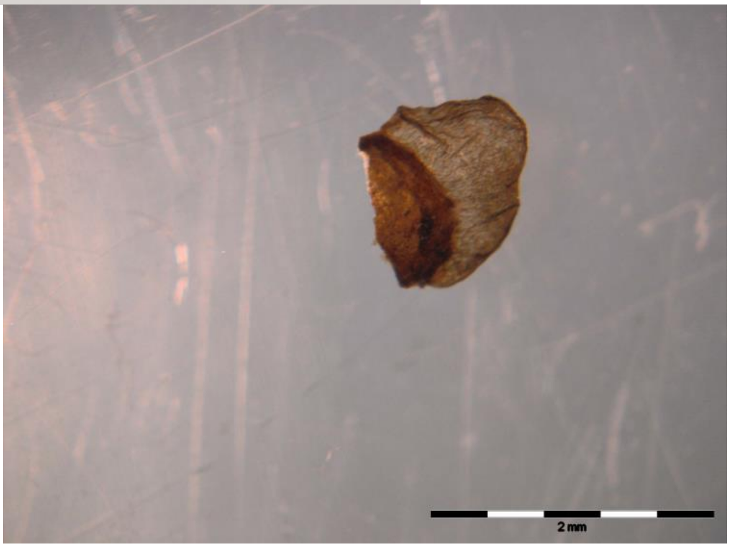
The Palaeoecology and Archaeobtonay of Lake Nussbaumersee (Switzerland) and the Neolithic village Nussbaumersee-Inseli

Martina Hillbrand



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Abstrakt

Verschiedene Methoden wurden verwendet um die Umwelt des Nussbaumersees und seiner prähistorischen Besiedler, sowie die Auswirkungen der menschlichen Besiedlung in der Vergangenheit auf die Umwelt zu erforschen. Drei Pfahlbau-Dörfer sind von den Ufern des Nussbaumersees bekannt (neolithisch, früh- und spät-bronzezeitlich), die jeweils zu Zeiten von niedrigen Seespiegeln bestanden. Ein Bohrkern von der Mitte des Sees wurde auf Pollen, Nicht-Pollen-Palynomorphe (NPPs) und (vor allem botanische) Makroreste hin untersucht. Diese Daten wurden verwendet um die umliegende Vegetation und Veränderungen in Wasserständen sowie Änderungen im Nährstoffgehalt des Wassers zu rekonstruieren. Andererseits wurden mithilfe von archäobotanischen Untersuchungen von Profilsäulen aus der neolithischen Siedlung Nussbaumersee-Inseli (datiert auf ungefähr 3840 - 3700 v.Chr.) die Subsistenz-Strategien der Siedler sowie deren Veränderungen über die Zeit der Besiedlung hin erforscht.

Die Ergebnisse der Pollen-Untersuchungen zeigten, dass die umliegende Vegetation durch die neolithische Siedlung stark beeinflusst wurde, was durch ein starkes Ansteigen der Nicht-Baumpollen-Prozentwerte widergegeben wird. Dies weist auf ein generelles Öffnen der Landschaft hin, was einerseits dadurch kommt, dass die Siedler das offene Land für ihre landwirtschaftlichen Aktivitäten benötigten, und andererseits dadurch, dass für das Bauen der Siedlung sehr viele Bäume nötig waren. Die Makrofossil-Analyse konnte mehrere Veränderungen in Wasserständen aufzeigen. Zudem zeigen die Ergebnisse radikale Veränderungen der Sedimentation im ersten Jahrtausend vor Christus, von wo an der organische Anteil im Sediment stark zunimmt, was darauf hinweist, dass viel mehr Material von außerhalb des Sees eingetragen wurde als davor, wo das Sediment hauptsächlich aus den Überresten von Wasserpflanzen und –tieren bestand. Die Ergebnisse der NPP-Analyse stützen die Annahme, dass die Veränderung in der Sedimentation im 1. Jahrtausend v. Chr. durch menschlichen Einfluss verursacht sein könnte. Zusätzlich weisen die NPPs auf drei verschiedene Phasen mit hohen Trophie-Niveaus (Eutrophierung) hin (die angezeigt werden durch hohe Prozente von Blaualgen und Grünalgen), wovon die erste deutlich mit dem neolithischen Dorf zusammen hängt, während die anderen beiden wahrscheinlich der Schnurkeramik und der Spätbronzezeit zuzuordnen sind. Aufgrund der Ungenauigkeit der ^{14}C-Datierungen ist dieser Zusammenhang aber nicht gesichert.

Die arbäobtoanischen Untersuchungen des Sediments aus der neolithischen Siedlung zeigen, dass sich der Seespiegel auch innerhalb der 150-jährigen Besiedlungszeit des Dorfes veränderte. Veränderungen in der Zusammensetzung der Überreste von Kulturpflanzen (sowohl Getreidearten wie das Verhältnis von Getreide zu anderen Kulturpflanzen) werfen die Frage auf, ob die geänderten Umweltbedingungen zu einer Anpassung der Subsistenzstrategien der neolithischen Siedler führten.

Zusammenfassend kann festgestellt werden, dass die prähistorischen Siedler mit einer großen Anzahl von Veränderungen in ihrer Umwelt umgehen mussten, aber dass sie auch selbst ihre Umwelt auf verschiedene Weise beeinflussten. Diese Veränderungen zwangen sie, ihre Lebens- und Wirtschaftsweise anzupassen. Während die Ergebnisse, die hier präsentiert werden, weitere Einsicht in diese verschiedenen Abhängigkeiten bieten, bleiben Fragen über

kausale Zusammenhänge und die gesellschaftlichen Auswirkungen auf die prähistorischen Besiedler weiterhin offen.

Abstract

Different methods have been used to analyse the past environment of Lake Nussbaumersee and its settlers as well as to identify human impact on the environment. Three lake-side settlements are known to have existed on the shores of Lake Nussbaumersee in periods of lower lake-levels (Neolithic, Early and Late Bronze Age). A lake core from the centre of the lake was analysed for pollen, Non-Pollen-Palynomorphs (NPPs) and macrofossils (mainly botanical). These data were used to reconstruct surrounding vegetation and lake-level changes as well as changes in trophy levels of the lake water. On the other hand, archaeobotanical analyses of several sediment columns taken from the Neolithic settlement Nussbaumersee-Inseli (dated to approximately 3700 to 3840 BC) were used to research subsistence strategies of the Neolithic settlers, as well as changes of these over time.

The results of pollen analysis showed that the surrounding vegetation was heavily influenced by the Neolithic settlement, which coincides with a severe increase of non-tree-pollen percentages. This indicates an opening of the countryside probably both because the land was used for agriculture and because trees were needed to construct houses and especially the platforms that they were built on. Macrofossil analysis shows frequent changes in lake levels and also indicate the low lake levels coinciding with the known settlements. The results also show major changes in lake sedimentation in the first millennium BC, from when the organic content of the sediment is much increased which indicates that more material from outside the lake is disposed in the lake than before when the sediment was mainly calcareous gyttja consisting mainly of the remains of aquatic organisms. The results of the NPP-analysis deliver further evidence for the assumption that the changed sedimentation in the first millennium BC may be caused by human impact. Additionally, NPPs indicate three separate phases of very high trophy levels (indicated by high percentages of cyanobacteria and Chlorophyceae) of which the first was definitely closely linked to the Neolithic settlement, whereas the other two eutrophication phases are assumed to have been caused by human activity in the period of the Corded Ware Culture and the Late Bronze Age, respectively. Due to large confidence intervals of the radiocarbon dates, however, these relations are not entirely certain.

The archaeobotanical research of the sediment from the Neolithic settlement shows that there were changes in lake level even in the 150-year period of the settlement. Changes in the composition of the cultivated plant remains (both cereal species and the relation between cereals and other cultivated plants) pose the question, whether changing environments led Neolithic settlers to change their subsistence strategies.

In conclusion it can be said that prehistoric settlers had to deal with many changes in their living environments, but that they also influenced their direct environment in several ways. These changes made it necessary for them to adjust their lifestyle and subsistence. While the results presented here provide further insights into these various interdependencies, questions as to causal correlations and the societal impacts on the prehistoric settlers remain.

Introduction

Several palaeoecological methods are nowadays frequently used in archaeological research and the reconstruction of past landscapes. These methods include pollen and macrofossil-analysis and regularly now also the analysis of Non-Pollen-Palynomorphs (NPPs). The results of these methods are heavily dependent on the type of sediment that they are used on. The two main options are: (1) Archaeobotanical methods (mainly macrofossils) used in sediments of archaeological findings; and (2) palaeoecological methods (macro- and microfossils) used on lake sediments or bogs. While the first can only be used in the presence of archaeological findings and should mainly give insights into subsistence strategies and nutrition of prehistoric peoples, the latter can be used almost anywhere and for a wide range of questions concerning changes in the vegetation of an area either in relation to human impact or natural causes (e.g. climate change).
The research of all of these questions is getting more important recently with questions of climate change, protected area management, and questions of food sovereignty. The idea thereby is to learn from the past and to gain understanding about natural vegetation and the effect of human impact in the past to be able to make predictions for the future.

Due to time constraints or the unavailability of certain sediments usually only a small selection of palaeoecological methods is used in research. However the sum of several methods can give deeper insights into how and why landscapes changed. In this work several methods have been used in addition to extensive archaeological research and still many questions have to remain open. As one part of this project I tried to find out which questions can be answered best using which methods, but results are only partly (probably) true in most settings while other results really only hold in this very study. Therefore it should always be aimed to use as many different methods as possible in order to gain a better understanding of ecological settings in the past.

Lake-side-settlements – especially from the Neolithic – are among the best researched archaeological findings in Europe since the remains are all preserved in water-logged conditions and therefore even fragile organic remains are often still in almost unaltered conditions. The site of Lake Nussbaumersee has been researched extensively by archaeologists in the second half of the 20th century. Thanks to the openness of the archaeologists working on this site to scientific methods, palaeoecological methods were also part of the wider research. Two pollen diagrams have been produced from the area (Rösch, 1983, Haas and Hadorn, 1998) and gave additional important insights into human activities and the natural changes in vegetation patterns in the area. Also during the archaeological excavations the sampling for later archaeobotanical research was a priority and very well done. Unfortunately the archaeobotanical investigations could not be completed in the first part of the project because of lack of funding.
Since the archaeological settings at the site Nussbaumersee-Inseli are very special (the village has been occupied for 150 years, which is extraordinarily long for that period) the Amt für

Archäologie of the Canton Thurgau was interested in having the research completed even after 20 years.

Location

The Valley of Seebachtal is located to the South-West of Lake Constance in an area densely covered with the remainders of Neolithic and Bronze-Age lake-side-settlements. The settlement Nussbaumersee-Inseli is one of the westernmost of these villages. The valley (fig. 1) contains three lakes today: Nussbaumersee, Hüttwilersee (the biggest) and Hasensee. Lake Nussbaumersee, however, is the only one of them, in which complete villages have been found, while only single findings have been found in various places in the valley.
The valley was formed during the last glacial when ice-blocks have been left by the withdrawing glaciers which then formed the valley and the lake. When the water level of the lake was sinking, the water body was separated into smaller lakes (today three).
The valley is very flat, which means that even small changes in lake levels have considerable effects on the size of the lakes. Due to the relief this meant in the past that the number of lakes in the area also changed (Rösch, 1983). The land bridge separating the two western basins of Lake Nussbaumersee in periods of low lake levels was also the place where three lake-side settlements have been found, dating to the Neolithic and the Early and Late Bronze Age.

In the past century the area has undergone some major changes due to melioration activities and the extraction of peat. Extraction of peat in large scales continued probably for several centuries. The Seebachtal "correction" at the end of the 19th century led to a drying up of surrounding bogs and finally the melioration performed in the final years of the Second World War led to a lowering of the lake level by more than 1 m and further draining of surrounding bogs and swamps so they could be used for agricultural production (Hasenfratz and Schnyder, 1998, Ellminger, 2002). The result of the drying of the soil was that preservation conditions of organic material above today's water level was strongly decreased.

Figure 1: Study Site. Upper left: location of the study site (D: Germany, CH: Switzerland, A: Austria); upper right: Seebachtal Valley with the Lakes Nussbaumersee, Hüttwielersee and Hasensee; below: Lake Nussbaumersee with the approximate location of the Neolithic and Early Bronze Age village (orange circle), the Late Bronze Age village and the Corded Ware Culture house (red circle), the coring site of the core NBS-A/B (blue star) and the location of the profiles taken for archaeobotanical analysis from the Neolithic settlement (yellow star). (Source map: Google Earth (photo taken in July 2009))

Hydrology

The hydrology of Lake Nussbaumersee has been changed considerably as a result of human influence in the past centuries. In the researched period, however, between 6000 BC and the Medieval, the only surface inlet and outlet were located in the easternmost basin of the lake (Ellminger, 2002). While underground inlets probably played a role, for the work presented here, we can assume that at times of low lake levels, when the three lake basins were separated from each other, the central and western lake basin did not have any major inlets or outlets.

Archaeology

Archaeological investigations in the region of Seebachtal started with first findings of single stone tools in the 19th century. Due to the melioration of the area in the 20th century more archaeological findings were discovered. Since then, it was common knowledge that prehistoric people had used the area. However, human activities in the area in the last centuries probably also destroyed a large amount of archaeological remains which now make it impossible to reconstruct prehistoric human activities in the wider surroundings of the lakes. Below today's water level, on the other hand, preservation conditions were very good and allowed archaeologists to perform in depth research of remains of settlements found there.

Lake Nussbaumersee has been studied intensely by archaeologists and palaeoecologists. The research showed that there were at least three prehistoric settlements along the shores of the lake. For the Palaeolithic, the Mesolithic and the Early Neolithic single archaeological finds prove the presence of humans in the region (Hasenfratz and Schnyder, 1998). The earliest settlement excavated by archaeologists was dendro-chronologically dated between 3840 and 3695 BC (Pfyner Period). The settlement is thought to have consisted of at least 25 to 30 buildings which were situated on the land-bridge between the two western lake basins (fig. 1). Nowadays this area is inundated apart from the artificial island, which partly covers the archaeological layers. The location of the settlement indicates that the lake level was then around 4 m below today's lake level. The later Neolithic is only represented by a few single findings. A pit house from the Corded Ware Culture was found on the peninsula Horn. Charcoal found in the house was radiocarbon dated to approximately 2500 – 2900 BC.

Two later lake-side settlements were present during the Bronze Age. A settlement from the late Early Bronze Age was found in the same area as the Neolithic settlement. Based on dendro-chronology it was dated to the period 1580 to 1538 BC. The Late Bronze Age settlement is situated on the peninsula "Horn" on the southern side of the lake. It was much bigger than the Neolithic and early Bronze Age settlements and is thought to have consisted of up to 100 buildings. The earliest dendro-chronological dates for this settlement are from 850 BC. It is not clear how long the village lasted but it is thought to have been given up no later than 800 BC.

During the excavation of the Late Bronze Age village, remains of an Iron Age village (7th century BC) were found. This village was not further researched, and apart from it very few single findings from the Iron Age are known, indicating that there were no major settlements in the area, but Roman Time artefacts were of regular occurrence and the area is thought to have been used intensively for agriculture. Since Roman Times the region has been populated continuously.

Settlement Nussbaumersee-Inseli

Only in 1985 the first proper excavations started on the peninsula Horn (Hasenfratz and Schnyder, 1998). Later archaeological activities were extended to under water excavations around the island when it was clear that the remains of the Neolithic settlement were in danger due to erosion caused by movements of the water and to human impact.
The first excavations brought to light a complete pile-dwelling village from the Neolithic, which was dated by means of artefacts and dendrochronology to the Pfyner Culture (Hasenfratz and Schnyder, 1998). Preservation conditions were extremely good and the findings have added much to the knowledge about the Pfyner Culture in the region. Only a small part of the village (south of the island) was excavated, however find density was very high there. Archaeologists found that the layering was disturbed considerably, probably by frequent rises of the lake level. No house locations could be determined and parts of pots have been spread through several layers. The high density of wooden piles indicates that the village experienced several phases of settlement activities.
Several piles have been dated dendro-chronologically. The results show that settlement activities started around 3840 BC. Only few piles resulted in somewhat older dates. The latest certain dates are 3695 BC. Most piles are dated in between these. Six piles were dated to 3582 BC, however all of these dates are uncertain. It is therefore assumed that the village existed between 3840 and 3695 BC.

Material and Methods

Several palaeoecological methods have been used in this research to get as complete a picture of past ecological settings as possible. In a further step these methods have been compared to find out which methods were best suited to answer which questions.
Since the samples had all been taken in the 1990ies, I had no influence on the selection of samples for my study but could only decide which methods to use on which samples. The focus of the research was always on botanical remains, however, animal remains have been counted where they could be identified.
The available sediments were a core from the deepest point of the lake (NBS-A/B), a sediment core from the Purenriet (Northeast shore of Lake Nussbaumersee, NBS-P1) and the sediment samples taken during the excavation of the Neolithic settlement.

Lake cores

Macrofossils

- NBS-P1

The core NBS-P1 has a length of 115 cm. 13 slices of 2 cm have been taken from the core in regular intervals to be analysed. Of all samples (13) the fractions 1.0, 0.5, and 0.25 mm were completely analysed – which means that from each sample every identifiable plant and animal remain was picked out and stored separately. In a second step these remains were identified to the highest level possible and counted. Some unidentified seeds were kept for later identification, which could be achieved in some cases after asking various experts.

- NBS-A/B

The core NBS-A/B consists of two parallel cores of 9.5 m length which have been taken from the deepest point of the lake (Fig. 1). The cores have been taken using a Livingston corer with different diameters (9 and 5 cm). However, of the core NBS-B (5 cm diameter) the uppermost 2.5 meters were not preserved due to the very loose condition of the sediment. The core NBS-B had also been used by Haas and Hadorn (1998) for their pollen studies (App. IV). They also took some samples for radiocarbon dating (see below).
The sediment in the core is very homogenous and consists of calcareous gyttja. Only the part between 734 cm and 707 cm is darker than the rest of the sediment.
For the analysis of macrofossils the core NBS-B (from 2.5 to 9.5 m) was cut into slices with a thickness of 2 cm. Of these in general every fourth slice (thus representing 8 cm intervals) was sieved using sieves of 1, 0.5, 0.25, and 0.125 mm mesh width. The fractions of 1.0 and 0.5 mm were often combined as the fraction of 1.0 mm usually contained very few remains. Since the uppermost 2.5 m of the sediment core NBS-B were not preserved well the core NBS-A was used for the analysis of this part.
The long time the cores have been stored meant that the smaller core (NBS-B, diameter 5 cm) was dried up in many places while others were still quite wet, so the weight of the samples analysed could not be assessed in a congruent way. The core NBS-A (diameter 9 cm) was still quite wet and therefore heavier. From this core 2 cm thick slices of half the core have been used for analysis. These had a higher volume but also a relatively higher weight since they still contained more water. Therefore for calibration of the results 10% of the weight was subtracted for samples obtained from NBS-A (0 – 250 cm). The fact that in the resulting curve a difference between the two cores is not visible seems to justify this way of calibration.

Of all samples (103) the fractions 1.0, 0.5, and 0.25 mm were completely analysed – which means that from each sample every identifiable plant and animal remain was picked out and stored separately. In a second step these remains were identified to the highest level possible and counted. Some unidentified seeds were kept for later identification, which could be achieved in some cases after asking various experts. Special thanks go to Jan Peter Pals who helped with the identification of several Poaceae species.

Pollen

Haas and Hadorn (1998) have completed a pollen analysis of the core NBS-B. Their results are used here for further interpretation. For the pollen analysis 1 cm^3 samples were taken at every 4 cm from the core NBS-B (between 230cm and 948 cm). These were prepared for pollen analysis following standard procedures (Moore et al. 1991). 1 to 5 tablets of *Lycopodium* spores were added to the samples as reference to determine the concentration of microfossils.

Non-Pollen-Palynomorphs (NPP)

The residues from the pollen analysis were now also used for the analysis of Non-Pollen-Palynomorphs (NPPs, Hillbrand et al. 2014). At the Hugo de Vries Laboratory at the University of Amsterdam NPPs were counted in slides prepared there from these residues. In general samples were counted at 8 cm intervals. Only in the sequence representing the Neolithic settlement phase, samples were analysed at 4 cm intervals. This analysis was done using a light microscope at a magnification of 600x. Pollen were neglected in this study which helped to focus on NPPs.

The Non-Pollen Palynomorphs were identified using the catalogue of Types of NPPs and the reference collection at the Hugo de Vries Laboratory, University of Amsterdam and available literature (Lundqvist, 1972, van Geel, 1972, Pals et al., 1980, van Geel et al. 1981, 2003, 2011, van Geel and Aptroot, 2006). The HdV-Type numbers referred to are types as labeled by van Geel et al. at the Hugo de Vries Laboratory. New Types are labeled IIB (Innsbruck Institute of Botany) XXX (e.g. IIB-001, Appendix II).
Haas and Hadorn (1998) counted at least 500 pollen in each sample and calculated the percentage of each taxon in comparison to the pollensum. For the NPPs at least 10 *Lycopodium* spores were counted per tablet that was added, which was approximately the part of the sample that had been studied during the pollen analysis. This resulted in 140 to more than 1500 non-pollen microfossil remains counted in each sample (average 576). Some samples had very high numbers akinetes of *Anabaena* and *Aphanizomenon* in which case these Types were counted only in a smaller fraction of the sample and extrapolated using the number of *Lycopodium* spores.

Related to the number of *Lycopodium* spores counted in each sample NPP-percentages were calculated comparing the NPPs to the pollen percentages found by Haas and Hadorn (1998).

Sediment from the settlement Nussbaumersee-Inseli

More than 150 samples have been taken for archaeobotanical research during the archaeological excavations in the 1990ies. These include surface samples, samples of single findings like *Corylus* (hazel) nut shells, faeces or cereal remains as well as the ingredients of pots or other archaeological remains. All of these could unfortunately not be analysed in the present studies.
Among the samples were four columns representing the whole of the Neolithic settlement layer which had a thickness of up to 2 m in some places. This is especially interesting since the settlement Nussbaumersee-Inseli is one of the Neolithic villages with the longest duration of human occupation. Therefore these columns have been considered especially interesting for the research of changes in subsistence strategies over the period of occupation.
The profiles are located very close to each other in the NW part of the excavation. For analysis they were cut into a number of samples and each sample has been sieved through sieves of 8.0, 4.0, 2.0, 1.0, 0.5 and 0.25 mm mesh width. All of this work has been done by Franziska Feigenwinter as part of her research on the project in the 1990ies. Three of these columns have been analysed for the present research. The samples were still in very good conditions even after 20 years of storage and could be analysed in this research. Table 2 shows a list of all samples analysed from the three profiles with some results of the analysis.
For comparision the counts of each sample were extrapolated to represent a volume of 1 l. Many samples already had this volume and most were within a small range of 1 l.
All data obtained are presented using TILIA Graphs (Grimm, 2011).

- NBS 58

The column 58 is the shortest (125 cm) and contains the fewest samples (16, of which 5 are single findings which have not been included in the analysis. The sample volumes are on average much larger than the samples from the other columns.
The conditions of the plant remains in this column vary considerable. The material looks like it has dried up at one point after sampling since fragile plant seeds (e.g. *Linum*) were often completely destroyed, however it is unclear how this could have happened. This meant that several difficult species could not be well determined (especially *Fragaria*). When a fraction contained large amounts of botanical material then only a certain part of the sample was counted and the results were extrapolated. This was mainly done for the fractions bigger than 0.5 mm where the small seeds, which guarantee an even distribution in the sample, should ensure that no data get lost in this procedure.

For most of the samples the archaeological layer they belong to could not be identified with certainty.

- <u>NBS 75</u>

This column is 180 cm long, however it has been taken in three cases so that parts between these cases may be missing or overlapping. The core has been separated into 22 samples. The average volume of the samples was 1 l (10 cm thick). One sample (NBS 75.17) was a sample of a piece of wood with some sediment on it. The sediment has been analysed but due to the small size (100 ml) results have to be looked at with caution.
This profile is the only one which contains samples from every archaeological layer identified. A separation between the layers 20 and 22 was not possible in this place however. Preservation conditions in these samples were extraordinarily good. The fractions > 8.0, 4.0, 2.0, 1.0 and 0.5 mm have all been analysed and all plant and animal remains which were identifiable have been extracted and kept separately for further determination later. When a fraction contained large amounts of botanical material then only a certain part of the sample was counted and the results were extrapolated. This was mainly done for the fractions bigger than 0.5 mm where the small seeds, which guarantee an even distribution in the sample, should ensure that no data get lost in this procedure.

- <u>NBS 93</u>

The column NBS 93 was analysed by F. Feigenwinter but unfortunately the documentation was missing. The remains that she found in the column NBS 93 were mostly dried up and not in the best conditions so counts were possible but mistakes must be assumed. Unfortunately the paperwork which belonged to this column has been lost so the original volume and the part which has been analysed are not known and had to be guessed. The volume could be guessed quite easily from the drawing which indicates the sampling, while the part which had been analysed was mostly indicated on the pots which contained the samples but mistakes have been found and it was sometimes impossible to follow the marks on the pots. Therefore mistakes have to be attested to the samples from NBS 93. Still they will be presented here since the results fit quite well with the other two columns and are interesting even of themselves.
The column has a length of 190 cm and is split into 30 samples. An additional 5 small samples have been analysed but no equivalent is indicated in the sketches so they have probably been renamed later on and are part of other samples. This means that probably a small amount of data is missing in the final results.

Statistical analysis

Principal Component Analysis (PCA)

Statistical analyses were used in order to interpret the data obtained from pollen, NPP and macrofossil analysis on the sediments from the lake core from Lake Nussbaumersee. The aim of the Principal Component Analysis (PCA) is to filter the most important taxa from a given dataset. Since the data I used for this analysis came from different methods and also from slightly different samples, one should not rely entirely on the PCA. However it is a good method to get some organization into a large dataset. The PCA was performed using CANOCO (Braak and Smilauer, 2002).
For the macro remains from the core NBS-A/B, the PCA was not performed because the dataset was too small to allow for good results.

Zonation

Using the TILIA program (Grimm, 2011) a diagram with all the NPP-Types was made and using a CONISS analysis, seven successive zones (LNPPAZ) could be distinguished (Fig. 5). The CONISS analysis was based on counts of all non-pollen-microfossils, which were transformed into percentages for the calculation.

Radiocarbon dating

All radiocarbon dating has been performed at the ETH Zürich. Samples which have been dated after 2000 were pre-treated at the University of Zürich. All obtained radiocarbon ages have been calibrated using OxCal v3.10 (Bronk Ramsey, 2005).

- NBS P1

Two samples of terrestric botanical remains from the core NBS-P1 have been dated to get an idea of the age of this core (Tab. 1). The results showed that the lowermost parts of the core date to the early Bronze Age. A simple age-depth model has been calculated using TILIA software (Grimm, 2011). Due to known changes in lake levels the age-depth model must be considered as very uncertain as changes in sedimentation rate are to be expected with changes in lake levels.

Table 1: Radiocarbon dates from the core NBS-P1

Sediment core	Depth (cm)	Sample Nr. (ETH Zürich)	14 C date	Delta 13C	Age calibrated (95.4%-Interval)	Age calibrated (Mean)	Dated Material
NBS-P1	64-66	41470 (UZ 5918)	1825 ± 35 BP	26,7±1.1	AD 318 – 85 BC	AD 201.5 ± 116.5	Bark remains
NBS-P1	114-116	41471 (UZ 5919)	3260 ± 35 BP	26,9±1.1	1450 – 1620 BC	1535 BC ± 85	Wood remains

- Lake core NBS-A/B

The sediment core NBS-A/NBS-B was dated by 16 radiocarbon dates, which were all obtained from terrestric plant macroremains as indicated in Table 2. The dates are more or less consistent, however in order to get a somewhat linear age-depth model, some dates were excluded from the analysis. These were generally the dates from the initial study, where the new dates were considerably younger, as well as one date that was excluded due to a very high delta ^{13}C value. It should be kept in mind, however, that the selection of ^{14}C-dates used for the age-depth model was somewhat arbitrary and the model should therefore be used with care. In general dates of the upper half of the core should be considered as an average, where the real date may be several hundred years older.
An age-depth-model was made using clam software (Blaauw, 2010; Fig. 2). This model was then used in all further analysis and in the TILIA graphs.

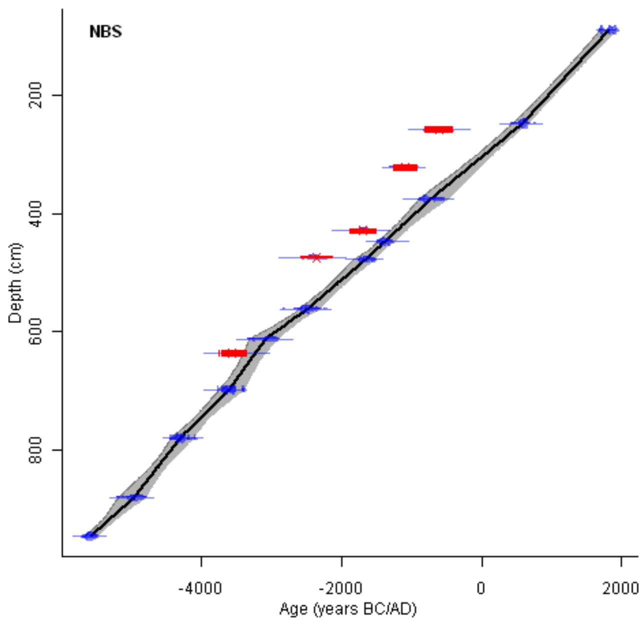

Figure 2: Age-depth model for the core NBS-A/B resulting from the analysis with the Clam model. Radiocarbon dates not used for the model are in red. (published in Hillbrand et al., 2012, 2014)

Table 2: Radiocarbon dates from the core NBS-A/B. Dates in italics have not been used for the age-depth-model. (Hillbrand et al., 2012, 2014)

Sediment core	**Depth (cm)**	**Sample Nr. (ETH Zürich)**	**14 C date**	**Delta 13C**	**Age calibrated (2σ- Interval)**	**Age calibrated (Mean)**	**Dated Material**
NBS-A	88 – 90	41472 (UZ 5920)	75 ± 40 BP	-61.1 ± 1.1	AD 1935-1682	**AD 1808.5 ± 126.5**	Wood remains
NBS-B	246 – 248	17753	1455 ± 60 BP	-24.6 ± 1.2	AD 496-678	**AD 587 ± 91**	Bud scale *Fagus sylvatica*
NBS-B	*253.5 - 262.5*	*14265*	*2500 ± 95 BP*	*-2.7 ± 1.2*	*402-803 BC*	***603 BC ± 200***	*Seed Alnus glutinosa, wood remains*
NBS-B	*316.5 - 325.5*	*11845*	*2905 ± 55 BP*	*-28.7 ± 1.1*	*925-1223 BC*	***1074 BC ± 149***	*Seeds Alnus glutinosa, Betula sect. alba, Betula pendula, bud scale Fagus sylvestris*
NBS-B	374 – 376	41473 (UZ 5921)	2600 ± 70 BP	-73.7 ± 1.1	513-914 BC	**713.5 BC ± 200.5**	Catkin *Alnus* sp., bud scales indet.
NBS-B	*424.5 - 430.5*	*14266*	*3385 ± 75 BP*	*-22.7 ± 1.3*	*1513-1827 BC*	***1670 BC ± 157***	*Seed Alnus glutinosa, Betula pubescens, wood remains*
NBS-B	446 – 448	41474 (UZ 5922)	3115 ± 55 BP	-78.6 ± 1.1	1222-1501 BC	**1361.5 BC ± 139.5**	Bud scale *Fagus* sp.
NBS-B	*472.5 - 475.5*	*14267*	*3900 ± 80 BP*	*-19.8 ± 1.2*	*2138-2576 BC*	***2357 BC ± 219***	*Seed Alnus glutinosa, leaf remains indet.*
NBS-B	476 – 478	41475 (UZ 5923)	3360 ± 55 BP	-74.1 ± 1.1	1506-1862 BC	**1684 BC ± 178**	Catkin *Alnus* sp., leaf remains
NBS-B	559.5 - 562.5	11846	3970 ± 50 BP	-29.7 ± 1.1	2407-2561 BC	**2484 BC ± 77**	Catkin *Alnus* sp.
NBS-B	610.5 - 613.5	11847	4405 ± 60 BP	-30.6 ± 1.2	2894-3132 BC	**3013 BC ± 119**	Catkin *Alnus* sp.
NBS-B	*631.5 - 640.5*	*11848*	*4785 ± 90 BP*	*-19.9 ± 1.2*	*3359-3722 BC*	***3541 BC ± 181***	*Catkin Alnus sp.,seed Alnus glutinosa, bud scale Tilia sp., bark remains*
NBS-B	692.5 - 704.5	11849	4830 ± 65 BP	-20.8 ± 0.9	3500-3766 BC	**3633 BC ± 133**	Catkin *Alnus* sp.,seed *Alnus glutinosa, Betula pubescens, Betula* sect. *alba*
NBS-B	775.5 - 784.5	11850	5460 ± 60 BP	-27.7 ± 1.1	4221-4405 BC	**4313 BC ± 92**	Seed *Alnus glutinosa*, catkin *Alnus* sp., bud scale *Tilia* sp.
NBS-B	878.5 - 881.5	11851	6045 ± 60 BP	-32.4 ± 1.2	4790-5074 BC	**4932 BC ± 142**	Wood remains indet.
NBS-B	943.5 - 949.5	11852	6665 ± 65 BP	-29.7 ± 1.1	5441-5629 BC	**5535 BC ± 94**	Catkin *Alnus* sp., seed *Alnus glutinosa*, bud scale *Tilia* sp.

- Columns from settlement

As indicated above, the settlement has been dendro-chronologically dated to 3840 to 3700 BC. There were also some younger dates which were uncertain (3582 BC). Also the settlement layer is between 1 and 2 metres thick and in order to analyse it, it is helpful to get an idea of sedimentations rates. Therefore several twig remains from the profile columns NBS- 75 and NBS-93 were used for radiocarbon dating. The results are shown in table 3. It is obvious that, due to a ^{14}C plateau, it is not possible to draw any conclusions about the sedimentation rate during the time of the settlement. However, the dates obtained indicate that the settlement really ended around 3700 BC and that the piles dated to 3582 BC are either not dated correctly or do not belong to the settlement.
On the other hand, as also mentioned before, layering has been found to be largely disturbed in most parts of the settlement. In order to find trends in archaeobotanical analysis it has to be known if the sediment layering is still intact in the columns studied. Again no definite answer could be found for this, as several dates were the same or very close even though the samples were taken several decimetres apart. There is, however, no one older date above a younger date, which indicates that the layering, although probably not wholly intact, is not completely disturbed in the two dated columns. For the column 58 it is assumed that the same is true. Additional datings are not expected to lead to much additional information due to the ^{14}C plateau.

Table 3: Radiocarbon dates for sediment from the settlement Nussbaumersee-Inseli (profiles NBS-75 and NBS-93)

Sediment Core	Sample Nr. (in core)	Sample Nr. (ETH Zürich)	14 C date	Delta 13C	Age calibrated (95.4%- Interval)	Dated Material
NBS-75	75.1/1	ETH-48393	4941 ± 30 BP	-29,1 ± 1.1	3780 – 3650 BC	Wood remains
NBS-75	75.5	ETH-49203	4940 ± 30 BP	-35,8 ± 1.1	3780 – 3650 BC	Wood remains
NBS-75	75.10	ETH-48394	4948 ± 30 BP	-32,3 ± 1.1	3790 – 3650 BC	Wood remains
NBS-75	75.14	ETH-49204	4949 ± 30 BP	-36,5 ± 1.1	3790 – 3650 BC	Wood remains
NBS-75	75.22	ETH-48395	5049 ± 30 BP	-31,9 ± 1.1	3960 – 3770 BC	Wood remains
NBS-93	93.4	ETH-48396	4968 ± 30 BP	-30,3 ± 1.1	3800 – 3650 BC	Wood remains
NBS-93	93.16	ETH-48397	4968 ± 30 BP	-27,7 ± 1.1	3800 – 3650 BC	Wood remains

Results

Macrofossils

The analysis of macrofossils was done to complement the earlier pollen analysis (by Haas and Hadorn) in order to (1) find out which of the plants found in pollen analysis were really growing in the near surroundings of the lake, and (2) to be able in certain cases to identify plant remains to a higher level of determination (ideally species level).
While the above questions could mainly not be answered with the results obtained, the analysis of macrofossils brought other interesting results.

NBS-P1

The results of the macrofossil analysis of the sediment core obtained from the lake shore at Pureriet (Fig. 3) is of only minor importance for the topic of this research since the core is dated back only to the Bronze Age (1535 BC). 13 samples have been analysed for plant seeds and other macro-remains. Only a small number of seeds (193) has been found. A relatively high number of oogonia of Characeae (554) were identified, but the vast majority of macro-remains found in this study were unidentifiable vegetative remains of plants and remains of animals. Also, the seeds found were mainly not in a condition to be identified to species level. Therefore the information gained from the analysis of this sediment core is very limited.

Tree seeds are only found in the upper part of the core (dating to the Roman Age and Medieval). With very few exceptions, all remains found are directly related to the aquatic environment (growing in the lake or on the lake shores). This indicates that the plants extracted from this core only represent the very close surroundings of the coring site. When comparing results gained from the analysis of the lake core NBS-B, these results were therefore neglected.

Between approximately 20 and 40 cm of depth (AD 1000 to 1400) high numbers of oospores of *Chara* sp indicate a higher lake level at that time, which was probably lowered by first melioration activities in the late 19th century. This also explains the major changes in the finds of insect remains in that period.

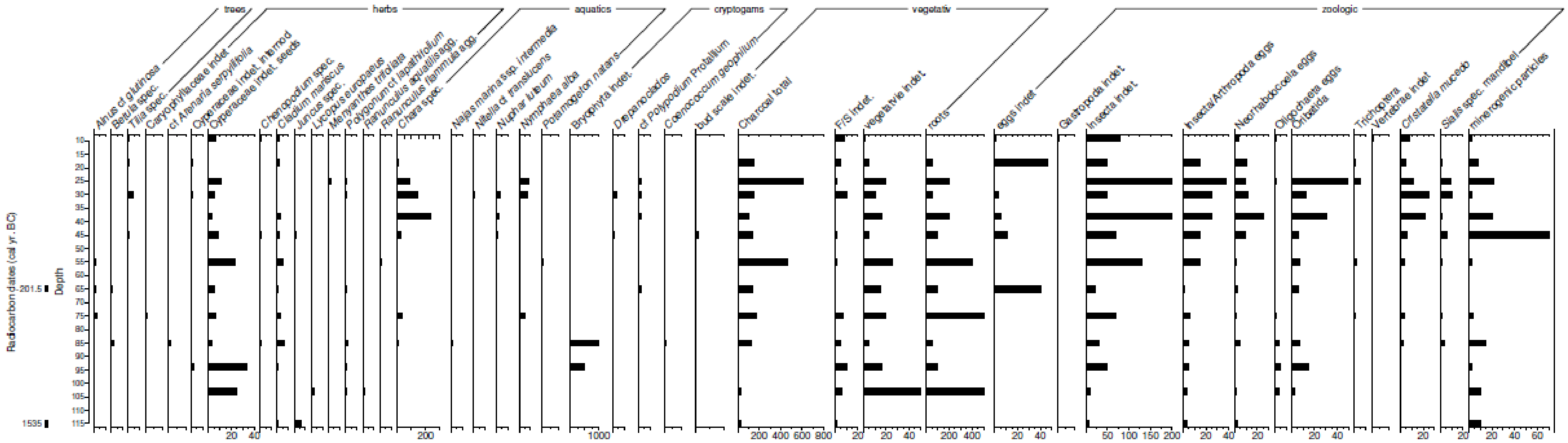

Figure 3: Diagram of the most important macro remains found in lake-core NBS-P1. (Diagram drawn with Tilia Graph).

NBS-A/B

The results of the macrofossil analysis of the lake core are presented in figure 4.
A total of 7,317 identifiable plant and animal remains have been found belonging to 29 plant and 12 animal taxa. An average of approximately 1 plant remain was found per 10 g sediment. The vast majority of plant remains are from aquatic species.
The most striking outcome of the analysis of macrofossils from the lake core NBS-A/B was the major change in sedimentation at around 350 cm depth (around 500 BC), which is shown by a sharp increase in Bryophyta (mosses) and *Sphagnum* (peat moss) remains above 350 cm and the decrease of Gastropoda (snails) and respiratory organs of Chaoboridae (non-biting midges).
A considerable number of water plants have been found which could be used to get an idea of lake level changes and which were not found in pollen analysis.
Seeds from trees were not found in large quantities and *Betula* (birch) seeds often lacked the wings necessary to identify the species. Also many bud scales could not be identified to species level but give an idea of the presence of trees in the near surroundings of the lake as they do not spread very far.
A large part of macrofossils were in fact animal remains which, however, can also be used as ecological indicators to reconstruct past landscapes.

The majority of identifiable plant remains found are from water plants, mainly oospores from *Chara* and seeds from *Najas* species as well as *Nymphaea alba*. These can give some indication of water levels. Tree remains are dominated by *Alnus* and *Betula*, both of which have definitely grown in the near surroundings of the lake. While these remains are spread out through most of the core, there are suspicious clusters of samples with more tree remains (around 200 cm depth, 500-550 cm and 650-750 cm). These are very similar for both *Alnus* and *Betula*. *Tilia* remains also show some clustering and it seems that they occur mainly when *Alnus* und *Betula* do not occur, but the number of *Tilia* remains is too small to ascertain such a connection. Seeds of Orchidaceae are found in almost all samples in the upper third of the core (0-300 cm). This is clearly related to the changes mentioned above.
Larger amounts of charcoal are present throughout most of the core, starting at a depth of approximately 800 cm.

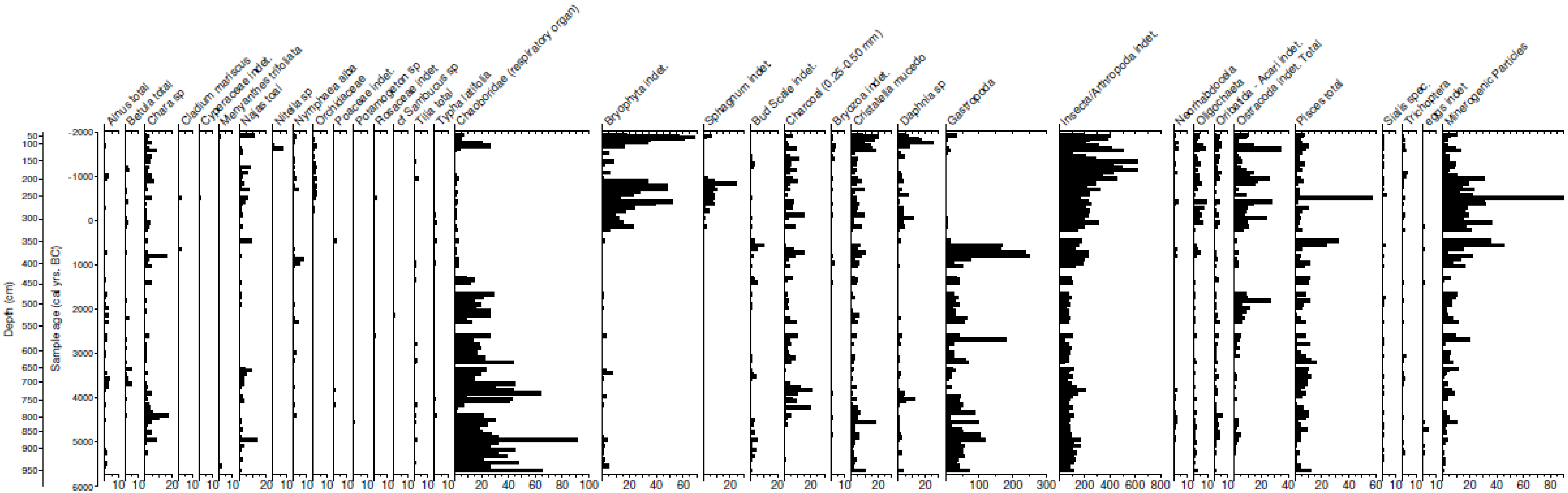

Figure 4: Diagram of the most important macro remains found in lake-core NBS-A/B. Numbers are calibrated per 30 ml sample volume. (Diagram drawn with Tilia Graph).

Non-Pollen-Palynomorphs (NPPs)

Figure 5 shows a diagram with the most important Non-Pollen-Palynomorphs (NPPs) and the Local Non-Pollen-Palynomorph assemblage zones (LNPPZ, Hillbrand et al, 2014).
62 types of NPPs have been found in the 98 samples analysed. These included fungal spores, animal remains, algal remains and Cyanobacteria, as well as microfossil types of unknown origin. Most of the remains found could be attributed a known NPP-type number or name. Where types have been described earlier but the origin is not known, the number indicates the number of the NPP-type according to the nomenclature started by the Hugo de Vries (HdV)-Laboratory at the University of Amsterdam.
Four types, which did not fit into any of the existing type descriptions, were given a new number (IIB [Innsbruck Institute for Botany]-001 to IIB-003 and IIB-010).

Some common taxa shall shortly be described here (see also pictures in app. II):

Cyanobacteria (*Anabaena, Aphanizomenon, Gloeotricha*): Cyanobacteria can fix nitrogen from the air, which gives them a competitive advantage in situations of nitrogen limitation. In aquatic systems phosphorous, rather than nitrogen, is usually the limiting factor (in contrast to terrestric systems; Schindler, 1977). This means that Cyanobacteria can only experience a competitive advantage leading to blooms in case of high phosphorous input into the system. Usually this is directly related to human influence in the ecosystem. *Anabaena* shows a single high peak in the core NBS-B at a depth between 700 and 750 cm. *Aphanizomenon* shows three different peaks throughout the core, the first being at the same period as the peak of *Anabaena*, the second between 500 and 550 cm and the latest around 350 cm.

Green Algae (*Botryococcus, Coelastrum, Pediastrum, Tetraedron*): Green Algae are usually always present in a lake system, however their abundance gives a good indication of trophy level of the lake (high abundance of algae indicates a high trophy level meaning high abundance of nutrients in the system). Green Algae are, however, dependent on sunlight for photosynthesis and can therefore not exist to very large depths. A first peak of Green Algae is clearly visible at the same time when Cyanobacteria first bloom. After that none of the algae species show such strong peaks again, however a substantial increase in the abundance of all species (but mainly *Pediastrum*) can be seen above from 550 cm.

Kretzschmaria deusta: This fungus is a known parasite on various tree species (like *Tilia, Fraxinus, Betula,* and *Fagus*; van Geel and Andersen, 1988). In this study it shows a close correlation with *Fagus* pollen.

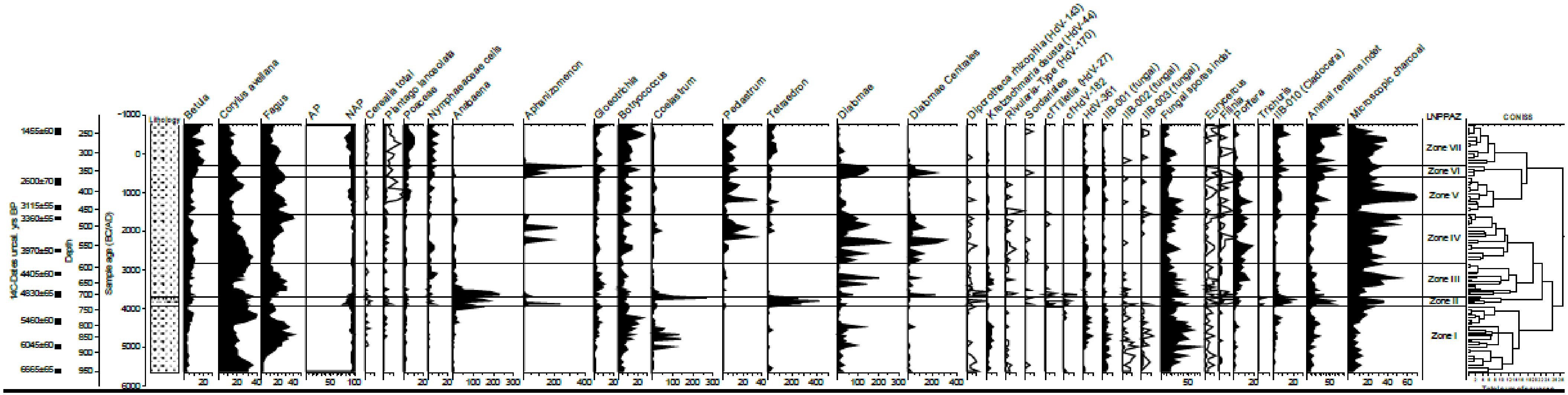

Figure 5: Diagram of the most important Non-Pollen-Palynomorphs (NPPs) and pollen taxa including the zonation derived from CONISS analysis. (Diagram produced with Tilia Graph; from Hillbrand et al., 2014).

Diatoms: There is a large number of diatom species, all of which have different ecological requirements. Without identifying them to genus (or preferably species) level it is not possible to draw any conclusions on the ecology of the lake based on the density of diatoms. It is interesting however, to see that there are two main peaks of diatoms in the core, both of which occur in the same depths as the peaks of *Aphanizomenon* (where *Anabaena* does not peak). It must be assumed, therefore, that the two taxa indicate similar situations. It must be kept in mind, however, that the Diatom curve is made up of a range of different species with different ecological amplitudes meaning that even if the two taxa coincide in this case, this does not mean that Diatoms in general have a similar ecology as *Aphanizomenon*, it only shows that the dominant Diatom species in this period react similar to the Cyanobacertium.

Trichuris: *Trichuris* is a parasitical worm in the digestive system of big mammals (like cows, horses, sheep or humans). Two eggs of *Trichuris* have been found in the lake core several tens of meters from the shore, indicating that quite a large number of these animals must have stayed close to the lake in that period. The two eggs found, can therefore be used as a definite proof that human settlers lived at the shores of the lake in that period (between 700 and 750 cm, dating to the time of the Pfyner Age settlement).

Diporotheca: The ecological indicator value of *Diporotheca* based on the findings in this core has been discussed in Hilbrand et al. (2012).

Local Non-pollen-palynomorph assemblage zones (LNPPAZ):

The CONISS analysis of the results of the NPP analysis of the lake core NBS-B enabled us to separate seven distinct NPPAZ. Detailed descriptions of all zones can be found in the original publication of the results (Hillbrand et al., 2014). While all taxa show changes over time to some extent the most obvious changes are visible in algal and cyanobacteria taxa. The separation into seven zones mainly stems from the alternating 'eutrophication' zones with zones of little or no eutrophication. The eutrophication zones are characterized by high levels of cyanobacteria (*Anabaena* and *Aphanizomenon* mainly) which – as described above – are highly likely to indicate periods of high nutrient levels in the lake. The earliest eutrophication zone (zone II) is also characterized by high values of green algae. This is not so much true for the later peaks of cyanobacteria. These (zone IV and zone VI), also differ from zone II as *Anabaena* does not show increased values in any of these zones.

Over time (i.e. in the higher parts of the core) it can be seen that some taxa that are related to higher nutrient loads increase. These include *Pediastrum*, *Tetraedron*, *Botryococcus*, Nymphaeaceae cells, and animal remains. Also in the topmost part of the core taxa indicating the continued presence of humans through an opening of the landscape show stable low percentages (e.g. Poaceae, *Plantago*). Also in this part of the core non-arboreal pollen are present in higher percentages, again showing an opening of the landscape. In the lowest part of the core (zone I) several taxa show increased values for a short time (e.g. *Coelastrum*, *Botryococcus*, *Fagus*, fungal spores).

While all taxa show considerable ups and downs throughout the core, few of them are parallel and can therefore be assumed to show reactions to similar environmental changes. Also, with the above mentioned exceptions most changes are not continuous and sometimes resemble oscillations.

Archaeobotany

The three sediment cores analysed from the settlement Nussbaumersee-Inseli differ quite a lot as far as conservation of seeds and seed density is concerned. The most important species are the same in all cores, and some similarities can be seen in the changes over time. The only thing that can be concluded for certain is, however, that the distribution of botanical remains varies both between locations and over time.
In general cereals and other cultivated plants were found in almost all samples. The largest part of plant remains represents species growing on nutrient rich, wet, and agricultural land. Table 4 shows a short summary of the main results, appendix I lists all plant taxa found including their English and German names, appendix III shows plates of some interesting species, and appendix V lists the frequencies of occurrence of all taxa.

Table 4: List of all samples from the profiles of Nussbaumersee-Inseli and the main results. (Total seeds include cereal remains)

Profile 58						
sample number	**volume (ml)**	**remarks**	**archaeological layer**	**total seeds found (calibrated per l)**	**most frequent species**	**most frequent cereal species**
58.1	x	charred rachis fragment	20	x	x	x
58.2	x	charred rachis fragment		x	x	x
58.3	x	*Linum* fruit		x	x	x
58.4.1	400			1170,0	*Chara, Potentilla/Fragaria, Chenopodium album, Papaver*	*Trititcum mono/dicoccum*
58.4.2	2000			3061,3	*Papaver, Linum, Potentilla/Fragaria, Chenopodium album*	*Trititcum mono/dicoccum*
58.5	3000			2820,7	*Papaver, Potentilla/Fragaria, Linum, Fragaria vesca*	*Triticum aestivum*-type
58.6	3700			1408,6	*Papaver, Potentilla/Fragaria, Chara, Rubus sp*	*Triticum aestivum*-type
58.7	3000	somewhat sandy	22	1342,7	*Papaver, Carex tricarpellat, Chenopodium sp, Potentilla/Fragaria*	*Hordeum*
58.8	3600		24	2178,4	*Papaver, Chenopodium album, Potentilla/ Fragaria, Linum*	*Hordeum*
58.9	1950		26	1310,3	*Chenopodium album, Papaver, Potentilla/Fragaria, Linum*	*Triticum aestivum*-type
58.10	550		26?	2852,7	*Chenopodium album, Papaver, Potentilla/Fragaria, Rubus*	*Triticum aestivum*-type
58.11	100		28?	1470,0	*Papaver, Linum, Potentilla/Fragaria,*	*Trititcum*

					Chenopodium sp	*mono/dicoccum*
58.12	500		28?	2480,0	*Papaver, Potentilla/Fragaria, Chenopodium album, Chara*	*Trititcum mono/dicoccum*
58.15	650	lake marl	?	284,6	*Chara, Najas marina, Cladium mariscus*	*Hordeum*
Average				1852,7		
Sum				20379,2		
Profile 75						
sample number	**volume (ml)**	**remarks**	**archaeological layer**	**total seeds found (calibrated per l)**	**most frequent species**	**most frequent cereal species**
75.1/1	1300	probably same sample as they got mixed up	10 (?)	1401,5	*Papaver, Chara, Potentilla/Fragaria, Chenopodium sp*	*Triticum aestivum*-type
75.1/2	1050			1281,0	*Papaver, Chara, Linum, Rubus sp*	*Triticum sp*
75.2/3	1400	archaeological layers not visible, profile cut into 10 cm thick samples	20/22	585,0	*Papaver, Linum, Chara*	*Trititcum mono/dicoccum*
75.2/4	1400			2743,6	*Papaver, Chara, Linum, Rubus sp*	*Triticum aestivum*-type
75.2/5	1500			4360,0	*Papaver, Potentilla/Fragaria, Sambucus sp, Chenopodium sp*	*Trititcum mono/dicoccum*
75.2/6	1300			3553,8	*Papaver, Carex tricarpellat, Sambucus sp, Rubus sp*	*Trititcum mono/dicoccum*
75.2/7	1600			2353,1	*Papaver, Fragaria vesca, Carex tricarpellat, Potentilla/Fragaria*	*Trititcum mono/dicoccum*
75.2/8	1500			1677,3	*Papaver, Linum, Potentilla/Fragaria, Fragaria vesca*	*Trititcum mono/dicoccum*
75.2/9	900			2658,9	*Papaver, Linum, Verbena officinialis, Fragaria vesca*	*Triticum aestivum*-type

75.2/10	1100			7410,0	*Papaver, Linum, Rubus sp, Fragaria vesca*	*Triticum aestivum*-type
75.3/11	1100		24	3242,4	*Papaver, Linum, Verbena officinialis, Rubus sp*	*Triticum aestivum*-type
75.3/12	900	maybe the same sample (overlap of sample cases)		1108,9	*Papaver, Potentilla/Fragaria, Linum, Verbena officinalis*	*Hordeum*
75.3/13	900			2284,4	*Papaver, Linum, Fragaria vesca, Persicaria hydropiper*	*Hordeum*
75.3/14	2000			855,6	*Papaver, Linum, Potentilla/Fragaria, Carex tricarpellat*	*Hordeum*
75.4/15	700		?	2655,2	*Papaver, Linum, Rubus sp, Persicaria hydropiper*	*Hordeum*
75.5/16	550	clayey layer	?	2385,5	*Papaver, Linum, Chenopodium sp, Persicaria hydropiper*	*Triticum aestivum*-type
75.6/17	100	wood	?	2480,0	*Papaver, Linum, Chenopodium sp, Potentilla/Fragaria*	*Hordeum*
75.7/18	1200		26	2448,3	*Papaver, Linum, Chenopodium sp, Fragaria vesca*	*Hordeum*
75.7/19	1400			2190,0	*Papaver, Linum, Fragaria vesca, Chenopodium sp*	*Hordeum*
75.8/20	1100		28	1841,8	*Linum, Papaver, Chara, Fragaria vesca*	*Hordeum*
75.8/21	1000	split due to different colouring	30	1069,0	*Papaver, Linum, Chara, Najas sp*	*Trititcum mono/dicoccum*
75.9/22	900			623,3	*Chara, Papaver, Linum*	*Hordeum*
Average				2327,7		
Sum				51208,8		

Profile 93						
sample number	**volume (estimated from sketch)**		**archaeological layer**	**total seeds found (calibrated per l)**	**most frequent species**	**most frequent cereal species**
93.1a	1100		20	1879,1	*Rubus idaeus, Alnus glutinosa, Urtica dioica, Caryophyllaceae*	*Triticum aestivum*-type
93.1b	1100			1411,8	*Rubus sp, Urtica dioica, Alnus glutinosa, Corylus avellana*	*Triticum aestivum*-type
93.1c	1000		22	1818,0	*Rubus sp, Chenopodium album, Urtica dioica, Sambucus sp*	*Triticum aestivum*-type
93.2a	500			2962,0	*Linum, Rubus sp, Papaver, Fragaria vesca*	*Triticum aestivum*-type
93.2b	1000			1394,0	*Linum, Rubus sp, Papaver, Fragaria vesca*	*Triticum aestivum*-type
93.2c+c1	1000			1328,0	*Rubus sp, Linum, Papaver, Fragaria vesca*	*Triticum aestivum*-type
93.2d+d1	1000			1427,0	*Linum, Rubus sp, Caryophyllaceae, Papaver*	*Triticum aestivum*-type
93.3	200			1780,0	*Linum, Papaver, Betula, Poaceae*	*Trititcum mono/dicoccum*
93.4	200			5445,0	*Papaver, Linum, Verbena officinalis, Betula*	*Hordeum*
93.5	200			2380,0	*Papaver, Linum, Eupatorium cannabinum, Verbena officinalis*	*Hordeum*
93.6	400			467,5	*Linum, Papaver*	*Triticum aestivum*-type
93.7	450			1600,0	*Linum, Papaver, Brassicaceae, Juncus sp*	*Triticum aestivum*-type

93.8	300			3510,0	*Papaver, Verbena officinalis, Linum, Malus sylvestris*	*Triticum aestivum*-type
93.9	300			876,7	*Linum, Verbena officinalis, Papaver*	*Trititcum mono/dicoccum*
93.10	450			1286,7	*Linum, Malus sylvestris, Poaceae, Verbena officinalis*	*Trit. aestivum/Hordeum*
93.11	200			1735,0	*Linum, Urtica dioica, Papaver, Caryophyllaceae*	*Triticum aestivum*-type
93.12	1000			1304,0	*Linum, Rubus sp, Papaver, Solanum dulcamara*	*Triticum aestivum*-type
93.13	800			1532,5	*Linum, Papaver, Fragaria vesca, Verbena officinalis*	*Triticum aestivum*-type
93.14	200			345,0	*Sambucus sp, Urtica dioica, Linum, Papaver*	*Triticum aestivum*-type
93.15	600		24	648,3	*Linum, Papaver, Urtica dioica, Carex tricarpellat*	*Triticum aestivum*-type
93.16	1300			684,0	*Linum, Papaver, Urtica dioica, Rubus sp*	*Triticum aestivum*-type
93.17	2000		26	889,5	*Papaver, Linum, Malus sylvestris, Carex tricarpellat*	*Triticum aestivum*-type
93.18	1000			750,0	*Papaver, Linum, Malus sylvestris, Carex tricarpellat*	*Hordeum*
93.19	200		?	1100,0	*Papaver, Linum, Carex tricarpellat, Fragaria vesca*	*Trititcum mono/dicoccum*
93.20	200		28	3360,0	*Fragaria vesca, Papaver, Linum, Rubus sp*	*Triticum aestivum*-type
93.21	300			3140,0	*Papaver, Fragaria vesca, Linum,*	*Triticum aestivum*-type

					Polygonaceae	
93.22	400			4682,5	*Papaver, Linum, Fragaria vesca, Chenopodium album*	*Trititcum mono/dicoccum*
93.23	400			3452,5	*Papaver, Linum, Fragaria vesca, Rubus sp*	*Trititcum mono/dicoccum*
93.24	700		30	3470,0	*Papaver, Linum, Fragaria vesca, Rubus sp*	*Triticum aestivum*-type
93.25	1000			155,0	*Papaver, Linum, Fragaria vesca, Potamogeton*	*Triticum aestivum*-type
Average				1893,8		
Sum				56814,1		

- NBS-75

A total amount of 92,991 identifiable botanical and animal remains has been found in the sediment analysed. Over the 22 samples the average density of seeds (excluding cereal rachis parts and animal remains) was 2,328/l sediment. However it is clearly visible that the densities were considerably lower in the lowermost and uppermost parts of the core (Fig. 6, 9, Tab. 4).
Both ends of the core are largely dominated by aquatic plants, suggesting that the sediment analysed contains the whole sequence of low lake levels.
A clear sequence is visible in core 75 (Fig. 6): It starts with the first sample dominated by *Chara* species and Gastropoda, and from there shows an increase of terrestric plants, most of which grown on agricultural land or nutrient rich lake shores (Polygonaceae, Amaranthaceae) and can also be used for food. This increase goes together with an increase in Cerealia and in collectable plants (e.g. berries like *Rubus*). Also flax (*Linum usitatissimum*) shows an increase in the lower part of the core, however not as sharp as cereals. In the middle part of the core (around sample number 14, approximately 70 cm from the bottom of the core) all of these species show a decline where especially apple (*Malus sylvestris*) and hazel nuts (*Corylus avellana*) suddenly become more frequent. Just above that remains of *Chara* were found again, suggesting a short-time rise in lake level. At this time *Linum* has its highest values, together with *Papaver somniferum*. After this peak, more cereals are found again and collected fruits are found in high densities.
In the uppermost parts of the core *Chara* and *Najas* indicate rising water levels, while most terrestric plants are still quite abundant in the samples, with exception of cultivated crops (cereals and *Linum*).

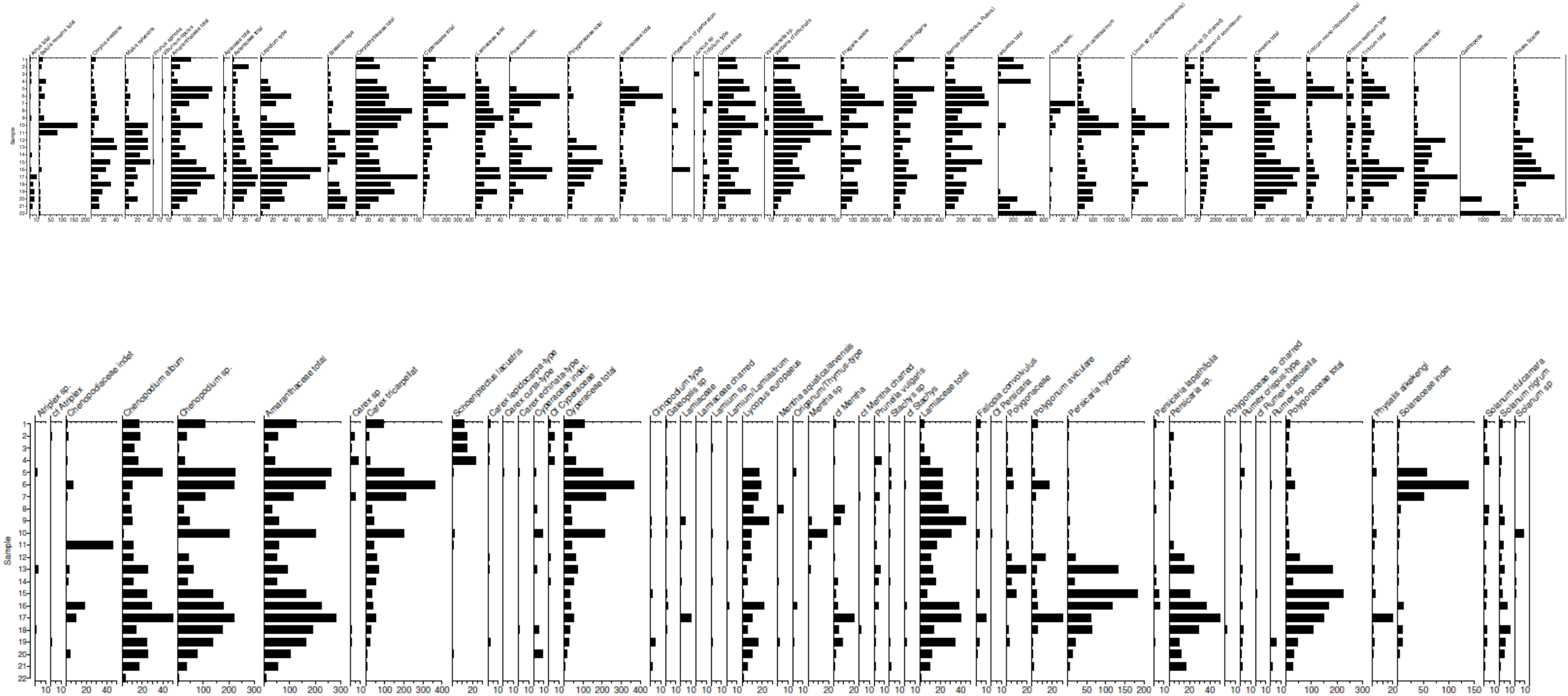

Figure 6: Diagram of the main plant groups found in the profile NBS-75 (above) and single taxa of the most important plant groups (below). Numbers are calibrated per litre. (Diagram drawn with Tilia Graph).

- <u>NBS-58</u>

In the sediment of column 58 a total of 114,558 identifiable plant and animal remains have been found. This is much more than in the other columns, however, the samples were also much larger. The average number of seeds per litre is lower than in NBS-75: 1,853/l (Tab. 4, fig. 7, 9).
The samples of core 58 are very unevenly spread with few samples of large volumes and many small samples, making it quite difficult to really interpret them chronologically. In general however, the most important features of core 75 are also present in core 58 to some extent: aquatic species dominate both the uppermost and the lowermost part of the core. *Chara* is present in small numbers in almost all samples, however shows a slight peak in the middle of the core, possibly indicating a rising lake level there. *Papaver* and *Linum* show a strong peak at the same time. Contrasting to core 75, however, this peak occurs parallel to peaks in most other cultivated and collected plants. At the same time *Betula* seeds are very abundant.

- <u>NBS-93</u>

This core is the longest and the sequence with the best resolution. However, as mentioned above, some mistakes must be assumed in the counting and calibration of the results because of the missing paperwork. Also the samples have been analysed by a different person, which resulted in some seeds being determined to a higher level of determination and others being put in different groups and animal remains being left out for a big part. Nonetheless the results look reliable, especially compared to the other columns, so it can be assumed that they are more or less correct.
The average number of seeds per litre was similar as in NBS-58 (1,894). The total number of plant and animal remains was the lowest of all three profiles (86,104) however, this may also be partly because many animal remains have not been counted (Fig. 8, 9, tab. 4).
Like in the other cores aquatic species are found in the lowermost and uppermost parts of the core as well as in the middle. Collectable as well as cultivated plants and species growing on farmland all show a sharp increase in the first few samples. After that a sharp decline is seen especially in collected plants. This is followed by several samples with rather low densities of edible plants, with some fluctuations in both collected fruits and cereals. This is also the period where aquatics are found again. Single extreme values in this case have to be doubted due to methodological problems in this core.
The period of low abundances ends with a steady increase of *Linum* remains which peaks at the same time as *Papaver*, cereals and *Betula*. After this, all of these decline again, while collected fruits like *Sambucus* and *Rubus*, as well as other edible plants like *Chenopodium* and *Urtica* show high values continuing in the uppermost samples which also contain aquatics again.

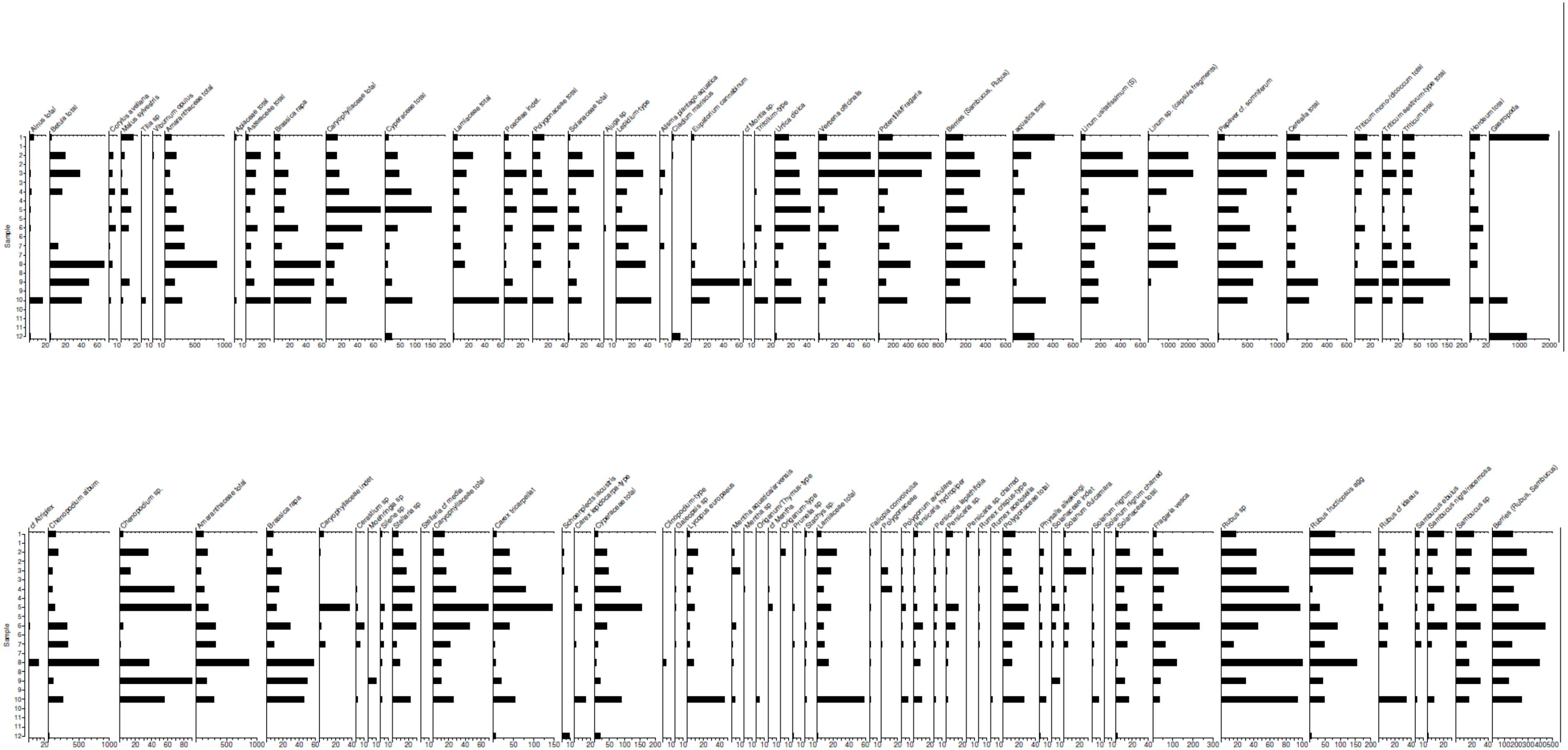

Figure 7: Diagram of the main plant groups found in the profile NBS-58 (above) and single taxa of the most important plant groups (below). Numbers are calibrated per litre. (Diagram drawn with Tilia Graph).

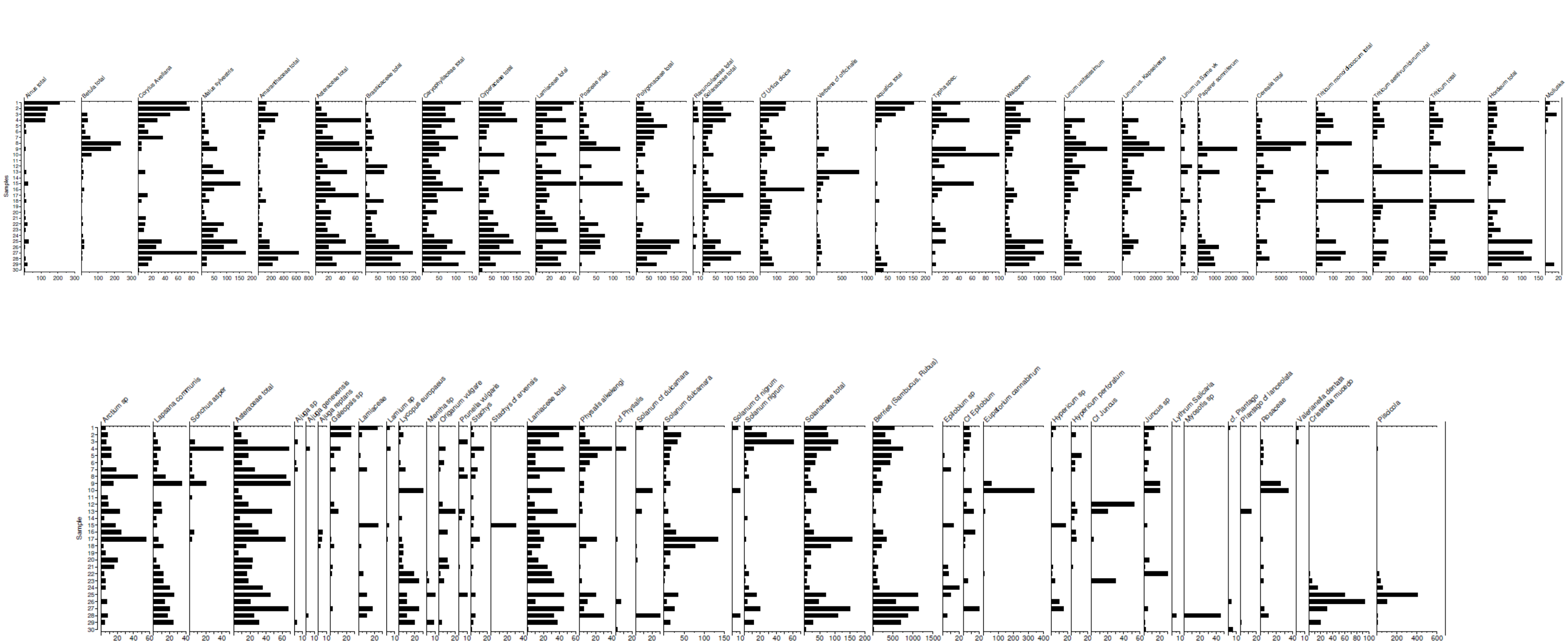

Figure 8: Diagram of the main plant groups found in the profile NBS-93 (above) and a selection of interesting taxa (below). Numbers are calibrated per litre. (Diagram drawn with Tilia Graph).

➢ Comparison of the three cores

In order to compare the three different profiles the samples are summed up in the different archaeological layers. This is difficult because in some places the archaeological layers could not be identified and in general the definition of the layers is not very clear in all places. However, since not all layers are represented in all the three profiles, this is the only way to compare them.
Comparing the preservation and density of plant remains in the three profiles, it can be seen that all of them are very well preserved and show a high density of plant remains (Tab. 4, Fig. 9). The profile 75 has the highest density of identified seeds. This is mainly due to the sample 75.2/10 which has a density of more than 7000 seeds/litre (of which more than 4000 are poppy seeds), which is far above average for both the settlement Nussbaumersee-Inseli and other settlements in the region.

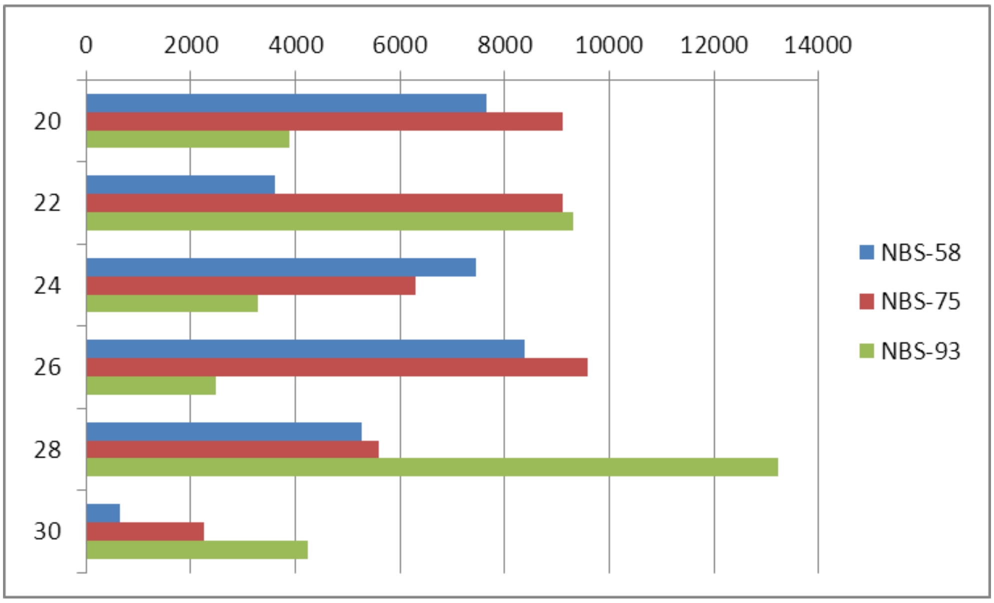

Figure 9: Comparison of the total number of botanical finds in the three profiles in the archaeological layers of the settlement Nussbaumersee-Inseli. Numbers are calibrated per 2 litres.

If the various archaeological layers are examined separately it is obvious that the seed density is quite low in the lowest layer (30), which also consists mainly of lake marl. The same is to a certain extent true for layer 10, however, it is only represented in profile 75, so it cannot be compared with other profiles. Profile 93 has its highest density in layer 28 and then another peak in layer 22, while for the layers in between densities are much lower than in the other cores. Core 58 shows an increase at the bottom and then a decrease at the top of the core, but in layer 20 shows another increase in plant density. Similarly, core 75 shows an increase and decrease from layer 30 to layer 24 and then an increase again to layer 20/22 (which was not differentiated in that core). While the development in the different cores is not exactly parallel, it can be assumed that the lower layers (26/28) and the higher layers (20/22) have a higher density of plant remains than the lowest, the medium and the highest layer (30, 24, 10). This is consistent with the observation that many plant remains show a sharp increase in the lowest part of each core, then decrease again and then increase before decreasing again at the end of the core.

Also the species found in each of the cores are very similar (Fig. 10). The main species are found in each core and in high densities. Several species are only represented by one or two seeds, and then only in one core. In general it can be assumed that the large amount of sediment examined in this research allowed for the long list of species, which contains almost all species that other studies of settlements from the region found. Looking at the most frequent species in each of the cores, it becomes clear that core 58 is quite different from the other two. Core 75 is highly dominated by *Papaver* and *Linum*, and so is profile 93, where *Linum* is the most common species in most samples. In profile 58, *Linum* is present in every sample, but not in such high densities and ruderal plants (like *Chenopodium*) are very dominant in many samples.

In total there are only two species that are present in every sample in each of the three cores: *Linum* and *Papaver* (App. V). Also cereal remains are found in every sample, but many of them are not identifiable to species or genus level. Many taxa are found in each profile but not in every sample. The fact that in core 93 many more species were found than in the other cores, is largely related to the fact that the seeds found in that core have been determined to a higher level of identification. In general there are several species where only one or two seeds have been found, but they are not the majority.

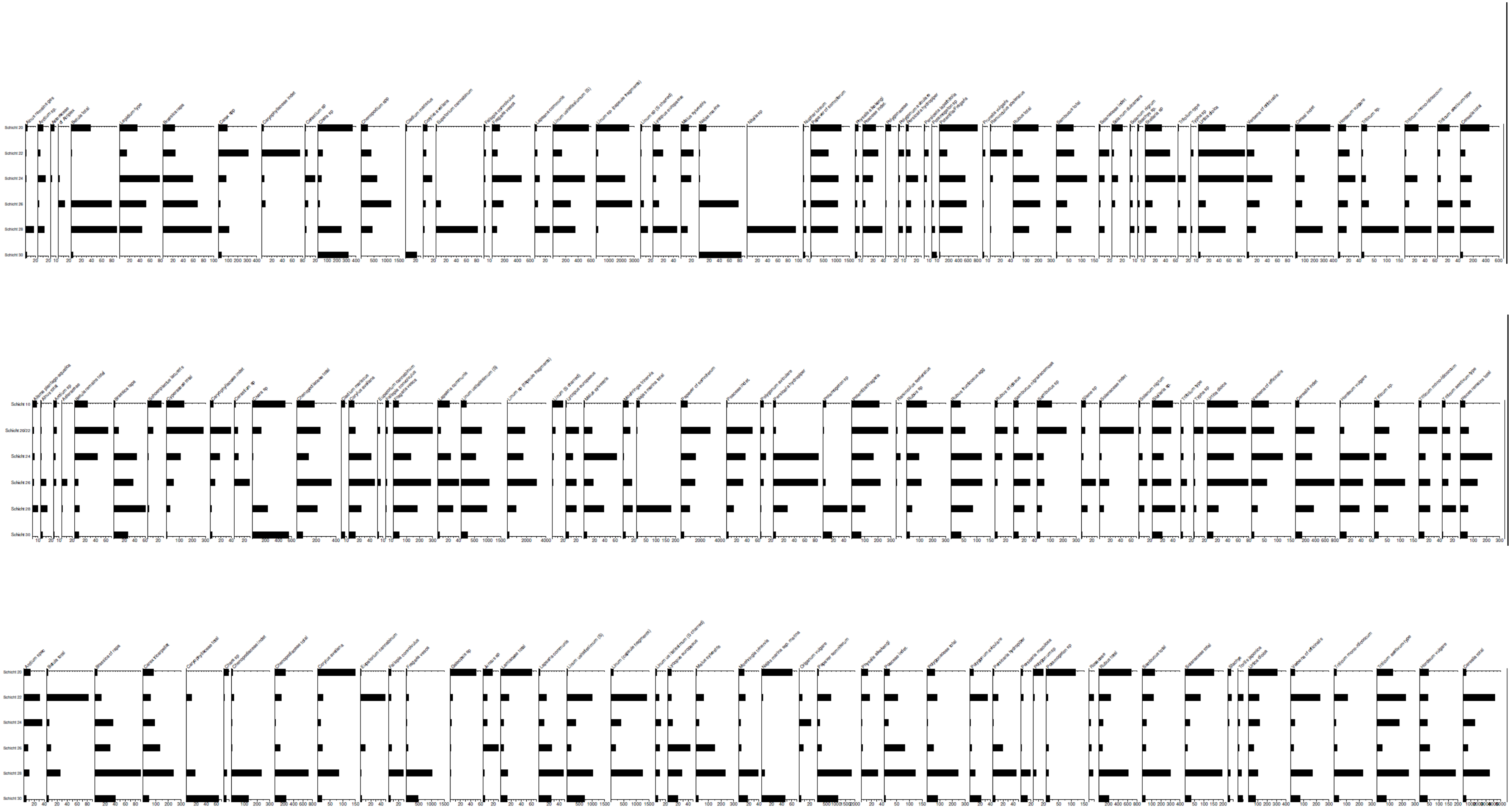

Figure 10: Diagram of the main plant groups of all profiles (above: NBS-58, middle: NBS-75, below: NBS-93) as spread over the archaeological layers found in the settlement. (in NBS-75 layer 20 and 22 could not be distinguished, therefore the average of the layer 20/22 has been used for both layers). Numbers are calibrated per 2 litres. (Diagram drawn with Tilia Graph).

Discussion

Dating results NBS-B

Due to the analysis of NPPs and macrofossils the radiocarbon dates received from samples from the sediment core NBS-A/B have to be reviewed. Initially several dates were excluded from an age-depth curve (Fig. 2). Even keeping in mind that many dates have large confidence intervals (up to more than +/- 100 years) it is still difficult to match events seen in the botanical analysis with the known archaeological activities. Experimenting with the use of different dates for a new age-depth model resulted in better matches in some parts of the core and worse differences in others. It was viewed as not reliable to make a new selection of dates to use for a new model, solely based on matches between archaeological facts and human influence indicators observed in the various ecological analyses, therefore I refrained from making a new age-depth model, and rather printed a graph to show the potential range of calibrated dates in the upper half of the core especially. This graph is shown in Fig. 11 and should be used as a reference when interpreting the results of the study. It becomes obvious that for many depths in the upper half of the core the possible ages have a range of about 1000 years. It should be noted however, that a linear age-depth curve must be seen as highly unlikely due to the changing water levels. Certain changes in sedimentation rates must be assumed, meaning that it is not impossible that all radiocarbon dates are actually correct and there is no (near-) linear age-depth curve.

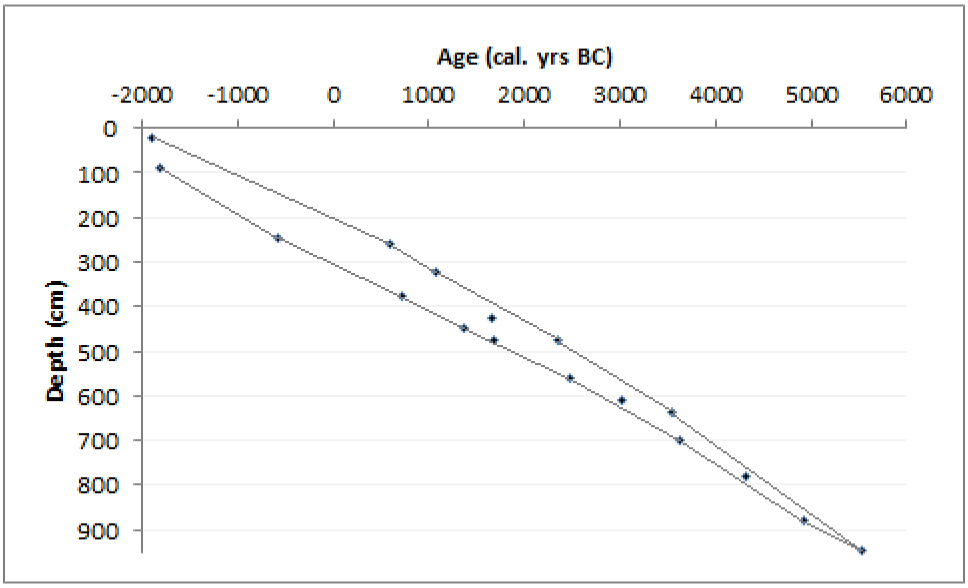

Figure 11: Diagram of potential age ranges for the core NBS-A/B if no radiocarbon dates are excluded from the analysis to be used for better interpretation of results.

Macrofossil Analysis of Lake Cores

NBS-P1

The macrofossils found in the core NBS-P1 indicate that the vegetation represented in this core is only very limited to the close surroundings of the site where the core has been taken. This means that these results are of limited use for the reconstruction of the wider landscape. Also the comparably young age of the lowermost samples of the core (Bronze Age) make this core much less valuable than the much longer core NBS-B.
The tree remains found in the Medieval Period in this core indicate that the region was settled by humans in the Medieval but was not constantly used heavily since apparently trees could recover for at least several years to produce seeds, before they were cut down. The area was still swampy then so it could not be used for agriculture. However it is likely that trees have been cut down at regular intervals to provide wood for building or burning.
The high numbers of *Chara* between 25 and 40 cm depth (AD 1000-1400) indicate a higher lake level during this period which was then lowered by about 1.5 m in modern times. The same is also indicated by several remains of aquatic animals.
Compared to the major changes found in the core from the lake bottom there is little evidence for such changes in the core NBS-P1. The lowermost sample is quite different from the others, however, which might indicate that the changes seen in the core NBS-B around 350 cm may be paralleled by the lowermost part of NBS-P1. The limited number of samples, and the fact that the core is not longer, however, make it impossible to prove these assumptions.

NBS-A/B

The macrofossils from this core can be used as an indicator of the vegetation of the lake shores and their near surroundings. The tree remains found are mainly from *Betula* and *Alnus*. Rather than assuming that this was the predominant vegetation of the area in the past, we must consider that the seeds of *Betula* and *Alnus* spread much further than for example those of *Corylus*, *Quercus*, and *Fagus*. Also *Betula* and *Alnus* produce many more seeds than other climax-trees. It should also be considered that seeds of several trees (e.g. *Corylus, Fagus, Quercus*) have been used as food for humans or animals in the past and would therefore also be stopped from entering the lake to be preserved there and found in this analysis. This means that the tree cover of the area should rather be reconstructed using the results of pollen analysis instead of relying on macrofossils. It can, however, be stated, from the macrofossils that trees have always been present in the near surroundings of the lake, until at least 500 years ago. It is especially interesting that many tree remains have been found in the part of the core representing the Pfyner Age settlement.

Macrofossils however, have many advantages to pollen. One big advantage is the representation of water plants which do not produce pollen (e.g. *Chara*). These can be used as an indicator of lake level changes and thereby of climatic changes.
Around 5000 BC a sample with very high numbers of *Najas* seeds indicates that there was a short period with probably very low lake levels. Then, around 4500 BC, the lake level rose as indicated by high values in *Chara* in several consecutive samples. Around 4000 BC *Chara* remains become more scarce, indicating a lowering of the lake level which between 3700 and 3850 BC facilitated the building of the Pfyner Age settlement on the land bridge between the westernmost and the central basin of the lake. Again relatively high numbers of *Najas* indicate the water level being low.
After that remains of both *Najas* and *Chara* remain scarce, which means that there is no possibility to get an indication of the lake level from the macrofossils. Between the two Bronze Age settlement phases, however, high values in *Chara* oospores again indicate a high lake level and a sudden decline around 850 BC facilitating the Late Bronze Age settlement.

The big change in sedimentation happening around 350 cm (around 500 BC) must be related to major changes in the surroundings of the lake. It is possible that the changes seen in the core are a result of changed runoff and erosion due to major deforestation, however neither the pollen diagram nor the results of the macrofossil analysis support this assumption. It is possible that continued human presence (for example if combined with animal grazing close to the lake) induced the changes in sedimentation. Another possibility is that due to the activities of the latest settlers (Late Bronze Age) the area changed so much, that erosion also changed. This is possible, for example, if bogs have been drained. With the available evidence it is not possible to determine what really happened in the surroundings of the lake.

Microfossil (NPP) Analysis of Lake Core NBS-B

The results of the analysis of NPPs are discussed in detail in the original publication (Hillbrand et al., 2014). The seven distinct non-pollen-palynomorph assemblage zones are mainly based on the three eutrophication zones interspersed with zones of little eutrophication which we interpret as periods of little human influence. Climatic changes will probably have favoured rapid changes in the trophy level of the lake water, however, human influence is very likely to have played an important part in the changes in the species composition in the lake.

Lake Eutrophication and Human Impact

Cyanobacteria have the ability to fix nitrogen from the air and therefore have a competitive advantage over other algae in the case of phosphorous enrichment of the lake water. This led to the conclusion that blooms of cyanobacteria are caused by human impact and resulting introduction of phosphorous (e.g. from faeces from humans and livestock) into the lake. In this case cyanobacteria can bloom initially and fixed nitrogen can later become available to other algae and enable blooms of green algae at a later point (cf. van Geel et al., 1994).

It is likely that human impact was not the only driver for eutrophication and algal or cyanobacterial blooms in Lake Nussbaumersee, as all known human settlements date to periods of low lake levels. The smaller water body in the case of low lake levels will react much faster to the introduction of additional nutrients, meaning that trophy levels would increase more and faster in a decreasing water body. The opposite is true for increasing lake levels which would facilitate the restoration of the initial low trophy level. Since it seems that human presence and low lake levels were very much correlated in the pre-history of Lake Nussbaumersee it is impossible to determine which of the two factors was the main driving force for the change in trophy levels.
Looking at climatic data (cf. Magny, 2004), however, there was a period of warmer climate with related low lake levels in central Europe before the first known human settlement on the shores of Lake Nussbaumersee. It is possible that the first increase of Coelastrum and diatoms in zone I (around 5000 BC) is related to this climatic impact, which was also visible in the macrofossil analysis. This may be an indication of how climatic drivers alone (without human impact) change the lake ecosystem.

Interestingly the first eutrophication zone (zone II) is very different from the following ones (zones IV and VI). This is visible on the one hand from the fact that zone II shows the only peak of *Anabaena*, and on the other hand, almost all taxa show major changes between zones I and II whereas in zones IV and VI some taxa show similar ups or downs as in zone II but others do not show any changes at all. While it is not known what exactly caused the differences in the species composition in the various eutrophication zones, several reasons are possible: (1) as far as we know from archaeological research, the settlement connected to the first eutrophication phase (Nussbaumersee-Inseli, around 3840-3695 BC) was the longest phase of human occupation in the pre-history of the area. It was also the only settlement that had an effect on the landscape that is visible in the pollen diagram (as an opening of the forest, visible in the increased non-arboreal pollen percentages). (2) Besides, this was also the first major human impact on the natural ecosystem and changes in some taxa suggest that, while the trophy level of the lake probably returned to the initial state, the ecosystem has probably suffered some long-term changes, visible for instance in the increased values of some green algae. If initial trophy levels were higher before the start of the human occupation then the resulting cyanobacteria blooms should be less compared to a very oligotrophic system. Therefore long-term effects of the first phase of human impact can have changed the eutrophication effects of the later periods of human impact. (3) According to climatic research probably the first human impact zone also equals the phase with lowest lake levels in Lake Nussbaumersee throughout the Holocene (Magny, 2004). (4) Finally, a different life style, can have resulted in different effects of human settlements in later times. For example if livestock was kept further away from the lake, the phosphorous input would have been smaller.

Dating Problems

As mentioned above, we assume that the three observed eutrophication zones relate to three human settlements in the pre-history of the area. The first eutrophication zone (zone II) dates to the time of the settlement Nussbaumersee-Inseli and is definitely caused (at least to some extent) by that settlement. The other two eutrophication zones (zones IV and VI) are dated to 2800 to 1550 BC (zone IV) and to 620 to 280 BC (zone VI). The other two known lake-side settlements are dated to 1580-1538 BC and to 850 to 800 BC, respectively. The problem hereby is, however, that the settlements are dated using dendrochronology and the dates of the villages mentioned are therefore exact dates, whereas the sediment core is dated using radiocarbon dating on small botanical remains found in the core and therefore have a large calibration range. Besides, several radiocarbon dates were not used for the age depth-model (fig. 2) as they were older or did not seem as reliable. To include the uncertainty about which dates to choose for the model the original selection of radiocarbon dates used for the model has been revised (fig. 11). The figure shows that especially in the upper part of the core, uncertainties of up to 1000 years must be assumed for the ages in each depth. This could mean that the second eutrophication phase (zone IV) is actually related to a settlement of the Corded Ware Culture. One pit house was found during the excavations at Lake Nussbaumersee which was dated to 2500 – 2900 BC by charcoal remains. It is likely that the house was part of a bigger settlement, but houses built above ground have not been preserved. The assumption that this settlement from the Corded Ware Culture was bigger than the remains found is supported by the fact that peaks of cyanobacteria are found in this period. Then there are two settlements in the Bronze Age that may have caused the eutrophication phase in zone VI. Again, because of the large range of the radiocarbon dates it is impossible to be sure which of the two settlements known from the Bronze Age was responsible for the eutrophication found in the NPP analysis. However, the Late Bronze Age settlement (850 – 800 BC) is thought to have been a lot bigger than the Early Bronze Age settlement (1580 – 1538 BC). Also the radiocarbon dates of the eutrophication phase point more towards the Late Bronze Age. It must be assumed that the effects of such a big settlement could not easily be missed in the NPP study. On the other hand, the Early Bronze Age settlement was small and existed only for a short period, compared to Neolithic settlement. This means that apparently the Early Bronze Age settlement did not cause any peaks in cyanobacteria, however there is a large peak in microscopic charcoal which might be related to that settlement and in the same period there are also peaks of *Pediastrum*.

While this explanation is very likely, there are also other possible explanations for how the eutrophication phases coincide with the various settlements in the area. Another possibility is that the latest peaks of cyanobacteria were caused by activities of Romans in the region. It is also not sure if the Corded Ware Culture settlement was really big and caused the eutrophication visible in zone IV but it seems the likeliest explanation. In this case the eutrophication signs indicate major settlement activities, probably in several phases or over a long period of time. Further archaeological and palaeoecological research could possibly deliver more indicators to help answer this question.

Further changes in NPPs

Several other NPP types show changes throughout the core. Some are parallel but most are not. Especially for the newly defined types it is helpful to know in which environments they are abundant to help identify them. The Types IIB-001, IIB-002, and IIB-003 show the highest abundance in zone I suggesting that they are dependent on natural oligotrophic conditions. The curves are very similar to the Type HdV-361.

If the ecology of all the NPP types is better known, it may be possible to make more assumptions about the changes in the ecosystem of the lake and its surroundings but currently we can mainly see that the ecosystems changed but can only guess what caused the changes and which effect they had on the landscape. Some further changes in NPPs are discussed in the original publication (Hillbrand et al., 2014).

Principal Component Analysis (PCA)

- Pollen results

In the PCA for pollen, *Fagus* is the single most determining species (Fig. 12, 13, compare also app. IV). In the pollen diagram it is visible that *Fagus* alternates with *Corylus* dominated phases. This is also visible in the PCA, as they are found on two opposing ends in the graph. *Corylus* is often viewed as an indicator of human influence, resulting from deforestation, while the alternating phases of *Fagus* dominance show the re-establishment of the climax-system (e.g. Ammann et al., 1988; Liese-Kleiber, 1993).
However, it is not clearly visible that this is so in the case of Lake Nussbaumersee. It is also possible that the pollen diagram represents a rather natural forest system that does not have a steady state climax stadium but rather remains in a constant alternation between *Corylus* and *Fagus* domination. It is visible, however, that the main human impact phases occur in times of *Corylus* domination. Only the earliest phase represented in the pollen diagram is dominated by *Corylus*, where human influence probably did not play a big role. In this time *Fagus* had not yet re-established its populations in the inner-alpine region after the glacial.

Whether or not in the case of Lake Nussbaumersee the alternating phases of *Corylus* and *Fagus* domination represent different intensity of human impact or a natural cycle, from the PCA diagram it is clearly visible that the development of the vegetation is very directed from a more closed and dark forest ecosystem towards a more open, grazing impacted eutrophic and rather dry vegetation. The settlement phases do not really stand out in the diagram, suggesting that this change occurred rather continuously and not – as might be expected from the settlement history – in several steps which each had a major impact in a short time. This also indicates, that human occupation of the area was not limited to the known settlements but rather a continuous factor that the ecosystem adjusted itself to.

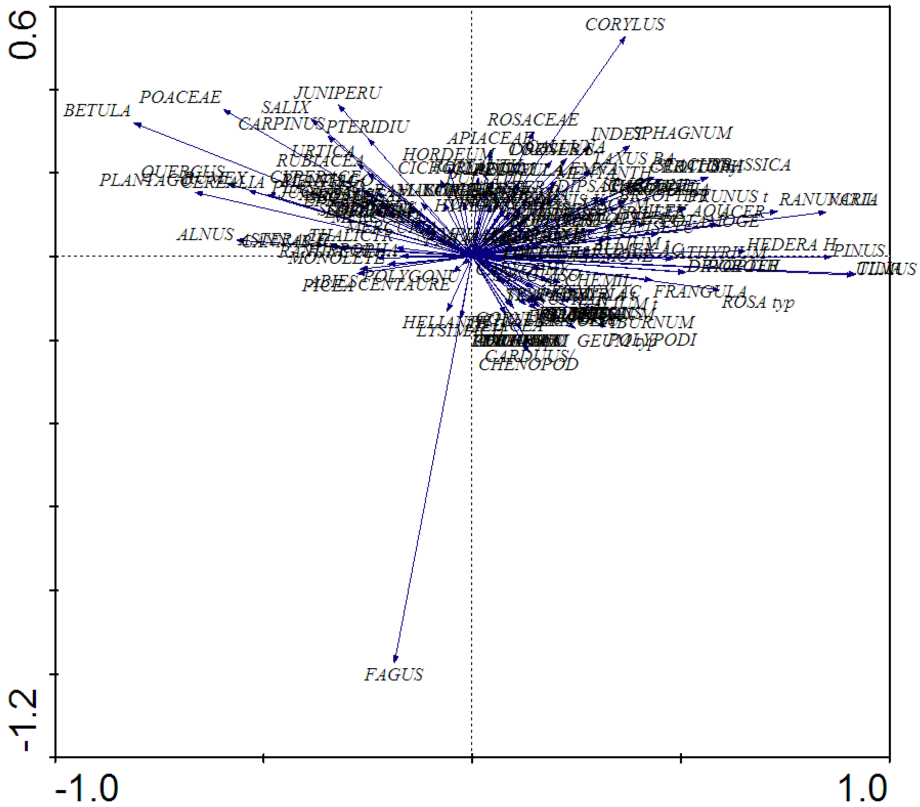

Figure 12: Results of the Principal Component Analysis (PCA) for pollen: species results. (Diagram drawn with CANOCO).

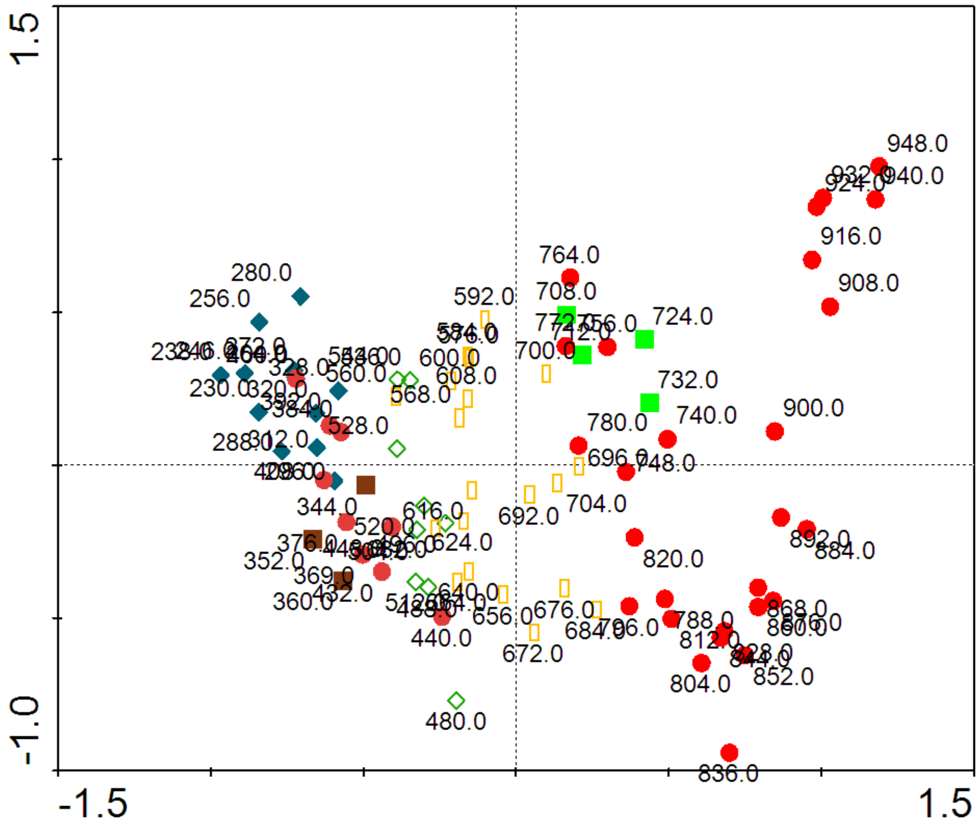

Figure 13: Results of the Principal Component Analysis (PCA) for pollen: sample results. The colours indicate the various phases of human occupation of the region: bright red circles: pre-settlement phase; green squares: period of the Neolithic settlement; yellow squares: Late Neolithic period including the Corded Ware Culture; red circles: Period between Neolithic and Bronze Age settlements; green diamonds: Early Bronze Age; brown squares: period of the Late Bronze Age settlement; blue diamonds: Roman Age and Medieval Period. (Diagram drawn with CANOCO).

- <u>NPPs</u>

Just like the pollen data, NPP data are dominated by few highly influential species (Fig. 14, 15). In this case these are Chlorophyceae on the one hand and Diatoms on the other. Not surprisingly therefore, the samples which represent the eutrophication phases identified, are the ones which stand out in the PCA. Interestingly according to the PCA analysis, the difference between the lake samples from any of the phases without eutrophication indicators can be neglected, meaning that the lake ecosystem did recover very well after each of the eutrophication phases. This is opposed to the view presented before, that after the second eutrophication phase, the lake never returned to the initial oligotrophic state. Obviously it depends on the weighting of different factors, which conclusion is being drawn. It is possible that the PCA overrates the eutrophication indicators and therefore does not detect smaller changes. It must, however, also be noted that – as stated before – each of the eutrophication phases did last only for a rather short period and the lake did recover rather efficiently after each of them, even if, in the later stages, it did not return to the initial oligotrophic state. This may, however, also be the result of ongoing human influence, rather than simply a loss of resilience.

- <u>Combined PCA</u>

A principal component analysis has also been performed using all data available. It did, however, not show any useful results, probably because the methods used cannot easily be compared. In several species that were detected by different methods, these seem to be indicating different ecological conditions. This also supports the idea, that the results derived from the various methods should be interpreted separately rather than combining them.

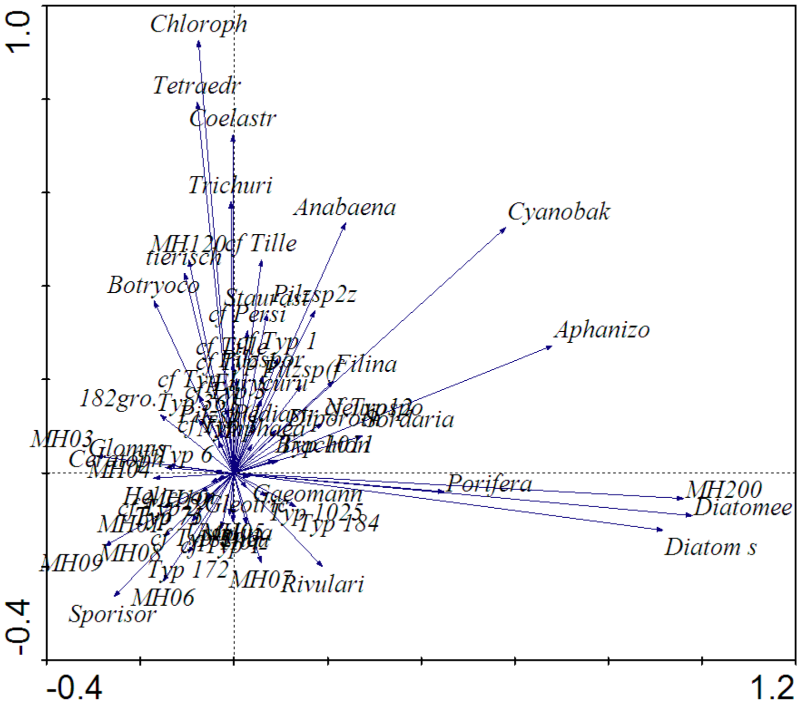

Figure 14: Results of the Principal Component Analysis (PCA) for NPPs: species results. (Diagram drawn with CANOCO).

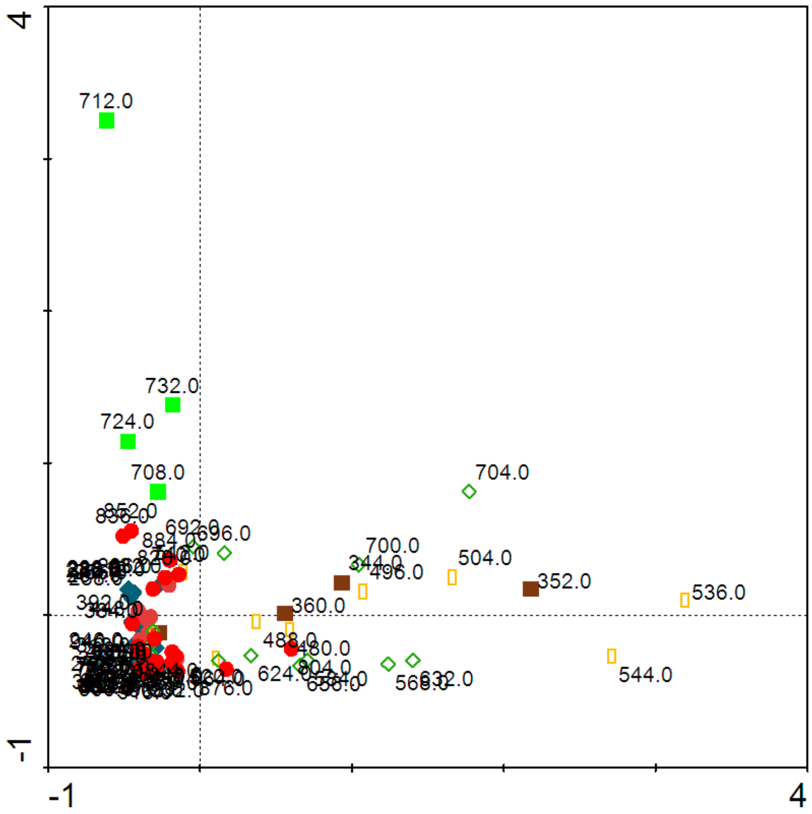

Figure 15: Results of the Principal Component Analysis (PCA) for NPPs: sample results. The colours indicate the various phases of human occupation of the region: bright red circles: pre-settlement phase; green squares: period of the Neolithic settlement; green diamonds: Late Neolithic period including the Corded Ware Culture; red circles: Period between Neolithic and Bronze Age settlements; yellow squares: Early Bronze Age; brown squares: period of the Late Bronze Age settlement; blue diamonds: Roman Age and Medieval Period. (Diagram drawn with CANOCO).

Archaeobotany of the Pfyner Age settlement

The archaeobotanical alanysis of the sediment from the Neolithic settlement resulted in a long list of plant species which must have grown in the near surroundings of the settlement and many of which have been used for food or medical purposes. The plants found are similar to comparable settlements in the surrounding area (see below).

What makes the analysis of this settlement special is the possibility to see changes over time, which can be represented in plant remains. However, as Jacomet and Brombacher (2005) pointed out, plant fossils are not evenly distributed within a settlement, and it must be assumed that the same limitations are true for the vertical distribution of the remains. Keeping these limitations in mind, the main conclusion that must be drawn is: plant use did change over time, but there are few clear trends visible.

Despite that, several observations can be made, which can be seen to a varying extent in all three profiles and can therefore be considered to be a general feature of the development of the settlement. Firstly, it can be observed that the density of plant remains and especially the density of food plants is very low in the lowermost samples, and increases rapidly thereafter. This can be assumed to indicate the initial growth of the settlement, which may have started off as only a few fishermen's huts, later growing into a village that also produced a larger amount of agricultural products. At the same time remains of aquatic plants, which are dominant in the lowest samples, decrease, indicating the lowering of the lake level. Around the middle of the settlement layer each profile shows a sudden increase of remains of water plants which hints at a rising lake level, which will probably have remained at a higher level for several years or even decades. At the same time remains of food plants and especially cereal remains decrease considerably, indicating, probably that the settlement was smaller in this period, and agricultural activities have been reduced. It is possible that in this period, some inhabitants of the village moved away and fishing and other occupations became more important again as a source of food. Higher up in the cores aquatics are not found any more and food plants increase, probably showing a growing village population again when the lake level decreases. The uppermost samples again show a fast decline of plants used for food and an increase of aquatic plants. This can be interpreted as a sign for a slow retreat of people from the village, when the lake level started to rise, as opposed to a situation where a village is suddenly left by all its inhabitants at once.
Archaeologists stated that at least three phases of settlement activities must be expected in the village. The above considerations seem to prove at least two of these phases.

Subsistence strategies Nussbaumersee-Inseli

From the results of the archaeobotanical analysis of the sediment from the Neolithic settlement Nussbaumersee-Inseli it can be concluded that subsistence strategies of the settlers were based on a wide array of plant and animal species and different methods of food production. On the one hand it is clear that agricultural production played an important role – both for the production of cereals and flax – while it is also obvious that collected foods like apples, berries, several vegetable plants, and also spices played a very important role in the subsistence of the villagers. This also means that extended forested areas must have been present in the near surroundings where all these plants could have grown. The zoological research conducted earlier (Market, 1998) indicated that animal husbandry as well as hunting were also integral parts of Neolithic subsistence. The results presented here should be able to point to changes in subsistence strategies over time during the 150- year existence of the settlement. Due to big differences between sites, unfortunately such conclusions cannot be drawn. Some assumptions can be made about the development of the village, however it must be clear that it is not possible with existing data to make any definite statements.

It is obvious however, that at least two different settlement phases can be identified, which are separated by a period of rather high lake levels. Since every single sample analysed contains cereal remains, it is unclear if in the periods with low settlement activity agriculture was practiced or not. The cereal remains could also have been introduced into these layers by mixing of sediments due to the higher lake levels. Using some care because of the uneven distribution of botanical remains in the settlement, it can still be stated that the two phases before and after the high lake level differ to a certain extent. It seems that hazel nuts (*Corylus*) as well as *Brassica rapa* are much less common in the later phase. On the other hand, *Linum* (flax) and *Papaver* (poppy) are more common in the upper part of the profile. Several other differences between the various periods of the settlement are not common features of the three cores, so it is difficult to say if they result only from the uneven horizontal distribution of the fossils or if they really indicate changes in subsistence strategies.
A striking feature which can be seen in all profiles is that there are few samples in the upper half of the cores which contain very large amounts of remains of *Linum*. It is unclear what this indicates, but it could be speculated that the villagers specialized in the production of linen for a short period.

Cereals

Due to the different levels of identification, for comparison cereals were put into different groups: (1) Hordeum: all types of *Hordeum vulgare*, (2) Triticum mono-/dicoccum: includes *T. monococcum, T. dicoccum* and cf of both, (3) Triticum aestivum type: includes all *Triticum* not included in (2). It must also be noted that the largest part of cereal remains found in this study are rachis fragments rather than grains. The grain density was in fact very low (10/l in NBS 58 and 75, and 40/l in NBS 93)
The composition of cereal remains shows big changes over time in each of the three profile columns (Fig. 16). The changes are, however, not really parallel in the three cores. Considering the short distance that separates the cores from each other, large differences within the settlement must be assumed. Therefore it is very difficult to make any assumptions about overall changes over time. It is obvious from the results that a much larger part of *Triticum* remains has been identified in the profile NBS 93. This is on the one hand because the samples were analysed by a different analyst, on the other hand it is probably also influenced by preservation conditions – mainly by the amount of charred and uncharred remains, as uncharred remains are usually not identifiable to species level.
It is interesting in any case, to see that all three columns include one layer (24 and 26, respectively) in which cereal remains are dominated by *Hordeum*. *Hordeum* is usually considered to have been cultivated predominantly only after the Pfyner Period, when it seems to have been fully established in the Alpine region (Jacomet nad Kreuz, 1999). In each of the profiles the dominance of *Hordeum* lasts only for a short period. It is unclear how these results must be interpreted but it seems that people in the Neolithic were very flexible in the use of cultivated and collected plants, which means that it is not generally possible to classify different cultures or periods by the use of cereal crops.

On the other hand, and more expectedly all three columns show an overall change within *Triticum* use, from *Triticum monococcum* and *T. dicoccum* towards other *Triticum* species. These results are not as clear as might be expected, mainly due to the large amount of unidentified *Triticum* remains. Also here it is not a continuous change, but rather a general tendency that is visible overall but is regularly broken by local and short-term changes.

Landscape

It is not the primary intention of archaeobotanical research to reconstruct past landscapes, as there are methods better suited for this. In the present study, the landscape can best be reconstructed using the results from pollen analysis, while lake ecology can be studied using macrofossil and NPP results from the lake core. However, the number of species found in the archaeobotanical study is much larger than the species found in the pollen analysis, and more importantly, the species differ quite significantly (App. I). While seeds can generally be identified to a higher level than pollen, which helps to get a better understanding of which species were actually present in the area, pollen are spread much further than seeds, meaning that seeds represent rather local vegetation, while pollen give an indication of the regional landscape. On the other hand, in an archaeological setting, seeds are not necessarily spread by natural forces, but often are also spread by human activities, which means that they can travel further than they would without human interference. Therefore the presence of seeds in the sediment of the Neolithic village, does not necessarily mean that the plants grew in the close surroundings, especially if the plants are edible, or used for other purposes. Additionally there are several plants, which, for various reasons, can only be found using one of the two methods (e.g. *Chara* does not produce pollen, ferns do not produce seeds, while *Ulmus* seeds are very fragile and usually not preserved). For the purposes of this study it can mostly be assumed that species only found in the pollen analysis did not grow in the near surroundings of the lake, while species found only in the archaeobotanical research are not identifiable as pollen. This is not always true, however, and in order to know, whether or not a certain species grew next to the lake in the time of the settlement, it must be determined on a case to case basis why certain remains were or were not found in the various parts of the study.
But even with the new species added to the list by the archaeobotanical analysis the reconstruction of the landscape does not change considerably. It seems obvious that a lot of open vegetation must have surrounded the settlement, which was either used for agricultural production or for grazing cattle, whereas in a certain distance more or less open forests must have existed to allow all forest species, many of which were used for food (e.g. berries), to grow. Most species found generally grow on nutrient rich soils, however since the local area has been inundated probably for centuries before the settlement was established, the soils must naturally be nutrient rich – which probably was one of the main features that drew Neolithic people to this area initially.

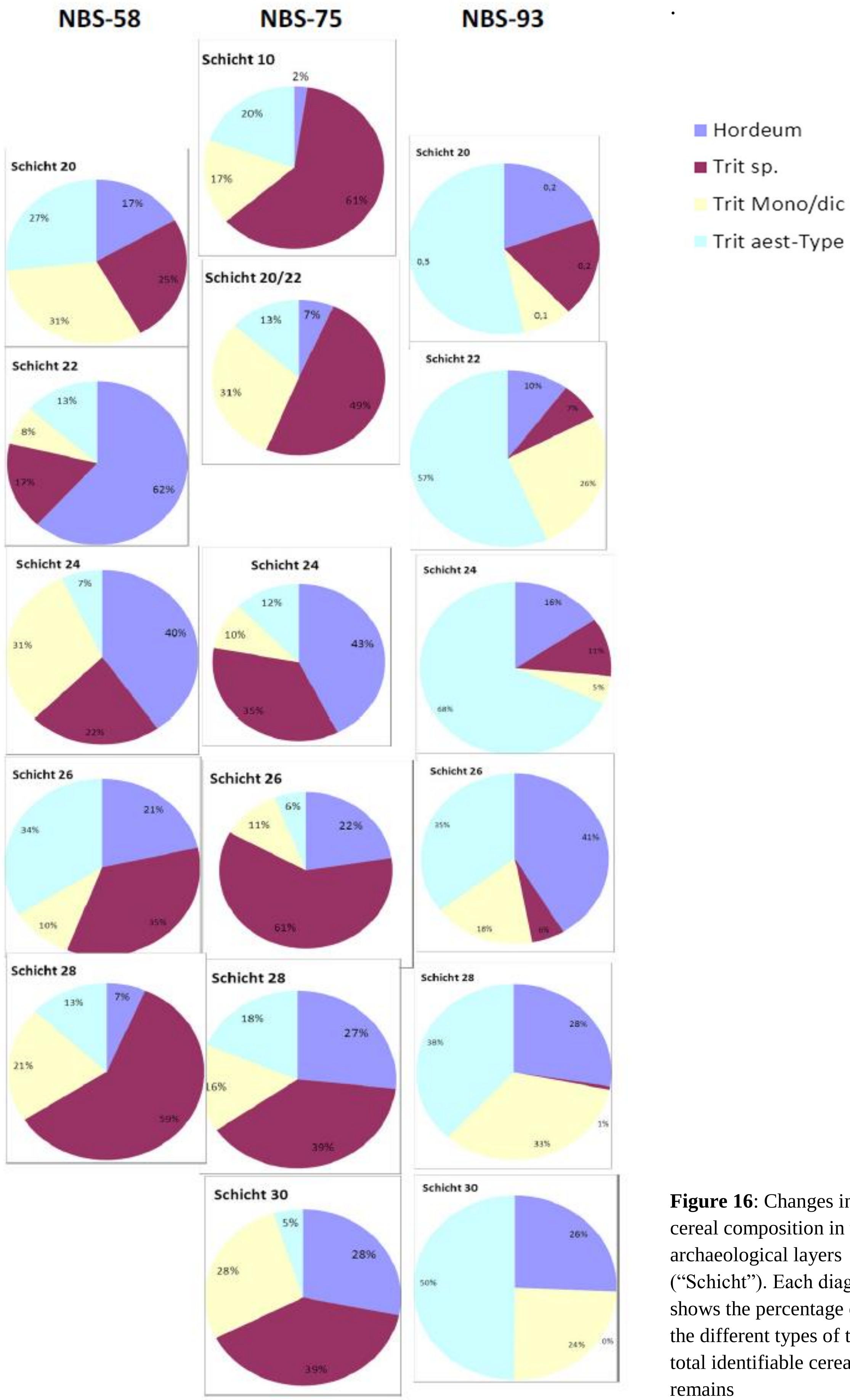

Figure 16: Changes in cereal composition in the archaeological layers ("Schicht"). Each diagram shows the percentage of the different types of the total identifiable cereal remains

Comparison of results with other settlements in the area

There are not many settlements form this period where archaeobotanical studies are available to be compared. Some that are available are not from waterlogged sites and can therefore not really be compared as small and fragile seeds will not be preserved if not charred and in general the majority of seeds from a settlement is not charred. Compared to similar studies, the seed density in the sediment of Nussbaumersee-Inseli is rather high. In the literature an average of around 2000 seeds/l is discussed. In Arbon Bleiche, however, the find density was 7800/l (Jacomet et al. 2004), which is more than the sample NBS 75.10 which had by far the highest density of all analysed samples in the present study.
The species composition is very similar to similar sites in the region (Jacomet et al., 2004; Brombacher, 1997; Karg and Märkle, 2002; Maier, 1999). From the literature it seems clear that high densities of *Linum* and *Papaver* seem to be restricted to the lake-side settlements of the region of Lake Constance. On the other hand, seeds of both species contain high percentages of oil, which means that they are not often preserved charred. Therefore *Linum* and *Papaver* are probably only detectable in large amounts in water-logged sites. In comparison with other sites around Lake Constance (Herbig, 2009) densities of *Linum* are quite high in Nussbaumersee-Inseli, while *Papaver* densities are average (Karg and Märkle, 2002).
Cereal composition also seems to be in line with other data from the literature, however it is also obvious that there are large local differences, which is especially visible in cereals as they are also preserved in dry conditions (when charred; e.g. Kohler-Schneider and Caneppele 2009).
Nussbaumersee-Inseli sediments contain considerably more seeds of plants growing in wet environments than other sites (especially *Persicaria hydropiper*). This could mean that these plants were growing on the sample site, but this is difficult to reconstruct, as the exact locations of houses could not be determined in this village.
On the other hand, big seeds of common fruits (e.g. *Prunus, Cornus, Quercus, Fagus*) are very rare in the sediment of Nussbaumersee-Inseli, also compared to other studies (e.g. Brombacher, 1997; Karg and Märkle, 2002). It is possible that this is because the sample sizes were rather small (Jacomet et al. (2004) advise sample sizes of at least 3 l for the fraction > 2 mm). It is also possible, however that these remains did not arrive at the sample sites, should they have been a certain distance from the houses.
The best studied settlements which are most similar to Nussbaumersee-Inseli are Arbon Bleiche, Biel, and Hornstaad-Hörnle. The main difference of Arbon Bleiche is that it is assumed that due to seasonal flooding the sediment is from only one year (Jacomet et al., 2004). The large densities of seeds found in this sediment may be a result of a combination of wave activity of the lake and human input. In Hornstaad-Hörnle on the other hand, the main study was done on food storage sites (Maier, 1999) which means that densities are not comparable with the other studies. The settlement of Biel (Brombacher, 1997) was occupied a little later than Nussbaumersee-Inseli, however the results of archaeobotanical research are well comparable. Compared to all of these, the list of taxa found is quite similar, however in

the present study “weeds” (most of which could also be used as food, spices, or medicine) are much more common than in the other sites, where archaeobotanical finds are largely dominated by remains of cultivated and collected food plants. Many of these were comparably rare in the present study (e.g. *Rubus, Fragaria, Quercus, Fagus, Prunus, Malus, Corylus*). Much higher densities than in other sites were found for example in *Sambucus, Verbena, Urtica*, Polygonaceae, and Amaranthaceae. This again points to the possibility that the profiles were not actually taken from sites very close to buildings, but rather a site, where local vegetation was also growing, which may account for part of the seeds found. However, it is also possible that more plants were used in this (part of the) village, than in other places, and that most seeds have actually been introduced by human activities. Considering that the three profiles analysed all share the same characteristics to a certain extent, this may be a better explication.

Comparison of different methods

In order to interpret the dataset properly it has to be kept in mind that even though all methods used (pollen, NPPs and macrofossils) are used to reconstruct past landscapes, in the case of Lake Nussbaumersee, the data obtained from applying different methods actually resulted in the reflection of very different parts of the past environment. These are mainly: (1) past vegetation in the wider surroundings of the lake represented by pollen analysis, (2) the trophy levels of the lake water as represented by algal and bacterial remains found in NPP analysis, and (3) the vegetation on the shores of the lake and in the lake as well as sedimentation conditions reflected by the results of macrofossil analysis.
While in the pollen analysis (Haas and Hadorn, 1998, App. IV) a continuous change of vegetation in the area during the last 7500 years – as an effect of both human and climatic influence – can be observed, the analysis of NPPs resulted in three peaks of Cyanobacteria which have been interpreted as phases of high trophy levels in the lake, and a radical change in the trophy level of the lake around 2500 BC, starting with the second peak of *Aphanizomenon* and represented by a sharp increase of several taxa of Chlorophyceae.
On the other hand, the results of the analysis of macrofossils show a radical change around 800 BC, which can probably be attributed to changes in erosion and sedimentation due to climatic change around that period as well as the lasting impact of the Late Bronze Age village.
This shows that rather than complimenting each other the results achieved using different methods added new information about a different part of the environment. This makes it hard to compare the data gained from the different methods used.
In total, however, a long list of taxa that used to grow in the area could be achieved (App. I for the Pfyner Period). With this, it is possible to get quite a good understanding about the vegetation types that used to exist in the area. However, it is impossible to establish, where these vegetation types grew. It is therefore, for example still not known, if *Papaver* fields existed, or if *Papaver* grew as weed on flax fields (as might be expected by the parallel peaks

of the two). It is not clear, how big agricultural fields were, and how far away the forests were, where Neolithic people hunted deer and collected forest fruits.
Besides, while archaeologists already know much about prehistoric human activities in the region, the current study could not add much to our understanding in this respect either. The NPP-results probably point to major settlement activities during the period of the Corded Ware Culture, but even this is not entirely certain.

Conclusions

Vegetation history and human impact

From all the data that have been obtained through pollen analysis (Haas and Hadorn, 1998) and the research presented in this work, several conclusions can be derived concerning the vegetation in the Seebachtal Valley as well as climatic and human impact on the landscape. Archaeological research gave first indications of when major human impact had to be assumed to be the major drive of vegetation change, however archaeological findings were mainly restricted to times with low lake levels. It should not automatically be assumed that these were also the only times when humans were living in the area as preservation conditions outside the lakes were very poor as discussed before (see *Location*).

Lake Level Changes

The most important evidence of changes in lake levels in the past are the three lake-side settlements which have been found lying below today's water level meaning that lake levels had to be considerably lower in the times of human occupation in the Neolithic and the Early and Late Bronze Age.
In addition to that the presence of various types of water plants in the lake sediment are good indicators of lake levels since most water plants have very specific requirements concerning water level and nutrient availability.
As can be seen in the analysis of the lake core NBS-A/B, especially in the lower part, a change from *Chara* species to *Najas* species indicates rising, respectively sinking water levels. While the remains of *Chara* oospores could not be identified to species level it is still clear that *Chara* species need higher water tables than *Najas* species which means that the times where *Najas* is present in higher numbers in the sediment indicate the times of low lake levels.
In younger times, however, the curves are not so clear and *Najas* and *Chara* occur both in the same sediments. This is probably due to the changed sedimentation in this period. The findings of large numbers of Bryophyta and Sphagnum in this part of the sediment core indicate erosion which probably also led to the transport of *Najas* seeds to the lower parts of

the lake. This means that only the presence or absence of *Chara* oospores can be used as evidence of higher or lower lake levels.
An important thing to keep in mind is that the change in water level also changes the sizes of the lakes and therefore the catchment area of pollen and also macro-remains. This means that it is important to have a good understanding of changes in lake levels before interpreting data obtained from pollen and NPP-analysis.

Eutrophication

The results of the analysis of NPPs of the core NBS-B showed clear signs of eutrophication represented by blooms in Cyanobacteria and in Chlorophyceae (Hillbrand et al., 2014).
Few studies so far have used NPPs to track eutrophication processes of lakes in the past (e.g. van Geel et al., 1994). Extreme eutrophication is often connected with extensive human activities along the lake border or elsewhere in the catchment area of a lake. Our study is the first to show lake water eutrophication already in Neolithic times. However, considering the proximity of lake-side settlements to the lake and the agricultural and animal husbandry it is not a surprise that the quality of the lake water was negatively influenced by human activities. The input of human and animal faeces as well as waste from food processing would lead to eutrophication. The Pfyner Age settlement at Lake Nussbaumersee is one of the few known settlements from that period that lasted more than only a few decades, but we expect that other settlements also caused lake eutrophication. The study of NPP is still not regularly conducted in palaeoecological studies. The significance of NPP in archaeo-ecological research is evident, and the present study should be one more incentive for researchers to analyse NPPs in pollen slides. Only then will we get a more complete record of past environmental conditions and human impact.
It must also be acknowledged, however, that the specific hydrologic features of this site promoted the establishment of such pronounced eutrophication phases, as the central lake basin did not have any freshwater inlet at times of low lake levels.

Archaeobtoany

From the archaeobotanical analysis of the settlement Nussbaumersee-Inseli, it has been observed, that the settlement was heavily influenced by changes in lake level. The settlement started to grow, when the lake water table subsided. Some time during the occupation of the village, the water level increased, leading apparently to a shrinking of the village. The lake level was lowered again later on, after which the settlement experienced a second phase of flourishing. When the lake level rose again, the settlement was left completely.
The fact that in all samples cereal remains, and then especially remains from the production of cereals (rather than only grains, which could have been imported), points to the assumption

that even when the settlement was very small and probably specialized in fishing, cereal was grown in the area.
Apart from cereal, large amounts of flax were found in the settlement, meaning, that it was also grown in the near surroundings of the village and played an important role in Neolithic food and fabric production. Also poppy seeds were found in extremely large numbers. The exact use of these is not entirely clear.

With the existing data no conclusions can be drawn regarding agricultural methods or the exact uses of different kinds of wild plants. It can only be assumed that plants that occur very regularly and in large numbers in many samples (like *Chenopodium* and *Verbena*) and which are edible, or can be used as medicine respectively, did not enter the village by chance, but have been collected in the area. Other plants can help reconstruct the landscape present in the area at the time of the settlement (e.g. trees, grasses, water plants). However, many of these plants are also edible either for humans or for cattle and can still have been collected from further away and introduced into the village by human activity. Therefore settlement sediments should not be used to reconstruct landscapes if other options are available.

In general it can be noted that the list of plants found in the settlement Nussbaumersee-Inseli did not contain any plants that were highly unexpected, but was very long, also compared to similar studies, showing that the preservation of plant remains was extraordinarily good and that the study of sediment from different layers can yield very good results.

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Appendix I: Species List

List of all taxa found in lake Nussbaumersee for the time period of the settlement Inseli (3840-3700 BC) as represented by pollen analysis and archaeobotanical analysis of the sediment from the village. (x indicates that a taxon was found in the pollen study or in the archaeobotanical study.)

Scientific Name	**English Name**	**Deutscher Name**	**pollen/ spores**	**macro-remains**
Abies alba	Silver Fir	Weißtanne	x	x
Acer sp.	Maple	Ahorn	x	
Achillea type	Yarrow-type	Schafgarbe (Typ)	x	
Adiantum	Maidenhair Fern	Frauenhaarfarn	x	
Adonis vernalis	Pheasant's Eye	Frühlings-Adonis	x	
Aethusa cynapium	Fool's Parsley	Hundspetersilie		x
Agrimonia eupatoria	Common Agrimony	Ackerkraut		x
Ajuga genevensis	Geneva Bugleweed	Genfer Günsel		x
Ajuga reptans	Common Bugle	Kriechender Günsel		x
Ajuga spec	Bugle	Günsel	x	x
Alchemilla	Lady's Mantle	Frauenmantel	x	
Alisma spec.	Water-Plantains	Froschlöffel		x
Allium type	Onion type	Lauch (Typ)	x	
Alnus glutinosa	Black Alder	Schwarzerle		x
Alnus spec.	Alder	Erle	x	x
Amaranthaceae	Goosefoot family	Gänsefuß	x	x
Anagallis arvensis	Scarlet Pimpernel	Acker-Gauchheil		x
Anemone nemorosa (cf)	Wood Anemone	Buschwindröschen	x	x
Apiaceae	Carrot Family	Doldenblütler	x	x
Apium graveolens	Celery	Echter Sellerie		x
Apium/Carum-type	Celery/Caraway type	Sellerie/Kümmel-Typ		x
Arctium spec	Burdock	Klette		x

Arenaria serpyllifolia	Thyme-leaved Sandwort	Quendel-Sandkraut		x
Arenaria spec	Sandwort	Sandkraut		x
Artemisia	Sagebrush	Beifuß	x	
Asteraceae	Sunflower Family	Korbblütler	x	x
Astragalus type	Milk-Vetch type	Tragant (Typ)	x	
Athyrium filix-femina type	Lady Fern type	Frauenfarn (Typ)	x	
Atriplex purpurea	Mountain Spinach	Garten-Melde		x
Atriplex sp	Orache	Melde		x
Avena	Oat	Hafer		x
Betula nana	Dwarf Birch	Zwerg-Birke		x
Betula pendula	Silver Birch	Hänge-Birke		x
Betula pubescens	Downy Birch	Moor-Birke		x
Betula sect. *alba*	Silver/Downy Birch	Moor-/Hänge-Birke		x
Betula sp	Birch	Birke	x	x
Brassica cf *rapa*	Turnip Rape	Rübsen		x
Brassicaceae	Cabbage family	Kreuzblütler	x	x
Bupleurum type	Hare's-ear type	Hasenohr	x	
Caltha type	Marsh-marigold type	Dotterblume (Typ)	x	
Camelina sativa	Camelina	Leindotter		x
Campanualceae	Bellflower family	Glockenblumen	x	
Cannabaceae	Hemp family	Hanfgewächse	x	
Capsella type	Shepherd's-purse type	Hirtentäschelkraut		x
Carduus (cf)	Thistle	Ringdistel		x
Carex curta type	White Sedge type	Graue Segge (Typ)		x
Carex echinata type	Star Sedge type	Igel-Segge (Typ)		x
Carex lepidocarpa type	Long-stalked Yellow-	Schuppenfrüchtige Gelb-		x

	sedge type	Segge (Typ)		
Carex sp.	Sedge	Segge		x
Carex tricarpellat	Sedge	Segge		x
Caryophyllaceae	Carnation family	Nelkengewächse	x	x
Cerastium cf *fontanum*	Common Mouse-ear	Quellen-Hornkraut		x
Cerastium sp.	Mouse ear	Hornkraut	x	x
Ceratophyllum demersum	Rigid Hornwort	Raues Hornblatt		x
Cerealia indet	Cereals	Getreide		x
Chara sp.	Stonewort	Armleuchteralge		x
Chenopodium album	Fat-hen	Weißer Gänsefuß		x
Chenopodium ficifolium	Fig-leaved Goosefoot	Feigenblättriger Gänsefuß		x
Chenopodium cf *polyspermum*	Many-seeded Goosefoot	Vielsamiger Gänsefuß		x
Chenopodium vulvaria	Stinking Goosefoot	Stinkender Gänsefuß		x
Chenopodium sp	Goosefoot	Gänsefuß		x
Cicuta virosa	Cowbane	Wasserschierling		x
Cladium mariscus	Great Fen-sedge	Binsenschneide	x	x
Clematis vitalba (cf)	Traveller's-joy	Gemeine Waldrebe		x
Clinopodium type	Basil type	Wirbeldost (Typ)		x
Cornus sanguinea	Dogwood	Roter Hartriegel		x
Corylus Avellana	Hazel	Hasel	x	x
Crataegus monogyna	Hawthorn	Eingriffeliger Weißdron		x
Crepis (cf)	Hawk's-beard	Pippau		x
Cyperaceae	Sedge family	Sauergräser	x	x
Cystopteris fragilis	Brittle Bladder-fern	Zerbrechlicher Blasenfarn	x	
Dryopteris filix-mas	Male-fern type	Echter Wurmfarn (Typ)	x	

type				
Eleocharis palustris (cf)	Common Spike-rush	Gemeine Sumpfbinse		x
Epilobium	Willowherb	Weidenröschen		x
Epilobium cf *hirsutum*	Great Willowherb	Zottiges Weidenröschen		x
Equisetum	Horsetail	Schachtelhalm	x	
Eupatorium cannabinum	Hemp-agrimony	Gewöhnlicher Wasserdost		x
Euphorbia sp.	Spurge	Wolfsmilch		x
Fabaceae	Bean family	Hülsenfrüchtler		x
Fagus silvatica	Beech	Rotbuche	x	x
Fallopia convolvulus	Black Bindweed	Windenknöterich		x
Fallopia dumetorum	Copse Bindweed	Hecken-Windenknöterich		x
Fallopia sp	Bindweed	Flügelknöterich		x
Filipendula	Meadowsweet	Mädesüß	x	
Fragaria vesca	Wild Strawberry	Wald-Erdbeere		x
Frangula alnus	Alder Buckthorn	Faulbaum	x	
Fraxinus excelsior	Ash	Esche	x	
Fumaria	Fumewort	Erdrauch	x	
Galeopsis sp	Hempnettle	Hohlzahn		x
Galium aparine	Cleavers	Kletten-Labkraut		x
Galium sp	Bedstraw	Labkraut	x	x
Geum type	Avens	Nelkenwurz	x	
Hedera helix	Ivy	Efeu	x	
Heracleum	Hogweed	Bärenklau	x	
Hordeum vulgare	Barley	Gerste	x	x
Hyoscyamos niger	Henbane	Schwarzes Bilsenkraut		x
Hypericum hirsutum	Hairy St. John's Wort	Behaartes Johanniskraut		x

Hypericum perforatum	Common St. John's Wort	Echtes Johanniskraut		x
Hypericum sp	St. John's Wort	Johanniskraut	x	x
Juncus sp.	Rush	Binse		x
Lamiaceae	Mint family	Lippenblütler		x
Lamium album (cf)	White Deadnettle	Weiße Taubnessel		x
Lamium maculatum (cf)	Spotted White Deadnettle	Gefleckte Taubnessel		x
Lamium sp.	Deadnettle	Taubnessel		x
Lapsana communis	Nipplewort	Gemeiner Rainkohl		x
Lemna	Duckweed	Wasserlinse	x	
Lepidium type	Peppercress	Kresse		x
Leucanthemum (cf)	Oxeye Daisy	Margerite		x
Liliaceae	Lily family	Liliengewächse	x	
Linum usitatissimum	Flax	Gemeiner Lein		x
Lycopus europaeus	European Bugleweed	Ufer-Wolfstrapp		x
Lythrum salicaria	Purple-loosestrife	Gewöhnlicher Blutweiderich		x
Malus sylvestris	Crab Apple	Wildapfel		x
Malvaceae	Mallow family	Malvengewächse	x	
Mentha aquatica	Water Mint	Wasserminze		x
Mentha sp.	Mint	Minze		x
Menyanthes trifoliata	Bog-bean	Fieberklee	x	
Mercuruialis sp	Mercury	Bingelkraut		x
Moehringia trinervia	Three-nerved Sandwort	Dreinervige Nabelmiere		x
Montia (cf)	Miner's Lettuce	Quellkraut		x
Myosotis sp.	Forget-me-not	Vergissmeinnicht		x
Myriophyllum verticillatum	Whorled Water Milfoil	Quirliges Tausendblatt	x	

Najas marina	Holly-leaved Naiad	Großes Nixenkraut		x
Najas marina ssp. intermedia	Holly-leaved Naiad	Mittleres Nixenkraut		x
Najas marina ssp. marina	Holly-leaved Naiad	Großes Nixenkraut		x
Najas minor	Brittle Naiad	Kleines Nixenkraut		x
Najas sp.	Naiad	Nixenkraut		x
Nitella sp.	Stonewort	Glanzleuchteralge		x
Nuphar lutea	Yellow Water-lily	Gelbe Teichrose		x
Nuphar sp.	Water-lily	Teichrose	x	x
Nymphaea alba	White Water-lily	Weiße Seerose	x	x
Odontites	Bartsia	Zahntroste	x	
Onobrychis type	Sainfoins type	Esparsette	x	
Ononis type	Restharrow	Hauhechel	x	
Origanum vulgare	Oregano	Oregano		x
Origanum/Thymus type	Oregano/Thyme type	Oregano/Thymian (Typ)		x
Papaver somniferum	Opium Poppy	Schlafmohn		x
Pedicularis palustris type	Marsh Lousewort type	Sumpf-Läusekraut (Typ)	x	
Persicaria hydropiper	Water-pepper	Wasserpfeffer		x
Persicaria lapathifolia	Pale Smartweed	Ampfer-Knöterich		x
Persicaria maculosa	Redshank	Floh-Knöterich		x
Persicaria maculosa/lapathifolia	Pale Smartweed/Redshank	Ampfer-/Floh-Knöterich		x
Persicaria sp.	Knotweed	Knöterich		x
Physalis alkekengi	Chinese Lantern	Lampionblume		x
Phyteuma	Rampion	Teufelskralle	x	
Picea abies	European Srpuce	Fichte	x	x
Picris sp (cf)	Oxtongue	Bitterkraut		x

Pinus sp.	Pine	Kiefer/Föhre	x	x
Plantago	Plantain	Wegerich		x
Plantago cf *lanceolata*	Ribwort Plantain	Spitzwegerich	x	x
Plantago major	Greater Plantain	Breitwegerich	x	x
Poaceae	Meadow-grass family	Süßgräser	x	x
Polygonaceae	Knotweed family	Knöterichgewächse		x
Polygonum aviculare	Common Knotgrass	Vogelknöterich	x	x
Polypodium	Polypody	Tüpfelfarn	x	
Potamogeton sp.	Pondweed	Laichkraut	x	x
Potentialla sp.	Cinquefoil	Fingerkraut	x	x
Potentilla/Fragaria	Cinquefoil/Strawberry	Fingerkreut/Erdbeere		x
Prunella vulgaris	Selfheal	Kleine Braunelle	x	x
Prunus cf *spinosa*	Blackthorn	Schlehdorn		x
Prunus sp.	Cherry	Pflaume	x	x
Pteridium aquilinum	Bracken	Adlerfarn	x	
Pulsatilla type	Pasque Flower type	Küchenschelle	x	
Quercus sp.	Oak	Eiche	x	x
Ranunculus aquatilis-type	Common Water Crowfoot	Wasserhahnenfuß (Typ)		x
Ranunculus cf *acris*	Meadow Buttercup	Scharfer Hahnenfuß	x	x
Ranunculus cf *bulbosus*	Bulbous Buttercup	Knolliger Hahnenfuß		x
Ranunculus cf *reptans*	Creeping Spearwort	Ufer-Hahnenfuß		x
Ranunculus sceleratus	Cursed Buttercup	Gift-Hahnenfuß		x
Ranunculus sp.	Buttercup	Hahnenfuß		x
Rhamnus sp. (cf)	Buckthorn	Kreuzdorn	x	x
Rhinanthus type	Rattle type	Klappertopf	x	
Rosaceae	Rose family	Rosengewächse	x	x

Rubus caesius	Dewberry	Kratzbeere		x
Rubus fructicosus agg	Bramble	Brombeere		x
Rubus idaeus	Raspberry	Himbeere		x
Rubus idaeus/fructicosus	Bramble/Raspberry	Him-/Brombeere		x
Rubus sp	Bramble/Raspberry	Him-/Brombeere		x
Rumex acetosa type	Common Sorrel	Wiesen-Sauerampfer	x	
Rumex cf *acetosella*	Sheep's Sorrel	Kleiner Sauerampfer	x	x
Rumex conglomeratus	Sharp Dock	Knäuel-Ampfer		x
Rumex crispus type	Curled Dock	Krauser Ampfer		x
Rumex sp.	Dock	Ampfer		x
Salix	Willow	Weide	x	
Sambucus ebulus	European Dwarf Elder	Zwergholunder		x
Sambucus nigra/racemosa	Black/Red Elder	Schwarzer/Roter Holunder		x
Sambucus sp.	Elder	Holunder	x	x
Sanguisorba	Burnet	Wiesenknopf	x	
Scabiosa	Scabious	Skabiose	x	
Schoenplects lacustris	Common Tule	Gewöhnliche Teichbinse		x
Scirpus (cf)	Club-rush	Waldbinse		x
Scrophulariaceae	Figwort family	Rachenblütler	x	x
Senecio viscosus (cf)	Sticky Ragwort	Klebriges Greiskraut		x
Silene cf *cretica*	Cretan Catchfly	Kreta-Leimkraut		x
Silene sp.	Campion	Leimkraut		x
Solanaceae	Nightshade family	Nachtschattengewächs		x
Solanum dulcamara	Bittersweet	Bittersüßer Nachtschatten		x
Solanum nigrum	Black Nightshade	Schwarzer Nachtschatten		x

Sonchus asper	Prickly Sow-thistle	Raue Gänsedistel		x
Sonchus palustris	Marsh Sow-thistle	Sumpf-Gänsedistel		x
Sparganium type	Bur Reed type	Igelkolben (Typ)	x	
Stachys cf *arvensis*	Field Woundwort	Ackerziest		x
Stachys sp	Woundwort	Ziest	x	x
Stellaria cf *aquatica*	Water Chickweed	Waaserdarm		x
Stellaria cf *media*	Common Chickweed	Vogel-Sternmiere		x
Stellaria sp	Stitichwort	Sternmiere		x
Taxus baccata	Yew	Eibe	x	
Teucrium	Germander	Gamander	x	
Thalictrum sp	Meadow-rue	Wiesenraute		x
Thelypteris palustris	Marsh Fern	Wurmfarn	x	
Tilia sp.	Lime	Linde	x	x
Torilis japonica	Japanese Hedge Parsley	Gewöhnlicher Klettenkerbel		x
Trifolium type	Clover type	Klee (Typ)	x	x
Triticum aestivum/durum	Common/Durum Wheat	Saat-/Hartweizen		x
Triticum monococcum/dicoccum	Einkorn/Emmer	Einkorn/Emmer		x
Triticum sp.	Wheat	Weizen	x	x
Trollius	Globeflower	Trollblume	x	
Typha sp.	Cattail	Rohrkolben	x	x
Ulmus	Elm	Ulme	x	
Urtica dioica	Common Nettle	Große Brennnessel	x	x
Valeriana	Valerian	Baldrian	x	
Valerianella dentata	Narrowfruit Corn Salad	Gezähnter Feldsalat		x
Valerianella sp	Corn Salad	Feldsalat		x

Verbena officinalis	Common Vervain	Echtes Eisenkraut		x
Veronica type	Speedwell type	Ehrenpreis	x	x
Viburnum lantana	Wayfaring-tree	Wolliger Schneeball		x
Viburnum opulus	Guelder-rose	Gemeiner Schneeball		x
Vicia sp.	Vetch	Wicke	x	x
Vicia villosa	Hairy Vetch	Zottige Wicke		x
Viola sp.	Violet	Veilchen	x	x
Viscum	Mistletoe	Mistel	x	
Vitis	Grapevine	Weinrebe	x	

Appendix II: NPP plates

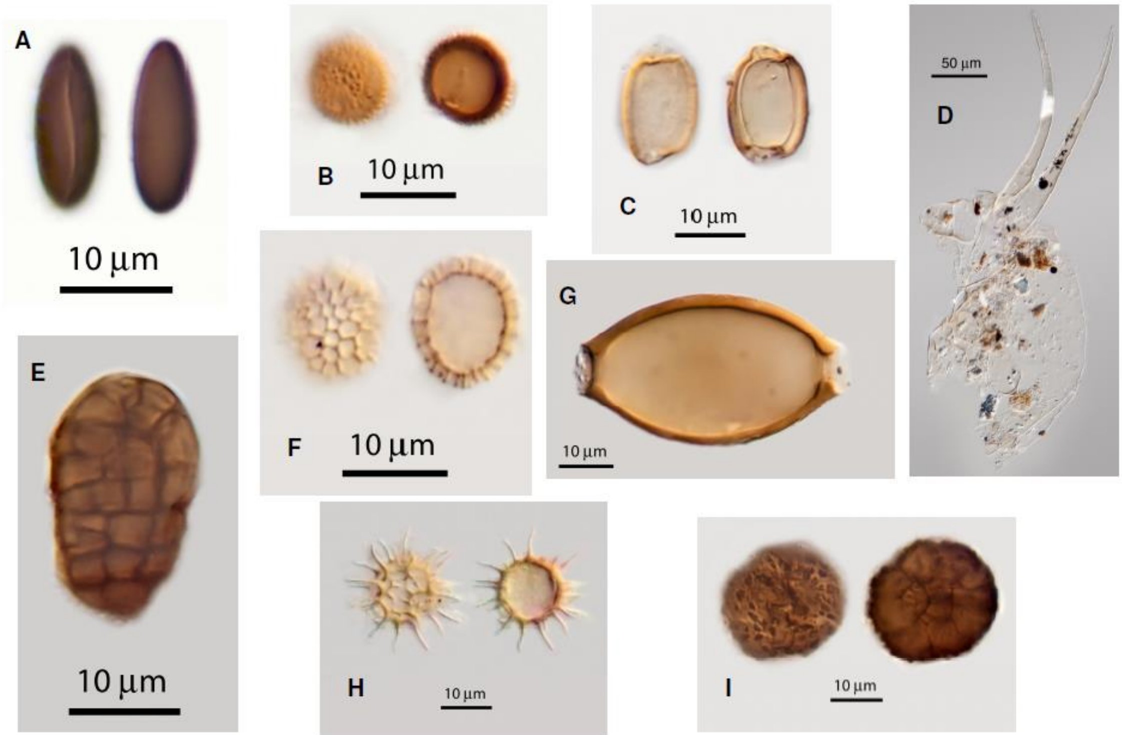


Plate I: A: IIB001; B: IIB002; C: IIB003; D: IIB010; E: *Tilletia*; F: *Trichuris* egg; G: cf Type 3a; H: cf Type 182; I: cf Type 1011; Pictures by Jan van Arkel, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam

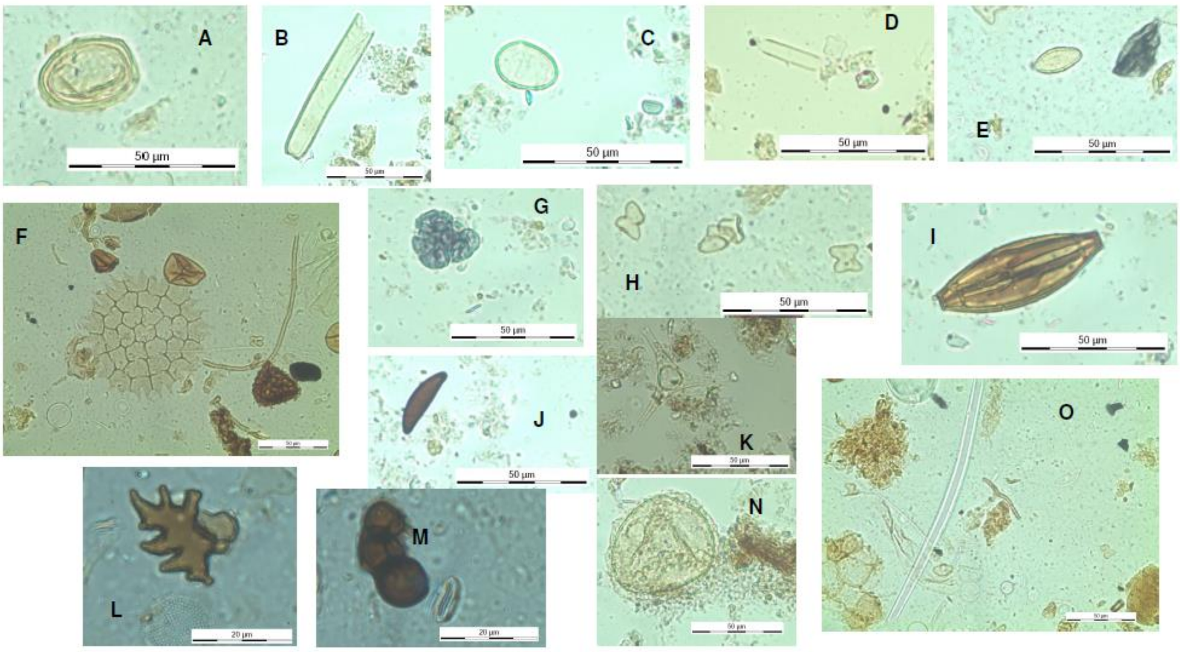


Plate II: A: Nymphaceae cell; B: *Gloeotrichia*; C: *Anabaena*; D: *Aphanizomenon*; E: *Rivularia*-Type; F: *Pediastrum*; G: *Botryococcus*; H: *Tetraedron*; I: *Diporotheca*; J: *Ustulina*; K: *Staurastrum*; L: *Gaeomannomyces*; M: Type 361; N: *Filinia* egg; O: Porifera needle; Pictures M.Hillbrand

Appendix III: Photos macro remains

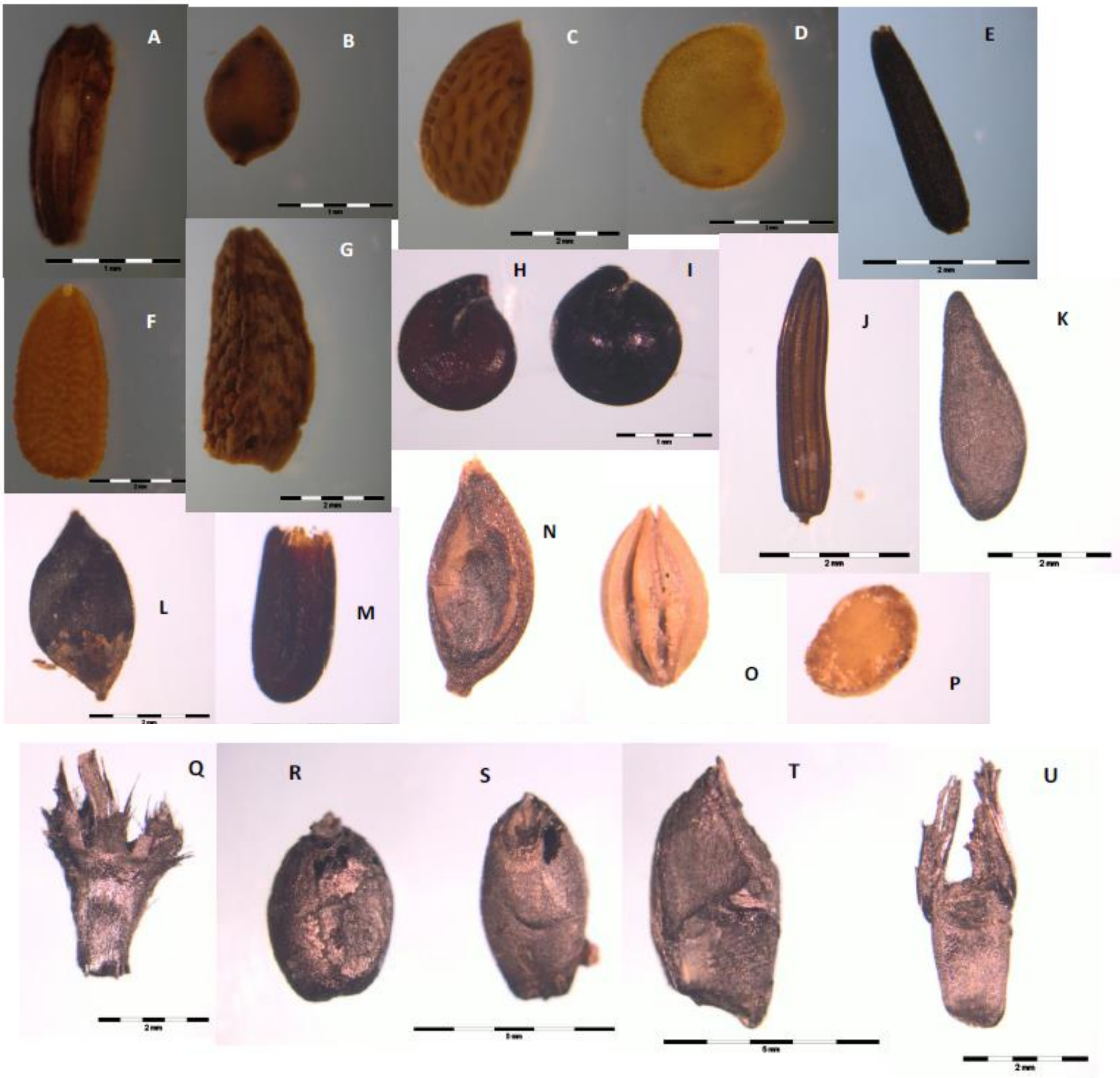
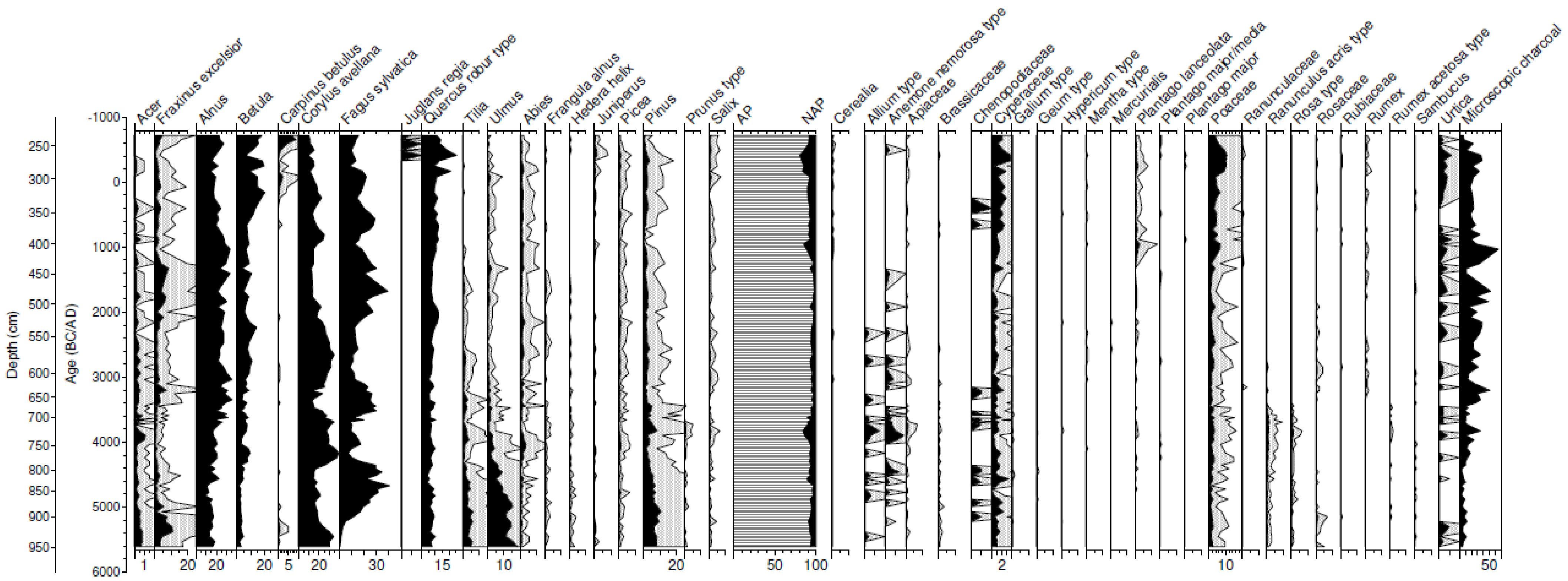


Plate III: Macrofossils from Nussbaumersee-Inseli (selection): A: *Verbena officinalis*, B: *Urtica dioica*, C: *Rubus fruticosus* (agg.), D: *Solanum dulcamara*, E: *Eupatorium cannabinum*, F: *Sambucus nigra/racemosa*, G: *Arctium* sp., H: *Atriplex* sp., I: *Chenopodium album*, J: cf. *Senecio* sp., K: *Thalictrum* sp., L: *Persicaria hydropiper*, M: *Alisma plantago-aquatica*, N: cf. *Anemone nemorosa*, O: *Aethusa cynapium*, P: *Ranunuculus sceleratus*, Q: *Hordeum vulgare* (rachis part), R: *Triticum* cf. *aestivum*, S: *Hordeum vulgare*, T: *Triticum dicoccum*, U: *Triticum monococcum* (rachis part); (Photos: M.Hillbrand)

Appendix IV: Pollen Diagram



Appendix IV: Diagram of selected taxa from the pollen analysis from Haas and Hadorn (1998). The black curves show percentages of the pollen sum, the gray curves are 5x exaggerated. Where no numbers are printed, the length of the x-axis is 1 (the first tic marc being at 0.5). (Diagram drawn with Tilia Graph).

Appendix V: Frequencies

Frequencies of occurrence of all taxa found in the archaeobotanical analysis of the sediment profiles from Nussbaumersee-Inseli per profile. (1 means that the taxon was present in every sample of the profile).

	NBS-58	NBS-75	NBS-93
Abies alba			0,13
Aethusa cynapium			0,13
cf Aethusa		0,18	
Agrimonia eupatoria	0,09	0,27	0,10
Ajuga spec	0,27	0,41	0,17
Ajuga genevensis			0,07
Ajuga reptans			0,10
Alisma spec.		0,23	
Alnus glutinosa	0,36	0,27	0,57
Alnus spec.	0,45	0,32	0,37
Alnus total	0,73	0,59	0,67
Anagallis arvensis			0,03
cf Anemone nemorosa		0,09	
Apiaceae	0,09	0,05	0,20
Apium graveolens			0,03
Apium/Carum-type	0,18	0,23	
Arctium spec	0,82	0,91	0,87
Arenaria spec			0,27
Arenaria serpyllifolia			0,10
Asteraceae	0,27	0,23	0,17
Atriplex purpurea			0,03
Atriplex sp	0,09	0,14	0,30
Betula nana			0,03
Betula pendula	0,36	0,45	0,30
Betula pubescens		0,14	0,17
Betula sect. "alba"	0,82	0,86	0,73
Betula sp			0,03
Betula total	0,91	0,91	0,87

Brassicaceae			0,63
Brassica cf rapa	0,91	0,91	0,80
Cf Camelina			0,03
Camelina sativa			0,03
Capsella type	0,36	0,27	0,03
Cf Carex			0,20
Carex spec.	0,27	0,27	0,37
Carex tricarpellat	1,00	0,95	0,83
Carex lepidocarpa-type	0,36	0,41	
Carex curta-type	0,18	0,05	
Carex echinata-type		0,09	
cf Carduus		0,14	
Caryophyllaceae indet	0,45	0,73	0,93
Caryophyllaceae total	0,91	0,95	0,43
Cerastium Spec	0,45	0,55	0,03
Cerastium cf fontanum			0,03
Ceratophyllum demersum			0,10
Chara spec.	1,00	0,59	0,27
Amaranthaceae	0,18	0,50	0,63
Chenopodium album	1,00	1,00	0,80
Chenopodium cf album			0,47
Chenopodium vulgare			0,03
Chenopodium ficifolium			0,70
Chenopodium cf polyspermum			0,30
Chenopodium sp	0,91	0,95	0,07
Cicuta virosa	0,27	0,18	0,10
Cladium mariscus	0,55	0,23	0,20
Cf Clematis vitalba			0,03
Clinopodium type	0,09	0,23	
Cornus sanguinea	0,09	0,05	0,13
Corylus Avellana	0,73	0,95	0,70
Crataegus monogyna			0,07
cf Crepis		0,05	0,10
Cyperaceae indet.	0,18	0,27	0,20

cf Eleocharis palustris			0,03
Epilobium cf hirsutum			0,27
Epilobium spec.		0,09	0,47
Cf Epilobium	0,18	0,14	0,33
Eupatorium cannabinum	0,45	0,27	0,03
Euphorbia sp.	0,09		
Fabaceae		0,05	
Fagus silvatica		0,14	0,03
Fallopia sp	0,73	0,59	0,07
Fallopia chinchap			0,03
Fallopia dumetorum			0,23
Fallopia convolvulus			0,60
Fragaria vesca unvk	0,91	0,91	1,00
Galeopsis spec	0,36	0,41	0,40
Galium aparine			0,07
Galium sp	0,09		
Hypericum sp	0,09	0,14	0,30
Hypericum hirsutum	0,09	0,05	0,20
Hypericum perforatum	0,27	0,32	0,33
Hyoscyamos niger			0,03
Cf Juncus			0,13
Juncus spec.		0,09	0,50
Lamiaceae	0,09	0,18	0,33
Lamiaceae total	0,91	1,00	0,70
Lamium sp		0,27	0,13
Cf Lamium maculatum			0,07
Cf Lamium album			0,03
Lapsana communis	0,73	0,91	0,80
Lepidium-type	0,73	0,86	
cf Leucanthemum		0,05	
Linum usitatissimum	1,00	1,00	1,00
Linum us. Kapselreste	0,91	0,95	0,97
Lycopus europaeus	0,82	0,91	0,63
Cf Lythrum	0,09	0,09	0,03

Lythrum Salicaria	0,09	0,05	0,03
Malus sylvestris	0,73	0,91	1,00
Mentha aquatica	0,55	0,14	0,03
Mentha spec.	0,09	0,18	0,13
Mercuruialis sp	0,09		
Moehringia trinervia	0,09	0,64	0,80
cf Montia	0,27	0,05	
Myosotis sp			0,03
Najas spec	0,09		0,20
Najas marina ssp. intermedia			0,13
Najas marina ssp. marina			0,30
Najas marina	0,82	0,32	
Najas minor	0,09	0,09	
Nitella spec.	0,09		
Nuphar luteum	0,55	0,23	0,20
Nuphar spec.			0,13
Nymphaea alba	0,36	0,09	0,10
Origanum vulgare			0,37
Origanum/Thymus-type	0,18	0,18	
Papaver somniferum	1,00	1,00	1,00
Papaver verkohlt			0,03
Persicaria hydropiper	0,82	0,86	0,47
Persicaria lapathifolia	0,64	0,36	0,27
Persicaria sp.	0,73	0,73	0,23
Persicaria maculosa			0,50
Persicaria maculosa/lapathifolia			0,10
Physalis alkekengi	0,73	0,73	0,63
Cf Physalis			0,13
Picea abies			0,03
cf Picris sp	0,09		
Pinus spec.		0,05	0,03
cf. Plantago		0,09	0,10
Plantago major			0,27

Plantago cf lanceolata			0,07
Cf Poaceae			0,03
Poaceae indet.	0,91	0,77	0,73
Polygonaceae	0,27	0,59	0,57
Polygonaceae total	0,82	0,95	0,90
Polygonum aviculare	0,64	0,95	0,70
Potamogeton spec.	0,64	0,32	0,47
Potentilla/Fragaria	1,00	0,95	
Cf Potentialla spec.	0,09	0,05	
Prunus cf spinosa	0,18		0,30
Prunus sp.	0,09	0,18	
Prunella vulgaris	0,45	0,55	0,23
Quercus spec.		0,14	0,03
Ranunculus aquatilis-type	0,09	0,14	
Ranunculus cf bulbosus			0,07
Ranunculus cf reptans			0,10
Ranunculus cf acris	0,09		0,07
Ranunculus sceleratus	0,36	0,36	0,00
Ranunculus spec.		0,05	0,27
Ranunculaceae total			0,37
cf Rhamnus sp		0,05	
Rosaceae	0,18		0,40
Rubus sp	0,91	1,00	0,23
Rubus fructicosus agg	1,00	1,00	0,93
Rubus idaeus			0,83
Rubus idaeus/fructicosus	0,64	0,77	0,57
Rubus caesius			0,13
Rubus total			0,97
Rumex spec		0,14	0,20
Rumex cf acetosella	0,09	0,05	
Rumex conglomeratus			0,03
Rumex crispus-type	0,45	0,50	
Sambucus Ebulus	0,73	1,00	0,67
Sambucus nigra/racemosa	0,82	1,00	0,87

Sambucus spec.	0,91	1,00	0,67
Schoenplects lacustris	0,45	0,36	0,03
Cf Scirpus			0,07
Scrophulariaceae	0,27	0,18	
cf Senecio viscosus		0,05	
Silene cf cretica			0,07
Silene sp	0,64	0,86	0,07
Solanaceae indet	0,45	0,23	0,53
Solanum dulcamara	0,64	0,68	0,83
Solanum nigrum	0,73	0,68	0,60
Solanaceae total	1,00	0,95	1,00
Sonchus palustris			0,03
Sonchus asper	0,45	0,36	0,33
Stachys sp	0,73	0,36	0,57
Stachys cf arvensis			0,03
Stellaria cf aquaticum			0,03
Stellaria cf media	0,09	0,27	0,03
Stellaria sp	0,82	0,95	
Thalictrum sp	0,09		
Tilia spec.	0,09	0,05	0,03
Torilis japonica		0,41	0,47
Trifolium-type	0,45	0,50	
Typha spec.	0,18	0,41	0,73
Urtica dioica	1,00	0,95	1,00
Valerianella dentata			0,07
Valerianella sp	0,09	0,18	
Veronica-type	0,36	0,32	
Verbena cf officinalis	1,00	1,00	0,97
Viburnum lantana			0,07
Viburnum Opulus	0,18	0,14	0,03
Vicia spec	0,09		0,03
Vicia villosa	0,09		
Viola sp	0,09	0,14	0,10

Triticum aestivum/durum	0,91	0,86	0,97
Triticum mono/dicoccum	0,91	0,95	0,93
Hordeum	0,91	0,95	0,87
Avena			0,03
Cerealia total	1,00	1,00	1,00