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Marine climatic seasonality during medieval times (10th to 12th centuries) based on isotopic records in Viking Age shells from Orkney, Scotland

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ABSTRACT

Seasonal sea-surface temperature (SST) variability during the Medieval Climate Anomaly (MCA), which corresponds to the height of Viking exploration (800–1200 AD), was estimated using oxygen isotope ratios ($\delta^{18}O$) obtained from high-resolution samples micromilled from archaeological shells of the European limpet, *Patella vulgata*. Our findings illustrate the advantage of targeting SST archives from fast-growing, short-lived molluscs that capture summer and winter seasons simultaneously. Shells from the 10th to 12th centuries (early MCA) were collected from well-stratified horizons, which accumulated in Viking shell and fish middens at Quoygrew on Westray in the archipelago of Orkney, Scotland. Their ages were constrained based on artifacts and radiocarbon dating of bone, charred cereal grain, and the shells used in this study. We used measured $\delta^{18}O_{WATER}$ values taken from nearby Rack Wick Bay (average 0.31 ± 0.17‰ VSMOW, n = 11) to estimate SST from $\delta^{18}O_{SHELL}$ values. The standard deviation of $\delta^{18}O_{WATER}$ values resulted in an error in SST estimates of ±0.7 °C. The coldest winter months recorded in the shells averaged 6.0 ± 0.6 °C and the warmest summer months averaged 14.1 ± 0.7 °C. Winter and summer SST during the late 20th century (1961–1990) was 7.77 ± 0.40 °C and 12.42 ± 0.41 °C, respectively. Thus, during the 10th to 12th centuries winters were colder and summers were warmer by ~2 °C and seasonality was higher relative to the late 20th century. Without the benefit of seasonal resolution, SST averaged from shell time series would be weighted toward the fast-growing summer season, resulting in the conclusion that the early MCA was warmer than the late 20th century by ~1 °C. This conclusion is broadly true for the summer season, but not true for the winter season. Higher seasonality and cooler winters during early medieval times may result from a weakened North Atlantic Oscillation index.

1. Introduction

Late Holocene climate episodes provide critical information about pre-industrial climate change relevant to understanding natural variation in the climate system. Recent attention has focused on temporal and spatial variability during the Medieval Climate Anomaly (MCA) and Little Ice Age (LIA) (Jansen et al., 2007; Mann et al., 2009; Trouet et al., 2009; Diaz et al., 2011; Graham et al., 2011). Graham et al. (2011) and Diaz et al. (2011) provide an excellent historical background and synthesis of proxy records, regional climate reconstructions, and results from climate model experiments supporting global climate reorganization during the MCA and LIA. This interval of time is significant culturally because it spans the height of Viking (Scandinavian) exploration and economic intensification during the MCA (800–1200 AD), and subsequent retrenchment in the early LIA (1200–1550 AD). Paleoclimate reconstructions that use archaeological sources contribute to our understanding of human–climate interactions (Surge and Walker, 2005; Walker and Surge, 2006; Hallmann et al., 2009; Hufthammer et al., 2010; Jones et al., 2010; Andrus, 2011; Helama and Hood, 2011; Wang et al., 2011, 2012), especially in regions that are sensitive to climate change.

Proxy records reconstructing climatic conditions during the MCA are strongly biased towards decadal to annual resolution and summer/growing seasons (e.g., Table 6.1 in Jansen et al., 2007 and Table 1 in Christiansen and Ljungqvist, 2011). Few studies resolve the winter season. Those that do focus on winter precipitation and even fewer report on winter air temperatures, which are reconstructed based on documentary evidence (Ogilvie and Farmer, 1997; Pfister et al., 1998). Studies of pre-industrial climate change that resolve summer and winter variability in sea surface temperature (SST) are scarce (Patterson et al., 2010; Wanamaker et al., 2011). Regional climate models illustrate the need for such high-resolution studies at seasonal time scales. Numerical (idealized multi-level primitive equation) and sensitivity (ECBilt-Clio) model experiments demonstrate that small changes in the coupled atmospheric-oceanographic climate system influence regional mid-latitude seasonality (Lee and Kim, 2003; van der Schrier et al., 2007). These model simulations for the North Atlantic sector show that minute changes in the position and intensity of the subtropical jet stream at low latitudes restrict the polar front jet stream

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Table 1
Time range of the archaeological limpet shells.

Specimen no.	NOSAMS no.	AMS radiocarbon age, ^{14}C cal BP	$\delta^{13}C$ (VPDB ‰)	2 Sigma calibration
QG2-7180-1	OS-95722	1250 ± 25	0.39	cal BP 721–979 (cal AD 971–1229)
QG2-7180-2	OS-95723	1250 ± 25	2.13	cal BP 721–979 (cal AD 971–1229)
QG2-1064-1	OS-95724	1260 ± 20	0.59	cal BP 730–988 (cal AD 962–1220)
QG2-1061-1	OS-95725	1270 ± 20	1.54	cal BP 739–1005 (cal AD 945–1211)
QG1-7246-1	OS-95727	1350 ± 30	−0.39	cal BP 822–1122 (cal AD 828–1128)
QG1-7189-2	OS-95726	1370 ± 20	1.68	cal BP 876–1140 (cal AD 810–1074)
QG1-7188-1	OS-95728	1390 ± 25	1.10	cal BP 896–1156 (cal AD 794–1054)

to high latitudes. As with a positive North Atlantic Oscillation (NAO) index (a stronger than usual subtropical high pressure center and a deeper than usual Icelandic low), restriction of the polar front jet stream to high latitudes (i.e., a decrease in atmospheric meridional heat transport) and an intensified Gulf Stream (i.e., an increase in oceanic meridional heat transport) transfers a broad band of moisture and latent heat farther northeast. Simulations of the enhanced meridional heat transport as a result of these complementary atmospheric–oceanic processes generate equable climate at mid latitudes and demonstrate the potential sensitivity of mid-latitude regions to seasonal-scale changes.

Archives from fast-growing shells can potentially capture summer and winter seasons and, thus, approach the full seasonal range of sea surface temperature (SST). Often, fast-growing shells are short-lived and, thus, provide "snapshots" of multi-year seasonal cycles. Archaeological limpet shells of the genus, *Patella*, collected by the local human inhabitants are potentially valuable archives of variability in seasonal SST from coastal marine environments (Shackleton, 1973; Cohen and Branch, 1992; Fenger et al., 2007; Ferguson et al., 2011; Wang et al., 2012). This study presents reconstructed mid-latitude SST at seasonal time scales using oxygen isotope ($\delta^{18}O$) proxy data from shells of the European limpet, *P. vulgata*, harvested by the inhabitants of the Quoygrew archaeological site on Westray in the archipelago of Orkney (a Scandinavian colony of the Viking Age that came under Scottish rule in 1468 AD) (Fig. 1). We tested the hypothesis that seasonal variability in coastal SST during the 10th to 12th centuries was similar to that of the late 20th century (1960–1991).

2. Study area

2.1. Archaeological context

The Quoygrew archaeological site (59.34°N, 2.98°W) is located at the head of Rack Wick Bay on the island of Westray in the archipelago of Orkney, north of mainland Scotland (Fig. 1). It was a rural farming and fishing settlement occupied between the 10th century AD and 1937. Excavation focused on houses and associated middens (refuse dumps) dating from the earliest seven centuries of this millennium-long sequence. Midden deposits from the 10th to 15th centuries (MCA-LIA) were particularly well stratified. For the present study we focus on shells from layers radiocarbon dated to the 10th century (Phase 1) and to the 11th to 12th centuries (Phase 2). The Phase 1 specimens derive from early midden strata of the so-called farm mound, a build-up of superimposed household refuse, discarded animal bedding, fuel residues and demolished buildings approximately 50 m from the shoreline. The Phase 2 specimens derive from strata higher in the same farm mound (QG2-7180-1, and QG2-7180-2) and from the basal layers of a semi-specialized fish processing midden at the wave-cut bank (QG2-1061-1, QG2-1064-1) (Barrett, 2005, in press; Simpson et al., 2005). Limpets were the most common molluscs represented in the fish midden and farm mound at Quoygrew. Their abundant shells probably represent the collection of bait for fishing, although some limpets may also have been eaten by the site's inhabitants (Milner et al., 2007).

2.2. Oceanographic setting

Physical and chemical oceanographic features of continental slope and shelf waters along western Scotland have been well studied since the 1980s (Inall et al., 2009 and references therein). Offshore, the northward flowing European Slope Current acts as an effective barrier to lateral exchange between coastal shelf and deep ocean waters (Huthnance, 1992, 1995), although Souza et al. (2001) have observed winter intrusions of European Slope Current water onto the shelf.

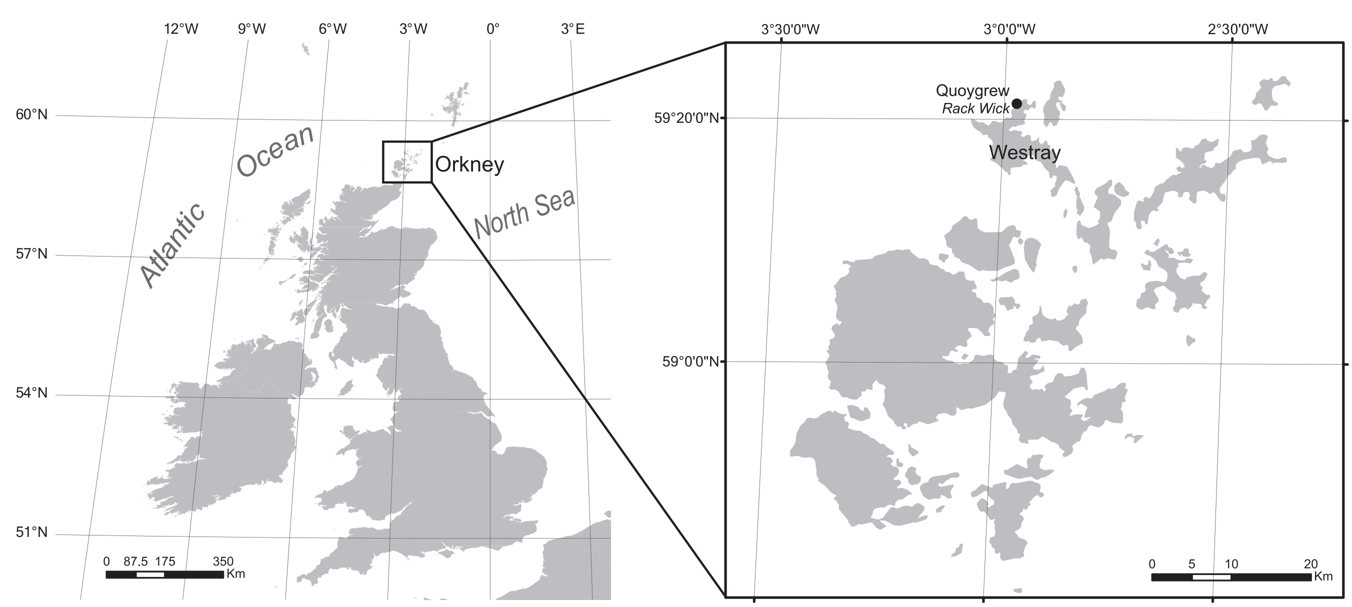

Fig. 1. Map of Scotland and Orkney locating the Quoygrew archaeological site on Westray and Rack Wick Bay.