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Time-transgressive environmental shifts across Northern Europe at the onset of the Younger Dryas

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ABSTRACT

Until lately, it has commonly been assumed that the last major reorganization of the North Atlantic ocean–atmosphere system, the Younger Dryas climatic reversal, spread synchronously on continental to hemispheric scales. This assumption arose because reliable chronologies, which would allow capturing the complexity surrounding local responses to abrupt climate change, were lacking. To better understand the temporal structure at the inception of the Younger Dryas across the North Atlantic, we revised, updated and compared the chronological framework of four Northern European sediment sequences (Lake Kråkenes, Lake Madtjärn, Lake Gammelmose, Sluggan Bog) by applying classical Bayesian modelling. We found distinct and spatially consistent age differences between the inferred ages of the Allerød interstadial – Younger Dryas stadial pollen zone boundaries among the four sites. Our results suggest an earlier vegetation response at sites along latitude 56–54°N as compared to sites located at 60–58°N. We explain this time lag by a gradual regional cooling that started as early as c. 12,900–13,100 cal. BP. This phenomenon was probably linked to cooling around the Nordic Seas as a result of enhanced iceberg calving from the Fennoscandian Ice Sheet during the final stage of the Allerød interstadial. By contrast, vegetation shifts at sites located further north occurred significantly later and in concert with the establishment of full stadial climate conditions (c. 12,600–12,750 cal. BP). Our study emphasizes the need to develop solid regional ^{14}C chronologies and to employ the same age modelling approach to determine the temporal and spatial response to a climatic shift.

1. Introduction

The Younger Dryas stadial (YD) is the most recent and widespread abrupt climate oscillation, which occurred towards the end of the last deglaciation. It is recorded in numerous paleoclimate archives around the North Atlantic region as a c. 1000-year long cold interval (Lowe et al., 2008). The onset of the YD is often attributed to a reduction in the North Atlantic meridional overturning circulation (Broecker, 1998; McManus et al., 2004) resulting from a major meltwater pulse into the North Atlantic (Duplessy et al., 1992; Bard et al., 2000; Bradley and England, 2008).

The pollen-stratigraphic transition associated with the onset of the YD has long been used as a common and synchronous stratigraphic boundary in the region (Mangerud et al., 1974; Björck et al., 1996, 1998a,b; Wohlfarth, 1996; Lowe et al., 2008). Related shifts observed in diverse proxy records in locations far from the North Atlantic region are often assumed to reflect the same climatic event (e.g. Cheng et al., 2009).

In the Greenland NGRIP ice core, the onset of the regional counterpart of the YD is defined by a marked increase in deuterium excess (Steffensen et al., 2008), a proxy for far-field changes in the precipitation source region. This distinct shift occurs over 1–3 years and marks the onset of a cold phase that is referred to as Greenland Stadial 1 (GS-1) (Steffensen et al., 2008).

Various problems commonly arise when attempting to correlate the start of the YD/GS-1 between terrestrial records and ice cores (Lohne et al., 2013). Since the majority of terrestrial sedimentary archives do not provide the time resolution that would allow for a precise correlation to annually resolved ice cores. Moreover, the various proxies that are used to infer past climatic shifts have different environmental sensitivities, and these do not necessarily change in phase across major climate transitions. Due to these limitations, it has been commonly assumed that abrupt climate changes occurred more or less synchronously on continental to hemispheric scales, and for simplification proxy records are often tuned to template sequences such as the Greenland ice core records (e.g. Schwander et al., 2000; Bakke et al., 2009).

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However, a recent study has convincingly shown that although climate transitions may appear locally abrupt, this feature is not a precondition for assuming synchronicity on regional or larger scales (Lane et al., 2013). Rather, it seems that rapid local shifts can be part of a time-transgressive propagation of a large-scale atmospheric phenomenon. These findings have encouraging prospects and stress the importance of establishing a robust regional network of densely dated, chronologically reliable, and temporally well resolved proxy-based climate reconstructions. These qualifications are critical not only for capturing the complexity that surrounds local-to-regional responses to abrupt climate change, but are also important for understanding the mechanisms driving the inception and propagation of abrupt climate shifts.

The latest advancement of the IntCal radiocarbon calibration curve (IntCal13) (Reimer et al., 2013) offers the opportunity to better constrain the age of the transition from the warm Allerød (AL) interstadial to the cold YD stadial. By using new tree-ring ^{14}C records, the gap in the European tree-ring radiocarbon chronologies prior to and during the early YD, has been filled, replacing the ocean-based ^{14}C data from the Cariaco Basin (Hughen et al., 2000). The new IntCal13 chronology, which is based on tree-ring data, constitutes a more reliable representation of atmospheric radiocarbon variations and has minimised previous uncertainties associated with the age reservoir fluctuations in the marine Cariaco record (Hua et al., 2009).

In order to better constrain the timing of the terrestrial environmental responses to the onset of the YD, and to examine the uncertainties associated with radiocarbon dating, we revised, updated and compared the chronological framework of four non-varved Northern European sediment sequences from Lake Kråkenes (Birks et al., 2000), Lake Madtjärn (Björck et al., 1996), Lake Gammelmose (Andresen et al., 2000), and Sluggan Bog (Lowe et al., 2004), the chronologies of which are underpinned by a large number of AMS ^{14}C dates. By employing classical Bayesian age modelling with two independent Bayesian softwares, we here provide new calibrated ages for the AL–YD pollen-stratigraphic boundary defined in each of the four sequences. The results are discussed in the light of potential mechanisms that may have caused a difference in timing among ecosystem shifts in Northern Europe. We also broach some considerations that must be taken into account when assessing the true duration and timing of climate events from terrestrial sedimentary data sets.

2. Methods

2.1. Selection criteria

The four non-varved Northern European Lateglacial sedimentary sequences (Fig. 1; Table 1) were selected on the basis of i) the number of published ^{14}C measurements on terrestrial plant macrofossils. We preferred records characterised by densely spaced, continuous and evenly distributed sequences of radiocarbon dates, with the ability to provide a highly resolved age model. More importantly, in order to restrict the uncertainty on the determination of the AL–YD pollen-zone transition, we established that ii) the pollen-stratigraphic boundary should be closely constrained by means of one radiocarbon measurement on either side of the transition (Table 1), and that iii) the resolution of the pollen sample must not exceed a one-cm interval in close proximity to the transition between the pollen zones.

2.2. Site settings and definition of the AL–YD transition

Lake Kråkenes is located on the west coast of Norway (Fig. 1) and contains a continuous sedimentary sequence that records the environmental history of the catchment since the early AL. Birks et al. (2000) and Birks and Ammann (2000) suggested that Lateglacial biotic and abiotic changes within the small catchment were primarily affected by changes in temperature, which in turn were influenced by the formation and melting of the cirque glacier located above the lake. However, recently Lohne et al. (2013) could show that the glacier formed 20–40 years after the AL/YD transition, and that it did not influence the environmental changes recorded in the sediments until later. The AL–YD pollen-zone boundary was defined using a rate-of-change analysis approach (Birks et al., 2000), which identifies statistically significant rates of change (lithostratigraphy, changes in aquatic and terrestrial biota) based on Monte Carlo permutation tests.

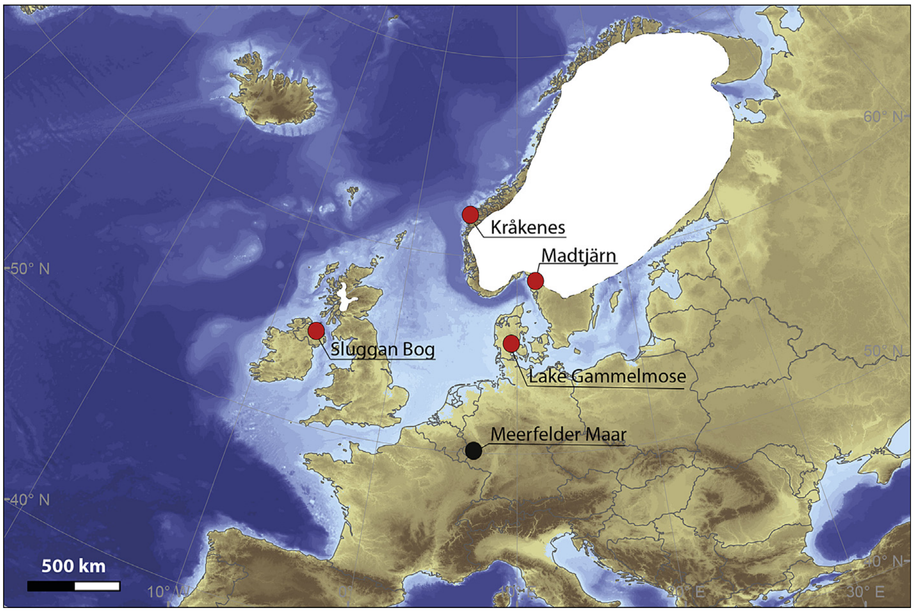

Fig. 1. Location of the sites for which new age-depth models were constructed (red dots). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)