an increase in ocean turbulence (and upwelling) with the increase of north winds and boreal influence produced in phases of positive NAO, as opposed to an increase in water column stability, higher sea surface temperature (and a decrease in upwelling) produced in phases of subtropical influence. The decrease in the intensity of the North Atlantic gyre, indicated by OCE2, is associated to a relative increase of phytoplankton in the region (PZI) that may be linked to an enhancement of the effects of upwelling through a reduction in the dispersal of phytoplankton cells into the ocean (Fig. 6.1.4.6b). Finally, RIS is negatively associated to OCE1, particularly if the data for years 1958 and 1960 were excluded (Fig. 6.1.4.6c). This relationship indicates the positive effect of increasing turbulence (strong wind stress) on the relative abundance of sardine during the study while more stable water column (high mean surface temperature) favours the relative dominance of anchovy. The excluded outliers are observed in the period when both species coexisted with high abundances.

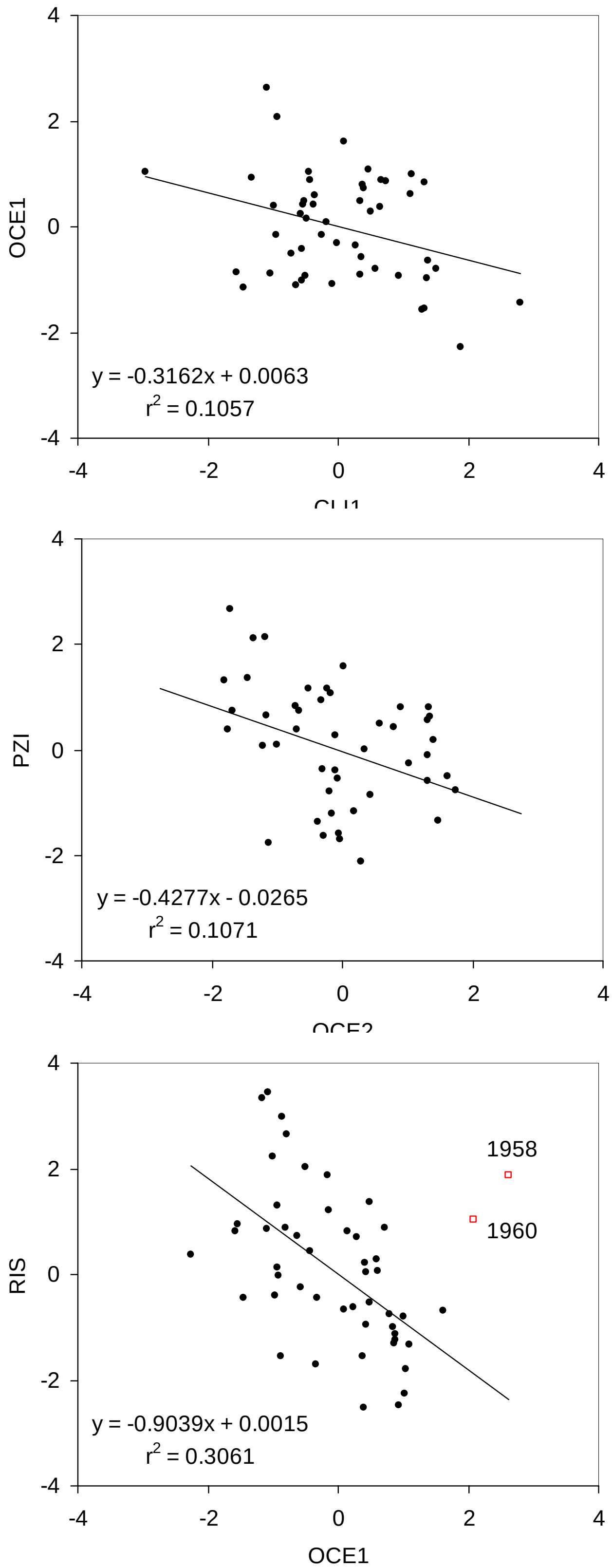


Fig. 6.1.4.6.. Selected examples of linear relationships between the main indices of variability in climate versus ocean (a), ocean versus plankton (b) and fish versus ocean (c).

6.1.5 Summary and conclusions:

1) Significant interannual trends in climatic, oceanographic and ecosystem variables integrated in the NW Iberia and Bay of Biscay region are indicative of a clear signal of global warming in the region since ca. 1950.

2) The regional decrease in copepods and planktivorous fish can be related to reduced upwelling and increasing stratification. In contrast, an increase in phytoplankton may be due to various mechanisms, such as the reduction in turbulence, the lack of coupling between phytoplankton and zooplankton and the increase in westward currents in the N Atlantic.

3) Besides the interannual trends, multiannual periods of relative positive and negative anomalies have been identified for all variable types. Quasi-decadal scales are characteristic of climatic, oceanographic and fish abundance indices, while plankton indices display generally shorter periods.

4) A major shift affecting the succession patterns of positive and negative anomalies of all indices in late 1970s has been identified. The main changes were related to the periodicity and amplitude of the anomaly oscillations, and with the phasing of paired indices.

5) The mechanisms linking climatic to oceanographic and ecosystem variability can be summarized by a conceptual model leading to two alternative states. When boreal components dominate atmospheric climate over the N Atlantic, high upwelling and relatively turbulent surface ocean favours the growth of small copepods, that are consumed efficiently by filter feeding sardines. When the climate is influenced by subtropical modes, reduced upwelling and stratification in the upper ocean causes a general reduction in plankton productivity and small copepods. In this situation, anchovies are able to increase their populations if large copepods are available.

6.2 Case study 2 – local – Portugal

The data set analysed is comprised of catch time series in Northwest, West, Southwest and South Portugal. Figure 6.2.1. shows the time evolution of these catches. By simple visual inspection we see some of the main features of these series. Southern regions off Portugal have a similar behaviour, with higher catches in the beginning of the century, followed by a decreasing trend, until they reach stability in the volume of catches. The Northwest coast, the region with the highest catches, shows an upward trend until the 70´s, after which the series seems to suffer a structural change to a lower mean and variance.

One of the main patterns influencing atmospheric and oceanic circulation in the North Atlantic is the NAO. It can influence ecosystems in the Portuguese waters, mainly due to its influence on north-westerly (upwelling favourable) winds, the transfer of turbulent kinetic energy to the sea, and the circulation in the North Atlantic, for instance, the Gulf Stream position.

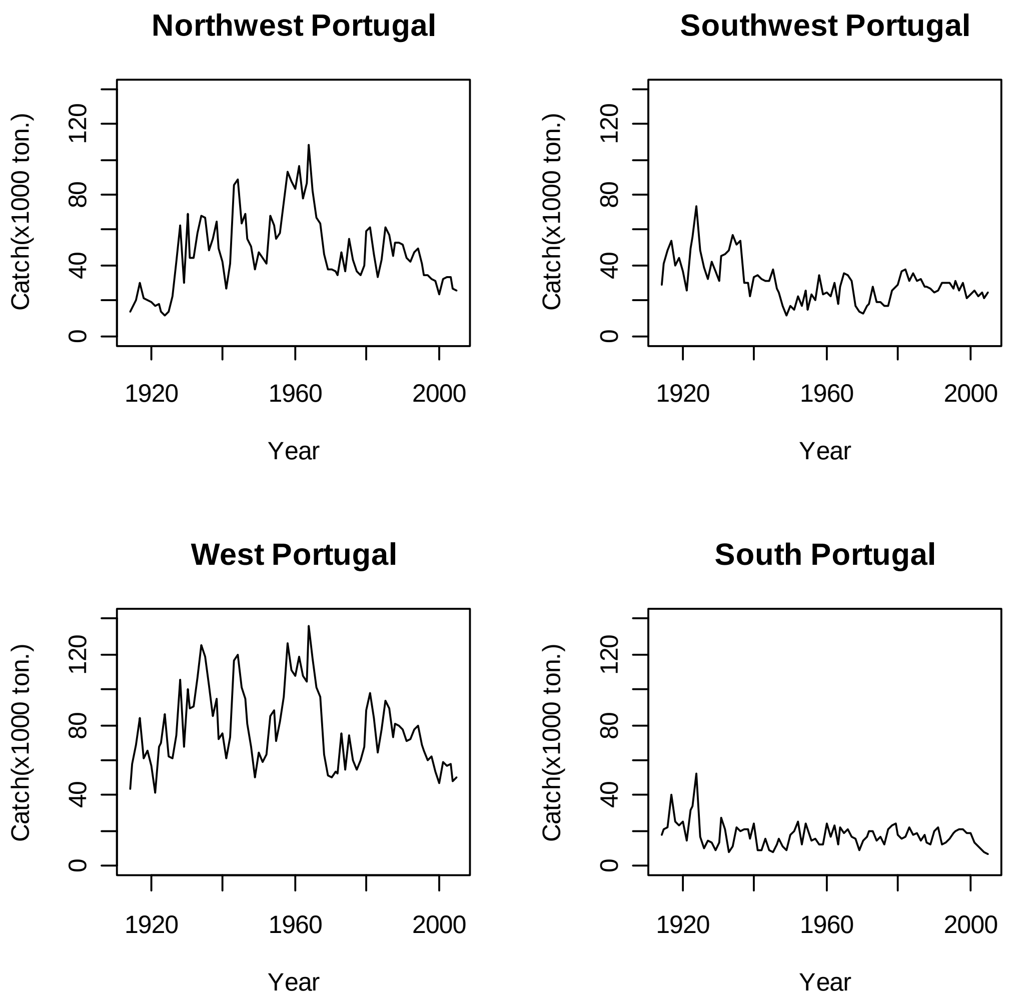


Figure 6.2.1. – Sardine catches from 1915 to 2005 of the Northwest, Southwest, West (combined catches from Southwest and Northwest) and South Regions off Portugal.

Figure 6.2.2. shows the NAO index and north-westerly wind during the analysed period, where both variables are strongly and positively correlated (northerly winds are considered positive when blowing from the north). It can also be observed that low NAO values during periods of several years seem to correspond to high catches and vice versa.

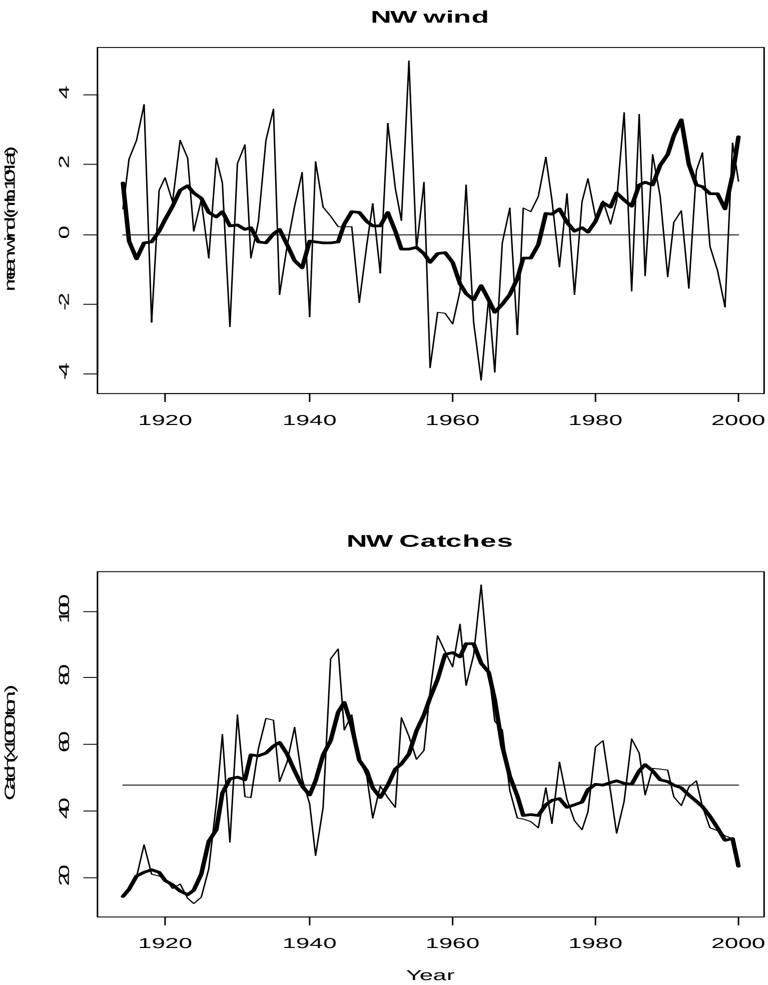


Figure 6.2.2. – Winter NAO index, mean North wind (NW wind) and Northwest Catches (NW catches), the bold line represents a 5 point moving average.

A visual inspection of the plots shows that there is low-frequency variability with alternating increasing and decreasing periods. Although a spectral analysis detects it (see following section), these changes seem to have a decadal character. Superimposed to this smooth variability, there is a high frequency variability linked to the year to year changes in the catches. Figure 6.2.2. shows the low-frequency variability estimated by means of a five year moving average (thick line).

Table 6.2.1. – Correlation matrix of the estimated linear association between the Northwest, Southwest and South sardine catches from 1914-2005.

	NORTHWEST	SOUTHWEST	SOUTH
Northwest	1.00		
Southwest	-0.20	1.00	
South	-0.25*	0.48***	1.00

***** Highly significant correlation (*p*-value<0.001; 0.1% level)**

*** Significant correlation (*p*-value<0.05; 5%level)**

From the simple linear association we observed a negative correlation between the South and the Northwest series and a positive highly significant correlation with the Southwest region.

6.2.1 Time domain methods

There are two general approaches to analyse time series. One is to use time domain methods in which the values of the processes are used directly (autocorrelations). The statistical time series analysis was performed using autocorrelation analysis. The Autocorrelation Function measures the correlation between observations at different time lags.

Figure 6.2.1.1. plots the sample ACF for the four sub-areas, the two horizontal lines show significance limits at a 95 % level. Significant autocorrelations coefficients appear in the northwest and southwest regions up to the time lag of 7 and 12, respectively. The South region, despite the significant 1 year lag correlation, seems to have no clear memory structure.

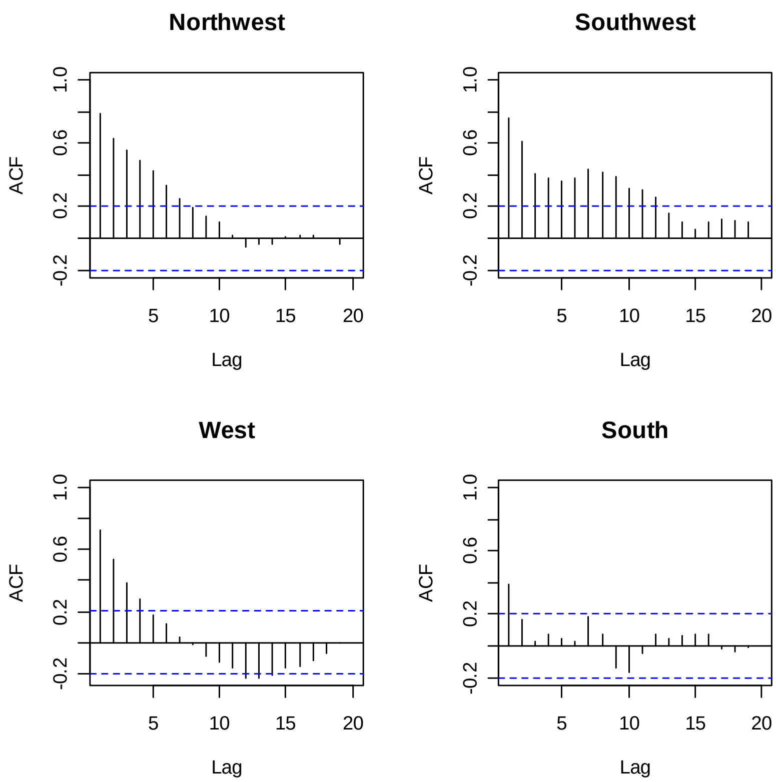


Figure 6.2.1.1. – Sample Autocorrelation function for the studied areas

Through the sample autocorrelation coefficients we computed the index of dissimilarity defined as

$$\sqrt{\sum_{t=1}^{n}\left(\rho_{n,t}-\rho_{m,t}\right)^{2}}$$

between the different regions up to 20 years time lag.

Table 6.2.1.1. – Measure of dissimilarity for 20 years time lag between the series (the higher the values the more different – in a time series perspective – are the series)

	Northwest	Southwest	South
Northwest	0.00		
Southwest	0.53	0.00	
South	**1.28**	**1.70**	0.00

Despite the non significant linear association between the southwest and the northwest series there is a similarity in the stochastic behaviours. The south region shows no memory structure and clearly distinguishes itself from the other two regions.

6.2.2 Frequency domain methods

As we said before there are two general approaches for studying time series, time domain methods and the other is to use frequency domain methods to investigate periodic properties of the series. Some authors tend to focus in one domain or the other. To a large extent, this division arises from the types of question that are being asked to the data. However, combining the approaches can at times give a more thorough understanding of the data.

The estimated spectrum decomposes the movement of the series in various sinusoidal waves of different frequencies and shows the relative strength of each frequency oscillation. The lower frequencies (at left) measure the contribution of long-run oscillations and the high frequencies (at right) measure the contribution of short-run oscillations. Variation in the data at high and low frequencies will correspond to long and short term cyclical variation with period=1/f.

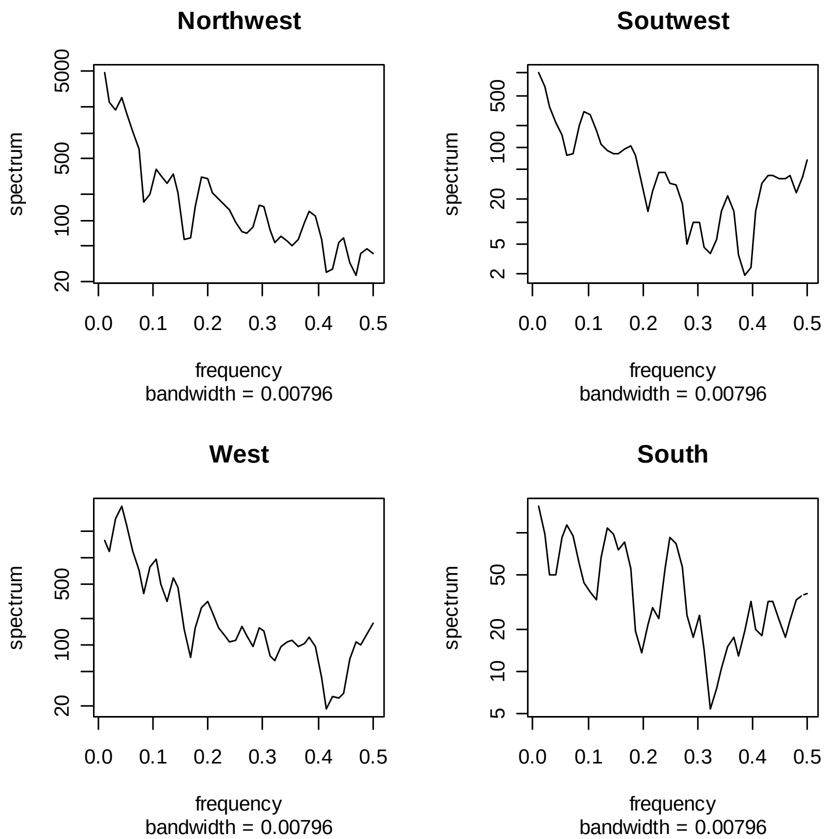


Figure 6.2.2.1. – Spectrum analysis for Northwest, Southwest, West and South Portugal sardine catches.

The shortness of the series – in a time series perspective – for this case study is one of the limiting factors in analyzing periodicity, spectrum analysis made through autoregressive modelling as better results in short time series and this method provides a good estimation of the true spectrum of the series. The order was selected subjectively based on the partial and autocorrelation function.

In figure 6.2.2.2. is the autoregressive spectral analysis made on the Northwest, Southwest, West and South catches. Comparing with the common analysis we observe that the spectrum of the series in the two methodologies are very similar, but the peaks in the autoregressive method seem to be more pronounced.

It is clear that the series are dominated by long-run movements with strong memory. A common peak occurs in the three regions at a low frequency roughly corresponding to a 20-29 years period. Another low frequency peak is present in both northwest and southwest catch series, implying a period of about 10 years. The remaining high frequency peaks are dominated by the intra annual variability.

In a preliminary analysis, made through the cumulative periodogram, a time series tool that checks if a series follows a white noise (purely random series) we observed that the peaks in the south series spectrum were non significant.

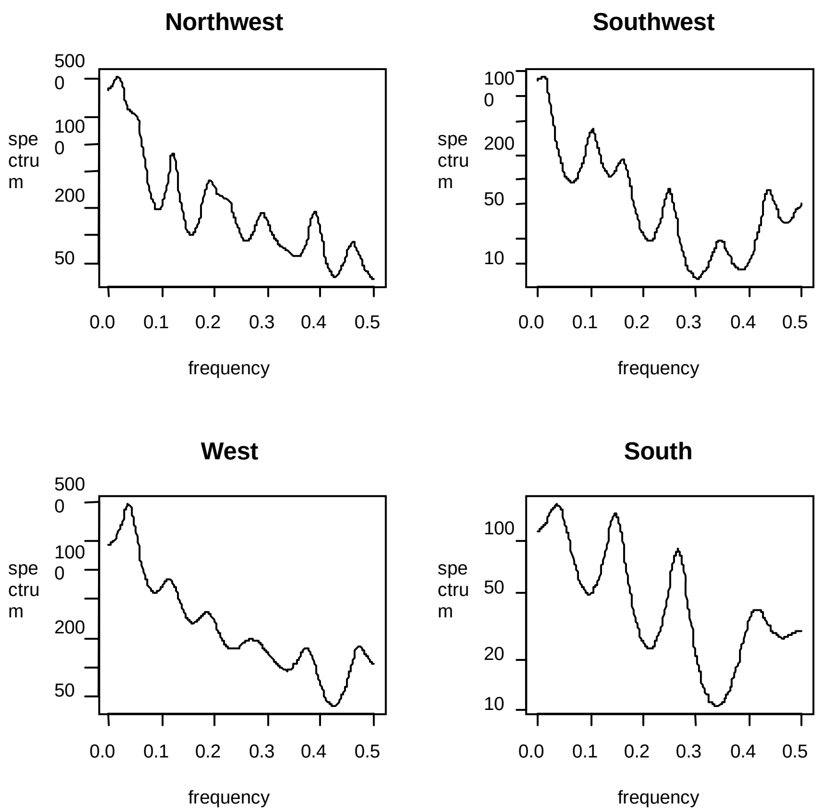


Figure 6.2.2.2. – Autoregressive spectrum analysis for Northwest, Southwest, West and South Portugal sardine catches.

6.3 Case study 3 – local – Bay of Biscay

The climatic and oceanographic features of the inner part of the Bay of Biscay follow the main trends and patterns described in section 3.1 for the Iberian Atlantic coasts, showing thus the main trends and anomaly patterns described for the intergyre region of the north eastern Atlantic Ocean (Valencia *et al*., 2003). The Eastern North Atlantic Central Water (ENACW) is the main water mass in the upper layers of the Bay of Biscay; it occupies almost all the water volume over the continental shelf and the continental slope. However the upper layers of waters suffer some modifications (at regional and seasonal scales) due largely to the close coupling between meteorological and oceanographic data in the inner part of the Bay of Biscay (Pérez *et al*., 1995, Pérez *et al*., 2000; Valencia *et al*., 2003) as for instance the relationships between atmospheric temperature, SST and heat content and salinity, in relation to the precipitation minus evaporation balance and the direct influences of river outflows.

In this region, two varieties of ENACW can be identified: colder and fresher ENACWP, of sub-Polar origin, and warmer and saltier ENACWT of sub-Tropical origin (Ríos *et al*., 1992). The relative occurrence of those water masses in the SE Bay of Biscay, as well as the degree of modification of their characteristics, is related with the main seasonal cycle and with the specific climatic conditions. During autumn and winter, southerly and westerly winds are dominant and a poleward current prevails, with associated mechanisms of convergence, downwelling and vertical mixing. During spring and summer southerly and westerly winds decline, being dominant weaker north and north-easterly wind with associated mechanisms of divergence, upwelling and stable stratification. These regimen increases also the proportion of relatively colder and less saline waters (ENACWP) into SE Bay of Biscay in summer (Valencia *et al*, 2004).

The duality between upwelling and downwelling and the relative prevalence of the climatic and oceanographic conditions related with those regimes seems to be a very important factor influencing the Bay of Biscay anchovy recruitment. Two environmental indices studied during the last 10 years (Borja *et al*. (1996; 1998) and Allain *et al*. 2001) have shown that the prevalence of North-eastern winds during spring and early summer induce weak upwelling and favours the onset of good anchovy recruitments in the Bay of Biscay. In addition strong gales or storms in June July inducing turbulence and disruption of stratification are detrimental for the success of anchovy recruitment (Allain *et al*. 2001). Therefore the balance of wind stress and direction in the SE corner of the Bay of Biscay has implications for tendencies of the anchovy population in the Bay of Biscay.

In this section we review some of the interrelationship between the general Climatic indices of the North East Atlantic analysed in section 6.1 and some oceanographic and biological local indices for the Bay of Biscay in relations as well to the Anchovy Recruitment indexes. The analysis is restricted to the period 1967 onwards for which a series of anchovy recruitment index is available. The selected indices to reflect some of the relevant features within the Bay of Biscay are the following subset of the original list:

VARIABLE	DEFINITION
NAO	North Atlantic Oscillation
EA	Eastern Atlantic Pattern
SCA	Scandinavia Pattern
POL	Polar / Eurasia Pattern
NAO_DM	North Atlantic Oscillation Hurrell (1995) Dec-March
NAO_m	North Atlantic Oscillation Hurrell (1995) annual mean
AMO	Atlantic Multidecadal Oscillation (sea surface temperature anomaly from detrended mean global warming value)
RFG	Mean annual river flow Gironde (Garonne+Dordogne, m3/s)
SSTSS	Mean sea surface temperature at San Sebastian Aquarium (ºC)
POLE	Poleward index at 43ºN, 11ºW from geostrophic winds (Qy, October-December of preceding year)
TPEA	Mean water transport from Potential Energy Anomaly North Atlantic (Mtons/s)
SST_4503	Mean sea surface temperature (45ºN,03ºW, ºC)
UILm_4502	Upwelling index Landes (45ºN, 2ºW, annual mean, m3/(s km))
UIBm_4502	Upwelling index Basque coast (45ºN, 2ºW, annual mean, m3/(s km))
UIBs_4502	Upwelling index Basque coast (45ºN, 2ºW, annual mean of positive values, March-July, m3/(s km))
TURB_4502	mean annual turbulence Bay of Biscay (at 45ºN, 2ºW, m3/s3)
SHF_4503	annual mean sensible heat fluxes Bay of Biscay (45ºN, 3ºW, W/m2)
ZMF_4503	annual mean zonal momentum flux Bay of Biscay (45ºN, 3ºW, N/m2)
ARI	anchovy recruitment index (ICES VIII) relative units
AR	anchovy recruitment (Bay of Biscay) ICES area VIII (x10^9 indiv.)
HMR	horse-mackerel recruitment (European Atlantic, ICES) (x10^9 indiv.)

PCI_E4	Phytoplankton Colour Index (CPR) annual mean area E4 (Bay of Biscay)
COP_E4	Copepod abundance from CPR (n/1000) area E4
DWCPR	Mesozooplankton biomass (mg DW/m3) estimated from abundance for E4+F4 CPR areas
PCI_m	Phytoplankton Colour Index (CPR) annual mean areas F4-E4
COP_m	Copepod abundance from CPR (n/1000) areas F4-E4
PZI	Phytoplankton-Zooplankton Index (CPR areas F4-E4)
PZI_E4	Phytoplankton-Zooplankton Index (CPR areas E4)

Here, as in section 6.1, the series were standardized and any time trend during the series 1967-2004 was removed.

The region seems not to be heavily conditioned by NAO directly as suggested by Triguero *et al.*, IN fact, from the NAO indexes were not related with the hydrographic factors included in the analysis (Table 6.3.1). Only the Gironde River outflow was at the edge of being significantly related to the NAO computed from December to March each winter. The East Atlantic pattern (EA), structurally similar to the NAO and the Polar/Eurasia (POL) patterns, affecting the longitudinal circulation of winds and storms, are both weakly related to the potential energy anomaly (TPEA) and they all with the Upwelling indexes of the region (although only occasionally being statistically significant, as POL and TPEA with the Spring upwelling index UIBs at 45º02'N).

The East Atlantic pattern (EA) and the Polar/Eurasia (POL) patterns both are related significantly to the long Recruitment index series of anchovy (ARI) although do not achieve significance for the short series, AR). This relationship might be partly related to their relationship with the Landes and spring upwelling indexes in the region.

Gironde River discharge seems to be affected only weakly by the SCA or POL and more directly by NAO from December to March (NAO_DM), the annual upwelling index along Landes (UILm) and with temperature (SSTSS) and Sensible heat fluxes (SHF) related to water column stability. Nor temperature or river discharge are significantly related with the anchovy recruitment, although there might be some negative limiting role of river runoffs as indicated by Buffaz and Planque (2006) by quartile regression.

Table 6.2.2 shows that Recruitment of anchovy is significantly affected by the upwelling index in 45º02'N for both the long (ARI, Borja *et al.* 1996) and short (AR, ICES 2006) and this independently of retrieving tendencies or not from the series. So the significance of this environmental index holds on still 10 years after publication. Biological variables from the Continuous Plankton Recorder (CPR) survey do not show a clear relationship with anchovy recruitment, except perhaps for the negative relationship shown for the Mesozooplankton biomass (mg DW/m3) estimated from abundance for E4+F4 CPR areas (DWCPR) not easily understood.

It is interesting however the positive relationship between the Horse Mackerel series of recruitment and Phytoplankton-Zooplankton Index (CPR areas F4-E4) (PZI), probably resulting from the opposite signs of the potential influences of Copepod and Phytoplankton indexes on horse mackerel recruitment (table 6.2.2 bottom line).

Table 6.3.1: Selected relationships between Climatic variables and some Oceanographic indices for the Bay of Biscay

DETRENDED	RFG	SSTSS	POLE	TPEA	SST_4503	UILM_4502	UIBM_4502	UIBS_4502	TURB_4502	SHF_4503	ZMF_4503	ARI	AR
NAO	-0.0789	-0.0864	-0.0014	0.0311	-0.0725	0.0704	-0.0491	0.1186	-0.1768	0.1259	0.0932	0.3191	0.0666
n	38	38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)	0.6378	0.6060	0.9934	0.8965	0.6654	0.6832	0.7762	0.4781	0.3022	0.4513	0.5779	0.0543	0.7864
EA	0.1244	0.0169	0.2868	-0.3448	0.0797	-0.2896	-0.1095	-0.2140	0.1013	0.1478	-0.1409	-0.4366	-0.3262
n	38	38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)	0.4567	0.9197	0.0808	0.1366	0.6344	0.0866	0.5250	0.1971	0.5564	0.3758	0.3988	0.0069	0.1729
SCA	0.2699	-0.1933	-0.2828	0.2301	-0.0544	0.0853	-0.0686	-0.0198	0.0656	-0.0933	-0.1317	-0.1158	0.0810
n	38	38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)	0.1013	0.2448	0.0854	0.3291	0.7455	0.6210	0.6910	0.9062	0.7040	0.5773	0.4306	0.4949	0.7417
POL	-0.2362	0.1251	-0.1975	0.3790	0.1315	0.1039	0.1232	0.3305	-0.0138	0.1462	0.1793	0.5030	0.3514
n	38	38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)	0.1533	0.4544	0.2345	0.0993	0.4314	0.5466	0.4740	0.0427	0.9363	0.3811	0.2815	0.0015	0.1402
NAO_DM	-0.3075	-0.1157	-0.0363	0.1271	-0.0514	-0.0261	-0.0341	0.1677	-0.0938	0.1258	0.1669	0.3949	0.1727
n	38	38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)	0.0604	0.4890	0.8289	0.5934	0.7594	0.8797	0.8435	0.3143	0.5865	0.4518	0.3166	0.0156	0.4797
NAOm	-0.1568	-0.0827	-0.0898	0.0343	0.0538	0.1383	-0.1755	0.1237	-0.0593	0.1667	0.1810	0.3460	0.0441
n	36	36	36	20	36	36	36	36	36	36	36	36	19
Prob(R)	0.3610	0.6314	0.6023	0.8857	0.7554	0.4212	0.3059	0.4721	0.7314	0.3311	0.2908	0.0387	0.8578
AMO	-0.0911	0.1999	0.2637	-0.3285	0.2762	-0.1230	-0.0248	-0.1471	0.1953	-0.0835	0.0046	-0.2674	-0.2082
n	38	38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)	0.5864	0.2289	0.1097	0.1573	0.0932	0.4747	0.8856	0.3781	0.2536	0.6181	0.9781	0.1096	0.3923
RFG		-0.3614	-0.0829	0.1864	-0.0984	0.4001	0.1170	0.2887	-0.3222	0.4367	0.0954	-0.2487	-0.0137
n		38	38	20	38	36	36	38	36	38	38	37	19
Prob(R)		0.0258	0.6206	0.4314	0.5568	0.0156	0.4967	0.0788	0.0553	0.0061	0.5688	0.1378	0.9555
SSTSS			0.0736	0.1516	0.4194	-0.3789	-0.2395	-0.4067	0.3767	-0.3637	-0.3282	-0.0198	-0.0325
n			38	20	38	36	36	38	36	38	38	37	19

Prob(R)			0.6607	0.5233	0.0088	0.0227	0.1595	0.0113	0.0236	0.0248	0.0442	0.9072	0.8950
POLE				-0.0066	0.0674	-0.1604	0.0747	-0.0968	-0.0817	-0.0548	-0.0083	-0.2951	-0.1983
n				20	38	36	36	38	36	38	38	37	19
Prob(R)				0.9780	0.6877	0.3501	0.6650	0.5631	0.6359	0.7439	0.9605	0.0762	0.4158
TPEA					0.1416	0.3442	0.2876	0.6343	-0.1109	0.5531	0.0867	0.3114	0.3272
n					20	20	20	20	20	20	20	20	19
Prob(R)					0.5514	0.1373	0.2188	0.0027	0.6415	0.0114	0.7163	0.1814	0.1715

Table 6.3.2. Selected relationships between oceanographic variables and biological indices for the Bay of Biscay

DETRENDED	ARI	AR	HMR	PCI_E4	COP_E4	DWCPR	PCI_M	COP_M	PZI	PZI_E4
RFG	-0.2487	-0.0137	0.1960	0.2984	0.1567	0.0134	0.2796	0.2166	0.0492	0.0873
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.1378	0.9555	0.3700	0.0688	0.3475	0.9372	0.0891	0.1915	0.7694	0.6021
SSTSS	-0.0198	-0.0325	0.1342	0.1885	-0.1091	-0.0787	-0.0127	-0.1130	0.0781	0.2050
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.9072	0.8950	0.5415	0.2571	0.5142	0.6433	0.9399	0.4994	0.6413	0.2171
POLE	-0.2951	-0.1983	-0.1295	0.0442	0.0644	0.0793	0.4289	-0.0299	0.3572	-0.0167
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.0762	0.4158	0.5560	0.7922	0.7008	0.6407	0.0072	0.8586	0.0277	0.9206
TPEA	0.3114	0.3272	0.1163	0.5433	0.2527	-0.1362	0.3852	0.4035	0.0474	0.2379
n	20	19	20	20	20	20	20	20	20	20
Prob(R)	0.1814	0.1715	0.6252	0.0133	0.2824	0.5668	0.0935	0.0777	0.8428	0.3124
SST_4503	0.0636	-0.1772	0.2713	0.2408	-0.2520	-0.1830	0.0074	-0.3278	0.2608	0.3429
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.7083	0.4681	0.2105	0.1453	0.1269	0.2782	0.9650	0.0445	0.1137	0.0351
UILm_4502	0.4220	0.1790	0.0828	0.0225	-0.0270	-0.0784	0.0580	0.0475	0.0092	0.0341
n	36	19	23	36	36	36	36	36	36	36
Prob(R)	0.0104	0.4634	0.7072	0.8965	0.8759	0.6493	0.7367	0.7834	0.9574	0.8437
UIBm_4502	0.1924	0.1302	-0.1444	-0.0152	0.0779	0.1142	-0.0313	0.1041	-0.1024	-0.0650

n	36	19	23	36	36	36	36	36	36	36
Prob(R)	0.2610	0.5953	0.5108	0.9298	0.6516	0.5072	0.8561	0.5455	0.5523	0.7065
UIBs_4502	0.3973	0.4812	0.2032	0.1265	0.1279	0.0027	0.0232	0.1112	-0.0685	-0.0073
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.0149	0.0370	0.3524	0.4492	0.4439	0.9873	0.8899	0.5061	0.6829	0.9654
TURB_4502	-0.1571	0.0877	0.0625	0.1699	-0.0924	-0.1934	0.0703	-0.0619	0.1008	0.1791
n	36	19	23	36	36	36	36	36	36	36
Prob(R)	0.3601	0.7210	0.7768	0.3218	0.5921	0.2585	0.6836	0.7200	0.5585	0.2960
SHF_4503	0.0031	0.0416	0.2983	0.0710	-0.1870	-0.1476	0.1049	-0.0909	0.1524	0.1822
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.9854	0.8656	0.1668	0.6718	0.2610	0.3832	0.5308	0.5873	0.3610	0.2736
ZMF_4503	0.2228	-0.1619	-0.1431	-0.0741	-0.0009	0.0451	-0.1222	-0.0388	-0.0649	-0.0491
n	37	19	23	38	38	37	38	38	38	38
Prob(R)	0.1851	0.5079	0.5148	0.6583	0.9957	0.7911	0.4650	0.8170	0.6986	0.7699
ARI		0.8504	0.4024	-0.0366	0.0430	-0.0564	-0.0593	-0.0848	0.0200	-0.0545
n		19	23	37	37	37	37	37	37	37
Prob(R)		0.0000	0.0569	0.8296	0.8007	0.7404	0.7275	0.6178	0.9067	0.7485
AR			-0.176001612	0.1480	-0.0316	-0.5540	-0.2664	-0.1331	-0.1496	0.1652
n			19	19	19	19	19	19	19	19
Prob(R)			0.4711	0.5453	0.8977	0.0139	0.2702	0.5871	0.5410	0.4990
HMR				0.4487	-0.2351	-0.1976	0.4975	-0.2556	0.6471	0.4872
n				23	23	23	23	23	23	23
Prob(R)				0.0317	0.2802	0.3661	0.0157	0.2391	0.0008	0.0184

7 General Discussion

Trends and global warming. All the observed trends are consistent with a general increase in both atmospheric and sea surface temperature in the late century (Kerr 2000, Hansen *et al.* 2005). Considering the study period, the influence of boreal components (e.g. north winds indicated by positive NAO values) on the climate in the N Atlantic region decreased while that of subtropical components (e.g. EA) increased. This influence may explain the increasing stratification of surface waters, the reduction of the upwelling in the E Atlantic, along with an intensification in the water transport to the east by the N Atlantic gyre. This interpretation is consistent with observations (Curry *et al.* 2001) and model predictions of N Atlantic currents (Bryden *et al.* 2005). The overall decrease in zooplankton and fish is also consistent with an increase in the stratification of the surface which would reduce productivity. Similar trends were reported using CPR data over the N Atlantic revealing a reduction in phytoplankton in warmer regions while that of cooler regions increase (Richardson and Schoeman 2004). In this way, the observed increase in phytoplankton biomass while upwelling intensity is reduced may be explained either by metabolic enhancement by the increasing temperature or by a progressive uncoupling from zooplankton consumers (Edwards and Richardson 2004). A similar increase in recent years was described for coastal phytoplankton at some sites within the study region (e.g. Bode *et al.* 2006). While there is evidence of a strong bottom-up control of climate on the planktonic food web, several mechanisms have been invoked to explain the changes (e.g. Beaugrand 2004, Edwards and Richardson 2004, Richardson and Schoeman 2004). Because of the rapid response of plankton to oceanographic conditions, comparative studies between adjacent regions may reveal the dominance of a particular mechanism in shaping planktonic communities. For instance, the rate of change of zooplankton communities varies along the N Iberian coast in relation to the change in water column stratification (Valdés *et al.* in press).

Periodic changes and bottom-up forcing. The study revealed the succession of periods at interannual, in many cases quasi-decadal, scales for climatic, oceanographic and ecosystem indices. Similar changes were also observed in other regions characterized by coastal upwelling (e.g. Chavez *et al.* 2003). Interestingly, the observed changes off NW Iberia occurred in an upwelling system characterized by a range of variability of absolute values of upwelling intensity and ecosystem productivity much smaller than those in other oceanic regions, as Peru or S Africa (Schwartzlose *et al.* 1999). It must be taken into account, however, that the employed database only spans for up to 60 y, allowing for the identification of a few decadal periods. Therefore the role of different mechanisms can only be advanced. In any case, we can explore the possible role of direct effects of climate versus food web mediated controls on the observed succession of alternative states of the ecosystem.

Direct effects of climate on plankton and sardine populations have been shown in subzones of the study area. For instance, several studies (Dickson *et al.* 1988, Borges *et al.* 2003, Guisande *et al.* 2004) analyzed the negative relationship between north wind intensity in spring and sardine landings off Portugal and Galicia. Other studies showed the negative effect of intense winter and spring upwelling on the recruitment of sardines likely by increasing larval dispersion (Guisande *et al.* 2001, Santos *et al.* 2004). In contrast, moderate upwelling seem to favour anchovy recruitment in the eastern Bay of Biscay (Borja *et al.* 1998, Allain *et al.* 2001). Besides direct effects of climate and oceanographic conditions, indirect effects on upper trophic levels may operate through changes in productivity and structure of plankton communities (Chavez *et al.* 2003, Vander Lingen *et al.* 2006). In the latter case, the availability of the appropriate preys favours the dominance of one or another species of planktivorous fish. Adult sardines are better suited to filter-feeding on small copepods than anchovies, but the latter are efficient predators of large copepods (Van der Lingen *et al.* in press). In addition, sardines are able to consume phytoplankton (Bode *et al.* 2004, Cunha *et al.*

2005). These trophic characteristics may favour the dominance of one fish species when the appropriate environmental conditions for the development of the appropriate food occur. In the case of the southern Benguela upwelling, intermittent upwelling is hypothesised as the driver of high phytoplankton biomass in large cells that feed large copepods, thus favouring anchovy dominance (Van der Lingen *et al*. 2006). Warm surface waters during reduced upwelling conditions are related to the proliferation of small phytoplankton cells and copepods which are adequate for sardines. Similar hypothesis were proposed for the Pacific (e.g. Chavez *et al*. 2003) although the association between upwelling intensity and a particular fish species seem to vary among geographic locations (Chavez *et al*. 2003, Bertrand *et al*. 2004).

The link between climate, oceanography and the structure of the ecosystem in the N Atlantic Iberian waters can be formulated as a conceptual model in which alternative modes of the climatic system lead to divergent oceanographic conditions and in turn to the dominance of alternative plankton and fish species (Fig. 7.1.). On one side, dominance of boreal climatic modes, as those indicated by positive NAO and the influence of northern winds and pressure anomalies, is associated to increased turbulence in the surface ocean, relatively low water temperature and high average upwelling intensity. Such conditions favour phytoplankton productivity during upwelling-induced blooms and small copepod species (e.g. Acartia) that are able to track the food increase at short time-scales. In turn, the abundance of small copepods and phytoplankton can be used efficiently by sardines through filter-feeding. On the other side, a growing influence of subtropical climatic components, as indicated by EA, would increase water surface temperature and the stratification of the surface layer, while average upwelling intensity and frequency decrease. Phytoplankton productivity would decrease because of the reduced nutrient inputs, but changes in the dominance of species (i.e. dinoflagellates versus diatoms) or local blooms caused by changes in currents may lead to increases in biomass (Richardson and Schoeman 2004). The reduced upwelling would be a positive factor for anchovy recruitment and large copepods which are able to feed on relatively large phytoplankton, as some dinoflagellates. Also, adult anchovies would find food of appropriate size for sustaining the population and producing large reproductive outputs.

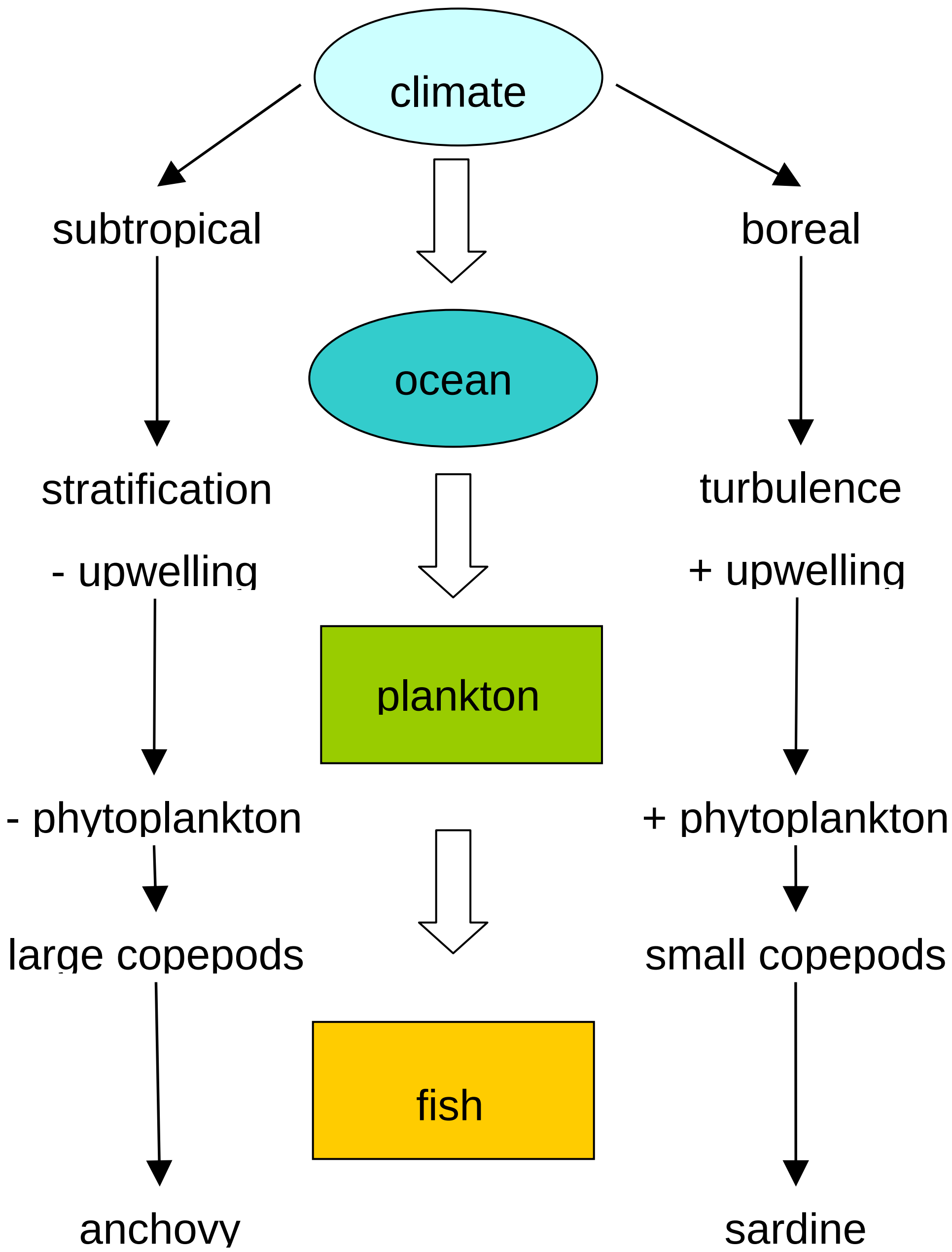


Fig. 7.1. Conceptual model linking changes in climate to those in the ocean and ecosystem components at a regional scale in NW Iberia and Bay of Biscay.

The conceptual model described in Figure 7.1. describes the average multiannual dynamics in the main climatic, oceanographic and ecological features in the study region. It must be noted, however, that the conditions leading to the alternative states of the ecosystem are opposed to those proposed for other upwelling regions (e.g. van der Lingen *et al.* 2006). One possible explanation of such difference is the nature of the main direct external forcing on the ecosystem, in this case the upwelling. Being a marginal upwelling area within the large NE Atlantic upwelling region, the NW Iberian shelf displays upwelling events of much shorter duration and intensity than those in areas located to the south (e.g. NW Africa or S Benguela). In this context, relative anomalies of upwelling intensity or frequency occurring within a particular region may represent very different energy inputs in absolute value when comparing upwelling regions. Also, the terms reduced upwelling or increased stratification must be taken in relative value, as upwelling events never ceased completely in the region. Subregional analysis may reveal the exact mechanisms triggering the biological response at each site, thus adding local complexity to the processes depicted in the model of Figure 7.1. An example of the interaction of factors at climatic, biogeographic and local scales was provided for the North Sea (Beaugrand 2004).

Regime shifts. The underlying causes of the described variability may also change during the observational period. This is suggested by the match and mismatch of positive and negative anomaly periods when comparing indices (e.g. Fig. 6.1.4.5.). Sudden changes in most series, as those observed in the late 1970s in this study, are generally associated with shifts in the oceanographic and ecosystem regimes (e.g. De Young *et al*. 2004). Similar shifts were recognized in most upwelling regions (Borges *et al*. 2003, Chavez *et al*. 2003, Alheit and Ñiquen 2004, Cury and Shannon 2004). Large changes in climate related to El Niño-Southern Oscillation (ENSO) were often claimed as one of the major underlying causes of ecosystem shift, mainly in the Pacific (e.g. Chavez *et al*. 2003) but it also can affect other oceans because of climatic teleconnections (Barnston and Lievezey 1987). Major changes in the ecosystems of the NE Atlantic have been described for the period between late 1970s and 1990, but the exact timing of the shift varied among the target variables (Beaugrand 2004, Edwards and Richardson 2004, Richardson and Schoeman 2004). Climate effects, as the change in wind speed and direction in the late 1970s, may need a different time to integrate as a clear response in some biological compartments. In this regard, plankton and short-living pelagic fish are among the first to show alterations, but the ability to identify the timing is also dependent of the statistics employed (Beaugrand 2004). The shift in the late 1970s identified in this study is coincident with a major ENSO-related shift in the Pacific (Chavez *et al*. 2003, Alheit and Ñiquen 2004) and it has been also indicated in zooplankton CPR data from the NE Atlantic (Dickson *et al*. 1988, Richardson and Schoeman 2004). One major feature of the shift detected in the Iberian case is the coincidence of peak abundances of both sardine and anchovy species prior to 1975. Fishery data report a marked decrease in the distribution area of Iberian anchovy, formerly well distributed through the shelf (Junquera 1984) but now restricted to major populations in the E Bay of Biscay and the Gulf of Cadiz (e.g. ICES 2005). In contrast, sardine populations have fluctuated in abundance but never abandoned the main distribution centres (ICES 2005, Carrera and Porteiro 2003). The continued operation of upwelling, even reduced by global trends, and the decrease of suitable preys for anchovy in the region may explain the poor success of anchovy in most areas of the region after 1980. Only the appropriate conditions at local scales, as the moderate upwelling and the existence of thermohaline fronts in the E Bay of Biscay (Borja *et al*. 1998, Allain *et al*. 2001) would allow the maintenance of this species despite the average negative conditions in the region. Changes observed in the region considered in this study in early 1990s were also similar to those described in the Pacific (Chavez *et al*. 2003) and were also found at subregional scales (e.g. Borges *et al*. 2003). This supports a major role of teleconnection patterns at multidecadal scales, causing abrupt changes in the relationships between environmental and biological variables.

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Annex 2: Agenda

ICES/GLOBEC Workshop on Long-term Variability in SW Europe

Lisbon, 13 – 16 February, 2007

Agenda

<u>Tuesday 13 February (Sala Castanha IPIMAR)</u>

9:30 – Convener's opening; welcome to the participants, objectives workshop

General presentations (amphitheatre IPIMAR)

10:00 – J. Alheit: Climate variability and regime shifts in Atlantic and Pacific.

11:00 – coffee-break

11:15 – A.Uriarte: Multidecadal changes in anchovy recruitment in Bay of Biscay

11:45 – V. Valencia: Hydrography SE corner of Bay of Biscay

12:15 – Lunch

13:30 – M. Vargas: Decadal and long term changes in the western Mediterranean.

14:15 – A. Lavín: Environmental variability in the North Atlantic and Iberian waters

15:00 – A.M. Santos: Decadal changes in the Canary upwelling system as revealed by satellite observations.

15:30 – M.F. Borges: Regime shifts in West Portuguese waters

16:00 – coffee-break

16:30 – J. Alheit: Impact on NAO on European aquatic systems

17:00 – Ricardo Trigo: The impact of large-scale major modes off atmospheric circulation in the Iberian climate

17:30 – J.C. Mendes: West Iberian Plankton-Time series from an intermittent sampling (Sb route of the CPR survey)

18:00 – Omar Etahiri: Habitats de ponte de la sardine "sardina pilchardus" au niveau des côtes atlantiques sud marocaines

<u>Wednesday 14 February (Sala Castanha IPIMAR)</u>

9:00 – A. Bode: Updated version of the data on climate and oceanographic indices, sardine, anchovy and plankton biomass on the Bay of Biscay and NW Iberian shelf

10:30 – M. Luz Fernandez: The zooplankton variability in relation to hydrography during the last decade in waters of the Balearic Sea, Western Mediterranean

11:00 – Yorgos Stratoudakis – Changes in the distribution of sardine eggs and larvae Off Portugal

12:00 – coffee break

12:15 – Statistical methodology: Time Series analysis, Auto-Correlations, Cross-Correlation, Uncertainty measures and other statistical measures

12:45 – Material: Data availability by region: Upwelling waters of Spain and Portugal, Bay of Biscay, Western Mediterranean, Upwelling water of NW Africa.

13:00 – Lunch

14:00 – Synthesis of the state of the art based on the presentations: questions to address.

14:15 – 16:00: Report structure and sub-group assignments. Data analysis by sub-groups.

16:00 – coffee break

16:15 – 18:00: Data analysis by sub-groups

Thursday 15 February (Sala Castanha IPIMAR)

9:00 – 9:30: Plenary to present progress on report

9:30-11:00: short presentations on undergoing Research Projects that are relevant to the GLOBEC Programme on climate change and productivity of ecosystem components and implications for management of ecosystem services

11:00 – coffee break

11:15 – 12:15: Report writing and data analysis by sub-groups

12:15 – Lunch

13:45 – 18:00: Report writing and data analysis by sub-groups

20:00- dinner

Friday 16 February (Sala Castanha IPIMAR)

9:00 – 13:00 – Report and closing

Annex 3: Minutes of the presentations by the meeting rapporteur

ICES/GLOBEC Workshop on Long-term Variability in SW Europe

Lisbon, 13 – 16 February, 2007

J. Alheit, M.F. Borges, A. Lavin, A. Uriarte (conveners)

A. Bode (rapporteur)

Agenda & rapport

Tuesday 13 February (Sala Castanha IPIMAR)

9:30 – Convener's opening; welcome to the participants, objectives workshop

Welcome address and logistic briefing (M.F. Borges)

Objectives of the workshop (J. Alheit) and general presentation of participants

General presentations (amphitheatre IPIMAR)

10:00 – J. Alheit: Synchrony in decadal scale dynamics of small pelagic fish in and Humbold Kuroshio Current systems.

Focus on regime shifts

Historic review of sardine-anchovy fluctuations (Kawasaki 1983): synchrony between populations –phase, ou-of-phase- wordlwide.

Benguela: now not following fluctuations as in the past (not synchrony with Pacific populations)

Humboldt: regime shifts anchovy->sardine 1969-1971, sardine->anchovy mid 1980s not so related to El Niño as previously thought (changes started before)

Process:

1. decrease in biomass anchovy, increase recruitment sardine, decrease in zooplankton
2. decrease in surplus production anchovy, increase in sardine
3. recruitment collapse anchovy, high sardine biomass

Parallel changes in SST anomalies

Mechanisms:

1. slackening of trades-> reduced upwelling
2. slow meandering flow, deepening thermoclines, advection of warm oceanic waters to the coast (wester, high salinity waters, instead of northern, tropical waters, typical of El Niño, less saline).
3. reduction in cool anchovy habitat, productivity changes
4. negative impacts on anchovy trophodynamics:

a. density-dependent processes (e.g. cannibalism, increased catchability)

b. increased predation on eggs, larvea and adults (oceanic predators near the coast)

c. changes in prey fields (less large copepods, more small copepods?)

Relationship with El Niño: anchovy biomass rapidly reduces but readily recovers when El Niño dissapears.

Kuroshio: similar changes to Humboldt. In this system, however, sardines increase when temperatures are cool (as opossed to Humboldt). Mixed layer depths change 3 years before SST anomalies (changes in subsurface structure -> changes in productivity).

Sardine in Humboldt and Kuroshio are in synchrony (period 1960-2000). Biomass of large copepods increase several years after anchovy increased (why?)

Conclusions:

- Teleconnections?
- Mechanism proposed for Humboldt (valid also for Kuroshio?)
- Turning points preceded by changes in sub-surface structures
- No strong signals in climate regime shits related to small pelagics

10:50 – coffee-break

11:00 – A.Uriarte: Multidecadal changes in anchovy recruitment in Bay of Biscay (change in title)

Review of data on anchovy and environmental variables.

landings (from 1940-2005): now fishery closed

Changes in fishery spatial range (spring: all NW Iberia before 1965, restricted ever more since then, autumn French S Bay of Biscay)

Recruitment favored by local upwelling in spring (NE winds along French and Spanish coast) and decreased by summer SW winds. Quantitative relationships between upwelling and recrutiment but there are recent outliers. Forecasting not good in recent years?

Focus on the SE Bay of Biscay

Local Upwelling series (1958-2005) from NOAA at 45ºN, 2ºW (accumulated positive values): now there are smaller windows of upwelling events during spring (since 1997-1998) and mean upwelling intensity is lower than before.

After 1997 turbulence? is high and upwelling low without a clear relationship as before.

The relationship between upwelling and recruitment seems to have changed: small continuous upwelling events seem to have a detrimental effect on recruitment.

Multiple relationships with recruitment: PCA. Upwelling (and turbulence in negative form) the dominant mode, also NAO and temperatures, river flows and other variables having minor roles.

Conclusion:

upwelling (+) and turbulence (-)

river fertilization important for spawning areas

regime shift after 1997?

relationship with NAO: through wind (more western winds)

low variance explained by multiple models (=55%), futher investigation of fishery pressure and status of fishing grounds.

11:40 – V. Valencia: Hydrography SE corner of Bay of Biscay

Review of relevant information for fish population changes.

- Climate: away from main atmospheric gyres (low in N Europe and high in Azores). Local lows near British Islands more important: western winds and rains.

- Oceanography: upper water mass generally following heat balance, except for advection events. Depth of winter mixed layer (MLD) follows surface temperature changes (low temperature = high MLD). Maximum salinity anomalies in the early 1990s (max 1994-1995) and around 2000 (max 2000). Strong change in anomalies of precipitation and river flow (Gironde, Adour) in 1992 = cause of salinity anomalies (significant correlation for most of the year, except for spring, between precipitation and river flow). Importance of reference period for computed anomalies (relative values the same but absolute values change) and mainly for the study of trends.

- Present work: comparative study of patterns and trends in anomalies in 1961-2000 time series air temp, SST precipitation/river from from Tromso and Bay of Biscay. Periods in phase and out of phase (time-lags?) for all variables.

12:00 – Lunch

13:30 – M. Vargas: Decadal and long term changes in the western Mediterranean.

Spatial scale: Western Mediterranean (Spanish shelf)

Areas:

- Catalan Sea
- Balearic sea
- Alboran Sea (upwelling, Atlantic inflow): relationships with Gibraltar

Data:

- RADIALES (IEO), L'Estartit (ICM)
- Tide gauges
- Meteorological (local stations INM)
- Buoys (Puertos del Estado)
- NCEP (NOAA)

- satellite information (SST. chlorophyll)

Aim (primary phases):

- Data collection and statistics
- Annual status report on oceanographic status

Results:

- South: (ej. Malaga) significant warming (mainly in Mediterranean waters, bottom waters) 0.008ºC but decadal oscillations (after 2000 temperature anomalies decreased for some years). Increase in heath content of the water related to increase in sea level (thermal expansion of the water) except in recent years (after 2000). SST fron satellite (regional) significant decrease in 1993-2005 up to 0.08 ºC/y in the southern region (Alboran)
- Balearic: In Mallorca temperatures are decreasing but salinity increasing. Decrease in sea level (also related to thermal expansion). Cooling trends in SST not significant.
- Northern: In L'Estartit temperature increases (0.02ºC/y) but decreases in recent years (after 2000). Increase in heath content of the water related to increase in sea level (thermal expansion of the water) except in recent years (after 2000). Cooling trends in SST not significant.
- Local trends in sea level agree with general trend (except in Balearic sea).
- Overall decreasing trend in STT over the region but due to Atlantic inflow (more effect in the south).

Conclusions:

- increase in SST and S since 1970
- warming at increasing rates since 1990
- reversal of warming after 2000 (severe winters)
- sea level driven by thermal expansion
- Atlantic and Mediterranean waters changes in opposite direction (for most of the series) but in the same direction since 2000.

14:00 – Ricardo Trigo: The impact of large-scale major modes off atmospheric circulation in the Iberian climate

Content:

- Major modes of atmospheric circulation affecting Iberia
- Circulation weather over Iberia
- Changing pattern in precipitation

Major modes: NAO and EA (Eastern Atlantic Pattern) also SCA (Scandinavian Pattern) dominant modes for winds and precipitation over Iberia. (3 first eigenvalues explaining sea level pressure)

- NAO:
  - o storm tracks through Iberia with NAO<0; more to the north when NAO>0

- o also air temperature in NW Iberia is controlled to a large extent by NAO;
- o precipitation: NAO<0 high precipitation

Precipitation over Portugal:

- NAO*-1 = precipitation series.
- Dry years = NAO>0.5 (valid for Portugal and adjacent Spain (Zamora, Ourense, Extremadure, W Andalucia). Basque country and Mediterranean Spain not connected to NAO (in terms of precipitation in March)
- Low large river (Duero, Guadiana) flow when NAO>0.5

Circulation weather for Iberia: (1880-1995)

- using regional circulation analysis patterns for precipitation are bettter resolved.
- Anticyclonic circulation dominates through the year (max. in December). Cyclonic , W and SW types are the major influence monthly precipitation.

Application: Decline in precipitation in Iberia in March (including Duero, Tajo and Guadiana hydrographic systems). River flow reduced since 1950s following reduced precipitation in March. NAO positively related to precipitation in March (and also by C+W+SW circulation types, negatively related to precipitation in March, the opposite as in UK).

Role of other modes: SCA and EA contribute to the net effect (e.g. in precipitation) by blocking or allowing wet winds reaching Iberia.

Conclusion:

- March precipitation decreased 50% since the 1960
- Strong links with reverse positive trend in NAO and northward moving of storm tracks
- NAO important but also other patterns as SCA and EA (blocking storms in March, for instance)

Discussion:

- Changes in NAO trends (after 1995) but also a displacement to the NW of the northern Low (Iceland->Scandinavia) in the last 20 y (the southern High also moved).
- Relevance of decadal changes, probably but more studied in the case of NAO.

14:50 – A. Lavín: Environmental variability in the North Atlantic and Iberian waters and its influence on horse mackerel

Aim: predicting horse-mackerel recruitment from oceanographic – climatic variability.

Data:

- large scale data: NAO, Gulf Stream Index (GSI), Potential energy anomaly index (=transport in the N Atlantic)
- COADS SST, wind, turbulence at two reference points
- Wind data (local, geostrophic) Upwelling index, Ekman transport
- Meteorological local data

- Horse mackerel recruitment (short time series)

Preliminary data analysis and selection of variables correlated to mackerel recruitment (SST, N-S and E-W components, upwelling,...

Results:

- Correlation between PEA and other large scale circulation indices
- PCA physical variables: 1st. thermal (19%), 2nd. oceanic (16%), 3rd N-S wind (11%)

o Two main periods: before and after 1990 (dominating thermal components in the latter)

o Recruitment negatively correlated to thermal component (1st. comp.)

- Multiple regression analysis: SST and N-S winds (spring and summer) main variables (r2=0.655)
- Cross-validation model showed that correlation was strong by chance (!): prediction not better than the mean value of the series (because of having a short-time series for recruitment).

Conclusion: The lenght of the time-series affects the predictability

15:15 – A.M. Santos: Decadal changes in the Canary upwelling system as revealed by satellite observations.

Aim: SST satellite information illustrating decadal variability in the upwelling area (Santos *et al*. 2005, J. Mar. Res.)

Data:

- Satellite: 1982-2001 AVHRR
- Observations: Upwelling indices, SST,... in three zones (S and N Canary, western Portugal (seasonal and monthly means)

Results:

- Portugal:

o summer SST anomaly pattern change in the 1990s

o between 1980-1990: quasi-regular oscillations in the ocean but a shift in the coastal zone (<100 km), always negative since 1990

- N and S Canary:

o similar pattern but shift later (1996-1998). Related to shifts in upwelling index and wind.

- Relationship with biology:

o sardine (W Iberia): descrease in landings and recruitment since 1993 (general low values in the 1990s)

o small pelagics in Canary: less Sardina captured since 1994 but increase in Sardinella (after 2000 trend reversed).

o egg distribution (sardine in Portugal): reduction in the area of presence after 1990, (1997: mainly in south and near the coast, less in the north).

Conclusion: Strong summer upwelling and increase in winter upwelling: detrimental for recruitment (Optimal Environmental Window hypothesis) after 1990.

15:45 – coffee-break

16:00 – M.F. Borges: Regime shifts in West Portuguese waters

Aims: applied aspects of regime shifts for pelagic fish

• validation of hypothesis that offshore transport by upwelling in winter is detrimental for recruitment of small pelagics (Santos *et al*. 2004 Cont. Shelf Res. 34:149-165)

• inclusion of regime shift indices in fish stock management?

Results:

• Catches decrease with northerlies (southwards)

• NAO and north winds (frequency and intesity): short-term (6-7 y), mid-term (10-12 y) long-term (55-60 y) periods. High positive correlation NAO:mean N wind.

• Regime shift in 1990s (list of published evidences)

• Fertility Index (for sardine) = Recruitment/spawning stock biomass (R/SSB) index: out of phase with NAO positive periods. Significant negative correlation (time lag of 3 years).

• Operational indicator:

o NAO+ (winter upwelling, low productivity, low recruitment), northern shelf (supported by Dickson *et al*. paper, data collected near Porto)

o NAO- (converse situations), northern shelf

o correlations with R/SSB change with the orientation of the shelf

16:36 – J. Alheit: Impact of NAO on European aquatic systems

Results from German GLOBEC program on zooplankton – fish interactions

Aim: Impact of NAO since late 1980s (climate variability) in Baltic, North Sea, NW Mediterranean and European lakes.

Results:

• NAO winter index increased since late 1980s along with increases in SST

• Baltic:

o observations: decrease in diatoms and increase in dinoflagellates (also decrease in Si consumption), increase in Acartia and Temora (small copepods), and increase in fish (sprat)

o mechanism: inflow of warm N Sea water in summer and fall favours hatching of copepod eggs in sediments by increasing ambient temperature. These copepods will feed sprat larvae and juveniles thus enhance succes of recruitment. In addition, reduced spring convection favours dinoflagellates over diatoms (change in food web?)

• North Sea:

o similar changes as in Baltic (but diatoms increase in winter)

• NW Mediterranean:

o similar changes with NAO but change in food web: more jellyfish and less copepods, less anchovy captured.

• Lakes: decrease in clear water phase timing (after spring blooms) with positive NAO increase in 28 european lakes: clear water starts earlier. Diatoms decrease and cyanobacteria increase.

Conclusion: regime shift (after 1990) observed in climate and biology (food web) in the sea and lakes. Also in Iberia? Role of time lags?

17:05 – Jose Carlos Mendes: West Iberian Plankton-Time series from an intermittent sampling (Sb route of the CPR survey)

Aim: investigation of interannual variability in plankton

Method: CPR transect Sb (Lisbon to UK)

• 1958-1977 Galicia-Britany, 1986 Lisbon, 1987.... different lenght and orientation: the time series is not always sampling the same water.

• 1978-1986, 1997-2005 periods more consistent

Results:

• Cluster analysis species: two main groups of copepods (small and large), phytoplankton (winter and summer groups)

• Phytoplankton colour: earlier blooms between 1990-2000 related to winter upwelling?

• Some species bloom earlier in the year (in second series)

• Other species shift from two seasonal peaks to near constant abundance through the year.

• Other species appeared only in recent years (C. chierchiae, Euchaeta hebes).

• Acartia and Oithona decreased (ca. all months)

• Dinophysis changed seasonal peaks.

• Diatoms (but also dinoflagellates) mostly decreased

• Good correspondence after 1980 between sardine catches and copepods (CPR from North Galicia).

17 :25 – Omar Etahiri: Habitats de ponte de la sardine “sardina pilchardus” au niveau des côtes atlantiques sud marocaines

Aim : variability in spawning grounds.

Three stocks (northern, central and southern) relative to Cape Bojador. Here: southern stock

Results:

- permanent upwelling in the S (maximum in summer), summer upwelling north of Cape Bojador
- High variability of optimal values (both for larvae and eggs) for SST in winter and summer : generally more eggs in the north and more larvae in the south (winter and summer), distance between areas of maximum (centers of gravity) related to wind speed (increase by a factor of two from winter to summer)
- abrupt decrease in adult sardine biomass after 1996, but slow recovery after 1997 (reaching in 2002 values similar to those beforen 1996).

Conclusions

- Main spawning in winter (but continuous all year round)
- North hatching, south nursery
- Possible retention areas
- Thermal preference 15.5-17.5ºC

Discussion :

- After 1996 Sardinella migrates from the south and occupies Sardina areas: driving factor temperature (also reported from 1970s).
- Spawning area (from modelling) decreased in 1996.

Closing at 17:50 h

Wednesday 14 February(Sala Castanha IPIMAR)

9:00 – A. Bode: Updated version of the data on climate and oceanographic indices, sardine, anchovy and plankton biomass on the Bay of Biscay and NW Iberian shelf

10:00 M.L. Fernandez de Puelles. The zooplankton variability in relation to hydrography during the last decade in waters of the Balearic Sea, Western Mediterranean.

Aim: zooplankton seasonal and interannual variability 1993-2003, Balearic Sea.

Results:

- seasonal physical variability winter: influence from cold, salty northern waters; summer: influence of southern, Atlantic-modified waters. Fronts separating norther waters near the sampling station.
- interannual changes: high salinity 1996 and near 2000: input of nutrients (causing larger blooms) from northern waters. Increasing trend in maximum temperature values but mean annual values showed warming up to 1998 and cooling thereafter
- zooplankton: copepod peaks in 1996 and 2000 (related to norther waters and phytoplankton blooms). No clear trends in total zooplankton using seasonal values. Mean annual biomass decreased, peaks in mean annual abundance (copepods) in 1996 and 2000.

- Relationships with oceanography: abundance decreased with temperature and increased with salinity (mostly copepods) but other groups (gelatinous and ostracoda) negatively correlated with salinity

- Relationships with NAO: negative correlations with abundance

- Warming period: (after 1996) salinity, nutrients and zooplankton decreased. Changes in some species: Centropages typicus expanded presence (more months with high values) during cool periods, Acartia clausi increased in warm periods

Conclusions:

- high variability in oceanography (related to input of northern waters) and plankton composition and biomass.

- rapid response of zooplankton to changes in northern water input

- links to NAO (local related to large scales changes)

10:42: Yorgos Stratoudakis: Changes in the distribution of sardine eggs and larvae off Portugal.

Aim: Variability in spawing in the last 20 y: identification of spawning habitats, trends and spatial changes (summary Bernal *et al*., GLOBEC-IBERIA issue Prog. Oceanogr.)

Method: collect and paste fragmented time series in different areas (1988-2005)

Data: Box from Biscay to all NW Iberia.

Results:

- 12-13ºC: preference range, preferently near the coast, in all the regions except near Vigo (no spawning in all years: but perhaps inside rias), also innner Biscay and near Cap St. Vincent (sometimes).

- Major spawning in the French shelf and Portugal, also in the Cantabrian, related to stock biomass (but not directly, depends on distribution of SSB)

Conclusion:

- continuous spawning over the shelf (minor discontinuities)

- major intreannual changes: minimum occupation of shelf areas after first 10 y (1997) year of minimum spawning area) but recovery with SSB

Theoretical spawning seasons: (summary Coombs *et al*. ... for SARDYN)

- north: spring and autumn (narrow seasons)

- south: longer seasons to near continuous spawning

- agreement with field data

Other considerations:

- low magnitude of population size and relative change of populations in NW Iberia to detect large shifts? (difference with Pacific)

- large differences between local areas difficult interpretation of dynamics in the whole region

11:45 – coffee break

12:00: Synthesis of the state of the art based on the presentations of the previous day: questions to address.

Objective: as stated in ICES mandate, major changes in decadal regimes:

ToR: focus on decadal scales, teleconnections

Formulation: “Show multidecadal changes and teleconnections in Iberia and surrondings”

- whole area
- regional areas (case studies)

Data: compile data, PCA, add new data (climate, oceanography, plankton, small pelagic fish)

Analysis: address objectives, statistics (ACF –Manuel Vargas)

Report: Index and responsabilities

o Introduction: J. Alheit

o Data series: A. Bode (A. Uriarte)

o Methods:

o ACF (autocorrelation): H. Mendes + M. Vargas

o PCA: A. Lavin + A. Bode + O. Etahiri

12:20 Hugo Mendes. Presentation on Time-Series Analysis of climate and sardine in Portugal (by ICES areas)

Data: early 1900 to 2002, N wind (39.5ºN, 9.5ºW), upwelling, NAO, sardine catches (4 ICES areas of Portugal)

- similarities between areas: S and SW, N and NW Portugal
- autocorrelation (sardine catches) up to 7 y lag in N, up to 10 y in SW (random in S). Autocorrelation should be removed before crosscorrelations.
- similarity between series using sample autocorrelation coefficients (20 y periods): (SW more similar to NW)
- Frequency (spectrum) analysis:

o after autoregression models for the series (peaks more defined)

o periods (NW 20-29 y, 10-9 y, 7-6 y, 5 y, 3 y; SW: 10-9, 4, 3; W: 20-29, 10-9 y)

o significance: comparison with white-noise (NW and SW significant periods at decadal scales, not at lower time scales)

- Same analysis for climatic, SST, N wind
- linear association: NAO positively correlated with wind and SST

- Associations:

o NAO (and N wind) vs. NW catches = inverse relationships of maximum and minium periods: crosscorrelation NAO-N wind lag up to 1 y, NAO-NW catches lag up to 3 y, wind-NW catches lag up to 1 y

o Phase analysis: in process

o cross-spectrum analysis: next stept

11:00: Material: Data availability by region: Upwelling waters of Spain and Portugal, Bay of Biscay, Western Mediterranean, Upwelling water of NW Africa.

11:15 – 12:15: Statistical methodology: Time Series analysis, Auto-Correlations, Cross-Correlation, Uncertainty measures and other statistical measures

12:15 – Lunch

Annex 4: Extended abstracts of the meeting presentations

Synchrony in decadal-scale dynamics of small pelagic fish in Humboldt and Kuroshio Currents

Jürgen Alheit

The long-term dynamics of the Humboldt Current ecosystem are characterized by alternating sardine and anchovy regimes and an associated restructuring of the entire ecosystem from phytoplankton to the top predators (Alheit and Niquen 2004). These regime shifts seem to be linked to lasting periods of warm or cold water anomalies related to the approach or retreat of warm subtropical oceanic waters to the coast of Peru and Chile. Phases with mainly negative temperature anomalies parallel anchovy regimes (1950s- about 1970; 1985-up to now) and the rather warm period from about 1970-1985 was characterised by sardine dominance. The transition periods (turning points) from one regime to the other were 1969-1971 and 1985-1988. The KCE is similarly characterized by alternating periods of sardines and anchovies. Anchovies and sardines in the waters around Japan have been alternating over the last 100 years on a decadal-scale pattern. The most recent transition periods between the two Kuroshio species were strikingly synchronous to those of their Humboldt cogeners (Fig. 1,2). In contrast to the Humboldt populations, Japanese sardines thrived during cold and anchovies during warm periods. The mechanisms causing these abundance alternations are largely unknown, however, the timing of the changes (turning points) from sardine to anchovy periods and back to sardines can be determined now rather exactly. At the time of these ecosystem shifts substantial changes in physical and biological variables in the waters off the east coast of Japan and in the Humboldt Current ecosystem have been observed. The striking synchronies between the two systems extend to the timing of (i) changes between temperature regimes, (ii) sub-surface processes (thermocline depth, MLD), (iii) anchovy and sardine periods, (iv) zooplankton and (v) other nektonic populations. The question remains: how were the changes in temperature regimes and sub-surface processes in both ecosystems synchronized. Evidence is emerging that these ecosystem shifts are associated with large-scale changes in subsurface processes and basin-scale circulation (Alheit and Bakun 2007).

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Alheit and Bakun. 2007. Population synchronies within and between ocean basins: apparent teleconnections and implications as to physical-biological linkage mechanisms. Subm. to J. mar. Syst.

Alheit, J. and M. Niquen. 2004. Regime shifts in the Humboldt Current ecosystem. Progr. Oceanogr. 60: 201-222.

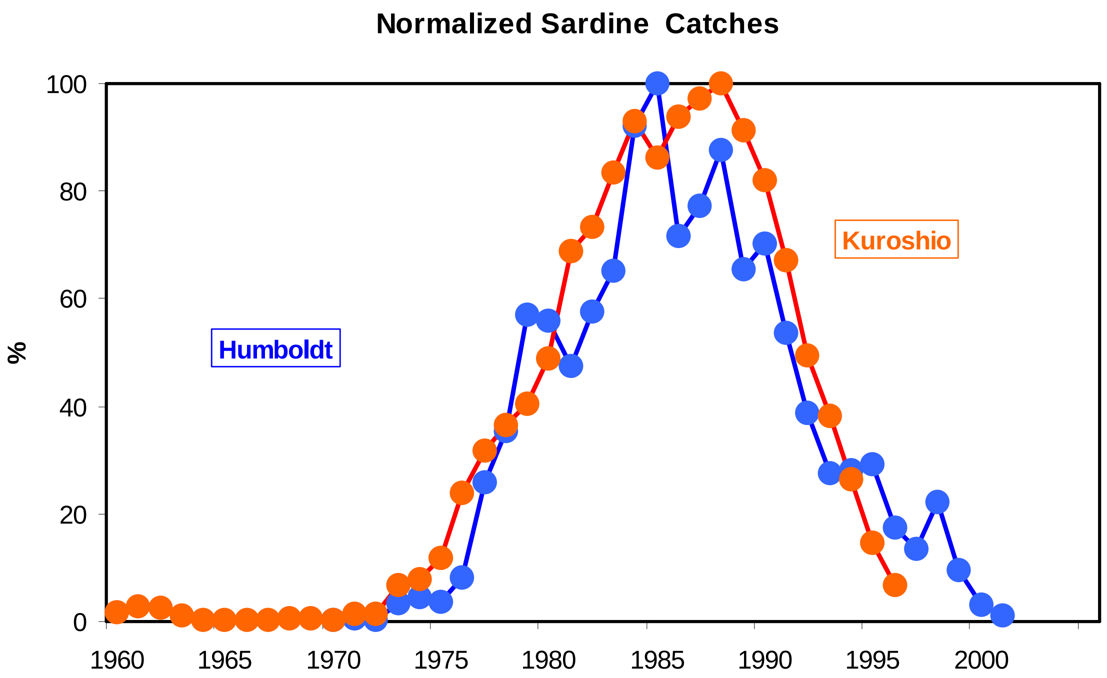

Fig. 1: Normalized sardine catches in Humboldt and Kuroshio Currents

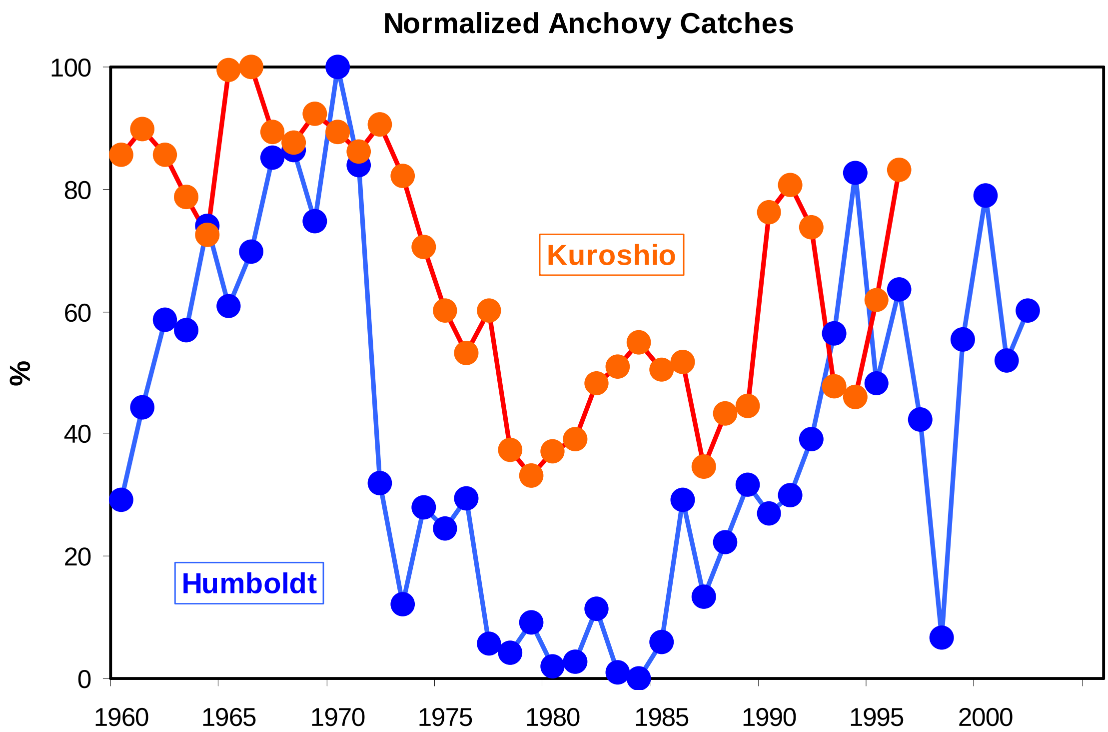

Fig. 2: Normalized anchovy catches of Humboldt and Kuroshio Currents.

Bay of Biscay anchovy: recent changes in environmental and recruitment patterns

By A. Borja, A. Fontán, A. Uriarte, & V.Valencia

AZTI-Tecnalia, Marine Research Division

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The fishery on the Bay of Biscay anchovy, shared by Spain and France, rose up during the 30's and 40's of the past century (Uriarte *et al*., 1996). Catches peaked in the 60's and subsequently dropped down until mid 80's; this led to a strong reduction of the Spanish purse seine fishery which accounted for about 90% of the international catches. Subsequently, in the late 80's and 90's there was a recovery of the catches and the French fishery also increased through the incorporation of the pelagic trawlers. In this century repeated failures of recruitment since 2001 led to the collapse of the fishery and population in 2005 (ICES, 2006) (Figure 1). Junquera (1984) showed that the drop of catches in the 60's and 70's was parallel to a shrinkage in the fishing grounds along the North of Spain (Cantabrian sea). In the Galice Atlantic waters anchovy catches first disappeared about 1960, and later on (in 1968) the same happened in the Western and central part of the Cantabrian sea (Division VIIIc), what was followed by the drop of catches until 1986.

The anchovy spawning population heavily depends upon the strength of the recruitment. This means that the dynamics of the population directly follow those of the recruitment with a very small buffer. A key factor to understand the dynamics of the population is therefore to study the factors that control the recruitment: There have been several studies on the influence of climate forcing and oceanic environment on the recruitment of anchovy. Two environmental indices have been studied and suggested during the last 10 years (Borja *et al*. (1996; 1998) and Allain *et al*. 2001) and a review of the role of these environmental indices in setting the anchovy recruitment in the Bay of Biscay was made by Uriarte *et al*. (2002). Borja's *et al* (1996) upwelling index showed the positive influence of the northern and eastern winds of medium and low intensity blowing in spring and early summer in the Bay of Biscay by favouring the onset of good levels of recruitment from the spawning taking place that year. This index, which explained about 55% of the inter-annual variability of the anchovy recruitment (assessed by ICES) up to 1998, failed to predict the good recruitments occurring in 1999 and 2000. However, the persistence of low upwelling indices up to 2005 has been accompanied by the subsequent failures of recruitment in recent years. Allain''s *et al* (2001) recruitment index is based on a two-covariate model. One covariate, an upwelling index (UPW), is positively related to recruitment and the other covariate, a water column stratification breakdown index (SDB), is negatively related to recruitment. The two covariates are estimated from outputs of a 3D hydrodynamic model forced by wind, tide and river discharges. The model explained 69% of the interannual variability up to 2001, but failed to predict the failures of recruitment occurring since then. ICES considers that both indices are by the time being too imprecise for any forecast purposes.

In this work we re-examine the role of the environment on determining the recruitment of anchovy after the experience of the recent succession of low recruitments resulting in the collapse of the stock in 2005. Several possible oceano-meteorological factors are examined and the likelihood of future scenarios is considered, taking into account global environmental changes. The results obtained show that still nowadays (Figure 2), in a long term perspective, 55% of the recruitment variability of this particular population is driven by upwelling over the spawning area, together with turbulence in a secondary role. In addition we find that catches are statistically related to river discharge outflow, temperature and daily sun hours.

Since 1998 Borja's upwelling index is low, and at the same time winds are inducing a relatively high turbulence (Figure 3). Despite the good recruitments occurring in 1999 and 2000, overall it seems that this change has led to an increase in the probability of poor anchovy recruitments in the region, culminating in a collapse of the stock after successive failures of recruitment since 2001. The conceptual understanding system proposed for the Bay of Biscay anchovy suggests that negative NAO periods could lead to north-easterly wind circulation, producing upwelling over the continental shelf and general stability over the area, together with enrichment and adequate food availability. This water circulation pattern produces transport to the south-western part of the Bay, resulting in a success in the recruitment, either through access to food or transport to areas of low predation. The opposite pattern produces downwelling over the continental shelf, food dispersion, and a transport of larvae to the bottom waters (this limiting food availability), or convective retention over the shelf (this increasing predation mortality), both resulting in increased mortality rates. Future climate change could lead to predominantly positive values of the NAO index (Cook *et al.* 2005); it is proposed that lower than average anchovy recruitment levels are expected in the Bay of Biscay anchovy if that tendency persists.

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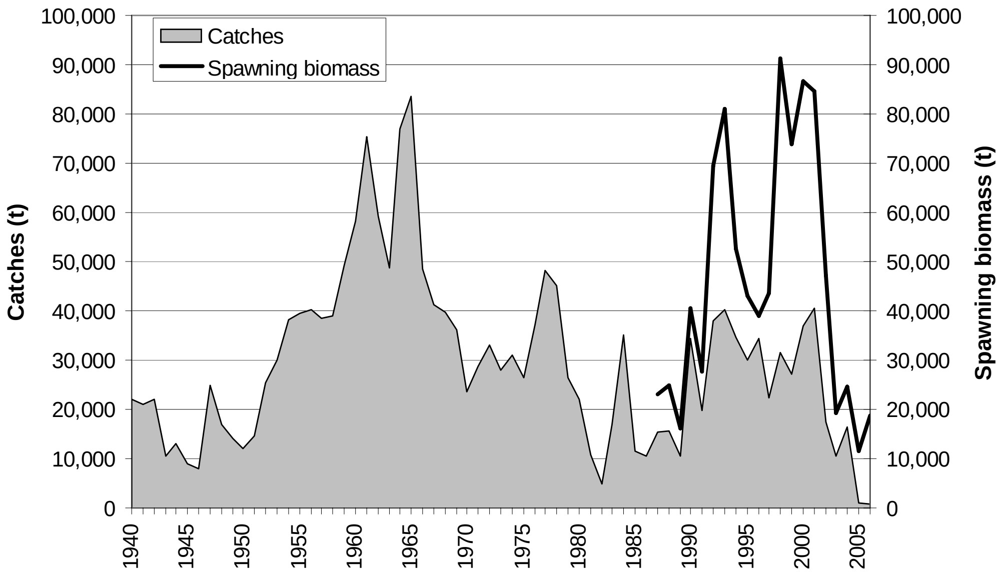

Figure 1: Historical Catches and recently assessed spawning Biomass of the Anchovy in the Bay of Biscay, till recent collapse of the fishery in 2005.

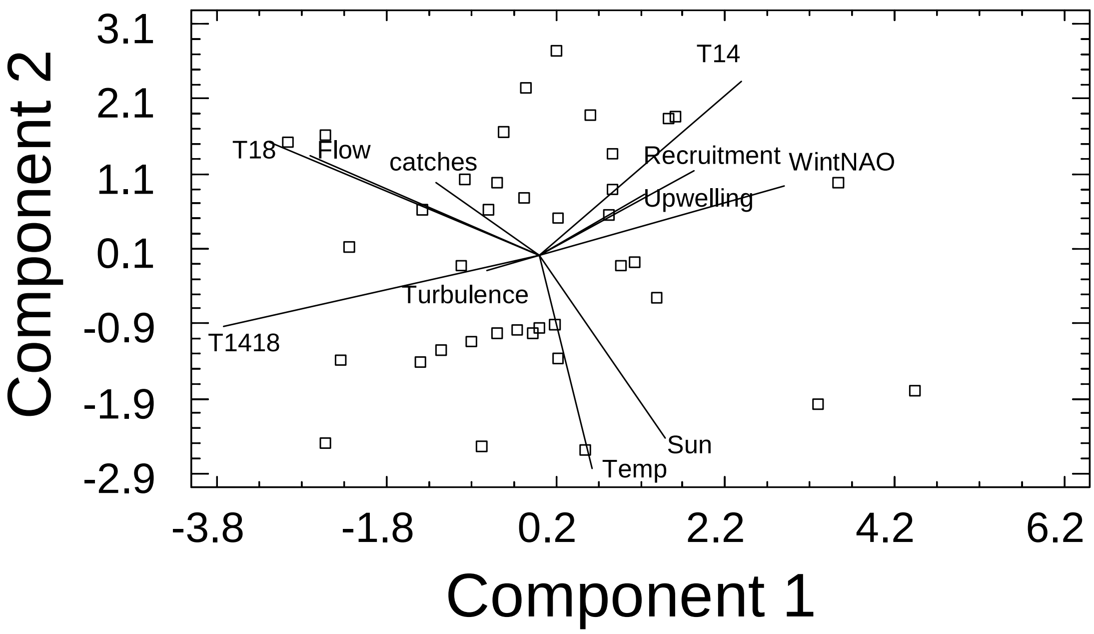

Figure 2: Principal Component Analysis, including different environmental variables, together with anchovy recruitment and catches. Key: Upwelling: upwelling in the Basque Country and Landes for the period March-July; Temp: annual sea surface temperature; T14: first Julian day in which 14ºC is reached; T18: first Julian day in which 18ºC is reached; T1418: days between T14 and T18; Sun: total annual sun hours; WintNAO: winter NAO; Flow: annual flow of Adour and Gironde rivers together.

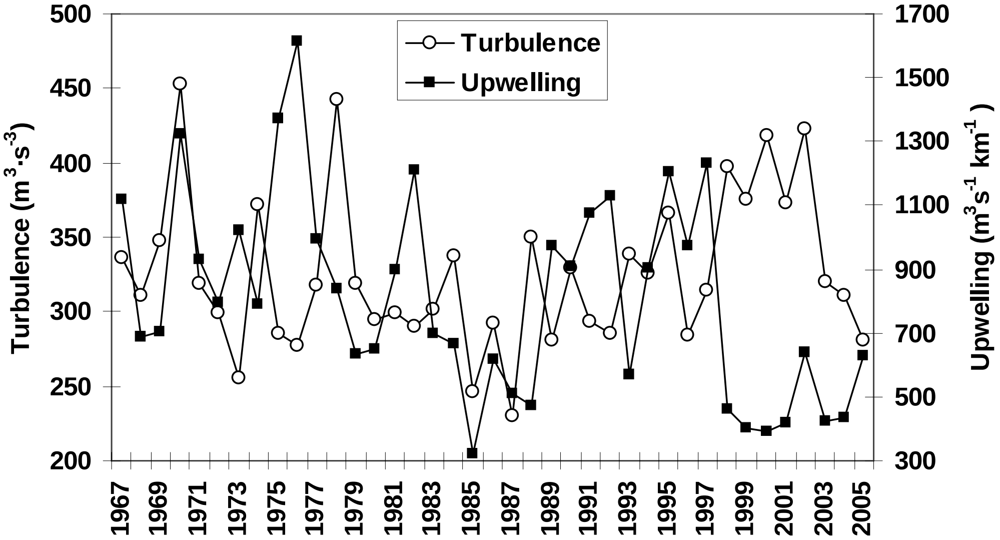

Figure 3: Series of upwelling index (for the Basque Country and the Landes area, for the March-July period, together with turbulence, between 1967 and 2005.

HYDROGRAPHY OF THE SE CORNER OF BAY OF BISCAY (WITH SPECIAL REFERENCE TO THE FRESHWATER INPUTS)

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In spite of the local character of the meteorological and oceanographic data collected along the Basque Coast, they are representative of mesoscale features in the Bay of Biscay and also indicate teleconnections with global scale factors such as the NAO. In fact, the climatic and oceanographic features of the inner Bay of Biscay follow the main trends and anomaly patterns described for the intergyre region of the north eastern Atlantic Ocean. The last years (2001-2005) frequent seasonal anomalies are evident and, in general, it means that winter-summer duality prevails against the establishment (in terms of values and mean duration) of spring and autumn as typical transitional seasons at mid-latitudes and the intergyre region of the north eastern Atlantic Ocean. Multidecadal time series show very significant coupling between meteorological and oceanographic data in the southeastern Bay of Biscay. This will be studied from several points of view: i) relationships between atmospheric temperature, SST and heat content; ii) salinity in relation to the precipitation-evaporation balance and river flow; and, iii) comparisons with other marine systems. In addition, trends and anomaly patterns of some periods will be examined and a comparative assessment (in terms of slope, absolute or accumulated anomalies) will be made concerning the reference period as well as the start and end points of the period of observation itself. Finally, practical reference periods are proposed for some oceano-meteorological variables in the southeastern Bay of Biscay.

Several reference periods have been defined in order to compare different climate indices obtained from different parts of the world. The 'World Meteorological Organization' (WMO) defines "normal" reference periods as "period averages computed from uniform and relatively long period comprising at least three consecutive 10-year periods" (WMO, 1984). Hence, the latest standard reference period is 1971-2000. Depending upon the adopted reference period, century-long data or sub-periods, there will be differences between climatological averages. Moreover, different 30-year periods have been shown to exhibit differences in regional annual mean baseline temperature and precipitation of up to ±0.5ºC and ±15%, respectively (Houghton *et al*., 2001).

For this work we used the accumulated anomalies for the monthly averages respect the monthly average of the whole period. That is, we used the whole period (1961-2000) as internal reference period for each time series.

The study area is located in the innermost part of the Bay of Biscay (Basque coast) between the west-east oriented coast of Spain and the north-south oriented coast of France (Figure 1).

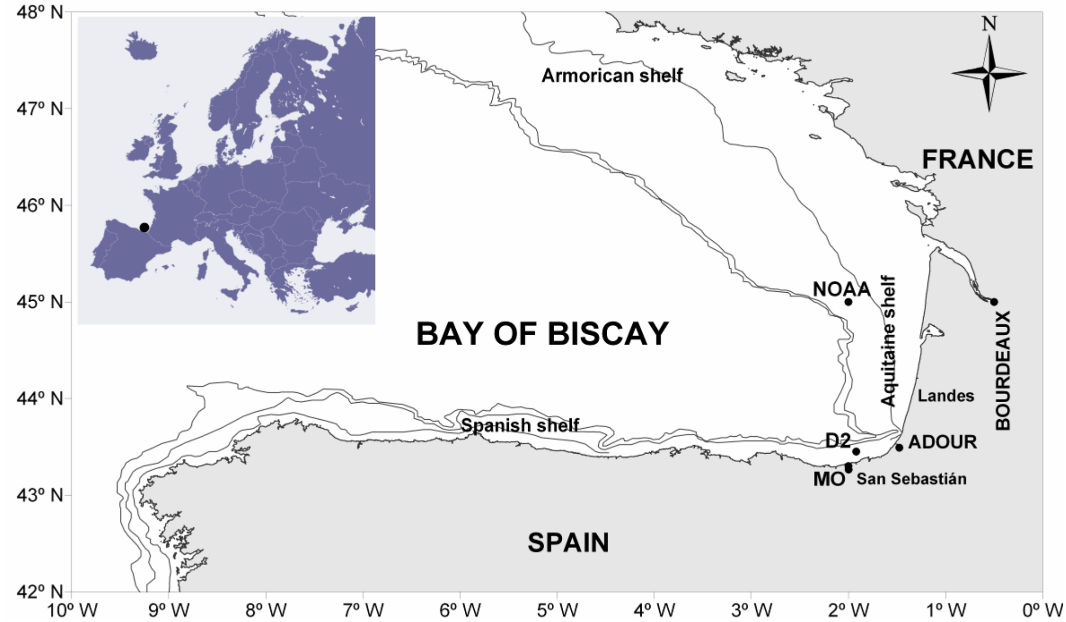

Figure 1. Location of the study area, showing the position of data series. Contour lines indicate 100 m, 200 m and 500 m isobaths. MO: Meteorological Observatory of San Sebastián; D2: AZTI's hydrographical station; NOAA: PFEL-NOAA; BORDEAUX: Bordeaux Port Authority; ADOUR: Adour River.

A brief description of available data set including its source, record length and sampling rate is listed in Table 1.

Table 1. Description of presented dataset including its source, record length and sampling rate.

DATA	LOCATION	SOURCE	RECORD LENTGH	SAMPLING RATE
SST	San Sebastián	Oceanographic Society of Gipuzkoa	1961-2000	daily
Meteorological	San Sebastián	Meteorological Observatory	1961-2000	daily/monthly
River flow	Gironde	Bordeaux Port Authority	1961-2000	daily
Hydrographical data	Basque shelf 43° 27'N, 1° 55'W	AZTI Foundation	1986-2000	monthly

The oceanographic data collected in this study show a coupling with the meteorological conditions observed over the southeastern Bay of Biscay. As an example, figure 2 shows the covariance, in terms of accumulated anomalies, between the atmospheric temperature and the sea surface temperature in San Sebastián. In the same way, figure 3 shows the covariance, in terms of accumulated anomalies, between the precipitation in San Sebastián and the Gironde (Garonne+Dordogne) river flow as two representative variables of freshwater inputs into the SE Bay of Biscay. Moreover, both anomalies show significant correlation with the anomalies of the average salinity of the shelf waters in the area as well as with the Adour river flow.

Finally, concerning the comparisons with other areas and the aim of identify possible links to climate variability, figure 4 shows the accumulated anomalies of the precipitation in San Sebastián and in Tromso (Norway). Appearance of some periods in phase, against other period of opposite phase, will be related with variations of the pattern of transport of humidity driven by the NAO anomaly.

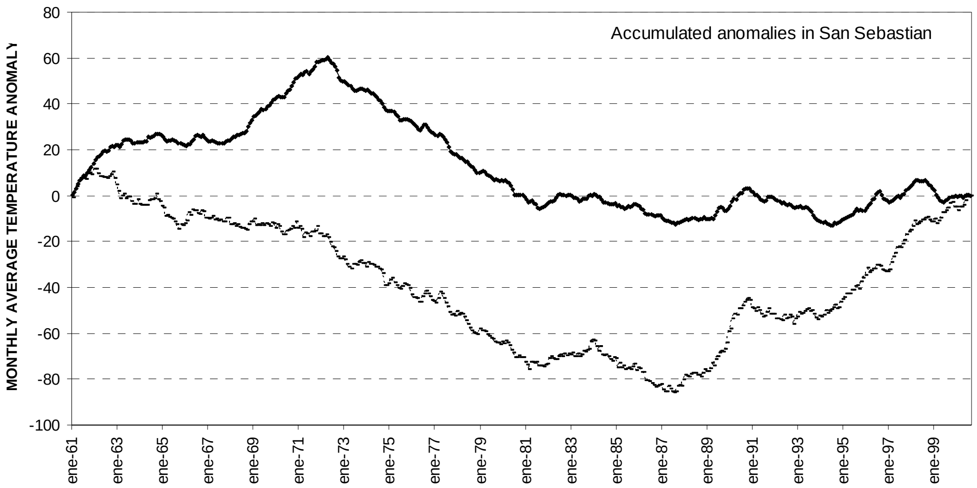

Figure 2. Accumulated anomalies for the monthly mean air temperature (dots) and sea surface temperature (solid line) in °C in San Sebastián, for the period 1961-2000, in comparison with the mean ± standard deviation, for the period 1986-2005. Data courtesy of the Meteorological Observatory of San Sebastián and the Oceanographic Society of Gipuzkoa.

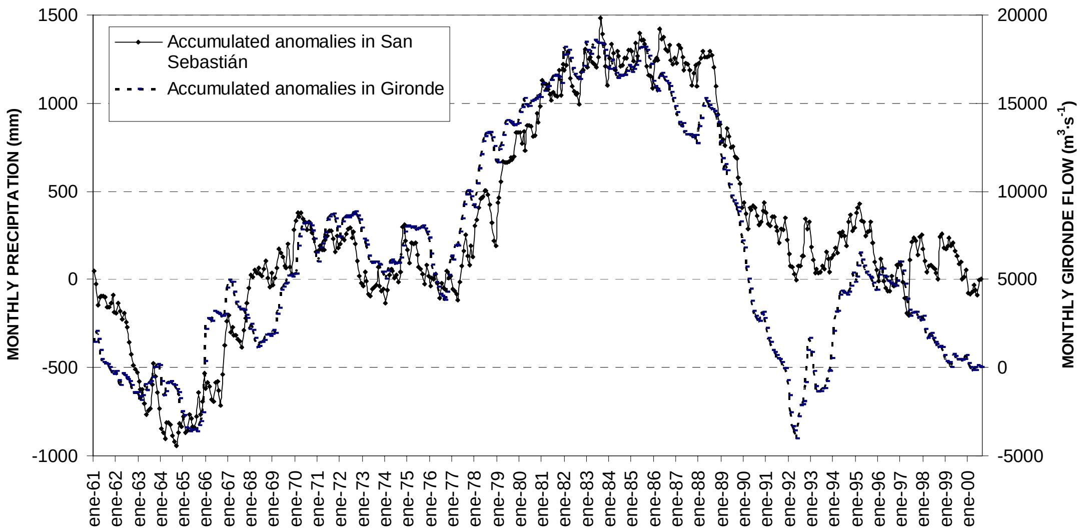

Figure 3. Accumulated anomalies for monthly average precipitation (mm) in San Sebastián (solid line) and the monthly average Gironde River flow (m3•s-1) (dots) in the period 1961-2000 Data Courtesy of the Meteorological Observatory of San Sebastián and the Bordeaux Port Authority, respectively.

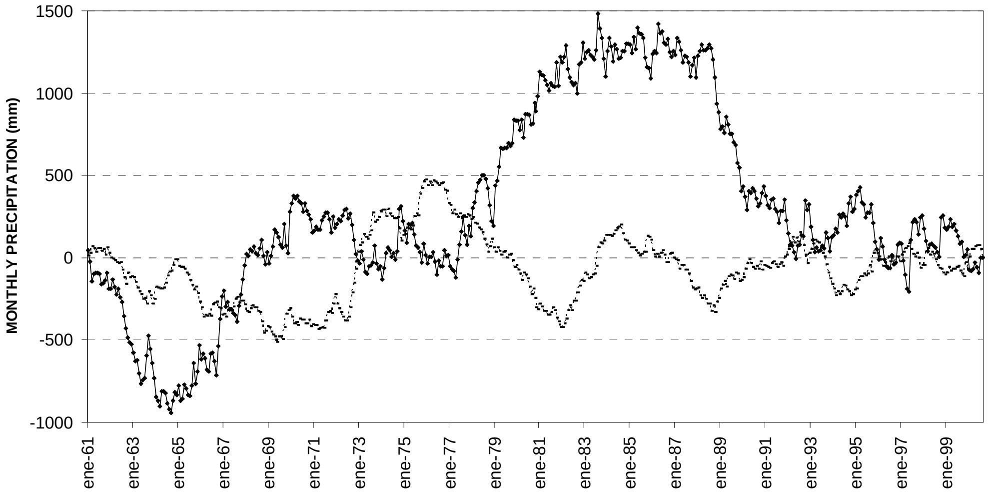

Figure 4. Accumulated anomalies for monthly average precipitation (mm) in San Sebastián (solid line) and in Tromso (North Norway) (dots) in the period 1961-2000.

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Environmental variability in the North Atlantic and Iberian waters, and its influence on horse mackerel (*Trachurus trachurus*)

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We explore the potential impact of climatic and oceanic variables on the dynamics of horse mackerel *Trachurus trachurus* (coastal distribution). Principal Components Analysis of a set of environmental parameters for the years 1966–2000 allowed us to characterize the system by three components. The first consisted mainly of sea surface temperature (SST; 18.5% of variability), the second was determined by the oceanic transport indices, Potential Energy Anomaly (PEA) and the Gulf Stream Index (15.6%), and the third by the meridional wind component and Ekman transport (11.5%). Horse mackerel recruitment was negatively correlated mainly with the first thermal component. Cross-validation analysis showed that environmental conditions did not consistently explain horse mackerel recruitment, probably because of the short time-series available (15 years) (Lavín *et al*., 2007).

Introduction

Meteorological and oceanic parameters display variability over a range of scales, and this variability potentially influences the living marine resources at different trophic levels and in different ecosystems, particularly pelagic ecosystems, where the atmosphere/ocean interrelationship is close (Pitcher, 1995).). In addition to large-scale forcing, there may be local or regional events, such as coastal upwelling or low-range thermohaline-forced currents, which can contribute extensively to recruitment variability.

The North Atlantic Oscillation (NAO) index accounts for much of the atmospheric variability in the North Atlantic (Rogers, 1984; Hurrell, 1995), and is therefore a dominant exogenous driving factor for biological systems. An oceanic index, estimated similarly to the atmospheric NAO index, was presented by Curry and McCartney (2001) as a two-point baroclinic pressure difference between the subtropical and subpolar gyre centres. The Potential Energy Anomaly (PEA). A second index of oceanic circulation is the position of the northern wall of the Gulf Stream (Taylor, 1996).

The region of interest (Figure 1) is the northern part of the Subtropical Gyre and the Atlantic temperate area around the Iberian Peninsula. Table 1 lists the data sets, sources, and acronyms used in our analysis.

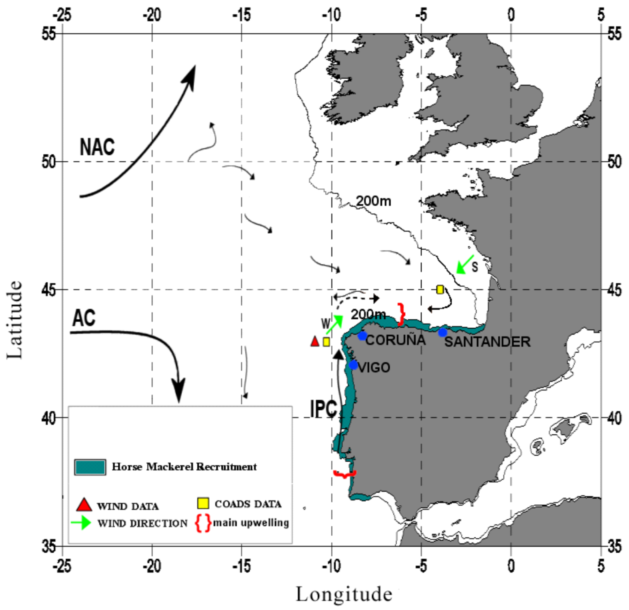


Figure 1. Study area showing the location of environmental measurements (wind data and COADS data), main currents (North Atlantic Current, NAC, Azores Current, AC, and Iberian Poleward Current IPC) and wind regimes, main upwelling and horse mackerel recruitment area.

To take into account the spatial conditions, we selected two areas 43ºN 11ºW; 45ºN 3ºW. There are two main seasons: spring/summer, characterized by near-surface stratified waters; and autumn/winter, with mixed waters.

Estimates of horse mackerel recruitment for the period 1985–1999 were taken from the ICES working group assessments (ICES, 2001) applying XSA (eXtended Survivors Analysis; Shepherd, 1999)

Principal Components Analysis

Principal Components Analysis (PCA) is used to reduce the dimensionality of the set of environmental variables, and to characterize variability in the data.

Multiple linear regression analysis

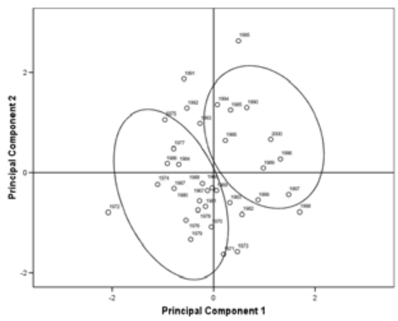
The set of environmental variables for this analysis was the same as for the PCA (Table 1). The number of cases was smaller than the number of independent variables, so the number of variables was reduced. To do so, pairwise correlations between independent variables were calculated. When the simple correlation (r) was >0.6, the variable with the higher correlation with horse mackerel recruitment was selected, reducing the number of variables from 23 to 18

To assess the performance of the horse mackerel recruitment prediction model, we applied cross-validation. The predictor variables used in the cross-validation (18 variables) were those selected in the pre-screening procedure using correlation analysis (see above). For cross-validation we followed the method of Francis (2006), applying a repeated leave-one-out procedure in which we: (i) dropped all data for year i from the predictors and recruitment; (ii) applied a stepwise regression to select the best predictors; (iii) calculated a regression equation using these best predictors; and (iv) used this equation to predict the recruitment in year i. In the stepwise regression, the maximum p-value considered to add the variables to the model was 0.05, and the minimum p-value to remove a variable was 0.10. The percent variance explained statistic (PVE; Francis 2006) was calculated to measure how much better a regression-based estimator of recruitment was than the default (arithmetic mean) estimator

ACRONYM	VARIABLE	SOURCE
SST4311 s / a	Sea surface temperature at 43ºN 11ºW	COADS
U4311 s / a	East-west component of the wind (U) at 43ºN 11ºW	COADS
V4311 s / a	North-south component of the wind (V) at 43º N 11ºW	COADS
W4311 s / a	Turbulence of the wind (W) at 43ºN 11ºW	COADS
SST4503 s / a	Sea surface temperature at 45ºN 3ºW	COADS
U4503 s / a	East-west wind component (U) at 45ºN 3ºW	COADS
V4503 s / a	North-south wind component (V) at 45ºN 3ºW.	COADS
W4503 s / a	Turbulence of the wind (W) at 45ºN 3ºW	COADS
GSI s / a / w	Position of the Gulf Stream Index (GSI)	Taylor (1996)
PEA	Transport Index derived from the difference of the Potential Energy Anomaly at Labrador and Bermuda.	R. G. Curry (Woods Hole Oceanographic Institution)
NAO DJFM	North Atlantic Oscillation index	Rogers (1990)
Qx4311 s / a	Ekman transport at 43ºN 11ºW = –Upwelling Index	Lavín *et al.* (1991)
HMR	Horse mackerel recruitment	ICES (2001)
Alb CAA2	Total catches of northern stock of albacore aged 2	Anon. (2001)
Alb CAA3	Total catches of northern stock of albacore aged 3	Anon. (2001)

Principal Components Analysis

Environmental factors



The first component explained 18.5% of the total variability and was positively related to SST off the western Iberian Peninsula (43ºN 11ºW) and in the Cantabrian Sea (45ºN 3ºW) for the annual period and the summer season. The second component was related to the oceanic transport indices, i.e. PEA and annual, summer and winter GSI, and explained 15.6% of the system variance.

The first PC or thermal axis represents the local pattern in the Bay of Biscay. The second PC represents oceanic transport variability.

Environmental factors and horse mackerel recruitment

The analysis of horse mackerel recruitment vs. the first principal component, the thermal one, revealed a significant negative correlation (r = –0.74; p = 0.002).

Multiple regression analysis for horse mackerel recruitment. Statistics are shown in the table.

	Non-standardized coefficients		**Standardized coefficients**		
Variables	**Beta**	**s.e.**	**Beta**	***t***	***p***
(Constant)	2*E +007	3 298 370		5.718	0.000
SST4311s	–1 051 609	196 887.200	–0.947	–5.341	0.000
V4503s	–214 140	82 601.354	–0.460	–2.592	0.024
Adjusted r^2	0.655				

Variable V at 45ºN 3ºW (spring/summer meridional wind) included in the regression model has a negative correlation, meaning that northerly winds favour horse mackerel recruitment. This is probably because in the Bay of Biscay, northerly winds bring cooler air temperatures, which favour heat transfer from the ocean to the atmosphere, so decreasing SST, itself propitious to horse mackerel recruitment. In the western part of the study area, northerly winds generate upwelling events during spring and summer, but this phenomenon should be more appropriate to the sampling station at 43ºN 11ºW. In addition, throughout the Cantabrian Sea (which longitudinally orientated), northerly wind could cause young stages of fish to be retained over the continental shelf, where the environment may be more favourable for thir survival. It is in spring and summer when most horse mackerel eggs and larvae are present in the Cantabrian Sea (Solá *et al*., 1990).

The finding that the linear regression model explained 65.5% of recruitment variability with three environmental variables could represent a significant step towards resolving one of the central problems in short-term forecasting of catch and biomass: the estimated strength of incoming year classes (Shepherd and Pope, 2002). However, one of the common errors in statistics is to use the same data to select variables for inclusion in a model as to assess their significance (Good and Hardin, 2003). Cross-validation is one of the appropriate approaches to avoid this error. The PVE statistics obtained (–20.71) was negative, so the regression model did not show a superior ability to predict horse mackerel recruitment over the application of a simple arithmetic mean. However, the stepwise screening procedure through the different years almost always selected the same two variables: SST4311s and V4503s with an adjusted r^2 always >0.59. This result is accords with the high negative correlation value obtained between horse mackerel recruitment and the first principal component. These arguments led us to think that one of the main issues in the reliability of the model is the length of the time-series.

In summary, our results have confirmed the advice by Francis (2006) to use a validation technique when developing predictive recruitment models. Moreover, the horse mackerel case showed that extension of the time-series determines the ability of the regression model to detect environment–recruitment relationships.

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Climate Induced Regime shifts in the Upwelling productivity system off Portugal

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Decadal changes have been observed in the annual catch of sardine (*Sardina pilchardus* W). Long-term changes have also been observed in alongshore winds off Portugal in the last decades in winter months. During sardine spawning season (winter), northerly winds that favour upwelling led to unfavourable conditions for egg and larval survival.

By using time series analysis, we investigated the effect of wind conditions and North Atlantic Oscillation (NAO) on the sardine catches, in the period from 1946-1991. We also investigated the time lag between recruitment strength and its turnout in catches. We concluded that recruitment is forced to a lower level when the frequency and intensity of northerly wind exceeds a certain limit in winter. Our time series retrospective analyses led to evidence of climatic driven regime-shifts in West Portugal sardine productivity in late 1960s-early 1970s.

Off Portugal typical seasonal upwelling is characterized during Summer by coastal upwelling with the presence of long filaments which can extend more than 200 km offshore, and during Winter by coastal convergence, low salinity buoyant plumes and a warm surface poleward current. During 1993-1995 Winter upwelling positive anomaly was observed coincidental with extremely low fish recruitment in sardine and horse mackerel

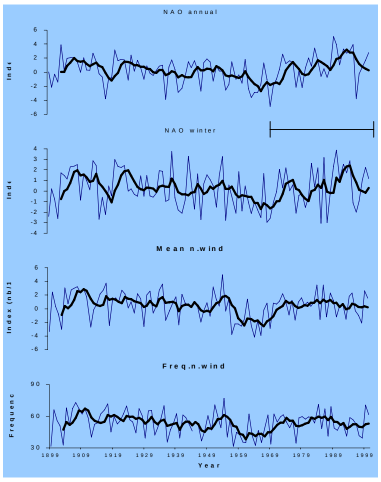
At least two alternate productivity regimes were identified:

1) One coincidental with extreme positive Winter NAO indices; and increase of winter northern winds- detrimental for sardine recruitment

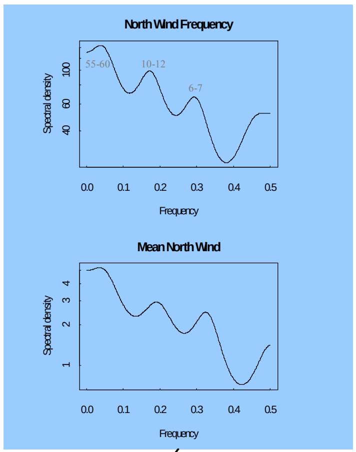
2) Another coincidental with negative Winter NAO indices, minimum winter northern winds- favourable to sardine recruitment.

These results are discussed in terms of their implications in fisheries management recovery plans.

NAO and North wind (1899-2000)

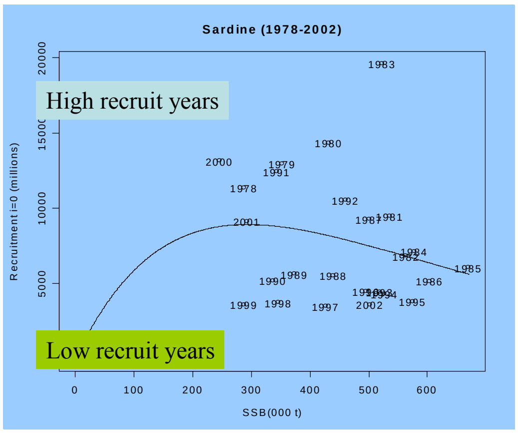


High NAO index since the 70s



- Short term periods of 6-7 years
- Medium term periods of 10-12 years
- Long term periods of 55-60 years

Sardine Ricker stock-recruitment model



$$R_t = \alpha SSB_{t-i} e^{(-\beta SSB_{t-i})}$$

Decadal changes in the Canary upwelling system

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Satellite-derived sea surface temperature (SST) data were used to study the variability of the Canary Upwelling Ecosystem-CUE (12º to 43º N) over the last two decades of the 20th century. We use weekly-mean multi-channel SST (MCSST) at approximately 18-km resolution based on the Advanced Very High Resolution Radiometer (AVHRR) nighttime measurements. The MCSST data for the period 1982-2001 were prepared by the RSMAS of the University of Miami and are available from NASA-JPL-PO.DAAC. Weekly-mean SST was averaged over a month and seasonal SST were calculated for summer (July, August, September) and winter (December, January, February) of each year in the time series. In order to suppress mesoscale features and reveal general patterns of long-term variability in the three main parts of the upwelling system, we averaged SST meridionally along the coastline between 37□-42□N (Iberian coast with seasonal coastal upwelling), 22□-30□N (Northwest African coast with year-round upwelling) and 12□-20□N (southern part of Northwest African coast with seasonal upwelling), beginning from the coast and up to 2000 km offshore (Fig. 1). We then use this meridionally averaged SST, to calculate an integral upwelling index defined as the SST difference between coastal (20 km to 40 km) and oceanic (500 km offshore) locations for each sub-area, an upwelling index anomaly, and the magnitude of the zonal gradient of meridionally averaged SST, as an alternative indicator of upwelling intensity (Santos *et al*., 2005).

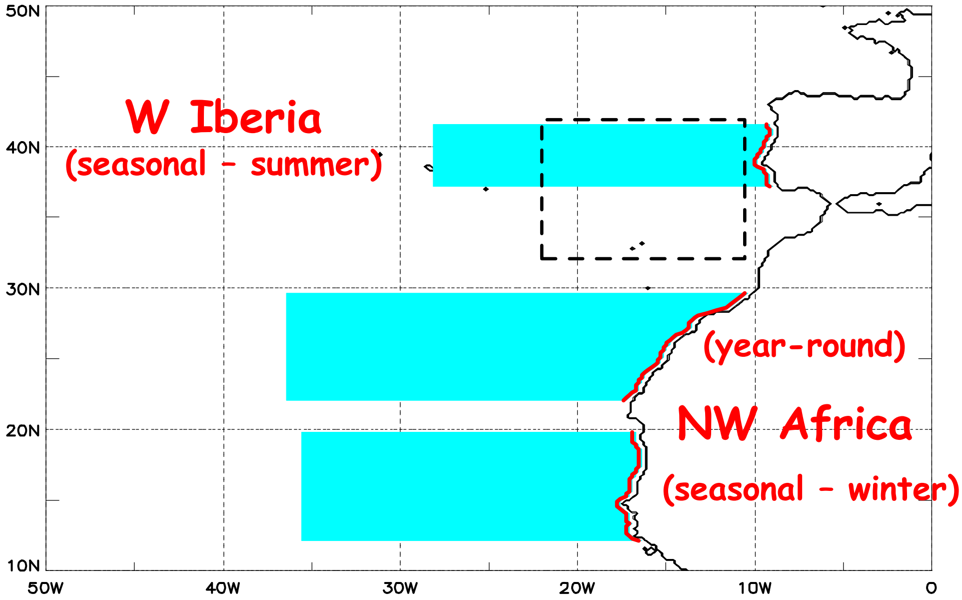

Fig. 1. Study area. Solid bold red lines along the coast and shaded blue areas indicate meridional and zonal extents of the three sub-areas where meridional averaging was applied.

The analysis reveals well known patterns of climatology and seasonal variability in this upwelling system. In contrast to quasi-regular decadal oscillations of SST anomalies observed in the open ocean, the coastal variability during the 1980s– 1990s was better described as a decadal scale shift of the upwelling regime intensity. The analysis of the upwelling index and coastal zonal gradient of SST showed that this shift occurred earlier (~1992) in the northern part of the CUE (off western Iberia) and some years later (~1995) off the northwest African coast. The long-term variability of upwelling favourable wind forcing during the examined period provides reasonable explanations for the observed shift of the upwelling intensity and its timing for the whole CUE. Finally, changes in the productivity of several small pelagic fish species observed for the same period suggest that there was a response of the ecosystem to these changes (Santos *et al*., 2005).

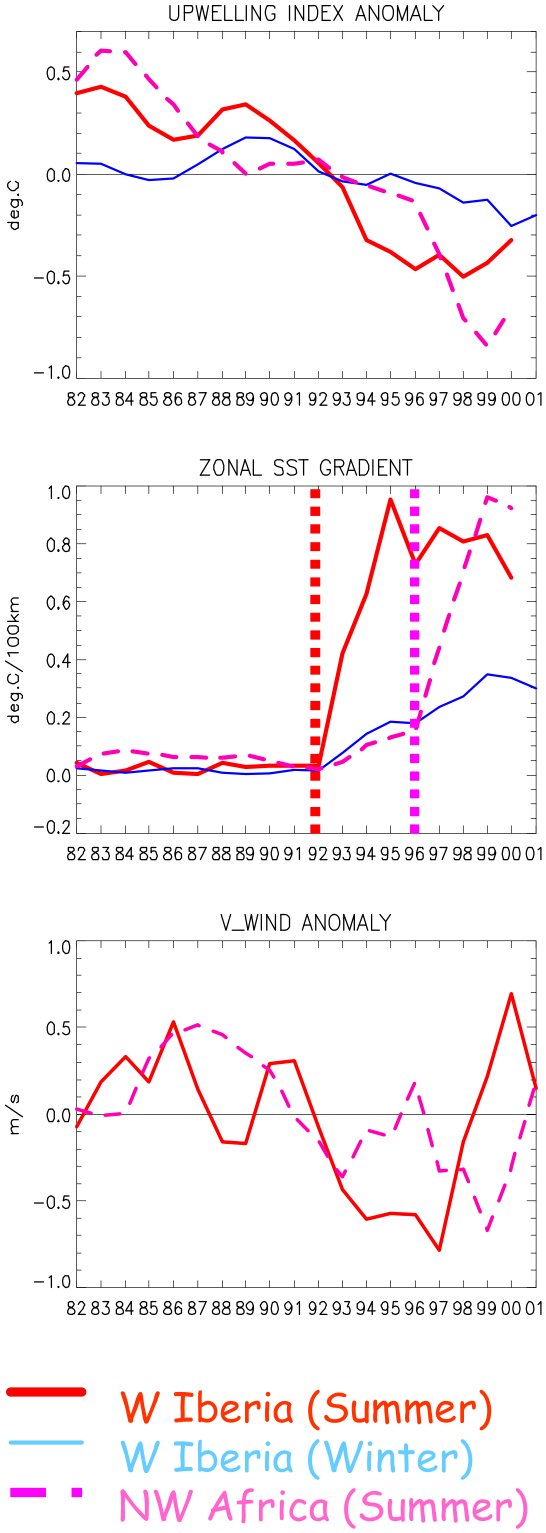

Fig. 2. Meridional averages for the upwelling index anomaly (top panel), the magnitude of the coastal zonal SST gradient (mid panel), and the anomaly of meridional components of the surface wind (bottom panel). The bold solid red lines present the values for the summer season on the Iberian coast (37 N-42 N) and the thin solid blue line the winter season in the same region. The dashed pink lines show the values for the summertime on the NW African coast (22 N-30 N)

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Impact of NAO on European aquatic systems

Jürgen Alheit

The North Atlantic Oscillation (NAO) is the dominant mode of climatic variability in the North Atlantic region. Decadal NAO variability influences, inter alia, regional temperatures, precipitation, wind speed and wind direction over Europe (Hurrell, 1995). A high (low) NAO index is associated with increased (reduced) westerly winds, milder (cooler) temperatures and increased (reduced) precipitation over northern and central Europe, whereas it is linked with reduced (increased) westerlies and reduced (increased) precipitation over the nortwestern Mediterranean. Besides the associated wind forcing, the impact of the NAO on the marine ecosystems is mainly through the heat flux exchange between the atmosphere and the ocean, which controls the temperature of the upper mixed layer.

The NAO seems to synchronize aquatic ecosystems of the marine and the freshwater realm across Europe. The increase of the NAO index in the late 1980s was associated with drastic changes in all trophic levels of the pelagial of the North Sea, the central Baltic (Fig. 1) (Alheit *et al.* 2005) and the NW Mediterranean: phytoplankton, zooplankton and fish (Fig. 2) (Alheit and Bakun 2007). The impact on lake ecosystems was similar, however, so far no data have been given on freshwater fish and fisheries, probably due to a lack of long-term time series. The consequences of the change of the NAO to a lasting positive index were synchronous regime changes in the marine systems leading to different trophodynamic pathways and relationships indicating that the systems are driven by bottom-up processes. Interestingly, the change of the NAO to a positive mode resulted in a switch from diatom dominance to increased dinoflagellate biomass in all marine systems and in some lakes. The mechanisms leading from the climate signal to the decrease of diatom abundance were different in the three marine systems. The effects of these changes in the phytoplankton communities for higher trophic levels are still unknown.

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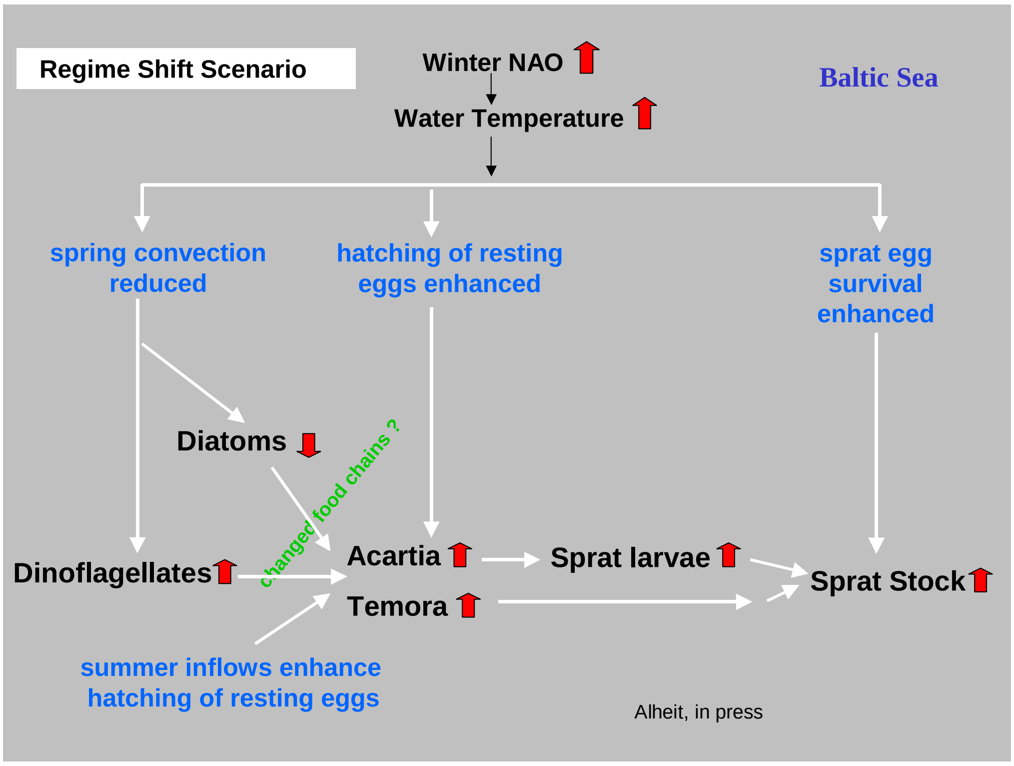

Fig. 1: Regime shift scenario for central Baltic Sea (Alheit and Bakun 2007).

Regime Shift → late 1980s

Changes in marine system function that are relatively abrupt, persistent, occurring at a large spatial scale, observed at different trophic levels and related to climate forcing

Changes in	Baltic	North Sea	NW Mediterranean	Lakes
Physics	yes	yes	yes	yes
Phytoplankton	yes	yes	yes	yes
Zooplankton	yes	yes	yes	yes?
Fish	yes	yes	yes	?
Regime Shift	yes	yes	yes	?

Fig. 2: Physical and biological variables affected in association with increase in NAO index in late 1980s.

CHARACTERISTICS OF SPAWNING HABITAT OF SARDINA PILCHARDUS OFF THE SOUTH MOROCCAN ATLANTIC COAST (21-26°30´N)

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Abstract

The sardine is a commercially important fish in Morocco that occurs in high abundance along the margin of the Moroccan Atlantic coast. Its distribution area extends from Cape Blanc (21°N) to Cape Spartel; (35°45'N). This work concerns investigations of the spawning grounds and nursery areas of sardine in the southern stock between 21° and 26°N.

Sampling for sardine eggs and larvaes was carried out along the Moroccan Atlantic coast using the R/V Russian AtlantNIRO ship. The sampling grid was composed of transects 30 nautical miles spaced and each comprises 3 to 5 stations. The temporal distribution of sardine eggs and larvaes was studied over 1994 and 1999 period, during winter (January-February) in 1994 -1997, in Spring in 1998-1999 and in summer (July-August) in 1994-1999.

The area of maximum egg abundance was located north of Dakhla (24°N). Maximum densities of larvae were localized between Dakhla and Cap Barbas.

The quotient analysis shows that the maximal densities show only one major peak per season (15.5°C in spring, 17°C in winter, and 22°C in summer).

The distribution of eggs and larvaes of pelagic fish is generally under the influence of oceanographic conditions (temperature, current, wind, availability of food etc.) that affect the geographical distribution of adults at the time of reproduction.

The distribution of sardine eggs and larvaes densities reveals that winter is the main spawning season; with maximum egg abundance located North of Dakhla. Sardine larvae occur along the coast from Cape Blanc to Cape Boujdor with maximum densities between 23° and 25°N (Ettahiri *et al*. 2003).

Blaxter and Hunter (1982) suggest that pelagic fish spawns in areas of substantial biological production to ensure adequate juvenile feeding. An area with such characteristics that acts as the spawning ground and nursery at the same time, and provides retention and concentration, fulfills Bakun's (1996) three conditions for the success of larval development: namely enrichment, concentration, and retention of the larvae in a favourable habitat (South of Dakhla).

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THE ZOOPLANKTON VARIABILITY THROUGHOUT THE TIME-SERIES DURING THE LAST DECADE IN THE BALEARIC SEA: 1994-2003

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In order to know the temporal variability of the zooplankton community and the main factors driving their changes in the surface waters of the Balearic Sea several time-series were carried out attempting to discern recurrences and trends and their relation to global climatic change. The zooplankton data generated during the last decade were collected mainly in the Mallorca channel although some large surveys gave spatial information of the Balearic sea. Accordingly, monthly samples were collected from three stations along a cross shelf transect in the SW of the Mallorca island from 1994 to year 2000 and onward seasonally samples. However, to understand the fine pattern of zooplankton variability the samples were collected in the coastal area (at 75 m depth) every 10 days from 1994 to 2003 and seasonally after year 2004 (St. 1; Fig. 1).

Environmental factors: A clear seasonality marks the typical thermic regime of this temperate latitude (Estrada *et al*.,1985) where the high stratification during almost 7 months conditions the biological production and a short mixing water period during winter. Interannual variability was also important during the decade of 1994-2003. A cooler years were found separated from the warmer with mean annual values ranging from 13º C in early March to 28ºC in late August (Fernández de Puelles *et al*., 2004a). During summer 2003 was recorded the highest value of 30ºC. A warming trend was evident due to the milder winter between 1994 and 1998, if we except the cold years 1996 and after 2001 (Fernandez de Puelles *et al*., submitted). No seasonal cycle is evident in salinity and monthly fluctuations dominated the signal. A significant mesoscale oscillations modulated the interannual signal, as a consequence of the location of the Mallorca channel in the fluctuating boundary region. The saltier years were characterized by northern waters while the lowest by warm waters of recent atlantic origin. The low salinity values were associated with mild winter conditions and high salinity with severe winters. So that, in the Balearic sea it was reflected the fact that cold stormy weather favour the southwards spread of northern waters while milder conditions allow for the northward spread of waters of Atlantic origin. Nitrates highly correlated to salinity indicated that the northern waters had more nutrients than less mixed waters of southern origin (Pinot *et al*., 2002; Fernandez de Puelles *et al*., 2004b).

Zooplankton variability- During the period considered, the zooplankton biomass was very low if it is compared with other areas of the Western Mediterranean (Rodriguez, 1983; Mazzocchi and Ribera d'Alcala, 1995; Champalbert, 1996) and similar to the Eastern Mediterranean (Siokou-Frangou, 1996; Christou, 1998) but considering the zooplankton abundance higher variability was observed. Moreover, the small size of the zooplankton organisms represented the area. Plankton biomass and abundance were significantly correlated indicating that both indices depicted the same changes with a decreased abundance on going offshore from coastal-offshore (Fernandez de Puelles *et al*., 2003).

Copepods were the most abundant group with higher peaks in winter and spring and a decreasing during the warming years. However, considering the whole period a linear trend was found. They were followed by the gelatinous, in particular the appendicularians. The cladocerans were the second abundant group specially in the stratified season. Due to the cooler years at the end of the period, siphonophores showed an increasing in their abundance, meanwhile, other groups such as doliolids or chaetognaths decreased during the study (Fig. 2).

A significant relation and opposite was found between temperature, salinity and zooplankton. Besides the jelly group, all the zooplankton groups decreased in abundance when the temperature increased but differences were found among them with the increasing of salinity. Copepods, appendicularians and siphonophors were positively correlated but doliolids, chaetognaths, pteropods and ostracods showed negative correlation, indicating their preference for different water masses in the area.

More than 80 copepod species were identified and Clausocalanus and Oithona were the most abundant genera (50% of the total). The increase in zooplankton during the cold years were related to northern waters, whose fertility is higher in relation to the rest of the basin (Flos, 1985; Garcia *et al*., 1994). On the contrary, the lowest zooplankton abundance found during 1998 or 2003, could be a clear response to warming, when the waters were highly stratified (Fernandez de Puelles *et al*., 2003b). Nutrient depletion in relation to higher temperatures and stratification was also found during 30 years studies in the Californian Current (Roemmich and McGowan, 1995).

Considering the abundance of copepods and large scale climate factors, relationship was found with the winter NAO index ($R2=0.56$; $p<0.05$). An interesting signal was observed when the NAO index was strongly negative (<-1) and the highest copepod abundance was obtained (Fernandez de Puelles *et al*., 2004a). A direct influence of an atmospheric teleconnection seems to merge throughout air-sea interaction processes in the northern Western Mediterranean (Vignudelly *et al*., 1999). A negative NAO index could bring cold air to northern Europe and moist air into the Mediterranean with cooler winters favouring rich northern Mediterranean waters into the area and higher amounts of zooplankton. All of that, suggests a possible link between atmospheric forcing and zooplankton abundance. On the other hand positive NAO index was not related to lower zooplankton abundance and should be explored further with longer time-series.

In this sense, it can be considered that 10 years data are not enough in this boundary area, and larger investigations should be conducted specially to further determine the relationship between NAO and zooplankton populations. In summary, since changes in temperature and salinity are linked to large-scale processes and a synchronous variation appeared between zooplankton and hydrology. Linking can be suggested between this community and mechanisms acting over large spatial scales in the WM basin. All of that may help us towards a better understanding of the zooplankton variability in temperate latitudes, and particularly in our knowledge of the Mediterranean ecosystem.

Acknowledgements

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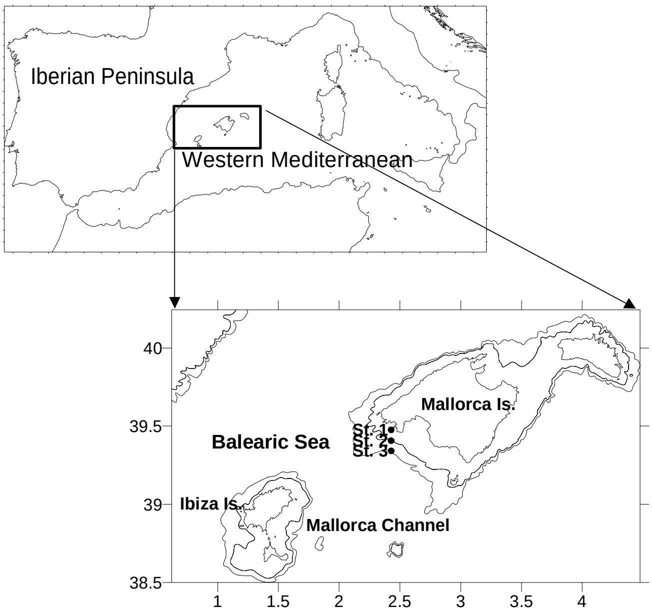

Fig. 1 Location of the sampled stations in the Mallorca channel (Balearic Sea)

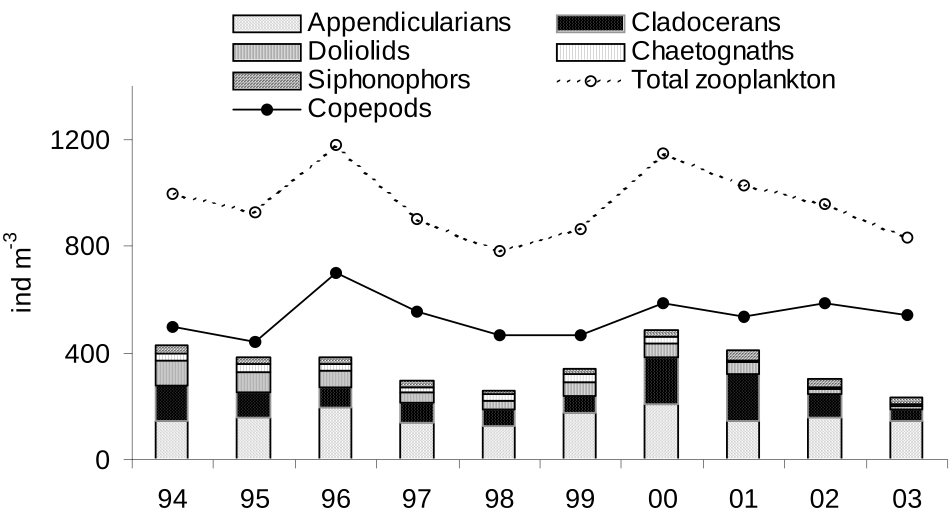

Fig. 2- Mean annual values of total zooplankton abundance and main groups (ind m-3)

Annex 5: Background on teleconnections

Notice: The daily and monthly Northern Hemisphere teleconnection indices have been changed as of June 1, 2005.

Introduction

Pattern Calculation Procedures: Description of Rotated Principle Component Analysis (RPCA) technique used to identify teleconnection patterns.

Index Calculation Procedures: Description of RPCA technique used to calculate monthly teleconnection indices.

Explained Variance time series showing monthly total explained variance by the ten leading teleconnections patterns.

Individual teleconnection patterns: Discussion, Height Anomaly Map, and plotted historical Time series for the period January 1950-March 1997

- **North Atlantic Oscillation** (NAO)
- **East Atlantic** (EA)
- **East Atlantic/Western Russia**
- **Scandinavia** (SCAND)
- **Polar/Eurasia**
- **West Pacific** (WP)
- **East Pacific-North Pacific** (EP-NP)
- **Pacific/North American** (PNA)
- **Tropical/Northern Hemisphere** (TNH)
- **Pacific Transition** (PT)

Historical Archive of all Indices: Monthly Tabulated Indices for all teleconnection pattern amplitudes dating back to 1950.

Monthly Tabulated indices: Last 12 months of indices for selected teleconnection patterns, as appears in the Climate Diagnostics Bulletin.

Recent Monthly Time series: Time series of pattern amplitudes for the last few years for selected teleconnection patterns, from the Climate Diagnostics Bulletin.

Link to The Climate Diagnostics Bulletin

Link to Annual Climate Assessment

Link to Special Climate Summaries

Link to some References in the Meteorological Literature concerning atmospheric teleconnection patterns.

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Page last modified: June 1, 2005

Introduction:

The atmospheric circulation is well-known to exhibit substantial variability. This variability reflects weather patterns and circulation systems that occur on many time scales, lasting from a few days (characteristic of a normal storm system and frontal passage), to a few weeks (characteristic of a mid-winter warm-up or a mid-summer wet period) to a few months (characteristic of particularly cold winters or hot summers), to several years (characteristic of abnormal winters for several years in a row), to several centuries (characteristic of long-term climate change).

The term "teleconnection pattern" refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that spans vast geographical areas. Teleconnection patterns are also referred to as preferred modes of low-frequency (or long time scale) variability. Although these patterns typically last for several weeks to several months, they can sometimes be prominent for several consecutive years, thus reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. Many of the teleconnection patterns are also planetary-scale in nature, and span entire ocean basins and continents. For example, some patterns span the entire North Pacific basin, while others extend from eastern North America to central Europe. Still others cover nearly all of Eurasia.

All teleconnection patterns are a naturally occurring aspect of our chaotic atmospheric system, and can arise primarily a reflection of internal atmospheric dynamics. Additionally, some of these patterns, particularly those over the North Pacific, are also sometimes forced by changes in tropical sea-surface temperatures and tropical convection associated with both the ENSO cycle **(Mo and Livezey 1986, Barnston and Livezey 1991)** and the Madden-Julian Oscillation (MJO).

Teleconnection patterns reflect large-scale changes in the atmospheric wave and jet stream patterns, and influence temperature, rainfall, storm tracks, and jet stream location/ intensity over vast areas. Thus, they are often the culprit responsible for abnormal weather patterns occurring simultaneously over seemingly vast distances. For example, the 1995/986 winter was very cold and snowy over much of eastern North America, while northern Europe and Scandinavia were cold and southern Europe/ northern Africa experienced very wet and stormy conditions. These conditions were all partly related to the same teleconnection pattern: a strong negative phase of the **North Atlantic Oscillation** **(NAO)**.

The Climate Prediction Center routinely monitors the primary teleconnection patterns and is involved in continuing research to better understand their role in the global climate system. Ten prominent teleconnection patterns can be identified in the Northern Hemisphere extratropics throughout the year, and all of these patterns have appeared previously in the meteorological literature **(Barnston and Livezey 1987)**.

The following is a list of the prominent teleconnection patterns and their affected regions. Click on the desired pattern name for Discussion, Map and plotted historical Time series of that pattern.

Prominent patterns over the North Atlantic

North Atlantic Oscillation (NAO), exists in all months

East Atlantic Pattern (EA), exists in all months

Prominent patterns over Eurasia

East Atlantic/Western Russia pattern (EATL/WRUS), exists in all months

Scandinavia pattern (SCAND), exists in all months

Polar/Eurasia pattern , exists in all months

Prominent patterns over North Pacific/North America

West Pacific pattern (WP), exists in all months

East Pacific - North Pacific pattern (EP-NP), exists in all months

Pacific/North American pattern (PNA), exists in all months

Tropical/Northern Hemisphere pattern (TNH), during December-February

Pacific Transition pattern (PT),exists during August-September

Note that the East Atlantic/Western Russia pattern and the Scandinavia pattern are referred to by **Barnston and Livezey (1987)** as the Eurasia-2 and Eurasia-1 patterns, respectively.

Technique for Identifying the Northern Hemisphere Teleconnection Patterns.

The procedure used to identify the Northern Hemisphere teleconnection patterns and indices is the Rotated Principal Component Analysis --RPCA (Barnston and Livezey 1987, Mon. Wea. Rev., 115, 1083-1126). This procedure isolates the primary teleconnection patterns for all months and allows time series of the patterns to be constructed. For our monitoring purposes, we apply the RPCA technique to monthly mean standardized 500-mb height anomalies obtained from the CDAS in the analysis region 20°N-90°N between January 1950 and December 2000. The anomalies are standardized by the 1950-2000 base period monthly means and standard deviations.

For each of the twelve calendar months, the ten leading unrotated EOFs are first determined from the standardized monthly height anomaly fields in the three-month period centered on that month: [i.e., The July patterns are calculated based on the June through August monthly standardized anomaly fields]. A Varimax rotation is then applied to these ten leading un-rotated modes, yielding the ten leading rotated modes and their time series for that calendar month. Therefore, these ten leading rotated modes for each calendar month are based on 153 (51 x 3) monthly standardized anomaly maps. Click here for additional discussion on how the teleconnection indices are calculated.

An examination of all twelve sets of rotated modes revealed ten dominant teleconnection patterns, of which eight to nine appear in each of the twelve calendar months. These patterns are referred to as the North Atlantic Oscillation, the Pacific/North American teleconnection pattern, the East Atlantic pattern, the West Pacific pattern, the East Pacific – North Pacific pattern, the East Atlantic/ Western Russia pattern, the Tropical/ Northern Hemisphere pattern, the Polar-Eurasian pattern, the Scandinavia pattern, and the Pacific Transition pattern. The remaining 1-2 spurious modes in each month have no apparent physical meaning.

To calculate the teleconnection indices, these spurious modes are omitted from the Least Squares equations. The solution to this system of equations yields the resulting teleconnection indices, which represent the combination of teleconnection patterns (instead of the combination of the ten leading rotated modes) that accounts for the most spatial variance of the observed standardized anomaly map in the month.

This analysis accounts for variability in the structure and amplitude of the teleconnection patterns associated with the annual cycle of the extratropical atmospheric circulation. It also allows for better continuity of the time series from one month to the next, than if the patterns were calculated based on the data for each month independently. Finally, the analysis allows for more robust results due to the increased number of fields used to calculate the modes for each calendar month. The RPCA procedure is superior to grid-point-based analyses, typically determined from one-point correlation maps, in that the teleconnection patterns in the RPCA approach are identified based on the entire flow field, and not just from height anomalies at select locations.

The teleconnection patterns are displayed with the positive phase shown in all maps. Note that the sign of the plotted values is reversed for the negative phase of the pattern. For the calendar months shown, the plotted values represent the temporal correlation during 1950-2000 between the index time series valid for that calendar month and the standardized monthly anomalies in the three-month period centered on that month. For example, the plotted values at each point for the January NAO pattern represent the temporal correlation between the January NAO index values and the standardized monthly anomalies for all December, January, and February months during the period 1950-2000.

NAO:

One of the most prominent teleconnection patterns in all seasons is the North Atlantic Oscillation (NAO) **(Barnston and Livezey 1987)**. The NOA combines parts of the East-Atlantic and West Atlantic patterns originally identified by **Wallace and Gutzler (1981)** for the winter season. The NAO consists of a north-south dipole of anomalies, with one center located over Greenland and the other center of opposite sign spanning the central latitudes of the North Atlantic between 35°N and 40°N. The positive phase of the NAO reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over the central North Atlantic, the eastern United States and western Europe. The negative phase reflects an opposite pattern of height and pressure anomalies over these regions. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport **(Hurrell 1995)**, which in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe **(Walker and Bliss 1932, van Loon and Rogers 1978, Rogers and van Loon 1979).**

Strong positive phases of the NAO tend to be associated with above-averagel temperatures in the eastern United States and across northern Europe and below-average temperatures in Greenland and oftentimes across southern Europe and the Middle East. They are also associated with above-average precipitation over northern Europe and Scandinavia in winter, and below-average precipitation over southern and central Europe. Opposite patterns of temperature and precipitation anomalies are typically observed during strong negative phases of the NAO. During particularly prolonged periods dominated by one particular phase of the NAO, anomalous height and temperature patterns are also often seen extending well into central Russia and north-central Siberia.

The NAO exhibits considerable interseasonal and interannual variability, and prolonged periods (several months) of both positive and negative phases of the pattern are common. The wintertime NAO also exhibits significant multi-decadal variability **(Hurrell 1995, Chelliah and Bell 2005)**. For example, the negative phase of the NAO dominated the circulation from the mid-1950's through the 1978/79 winter. During this approximately 24-year interval, there were four prominent periods of at least three years each in which the negative phase was dominant and the positive phase was notably absent. In fact, during the entire period the positive phase was observed in the seasonal mean only three times, and it never appeared in two consecutive years.

An abrupt transition to recurring positive phases of the NAO then occurred during the 1979/80 winter, with the atmosphere remaining locked into this mode through the 1994/95 winter season. During this 15-year interval, a substantial negative phase of the pattern appeared only twice, in the winters of 1984/85 and 1985/ 86. However, November 1995 - February 1996 (NDJF 95/96) was characterized by a return to the strong negative phase of the NAO. **Halpert and Bell (1997; their section 3.3)** recently documented the conditions accompanying this transition to the negative phase of the NAO.

East Atlantic

The East Atlantic (EA) pattern is the second prominent mode of low-frequency variability over the North Atlantic, and appears as a leading mode in all months. The EA pattern is structurally similar to the NAO, and consists of a north-south dipole of anomaly centers spanning the North Atlantic from east to west. The anomaly centers of the EA pattern are displaced southeastward to the approximate nodal lines of the NAO pattern. For this reason, the EA pattern is often interpreted as a "southward shifted" NAO pattern. However, the lower-latitude center contains a strong subtropical link in association with modulations in the subtropical ridge intensity and location. This subtropical link makes the EA pattern distinct from its NAO counterpart. This EA pattern is similar to that shown in the **Barnston and Livezey (1987)** study, but is distinctly different from the EA pattern originally defined by **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 U.S. during January-May and in the north-central U.S. during July-October. It is also associated with above-average precipitation over northern Europe and Scandinavia, and with below-average precipitation across southern Europe.

The EA pattern exhibits very strong multi-decadal variability in the 1950-2004 record, with the negative phase prevailing during much of 1950-1976, and the positive phase occurring during much of 1977-2004. The positive phase of the EA pattern was particularly strong and persistent during 1997-2004, when 3-month running mean values routinely averaged 1.0-2.0 standard deviations above normal.

East Atlantic / West Russia

The East Atlantic/ West Russia (EATL/WRUS) pattern is one of three prominent teleconnection patterns that affects Eurasia throughout year. This pattern has been referred to as the Eurasia-2 pattern by Barnston and Livezey **(1987)**. The East Atlantic/ West Russia pattern consists of four main anomaly centers. The positive phase is associated with positive height anomalies located over Europe and northern China, and negative height anomalies located over the central North Atlantic and north of the Caspian Sea.

The main surface temperature anomalies associated with the positive phase of the EATL/ WRUS pattern reflect above-average temperatures over eastern Asia, and below-average temperatures over large portions of western Russia and northeastern Africa. The main precipitation departures reflect generally above-average precipitation in eastern China and below-average precipitation across central Europe.

Scandinavia

The Scandinavia pattern (SCAND) consists of a primary circulation center over Scandinavia, with weaker centers of opposite sign over western Europe and eastern Russia/ western Mongolia. The Scandinavia pattern has been previously referred to as the Eurasia-1 pattern by **Barnston and Livezey (1987)**. The positive phase of this pattern is associated with positive height anomalies, sometimes reflecting major blocking anticyclones, over Scandinavia and western Russia, while the negative phase of the pattern is associated with negative height anomalies in these regions.

The positive phase of the Scandinavia pattern is associated with below-average temperatures across central Russia and also over western Europe. It is also associated with above-average precipitation across central and southern Europe, and below-average precipitation across Scandinavia.

Polar / Eurasia

The Polar/ Eurasia pattern appears in all seasons. The positive phase of this pattern consists of negative height anomalies over the polar region, and positive anomalies over northern China and Mongolia. This pattern is associated with fluctuations in the strength of the circumpolar circulation, with the positive phase reflecting an enhanced circumpolar vortex and the negative phase reflecting a weaker than average polar vortex.

The Polar/Eurasian pattern is mainly associated with above-average temperatures in eastern Siberia and below-average temperatures in eastern China. It is also associated with above-average precipitation in the polar region north of Scandinavia.

The Polar/Eurasian pattern can exhibit strong low-frequency variability. For example, a negative phase of the pattern prevailed during 1955-1961, followed by appositive phase during 1964/65 - 1969/70. Similar persistent negative and positive phases of the pattern were observed during the 1980s-1990s.

West Pacific

The WP pattern is a primary mode of low-frequency variability over the North Pacific in all months, and has been previously described by both **Barnston and Livezey (1987) and Wallace and Gutzler (1981)**. During winter and spring, the pattern consists of a north-south dipole of anomalies, with one center located over the Kamchatka Peninsula and another broad center of opposite sign covering portions of southeastern Asia and the western subtropical North Pacific. Therefore, strong positive or negative phases of this pattern reflect pronounced zonal and meridional variations in the location and intensity of the entrance region of the Pacific (or East Asian) jet steam. These anomalies exhibit a strong northward shift from winter to summer, which is consistent with the observed northward shift of the Eat Asian jet stream. A third anomaly center is located over the eastern North Pacific and southwestern United States in all seasons.

The positive phase of the WP pattern is associated with above-average temperatures over the lower latitudes of the western North Pacific in both winter and spring, and with below-average temperatures over eastern Siberia in all seasons. It is also associated with above-average precipitation in all seasons over the high latitudes of the North Pacific, and below-average precipitation across the central North Pacific especially during the winter and spring.

East Pacific / North Pacific

The East Pacific - North Pacific (EP- NP) pattern is a Spring-Summer-Fall pattern with three main anomaly centers. The positive phase of this pattern features positive height anomalies located over Alaska/ Western Canada, and negative anomalies over the central North Pacific and eastern North America. Strong positive phases of the EP-NP pattern are associated with a southward shift and intensification of the Pacific jet stream from eastern Asia to the eastern North Pacific, followed downstream by an enhanced anticyclonic circulation over western North America, and by an enhanced cyclonic circulation over the eastern United States. Strong negative phases of the pattern are associated with circulation anomalies of opposite sign in these regions.

The positive phase of the EP-NP pattern is associated with above-average surface temperatures over the eastern North Pacific, and below-average temperatures over the central North Pacific and eastern North America. The main precipitation anomalies associated with this pattern reflect above-average precipitation in the area north of Hawaii and below-average precipitation over southwestern Canada.

Bell and Janowiak (1995, Bull. Amer. Meteor. Soc.) noted that the atmospheric circulation during the several months prior to the onset of the Midwest floods of June-July 1993 was dominated by a very strong positive phase of the EP-NP pattern. Their study concluded these conditions were indirectly important to the onset and overall magnitude of the floods, since they fostered an anomalously intense storm track over the midlatitudes of the North Pacific. Dramatic changes in this storm track during June then ultimately initiated the Midwest floods.

Pacific / North America

The Pacific/ North American teleconnection pattern (PNA) is one of the most prominent modes of low-frequency variability in the Northern Hemisphere extratropics. The positive phase of the PNA pattern features above-average heights in the vicinity of Hawaii and over the intermountain region of North America, and below-average heights located south of the Aleutian Islands and over the southeastern United States. The PNA pattern is associated with strong fluctuations in the strength and location of the East Asian jet stream. The positive phase is associated with an enhanced East Asian jet stream and with an eastward shift in the jet exit region toward the western United States. The negative phase is associated with a westward retraction of that jet stream toward eastern Asia, blocking activity over the high latitudes of the North pacific, and a strong split-flow configuration over the central North Pacific.

The positive phase of the PNA pattern is associated with above-average temperatures over western Canada and the extreme western United States, and below-average temperatures across the south-central and southeastern U.S. The PNA tends to have little impact on surface temperature variability over North America during summer. The associated precipitation anomalies include above-average totals in the Gulf of Alaska extending into the Pacific Northwestern United States, and below-average totals over the upper Midwestern United States.

Although the PNA pattern is a natural internal mode of climate variability, it is also strongly influenced by the El Niño/ Southern Oscillation (ENSO) phenomenon. The positive phase of the PNA pattern tends to be associated with Pacific warm episodes (El Niño), and the negative phase tends to be associated with Pacific cold episodes (La Niña).

Tropical / Northern Hemisphere

The Tropical/ Northern Hemisphere (TNH) pattern was first classified by Mo and Livezey (1986), and appears as a prominent wintertime mode during December-February. The positive phase of the TNH pattern features above-average heights over the Gulf of Alaska and from the Gulf of Mexico northeastward across the western North Atlantic, and below-average heights throughout eastern Canada.

The TNH pattern reflects large-scale changes in both the location and eastward extent of the Pacific jet stream, and also in the strength and position of the climatological mean Hudson Bay Low. Thus, the pattern significantly modulates the flow of marine air into North America, as well as the southward transport of cold Canadian air into the north-central United States.

The positive phase of the TNH pattern is associated with below-average surface temperatures throughout the western and central United States, and across central and eastern Canada. It is also associated with above-average precipitation across the central and eastern subtropical North Pacific, and below-average precipitation in the western United States and across Cuba, the Bahama Islands, and much of the central North Atlantic Ocean.

The negative phase of the TNH pattern is often observed during December and January when Pacific warm (ENSO) episode conditions are present **(Barnston *et al.* 1991)**. One recent example of this is the 1994/95 winter season, when mature Pacific warm episode conditions and a strong negative phase of the TNH pattern were present. During this period, the mean Hudson Bay trough was much weaker than normal and shifted northeastward toward the Labrador Sea. Additionally, the Pacific jet stream was much stronger than normal and shifted southward to central California, well south of its climatological mean position in the Pacific Northwest. This flow pattern brought well above-normal temperatures to eastern North America and above-normal rainfall to the southwestern United States

Pacific Transition

The Pacific Transition (PT) pattern is a leading mode during August and September. This pattern captures anomalous wave-train of 500-hPa heights extending from the central subtropical North Pacific to the eastern United States. The positive phase of the PT pattern features above-average heights west of Hawaii and across western North America, and below-average heights in the Gulf of Alaska and over the southeastern United States.

The PT pattern is associated with above-average surface temperatures in the western subtropical North Pacific, the subtropical North Atlantic, and throughout western North America, and with below-average temperatures over the eastern half of the United States. The main precipitation departures associated with the PT pattern include above-average precipitation in the southeastern U.S., and below-average precipitation near Hawaii and across the northern tier of the United States.

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Annex 6: Recommendations

- The recommendations resulting from this workshop are collated and listed in the following table. These recommendations are addressed to the ICES DATA CENTRE as well as to members of WKLTVSWE.

RECOMMENDATION	ACTION
1. To maintain the TABLE (Annex 6) updated and make it available through the group portal as well as via ICES.	
2.	
3.	
4.	
5.	
6.	