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# Absence of an internal multidecadal oscillation in the North Atlantic has consequences for anticipating the future of marine ecosystems

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1 **The recently suggested absence of an internal multidecadal oscillation in the**  
2 **North Atlantic has consequences for anticipating the future of marine**  
3 **ecosystems**

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**Opinion Piece**

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7 **Running head: future of North Atlantic marine ecosystems**

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26

27 **Abstract**

28

29 The North Atlantic marine ecosystem was expected to adjust imminently to a  
30 negative phase of the Atlantic Multidecadal Oscillation (AMO). Recent results  
31 suggest however, that the AMO is not a regular internal source of variability but has  
32 been driven by both volcanism and sulphate aerosol emissions that have influenced  
33 temperature negatively and a period of greenhouse gas accumulation causing  
34 temperatures to be higher than normal. The demise of the AMO removes the  
35 expected and imminent cyclical change from the current warm phase to a negative  
36 cool phase in the North Atlantic. Here, we discuss the implications of this new finding  
37 for the near-future of North Atlantic marine ecosystems in a context of rapid climate  
38 warming.

39 **Main text**

40 For centuries, humans have tried to recognise patterns in natural systems and  
41 determine their controlling mechanisms, not least in marine ecosystems (Cheung et  
42 al. 2009, Rombouts et al. 2012, Raybaud et al. 2013, Schickele et al. 2021) where it  
43 helps to enhance predictability and especially, with regard to commercial fisheries,  
44 e.g. the European herring Bohuslän periods (Alheit & Hagen 1997) or the  
45 multidecadal fluctuations of sardines and anchovies in different oceans (*Chavez et*  
46 *al. 2003*).

47

48 Until now, an inherent large-scale oceanic phenomenon called the AMO was thought  
49 to explain periodic changes observed in key physical and biological systems in the  
50 North Atlantic, with a periodicity of ~60 years (Mann et al. 1995, Kerr 2000, Enfield et  
51 al. 2001, Edwards et al. 2013). Climate change biologists have documented  
52 significant correlations between the cyclical nature of the AMO index and North  
53 Atlantic biological systems to try to understand the ecosystem and how it might  
54 evolve, even postulating that the next negative AMO phase could alleviate or  
55 momentarily reverse the current warming trend (Frajka-Williams et al. 2017). For  
56 example, in the English Channel, the Russell Cycle that describes an alternation of  
57 periods dominated by cold-water (i.e. herring, *Clupea harengus*, and the

58 chaetognath *Sagitta elegans*) and warm-water species (i.e. pilchard, *Sardina*  
59 *pilchardus*, and the chaetognath *S. setosa*) has been related to the AMO (Russell et  
60 al. 1971, Edwards et al. 2013). Sardine (and *S. setosa*) dominates during positive  
61 phases and herring (and *S. elegans*) during negative phases of the AMO. In the  
62 North Atlantic, bluefin tuna has been shown to exhibit a long-term, quasi-cyclical,  
63 north to south, seesaw-like population movement and changes in abundance driven  
64 by climatic variation that correlates with the AMO: when the AMO phase is positive  
65 or negative, bluefin tuna are distributed further north or further south, respectively  
66 (Faillettaz et al. 2019).

67

68 While previous studies attributed the AMO to internal climatic processes, a recent  
69 study by Mann *et al.* (Mann et al. 2021) showed that positive (warm) and negative  
70 (cool) phases of the AMO have been due to external forces, such as volcanic  
71 activity, sulphate aerosol cooling, and greenhouse-gas-induced warming. The last  
72 negative AMO phase was mostly caused by the negative forcing exerted by the  
73 increasing sulphate aerosol emission, and the current warm phase by the  
74 predominant effect of increasing greenhouse gases at a time of diminishing sulphate  
75 aerosol emission (Mann et al. 2021). The AMO-like pattern has therefore, never  
76 been governed fully by internal hydro-climatic variability and this new knowledge is of  
77 profound importance for our understanding of the regional climate and marine  
78 ecosystems.

79

80 To illustrate the strong influence of multidecadal changes in temperature on extra-  
81 tropical North Atlantic marine resources, we have updated a previous Principal  
82 Component Analysis (PCA) on Sea Surface Temperature (SST) (Beaugrand et al.  
83 2002) for the region 20°N-65°N and 100°W-20°E using SST data from the COBE  
84 interpolated 1°x1°dataset from 1891 to 2020 (Ishii et al. 2005). Expectedly, this  
85 analysis shows two cold and two warm phases superimposed on a long-term  
86 positive SST trend for most areas of the North Atlantic except for the central and  
87 south-western regions (Figure 1a-b). Detrending the first principal component (PC1,  
88 49.8% of the total variance) gives a pattern similar to the classic AMO index, albeit

89 the AMO index is usually based on a larger area than the one we considered here  
90 (Enfield et al. 2001, Mann et al. 2021, Murphy et al. 2021).

91

92 When we include long-term changes in an index of phytoplankton concentration in  
93 the North Sea (Reid et al. 1998), Norwegian spring spawning herring (Toresen &  
94 Østvedt 2008) and bluefin tuna distribution in the north-east Atlantic (Faillettaz et al.  
95 2019), we see that changes across three trophic levels in different regions correlate  
96 with long-term changes in North Atlantic SST, exhibiting a clear oscillation (Fig. 1c-  
97 e). High North Sea phytoplankton concentration, high Norwegian Sea herring and  
98 north-east Atlantic tuna abundance are observed during a positive (warm) phase of  
99 the AMO and inversely. Because the AMO is considered to cause these changes in  
100 addition to other factors (e.g. overfishing of North-east Atlantic tuna and Norwegian  
101 Spring-Spawning herring at the beginning of the 1960s) (Lorentzen & Hannesson  
102 2004, Fromentin et al. 2014, Cort & Abaunza 2015), and because the nature of the  
103 phenomenon was cyclical, a reversal of the AMO was soon expected to occur  
104 (Frajka-Williams et al. 2017) with its putative consequences for the marine  
105 ecosystem and its exploited resources. Results from Mann et al. (Mann et al. 2021)  
106 imply that an imminent reversal to a cool period is now unlikely and so we should not  
107 expect an imminent shift in the North Atlantic marine ecosystem and provisioning  
108 services.

109

110 While overfishing has been an important component of the collapse of North-east  
111 Atlantic tuna or Norwegian Spring-Spawning herring and so management actions  
112 may have played an important role in the rebuilding of the different stocks (Lorentzen  
113 & Hannesson 2004, Toresen & Østvedt 2008, Fromentin et al. 2014, Cort & Abaunza  
114 2015), it often interplayed with changing environmental conditions (Beaugrand et al.  
115 2003, Faillettaz et al. 2019). A shift in the state of the AMO from positive to negative  
116 could have caused another rapid retreat of bluefin tuna southwards as was observed  
117 notoriously at the beginning of the 1960s together with another biological shift in the  
118 Russel cycle bringing a new period of high productivity to the English Channel. So,  
119 while the demise of the AMO does not negate the climatic modulation of North

120 Atlantic biology, it does have significant implications for our understanding of the  
121 drivers of change and how ecosystems and provisioning services may change in the  
122 future. Consequently, the recent northward shift of bluefin tuna is likely due to  
123 greenhouse gas-induced global warming and the well-known Russell Cycle is not  
124 necessarily a cycle anymore (McManus et al. 2016), and there is now, no *a priori*  
125 reason that the North Atlantic region will return soon to the negative AMO phase that  
126 has been anticipated (Frajka-Williams et al. 2017, Mann et al. 2021).

127

128 The latest IPCC report includes the influence of anthropogenic and volcanic activity  
129 on Atlantic multidecadal variability (Masson-Delmotte et al. In press). Climatologists  
130 now also use the term Atlantic Multidecadal Variability (AMV) instead of the AMO  
131 because multidecadal variability in the Atlantic may result from broad, low-frequency  
132 signals (Lapointe et al. 2020, Murphy et al. 2021, Masson-Delmotte et al. In press).  
133 The AMV includes the influence of the North Atlantic Oscillation (NAO) that is a  
134 natural source of atmospheric variability (Hurrell 1995) and which interacts with the  
135 AMOC, although the mechanisms involved and their relative strengths are still  
136 unclear (Masson-Delmotte et al. In press). As a result, we also think it is better to  
137 replace the AMO by AMV in climate change biology and to therefore recognise that  
138 the oscillatory behaviour of Atlantic multidecadal variability observed during the last  
139 two centuries may not continue. Consequently, we cannot predict a return to a lower  
140 temperature regime with all that entails, i.e. rapid shift in the marine ecosystems with  
141 its consequences for exploited resources.

142

143 A fundamental question in ecology is, why is what where? (Berry 1989). Sea surface  
144 temperature is a key determinant of the abundance and distribution of marine pelagic  
145 species. Of course, knowing that an anticipated and imminent climate reversal in the  
146 North Atlantic will not now occur due to the AMO neither invalidates previous  
147 environment-driven, cyclical variation seen in species such as bluefin tuna (Faillettaz  
148 et al. 2019) nor helps predict the future direction of marine ecosystems, but it does  
149 help us focus on those drivers of change that are important. While climatic surprises  
150 remain possible (*e.g.* the slow-down of the Atlantic Meridional Overturning

151 Circulation and its negative influence on North-east Atlantic climate (Boers 2021,  
152 Caesar et al. 2021)), if the results of Mann et al. (Mann et al. 2020, Mann et al. 2021)  
153 are confirmed, and recent works suggest, at least in part, that they are (Murphy et al.  
154 2021, Masson-Delmotte et al. In press), they have now eliminated the AMO as one  
155 variable thereby simplifying a complex world where ecosystem shifts are moving  
156 towards a warmer dynamic regime in response to anthropogenic climate change  
157 (Beaugrand et al. 2002).

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159

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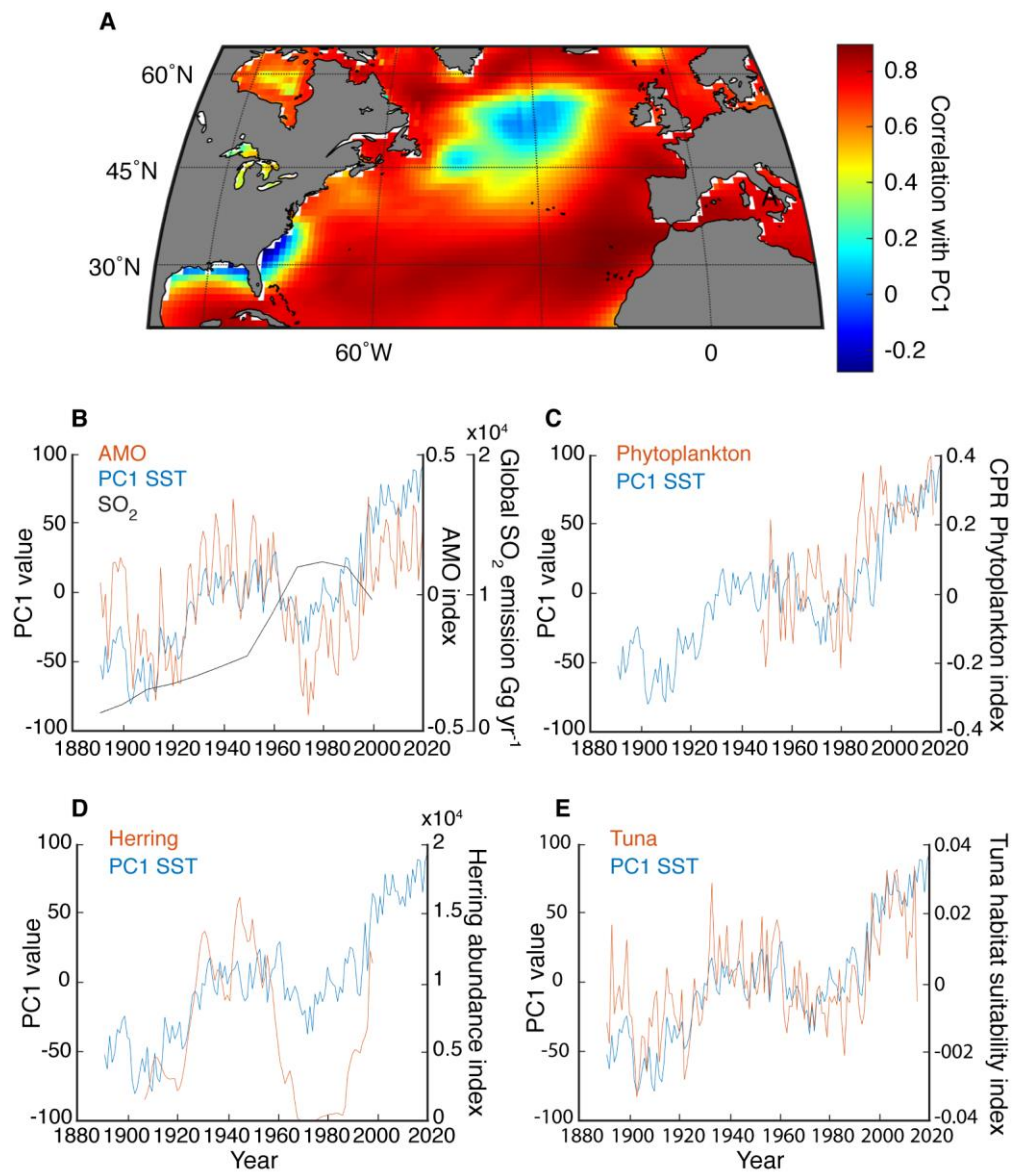
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## 256 **Figure legend**

257 **Figure 1.** Relationships between changes in North Atlantic annual SST and pelagic  
258 life. A) First standardised eigenvector (49.8% of the total variance) showing the long-  
259 term changes in annual SST and the first principal component (SST PC1). B) The  
260 long-term changes in SST PC1 and an AMO index (Spearman correlation  $r_{sp}$  0.68,  
261  $p < 0.01$ ), and long-term changes in global sulphate aerosol emissions. C) The long-  
262 term changes in SST PC1 and the CPR phytoplankton colour index (PCI) in the  
263 North Sea ( $r_{sp}$  0.66,  $p < 0.01$ ) (Reid & Hunt 1998). D) The long-term changes in SST  
264 PC1 and Norwegian spring spawning herring ( $r_{sp}$  0.43,  $p < 0.01$ ) (Toresen & Østvedt  
265 2008). E) The long-term changes in SST PC1 and a bluefin tuna occurrence index  
266 ( $r_{sp}$  0.75,  $p < 0.01$ ) (Faillettaz et al. 2019). Although based on temperature, the  
267 occurrence index has been validated with the observed changes in tuna abundance  
268 that took place in the North-east Atlantic (Faillettaz et al. 2019). The given  $r_{sp}$  is the  
269 coefficient of Spearman correlation and values are based upon a Montecarlo test  
270 with 10,000 simulations.

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