



# Atlantic Multidecadal Oscillation (AMO) modulates dynamics of small pelagic fishes and ecosystem regime shifts in the eastern North and Central Atlantic



Jürgen Alheit <sup>a,\*</sup>, Priscilla Licandro <sup>b</sup>, Steve Coombs <sup>c</sup>, Alberto Garcia <sup>d</sup>, Ana Giráldez <sup>d</sup>, Maria Teresa Garcia Santamaría <sup>e</sup>, Aril Slotte <sup>f</sup>, Athanassios C. Tsikliras <sup>g</sup>

<sup>a</sup> Leibniz Institute for Baltic Sea Research, Seestr. 15, 18119 Warnemünde, Germany

<sup>b</sup> Sir Alister Hardy Foundation for Ocean Science, The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK

<sup>c</sup> The Marine Biological Association of the UK, The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK

<sup>d</sup> Instituto Español de Oceanografía (IEO), C. O. de Málaga, Puerto Pesquero s/n, 29640 Fuengirola, Spain

<sup>e</sup> Instituto Español de Oceanografía (IEO), C. O. de Canarias, Vía Espaldón, dársena pesquera, Parcela 8, 38180 Santa Cruz de Tenerife, Spain

<sup>f</sup> Institute of Marine Research, PO Box 1870, Nordnes, 5817 Bergen, Norway

<sup>g</sup> Laboratory of Ichthyology, School of Biology, Aristotle University of Thessaloniki, UP Box 134, University Campus, 541 25 Thessaloniki, Greece

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## ABSTRACT

Dynamics of abundance and migrations of populations of small pelagic clupeoid fish such as anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), sardinella (*Sardinella aurita*), sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) in the eastern North and Central Atlantic between Senegal and Norway vary in synchrony with the warm and cool phases of the Atlantic Multidecadal Oscillation (AMO). This is shown by compiling retrospective data on fish catches and anecdotal observations, which in some cases date back to the mid-19th century. The AMO is defined as the de-trended mean of North Atlantic (0–60°N) sea surface temperature anomalies. However, it is not primarily the temperature which drives the dynamics of the small pelagic fish populations. Instead, the AMO seems to be a proxy for complex processes in the coupled atmosphere–ocean system of the North Atlantic. This is manifested in large-scale changes in strength and direction of the current system that move water masses around the North Atlantic and likely involves the North Atlantic Oscillation (NAO), the Atlantic Meridional Overturning Circulation (AMOC), the Mediterranean Overflow Water (MOW) and the subpolar gyre (SPG). The contractions and expansions of the SPG apparently play a key role. This was particularly obvious in the mid-1990s, when the SPG abruptly contracted with the result that warm subtropical water masses moved to the north and east. Small pelagic fish populations in the eastern North and Central Atlantic, including those in the Mediterranean responded quickly by changing abundances and migrating northwards. It seems that the complex ocean–atmosphere changes in the mid-1990s, which are described in the text in detail, caused a regime shift in the ecosystems of the eastern North and Central Atlantic and the small pelagic clupeoid fish populations are the sentinels of this shift.

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## 1. Introduction

“The fauna of the southern North Sea exhibits clear changes. Particularly conspicuous is the increase of Mediterranean fish species and the occurrence of sardine eggs and larvae. There is no doubt, that these observations are associated with the climate change which has been shown to occur since several decades, and which, over the last years,

has had important consequences for fisheries: decrease of catches, northwards shift of fishing grounds, adaptation to fisheries for different species. ...particularly interesting questions are: will climate change continue and, also, shifts and changes of fish stocks, how long will this last, and which are the consequences, if this trend reverses?” This is not a recent statement, but is the translation of the introduction of H.J. Aurich's (1953) paper on “Distribution and spawning relationships of anchovy and sardine in the southeastern North Sea and the changes as the consequence of climate change” published 60 years ago.

The North Atlantic was in a warm state in the 20th century from about 1925 to about 1965, very similar to the situation we have been observing since about the mid-1990s. The increased surface air temperatures (SAT) during both periods, particularly in the Arctic, have been highlighted by Johannessen et al. (2004). Elevated sea temperatures,

\* Corresponding author at: Hohe Lieth 12, 27607 Langen, Germany. Tel.: +49 1726517386.

E-mail addresses: [juergen.alheit@web.de](mailto:juergen.alheit@web.de) (J. Alheit), [prli@sahfos.ac.uk](mailto:prli@sahfos.ac.uk) (P. Licandro), [shc@mba.ac.uk](mailto:shc@mba.ac.uk) (S. Coombs), [agarcia@ma.ieo.es](mailto:agarcia@ma.ieo.es) (A. Garcia), [agiraldez@ma.ieo.es](mailto:agiraldez@ma.ieo.es) (A. Giráldez), [teresa.garcia@ca.ieo.es](mailto:teresa.garcia@ca.ieo.es) (M.T.G. Santamaría), [aril.slotte@imr.no](mailto:aril.slotte@imr.no) (A. Slotte), [atsik@bio.auth.gr](mailto:atsik@bio.auth.gr) (A.C. Tsikliras).

reduced sea-ice conditions and enhanced Atlantic inflow in northern regions were reported for the former period (Drinkwater, 2006). In his review, Drinkwater (2006) describes the extensive ecosystem changes with respect to the northern regions of the North Atlantic associated with this period, such as the northwards migration of zooplankton, fish and benthos and changes in the phenology. Cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and herring (*Clupea harengus*) expanded farther north, whereas colder-water species withdrew from their southern ranges. New spawning sites were established farther north and more southern species appeared occasionally or were frequently observed in regions where they had been unknown before the warming. As the ecosystem changes were so significant, The International Council for the Exploration of the Sea (ICES) conducted its first scientific meeting on climate change (ICES, 1949) as reported by Drinkwater (2006). The North Atlantic experienced a regime shift during this warming period according to Drinkwater (2006). The conspicuous biological events have already been described by Cushing (1982) in the chapter called “The Recent Period of Warming” of his famous monograph on “Climate and Fisheries” where he refers to four major events: (i) the northwards movement of animals between the 1920s and 1940s, (ii) the spread of intertidal organisms, (iii) the rise and decline of the West Greenland cod fishery, and (iv) the Russell Cycle, a series of changes, particularly in the plankton community, in the waters off Plymouth, UK, between the 1930s and the 1970s (Coombs and Halliday, 2011; Hawkins et al., 2003; Mieszkowska et al., in press; Southward, 1980; Southward et al., 2005).

Apparently, what has been described by Cushing (1982) and Drinkwater (2006) and what was the theme of the ICES meeting in 1949 was the warm phase of the Atlantic Multidecadal Oscillation (AMO) in the first half of the 20th century. The term AMO was coined by Kerr (2000) in an editorial article for Science to describe a multidecadal oscillation of alternating warm and cold periods of the North Atlantic over the last 150 years. The AMO is defined as the de-trended, 10-year running mean of North Atlantic (0°–60°N) sea surface temperature (SST) anomalies (Alexander et al., in press). It swings between cool and warm phases that may last for 20–40 years, where the difference between extremes is ~0.5 °C (Alexander et al., in press). The approximate period of the oscillation based on the instrumental records of the past 130 years is estimated to be 60–80 years (Deser et al., 2010; Guan and Nigam, 2009; Schlesinger and Ramankutty, 1994; Ting et al., in press). Knudsen et al. (2011) found a quasi-persistent 55–70 year signal in a number of different paleo-proxies, concluding that the AMO is a regular, but intermittent, feature throughout most of the Holocene (Kilbourne et al., in press). The AMO seems to be related to a number of climatic phenomena including Atlantic sector hurricane frequency (Goldenberg et al., 2001), precipitation in North America (Enfield et al., 2001) and rainfall over the African Sahel zone and Northeast Brazil (Knight et al., 2006). It is also suggested that the AMO has a hemispheric-wide influence, including the Tibetan Plateau and the Indian monsoon (Feng and Hu, 2008). Retrospective research indicates five major phases of the AMO over the last 150 years (Fig. 1). A mainly positive phase from about the mid- to late 19th century, a negative phase until 1925, another positive phase until 1965, a negative phase until 1995, and a still lasting positive phase since (Deser et al., 2010).

The AMO impacts the long-term development in fish populations like the Norwegian spring-spawning herring (Toresen and Østvedt, 2000), the Northeast Arctic cod (Nakken, 2002) and the English Channel sardines (Edwards et al., 2013). Moreover, shifts in distributions of plankton to fish have been shown to occur over multidecadal time periods (Beaugrand et al., 2002; Drinkwater, 2006; Genner et al., 2004, 2010; Hawkins et al., 2003; Southward et al., 1988; Sundby and Nakken, 2008). The aim of this study is to continue the studies of Aurich (1953) and Cushing (1982) and to complement the observations from the northern North Atlantic reported by Drinkwater (2006) with past and recent observations from more southern regions. The targets

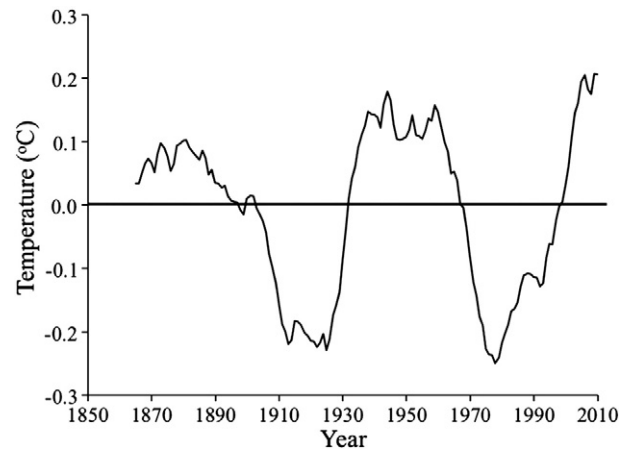


Fig. 1. Atlantic Multidecadal Oscillation. The data are from: Enfield et al. (2001).

of this investigation are the large populations of clupeoid fish species such as anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*), round sardinella (*Sardinella aurita*), Norwegian spring spawning herring and sprat (*Sprattus sprattus*) in the large region of the continental margin from Senegal in the South to Norway in the North, including the Mediterranean, the North Sea and the Baltic Sea (Fig. 2). Particular importance is given to old literature from about 1880 to 1950, first as these old publications highlight what happened during the warm AMO phases in the 19th and 20th centuries and, second, to ensure that this important information will not be lost. The possible impact of the coupled ocean–atmosphere system is discussed in detail to highlight its importance for the dramatic changes in the dynamics of ecosystems and fish populations.

## 2. Material and methods

In order to compare long-term changes of the small pelagic fish species in this study, multidecadal records were assembled for the different regions of the eastern North Atlantic and Mediterranean, each series covering a different time span.

- Data on Spawning Stock Biomass (SSB) and catches (landings) for Norwegian spring spawning herring during 1907–2010 were based on a combination of Tøresen and Østvedt (2000) reporting virtual population analyses (VPA) from 1907 to 1998 and ICES (2011) reporting stock assessment data with VPA tuned with acoustic estimates and larval indices from 1988 to 2010. In order to get a full time series data were taken from Tøresen and Østvedt (2000) from 1907 to 1987 and merged with the ICES (data) from 1988 to 2010.
- Sardine eggs sampled off Plymouth since 1924, with intermittent breaks, were used as a proxy for the sardine stock in the western English Channel (Coombs and Halliday, 2011).
- Landing data for round sardinella from Northwest Africa were used from 1990 to 2010 (FAO, 2011).
- Landing data for anchovy and round sardinella from the western Mediterranean caught by the Spanish fisheries were from 1945 to 2010 (Abad et al., 1991; Giráldez and Abad, 2000). Data for 2000 onwards were recovered from FROM (Fondo de Regulacion y Ordenacion de los Mercados de la Pesca) fisheries sales report sheets provided by different fisheries organisations of the different Spanish autonomic governments.
- For round sardinella in the Aegean Sea data from 1928 to 2009 (with an interruption between 1950 and 1962) were used. In order to compensate for changes in purse seine effort, the catches were transformed as a ratio of round sardinella to combined

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