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Late-Glacial and Holocene forest dynamics at Steregoiu in the Gutaiului Mountains, Northwest Romania

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Abstract

Pollen analyses and AMS ^{14}C measurements were performed on lacustrine sediments and peat deposits from the former crater lake Steregoiu in a mid-altitude area in the Gutaiului Mountains in NW Romania in order to provide a detailed reconstruction of the vegetational development of the area during the Late-Glacial and Holocene. The bottom sediments are siliciclastic and were deposited probably during the Full Glacial, which is characterised by open patchy vegetation consisting of a mosaic of shrubs, herbs, and ungrown grounds. Around 14 700 cal yr BP an open *Pinus–Betula* forest expanded, at the same time as organic-rich lake sediments started to be deposited. This change was likely a response to the first deglacial warming phase at the beginning of the Bølling period, or GI-1e, in the GRIP event stratigraphy. Between 13 750 and 12 950 cal yr BP an open forest dominated by *Betula*, *Picea*, *Pinus*, and *Ulmus* developed in the area. The forest composition implies rather warm climatic conditions, which may correspond to the Allerød, or GI-1c–GI-1a. Around 12 950 cal yr BP the forest retracted, and at 12 600 cal yr BP open patchy vegetation became re-established. These changes imply a return to significantly colder conditions, which may correspond to the Younger Dryas, or GS-1. At 11 500 cal yr BP *Betula*, *Pinus*, and *Alnus* quickly responded to the temperature rise, characterising the beginning of the Holocene. Within a few hundred years, around 11 300 cal yr BP, *Ulmus* and *Picea* became re-established and a mixed forest type expanded. *Quercus*, *Tilia*, and *Fraxinus* likely arrived at around 10 750 cal yr BP, and from about this time *Betula*, and *Pinus* started to diminish. Around 10 500 cal yr BP a dense mixed forest dominated by *Ulmus*, *Picea*, *Quercus*, *Tilia*, and *Fraxinus* had developed in the area. *Corylus* probably became locally established around 10 500 cal yr BP, but it did not expand until 10 200 cal yr BP. *Tilia* and *Fraxinus* were locally important until 8600 cal yr BP, when *Picea* gained renewed importance and the lake became completely overgrown. *Picea* was probably an important constituent in the carr forest at the site as well as in the upland forest. Around 4800 cal yr BP *Fagus* and *Carpinus* became important in the local stand, apparently without any major disturbance of the forest. Until around 3400 cal yr BP the forest was highly diverse, but when *Fagus* eventually expanded, *Ulmus*, *Tilia*, *Picea*, and *Corylus* diminished. From about 2200 cal yr BP onwards *Fagus* has been the local forest dominant, but some *Quercus* and *Carpinus* individuals have been present as well. Pollen evidence for human influence on the local vegetation is comparatively scant. The area may have been used for forest grazing from about 1050 cal yr BP, but the grazing pressure was probably low until ca. 300 cal yr BP.

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1. Introduction

For a long time Romania has been regarded as a 'white spot' in the palaeoecological literature because well-dated pollen sequences had not been collected and analysed (e.g. Huntley and Birks, 1983; Willis, 1994; Berglund et al., 1996). Pollen stratigraphic work has a long tradition in Romania (e.g. Pop, 1960) but, until recently, the focus of these investigations had been published only in national journals (e.g. Coldea, 1971; Diaconeasa and Stefuriac, 1971; Lupsa, 1980; Farcas, 1996; Diaconeasa and Farcas, 1996), and many of these works have remained nearly unknown outside the country. Furthermore, the earlier investigations totally lack radiocarbon dates, often have low sampling resolution, and mostly focus only on the Holocene. In some areas, for instance on the Romanian Plain south of the Carpathian Mountains, pollen analyses mainly have been carried out on loess deposits and material from anthropogenic sites at which the preservation conditions are not optimal (Tomescu, 2000). Reconstructions based on such material may be unreliable as pollen concentration usually is low and pollen assemblages are biased by selective pollen preservation. Age estimates for the studied sequences in Romania were obtained mainly by comparing the vegetational development to the Holocene vegetational zonation for Central Europe (Firbas, 1949, 1952). The lack of independent radiocarbon dates makes it very difficult to compare the timing of the vegetational development with other, well-dated, European sequences (Berglund et al., 1996). However, this situation is changing. Farcas et al. (1999) and Rösch and Fischer (2000) recently published the first ^{14}C dates from Holocene deposits, and Wohlfarth et al. (2001) and Björkman et al. (2002) presented sequences from Northwest Romania with high sampling and dating resolution.

The lack of good, well-dated pollen diagrams from Romania is problematic because questions related to glacial tree refugia and the Late-Glacial and Holocene expansion of trees from these refugia (e.g. Björkman et al., 2002) cannot adequately be addressed. Many tree species are believed to have survived the last glaciation in refugia in southernmost Europe, for instance on the Balkans (e.g. Huntley and Birks, 1983). When climatic conditions improved during the warmer phases of the Late-Glacial and at the beginning of the Holocene, several tree species rapidly migrated from these refugia and quickly re-established populations in areas that had been more or less treeless during the Full Glacial. The exact location of these refugia is not fully known, but it is believed that they might have been located particularly at climatically favourable mid-altitude sites (e.g. Willis, 1994). Recent studies have shown that coniferous forests existed in sheltered areas on the Hungarian Plain during the Full Glacial (Willis et al., 1995, 2000; Rudner and Sümegi, 2001), which may indicate that refugia occurred in a variety of settings, but excluding sites that were too cold or too dry. A find of macroscopic charcoal of *Carpinus* dated to 27 000 ^{14}C yr BP (Willis et al., 2000) also indicates the presence of deciduous trees in Hungary during the last glaciation.

It is highly possible that tree refugia also existed in neighbouring Romania where the large mid-altitude areas and deep incised river valleys could have provided sufficient shelter for tree survival. The occurrence of such refugia is, however, difficult to evaluate as very few published pollen profiles in Romania go back into the Full Glacial. During the Late-Glacial and Early Holocene several tree species also might have migrated through Romania from refugia located further to the south in Greece and Bulgaria. To be able to detect such range expansion patterns, a network of well-dated sites located throughout Romania is needed. In due time, these questions may be possible to answer when new pollen stratigraphic data emerge.

This article is the third in a series of papers dealing with Late-Glacial and Holocene climate and vegetational changes in the Gutaiului Mountains of Northwest Romania. Earlier papers have addressed Late-Glacial environmental changes (Wohlfarth et al., 2001) and summarised Late-Glacial and Early Holocene vegetational changes (Björkman et al., 2002). This paper presents a detailed reconstruction of the Late-Glacial and Holocene vegetational development at Steregoiu. It is our aim that this paper will form an important contribution to the discussion about glacial refugia and Late-Glacial and Holocene tree migration patterns in Southeast Europe. It will, hopefully, also highlight other, more general, questions about Holocene vegetation dynamics; for example, the establishment of *Fagus*.

2. Study area

Steregoiu is situated southeast of the small town of Negresti-Oas, on the western flank of the Gutaiului Mountains in Northwest Romania (Figs. 1 and 2). This massif is part of the Eastern Carpathian mountain chain, which stretches in a NNW–SSE direction and has peaks rising up to ca. 1200–1400 m above sea level (a.s.l.).

The site is a former crater lake, situated at ca. 790 m a.s.l. (47°48′48″N, 23°32′41″E), with a roughly elongated surface (ca. 50 × 100 m) of ca. 0.5 ha. Fairly steep slopes to the south and west surround the site. Towards the northwest, steep slopes lead down to the Talna Valley (Fig. 2). Apart from groundwater, the basin is fed by a small stream in the western part and drained by a small stream in the eastern part. The surrounding vegetation is dominated by young *Fagus* (approximately 30–50 years) and *Picea* stands. The site can be described as an eutrophic to mesotrophic mire with a field layer dominated by grasses, sedges, and herbs.

The present vegetation has been described by Lupsa (1980), who also made a simplified pollen diagram and briefly discussed the forest development in the area. However, her pollen diagram is not supported by radiocarbon dates, has low pollen counts and fairly low sampling resolution, and

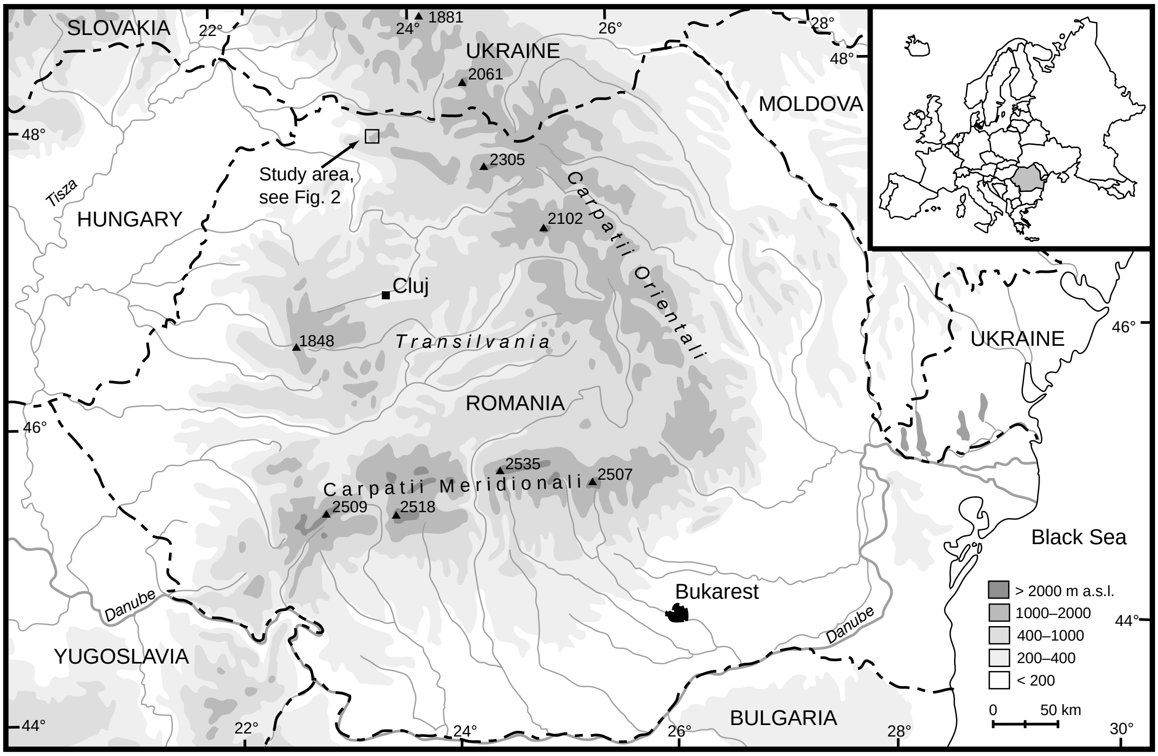

Fig. 1. Location of the study area in Northwest Romania.

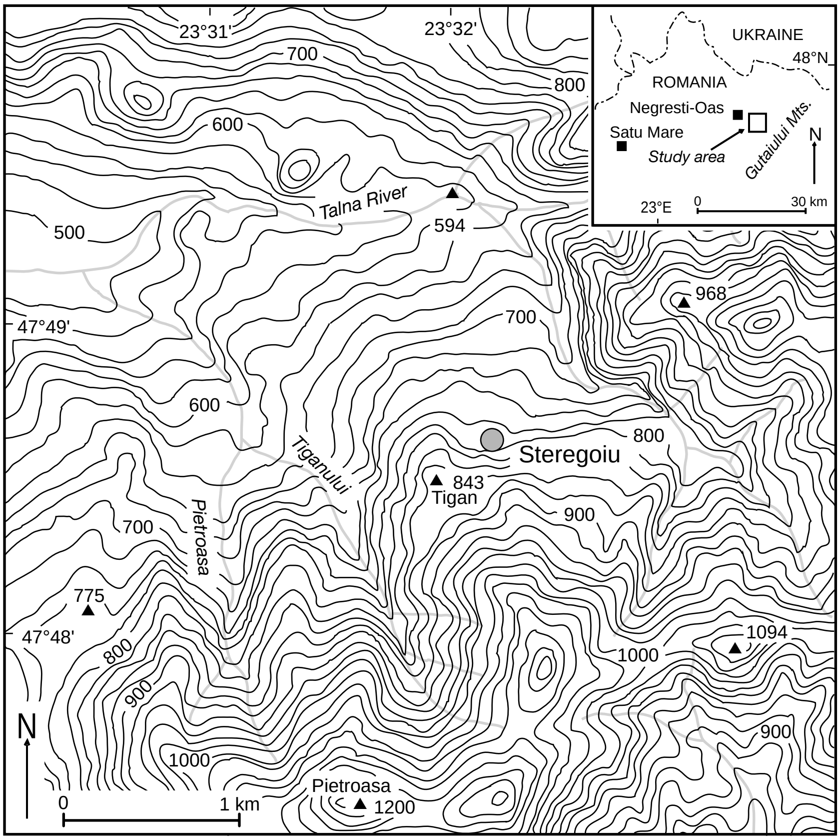

Fig. 2. Topographic map of the surroundings of the coring site in the Gutaiului Mountains. The position of the investigated site, Steregoiu, is shown by a filled dot. Contour lines show intervals of 20 m.

seems to cover only the Middle and Late Holocene, which makes comparisons to the present investigation difficult.

There are no climatic records directly available for the study area, but records from weather stations in Satu Mare (Fig. 2) and Baia Mare, and from the eastern and northern part of the Gutaiului Mountains, may be used as a proxy. Highest mean annual air temperatures of 9.5°C are recorded at Satu Mare and Baia Mare, while temperatures range slightly lower at 7.8 and 8.5°C east and north of the mountain chain. Mean annual precipitation is lowest in Satu Mare (ca. 600 mm). It rises towards the east to ca. 850 mm around Baia Mare, and then decreases slightly to ca. 700 and 750 mm towards the east and north.

Geologically, the area represents the northwestern termination of a volcanic arc, situated in the inner part of the Eastern Carpathian Mountains. The volcanic activity in this region took place during the Late Pliocene, generating a large range of intermediary and acidic rocks, including dacites, andesites, and rhyolites (Borcos et al., 1979). Primary bedrock in the study area is andesite. There is no published information about the Quaternary deposits, but our own field observations of, for instance, road cuts indicate that most of the soil cover is derived from slope processes. It is also assumed that alpine glaciers did not reach below 1800 m a.s.l. in the Carpathian Mountains during the Last Glacial Maximum (Balteanu et al., 1998). The low elevation of the Gutaiului Mountains makes it unlikely that the area was glaciated during the Weichselian, although periglacial conditions may have been widespread during the Last Glacial Maximum.

3. Methods

Sediment cores were taken in the centre of the basin in May 1999, where the organic-rich deposits were thickest (Table 1). Coring was performed with a strengthened Russian corer (diameter: 5 cm, length: 1 m), and each core was taken with an overlap of 50 cm to obtain enough material for analysis. The cores were described in the field, wrapped in plastic film, and placed in half PVC tubes. Subsequently they were transported to the Department of Geology in Lund, Sweden, where they were stored at 4°C. Prior to sub-sampling all cores were cleaned carefully, re-described, and visually correlated with each other.

The profile was continuously subsampled at ca. 2.5-cm intervals for pollen analysis. The preparation of the samples (1 cm^3) followed standard methods (Berglund and Ralska-Jasiewiczowa, 1986; Moore et al., 1991). To enable the calculation of the pollen concentrations, tablets with a known content of *Lycopodium* spores were added to each subsample (Stockmarr, 1971). Microscope slides were prepared from the residue and scored for pollen. At least 450–500 grains were counted in each subsample; when pollen concentration was low, a minimum of 300 grains was accepted. Pollen counts were made at 400× magnification, but 1000× was used for some critical determinations. Pollen keys and illustrations in Moore et al. (1991) and Reille (1992, 1995) were used for pollen identification. Pollen slides in the reference collection at the Department of Geology, Lund University, were used to check some pollen types. Microscopic charcoal particles have not been counted. Pollen nomenclature largely follows Moore et al. (1991) except for the subfamilies within Asteraceae, which in this paper are referred to as Liguliflorae and Tubuliflorae. The pollen diagrams were constructed using the TILIA and TILIA-GRAPH computer programmes (Grimm, 1992).

AMS ^{14}C measurements were carried out on terrestrial plant macrofossils (Table 2). The samples were treated with 1% HCl (6 h below boiling point) and 0.5% NaOH (1 h at 60°C), then dried at 100°C overnight in small glass bottles and sent to the AMS facility in Uppsala, Sweden. In all 17 samples were dated.

Table 1
Simplified lithostratigraphic description of the analysed profile from Steregoiu

Depth (m)	Description
0–1.25	Fen peat, gradual lower boundary
1.25–2.80	Carr peat, gradual lower boundary
2.80–4.28	Coarse detritus gyttja, gradual lower boundary
4.28–4.57	Gyttja, gradual lower boundary
4.57–5.225	Clayey gyttja, gradual lower boundary
5.225–5.26	Silty, slightly sandy clayey gyttja, sharp lower boundary
5.26–5.44	Gyttja clay, gradual lower boundary
5.44–5.70	Silty clay (partly laminated) with gravely, sandy layers, gradual lower boundary
5.70–5.84	Clayey sandy silt with gravel, sharp lower boundary
5.84–5.92	Silty clay with sand and gravel

4. Results and interpretations

4.1. Lithostratigraphy

A simplified stratigraphy for the analysed profile (0–5.92 m) is presented in Table 1 (see also lithology column in the pollen diagram, Fig. 4). The bottom part of the profile, below 5.44 m, comprises siliciclastic materials. These were probably deposited by slope processes or washed in by streams originating at higher altitudes. The first slightly organic sediments (gyttja clay), which mark the beginning of the lake, start at 5.44 m. The contact with the overlying clayey gyttja at 5.26 m is erosive and points to a hiatus. The succession clayey gyttja, gyttja, and coarse detritus gyttja implies that the basin was a lake until it became overgrown at 2.80 m; subsequently, carr peat started to accumulate (Fig. 4) and the site became a mire. Fen peat started to develop at 1.25 m, showing that the site had become an open fen.

4.2. Chronology

The AMS ^{14}C measurements from the site result in reasonably concordant ages with respect to depth and sediment types (Table 2). However,

Table 2
AMS ^{14}C dates from Steregoiu.

Depth (m)	Laboratory number	Dated material	^{14}C age BP	Calibrated years BP	Date used to construct a chronology (cal yr BP)
0.12–0.084	Ua-16782	Mosses (indet.)	50 ± 75	280–170 (31.7%), 150-.... (63.7%)	225 at 0.102 m
0.44–0.39	Ua-16781	Mosses (indet.)	1180 ± 75	1270–950	1110 at 0.415 m
0.66–0.614	Ua-16780	Mosses (indet.)	2100 ± 75	2310–1890	1900 at 0.637 m
1.114–1.07	Ua-16779	Bark, twig (indet.)	3130 ± 75	3550–3510 (1.3%), 3480–3140 (94.1%)	3310 at 1.092 m
1.32–1.274	Ua-16778	Wood (indet.)	3680 ± 70	4240–3830	4100 at 1.297 m
1.804–1.754	Ua-16777	Wood (indet.)	6425 ± 75	7480–7200	7340 at 1.779 m
2.55–2.50	Ua-16776	Bark (indet.)	7560 ± 80	8520–8490 (1.5%), 8480–8170	8250 at 2.525 m
2.73–2.684	Ua-16775	*Picea* needles	7655 ± 85	8610–8290 (92.6%), 8270–8210 (2.8%)	8450 at 2.707 m
2.96–2.91	Ua-16774	*Picea* needles, leaf fragments (indet.)	7870 ± 75	9000–8450	8725 at 2.935 m
3.28–3.23	Ua-16329	*Picea* needles	8300 ± 85	9490–9030	9200 at 3.255 m
3.464–3.414	Ua-16773	*Picea* needles	8215 ± 85	9430–9000	9400 at 3.439 m
4.05–4.004	Ua-16328	*Picea* needles, twigs, leaf fragments (indet.)	9130 ± 95	10 600–9900	10 250 at 4.03 m
4.36–4.32	Ua-16327	*Picea* needles	9530 ± 85	11 200–10 550	10 700 at 4.34 m
4.544–4.50	Ua-16326	Wood (indet.)	9665 ± 110	11 250–10 600	11 100 at 4.52 m
4.694–4.64	Ua-16325	Charcoal, leaves, wood (indet.)	10 325 ± 150	12 850–11 350	11 400 at 4.67 m
5.164–5.12	Ua-16324	wood fragments	10 910 ± 105	13 200–12 800 (80.6%), 12 750–12 600 (14.8%)	13 150 at 5.14 m
5.324–5.274	Ua-16323	leaves, *Picea* needle, wood	12 365 ± 115	15 450–14 050	14 000 at 5.30 m

Calibrated ages at ±2σ are given as derived by the OxCal 3.5 computer programme (Bronk Ramsey, 1995). The date used to construct a chronology for the pollen diagrams (Fig. 4) is either a mid-point of the calibrated interval (at ±2σ) or an adjusted date which takes into account the calibration curve and the most probable interval (at ±2σ), and the stratigraphic position of the sample.

some of the dates fall within a complicated part of the radiocarbon calibration curve (Stuiver et al., 1998). For instance, there is a long plateau at ca. 12 600 ^{14}C yr BP, as well as several other smaller plateaus. These make it difficult to obtain good calibrated dates. Consequently, calibration of these dates will result in large standard errors, which do not allow for the development of a reliable chronology with respect to the vegetation development.

To avoid the problem with large standard errors, an age–depth curve was constructed (Fig. 3). However, the use of such a curve assumes that the sedimentation rate is fairly uniform, which is not always the case (hiatuses may be a problem, and at least one hiatus is present in the profile at 5.26 m, see above). However, the curve for total pollen concentration is an independent test for this assumption (Fig. 4). The curve for Steregoiu is reasonably smooth and does not indicate any large deviations from an overall uniform accumulation rate, except for the bottom part of the profile where pollen concentrations are low, and around 1.20 m where concentrations are exceptionally high. The high values around 1.20 m may indicate a prolonged phase with low peat accumulation rates, or drier conditions resulting in decomposition of peat.

The age–depth curve was established on base of dates falling in uncomplicated parts of the calibration curve, and dates that have relatively small standard errors (Table 2). Using these dates, it is possible to calculate an accumulation rate of ca. 41 yr/cm for the clayey gyttja sequence between 5.25 and 4.67 m, and of ca. 14 yr/cm for the gyttja and carr peat sequence between 4.67

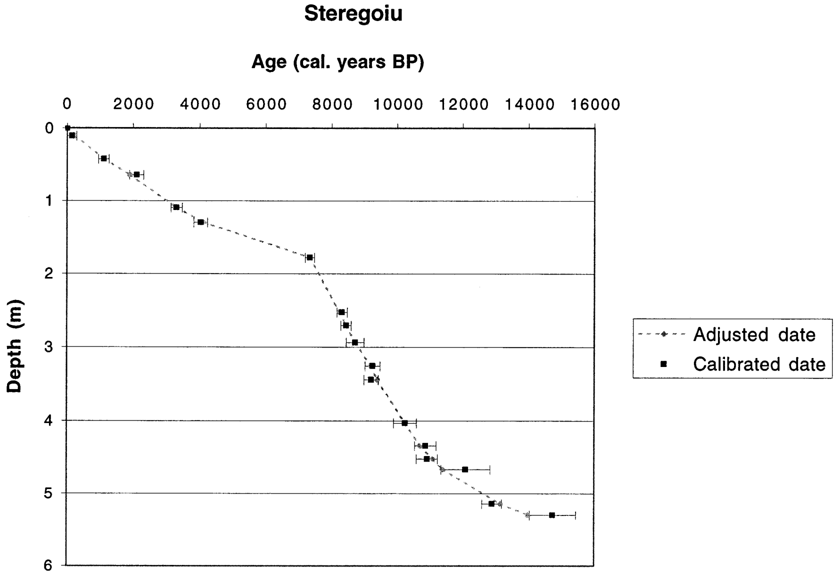

Fig. 3. Calibrated AMS radiocarbon dates and suggested age–depth curve for the site Steregoiu (see also Table 2).

and 1.78 m. The upper part of the carr peat sequence between 1.78 and 1.30 m, where pollen concentration is significantly higher, has a marked lower accumulation rate of around 67 yr/cm. The topmost fen peat sequence between 1.30 and 0.10 m, instead, has an accumulation rate of approximately 32 yr/cm. The accumulation rate for the bottommost part (below 5.40 m) with siliciclastic deposits is unknown, as it was not possible to find any datable plant macrofossils.

The second step in constructing a reliable age–depth curve for the site was to plot the 'complicated' dates on the curve, and then to assign ages that better fit the age–depth curve than the earlier obtained calibrated ages (cf. curve for adjusted dates in Fig. 3; Table 2). Thus, the method used in this study allows calibrated years BP to be assigned to all the individual AMS ^{14}C measurements and to all zone boundaries.

4.3. Pollen stratigraphy and vegetational development

The pollen data are presented in a percentage diagram with all terrestrial pollen types included in the calculation sum (Fig. 4). To facilitate description and interpretation of the pollen diagram with respect to vegetational changes, 19 Local Pollen Assemblage Zones (LPAZ S1–19) were established (Table 3; Fig. 4). These zones have been established visually, and each zone boundary denotes significant changes in pollen deposition and, hence, represents major changes in vegetation cover. This zonation is mostly based on changes in the dominant pollen taxa (i.e. trees, *Corylus*, *Juniperus*, Poaceae undiff. <40 µm, *Artemisia*, and Chenopodiaceae), but also changes in minor, but highly indicative, pollen taxa (i.e. *Acer*, *Salix*, Poaceae undiff. >40 µm, *Plantago lanceolata*, and *Rumex acetosa*/*R. acetosella*) are taken into account, as well as changes in lithology. The validity of the zonation has been confirmed by CONISS (Grimm, 1987) (Fig. 4B), which shows that most zones are statistically significant. The local site development and the on-site vegetation are presented in detail in Table 3. A summary of the Late-Glacial and Holocene vegetational development, based on a synthesis of the pollen zones, is given below. The general vegetational development is described according to 15 time periods (A–O). These periods also are presented in a diagram with selected tree, shrub, and herb pollen taxa drawn on a linear timescale (Fig. 5).

4.3.1. *(A) >14 700 cal yr BP (S1): open patchy vegetation consisting of a mosaic of shrubs, herbs, and un-vegetated ground*

The upland vegetation surrounding the basin before 14 700 cal yr BP had probably an open structure. Most likely it can be characterised as a mosaic with areas dominated by low shrubs, e.g. *Salix* and *Juniperus* (and possibly also *Betula*), and areas dominated by grasses, sedges and herbs, e.g. *Artemisia*, Chenopodiaceae and *Helianthemum*, and several species from the Asteraceae, Caryophyllaceae and Ranunculaceae families. Areas with more or less ungrown grounds also occurred, which is indicated by the siliciclastic sediments. The percentages for *Pinus* are comparably high and difficult to interpret. *Pinus* may have been present in the region, but it was certainly not forming a local tree cover. Instead, it may have been growing in valleys with favourable microclimate, or it could have formed more or less dense forests in the lowlands west of the study area.

4.3.2. *(B) 14 700–13 750 cal yr BP (S2, S3): open* Pinus–Betula *forest*

The vegetation during this time period may have been composed of rather open forests dominated by *Pinus* and *Betula*. *Pinus* has very high percentages and reaches its highest values of the entire profile, while total pollen concentration and *Betula* percentages have increased and many herb pollen types display low values. This may indicate a regional and local expansion of *Betula* and *Pinus* and a decrease of the open vegetation. This development is supported by macrofossil analyses from the nearby site Preluca Tiganului (Wohlfarth et al., 2001). Around 14 150 cal yr BP *Alnus* seems to have expanded, most likely becoming a dominant tree in the carr forest which surrounded the lake. The presence of *Juniperus* pollen and the fairly high values for Poaceae undiff. <40 μm and *Artemisia* probably indicate that areas with open vegetation occurred, however, most likely at higher altitudes.

4.3.3. *(C) 13 750–12 950 cal yr BP (S4): open forest dominated by* Betula*,* Picea*,* Pinus*, and* Ulmus

At the beginning of this time interval the open *Betula* and *Pinus* forest was replaced by an open *Betula* and *Picea* dominated forest. *Pinus* was probably still common although its pollen values are considerably lower than before. Most likely *Picea* had not been present locally before, but it must have become established rather early and then expanded rapidly. Around 13 400 cal yr BP *Ulmus* attains remarkably high values, which may imply that it formed a considerable population in the area. *Quercus* appears in low percentages around 13 000 cal yr BP, which may indicate that it was present in the region. The seemingly rapid expansion of initially *Picea*, and subsequently *Ulmus*, shows that these trees must have been present in the region already, but with very low populations, otherwise they would not have become established so rapidly. If they had to immigrate from areas much farther away, they would not have responded so quickly. The upland forest probably had a rather open structure, which is suggested by the seemingly high percentages of herbaceous pollen types. *Juniperus* pollen and the comparatively high values for Poaceae undiff. <40 μm, *Artemisia*, and Chenopodiaceae indicate that areas with open vegetation occurred, most likely at higher altitudes.

4.3.4. *(D) 12 950–12 600 cal yr BP (S5): open forest dominated by* Betula*,* Picea*, and* Pinus*; expansion of open vegetation*

The forest was rather open and dominated by *Betula*, *Pinus*, and *Picea*. *Ulmus* seems to have diminished at the beginning of the period. Also, *Betula*, *Pinus*, and *Picea* seem to have decreased rapidly. At the same time particularly *Artemisia* and Chenopodiaceae expanded their representation. At the end of the period probably only *Betula* and *Picea* locally formed an open forest. The strong expansion of *Artemisia* and Chenopodiaceae implies that open vegetation had started to spread regionally, although probably mainly at higher elevations.

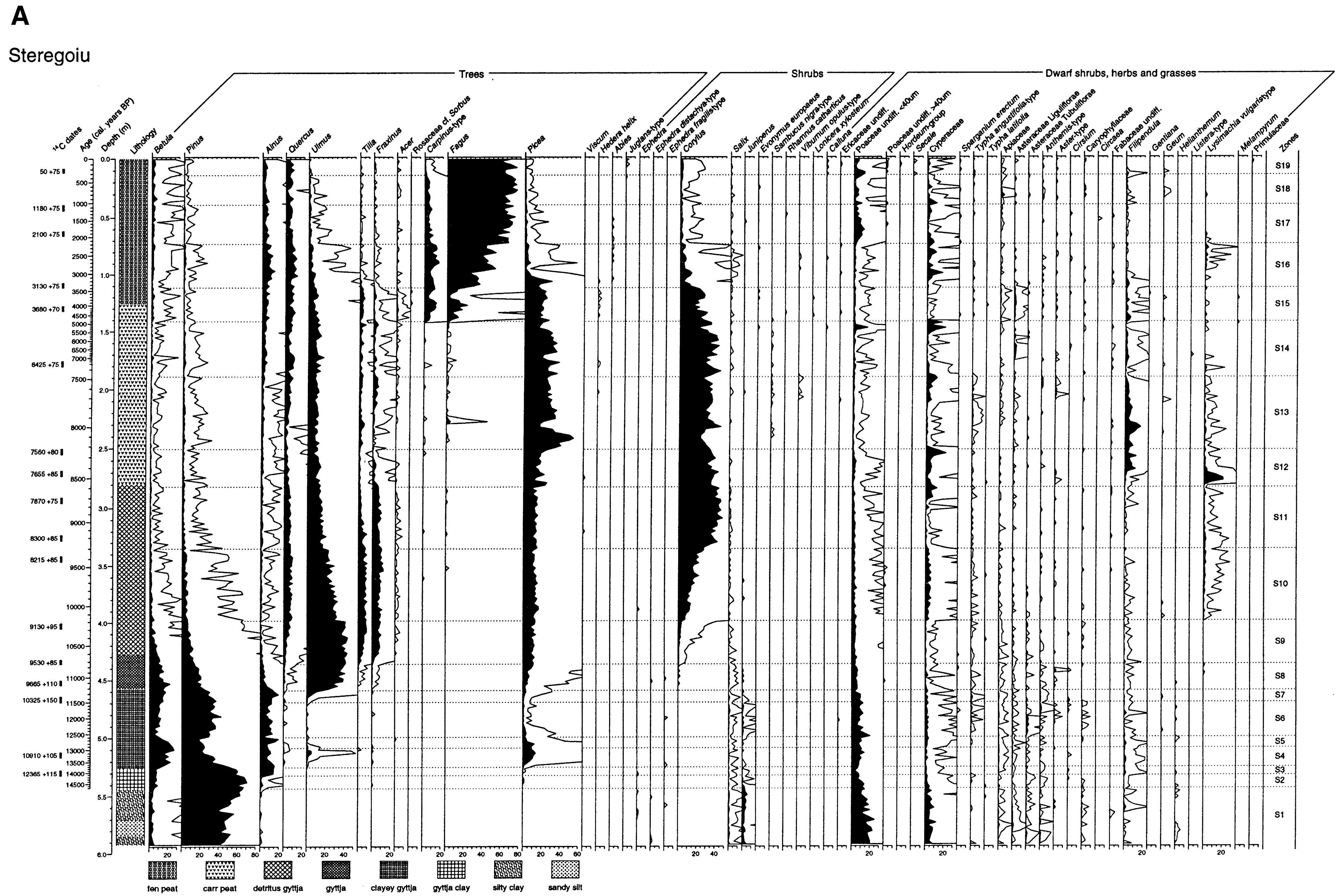

Fig. 4. (A,B) Percentage pollen diagram with all identified pollen and spore taxa presented on a linear depth scale (covering the profile between 0 and 5.92 m). Radiocarbon dates (black bars) and a non-linear timescale in calibrated years BP are shown to the left of the diagram, as well as a simplified stratigraphy. The pollen diagram covers roughly the time interval between ca. 15 500 cal yr BP and the present (AD 1950).

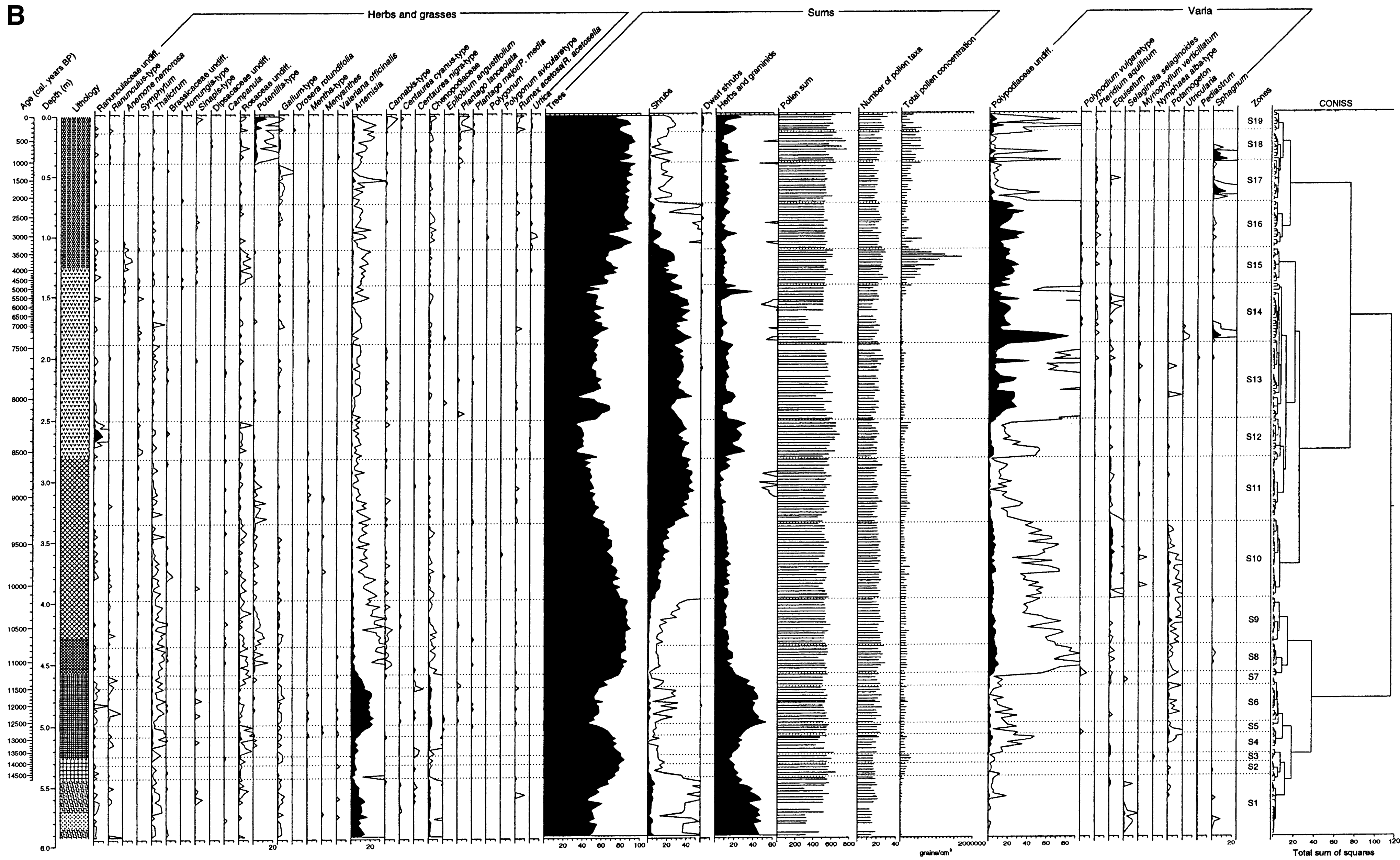

Fig. 4 (*Continued*).

Table 3
Summary of the pollen stratigraphy, chronology and vegetation history of Steregoiu (see Fig. 4 for pollen diagram)

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S1, *Pinus*–Poaceae–*Artemisia* LPAZ				
5.92–5.43	> 14 700	Characterised by high pollen percentages for *Pinus* (40–55%), fairly high percentages for Poaceae undiff. < 40 µm (10–20%), *Artemisia* (5–15%) and Cyperaceae (5–10%), and low but significant values for *Betula* (ca. 5%), *Juniperus* (3–5%) and Chenopodiaceae (ca. 3%). Among other pollen types, *Salix*, Apiaceae, Asteraceae Liguliflorae and Asteraceae Tubuliflorae have significant occurrences. In the upper part of the zone *Filipendula* and *Thalictrum* occur more regularly than before. There is also a noteworthy presence of scattered pollen grains of *Ephedra*, Caryophyllaceae, *Helianthemum*, Ranunculaceae undiff., *Galium*-type, *Centaurea cyanus*-type and *C. nigra*-type. Additionally, there is a slight presence of Polypodiaceae undiff. and *Potamogeton* in the topmost samples, and of *Selaginella selaginoides* in the botton samples. The total pollen concentration is low, reaching just above 50 000 grains/cm^3 in a few samples.	Mainly siliciclastic material was accumulating, probably transported to the basin with streams coming from higher elevations and by slope processes and strong winds. The on-site vegetation probably was scarce as is suggested by the low pollen concentration. It may have been dominated by grasses, sedges, Ranunculaceae, *Thalictrum*, *Galium* and *Selaginella selaginoides*.	Open vegetation, most likely a mosaic with low shrubs, grass, sedges and herbs.
S2, *Pinus*–Poaceae–*Betula* LPAZ				
5.43–5.32	ca. 14 700–14 150	Characterised by very high pollen percentages for *Pinus* (60–70%), fairly high percentages for *Betula* and Poaceae undiff. < 40 µm, and low but significant values for Cyperaceae and *Artemisia*. Among other pollen types, *Alnus*, *Salix*, *Juniperus*, Asteraceae Tubuliflorae and *Filipendula* have significant occurrences. There is also a presence of single, or scattered pollen grains of Caryophyllaceae, Ranunculaceae undiff., *Thalictrum*, *Centaurea nigra*-type and Chenopodiaceae. Compared to S1, *Betula*, *Pinus*, and *Alnus* have increased, while *Salix*, *Juniperus*, Poaceae undiff. < 40 µm, Cyperaceae, *Artemisia*, and Chenopodiaceae-have decreased. The total pollen concentration is higher than in S1, and reaches values above 100 000 grains/cm^3.	Slightly organogenic sediments were deposited (a gyttja clay), indicating that the site had become a lake, but the organic production was still low and inflow of siliciclastic material continued. The lake may have been surrounded by a rim with some *Betula* and *Alnus* trees and *Salix* shrubs. Sedges and grasses may also have been common around the site.	Open vegetation with scattered *Pinus* and *Betula* individuals.
S3, *Pinus*–*Alnus*–*Betula* LPAZ				
5.32–5.25	14 150–ca. 13 750	Characterised by very high pollen percentages for *Pinus*, fairly high percentages for *Betula* and *Alnus*, and low but significant values for Poaceae undiff. < 40 µm, Cyperaceae, and *Filipendula*. Among other pollen types, *Salix*, *Juniperus*, and *Galium*-type have significant occurrences. Single or scattered pollen grains of *Picea*, *Ephedra*, Ranunculaceae undiff., *Helianthemum*, and Chenopodiaceae are present. Additionally, Polypodiaceae undiff. occurs. Compared to S2, *Alnus*, *Filipendula*, and *Galium*-type have increased, while *Pinus*, Poaceae undiff. < 40 µm, and Cyperaceae have decreased.	Gyttja clay was deposited in the lake, signalling that organic production was low and that inflow of siliciclastic material was still important. The lake was probably surrounded by carr forest in which *Salix*, *Betula*, and particularly *Alnus* were common. It also had a rim with an open fen vegetation with grasses, sedges, *Filipendula*, and *Galium*.	Open forest dominated by *Pinus* and *Betula*.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S4, *Betula–Pinus–Picea* LPAZ				
5.25–5.09	13 750–12 950	Characterised by high pollen percentages for *Betula* (15–25%) and *Pinus*, fairly high percentages for *Picea* (5–15%), *Alnus*, Poaceae undiff. < 40 µm, and *Artemisia*, and low but significant values for *Ulmus* (has a top at 5.3% in the middle of the zone), Chenopodiaceae, Cyperaceae, and *Filipendula*. Among other pollen types, Apiaceae, Rosaceae undiff., and *Thalictrum* have significant occurrences. Conspicuous is also the presence of single, or scattered pollen grains of several tree pollen types, e.g. *Fraxinus*, *Quercus* (around 1% in the topmost samples), and *Tilia*. Additionally, there is also a significant presence of Polypodiaceae undiff. Compared to S3, *Betula*, *Quercus*, *Ulmus*, *Picea*, Apiaceae, Chenopodiaceae, and Polypodiaceae undiff. have increased, while *Pinus*, *Alnus*, and *Juniperus* have decreased.	The clayey gyttja indicates decreased input of siliciclastic material and an increase in the organic production during the latter part of the zone. *Potamogeton* was common in the lake. The lake was probably surrounded by carr forest in which *Salix*, *Betula*, and *Alnus* were common. It also had a rim with fen vegetation in which grasses, sedges, Apiaceae, and *Filipendula* were common.	Open forest dominated by *Betula* and *Picea*. *Pinus* was probably also common. Establishment and expansion of *Ulmus*.
S5, *Betula–Pinus–Alnus* LPAZ				
5.09–4.99	12 950–12 600	Characterised by high pollen percentages for *Betula* (15–25%) and *Pinus*, fairly high percentages for *Alnus* (has a peak around 20% at the top of the zone), *Picea*, Poaceae undiff. < 40 µm, and *Artemisia* (increases strongly, from ca. 10% at the bottom to ca. 20% at the top), and low but significant values for Cyperaceae, *Filipendula*, *Thalictrum*, Rosaceae undiff., and Chenopodiaceae. Among other pollen types, *Salix*, Apiaceae, and Asteraceae Liguliflorae have significant occurrences. Noteworthy is also the occurrence of *Quercus* and *Ulmus* pollen in the bottom sample of the zone. Additionally, there is also a significant presence of Polypodiaceae undiff. and *Potamogeton*. Compared with S4, *Betula*, *Alnus*, and *Artemisia* have increased while *Pinus*, *Picea*, *Ulmus*, and Polypodiaceae undiff. have decreased.	The clayey gyttja deposited in the lake shows that some siliciclastic material was still transported into the basin, probably by small streams from higher elevations where open vegetation had started to spread. The lake was surrounded by carr forest in which *Salix*, *Betula*, and in particular *Alnus* were common. (*Alnus* has peak values at the end of the zone.) The lake had a rim with fen vegetation in which grasses, sedges, and *Filipendula* were common.	Open forest dominated by *Betula*, *Pinus*, and *Picea*. *Ulmus* diminished at the beginning of the zone. Expansion of open vegetation, particularly *Artemisia* and Chenopodiaceae.
S6, *Pinus–Artemisia*–Poaceae LPAZ				
4.99–4.69	12 600–11 500	Characterised by high pollen percentages for *Pinus* (30–40%), fairly high percentages for *Artemisia* (ca. 20%), *Alnus*, *Betula*, and Poaceae undiff. < 40 µm, and low but significant values for Chenopodiaceae and Cyperaceae. Among other pollen types, *Picea*, *Salix*, *Juniperus*, Asteraceae Tubuliflorae, *Filipendula*, and *Thalictrum* have significant occurrences. There is also a noteworthy presence of single or scattered pollen grains of *Quercus*, *Ulmus*, *Ephedra*, *Typha angustifolia*-type, Caryophyllaceae, *Helianthemum*, Ranunculaceae undiff., *Galium*-type, *Centaurea cyanus*-type, and *C. nigra*-type. Additionally, there is a continuous presence with low values of Polypodiaceae undiff. Among aquatic pollen types, *Potamogeton* is represented with low values. Compared to S5, *Pinus*, *Juniperus*, Poaceae undiff. < 40 µm, Asteraceae Tubuliflorae, Ranunculaceae undiff., Chenopodiaceae, *Artemisia*, and Cyperaceae have increased while *Betula* and *Picea* have decreased.	The clayey gyttja indicates that siliciclastic material was transported into the basin, probably by streams coming from unstable ground. The lake was probably surrounded by carr forest, with *Salix*, *Betula*, and *Alnus*, and had a rim with open fen vegetation in which grasses, sedges, *Sparganium*, *Filipendula*, and *Galium* were common.	Open vegetation, most likely a mosaic with low shrubs, grass, sedges, and herbs. Scattered *Betula* individuals.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S7, *Pinus–Betula–Alnus* LPAZ				
4.69–4.59	11 500–11 250	Characterised by high pollen percentages for *Pinus* (35–40%), fairly high percentages for *Betula* (ca. 15%), *Alnus* (10–20%), Poaceae undiff. < 40 µm, and *Artemisia*, and low but significant values for *Ulmus*, Cyperaceae, and Chenopodiaceae. Among other pollen types, *Picea*, *Salix*, Apiaceae, *Filipendula*, and *Thalictrum* have significant occurrences. There is also a conspicuous presence of single or scattered pollen grains of *Quercus*, *Juniperus*, *Typha angustifolia*-type, Ranunculaceae undiff., *Ranunculus*-type, and *Centaurea nigra*-type. In addition, there is a slight presence of Polypodiaceae undiff. Compared to S6, *Betula*, *Alnus*, and *Ulmus* have increased while *Pinus*, *Juniperus*, *Artemisia*, and Chenopodiaceae have decreased. Noteworthy is also that *Ulmus* shows increasing values throughout the zone (has very low values in the bottom samples and ends with ca. 10% in the top), while *Pinus* and *Artemisia* show decreasing values.	Deposition of clayey gyttja shows that siliciclastic material was still transported into the lake, which was surrounded by carr forest in which *Salix*, *Betula*, and particularly *Alnus* were common. It probably also had a rim with fen vegetation, consisting of, among others, grasses, sedges, *Sparganium*, and *Filipendula*.	Open forest dominated by *Betula* and *Pinus*. Establishment and expansion of *Ulmus*.
S8, *Ulmus–Pinus–Betula* LPAZ				
4.59–4.36	11 250–10 750	Characterised by very high pollen percentages for *Ulmus* (20–45%), fairly high percentages for *Pinus*, *Betula*, and *Picea*, and low but significant values for *Alnus*, Poaceae undiff. < 40 µm, and *Artemisia*. Among other pollen types, *Fraxinus*, *Quercus*, *Tilia*, *Salix*, Cyperaceae, *Filipendula*, Rosaceae undiff., and *Potentilla*-type have significant occurrences. Scattered pollen grains of *Corylus*, *Ephedra*, *Juniperus*, and *Cannabis*-type occur. Additionally, Polypodiaceae undiff. have fairly high values, while *Potamogeton* and *Equisetum* only have slight occurrences. Compared to S7, *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, *Picea*, Rosaceae undiff., *Potentilla*-type, *Cannabis*-type, and Polypodiaceae undiff. have increased while *Alnus*, *Pinus*, *Juniperus*, Poaceae undiff. < 40 µm, Cyperaceae, *Artemisia*, and Chenopodiaceae have decreased. Several tree pollen types, in particular *Fraxinus*, *Picea*, *Quercus*, and *Tilia*, are showing increasing values throughout the zone.	Deposition of gyttja shows that the siliciclastic input to the lake had ceased and that upland soils were stable and covered with vegetation. The lake was surrounded by carr forest in which *Salix*, *Betula*, and *Alnus* probably were common. It also had a rim with fen vegetation in which grasses, sedges, *Equisetum*, and several herbs, such as *Filipendula* and *Potentilla*, occurred frequently.	Dense forest dominated by *Ulmus*, but *Picea*, *Betula*, and *Pinus* were also common. Establishment of *Quercus*, *Tilia*, and *Fraxinus*.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S9, *Ulmus–Picea–Fraxinus* LPAZ				
4.36–3.98	10 750–10 200	Characterised by very high pollen percentages for *Ulmus* (40–45%), fairly high percentages for *Picea*, *Pinus*, *Betula*, *Fraxinus*, *Tilia*, and *Quercus*, and low but significant values for *Alnus*, *Corylus* (has a low occurrence around 0.2% at the bottom, but increases to about 4% at the top), Poaceae undiff. <40 µm, and *Artemisia*. Among other pollen types, *Salix*, Cyperaceae, *Filipendula*, *Thalictrum*, Rosaceae undiff., *Potentilla*-type, *Thalictrum*, and Chenopodiaceae have significant occurrences. There is also a presence of scattered pollen grains of *Acer*. Additionally, Polypodiaceae undiff. have fairly high values, while *Potamogeton* has significant values. Compared to S8, *Fraxinus*, *Tilia*, *Quercus*, and *Corylus* have increased, while *Pinus*, *Betula*, Poaceae undiff. <40 µm, Cyperaceae, *Artemisia*, and Chenopodiaceae have decreased.	The site was a shallow lake where coarse detritus gyttja was deposited. It was surrounded by carr forest in which probably *Salix* and *Betula* were common. Instead, *Alnus* seems to have disappeared from the site. The lake probably had a rim with fen vegetation in which grasses, sedges, and several herbs, such as *Filipendula* and *Potentilla*, were common.	Dense forest dominated by *Ulmus*, but *Picea*, *Quercus*, *Tilia*, and *Fraxinus* were also common. Establishment of *Corylus* and *Acer*.
S10, *Ulmus–Corylus–Picea* LPAZ				
3.98–3.35	10 200–9300	Characterised by high pollen percentages for *Ulmus* (25–30%) and *Corylus* (10–25%), fairly high percentages for *Picea*, *Fraxinus*, *Tilia*, and *Quercus*, and low but significant values for *Pinus*, Cyperaceae, and Poaceae undiff. <40 µm. Among other pollen types, *Betula*, *Lysimachia vulgaris*-type, *Artemisia*, and *Alnus* have significant occurrences. There is also a regular presence of pollen grains of *Acer*, *Typha angustifolia*-type, and Chenopodiaceae. Among the aquatic pollen types, *Potamogeton* is fairly well-represented. Noteworthy are the comparatively high values for *Equisetum*. Compared to S9, *Corylus*, Cyperaceae, *Lysimachia vulgaris*-type, and *Equisetum* have increased while *Pinus*, *Betula*, *Alnus*, *Ulmus*, Poaceae undiff. <40 µm, *Artemisia*, and Chenopodiaceae have decreased. Conspicuous are the gradually increasing values for *Corylus*, and the gradually decreasing values for *Ulmus*.	The site was a shallow lake where coarse detritus gyttja was deposited. *Betula* and *Salix* have low values, which may suggest that there was no carr forest surrounding the lake. However, a few *Betula* individuals may still have occurred near the site. The lake probably had a well-developed rim with open fen vegetation dominated by sedges, *Sparganium*, *Lysimachia vulgaris*, and *Equisetum*.	Dense forest dominated by *Ulmus*, *Corylus*, and *Picea*, but *Quercus*, *Tilia*, *Fraxinus*, and *Acer* were also common. Expansion of *Corylus*.
S11, *Corylus–Ulmus–Picea* LPAZ				
3.35–2.82	9300–8600	Characterised by very high pollen percentages for *Corylus* (ca. 45%), fairly high percentages for *Ulmus*, *Fraxinus*, *Picea*, *Quercus*, *Tilia*, and Cyperaceae (only in the topmost samples), and low but significant values for *Alnus*, *Pinus*, *Lysimachia vulgaris*-type, and Poaceae undiff. <40 µm. Among other pollen types, *Acer*, *Artemisia*, *Potentilla*-type, and *Thalictrum* occur more or less regularly, but with very low values. Additionally, Polypodiaceae undiff. and *Equisetum* have a low presence. Compared to S10, *Corylus* has increased while *Ulmus*, *Tilia*, *Artemisia*, Polypodiaceae undiff., and *Equisetum* have decreased. Cyperaceae have also decreased, but at the top of the zone a strong increase up to values around 10% can be observed. Noteworthy is also that *Ulmus* is showing slightly decreasing values throughout the zone.	The site was a very shallow lake where coarse detritus gyttja was deposited. *Betula* and *Salix* have very low values, which may suggest that there where no carr forests surrounding the lake. It probably had a well-developed rim with open fen vegetation dominated by sedges (particularly at the end of the zone when the lake was almost overgrown), *Lysimachia vulgaris*, *Potentilla*, and *Equisetum*.	Dense forest dominated by *Corylus* and *Ulmus*, but *Picea*, *Quercus*, *Tilia*, *Fraxinus*, and *Acer* were also common.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S12, *Corylus–Picea–Ulmus* LPAZ				
2.82–2.50	8600–8200	Characterised by very high pollen percentages for *Corylus* (ca. 40%), high or fairly high percentages for *Quercus*, *Ulmus*, *Picea* (15–25%), Cyperaceae, *Filipendula*, and *Lysimachia vulgaris*-type (only in lowermost samples), and low but significant values for *Alnus*, *Tilia*, *Fraxinus*, Poaceae undiff. <40 µm, and *Ranunculus*-type. Among other pollen types, *Betula*, *Pinus*, Rosaceae undiff., and *Artemisia* occur regularly, but with very low values. Additionally, Polypodiaceae undiff. have a low presence. Compared to S11, *Picea*, Cyperaceae, *Filipendula*, *Lysimachia vulgaris*-type, *Ranunculus*-type, and Polypodiaceae undiff. have increased while *Pinus*, *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, *Corylus*, *Potentilla*-type, and *Artemisia* have decreased.	Carr peat started to accumulate when the lake had become completely overgrown. The tree cover was probably rather scant as several herb pollen types have high values. Some *Alnus* and *Picea* individuals may have grown at the site. Some parts of the site probably had an open fen vegetation dominated by sedges, *Filipendula*, *Lysimachia vulgaris*, and *Ranunculus*.	Dense forest dominated by *Corylus*, *Picea*, and *Ulmus*, but *Quercus* was also common. Decrease of *Tilia*, *Fraxinus*, and *Acer*.
S13, *Corylus–Picea–Ulmus–Filipendula* LPAZ				
2.50–1.89	8200–7500	Characterised by very high pollen percentages for *Corylus* (30–45%) and *Picea* (20–55%), fairly high percentages for *Quercus*, *Ulmus*, Cyperaceae (topmost samples), and *Filipendula*, as well as low but significant values for *Pinus*, *Alnus*, *Tilia*, *Fraxinus*, and Poaceae undiff. <40 µm. Among other pollen types, *Betula*, *Typha angustifolia*-type, *Lysimachia vulgaris*-type, and *Artemisia* occur regularly, but with low values. Conspicuous is also the presence of single or scattered pollen grains of *Acer*, *Carpinus*-type, *Fagus* (has an isolated peak value of around 5%), and *Cannabis*-type. Additionally, Polypodiaceae undiff. have comparatively high values. Compared to S12, *Pinus*, *Quercus*, *Tilia*, *Fraxinus*, *Fagus*, *Picea*, *Typha angustifolia*-type, and Polypodiaceae undiff. have increased, while *Ulmus*, Poaceae undiff. <40 µm, Cyperaceae, *Lysimachia vulgaris*-type, and *Ranunculus*-type have decreased.	Carr peat was deposited at the site, which had a denser tree cover than previously. Apparently, *Picea* was the dominant tree at the site. Some parts of the site probably had open fen vegetation dominated by sedges, *Filipendula* and *Lysimachia vulgaris*. Pteridophytes also seem to have been common on the site.	Dense forest dominated by *Corylus*, *Picea*, and *Ulmus*, but *Quercus*, *Tilia*, *Fraxinus*, and *Acer* probably also occurred in the area. Local expansion of *Picea*. *Fagus* failed to become established locally.
S14, *Corylus–Picea–Ulmus–Quercus* LPAZ				
1.89–1.41	7500–4800	Characterised by very high pollen percentages for *Corylus* (25–45%) and *Picea* (20–35%), fairly high percentages for *Alnus*, *Quercus*, *Ulmus*, Poaceae undiff. <40 µm (topmost samples), and Cyperaceae, and low but significant values for *Betula*, *Pinus*, Asteraceae Liguliflorae, and *Filipendula*. Conspicuous is also the presence of scattered pollen grains of *Acer*, *Fagus*, and *Artemisia*. Additionally, Polypodiaceae undiff., *Pteridium aquilinum*, *Equisetum*, and *Sphagnum* occur with relatively high values. Compared to S13, *Alnus*, *Quercus*, Poaceae undiff. <40 µm, Asteraceae Liguliflorae, Polypodiaceae undiff., and *Equisetum* have increased, while *Picea*, *Filipendula*, and *Lysimachia vulgaris*-type have decreased. The total pollen concentration is exceptionally low and hardly reaches above 50 000 grains/cm^3 in the samples.	Carr peat was deposited at the site, which probably had a tree cover dominated by *Picea*, but some *Alnus* individuals probably also occurred. In the field layer pteridophytes were common. A minor part of the site may have had an open fen vegetation with grass, sedges, *Filipendula*, and *Equisetum*. The low pollen concentration may imply a higher rate of peat accumulation.	Dense forest dominated by *Corylus*, *Picea*, *Ulmus*, and *Quercus*. *Tilia*, *Fraxinus*, and *Acer* probably also occurred in the area.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S15, *Corylus–Picea–Fagus* LPAZ				
1.41–1.11	4800–3400	Characterised by high pollen percentages for *Corylus* (20–30%) and *Picea*, fairly high percentages for *Alnus*, *Quercus*, *Ulmus*, *Carpinus* (5–15%), and *Fagus* (5–20%), and low but significant values for *Betula*, *Tilia*, *Fraxinus*, Poaceae undiff. < 40 µm, and *Filipendula*. Among other pollen types, *Pinus*, *Acer*, Cyperaceae, Apiaceae, Asteraceae Liguliflorae, Rosaceae undiff., and *Artemisia* occur regularly, but with low values. Conspicuous is also the regular presence of scattered pollen grains of *Hedera helix*, Ranunculaceae undiff., and *Anemone nemorosa*. Additionally, Polypodiaceae undiff. have high values. Compared to S14, *Betula*, *Acer*, *Carpinus*-type, *Fagus*, Asteraceae Liguliflorae, *Filipendula*, and Rosaceae undiff. have increased while *Pinus*, *Fraxinus*, *Picea*, *Corylus*, Poaceae undiff. < 40 µm, and Cyperaceae have decreased. The total pollen concentration is remarkably high, reaching above 500 000 grains/cm^3 in most samples.	Initially, carr peat was deposited, but later fen peat started to accumulate. The accumulation of fen peat may have been rather slow in the beginning as the pollen concentration is very high. However, it is also possible that the fen peat has been highly decomposed due to drier conditions. The tree cover may have been rather dense when carr peat was deposited, but later the site became more open. The tree cover may have been dominated by *Picea*, but some *Alnus* and *Betula* individuals probably also occurred. Some parts of the site may have had an open vegetation dominated by *Filipendula*, Apiaceae and Asteraceae Liguliflorae.	Dense forest dominated by *Corylus*, *Picea*, *Ulmus*, *Quercus*, *Tilia*, *Acer*, *Carpinus*, and *Fagus*. Local establishment of *Carpinus* and *Fagus*.
S16, *Fagus–Picea–Carpinus* LPAZ				
1.11–0.73	3400–2200	Characterised by very high pollen percentages for *Fagus* (30–50%), fairly high percentages for *Alnus*, *Quercus*, *Ulmus*, *Carpinus*-type, *Picea* (has high values only in bottom samples), *Corylus*, and Cyperaceae, as well as low but significant values for *Betula*, *Pinus*, Poaceae undiff. < 40 µm, *Filipendula* (only in bottom samples), and *Lysimachia vulgaris*-type. Among other pollen types, *Tilia*, *Fraxinus*, *Salix*, and *Artemisia* occur regularly, but with low values. Additionally, Polypodiaceae undiff. have high values. Compared to S15, *Pinus*, *Alnus*, *Fagus*, Cyperaceae, and *Lysimachia vulgaris*-type have increased while *Ulmus*, *Tilia*, *Fraxinus*, *Acer*, *Picea*, *Corylus*, Apiaceae, Asteraceae Liguliflorae, *Filipendula*, and Rosaceae undiff. have decreased. The total pollen concentration has decreased to values around 200 000 grains/cm^3 in most samples.	Fen peat was deposited at the site, which now had become dominated by open fen communities, particularly by sedges. Pteridophytes were probably also common. Some scattered *Alnus* and *Picea* individuals may have occurred on the peat land.	Dense forest dominated by *Fagus*. *Quercus*, *Ulmus*, *Carpinus*, *Picea*, and *Corylus* also occurred but they were less common. Marked expansion of *Fagus*. Local decreases of *Picea* and *Corylus*. *Tilia* and *Fraxinus* may have disappeared from the local forests.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S17, *Fagus*–Poaceae–*Carpinus* LPAZ				
0.73–0.39	2200–1050	Characterised by very high pollen percentages for *Fagus* (55–75%), fairly high percentages for *Alnus*, *Quercus*, *Carpinus*, and Poaceae undiff. <40 μm, and low but significant values for *Betula*, *Ulmus*, *Picea*, *Corylus*, and Cyperaceae. Among other pollen types, *Pinus*, *Galium*-type, and *Artemisia* occur regularly, but with very low values. Conspicuous is also the presence of scattered pollen grains of *Tilia*, *Fraxinus*, *Acer*, and *Abies*. Additionally, Polypodiaceae undiff. have low values, while *Sphagnum* has relatively high values in the bottom part. Compared to S16, *Fagus*, Poaceae undiff. <40 μm, *Galium*-type, and *Artemisia* have increased while *Pinus*, *Alnus*, *Quercus*, *Ulmus*, *Carpinus*, *Picea*, *Corylus*, *Lysimachia vulgaris*-type, and Polypodiaceae undiff. have decreased.	Fen peat was deposited at the site, which was dominated by open fen vegetation, particularly by grasses, sedges, and *Galium*.	Dense forest dominated by *Fagus*. *Quercus* and *Carpinus* also occurred but they were less common. *Ulmus*, *Picea*, and *Corylus* disappear from the local forests.
S18, *Fagus*–*Quercus*–*Carpinus* LPAZ				
0.39–0.14	1050–300	Characterised by very high pollen percentages for *Fagus* (65–75%), fairly high percentages for *Alnus*, *Quercus*, *Carpinus*-type, Poaceae undiff. <40 μm, and Cyperaceae (bottom sample), and low but significant values for *Betula*, *Corylus*, and *Potentilla*-type. Among other pollen types, *Pinus*, *Ulmus*, *Picea*, Apiaceae, *Filipendula*, and *Artemisia* occur regularly, but with very low values. Conspicuous is also the presence of scattered pollen grains of *Tilia*, *Fraxinus*, *Acer*, *Salix*, Rosaceae undiff., and *Plantago lanceolata*. Additionally, *Sphagnum* has relatively high values in the bottom samples, while Polypodiaceae undiff. have low values. Compared to S17, *Fagus*, Apiaceae, *Filipendula*, *Potentilla*-type, and *Plantago lanceolata* have increased while *Quercus*, *Ulmus*, *Picea*, *Corylus*, and Poaceae undiff. <40 μm have decreased. The total pollen concentration has increased to values above 300 000 grains/cm^3 in most samples.	Fen peat was deposited at the site, which was dominated by open fen vegetation, particularly by grasses, sedges, Apiaceae, *Filipendula*, and *Potentilla*.	Dense forest dominated by *Fagus*. Some *Quercus* and *Carpinus* individuals probably also occurred locally. Forest grazing may have been introduced in the area.

Table 3 (*Continued*).

Depth (m)	Age (cal yr BP)	Description	Inferred on-site vegetation and site development	Inferred local upland vegetation
S19, *Fagus*–Poaceae–*Quercus* LPAZ				
0.14–0.005	300–present time	Characterised by very high pollen percentages for *Fagus* (60–75%), fairly high percentages for *Alnus*, *Quercus*, Poaceae undiff. <40 µm, and *Potentilla*-type, and low but significant values for *Betula*, *Corylus*, and Cyperaceae. Among other pollen types, *Pinus*, *Carpinus*, *Artemisia*, *Cannabis*-type, and *Plantago lanceolata* occur regularly, but with low values. Conspicuous is also the presence of single or scattered pollen grains of *Acer*, *Juglans*-type, *Calluna*, Poaceae undiff. >40 µm, *Hordeum*-group, *Secale*, *Centaurea cyanus*-type, Chenopodiaceae, *Plantago major*/*P. media*, and *Rumex acetosa*/*R. acetosella*. Additionally, Polypodiaceae undiff. have relatively high values. Compared to S18, *Corylus*, Poaceae undiff. <40 µm, *Potentilla*-type, *Cannabis*-type, *Plantago lanceolata*, *Rumex acetosa*/*R. media*, and *Rumes acetosa*/*R. acetosella*. Additionally, Polypodiaceae undiff. have relatively high values. Compared to S18, *Corylus*, Poaceae undiff. <40 µm, *Potentilla*-type, *Cannabis*-type, *Plantago lanceolata*, *Rumes acetosa*/*R. acetosella*, and Polypodiaceae undiff. have increased while *Ulmus*, *Carpinus*-type, Apiaceae, and *Filipendula* have decreased.	Fen peat was deposited at the site, which was dominated by open fen vegetation, particularly by grasses, sedges, Apiaceae, and *Potentilla*.	Rather open forest dominated by *Fagus*. Some *Quercus* individuals probably also occurred locally. *Carpinus* had disappeared from the local forests. The grazing pressure in the forests had increased. Some arable fields were established at lower altitudes in the area, where *Secale*, *Hordeum*, and *Cannabis sativa* were grown.

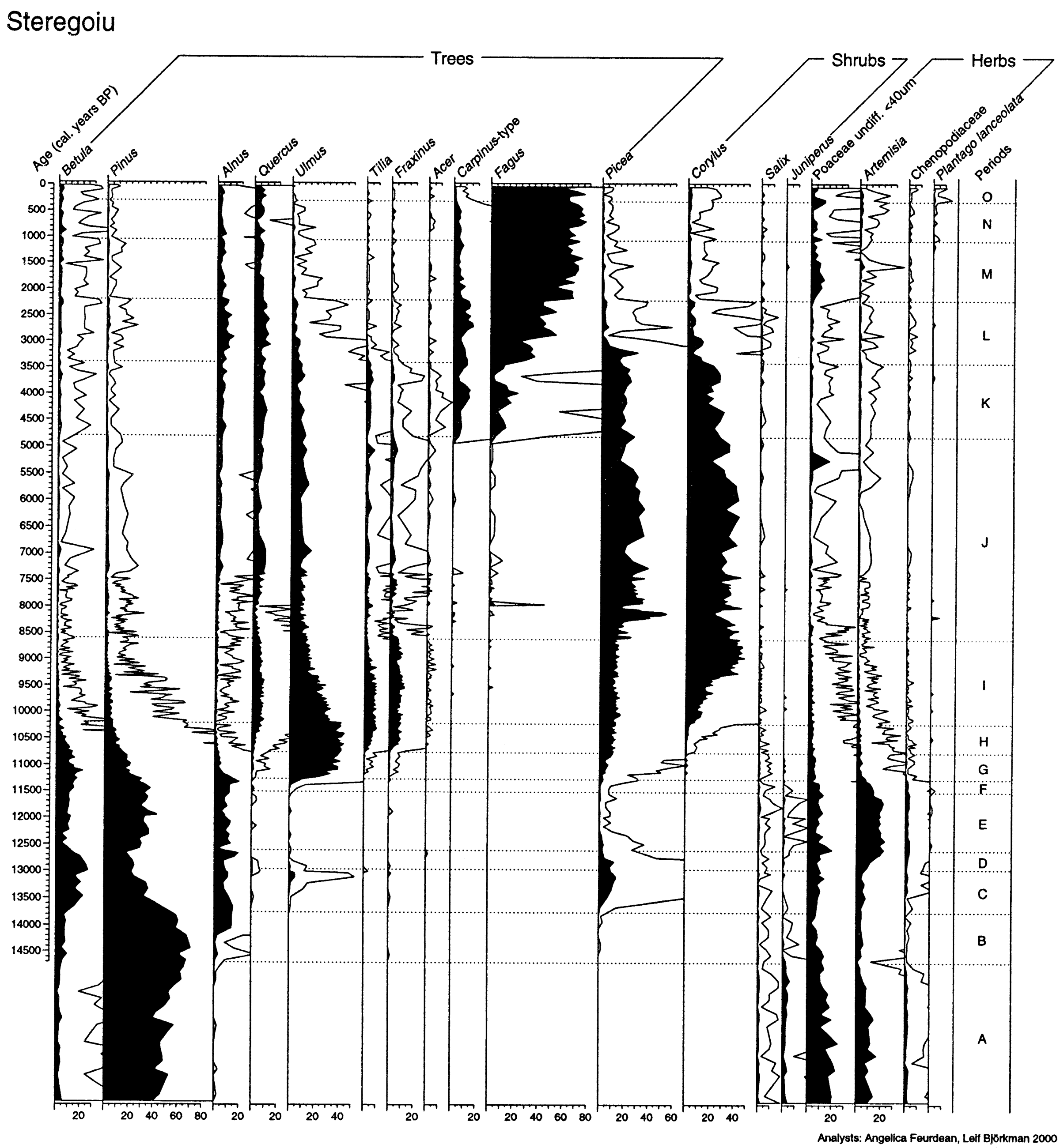

Fig. 5. Percentage pollen diagram from the site Steregoiu showing selected tree, shrub and herb pollen taxa on a linear timescale. The time periods A–O represent a summary of the vegetational development reconstructed from the pollen data and are discussed in the text (Fig. 4; Table 3).

4.3.5. (E) 12 600–11 500 cal yr BP (S6): open patchy vegetation consisting of a mosaic of shrubs, herbs, and ungrown grounds

The local vegetation may be characterised as a mosaic with areas dominated by low shrubs, e.g. *Salix* and *Juniperus* (and possibly also *Betula*), and patches dominated by grasses and herbs, e.g. *Artemisia*, Chenopodiaceae, and *Helianthemum*, and several species of Asteraceae, Caryophyllaceae, and Ranunculaceae. Areas with more or less ungrown grounds probably were also present in the region, particularly at higher altitudes. The percentages for *Betula* and *Pinus* are comparably high and suggest that these trees occurred regionally, but that they were not forming a tree cover near the site. Instead, they may have formed more or less dense stands in valleys with a favourable microclimate (Björkman et al., 2002). *Picea* has low but significant values throughout the period, which may indicate that it, too, was present regionally, but probably only at favourable sites. *Alnus* probably occurred in the local carr vegetation close to the site.

4.3.6. (F) 11 500–11 250 cal yr BP (S7): open Betula–Pinus *forest; establishment of* Ulmus *and* Picea

The beginning of this time period is characterised by an expansion of *Betula* and *Alnus* while herb pollen values decrease. Initially, *Betula* probably dominated the rather open forest, which also may have had some *Pinus*. *Ulmus* may not have occurred in local stands at the very beginning of the period, but seems to have become established rather early. It quickly expanded and replaced *Betula* as the dominant tree at the end of this time interval. At about the same time, *Picea* seems to have become established and also started to expand. The upland forest near the site had initially probably a rather open structure, which is suggested by the seemingly high percentages for herb pollen types, mainly Poaceae undiff. < 40 µm, *Artemisia* and Chenopodiaceae. However, this open structure diminished rapidly when *Betula* and *Ulmus* started to expand and areas with open vegetation became most likely restricted to higher altitudes.

4.3.7. (G) 11 250–10 750 cal yr BP (S8): dense forest dominated by Ulmus, Betula, *and* Picea*; establishment of* Quercus, Tilia, *and* Fraxinus

Dense forests dominated by *Ulmus*, but also with abundant *Betula*, *Picea*, and *Pinus*, become widespread now. Broad-leaved trees, e.g. *Quercus*, *Tilia*, and *Fraxinus*, possibly had become established regionally, but probably they did not yet occur in stands close to the site. *Ulmus* and *Picea* seem to expand significantly in the local, as well as regional forest stands. The local forest most likely had a dense structure, as herb pollen types generally have low values. The field layer in the forests may have been dominated by pteridophytes, as Polypodiaceae undiff. occur with comparably high values. The occurrence of pollen grains of *Cannabis*-type may suggest that *Humulus* was present in the area. The presence of *Juniperus* pollen and the significant values for Poaceae undiff. < 40 µm and *Artemisia* probably indicate that some areas with open vegetation still occurred in the region, most likely at higher altitudes.

4.3.8. (H) 10 750–10 200 cal yr BP (S9): dense mixed forest dominated by Ulmus, Picea, Quercus, Tilia, *and* Fraxinus*; establishment of* Corylus

The forest surrounding the site was of a dense, mixed type dominated by *Ulmus*, *Picea*, *Quercus*, *Tilia*, and *Fraxinus*. The presence of *Acer* pollen grains in low numbers suggests that *Acer* also had become established locally. *Betula* and *Pinus* were now rather rare in the regional forests, and likely absent from the local stand. A low presence of *Corylus* pollen suggests that it had started to expand regionally, but was probably not present locally until the latter part of the period. *Quercus*, *Tilia* and *Fraxinus* seem to have expanded significantly, locally as well as regionally. The field layer in the forests may have been dominated by pteridophytes, as Polypodiaceae undiff. occur with fairly high values. The low, but significant values for Poaceae undiff. < 40 µm and *Artemisia* probably indicate that some areas with open vegetation occurred in the region, but most likely rather far from the cored site.

4.3.9. (I) 10 200–8600 cal yr BP (S10, S11): dense mixed forest dominated by Ulmus, Corylus, Picea, Quercus, Tilia, Fraxinus, *and* Acer

The forest close to the site was dominated by *Ulmus*, *Corylus*, and *Picea*, but *Quercus*, *Tilia*, and *Fraxinus* were probably also abundant. The regular presence of *Acer* pollen suggests that *Acer* was common locally. *Betula* and *Pinus* were rare in the regional forests, and likely absent from the local stand. An important change in composition of the vegetation is indicated by the gradually increasing values for *Corylus* and the gradually decreasing ones for *Ulmus*, which implies an expansion of *Corylus* at the expense of *Ulmus*. Other trees seem to have had quite stable populations during the period. The forest most likely had a dense structure, as herb pollen types have low values and the field layer may have been dominated by pteridophyts. The low values for Poaceae undiff. < 40 μm and *Artemisia* show that some areas with open vegetation occurred, but most likely far from the site.

4.3.10. (J) 8600–4800 cal yr BP (S12, S13, S14): dense Picea–Corylus *forest with some* Ulmus, Quercus, *and* Tilia

The dense forest in the area was dominated by *Corylus* and *Picea*. *Ulmus*, *Quercus*, and *Tilia* probably also occurred, but were less common. There were probably fewer areas with open vegetation in the region, except for locally on the wetlands and higher elevated grounds. Locally, *Picea* seems to have expanded around 8600 cal yr BP, while *Fraxinus*, *Quercus*, and *Acer* diminished. The seemingly major expansion of *Picea* may have been caused by its establishment in the local carr vegetation at the site, which at the beginning of the period had become completely overgrown. Around 7900 cal yr BP *Fagus* appears to have become established locally, as it shows rather high pollen percentages in a few consecutive samples, but it seems to have failed to expand further as it soon disappears. It may, however, have become established in the regional forests, since scattered *Fagus* pollen grains occur regularly throughout the stratigraphic interval.

4.3.11. (K) 4800–3400 cal yr BP (S15): dense mixed Picea–Corylus–Fagus–Carpinus *forest with some* Quercus, Ulmus, Tilia, *and* Acer*; establishment and expansion of* Fagus *and* Carpinus

At the beginning of this period *Fagus* and *Carpinus* became established in the local stand. They expanded rapidly and were soon important forest constituents. The forest seems to have been of a dense and highly mixed type, with mainly *Fagus* and *Carpinus*, *Picea*, and *Corylus*, although *Quercus*, *Ulmus*, *Tilia*, and *Acer* were also common. In the local stand *Hedera helix* became probably also established.

4.3.12. (L) 3400–2200 cal yr BP (S16): dense Fagus–Carpinus–Quercus *forest with some* Corylus, Picea, *and* Ulmus

During this period *Fagus* expanded, at the same time as *Ulmus*, *Tilia*, *Acer*, *Picea*, and *Corylus* diminished. The result of these changes was a forest type dominated by *Fagus*, although *Carpinus* and *Quercus* were probably still important components. Some *Ulmus*, *Picea*, and *Corylus* individuals remained in the area, but were not important in the local stand. The forest was probably dense, as is indicated by the rather low values for herb pollen types. Most likely there were fewer areas with open vegetation in the region, except for wetlands. By this time the studied site, for instance, had evolved into an open fen, dominated by sedges.

4.3.13. (M) 2200–1050 cal yr BP (S17): dense Fagus *forest with some* Quercus *and* Carpinus

A dense forest dominated by *Fagus* became widespread in the area. *Quercus* and *Carpinus* also occurred, but were less common. *Ulmus*, *Picea* and *Corylus* seem to have disappeared from the local stand at the beginning of the period. Poaceae undiff. < 40 μm is showing comparatively high values, which could be interpreted as indicating rather open vegetation in the area. However, these high values are not followed by increases for other herbs, except for some wetland taxa, which means that the grasses most likely were dominant only at the studied site.

4.3.14. (N) 1050–300 cal yr BP (S18): rather dense Fagus *forest with some* Quercus *and* Carpinus*; introduction of forest grazing*

The forest in the area during this period was dominated by *Fagus*, but some *Quercus* and *Carpinus* individuals also occurred. Most other tree species were absent from the area. The forest probably had a slightly more open structure than previously due to the introduction of forest grazing in the area. This is possibly indicated by the regular presence of scattered pollen grains of *Plantago lanceolata*.

4.3.15. (O) 300 cal yr BP to present (S19): rather dense Fagus *forest with some* Quercus*; regular use of the area for forest grazing, some arable fields at lower altitudes*

The forest in the area during the past 300 years can be characterised as a rather dense type dominated by *Fagus*, but with some *Quercus* individuals. There were only few other tree species present in the area during this period. *Carpinus* had probably disappeared from the local forest. There is strong evidence for regular use of the area for forest grazing, which is shown by the particularly high values for *Plantago lanceolata*. This rise in grazing pressure is probably also indicated by the high values for Poaceae undiff. < 40 μm, but these pollen grains may as well have originated from the local wetland. Several human impact indicators are present in the pollen data, indicating arable fields and fallow land (e.g. *Hordeum*-group, *Secale*, *Cannabis*-type, *Centaurea cyanus*-type, *Rumex acetosa*/*R. acetosella*). However, the values for these indicators are relatively low, which may indicate that these fields were not located close to the site. No traces of arable fields are found near the site, but fields are numerous in the Talna valley below 400 m a.s.l. Thus, an expansion of agriculture in the Talna Valley may have started around 300 cal yr BP.

5. Discussion

5.1. Pinus

The most abundant pollen type at the bottom of the profile is *Pinus* (Figs. 4A and 5). Until the beginning of period H (10 750 cal yr BP) its percentages never fall below 15%. They decrease rapidly from then on, and from about 9000 cal yr BP until present *Pinus* never reaches percentages higher than 3%. The pollen data clearly indicate that *Pinus* was an important forest constituent in the area only during the Late-Glacial and the earliest part of the Holocene.

During period A ($> 14\,700$ cal yr BP) *Pinus* shows very high percentages (40–65%), but these values are difficult to interpret. Total pollen concentration is generally low and the other pollen types are indicative of an open patchy vegetation. Thus, the high values for *Pinus* may be an effect of long-distance transport, which becomes significantly more pronounced in an environment with a sparse vegetation cover. During the last part of the Full Glacial, which roughly corresponds to period A (Björkman et al., 2002), *Pinus* was an abundant tree in the lowlands west of the study area, particularly on the Hungarian Plain (Willis et al., 1995, 2000; Rudner and Sümegi, 2001). These widespread forests may have been the source for the *Pinus* pollen deposited at Steregoiu before 14 700 cal yr BP. However, *Pinus* may have grown closer to the site as well, i.e. in nearby valleys where favourable microclimatic conditions may have prevailed. The presence of *Pinus* at lower altitudes in the Gutaiului Mountains may explain the rapid expansion of the species at about 14 700 cal yr BP, when total pollen concentration increased and *Pinus* pollen percentages reached values between 60 and 70%. That *Pinus* really did expand in the area at this time is corroborated also by the occurrence of macrofossils at a nearby site, Preluca Tiganului (Wohlfarth et al., 2001). The expansion of *Pinus* and the establishment of an open forest type occurred at the same time as organic-rich sediments started to accumulate. This probably correlates with the beginning of the first deglacial warming phase (GI-1e) in the GRIP ice core event stratigraphy (Björck et al., 1998; Walker et al., 1999; see also Björkman et al., 2002).

Around 13 750 cal yr BP the *Pinus* percentages drop markedly, and around 12 700 cal yr BP a minimum value close to 20% is reached. This gradual decrease of *Pinus* is followed by an expansion of several other tree pollen types. During this period the open forest was dominated by *Picea* and *Betula*. *Pinus* was probably also common, although its pollen values are lower than during previous periods. The influence of long-distance transport of *Pinus* pollen may have decreased when the forest structure became denser. This development strongly indicates warmer climatic conditions, particularly during period C (13 750–12 950 cal yr BP), which most likely corresponds to the Allerød, or GI-1c–GI-1a in the GRIP event stratigraphy (Björck et al., 1998; Walker et al., 1999).

During period E (12 600–11 500 cal yr BP) the *Pinus* percentages increase again (up to 30–40%). The re-expansion of *Pinus* is followed by higher values for many herbaceous pollen types, and lower values for *Betula* and *Picea*. This development points towards the re-establishment of an open patchy vegetation and colder climatic conditions. These changes may correspond to the Younger Dryas or GS-1 in the GRIP event stratigraphy. The climatic conditions during this period seem, however, not to have been as severe as before > 14 700 cal yr BP, because several tree species still have comparatively high pollen values. This may indicate that these trees, and probably also *Pinus*, retreated into more favourable sites at lower altitudes.

At around 11 500 cal yr BP *Pinus*, *Betula*, and *Alnus* expanded and several herbaceous pollen types occur in lower proportions. These changes coincide with the beginning of the Holocene and the rapid replacement of open vegetation with forest communities. *Pinus* probably was rather widespread in the stands during the earliest phase of the Holocene, but later, when the woodlands became denser as a result of the expansion of *Ulmus* and *Picea* during period G (11 250–10 750 cal yr BP), *Pinus* became less abundant. The dense forest type prevailing during the Early Holocene probably prevented a regeneration of *Pinus*. From period I (10 200–8600 cal yr BP) onwards, *Pinus* has had a very restricted occurrence in the area, and probably was absent from the local forest stand.

5.2. Betula

Betula is an abundant species only at the bottom of the profile (Figs. 4A and 5). It reaches percentages above 15% only during two phases: the first during periods C and D (13 750–12 600 cal yr BP), and the second during periods F and G (11 500–10 750 cal yr BP). Values above 5–7% are reached during periods B (14 700–13 750 cal yr BP), E and F (12 600–11 250 cal yr BP), as well as H (10 750–10 200 cal yr BP). Around 10 000 cal yr BP its percentages decline below 3%, and higher values are seldom reached until the present time.

During period A (> 14 700 cal yr BP) the values for *Betula* are around 5%. The pollen assemblages for this period indicate an open patchy vegetation with shrubs, herbs, and ungrown grounds. *Betula* shrubs may have been present during this period, which is believed to correlate to the Full Glacial (Björkman et al., 2002). At the beginning of period B (14 700 cal yr BP) the *Betula* percentages increase to 8–10%, which may indicate a local expansion of the species. This expansion coincides with an increase of *Pinus* and the development of an open *Pinus–Betula* forest. This expansion most likely corresponds to the first deglacial warming phase (GI-1e) documented in the GRIP ice core stratigraphy (Björck et al., 1998; Walker et al., 1999). The rapid response of *Betula* to this climatic amelioration may indicate that it had been present in glacial refugia in the area, most likely located at a lower altitude than the site.

An expansion of *Betula* is registered at the beginning of period C (13 750 cal yr BP). At this time an open forest with *Betula*, *Pinus*, and *Picea* was becoming established in response to the warmer climatic conditions (Allerød, or GI-1c–GI-1a in the GRIP event stratigraphy). During period D (12 950–12 600 cal yr BP), the *Betula* values decrease rapidly in response to the colder conditions, which can be correlated to the onset of the Younger Dryas, or GS-1 in the GRIP event stratigraphy. At this time an open patchy vegetation became re-established in the area. However, the percentages for *Betula* remain between 7 and 13% during period E (12 600–11 500 cal yr BP), which probably indicates that *Betula* still occurred in the area, perhaps around the lake, or that it was rather abundant in valleys at lower altitudes.

Around 11 500 cal yr BP *Betula*, *Pinus*, and *Alnus* expanded and, according to the pollen diagram, many herbaceous species decreased in abundance. This change in vegetational type coincides with the climatic warming at the beginning of the Holocene. *Betula* was common in the stands during the earliest phase of the Holocene, but later, when *Quercus*, *Tilia*, and *Fraxinus* expanded during period H (10 750–10 200 cal yr BP), *Betula* diminished. From period I (10 200–8600 cal yr BP) to the present time, it has had a very restricted occurrence in the area.

5.3. Ulmus

The most abundant pollen type in the middle part of the profile is *Ulmus* (Figs. 4A and 5). During periods G and H (11 250–10 200 cal yr BP) *Ulmus* represents around 30–45% of the assemblages. During period I (10 200–8600 cal yr BP) *Ulmus* decreases in proportion, from about 30% at the beginning to 15% at the top. *Ulmus* is well represented in the profile until the end of period L (2200 cal yr BP). From this point to the present it was probably more or less absent from the area. *Ulmus* was also significant (1–5%) during a short phase at the end of period C (13 750–12 950 cal yr BP).

The first local establishment of *Ulmus* appears to have taken place around 13 200 cal yr BP during the latter part of period C (13 750–12 950 cal yr BP). In this episode an open forest dominated by *Betula*, *Pinus*, and *Picea* expanded in the area in response to the warmer climatic conditions during the Allerød, or GI-1c–GI-1a in the GRIP event stratigraphy (Björck et al., 1998; Walker et al., 1999). The late arrival of *Ulmus* during this phase may indicate that it had been present in refugia, which were located not too far from the area. These refugia may have occurred in Northwest Romania, or on the Hungarian Plain. Macroscopic remains of several tree genera including *Pinus*, *Picea*, *Larix*, *Betula*, and *Carpinus* have been found in Full Glacial deposits in Hungary (Willis et al., 2000), but the existence of *Ulmus* has not yet been confirmed. However, *Ulmus* is represented by low pollen values at several Hungarian sites covering the Late-Glacial, for instance at Bátorliget and Sárrétt in westernmost and central Hungary (Willis et al., 1995, 2000). These values may indicate that *Ulmus* also occurred at Full Glacial refugia on the Hungarian Plain.

During period D (12 950–12 600 cal yr BP) the *Ulmus* percentages in the pollen diagram drop to almost zero, and until period F (11 500–11 250 cal yr BP) only scattered pollen grains are found. The decline of *Ulmus* coincides with the re-expansion of open vegetational communities and can be correlated to the onset of the colder conditions during the Younger Dryas, or GS-1 in the GRIP event stratigraphy. Most likely, the local *Ulmus* population was extirpated during this period.

A re-establishment of *Ulmus* occurred during period F (11 500–11 250 cal yr BP). However, its establishment and expansion did occur somewhat later than *Betula*, *Pinus*, and *Alnus*, which apparently responded immediately to the rapid warming at the beginning of the Holocene. *Ulmus* expanded during the latter part of period F, which means that its appearance at the site was delayed by ca. 150–200 years when compared to *Betula*, *Alnus*, and *Pinus*. Thus, *Ulmus* had to re-invade the site from refugia located somewhere in the region, but obviously these refugia cannot have been situated too far from the area. We speculate that *Ulmus* survived the Younger Dryas period in refugia in Romania. An early expansion of *Ulmus* during the Holocene is also shown at other recently investigated sites in Romania (Farcas et al., 1999).

Until 10 200 cal yr BP *Ulmus* appears to have been the local forest dominant, but from then to the present time its dominance was seemingly broken. *Corylus* became locally established around 10 500 cal yr BP and seems to have expanded much at the expense of *Ulmus*. During period I (10 200–8600 cal yr BP) *Ulmus* gradually declined at the same time as *Corylus* expanded. Other tree pollen types show more or less constant values during this period, which may indicate that *Ulmus* became less important in the local stand throughout the period. However, *Ulmus* seems to have been an important forest constituent in the area until at least period L (3400–2200 cal yr BP), and appears to have decreased at about the same time as *Fagus* started to expand. Thus, the local disappearance of *Ulmus* is probably connected to the expansion of *Fagus*, which may have out-competed *Ulmus* within the local forest stand.

5.4. *Picea*

Picea and *Corylus* are the two dominant pollen types in the middle part of the profile (Figs. 4A and 5), but the abundance of *Picea* starts somewhat earlier than that of *Corylus* and, in addition, *Picea* is represented by high values during a short phase in the lower part of the profile. *Picea* is well represented during periods C and D (13 750–12 600 cal yr BP), where values of around 10–15% are reached. It was also important during an extended phase from the beginning of period G (11 250 cal yr BP) up to around 3000 cal yr BP in period L. Maximum values of more than 30% are reached during period J (8600–4800 cal yr BP).

The first local establishment of *Picea* occurred during an early phase of period C (13 800–12 950 cal yr BP). In this period an open forest with *Betula* and *Pinus* expanded in response to the warmer climatic conditions in the Allerød, or GI-1c–GI-1a in the GRIP event stratigraphy (Björck et al., 1998; Walker et al., 1999). That *Picea* really did expand in the area at this time is confirmed by the presence of macrofossils at a nearby site, Preluca Tiganului (Wohlfarth et al., 2001). The early date for the expansion of *Picea* strongly suggests that it had been present in refugia located not too distant from the study area. Otherwise, it would have responded much later, as, for instance, *Ulmus* did. *Picea* is known to have occurred in Hungary during the Full Glacial (Willis et al., 2000; Rudner and Sümegi, 2001), and this area may have acted as a refugium from where *Picea* could expand its range into Romania when climatic conditions improved during the warmer phases of the Late-Glacial.

In period D (12–950–12–600 cal yr BP) the pollen values of *Picea* decreased, which continued during the earliest phase of period E (12 600–11 500 cal yr BP). During this phase the local woodland disappeared and open vegetation became re-established in response to the harsher climatic conditions during the Younger Dryas, or GS-1 in the GRIP event stratigraphy. However, the percentages for *Picea* do not drop to values close to zero; instead, these low values may indicate a restricted occurrence of the species in the region at favourable sites in valleys at lower altitudes.

A re-expansion of *Picea* did not occur until the earliest part of the Holocene. It appears to have become locally re-established around the beginning of period G (11 250 cal yr BP). For some time, *Picea* had a rather restricted occurrence in the area, but from about the beginning of period H (10 750 cal yr BP), it became an important forest constituent. From the time when the site became overgrown by carr vegetation at ca. 8600 cal yr BP until that when carr peat accumulation ceased, *Picea* probably also was an important tree in the carr forest at the site. This local dominance may explain partly its high pollen values during period J (8600–4800 cal yr BP). However, *Picea* remained a dominant species locally until about 3000 cal yr BP when it appears to have diminished rapidly at the same time as *Fagus* seems to have expanded. Thus, *Picea* appears to have been replaced by *Fagus*. During the last ca. 3000 years *Picea* probably had a rather restricted presence in the local forest. At present some small *Picea* stands are to be found in close vicinity to the site, but *Picea* is not recorded in the uppermost pollen samples, which may point to a quite recent origin of the present trees.

5.5. *Quercus*, *Tilia*, *Fraxinus*, and *Acer*

The broad-leaved trees *Quercus*, *Tilia*, and *Fraxinus* are important forest constituents in the middle part of the profile (Figs. 4A and 5). Individually, their pollen percentages reach around 10% at most, but together they make up around 25–30% of the pollen sum during periods H and I (10 750–8600 cal yr BP). This certainly implies that they were important in the local stand during phases of the Early Holocene. After 8600 cal yr BP *Tilia* and *Fraxinus* decreased significantly, and at the end of period K (3400 cal yr BP) they seem to have almost disappeared from the area. In contrast, *Quercus* appears to have been nearly as abundant until the present as during the Early Holocene.

Another broad-leaved tree-pollen type in the diagram is *Acer*, but this is difficult to interpret as it only occurs in low percentages. *Acer* is an insect pollinated species which is rarely represented with high values in pollen diagrams. A regular occurrence of scattered *Acer* pollen grains normally can be indicative of a local presence of the species. *Acer* pollen grains are found more or less regularly throughout the profile starting at about 10 400 cal yr BP. It is well represented, particularly during periods I (10 200–8600 cal yr BP) and K (4800–3400 cal yr BP), which implies that it was important in the forest at least during these periods.

A regional expansion of *Quercus*, *Tilia*, and *Fraxinus* probably started during period G (11,250–10,750 cal yr BP). During this period their presence increased from single pollen grains up to values of around 1%. The local establishment most likely occurred around the beginning of period H (10 750 cal yr BP) when their percentages started to increase to values around 5%. The late expansion of these trees, compared to *Ulmus* and *Picea* which expanded locally nearly 500 years earlier, must indicate that *Quercus*, *Tilia*, and *Fraxinus* did not occur in local refugia during the Late-Glacial. They seem, instead, to have immigrated into the area from refugia located further away. The timing of their establishment at Steregoiu is in accordance with other recent studies in Romania (e.g. Farcas et al., 1999), but these trees occurred slightly later in the Carpathian Mountains of Poland, at around 10 400 cal yr BP (Ralska-Jasiewiczowa and Latalowa, 1996). However, at Bátorliget on the Hungarian Plain west of the study area, their establishment appears to have occurred at around 11 500 cal yr BP, at the beginning of the Holocene (Willis et al., 1995, 2000). Taken together, these data sets indicate that their refugia cannot have been situated very far from the study area, otherwise the expansion would have occurred much later. Most likely, these refugia were located in the southern part of Romania, or on the Hungarian Plain.

The decline of *Tilia* started around 9000 cal yr BP, apparently at about the same time when *Corylus* increased and reached maximum values. The decline of *Fraxinus* occurred somewhat later, i.e. at the beginning of period J (8600 cal yr BP), and appears to have been more abrupt than the decline of *Tilia*, which was more gradual. At the same time that *Fraxinus* more or less disappeared from the local stand, *Picea* expanded. *Fraxinus* usually prefers wet soils, and its habitat may have been taken over by *Picea*. At about this time the site had become completely overgrown by carr forest, and it may be suggested that *Picea* had become a dominant species at the site and around it, completely out-competing *Fraxinus* in the local vegetation.

5.6. Corylus

Corylus is one of the most abundant pollen types in the middle part of the profile (Figs. 4A and 5). From the beginning of period I (10 200 cal yr BP) until the end of period K (3400 cal yr BP), it dominates the pollen samples together with *Picea* and *Ulmus*. From about 9500 until ca. 4200 cal yr BP it is continuously present with percentages above 20%. Maximum values of around 45% are reached at about 9000 cal yr BP. It probably became locally established during period H (10 750–10 200 cal yr BP), but it was not until period I (10 200–8600 cal yr BP) that it expanded and became a dominant forest constituent. During period L (3400–2200 cal yr BP) *Corylus* decreased, and from the beginning of period M (2200 cal yr BP) until the top of the profile it is only present with low values around 1–2%.

The late date for the regional *Corylus* establishment at Steregoiu – compared to those of *Quercus*, *Tilia*, and *Fraxinus* – at around 10 750 cal yr BP may indicate that it was not present in local refugia in North Romania during the Late-Glacial. Whereas the date of establishment is in accordance with other recent studies in Romania (e.g. Farcas et al., 1999), it is somewhat earlier than what is known from the Carpathian Mountains in Poland, where *Corylus* was present 300–500 years later (Ralska-Jasiewiczowa and Latalowa, 1996). However, at Bátorliget on the Hungarian Plain its establishment already occurred at the beginning of the Holocene around 11 500 cal yr BP (Willis et al., 1995). However, other dates for the establishment/expansion of *Corylus* in Hungary provide a more complex picture. For instance, at the site of Kis-Mohos Tó in North Hungary *Corylus* appears to expand at about 9500 cal yr BP, and at Sárrétt in Central Hungary it may have been present in low numbers around 11 500 cal yr BP but did not expand much until 9000 cal yr BP (Willis et al., 2000). It seems unlikely that *Corylus* was present in Northwest Romania during the Late-Glacial, and the late expansion date most likely indicates that it had to immigrate into the area from distant refugia, probably located in South Romania, or in lowland areas further to the west on the Hungarian Plain.

During the *Corylus* expansion phase at Steregoiu, values increase from about 10% around the beginning of period I (10 200 cal yr BP) to above 40% around 9300 cal yr BP. The only tree pollen type showing a marked decrease during this phase is *Ulmus*, which decreases from percentages of above 30% to values below 20%. These changes in pollen deposition may indicate that *Corylus* expanded in the local stand mainly at the expense of *Ulmus*.

The decline of *Corylus* started at about the same time as *Fagus* and *Carpinus* became established, around 4800 cal yr BP. During period K (4800–3400 cal yr BP) *Corylus* still is an important constituent of the local forest, but during period L (3400–2200 cal yr BP) it declines successively at the same time as *Fagus* becomes dominant. During the last ca. 2000 years, when *Fagus* was the main forest dominant, *Corylus* had a very restricted occurrence and it probably was absent from the local forest stand.

5.7. Fagus *and* Carpinus

The most abundant pollen type in the upper part of the profile is *Fagus* (Figs. 4A and 5). Its percentages are beyond 60% from the beginning of period M (2200 cal yr BP) until the present. *Fagus* became locally established at the beginning of period K (4800 cal yr BP), but it was not until period L (3400–2200 cal yr BP) that it expanded and became the local forest dominant. The only pollen taxon showing a similar occurrence as *Fagus* in the profile is *Carpinus*-type; however, this type is represented by much lower values. *Carpinus* appears to have become established locally at about the same time as *Fagus*, at around 4800 cal yr BP, and during period K (4800–3400 cal yr BP) *Carpinus* may have been as abundant as *Fagus*. But from about 3400 cal yr BP onwards *Carpinus* did not expand further, and during period O (300 cal yr BP to the present) it seems to have almost disappeared from the area.

The local establishment of *Fagus* around 4800 cal yr BP and the development of *Fagus* dominated stands around 3400 cal yr BP occur at a remarkably late date, when considering that this taxon is believed to have survived the Full Glacial in refugia in Southeast Europe (e.g. Huntley and Birks, 1983). Other broad-leaved trees, for instance *Quercus*, *Tilia*, and *Fraxinus*, expanded at an early phase of the Holocene (see above). However, the late establishment and expansion of *Fagus* at Steregoiu is in accordance with other studies made at sites in different countries of Southeast Europe (e.g. Farcas et al., 1999; Willis et al., 2000), where dates for its establishment usually range between 4500 and 5700 cal yr BP (Table 4). However, some earlier dates are known from the westernmost part of the Balkans in Slovenia (e.g. Willis, 1994), where expansion occurred around 8000–7800 cal yr BP.

The establishment of *Fagus* and *Carpinus* at Steregoiu around 4800 cal yr BP appears to have occurred without any major disturbance of the existing forest. In Northern Europe, particularly in Scandinavia, the Late Holocene establishment of *Fagus* is usually connected to the disturbance of the previous forest community (e.g. Björkman, 1996, 1999). In many cases, disturbance of the forest was caused by human influence (e.g. changes in land-use, grazing pressure, forestry, etc.), but natural factors were sometimes also important (e.g. wildfires, storms, climatic change). An undisturbed forest may withstand an invasion of *Fagus* for a long time (e.g. Aaby, 1986), because seed beds favourable to its regeneration usually are not created without any external disturbance factor (e.g. Björkman, 1996). At

Table 4
The establishment of *Fagus* at selected sites in Southeast Europe

Site and country	Establishment (cal yr BP)	Reference
Lake Maliq, Albania	ca. 5000	Denèfle and Lézine, 2000
Lake Sedmo Rilsko, Southwest Bulgaria	ca. 5700	Bozilova and Tonkov, 2000
Kis-Mohos Tó, North Hungary	ca. 5500	Willis et al., 2000
Puscizna Rekowianska, South Poland	ca. 5150	Ralska-Jasiewiczowa and Latalowa, 1996
Tarnawa Wyzna, Southeast Poland	ca. 5700	Ralska-Jasiewiczowa and Latalowa, 1996
Steregoiu, Northwest Romania	4800	This study
Iezerul Calimani, East Romania	ca. 4450	Farcas et al., 1999
Taul Zanogutii, Southwest Romania	5700–3200	Farcas et al., 1999

The dates generally describe the time when *Fagus* started to be locally abundant. It can, however, have been present in the region earlier, but then only in a very low abundance.

Steregoiu, but probably also at many other localities in Southeast Europe, Early and Middle Holocene woodlands were not favourable for the expansion of *Fagus*. The dense woodlands dominated by broad-leaved trees and shrubs, e.g. *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, and *Corylus*, and by conifers, e.g. *Picea*, probably did not have a disturbance regime (wildfires, storms, etc.) that enabled *Fagus* to become established.

If *Fagus* was present in refugia of Southeast Europe, it did not expand much beyond these areas until ca. 5700 cal yr BP. The distribution of *Fagus* at several sites spread over Southeast Europe during an interval between 5700–4500 cal yr BP is puzzling, and certainly does not describe a successive expansion of *Fagus* northwards from distant refugia located in Greece and Bulgaria (see Willis, 1994). Instead, this pattern rather points towards the occurrence of *Fagus* within several refugia, which may have been distributed evenly across Southeast Europe, or that *Fagus* had been expanding its range for a long time, but with densities too low to be detectable with standard pollen analysis counting only 500–1000 pollen grains (Bennett, 1986). If *Fagus* was present in the study area before 4800 cal yr BP, it certainly had a very restricted presence. During period J (8600–4800 cal yr BP) *Fagus* is present in low, but nearly continuous proportions. Around 7900 cal yr BP it has rather high percentages in a few consecutive samples, which might indicate a local presence but, for some reason, *Fagus* seems to have failed to expand further. This event may prove that *Fagus* did occur in the area before the local establishment around 4800 cal yr BP, but that it certainly was very rare in the area until the main expansion phase.

The expansion phase of *Fagus*, which starts at most sites in Southeast Europe at about the same time, certainly must have been triggered by an external factor. This factor may have been climatic change or human influence, which at this time had started to increase, at least in lowland areas (e.g. Willis, 1994). At Steregoiu, which is a mid-altitude site, human influence was probably not the triggering factor. During period J (8600–4800 cal yr BP), which preceded the local establishment of *Fagus*, no apparent changes in pollen deposition can be convincingly attributed to human influence. A clue to the establishment of *Fagus* at Steregoiu may be the curve for total pollen concentration, which starts to increase around 5000 cal yr BP and reaches peak values around 3500 cal yr BP (Fig. 4B). The high pollen concentration during this period could be explained by reduced accumulation of peat or by the fact that the peat became partly decomposed following a period with drier climate. In any case, this event must have been caused by a change in regional climate, which might have been the ultimate trigger in disturbing the existing forest community, eventually leading to the local establishment of *Fagus* (and *Carpinus*).

5.8. Late Holocene human influence on the vegetation

Today, the area close to the site is used for forestry, but in the recent past it probably was used also for grazing by cattle and sheep. At lower altitudes in the Talna Valley (Fig. 2), the land is used for grazing and quite large areas exist with open vegetation. At higher altitudes the grazing pressure probably has decreased radically during the last few decades. The forest surrounding the site is mostly of a very young age, and it has probably become much denser only quite recently. Pollen evidence for human influence on the local vegetation is very scarce except for period O (300 cal yr BP to the present). During this period the area was likely used for forest grazing, which is indicated by notably high values of *Plantago lanceolata*. The presence of several human impact indicators (e.g. *Secale*, *Cannabis*-type, *Centaurea cyanus*-type, *Plantago lanceolata*, and *Rumex acetosa/R. acetosella*) indicates arable fields and fallow land. However, the values are comparatively low (usually single pollen grains, or values below 1%), which means that these fields were not located close to the site. Furthermore, no traces of fields are found near the site, but they are rather abundant at lower altitudes in the Talna valley, particularly below 400 m a.s.l. Therefore, an expansion of agriculture most likely occurred in the valley around 300 cal yr BP. Previous to this date, the area close to the site may have been grazed, at least since the beginning of period N (1050 cal yr BP), as indicated by scattered pollen grains of *Plantago lanceolata*, but the grazing pressure was low. The disappearance of *Carpinus* and *Ulmus* from the area around 300 cal yr BP possibly can be attributed to human influence, but other changes in the tree composition prior to this date are more difficult to interpret as having been caused by human impact.

6. Conclusions

The present study is the first investigation from Romania where the Late-Glacial and Holocene vegetational development is reconstructed with high temporal resolution. The study has revealed that the Full Glacial vegetation in the Gutaiului Mountains in Northwest Romania was characterised by an open patchy mosaic of shrubs, herbs, and ungrown grounds. Forests dominated by *Pinus* probably existed on the lowlands west of the area.

Around 14 700 cal yr BP an open forest dominated by *Pinus* and *Betula* expanded at the site, most likely in response to the first deglacial warming phase at the beginning of the Bølling period, or GI-1e in the GRIP event stratigraphy. Between 13 750 and 12 950 cal yr BP an open forest dominated by *Betula*, *Picea*, and *Pinus* developed in the area. Around 13 200 cal yr BP *Ulmus* also became established locally. The forest composition implies rather warm climatic conditions, which probably correspond to the Allerød period, or GI-1c–GI-1a. Around 12 950 cal yr BP the forest started to retract and at the same time open vegetation communities expanded. At 12 600 cal yr BP an open patchy vegetation became re-established locally, and forest vegetation was restricted mainly to favourable sites at lower altitudes. These changes in vegetational cover imply a return to significantly colder conditions, which likely correspond to the Younger Dryas period, or GS-1.

At 11 500 cal yr BP *Betula*, *Pinus*, and *Alnus* quickly responded to the rapid temperature rise that characterises the onset of the Holocene. Within a few hundred years, around 11 300 cal yr BP, *Ulmus* and *Picea* became re-established and a mixed forest type developed. *Quercus*, *Tilia*, and *Fraxinus* became established locally around 10 750 cal yr BP. From about this time a dense mixed forest type dominated the area. *Betula* and *Pinus* populations started to diminish when the forests became denser. *Corylus* became established around 10 500 cal yr BP and about 10 200 cal yr BP its values increased strongly. *Tilia* and *Fraxinus* were important forest constituents until 8600 cal yr BP, when *Picea* gained renewed importance. Between 8600 and 4800 cal yr BP the local forest was dominated by *Picea* and *Corylus*, but *Quercus*, *Ulmus*, and *Tilia* were also important. Around 4800 cal yr BP the forest composition changed radically when *Fagus* and *Carpinus* appeared. The local forest became more diverse when the earlier dominance of *Picea* and *Corylus* was broken. Between 4800 and 3400 cal yr BP the forest was of a highly mixed type in which *Picea*, *Fagus*, *Corylus*, *Carpinus*, *Quercus*, *Ulmus*, *Tilia*, and *Acer* were important constituents. Around 3400 cal yr BP *Fagus* expanded and a dense *Fagus*-*Carpinus*-*Quercus* forest became established. From about 2200 cal yr BP onwards *Fagus* has been the local forest dominant, but some individuals of *Quercus* and *Carpinus* also have been present. *Ulmus*, *Tilia*, *Fraxinus*, *Picea*, and *Corylus* have been rather rare in the area during the last 2000 years. *Fagus* has been the local forest dominant from 300 cal yr BP until the present day.

During the later part of the Late-Glacial the pollen data indicate that beside *Pinus* and *Betula*, *Alnus*, *Ulmus* and *Picea* also occurred in the area. The increased representation of *Alnus* at ca. 14 150 cal yr BP and that of *Picea* and *Ulmus* between 13 750 and 13 200 cal yr BP may indicate that these trees immigrated from nearby refugia, most likely located in Northwest Romania. Between 12 600 and 11 500 cal yr BP *Ulmus* and *Picea* may have survived the Younger Dryas period regionally in sheltered places. Otherwise it is probable that these taxa would not have become locally re-established within a few hundred years after the beginning of the Holocene. The late expansion of *Quercus*, *Tilia*, *Fraxinus*, *Acer*, and *Corylus* between 10 750 and 10 200 cal yr BP may indicate that these trees and shrubs did not occur in local refugia in the study area during the Late-Glacial. Instead, they had to immigrate into the area from refugia further away. However, these refugia cannot have been situated very far from the investigated area; otherwise the expansion of these tree species would have occurred much later. It seems most likely that these refugia were located further to the south in Romania, or in lowland areas further to the west (e.g. on the Hungarian Plain).

The establishment of *Fagus* around 4800 cal yr BP appears to have occurred without any major disturbance of the existing forest. However, the establishment probably was influenced by a change in the regional climate. The late expansion of *Fagus* in Southeast Europe during an interval between 5700 and 4500 cal yr BP is puzzling, and certainly does not describe a successive expansion of the species from distant refugia in Greece and Bulgaria. Instead, this pattern points towards the existence of several refugia evenly distributed over Southeast Europe. Alternatively, *Fagus* may have been expanding its range for a long time from the south but with very low population densities.

Pollen evidence for human influence on the local vegetation is scant except for the last few hundred years. The area may have been used for forest grazing by cattle and sheep since 1050 cal yr BP, but the grazing pressure probably was low until about 300 cal yr BP when an expansion of agriculture took place in the Talna Valley west of the study area. From about this time the forests close to the site may have been used more regularly for grazing.

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