North Atlantic Oscillation dynamics recorded in shells of a long-lived bivalve mollusk

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ABSTRACT

Existing reconstructions of the winter North Atlantic Oscillation (WNAO) are based on terrestrial proxies and historical documents. No direct high-resolution, long-term records from marine settings are available for this major climate-dictating phenomenon, which severely affects a variety of economic aspects of our society. Here we present a 245 yr proxy WNAO index based on shells of the long-lived marine bivalve mollusk *Arctica islandica*. Variations in annual rates of shell growth are positively correlated with WNAO-related changes in the food supply. Maximum amplitudes in frequency bands of 7–9 and 5–7 yr fall exactly within the range of instrumental and other proxy WNAO indices. These estimates were obtained for specimens collected live, 2000 km apart, in the central North Sea and on the Norwegian Shelf. Hence, the WNAO influences hydrographic regimes of large regions of the ocean. Our study demonstrates that *A. islandica* can reliably reconstruct WNAO dynamics for time intervals and regions without instrumental records. Our new tool functions as a proxy for the WNAO index prior to the twentieth-century greenhouse forcing and has the potential to further validate other proxy-based WNAO records.

Keywords: bivalves, increment, North Sea, North Atlantic, climate, Holocene.

INTRODUCTION

Much of the current debate on the North Atlantic Oscillation (NAO) focuses on its predictability (e.g., Griffies and Bryan, 1997; Hurrell et al., 2001; Rodwell, 2003). The NAO steers the climate variability over major parts of the Northern Hemisphere (van Loon and Rogers, 1978; Hurrell et al., 2003), thereby affecting the world's economic hot spots in multiple ways. Immense costs are required to repair damages caused by increased NAO-driven storms (Kushnir et al., 1997). Other major economic losses can result from dramatic slumps in fishery (Ottersen and Stenseth, 2001; Wieking and Kröncke, 2003) and crop yields (Cullen and deMenocal, 2000) caused by NAO-related fluctuations. Shortages in water supply (Cullen and deMenocal, 2000) and sharp fluctuations in hydropower-generated electricity (Visbeck et al., 2003) were recognized to be primarily controlled by changes of the NAO. The NAO's measure of state, the NAO index—typically defined as the pressure difference between the Azores and Iceland (Hurrell, 1995)—has remained predominantly positive since ca. 1970. Concurrent surface-temperature warming in the Northern Hemisphere (Hurrell, 1996) has had a strong impact on the European climate and on ecological processes in the North Atlantic and adjacent seas (Hurrell, 1995; Stenseth et al., 2002; Ottersen et al., 2001). Forecasting the NAO index requires long-term, high-resolution records from many different environmental settings (Schmutz et al., 2000). However, instrumental records are limited in time and space, and existing reconstructions of the NAO (Hurrell, 1995; Jones et al., 1997) are primarily based on terrestrial proxies, such as ice cores (e.g., Appenzeller et al., 1998), stalagmites (Proctor et al., 2000), tree rings (e.g., Cook et al., 2002), snow-accumulation rates (Glueck and Stockton, 2001), and historical records (Rodrigo et al., 2001). Despite an increase in efforts to investigate the NAO (Wanner et al., 2001), no marine proxy data from boreal and temperate regions have been utilized in the reconstruction of the NAO.

Here we present the first ocean-based long-term proxy record of the WNAO (W—winter) index based on growth increments in the shells of the bivalve mollusk *Arctica islandica* (Linnaeus 1767). Like many other NAO studies we focus on the WNAO, because NAO-induced environmental variability is most pronounced during the coldest period of the year (Hurrell, 1995). Shells of *A. islandica*, the ocean quahog, are particularly suitable for WNAO reconstructions. (1) As inferred from oxygen isotope records (Witbaard et al., 1997; Marchitto et al., 2000), ocean quahogs regularly accrete aragonite to their shells between about January–February and August, and annual growth breaks (Jones, 1983) allow for assigning precise calendar dates to each part of the shells. (2) *A. islandica* specimens can live as long as 220 yr (Jones, 1983), providing extremely useful long-term records of marine environmental variables (Marchitto et al., 2000; Jones, 1983). (3) Shells of *A. islandica* record changes in their environment, predominantly food and temperature, in variable annual shell-growth rates (Witbaard et al., 1997; Marchitto et al., 2000). Ocean-based reconstructions of the WNAO are critical for rigorous testing of ocean-atmosphere models and to verify existing NAO proxies.

MATERIALS AND METHODS

We obtained 21 specimens of *A. islandica* from museum collections. These specimens were collected by dredging from 30 to 60 m water depths in the central North Sea and the Norwegian Sea (Fig. 1). Between 1903 and 2002, 17 live-collected and 2 dead specimens with articulated valves were collected from the central North Sea. Two more live-collected (July 1861) specimens came from the Norwegian Sea. These areas are suitable to study changes of the WNAO because the wind-driven northeastward currents (North Atlantic Water) enter the central North Sea from the north through the Fair Isle region and also flow farther northward, thereby affecting the biota of the Norwegian Shelf (Turrell, 1992).

We employed routine techniques used by dendrochronologists (Cook and Kairiukstis, 1990) and sclerochronologists (Marchitto et al., 2000; Schöne, 2003) to calculate standardized growth indices (SGI) from measured annual increment widths and then computed two re-

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