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Local and regional Holocene vegetation dynamics at two sites in eastern Latvia

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The study compares the local and regional Holocene vegetation dynamics of two sites in eastern Latvia. Both sites show similar trends in vegetation change. Differences were found in local abundances of *Betula*, *Pinus* and *Picea*. Lower amounts of *Betula* at the local site suggest stronger regional pollen influx into the regional site. The continuous presence of conifer stomata indicates the development of a stand-scale conifer forest at the local site since 5000 cal yr BP. Similar presence and dynamics in thermophilous tree species at both sites suggest that the pollen values of the regional site may truly show the local presence of thermophilous tree taxa. Apart from general vegetation succession, the strongest cause for the vegetation differences at both sites were water-level changes, as shown by the peat decomposition rate.

Introduction

Palaeoecological records preserved in sedimentary deposits provide a unique insight into the history of past ecosystems and long-term plant community dynamics. Although the postglacial vegetation history of Latvia has been studied for a long time (Galenieks 1935, Levkovskaya 1987, Kalnina *et al*. 2004), many postglacial sequences are still not dated and are described solely through comparisons of pollen zones; therefore, many questions still remain open, particularly regarding succession of regional and local vegetation. The main questions regarding the use of fossil pollen data are: (1) how credible are the results with regard to actual vegetation, and (2) what is the role of local *vs*. regional changes in vegetation dynamics? Smaller, stand-scale sites reflect better immediate changes in the vegetation than larger sites (Sugita 2007), where long-distance effects of pollen cannot be overlooked (Broström *et al*. 2008, Kuneš *et al*. 2008). Therefore, the comparison of two sites situated close to each other but with different pollen source areas may reflect differences between local and regional changes in vegetation dynamics.

The aim of this study was to compare local and regional Holocene vegetation dynamics in eastern Latvia. We analysed two adjacent sediment sequences and evaluated the vegetation dynamics in addition to possible factors controlling the development of vegetation at the local and regional sites.

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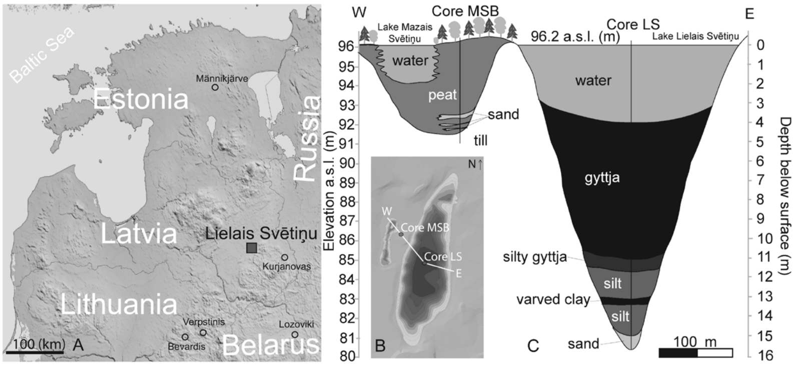

Fig. 1. (**A**) Map of the eastern Baltic area showing sites discussed in the text. (**B**) Location of the analysed sediment cores: Core LS, Lake Lielais Svētiņu; Core MSB, stand-scale site. (**C**) W–E sediment cross-section.

Study area

Lake Lielais Svētiņu (LS) (water depth 4 m; 56°45´N, 27°08´E) and the kettle-hole bog Mazais Svētiņu (MSB) (56°45´N, 27°08´E) are located in the Rēzekne district of eastern Latvia (Fig. 1) in the Lubāns lowland 13 km east of Lake Lubāns, and they are relics of an ancient large body of water (Seglins *et al*. 1999). The present-day topography was largely formed during the Weichselian glaciation and deglaciation (Zelčs and Markots 2004, Zelčs *et al*. 2011). The bedrock consists of Devonian dolomite covered by Quaternary deposits with a thickness of 5–10 m consisting of sand, silt and clay. LS is a drainage lake with an area of 18.8 ha, located at an elevation of 96.2 m above the sea level (a.s.l.). Its catchment (~12 km^2) is predominantly forested but also partly covered by fields. The flat shores of the lake are surrounded by *Betula*, *Picea*, and *Pinus* with scattered stands of *Ulmus*, *Tilia*, *Alnus* and *Quercus*. The radius of assumptive source area of pollen for LS is greater than 5 km, whereas MSB is a stand-scale site situated under a closed canopy of *Betula*, *Picea* and *Pinus*; therefore, its pollen source area is limited to 20–100 m (Overballe-Petersen and Bradshaw 2011).

The climate in the area is a combination of continental (Eurasia) and maritime (Atlantic Ocean); thus, the annual frequency of arctic and sub-polar air masses is fairly high (Draveniece 2009, Avotniece *et al*. 2010). The mean annual temperature of approximately the last 55 years in the closest city Rēzekne was +5.2 °C, with mean July and December temperatures of +16.9 °C and –4.1 °C, respectively (Dauškane *et al*. 2011).

Material and methods

Coring and lithostratigraphy

Sampling of sediments in LS (Fig. 1 and Table 1) was performed in March 2009 from ice using a Russian type corer with a diameter of 10 cm. The sediment thickness reached 1135 cm (the base of the core was 1550 cm below the surface of the water), of which the Holocene gyttja comprised 760 cm. Water depth of the lake was 400 cm. Multiple parallel overlapping sediment cores were documented, packed into film-wrapped 1-m plastic semi-tubes and transported to the laboratory for further analysis. The Holocene interval of the sediment core was examined for the present study. The lateglacial (LG) sequence of LS

Table 1. Lithostratigraphy of Lake Lielais Svētiņu.

Depth from water surface (cm)	Sediment description
400–1105	Gyttja, homogenous
1105–1160	Silty gyttja, homogenous
1160–1190	Silt with organic matter
1190–1270	Silt
1270–1320	Silt with organic matter
1320–1335	Clay, laminated
1335–1500	Silt, increasingly dark coloured from organic matter towards the upper limit
1500–1515	Sand with organic matter
1515–1535	Sand, compact

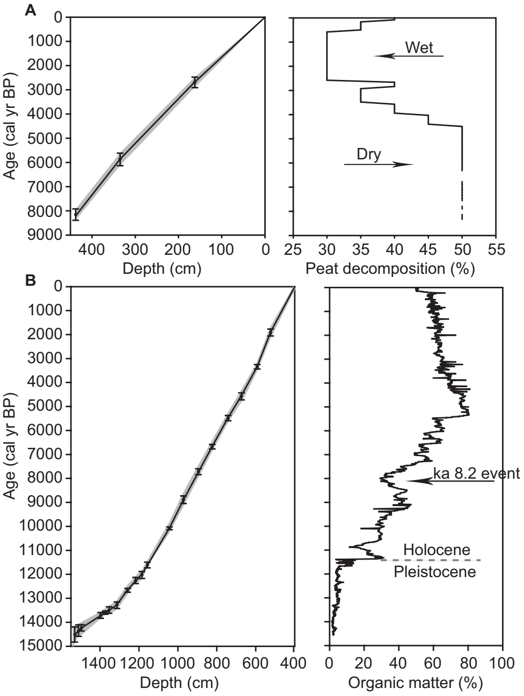

Fig. 2. (**A**) Mazais Svētiņu bog (MSB) age–depth model (bars indicate error of individual calibrated ages; shading shows the model uncertainty) and peat decomposition. (**B**) Lake Lielais Svētiņu (LS) age–depth model (bars indicate error of individual calibrated ages; shading shows the model uncertainty), and organic matter content.

was previously discussed in detail (Veski *et al.* 2012) and will be mentioned here only briefly. In October 2009, a 500-cm-long sediment sequence was taken from MSB using an Ejelkamp peat sampler with a 5-cm diameter and 50-cm length (Fig. 1 and Table 2); the sampling site is currently a stand-scale site beneath a closed canopy. The sampling procedure was performed as described above. The organic matter content of the LS sediment (Fig. 2) was determined by loss-on-ignition (LOI) at 550 °C for 4 h (Heiri *et al.* 2001). Measurements were performed on continuous 1-cm-thick subsamples, and LOI was calculated as a percentage of the dry weight. The degree of decomposition of the MSB peat (Fig. 2) was determined by the von Post pressing method (von Post 1924, Stanek and Silc 1977, Malterer *et al.* 1992) and centrifuging according to the Standard GOST 10650-71.

Table 2. Lithostratigraphy of Bog Mazais Svētiņu.

Depth from surface (cm)	Sediment description
0–5	*Sphagnum* peat
5–30	Wood-grass peat
30–155	Sedge peat
155–170	Wood-sedge peat
170–205	Wood-grass peat
205–360	Wood peat
360–375	Sand
375–410	Wood peat
410–420	Sand
420–425	Wood peat
425–435	Sand
435–450	Wood peat
450–500	Till

Chronology

The LS chronology was based on ^{14}C radiocarbon dates from 8 bulk (6-cm-thick) samples and 12 samples of terrestrial plant remains. The chronology of the MSB was based on conventional ^{14}C dating of three bulk (10-cm-thick) samples (Table 3). Macrofossils were radiocarbon-dated using the AMS method in the Poznań Radiocarbon Laboratory (Poz) in Poland, and bulk samples were dated by conventional liquid scintillation method at the Institute of Geology at Tallinn University of Technology (Tln) in Estonia. Radiocarbon dates were converted to calendar years using the IntCal09 calibration dataset (Reimer *et al.* 2004) and OxCal 4.2 programme deposition model (Bronk Ramsey 2001, 2008) with a two σ (95.4%) confidence level. The ages in the text refer to calendar years before present (cal yr BP; 0 = AD 1950).

Pollen analysis

Pollen subsamples (177 samples overall) of known volume (0.5–1 cm^3) and thickness (1 cm) were treated with 10% HCl, boiled in 10% KOH and then acetolysed for 5 min using standard acetolysis procedures (Berglund and Ralska-Jasiewiczowa 1986, Fægri and Iversen 1989) combined with cold concentrated HF treatment to remove inorganic matter (Bennett and Willis

2001). At least 500 terrestrial pollen and spores per sample were counted and identified to the lowest possible taxonomic level using the reference collection at the Institute of Geology at Tallinn University of Technology and published pollen keys. Although for both sites conifer stomata were identified according to Sweeney (2012), only for LS they were differentiated to *Pinus* and *Picea*; for MSB solely conifer stomata were registered. The percentage of dry-land taxa was calculated using arboreal (AP) and non-arboreal (NAP) pollen sums (excluding sporomorphs of aquatic and wetland plants). Counts of spores were calculated as percentages of the total sum of terrestrial pollen.

A pollen diagram was compiled using the TILIA 1.7.16 software (Grimm 2012), and zonation was performed according to the broken-stick model (Bennett 1996) based on binary splitting of the sum-of-squares method using the PSIMPOLL 4.27 software (Bennett 1992).

Results and discussion

Lithostratigraphy and chronology

The LS sediments (Fig. 2) in the lowermost portion from 1550 to 1160 cm consist of sand and silt with a thin layer of distinctly laminated clay, but the upper part from 1160 to 400 cm consists of silty gyttja and homogenous gyttja. The organic matter (OM) content fluctuated from 1550 to 1160 cm, but then sharply increased to 30% at 1160 cm. The OM content then increased to 82% at 750 cm and decreased to 50% at 400 cm.

The MSB sediment sequence (Fig. 2) was composed of wood peat from 450 to 205 cm with a few sand layers in the basal part from 434 to 427 cm, 419 to 410 cm and 373 to 359 cm. Further, continuous *Phragmites* wood peat (205–170 cm), *Phragmites* peat (170–155 cm), *Carex* peat (155–30 cm), *Carex–Sphagnum* peat

Table 3. Radiocarbon ages of Lake Lielais Svētiņu and Bog Mazais Svētiņu sediment.

Depth (cm)	Laboratory code	^{14}C date (yr BP)	Calibrated age (cal yr BP) 2σ	Model age (cal yr BP)	Material dated
Lake Lielais Svētiņu					
523	Tln-3167	1848 ± 70	2110–1725	1885	Bulk gyttja
593	Tln-3168	3231 ± 70	3480–3170	3350	Bulk gyttja
673	Tln-3169	4091 ± 70	4680–4420	4540	Bulk gyttja
743	Tln-3170	4701 ± 70	5590–5350	5490	Bulk gyttja
823	Tln-3171	5822 ± 90	6790–6500	6655	Bulk gyttja
893	Tln-3172	6876 ± 90	7840–7590	7720	Bulk gyttja
973	Tln-3173	7974 ± 90	9090–8730	8920	Bulk gyttja
1043	Tln-3174	9169 ± 100	10300–9900	10070	Bulk gyttja
1157	Poz-30426	10100 ± 60	11650–11590	11625	Wood
1185	Poz-36710	10270 ± 50	12140–11810	11990	Twig
1215	Poz-31768	10330 ± 50	12400–12120	12290	Wood
1261	Poz-31769	10760 ± 50	12760–12560	12660	Twig, bark
1315	Poz-36711	11460 ± 60	13400–13160	13290	Bark
1355	Poz-36712	11670 ± 60	13620–13400	13510	Stem
1365	Poz-36715	11630 ± 60	13660–13460	13560	*Betula nana* leaf, *Potentilla* seed
1400	Poz-36713	11840 ± 60	13830–13640	13740	Twig
1445	Poz-36714	12410 ± 60	14240–13990	14110	Twig, *Betula nana* leaf
1492	Poz-31770	12380 ± 60	14400–14040	14220	Twig, bark
1510	Poz-29298	12420 ± 60	14590–14150	14350	Wooden material
1530	Poz-31771	12350 ± 60	14950–14180	14520	Wooden material
Bog Mazais Svētiņu					
165	Tln-3202	2613 ± 60	2860–2490	2710	Bulk peat
335	Tln-3203	5154 ± 70	6180–5730	5900	Bulk peat
435	Tln-3205	7297 ± 100	8340–7950	8125	Bulk peat

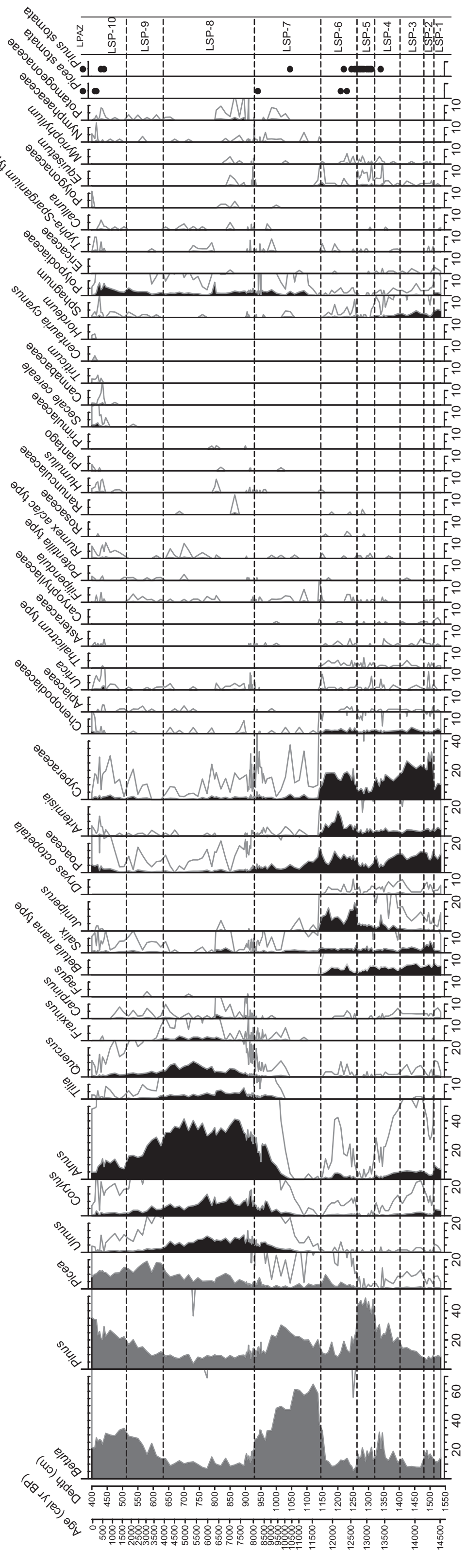

Fig. 3. Pollen diagram for Lake Lielais Svētiņu. Shaded line show ten-fold multiple abundance values.

(30–5 cm) and *Sphagnum* peat (5–0 cm) were observed. The peat was rather well decomposed (Fig. 2) between the depths of 450 cm (50%) and 205 cm (35%) and at a depth of 30 cm (40%).

The chronology of the studied sequences (Table 3) and age–depth models (Fig. 2) show that at LS the highest sediment accumulation rate of 0.16–0.17 cm^{-2} yr^{-1} was between 14 500 and 11 600 cal yr BP in LS. Later in the Holocene, the sedimentation rate was 0.06–0.08 cm^{-2} yr^{-1}. At MSB, a lower accumulation rate of 0.3–0.4 cm^{-2} yr^{-1} was found between 8300 and 6000 cal yr BP, and higher, 0.6 cm^{-2} yr^{-1}, after 4000 cal yr BP.

Pollen stratigraphy

The LG pollen diagram for LS was presented by Veski *et al*. (2012), and when combined with the Holocene pollen record it becomes the longest continuous documentation currently available for postglacial vegetal evolution in Latvia.

The pollen diagram for LS was divided into ten statistically significant, local-pollen-assemblage zones (LPAZ; Table 4 and Fig. 3) based on the broken-stick model using the PSIMPOLL 4.27 software (Bennett 1992). Core MSB pollen stratigraphy was divided into four statistically significant LPAZs (Table 5 and Fig. 4). Pollen taxa were selected to show similarities and differences for both sites.

Early Holocene (11 650–8000 cal yr BP)

The Holocene started at 11 650 cal yr BP (Lowe *et al*. 2008) with a rapid transition from cold to a generally warmer period. The early Holocene forests around LS were primarily dominated by *Betula* and *Pinus* (Table 4). In addition Heikkilä and Seppä (2010) point that the mean summer temperature of early Holocene was just 0.5 °C lower than reconstructed modern temperature from Lake Kurjanovas, eastern Latvia. The temperature controlled the duration of the growing seasons, and the shorter growing period favoured conifers over other species in the same overall climate and on similar soils (Ellenberg 2009).

The pattern of changes in the forest composition suggest that the conifer and *Betula* dominance started to weakened at the end of the early Holocene and later were suppressed by the thermophilous tree species. Similar pattern has been recorded in eastern Lithuania (Lake Verpstinis and Bevardis) (Gaidamavičius *et al*. 2011) and in northern Belarus (Lake Lozoviki) (Novik *et al*. 2010).

Table 4. Local pollen assemblage zones description of Lake Lielais Svētiņu.

Age (cal yr BP)	LPAZ	LPAZ description and vegetation type
1500–0 Late Holocene	LSP-10	Zone is dominated by arboreal pollen (AP). *Pinus* gradually increases from 30% to 40% at the end of zone. *Betula* decreases from 30% to 20%. *Picea* fluctuates between 8% and 15%. Decrease in broad-leaved trees. Increase of non-arboreal pollen (NAP); *Secale cereale* (2%), *Rumex* type (3%) peak; *Avena*, *Triticum, Cannabis* and *Hordeum* appear and have highest values. *Poaceae* increases from 1% to 5% at the end of zone. Polypodiaceae abundance up to 40%.
4000–1500 Late Holocene	LSP-9	*Betula* and *Pinus* values gradually increase in the upper part of the zone: *Betula* 10% in the first half of the zone, sharply increases to 30% in the end of the zone; *Pinus* increases from 10% to 20%. Highest values for *Picea* (17%). *Pinus* and *Picea* stomata are present. Slight decrease in all thermophilous tree species. *Alnus* decreases from 40% at the beginning of the zone to 15% at the end of the zone. *Fraxinus* first decreases to a minimum, and then it is not recorded in the second half of the zone. Polypodiaceae values rise from 5% in the first half of the zone to 22% at the end of the zone. *Secale cereale* and *Taraxacum* type appear at the end of the zone.
8000–4000 Middle Holocene	LSP-8	Thermophilous tree species dominate zone. *Fraxinus* (4%), *Tilia* (6%), *Corylus* (15%), *Ulmus* (10%), *Alnus* (40%) and *Quercus* (9%) have their maximum values. Throughout the zone, *Betula* and *Pinus* with low values, 10% and 8%, respectively. *Carpinus* values fluctuate (1%–3%) with a peak occurring at 6500 cal yr BP (3%). *Picea* values gradually increase from 3% to 10%. Poaceae values vary in the range 1%–2%. Polypodiaceae 5%–10% with a peak at 6300 cal yr BP (40%).
11 650–8000 Early Holocene	LSP-7	*Betula* values rise to 60%. *Pinus* values increase from 15% at the beginning of the zone to 30% in the middle of the zone, but afterwards decrease to 10%. *Pinus* and *Picea* stomata are recorded. *Juniperus* extinct. Thermophilous trees appear. *Ulmus* and *Corylus* occur since 11 200 cal yr BP but *Ulmus* values rise to 6% at 8500 cal yr BP, while those of *Corylus* to 10% at 8600 cal yr BP *Alnus* appears since 10 500 cal yr BP, and *Quercus* since 10 000 cal yr BP. *Picea* values are 1%–3%. *Artemisia* decreases to a minimum (1%). Poaceae decrease gradually (15% to 5%). All values of thermophilous tree species sharply fluctuate or decline but *Betula*, *Pinus* and *Picea* increase between 8300 and 8100 cal yr BP.
12 700–11 650 Younger Dryas	LSP-6	Open forest tundra with scattered *Betula*, *Pinus* and *Picea*. Tree types *Betula* and *Pinus* are less than 20%, *Picea* present as pollen and occasional stomata. *Juniperus* culmination (20%). NAP is represented by Cyperaceae, Poaceae, *Artemisia*, Chenopodiaceae, *Dryas octopetala*, *Thalictrum*.
13 300–12 700 Allerød warming	LSP-5	*Pinus*–*Betula* forest with a distinct dominance of *Pinus*. AP dominates reaching 70%. *Pinus* values over 50%, *Pinus* stomata are recorded, shrubs and NAP decrease.
13 760–13 300 Early Allerød	LSP-4	*Betula*–*Pinus* forest tundra. AP share gradually rises at the expense of NAP and around 13 600 cal yr BP exceeds it.
14 200–13 760 Older Dryas	LSP-3	NAP dominates over AP. In *Betula*/*Betula nana* relationship the later dominates.
14 400–14 000 Bølling	LSP-2	Herb/shrub tundra. *Betula* and *Pinus* are less than 20%, *Betula nana* and *Salix* are present. NAP is dominated by Cyperaceae, Poaceae and *Dryas* and *octopetala*.
14 560–14 400 Early Bølling	LSP-1	Treeless pioneer tundra. *Betula nana* type peaks. Poaceae values 10%.

Local and regional prevailing factors in vegetation history

To compare the local and regional dynamics of vegetation (Fig. 5), seven main tree species (*Picea*, *Pinus*, *Betula*, *Alnus*, *Ulmus*, *Tilia* and *Quercus*) were selected. Generally, both sites had consistent and comparable vegetation signals. Before 7500 cal yr BP, *Pinus* had constantly higher and *Alnus* constantly lower values at MSB than at LS. Therefore, other tree species were locally more dominant, but it can still be assumed that alder trees were part of the lake-rim vegetation. *Picea* had locally higher values at MSB than at LS, suggesting that during the early Holocene *Picea* locally replaced *Betula* as the dominant tree species. The lower local abundance of *Betula* suggests regional pollen loading at LS and regional transport (Dąbrowska 2008, Veriankaitė *et al*. 2010, Piotrowska and Kubik-Komar 2012). The local fluctuations of spruce and birch suggest changes in humidity and water table around the lake which can be supported by variation in peat decomposition rate (Fig. 2). The MSB values of *Quercus Ulmus* and *Tilia* were consistently comparable to those at LS and showed no local *vs*. regional differences, suggesting that the regional and local sites contained uniform shares of thermophilous trees. Surprisingly, *Pinus*, which is known for its high pollen productivity (Lisitsyna *et al*. 2011) and long-distance pollen loading (Ertl *et al*. 2012), had lower values at LS but was a dominant taxon at MSB. All of the compared tree species were natural components at both sites.

Although the vegetation dynamics at LS and MSB differed, it is possible to pinpoint some common trends, like changes from mixed *Pinus*–*Betula* forest to deciduous-temperate forest, and at the end to *Betula*–*Pinus*/human-induced changes in vegetation.

The dominance of *Betula*–*Pinus* from 8300 to 7500 cal yr BP suppressed other tree species locally. At MSB, the prevalence of *Alnus*, *Ulmus*, *Tilia* and *Quercus* was lower than at LS. Additionally, the increase in *Alnus* at MSB was shifted by 500 years relative to the increase in *Alnus* at LS, possibly because of the water level fluctuations and erosion of slopes supported by the presence of sand layers at the base of MSB (Fig. 2). Therefore, the pollen assemblage may have been contaminated by washed-out or redeposited pollen. Alternatively, the start of sedimentation at MSB and the low thermophilous tree pollen content may suggest a local-scale impact of the cooling well defined in the regional signal of LS. Wood peat accumulation and sedimentation disturbance by the sand layers agree with a cooling event at approximately 8200 cal yr BP (8.2 ka event). Within the expansion of thermophilous tree species, a sudden decline of the pollen values of all the broad-leaved taxa occurred at LS (Fig. 3), which

Table 5. Local pollen assemblage zones description of Bog Mazais Svētiņu.

Age (cal yr BP)	LPAZ	LPAZ description
1750–0 Late Holocene	MSB-4	NAP is dominated by Cyperaceae. Accompanied with Poaceae (5%), *Urtica* (4%), *Plantago* (6%), *Secale cereale* (2%) and *Cannabis* (2%). *Betula* constantly 10% with peak (55%) at the upper part of zone. *Picea* ca. 15% but decreases upwards. *Alnus* is present in low values. *Pinus* fluctuates between 10% and 20%. Reappearance of *Corylus*, *Ulmus*, *Quercus* and *Juniperus*. *Betula*–*Pinus* forest affected by human activities.
4600–1750 Late Holocene	MSB-3	*Alnus* values decrease from 40% to 10%. Strong dominance of Cyperaceae. Polypodiaceae and *Typha* maximum values (23%). *Picea* frequency varies between 10% and 35% and dominates together with *Pinus*. *Betula* is mostly around 10% with peak at ca. 4200 cal yr BP. *Betula*–*Pinus*–*Picea* forest.
7600–4600 Mid-Holocene	MSB-2	*Alnus* (40%), *Quercus* (15%), *Ulmus* (10%), *Corylus* (10%), *Tilia* (5%) and *Fraxinus* (4%) have their peak values. *Fraxinus* appears since 6500 cal yr BP. *Pinus* and *Betula* values below 15%. Mixed forest.
8300–7600 Mid-Holocene	MSB-1	AP dominated by *Pinus* and *Betula*. Among NAP, Poaceae, *Urtica*, Cyperaceae and *Artemisia* have higher values. Appearance of *Alnus*, *Quercus* and *Tilia*, but slight increase of *Picea* and *Ulmus*. Mixed forest.

is a reflection of the 8.2 ka event (Veski *et al.* 2004). The LS vegetation response to the 8.2 ka event was approximately 200 years long, and the OM of the LS sediments (Fig. 2) demonstrated a strong environmental disturbance for nearly 700 years. Hammarlund *et al.* (2003) performed an isotope δ^{18}O analysis of limnic carbonates at Igelsjön and found a decrease in the evaporation/inflow ratio during the summer that led to an increase in the lake level, whereas Hammarlund *et al.* (2005) detected cold and dry conditions during winters. An increase in the lake level caused increased catchment erosion and lead to a reduction of OM at LS, and sand layer accumulation in MSB sediments. Hede *et al.* (2010) found that increased $\delta^{16}C_{org}$ and algal pigment abundance strongly indicate erosional export of nutrients to Højby Sø in Denmark, thus leading to nutrient enrichment of the water column at approximately 8500–7900 cal yr BP. Although the reduction of OM in the sediments of Højby Sø lasted for approximately 250 years, after which it gradually decreased, parallel trajectories with small shifts in timing and duration were found for both LS and Højby Sø.

The middle Holocene between 8000 and 4000 cal yr BP marks the thermal maximum (HTM), which was characterised by a warm (~3.5 °C above the modern temperature), dry period (Birks and Seppä 2010, Heikkilä and Seppä 2010, Wanner *et al.* 2011) with reduced groundwater and lake levels (Hammarlund *et al.* 2003, Hammarlund *et al.* 2005, Sohar and Kalm 2008, Novik *et al.* 2010, Terasmaa 2011, Edvardsson *et al.* 2012). The expansion of thermophilous tree taxa at LS and MSB, and pollen-based temperature reconstructions from Lake Kurjanovas (Heikkilä and Seppä 2010) indicate that in eastern Latvia HTM occurred at 7500–5000 cal yr BP. The high peat decomposition at MSB (Fig. 2) supports this estimation of HTM and domination of dry and warm environmental conditions. During HTM, the soil and bog surfaces were warm and dry, which increased decomposition of fine, woody debris in temperate forests, and induced peat decomposition in bogs (Berbeco *et al.* 2012). The thermophilous forest expansion occurred between 7500 and 4500 cal yr BP at MSB, and between 8000 and 4000 cal yr BP at LS. Abundance of *Quercus* at

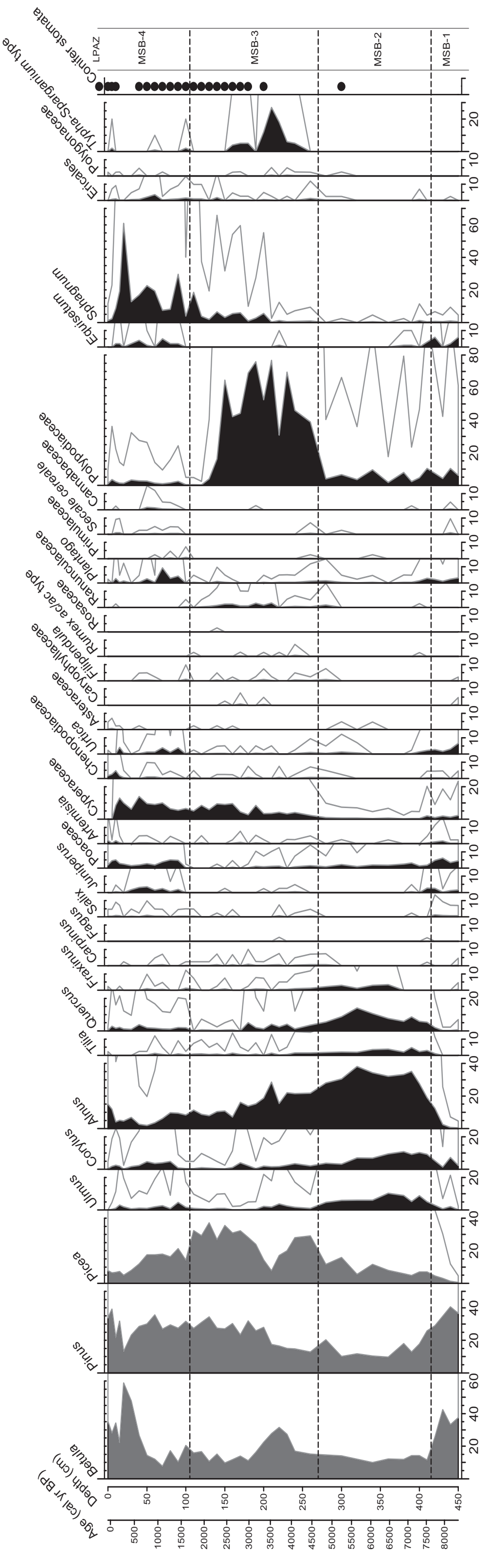

Fig. 4. Pollen diagram for Mazais Svētiņu bog. Shaded line show ten-fold multiple abundance values.

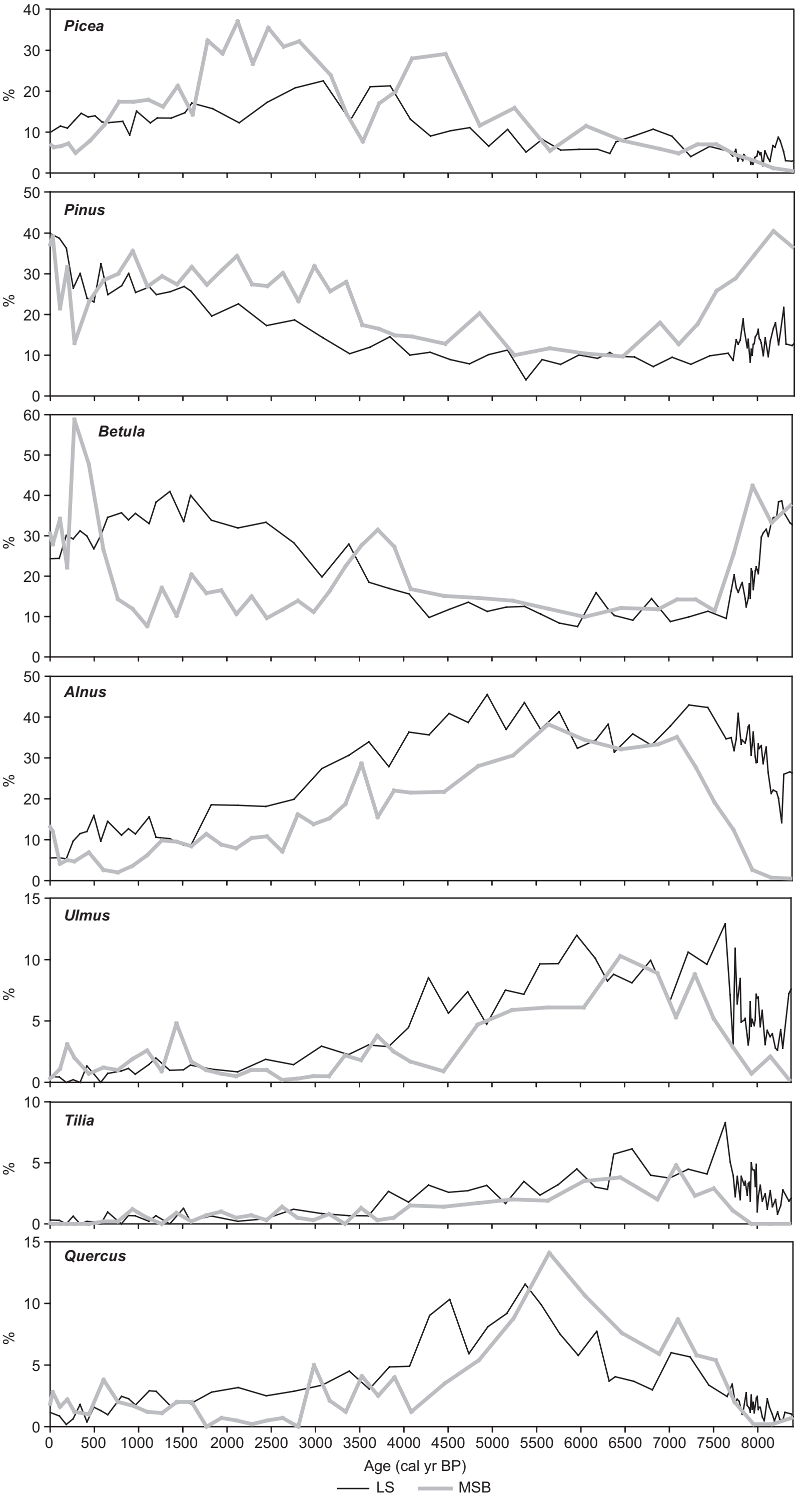

Fig. 5. Main tree pollen comparison of Lake Lielais Svētiņu (LS) and Mazais Svētiņu bog (MSB).

MSB suggests strictly local changes in the forest composition and availability of light. Although at the stand level *Quercus* can persist for multiple generations under a closed canopy, it has a wide-spreading crown, and it is thus a relatively light-demanding species that regenerates poorly in such conditions (Lindbladh and Foster 2010, Ikauniece *et al*. 2012).

The appearance and rapid increase in ferns (Polypodiaceae) at MSB (Fig. 4), and decrease in the peat decomposition rate (Fig. 2) since 4500 cal yr BP may indicate wetter conditions and an instant decline in thermophilous tree taxa even slightly earlier. In addition, the presence of *Picea* supports the existence of colder winters, moister soil and thicker snow cover (Giesecke and Bennett 2004). This change in environmental conditions matches the post-HTM cooler (Seppä and Poska 2004) and wetter (Hammarlund *et al*. 2003) phase previously shown at the regional level. Therefore, due to climate change strong difference between two sites appeared in transitional zone from HTM to post-HTM, i.e. from 4700 to 4000 cal yr BP. Whilst MSB showed reorganization in local-scale vegetation, LS still may have had possible regional pollen loading.

Starting at 3500 cal yr BP, MSB became an overgrown stand with a closed canopy composed of *Picea* and *Pinus*. The continuous presence of *Pinus* and/or *Picea* at MSB is supported by the finding of conifer stomata (Fig. 4). The presence of conifer stomata in the lake sediment or peat gives a reliable indication of local abundance of conifers within 20 m of the sampling location (Sweeney 2004, Parshall 1999). Bjune *et al*. (2009) indicated the usefulness of stand-scale site investigations because of their restricted pollen-source area, which can be directly linked to previous local vegetation. Therefore, the increase in *Pinus* and *Picea* pollen values at MSB indicates that a true local conifer forest was present and may have developed since 5000 cal yr BP, which is also supported by the findings of conifer stomata. In addition dissimilarity in values of *Picea* may represent local stands of *Picea* at MSB whilst the *Pinus* values at both sites showed similar trends. Development of the local stand-scale conifer forest may have been disrupted by an increase in the groundwater level. The expansion of *Typha–Sparganium* between 4000 and 3400 cal yr BP at MSB suggests wetter conditions and/or an increase in the groundwater level that caused *Picea* to decrease, thus making way for an increase in *Betula* and *Alnus*. Distinct vegetation changes were detected at MSB, whereas minor variation was found at LS. Therefore, the regional-scale site does not reveal all vegetation stress factors as well as the stand-scale site.

Although eastern Latvia has been inhabited by humans since the Mesolithic (Kalnina *et al*. 2004), human-induced vegetation changes with appearance of *Secale cereale*, Cannabaceae and increase in Poaceae at MSB came along around 1500 cal yr BP, which is nearly 1000 years earlier than the LS records suggests. Because of the generally forested and wet soil conditions, this area was inappropriate for early agriculture. The continuous presence of local forests in the vicinity from the establishment of terrestrial vegetation up to the present indicates that this area was unsuitable for early human land use before 1500 cal yr BP. Clear signs of landscape openness and human activity locally contrast with the LS records and suggest that human activity was minimal and/or local, and it primarily occurred near MSB. Differences in *Betula* pollen (Fig. 5) between the local and regional scales may be explained by differences in pollen sources, changes in soil properties or groundwater level fluctuation, which may be supported by the increase in *Sphagnum* and the low peat decomposition rate. The gap in conifer stomata from 600 to 200 cal yr BP may be attributed to increased wetness, which led to expansion of *Betula* as the main local-stand species. Sillasoo *et al*. (2007) studied *Testate amoebae* from the Männikjärve bog in Estonia and found a wetter phase since approximately 600 cal yr BP. The rapid drop in *Betula* and re-appearance of conifer stomata starting at 200 cal yr BP supports conifer and *Betula* co-domination around MSB and LS. A sudden change in water level may be responsible for these changes because of the start of ditching in the landscape, which is supported by an increase in peat decomposition at MSB and a decrease in OM at LS (Fig. 2). In addition to the fluctuation of the forest structure during the last 1500 cal yr BP, the decrease in OM also points to anthropogenic activities around MSB and LS. Human impact is supported by the increase in ruderal communities and cereals: *Urtica* since 1200, *Rumex acetosa*/*acetosella*-type since 1500, *Avena* since 200, *Secale cereale* since 600, *Triticum* since 500, *Hordeum* since 150 and *Cannabis* since 600 cal yr BP. Given the relatively late human-induced disturbance of MSB and LS sediments, this area appears to have been primarily affected by natural climate and environmental variability.

Conclusions

A comparison of local and regional pollen evidence obtained from two adjacent sites suggests comparable vegetation trends at local and regional sites. The local site showed higher abundance of conifers. Conifer stomata show that conifers (pine and spruce) were present and co-dominant in the vicinity as a stand-scale forest starting at 5000 cal yr BP with a gap at approximately 500 cal yr BP, when other taxa dominated. Lower pollen values at the local site suggest that the prevalence of birch was somewhat overestimated at the regional site in the period 3500–500 cal yr BP. Consistent abundance of *Quercus*, *Ulmus* and *Tilia* over time suggests that their pollen found regionally may actually represent their stable presence.

Local environmental conditions and regional to supraregional events can be seen as the main reasons for vegetation fluctuation and differences in local and regional vegetation dynamics. The stand-scale site experienced greater impacts and reacted stronger to different types of stress factors (mostly ground and lake water level changes and temperature) than the regional site; however, the two data sets were surprisingly similar.

Ditching in the landscape has increased the peat decomposition rate and reduced the ground water and lake water level in recent years, which is one of the main factors for the disturbance of the local vegetation dynamic. Human activities in this area such as land use and clearance of the landscape started 1500 cal yr BP. Therefore, given the relatively late timing of human-induced disturbance, this LS presents natural vegetation dynamic.

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References

Avotniece Z., Rodinov V., Lizuma L., Briede A. & Kļaviņš M. 2010. Trends in the frequency of extreme climate events in Latvia. *Baltica* 23: 135–148.

Bennett K.D. 1992. PSIMPOLL — a QuickBASIC program that generates PostScript page description files of pollen diagrams. *INQUA Commission for the Study of the Holocene: Working Group on Data-handling Methods Newsletter* 8: 11–12.

Bennett K.D. 1996. Determination of the number of zones in a biostratigraphical sequence. *New Phytologist* 132: 155–170.

Bennett K.D. & Willis K.J. 2001. Pollen. In: Smol J.P., Birks H.J.B. & Last W.M. (eds.), *Tracking environmental change using lake sediments*, vol. 3: *Terrestrial, algal, and siliceous indicators*, Kluwer Academic Publishers, Dordrecht, pp. 5–32.

Berbeco M.R., Melillo J.M. & Orians C.M. 2012. Soil warming accelerates decomposition of fine woody debris. *Plant and Soil* 356: 405–417.

Berglund B.E. & Ralska-Jasiewiczowa M. 1986. Pollen analysis and pollen diagrams. In: Berglund B.E. (ed.), *Handbook of Holocene palaeoecology and palaeohydrology*, Wiley, Chichester, pp. 455–484.

Birks H.J.B. & Seppä H. 2010. Late-Quaternary palaeoclimatic research in Fennoscandia — a historical review. *Boreas* 39: 655–673.

Bjune A.E., Ohlson M., Birks H.J.B. & Bradshaw R.H.W. 2009. The development and local stand-scale dynamics of a *Picea abies* forest in southeastern Norway. *The Holocene* 19: 1073–1082.

Bronk Ramsey C. 2001. Development of the radiocarbon calibration program OxCal. *Radiocarbon* 43: 355–363.

Bronk Ramsey C. 2008. Deposition models for chronological records. *Quaternary Science Reviews* 27: 42–60.

Broström A., Nielse A.B., Gaillard M.-J., Hjelle K., Mazier F., Binney H., Bunting J., Fyfe R., Meltsov V., Poska A., Räsänen S., Soepboer W., von Stedingk H., Suutari H. & Sugita S. 2008. Pollen productivity estimates of key European plant taxa for quantitative reconstruction of past vegetation: a review. *Vegetation History and Archaeobotany* 17: 461–478.

Dąbrowska A. 2008. The influence of weather conditions on the course of pollen seasons of alder (*Alnus* spp.), hazel (*Corylus* spp.) and birch (*Betula* spp.) in Lublin (2001–2006). *Acta Agrobotanica* 61: 53–57.

Dauškane I., Brūmelis G. & Elferts D. 2011. Effect of climate on extreme radial growth of Scots pine growing on bogs in Latvia. *Estonian Journal of Ecology* 60: 236–248.

Draveniece A. 2009. Detecting changes in winter seasons in Latvia: the role of arctic air masses. *Boreal Environment*

Research 6095: 89–99.

Edvardsson J., Linderson H., Rundgern M. & Hammarlund D. 2012. Holocene peatland development and hydrological variability inferred from bog-pine dendrochronology and peat stratigraphy — a case study from southern Sweden. *Journal of Quaternary Science* 27: 553–563.

Ellenberg H. 2009. *Vegetation ecology of central Europe*, 4th ed. Cambridge University Press.

Ertl C., Pessi A.-M., Huusko A., Hicks S., Kubin E. & Heino S. 2012. Assessing the proportion of “extra-local” pollen by means of modern aerobiological and phenological records — an example from Scots pine (*Pinus sylvestris* L.) in northern Finland. *Review of Palaeobotany and Palynology* 185: 1–12.

Fægri K. & Iversen J. 1991. *Textbook of pollen analysis*, Wiley, Chichester.

Gaidamavičius A., Stančikaitė M., Kisielienė D., Mažeika J. & Gryguc G. 2011. Post-glacial vegetation and environment of the Labanoras Region, East Lithuania: implications for regional history. *Geological Quarterly* 55: 269–283.

Galenieks M. 1935. *The development of bogs and forests in the post-glacial period in Latvia*. Acta Universitatis Latviensis, Riga.

Giesecke T. & Bennett K.D. 2004. The Holocene spread of *Picea abies* (L.) Karst. in Fennoscandia and adjacent areas. *Journal of Biogeography* 31: 1523–1548.

Grimm E.C. 2012. *Tilia* version 1.7.16. Illinois State Museum, Research and Collections Center, Springfield.

Hammarlund D., Björck S., Buchardt B., Israelson C. & Thomsen C.T. 2003. Rapid hydrological changes during the Holocene revealed by stable isotope records of lacustrine carbonates from Lake Igelsjön, southern Sweden. *Journal of Quaternary Science Reviews* 22: 353–370.

Hammarlund D., Björck S., Buchardt B. & Thomsen C.T. 2005. Limnic responses to increased effective humidity during the 8200 cal. yr BP cooling event in southern Sweden. *Journal of Paleolimnology* 34: 471–480.

Hede M.U., Rasmussen P., Noe-Nygaard N., Clarke A.L., Vinebrooke R.D. & Olsen J. 2010. Multiproxy evidence for terrestrial and aquatic ecosystem responses during the 8.2 ka cold event as recorded at Højby Sø, Denmark. *Quaternary Research* 73: 485–496.

Heikkilä M. & Seppä H. 2010. Holocene climate dynamics in Latvia, eastern Baltic region: a pollen-based summer temperature reconstruction and regional comparison. *Boreas* 39: 705–719.

Heiri O., Lotter A.F. & Lemcke G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology* 25: 101–110.

Ikauniece S., Brūmelis G. & Kondratovičs T. 2012. Naturalness of *Quercus robur* stands in Latvia, estimated by structure, species, and processes. *Estonian Journal of Ecology* 61: 64–81.

Kalnina L., Cerina A. & Vasks A. 2004. Pollen and plant macro-remain analysis for the reconstruction of environmental changes in the early Metal period. In: Scott E.M., Alekseev A.Yu. & Zaitseva G. (eds.), *Impact of the environment on human migration in Eurasia*, Proceedings of the NATO Advanced Research Workshop, held in St. Petersburg, 15–18 November 2003, Nato Science Series IV, vol. 42, Springer, pp. 275–289.

Kuneš P., Pokorný P. & Šída P. 2008. Detection of the impact of early Holocene hunter-gatherers on vegetation in the Czech Republic, using multivariate analysis of pollen data. *Vegetation History and Archaeobotany* 17: 269–287.

Levkovskaya G.M. [Левковская Г.M.] 1987. [*The environment and the prehistoric man in the middle Holocene of the Lubana lowland*]. “Zinātne”, Riga. [In Russian with English summary].

Lindbladh M. & Foster D.R. 2010. Dynamics of long-lived foundation species: the history of *Quercus* in southern Scandinavia. *Journal of Ecology* 98: 1330–1345.

Lisitsyna O.V., Giesecke T. & Hicks S. 2011. Exploring pollen percentage threshold values as an indication for the regional presence of major European trees. *Review of Palaeobotany and Palynology* 166: 311–324.

Lowe J.J., Rasmussen S.O., Björck S., Hoek W.Z., Steffensen J.P., Walker M.J.C. & Yu Z.C. 2008. Synchronisation of palaeoenvironmental events in the North Atlantic region during the Last Termination: a revised protocol recommended by the INTIMATE group. *Journal of Quaternary Science Reviews* 27: 6–17.

Malterer T.J., Verry E.S. & Erjavec J. 1992. Fiber content and degree of decomposition in peats: review of national methods. *Soil Science Society of America Journal* 56: 1200–1211.

Novik A, Punning J.-M. & Zernitskaya V. 2010. The development of Belarusian lakes during the Late Glacial and Holocene. *Estonian Journal of Earth Sciences* 59: 63–79.

Parshall, T. 1999. Documenting forest stand invasion: fossil stomata and pollen in forest hollows. *Canadian Journal of Botany* 77: 1529–1538.

Piotrowska K. & Kubik-Komar A. 2012. The effect of meteorological factors on airborne *Betula* pollen concentrations in Lublin (Poland). *Aerobiologia* 28: 467–479.

Reimer P.J., Baillie M.G.L., Bard E., Bayliss A., Beck J.W., Bertrand C.J.H., Blackwell P.G., Buck C.E., Burr G.S., Cutler K.B., Damon P.E., Edwards R.L., Fairbanks R.G., Friedrich M., Guilderson T.P., Hogg A.G., Hughen K.A., Kromer B., McCormac G., Manning S., Ramsey C.B., Reimer R.W., Remmele S., Southon J.R., Stuiver M., Talamo S., Taylor F.W., van der Plicht J. & Weyhenmeyer C.E. 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46: 1029–1058.

Seglins V., Kalnina L. & Lacis A. 1999. The Lubans Plain, Latvia, as a reference area for long term studies of human impact on the environment. *PACT* 57: 105–129.

Seppä H. & Poska A. 2004. Holocene annual mean temperature changes in Estonia and their relationship to solar insolation and atmospheric circulation patterns. *Quaternary Research* 61: 22–31.

Sillasoo Ü., Mauquoy D., Blundell A., Charman D., Blaauw M., Daniell J.R.G., Toms P., Newberry J., Chambers F.M. & Karofeld E. 2007. Peat multi-proxy data from Männikjärve bog as indicators of late Holocene climate changes in Estonia. *Boreas* 36: 20–37.

Sohar K. & Kalm V. 2008. A 12.8-ka-long palaeoenvironmental record revealed by subfossil ostracod data from lacustrine freshwater tufa in Lake Sinijärv, northern Estonia. *Journal of Paleolimnology* 40: 809–821.

Stanek W. & Silc T. 1977. Comparisons of four methods for determination of degree of peat humification (decomposition) with emphasis on the Von Post method. *Canadian Journal of Soil Science* 57: 109–117.

Sugita S. 2007. Theory of quantitative reconstruction of vegetation I: pollen from large sites REVEALS regional vegetation composition. *The Holocene* 17: 229–241.

Sweeney, C. A. 2004. A key for the identification of stomata of the native conifers of Scandinavia. *Review of Palaeobotany and Palynology* 128: 281–290.

Terasmaa J. 2011. Lake basin development in the Holocene and its impact on the sedimentation dynamics in a small lake (southern Estonia). *Estonian Journal of Earth Sciences* 60: 159–171.

Veriankaitė L., Siljamo P., Sofiev M., Šaulienė I. & Kukkonen J. 2010. Modelling analysis of source regions of long-range transported birch pollen that influences allergic seasons in Lithuania. *Aerobiologia* 26: 47–62.

Veski S., Amon L., Heinsalu A., Reitalu T., Saarse L., Stivrins N. & Vassiljev J. 2012. Lateglacial vegetation dynamics in the eastern Baltic region between 14,500 and 11 400 cal yr BP: A complete record since the Bølling (GI-1e) to the Holocene. *Journal of Quaternary Science Reviews* 40: 39–53.

Veski S., Seppä H. & Ojala A.E.K. 2004. Cold event at 8200 yr B.P. recorded in annually laminated lake sediments in eastern Europe. *Geology* 32: 681–684.

Von Post L. 1924. Das Genetische System der Organgogenen Bildungen Schwedens. *Committee Soil Science* 22: 287–304.

Zelčs V., Markots A., Nartišs M. & Saks T. 2011. Pleistocene Glaciations in Latvia. In: Ehlers J., Gibbard P.L. & Huges P.D. (eds.), *Quaternary glaciations — extent and chronology, A closer look*, Elsevier, Amsterdam, pp. 221–229.

Zelčs V. & Markots A. 2004. Deglaciation history of Latvia. In: Ehlers J. & Gibbard P.L. (eds.), *Quaternary Glaciations — extent and chronology of glaciations*, Elsiever, Amsterdam, pp. 225–243.