Journal of Marine Systems 133 (2014) 103–116

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Ecosystem effects of the Atlantic Multidecadal Oscillation

Janet A. Nye [a,*], Matthew R. Baker [b], Richard Bell [c], Andrew Kenny [d], K. Halimeda Kilbourne [e], Kevin D. Friedland [c], Edward Martino [f], Megan M. Stachura [g], Kyle S. Van Houtan [h,i], Robert Wood [f]

[a] *United States Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, 27 Tarzwell Dr, Narragansett, RI 02882, USA*
[b] *NOAA National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115, USA*
[c] *NOAA National Marine Fisheries Service, Northeast Fisheries Science Center, 28 Tarzwell Dr., Narragansett, RI 02882, USA*
[d] *Centre for Environment, Fisheries & Aquaculture Science, Lowestoft, UK*
[e] *Chesapeake Biological Laboratory, Center for Environmental Science, University of Maryland, Box 38, Solomons, MD 20688, USA*
[f] *National Oceanic and Atmospheric Administration, Cooperative Oxford Laboratory, Oxford, MD 21654, USA*
[g] *School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195–5020, USA*
[h] *NOAA Fisheries Service, Pacific Islands Fisheries Science Center, Honolulu, HI 96822, USA*
[i] *Nicholas School of the Environment and Earth Sciences, Duke University, Durham, NC 27708, USA*

ARTICLE INFO

Article history:
Received 26 April 2012
Received in revised form 21 November 2012
Accepted 15 February 2013
Available online 21 February 2013

Keywords:
Climate variability
Climate change
Ecosystem based management

ABSTRACT

Multidecadal variability in the Atlantic Ocean and its importance to the Earth's climate system has been the subject of study in the physical oceanography field for decades. Only recently, however, has the importance of this variability, termed the Atlantic Multidecadal Oscillation or AMO, been recognized by ecologists as an important factor influencing ecosystem state. A growing body of literature suggests that AMO-related fluctuations are associated with shifts in ecological boundaries, primary productivity, and a number of ecologically and economically important coastal and marine populations across the Atlantic basin. Although the AMO is a basin-wide index of SST, the drivers of ecosystem change encompass more than temperature anomalies and the mode of action differs within each ecosystem. A common theme in assessing ecosystem change indicates that fluctuations in water masses and circulation patterns drive shifts in ecosystem states, but the magnitude and rate of change is dependent on the physical characteristics of the region. Because of the wide ranging geographic effects of the AMO, and considering its multidecadal nature, a more complete understanding of its causes and effects would allow scientists and managers to more effectively inform ecosystem-based management across the Atlantic Basin.

1. Introduction

There are several modes of climatic variability in the North Atlantic that affect ecosystem processes, but one mode of variability that has received relatively little attention until recently is the Atlantic Multidecadal Oscillation (AMO sensu Kerr, 2005) also known as Atlantic Multidecadal Variability (AMV sensu Delworth et al., 2007; Knight et al., 2005). It is hypothesized that fluctuations in the strength of Atlantic Meridional Overturning Circulation (AMOC) cause internal variability in sea surface temperature (SST), sea level pressure, and ocean circulation all of which are represented by the AMO index (Knight et al., 2005; Ting et al., 2011). Many biological oceanographers are familiar with the AMO index and refer to this large-scale phenomenon as the AMO. For consistency we will use this terminology throughout this review of its effect on ecosystems. However, the AMO index represents a wide variety of processes such that AMV is perhaps the more appropriate terminology for this phenomenon. In particular, records of past climate variability indicate that the AMO is not an oscillatory cycle with regular periods of fixed length (Gray et al., 2004; Knudsen et al., 2011). Instead it appears to be a climate system feature with variance concentrated at multidecadal scales.

The AMO index (Fig. 1) is typically defined as the SST anomaly from 0-60^{o}N linearly detrended to account for the increase in temperature associated with anthropogenic climate change (Enfield et al., 2001; Sutton and Hodson, 2005). Modern observations of SST indicate that the AMO switches between positive and negative phases on the order of 65–70 years (Schlesinger and Ramankutty, 1994), but the length and consistency of the oscillatory cycle is the subject of considerable debate. The 65–70 year cycle is based on only ~130 years of observed and reconstructed SST data for which there are only 1.5-2 complete cycles of the AMO. Smoothing or detrending of SST to calculate the AMO index results in oscillations of different frequencies (Vincze and Janosi, 2011). Although the exact timing of the switch from the positive to negative phase depends on how the index is calculated, it is generally agreed that negative/cold phases occurred from approximately 1900–1925 and 1971–1994 while positive/warm phases occurred from 1875–1899, 1926–1970 and 1990–present (Goldenberg et al., 2001).

---

* Corresponding author at: School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, NY 11794-5000, USA. Tel.: +1 401 782 3165.
E-mail address: janet.nye@stonybrook.edu (J.A. Nye).

0924-7963/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmarsys.2013.02.006

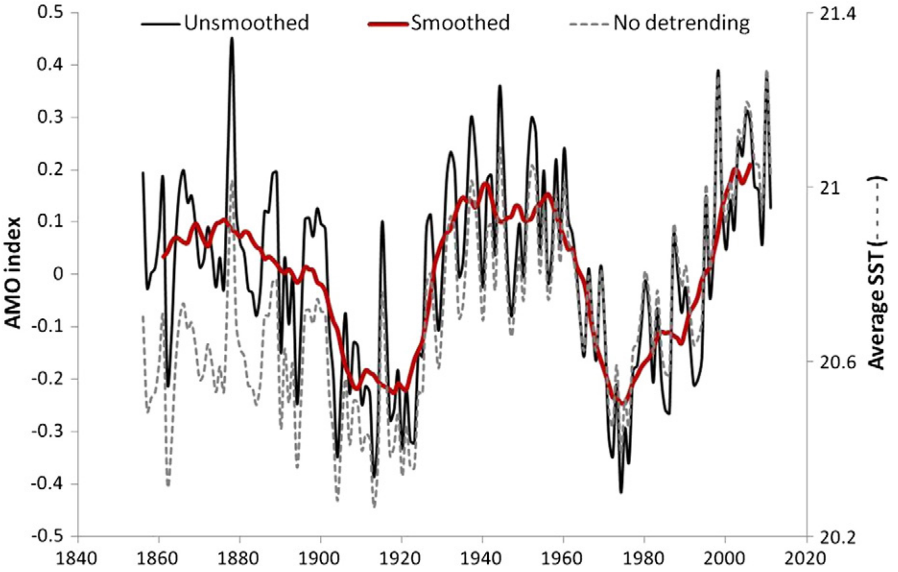

Fig. 1. The unsmoothed and smoothed AMO index calculated from Kaplan SST dataset detrended for the effects of climate change (Enfield et al., 2001). The dashed line is the unsmoothed, undetrended SST data with the 1951–1980 NOAA ERSST climatology added back in. All data obtained from the NOAA ESRL website (http://www.esrl.noaa.gov/psd/data/timeseries/AMO/).

The large scale warming and cooling related to the AMO interacts with anthropogenic warming. It has been suggested that the combined effects of anthropogenic climate change and the positive phase of the AMO since the 1990s has caused a more rapid warming than would be expected from climate change alone (Andronova and Schlesinger, 2000; Belkin, 2009; Knudsen et al., 2011). Similarly, cool (negative) phases of the AMO in the past may have masked the effects of climate change. The combination of warming trends from AMO and from anthropogenic climate change since the 1970s makes it difficult to distinguish the cause of changes in ecological time series unless the record length extends back before the mid to late 20th century.

The purpose of this review is to first explain the physical phenomena associated with the AMO so as to elucidate how this broad scale climatic index may be associated with more localized ecosystems in the Atlantic basin. Because the AMO index is usually presented as a time series in the ecological literature, we focus on the spatial aspects of the AMO to better understand the more proximate mechanisms by which this large scale process affects local ecosystem dynamics. Secondly, we review published ecological studies where the AMO was found to influence populations and ecosystems or where we suspect that the AMO may have influenced ecosystem dynamics. Lastly, we will discuss how the AMO affects large marine ecosystems (LMEs) around the Atlantic and how understanding this process is fundamental for informing Ecosystem Based approaches to Management (EBM).

2. Spatial patterns of the AMO

In contrast to the time series of the AMO index, the spatially explicit representation of the AMO suggests that the mechanisms through which this phenomenon affects ecosystems varies in different areas of the Atlantic and perhaps in other parts of the globe (Fig. 2). As in previous studies (Delworth et al., 2007; Grossmann and Klotzbach, 2009), a horseshoe-shaped spatial pattern (warm colors in Fig. 2) is generated in the Atlantic when the AMO is correlated with SST in the positive phase of the AMO. Thus, the regional effects of the AMO can vary throughout the Atlantic basin, but the positive phase of the AMO generally indicates a period of warmer temperatures. Whereas the AMO is primarily defined by oceanic phenomena (SST anomalies), it is related to atmospheric processes as well, since the ocean and atmosphere interact closely to form the Earth's climate system. During the positive phase of the AMO the position of the Intertropical Convergence Zone (ITCZ) shifts from the south (Fig. 2, brown ellipse), where precipitation is reduced, to the north, where precipitation is increased (Fig. 2, green ellipse). This ITCZ shift is associated with weaker northeast trade winds and a stronger cross equatorial wind flow from the southern equatorial zone. The weaker northern hemisphere winds are the result of a weakening of the Bermuda High and Icelandic Low atmospheric pressure zones. The AMO also appears to generate remote effects with anomalously low pressure over Eastern Europe and perhaps also over the northeast Pacific. The position of high and low pressure cells results in easterly winds over the central North Atlantic that influence the position and strength of the Gulf Stream and North Atlantic current. The mixed layer depth (MLD) is also shallower in the positive phase. The negative phase of the AMO has roughly opposite sign anomalies, but given the very long time scale of the AMO, there is not enough data to determine how linear the signal is (i.e. the extent to which the positive and negative phases are equal and opposite).

While it may be tempting to assume from this schematic that the areas with highest spatial correlations are the areas where ecosystem changes related to the AMO are most frequently found, the AMO's influence is still very strong in areas where correlations are low. For example, the highest correlations occur to the east of Spain (Delworth et al., 2007), while low correlations occur near the Chesapeake Bay, Northwest Atlantic and the continental US. However, strong ecosystem effects are observed in North America in part because of the influence of SST on atmospheric processes such as precipitation and wind patterns.

3. Links between AMO and other modes of climate variability

In addition to the AMO, other patterns of climate variability interact with the AMO to elicit ecosystem response. Such climatic processes include the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) or Northern Annular Mode (NAM), Atlantic Meridional Mode (AMM), El Niño and the Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The NAO is a north–south dipole in sea level pressure (SLP) that is primarily governed by internal atmospheric dynamics, although it can be influenced by both local and nonlocal SST anomalies (Hurrell and Deser, 2009; Hurrell et al., 2003). It affects the ocean via a number of processes, including surface heat fluxes, which drives a SST tripole pattern in the North Atlantic and influences deep water formation in the Labrador Sea, and the wind stress curl, which can alter the