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Dendroecological studies on subfossil pine and oak from "Totes Moor" near Hannover (Lower Saxony, Germany)

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Introduction

The “Totes Moor” is a 33 km² large wetland, located in the Weser-Aller lowlands, about 25 km north-west of Hannover on the southern margin of the North German lowlands (Lower Saxony, Germany; Schneekloth & Schneider 1970, Tüxen 1979). It is situated at the northern margin of a shallow depression northwest of lake “Steinhuder Meer”. The depression, which has been formed by thermokarst, is filled with fluvioglacial sediments and covered by peatlands. Surface inequalities containing small basins, channels and walls characterize the relief of the mineral ground at the end of the last glaciation (Merkt 1979). In the first half of the Holocene, this caused a heterogeneous vegetation mosaic with different tree stands, reeds and ponds to develop. In most parts of this area, raised bog growth started in the Atlantic period.
At present the area is used for industrial peat cutting. Thereafter the peat harvest fields are rewetted and classified as nature conservation areas.
The climate in the area is slightly of Atlantic character. Mean annual precipitation (based on the period 1961-1991) is 630 mm, more than half of which (c. 360 mm) precipitates from April through September (DWD 2007).
During peat harvesting, large amounts of subfossil wood, primarily pine (*Pinus*) and oak (*Quercus*), but also alder (*Alnus*), are excavated and provide evidence of former environments. This wood is most important for dendroecological investigations. They form the main focus of a supra-regional research project funded by the German Research Foundation (DFG; LE 1805/2-1) that investigates the usefulness of bog pines as indicators for climate change

The aims of the study are:

- Cross dating of the pine samples to establish dated or, floating chronologies. Although there exists no master pine chronology for northern Germany, it can be expected that well replicated and extended pine data series can be crossdated with the bog oak master chronology for Lower Saxony (LSBOC; Leuschner et al. 2006, Leuschner et al. 1987) which spans the period from 6,069 BC to AD 931.
- Reconstruction of the spatial and temporal distribution of former pine woodlands.
- Reconstruction of the ecological context of former mire pine woodlands, their establishment, population dynamics and decline.
- Documentation of stress as an indicator of changes of ecological conditions. It can be assumed that hydrology is a main factor for tree growth in mire woodlands, and therefore, common growth depression phases may indicate wetter conditions (Leuschner et al. 2002; Sass-Klaassen 2006).
- Determination of whether recorded stress, changes in growth pattern, and population dynamics of pines results from local environmental changes in the "Totes Moor" area or from regional phenomena which can be linked to supra-regional environmental shifts also documented from other Lower Saxony peatland sites like “Oytener Moor” and “Heseper Moor”.

Below first results of these investigations are discussed.

Material and Methods

Sampling

Samples were taken from the central part of the bog (52.51°N 9.39°E), where industrial peat harvesting proceeds. The sampling sites are distributed over an area of about 1 km². Most of the samples were recovered from four sub-sites with laboratory codes M723, M724, M725 and M726 (Fig. 1).

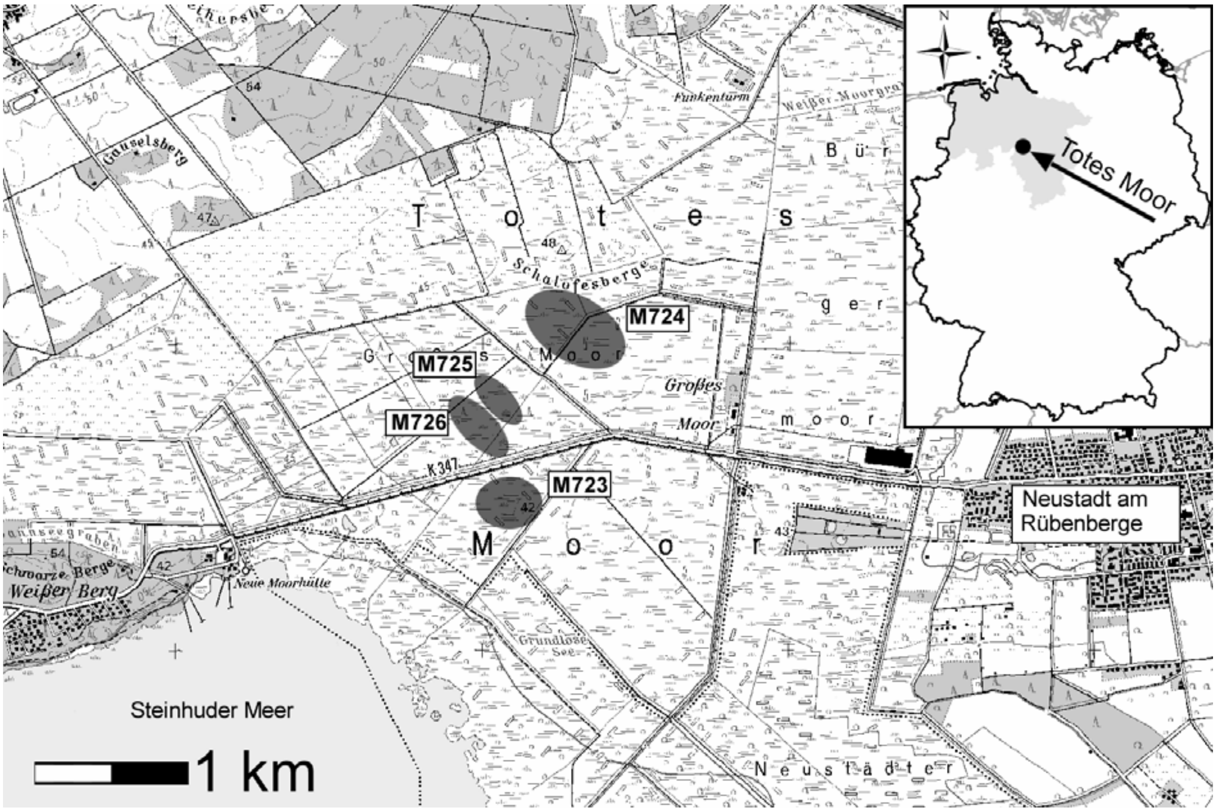

Figure 1: Outline map of the "Totes Moor" northwest of lake "Steinhuder Meer". Location of the four sample sites are indicated in dark grey.

The subfossil wood which has bee recovered during peat harvesting was removed from the fields and dropped at their edges. Most of the investigated samples were taken from these wood cops around the harvesting sites. In addition in situ samples had been taken from ditches and from the surface of the harvesting fields. Most of the wood is pine, whereas oak is relatively sparse and mainly preserved as lying tree trunks without any trace of trunk-bases or roots. Compared to oak, pine is mostly found as very short stumps with a more or less complete root system or, less frequently, as lying trunks, often with remains of roots. Our sampling strategy aimed at covering the entire spectrum of tree sizes, root system morphologies, and different states of preservation represented in the wood remains. 89 oak and 309 pine samples were collected in total.

Sample preparation, measurement of tree-ring width and dating

The dendrochronological investigation followed standard procedures, described for example by Leuschner (1994). Radial sections of the discs were cut and smoothed with surgical blades and razor blades (Iseli & Schweingruber 1989, Leuschner & Schweingruber 1996). Chalk was rubbed on the surface to enhance contrast and tree-ring boundary visibility. Tree-ring widths were measured with a precision of 1/100 mm by using a semi-automatic measuring stage (type Aniol) and the program CATRAS (Aniol 1983). Cross-dating between the tree-ring series was performed and matches were detected and statistically evaluated by calculating the coefficient of parallel variation (GL) and the t-value (Baillie & Pilcher 1973). The statistical approach was backed and finally proved by visual comparisons of the tree-ring series. Measuring mistakes and missing rings detected by statistical and visual cross-dating of the tree-ring series were manually corrected.

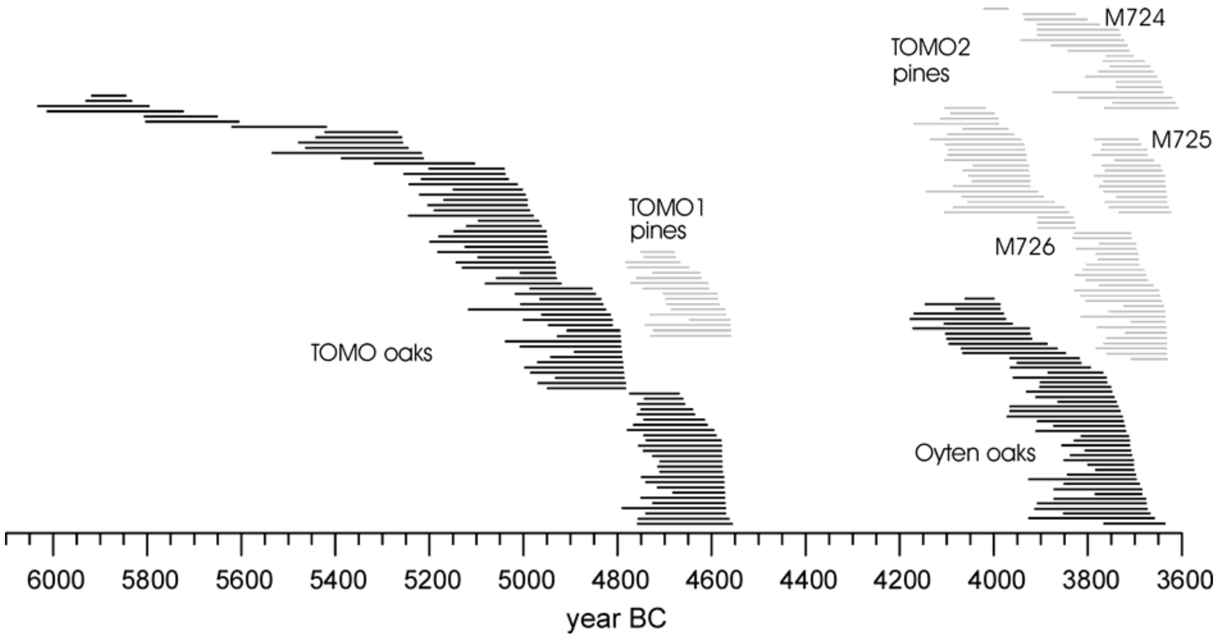

Figure 2: Temporal distribution of subfossil oaks (black) and pines (grey) from "Totes Moor" (TOMO) and oaks from "Oytener Moor" (Oyten), 80 km west of "Totes Moor", sorted by dying-off dates and grouped by site. TOMO1 and TOMO2 refer to two absolutely dated pine chronologies from "Totes Moor". If not preserved estimated missing rings to germination and dying-off are added.

Results

Crossdating

83 out of 89 oak samples could be crossdated with reference to the LSBOC. These samples cover the period 6,014 to 4,570 BC. The resulting TOMO oak chronology matches well with the LSBOC (t=19.6; GL=68 %). Pines were first crossdated among themselves by using inter series correlation t-values higher than 5.5. Then some series were corrected for missing rings but no false ring was detected. From 309 recovered pine samples 175 could be crossdated yielding 13 independent chronologies. Two chronologies, TOMO1 (224 years, 17 samples) and TOMO2 (563 years, 84 samples) yielded a significant match with the oak master LSBOC (t=6.9 GL=67 % and t=6.1 GL=61 % respectively). Eventually the positions for TOMO1 and TOMO2 were backed by visual comparison with the LSBOC. TOMO1 covers the period 4,782 4,559 BC and TOMO2 ranges from 4,170 – 3,608 BC.

Peat stratigraphy

A systematic study of peat profiles associated with wood remains in "Totes Moor" has yet to be carried out but preliminary investigations reveal that most of the pine samples occur at the fen/bog transition where pine did form dense stands. Pines were also present at various positions within the raised-bog peat, but in more open stands of only small trees. Several TOMO2 samples were found in situ along a drainage ditch at site M726 (Fig. 1). A peat profile taken adjacent to a sampled tree stump indicates their position at the fen/bog transition (Tab. 1) which is also confirmed by the pollen diagram (F. Schlütz unpubl.).

Table 1: Peat stratigraphy at site M726 with the TOMO2 pine wood layer.

Depth in cm	Description
-	due to peat extraction the upper part of the peat layer is missing,
0 - 40	weakly decomposed *Sphagnu*m peat (white peat), mostly Acutifolia peat containing *Oxycoccus*, *Calluna*, *Eriophorum vaginatum*
41 - 102	strongly humified *Sphagnum* peat (black peat) containing several layers of *Eriophorum vaginatum* and especially on its base *Pinus* wood remains (**TOMO2 wood layer**)
103 - 191	strongly humified fen peat containing *Betula*, *Carex*, *Menyanthes*
191 - 206	fine to medium organic silt containing *Betula*, *Alnus*
207 - 216	*Alnus* wood
217 - 224	*Carex* fen peat
225 - 251	moss fen peat containing *Scorpidium, Carex*, *Menyanthes*, *Alnus*
252 - 255	organic silt with fine sand
256 - 266	glacial fluviatile medium sand with some silt and gravel (< 7 mm)

Most of the youngest oaks from site M724 (Fig. 1) were found in situ in the fen/raised bog transition zone. They are pale in colour, indicating preservation in raised bog peat (without iron).They probably died due to increased raised bog growth at about 4,550 BC and were covered by *Sphagnum* peat.

Temporal distribution

The temporal distribution of both, pine and oak samples, shows that germination and dying-off (GDO) events are not randomly distributed over time (Fig. 2). Germination and dying-off phases sometimes overlap. This is not un-expected, since intensive regeneration has been only possible in open stands after the dying-off of old trees. TOMO1 pine samples parallel those of the youngest oak generation from "Totes Moor". Almost all sample trees germinated between 4,780 and 4,700 BC, and the last pine died off 4,559 BC (the last oak died off 4,555 BC). There must have been stress events affecting both pines and oaks over the same period in similar ways to create such equal patterns of temporal distribution. The results indicate a simultaneous occurrence of pines and oaks between 4,782 and 4,559 BC in the area. However, both species did not grow together at the same site. Locations of pine (M723) and oak (M724) samples from that period are about 1.2 km apart from each other. The TOMO2 pine samples are younger than the oak samples. Yet, in their temporal distribution they show a similar grouping in subsequent woodland generations (Fig. 2). Two generations can be recognised, one from 4,170 to 3,920 BC and another from 3,830 to 3,610 BC with only a few overlapping samples. These two woodland generations are most obvious for sampling site M726. At site M725, only trees from the younger generation are present. Oak samples from “Oytener Moor”, about 80 km west of "Totes Moor", show a very similar temporal distribution as the TOMO2 pines, with similar germination and dying-off phases (Fig. 2). This indicates that some of the stress factors triggering these population dynamics had a supra-regional dimension. However, more research is needed to get a better understanding of these relationships.

Stress signs

In order to identify the rules behind the germination and dying-off phases in former mire woodlands, we looked for stress indicators in the TOMO2 samples. Therefore we recorded scars, the start of reaction wood, burnt outer surface as a reference to fire, and common long term growth depression phases as stress indicators. About 23 % of the TOMO2 samples have a burnt outer surface, hinting at frequent fires. Yet, wounds which may also caused by fire are scattered over time and we do not observe common growth release phases which would point at large scale fire events. So, fires were frequent in the pine woodland but they had not the destructive power to explain the observed dying-off phases. Reaction wood may point at storm events if many trees were put in an inclined position in the same year. But the starting of reaction wood is also scattered over time and does not coincide with germination or dying-off phases among the TOMO2 samples. Therefore storm events can not explain the population dynamics.

Common growth depression phases are observed especially at the end of the TOMO2 layer. Periods during which many samples indicate growth depressions include around 3,720 BC and from 3,660 to 3,620 BC, when most of the younger sample trees died-off.

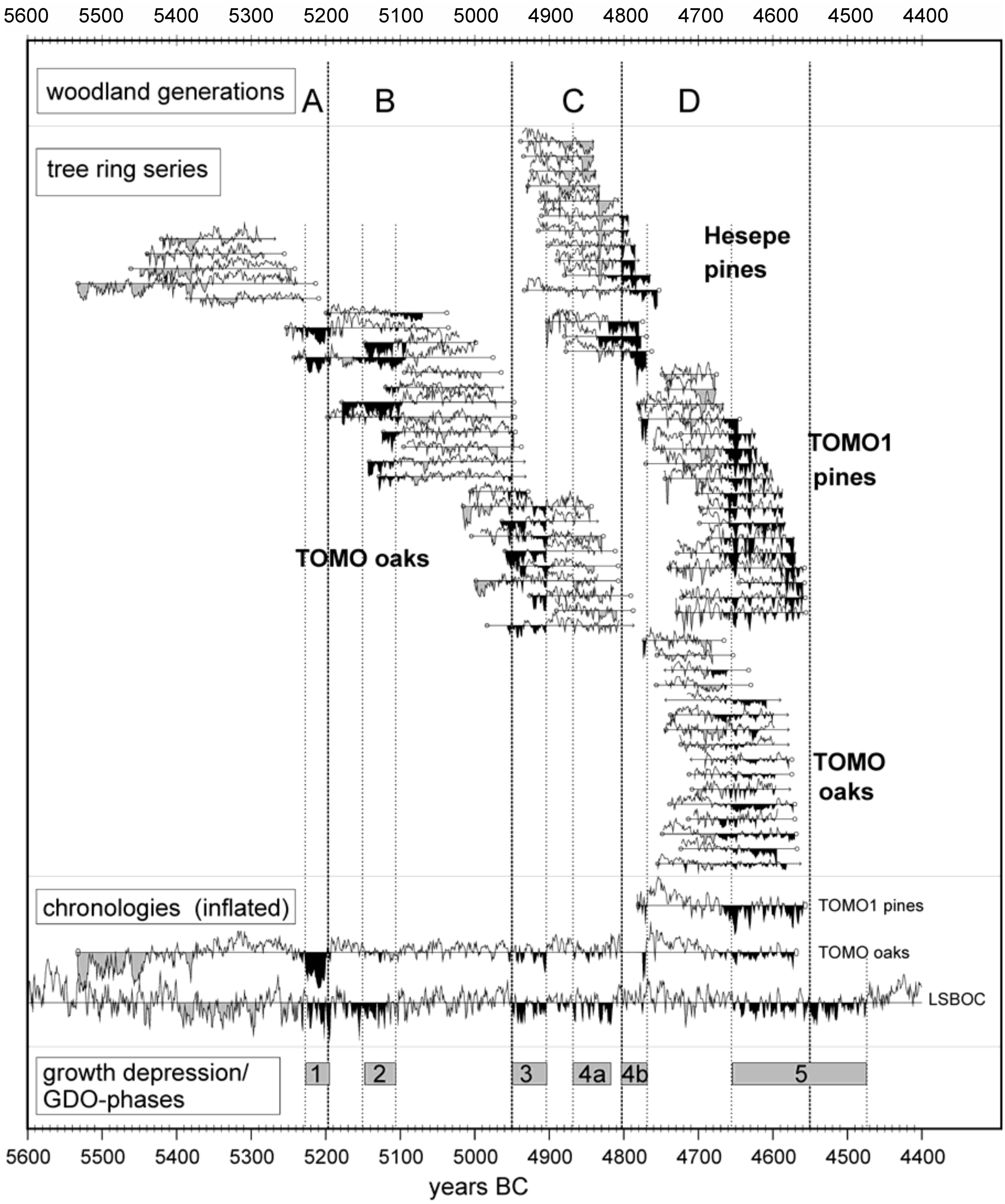

Figure 3: Tree ring series of oaks and pines from "Totes Moor" (TOMO) and “Heseper Moor” (Hesepe), 140 km north-west of “Totes Moor”. Periods with growth depression are coloured grey, or black if they coincide with germination and dying-off (GDO) phases (modified after Bauerochse et al. 2006).

A comparison of the tree ring series of the simultaneously occurring pines (TOMO1) and oaks shows that GDO phases are associated with growth depressions in both taxa (Fig. 3). These stress phases with very narrow rings do not only occur in tree-ring series of oaks and pines from “Totes Moor”, they are also present in the oak master LSBOC. In the period 4,800 to 4,770 BC (GDO phase 4b in Fig. 3) a GDO phase in the TOMO samples can be linked to growth depressions in pine samples from “Heseper Moor”, 140 km west of "Totes Moor". This relationship is further discussed by Bauerochse et al. (2006).

Discussion

Dendro-dated subfossil oak and pine remains from "Totes Moor" demonstrate the existence of extended pine and oak woods in the area of this wetland from about 6,100 to 3,600 BC. Yet, oaks and pines did not occur together at the same time in the same site. The start of raised-bog formation occurred at different times in different parts of "Totes Moor". At site M724, conditions changed to ombrotrophy around 4,550 BC and at site M726 around 3,600 BC, as indicated by *in situ* findings of oaks (site M724) and pines (M726). At that time, we have to imagine the "Totes Moor" area as a mosaic of different habitats where alder and birch carrs, oak stands, pine forests and raised bogs where riddled with patches of sandy hills and small lakes. This patchy landscape was a result of a varied relief shaped by the last ice age. Later, with increasing raised-bog formation the area was covered more and more by open *Sphagnum* bogs and the huge, more or less uniform, raised bog landscape – today´s “Totes Moor” – was created.

Both the pine and the oak samples show distinct woodland generations separated by GDO phases (Fig. 2 and Fig. 3). Burnt outer surfaces and scars at some samples demonstrate frequent fires in one of these pine stands (TOMO2). These fires must have been natural fires, lit by lightning, for there are no traces of human activities in the area during this time. The fires did not coincide with germination or dying-off phases and the patchy distribution of pine stands probably prevented fires from spreading over extended areas.

In many instances GDO phases are associated with long term growth depressions. In spite of the varied relief moulded during the last ice age and the patchy distribution of oak and pine woods, GDO and depression phases occurred simultaneously both in pine and oak samples from "Totes Moor" and can even be linked to other wetland sites in Lower Saxony. Since the depression phases persisted several decades, they cannot be explained by single catastrophes such as extended fires or heavy storm events, but must have caused by slow responding environmental factors. In wetlands a raising water table is an important stress factor for tree growth. Therefore long-term growth depressions are probably induced by increased wetness as proposed by Leuschner et al. (2002) for oak samples from mire sites. At least some of the GDO phases have a supra-regional dimension and therefore are probably triggered by climatic changes affecting the hydrology of wetland sites over a extended areas in the same way.

Future efforts will focus on extent and character of ecological changes during the fen/bog transition inferred by tree-ring width, shape of pine root systems, peat stratigraphy, intra-annual anatomical features and comparisons between many different sites in Lower Saxony.

Acknowledgements

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