Daily Growth Rates in Shells of *Arctica islandica*: Assessing Sub-seasonal Environmental Controls on a Long-lived Bivalve Mollusk

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Shells of the extremely long-lived bivalve mollusk Arctica islandica *(Linnaeus 1767) provide century-long, multi-proxy records of inter-annual environmental variability in middle- to high-latitude marine settings. Reliable interpretation of these climate archives, however, requires exact knowledge of the length and timing of the growing season and which environmental parameters control shell growth rate during the year. Here, intra-annual growth microstructures, δ^{18}O-derived ambient water temperatures, and δ^{13}C from* A. islandica *shells collected from the southern and central North Sea are studied. Such data were analyzed in conjunction with observational sea-surface temperature and primary productivity data.* Arctica islandica *produces circadian growth increments in its shell (on average 31.5 µm per day during age four, measured along the outer shell surface), which allow assignment of calendar dates to each shell portion. The growing season of* A. islandica *in the upper mixed layer of the ocean (here 25 m water depth) is not continuous over an eight-month period as previously suggested. Rather, it is interrupted during spawning between early September and mid-November. In addition, shell production ceases or is strongly retarded due to food scarcity between mid-December and mid-February. Water temperatures derived from oxygen-isotope ratios are in good accord with observed sea-surface temperatures. In specimens at 25 m water depth, abrupt changes in shell δ^{18}O-derived temperature ($T_{\delta 18O}$) were interpreted to represent vertical displacements of the seasonal thermocline. Daily shell growth is controlled by temperature and food availability. Up to 58% of the variation in daily growth rate is explained by these environmental parameters. This study demonstrates that* A. islandica *can provide seasonal to subseasonal, precisely dated proxies of environmental variables. Such data are of increasing importance for climate models.*

INTRODUCTION

Seasonal and sub-seasonal changes of environmental conditions are essential for climate-system modeling. For example, ice and sediment records indicate that the timing of climate change often is modulated by seasonality changes related to periodicities in Earth's orbital parameters (Broecker, 2000). However, existing instrumental records of seasonal environmental variables—in particular for the ocean in mid to high latitudes—are relatively sparse prior to about 1960. In addition, such datasets contain errors because measurement devices and measurement design changed over time (Hurrell and Trenberth, 1999). Although spatiotemporal inconsistencies and historical bias have been corrected in modern datasets, the temporal limitations of the datasets themselves still are a problem. Currently, the longest and most reliable record (i.e., the NOAA/NESDIS extended reconstructed sea-surface temperature dataset; Smith and Reynolds, 2003; henceforth "ERSST") exhibits monthly resolution and begins in 1854. Beyond those limitations, environmental variability must be estimated by proxy data.

In mid- to high-latitude settings, tree rings provide excellent proxies for summer air temperatures and precipitation on land (Briffa et al., 1990, 1998; Schweingruber et al., 1991). Proxies derived from tree rings, however, lack temporal resolution sufficient to determine seasonal to sub-seasonal environmental variability. Environmental records inferred from trees are summer-biased. More importantly, these data cannot be used reliably to interpret marine temperatures of the same latitudes. This is partly achieved by using marine sedimentary archives, such as microfossils contained in oceanic sediments (Williams et al., 1979; Fairbanks and Wiebe; 1980; Jiang et al., 2001; Andrews and Giraudeau, 2003). However, the temporal resolution of laminated sediments is limited, and ranges from decades to millennia depending on the dating technique (radiocarbon, ^{210}Pb, etc.) and sedimentation rate.