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Subfossil Swedish bog-pines as indicators of mid-Holocene palaeohydrology and climate

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SUMMARY

Dendrochronological analysis of subfossil bog trees in combination with peat stratigraphic data enables high temporal reconstructions of humidity variations during specific periods of the Holocene. Major bog-tree establishment phases in southern Sweden occurred during the relatively warm and dry Holocene Thermal Maximum (c. 8000-4400 cal. years before present). Increased peat density at stratigraphic levels equivalent to the location of subfossil trees indicate relatively dry surface conditions during these tree establishment phases. Within this project, ring-width chronologies covering c. 3500 years have been developed, and absolute ages have been obtained by dendrochronological cross-dating with bog-tree chronologies from Lower Saxony, Germany. The absolutely dated chronologies cover the periods of 5284-3728 BC and 2667-1108 BC, providing detailed regional palaeoclimate and hydrology records for southern Sweden.

KEY WORDS: Dendrochronology, Scots pine, raised bogs, Holocene Thermal Maximum

INTRODUCTION

Since the last deglaciation large continental areas have become covered by peatlands. About 400 million ha of Earth's land surface is covered by peatlands, and c. 90% of this area is located in the Northern Hemisphere (Strack, 2008), comprising one of the largest terrestrial carbon reservoirs (Smith *et al*., 2004). Improved understanding of the long-term dynamics of peatlands, especially in terms of hydrology, is of great importance for accurate reconstructions of Holocene climate variability and better predictions of future climate change.

Bog-surface wetness depends primarily on precipitation, temperature and evaporation. Peat-forming plants, e.g. *Sphagnum* mosses, depend for their nutrients and moisture exclusively on atmospheric precipitation and thus are sensitive to climate change (Aaby, 1976). Variations in effective moisture and groundwater tables of peat deposits are reflected by changes in peat humification, which therefore can be used for reconstructions of bog-surface wetness (Aaby, 1976; Barber *et al.*, 1994). In Scandinavia, visible transitions from more to less humified peat, known as recurrence surfaces, are believed to reflect large-scale shifts in effective moisture during the Holocene (Granlund, 1932; Aaby, 1976). The degree of humification in e.g. *Sphagnum* peat can therefore be used as a proxy for local bog-surface wetness, and synchronous shifts observed at several sites can be used for reconstructions of regional climatic variations.

Dendrochronology has proved to be a valuable source in palaeoclimatic research (Fritts, 1976). Trees growing at, or close to their limits of distribution are sensitive to climate and their ring-width variations provide quantitative climate information of annual resolution (Fritts, 1976). Periods of relatively dry climatic conditions and lowered groundwater levels allow tree establishment and spreading across peat bogs (Leuschner *et al*., 2002). As a consequence of inhibited root respiration, periods of persistently elevated groundwater tables are a major stress factor for peatland trees (Boggie, 1972), and may in some cases result in synchronous degeneration events. Therefore, ring-width records from bog trees provide valuable palaeohydrological data with annual resolution, whereas changes on decadal to millennial time scales can be observed in tree-ring replication records (Edvardsson *et al*., 2012a; 2012b). The main aim of this project is to reconstruct humidity variations during specific periods of the Holocene with high temporal resolution and precision based on dendrochronological analysis of subfossil trees from South Swedish raised bogs in combination with peat stratigraphy.

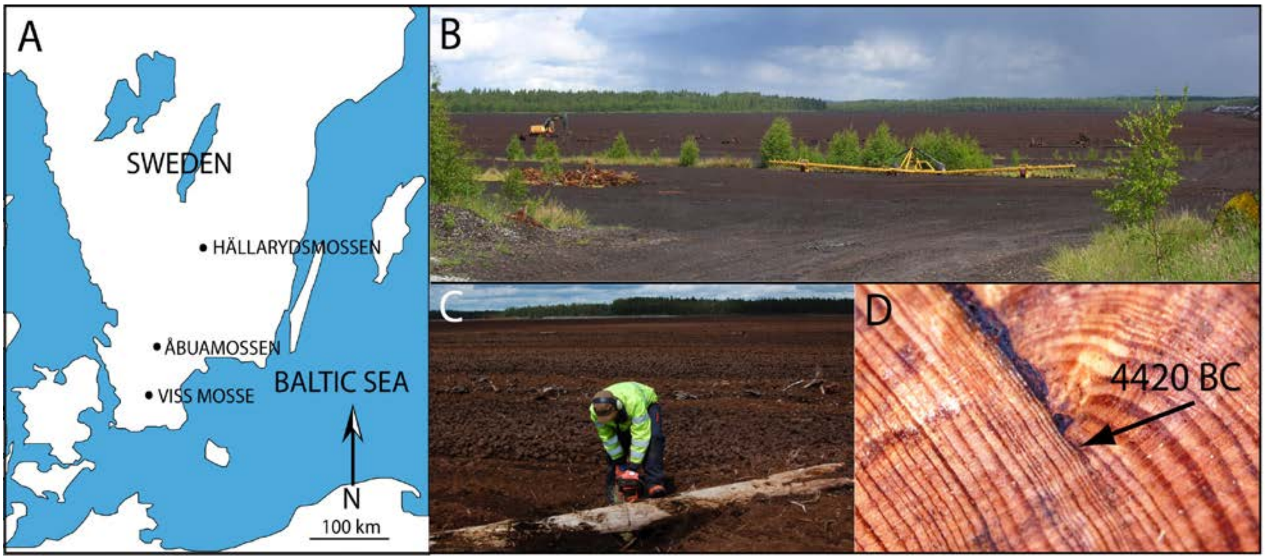

Figure 1. (A) Locations of raised bogs investigated. (B) At Hällarydsmossen, c. 6000-year old stumps and trunks are exposed at the bog surface due to extensive peat harvesting. (C) About 700 cross sections have been collected with a chainsaw. (D) Sequence of annual rings in a subfossil pine, showing signs of injury by fire at 4420 BC.

MATERIALS AND METHODS

During fieldwork campaigns cross sections from almost 700 subfossil trees, mainly Scots pine (*Pinus sylvestris* L.), were collected with a chainsaw. The majority of these samples were taken at the peat bogs Viss mosse, Åbuamossen and Hällarydsmossen (Fig. 1), where abundant stumps and trunks were exposed due to extensive peat harvesting. Ring-width records (Fig. 2) from each site were developed by measuring annual growth rings of the trees with a precision of 0.01 mm using standard dendrochronological instrumentation and methods (Schweingruber, 1988). Peat and sediment cores were obtained with a Russian peat sampler and used for comparison with the dendrochronological data to provide information on the long-term development of the sites.

RESULTS

Absolutely dated ring-width chronologies covering about 3100 years of the Holocene were developed from about 500 trees collected at Hällarydsmossen (Edvardsson *et al*., 2012a), Viss mosse (Edvardsson *et al*., 2012b) and Åbuamossen (Edvardsson 2010; unpublished data). A composite ring-width record from Viss mosse and Hällarydsmossen was assigned an absolute age span by statistical and visual cross-match and correlation tests against German bog-pine chronologies (Edvardsson *et al*., 2012a), whereas the Åbuamossen record (unpublished data) was cross-dated against German bog-oak chronologies (Leuschner *et al*., 2002). So far, the absolutely dated chronologies cover the periods 5284-3728 BC and 2667-1108 BC. Apart from these chronologies, several additional ring-width records have been radiocarbon dated. Studies of peat sequences show that peat density increases at the stratigraphic level where the analysed stump and trunks are located.

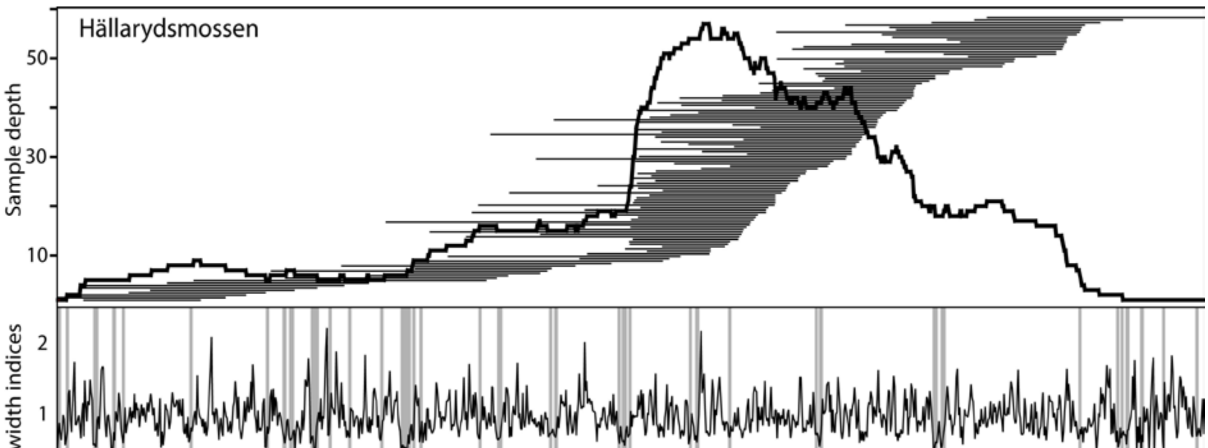

Figure 2. In total, 117 subfossil pine trees from Hällarydsmossen were used to construct an 1112-year ring-width chronology. Individual trees are represented by black horizontal bars. The thick black curve represents tree replication. The thin black curve (lower panel) is the standardized and averaged ring-width chronology (dimensionless indices). Periods of three years in a row or longer with weak growth (–1 standard deviation) are highlighted with grey bands.

DISCUSSION

Precise dating of phases of germination, growth depression, growth elevation and death of bog-tree populations, in combination with growth positions of the trees and peat stratigraphic data, allows detailed spatial reconstructions of stand dynamics linked to hydrological variability (Edvardsson *et al*., 2012b). The dynamics of the tree populations can thereafter be compared to regional, centennial-scale climate variations inferred from other sources. The peat humification record from Viss mosse (Edvardsson *et al*., 2012b) shows an increase in peat density around the stratigraphic level corresponding to the surface of the bog during the tree establishment phase. The establishment of pine populations on the investigated peat bogs (Fig. 3) generally coincides with known periods of relatively high temperatures and low lake-levels in southern Sweden (Seppä *et al*., 2005; Digerfeldt, 1988) during the Holocene Thermal Maximum (HTM) at c. 8000-4440 cal. BP (Seppä *et al*., 2005; de Jong *et al*., 2009). These climatic conditions led to wide-spread bog-tree establishment in both Sweden and Germany (Fig. 3). The remarkably strong cross-correlations between ring-width chronologies from sites in Sweden and Germany separated by 500-700 km (Edvardsson *et al*., 2012a), demonstrate that large-scale climate dynamics had pronounced impacts on peatland pine growth during the HTM.

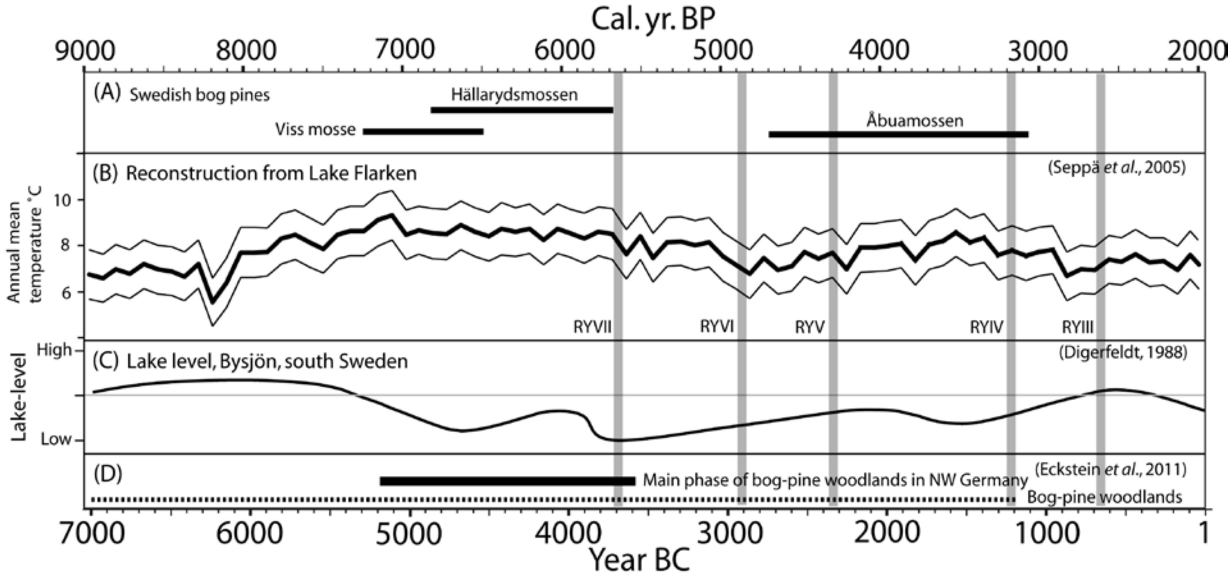

Figure 3. (A) Periods covered by absolutely dated bog-pine chronologies. (B) Pollen based temperature reconstruction for southern Sweden (Seppä *et al*., 2005). (C) Lake-level fluctuations in southern Sweden (Digerfeldt, 1988). (D) Temporal distribution of German bog pines (Eckstein *et al*., 2011). In both Sweden and Germany bog-pine populations established during relatively warm and dry periods, and several of these populations died close to wet shifts recorded as recurrence surfaces (RY) in Swedish peat bogs (Rundgren, 2008).

Conclusions and future challenges

Our studies demonstrate the usefulness of South Swedish subfossil bog pines as a climate proxy, with particular potential for reconstructions of regional, climate-driven variations in humidity at annual to centennial time scales, and local peatland development across centuries to millennia. Dendrochronologial data can successfully be used as a complement to peat stratigraphic data to improve reconstructions of both local and regional climate-driven changes in effective moisture. Continued studies of this kind are also of interest as forest dynamics and growth responses of peatland tree populations may provide important carbon-exchange feedback effects on the global climate.

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