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Böhringer See, western Lake Constance (Germany): an 8500 year record of vegetation change

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Abstract
During the last 35 years, a number of high-resolution pollen diagrams were made for the western Lake Constance area. Up to now, 12 such records exist, most of them covering the time from the early Neolithic to the present, and all of them independently dated by accelerator mass spectrometry (AMS) radiocarbon dates. Here, we present a new pollen record from Böhringer See, a small dead ice lake, analysed in the course of a project on land-use change in the Neolithic and Bronze Age. Pollen analysis was carried out in closed sampling in 1 cm or 0.5 cm sections, amounting to 465 samples. For all samples at least 1000 terrestrial pollen were counted and 334 taxa were identified. Twenty-three local pollen assemblage zones were distinguished covering the time from AD 6400–2000. The pollen record fits well into the regional framework. It depicts the regional vegetation development and human impact in detail but shows also minor local variations to the regional development featuring some original, local traits. The pollen record is rather similar to that from Litzelsee and Steisslinger See, both of which are located in close vicinity to the Böhringer See. The older pollen zones correlate very well chronologically with all pollen records in the area, the younger ones (from the Neolithic onwards) show stronger differentiation with regard to the duration and timing of pollen zones and the intensity of human impact. The raw data for this study will be published in the European Pollen Database.

Keywords: *pollen analysis, Böhringer See, western Lake Constance area*

During the last 35 years, a number of high-resolution pollen studies have been carried out at Lake Constance and at smaller dead ice lakes and mires in the vicinity (Rösch 1983, 1985a, 1985b, 1990, 1991, 1992, 1993, 1997, 2002, 2013; Lechterbeck 2001; Wick & Rösch 2006; Lechterbeck et al. 2014a, 2014b; Rösch & Lechterbeck 2016; Rösch & Wick 2019a, 2019b). Up to now, 12 such records exist (Figure 1, Table I), most of them covering the time span from the early Neolithic to the present day; all of them are independently dated by accelerator mass spectrometry (AMS) radiocarbon dates on terrestrial material. 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 longsettled landscapes in Europe. The archives of the region allow to study the development and intensity of human influence over time in great detail and resolution.

Böhringer See is one of them and was analysed in the course of a project on land-use and land-use change in the Neolithic and Bronze Age (DFG grants PL 95/39 and RO 2282/8).

Material and methods

Site details

The western Lake Constance region extends over an area of *c.* 800 km^2 at elevations between 395 and 750 m above sea level (a.s.l.). The climate is sub-oceanic, with annual mean temperatures of 9 °C and an annual precipitation of 900 mm. Most common

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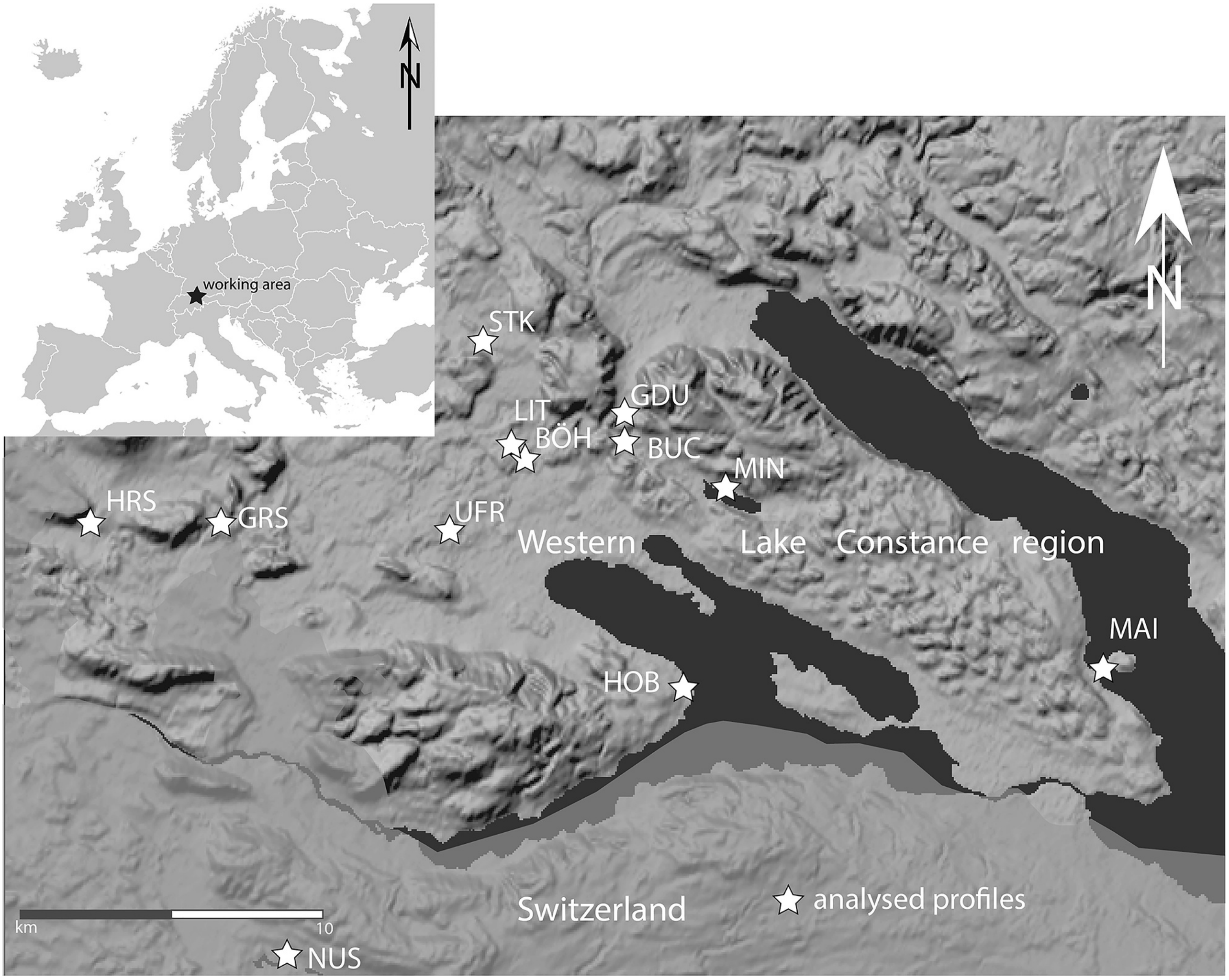

Figure 1. Map of the working area showing all analysed archives in the region. For details see Table I.

soils are luvisols and haplic luvisols on glacial tills or Mollassic sandstones. The potential natural vegetation would be deciduous woodland dominated by *Fagus sylvatica*. The actual vegetation is dominated by farmland. The Böhringer See (Lake Böhringen, 8° 56′ 18″ E, 47° 45′ 47″ N, 406 m a.s.l.) is situated in the Northern alpine foreland in the western Lake Constance area. It has a size of 5.1 ha and a maximum depth of 9 m. The lake is surrounded by farmland in the south, by woodland in the west and east, and by wet meadows in the north. In the south at a distance of 400 m, the village of Böhringen is located.

A sediment core of 7 m length, in seven segments of 1 m each, was retrieved from the lake's centre at 9 m water depth using a modified Livingstone sampler (Merkt & Streif 1970). The sediments consisted of calcareous lake marl and mud on top of glacial clay and silt. Apart from pollen analysis, organic and inorganic carbon was measured by loss-on-ignition (LOI) at 1 cm intervals. The 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 measuring the difference between dry weight and ash the samples were heated again to 925 °C for 4 h to combust inorganic carbon from calcite (procedure after Berglund & Ralska-Jasiewiczowa 1986).

Dating

For radiocarbon dates, terrestrial plant macro remains were extracted by sieving sediment samples with a mesh size of 0.5 mm. Plant remains were selected under a stereo microscope. It was not always possible to determine the plant remains to species level as these were mostly leaf fragments, bud scales, bark, charcoal and twig fragments.

Table I. Details and references for all analysed pollen profiles in the western Lake Constance area.

No	Code	Site	Coordinates N	Coordinates E	Above sea level (m)	Size (ha)	Maximum depth (m)	Core length (m)	Pollen ^{14}C Reference levels (m)	Dates	Reference
1	MAI	Mainau-Obere Güll	47° 42′ 20″	9° 11′ 01″	394	473 km^2	2/147	14	985	19	Rösch and Wick (2019a)
2	MIN	Mindelsee	47° 45′ 20″	9° 01′ 22″	406	100	14	6	402	15	Rösch (2013); Rösch et al. (2014a, 2014b)
3	BUC	Buchensee- Südost	47° 46′ 01″	8° 59′ 05″	431	1.6	2	9	797	8	Rösch and Wick (2019b)
4	BÖH	Böhringer See	47° 45′ 48″	8° 56′ 18″	409	5.1	9	7	525	15	Lechterbeck, Rösch, this article
5	LIT	Litzelsee	47° 46′ 08″	8° 55′ 50″	413	1.3	8	7	449	28	Rösch and Lechterbeck (2016)
6	UFR	Feuenried	47° 44′ 40″	8° 54′ 13″	406	11.4	N/K	5	161	33	Rösch (1985a)
7	STK	Steisslinger See	47° 47′ 57″	8° 55′ 01″	450	11.3	20	6	464	11[a]	Lechterbeck (2001)
8	GRS	Grassee	47° 44' 30"	8° 48' 9"	439	16.7	N/K				Lechterbeck, unpublished.
9	HAR	Hardtsee	47° 44' 29"	8° 45' 11"	436	8	N/K				Lechterbeck, unpublished.
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 Philippe (1998); Rösch (1983, 1985b)

The chronology is based on 21 mass spectrometer carbon-14 (^{14}C) dates measured on terrestrial plant material (Table II). The dates were calibrated with the OxCal radiocarbon calibration program and a time-depth model (Figure 2) was constructed using Bayes modelling (Bronk Ramsey et al. 2008).

Pollen analysis

After the initial pollen analysis with sampling intervals of 10 cm carried out by one of the authors (MR) the upper part of the core starting with the first occurrence of *Fagus sylvatica* (400 cm) was sampled in continuous intervals: between 349 and 260 cm in 0.5 cm, between 260 and 2 cm (top of core) in 1 cm distances. This amounted to a total of 464 samples. One of the authors (JL) analysed all samples up to 260 cm, MR all samples from 260 cm to the top.

Preparation of the samples for pollen analysis was done using hot hydrochloric acid (HCl), hot hydrogen fluoride (HF), hot potassium hydroxide (KOH) or chlorination, and acetolysis (Berglund & Ralska-Jasiewiczowa 1986).

The material was stored in glycerol and the analysis was carried out on unstained mounted slides. For pollen determination Beug (2004), Punt (1976, 1980, 1981, 1984, 1988, 1991, 1995, 2003), Reille (1992) and the reference collection of the Laboratory for Archaeobotany at the Landesamt für Denkmalpflege Baden-Württemberg were used. The data were recorded and processed using the programs Taxus (Schnelke unpublished) and Tilia (Grimm 1991).

All samples were counted up to a pollen sum of 1000 terrestrial pollen grains, Cyperaceae, water plants, moss spores and pteridophytes were excluded from the pollen sum. Of the 334 pollen taxa identified only the most common and important could be documented in the pollen diagram (Figures 3, 4). They are shown as percentages of the terrestrial pollen sum. The zonation of the diagram was done with CONISS (Grimm 1987). Twenty-three local pollen assemblage zones (LPAZs) can be distinguished.

Results

Local pollen assemblage zones

LPAZ 1 (6391–5705 BC, 399–392 cm). — The pollen record is dominated by *Corylus* and *Quercus*, accompanied by other taxa of the oak-mixed-forest (*Quercetum mixtum*, QM) such as *Acer*, *Fraxinus*, *Ulmus* and *Tilia*. The low values of *Alnus* indicate that *Corylus* also dominated on wet stands. Based on the continuous curve, *Fagus* is already present in the vegetation, although with low percentages.

LPAZ 2 (5705–5150 BC, 392–384.5 cm). — *Quercus* is more abundant than *Corylus*, while all other QM taxa remain unchanged. *Fagus* is spreading further, which indicates that *Fagus* might have replaced *Corylus* on well-drained sites.

Table II. Radiocarbon dates measured on terrestrial macro remains for the profundal of Böhringer See.

Lab.-Nr. MAMS	Depth (cm)	C^{14} Age	±	^{13}C	Cal 1 sigma	Cal 2 sigma
11475	226–228	1259	24	−10.6	AD 692–774	AD 672–857
11476	280–281	2371	74	−3.9	734–382 BC	763–233 BC
11477	293–294	2418	38	−26.1	716–406 BC	750–399 BC
11478	308–310	2777	39	−15.8	977–849 BC	1012–830 BC
11479	315–318	2897	33	−30.8	1126–1018 BC	1246–980 BC
11480	318–319	3072	35	−25.6	1399–1311 BC	1423–1262 BC
11481	320–322	3447	32	0.7	1870–1693 BC	1879–1687 BC
11482	325–326	3549	46	−35.6	1952–1777 BC	2020–1751 BC
11483	327–328	3869	61	−31.1	2461–2236 BC	2546–2143 BC
11484	330–332	3804	36	−29.5	2293–2151 BC	2454–2136 BC
11485	333–335	3858	29	−14.6	2453–2235 BC	2461–2209 BC
11486	335–336	3802	35	−28.0	2290–2152 BC	2432–2136 BC
11487	336–340	3891	39	−26.8	2462–2310 BC	2473–2211 BC
11488	343–344	4159	47	−32.9	2872–2676 BC	2885–2586 BC
11489	345–346	4221	43	−34.6	2897–2705 BC	2910–2668 BC
11491	352–354	4237	40	−28.4	2904–2762 BC	2917–2679 BC
11492	354–356	4486	32	−22.1	3331–3099 BC	3344–3032 BC
11493	356–358	4547	44	−46.0	3365–3117 BC	3487–3098 BC
11494	362–364	4758	58	−40.8	3637–3385 BC	3645–3376 BC
11495	364–366	4894	32	−42.8	3694–3650 BC	3759–3638 BC
11496	402–404	7739	61	−33.1	6632–6504 BC	6678–6460 BC

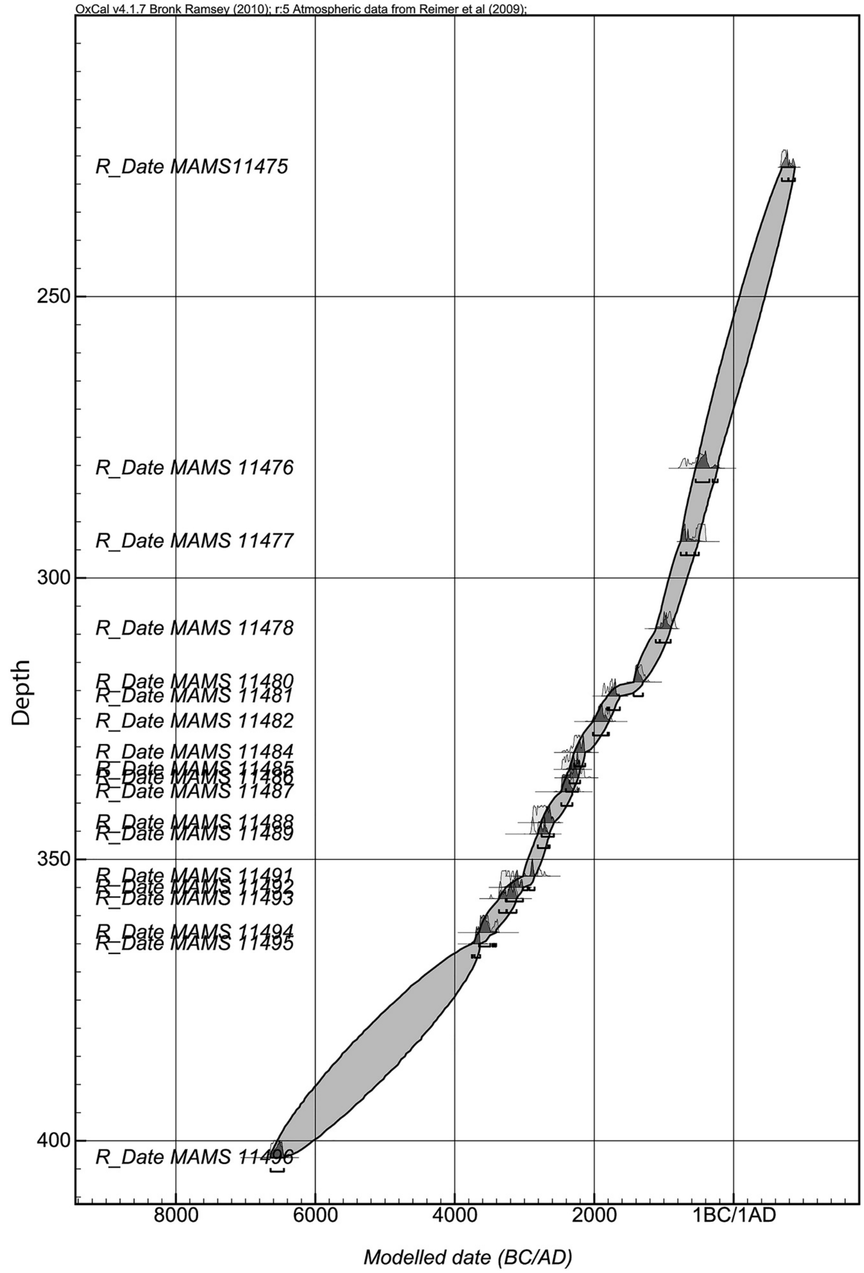

Figure 2. Time-depth model based on radiocarbon dates, Table II

LPAZ 3 (5150–4654 BC *384.5–378 cm)*. — A first strong increase of *Fagus* is recorded. This increase is accompanied by a decline in *Quercus*, *Corylus* stays roughly at the same level and the increase of *Alnus* towards the end of the zone shows that *Alnus* is now beginning to spread on wet stands as well. The end of the zone is characterised by a massive decline in *Fagus*, a strong increase of *Corylus* and the final *Ulmus* decline.

LPAZ 4 (4654–4150 BC*, 378–371.5 cm)*. — *Corylus* has a second maximum. There is also a slight increase in non-arboreal pollen (NAP). – mostly grasses, which might indicate the presence of open spaces. Otherwise, there are almost no indicators for human impact.

LPAZ 5 (4150–3532 BC*, 371.5–362.5 cm)*. — A forest regeneration phase with the spreading of *Fagus* occurs. As mentioned before this is a regional feature because alternating *Corylus*- and *Fagus*-peaks can be observed between 7000 and 2000 BP roughly corresponding with the Younger Neolithic (for a summary see Lechterbeck et al. 2014a; Rösch & Lechterbeck 2016).

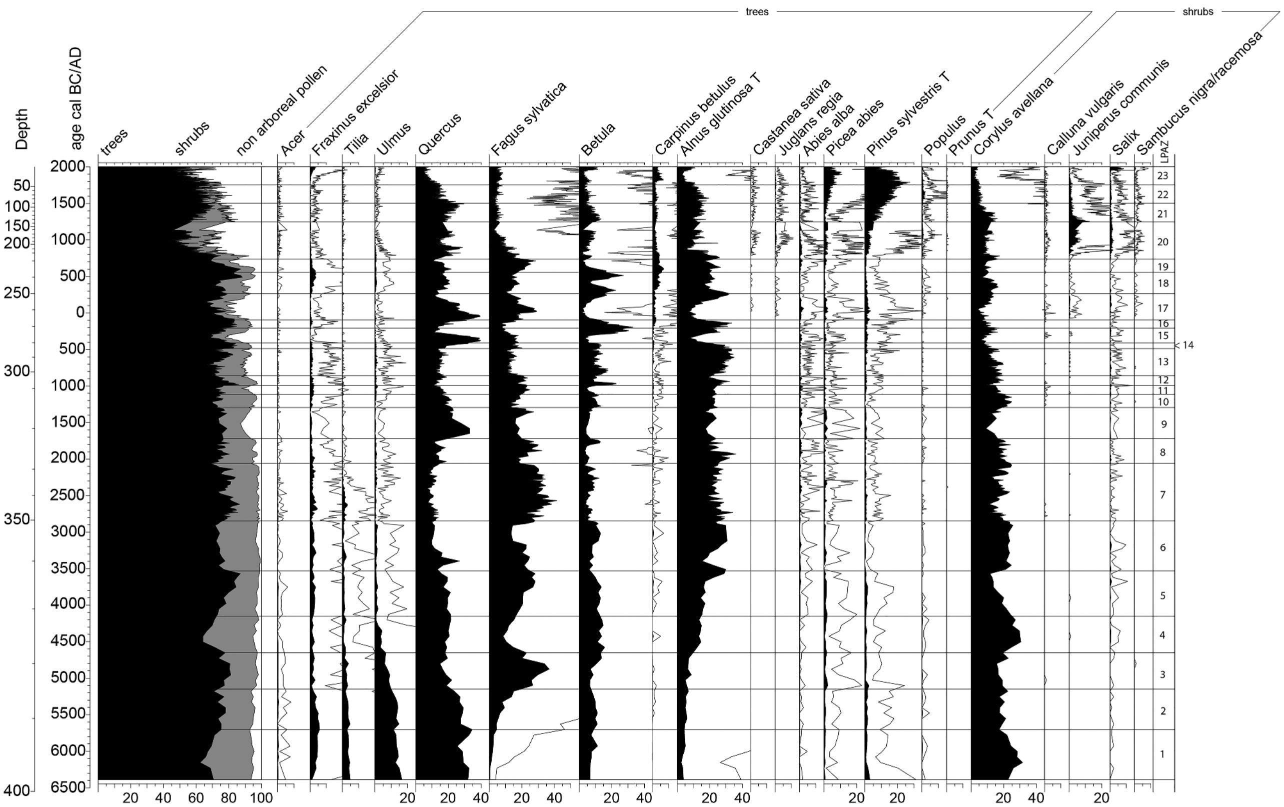

Figure 3. Pollen diagram from Böhringer See (western Lake Constance area, Germany). Selected tree and shrub pollen, plotted against age (cal BC/AD) and depth. White curves are exaggerated 10 ×.

LPAZ 6 (3532–2849 BC, 362.5–350.5 cm). — *Cory-*Corylus has another maximum, but now also *Betula* and *Alnus* increase. In the course of the Neolithic slash-and-burn cultivation, new plots were opened, cultivated for a short time, and then left again to reforestation and the cultivation plots were opened elsewhere. This zone corresponds to the Late Neolithic.

LPAZ 7 (2849–2061 BC, 350.5–328.5 cm). — *Fagus* is dominating for a rather long period. During these almost 800 years, the human impact near the lake was very weak and the forest could re-establish. However, the presence of *Plantago lanceolata* and *Artemisia* evidence human presence and animal browsing. Corresponds to the Late and Final Neolithic and the Earliest Bronze Age.

LPAZ 8 (2061–1721 BC, 328.5–321 cm). — The pattern of alternating *Corylus* and *Fagus* peaks indicating changes of land-use intensity is replaced by a different pattern: For the first time, land use is recorded by high values of non-arboreal pollen and *Quercus* peaks. At the end of this phase, *Corylus* and/or *Betula* peaks indicate a decrease of land use and reforestation of open land. The pattern is fairly distinct in this zone, but less pronounced than in subsequent pollen zones. It is accompanied by an increase of cultural indicators such as *Artemisia* and *Plantago lanceolata* and by a now quite continuous presence of various cereal pollen grains (*Hordeum* type, *Triticum* type). Cereal pollen grains were already recorded in the lower parts of the profile but not as regularly as now. This zone corresponds to the Early Bronze Age.

LPAZ 9 (1721–1294 BC, 321–316.5 cm). — This short zone consists of a strong *Quercus* peak and a rise in non-arboreal pollen All other arboreal pollen decline. It is a phase reflecting strong human impact. During the Middle Bronze Age, the specific kind of land use is indicated that had been practised since the Early Bronze Age and was based on extensive ard cultivation and animal browsing.

LPAZ 10, (1294–1113 BC, 316.5–312 cm). — A short reforestation phase with decreasing land-use activity during the transition from the Middle to the Late Bronze Age.

LPAZ 11 (1113–992 BC, 312–309 cm). — A short rise in NAP and cultural indicators occur; probably

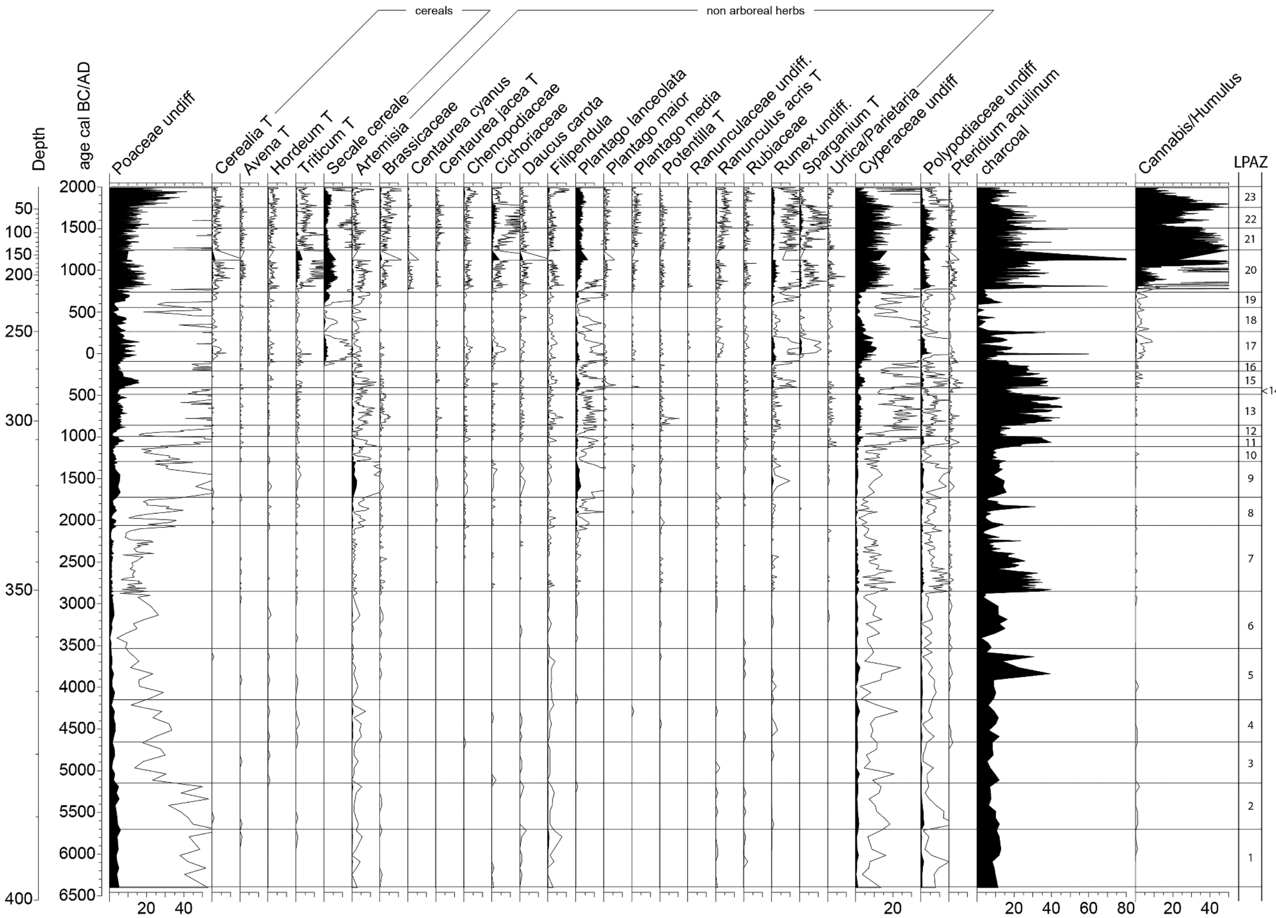

Figure 4. Pollen diagram from Böhringer See (western Lake Constance area, Germany). Selected non-arboreal pollen, spores of ferns and charcoal plotted against age (cal BC/AD) and depth. White curves are exaggerated 10 ×.

quite local as the arboreal pollen as well as the NAP peaks coincide with a *Fagus* maximum. This pollen zone corresponds to the older part of the Late Bronze Age.

LPAZ 12 (992–858 BC*, 309–302.5 cm).* — A strong decrease of NAP and human indicators, a short *Betula* maximum and afterwards an increase of *Fagus* indicates farmland abandonment during the younger part of the Late Bronze Age.

LPAZ 13 (858–487 BC*, 302.5–284 cm).* — Quite a long zone with high NAP and cultural indicator values. The very high *Alnus* values indicate that the nearby lake was not affected by human impact. This zone starts with the Bronze Age/Iron Age transition and covers the older part of the pre-Roman Iron Age, obviously a long phase with strong human impact and not much change in the land-use intensity.

Towards the end of the zone, the common pattern of a rise of *Betula* followed by a rise of *Fagus* indicating reforestation and less land-use pressure can be observed.

LPAZ 14 (487–408 BC*, 284–280 cm).* — This is a short phase of decreased land-use intensity with some reforestation. However, human impact does not cease altogether. The pollen record of the nearby lakes Steißlinger See and Litzelsee show similar patterns at this time (Lechterbeck 2001; Kerig & Lechterbeck 2004; Rösch & Lechterbeck 2016).

LPAZ 15 (408–296 BC*, 280–275 cm).* — The strong *Quercus* peak in connection with an increase in NAP as well as a decrease in *Alnus* and *Fraxinus* indicates that during this phase land use again increased close to the lake. It is a very distinct phase, corresponding to the late Latène period, which is also present in the profiles of Litzelsee and Steißlinger See (see earlier).

LPAZ 16 (296–94 BC, 275–266 cm). — Very distinct increases of *Betula, Alnus* and *Fraxinus* indicate an initial reforestation, all cultural indicators and other NAP decline. This is the younger part of the late pre-Roman Iron Age.

LPAZ 17 (94 BC–AD 265, 266–250.5 cm). — A strong land-use phase, followed by a decline of land use and increase of *Betula* and *Alnus*. This is the first phase when *Secale cereale* is recorded regularly and in large quantities and the *Cannabis*/*Humulus* curve becomes continuous.

LPAZ 18 (AD 265–557, 250.5–237 cm). — This zone covers two *Betula* maxima, separated by an increase of *Corylus, Quercus, Fraxinus*; NAP are decreasing. Overall, this is a reforestation phase though with some fluctuation. The cultural indicators and the charcoal values are very low throughout the zone.

LPAZ 19 (AD 557–737, 237–229 cm). — A last *Fagus* maximum together with high *Alnus* and low NAP values indicate weak human impact and a wet climate. Towards the end of this zone, NAP and anthropogenic indicators increase. The phase corresponds to the Merovingian period.

LPAZ 20 (AD 737–1247, 229–136 cm). — In this zone, the NAP values rise to very high values around 30%. *Juniperus* becomes very common indicating openness of the landscape. Cereal pollen and all other cultural indicators are very abundant. The openness of the landscape actually equals or even exceeds that of today. At the end of the zone, the *Cannabis* values rise to 60% of the pollen sum. This indicates retting of hemp in the lake as it is also recorded for Litzelsee and Steißlinger See. Human impact is increasing at the beginning, has a short decline in the eighth century, increases afterwards and remains at very high levels between the ninth and twelfth centuries. Afterwards it is decreasing slightly. The zone corresponds to the Early and High Medieval periods.

LPAZ 21 (AD 1247–1507, 136–90 cm). — *Quercus* becomes dominant again, after short and weak maxima of *Betula* and *Corylus*. The NAP sum is relatively low at the beginning but slowly increases throughout the zone with short decreases in the fifteenth century. *Juniperus* is less abundant; *Pinus* and *Picea* start to increase. A reduction of human impact is clearly visible.

LPAZ 22 (AD 1507–1755, 90–46 cm). — *Pinus* is increasing and becomes dominant. *Quercus* is less abundant but maintains high percentages. *Picea* and NAP are also slowly increasing. This zone corresponds to the early Modern times.

LPAZ 23 (AD 1755–2003, 45–2 cm). — This last zone is characterised by dominance of *Pinus* and a further increase of *Picea*. The NAP values rise again, because of a strong increase of Poaceae. Only in the uppermost centimetre, in the twentieth century, they decline. In the uppermost part, *Pinus* is slightly less abundant and *Carpinus, Alnus*, and *Betula* increase. NAP has a maximum of more than 50%.

The regional pollen biostratigraphy has long since been established (Rösch 1983, 1985a, 1985b, 1990) and was confirmed by further studies (Lechterbeck 2001; Kerig & Lechterbeck 2004; Rösch 2013; Rösch & Wick 2019a, 2019b). The zonation of the Böhringer See profile fits into this regional framework and we did not observe any hiatus.

Discussion

It is possible to directly compare the Böhringer See record to the closest neighbouring sites Litzelsee (Rösch & Lechterbeck 2016) and Steisslinger See (Lechterbeck 2001; Kerig & Lechterbeck 2004).

The most important factor for vegetation development in the originally forested parts of middle Europe is human impact. The scale and nature of past climate changes in the Holocene are either not likely to have a lasting effect on the stable, resilient climax vegetation of Middle Europe or the effects of climatic events are obscured by human action (Lechterbeck 2001). The picture is different for less stable ecosystems in fringe positions, for example at the tree line in the Alps or at high latitudes (e. g. Barnekow 1999; Bjune et al. 2005; Nussbaumer et al. 2011). The present climatic changes though have a magnitude that already affects hitherto stable systems – but also these changes are brought about by human action. One might say that this development starts with the onset of the Neolithic when humans started to not only exploit resources but also shape their environment to the needs of agricultural production. Pollen analysis allows to detect, quantify and qualify human impact (Behre 1981, 1986). In pollen diagrams, human impact on the landscape is mainly indicated by deforestation, visible as a decrease of tree pollen, by changes of the forest composition and structure, visible as fluctuating abundances of 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 recorded or were present only as single grains in the pollen record.

The pollen record of Böhringer See starts around 6500 BC with high amounts of *Corylus* and of oak mixed forest taxa between 6000 and 5100 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 cannot be detected at that time. However, it has been frequently discussed whether Mesolithic hunter-gatherers fostered hazel for the enhancement of nuts and wood resources. Hazelnuts provide a fat- and protein-rich food resource and were extensively used in the Mesolithic (e.g. Holst 2010, 2014; Groß et al. 2019). The presence of large amounts of charcoal in Mesolithic contexts in combination with nitrogen indicators and light indicators is seen as evidence for deliberate burning to favour the spreading of hazel (Bos & Urz 2003). Burning for the enhancement of hunting possibilities was discussed for the British Mesolithic (Bell & Walker 1992) but this could not be proven for the Lake Constance area (Clark et al. 1989). The Böhringer See profile has relatively high charcoal values at that time but that is a unique feature, as the neighbouring profiles do not have increased micro-charcoal values. The charcoal records of the Western Lake Constance region need a thorough analysis, which exceeds the scope of this article.

For the time between 5500 and 5000 BC – corresponding to the Linear Pottery Culture (LBK) period – some single cereal pollen grains are recorded. There are two grains of *Avena*-type which are almost certainly from wild oat as *Avena* was first cultivated in the pre-Roman Iron Age (cf. Behre 2007). Two single finds of *Triticum*-type pollen grains might be related to cereal cultivation in the area but otherwise no significant signs for human impact are recorded in the pollen record. LBK settlements are not known from the direct vicinity of the Böhringer See. LBK settlement in the area is concentrated in the Hegau region at a distance of more than 5 km from Böhringer See. Early Neolithic land use has only a small impact on woodland communities. Bogaard (2004) describes intensive garden cultivation as 'the most plausible and wide-spread 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 (2009) 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, the consequences of which are commonly invisible in the pollen record.

During the first half of the Middle Neolithic, the *Fagus* expansion takes place in the Böhringer See region. *Fagus* immigrates already around 6000 BC and investigations of pollen influx in Lake Steisslingen show that *Fagus* could spread without a decline of *Quercus* (Lechterbeck 2001; Kerig & Lechterbeck 2004). *Corylus* still prevails on wet stands.

It is possible that the previous clearance activities of Linear Pottery people supported the expansion of *Fagus*. As they are shade tolerant, the saplings of beech could survive under the canopy of the oak mixed forest and could then blend in the forest community on a small scale where single trees were felled or where larger clearings where made (Rösch 1990; Haas & Philippe 1998). 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 Böhringer See, some pollen grains of *Hordeum*-type occur in the Middle Neolithic. A first major phase of human impact is recorded at the transition to the Younger Neolithic: the *Fagus* curve declines dramatically, the curve of *Corylus* increases, also the values of *Artemisia* and *Plantago lanceolata* increase. This phase lasts up to 4000 BC, when the *Fagus* curve increases again. The nearby Litzelsee profile records an increase in charcoal during the *Corylus* increase (Rösch & Lechterbeck 2016) – a feature which is not visible in the Böhringer See record. The charcoal record might thus be a very local signal. The following phase, which is largely synchronous with the Young Neolithic Pfyn culture, is characterised by reforestation and a decrease of human impact. However, it does not cease altogether, some cereal pollen grains, *Plantago lanceolata* and *Artemisia* still evidence human activities. During the Pfyn culture – and the preceding Hornstaad phase – the first pile dwellings occur at Lake Constance. The Böhringer See 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 Böhringer See profile. This *Fagus* maximum is recorded in all profiles from the region, although it is not entirely synchronous. We 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). The charcoal curve has a peak in the second half of this phase – possibly indicating an opening of the forest in the vicinity of the lake. Once again, strong human impact occurs between 3300 and 2900 BC with an increase of the *Corylus* 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. The end of the Neolithic phase is characterised in the Böhringer See profile as a phase of reforestation and little human impact is visible though the charcoal values have a high maximum. Steisslinger See and Litzelsee record substantial human impact at that time. Thus, these impacts must have been small scaled and local.

Human impact in the Neolithic at Lake Constance is generally characterised by alternating *Corylus* and/or *Betula* and *Fagus* peaks. During phases with strong human impact in the Neolithic, NAP stay low, but micro-charcoal and other indicators of human impact – such as ruderals or even cereals – might be frequent. In the course of the assumed Neolithic slash-and-burn cultivation (Rösch et al. 2017), new plots were opened, cultivated for a short time and then left again to reforestation and the cultivation plots were opened elsewhere. This explains the similarity of the overall pattern as well as the lacking synchrony of the single *Fagus* and *Corylus*/*Betula* peaks in the different pollen records.

The assumption of Neolithic slash-and-burn cultivation is not undisputed (for example Baum et al. 2016; Jacomet et al. 2016; Rösch et al. 2017; Schier 2017). From a palynological point of view the extent of the observed vegetation changes and the massive increase in secondary woodland cannot be explained by permanently working of small plots – this would rather result in a LBK like vegetation pattern. Patterns similar to the typical alternating *Fagus* and *Corylus*/*Betula* peaks can be observed in other regions of the Lake Constance basin (e.g. Degersee, Mainberger et al. 2015) or the central Swiss plateau (e.g. Lobsigensee, Ammann 1989). This kind of agricultural technique was probably widespread in temperate Middle Europe though clear evidence is lacking up to now. Probably similar practises were in use during the early Funnel Beaker culture (Kirleis & Fischer 2014) but the pollen record is ambiguous (Wiethold & Erlenkeuser 1998; Dörfler et al. 2012). Whether the Neolithic slash-and-burn cultivation is a direct reaction to the vast expansion of *Fagus* or whether the presence of *Fagus* just makes it more easily visible in the pollen record remains to be discussed.

With the onset of the Bronze Age, the pattern changed. In the Bronze Age, land use is for the first time recorded by high values of non-arboreal pollen and *Quercus* peaks, accompanied by a rise of cultural indicators. A *Corylus* and/or *Betula* peak indicating the beginning of a reforestation marks the end of such phases of strong human impact. This new pattern reflects a change in land use: whereas Neolithic agriculture was mainly forest based, the Bronze Age land-use system had for the first time open spaces that were kept open for a longer period. This was also the time when grassland is indicated. However, *Quercus* peaks in a landscape, where *Fagus* had already been established, can only be explained by forest management. Evidence from pollen records and macro remains show that this development already started at the transition from the Neolithic to the Bronze Age in the region (Lechterbeck et al. 2014b). The end of the Bronze Age is marked by decreasing land-use pressure.

At the transition from the Bronze Age to the pre-Roman Iron Age there is a long phase of strong land use recorded, which ends with a short reforestation phase (*c.* 500–400 BC).

A major phase of abandonment is recorded in the period between *c.* 300 and 100 BC: distinct peaks of *Betula, Alnus* and *Fraxinus* witness an initial reforestation. All non-arboreal pollen as well as cultural indicators decline. Apparently, some land was abandoned. This might correspond – at least partly – to a major phase of land abandonment in the late pre-Roman Iron Age – the so-called 'Helvetier-Einöde', although the archaeological record and the written sources are ambiguous (Dobesch 1999).

The Roman occupation of the area occurred during the first century AD and the impact of the Roman land use is recorded in various ways in the different archives in the region.

Major changes in the land-use system occur between *c.* 100 BC to AD 270. Here, for the first time, *Secale* is recorded regularly and in large quantities and the *Cannabis*/*Humulus*-curve becomes continuous. Both features indicate major changes in land-use strategies regarding crops as well as weeds. The relatively small amounts of *Cannabis*/*Humulus* seem to indicate the growing of *Cannabis* rather than retting in the lake. At Steißlinger See (Lechterbeck 2001; Kerig & Lechterbeck 2004) and at Litzelsee (Rösch & Lechterbeck 2016) the hemp curve sets in roughly at the same time.

The migration period when Alemannic tribes occupied the northern shore of Lake Constance and the Roman economy declined, is recorded by a reforestation phase. Cultural indicators as well as charcoal values during this period are very low but do not disappear altogether. The early and high medieval period is characterised by high values of hemp indicating that now hemp retting takes place in the lake. Modern forest management becomes visible by the spread of *Picea*. The deforestation of the region reaches a maximum in the nineteenth century, during the twentieth century a reforestation is visible, mostly due to the expansion of deciduous trees and shrubs.

Conclusions

With the high-resolution and well-dated pollen record from Böhringer See a new pollen profile is added to the western Lake Constance area, which represents one of the most thoroughly analysed regions in Europe. The pollen record of Böhringer See fits well whithin the regional framework. Although the Böhringer See profile largely confirms the regional biostratigraphy, local traits are visible. Especially the charcoal record seems to carry a markedly local signal, as it is not even correlated with the charcoal record from nearby Litzelsee. It would be worthwhile to investigate the charcoal records of the region in more detail to see whether there is an underlying regional pattern.

The raw data presented here will be published in the European Pollen Database.

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References

Ammann B. 1989. Late-quaternary palynology at Lobsigensee - regional vegetation history and local lake development. Dissertationes Botanicae 137. Stuttgart: Schweizerbart.

Barnekow L. 1999. Holocene tree-line dynamics and inferred climatic changes in the Abisko area, northern Sweden, based on macrofossil and pollen records. The Holocene 9: 253–269. doi:10.1191/095968399676322637.

Baum T, Nendel C, Jacomet S, Colobran M, Ebersbach R. 2016. "Slash and burn" or "weed and manure"? A modelling approach to explore hypotheses of late neolithic crop cultivation in pre-alpine wetland sites. Vegetation History and Archaeobotany 25: 611–627. doi:10.1007/s00334-016-0583-x.

Behre K-E. 1981. The interpretation of anthropogenic indicators in pollen diagrams. Pollen et Spores 23: 225–245.

Behre K-E. 1986. Anthropogenic indicators in pollen diagrams. Rotterdam: Balkeema.

Behre K-E. 2007. Wo sind die Nachweise für mesolithischen Ackerbau in Mitteleuropa? Zum Diskussionsbeitrag von W. Schön und B. Gehlen in Archäologische Informationen 29. Archäologische Informationen 30: 53–57.

Bell M, Walker MJC. 1992. Late quaternary environmental change: Physical and human perspectives. Harlow: Longman.

Berglund B, Ralska-Jasiewiczowa M. 1986. Handbook of holocene palaeoecology and palaeohydrology. Chichester: Wiley.

Beug HJ. 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. München: Friedrich Pfeil.

Bjune AE, Bakke J, Nesje A, Birks HJB. 2005. Holocene mean July temperature and winter precipitation in western Norway inferres from palynological and glaciological lake-sediment proxies. The Holocene 15: 177–189. doi:10.1191/0959683605hl798rp.

Bogaard A. 2004. Neolithic farming in central europe: An archaeobotanical study of crop husbandry practices. London: Routledge.

Bos JAA, Urz R. 2003. Late glacial and early holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early mesolithic people—pollen and macrofossil evidence. Vegetation History and Archaeobotany 12: 19–36. doi:10.1007/s00334-003-0006-7.

Bronk Ramsey C, Yu ZC, Hoek WZ, Lowe JJ. 2008. Deposition models for chronological records. Quaternary Science Reviews 27: 42–60.

Clark JS, Merkt J, Müller H. 1989. Post-glacial fire, vegetation, and human history on the northern alpine forelands, southwestern Germany. Journal of Ecology 77: 897–925. doi:10.2307/2260813.

Dobesch G. 1999. Helvetiereinöde. Reallexikon der Germanischen Altertumskunde, Vol. 14, 2nd ed., 351–374. Berlin: Walter de Gruyter.

Dörfler W, Feeser I, van Den Bogaard C, Dreibrodt S, Erlenkeuser H, Kleinmann A, Merkt J, Wiethold J. 2012. A high-quality annually laminated sequence from lake Belau, northern Germany: Revised chronology and its implications for palynological and tephrochronological studies. The Holocene 22: 1413–1426. doi:10.1177/0959683612449756.

Grimm E. 1987. CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Computers & Geosciences 13: 13–35. 1 doi:10.1016/0098-3004(87)90022-7

Grimm E. 1991. Tilia and tiliagraph. Illinois State Museum 101, Springfield.

Groß D, Lübke H, Schmölcke U, Zanon M. 2019. Early mesolithic activities at ancient lake Duvensee, northern Germany. The Holocene 29: 197–208. doi:10.1177/0959683618810390.

Haas JN, Philippe H. 1998. Die Vegetations- und Kulturlandschaftsgeschichte des Seebachtals von der Mittelsteinzeit bis zum Frühmittelalter anhand von Pollenanalysen. In: Hasenfratz A, Schnyder M, eds. Das Seebachtal – Eine archäologische und paläoökologische Bestandesaufnahme (Archäologie im Thurgau 4), 221–255. Frauenfeld: Amt für Archäologie Thurgau.

Holst D. 2010. Hazelnut economy of early holocene hunter–gatherers: A case study from mesolithic Duvensee, Northern Germany. Journal of Archaeological Science 37: 2871–2880. doi:10.1016/j.jas.2010.06.028.

Holst D. 2014. Subsistenz und Landschaftsnutzung im Frühmesolithikum: Nussröstplätze am Duvensee. Mainz: Verlag des Römisch-Germanischen Zentralmuseums.

Jacomet S, Ebersbach R, Akeret Ö, Antolin F, Baum T, Bogaard A, Brombacher C, Bleicher N, Heitz-Weniger A., Hüster-Plogmann h, Gross E, Kühn M, Rentzel P, Steiner B L, Wick L, Schibler J. 2016. On-site data cast doubts on the hypothesis of shifting cultivation in the Late Neolithic (*c.* 4300-2400 cal. BC): Landscape management as an alternative paradigm. The Holocene 26: 1858–1874.

Kerig T. 2008. Als Adam grub … Vergleichende Anmerkungen zu landwirtschaftlichen Betriebsgrößen in prähistorischer Zeit. Ethnographisch-Archäologische Zeitschrift 48: 375–402.

Kerig T. 2013. Introducing economic archaeology: Examples from neolithic agriculture and hallstatt princely tombs. In: Kerig T, Zimmermann A, eds. Economic archaeology: From structure to performance in European archaeology. Universitätsforschungen zur Prähistorischen Archäologie 237, 13–28. Bonn: Habelt.

Kerig T, Lechterbeck J. 2004. Laminated sediments, human impact, and a multivariate approach: A case study in linking palynology and archaeology (Steisslingen, Southwest Germany). Quaternary International 113: 19–39. doi:10.1016/S1040-6182(03)00078-8.

Kirleis W, Fischer E. 2014. Neolithic cultivation of tetraploid free threshing wheat in Denmark and northern Germany: Implications for crop diversity and societal dynamics of the funnel beaker culture. Vegetation History and Archaeobotany 23: 81–96. doi:10.1007/s00334-014-0440-8.

Kreuz AM. 1990. Die ersten Bauern Mitteleuropas: Eine archäobotanische Untersuchung zu Umwelt und Landwirtschaft der ältesten Bandkeramik. Analecta Praehistorica Leidensia 23. Leiden: Institute of Prehistory, University of Leiden.

Lechterbeck J. 2001. “Human Impact” oder “Climatic Change”? Zur Vegetationsgeschichte des Spätglazials und Holozäns in hochauflösenden Pollenanalysen des Steißlinger Sees (Südwestdeutschland). Tübinger Mikropaläoontologische Mitteilungen 25. Tübingen: Institut und Museum für Geologie und Paläontologie der Universität.

Lechterbeck J, Edinborough K, Kerig T, Fyfe R, Roberts N, Shennan S. 2014a. Is neolithic land use correlated with demography? An evaluation of pollen-derived land cover and radiocarbon-inferred demographic change from Central Europe. The Holocene 24: 1297–1307. doi:10.1177/0959683614540952.

Lechterbeck J, Kerig T, Kleinmann A, Sillmann M, Wick L, Rösch M. 2014b. How was Bell Beaker economy related to corded ware and early bronze age lifestyles? Archaeological, botanical and palynological evidence from the Hegau, Western Lake Constance region. Environmental Archaeology 19: 95–113. doi:10.1179/1749631413Y.0000000010.

Mainberger M, Merkt J, Kleinmann A. 2015. Pfahlbausiedlungen am Degersee. Archäologische und naturwissenschaftliche Untersuchungen. Materialhefte zur Archäologie in Baden-Württemberg 102. Stuttgart: Theiss.

Merkt J, Streif H. 1970. Stechrohr-Bohrgeräte für limnische und marine Lockersedimente. Geologisches Jahrbuch 88: 137–148.

Nussbaumer S, Steinhilber F, Trachsel M, Breitenmoser P, Beer J, Blass A, Grosjean M, Hafner A, Holzhauser H, Wanner H, Zumbühl HJ. 2011. Alpine climate during the Holocene: A comparisonbetween records of glaciers, lake sediments and solaractivity. Journal of Quaternary Science 26: 703–713. doi:10.1002/jqs.1495.

Punt W. 1976. The Northwest European pollen flora 1: Parts 1–7. Amsterdam: Elsevier.

Punt W. 1980. The Northwest European pollen flora 2: Parts 8–20. Amsterdam: Elsevier.

Punt W. 1981. The Northwest European pollen flora 3: Parts 21–28. Amsterdam: Elsevier.

Punt W. 1984. The Northwest European pollen flora 4: Parts 29–37. Amsterdam: Elsevier.

Punt W. 1988. The Northwest European pollen flora 5: Parts 38–43. Amsterdam: Elsevier.

Punt W. 1991. The Northwest European pollen flora 6: Parts 44–51. Amsterdam: Elsevier.

Punt W. 1995. The Northwest European pollen flora 7: Parts 52–56. Amsterdam: Elsevier.

Punt W. 2003. The Northwest European pollen flora 8: Parts 57–68. Amsterdam: Elsevier.

Reille M. 1992. Pollen et spores d’Europe et d’Afrique du Nord. Marseille: Laboratoire de botanique historique et palynologie.

Rösch M. 1983. Geschichte der Nussbaumer Seen (Kanton Thurgau) und ihrer Umgebung seit dem Ausgang der letzten Eiszeit aufgrund quartärbotanischer, stratigraphischer und sedimentologischer Untersuchungen. Mitteilungen der Thurgauischen Naturforschenden Gesellschaft 45. Frauenfeld: Huber.

Rösch M. 1985a. Ein Pollenprofil aus dem Feuenried bei Überlingen am Ried: Stratigraphische und landschaftsgeschichtliche Bedeutung für das Holozän im Bodenseegebiet. Materialh. Vor- u. Frühgesch. Bad.-Württ. 7: 43–79.

Rösch M. 1985b. Nussbaumer Seen—Spät- und postglaziale Umweltveränderungen einer Seengruppe im östlichen Schweizer Mittelland. In: Lang G, ed. Swiss lake and mire environments during the last 15 000 years. Dissertationes Botanicae 87, 337–379. Vaduz: Borntraeger.

Rösch M. 1990. Vegetationsgeschichtliche Untersuchungen im Durchenbergried. Siedlungsarchäologie im Alpenvorland 2. Forschungen und Berichte zur Vor- und Frühgeschichte Baden-Württembergs 37: 9–56.

Rösch M. 1991. Ein Pollenprofil aus dem Profundal der Radolfzeller Bucht (Bodensee–Untersee). Fundber Bad-Württ 16: 57–62.

Rösch M. 1992. Human impact as registered in the pollen record: Some results from the western Lake Constance region, southern Germany. Vegetation History and Archaeobotany 1: 101–109. doi:10.1007/BF00206090.

Rösch M. 1993. Prehistoric land use as recorded in a lake-shore core at Lake Constance. Vegetation History and Archaeobotany 2: 213–232. doi:10.1007/BF00198163.

Rösch M. 1997. Holocene sediment accumulation in the shallow water zone of Lake Constance. Arch Hydrobiol,Suppl 107, (Monographic Studies) 4: 541–562.

Rösch M. 2002. Ein Pollenprofil von Wangen, Hinterhorn, Gemeinde Öhningen, Kreis Konstanz. Fundber Bad-Württ 26: 7–19.

Rösch M. 2013. Change of land use during the last two millennia as indicated in the pollen record of a profundal core from Mindelsee, Lake Constance Region, Southwest Germany. In: Von Carnap-Bornheim C, Dörfler W, Kirleis W, Müller J, Müller U, eds. Von Sylt bis Kastanas: Festschrift für Helmut Johannes Kroll. Offa 69/70, 335–370. Neumünster: Wachholtz.

Rösch M, Biester H, Bogenrieder A, Eckmeier E, Ehrmann O, Gerlach R, Hall M, Hartkopf-Fröder C, Herrmann L, Kury B, Lechterbeck J, Schier W, Schulz E. 2017. Late neolithic agriculture in temperate Europe. A long-term experimental approach. Land 6: 1–17. doi:10.3390/land6010011.

Rösch M, Lechterbeck J. 2016. Seven Millennia of human impact as reflected in a high resolution pollen profile from the profundal sediments of Litzelsee, Lake Constance region, Germany. Vegetation History and Archaeobotany 25: 339–358. doi:10.1007/s00334-015-0552-9.

Rösch M, Wick L. 2019a. Contributions to the European pollen database. 41. Western Lake Constance (Germany): Überlinger See, Mainau. Grana 58: 78–80. doi:10.1080/00173134.2018.1509123.

Rösch M, Wick L. 2019b. Contributions to the European pollen database. 43. Buchensee (Lake Constance region, Germany). Grana 58: 308–310. doi:10.1080/00173134.2019.1569127.

Schier W. 2009. Extensiver Brandfeldbau und die Ausbreitung der neolithischen Wirtschaftsweise in Mitteleuropa und Südskandinavien am Ende des 5. Jahrtausends v. Chr. Praehistorische Zeitschrift 84: 15. doi:10.1515/pz.2009.002.

Schier W. 2017. Die tertiäre Neolithisierung – Fakt oder Fiktion? In: Lechterbeck J, Fischer E, eds. Kontrapunkte. Festschrift für Manfred Rösch. Universitätsforschungen zur prähistorischen Archäologie 300, 129–145. Bonn: Habelt.

Wick L, Rösch M. 2006. Von der Natur- zur Kulturlandschaft – Ein Forschungsprojekt zur jungsteinzeitlichen und bronzezeitlichen Landnutzung am Bodensee. Denkmalpflege in Baden-Württemberg 35: 225–233.

Wiethold J, Erlenkeuser H. 1998. Studien zur jüngeren postglazialen Vegetations- und Siedlungsgeschichte im östlichen Schleswig-Holstein. Universitätsforschungen zur prähistorischen Archäologie 45. Bonn: Habelt.