Veget Hist Archaeobot
DOI 10.1007/s00334-016-0568-9

ORIGINAL ARTICLE

# Present-day vegetation and the Holocene and recent development of Egelsee-Moor, Salzburg province, Austria

**Robert Krisai**[1] · **Jacqueline F. N. van Leeuwen**[2] · **W. O. van der Knaap**[2]

Received: 15 October 2015 / Accepted: 16 March 2016


**Abstract** This paper describes the present-day vegetation, stratigraphy and developmental history of the mire of Egelsee-Moor (Salzburg, Austria; 45°45′N, 13°8.5′E, 700 m a.s.l., 15 ha in area) since the early Late Glacial on the basis of 4 transects with 14 trial borings across the peatland. We present a vegetation map of the mire, a longitudinal section through the peat body based on six cores showing the peat types, overview macrofossil diagrams of six cores showing the local mire development and two pollen diagrams covering the Late Glacial and Holocene. The chronology of the diagrams depends on biostratigraphic dating for the Late Glacial and early Holocene and radiocarbon dating for the remaining Holocene. The northern part of the mire originated through terrestrialisation of nutrient-rich, mostly inundated fen and the southern part through paludification of wet soils. The very small lake of today was a reservoir until recently for providing water-power for timber rafting (‘Holztrift’). The mire vegetation today is a complex of forested parts (mainly planted *Pinus sylvestris* and *Thuja occidentalis*, but also spontaneous *Picea abies*, *Betula pubescens* and *Frangula alnus*), reed-lands (*Phragmites*) and litter meadows (Molinietum, Schoenetum, etc.). The central part has hummock-hollow complexes with regionally rare species of transitional mires (*Drosera anglica*, *D. intermedia*, *Lycopodiella inundata*, *Scorpidium scorpioides*, *Sphagnum platyphyllum*, *S. subnitens*). The results indicate that some of the mid-Holocene sediments may have been removed by the timber-rafting practices, and that water extraction from the hydrological catchment since 1967 has resulted in a partial shift of transitional mire to ombrotrophic bog. The latter potentially endangers the regionally rare species and was used as an argument to stop further water extraction.

**Keywords** Mire stratigraphy · Pollen · Vegetation history · Macrofossils · Present-day vegetation · Nature conservation

## Introduction

The mire Egelsee-Moor lying in the northern Alps close to the town of Salzburg, Austria, is important for its natural qualities, such as the presence of rare moss species and all three native sundew (*Drosera*) species and their hybrids. Recent water extraction from springs near the mire had raised concern as it might impact the mire hydrology, and the effect of the former use of a stream running through the mire for timber rafting was unclear. Since intact hydrological conditions are essential for the functioning of mire ecosystems, the Nature Conservation Department of the Salzburg province invited the first author in 1989 to study the structure and development of the mire. Only old information on the mire’s vegetation existed (Schreiber 1913; Fischer 1958), so investigations on the present vegetation were initiated (Hofstätter 1992). To clarify the stratigraphy of the mire complex and its development and age we described the stratigraphy and botanical composition of the peat in one

Communicated by K.-E. Behre.

✉ W. O. van der Knaap
pim.vanderknaap@ips.unibe.ch

Robert Krisai
robert.krisai@sbg.ac.at

[1] Department of Ecology and Evolution, University of Salzburg, Hellbrunnerstr. 34, 5020 Salzburg, Austria

[2] Institute of Plant Sciences and Oeschger Centre for Climate Change Research, University of Bern, Altenbergrain 21, 3013 Bern, Switzerland

Published online: 26 March 2016

longitudinal and three transversal transects across the mire. Two pollen diagrams would document the age of the basin and the environmental history. Of interest in this context are traces of early Mesolithic presence of man in the nearby valley of the Salzach river (Rettenbacher and Tichy 1994). Results are presented in this article.

There were no possibilities for absolute dating in early studies on mire development in the Alps (Bersch and Zailer 1902; Gams 1927; Paul and Ruoff 1927, 1932). Not much was done in this respect for a long time after this, apart from a few, short remarks for example in Sarnthein (1936 and later). After 1970 the first author, working in the tradition of for example Rybníček (1974), Rybníčková (1974), Rybníček and Rybníčková (1977), Grosse-Brauckmann (1974b and later) and Jankovská (1980 and later), started to study the structure and genesis of mire bodies as an additional means to understand the history of the present-day vegetation, and also using radiocarbon dating (Krisai 1975; Krisai and Friese 1986; Krisai et al. 1991). Furthermore, in pollen-analytical studies from mires in the Alps if macrofossils are mentioned they are mostly not further discussed. For an understanding of present-day vegetation patterns and composition it is however highly relevant to consider the structure of the underlying mire body and the timing of formation of the different layers. The primary aim of this study is therefore to describe and date the processes that have led to the present-day vegetation and distribution of the plant communities. Few examples exist in the Alps of this type of investigation, which is based on multiple proxies and supported by radiocarbon dating (e.g., Schmidt 1983; Oeggl 1988; van der Knaap et al. 2011). Former timber-rafting practices may have affected the hydrology of mires and as a consequence the present-day vegetation, but this type of human impact has hardly ever been mentioned for mires in the Alps. Data on sub-fossil occurrences of mire plants, especially mosses, are very scarce, and studies such as Dickson (1973) and Hughes et al. (2000) for the British Isles are completely absent for the Alps. This study endeavours to fill these gaps at least in part.

## Site and surroundings

The mire Egelsee-Moor (47°45′11″–47°44′41″N, 13°08′19″–13°08′38″E) is situated at an elevation of 700 m in the Alps a few km SE of the town of Salzburg between the mountains Mühlstein, Schwarzenberg and Schatteck (Fig. 1), in the community Puch bei Hallein (previously Thurnberg). Geologically, the area is part of the Tirolicum of the northern limestone Alps (Jurassic limestones, Pestal et al. 2009). The region has a relatively wet climate with 1,200–1,400 mm annual precipitation. The name ‘Egelsee’ (Leech Lake) indicates that the site was in part a lake in historic times, but

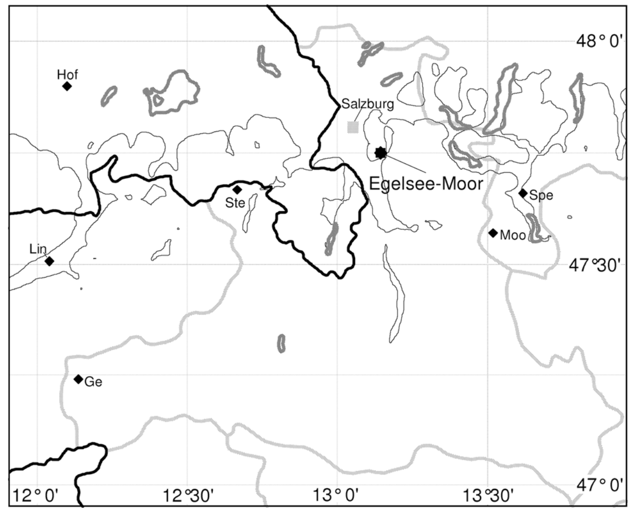


**Fig. 1** Geographical setting of study-site Egelsee-Moor. Pollen sites discussed in text: *Hof* Hofstättersee, *Lin* Lindenmoos, *Ge* Gerlos, *Ste* Steinpass, *Spe* Sperrer, *Moo* Moosklausalm. *Thick black line*—national boundary, *thick dark-gray line*—lake, *thick light-grey line*—province boundary (Salzburg is completely outlined), *thin black line* −700 m contour (elevation of Egelsee-Moor)

today it is a transitional mire 300 by 700 m in size (15 ha according to Biotopkartierung Salzburg; personal communication) with hardly any open water surfaces. The Klausbach brook runs lengthwise through the mire from S to N and finally enters the river Salzach.

The mire had already attracted the attention of the botanists of Salzburg a while ago. It is object No. 112 in Schreiber’s (1913) book on the mires of Salzburg province, which states that the mire has a surface area of 25 ha and consists of pristine mire (“Ödung”), litter meadows (“Streuwiese”) and forest (“Wald”). Remarkably, Schreiber lists *Thuja* in his survey made in 1910 but not *Pinus mugo*; the first is still there and the second grows today scattered in the southern part of the mire and can’t have been overlooked if it was as abundant as today. Fischer (1958) describes the mire and lists all three native *Drosera* species, which are still present today, and also their hybrids, of which the first author has seen only one: *D. anglica* × *rotundifolia*.

Drinking water has been extracted since 1967 from productive springs on the eastern slope of the Mühlstein mountain west of the mire. Further plans for water extraction led however to protests for fear of negative impacts on the Klausbach brook—probably with good reason, so the present investigation was initiated. A vegetation map was produced in 1990 (Hofstätter 1992), ten permanent plots 4 × 4 m in size were installed for monitoring the mire development and a landscape management plan was made (Wittmann and Krisai 2003; Wittmann et al. 2005), but until now, all efforts to create a nature reserve have failed.

Egelsee-Moor has long since been used for agriculture and forestry but up to 1880 was also used as a water reservoir for "Holztrift", which is a special way of timber rafting down a mountain, operated as follows. At intervals, the water table of the Klausbach brook was artificially increased by about 2 m by closing the sluice in a dam where the brook left the mire at its northern end. Without doubt this considerably increased the level of the Egelsee lake lying upstream in the northern part of the mire. The sluice was opened from time to time for the rafting of timber down the Klausbach brook into the Salzach river, abruptly lowering the level of the Egelsee lake. Koller (1975) provides more information about these practices, which probably reached their maximum during the reign of Empress Maria Theresia AD 1740–1780 and ended around 1880 when a new access road was opened for the transport of timber.

The mire was always too wet for pasturing, but after the period of timber rafting the fen was used as a litter meadow; it was mown normally every autumn to produce litter for use in stables. The mowing largely prevented tree growth on the mire, just as the increasing of water levels by the dam had done earlier. Nevertheless, the presence of basal alder carr peat in the southern part of the mire shows that trees were growing on the mire in older times. The northern part today still has at times an open water surface adjacent to a reed belt bordering the litter meadows. Most of this fen is dominated by *Molinia*, but the wettest part has hummock–hollow complexes with regionally rare taxa such as *Drosera anglica*, *D. intermedia*, *Utricularia minor*, *Scorpidium scorpioides* and *Sphagnum subnitens*. Probably soon after 1880 a central part of the mire was afforested with *Thuja occidentalis*.

The use of the mire changed again after ca. 1970. Parts of the litter meadows on the mire were abandoned and either left alone or ploughed over and planted with mainly Scots Pine (*Pinus sylvestris*), whereas other trees appeared naturally (mainly *Betula pubescens*, *Picea abies*, *Frangula alnus* and *Pinus mugo*). Fortunately, the wettest parts with the valuable hummock–hollow complexes remained untouched. *Sphagnum* expanded on many places—even a hummock of the very rare *S. imbricatum* (ssp. *affine*) was found (Christian Schröck, personal communication, confirmed by the first author), and in the southern part *S. magellanicum* and other *Sphagnum* spp. occur.

## Materials and methods

### Palaeobotany and pollen analysis

The peat stratigraphy was studied in the field on 6 April 1990. Twelve trial borings were made by the first author with a small Dachnowski corer (Moore et al. 1991) along one longitudinal and three transversal transects (Fig. 2). Core sections are 20 cm long and 2.5 cm in diameter. Cores were taken at 0.5 m depth intervals. 20 m W of locality 3 (Fig. 2) an additional core A was collected for pollen analysis on 5 May 1990 with a large Dachnowski corer, which produces 40 cm long core sections 5 cm in diameter. This coring ended at 10.75 m depth in impenetrable glacial clay. A second core B was taken for pollen analysis about 400 m south of core A, 50 m south of coring location 7 on 2 March 1995 with a Russian corer. This core ended at 3.5 m depth in alder carr peat; deeper layers were not cored. All cores were kept frozen at the University of Salzburg until further analysis.

Macrofossil analysis was carried out on selected samples from the six cores of the N-S longitudinal transect (Nos. 1–6 in Figs. 2, 3). The studied samples are 10 cm in vertical length and, following the recommendation by Grosse-Brauckmann (1974b), are about 50 ml in volume. The samples were boiled in diluted KOH and sieved over a 1 mm mesh. The residue was analysed under a Wild binocular microscope at 6.4 times magnification by the first author, and sub-samples of the fraction <1 mm were tested for small fragments. Identification was aided by Grosse-Brauckmann (1972, 1974a, b), Grosse-Brauckmann and Streitz (1992), other specialized literature (Bertsch 1941; Berggren 1969, 1981; Aalto 1970; Schweingruber 1978; Mauquoy and van Geel 2007; etc.), and the personal reference collection of the first author. Seeds were counted, whereas quantities of other fragments were estimated according to Grosse-Brauckmann (1974a). Voucher specimens are stored at Salzburg University. The results are shown graphically on an ordinal scale in the N-S longitudinal section through the mire (Fig. 3) and as a diagram (Fig. 4).

Samples for pollen analysis of 1 $cm^3$ were taken in Salzburg from cores A and B at intervals of 10 cm, in some sections refined to 5 cm. Laboratory treatment followed standard procedures (Seiwald 1980). Pollen percentages were calculated for each sample, based on a pollen sum

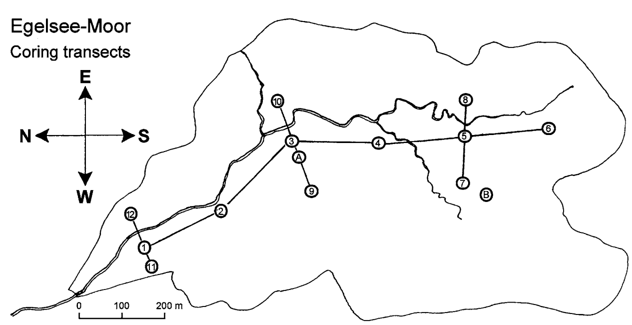


**Fig. 2** Sketch of the coring grid. Points 1–6 are the coring locations on the longitudinal section shown in Fig. 3. Points *A* and *B* are the coring locations of pollen diagrams *A* and *B* (Figs. 5, 6)

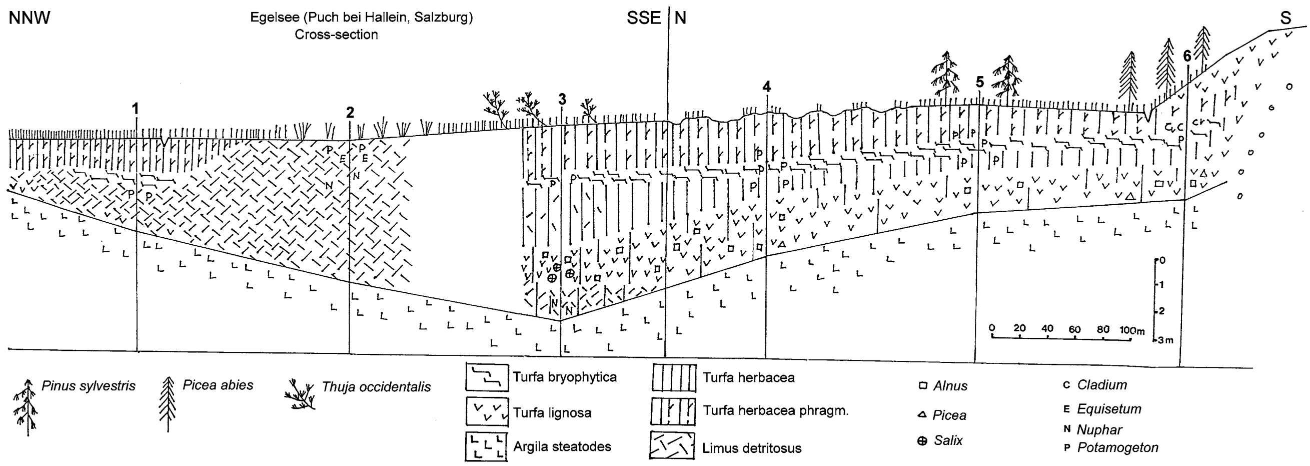


**Fig. 3** N-S longitudinal section through the mire. Symbol names are according to Troels-Smith (1955). The coring points *1–6* (used for macrofossil analysis: Fig. 4) and *A* and *B* (used for pollen analysis: Figs. 5 and 6) are shown on Fig. 2. The positions of cores *A* and *B* are approximate. The blank part in the middle represents the transition between peat deposits and gyttja, which was not mapped in detail

including pollen of dry-land trees, shrubs and upland herbs. Percentages of other palynomorphs were calculated on the same pollen sum. The pollen sum is 600 ± 186 (mean, 1 SD). The results were plotted using TILIA, TILIA-Graph and TGView software (Grimm 2004).

The two pollen sequences of Egelsee-Moor, A (Fig. 5) and B (Fig. 6) were zoned subjectively on the basis of pollen stratigraphy. The zone boundaries are chosen to mark changes in the pollen stratigraphy, primarily tree pollen, supported by upland herb pollen. The two diagrams were biostratigraphically correlated based on the assumption that zones in the two diagrams are synchronous when they have comparable tree and upland herb pollen assemblages, which is justified by the close proximity between the two coring locations. Zones considered to be synchronous between the two diagrams received the same zone number, starting from the base with Ege-1. Zones Ege-1–8 occur only in Egelsee-Moor A, zones Ege-9–13 occur in both diagrams and have a pollen stratigraphy that is closely similar between the two diagrams, and zone Ege-14 occurs only in Egelsee-Moor B.

### Dating

Radiocarbon dating was carried out on eight levels of core A, five levels of core B and one level of core 3 (Table 1). Bulk peat or gyttja was dated by the decay-counting method for four levels in core A, all the five levels in core B and the one in core 3. For the four levels in core A dated by AMS, black particles (presumed to be charcoal) were extracted from the marginal part of the core sections. The radiocarbon ages were transformed to calendar ages BP (cal year BP = years before AD 1950) using Calib.7 (Reimer et al. 2013). Results are shown in Table 1 and Fig. 7.

## Results and discussion

### Chronology

The radiocarbon dating obtained for Egelsee-Moor A (Table 1) appears to be highly problematic. The dates don't constitute a sequence of older ages with increasing depth, and the majority of them do not make pollen-stratigraphic sense. Two conflicting dates lying close together are an AMS date at 619 cm yielding 11,865 cal BP and a decay-counting date at 587.5 cm yielding 8,550 cal BP. The AMS date indicates Younger Dryas and is therefore too old in light of the Holocene pollen stratigraphy, and can thus safely be rejected. The decay-counting date is younger than the next-overlying date at 442.5 cm that yields 9,615 cal BP, so either the former date is too young or the latter is too old, or both. Among the three AMS-dated levels with Late Glacial pollen stratigraphy, two dates yield Holocene ages and can thus be rejected (749 and 871 cm). This makes four radiocarbon dates rejected ab initio among eight in total.

Because of these dating problems, we use bio-stratigraphic dating in addition to the radiocarbon dating for the construction of the depth-age model of core A. The model was created in several steps. First, the radiocarbon dates of core B were transferred to core A according to their pollen-stratigraphic position (Table 2). This is unproblematic because pollen-stratigraphic correlation between cores A and B is straightforward. All radiocarbon dates in core B correspond to the upper part of core A, not deeper than 220 cm depth. Second, we derived pollen-stratigraphic dates for the Late Glacial and early Holocene from Soppensee (Lotter 1991; Lotter et al. 1992; Tinner et al. 2005), which appears to have an amazingly similar pollen stratigraphy in main features; we used the ages of the zone boundaries in Soppensee shown in Fig. 8 (listed in Table 2). Soppensee lies in the northern forelands of the Alps in Switzerland and the sequence is extremely well-dated for most of the Late Glacial and early Holocene. Recently, still more accurate dating became available for the early Late Glacial pollen stratigraphy of Gerzensee (Ammann et al. 2013; van Raden et al. 2013). Gerzensee lies nearly 50 km SW of Soppensee in the same general region and has a highly comparable pollen stratigraphy, so we adapted the dating of the early part of Soppensee according to Gerzensee. We have chosen Soppensee for biostratigraphic chrono-correlation with Egelsee-Moor A because it is well-dated, covers the entire period of interest, and has a Late Glacial biostratigraphy that is highly comparable to that of Egelsee-Moor A. Gerzensee also correlates well with Egelsee-Moor A but misses the Holocene part. All other published sites in or north of the Alps in Austria and Switzerland that have pollen stratigraphies for the period of interest are at the same time less detailed, insufficiently dated and in many cases less similar to Egelsee-Moor A. Among these are the diagrams in Schantl-Heuberger (1994) from three sites ca. 50 km W and S of our site at comparable elevations, the diagrams in Beug (1976) from SE Germany, among which the two of Hofstätter See (ca. 70 km WNW of our site at 484 m a.s.l.) are fairly similar to our site in their main features, the diagrams of Gerlos and Lindenmoos in Bortenschlager (1984) ca. 60–100 km W of our site, and the diagrams of Ramsau-Sperrer (40 km ESE of our site) and Moosklausalm (35 km E of our site) by Draxler (1977). A remaining uncertainty is that the biostratigraphic events used for correlation might not be fully synchronous. Nevertheless, the correlation strongly suggests that the *Juniperus* maximum in Egelsee-Moor (1,170–965 cm) represents the first part of the Late Glacial Interstadial. Diagrams from the southern foot of the Alps, such as Ragogna (Monegato

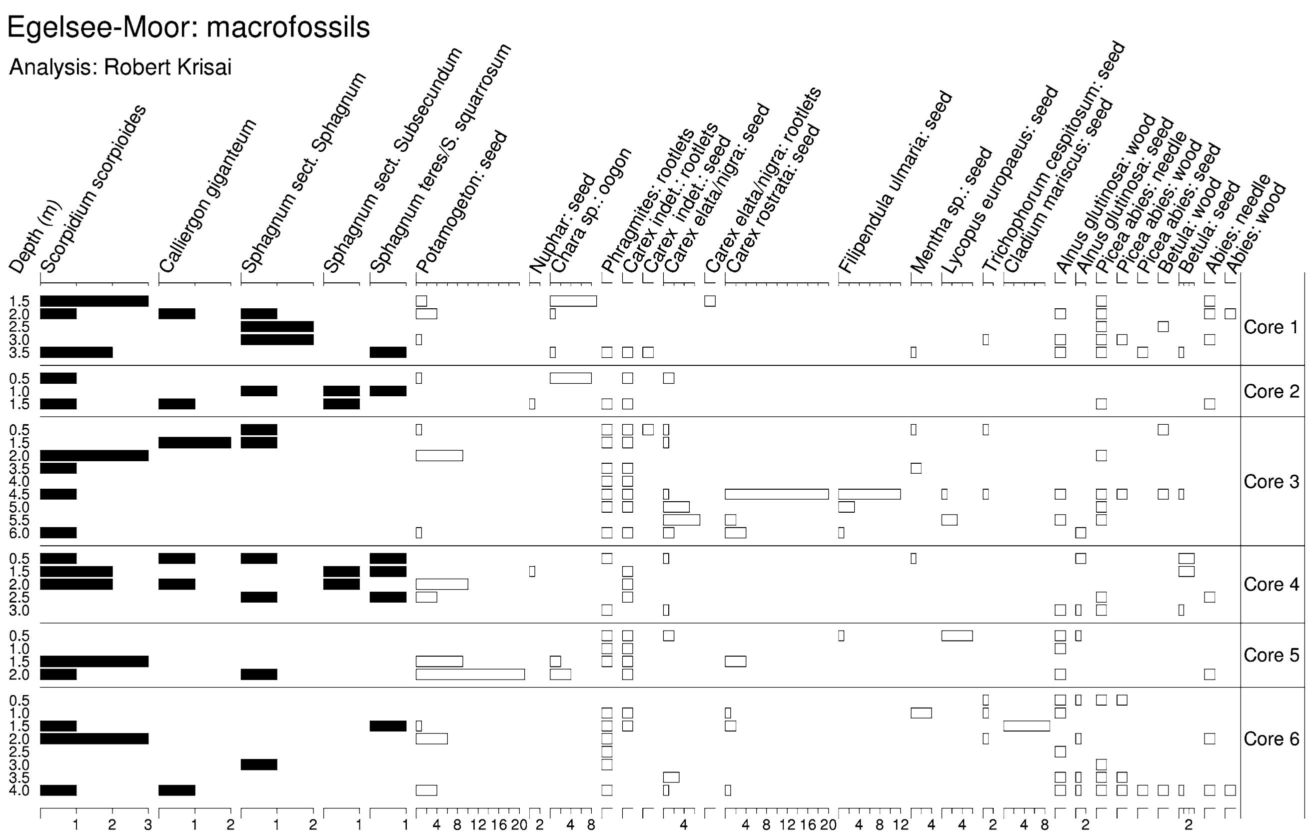


**Fig. 4** Macrofossil analysis of peat sections through Egelsee-Moor. The studied samples are 10 cm in vertical depth and are ca. 50 $cm^3$ in size. Bryophyte quantities (black histograms) are in 3-point scale (*1*—rare; *2*—frequent; *3*—abundant); taxa without X-axis labels are presence/absence; other taxa are given as counts. The coring locations are shown in Fig. 2. The distinct *Scorpidium* layer discussed in the text is represented by *S. scorpioides* 'abundant' or (in core 4) 'frequent'. Cores 7–12 (see Fig. 2) are in general agreement with the nearest studied cores but were studied in less detail

**Table 1** Radiocarbon dates

| Lab. code | Depth (cm) of midpoint | Thickness (cm) | Method[a] | $^{14}$C age BP | Calibrated age (cal year BP) |
|---|---|---|---|---|---|
| Egelsee-Moor A | | | | | |
| VRI-1420 | 152.5 | 5 | Decay | 3,060 ± 50 | 3,283 ± 65 |
| B-6519 | 302.5 | 5 | Decay | 7,240 ± 40 | 8,079 ± 77 |
| B-6520 | 442.5 | 5 | Decay | 8,680 ± 50 | 9,613 ± 60 |
| B-6521 | 587.5 | 5 | Decay | 7,790 ± 60 | 8,548 ± 85 |
| UTC-4241 | 619.0 | 1 | AMS | 10,157 ± 47 | 11,864 ± 110 |
| UTC-4242 | 749.0 | 1 | AMS | 9,021 ± 59 | 10,292 ± 45 |
| UTC-4243 | 871.0 | 1 | AMS | 7,957 ± 52 | 8,851 ± 128 |
| UTC-4244 | 949.0 | 1 | AMS | 10,590 ± 190 | 12,406 ± 258 |
| Egelsee-Moor B | | | | | |
| B-6518 | 55.0 | 5 | Decay | 1,300 ± 70 | 1,226 ± 72 |
| B-6678 | 144.5 | 5 | Decay | 1,650 ± 30 | 1,562 ± 40 |
| B-6677 | 203.5 | 5 | Decay | 2,720 ± 30 | 2,814 ± 32 |
| B-6676 | 215.5 | 5 | Decay | 2,830 ± 30 | 2,921 ± 43 |
| B-6675 | 285.5 | 5 | Decay | 5,910 ± 40 | 6,726 ± 52 |
| Egelsee-Moor 3 | | | | | |
| VRI-1421 | 202.5 | 5 | Decay | 10,280 ± 90 | 12,101 ± 275 |

[a] Material dated is bulk sediment for the decay dates, unidentified black particles in the AMS dates. The dated material in Egelsee-Moor 3 is *Scorpidium* peat

et al. 2007), differ markedly from all those listed above especially in the deciduous trees already expanding before the Younger Dryas (*Quercus*, *Tilia*, *Ulmus* and others).

The third step in depth–age modelling of Egelsee-Moor A was the selection of the radiocarbon dates to be used in the Holocene part of the model. We selected the date at 442.5 cm in favour of that at 587.5 cm, because this results in less drastic shifts in sediment-accumulation rates. In the late Holocene, the radiocarbon date at 152.5 cm falls out of sequence when compared with the two dates transferred from core B at 165 and 175 cm, and was therefore not used. The final balance is that only two out of the eight radiocarbon dates in core A were used for the depth–age model. We are, therefore, inclined to have limited confidence in the two early-Holocene dates that were used, so the modelled sediment ages between 10.5 and 7.5 ka BP are considered to be approximate.

Finally, the late Holocene date at 50 cm in core A transferred from core B was not used because this ensures a more constant sediment-accumulation rate in the upper m of the core. The depth-age model of core B was constructed using the same dates as in core A (Fig. 7).

## Vegetation

The present-day vegetation is shown in Fig. 9. About two-thirds of the mire are covered by treeless communities, mostly different forms of Molinietum (named after *Molinia caerulea*, purple moor grass; Nos. 11 and 12 in Fig. 9) mixed with Schoenetum ferruginei (No. 6 in Fig. 9). Some of the characteristic, and for nature protection interesting, species in these communities are *Gentiana asclepiadea*, *Dactylorhiza majalis*, *Drosera* spp., *Eriophorum latifolium*, *Primula farinosa*, *Tofieldia calyculata* and *Viola palustris*. In the central part bog-hollows (depressions) occur (No. 13 in Fig. 9) with *Carex limosa*, *Dactylorhiza incarnata*, *D. majalis*, *Drosera anglica*, *D. intermedia*, *Utricularia minor*, *Calliergon trifarium*, *Drepanocladus cossonii* (syn. *Scorpidium cossonii*, *Limprichtia cossonii*), *Scorpidium scorpioides*, *Sphagnum platyphyllum* and *S. subnitens*. Wet meadows in the marginal parts of the mire (No. 9 in Fig. 9) contain *Carex elata*, *C. acutiformis*, *C. vesicaria*, *Phragmites australis*, *Cirsium rivulare*, *Trollius europaeus* and *Thalictrum lucidum*. Following the abandonment of mowing of part of the litter meadows, about one third of the mire was afforested (Nos. 12 and 15 in Fig. 9), either with *Pinus sylvestris* and *Thuja occidentalis* or became invaded by other trees and shrubs such as *Frangula alnus*, *Betula pubescens* agg., *Alnus glutinosa* (and also *A. incana*) and *Picea abies*. Productive hay meadows are found nowadays only around a farm on the hill bordering the northwest side of the mire, whereas the other slopes towards the mire are clad in managed *Fagus* and *Picea* forest.

Today, almost a quarter of a century after the mapping of vegetation (1990–2012), personal observations by the first author indicate that the inflows on the western side are

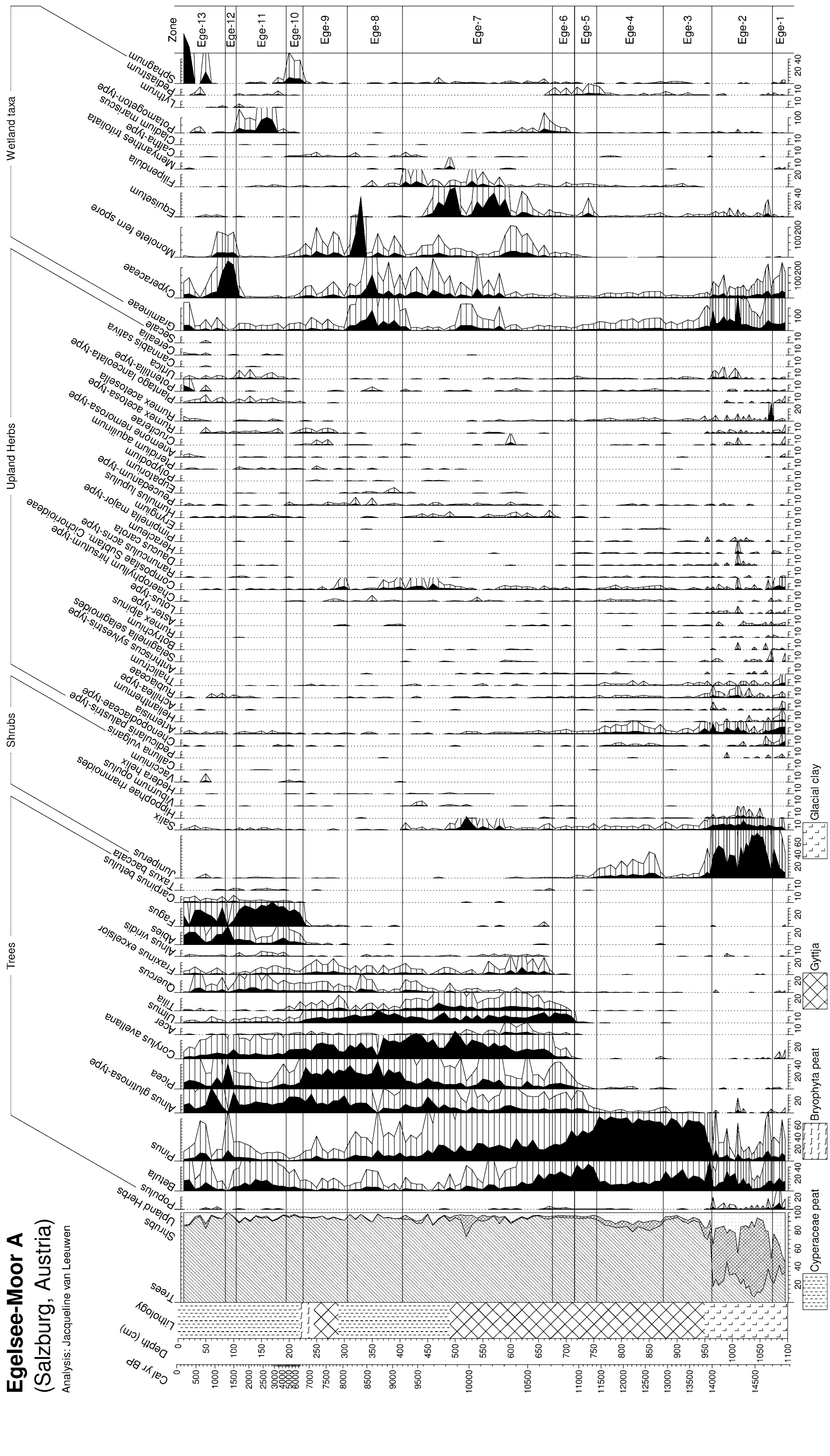


**Fig. 5** Pollen percentage diagram of Egelsee-Moor A based on a pollen sum of trees, shrubs and upland herbs (summed on the left). Selected pollen types are shown

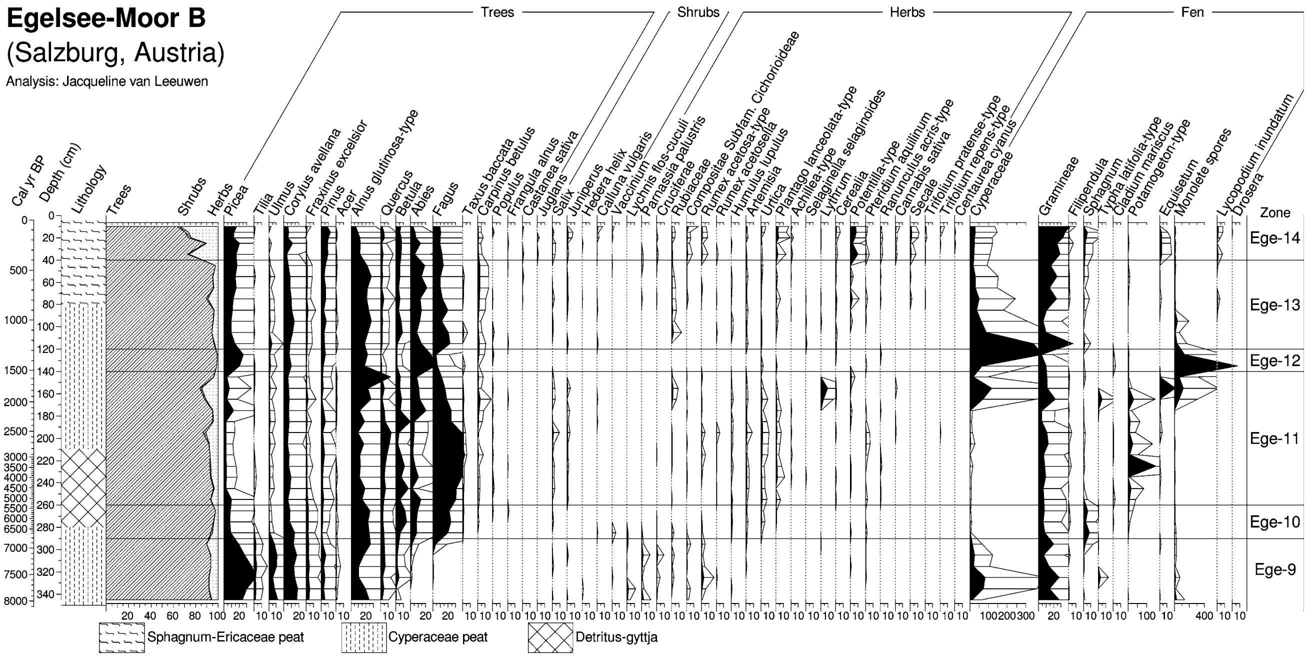


**Fig. 6** Pollen percentage diagram of Egelsee-Moor B based on a pollen sum of trees, shrubs and upland herbs (summed on the left). Selected pollen types are shown

periodically dry, probably due to the water extraction from springs since 1967, and the mire has become slightly drier, whereas the inflows on the eastern side were always very minor. The trees on the mire had grown, of course, older and taller, but otherwise no significant changes could be traced. Some of the planted *Pinus sylvestris* trees had died off, but not the *Thuja* trees, which are still living today and even regenerating. In the southern part *Pinus mugo* and *Sphagnum* (*magellanicum*, *angustifolium* and others) spread in recent decades, which indicate a tendency towards acidification in this part of the mire. Most species of interest for nature protection were again observed.

## Pollen stratigraphy and vegetation history

We discuss here the two diagrams together (Figs. 5, 6).

Zones Ege-1 and 2 are in clay. We assign zone Ege-1 (beginning ca. 14,850 cal year BP) to the end of the Oldest Dryas, during which trees and shrubs, mainly *Juniperus*, rapidly outcompeted steppe plants (*Achillea*-type, *Artemisia*, Chenopodiaceae, Cichorioideae, *Helianthemum*, *Thalictrum*).

Zone Ege-2 (beginning ca. 14,700 cal year BP) corresponds to the Bølling. *Juniperus* pollen is remarkably abundant; this has with up to 60 % no parallel in other diagrams from the region, but closely resembles the diagrams of Soppensee and Gerzensee north of the Swiss Alps (Lotter 1991; Ammann et al. 2013). Percentages of other typical Late Glacial pollen types are as a result suppressed; the most important are *Salix* (possibly *S. herbacea*), *Artemisia*, *Rumex acetosella* and *Hippophaë*. *Betula* might be *B. nana*. Poaceae and Cyperaceae were the main constituents of the well-known cold *Artemisia* steppes in which Ericaceae play no more than a subordinate role. Trees are scarce but not completely absent (*Pinus*, *Betula*, *Populus*). This zone corresponds well with zone 3 of Steinpaß, which is situated about 50 km W at a comparable elevation (Schantl-Heuberger 1994). Schantl-Heuberger, however, considers this zone as part of the Oldest Dryas. Beug (1976) found similar, though less pronounced *Juniperus* peaks (up to 35 %) in several diagrams from SE Germany ca. 70 km WNW of our site, and correlated this with the Bølling chronozone.

Zone Ege-3 (beginning ca. 14,000 cal year BP) corresponds to the Allerød. *Juniperus* and *Salix* declined markedly and forests with *Pinus* and *Betula* developed. The sediment in the northern part of the mire changed from glacial clay to detritus-gyttja.

Zone Ege-4 (beginning ca. 12,900 cal year BP) corresponds to the Younger Dryas. *Juniperus*, *Artemisia* and various steppe herbs (Chenopodiaceae, Cichorioideae etc.) increased, but to lower values than in zone Ege-2 (Bølling). *Betula* percentages declined but not *Pinus*.

The Holocene starts with zone Ege-5 (beginning ca. 11,450 cal year BP), which corresponds to the Preboreal. *Betula* (probably tree-birch) expanded and the steppe plants of the Younger Dryas declined.

In zone Ege-6 (beginning ca. 10,900 cal year BP) *Ulmus* expanded, which corresponds to the regional development

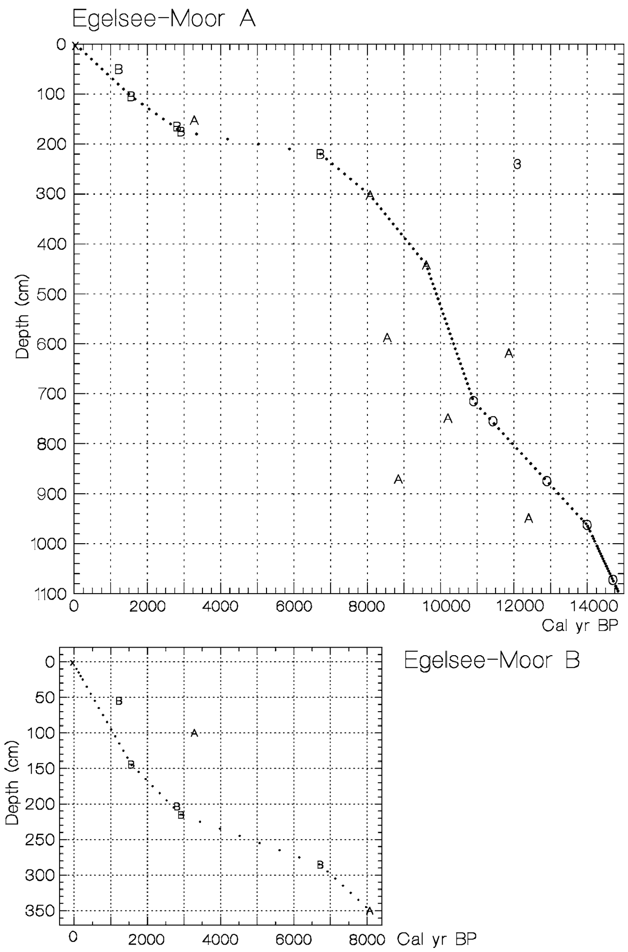


**Fig. 7** Depth-age model of Egelsee-Moor, sections *A* and *B*. Ages are calendar years before AD 1950 (cal year BP). Pollen samples are small dots. Dates are symbols: *A*—radiocarbon dates in Egelsee-Moor *A*, in section *B* transferred on the basis of pollen stratigraphy; *B*—radiocarbon dates in Egelsee-Moor *B*, in section *A* transferred on the basis of pollen stratigraphy; 3—radiocarbon date in Egelsee-Moor 3, in section A transferred on the basis of peat stratigraphy (*Scorpidium* layer); *O*–biostratigraphic dates derived from Soppensee (for explanation see text and Fig. 8); *x*—top of section (−40 cal year BP)

(Krisai 1975). Also *Picea* expanded, and *Acer*, *Corylus* and *Tilia* arrived or started to expand.

Zone Ege-7 (beginning ca. 10,700 cal year BP) marks the final transformation to deciduous forest. Percentages of *Pinus* and *Betula* declined markedly, *Corylus* expanded massively and *Ulmus*, *Tilia* and *Acer* were important, whereas *Quercus* remained subordinate. *Picea* remained of little importance, which may be due to the relatively moderate elevation of the site (700 m), where *Abies* and *Fagus* are better adapted and became more abundant. The slopes towards the mire were probably clad in mixed deciduous forest of *Ulmus*, *Tilia*, *Acer* cf. *pseudoplatanus* and some *Pinus sylvestris*, whereas *Alnus glutinosa*/*A. incana*, *Salix* cf. *cinerea* and *Fraxinus excelsior* were probably growing on the mire or on its edges. *Hedera* pollen is scarce, which may be related to the elevation being rather high for this thermophilous taxon. The first trace of *Cladium* appeared near the end of the zone.

Zone Ege-8 (beginning ca. 9,200 cal year BP) is characterized by a marked increase of *Picea* and a marked decline of *Tilia*. The *Picea* increase indicates that the climate became moister. Poaceae (probably *Phragmites*) and Cyperaceae expanded in parts of the mire.

Zone Ege-9 (beginning ca. 8,100 cal year BP) consists in Egelsee-Moor B of Cyperaceae peat, but in core A it includes a 25 cm thick layer of *Scorpidium* peat at the transition to zone Ege-10. Expansion of *Alnus*, *Fraxinus*, Cichorioideae and *Rumex acetosa*-type suggest increased wetness and the development of nutrient-rich fen close to the coring-sites. This increase in wetness might reflect the 8.2 ka event; a radiocarbon date just below the base of the zone yields 8,079 ± 77 cal year BP. Kofler et al. (2005) detected the 8.2 ka 'cold event' in pollen diagrams in the Eastern Alps at high elevation.

In zone Ege-10 (beginning ca. 6,700 cal year BP) *Fagus* and *Abies* increased markedly and *Carpinus* was present, whereas *Picea*, *Pinus* and *Ulmus* declined. *Sphagnum* was abundant in the mire; this, together with *Vaccinium* and *Calluna*, suggests nutrient-poor mire. An increase of *Plantago lanceolata* is a first clear indication of human impact on the landscape.

Zone Ege-11 (beginning ca. 5,000 cal year BP) reflects clear indications of human impact on the landscape. Pioneer trees or shrubs increased (*Populus*, *Salix*, *Juniperus*), herbs of pastures and ruderal places increased (*Artemisia*, *Plantago lanceolata*, *Urtica*), and Cerealia appeared. High abundance of *Potamogeton* indicates that the mire was from time to time inundated.

Zone Ege-12 (beginning ca. 1,600 cal year BP) shows the temporary forest recovery of the Migration Period: all conifer trees (*Picea*, *Abies* and *Pinus*) had a clear maximum and trees, shrubs and herbs of open areas had a minimum (*Betula*, *Salix*, *Juniperus*, *Artemisia*, *Plantago lanceolata*, *Urtica*). Sedges (Cyperaceae) and ferns (Monolete fern spores, possibly representing *Thelypteris palustris*) dominated the mire vegetation, and *Cladium* is recorded for the last time.

Zone Ege-13 (beginning ca. 1,300 cal year BP) represents the Middle Ages. The coniferous trees declined again and the above-mentioned plants of open areas recovered. Compared to other diagrams from mires in the region, however, these plants have a low representation (Krisai 1975; Schantl-Heuberger 1994), which indicates that arable fields and grasslands were not abundant in the surroundings. Humans penetrated this remote valley apparently late, although they were present during the Mesolithic in the nearby Salzach valley. The latter is shown by a mesolithic

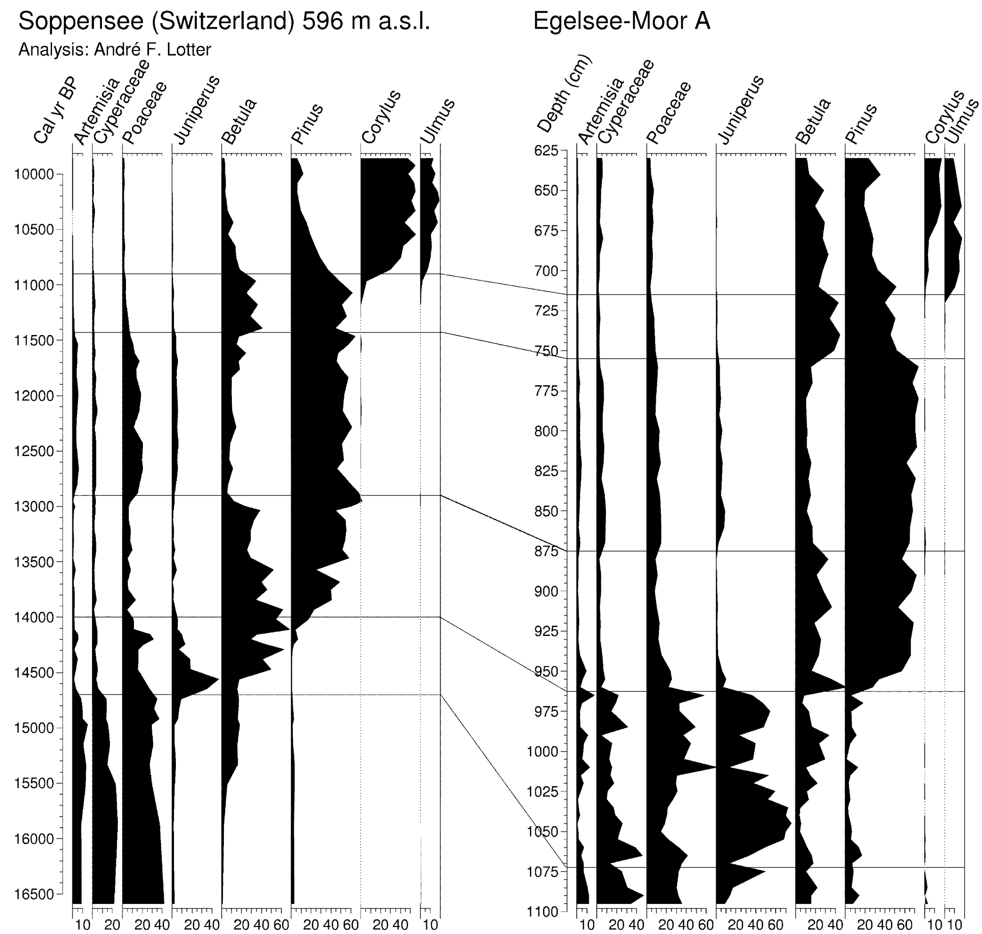


**Fig. 8** Biostratigraphic chrono-correlation between Soppensee and Egelsee-Moor A. Ages in the Soppensee diagram are transferred to Egelsee-Moor A according to the horizontal lines, for use in the depth-age model (Table 2; Fig. 7). See text for details

children's grave discovered in the abri Zigeunerhöhle (community Elsbethen; Rettenbacher and Tichy 1994).

Zone Ege-14 (beginning ca. 200 cal year BP?) represents the last few centuries and is represented in diagram B only. Climax trees like *Abies* and *Carpinus* declined. Pastures expanded (*Plantago lanceolata*, *Rumex acetosa*, *Trifolium*-types). Cultivation of crops increased (*Cannabis*, Cerealia, *Secale*). Records of interesting mire plants are *Drosera* (only at the top) and *Lycopodiella inundata* (present since the Middle Ages). The elevated values of *Juniperus*-type pollen towards the top of the zone represent not only *J. communis* but also *Thuja occidentalis* (which has the same type of pollen) planted on the mire after 1880. The *Pinus* pollen values of the uppermost levels, on the other hand, are lower than could be expected, as scattered *P. mugo* shrubs occur in the southern part of the mire today. Examples of diagrams with elevated *Pinus* pollen near the top from bogs with abundant *P. mugo* today are Etang de la Gruère in the Swiss Jura mountains and Schöpfenwaldmoor in the northern Swiss Alps (van der Knaap et al. 2000), and some of the Lungau mires (Krisai et al. 1991).

The diagrams include sporadic occurrences of taxa during the Holocene that are absent in the surroundings today and most likely also in the past, which can only be explained by long-distance pollen transport, including *Olea* and *Vitis* in zone Ege-11 and *Xanthium* in zone Ege-9 (not shown). Some other sporadic pollen occurrences represent taxa that are also absent in the surroundings today but were likely growing in the close surroundings for some duration during the Holocene, including *Cladium mariscus*, *Eryngium* and *Typha angustifolia*.

## Peat stratification and mire development

The mire has a clear tendency to become wetter and more nutrient-rich northwards, in the flow direction of the Klausbach brook that runs lengthwise through the mire. The

**Table 2** Dating points in Egelsee-Moor A

| Depth (cm) Soppensee | Depth (cm) Egelsee-Moor B[a] | Depth (cm) Egelsee-Moor A[a] | Age of dating point[b] (cal year BP) | Type of date in Egelsee-Moor | Age model (cal year BP) |
|---|---|---|---|---|---|
| | 0.0 | | **−40** ± 1 | Top of section | −40 |
| | 55.0 | (50.0) | 1,226 ± 72 | Decay $^{14}$C date | 768 |
| | 144.5 | (104.5) | **1,562** ± 40 | Decay $^{14}$C date | 1,562 |
| | | (230.0)[c] | 12,101 ± 275 | Decay $^{14}$C date | 7,000 |
| | (190.0) | 152.5 | 3,283 ± 65 | Decay $^{14}$C date | 2,485 |
| | 203.5 | (165.0) | 2,814 ± 32 | Decay $^{14}$C date | 2,700 |
| | 215.5 | (175.0) | **2,921** ± 43 | Decay $^{14}$C date | 2,921 |
| | 285.5 | (220.0) | **6,726** ± 52 | Decay $^{14}$C date | 6,726 |
| | (350.0) | 302.5 | **8,079** ± 77 | Decay $^{14}$C date | 8,079 |
| | | 442.5 | **9,613** ± 60 | Decay $^{14}$C date | 9,613 |
| | | 587.5 | 8,548 ± 85 | Decay $^{14}$C date | 10,298 |
| | | 619.0 | 11,864 ± 110 | AMS $^{14}$C date | 10,447 |
| 529.0 | | (715.0) | **10,900** | Pollen stratigraphy | 10,900 |
| | | 749.0 | 10,292 ± 45 | AMS $^{14}$C date | 11,350 |
| 541.5 | | (755.0) | **11,430** | Pollen stratigraphy | 11,430 |
| | | 871.0 | 8,851 ± 128 | AMS $^{14}$C date | 12,850 |
| 589.0 | | (875.0) | **12,900** | Pollen stratigraphy | 12,900 |
| | | 949.0 | 12,406 ± 258 | AMS $^{14}$C date | 13,830 |
| 621.5 | | (962.5) | **14,000** | Pollen stratigraphy | 14,000 |
| 641.5 | | (1072.5) | **14,700** | Pollen stratigraphy | 14,700 |

[a] Depths in brackets are transferred from one of the other two diagrams based on pollen stratigryaphy

[b] Ages in bold print were used to create the depth–age models (Fig. 3)

[c] Egelsee-Moor 3, $^{14}$C date in core

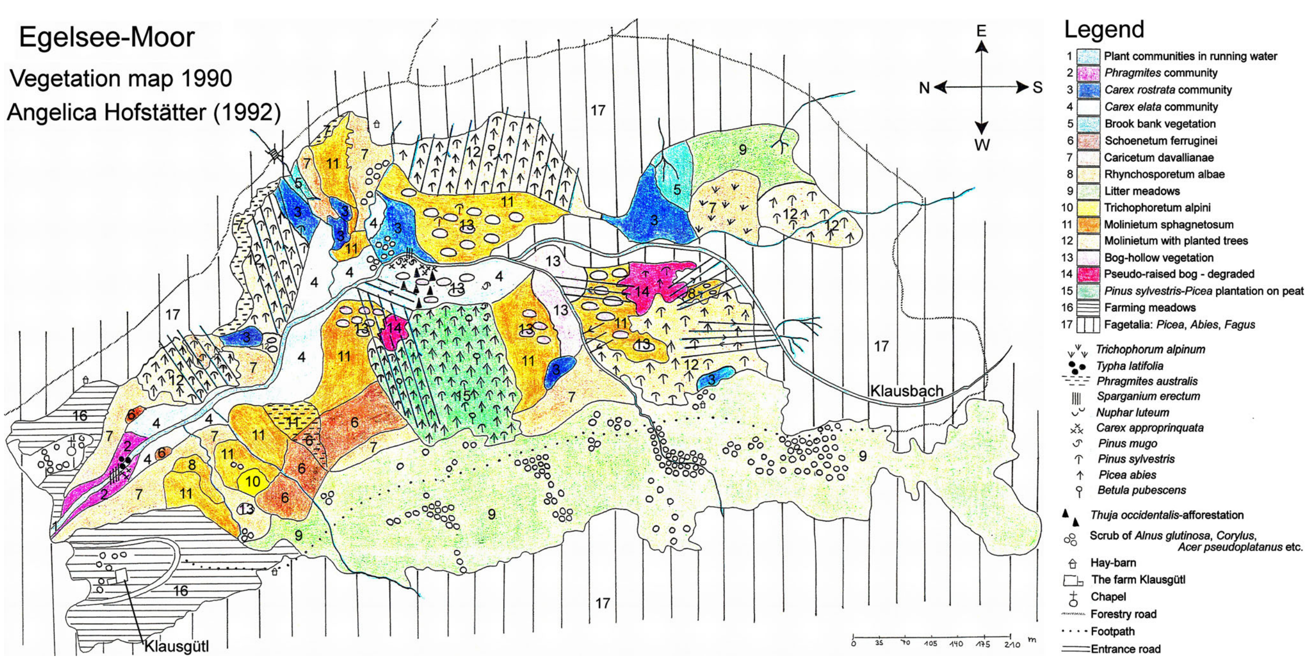


**Fig. 9** Vegetation of the Egelsee mire in 1990 (from Hofstätter 1992)

nutrient-poor, raised-bog vegetation types lie in the southern part (Nos. 13 and 14 in Fig. 9), whereas the wettest, nutrient-rich vegetation is concentrated around the northern outflow (Nos. 1 and 2). This is also reflected in the sediments (Figs. 2, 3). The southern part is built up of different types of peat, whereas the northern part consists of continuous coarse-detritus gyttja containing *Potamogeton* and *Nuphar* seeds, *Chara* oogonia and *Daphnia* ephippia, which implies open water throughout the post-glacial (Fig. 4). This gyttja nevertheless contains macrofossils of mire plants. We therefore envisage a past vegetation of mostly inundated fen with patches of wet fen where the mire plants were growing. The transition between peat deposits in the south and coarse-detritus gyttja in the north may be gradual but has not been mapped in detail (Fig. 3). Surface water seems to have disappeared only recently, or was reduced to temporarily inundated reedlands along the brook (No. 2 in Fig. 9), which is evidently the result of the water extraction. South of coring location 3 the sediments contain a layer of wood-rich sedge-alder carr peat directly on top of the glacial clay, rich in wood of *Alnus*, *Pinus* and *Picea* and also in *Picea* needles. In the shoreline area near coring location 3 this alder carr temporarily pushed somewhat further north, as shown by a layer of carr peat on top of gyttja. After the period of alder carr the mire became wetter, as shown by wood-free sedge peat even with some *Potamogeton* seeds overlying the wood-rich carr peat.

A 30–50 cm thick layer of *Scorpidium* peat occurs at about 1.5–2.0 m sediment depth; at the position of core A it is slightly deeper (220–245 cm). This layer has a large extent, continuing to the northern part near coring location 1 on top of gyttja and also occurring in core A studied for pollen, but is not distinct near coring location 2 and at the coring location of diagram B. The *Scorpidium* layer occurs at roughly the same depth throughout most of the mire, so all of it may have formed in approximately the same period. Late Glacial *Scorpidium* peats with *Calliergon trifarium* and often also *Meesia* are widespread in the region, for example in Waidmoos and Bürmoos (Krisai 1985; Andreaus 2002; R. Krisai personal observations). The *Scorpidium* layer in Egelsee-Moor is indeed radiocarbon dated to a Late Glacial age (10,280 $^{14}$C year BP; Table 1). The layer has, however, an age of around 7,000 ± 200 cal year BP in our depth–age model of core A (Table 2; Fig. 7), which is about 4 $^{14}$C ka younger. It is highly unlikely that the entire *Scorpidium* layer has been reworked from older deposits, not only because of its large extent but also because its pollen assemblage (top of zone Ege-9 in Fig. 5) has no traces of Late Glacial or early-Holocene pollen. Zone Ege-9 in core A, which has the *Scorpidium* layer, fits perfectly in the pollen stratigraphy and does not differ from the same zone in core B (Fig. 6) where the *Scorpidium* layer is absent. Part of the explanation of the old $^{14}$C age might be a reservoir effect in the radiocarbon date. This may have been caused by seepage of $^{14}$C-depleted Ca-rich water through the surface of most of the mire in that period. This would agree with the ecological requirements of *S. scorpioides*, which grows mostly in Ca-rich fens. Nevertheless, *Scorpidium* layers of mid-Holocene age have not been found before in the region.

On top of the *Scorpidium* peat a 1–2 m thick reed-sedge (*Phragmites–Carex*) peat developed, which forms much of the surface today. Seeds of *Cladium*, a taxon absent from the mire today, were found in this peat in the southern part of the mire. Reed-sedge peat also developed at the northern edge of the open water (near coring location 1), though with hardly any moss remains. In the south, near the site of pollen diagram B, *Sphagnum* expanded during this youngest phase. This indicates a change to more ombrotrophic conditions, probably related to the decreased inflow of spring-water due to water withdrawal.

The mire is known for its rare species of transitional mires (*Drosera intermedia*, *D. anglica*, *D. x obovata*, *Lycopodiella inundata*, *Utricularia minor*, etc.). No seeds of these species were however found among the macrofossils, but *Drosera* pollen and spores of *L. inundata* were found.

## Conclusions

The sediments of Egelsee-Moor yielded a pollen sequence for the Late Glacial period and the Holocene, starting near the end of the Oldest Dryas (ca. 14.7 cal ka BP). Chronological control for the wonderfully detailed Late Glacial and earliest Holocene had to be based on pollen-stratigraphic correlation with well-dated pollen diagrams from the north-western Alps, as radiocarbon dating failed. The remaining Holocene pollen sequences were dated by radiocarbon. The '8.2 ka cold event' is possibly reflected in pollen assemblages showing increased wetness.

Our extensive peat-stratigraphic analyses showed that Egelsee-Moor is a complex in which the southern part had formed by paludification (mire formation on initially dry ground) and the northern part by terrestrialisation (mire formation on filled-up inundated fen), and that the northern part was later impacted by artificially fluctuating water levels in relation to timber rafting ('Holztrift'). Mire complexes formed by paludification and terrestrialisation are not rare in the Alpine forelands; examples are Murnauer Moor in Bavaria, Germany (Paul and Ruoff 1932), Ibmermoos in Austria (Gams 1947) and Filzmöser am Warscheneck in Austria (Schmidt 1983). The paludification in the southern part of Egelsee-Moor began with alder carr on glacial clay, which after a relatively short interval with gyttja deposition changed into reed-sedge peat (*Phragmites*, *Carex*) with *Sphagnum*. In recent decades trees colonized the mire or were planted, the latter including *Pinus sylvestris* and *Thuja occidentalis*.

The radiocarbon dating of two sediment sections from the mire indicates a very low rate of sediment accumulation in the period ca. 6.5–3.0 ka cal BP (2–2.5 m depth). It seems a possibility that more sediments formed during this period but that they were in part washed away during the repeated strong fluctuations of water level before AD 1880 caused by closing and opening the sluice in the dam at the lower, northern end of the Egelsee Lake with the aim of timber rafting down the out-flowing stream. A very coarse estimate based on the accumulation rates of the adjacent sediment sections is that 1–2 m of sediment may have been removed.

In the northern part of Egelsee-Moor a lake persisted for a long time as evidenced by the name 'Egelsee' (Leech Lake) and by the presence of gyttja layers. This lake was temporary enlarged during the period of timber rafting but was then completely overgrown with reed-sedge fen with brown mosses (Hypnaceae). Initially this fen was mown regularly as litter meadows, but it was later abandoned for most of its surface and on it conifer trees were planted (mostly *P. sylvestris*, also *T. occidentalis*).

Hummock-hollow complexes developed in the transitional zone between the northern and southern parts of the mire, in which regionally rare species are found today typical for transitional mire (*Drosera anglica*, *D. intermedia*, *Lycopodiella inundata*, *Scorpidium scorpioides*, *Calliergon trifarium*, *Sphagnum subnitens*, *S. platyphyllum* and others). In 1967 water extraction started from some of the springs that provided the mire with surface water, leading to decreased inflow and terrestrialisation of most of the remaining Egelsee lake. No significant change in vegetation was observed between 1990 when the vegetation map was made and 2012. The time may be too short to estimate long-term effects of the water extraction, but the absence of significant change makes us optimistic that no damage has been done. However, further water extraction from the surroundings of the mire might well endanger the transitional-mire habitat including its rare species, because this could shift the balance between rain water and surface water in the direction of the former, leading to ombrotrophic conditions unsuitable for these taxa or even to the drying out of the mire. These insights have helped to prevent a further increase of water extraction in the hydrological catchment of the mire. In addition, to retain the valuable vegetation types that include regionally rare plant taxa it is important that the remaining litter meadows are further mown and not fertilized, and that the water supply is at least not further diminished.

The planted population of *Thuja occidentalis* has now thrived for more than 100 years. This, together with the occurrence of uncommon species characteristic of transitional mire, lends the mire its special character that has no parallel in the northern Alpine forelands.

**Acknowledgments** We thank the "Amt der Salzburger Landesregierung, Abteilung Naturschutz" for financial support and the "Amt der Salzburger Landesregierung, Abteilung 6, Unterabteilung Landwirtschaftlicher Wasserbau" for measurement of the coring positions. Helpers in the field were Hans Egger and Christian Schwarz for the exploratory corings, Gertrude Friese for administration, Christian Schwarz and Dietmar Krisai for coring of profile A and Franz Xaver Wimmer for coring of profile B. Gertrude Friese helped with macrofossil analysis. Angelica Steiner-Hofstätter gave permission to publish her vegetation map from 1990. We thank several anonymous reviewers for their helpful comments.

## References

Aalto M (1970) Potamogetonaceae fruits I. Recent and subfossil endocarps of the Fennoscandian species. Acta Botanica Fennica 88. Department of Botany, University of Helsinki, Helsinki

Ammann B, van Leeuwen JFN, van der Knaap WO, Lischke H, Heiri O, Tinner W (2013) Vegetation responses to rapid warming and to minor climatic fluctuations during the late-glacial interstadial (GI-1) at Gerzensee (Switzerland). Palaeogeogr Palaeoclimatol Palaeoecol 391:40–59

Andreaus A (2002 unpublished) Das Moor von Bürmoos: Vegetation, Aufbau und Geschichte. Master Thesis, University of Salzburg, Salzburg

Berggren G (1969) Atlas of seeds and small fruits of Northwest-European plant species, part 2: Cyperaceae. Swedish Museum Natural History, Stockholm

Berggren G (1981) Atlas of seeds and small fruits of Northwest-European plant species, part 3: Salicaceae-Cruciferae. Swedish Museum Natural History, Stockholm

Bersch W, Zailer V (1902) Das Hochmoor Saumoos bei St. Michael im Lungau. Zeitschrift für das landwirtschafliche Versuchswesen in Österreich 1902:1,071–1,106

Bertsch K (1941) Früchte und Samen: ein Bestimmungsbuch zur Pflanzenkunde der vorgeschichtlichen Zeit. Handbücher der praktischen Vorgeschichtsforschung 1. Enke, Stuttgart

Beug HJ (1976) Die spätglaziale und frühpostglaziale Vegetationsgeschichte im Gebiet des ehemaligen Rosenheimer Sees (Oberbayern). Bot Jahrb Syst Pflanzengesch Pflanzengeogr 95:373–400

Bortenschlager S (1984) Beiträge zur Vegetationsgeschichte Tirols I. Inneres Ötztal und unteres Inntal. Ber nat-med Verein Innsbr 71:19–56

Dickson JH (1973) Bryophytes of the pleistocene: the British record and its chorological and ecological implications. Cambridge University Press, Cambridge

Draxler I (1977) Pollenanalytische Untersuchungen von Mooren zur spät- und postglazialen Vegetationsgeschichte im Einzugsgebiet der Traun. Jahrb der Geol Bundesanst 120:131–163

Fischer F (1958) Ein floristischer Streifzug zum Egelsee-Moor in der Klaus. Mitteilungen aus dem Haus der Natur Salzburg FS_70 (Tratz-Festschrift):18–23

Gams H (1927) Die Geschichte der Lunzer Seen, Moore und Wälder. Int Rev der Gesamten Hydrobiol und Hydrogr 18:305–386

Gams H (1947) Das Ibmer Moos. Jahrb. d. o. ö. Musealver. Linz 92:289–338

Grimm EC (2004) TILIA and TILIA-GRAPH software. Illinois State Museum, Springfield

Grosse-Brauckmann G (1972) Über pflanzliche Makrofossilien mitteleuropäischer Torfe I: Gewebereste krautiger Pflanzen und ihre Merkmale. Telma 2:19–55

Grosse-Brauckmann G (1974a) Über pflanzliche Makrofossilien mitteleuropäischer Torfe II. Weitere Reste (Früchte und Samen, Moose u.a.) und ihre Bestimmungsmöglichkeiten. Telma 4:51–117

Grosse-Brauckmann G (1974b) Zum Verlauf der Verlandung bei einem eutrophen Flachsee (nach quartärbotanischen Untersuchungen am Steinhuder Meer). I. Heutige Vegetationszonierung, torfbildende Pflanzengesellschaften der Vergangenheit. Flora 163:179–229

Grosse-Brauckmann G, Streitz B (1992) Pflanzliche Makrofossilien mitteleuropäischer Torfe III: Früchte, Samen und einige Gewebe (Photos). Telma 22:53–102

Hofstätter A (1992 unpublished) Die Vegetation des Egelseemoores in der Klaus. Master Thesis, University of Salzburg, Salzburg

Hughes PDM, Mauquoy D, Barber KE, Langdon P (2000) Mire-development pathways and palaeoclimatic records from a full Holocene peat archive at Walton Moss, Cumbria, England. Holocene 10:465–479

Jankovská V (1980) Paläogeobotanische Rekonstruktion der Vegetationsentwicklung im Becken Třeboňská pánev während des Spätglazials und Holozäns. Vegetace ČSSR A 11. Academia, Praha

Kofler W, Krapf V, Oberhuber W, Bortenschlager S (2005) Vegetation responses to the 8,200 cal BP cold event and to long-term climatic changes in the Eastern Alps: possible influence of solar activity and North Atlantic freshwater pulses. Holocene 15:779–788

Koller EJ (1975) Forstgeschichte des Landes Salzburg. Salzburger Druckerei, Salzburg

Krisai R (1975) Die Ufervegetation der Trumerseen (Salzburg). Dissertationes Botanicae 29. Cramer, Vaduz

Krisai R (1985) Zum rezenten und subfossilen Vorkommen subarktischer Moose im salzburgisch/oberösterreichischen Alpenvorland. Verh Zool-Bot Ges Österreich 123:143–150

Krisai R, Friese G (1986) Aufbau und Genese des Wenger Moores am Wallersee. Stud Forsch Salzburg 2:335–341

Krisai R, Burgstaller B, Ehmer-Künkele U, Schiffer R, Wurm E (1991) Die Moore des Ost-Lungaues: Heutige Vegetation, Entstehung, Waldgeschichte ihrer Umgebung. Sauteria 5. Institut für Botanik, Salzburg

Lotter AF (1991) Absolute dating of the late-glacial period in Switzerland using annually laminated sediments. Quat Res 35: 321–330

Lotter AF, Eicher U, Birks HJB, Siegenthaler U (1992) Late-glacial climatic oscillations as recorded in Swiss lake sediments. J Quat Sci 7:187–204

Mauquoy D, van Geel B (2007) Plant macrofossil methods and studies: Mire and Peat Macros. In: Elias SA (ed) Encyclopedia of Quaternary Science. Elsevier, Amsterdam, pp 2,315–2,336

Monegato G, Ravazzi C, Donegana M, Pini R, Calderoni G, Wick L (2007) Evidence of a two-fold glacial advance during the last glacial maximum in the Tagliamento end moraine system (eastern Alps). Quat Res 68:284–302

Moore PD, Webb JA, Collinson ME (1991) Pollen analysis, 2nd edn. Blackwell, Oxford

Oeggl K (1988) Pollenanalytische Untersuchungen zum Nachweis anthropogener Vegetationsveränderungen in einem großen Sedimentationsbecken. Ber nat-med Ver Innsbr Suppl 2:59–72

Paul H, Ruoff S (1927) Pollenstatistische und stratigraphische Mooruntersuchungen im südlichen Bayern, 1. Teil: Moore im außeralpinen Gebiet der diluvialen Salzach-, Chiemsee- und Inn-Gletscher. Berichte der Bayerischen Botanischen Gesellschaft 19, München

Paul H, Ruoff S (1932) Pollenstatistische und stratigraphische Mooruntersuchungen im südlichen Bayern, II. Teil: Moore in den Gebieten der Isar-, Allgäu- und Rheinvorlandgletscher. Berichte der Bayerischen Botanischen Gesellschaft 20, München

Pestal G, Hejl E, Braunstingl R, Schuster R et al (2009) Erläuterungen zur Geologische Karte von Salzburg 1:200.000. Geologische Bundesanstalt, Vienna

Reimer PJ, Bard E, Bayliss A et al (2013) IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55:1,869–1,887. doi:10.2458/azu_js_rc.55.16947

Rettenbacher C, Tichy G (1994) Ein früh-mesolithisches Kindergrab aus der Zigeunerhöhle in Elsbethen bei Salzburg. Mitt Ges Salzbg Landesk 134:625–642

Rybníček K (1974) Die Vegetation der Moore im südlichen Teil der Böhmisch-Mährischen Höhe. Vegetace ČSSR A 6. Academia, Praha

Rybníček K, Rybníčková E (1977) Mooruntersuchungen im oberen Gurgltal, Ötztaler Alpen. Folia Geobot Phytotaxon 12:245–291

Rybníčková E (1974) Die Entwicklung der Vegetation und Flora im südlichen Teil der Böhmisch-Mährischen Höhe während des Spätglazials und Holozäns. Vegetace ČSSR A 7. Academia, Praha

Sarnthein R (1936) Moor- und Seeablagerungen aus den Tiroler Alpen in ihrer waldgeschichtlichen Bedeutung. I: Brennergegend. Beih Bot Cent.bl 55 B:544–631

Schantl-Heuberger H (1994) Pollenanalytische Untersuchungen zur spät- und postglazialen Geschichte der Vegetation im Saalach- und Salzachtal (Salzburg/Austria). Ber nat-med Ver Innsbr 81:61–84

Schmidt R (1983) Entwicklungsgeschichte der Moore Oberösterreichs. In: Krisai R, Schmidt R (eds) Die Moore Oberösterreichs. Natur- und Landschaftsschutz in Oberösterreich 6, Linz, pp 38–71

Schreiber H (1913) Die Moore Salzburgs in naturwissenschaftlicher, geschichtlicher, landwirtschaftlicher und technischer Beziehung. Deutsch-österreichischer Moorverein, Staab

Schweingruber F (1978) Mikroskopische Holzanatomie: Formenspektren mitteleuropäischer Stamm- und Zweighölzer zur Bestimmung von rezentem und subfossilem Material. Eidgenössische Anstalt für Forstliche Versuchswesen. Kommissionsverlag Zürcher AG, Zug

Seiwald A (1980) Beiträge zur Vegetationsgeschichte Tirols IV: Natzner Plateau-Villanderer Alm. Ber nat-med Ver Innsbr 67:31–72

Tinner W, Conedera M, Ammann B, Lotter AF (2005) Fire ecology north and south of the Alps since the last ice age. Holocene 15:1,214–1,226

Troels-Smith J (1955) Karakterisering af løse jordarter. Danmarks Geologiske Undersøgelse Series IV. 3(10), p 73

Van der Knaap WO, van Leeuwen JFN, Fankhauser A, Ammann B (2000) Palyno-stratigraphy of the last centuries in Switzerland based on 23 lake and mire deposits: chronostratigraphic pollen markers, regional patterns, and local histories. Rev Palaeobot Palynol 108:85–143

Van der Knaap WO, Lamentowicz M, van Leeuwen JFN et al (2011) A multi-proxy, high-resolution record of peatland development and its drivers during the last millennium from the subalpine Swiss Alps. Quat Sci Rev 30:3,467–3,480

Van Raden UJ, Colombaroli D, Gilli A et al (2013) High-resolution late-glacial chronology for the Gerzensee lake record (Switzerland): $\delta^{18}O$ correlation between a Gerzensee-stack and NGRIP. Palaeogeogr Palaeoclimatol Palaeoecol 391:13–24

Wittmann H, Krisai R (2003) Untersuchungs- und Monitoringprogramm Egelsee-Moor: Teilbereich Flora und Vegetationskunde. Unpubl. report, Landesregierung Salzburg, Salzburg

Wittmann H, Krisai R, Illich I (2005) Landschaftspflegeplan Egelseemoor. Unpubl. report, Landesregierung Salzburg, Salzburg