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South Swedish bog pines as indicators of Mid-Holocene climate variability

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ABSTRACT

Dendroclimatic investigations of subfossil Scots pine (*Pinus sylvestris*) from two raised bogs in southern Sweden yielded a continuous floating 1492-year long tree-ring record. By cross-dating with bog-pine chronologies from Lower Saxony, Germany, the South Swedish record was assigned an absolute age of 5219–3728 BC. The cross-match between ring-width chronologies from these two regions, separated by 500–700 km, is remarkably strong and the correlation positive, which indicates that large-scale climate dynamics had a significant impact on the growth of bog pines during the Holocene Thermal Maximum (HTM) when bog-pine distribution reached a maximum in both regions. However, local population dynamics were also influenced by peatland ontogeny and competition, as shown by differences in replication and mean tree age between the Swedish and German records. Comparisons with chronologies developed from modern bog pines in southern Sweden indicate that more coherent climate was controlling pine growth on natural peatlands during warm periods in the past. This study demonstrates the usefulness of Swedish subfossil bog-pine material as a climate proxy, with particular potential for decadal- to centennial-scale reconstructions of humidity fluctuations.

Introduction

Scots pine (*Pinus sylvestris* L.) is a tree species commonly found on peat bogs in southern Sweden (Rydin et al., 1999), and it usually invades open and exposed sites rapidly after disturbances like drainage, deforestation, fire or insect invasion (Zackrisson, 1977; Freléchoux et al., 2000; Eckstein et al., 2010). Growth dynamics of trees growing on bogs usually differ from those on solid ground by being highly dependent on the depth and variability of the water table beneath the root system (Boggie, 1972; Freléchoux et al., 2000; Vitas and Erlickytë, 2007; Eckstein et al., 2009). High groundwater tables generate unfavourable growth conditions as a result of several physical, chemical, and biological processes, of which perhaps the most important is reduced availability of nutrients in the saturated zone (Boggie, 1972; Mannerkoski, 1991; Vitas and Erlickytë, 2007). Groundwater lowerings in peat deposits commonly lead to enhanced tree growth because of the increased availability of nutrients in the unsaturated zone (Penttilä, 1991), but also invasion of trees due to improved germination on drier peat surfaces (Freléchoux et al., 2000). Consequently, increased effective precipitation on peat bogs where the groundwater table is close to the surface results in an even shallower unsaturated zone (Schouwenaars, 1988; Hunt et al., 1999), which in most cases leads to stress and growth reductions in trees growing on the peat surface (Boggie, 1972; Leuschner et al., 2002; Linderholm et al., 2002; Eckstein et al., 2009). Given the strong link between groundwater fluctuations and the growth and establishment of trees on bogs, it can be assumed that ring-width records provide information on inter-annual to decadal-scale hydrological changes associated with regional climate change and variability in the past (Leuschner et al., 2002; Sass-Klaassen and Hanraets, 2006; Eckstein et al., 2009). Studies of establishment and degeneration phases in bog-tree populations may also provide information on changes in bog-surface wetness, hydrology and climate on the centennial time scale (Gunnarson, 2002).

Previous studies have demonstrated that bog pines are of limited use as high-resolution climate proxies, mainly because of weak correlation between ring-width patterns and observed meteorological parameters. Moreover, correlations between tree-ring records between neighbouring sites, or even within a single site, may be low. For example, negative correlations were observed between trees growing on the same peat bog in Lithuania (Pukiene,

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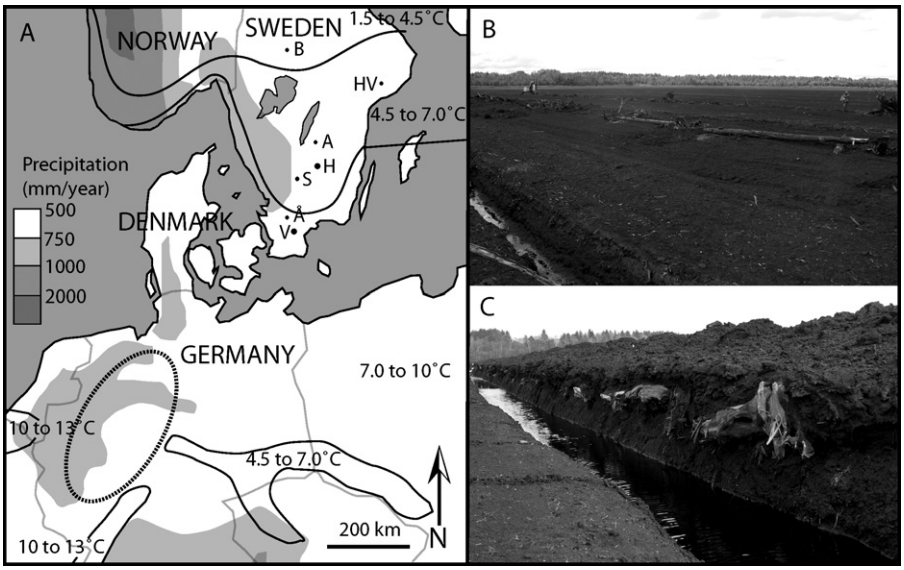

Fig. 1. (A) Locations of South Swedish bog-pine sites presented or discussed in this paper. Subfossil material has been obtained from Viss mosse (V) (Edvardsson, 2010; this study), Åbuamossen (Å) (Edvardsson, 2010) and Hällarydsmossen (H) (this study), whereas the modern material was obtained from Store mosse (S) (Edvardsson unpublished) and the previously published Anebymossen (A), Hanvedsmossen (HV) and Bredmossen (B) (Linderholm et al., 2002). Most of the German bog-pine material originates from the area inside the dotted circle. Annual mean precipitation (mm/year) is shown with shaded fields and average mean temperature with black lines (Wright, 1993). (B) Trunks and stumps exposed at the excavated surface of Hällarydsmossen. About 4 m of *Sphagnum* peat was removed during peat cutting before the stump horizon was reached. (C) Stump horizon with in situ pine stumps visible in a drainage ditch at Viss mosse.

1997), suggesting that shifts in bog-surface wetness are often caused by site-specific ontogeny, and thus weakly related to regional climate dynamics (Väliranta et al., 2007). However, in a regional study in Sweden, Linderholm et al. (2002) found that while the correlation with temperature and precipitation is lower for bog pines than for pines growing on neighbouring dry mineral soils, tree-ring chronologies from the former category exhibit substantially stronger correlations between sites. Furthermore, robust, long-distance correlations between subfossil bog tree-ring chronologies from Germany, Netherlands and Ireland demonstrate that spatial coherence in growth variability is related to large-scale climate variability (Leuschner, 1992; Leuschner et al., 2002, 2007; Eckstein et al., 2009).

Major investigations of subfossil pine and oak (*Quercus robur*) from peat bogs have been carried out in northwestern Germany (Leuschner et al., 1987, 2002, 2007; Eckstein et al., 2008, 2009, 2010) Ireland (Pilcher et al., 1995), Great Britain (Lageard et al., 1995, 2000) and Lithuania (Pukiene, 1997). In Sweden, dendrochronological studies of subfossil trees have mainly been based on wood preserved in dry mountain regions or lake sediments (Briffa et al., 1990; Grudd et al., 2002). Systematic studies of trees buried in peat bogs started relatively recently and are so far restricted to a few sites in central and northern Sweden (Gunnarson, 1999, 2008; Gunnarson et al., 2003) and some preliminary data from southern Sweden (Edvardsson, 2006, 2010).

The main aim of this study is to explore the potential of bog-pine tree-ring records from southern Sweden as indicators of spatial and temporal patterns of humidity variability during the Holocene. We present updated material from Viss mosse (Edvardsson, 2010), which, together with a new record from Hällarydsmossen, form a continuous 1492-year chronology. The absolute age of this new chronology, spanning 5219–3728 BC, was established through cross-dating against well-dated bog-pine chronologies from Lower Saxony, Germany (Eckstein et al., 2009; Leuschner, unpublished data). This new chronology provides novel insight into decadal- to centennial-scale climate variability during the Holocene Thermal Maximum (HTM), a period of relatively warm and dry summers dated to c. 6050–2450 BC (c. 8000–4400 cal. BP) in southern Sweden (Jessen et al., 2005; Seppä et al., 2005; De Jong et al., 2009).

Methods

Study sites and fieldwork

During fieldwork campaigns on six different peat bogs in 2006, 2008 and 2009, about 500 disks from subfossil pine trees were collected with a chainsaw. In total, 209 of these were from the two peat bogs Viss mosse and Hällarydsmossen (Fig. 1).

Viss mosse is located on the bedrock ridge Linderödsåsen in central Scania, southern Sweden (173 m a.s.l., 55°51′N, 13°49′E). It is c. 2 by 1 km in size and one of the most southerly raised bogs in Sweden (Malmberg Persson, 2000). Extensive peat excavation and removal of 2–4 m of *Sphagnum* peat during recent decades has exposed numerous stumps and trunks of mature pine trees with the root level generally c. 0.7 m above the base of the *Sphagnum* peat. These deposits are underlain by a sequence of c. 1 m of carr peat and various types of gyttjas on top of the mineral soil.

Hällarydsmossen is located in the central part of Småland (215 m a.s.l., 57°20′N, 14°35′E), c. 200 km north of Viss mosse. The area around the bog, which is c. 1.8 by 1.4 km in size, is dominated by coniferous forest in an undulating morphology with numerous lakes and bogs. Similarly to Viss mosse, Hällarydsmossen has been subjected to peat excavation, and an estimated 4 m of *Sphagnum* peat has been removed from above the layer where the pine material was collected. The pine horizon is underlain by 1.7–3.7 m of organic deposits, consisting of 0.2–0.8 m of *Sphagnum* peat resting on more than 1.2 m of carr peat and gyttja.

At Viss mosse, a total of 80 cross-sections of in situ stumps and trunks were sampled. In total, 129 cross-sections were collected at Hällarydsmossen, of which 48 were sampled from in situ pines, while the remaining 81 were taken from trees removed from their primary growth positions to enable further peat cutting at the bog surface. In the latter cases the exact stratigraphic