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ORIGINAL ARTICLE

Seven Millennia of human impact as reflected in a high resolution pollen profile from the profundal sediments of Litzelsee, Lake Constance region, Germany

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Abstract A profundal core from Litzelsee, a small cirque lake in the western Lake Constance region, was investigated by pollen analysis and dated radiometrically. The upper part of the core, chronologically between 5000 cal BC and 1850 AD, was sampled continuously, resulting in a total of 449 samples, each with a sum of 1,000 arboreal pollen grains. Also in this huge data set, rare taxa, normally lacking or very scarce in pollen profiles, were registered. The ecological evaluation of these, with a focus on anthropogenic indicators, sheds light on environmental and human impact history from the Neolithic to Modern times. Further, the results are put in a regional context, together with seven other mostly unpublished pollen profiles studied in the same way.

Keywords High-resolution pollen analysis · Rare pollen taxa · Human impact · Lake Constance · Neolithic to Modern times

Introduction

The impact of food producing economies on the landscape is one of the key issues for modern pollen analysis because land use is the major agent of land cover change in the second half of the Holocene. However, vegetation has also been subject to other drivers such as climate. Some authors argue that climate might be more important than human impact (e.g. Huntley 1990, 1999; Cayless and Tipping 2002; Gajewski et al. 2006; van Geel and Mauquoy 2010).

It remains undisputed that the first farmers in the Neolithic began the transformation of the natural landscapes into the cultural landscapes of today. The mode and tempo of this major change are equivocal, but it is nonetheless recorded at various levels of resolution in numerous natural archives. Fossil pollen records contain information about vegetation and land-use change and can serve as a proxy for land-use intensity. During its 100 year research history pollen analysis has developed into a major palaeoecological method fuelled also by progress in computer capacity and radiocarbon dating. Among the methodological improvements are better sampling techniques, finer chronological resolution by denser subsampling, higher pollen sums, better differentiation of pollen types, consideration of charred particles and non-pollen palynomorphs, and the choice of more suitable material for sampling. We are now aware that profundal sediments from the centre of small lakes are the best material for palaeoecological studies based on pollen analysis. The scientific questions and aims have changed as part of the framework of studies of the past in geosciences and archaeology/historical sciences.

Since there is evidence that climate and human impact have probably been entangled for many millennia (cf. Ruddiman 2014), the interest in human impact has

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increased, even among those who have been mainly interested in climatic change. Here issues of scale have to be taken into account. The consideration of human impact in palaeoclimatic studies on a global scale commonly relies on a rather coarse grid of palynological studies (e.g. Gaillard et al. 2010; Herbig and Sirocko 2013). Detailed studies of human impact must be done on a local scale and later transferred to a regional scale. High-quality pollen analysis cannot be done by machines, it is labour intensive and therefore it is often a question of providing sufficient work capacity.

In the last 35 years, our working group has tried to achieve such high-resolution studies on human impact for the last seven millennia at Lake Constance (Rösch 1983; 1985a, b, 1990, 1991, 1992, 1993, 1997, 2002, 2013; Lechterbeck 2001; Rösch et al. 2014a, b; Lechterbeck et al. 2014a, b; Wick and Rösch 2006). This region is well suited for such studies, because it provides numerous small lakes, as well as mires, all formed during the last ice age. Due to favourable climate and soils particularly suitable for agriculture, the human impact since the Neolithic has been intense and the region can be considered as one of the long-settled landscapes in Europe.

High resolution pollen analysis does not only mean the counting of more pollen grains or samples. Due to the high pollen sums counted rare pollen taxa occur more frequently in the pollen record. The interpretation of these rare taxa is difficult as the possibility of determining the pollen to a low taxonomic level is limited. We therefore tried to narrow the range of possible taxa for various rare pollen types by taking into account ecological and geographical issues. One of the aims of this study was to test whether this approach delivers sensible results and thus adds to the interpretation of the pollen record.

Materials and methods

Geographical setting

The western Lake Constance region has an area of about 818 km^2 (district of Constance) and lies between 395 m (level of lake Constance) and about 750 m a.s.l. (Lang 1990). The landscape shows a remarkably fine-grained division into a wide variety of distinct natural entities, including steep volcanoes, moraines, tertiary sandstones (Molasse), limestone mountains, and canyons, each in very close proximity to the others. The most common soils are luvisols and haplic luvisols developed from glacial tills and on sandstones. The potential natural vegetation would be deciduous forest dominated by *Fagus sylvatica*. The actual vegetation is strongly influenced by agriculture. Besides lower Lake Constance with a water surface of 62 km^2 and Überlinger See, a bay of upper Lake Constance covering 61 km^2 there are several smaller lakes as well as mires in the western foreland of lower lake Constance (“Untersee”), these originating from kettle holes and other glacial basins (Table 1; Fig. 1).

The coring site

The Litzelsee is one of these small lakes which were sampled for pollen analysis. It is situated northwest of the village of Radolfzell-Böhringen and not far from Böhringer See (Table 1). The nearly circular dead ice hole lake is situated 413 m a.s.l. and is nowadays surrounded by forest. With a size of 1.3 ha it is the smallest of the investigated lakes. The maximum water depth is 8 m.

Methods

The core was been taken in the centre of the lake at maximum water depth using a modified Livingstone sampler (Merkt and Streif 1970). The core has a diameter of 5 cm, a length of seven metres, and consists of 7 core sections, each of one metre. The basal part consists of Late Weichselian clay, the upper parts of organic calcareous mud. The core was stored at a temperature of 4 °C. It was opened and sampled for pollen analysis from 330 cm to the upper core limit. At first, samples of 1 cm thickness were taken at larger intervals of 4–10 cm to gain an overview of the pollen stratigraphy. Then the sampling density and thickness was adjusted to suit our scientific investigations. We aimed at a high resolution especially for the Neolithic section of the profile and therefore sampled the core every 0.5 cm between 309.5 and 159 cm. From 158 cm to the top the core was sampled at 1 cm intervals. This amounts to a total of 449 samples. The pollen analytical work was shared between both authors, the second author focusing on the Neolithic, the first on the younger sections. The older part of the profile before the occurrence of *Fagus*, dating to the middle and early Holocene and Late Weichselian, was not further investigated.

Preparation of the samples for pollen analysis was done using hot HCl, hot HF, hot KOH or chlorination, and acetolysis (Berglund and Ralska-Jasiewiczowa 1986). The material was stored in glycerol and the analysis was carried out on uncoloured permanent slides made with glycerol. For pollen determination Beug (2004), Punt et al. (1976–2003) for Apiaceae, Reille (1992) and the reference collection of the laboratory were used.

The pollen types are in accordance with Beug (2004). However Beug includes Central Europe, the Alps and the Northern Mediterranean in his study area. For the interpretation of the rare pollen types we excluded species from outside southern Central Europe, based on their areas of

Table 1 Pollen sites in the Lake Constance region

No	Code	Site	Coordinates		a.s.l. (m)	Size (ha)	Max. depth (m)	Core length (m)	Pollen levels (n)	^{14}C dates (n)	Reference
	Figure 1		N	E							
1	MAI	Mainau-Obere Güll	47°42′20″	9°11′01″	394	473 km^2	2/147	14	985	19	Rösch, Wick in prep.
2	MIN	Mindelsee	47°45′20″	9°01′22″	406	100	14	6	402	15	Rösch (2013), Rösch et al. (2014a, b)
3	BUC	Buchensee-Südost	47°46′01″	8°59′05″	431	1.6	2	9	797	8	Rösch, Wick in prep.
4	BÖH	Böhringer See	47°45′48″	8°56′18″	409	5.1	9	7	525	15	Lechterbeck, Rösch, in prep.
5	LIT	Litzelsee	47°46′08″	8°55′50″	413	1.3	8	7	449	28	Rösch, Lechterbeck, this paper
6	UFR	Feuenried	47°44′40″	8°54′13″	406	11.4	N/K	5	161	33	Rösch (1985a, b)
7	STK	Steisslinger See	47°47′57″	8°55′01″	450	11.3	20	6	464	11^a	Lechterbeck (2001)
10	GDU	Durchenbergried	47°46′34″	8°58′48″	434	3	N/K	10	500	50	Rösch (1990)
11	HOB	Hornstaad-Bodensee	47°41′45″	9°00′31″	394	63 km^2	2/45	14	862	25	Rösch (1992, 1993)
12	NUS	Nussbaumer See	47°37′01″	8°49′05″	434	25	7	10	182	22	Haas and Hadorn (1998), Rösch (1983)

1, 11 litoral profiles of large lakes

[a] Annually laminated sediment

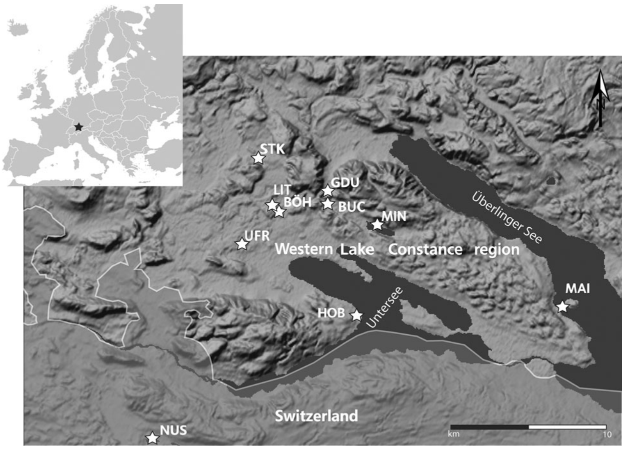


Fig. 1 Pollen sites in the Western Lake Constance region. For interpretation of the site codes see Table 1

distribution for the last two centuries according to Sebald et al. (1990–1998). We could thus narrow down the possible number of taxa belonging to a certain pollen type. Most of these taxa are not wind-pollinated, long-distance transport is therefore not probable. In each sample a pollen sum of at least 1,000 arboreal pollen grains was counted. Charred particles and some non-palyno microfossils were also registered. The data were recorded and processed using the programs Taxus (Schnelke unpub.) and Tilia (Grimm 1991, 1992). The description of the pollen events follows Bastin (1979).

Organic and inorganic sediment matter was determined by loss-on-ignition at 1 cm intervals; samples were dried at 102 °C for 12 h and then weighed for the determination of dry weight. Afterwards the samples were transferred to a muffle furnace and heated to 550 °C for 2 h to combust organic matter. After the determination of the difference of dry weight and ash weight the samples were heated again to 925 °C for 4 h to burn up inorganic carbon from calcitic matter (procedure follows Berglund 1986). Loss on ignition was only determined for the part of the core dating from prehistoric times up to the end of the Iron Age.

For radiocarbon dates terrestrial plant macro remains were obtained by sieving sediment samples with a mesh size of 0.5 mm. Plant remains were selected under a binocular microscope, dried and weighed. It was however not possible to determine the terrestrial plant remains to species level, as these were leaf fragments, bud scales, bark, charcoal and wood fragments. The latter three types were preferentially used for dating because of their size. The recent pollen precipitation was assessed by analysing the pollen content of several patches of epiphytic mosses (*Hypnum cupressiforme*) collected near the shore of the lake in different geographic directions.

Results

Biostratigraphy, time/depth model and loss-on-ignition

The pollen diagram (Fig. 2) is divided into 18 pollen zones, of which two can be further subdivided. The description of the pollen zones is summarized in Table 2. The regional pollen biostratigraphy has long since been established (Rösch 1983, 1985a, b, 1990) and could be validated by further studies (Rösch 2013; Lechterbeck 2001; Kerig and Lechterbeck 2004). The zonation of the Litzelsee profile fits into this regional framework. From the sediments of Litzelsee 28 radiocarbon dates were made on terrestrial macro-remains (Table 3). As the focus was on the Neolithic time window, this section of the core was very densely sampled. The time/depth model for the prehistoric period was constructed with Oxcal (Bronk-Ramsey 2008). The current model (Fig. 3) includes 13 dates (Table 3). The dates of prehistoric age are very close in depth and age. It was therefore possible to construct a number of alternative models with a good fit. These alternative models were then cross validated with the regional pollen stratigraphy and chronology and then the one which fitted best was chosen. However it proved impossible to construct a valid, probable time/depth model that connects the prehistoric dates with the medieval dates.

Based on the expectations from the regional pollen record the uppermost dates of the medieval period are slightly too old, the lowest date is slightly too young, only one date fitted. To obtain a sensible time control for the upper part of the core, the time/depth model was cross checked with other profiles from the region, especially that of Böhringer See which is in very close proximity to Litzelsee. Therefore it can be expected that major events occur synchronously and that the vegetation development is quite similar. The reasons for the difficulties in constructing a continuous time model incorporating most of the dates are not clear. For the prehistoric dates very little material per sample for dating was available because a first batch of samples sent to the laboratory got lost in the mail. We therefore had to resample the core and rely on second best material—this was terrestrial material but of mixed origin—the prehistoric dates however seem to be quite reliable. The uppermost dates of the Middle Ages might be too old because here charcoal and wood fragments were analysed both of which might be washed in from the erosion of older sediments. For the other dates no convincing explanation can be offered at the moment.

The loss-on ignition curve (Fig. 4) of Litzelsee is dominated by organic matter for the older phases of the Neolithic. Towards the end of the Younger Neolithic calcite precipitation sets in. This change of the sedimentation cannot be assigned to anthropogenic influence but probably to a change in the groundwater regime. Today the lake receives its water from submerged springs. The water originates in the calcite rich Weichselian moraine.

Clastic input is recorded in the form of inorganic ash. Litzelsee receives a quite steady clastic input, which seems to increase with the opening of the landscape during the late Bronze Age and apparently represents surface run-off.

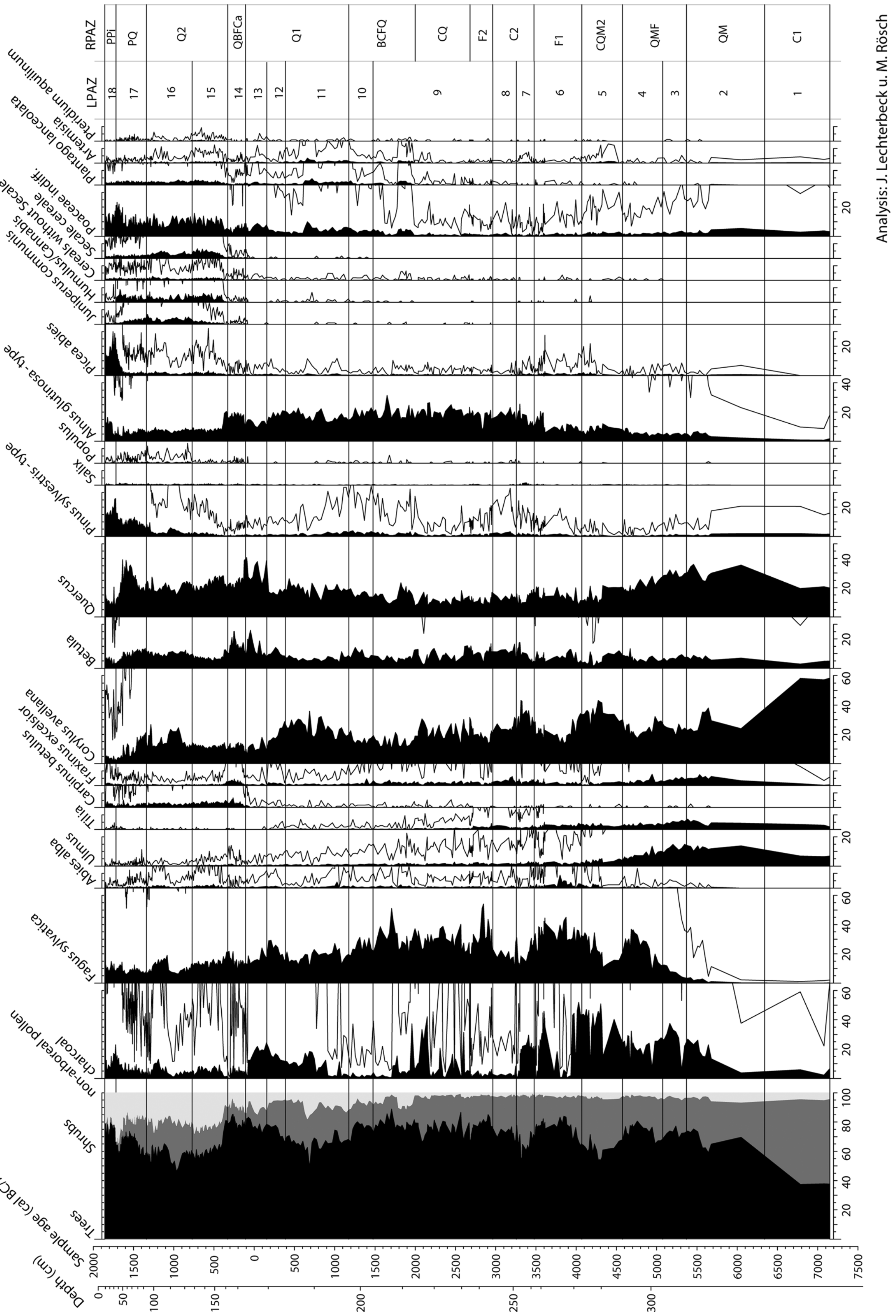
Fig. 2 Pollen diagram Litzelsee. LPAZ Local pollen zones; RPAZ Regional pollen zones (Rösch 1990); for pollen zone abbreviations see Table 2, values on x axes are *percentages*, the *white curves* are exaggerated tenfold, depth in cm ▶

Recent pollen precipitation and age of the core top

The result of the surface sample pollen analysis is shown in Table 4. The three samples, all epiphytic mosses on *Salix cinerea*, differ only slightly. Therefore an overall sum and percentages based on this sum were calculated. The pollen concentration is high, between 225,000 and 321,000 per ml. The mosses probably contain the pollen precipitation of more than one year. Tree pollen reaches a value of 83.5 %, shrub pollen up to 10.5 %, and terrestrial NAP pollen up to 6 %. *Picea abies* is dominant with 28 %, *Pinus* and *Alnus* are subdominant with 14.5 and 13 %. The cereal pollen sum is 0.7 %. The pollen precipitation is in good accordance with the vegetation cover in the lake's surroundings, which consist of closed forest. Open vegetation, mostly not very extensive wet grassland, is located in the east, at a distance of more than 100 m. Arable land is even farther away, about 1 km to the south, on slightly higher elevated ground near the village of Böhringen. In the topmost sample of the Litzelsee profile, tree pollen reaches 72.7 %, shrub pollen 6.6 %, and NAP pollen 20.7 %. *Quercus* and *Picea* are codominant with 16 %, *Fagus* and *Pinus* subdominant with 13 and 12 %. The cereal sum is 2.2 %. This reflects a far more open landscape with more agriculture and less artificial forest than today's surface samples. Most probably the lake's surroundings were more or less part of an open landscape, and not surrounded by forest. The local forest history is unknown, but considering that a forest with adult trees as occurring around Litzelsee needs nearly one century to develop, we can thus estimate that the last 100 years are lacking in the Litzelsee profile.

Human impact

Human impact on the landscape is mainly indicated by deforestation, visible as a decrease of the tree pollen, by changes of the forest composition and structure, visible as a


RPAZ
PPi
PQ
Q2
QBFCa
Q1
BCFQ
CQ
F2
C2
F1
CQM2
QMF
QM
C1
LPAZ
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Pteridium aquilinum
Artemisia
Plantago lanceolata
Poaceae indiff.
Secale cereale
Cereals without Secale
Humulus/Cannabis
Juniperus communis
Picea abies
Alnus glutinosa - type
Populus
Salix
Pinus sylvestris - type
Quercus
Betula
Corylus avellana
Fraxinus excelsior
Carpinus betulus
Tilia
Ulmus
Abies alba
Fagus sylvatica
charcoal
non-arboreal pollen
Shrubs
Trees
Sample age (cal BC/AD)
Depth (cm)
2000
1500
1000
500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
0
50
100
150
200
250
300
20
40
60
80
100
Analysis: J. Lechterbeck u. M. Rösch

decrease of several and increase of other arboreal pollen types and by the occurrence of introduced taxa such as Cerealia, *Linum usitatissimum*, *Juglans regia*, *Castanea sativa* and others. It is also indicated by the development of a substitute vegetation for forest, consisting of shrubs, dwarf shrubs, herbs and grasses—species which either immigrated into the region or were indeed present in the natural vegetation before, but were so rare that they were not registered or occurred only as weak traces in the pollen record. The human impact on the Litzelsee profile is discussed in chronological order and linked to the land use- and settlement history where possible (Fig. 2; Table 5).

The pollen record starts around 7000 BC with high amounts of *Corylus* and the expansion of oak mixed forest taxa between 6000 and 5500 BC. The comparatively high values for Poaceae and *Artemisia* are due to the fact that herbaceous vegetation could thrive in the relatively light oak-dominated forests. Human impact on the vegetation

Table 2 Local pollen zones of Litzelsee

Local Pollen Zone			Regional PZ			
No.	Depth (cm)	Short description	Name	Acronym	Age yrs cal BP	Age cal BC/AD
18	31 – 1	*Pinus*, *Picea* codominant, *Fagus* subdominant, *Juniperus, Cannabis/Humulus, Secale decreasing*	*Pinus-Picea*	PPi	200 - 100	1750 – 1850
17	95 – 31	*Quercus* predominant, *Pinus, Betula, Fagus, Corylus* subdominant, NAP 20 %	*Pinus-Quercus*	PQ	600 - 200	1350 – 1750
16	122 – 95	*Quercus*, *Corylus*, *Fagus* codominant, NAP about 15 %	*Quercus* 2	Q2	1,200 – 600	750 – 1350
15	161 – 122	*Quercus* predominant, *Fagus, Corylus* subdominant; decrease of *Alnus,* increase of NAP, *Juniperus, Secale, Cann*abis/*Humulus*	*Quercus* 2	Q2	1,600 – 1,200	350 – 750
14	174.5 – 161	*Quercus* predominant, *Betula, Fagus* subdominant; NAP about 10 %	*Quercus-Betula-Fagus-Carpinus*	QBFCa	1,800 – 1,600	150 – 350
13	180 – 174.5	*Quercus* dominating, 2 *Betula* peaks; *Fagus, Corylus* subdominant; *Carpinus* increasing; NAP up to 20 % during 2 *Quercus* peaks	*Quercus* 1	Q1 q2	2,100 – 1,800	150 BC – AD 150
12	183.5 – 180	*Fagus* predominant or codominant with *Betula;* decrease of *Corylus* and *Quercus*	*Quercus* 1	Q1 bq	2,300 – 2,100	300 – 150
11b	187 – 183.5	*Corylus* pre-, *Quercus, Fagus* subdominant	*Quercus* 1	Q1 q1	2,500 – 2,300	550 – 350
11a	197.5 – 187	*Corylus*, *Fagus*, *Quercus* codominant, *Corylus* dominating	*Betula-Corylus-Fagus-Quercus*	Q1	3,100 – 2,500	1150 – 550
10	202.5 – 197.5	*Fagus* predominant, *Quercus, Corylus* subdominant; *Carpinus* continuous, NAP 10 %, charcoal low	*Betula-Corylus-Fagus-Quercus*	BCFQ	3,400 – 3,100	1450 – 1150
9e	208 – 202.5	*Fagus* pre-, *Corylus* and *Quercus* subdominant	*Corylus-Quercus*	BCFQ	3,700 – 3,400	1750 – 1450
9d	213 – 208	*Fagus* pre-, *Quercus* subdominant	*Corylus-Quercus*	BCFQ	3,900 – 3,700	1950 – 1750
9c	231.5 – 213	*Fagus* weakly pre-, *Corylus* subdominant	*Fagus* 2	CQ	4,500 – 3,900	2550 – 1950
9b	235 – 231.5	*Fagus, Corylus* codominant	*Fagus* 2	CQ	4,600 – 4,500	2650 – 2550
9a	245.5 – 235	*Fagus* pre-, *Corylus* subdominant	*Fagus* 2	F2	4,900 – 4,600	2950 – 2650
8	257.5 – 245.5	*Corylus* predominant, *Fagus* subdominant, more *Betula* than *Quercus*	*Corylus* 2	C2	5,200 – 4,900	3250 – 2950
7	266.5 – 257.5	*Fagus* and *Corylus* codominant, *Fagus* decreasing, *Corylus* increasing, NAP low, charcoal high	*Corylus* 2	C2	5,400 – 5,200	3450 – 3250
6	282.5 – 266.5	*Fagus* predominant, *Corylus* subdominant; *Ulmus* <2 %	*Fagus* 1	F1	6,000 – 5,400	4050 – 3450
5	292 – 282,5	*Corylus* predominant, *Fagus* subdominant; *Quercus* decreasing, final *Ulmus* decline, charcoal very high	*Corylus*-Quercetum Mixtum 2	CQM2	6,500 – 6,000	4550 – 4050
4	302 – 292	*Fagus* predominant, *Quercus, Corylus* subdominant. *Ulmus, Tilia* decreasing, NAP very low, charcoal high	Quercetum Mixtum-*Fagus*	QMF	7,000 – 6,500	5050 – 4550
3	306 – 302	*Quercus* and *Corylus* codominant, *Quercus* dominating; *Ulmus* and *Fagus* subdominant, *Fagus* increasing charcoal high; maximum of *Tilia*	Quercetum Mixtum-*Fagus*	QMF	7,300 – 7,000	5350 – 5050
2		*Quercus, Corylus* codominant, *Quercus* dominating; *Ulmus* about 10 %, *Fagus* continuous, increasing	Quercetum Mixtum	QM	8,300 – 7,300	6350 – 5350
1	330 – 319	*Corylus* predominant, *Quercus* subdominant, *Corylus* decreasing, *Quercus*, *Ulmus*, *Fraxinus* increasing	*Corylus* 1	C1	9,100 – 8,300	7150 – 6350

Table 3 Radiocarbon dates of Litzelsee. Dates marked with x were used for the time model, depth in cm

Lab. code	^{14}C Age	Depth	^{13}C	Cal age (1 σ)	Cal age (2 σ)	TM
MAMS 21142	576 ± 17	30	−29	AD 1,323–1,405	AD 1,313–1,412	
MAMS 21143	435 ± 18	58	−35.0	AD 1,439–1,452	AD 1,432–1,468	
MAMS 21144	949 ± 31	82	−43.0	AD 1,029–1,151	AD 1,023–1,157	
MAMS 21145	842 ± 17	98	−23.7	AD 1,181–1,219	AD 1,163–1,251	x
MAMS 21146	1,181 ± 26	146	−36.8	AD 782–886	AD 774–945	
MAMS 11243	2,910 ± 27	185	−38.2	BC 1,188–1,046	BC 1,210–1,011	x
MAMS 11244	4,225 ± 26	234.5	−24.3	BC 2,895–2,778	BC 2,902–2,702	x
MAMS 11245	4,267 ± 25	238	−28.9	BC 2,903–2,886	BC 2,914–2,877	x
MAMS 11246	4,201 ± 25	239.5	−28.1	BC 2,884–2,714	BC 2,892–2,680	
MAMS 11247	4,080 ± 22	241	−26.4	BC 2,831–2,576	BC 2,848–2,499	
MAMS 11248	4,331 ± 23	245	−30.1	BC 3,007–2,901	BC 3,012–2,898	
MAMS 11249	4,192 ± 23	246	−29.7	BC 2,879–2,709	BC 2,888–2,679	
MAMS 11250	4,455 ± 23	248	−32.7	BC 3,315–3,029	BC 3,330–3,023	x
MAMS 11251	4,228 ± 23	249	−31.3	BC 2,895–2,780	BC 2,901–2,708	
MAMS 11252	4,324 ± 24	251	−31.4	BC 3,005–2,898	BC 3,011–2,894	
MAMS 11253	4,491 ± 22	252	−27.6	BC 3,330–3,104	BC 3,338–3,096	x
MAMS 11254	4,490 ± 25	254	−23.3	BC 3,330–3,102	BC 3,340–3,094	x
MAMS 11255	4,580 ± 26	255	−25.2	BC 3,484–3,198	BC 3,494–3,125	x
MAMS 11256	4,476 ± 26	255.5	−25.3	BC 3,326–3,096	BC 3,337–3,030	
MAMS 11257	4,531 ± 26	257	−27.0	BC 3,354–3,121	BC 3,360–3,104	x
MAMS 11258	4,512 ± 25	258	−24.4	BC 3,341–3,114	BC 3,349–3,101	x
MAMS 11259	4,565 ± 26	258.5	−25.1	BC 3,366–3,138	BC 3,488–3,113	x
MAMS 11260	4,687 ± 26	259	−23.7	BC 3,517–3,377	BC 3,624–3,372	
MAMS 11261	4,554 ± 24	261	−25.4	BC 3,362–3,136	BC 3,368–3,109	
MAMS 11262	4,481 ± 25	262	−20.9	BC 3,328–3,098	BC 3,338–3,032	
MAMS 11264	4,750 ± 28	264	−22.7	BC 3,632–3,521	BC 3,636–3,383	x
MAMS 11265	4,628 ± 28	268.5	−23.7	BC 3,496–3,363	BC 3,512–3,353	
MAMS 11266	4,829 ± 27	274	−24.9	BC 3,650–3,539	BC 3,691–3,529	x

TM time model

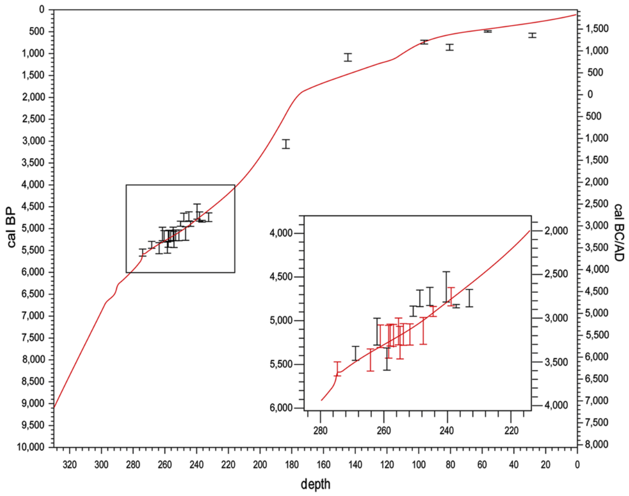


Fig. 3 Time-depth model of the Litzelsee profile. Time in calendar years, depth in cm. The *red line* is the continuous time-depth model based on the Oxcal construction. Those radiocarbon dates which went into the model are marked in *red* in the magnified section

cannot be detected at that time. However it is frequently discussed whether Mesolithic hunter-gatherers fostered hazel for the enhancement of nuts and wood resources. Hazelnuts were a fat- and protein-rich food resource and extensively used in the Mesolithic (e.g. Holst 2007, 2010).

The presence of large amounts of charcoal in Mesolithic contexts in combination with nitrogen- and light indicators is seen as evidence for deliberate burning to favour the spreading of hazel (Bos and Urz 2003). Burning for the enhancement of hunting possibilities was discussed for the British Mesolithic (Bell and Walker 1992) but this could not be proven for the Lake Constance area (Clark et al. 1989) and also the Litzelsee profile gives no hints, such as enhanced charcoal values, of burning in the Mesolithic.

For the time between 5500 and 5000 BC—corresponding to the Linear Pottery Culture (LBK) period—no significant signs for human impact are recorded although there is a distinct rise in the charcoal values. LBK settlements are not known from the direct vicinity of the Litzelsee. LBK

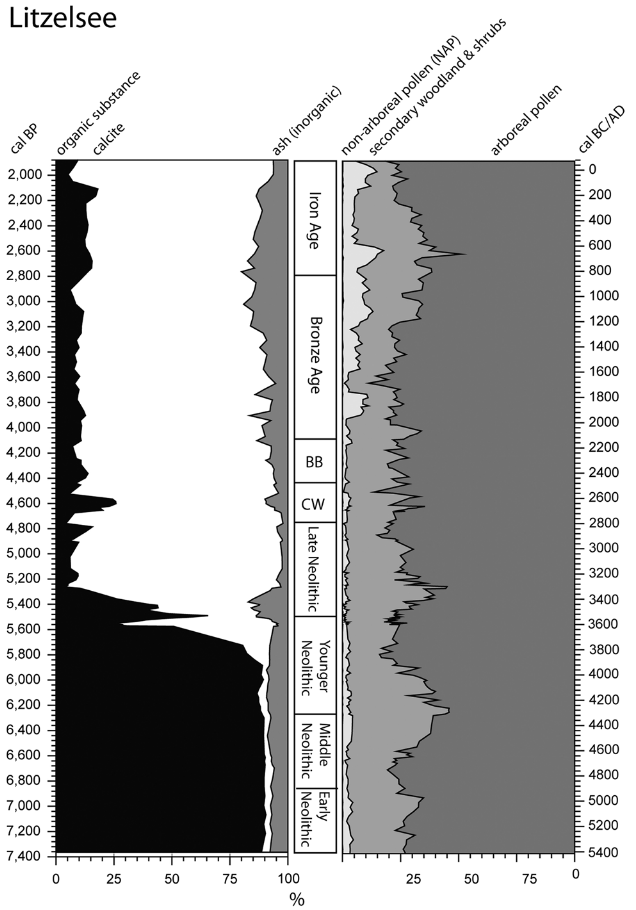


Fig. 4 Loss on ignition of the Litzelsee core and sum curves of trees, shrubs/secondary woodland and non-arboreal pollen. Loss on ignition was investigated up to the Iron Age. Time in calendar years, *CW* Corded Ware, *BB* Bell Beaker, see also Table 5. Calcite was calculated on the basis of combusted inorganic carbon

settlement in the area is concentrated in the Hegau region at a distance of more than 5 km from Litzelsee.

Early Neolithic land use has only a small impact on woodland communities. Bogaard (2004) describes intensive garden cultivation as "the most plausible and widespread form of crop husbandry" for the Early Neolithic Linear Pottery Culture. Kreuz (1990) states that from an archaeobotanical point of view intensive soil cultivation without ploughing is most probable, amongst other reasons because of the occurrence of annual weeds. Schier (2008) and Kerig (2008, 2013) argue that there is no proof for either plough or traction in the Early Neolithic in Europe and that the required agricultural land might well have been worked by hand. For intensive garden cultivation only small patches of woodland have to be cleared which are commonly invisible in the pollen record.

During the first half of the Middle Neolithic the *Fagus* expansion takes place in the Litzelsee region. Synchronously, pollen grains of the *Triticum*- and *Hordeum*-type indicate human impact. It is possible that the previous clearance activities of Linear Pottery people supported the expansion of *Fagus*, which as a shade tolerant tree benefits from clearing activities and could blend in the forest community on a small scale where single trees were felled or where larger clearings where made (Haas and Hadorn 1998; Rösch 1990). The first *Fagus* expansion in the lake Constance area took place between 5000 and 4500 BC. By the end of that time the post-glacial forest development can be considered as having reached an equilibrium state in accordance with soil and climatic conditions and *Fagus* has become the major tree taxon. From the Middle Neolithic onwards human impact is recorded constantly but with varying intensities.

At Litzelsee some pollen grains of *Triticum*- and *Hordeum*-type occur in the first part of the Middle Neolithic. During the *Fagus* expansion the charcoal values decrease. A first major phase of human impact is recorded at the transition to the Younger Neolithic: the *Fagus* curve declines dramatically, the curves of *Corylus* and of charcoal increase, also the values of *Artemisia* and *Plantago lanceolata*. This phase lasts up to 4000 BC, when the *Fagus* curve increases again and the charcoal values decline. The following phase, which is largely synchronous with the Young Neolithic Pfyn culture, is characterized by reforestation and a gradual decrease of human impact. However it does not cease altogether, some cereal pollen grains, *Plantago lanceolata* and *Artemisia* still evidence human activities. This *Fagus* increase and decrease of human impact is clearly earlier and shorter than in the pollen profiles closer to Lake Constance (Fig. 5).

During the Pfyn culture—and the preceding Hornstaad phase—the first pile dwellings occur at Lake Constance. The Litzelsee profile indicates a lessening of land use activities in the hinterland of the pile dwellings at this time. At the transition from Pfyn to the following Horgen culture there is a settlement gap at the lake shore which corresponds to the maximum of the *Fagus* curve in the Litzelsee profile. This *Fagus* maximum is recorded in all profiles from the region though not wholly synchronous (see Fig. 5, regional pollen zones, F1). The *Fagus* maximum is shortest in the profiles from Lake Constance itself. We would interpret this as a shift of the settlement focus towards the lake shore and an abandonment of the hinterland, correlated with a demographic decline (Lechterbeck et al. 2014a).

Once again strong human impact occurs between 3300 and 2900 BC with an increase of the *Corylus* as well as the *Artemisia* values, a continuous *Plantago lanceolata* curve and a decrease of the *Fagus* curve. Furthermore, pollen grains of *Triticum*- and *Hordeum*-type are recorded. This phase dates to the Young Neolithic Horgen culture. It is again connected with a rise in the charcoal curve. Unlike in

Table 4 Recent pollen precipitation at Litzelsee according to three moss samples analysed. For the calculation of concentration/influx (pollen grains per cm^3/pollen grains per cm^2 and year) 148,672 spikes have been added

Sample no.	1	2	3	Sum	Average
Volume (ml)	1	1	1		%
Spikes counted	700	556	500		
Trees					
Picea abies	370	139	392	901	27.83
Pinus sylvestris-type	103	138	227	468	14.46
Alnus glutinosa-type	84	291	54	429	13.25
Fagus sylvatica	95	104	93	292	9.02
Betula	47	101	65	213	6.58
Quercus	44	44	51	139	4.29
Fraxinus excelsior	28	50	11	89	2.75
Carpinus betulus	11	34	34	79	2.44
Larix decidua-type	4	12	9	25	0.77
Abies alba	8	3	9	20	0.62
Tilia	3	6	7	16	0.49
Juglans regia	4	3	7	14	0.43
Acer	5	3	1	9	0.28
Ulmus	3		1	4	0.12
Castanea sativa		1	2	3	0.09
Aesculus hippocast.	1		1	2	0.06
Shrubs					
Corylus avellana	124	76	44	244	7.54
Salix	61	7	2	70	2.16
Sambucus nigra/racemosa	10			10	0.31
Frangula alnus			6	6	0.19
Sorbus-type			4	4	0.12
Prunus-type	1	1	1	3	0.09
Vitis vinifera	1	1		2	0.06
Terrestrial NAP					
Poaceae undiff	28	48	17	93	2.87
Plantago lanceolata	7	3	9	19	0.59
Filipendula	2	10	3	15	0.46
Brassicaceae	2	1	6	9	0.28
Ranunculus acris-type	1		7	8	0.25
Triticum-type	4	2	2	8	0.25
Cerealia-type	1	2	2	5	0.15
Secale cereale	2		3	5	0.15
Artemisia	1	2	1	4	0.12
Chenopodiaceae		2	1	3	0.09
Rosaceae undiff.			3	3	0.09
Avena-type		1	1	2	0.06
Euphorbia	1	1		2	0.06
Hordeum-type		2		2	0.06
Impatiens	1		1	2	0.06
Potentilla-type	1		1	2	0.06
Cichoriaceae			1	1	0.03
Cirsium		1		1	0.03
Daucus carota		1		1	0.03
Epilobium		1		1	0.03
Plantago maior	1			1	0.03
Rubiaceae	1			1	0.03
Rumex undiff.	1			1	0.03
Sanguisorba minor	1			1	0.03
Sanguisorba officinalis			1	1	0.03
Senecio-type	1			1	0.03
Thalictrum	1			1	0.03
Urtica/Parietaria		1		1	0.03
Zea mays			1	1	0.03
Wetland					
Cyperaceae undiff	3	3		6	0.19
Spores					
Dryopteris dilatata	10	15	4	29	0.90
Athyrium	1	8	2	11	0.34
Polypodiaceae undiff	1	4	1	6	0.19
Polypodium vulgare	1			1	0.03
Pteridium aquilinum	1			1	0.03
Thelypteris palustris			1	1	0.03
Charcoal	11	5	9	25	0.77
indet	15	4	4	23	0.71
Picea abies Stomata		1	2	3	0.09
Sums					
Trees	810	929	964	2703	83.50
Shrubs	197	85	57	339	10.47
Terrestrial NAP	57	78	60	195	6.02
Pollen sum	1,064	1,092	1,081	3,237	100.00
Concentration/influx					
Trees	172,035	248,411	286,640		
Shrubs	41,841	22,729	16,949		
Terrestrial NAP	12,106	20,857	17,841		
Pollen sum	225,981	291,996	321,429		

the Pfyn phase, in the Horgen phase the hinterland of the lake shore is not abandoned. The Horgen phase ends with a rapid increase of *Fagus*. As the settlement density at the shore decreases also the land use pressure in the hinterland lessens. The Corded ware phase is again recorded by a decrease of the *Fagus* curve. Synchronously the *Plantago lanceolata* curve rises and quite a number of cereal pollen grains are recorded; however the charcoal values are low. The following Bell Beaker phase is characterized in the Litzelsee profile by low human impact compared to the previous phases. However human impact during the Bell Beaker phase in the hinterland of Lake Constance is generally low. From the lake itself no settlements are known and finds are almost exclusively restricted to the Hegau area (Lechterbeck et al. 2014b). In the Litzelsee profile no continuous land use from Bell Beaker to the Early Bronze Age (EBA) is recorded. The first distinct EBA impact is recorded between 1900 and 1700 BC. Here the high values for Poaceae, Cerealia, *Plantago lanceolata*, and *Artemisia* together with an actual decline of the *Corylus* and an increase of the *Quercus* curve indicate a change in the land use system: whereas in the Younger and Late Neolithic agriculture was forest based with quite intensively worked, small fields it now becomes more extensive with open land which is also kept open for a longer time. The beginning of this development can already be observed during the Bell Beaker phase in the Hegau area (Lechterbeck et al. 2014a). Between 1700 and 1600 BC there is a phase with almost no indication of land use. At 1600 BC land use indicators set in again and there is an even further increase at 1200 BC. There is no obvious interruption in land use activities at the transition from the Bronze Age to the Iron Age (900–800 BC). The next distinct decrease of land use occurs around 500 BC and is followed by a phase of low impact which lasts up to 200 BC. Though the human impact in this period does not cease altogether, it is clearly diminished. Obviously, arable land was abandoned in the time of the great Celtic migrations, but it would be too simple to identify our spatially restricted results with the migration itself. However the Steißlinger See profile also features a distinct phase of low land use activities and there it has been assumed that this might be in connection with the Celtic migrations (Kerig and Lechterbeck 2004). From 200 to 1 BC, a slight increase of land use can be observed.

For the last two millennia the intensity of human impact changes often, allowing the differentiation of several land use phases. To characterize them, percentages of the cereal sum, of other crops, crop weeds, grassland and the ruderal sum, as well as the NAP sum are given.

From 174.5 to 163 cm, the cereal pollen sum is between 0.6 and 1.3 %. Pollen from other crops, crop weeds, and wet grassland plants is rare. The pollen sum of grassland plants is between 1.1 and 3.6 %, of ruderals between 0.4 and 1.3 %. The NAP pollen sum is between 4.7 and 13.8 %. The age of this period is from AD 1 to 300 correlating with the Roman period.

From 163 to 161 cm the human impact is reduced. Charcoal values are very low, and the arboreal pollen curves increase, first *Betula* and afterwards *Fagus*. The *Carpinus* curve has its maximum of about 5 %. The period corresponds to the 4th century AD, after the conquest of South-west Germany by Alamannic tribes.

Between 160 and 154 cm the cereal pollen sum is between 0.8 and 1.3 %, the ruderal pollen sum between 0.2 and 1.1 %, grassland pollen between 1.1 and 2 % and the NAP pollen sum between 5.7 and 10.1 %. Pollen values of other crops, crop weeds and wet grassland plants are still low. This corresponds to the 5th and the first half of the 6th century AD, or the late Migration period and the beginning of the Merovingian period. Towards the end the curves of *Betula* and *Fagus* decrease and the curve of *Quercus* increases.

Between 153 and 146 cm the cereal pollen sum increases from 2 to 5.2 %. Pollen of other cultivars and crop weeds is more or less continuous. The grassland taxa show a strong, ruderals a weaker increase. Wet grassland pollen values are still low. But if Cyperaceae are included in the wet grassland pollen sum and the strong decrease of the *Alnus* values is taken into account, a deforestation of the wetlands and their usage as pasture is clearly evident. The *Humulus*/*Cannabis* curve increases up to 4.9 %. Microcharcoal becomes also more frequent, but has much lower values than in some prehistoric phases. This phase corresponds to the second half of the 6th and the first half of the 7th century AD, and therefore to the Merovingian period.

Between 145 and 123 cm, the cereal pollen sum is between 4.7 and 8 %, the grassland pollen sum between 4.5 and 9.1 %. The values for ruderals are more or less unchanged, as well as pollen from other crops and crop weeds. The values for wetland pollen are still low. The *Humulus*/*Cannabis* curve ranges between 1.4 and 6.1 %, charcoal stays on the same level. This phase corresponds to the second half of the 7th, the 8th and 9th century AD, therefore the end of the Merovingian and the Carolingian period.

Between 122 and 111 cm, the NAP and charcoal values are slightly reduced, as well as the cereal pollen sum, fluctuating between 3 and 5.6 %. Grassland pollen and ruderal pollen remain more or less unchanged. This phase corresponds to the 10th and the first half of the 11th century AD, the Ottonian and early Salian period.

Between 110 and 106 cm, the cereal pollen sum decreases to values between 2.5 and 4.3 %. Grassland pollen decreases from 8.6 to 5.8 %, ruderal pollen from 1.1 to 0.4 %. Amongst the arboreal pollen, there is a decrease of *Quercus* and *Fagus*, and an increase of *Betula* and particularly *Corylus*, as well as a slight increase of *Pinus*. This indicates a reduction of grown forests and a spread of coppiced forests, which indicates perhaps there is already a shortage of timber. *Humulus*/*Cannabis* and charcoal values are also reduced. The phase corresponds to the late 11th and early 12th century AD, the late Salian and early Staufian period.

Between 105 and 95 cm, the cereal pollen sum increases to values between 4.5 and 6.3 %, as do all other groups indicating human impact. *Juniperus* ranges between 1.2 and 4.4 %, the NAP pollen sum between 16 and 27.1 %. This phase corresponds to the late 12th and 13th century AD, the late High Medieval period.

Between 94 and 79 cm, the cereal curve decreases to values between 4.6 and 2.3 %. All other human impact indicator groups decrease too, with the exception of the grassland group. *Juniperus* has high pollen values, with a maximum of 6.7 %. This phase corresponds to the 14th, 15th and early 16th century AD.

Between 78 and 33 cm, the cereal pollen sum is between 1.3 and 3.8 %, the grassland pollen sum between 3.8 and 7.7 %. Other human indicator groups are slightly reduced, but oscillating. The pollen curves of *Corylus*, *Betula* and *Juniperus* decrease, but that of *Pinus* and particularly *Quercus* increase. This phase corresponds to the 17th and 18th century AD. Clear indications of reduced human impact caused by crises like the Little Ice Age or Thirty Years' War are absent.

Table 5 Historic and prehistoric periods in the Lake Constance area

Period	Acronym	Culture/era	Age cal BP	Cal BC/AD
Modern age	MA		500–0	1450–present
Late Medieval	LM		700–500	1250–1450
High Medieval	HM	Salian, Staufian	1,000–700	950–1250
Early Medieval	EM	Merovingian, Carolingian, Ottonian	1,500–1,000	450–950
Migration Period	MP		1,740–1,500	210–450
Roman Period	RP		2,000–1,740	0–210
Iron Age	IA	Latène	2,450–2,000	500–0
Iron Age	IA	Hallstatt	2,800–2,450	850–500
Late Bronze Age	LBA	Urnfield	3,300–2,800	1350–850
Middle Bronze Age	MBA	Gravemound	3,600–3,300	1650–1350
Early Bronze Age	EBA	Arbon	4,150–3,600	2200–1650
Final Neolithic	BB	Bell Beaker	4,450–4,150	2500–2200
Final Neolithic	CW	Corded ware	4,700–4,450	2750–2500
Late Neolithic	LN	Horgen	5,500–4,700	3550–2750
Younger Neolithic	YN	Hornstaad, Pfyn	6,300–5,500	4350–3550
Middle Neolithic	MN	Hinkelstein, Großgartach, Rössen	7,000–6,300	5050–4350
Old Neolithic	ON	Linear Pottery	7,400–7,000	5450–5050
Mesolithic			>7,400	>5450

Between 32 and 19 cm, the cereal pollen sum increases to a minimum of 1.3 and a maximum of 3.6 %. The charcoal curve increases strongly, the grassland curve slightly. The *Humulus*/*Cannabis* values remain stable. Among the arboreal curves, *Quercus* and *Juniperus* decrease, but *Pinus* and *Picea* increase up to 25 %. Towards the end, NAP values have a maximum up to 35.3 %. This phase corresponds to the end of the 18th and the first half of the 19th century AD.

Between 18 and 1 cm, the cereal sum is reduced to 2.2 % on average, oscillating between 1.4 and 4.8 %. Grassland pollen is even more strongly reduced. Initially, the *Humulus*/*Cannabis* curve abruptly decreases below 1 %. Charcoal values are only slightly reduced. The NAP pollen sum is slightly reduced, but still has considerable values between 14.1 and 24.8 %. Among the arboreals, *Pinus* and *Picea* are dominating, but *Alnus* increases. This phase corresponds to the second part of the 19th and the early 20th century AD. The still high NAP values and the difference from the pollen spectra of the surface samples indicate that the profile ends before the present, leaving a gap of perhaps one century, and that the forest around the lake is most probably rather young.

Rare pollen types/species

Pollen spectra with pollen sums between 200 and 500 typically consist of major components with percentages higher than 5, of minor components with percentages between 1 and 5, and of trace components with percentages lower than 1. The curves of these trace components can be continuous, but often they are subcontinuous or discontinuous. With terrestrial pollen sums of more than 1,000 as in our analyses, a fourth component occurs, which consists of types that have curves that are always discontinuous and percentages of less than 0.5, often less than 0.2. The significance of this group is not totally clear, because among them can be long-distance transported pollen and their interpretation is therefore difficult. In our experience however this group consists mainly of local or regional plants which are not wind-pollinated, thus long-distance transport is not probable. Because the pollen of these taxa is mainly transported by hexapods, they are heavily underrepresented in the pollen record, but among them are many types with a high ecological indicator value which makes their occurrence worth considering. A substantial drawback in the interpretation of these pollen types is the wide range of possible species which might be included. Beug (2004)—whose pollen type definitions were used, with the exception of the Apiaceae—includes Mediterranean and alpine taxa. In our study we narrowed down the number of possible species to those taxa which are distributed in our research area.

In the ESM the rare pollen types according to Beug (2004) are listed together with a list of most probable species for each type. For many types only one species remained probable. In Fig. 6 the stratigraphical occurrences of several rare pollen types which are important as indicators of human impact are displayed.

The most frequent pollen type of this group is *Avena*-type, which is autogamous. Among the 129 samples in which this type was found, always with values <0.5 %, are

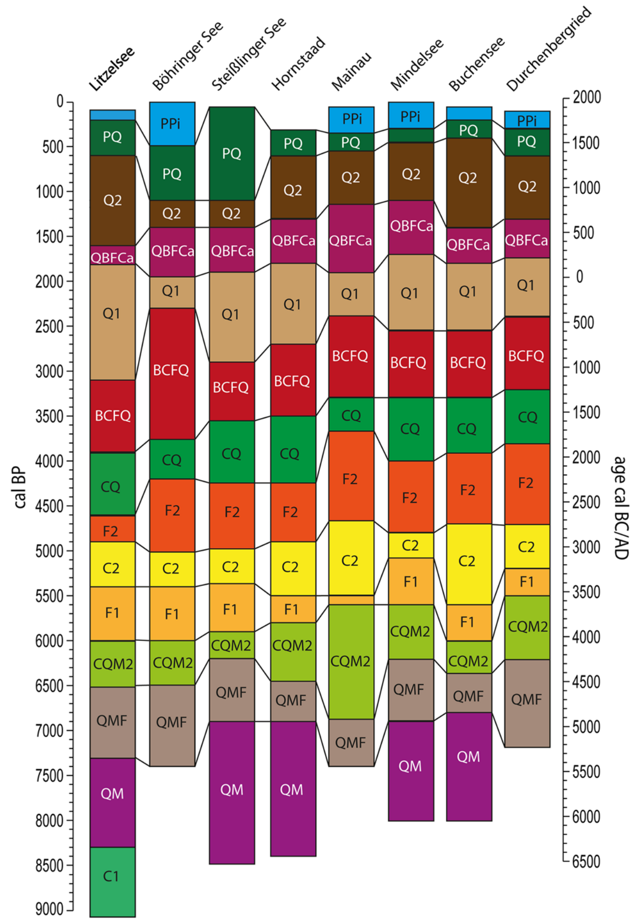


Fig. 5 The regional pollen zones of profiles of the Western Lake Constance area after Rösch (1990) and their correlation according to time in calendar years

several of prehistoric, even Neolithic age. There is no macrofossil proof of the growing of *Avena sativa* before the Iron Age or even later (Körber-Grohne 1987; Fischer et al. 2011). The earlier pollen grains should therefore represent wild *Avena* species (not *sativa*).

Another cultivated plant is *Zea mays,* documented by 20 pollen grains from the 16th to the 19th century AD. Even rarer is *Fagopyrum*, with only one grain from the 14th century AD. *Fagopyrum* is rare also in other profiles in the region, because poor, acidic soils which were preferred for *Fagopyrum* cultivation are lacking.

Linum usitatissimum is present with four pollen grains of Medieval and Modern Age. Regular cultivation of *Linum usitatissimum* is also documented by macrofossils from prehistoric lake shore dwellings. Unfortunately the species is so badly represented in the pollen record that these pollen grains do not permit any further conclusions about the cultivation history.

Anethum graveolens has six pollen grains of Medieval and Modern Age, but three pollen grains of the *Falcaria*-type of prehistoric and modern age can most probably also be correlated with *Anethum.*

Apium graveolens has five pollen grains of Medieval Age, but a 17th century grain of *Apium inundatum*-type can most probably also be correlated with *Apium graveolens*. *Anthriscus cerefolium* is present with two single grains of the 11th century AD. A single grain of *Coriandrum sativum* dates to the 7th century AD, a single grain of *Cucumis sativus* to the 6th century AD. Two pollen grains of *Ruta graveolens* date to the 16th and early 17th century AD.

Eight of the 49 *Vitis vinifera* pollen grains are prehistoric—the last from the MBA—and reflect the occurrence of *Vitis vinifera* ssp. *sylvestris* in the wetland forest. The other 36 pollen grains reflect most probably *Vitis vinifera* ssp. *vinifera*, the oldest from the Roman period, a hint that perhaps the Romans cultivated *Vitis* not only in the Mosel region, but also at Lake Constance. During the Medieval period until the 16th century the curve is discontinuous. Surprisingly *Vitis* is more frequent from the second half of the 16th until the 19th century, a time in which the historians believe there was a decrease of vine cultivation (Wunderer 2001). As an entomogamous plant, *Vitis vinifera* is not very well reflected in the pollen record, and the correlation between the pollen record and the presence of the plant in the landscape is not clear.

Buxus sempervirens is present with 31 pollen grains from the Neolithic and has a slightly higher frequency from the Roman period onwards. Today this evergreen tree with its west-(sub)mediterranean distribution area has its nearest natural, but isolated stands at the Hochrhein (Grenzach). The prehistoric pollen grains in this profile and others from the region indicate either long-distance transport or an area extending farther to the north and east during former times with a warmer climate and without shade trees. Finds from the Roman period onwards can also indicate the local cultivation of *Buxus* in gardens.

Castanea sativa with a total of 111 pollen grains is present since the Roman period. It also occurs today in the region, but sparsely, as it prefers acidic soils. *Ilex aquifolium* is present with 9 pollen grains from the Late Neolithic to the 10th century. The species occurs also today in the region, but seldomly, as a shrub in broad-leaf forests, fostered by former forest pasture.

Reseda luteola is present with 7 pollen grains from the 5th to the 17th century AD. It was already cultivated as a dyeing plant in prehistory and is today naturalized in warm landscapes of Central Europe, also in the western Lake Constance region (Sebald et al. 1990–1998).

A single grain of *Aesculus hippocastanum* was found, dating in the 17th century AD, and 32 pollen grains of *Platanus orientalis* from the 17th century AD onwards, both in good accordance with the late introduction of these ornamental trees from the south-eastern Balkan peninsula.

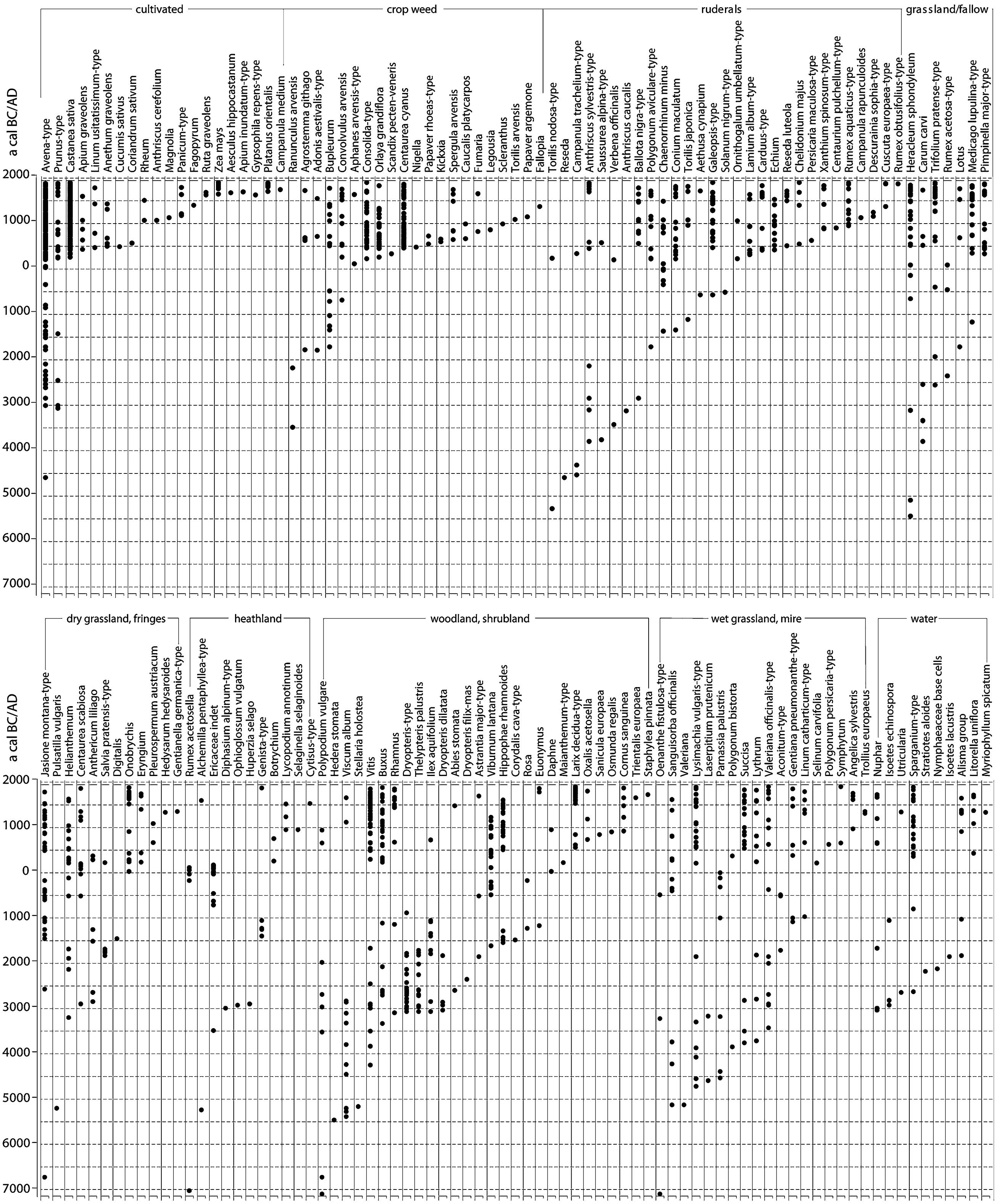


Fig. 6 Rare taxa occurring in less than 5 % of all samples in the Litzelsee profile. Time in calendar years. Additionally *Avena*-type, *Castanea sativa*, *Centaurea cyanus*, *Orlaya grandiflora, Consolida*-type, *Jasione montana*-type, *Vitis vinifera*, *Buxus*, and *Larix decidua*-type were included

One single grain of *Staphylea pinnata*, also present in the region today, dates to the 17th century AD.

Arable weeds are represented with many species among the rare taxa (Fig. 7). The most common species, *Centaurea cyanus*, is present with 58 pollen grains from the 7th century AD onwards. The next most common is *Orlaya grandiflora* with 33 pollen grains from the Roman period to the 19th century AD, with its highest frequencies in the 8th, 10th and 13th centuries AD. There were never floristic records of this species from dry, calcareous soils in the Lake Constance region.

The next most common species, *Consolida regalis*, with 28 pollen grains, has a similar chronological pattern of occurrence at Litzelsee and a similar ecological profile as *Orlaya*. Whereas *Orlaya* is today extinct in Southwest Germany, *Consolida* is still common in the low-elevated northern part, but is absent from the south.

Other crop weeds are much rarer in the pollen record. Of these, the most frequent with 18 pollen grains is *Bupleurum*, which can be correlated with *Bupleurum rotundifolium*, because other species of the genus do not occur in the Lake Constance region. The other taxa documented by few pollen grains are *Spergula arvensis* and *Agrostemma githago*, which occur on all soil types, *Adonis aestivalis/flammea*, *Scandix pecten-veneris*, *Aphanes arvensis*, *Kickxia elatine*/*spurium*, *Gypsophila* cf. *muralis*, *Legousia speculum-veneris*/hybrid and *Nigella* (cf. *arvensis*), which occur on basic soils, *Papaver argemone, Scleranthus annuus*, and *Torilis arvensis*, occurring on acidic soils.

There is one Iron Age *Aphanes* grain, a few *Bupleurum* pollen grains from the Iron and Bronze Age, as well as one *Agrostemma* and one *Adonis* grain from the Bronze Age. All other pollen grains of crop weeds are Roman age or younger. During the Neolithic typical crop weeds are absent.

With the exception of *Agrostemma*, *Spergula* and *Gypsophila*, occurring on all soil types, and *Centaurea cyanus*, *Aphanes*, *Papaver argemone* and *Scleranthus*, occurring on acidic soils, the documented arable weeds grow preferably on dry, calcareous soils. They form the plant community of the Caucalido-Adonidetum flammeae/Caucalidion, indicating low-yield agriculture, caused by low water storage of the thin soil, either as a consequence of the geological situation or—more probable—of soil erosion on slopes.

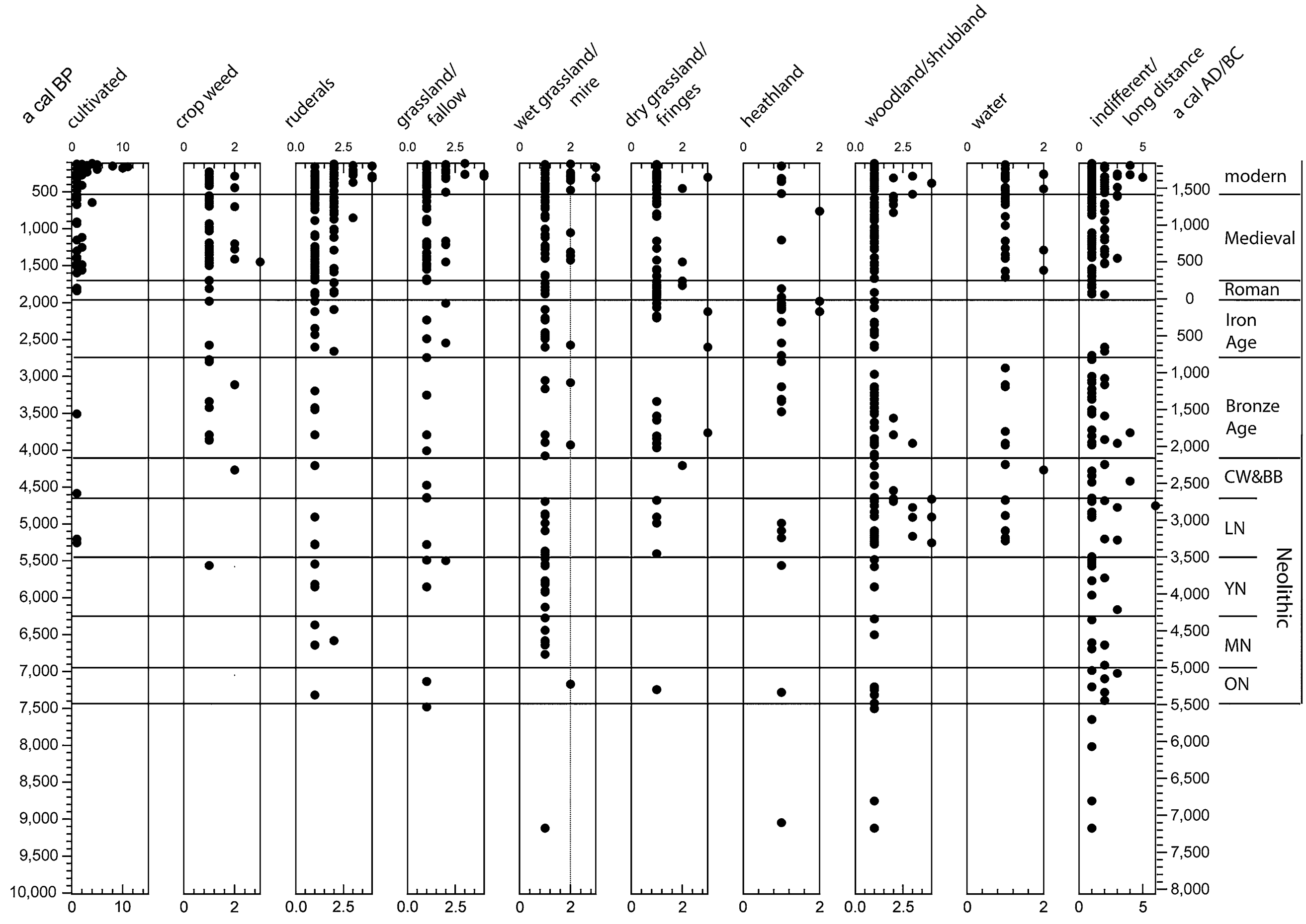


Fig. 7 The distribution of ecological groups based on rare taxa during time (calendar years), for historical periods see Table 5

Agriculture on such soils—today totally unviable—is an indicator of stress in agrarian production. Under this presumption, the situation seems to have been most critical between the 8th and 10th century AD, which is surprisingly early.

Among the ruderals—in contrast to the crop weeds—most observed species are still common in the region. Very rare today is *Conium maculatum*, present with 16 pollen grains.

The grassland group is smaller. Most of its members occur since prehistoric times, at that time indicating not meadows, but fallow land and forest fringes. Among the taxa of dry grassland and heath land, one half occurs from since the Neolithic, another big group from since the Bronze Age, while only a few from not before historic times. They indicate animal browsing in more or less disturbed woodland. Today very rare or even lacking in the region are *Jasione montana* and *Eryngium campestre*. The taxa originating from wet grassland mainly occur from since the Neolithic, only few from since the Bronze Age or historical times. Their biotope is disturbed woodland on wet soils near lake shores.

Among the rare woodland species most are indigenous. An example is *Hippophaë rhamnoides*, which most probably disappeared from the region after the Late Weichselian, but returned later, most probably re-introduced by man. The earliest grain is from the Bronze Age, but most pollen grains are Medieval or younger. *Larix*-type corresponds to either *Larix decidua* or *Pseudotsuga mendziesii*. Both are not indigenous, but were introduced as forest trees not before the 18th century AD. Most of the 112 pollen grains are indeed of very young age, but the oldest is from the 7th century AD. Most of the water plants occur rather early, which is not surprising, because they belong to the natural vegetation of the lake and its shores.

Discussion

The zonation of the Litzelsee profile does fit well into the regional framework. It can be concluded that the pollen record is thus complete and does not feature any hiatus, which even with profundal cores is not always the case. In Fig. 5 regional pollen zones (RPZ) for all Western Lake Constance pollen profiles and their respective ages are displayed. This compilation shows very clearly that the vegetation development in the Western Lake Constance area is quite homogenous insofar as it is possible to define the same regional biostratigraphical zones in all profiles. The absolute dating however reveals that these units are of variable length and timing. The "dogma" of absolute synchrony of biostratigraphical units comes from a time when pollen stratigraphies were of lower resolution and were not dated by numerous radiocarbon dates and hence the biostratigraphical correlation was the only mean of dating. Still, chronologies have to be interpolated between dated samples and this might well be a source for mistakes as the sedimentation rate between two dated samples might change.

The asynchrony of the respective pollen records is important for the assessment of human impact. Most of the analysed archives are small lakes with a limited pollen source area. Previous studies have shown that pollen assemblages from large sites (>100 ha) tend to be stable in a given region and that assemblages from smaller lakes are more sensitive to local variations (Berglund 1973; Jacobson and Bradshaw 1981; Sugita 1994, 2007). If such local variations occur in parallel in several small lakes it can be concluded that they express a rather regional than local phenomenon—hence if there is human impact recorded in all profiles then it is highly probable that the whole region was used and not only the respective pollen source areas. The well dated pollen stratigraphies allow on the other hand the spatial assessment of settlement and land use dynamic. The Litzelsee profile reflects the regional vegetation development but with local variations. It features for example a very short reforestation phase (RPZ F2) between two major *Corylus* phases.

Human impact is recorded in the Litzelsee profile in all prehistoric and historic periods but the pollen record also permits the differentiation of land use techniques. In the Lake Constance area *Fagus* immigrates around 7,200 BP and has a first expansion during the Middle Neolithic. This is of great importance as it alters the forests to a high degree. *Fagus* is a shade tolerant tree—the saplings do tolerate shading and can thrive in the undergrowth of the light oak forests. Pollen influx studies show that while the *Fagus* influx increases the *Quercus* influx does not decrease (Lechterbeck 2001). Once grown, the *Fagus* trees do shade the ground to a great extent, which is not tolerated by light demanding trees. The consequence is that these trees do not regenerate and *Fagus* will further expand. The forests will become darker and denser with less undergrowth. This has considerable consequences for the people and also for wild animals. Kreuz (2008) points out that several wild animals and also livestock are grazers or do at least require some grass—which does not grow under the beech trees. People would have to cope with this new situation. Due to the expansion of *Fagus*, the forest is denser and darker and the effort for clearing would be greater. The expansion of arable land to less fertile soils does require more extensive techniques. As fertilizer is not sufficiently available, the arable fields would often have to be shifted. This leads to open spaces and forest fringes, which are gradually reforested but allow light demanding species to thrive for a while. Thus these plots offer a habitat for a variety of species, such as hazelnuts, berries, grass and apples to name but a few. They can also be grazed by livestock and attract wild animals. If the arable fields are burned, then the area which has to be cleared has to be three times as large as the actual field which would extend the relatively favourable open areas and fringes even more. The effect on the pollen record of such a land use technique is a strong decrease in *Fagus* and a considerable increase in *Corylus*—which would profit from the clearing and the burning and is a strong pollen producer—and a considerable amount of micro charcoal. Both these effects are clearly visible not only in the pollen record of Litzelsee but in all profiles from the region: changing land use intensity caused a typical pattern of alternating *Fagus* and *Corylus*/*Betula* peaks. Similar patterns can be observed in other regions such as the central Swiss plateau (e.g. Lobsigensee, Ammann et al. 1985). This kind of agriculture was probably widespread in temperate Middle Europe though clear evidence is lacking up to now. There are hints that very similar land use techniques were practised during the early Funnel Beaker culture (Kirleis and Fischer 2014) but the pollen record is ambiguous (e.g. Dörfler et al. 2012; Wiethold 1998) as the pollen record does not feature the typical patterns recorded in the alpine foreland. The question remains whether the slash and burn cultivation of the Neolithic is a direct reaction to the vast expansion of *Fagus* or whether *Fagus* just makes it more easily visible in the pollen record as the species does not tolerate burning.

At the end of the Neolithic a new land use system is established. With the introduction of the plough, larger, more extensively worked permanent fields are created and new cultivars, such as spelt, are introduced (Lechterbeck et al. 2014a). At the same time, the first grassland occurs. In the pollen record this can be seen by a considerable rise of non-arboreal pollen and cultural indicators. The interdependency between *Corylus* and *Fagus* ends; from now on the rise of secondary forest elements is no longer a sign of increasing human impact but of the beginning of a reforestation phase and thus in fact decreasing impact. This kind of land use system leads to the managed forest systems of the Iron Age and actually to the cultural landscape of today.

Because the counted pollen sum per sample of the Litzelsee profile was very high, rare pollen species occurred in a considerable number. One aim of this study was to analyse whether they have any ecological meaning. In Fig. 7 the rare pollen species (present in less than 5 % of the samples) and their occurrences are summarized in ecological groups. These species are present through all times but a general increase toward the younger periods of prehistory, the Medieval and Modern Times can be observed. With the onset of the Neolithic, taxa representing ruderals, grassland and shrub land become visible. This might well reflect the effect first farmers had on the landscape by creating new ecological niches.

It is striking that rare pollen of cultivated plants occurs mainly from the Medieval onwards and so clearly shows that pollen of these species is included in the pollen record only in largely open, agriculturally dominated landscapes. Though open land is already present in the Bronze Age it seems that the degree of openness in prehistoric times is not sufficient to allow a larger precipitation of pollen from cultivated plants. Another aspect is the variety of cultivars which becomes more extensive from the Roman period onward. In the Litzelsee profile however, the high amounts of rare species in modern times are mostly due to high values of *Platanus orientalis* and *Zea mays*. Crop weeds on the other hand start to occur regularly from the Bronze Age onwards. This is in accordance with the introduction of the ploughing economy at the end of the Neolithic. Prior to that crop weeds in the modern sense do not occur. Ruderal plants and indicators for grassland and fallow land appear regularly from the beginning of the Neolithic. They can be seen in connection with agricultural and settlement activities in the source area of the Litzelsee.

In the Late and Final Neolithic an increase in several wood/shrub land taxa is recorded. This is in accordance with high amounts of *Corylus* which indicate vast areas of shrub and secondary forest vegetation. Microcharcoal is much more frequent in the Later Neolithic than before and afterwards, indicating the importance of burning processes. Interestingly, indicators for grassland and ruderals are only slightly better represented in the Bronze Age than in the Neolithic.

Despite the fact that the component of rare species certainly contains also species the pollen of which must be long distance transported, our analysis shows that pollen grains of this component also are ecologically meaningful and should be regarded as real ecological evidence for soil conditions or agricultural techniques. The Caucalidion associations are a good example of this; the crop weed communities of dry calcareous soils belonging to this group are today very rare and endangered. In the early days of phytosociology during the first half of the 20th century, when vegetation documentation with modern methods started, this group was already in a late stage of disappearance, caused by the intensification of agriculture since the 19th century (cf. Oberdorfer 1957). Therefore botanists found these plants only in a few regions with calcareous soils, and the common opinion was that their distribution reflects the geological conditions. Archaeobotanical macrofossil on-site evidence, for example for *Orlaya grandiflora* in the Roman period, outside these limestone areas was interpreted as food import (Körber-Grohne and Piening 1983). On-site evidence is still scattered in time and space and difficult to interpret. The western Lake

Constance region does not belong to those limestone areas where this plant association is expected, and floristic observations are lacking (Sebald et al. 1990–1998). Floristic examination of south-west Germany covers the last two centuries. The archaeobotanical record of the Late Bronze Age and High Medieval period is very scattered (Märkle 2005; Rösch 2008; Rösch and Günther 2015). In particular for *Orlaya grandiflora*, which, for an entomogamous species, is rather well represented in the pollen record, there is now proof from several pollen diagrams that this species did occur regularly and with high frequency in the lake Constance region from the Late Bronze Age to the 19th century AD. Several other species of the Caucalidion are also present in the pollen record, but less frequent, all reflecting the ecological conditions triggered by agriculture, which determines their occurrence rather than geology. Due to soil erosion most topsoils were thin, especially on slopes, and with low water capacity, the competition between crop and weeds was weak, and the yields were low. The weeds were distributed over long distances by migrating domestic animals, whereby fruits with spines like *Orlaya* or *Caucalis* had an advantage. From scattered finds of their pollen grains in high-resolution pollen profiles of Nordschwarzwald and Allgäu, regions where these plants were not expected at all, we can guess that the Caucalidion was more or less ubiquitous between Late Bronze Age and early Modern Ages in Central Europe and adjacent regions reflecting the tenuous situation of extensive ard agriculture. In north and north-west Europe, the extensive ard agriculture resulted in extended heath land which is well reflected in the pollen record, and in crop weed communities on acidic soils (Arnoserdion) which are difficult to detect in the pollen record (Behre 1993, 2008). In both cases the extensive pastures are well represented in the pollen record, however the fields are represented badly. Whereas in Central Europe *Orlaya* is a more or less obligate crop weed, it occurs in southern Europe mainly in dry forest fringes and is frequent in some pollen records since the Bronze Age (Perego et al. 2011).

At Litzelsee, *Orlaya* is recorded for the first time in the 6th century AD. It is present in five to seven samples per century from the 7th to the 10th century, becomes less frequent from the 11th to the 16th century, is frequent again in the 17th century, declining afterwards. The last pollen grain dates to the early 19th century. This confirms only partly the ideas of the development of agriculture and human population drawn from written sources and shows the need for more interdisciplinary research.

Interestingly, during the Neolithic there is no evidence of specific crop weeds at all, clearly indicating that Neolithic agriculture was totally different to that we know today.

Conclusions

The pollen profile from Litzelsee is the fifth published standard pollen profile in the Western Lake Constance area, after Durchenbergried, Hornstaad, Steißlinger See and Mindelsee. The publication of further profiles from Mainau, Buchensee, Böhringer See and Gnadensee is in preparation. The Litzelsee profile allows some deductions of general importance: a central core from a small lake reflects the regional vegetation history generally, but in detail it shows a local picture, at least since the onset of human impact in the middle Holocene. The changes of human impact intensity during the late Neolithic are most clearly expressed by the changing *Fagus/Corylus* ratio, visible in many pollen profiles in the northern pre-Alpine lowlands (cf. Ammann et al. 1985; Ammann 1989). It becomes clearly visible that human impact and land use are not synchronous on a regional scale but high-resolution pollen profiles like the Litzelsee profile allow the assessment of the dynamics of land use and settlement in time but also in space as part of a regional framework. Inside this framework the Litzelsee profile throws light on the prehistoric land use: Bronze Age and Iron Age and later land use is characterized by a permanent opening of the forest, caused by extensive ard cultivation and animal browsing, whereas the land use of the Younger, Late, and perhaps also Final Neolithic was totally different, not creating permanent open land. Whereas for the Early Neolithic extensive garden cultivation is most probable (e.g. Bogaard 2004), we would suggest for the land use system of the later phases of the Neolithic the term ‘extensive fire cultivation’, as a synonym for slash-and-burn cultivation as a specific form of shifting cultivation (Rösch 1987; Rösch et al. 2014a, b). Evidence for this kind of agriculture are the numerous finds of microcharcoal in the pollen samples which are very frequent in the Neolithic indicating that fire played a major role in forest management (see Fig. 2) and the expansion of secondary forest elements such as *Corylus* and *Betula*.

With high time resolution and a high pollen sum counted in each sample, even rare, non wind-pollinated pollen taxa are registered with such regularity that they can be interpreted in terms of land use and landscape ecology. This allows better insight into environmental conditions and changes. The Caucalidion for example—today a plant community that has almost disappeared and is very much restricted to special stands on dry calcareous soils—seems to have been more widespread from the Bronze Age to the Medieval, also occurring on different soil types indicating rather bad soil conditions under extensive ard cultivation.

High resolution pollen profiles state not only the presence of rare species, but reflect their frequency changes, for example decreases during times when, as a consequence of economic collapse, soils and vegetation could recover and these taxa as indicators of ecological stress disappeared. The example of the Caucalidion illustrates the additional scientific benefit which can be gained from the counting of high pollen sums as it allows at best tracing the development of a certain plant community through time and thus deriving ecological and economical conclusions from this. This is also of high value in combination with on-site macro remain analysis.

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