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Enigmatic cycles detected in subfossil and modern bog-pine chronologies from southern Sweden

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Introduction

Bog trees are commonly regarded as unsuitable high-resolution climate indicators, since their annual growth may be affected by ontogeny and other dynamics in the peat which are not directly related to climate or by processes that are related to climate over multiple years. Consequently, direct correlations between ring-widths of bog pines and observed climate may be weak or in some cases non-existent. However, bog-pine tree-ring records may provide valuable palaeoclimate information, especially on decadal and longer timescales (Eckstein et al. 2009, 2010, Edvardsson et al. in review), although further research is needed to fully understand the effects of climate change.

Growth dynamics of bog trees are highly dependent on the depth and variability of the water table beneath their root systems (Boogie 1972, Eckstein et al. 2009). Increased precipitation in areas where the groundwater table is close to the surface may result in a shallower unsaturated zone, which often leads to growth reductions (Gunnarson 1999). Similarly, a lowering of the water table may lead to increased growth (Linderholm 1999). It can therefore be assumed that hydrology is a major factor controlling tree growth on peat bogs, and that regional phases of synchronous growth depression/increase may indicate periods of wetter/drier conditions associated with large-scale climate dynamics (Leuschner et al. 2002, Eckstein et al. 2009). It has been suggested that variations in the solar and lunar cycles influence hydrology (Tomasino & Valle 2000), and therefore also groundwater levels in peat bogs. Thus, it may be possible that influences of e.g. variations in the sunspot cycle can be found in peat-bog tree-ring data.

There are several ways to advance our knowledge of factors affecting growth variability of bog trees, e.g. to combine dendroclimatology with peat strafigraphic investigations based on bulk density and macrofossil content of the peat or stable isotope analysis. In this study pine ring-width chronologies from seven peat bogs in southern Sweden were subjected to spectral and wavelet analyses to identify potential occurrences of periodicities in the tree-ring data during three separate parts the Holocene.

Material and methods

Site description and fieldwork

All analyses were performed on chronologies developed from Scots pine (*Pinus sylvestris*), a common species on South Swedish peat bogs (Zackrisson 1977), which normally invades open and exposed sites after disturbances like drainage, deforestation or fire (Freléchoux et al. 2000, Eckstein et al. 2010). The pine material was collected at seven South Swedish peat bogs (Fig. 1). The subfossil material originates from three bogs used for peat harvesting; Viss mosse, Hällarydsmossen (Edvardsson et al. in review) and Åbuamossen (Edvardsson 2010). In total 337 cross-sections from subfossil pine trees were collected with a chainsaw; 80 from Viss mosse, 128 from Åbuamossen and 129 from Hällarydsmossen. The modern material originates from four raised bogs with limited anthropogenic impact; Store mosse (Edvardsson unpublished data), Anebymossen, Hanvedsmossen and Bredmossen (Linderholm et al. 2002). During fieldwork at Store mosse 35 pine trees growing on peat exceeding 2 m in thickness were sampled with two cores per tree. The material from Anebymossen, Hanvedsmossen and Bredmossen has previously been described by Linderholm et al (2002).

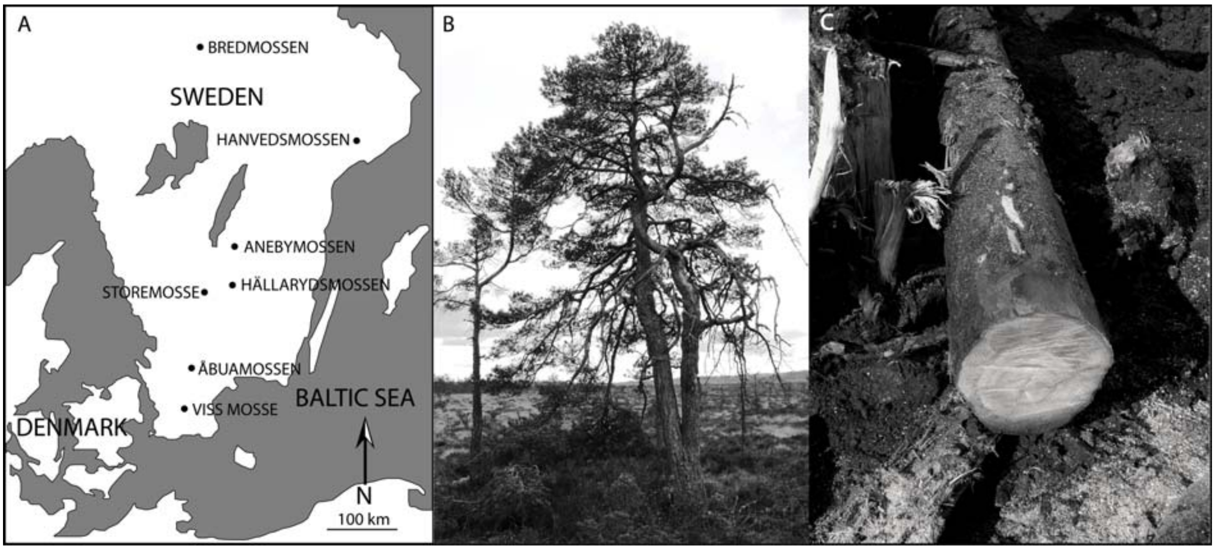

Figure 1: (A) The seven South Swedish peat bogs investigated. (B) Pine tree growing on Store mosse. (C) Subfossil pine tree from Viss mosse, which grew during the period 5077-4970 BC (Edvardsson et al. in review).

Data analysis

Annual ring-widths from each sampled tree were measured with a precision of 0.01 mm, using standard dendrochronological equipment (Schweingruber 1988). Measurements were performed using the CATRAS software (Aniol 1983). In order to detect missing or wedging rings and possible measuring errors, at least two radii or cores, separated by 90° or more, were measured for each tree. Averaged ring-width series from individual trees were thereafter combined into site records (master chronologies) and used in the further analysis. Assessments of the cross-dating and measurement quality, as well as the strength of the master chronologies, were performed with the COFECHA software (Holmes 1983).

One chronology from each site was developed (Tab. 1). Due to wide age distributions, only 259 of the 337 collected subfossil samples could be used for the chronologies, whereas almost all modern samples could be used. The ring-width records from Viss mosse and Hällarydsmossen were assigned calendar-age intervals based on cross-dating against German bog-pine chronologies (Edvardsson et al. in review), whereas the record from Åbuamossen (Edvardsson 2010) was dated with radiocarbon. Wiggle matching (Blaauw et al. 2003) against the IntCal04 radiocarbon calibration dataset (Reimer et al. 2004) was performed to improve the accuracy. The analysed chronologies cover 2680 years of the Holocene, and the material was divided into three separate periods, two based on subfossil material covering the periods 5219-3728 BC (Edvardsson et al. in review) and 2172-1204±9 BC (Edvardsson 2010), and one with modern material covering the period 1789-2008 AD (Linderholm et al. 2002, Edvardsson unpublished data). Standardization, also referred to as detrending, is a procedure which removes non-climatic trends related to e.g. age, geometry and height within the stem (Fritts 1976, Cook & Kairiukstis 1990) A flexible standardization method was applied to all individual ring-width series in order to remove effects of anomalously narrow rings during the first and last decades of growth, a growth trend observed especially on several of the subfossil trees. All ring-width series were standardized with a 67% spline with the ARSTAN software (Holmes et al. 1986). The expressed population signal (EPS) is a commonly used guide for quality tests of tree-ring datasets and evaluations of the reliable length of chronologies (Wigley et al. 1984). The ARSTAN software (Holmes et al. 1986) was used to calculate lengths of periods with EPS above the threshold value 0.85 (Wigley et al. 1984).

Table 1: Bog-pine chronologies used for spectral and wavelet analyses. The table shows site names, number of trees used in each chronology, lengths of chronologies, intercorrelations of series (r), periods with EPS above 0.85, total age spans of the respective chronologies and average ring widths (RW).

Site	No. of trees	No. of years	*r*	No. of years with EPS>0.85	Age spans	Average RW (mm)
Viss mosse	44	646	0.531	424	5219-4574 BC	1.00
Hällarydsmossen	117	1112	0.562	964	4839-3728 BC	0.74
Åbuamossen	98	969	0.526	858	2172-1204±9 BC*	0.89
Store mosse	35	159	0.534	97	1849-2008	0.70
Anebymossen	21	150	0.539	118	1846-1996	0.65
Hanvedsmossen	23	196	0.614	186	1800-1996	0.63
Bredmossen	21	208	0.632	191	1789-1997	0.44

**Uncertainty due to radiocarbon dating.*

To assess possible periodicities in the tree-ring data, spectral analysis was performed on each chronology, using a range of different spectral analysis models. The results shown and discussed below were calculated using a Tukey-Hanning window (Blackman & Tukey 1958). Wavelet analysis was also performed to visualize the temporal stability of the detected cycles over the time-span of each chronology. The Sysat software package Autosignal 1.7 was used for both spectral and wavelet analyses. Each chronology was studied separately in its total length and for the period with EPS values above 0.85. The three chronologies developed from subfossil material, spanning between 646 and 1112 years, were also divided into 300-year sequences that underwent identical analyses as the complete chronologies. These analyses were made in order to assess whether detected cycles occurred temporary or remained stable over time.

Results

Spectral analysis

Highly significant (p<0.01) cycles of c. 13, 15, 31, 57 and 62 years were found (Fig. 2). Also cycles of c. 14, 18, 21, 31 and 62 years with a significance of p<0.1 were detected.

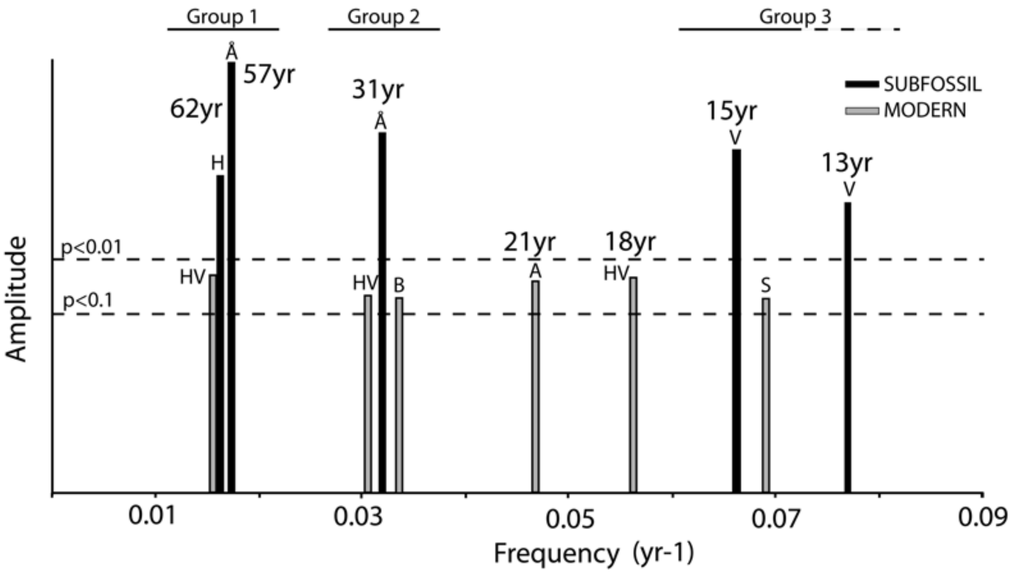

Figure 2: Comparison between cycles detected in the subfossil (black lines) and the modern (grey lines) ring-width chronologies. Lengths of the cycles in calendar years (yr) are shown above the lines. Each site is represented by letter/letters, V (Viss mosse), H (Hällarydsmossen), Å (Åbuamossen), S (Store mosse), A (Anebymossen), HV (Hanvedsmossen) and B (Bredmossen).

The cycles detected in the subfossil ring-width chronologies reached higher significance levels (five cycles with p<0.01) than those found in the modern chronologies (six cycles with significance level p<0.1 and no cycles reaching the highest significance level p<0.01).

Wavelet analysis

The c. 13- and the c. 15-year cycles detected in the Viss mosse record were seemingly stable over time and present during the full 646-year span of the chronology (Fig. 3).

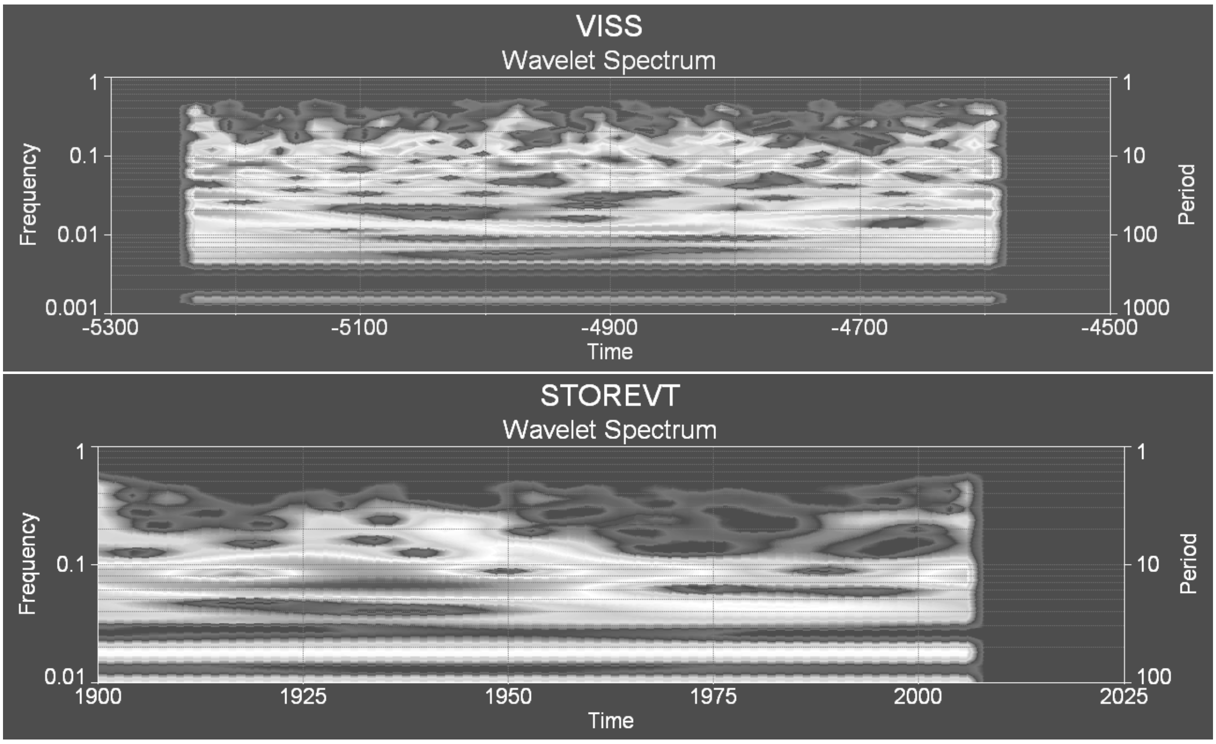

Figure 3: Upper panel: wavelet analysis of the Viss mosse ring-width chronology. The detected c. 13- and 15-year cycles appear to be present during most of the 646-year period. Also cycles between 50 and 80 years are present. However, these cycles have lower significance levels as they do not appear in the spectral analysis. Lower panel: wavelet analysis of the Store mosse ring-width chronology. Most cycles detected in the modern chronologies are not stable over time. For example, the cycles in the Store mosse chronology become markedly weaker between 1950 and 1975.

Similarly, the c. 62-year cycle in the Hällarydsmossen chronology is present during most of its 1112-year age span. However, the observed cycles in the 969-year long Åbuamossen chronology, of which the c. 31- and the c. 57-year cycles were the most significant, were not temporally stable. Moreover, the cycles detected in the four modern chronologies from Store mosse, Anebymossen, Hanvedsmossen and Bredmossen (Fig. 3) were not as robust or significant as those detected in the subfossil material.

Discussion

Several highly significant cycles were found, with cycles of c. 15, 30 and 60 years more frequently encountered (Fig. 2). These cycles may be associated with solar activity (e.g. sunspot variability), large-scale circulation of the North Atlantic Ocean and the atmosphere, precipitation cycles, or related to internal hydrological dynamics of the peat bogs. Groundwater fluctuations in peat deposits are the predominant growth-controlling factor for bog-tree growth (Boggie 1972), and as solar and lunar cycles affect groundwater levels, such planetary cycles may be encountered in ring-width chronologies from bog trees. However, the 11- and 22-year sunspot cycles were weak to absent in the records. A c. 11-year cycle was detected in the chronology from Viss mosse, but excluded as the significance level only reached p<0.5. The c. 21-year cycle detected in the Anebymossen chronology (Fig. 2) may be a solar cycle and the c. 18-year cycle detected in the Hanvedsmossen chronology (Fig. 2) may be related to lunar cyclisity. Yndestad (2006) linked an 18-20 year North Atlantic Oscillation (NAO) cycle to the 18.6-year lunar nodal cycle (O'Brien & Currie 1993). Both lunar cycles and atmospheric circulation indeces are believed to affect humidity and groundwater levels in peat bogs and can therefore be assumed to also affect peatland tree growth.

Similarities between cycles detected in modern and subfossil chronologies

When the material was divided into subfossil and modern chronologies (Fig. 2), three groups with similar common cycles were detected. Cycles around 60 years (Group 1) were detected in the chronologies from Hällarydsmossen, Åbuamossen and Hanvedsmossen. Multi-decadal variability connected to long-term changes in sea-surface temperature with a period of 62 years has been identified by e.g. Fischer & Mieding (2005). The 60-62 year cycle (Group 1), which is observed with different significance level in several chronologies, could therefore be related to internal dynamics of the climate system, such as the meridional overturning of the North Atlantic and/or the Atlantic Multidecadal Oscillation.

A second set of significant cycles (Group 2) clustered around a period of c. 30 years. These cycles were seen in the Åbuamossen, Hanvedsmossen and Bredmossen chronologies. The c. 30-year cycles are somewhat enigmatic, but may be related to previously described climate- and hydrology-related phenomena. An Atlantic Ocean oscillation cycle of c. 30 years that supports a coupled atmosphere-ocean mode was described by Justino & Peltier (2005). Moreover, a highly significant but puzzling c. 30-year cycle found in coral records was linked to a possible mixture of multiple solar cycles (3 times 11 years) and the NAO (4 times 7.7 years), amplified by e.g. changes in the polar front and North Sea salinity (Berger et al. 2002). Also, a 30-year sea-level cycle has been detected in the Finish Gulf and the Baltic Sea, and is significantly linked to the NAO (Johansson et al. 2001). It is difficult to judge to what extent these internal and external forcings have affected growth dynamics of pine trees on the South Swedish raised bogs as reflected by Group 2 cyclicity.

Finally, cycles of c. 15 years were detected in the Viss mosse and Store mosse chronologies (Group 3). Temperature variability observed in Norway identifies periods of warming and cooling in the entire northern North Atlantic with a cyclicity of c. 15 years (Yndestad 2006). Moron et al. (1998) described a 13- to 15-year oscillation cycle in North Atlantic sea-surface temperature, which can bee seen as a seesaw pattern between the Gulf Stream region and the North Atlantic drift. The 13-year cycle detected in the Viss mosse chronology may also be included in Group 3 as the cyclicity described by Moron et al (1998) ranges between 13 and 15 years. However, the highly significant 13-year cycle may also be linked to a 9-13 year periodicity in solar irradiance, which is thought to influence global sea-surface temperatures (White et al. 1997). In turn, these variations in sea surface temperature may affect precipitation patterns and humidity over land, which could potentially provide impacts on tree-growth patterns on raised bogs at mid to high latitudes.

Differences between modern and subfossil chronologies

The spectral and wavelet analyses also revealed some clear differences between the modern and subfossil bog-pines chronologies. The significance levels of cycles in the subfossil material were in general higher (five cycles above p<0.01 significance), than those identified in the modern material (six cycles above the p<0.1 significance level) and more stable through time. There are several likely reasons behind these differences. The climate of southern Sweden during the mid-Holocene was warmer and drier than at present (Jessen et al. 2005, Seppä et al. 2005), which probably created more favourable growth conditions for bog pines at that time. In addition, increasing anthropogenic impact on modern bog surfaces during the last c. 4000 years (Linderholm & Leine 2004), e.g. ditching and peat cutting, has most likely had an effect on bog pine growth, which complicates comparison between populations of widely different ages. The shorter time series available in the modern material also have to be taken into account. Consequently, differences in population dynamics and growth variability between living and subfossil trees are to be expected, and potentially associated differences in cyclicity should be interpreted with caution.

Conclusions

Consistent cycles of c. 60, 30 and 15 years in both modern and subfossil tree-ring chronologies from bog pines at several sites in southern Sweden may indicate coherent responses of tree populations to large-scale climate variability throughout the mid- and late Holocene. The nature of these cycles is still unclear, but external forcings mediated by atmospheric circulation dynamics in the North Atlantic region may be involved. Cycles may also be related to internal hydrological dynamics of the individual peat deposits. The low significance of most cycles observed in the modern material is likely due to relatively short time series and anthropogenic impact. Several questions remain regarding bog trees as climate indicators, and climate reconstructions based on subfossil material must rely on solid knowledge of local and regional factors controlling bog tree growth. However, more detailed analyses of growth dynamics of subfossil bog-pine populations may lead to increased understanding of hydrological variability and change during the Holocene.

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