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27 February – 2 March 2012

Fuengirola, Spain

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CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

Small pelagic fishes such as sardine, sardinella, anchovy, herring, sprat and others represent about 20–25 % of the total annual world fisheries catch. They support important fisheries in many European countries. Their dynamics have important economic consequences as well as ecological ones. 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. North Atlantic marine ecosystems are exposed to large-scale climate forcing by the North Atlantic Oscillation (NAO) on the decadal and by the Atlantic Multi-decadal Oscillation (AMO) on the multi-decadal scale, in addition to global warming. At present, a fascinating natural climate experiment involving small pelagic fish is going on in waters surrounding Europe, which has been largely ignored, in spite of its acute and future commercial importance for the European fishing industry. Numerous observations by European fishery scientists over the last 20 years demonstrate clearly that small pelagic fish populations in all shelf seas surrounding Europe from the North African upwelling and the Black Sea in the south up to the Baltic Sea and southern Norwegian coasts are shifting their distributional borders to the North with concomitant dramatic changes in abundance and recruitment. Spectacular examples are the invasion of the North Sea by anchovies and sardines since the mid-1990s which have established spawning populations in this northern shelf sea or the northward migrations of sardinella in the Mediterranean. Another example is the drastic increase of the Baltic sprat stock which was initiated in the late 1980s. To develop scenarios for future fluctuations of small pelagic populations, it is necessary to understand the climatic background of their fluctuations in the past. During the meeting, 12 case studies on long-term fluctuations of small pelagics from ecosystems spanning from the upwelling region off NW Africa to the Nordic Seas, including the Mediterranean, were presented and potential links with climate variability were discussed. The WG focused on the impact of the AMO during the 20th century. Apparently, many of the populations studied show population swings in synchrony with the warm and cold periods of the AMO, so displaying clear reactions to multi-decadal climate forcing. These studies will be continued during the intersessional period and result in a joint publication.

The meeting was attended by 26 scientists from 10 countries, including physical oceanographers, zooplankton experts and fisheries scientist. The close cooperation between scientists from the ICES area and from the Mediterranean proved to be highly successful and should be taken as an example for future collaboration between ICES and the General Fisheries Commission for the Mediterranean (GFCM) both of which have recently signed a memorandum of understanding.

1 Opening and Agenda

The second meeting of WGSPEC took place on 27 February – 2 March 2012 at the Centro Oceanográfico de Málaga (Fuengirola, Spain) of the Instituto Español de Oceanografía (IEO). The meeting was opened by the chairman of WGSPEC (Jürgen Alheit). The local host was Alberto Garcia. The meeting was attended by 26 scientists from 10 countries (List of participants: Annex 1). The agenda is given in Annex 2.

2 Introduction

2.1 Terms of Reference

a) Review the outcomes from the workshops WKAMO and WKNORCLIM;

b) Investigate the impact of climate variability and change on small pelagic fish populations (anchovy, sardine, sardinella, herring, sprat) in the area from NW Africa to the Barents Sea, incl. the Mediterranean, for the period from mid-1900s to the present;

c) Suggest relevant joint theme sessions and workshops for ICES and PICES which are also relevant to ICES assessment working groups on pelagic fish;

d) Prepare contributions for the 2012 SSGEF session during the ASC on the topic areas of the Science Plan.

2.2 Small pelagic fishes and climate impact

Small pelagic fishes such as sardine, anchovy, herring and others represent about 20–25 % of the total annual world fisheries catch (Hunter and Alheit 1995). 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). Thousandfold 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. 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 (Hunter and Alheit 199?).

North Atlantic marine ecosystems are exposed to several large scale climatic forcings, such as the North Atlantic Oscillation (NAO), the Atlantic Multidecadal Oscillation (AMO) and global warming. The interdependence between these different climate indicators and their individual as well as their combined impact on marine ecosystems are extremely poorly understood. At present, a fascinating natural climate experiment involving small pelagic schooling fish, such as sardines, sardinellas, anchovies, herrings and sprats, is going on in waters surrounding Europe, which has been largely ignored, in spite of its acute and future commercial importance for the European fishing industry. Numerous observations by European fishery scientists over the last 20 years demonstrate clearly that small pelagic fish populations in all shelf seas surrounding Europe from the North African upwelling and the Black Sea in the south up to the Baltic Sea and southern Norwegian coasts are shifting their distributional borders to the North with concomitant dramatic changes in abundance and recruitment. Spectacular examples are the invasion of the North Sea by anchovies and sardines since the mid-1990s which have established spawning populations in this northern shelf sea (Beare *et al.* 2004a,b; Alheit *et al.* 2012; Petitgas *et al.* 2012) or the northward migrations of sardinella in the Mediterranean (Sabatés *et al.* 2006; Tsikliras 2008). Another example is the drastic increase of the Baltic sprat stock which was initiated in the late 1980s (Alheit *et al.* 2005).

All these dramatic changes in distribution and abundance of small pelagics seem to be associated with recurrent climatic events or periods, oscillations, rather than with global warming. The late 1980s, when the Baltic sprat exploded and, similarly, sudden changes on other trophic levels in the central Baltic were recorded, were characterized by a sudden increase of the NAO index, a climatic signal which also was reflected in the dynamics of other European shelf sea ecosystems and even in northern and central European freshwater lakes (Alheit *et al.* 2005, Alheit and Bakun 2010). Anchovies and sardines started around the mid-1990s to extend their northern distribution limits into the entire North Sea, several years after the increase of the NAO index. Apparently, they had been spawning there already in the 1940s and 1950s, but disappeared again in the 1960s. Interestingly, from about 1930–1960 and again since the mid-1990s, the AMO, which represents North Atlantic water temperature, has been in a positive phase. Consequently, invasion of anchovies and sardines into North Sea and Baltic seems to be associated with the dynamics of the AMO (Alheit *et al.* 2012).

2.3 Climate indices

The **North Atlantic Oscillation** (NAO) is the leading pattern of climate variability over the North Atlantic and adjacent continents (Hurrell and Deser 2010). The NAO refers to a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic. Atmospheric impacts of the NAO include substantial changes in surface air temperature, wind direction and speed, storminess and precipitation. Ocean impacts include changes in heat content, gyre circulations, mixed layer depth, salinity, high latitude deep water formation and sea ice cover. The NAO index (NAOI) switches between positive and negative phases. Over northern and central Europe, high (low) index values are associated with increased (decreased) westerly winds, milder (cooler) temperatures and increased (decreased) precipitation. In contrast, over the Mediterranean, a high (low) NAO index is associated with less (more) precipitation.

The **Atlantic Multidecadal Oscillation** (AMO) reflects multidecadal warming and cooling periods of the North Atlantic and its index are linearly detrended SST anomalies (Ting *et al.* 2009) between 0–60°N with a 60–80 years cycle (Kerr 2005). It seems to be reflected by the occurrence of Sahel zone drought, variability in North East Brazilian rainfall, and North American climate (Knight *et al.* 2005).

2.4 Development of working group meeting

During the meeting, a large number of case studies from different stocks of small pelagics and their ecosystems was presented and discussed (Table 1). Statistical analyses were started but there was not sufficient time to finish them. Consequently, it was decided to continue these analyses during the intersessional period and aim for a joint publication on the results. Draft terms of reference for the 2013 meeting can be found in Annex 3.

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Table 1. Metadata table indicating the small pelagics time series that have been investigated during the 2012 meeting of the WGSPEC.

Sardinella aurita	Contact person	Start	Finish	Gaps	Frequency	Data	Source	Comments
NW Africa_Morocco	Maria Teresa Garcia & Eva Garcia-Isarch	1990	2010		yearly	landings	CECAF	
Mauritania_NW Africa	Maria Teresa Garcia & Eva Garcia-Isarch	1990	2010		yearly	landings	CECAF	
Senegal_NW Africa	Maria Teresa Garcia & Eva Garcia-Isarch	1970	2010		yearly	landings	CECAF	
NW Mediterranean_Spain	Isabel Palomera	1945	2010		yearly, monthly since 1940	landings	CSIC	
SW Mediterranean_Spain	Alberto Garcia & Ana Giraldez	1945	2010		yearly, but also monthly	landings	IEO	
Eastern Mediterranean_Greece	Athanasios Tsikliras	1928	2009	1949-1970	yearly, monthly since 1982	andings, CPUE since 198	Aristotele	
Northern Adriatic_Chioggia	Alberto Barausse-Carlotta Mazzoldi	1997	2011		yearly, monthly	landings	University of Padova	
Eastern Mediterranean_Israel		1970	2008		yearly	landings	GFCM	
Egypt*		1970	2008		yearly	landings	GFCM	* Sardinella spp.
Palestine*		1996	2008		yearly	landings	GFCM	* Sardinella spp.
Syria*		1976	2008		yearly	landings	GFCM	* Sardinella spp.

Engraulis encrasicolus	Contact person	Start	Finish	Gaps	Frequency	Data	Source	Comments
English Channel_	Steve Coombs	1910	2010		monthly	eggs	MBA	
Bay of Biscay(VIIIc)_Spain	ICES (Unai Cotano)	1940	2010		yearly	landings	ICES	
Portugal_Miguel (IXa_S_Portuga	ICES (Miguel Santos)	1943	2010		yearly	landings	IPIMAR, ICES	
Spain_Miguel (IXa_S_Spain)	ICES (Fernando Ramos)	1989	2010		yearly	landings	IEO, ICES	
NW Africa_Morocco	Eva García-Isarch	1970	2010		yearly	landings	CECAF	Includes IEO data
NW Africa_Morocco	Eva García-Isarch	1988	2010	2000-2006	yearly, monthly	landings, CPUE	IEO	Only Spanish Fishery - IEO
NW Mediterranean_Spain	Isabel Palomera	1940	2010		yearly, monthly since 1940	landings	CSIC	
SW Mediterranean_Spain	Ana Giraldez	1945	2010		yearly, but also monthly	landings	IEO	
Adriatic Sea_Italian coast	Piera Carpi & Alberto Santojanni	1975	2010		yearly	landings	CNR-ISMAR	
Adriatic Sea_Croatian coast	Alberto Santojanni	1975	2010		yearly	landings	Split IOF	It includes data from Slovenia til 1998
Adriatic Sea_Slovenian coast	Alberto Santojanni	1975	2010		yearly	landings	Lubjana FRIS	It includes data from Croatia til 1998
Northern_Adriatic_Chioggia	Alberto Barausse-Carlotta Mazzoldi	1945	2011		yearly, monthly	landings	University of Padova	
NW_Adriatic	Andrea DeFelice	1976	2010	some gaps	yearly	acoustic survey	CNR-ISMAR	
SW_Adriatic	Andrea DeFelice	1987	2010	some gaps	yearly	acoustic survey	CNR-ISMAR	
Greece	Athanasios Tsikliras	1928	2009		yearly, monthly since 1964	andings, CPUE since 198	Aristotele	
Turkey		1970	2009		yearly	landings	GFCM	

Sardina pilchardus	Contact person	Start	Finish	Gaps	Frequency	Data	Source	Comments
English Channel_	Steve Coombs	1910	2010		monthly	eggs and larvae?	MBA	eggs and larvae
Bay of Biscay(VIIIc)_Spain	ICES (Unai Cotano)	1940	2010		yearly	landings	ICES	
IXa_South_Portugal	ICES (Miguel Santos)	1940	2009		yearly	landings	IPIMAR, ICES	
IXa_North_Spain	ICES (Fernando Ramos)	1907	1997	1915-1921	yearly	landings	IEO, ICES	
IXa_Central_North_Portugal	ICES (Miguel Santos)	1927	1988		yearly	landings	IPIMAR*	Data from 1 harbour only till 1940. *Data provided by Rafael González-Quirós
IXa_Central_South_Portugal	ICES (Miguel Santos)	1940	2009		yearly	landings	IPIMAR, ICES	
NW Africa_Morocco	Maria Teresa Garcia & Eva García-Isarch	1976	2010		yearly	landings	CECAF	Includes IEO data
NW Africa_Morocco	Maria Teresa Garcia & Eva García-Isarch	1976	1999		yearly, monthly	landings, CPUE	IEO	Only Spanish Fishery - IEO
Mauritania_NW Africa	Maria Teresa Garcia & Eva García-Isarch	1995	2010		yearly	landings	CECAF	
Senegal_NW Africa	Maria Teresa Garcia & Eva García-Isarch	1990	2010		yearly	landings	CECAF	
NW Mediterranean_Spain	Isabel Palomera	1945	2010		yearly, monthly since 1940	"	CSIC	
SW Mediterranean_Spain	Ana	1945	2010		yearly, monthly	landings	IEO	
Adriatic Sea_Italian coast	Piera Carpi & Alberto Santojanni	1975	2010		yearly	landings	CNR-ISMAR	
Adriatic Sea_Croatian coast	Alberto Santojanni	1975	2010		yearly	landings	Split IOF	It includes data from Slovenia til 1998
Adriatic Sea_Slovenian coast	Alberto Santojanni	1975	2010		yearly	landings	Lubjana FRIS	It includes data from Croatia til 1998
Northern_Adriatic_Chioggia	Alberto Barausse-Carlotta Mazzoldi	1945	2011		yearly, monthly	landings	University of Padova	
NW_Adriatic	Andrea DeFelice	1976	2010	some gaps	yearly	acoustic survey	CNR-ISMAR	
SW_Adriatic	Andrea DeFelice	1987	2010	some gaps	yearly	acoustic survey	CNR-ISMAR	
Greece	Athanasios Tsikliras	1928	2009		yearly, monthly since 1964	andings, CPUE since 198	Aristotele	

Clupea harengus	Contact person	Start	Finish	Gaps	Frequency	Data	Source	Comments
Norvegian Sea_spring	Aril Slotte	**1907**	2010		**Yearly**	**Landings, SSB, R0**	Toresen and Østvedt 2000, ICES 2011	

3 Case studies

3.1 Long Term Variability of the Canary Current Upwelling System

P. Relvas, J. Luís, P. Laginha Silva and A. M. P. Santos

There is almost total consent that a global warming of the upper ocean is occurring. Accordingly, our analysis from several data sets (ICOADS, Portuguese Met. Office, satellite imagery) show a consistent warming of the coastal and offshore upper waters of the Canary Current Upwelling System (CCUS), defined from 10ºN (Senegal coast) to 43ºN (northern Iberian Peninsula). It includes a region south of Cape Blanc (21º N) were the upwelling is seasonal during winter, a central region of NW Africa (21–33º N) where upwelling is permanent and strong, and a northern sector that corresponds to the Iberian Peninsula (37–43ºN), where upwelling is seasonal during the summer. It includes also the discontinuity imposed by the entrance of the Mediterranean/Gulf of Cadiz.

Until the systematic observation of the ocean through satellites, the ocean circulation was viewed as consisting primarily of a large-scale slowly changing flow. However, the present view of the upwelling systems points to an extremely noisy ocean circulation, where the meso-scale activity obscures the large-scale climatologic patterns and largely governs the ecosystem functioning. A succession of jets, meanders, eddies, upwelling filaments, coastal counter-currents and buoyant plumes that represent the "weather" of the ocean, superimposes on the larger scale circulation distorting the classical view of the ocean circulation. This meso-scale activity is a fundamental scale for the marine ecosystem behaviour, because the spatial and temporal scales of importance for marine plankton communities are mainly related to meso-scale features.

The question is: How does the CCUS respond to the global scale warming?

To answer this question we made use of the satellite SST imagery (AVHRR Pathfinder SST Version 5.1 –quality 6 and 7 only), the most suitable data for the meso-scale analysis due to their good time-space resolution and continuous coverage. A considerable amount of years of continuous satellite remote sensing SST measurements is already available and long enough to attempt the analysis of long-term changes (1982–2009). A hierarchical suite of tests and procedures were applied to the imagery data to guarantee their quality and that the annual and seasonal averages are not biased towards the seasonally more abundant summer temperature data. A robust linear fit was then applied to each individual pixel, crossing along the time the same 4x4 km pixel in all the processed monthly mean AVHRR SST images from 1982 until 2008. The slope of the linear fit would represent the temporal variation of the SST. A warming field was created upon the slopes of the linear fits applied to each pixel, in a way that the value associated to each pixel represents the SST trend from 1982 to 2009 in ºC/year. The global synthesized image is shown below in the figure, along with enlargements of specific regions.

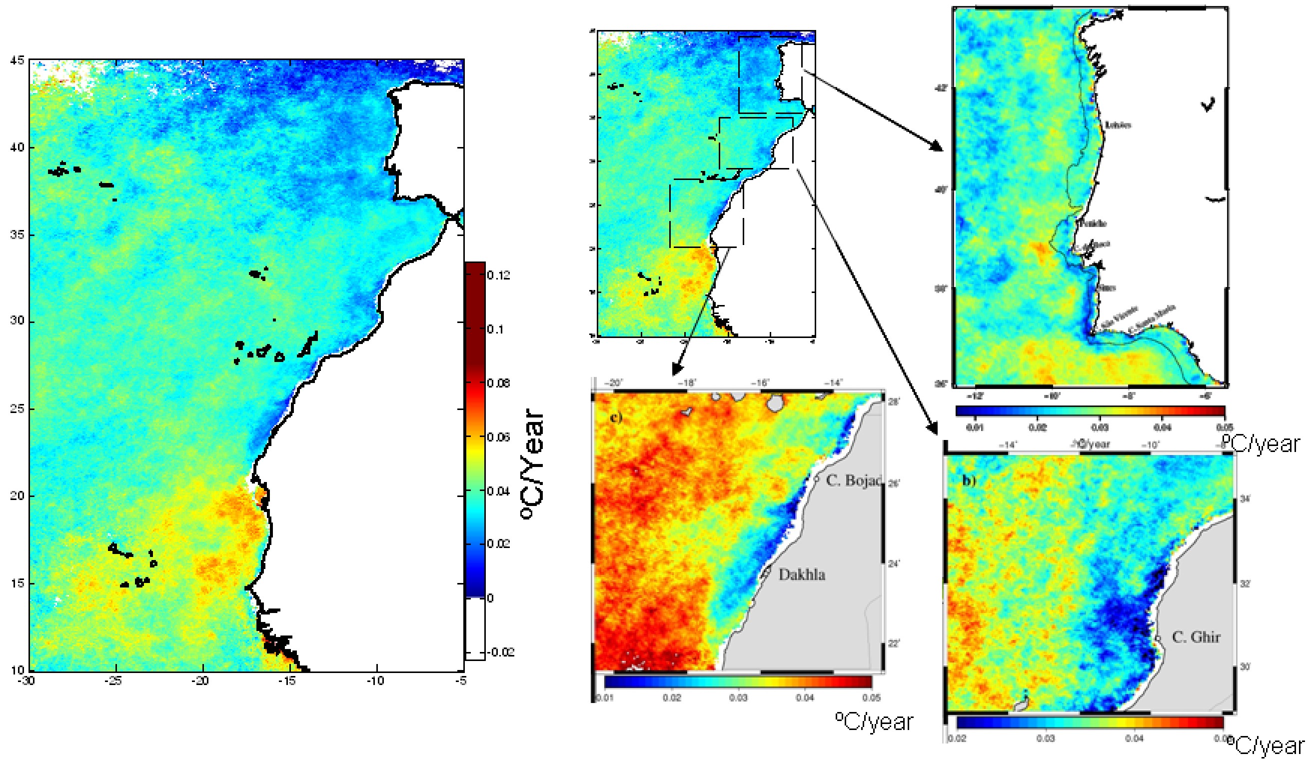

Figure A. Warming trends in the period 1982–2009. Entire CCUS region (left) and details of meso-scale features (right).

The computed field of SST trends exhibits regions with clear contrasting warming trends. The global warming affects the coastal ocean of the CCUS as a whole, but the response is not spatially uniform. Different meso-scale features respond to the rise of the temperature in different ways. If we assume that the SST contrast between coastal and offshore waters is a proxy for the upwelling intensity, the presented results point to an intensification of the meso-scale activity of the CCUS, with the intensification of the SST gradients as a response to the observed warming.

The spatial heterogeneities are an indication of the main role that meso-scale processes play in the modulation of the spatial and temporal variability of SST, namely at the decadal scale.

Specifically:

- Decrease of upwelling intensity in the southern part of the CCUS, between Cape Blanc and Cape Verde.
- Re-inforcement of the coastal upwelling structures off NW Africa: Dakhla upwelling center (from 22ºN to 28ºN) and Cape Ghir (31ºN) upwelling filament evidences an intensification of the upwelling intensity.
- Upwelling intensification off the southern part of the Iberian Peninsula, contrasting with a more regular behaviour further north.

We can conclude that in Eastern Boundary Upwelling Systems, where meso-scale structures play a major role in the description of the upwelling regime, to rely on sparse spatial observations to hypothesize about the decadal behaviour of the upwelling intensity at the basin scale may be questionable.

3.2 NAO related small pelagic fisheries fluctuations off Morocco and Senegal

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Introduction

The small pelagics are one of the most important fish resources off the North West African coast. These resources are shared between different countries and are exploited by artisanal and industrial fleets.

Cupleids as *Sardina pilchardus* and *Sardinella* spp (*S. aurita* and *S. maderensis*) are important target species and make up over 80% of small pelagic catches in Morocco and Senegal. The fishing activity in this area and their statistics provide us ecological time series, which are suitable to compare with the dynamics of the climatic system.

Hydroclimatic regime

The large-scale small pelagic fisheries are supported by an important productive marine region in the NW African region: The Canary Current ecosystem, which is one of the largest wind-induced upwelling systems.

The seasonality of the upwelling and the displacement of a marine front along the coast of Mauritania and Senegal cause a "contrasting hydroclimatic situations" with cold waters in winter, warm waters in summer and two short transition periods between both seasons. This area is an important transition zone, both hydrologic and faunistic, between an "equatorial" warm region and a "Canary" cold region. (Wooster and McLain, 1976; Belvèze and Erzini, 1983).

This large abundance of small pelagics means that there is an important intermediate trophic level in this large ecosystem. Despite their importance, little is known about the climate effects in the region.

NAO Index (Why use NAO?)

The NAO is the most robust pattern of recurrent atmospheric behaviour in the North Atlantic region (Hurrell and Dickson, 2003). NAO fluctuations are widest during the colder months (December–March) when the atmosphere is most active dynamically (Hurrell *et al.*, 2003; Stenseth *et al.*, 2003).

The NAO index reduces complexity of time-space variability into simple measures, representing a "weather package", and might provide an assessment of the ecological effects of climate fluctuations.

Most research about the NAO and its effects has been made in the North Atlantic, where this climatic *proxy* explains a great part of the climate variability., The research on the relationship between climate processes and the Northwest African upwelling system began only a few years ago.

The NAO effects in NW Africa produces during the positive phases (NAO+) an intensification of the trade winds from the northeast and, as a consequence, an increase of the upwelling and cooling water. An inverse situation occurs during the negative phases (NAO-). The fluctuations in the upwelling extension are controlled by the predominant winds that are initiated in the Subtropical Atlantic, the trade winds, which are largely determined by the NAO (Van Camp *et al.*, 1991; Nykjaer and Van Camp, 1994). The NAO explains 50% of SST annual variability in the open sea in this Atlantic area (Helmke, 2003). The wind stress north-south component (τ_y) of the wind vector correlates significantly with the winter NAO index in most of the Atlantic basin (Visbeck *et al.*, 1998)

Background in Morocco and Senegal

Wind stress

In the NW Africa, NAO explained a high percentage of the variability of the winds in Morocco, off 21ºN (Meiners, 2007). The wind stress component (τ_y) was in synchrony and positively correlated with the NAO index. This *proxy* explained around 41% of wind stress variability in this wide area.

The same results were obtained in Mauritania and Senegal waters (from 21ºN to 15ºN) where the wind stress component (τ_y), showed changes in accordance with opposite NAO phases during the period 1960–2004 (Meiners *et al.*, 2010). The Figure 1 shows the high synchrony between NAO index and wind stress v-component (τ_y) time-series at time t, and were positively and significantly correlated ($r=0.72$; $F_{1,43}=48.3265$, $p<<0.001$). NAO explained around 53% of wind stress variability in this southern area.

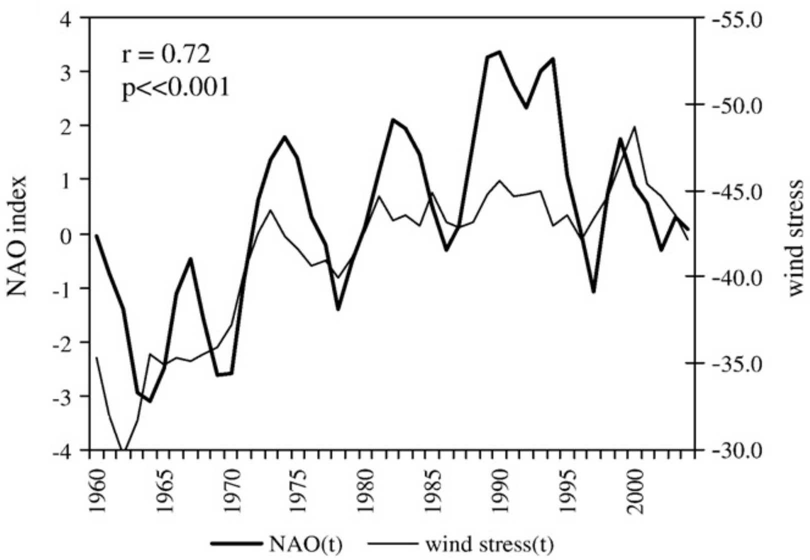

Figure 1. Synchrony between NAO index and wind stress v-component time-series at time t. Note that the negative sign indicates north–south vector (from Meiners *et al.*, 2010).

Upwelling

The NAO explains a high percentage of the upwelling variability periods to around 21ºN, and its changes were in phase and positively related with NAO fluctuations (Meiners, 2007).

A relation between the upwelling extension and intensity with the wind stress was observed in Mauritanian and Senegalese waters with high local variability. In the NAO-negative phases (1960–1973) the conditions for intense upwelling were less extended than during NAO-positive phases (1990–2000); (Meiners *et al.*, 2010).

Primary production

In this area, the high concentrations of photosynthetic pigments imply a significant productivity (Freudenthal *et al.*, 2001), due to the sustained supply of nutrients, the upwelling, and its retention or recirculation in the surface waters by the meso-scale processes.

Meiners (2007) find a strong and proportional relation at the same time t between wind stress, NAO and primary production with the chlorophyll concentrations from satellite imagery in Moroccan waters.

Objective

Recent studies in NW Africa waters have shown that wind-induced upwelling (τy) and primary production are related with the NAO. A significant relationship between hake abundance and the NAO index was observed (Meiners, 2007; Meiners *et al.*, 2010). Moreover, the hake is an important predator of clupeids and its abundances might be related.

Considering this, the goal of this approach was to perform an explorative analysis to test the possible relationship between the climate variability described by the NAO index and the abundance of small pelagics in Morocco and Senegal.

Methods

Fishery data

Annual CPUE data as abundance proxies from three commercial small pelagic species:

- *Sardinella aurita*: between 1981–2005 (25 years), from the artisanal fleet in Senegal. The catch is in tonnes and the effort in fishing trips.
- *Sardinella maderensis*: between 1990–2005 (16 years), from the artisanal fleet in Senegal. The catch is in tonnes and the effort in fishing trip.
- *Sardina pilchardus*: between 1990–1999 (10 years) from the industrial Spanish purse seiners fleet, fishing south to 26°N, in Saharan waters. The catch is in tonnes and effort in fishing days.

NAO index

The winter NAO index, between December to March. Source: National Center for Atmospheric Research (NCAR) http://www.cgd.ucar.edu/cas/jhurrell/indices.html. (Hurrell, 1995). NAO data were smoothed by a running average of 3 years to reduce time-series noise.

Analysis

Correlation techniques were used to analyze and quantify the relationships between climate variability (NAO index) and the annual yields of the small pelagic species at the same time. The statistical significance of each relation was estimated by an ANOVA (F test).

Results

A quadratic dependence between abundance series of small pelagic species and the NAO index of the same year (t) was found in all cases.

Sardinella aurita

There was a synchrony between the residuals of the CPUE and the smoothed NAO. The highest CPUE values coincided with the largest positive anomalies of the NAO, and negative residuals corresponded to negative NAO values.

A negative quadratic dependence was obtained and the polynomial regression was statistically significant ($p<0.05$) between the residuals CPUE and the NAO index. The *proxy* explains around 32% of abundance variability of this species (Figure 2).

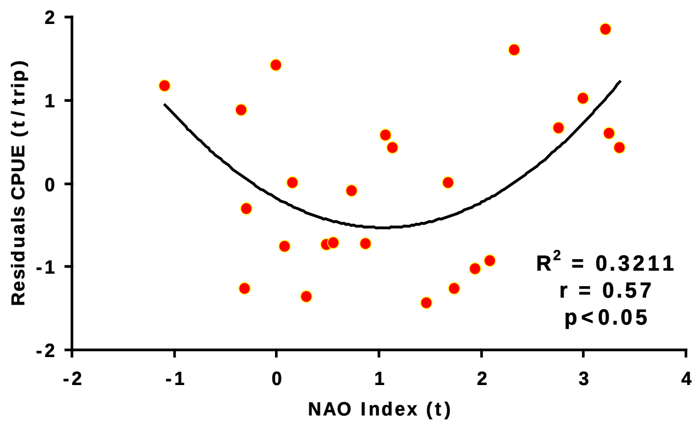

Figure 2. Negative polynomial relationship between residuals CPUE of *S. aurita* and NAO index at the same t.

Sardinella maderensis

A positive quadratic function was obtained, statistically significant ($p<0.05$), between the CPUE time series and the climatic *proxy*. In this case, the NAO explains around 42% of abundance variability of this species (Figure 3).

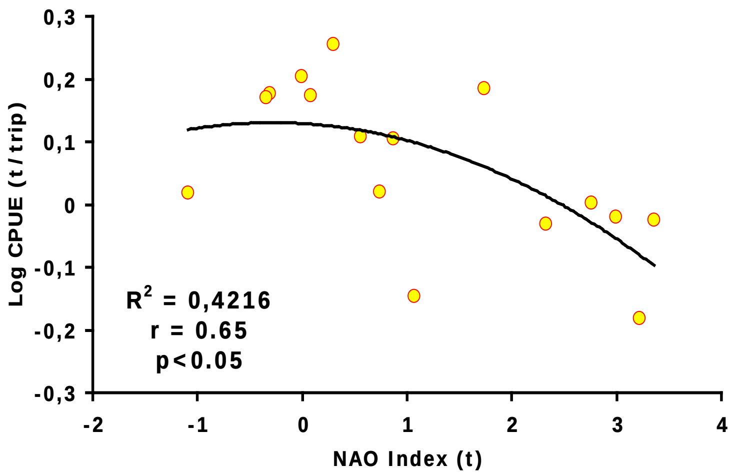

Figure 3. Positive polynomial relationship between residuals CPUE of *S. maderensis* and NAO index at the same t.

Sardina pilchardus

This species provided a weak fit, but one must take into account that is a very short time series (only 10 years).

The negative quadratic dependence obtained was not statistically significant ($p>0.05$). The NAO explains only 14% of abundance variability of this species. The results were not conclusive.

Discussion

The winter NAO index changes are supposed to have immediate effects on fast growing species such as small pelagics.

The quadratic responses may suggest an "environmental window" defined by the NAO for every species, showing a mid-high dependence of the abundance with respect to the NAO index for *Sardinella* species.

S. aurita presented a broad "environmental window", with optimal NAO values in the range from -1 to 0 and >2. *S. maderensis* showed an inverse relationship, with optimal NAO values between 0 and 1.7, given the fit to positive quadratic function.

S. pilchardus had the widest window (from -1.1 to 3.4) and a negative relationship with the NAO, as *S. aurita*, although the results are not conclusive, surely because the series is not long enough. However, this species has shown strong dependence with oceanographic conditions in the North Atlantic (Guisande *et al.*, 2001; Santos *et al.*, 2001), and one may assume that the response to the NAO index is close. Probably, a relationship would be indicated by a longer time series.

Contrasting reactions between *Sardinellas* species suggest important ecological differences in response to the same phenomena and a less competitive behavior of *S. maderensis*. In fact, this species is less abundant in the catches and its distribution is more restricted than that of *S. aurita*. In addition, the broad "environmental window" of this latter species could imply greater abundances and a wider latitudinal distribution when compared with *S. maderensis*, at it really occurs.

One may also deduce from these results that *S. maderensis* is a more "tropical" and *S. aurita* more "temperate" species.

The similar behaviour of *S. aurita* and *S. pilchardus*, another "temperate" species, could point to a comparable ecological role on both sides of the permanent upwelling, but the results are inconclusive with respect to the of sardine.

In general terms, it is necessary to use longer time series in order to establish conclusions about relationships with large-scale phenomena such as the NAO index and, in these cases, further analysis is required.

In any case, to describe and quantify these relationships it is helpful to consider climate factors as state variables in predictive and functional fishery models. Also, different kinds of relationships may explain diverse features in ecological terms, showing divergent effects over species under fishing pressure in the same region.

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3.3 Historical landings of small pelagics off North West Africa. "Signals" of the climatic effect on small pelagics in North West Africa and in the Canaries

M.T. García Santamaría, E. García-Isarch

Introduction

The North West African marine area located between 36ºN and 12ºN belongs to the Canary Current Large Marine Ecosystem, which is one of the most productive areas in the world. The high productivity of this ecosystem supports very important fishery resources that have led to a great development of the fishing activity in the area. West African stocks are exploited by the coastal countries as well as by foreign fleets. This fact advises the establishment of a scientific cooperation framework, over-arching cooperative actions, such as the assessment of the exploited resources. This scientific framework is provided by the Committee for the Eastern Central Atlantic Fishery (CECAF) and NW African stocks are assessed in the CECAF Working Groups (Subgroup North).

Three main data sources have been analysed to study the temporal evolution of small pelagics in North West Africa:

a) FishStat Plus-universal software for fishery statistical time series, compiled by the Food and Agriculture Organization (FAO). This provides only catch data.

b) Data compiled by the CECAF Working Groups of Small Pelagics (Subgroups North). These are catch data and effort data (not in all cases).

c) Spanish fishery data in Morocco. This source should be considered due to the higher disaggregation level in relation to the two above-mentioned. It corresponds to the anchovy and sardine data series of the Spanish fisheries developed in Moroccan waters which is managed by different fishing agreements since 1979. The control and monitoring of this fishery information is carried out by the Instituto Español de Oceanografía (IEO).

Temporal evolution of small pelagic catches in NW Africa

Figure 1 shows the catch trends of small and medium sized pelagic species in the last 20 years (1990–2010) in North West Africa, from Morocco to Senegal (both countries included).

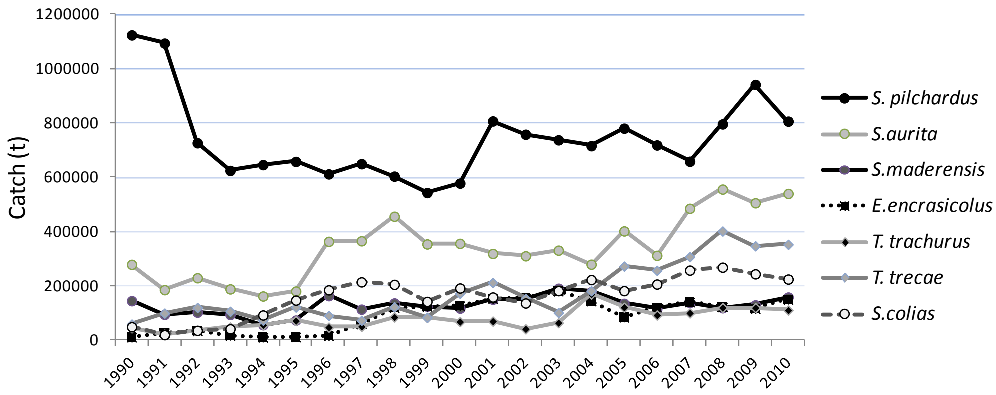

Figure 1. Catch trends of small and medium sized pelagic species in North West Africa. Period 1990–2010. Source: CECAF Small Pelagics Working Group, Subgroup North (FAO 2011, in press).

Sardine (*Sardina pilchardus*) comprises the highest catches during the whole period, followed by round sardinella (*Sardinella aurita*). It is worth mentioning the opposite catch trends of both species during this period. Sardine catches were maximal at the beginning of the nineties, when *S. aurita* was caught at very low levels. However, sardine showed a general decreasing trend in this decade, while sardinella increased to reach a very high level in 1998. The trends were opposite in the following years, with a sardine general increase in the period 1999–2005 and sardinella decrease in 1998–2004. Sardinella catches generally increased in the last years of the series, while sardine trends were more variable (decrease in 2005–2007, increased in 2007–2009 and new decrease in 2010).

Together with this opposite temporal catch trends, changes in the distribution patterns of sardine and round sardinella occurred in NW Africa during the last 20 years, with general displacement processes of both species (*S. pilchardus* towards the South, and *S. aurita* towards the North). In this sense, first records of sardine in Senegalese waters were reported at the end of the eighties, with maximal catches in the period 2004–2008. In the same period a general increase of *S. aurita* catches has been registered in Morocco.

Previous studies of climatic influence on small pelagics off NW Africa

There are several studies on the influence of climatic or other environmental conditions on fisheries and spatial and temporal reproduction/recruitment strategies of small pelagics in NW Africa. However, our research effort has not been concretely directed to this topic although we have developed several studies and observed certain evidences on the climatic/environmental effect on small pelagics that can be considered occasional and spread in time. Some examples are explained below:

- The analysis of the relationship between satellite-derived (AVHRR/NOAA-11) SST and the location of sardine fishing grounds of the Spanish purse seiner fleet in the NW African upwelling showed a SST range of 17.6°C–21.1°C in the sardine fishing grounds, while the SST corresponding to the maximal sardine yields was between 19.93°C–21.13°C (Ramos and Santamaría, 1998).
- The analysis of the relationship between SST and the catches of sardine and round sardinella in Mauritania in the period 2004–2007 showed a general decrease of sardine together with a progressive increase of *S. aurita* (Pascual-Alayón *et al*., 2008a). This clear seasonal variability in landings was coincident with both species spawning seasons (winter for sardine and early summer for sardinella).
- The analysis of the relationship between SST and the evolution of the Gonadosomatic Index (GSI) of *S. aurita* off Mauritania revealed the onset of the maturation process occurring during the SST rising periods, while the GSI decreased during the warmest months (Pascual-Alayón *et al*., 2008b).

Signals of the climatic influence on Small Pelagics off the Canary Islands

In the same way as in NW Africa, we have found certain signals that may reflect a climatic/environmental effect on the small pelagics off the Canary Islands. These are summarized as follow:

- The relationship between monthly satellite–derived SST and SST anomalies (SSTA) and a catch index (CI) of small and medium sized pelagic species (sardine *S. pilchardus*, round sardinella *S. aurita*, flat sardinella *S. maderensis*, anchovy *E. encrasicolus*, chub mackerel *Scomber colias* and horse mackerel *Trachurus picturatus*) in Gran Canaria was analyzed. Results showed that the CI increased with a lag in relation to a cooling process during the previous months and that , in turn, the CI decreased after the warming processes (López-Abellán *et al*., 2008). However, it is worth reminding that only two years were analysed and therefore these results should be considered with caution.
- Mean monthly lengths of *T. picturatus* sampled from Tenerife catches during the period from March 2005 to March 2006 were analysed in relation to monthly SSTs and SSTAs. Results showed that the species recruitment, considered as the period with the smaller mean lengths, occurred during the season with the maximal SST values and certain stabilization of SSTA (Jurado-Ruzafa and Santamaría, 2011).
- The spawning of *S. pilchardus* and *S. colias* was analysed in relation to SST, from Tenerife catches during the period March 2005 – March 2006. The GSIs of both species increased in the first quarter of the year coinciding with the period with the lowest SST values (about 19ºC).In contrast, GSIs were minimal during the warmest period. However, the qualitative analy-

sis showed that the GSI increases do not correspond to a spawning peak but to a post-spawning stage (Santamaría *et al*., 2008a). Although there are no studies about this, we wonder if this low spawning intensity could be related to a genetic migration process.

- A gradual replacement of sardine by round sardinella has been detected in the Canaries. Traditionally, sardine has been the second most important small pelagic species caught in the Canary Islands while round sardinella was an additional species without much importance. However, during the nineties, this situation changed and round sardinellas were more abundant than sardines during many years (Santamaría *et al*., 2008b). An important temperature rise was registered in the Canaries in 1995, with a maximum SST occurring in 1997. The warming of the sea water during this period may have favoured *S. aurita* and affected negatively *S. pilchardus*. However, last catch data from 2010/2011 revealed a new increase of sardine catches, reaching similar levels as round sardinella.
- The case of the anchovy off the Canary Islands in 1999: Anchovy catches traditionally had occurred off the eastern Canary Islands (Lanzarote, Fuerteventura and Gran Canaria). However, in 1999 large amounts of anchovy were caught off the western islands (Tenerife, La Gomera, La Palma and El Hierro). Satellite images showed unusual North-East trade winds during April and May 1999, that derived as an expansion of the African upwelling influence at the Canaries, at distances up to 450 km (El Hierro Island). This was reflected in the transport of cold and turbid waters (due to the high chlorophyll concentrations) to the traditionally oligotrophic insular ecosystems (Ramos, pers. comm.). The high anchovy catches offthe western islands could be attributed either to an exceptional recruitment due to better environmental conditions that favoured early life stages survival or to an exceptional larval transport from the African coastal waters to the Canary Islands. Currently, anchovy catches mainly occur (never in high amounts) off the eastern islands and are not very frequent off the western islands.
- An establishment of species of the Genus *Decapterus* has been observed off the Canary Islands. *Decapterus macarellus* and *D. punctatus* had been considered as rare species with sporadic presence off the western islands of the Canaries until the beginning of the 2000s. However, from 2007 onwards these species have been more or less continuously caught off a western island (La Palma) as well as off the central islands (Tenerife and Gran Canaria). This fact has been coincident with the SST and SSTA increases occurring during the same period that could have favoured the displacement and establishment of warmer species with high mobility such as these *Decapterus* spp (González-Lorenzo *et al*., 2011). On the other hand, there is a longitudinal gradient of temperature in the Canaries Islands in a way that the western islands are warmer than the others. This warmer and more oceanic character of the western islands could explain the higher presence of *D. macarellus* and *D. punctatus* ioff La Palma and El Hierro. The appearance and establishment of these species with southerly distributions off the Canaries lead us to suspect that a “tropicalization” phenomenon may be occurring in the area.

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3.4 Decadal changes in sardines and anchovies in the Canary Current Upwelling System

A.M. P. Santos

The Canary Current Upwelling System (CCUS) covers the latitudinal range 12–43º N and has some particularities in relation to the other three major Eastern Boundary Upwelling Systems (EBUS), namely a major interruption in the continuity of the system at the Strait of Gibraltar and that it is the only one with a sardine species from a different genus (*Sardina* vs *Sardinops)*. This poses, at least, two questions which have still not been answered: Is there a continuity of the flow between the northern (Iberia) and southern (NW Africa) part of the system? Why is there no alternation between sardine and anchovy regimes as in other EBUS?

The bulk of the sardine population is located in the southern part of CCUS off NW Africa. Important fluctuations in landings have been observed in the last 70 years but they seem to be out of phase between the two sub-regions (Iberian vs. NW Africa). The explanation for these fluctuations have been related, at least partially, to environmental drivers (e.g. Santos *et al.*, 2001, 2004, 2005; Borges *et al.*, 2003) but also to changes in exploitation (e.g. Carrera & Porteiro, 2003).

The normalised and detrended landing time series of sardine, anchovy and sardinella in the CCUS are presented in Figure 3.4. These time series were used to perform an exploratory analysis to investigate the relationships between small pelagic fish species in the CCUS and climatic indexes (the North Atlantic Oscillation (NAO) and the East Atlantic (EA) pattern).

The most interesting results of the correlation analysis between these time series showed:

1) Sardine and anchovy off NW Africa are positively correlated;

2) Sardine in ICES Div. IXa is negatively correlated to sardinella off NW Africa;

3) Sardine off NW Africa is negatively correlated to sardine in ICES Div. IXa. However, the correlation is not statistically significant at $p < 0.05$ (only at $p < 0.15$);

4) Sardine and anchovy in CCUS are, in general, correlated to the EA pattern, negatively in the case of sardine in ICES Div. IXa, and positively in the case of NW Africa sardine and anchovy in the whole CCUS;

5) Sardinella is only correlated to the NAO winter index.

The EA pattern positive phase is associated with above average temperatures and below average precipitation in these southern regions. This could, at least partially, explain:

1) The negative correlation of the EA pattern (January) with sardines in ICES Div. IXa, considering that buoyant plumes seem to be important features for the survival of sardine larvae in the spawning grounds off Western Iberia (e.g. Santos *et al.*, 2004).

2) The positive correlation with anchovies, considering that spawning in the region is triggered by an increase of sea surface temperatures. However, it does not explain the association between anchovy and rivers outflow.

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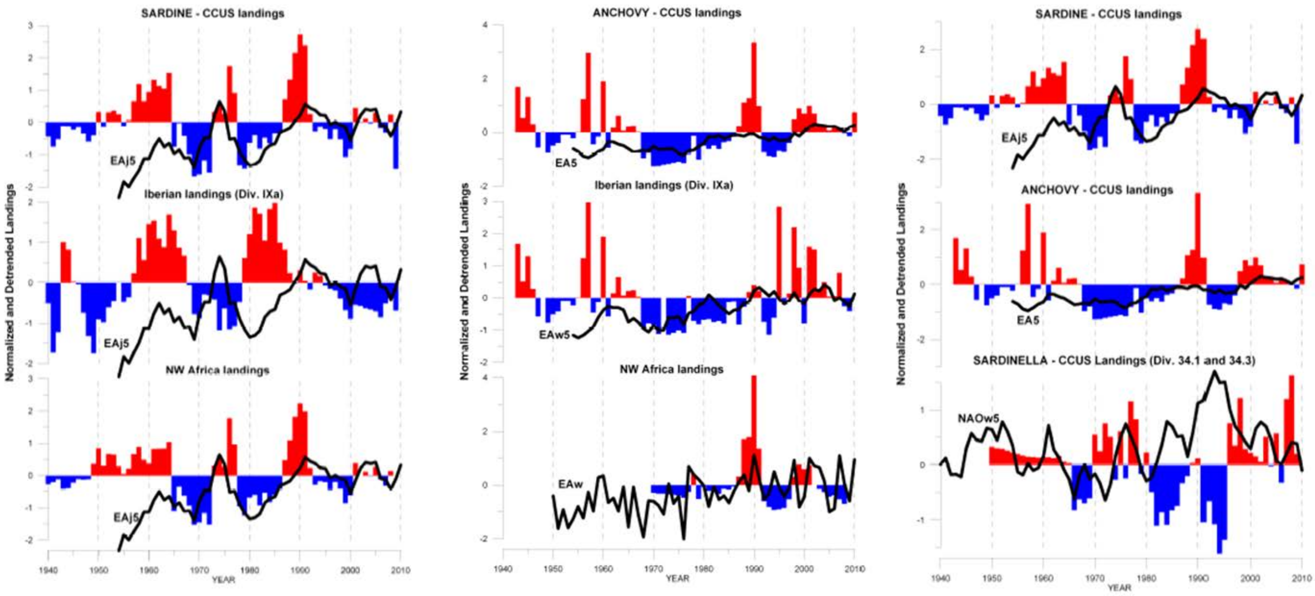

Figure 3.4. Normalised and detrended time-series of landings in the CCUS for sardine, anchovy and sardinella. Superimposed (black lines) are the climate indexes that showed the best correlations with the landing data (EAj5 is the 5-yrs running mean of the January East Atlantic (EA) pattern; EA5 is the 5-yrs running mean of the annual EA; EAw is the EA in winter months; EAw5 the 5-yrs running mean of the previous; NAOw5 is the 5-yrs running mean of the North Atlantic Oscillation winter index).

Data sources: Sardine and anchovy landing data from ICES WGSANSA; Sardine NW Africa landing data from Souad Kifani and FAO Working Group on the Assessment of Small Pelagic Fish off Northwest Africa; Anchovy NW Africa landing data from FAO Capture Production Statistics; Sardinella landing data from FAO Capture Production Statistics and FAO COPACE/PACE Series 91/58.

3.5 Overview of large and meso-scale oceanographic processes relevant to the Gulf of Cádiz

F. Ramos, R. Sánchez, Mª Paz Jiménez

The Gulf of Cádiz (GoC, Figure 1) is placed in the northern area of the Canary Current Large Marine Ecosystem and shares many of the oceanographic characteristics typical of the Eastern Boundary Upwelling Systems (EBUSs) in the mid-latitudes (e.g. seasonal alternation of a regime of winds favourable to the coastal upwelling, a high biological productivity associated to this process, a system of zonal fronts and currents, and a coastal transition zone with a set of mesoscale structures that deform the fronts favouring the coast-open ocean exchange). Its main distinctive features are: the rupture of the N-S orientation of the coastline typical of the *EBUS*s by an E-W orientated coastline, the influence of a northern branch of the Azores Current, the presence of the Strait of Gibraltar with its Atlantic-Mediterranean water exchanges and mixing, and the seasonality, that produces alternate regimes in the surface waters and an intense generation of mesoscale features, which modulate and are modulated by the exchange in the Strait (see e.g., García-Lafuente & Ruiz, 2007; Sánchez *et al*., 2006).

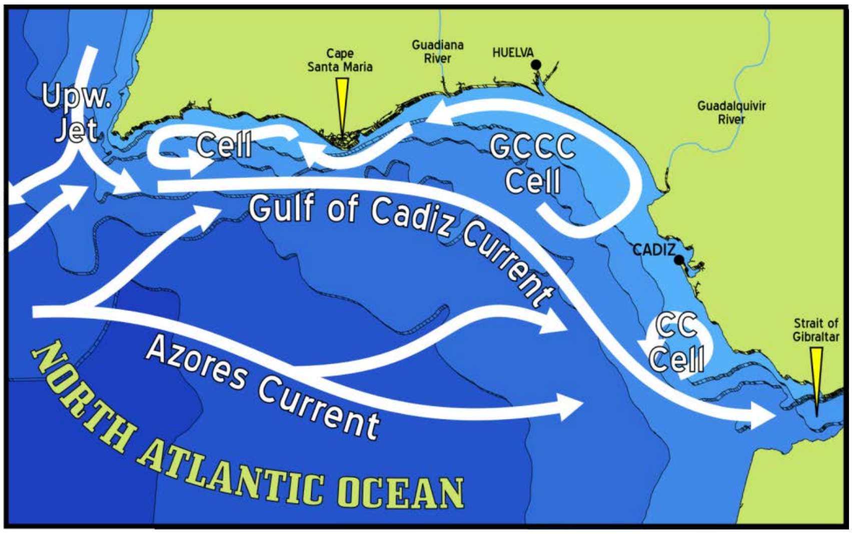

Figure 1. Surface circulation in the GoC. CC Cell: cyclonic cell over the shoals in front of Cape Trafalgar; GCCC Cell: Gulf of Cadiz Counter Current; Upw. Jet: Portuguese upwelling (after Folkard *et al*., 1997; Peliz and Fiuza, 1999; Relvas and Barton, 2002; Sánchez and Relvas, 2003; Criado-Aldeanueva *et al*., 2006; García-Lafuente *et al*., 2006; Sánchez *et al*., 2006; Peliz *et al*., 2009).

Cape Santa María divides the GoC shelf in 2 sectors that support different oceanographic processes (forcings by mass and energy inputs and tidal processes) with the consequence that the eastern shelf is warmer and more productive than the western one, which is subject to a more permanent upwelling (Navarro & Ruiz, 2006; Prieto *et al*., 2009). In this eastern sector, which is shallower and which has a lower intensity of currents, the Guadalquivir estuary also plays a relevant role (by constant tidal mixing) in the control of the biological activity on the shelf. For these reasons, these shelf waters of the NE GoC, mainly those ones in the inner shelf surrounding the Guadalquivir River mouth, offer a favourable environment for the development of anchovy eggs and larvae in spring-summer and have become the main GoC anchovy spawning area (Baldó *et al*., 2006). The outer stretch of the Guadalquivir estuary is used almost synchronously by anchovy post-larvae and juveniles as a nursery area. Recruitment to the estuary occurs when water temperature and salinity are relatively high, but turbidity and rainfall are relatively low. Some studies (Baldó & Drake, 2002; Drake *et al*., 2007; Fernández-Delgado *et al*., 2007; González-Ortegón *et al*., 2010) point out that, within this optimal window, the main factor regulating the nursery function of the estuary is the food availability of key-prey species (copepods for post-larvae, the mysid *Mesopodopsis slabberi* for juveniles).

However, persistent easterly bursts (preceded and followed by intervals with a lower frequency of this wind) may generate significant modifications in the oceanographic regime in the GoC (i.e. decrease of SST, oligotrophy, offshore advection of early stages away from favourable conditions), which can influence markedly the reproductive success of the species. These detrimental conditions were evident during the period 1990–1997 and they seemed to affect the development conditions of eggs and larvae, which could have resulted in failed recruitments in those years as evidenced by the severe drop of landings in 1995–1996 (Ruiz *et al*., 2006, 2009; Figure 2). According to the authors, this drop of landings resembled more the easterly signal than the NAO index or precipitation. Conversely, the 1996 rain fall peak (and associated river discharges) – clearly reflecting the dramatic change in the NAO index– may have played a role in the recovery of 1997 anchovy landings.

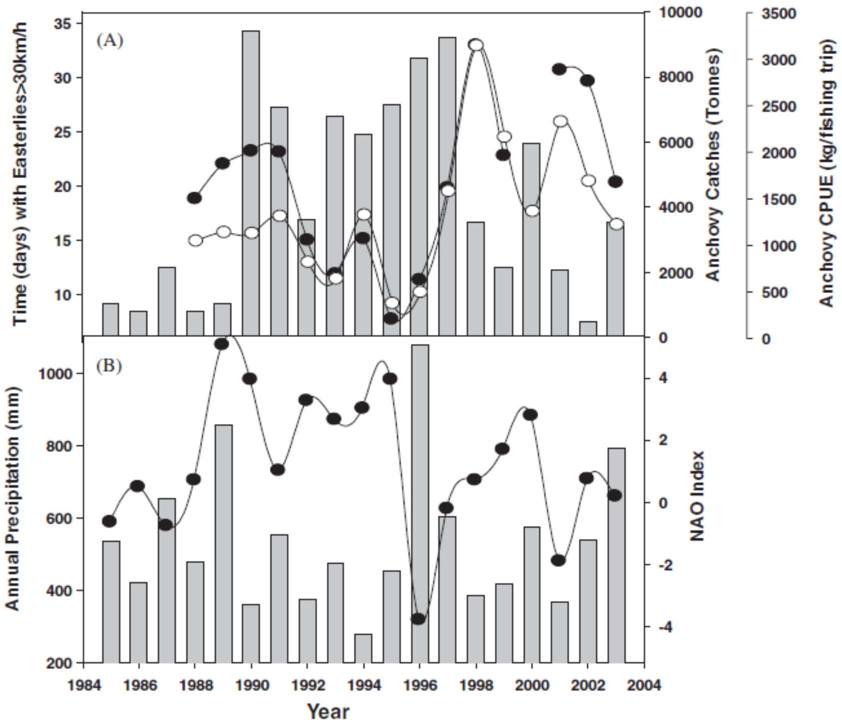

Figure 2. A) GoC anchovy landings (ICES Subdivision IXa South; black circles) and Barbate's single-purpose purse-seine fleet CPUE (white circles, in kg/fishing trip). Barbate is considered as a reference fleet in the GoC anchovy harvesting. Landing data for 2000 is not included in the graph as catches were not representative due to social conflicts in the fleet. Bars accumulate the time when easterlies stronger than 30 km/h hit Cádiz over the period from March to September. B) Circles and bars indicate North Atlantic Oscillation index and annual precipitation, respectively. Source: Ruiz *et al.* (2006).

The GoC anchovy population has also experienced a noticeable decreasing trend during the period 2008–2010 as a probable consequence of successive failures in the recruitment strength in those years (Figure 3; ICES, 2011). A man-induced alteration of the nursery function of the Guadalquivir estuary, caused by episodes of highly persistent turbidity events (HPTE; González-Ortegón *et al.*, 2010), during the anchovy recruitment seasons in 2008, 2009 and 2010 could be one plausible explanation. Thus, the control of the Guadalquivir River flow, from a dam 110 km upstream, has an immediate effect on the estuarine salinity gradient, displacing it either seaward (reduction) or upstream (enlargement of the estuarine area used as nursery). This also affects the input of nutrients to the estuary and adjacent coastal areas. The abovementioned HPTEs used to start with strong and sudden freshwater discharges after relatively long periods of very low freshwater inflow and caused significant decreases in abundances of anchovy recruits and the mysid *Mesopodopsis slabberi*, its main prey (Figure 4).

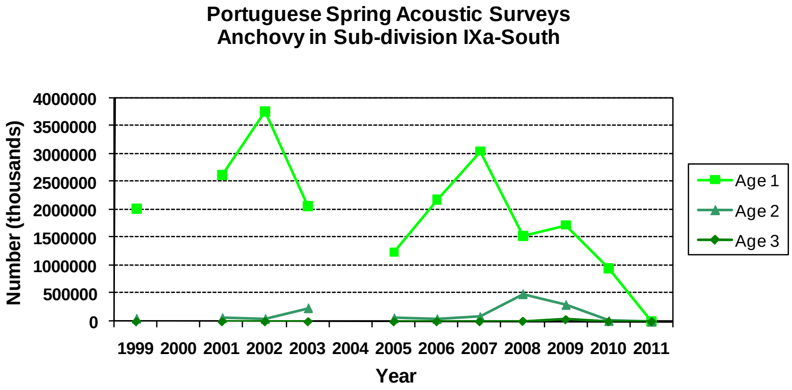

Figure 3. Age structured estimates of GoC anchovy abundance from the Portuguese acoustic survey series. The null estimates for the 2011 Portuguese survey should be considered with caution (ICES, 2011).

All of these evidences confirm that the GoC anchovy stock relies on recruits to persist and, therefore, is highly vulnerable to ocean processes and totally controlled by environment fluctuations.

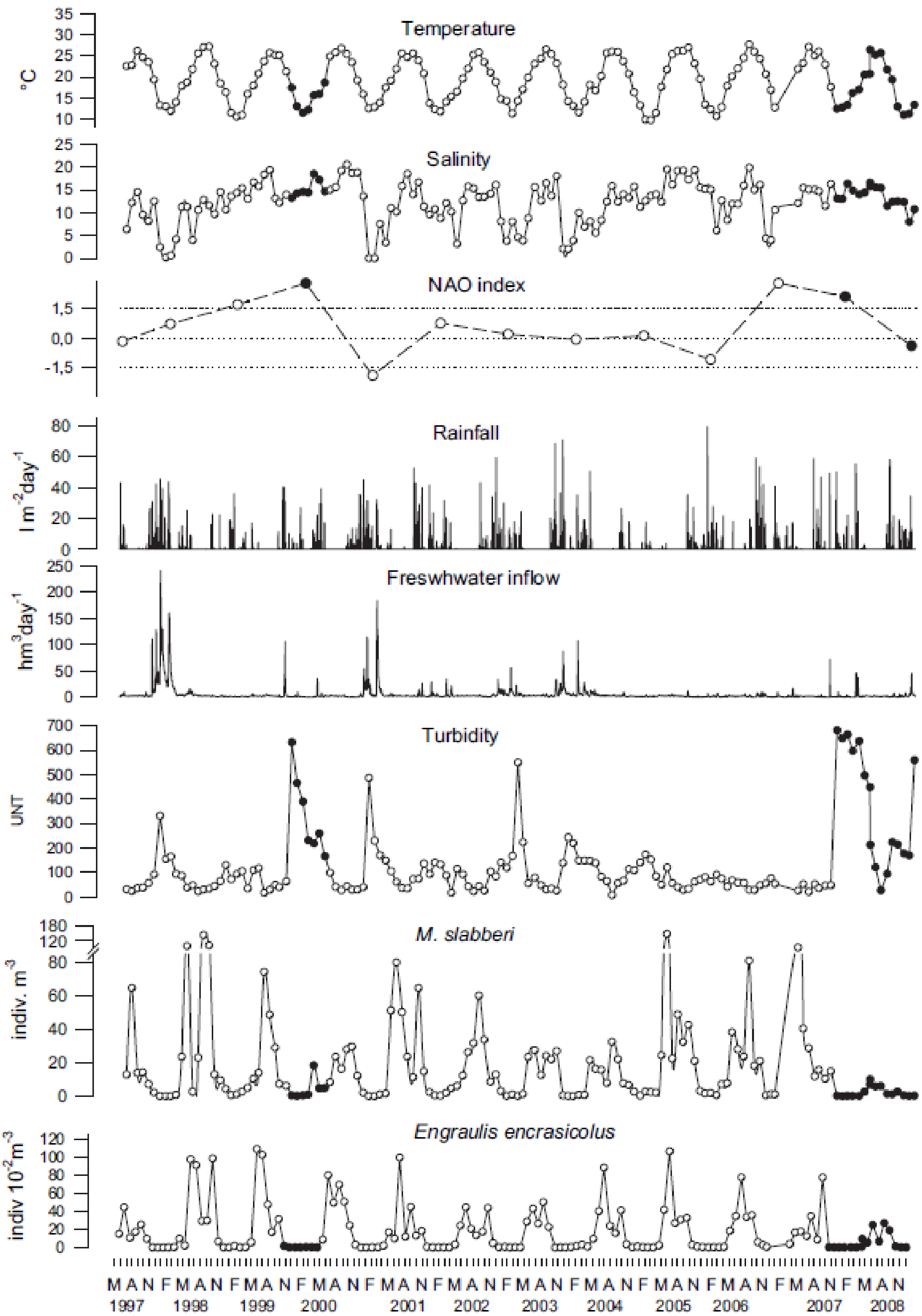

Figure 4. Monthly/daily mean values of environmental variables (water temperature, salinity, rainfall, freshwater inflow, and turbidity), mysid and anchovy recruits densities in the Guadalquivir Estuary from May 1997 to February 2009, and winter NAO index values for the same period. F, February, M, May, A, August, N, November. Shaded symbols, samples collected during HPTEs (composite figure from González-Ortegón *et al.*, 2010).

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3.6 Small pelagic fish research in the Mediterranean by the Spanish Institute of Oceanography: available data series for a climatic analysis

A. García, A. Giraldez

The Spanish Institute of Oceanography (IEO) as the official institution in charge of maritime affairs regarding fisheries and marine environmental research has the necessary infrastructure to provide assessment results to the Spanish administration. The small pelagic fisheries research division of the Mediterranean counts on different projects whose objectives have direct or indirect relationship with small pelagic fish research studies.

In first place, the evaluation of small pelagics is through the implementation of direct methods by echo-acoustic tracking surveys and by indirect methods using age-based modelling approaches. The project co-funded by the UE MEDIAS (Mediterranean Acoustics Surveys) covers on a yearly basis the Geographical Subarea GSA06 of the General Fisheries Council of the Mediterrean (GFCM) (Northen Spain) and partly GSA01 (Northern Alboran Sea); (Figure 1). The echo-acoustic surveys undertaken by the IEO represent the longest time series of annual surveys of the Mediterranean, dating back as far as 1990.

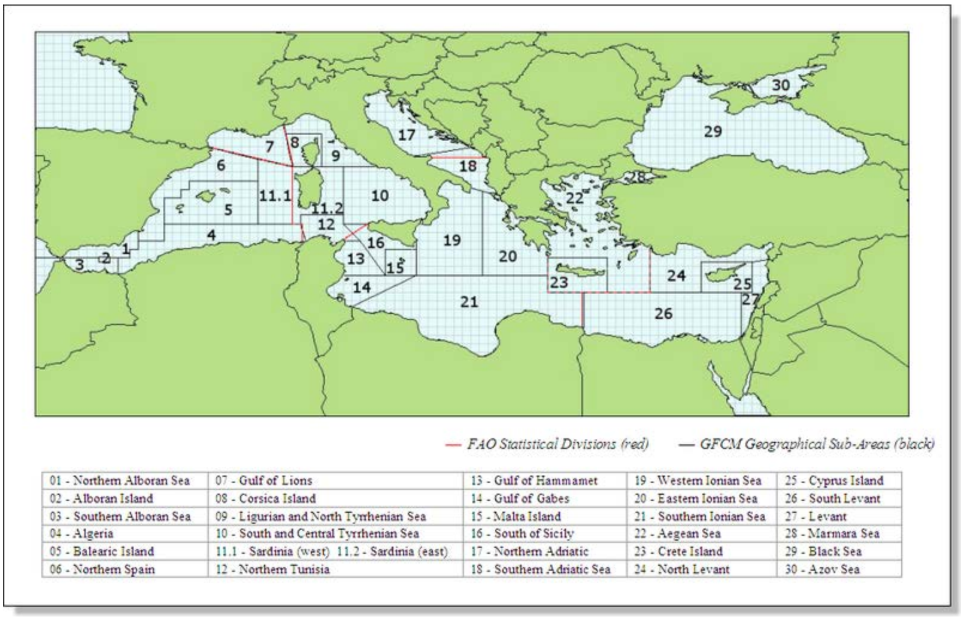


Fig. 1. GFCM Geographical Statistical divisions

The Data Collection Program of the IEO funded by the UE contains the information gathered from the fisheries, sampling surveys, and observers' embarkment surveys. Moreover, the ichthyoplankton group of the oceanographic centres of Málaga, Madrid and the Baleares provide expertise and collaboration in aspects related with early life history aspects of small pelagic fish ecology, as well as with the delimitation of spawning grounds by the use of CUFES (Continuous Underwater Fish Egg Sampler). Much of this collaboration has been envisaged in the framework of the project MEDIAS. Furthermore, projects financed by the Spanish National Research Council have allowed to study the early life trophic food web dynamics in key larval concentration sites off the SW Mediterranean coasts (TROFOALBORAN project).

The longest time series available with regards to small pelagic fisheries refer to the volume of landings. Some of these series date back as far as 1945. These landing data series were made available during the ICES Workshop on Small Pelagic Fishes, their Ecosystems and Climate Impact and used for analysis of climatic influence on stock fluctuations. Although one might think that landings are not the most ideal data set for this sort of analysis, important magnitudes in landing variability cannot be solely attributed to an increase or decrease of effort. Furthermore, the expert's advice on these changes was considered essential.

Small pelagic stocks off the Spanish Mediterranean coasts are included in two main GFCM statistical divisions: GSA01 which corresponds to the Alborán Sea and GSA06 which corresponds to the northern area generically called *Tramontana*. The main species found in these areas correspond to sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*) and sardinella (*Sardinella aurita*). The statistical divisions also correspond to distinct characteristics in relation to hydrography, bottom topography and biological features. The main mass of small pelagic stocks is within GSA06 due to its ample shelf whose hydrography and productivity is highly influenced by the outflows of the Rhone and Ebro rivers. Opposed to this situation, the Alborán Sea with its narrow continental shelf where river outflow is negligible in comparison with the NW Mediterranean and whose productivity is highly influenced by the incoming surface circulation of Atlantic waters.

An analysis of the sardine landings from both areas shows contrastingly distinct patterns (Figure 2). While the Alborán Sea's landings show strong fluctuations since the sixties, the landings of GSA06 increased till mid-1990. This increase was mainly caused by the progressive increase of fishing effort carried out during the mid-eighties. Nonetheless, although fishing effort decreased progressively from the mid-nineties onward, GSA06 shows a significant decreasing trend to the present time in opposition to the yearly fluctuations that are observed in GSA01.

With regards to anchovy, the same type of differences occurs in the comparison between both statistical areas (Figure 3). From the mid-1970 to the mid-1980, anchovy resources were very abundant in both areas mainly due to the fact that a great part of the exploitation was undertaken in waters of the Moroccan coasts. Nonetheless, in 1985, a collapse of this resource occurred in both areas. The state of depletion of the anchovy resource has been maintained since then in GSA01. The anchovy resources off the *Tramontana* region off the northern coasts (GSA06) recovered to its former levels in the late eighties till the mid-nineties when the species began to show another decline. With the exception of the good 2001 recruitment shown in both statistical divisions, the anchovy resource has shown a progressive decline till 2008. Within this rather sombre perspective, the resource has shown two good recruitments during 2009 and 2010.

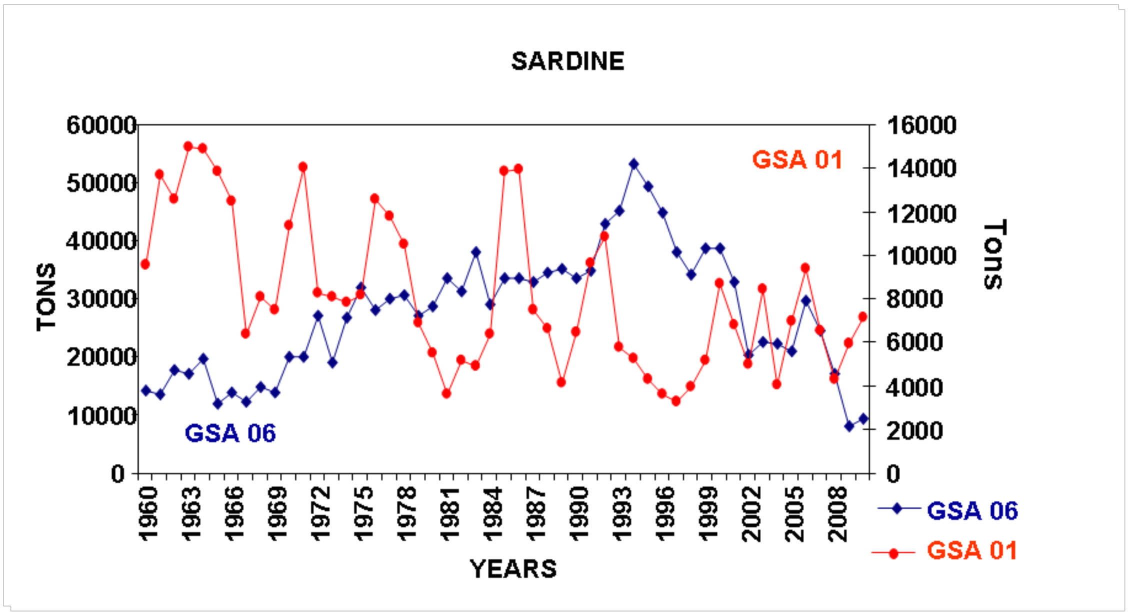


Figure 2. Sardine landing data series from 1960 to 2010.

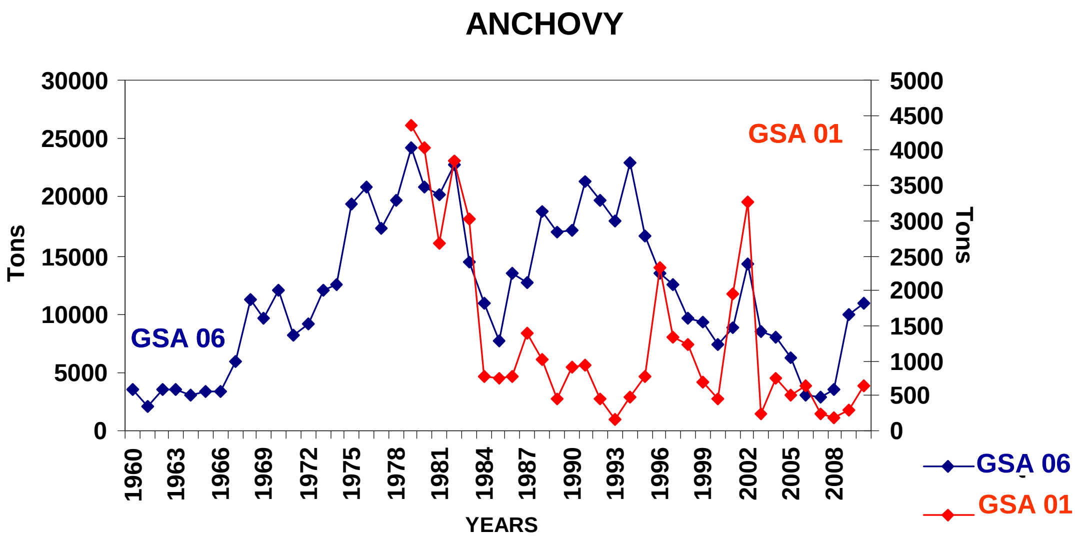


Figure 3. Anchovy landing data series from 1960 to 2010.

To examine the causes of such variability, various aspects of the reproductive biology of anchovy (*Engraulis encrasicolus* L.) in the Alboran Sea were studied for two time periods separated by 11 years: 1989–1992 and 2003–2007 (Giraldez, A.[1]). Correlation between the gonadosomatic index (GSI) and sea surface temperature was assessed by GAMs models. There was a significant positive correlation between GSI and sea surface temperature ($p < 0.001$). Temperatures in the fourth quarter of the second period

[1] Giráldez, A. 2009. Study on the temporal variability of reproductive parameters of anchovy (*Engraulis encrasicolus* L.) in the Alboran Sea. Memoria DEA Universidad de Málaga.

(2004–2007) were significantly higher than those for the first period (1990–1992), resulting in significantly higher GSI values in that quarter and period.

The GSI shows a more prolonged period of reproduction along the year in the period 2004–2007 in comparison with the period 1990–1992 (Figure 4). The condition factor (CF) showed a very different profile in both periods (Figure 5), which was not correlated with either the concentration of chlorophyll in the Alboran Sea and the GSI. A change in the nutritional status of anchovy is observed. During the first period, condition factor (CF) changes were sharper and more acute indicating environmentally induced changes, while during the second period a subsistence strategy seems to have prevailed.

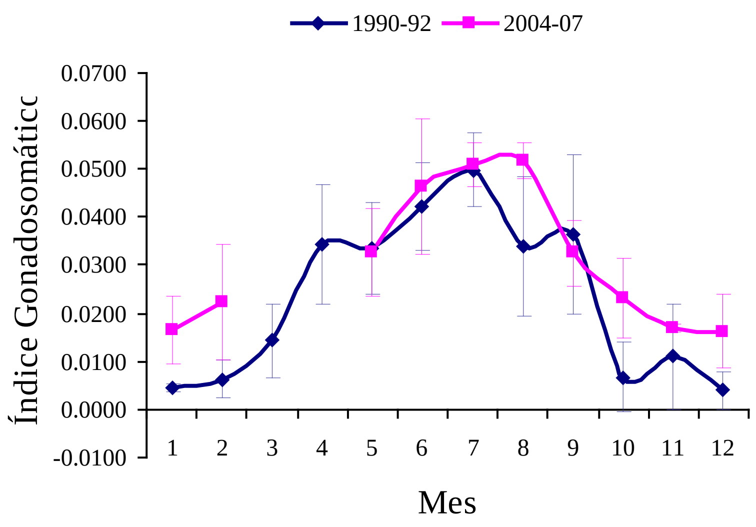


Figure 4. Mean monthly GSI between the two periods with standard deviations.

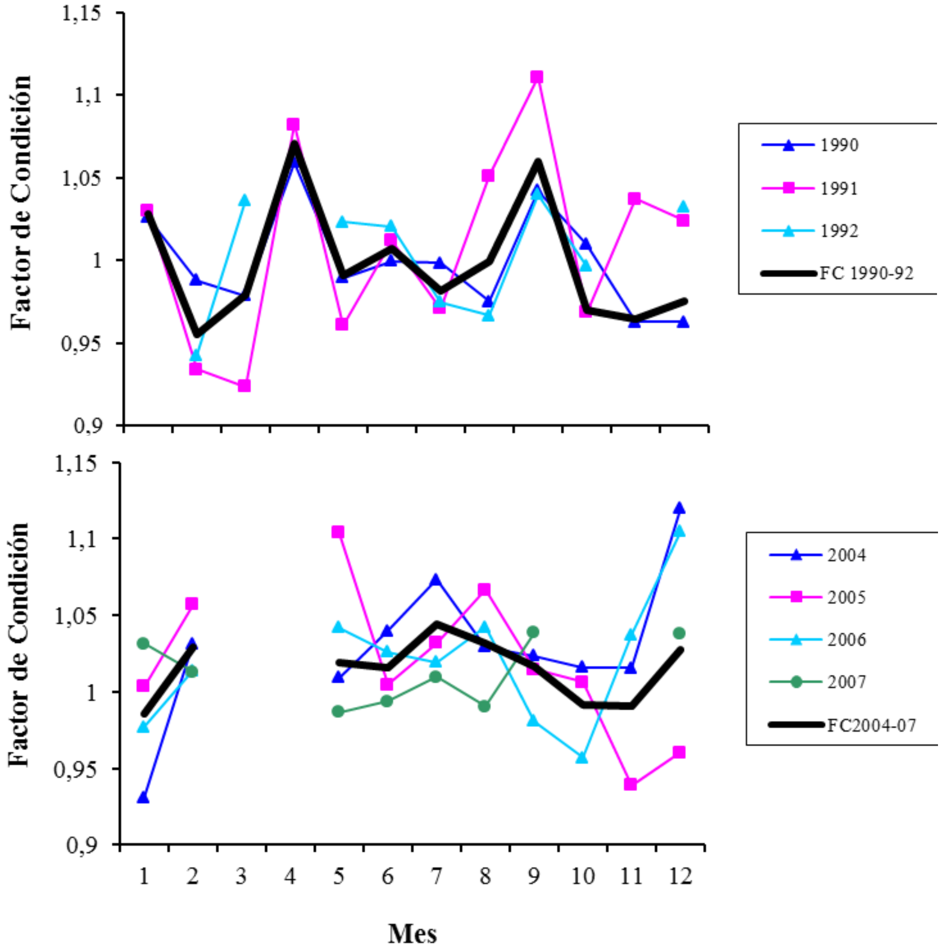


Figure 5. Condition factor for each of the years and monthly means for each period.

The decrease of sardine and anchovy stocks off the Mediterranean since the mid-nineties was accompanied by an increase of another clupeoid, *Sardinella aurita*, which was more pronounced in the NW Mediterranean region than in the Alborán Sea. Nonetheless, recovery of landing data series since 1945 shows that this species had shown similar peak periods of abundance from the mid-forties to the late fifties in the Mediterranean (Figure 6). *S. aurita* was not the only species that increased during the last period of the series. Data from the acoustic surveys undertaken on a yearly basis also observed the increase of medium sized pelagics species, among which different Mediterranean species of *Trachurus* stand out, together with *Scomber sp*. and *Boops boops*. Thus, it seems that the pelagic domain shifted in terms of relative composition (Internal IEO Reports of Acoustic surveys).

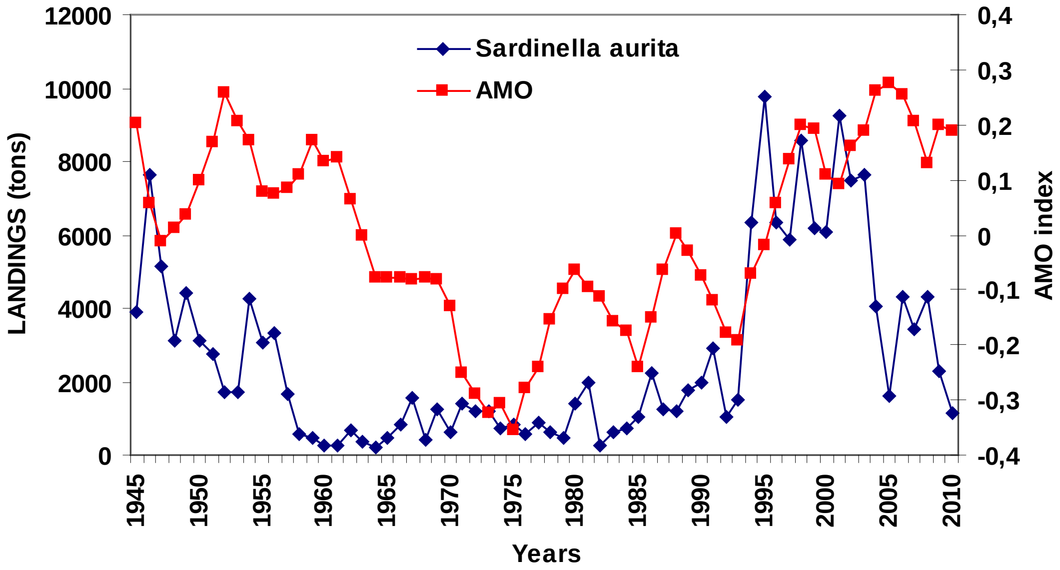


Figure 6. ***Sardinella aurita*** **landings data series together with the mean annual value of the AMO.**

In view of the signals of stock variability as shown by the historical data series of landings, an analysis of climatic indices with the oscillations of the catch was undertaken. The most adequate climatic index is the Atlantic Multidecadal Oscillation (AMO); (Figure 6). Positive values of this index are related with warm periods while negative values respond to cool climatic regimes. The increase of *S. aurita*, a tropical species preferably inclined to warmer temperatures, are clearly associated with the warm AMO periods of the Mediterranean. Inversely, anchovy showed highest abundances in the period corresponding to cooler weather regimes in the Mediterranean (Figure 7).

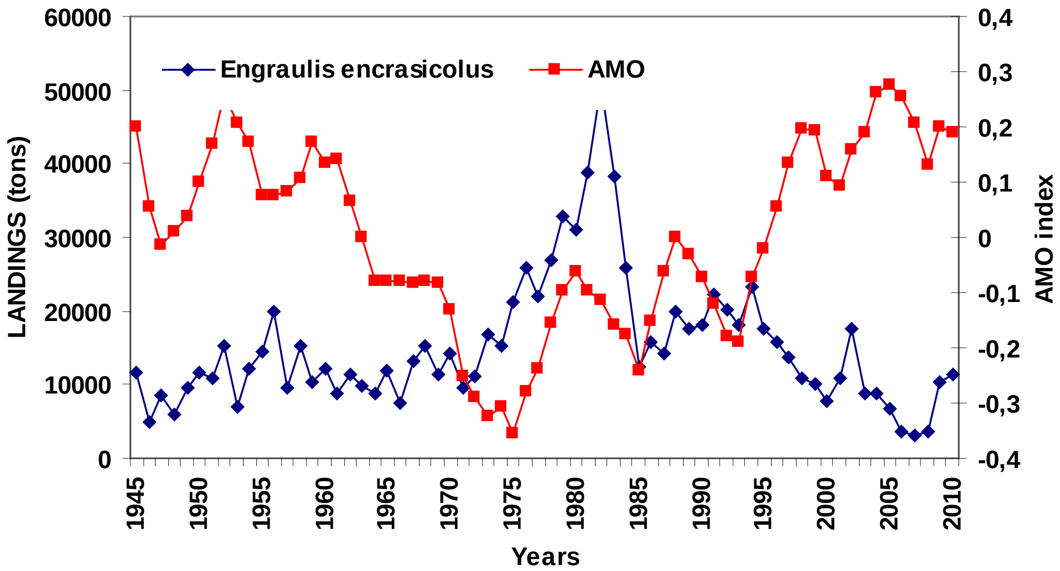


Figure 7. ***Engraulis encrasicolus*** **landings data series together with the mean annual value of the AMO.**

The relationship of AMO with sardine fluctuations was not that clear (Figure 8). It was discussed that this may be due to the fact that not all species respond in the same manner to climatic changes.

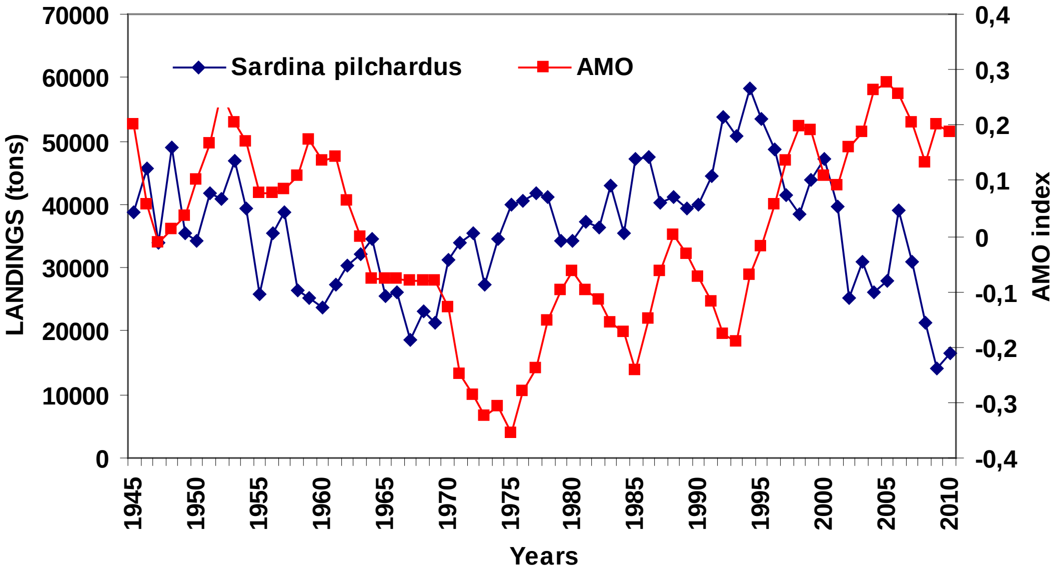


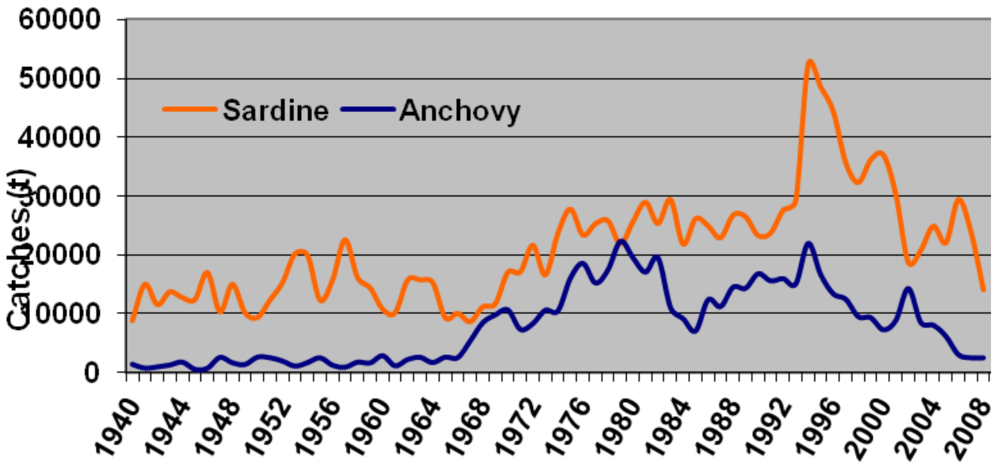
Figure 8. ***Sardina pilchardus*** **landings data series together with the mean annual value of the AMO.**

3.7 Environmental impacts on anchovies; sardines and sardinellas in the north western Mediterranean

I.Palomera

The small pelagic fish inhabiting the NW Mediterranean Sea are European anchovy (*Engraulis encrasicolus* L.), sardine (*Sardina pilchardus* Walb.), round sardinella (*Sardinella aurita*) and sprat (*Sprattus sprattus*). These four species represent almost 50% of the total fish landings in the whole Mediterranean. In the NW Mediterranean Sea, anchovy and sardine are the most important species in terms of both biomass and commercial interest. Round sardinella and sprat are also present at lower levels of biomass but they are of little commercial interest.

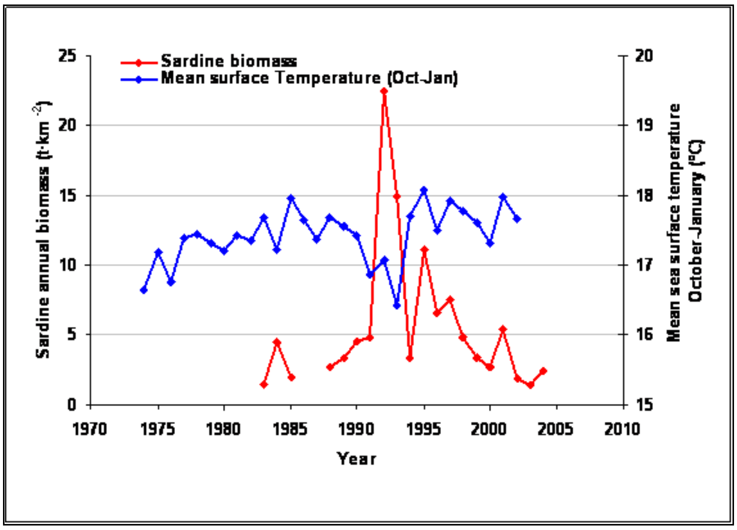
The commercial exploitation of small pelagic fish in the NW Mediterranean has been significant since the early 1940s. Catches were initially dominated by sardine, probably due to its coastal distribution. Improvements in fishing technology in the 1960s allowed fishing to be carried out offshore and anchovy catches increased substantially, in parallel with a continuous increase in sardine catches. Although sardine makes up the largest share, anchovy reaches a higher price in the market and is thus more important and subject to heavier fishing pressure.



Scientific acoustic surveys are routinely performed in the NW Mediterranean coast by Spanish and French research groups to assess the biomass of anchovy and sardine. Daily Egg Production Methods (DEPM) have also been sporadically applied in the region to anchovy spawning stocks in the Gulf of Lions and the Catalan Sea (Palomera *et al.* 2007).

Biomass data from the Gulf of Lions since the 1990s show a divergent trend for anchovy and sardine, with a peak in different years. But nowadays both species have very low levels of biomass. In the Catalan Sea both species are declining: the sardine from the 1990s on , and the anchovy from 2001 on. The sardine has now very low biomass levels and the anchovy seems to stabilize at low levels in 2009. Both regions show a decline in anchovy and sardine landings from the middle 1990s, which is more marked in the Catalan Sea.

In the NW Mediterranean production of sardine and anchovy is clearly influenced by changes in the environment (e.g. river runoff and wind mixing: Lloret *et al.*, 2002 and 2004). In the South Catalan Sea a negative relationship of sardine biomass and the mean SST has been also noticed during the spawning months, probably related with the colder water conditions required by sardine for spawning and larval development. The observed temperature increase during warm periods, with higher sea water temperatures during winter time from the 1970s on, had probably a negative impact on sardine spawning and recruitment (Palomera *et al.*, 2007).



At the global scale, two temperature regimes are evident in the NW Mediterranean between 1950 and 2003: the period 1950–1980, characterized by negative air temperature anomalies, and the period 1981–2003, with positive anomalies. Small pelagic fish biomasses in the NW Mediterranean region seem to have reacted to a global warming trend, as observed by a decrease in the abundance of sardine and anchovy and a increase in the distribution area and abundances of round sardinella (Sabatés *et al.* 2006).

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3.8 Population dynamics of small pelagic species in the Adriatic Sea: Stock Assessment Models and Environmental Factors

P. Carpi, A. Santojanni, A. Russo

The Adriatic Sea is a semi-enclosed basin, which communicates with the rest of the Mediterranean Sea through the Otranto Channel. The overall circulation is driven by the Po River outflow, that is the largest fresh water input of the basin, by the surface fluxes acting at the surface, which force the circulation to be seasonal, and by the external flow exchange with the Mediterranean, that brings heat and salty waters into the circulation.

The Italian fishery of small pelagic (mainly anchovy and sardine) is one of the most productive fisheries in the Adriatic: in the 2008, for example, this fishery accounted for about the 31% of the overall national catches. In the early 80s the landings reached the highest value of 54 000 t: the main reason for these high catches was a regulation from the Comunità Economica Europea (CEE) that entrusted an Italian agency to buy the unsold catches from the fishermen for a price sometimes higher than the market price itself.

Since 1975, The CNR-ISMAR of Ancona has been collecting data on landings and morphometric parameters of small pelagics, covering the main ports along the Italian coast and gathering information from the ports on the eastern side of the basin (i.e. from Yugoslavia first, then Slovenia and Croatia). The landings of anchovy dropped to really low values in the 1987, reaching the minimum values of 5900 t in the 1988, while sardine landings started a slow decrease in the late 1980s, reaching the minimum values in the 2006; after this year the catch started increasing again.

The preliminary results presented here refer only to the anchovy stock.

The total landings were treated in order to get catch at age time series and to obtain the input data necessary to estimate the total biomass at sea by the means of population dynamics methods (i.e. Virtual Population Analysis and Integrated Catch Analysis).

Once the annual recruitment and the total biomass at sea were estimated, the data were correlated to some environmental variables (i.e. SST, Po river flow rate, q coefficient which is the heat flux at the surface, NAO index and Mediterranean Oscillation Index (MOI)). Each environmental variable was averaged along the whole area and each year has been divided into 3 months periods. Besides, one year time lag between environment and recruitment was considered in the comparisons.

Autocorrelation between variables has been tested. Principal Component Analysis (PCA) and Redundancy Analysis (RDA) methods were chosen to explore the internal structure of the data. Both techniques stressed the importance of the SST and the Po river flow rate and detected a clear jump between the 1987/1988 (the years of the collapse) and the previous and following years.

Dynamic Factor Analysis (DFA) from Zuur *et al*. (2003) has been performed as well: this technique has been designed to work in time series analysis, to find latent common trends in the data. Two common trends have been detected, but the model has still to be improved.

General Linear Models (GLM) and Generalized Additive Models (GAM) have been developed: the results were consistent with previous studies (i.e.: significant relationship found for the SST, the Po river outflow rate and the NAO (Santojanni *et al.*, 2006)). In addition, the q coefficient was significant in spring, and contributed significantly to the model in the fall months.

Improvements to the models used are still necessary and some questions have to be investigated, such as: is the extension of the anchovy spawning season observed in the last years due to the increasing trend of the observed temperature?

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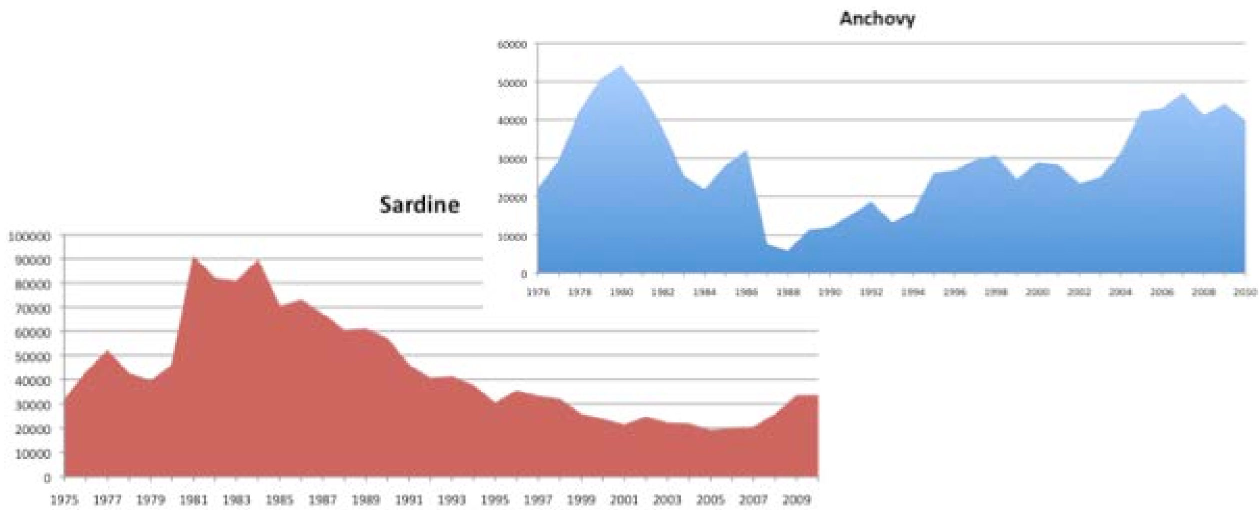

SEASON	MODEL	Variable	P-value	Deviance Expl
Winter	R ~ s(SST) + s(Po)	s(SST)	0.0114 *	79.4%
		s(Po)	0.0314 *	
Spring	R ~ s(SST) + s(Q)	s(SST)	1.27e-05 ***	66%
		s(Q)	0.0161 *	
Summer	R ~ s(SST) + s(Po) + s(NAO)	s(SST)	2.91e-05 ***	73.5%
		s(Po)	0.1004	
		s(NAO)	0.0368 *	
Fall	R ~ s(SST) + s(Q)	s(SST)	0.000797 ***	73.2%
		s(Q)	0.486725	

3.9 Biomass evaluation of anchovy (*E. encrasicolus*), sardine (*S. pilchardus*) and sprat (*S. sprattus*) in the western Adriatic Sea by means of acoustics and preliminary analysis of possible relationships with environmental parameters

A. De Felice

Acoustic surveys on small pelagic fish in the western side of the Adriatic Sea were carried out by ISMAR-CNR of Ancona since 1976 within the framework of several national and one EU (European Union) projects. From 2009 onwards, the above mentioned surveys are integrated into a group of coordinated acoustic surveys on small pelagic fish which are funded by the EU in cooperation with local Ministries under the MEDIAS framework (pan-MEDIterranean Acoustic Surveys). These mandatory MEDIAS acoustic surveys incorporate the joint work of many Mediterranean research institutions form several countries (Italy, Greece, Spain, France, Malta, Slovenia); also, Romania and Bulgaria joined the group and adopted the protocol for planned surveys in the Black Sea.

In addition to the MEDIAS surveys, other acoustic surveys to estimate small pelagic fish biomass were carried out in 2002, 2004 and 2005 on the continental shelf off Montenegro with the sponsorship first of Montenegro Government and then of the FAO AdriaMed Project (since 2005); afterwards the study area was extended to Albania in 2008, 2010 and 2011.

In synchrony with the acoustic survey an eggs and larvae survey is carried out on anchovy since 2005 while in the western side of GSA 18 this is carried out since 2010 in order to estimate Spawning Stock Biomass of anchovy by the Daily Egg Production Method.

The main target species of the acoustic surveys in the Adriatic are *E. encrasicolus* and *S. pilchardus*; small pelagics of secondary importance are *S. sprattus*, *S. scombrus*, *S. japonicus*, *T. trachurus*, *T. mediterraneus*, *S. aurita*, *B. boops*, *Spicara spp.* etc..

The survey design is made up by a grid of parallel transects, perpendicular to the coastline; inter-transect distance is 10 nautical miles, 8 in areas in which the continental shelf is narrow or where political boundaries are present.

In the Adriatic Sea, due to the Treaty of Osimo (1978), transects cannot go further than the Mid Line that subdivides this sea in two equal parts. Near Pomo Pits and along the Apulia coasts the limit is given by the 200 metres bathymetry (Figure 1).

Acoustic data are logged by the scientific echosounder Simrad EK60 and analyzed with Myriax Echoview software.

The geographical position is derived through a GPS system; the vessel speed is 9.5 knots during the survey.

The echosurvey is made every year during summer (July–September) since 1976 in the northern part of the Adriatic Sea (Trieste-Giulanova) and since 1987 in the central and southern Adriatic Sea (Giulianova-Brindisi).

The geographic Sub Area 17 (FAO subdivision) is covered in September in coordination with the Croatian survey carried out in the eastern side of the Adriatic Sea. This survey also covers Slovenian waters in cooperation with the Fishery Research Institute of Ljubljana. Geographic Sub Area 18 is covered in July for both the Italian and the Montenegro-Albania side, in cooperation with the Institute of Marine Biology of Kotor (Montenegro) and with the University of Tirane (Albania).

The main results of an acoustic survey are biomass estimates for the target species in the study area and their spatial distribution.

Some preliminary analysis dealing with the trends of anchovies and sardines and the environmental parameters were tried in the past and were the subject of some publications (Azzali *et al.*, 2002; Azzali *et al.*, 2007).

The main conclusions of these preliminary analyses were:

1) Pelagic biomass fluctuations show cycles of 3–5 years that are probably traceable to macro-scale climatic factors; the bigger variations in the biomass of single species (anchovies, sardines, sprats) are characterized by peaks and drops that seem less regular with respect to total pelagic biomass;

2) The anchovy stock collapse (climax in 1987) corresponds to the period (1984–1991) in which the average mean of SST in the Adriatic Sea (data from SeaWIFS sensor reprocessed and adapted at ISAC-CNR of Bologna by means of TeraScan software) show values that are much lower with respect to contiguous years; this could have had a negative influence on larvae survival.

Another analysis that was attempted consisted in a correlation test between the anchovy biomass trend in the northern Adriatic Sea and the mean seasonal surface temperature data (Leonori *et al.*, 2009). In the Northern Adriatic Sea anchovy biomass showed a positive correlation with mean spring surface temperature (March, April, May), with a time lag of one year. The correlation was highly significant ($r = 0.70$, $p<0.01$). Spring SST was minimum in 1986 at the beginning of anchovy stock collapse (Figure 2).

The situation is similar in the Central and Southern Adriatic Sea ($r = 0.77$, $p<0.01$).

Sardine biomass did not show a clear correlation with mean surface temperature of any season.

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Azzali M., Leonori I., De Felice A. 2007. Fluttuazioni spazio-temporali della biomassa dei piccoli pelagici nel Mare Adriatico in relazione ai cambiamenti climatici. In Clima e Cambiamenti Climatici le attività di ricerca del CNR, Ed. Consiglio Nazionale delle Ricerche, pp. 547-550.

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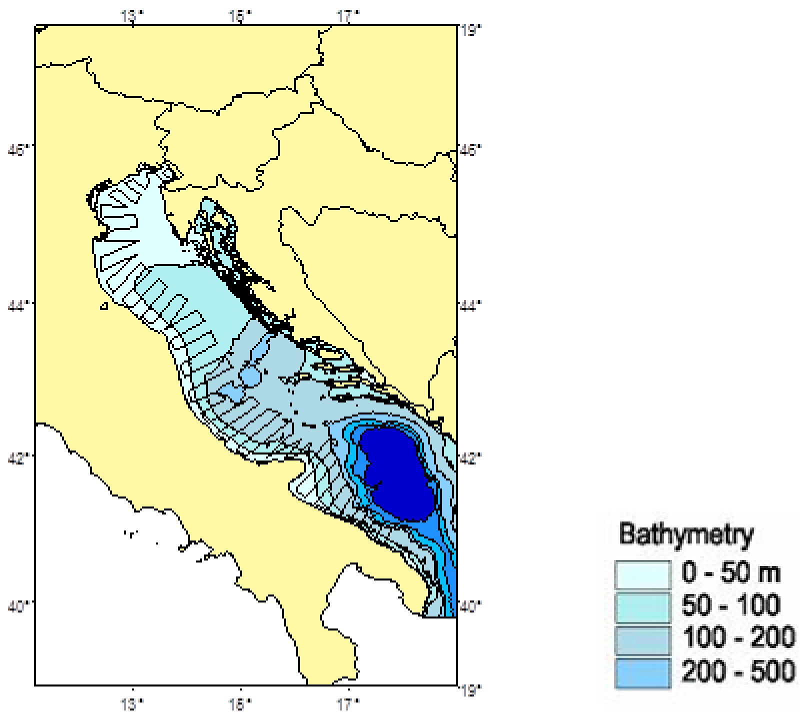

Figure 1. Survey design of the acoustic survey in the western Adriatic Sea.

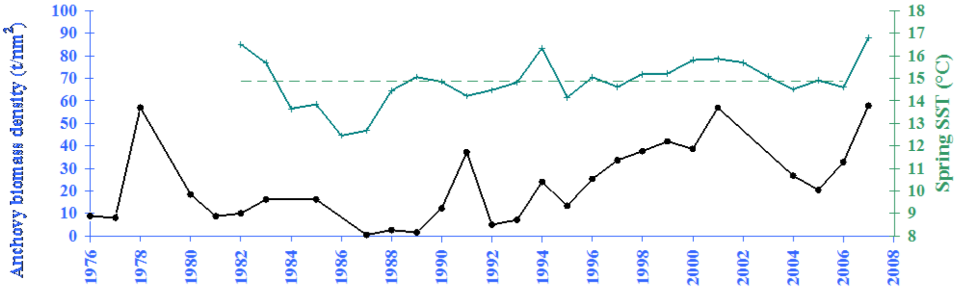

Figure 2. Above in green colour: trend of spring SST Survey design of the acoustic survey in the western Adriatic Sea; below in black colour: trend of anchovy biomass in north-western Adriatic Sea.

3.10 Impact of climate variability on small pelagic fishes in the Eastern Mediterranean

A. Tsikliras, A.G. Harlioglu

The landings of the 6 most important clupeiform species (Order: Clupeiformes) in the eastern Mediterranean Sea (Aegean and Levantine Seas) averaged around 205 000 t (±23 000 t) between 2000–2008 accounted for over 30% of the total catches. Five of them are members of the Clupeidae family (European pilchard or sardine *Sardina pilchardus*, round sardinella *Sardinella aurita*, Madeiran sardinella *Sardinella maderensis*, sprat *Sprattus sprattus* and red-eye round herring *Etrumeus teres*) and one belongs to the Engraulidae family (European anchovy *Engraulis encrasicolus*). As they share similar morphological characteristics, the catches of these species are often recorded/reported aggregated. Thus, the effect of potential climate variability on the distribution, biomass and population characteristics of a species may be masked.

Climatic variability, especially documented by sea temperature changes, has been shown to affect the geographic/bathymetric distribution and biomass, as well as certain population characteristics (e.g. Alheit *et al.*, 2012, *Prog. Oceanogr.* 96: 128-139). Some species, such as the sardinellas and red-eye round herring, have benefitted from temperature increase and expanded their distribution, while some others reduced their area of distribution (?), such as sprat and sardine. Indeed, round sardinella has expanded northwards in the Aegean Sea (Tsikliras, 2008, *Mar. Biol. Res.* 4: 477-481) and its catches have increased since 1990 (Figure 1). The combined catches of round and Madeiran sardinella (i.e. *Sardinella* spp.) have also increased in Levantine Sea since 1975 (data not shown). Alarming biomass declines and/or contractions of the area of distribution of psychrophilous species have not yet been observed across the eastern Mediterranean Sea.

Historical records of round sardinella catches in the Aegean (1928–1948: available in Moutopoulos & Stergiou, 2011, *Acta Adriat.* 52: 183-200) show that its biomass in the area was higher during this early period when compared to the time span from 1964-1990 (Figure 1). The round sardinella catches (plotted as a ratio of round sardinella over combined sardine and anchovy catches, in order to correct for fishing effort) in the Aegean Sea are generally higher during the warm periods of the Atlantic Multidecadal Oscillation (AMO: Enfield *et al.*, 2001, *Geophys. Res. Lett.* 28: 2077–2080) (Figure 1, top panel).

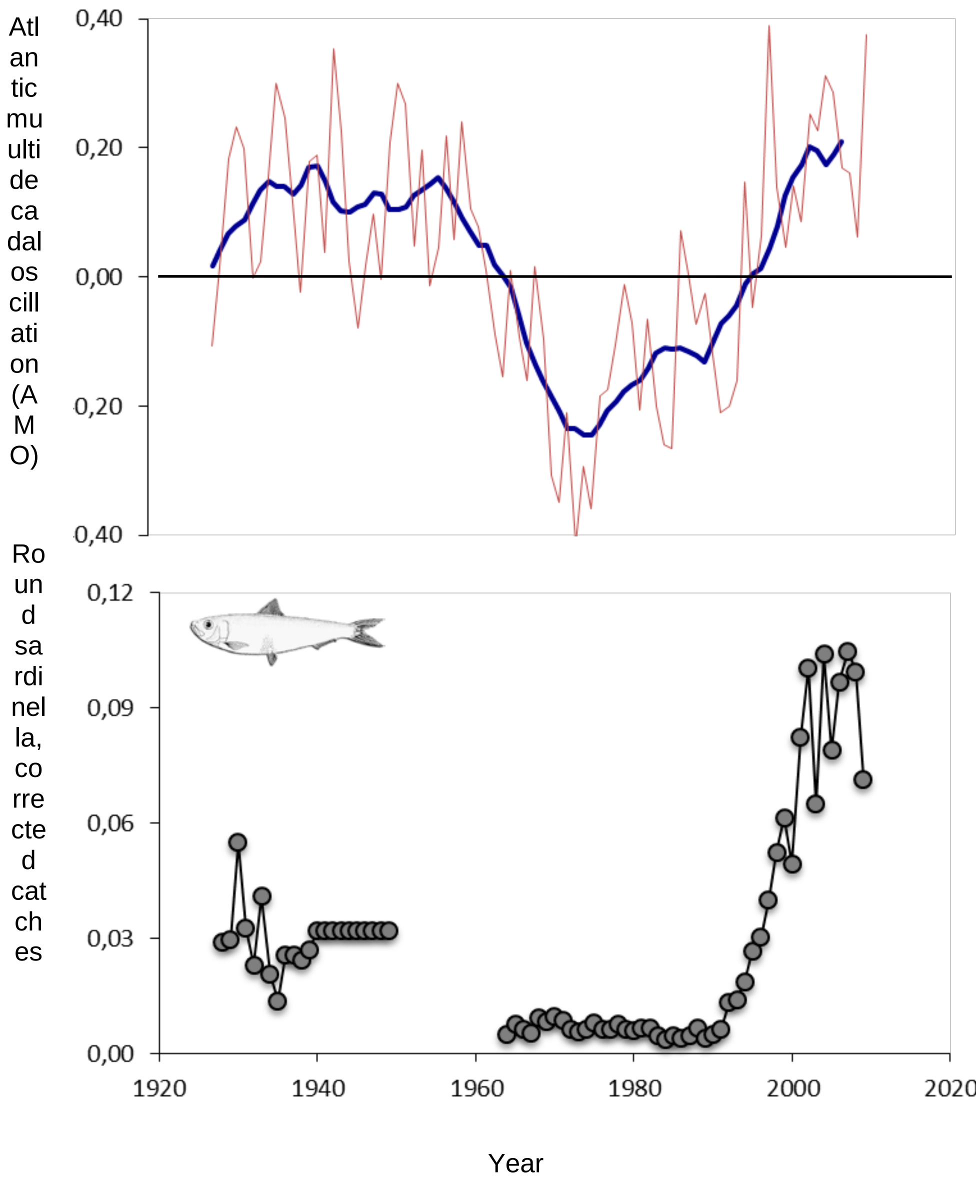

Figure 1. Atlantic Multidecadal Oscillation (AMO) for the period 1928–2009. Corrected (blue line) and uncorrected (red line) (top panel) and the ratio of round sardinella to combined sardine and anchovy catches of the Aegean Sea for the same period (bottom panel). Note that no catch data for round sardinella exists for the period between 1949–1963.

3.11 Anchovy: environment, biology and recruitment in the Bay of Biscay

U. Cotano, A. Uriarte

Favourable mechanisms for the recruitment of the European anchovy (*Engraulis encrasicolus*) in the Bay of Biscay have been traditionally interpreted in terms of the concept developed by Bakun (1996): the triad of retention, enrichment and concentration. Until the series of poor recruitment experienced by the anchovy fishery beginning in 2002, the upwelling strength and the stability of the thermal stratification had been pointed out as the most relevant environmental factors enhancing the anchovy recruitment, whilst the issue of how much drifting out or retention over the shelf was controversial among scientists (Borja *et al.*, 1996, 1998; Uriarte, 2001; Allain *et al.*, 2001, 2007).

Higher recruitments are associated with northeasterly winds enhancing upwelling (Borja *et al*., 1996, 1998, 2008; Allain *et al*., 2001), and higher productivity beyond that induced by river influence. However, northeasterly winds increased transport off the French shelf which contains the major spawning grounds. In the frame of a ''Bakun triad'' interpretation of the recruitment, the anchovy juveniles off the shelf would most likely be lost from the population but given the particular geography of the Bay of Biscay this is not necessarily true as a southwestern drift from the French shelf can lead through oceanic waters towards the Spanish shelf, which may facilitate a later return to the French shelf (Borja *et al*. 1998; Irigoien *et al*. 2007). In addition, several recent observations do not match with the idea of a detrimental effect of the transport off the French shelf: during recent years there is no clear relationship between zooplankton abundance over the shelf and anchovy recruitment (Irigoien, 2009); feeding activity of juvenile and adult anchovy may be even higher in oceanic waters (Plounevez and Champalbert, 1999, Bachiller 2012, *submitted*); both scientific studies and live bait tuna fishery data reported consistent observations of anchovy juveniles in oceanic waters (Uriarte *et al*. 2001; Carrera *et al*. 2006; Irigoien *et al*., 2007, 2008, Aldanondo *et al*., 2010); growth rates for anchovy larvae and juvenile are not lower in oceanic waters (Cotano, 2008, Irigoien, 2007, 2008; Aldanondo *et al*., 2010) and, finally, most recent environmental models have shown than the westwards transport has a significant positive effect on anchovy recruitment (Borja *et al*., 2008, Irigoien, 2009). On the other hand, larval dispersal during summer has been shown as a limiting factor for anchovy recruitment in IBM modelization (Allain *et al*., 2007, Hure *et al*., 2007 and Petitgas *et al*., 2011).

The relatively high productivity of oceanic waters in the Bay of Biscay associated with different physical events like shelf-break fronts or eddies, the relatively high abundance of bigger zooplankton size-classes, the theoretically higher capability of anchovies to capture zooplankton preys in less turbid waters far from coastal areas and the lower concentration of potential predators off the shelf could help to explain the survival rates of anchovy larvae and juveniles observed to be associated with oceanic waters during their recruitment process, as Uriarte *et al*. (2001) had previously proposed .

Therefore, although different environmental factors help to explain a relatively high percentage of variability associated with anchovy recruitment in the Bay of Biscay (Fernandes *et al*. 2010), there is still a lack of understanding on how some environmental processes affect the survival of early life stages and anchovy recruitment; especially those related to the retention-transport of anchovy larvae off the shelf. In any case, the "enrichment-retention-survival" recruitment theory associated to upwelling events cannot be interpreted in a strict way in the Bay of Biscay for anchovy.

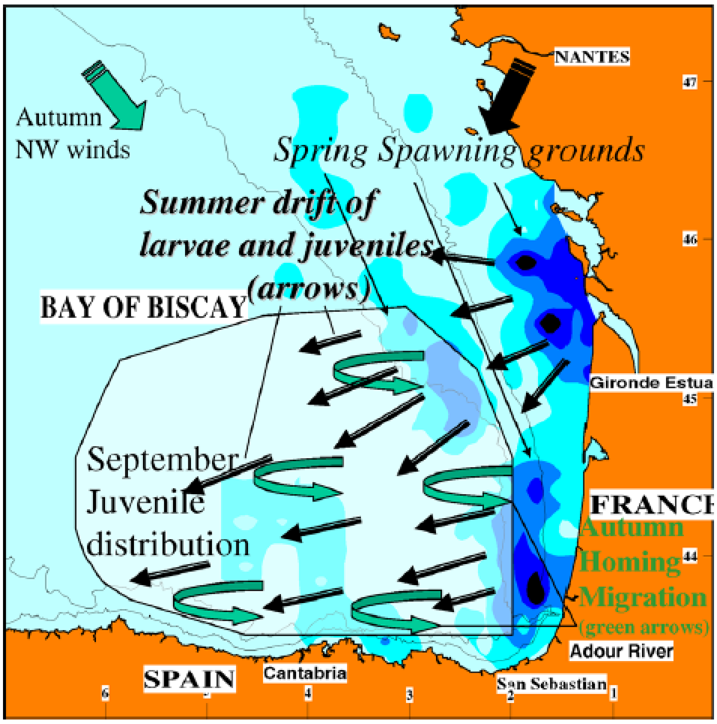

Figure 3.11. Scheme of the proposed spatial pattern of recruitment of the Bay of Biscay anchovy. Adapted from Uriarte *et al.* (2001).

3.12 Impact of climate variability on herring and capelin in northern seas

A. Slotte

The Institute of Marine Research in Norway has many cross sections from the coast into the Barents Sea, Norwegian Sea, North Sea, and Skagerak, which are surveyed several times a year to study environmental conditions (Figure 1). In addition, there are fixed coastal monitoring stations along the coast with weekly CTD sampling down to 200 m depth. These sources all pick up the AMO signal (Figure 2); (Skagseth *et al.* 2008).

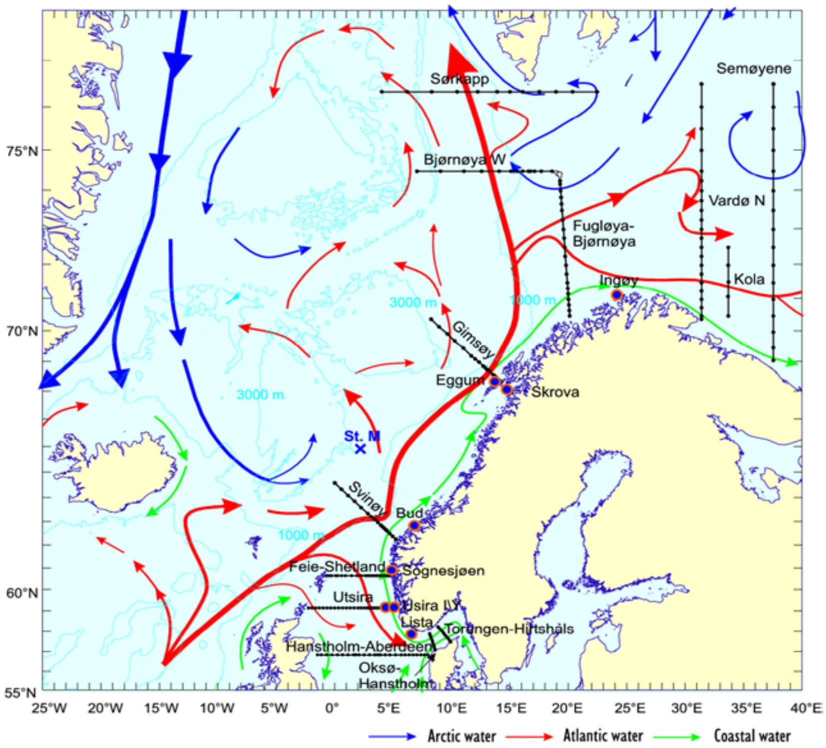

Figure 1. Overview of IMR's large scale monitoring of environmental conditions. Several cross sections covered several times every year. Coastal monitoring stations along the coast, with sampling every week. In addition the North Sea, Norwegian Sea, Barents Sea are covered twice every year during international ecosystem surveys.

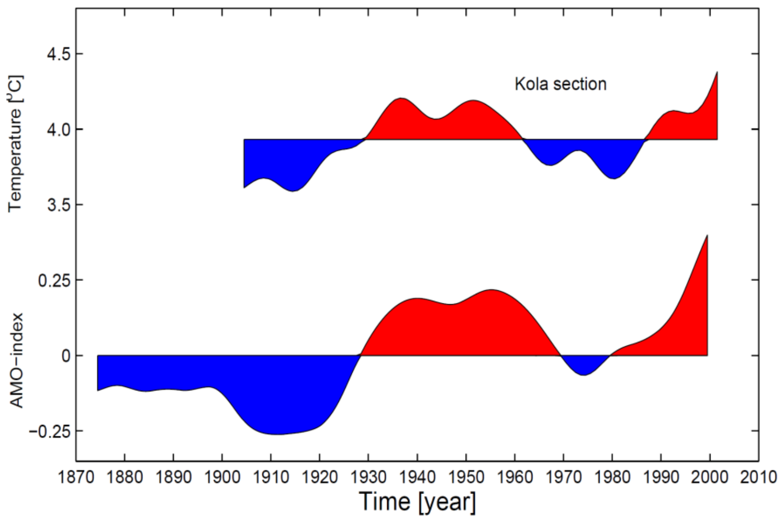

Figure 2. Comparison between historic fluctuations in the temperature from the Kola section in the Barents Sea and the AMO-index (From Skagseth *et al.* 2008).

Warm periods are characterized by increased recruitment and growing stocks in the Northern Seas. The times series on NSS herring is unique, giving SSB/catch (Figure 3) and recruitment (Figure 4) back to 1907. There was a clear increase in recruitment and growing SSB from 1.5 million t in 1907 to 16 million t in 1945, along with increasing temperatures in the area. After this the stock was overfished during a period with cooling climate, resulting in a total collapse of the stock from levels at 16 million t to levels below 0.1 million t. Simulations have indicated that, if the current harvest rule would have been used also during the 1930s–1960s, the stock would still have decreased during the cooling period, but it would have stabilized around 5 million t (Røttingen and Tjelmeland, 2011). From 1970s onwards there has been a warming period, and the stock increased due to very high recruitment in 1983. Other good recruitment years in 1991/1992, 1998/1999, 2002 and 2004 all happened during peaks in the temperature and AMO signal. This has led to SBB levels between 5 and 10 million t since the late 1990s, but after a period with low recruitment after 2004, the stock is now decreasing.

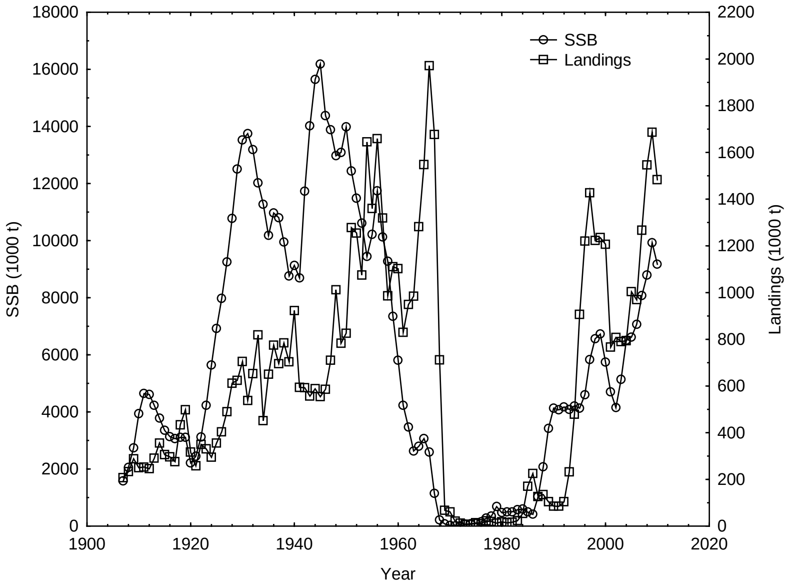

Figure 3 . Historic fluctuations in SSB and landing of NSS herring.

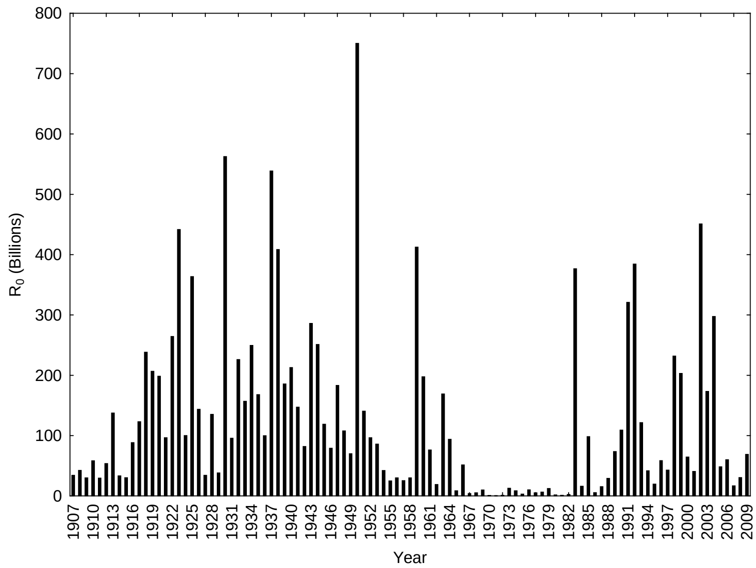

Figure 4. Historic fluctuations in recruitment (R0) of NSS herring.

Another abundant small pelagic in the Northern Seas is the capelin, which is the key species in the Barents Sea. The recruitment of this stock is related to sea temperatures in winter and spring, but recruitment failures are mostly caused by predation on larval stages from immature NSS herring using the Barents Sea as a nursery area, and by predation from Northeast Arctic cod, Figure 5 (Hjermann *et al.* 2010).

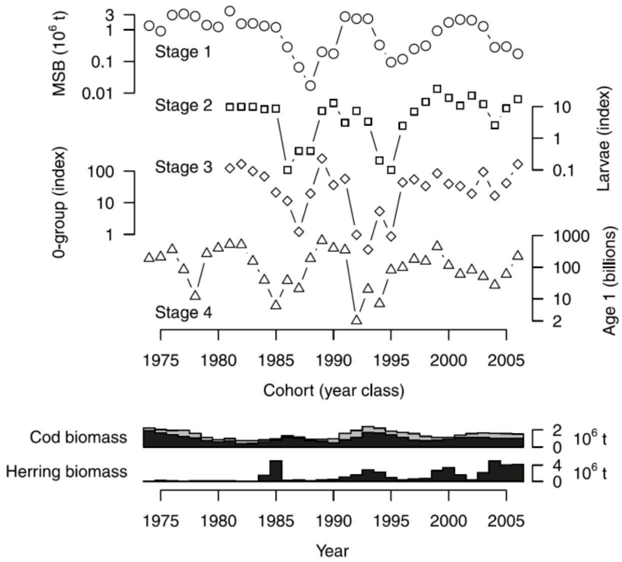

Figure 5. Abundance of capelin (*Mallotus villosus*) cohorts from 1974 to 2006 (year of spawning) in stages 1–4. Parent generations (stage 1) are represented by biomass of maturing fish in September. The two bar plots at the bottom show the annual biomass of the capelin predators cod (*Gadus morhua*) (ages 3–6, solid bars; ages 7–13, shaded bars) and young herring (*Clupea harengus*). From Hjerman *et al.* 2010.

Given equal stock size the distribution of capelin during the feeding season changes significantly with ocean temperature (Ingvaldsen and Gjøsæter, 2011); 1°C increase in temperature results in 125 000 km² increase in distribution area and a 150 km northward shift of the high-concentration areas. This is linked to changes in ice cover decreasing in recent years (Figure 6); (Ingvaldsen *et al.* 2011).

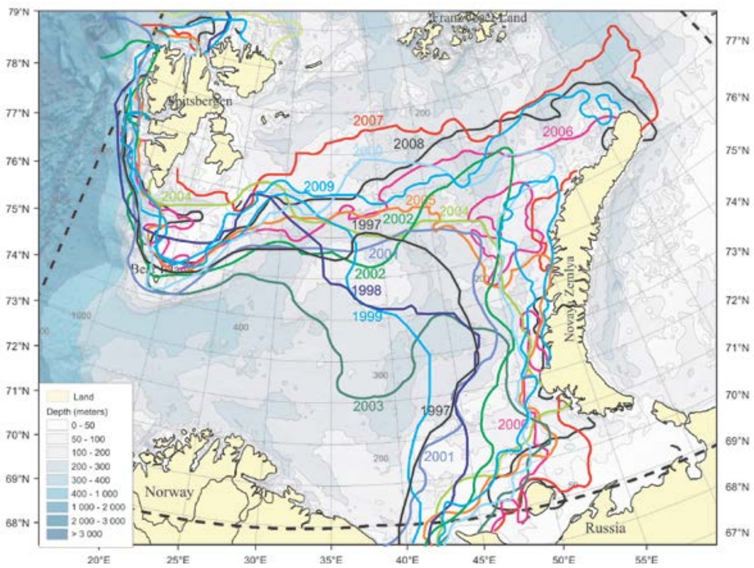

Figure 6. Observed changes in winter ice edge in the Barent Sea in late winter, 1997–2009.

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3.13 Impact of climate variability on North Atlantic plankton

P. Licandro

An analysis of plankton time-series reveals that, in the North Atlantic, important changes have occurred in the abundance, distribution, community structure, and population dynamics of phytoplankton and zooplankton. The changes in the plankton appear to be responding to regional climate variability, caused predominately by the warming of air and SSTs, and associated changes in hydrodynamics. Anthropogenic pressures (e.g. fishing) may also affect the community composition and abundance of plankton and may act synergistically with the climate. Changes in phytoplankton and zooplankton communities at the bottom of the marine pelagic food-web may affect higher trophic levels (e.g. fish, seabirds), because the synchrony between predator and prey (match –mismatch) plays an important role (bottom – up control of the marine pelagic environment) in the successful recruitment of top predators, such as fish, seabirds, and mammals.

The poor recruitment of several fish species of commercial interest and the low seabird breeding productivity recorded in recent years in some North Atlantic regions seem to be associated with changes in plankton biomass and in the seasonal timing of plankton production (Figure 1).

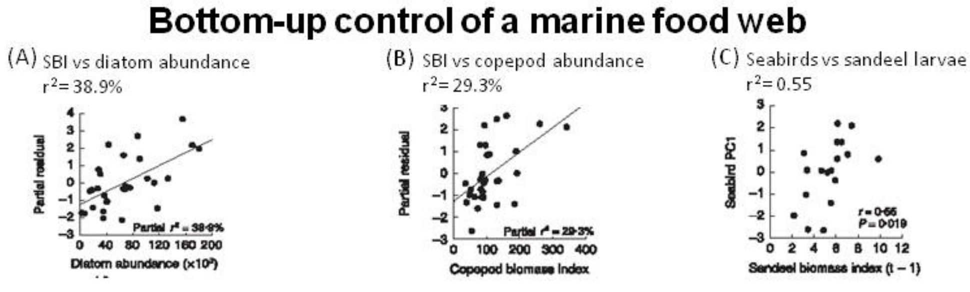

Figure 1. Partial residuals plots for the multiple regression of Sandeel Biomass Index (SBI) (1 May) against diatom (A) and copepod (B) records in the previous months (January–April). The influence of sandeels on the recruitment of seabirds was tested over the period 1986–2003 comparing the first principal component of seabird productivity (Seabird PC1) versus the SBI index in the previous year (C).

Figures reproduced from Frederiksen, M., Edwards, M., Richardson, A. J., Halliday, N. C., and Wanless, S. 2006. From plankton to top predators: bottom–up control of a marine food web across four trophic levels. Journal of Animal Ecology, 75: 1259–1268.

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3.14 Identifying drivers for zooplankton variability: the genetic programming approach

A. Conversi and S. Marini

The issue of what drives zooplankton populations still eludes scientific investigations. In the last couples of decades, climate indices have become very popular, and multiple correlations between these and the variations in zooplankton abundance/biomass have been identified. Still the issues remains, what indices, and why?

This choice of which indices is obviously very important. To this aim, the scientific community has mainly used two approaches: using pressure-based, large scale indices (mostly NAO), or temperature based indices (such as NHT or AMO); (Drinkwater *et al.*, 2003; Conversi *et al.*, 2010; Alheit *et al.*, 2012). Or making area-specific indices (e.g. Molinero *et al.*, 2008).

The first approach has the convenience of using indices proposed by expert climatologists, with the added bonus of being easily downloadable from climate sites (hence its widespread usage). However, these indices may not be appropriated for basins far from the pressure centres. For example, the North Atlantic Oscillation (NAO) index is not appropriate for the whole Mediterranean Sea, even if correlations have been found with the physical circulation and with copepod species in the western basin (Rixen *et al.*, 2005; Molinero *et al.*, 2005). Other large scale atmospheric patterns, as for instance those related to the monsoon systems, may become more prominent in the eastern basin (Raicich *et al.*, 2003), and the choice of a climate index that better synthesizes the influence of interannual to decadal climate variability in such areas is still under debate. Moreover, there is also a more general problem with NAO indices: since the 90s the centres of action of the NAO have moved east. In other words, the usual NAO index, measured at Reykjavik and Azores, since the 90s does not represent well the strength of the North Atlantic Oscillation.

The second approach, building an area-specific index, has the advantage that the index can be centred on the area investigated. However, doing this requires a substantial collaboration between ecologists/physicists and climatologists in order to make a meaningful index, which is no easy task. It also has the disadvantage of producing an increasing number of indices, which may be confusing for the larger scientific audience.

Both these approaches usually rely on identifying significant correlations between the indices and the marine populations, hence assume a linear behaviour. But ecosystems often present abrupt jumps (regime shifts), or other non-linear behaviour. A different approach needs to be used to capture this type of variability. An additional problem with the previous approaches is that it does take into consideration synergistic effects, as each index is considered as a unique driver.

We have chosen a third way: that of not making assumptions at all, and are currently investigating the use of Genetic Programming for identifying the drivers for zooplankton variability and possibly for predicting it. Genetic programming (GP) makes no assumptions, neither on the drivers, nor on the type of relationship. Through multiple iterative procedures, mathematical 'best fits' of the variable under study are selected.

As a test case we have used the copepod time series measured at station L4 off the Western Channel (Figure 1, red bars). A resulting approximation function is shown in Figure 1 (blue bars).

As possible drivers we have chosen:

- pressure-based climate variables, NAO, East Atlantic Pattern (EA), East Atlantic West Russia Pattern (EAWR), Scandinavian Pattern (SCA), Polar Eurasia Pattern (POL);
- temperature based global/regional variables, Northern Hemisphere Temperature (NHT), Atlantic Multidecadal Oscillation (AMO);
- local hydrographical variables, Sea Surface Temperature (sst), salinity (sal);
- and local trophic variables, chlorophyll (chl), microzooplankton (mzp), total organic carbon (toc), total organic nitrogen (ton).

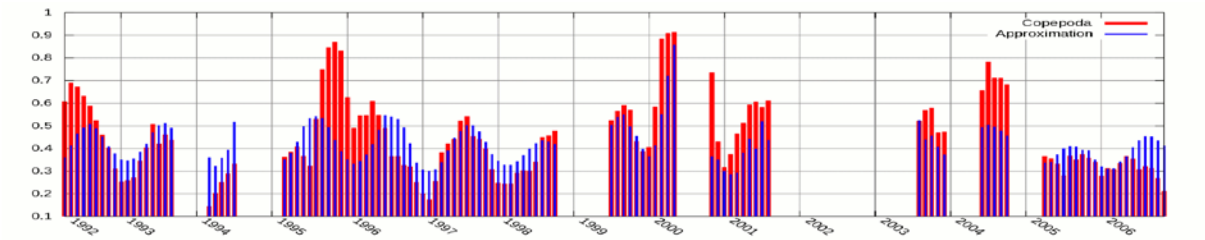

Figure 1. Copepod time series at station L4 (red) and approximation function derived from the genetic programming (blue). From Marini and Conversi (2012).

Figure 2 shows the variables that have been identified as more 'relevant' for the approximation of the copepod series out of about 100 runs. The most relevant variables belong to each group of drivers (pressure based climate indices, local hydrography, and trophic parameters). However, they are not what one may expect: for example, it appears that 'trophic' parameters (toc, ton), but not prey proxies (chlorophyll or microzooplankton), are more relevant than climate or temperature. Local temperature seems much more important than the hemispheric NHT. And EA seems much more relevant than NAO.

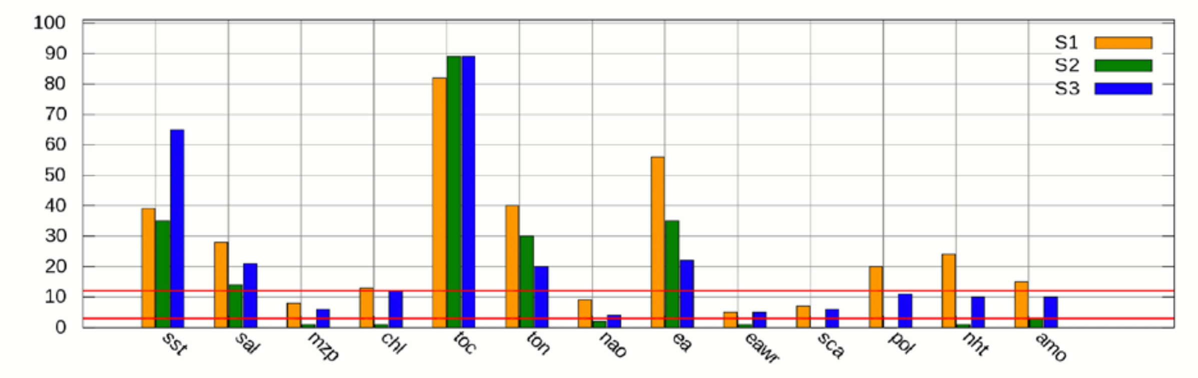

Figure 2. Relevance of the environmental drivers based on three different types of approximation. From Marini and Conversi (2012).

More details on the environmental variables used for the approximation of the copepod time series, on the GP approach used for this approximation, and on the three sets of operators S1, S2 and S3, are given by Marini and Conversi (2012), http://www.springerlink.com/content/l008166136683117.

Additional experiments on different basins will verify the validity of this approach.

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4 Results and intersessional activities

The discussion focused on the impact of the AMO on small pelagic fishes and their ecosystems. As time was not sufficient to deliver corresponding results on all populations of small pelagics under investigation, it was decided to continue the work during the intersessional period and present the results in a peer-reviewed publication as a contribution to a Special Issue on the AMO in the Journal of Marine Systems.

5 Elections, place and dates of the next meeting

Priscilla Licandro was elected as the co-chair for WGSPEC.

Because of logistical advantages it was decided to organize the 2013 meeting of WGSPEC again at the Centro Oceanográfico de Málaga in Fuengirola, Spain, from 25 February to 1 March 2013.

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Annex 2: Agenda

Monday, 27 February

10:30-10:40 Welcome

A. Garcia, J. Alheit, M. Sinclair

10:40-11:10 Small pelagic research framework in the Mediterranean

A. Garcia

11:10-11:

11:40-11:30 Coffee break

12:00-12:10 Vital rates of sardine and anchovy larvae determined in the laboratory

S. Garrido

12:10-12:30 Molecular characterization of the planktonic community diet in coastal waters of the Alborán Sea: *Sardina pilchardus* larvae and its zooplanktonic preys

L. Yebra

12:30-13:30 Introduction to working group meeting

J. Alheit

13:30-15:00 Lunch break

15:30-16:30 Climate variability in northern hemisphere

J. Alheit

16:30-17:00 Long Term Variability of the Canary Current Upwelling System

P. Relvas

17:00-18:00 Mediterranean climate, circulation and zoopalnkton

A. Conversi

Tuesday, 28 February

09:00-09:50 Impact of climate variability on North Atlantic plankton

P. Licandro

09:50-10:20 Atlantic herring: explanation of spatial patterns of spawning

M. Sinclair

10:20-10:35 Spatial and temporal distribution of clupeids in the Belgian part of the North Sea

K. van Ginderdeuren

10:35-10:50 Coffee break

11:00-10:30 Impact of climate variability on anchovies, sardines and sprat in North and Baltic Seas

J. Alheit

11:30-12:10 Anchovy: environment, biology and recruitment in Bay of Biscay

U. Cotano

12:10-12:40 Long-term variability of small pelagics and relationships with environment

R. González-Quirós

12:40-13:30 Decadal changes in sardines and anchovies in the Canary Current Upwelling System

M. Santos

15:40-16:30 An overview of large and mesoscale oceanographic processes relevant to the Gulf of Cádiz anchovy

F. Ramos

16:30-17:00 Historical landings of small pelagics off NW Africa (Spanish fisheries). Signals of the climatic effect on small pelagic in the Canary Islands

M.T. García Santamaría and E. García Isarch

17:00-17:40 Environmental impacts on anchovy, sardine and sardinella in the north-western Mediterranean

I. Palomera

17:40-18:00 Insights into the trophic dynamics of juveniles of anchovy and sardine in the NW Mediterranean and how climate change can affect it

D. Costalago

Wednesday, 29 February

09:10-09:40 Biomass evaluation of anchovy (*E. encrasicolus*), sardine (*S. pilchardus*) and sprat (*S. sprattus*) in the western Adriatic Sea by means of acoustics and preliminary analysis of possible relationships with environmental parameters

A. de Felice

09:50-10:10 Population dynamics of small pelagic species in the Adriatic Sea: stock assessment models and environmental factors

P. Carpi

10:10-10:30 Impact of climate variability on anchovies, sardines, sprat in Adriatic Sea

A. Conversi

10:30-11:10 Impact of climate variability on small pelagic fishes in eastern Mediterranean

A. Tsikliras

11:10-11:40 Coffee break

11:40-12:10 NAO related small pelagic fisheries fluctuations off Morocco and Senegal

L. Fernández-Peralta

12:10-13:00 Impact of climate variability on herring and capelin in northern seas

A. Slotte

13:00-15:00 Lunch break

15:00-15:40 Changes in the location and extent of North East Atlantic mackerel catches: possible fishery and climate change effects

K. Hughes

15:40-16.00

16:00-16:40 Impact of Atlantic Multidecadal Oscillation on small pelagics in NE Atlantic

J. Alheit

16:40-17:00 Coffee break

17:00-18:00 Comparison of data and statistical analysis

Thursday, 1 March

09:00-13:00 Comparison of data and statistical analysis (ctd.)

13:00-14:30 Lunch break

14:30-16:00 Comparison of data and statistical analysis (ctd.)

16:00-16:30 Coffee break

16:30-17:00 Report

17:00-18:00 Comparison of data and statistical analysis (ctd.)

Friday, 2 March

09:00-11:00 Presentation of results

11:00-11:30 Coffee break

11:30-13:00 Discussion of future activities of Working Group

Date and place of 2013 meeting

Election of co-chair

13:00 End of meeting

Annex 3: Draft terms of reference for the next meeting

a) Presentation and discussion of statistical analyses carried out during intersessional period;

b) Specific analysis of climate impact and respective physical and biological processes around the mid-1990s;

c) Study mechanisms that link the variability of the small pelagic fish populations in different ocean basins to the large scale climatic forcings;

d) Suggest relevant joint theme sessions and workshops for ICES and PICES which are also relevant to ICES assessment working groups on pelagic fish;

e) Prepare contributions for the 2012 SSGEF session during the ASC on the topic areas of the Science.

Annex 4: Cycles, trends, and residual variation in the Iberian sardine (*Sardina pilchardus*) recruitment series and their relationship with the environment

R. González-Quirós

Recruitment variability is an important component of the dynamics of Iberian sardine (Sardine *pilchardus*). Since 2006, poor recruitment has led to a decrease in stock biomass, the latest in a series of such crises for sardine fisheries. Understanding the mechanisms behind recruitment fluctuations has been the objective of many previous studies, and various relationships between recruitment and environmental variables have been proposed. However, such studies face several analytical challenges, including short time-series and autocorrelated data. A new analysis of empirical relationships with environmental series is presented, using statistical methods designed to cope with these issues, including dynamic factor analysis, generalized additive models, and mixed models.

Relationships are identified between recruitment and global (number of sunspots), regional (NAOAutumn), and local [winter wind strength, sea surface temperature (SST), and upwelling] environmental variables. Separating these series into trend and noise components permitted further investigation of the nature of the relationships. Whereas the other three environmental variables were related to the trend in recruitment, SST was related to residual variation around the trend, providing stronger evidence for a causal link, possible mechanisms for which are discussed. After the removal of trend and cyclic components, residual variation in recruitment is also weakly related to the previous year's spawning-stock biomass.

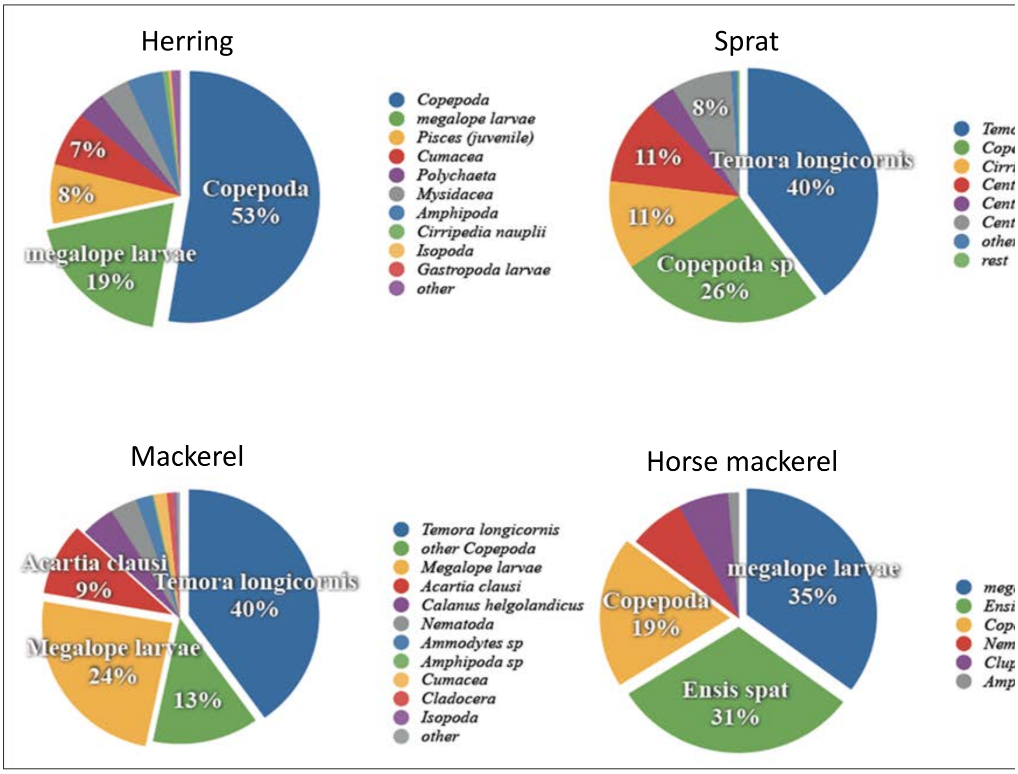
Annex 5: Small pelagic fishes and zooplankton in Belgian waters

K. van Ginderdeuren

In the Belgian Part of the North Sea, pelagic fish and zooplankton data are gathered by taking monthly samples with a (semi-)pelagic trawl (4*4m opening) and a WP2 (200µm) net. Herring *Clupea harengus* and sprat *Sprattus sprattus* are common in the BPNS but are rarely found in high numbers. Most fish belong to the 0- and 1-year cohorts and are mainly found near the shore. Adult herring are present in autumn, when large schools migrate through the BPNS on their way to the spawning grounds in the French Channel. Spring and summer bring along two other pelagic key species: mackerel *Scomber scombrus* and horse mackerel *Trachurus trachurus*. The latter reproduces in the BPNS and its larvae are very abundant, but also larvae of herring, sprat and sardine *Sardina pilchardus* are found in high numbers. Rarer catches included adult sardine, anchovy *Engraulus encrasicolus* and one blue whiting *Micromesistius poutassou*.

Preliminary analyses of the zooplankton point out that calanoid copepods are the dominant holoplanktonic fauna in the water column, with *Temora longicornis*, *Acartia clausi*, *Paracalanus parvus*, *Centropages typicus* and *C. hamatus* as most abundant species. Further offshore more oceanic species such as *Calanus helgolandicus* occur. In addition, meroplanktonic organisms such as larvae of polychaetes, echinoderms and barnacles are very common. Also, high densities of the invasive jellyfish *Mnemiopsis leidyi* are found in the plankton hauls during summer and autumn.

More knowledge concerning the spatial and temporal variation in zooplankton abundance, in relation to the presence of pelagic fish and their feeding ecology is crucial to assess the importance of the zooplankton as a fish food source. Stomach content analyses are carried out for herring, sprat, horse mackerel and mackerel to investigate the spatial and temporal variation in their diet (see figure for preliminary analysis).



Sprat is feeding almost exclusively on calanoid copepods, whilst herring often targets bigger prey items. This is also the case for juvenile herring the size of adult sprat. Mackerel stomachs sometimes contain fish in addition to plankton (mostly sandeels). Horse mackerel apparently forages closer to the bottom, resulting in polychaetes and bivalve spat being present in the stomach content.

Annex 6: Vital rates of pelagic fish larvae (VITAL)

S. Garrido

Laboratory experiments are being carried out as part of the project VITAL, financed by the Portuguese Foundation for Science and Technology (PTDC/MAR/111304/2009; http://projectvital.fc.ul.pt) with the objective of studying the vital rates of sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) larvae in relation to differences in several key physical and biological factors considered most important for regulating their growth and survival. The experiments aim at obtaining parameters such as 1) the upper and lower physiological tolerance limits of temperature, salinity and food availability for larvae survival and their influence on larvae growth; 2) the ingestion rates of different prey types offered at different concentrations and at different temperatures and salinities, simulating field values. The nutritional condition of larvae reared in the laboratory are being monitored and compared with larvae collected in the wild, validating combined techniques (fatty acids and RNA/DNA). The quantitative estimates of the vital rates for the larvae of these fish species under controlled laboratory conditions will be used to parameterize an individual-based model to be coupled to a hydrodynamic model developed for the western Portuguese coast (Project MODELA PTDC/MAR/098643/2008). Efforts to build models describing environmental regulation of these species in other systems around the world (e.g. to examine links between climate and recruitment) are currently hampered by a lack of data, namely of the vital rates of the vulnerable larval phase, that we hope to contribute with our research.

Annex 7: Changes in the location and extent of North East Atlantic mackerel catches: possible fishery and climate change effects

K. Hughes, M. Johnson, L. Dransfield

Widely available fisheries data is often ignored for fisheries research due to the complex nature of identifying anthropogenic from environmental signals. This research aims to use the north east Atlantic mackerel (*Scomber scombrus*) vessel log book data to identify and further investigate patterns from potential fisheries and environmental effects. The data were analysed by quarter using an EOF to identify locations of highest variability. Initial analysis of quarter one showed a strong increasing and decreasing signal around the Cornish peninsula of England around the time of the early 1980s. This pattern corresponded to the closure of the south west mackerel box from trawlers in the spring, summer and autumn months. Since the mid-1980s the mackerel fishery in this region is almost exclusively from handlines. The result supports the usefulness of an EOF as an effective method for depicting patterns in the data. Since we can be relatively confident the signal we were seeing was due to known fisheries legislation, the area of the SWMB was removed to test for other spatial patterns of variance in the data. In quarter one, an on shelf off shelf movement appears around the early 1980s, possibly a climate driven effect moving the spawning stock off shelf, alternatively a cohort effect may be influencing the fishery towards more off shelf areas whilst the overall distribution remains the same. In quarter two the catch is highly variable with large catches in sporadic positions north and west. There is a large catch in the International waters of the southern Norwegian Sea, probably due to fisheries area TACs. There is a general increase in catch in more northern areas along the continental shelf edge, possibly as a result of warming seas. In quarter three there are probable fishing effects between coastal Norway and International waters in the southern Norwegian Sea, with PC2 picking up an increase in catch in the southern Norwegian Sea from the mid-1990s. Highly variable catches are taken in coastal areas and in the North Sea. Quarter four showed an east-west movement in the early nineties which could be a fishing effect from closed areas and subsequent misreporting between ICES areas IVa and VIa. Future research will characterise each location by SST, Chla, *Calanus finmarchicus* abundance and bottom depth to address the different trends in the data and attempt to discern environmental from fisheries drivers.