A new look at late Neolithic plant economy from the site of Zürich-Parkhaus Opéra (Switzerland): methods, activity areas and diet

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Late Neolithic plant economy north of the Alps

Research on Late Neolithic agriculture and wild plant gathering (during the last third of the 4th millennium cal. BC) has been intensive in the Alpine Foreland (Jacomet 2009; Jacomet and Brombacher 2005; Jacomet et al. 2016). This is particularly true in connection to lakeside settlements, with their extraordinary preservation conditions that allow for large amounts of plant remains to be preserved in an uncharred state, having an enormous interpretive potential (e.g. Jacomet 2013). Despite one might think that our knowledge on this period can hardly be improved, recent research at the site of Zürich-Parkhaus Opéra (from now on ZHOPE) meant a step forward in our understanding of Late Neolithic plant economy in the region and prove that a lot of further potential is hidden in those waterlogged deposits. A big part of this step forward was achieved by implementing methods of systematic analysis that are the result of a constant revision of the procedures followed in previous research with the goal of achieving a standardised methodology that allows the best results possible with a reasonable time frame. The aim of this paper is to present some of the main contributions of the work done to date and some hints of what further research on this site will provide in coming years.

What is then actually known about plant economy in the last centuries of the 4th millennium cal. BC? We will focus our statements on the Western Alps, since research north the Austrian Alps is not yet in a good state (Jacomet, 2006), although significant improvements are expected from running projects. At a chronocultural level, this period is within the so-called Horgen Culture (ca. 3400–2850 cal. BC) in the region between western Switzerland and lake Constance (see e.g. Jacomet 2007).

One of the drawbacks of previous research is the quality of sampling and the representativeness of the analyses, which, for several reasons, was often limited (see an overview in Jacomet and Brombacher 2005). The site of ZHOPE, with two Horgen settlement layers (no. 13 and 14) spreading over large areas, was the perfect scenario for implementing an ideal *surface* sampling program and target many of the questions that had since long (e.g. Jacomet et al. 1989) been formulated.

Agriculture during the period between 3400 and 3000 cal. BC involved several cereals, mostly naked wheat (typically of the tetraploid type, *Triticum durum/turgidum*), emmer (*Triticum dicoccon*), and barley (mostly of the multi-rowed naked type, *Hordeum vulgare*). Besides, pea (*Pisum sativum*), flax (*Linum usitatissimum*), and opium poppy (*Papaver somniferum*) were also cultivated. It was emphasised in previous work that pea (*Pisum sativum*) must have been regularly cultivated, but that it was underrepresented in our records (partly due to the difficulties in the identification of

Antolín, F., C. Brombacher, M. Kühn, B.L. Steiner, N. Bleicher, S. Jacomet (2020). 'A new look at late Neolithic plant economy from the site of Zürich-Parkhaus Opéra (Switzerland): methods, activity areas and diet'. In: *Settling Waterscapes in Europe. The Archaeology of Neolithic and Bronze Age Pile-Dwellings*. Ed. by A. Hafner, E. Dolbunova, A. Mazurkevich, E. Pranckenaite and M. Hinz. Open Series in Prehistoric Archaeology 1. Bern and Heidelberg: Propylaeum, pp. 157–172. DOI: 10.11588/propylaeum.714

uncharred fragments of pea pods) and therefore impossible to establish its importance in the economy (Brombacher 1995, 1997; Brombacher and Jacomet 1997; Favre 2002; Hosch and Jacomet 2004; Jacomet 2006, 2009). Only at Hornstaad Hörnle I, a site in lake Constance that dates ca. 3900 BC, were concentrations of uncharred pea pods found (Maier 2001), mainly because they were very well preserved. Even at Torwiesen II, a site located nearby lake Federsee in Germany and dated to ca. 3300 cal. BC and studied by the same researchers, no remains of pea pods were found (Maier and Herbig 2011). This problematic was directly approached during the analyses of ZHOPE and the criteria for identification of legume pods (probably pea pods, but with an unsure identification to species level) were finally established. This was too late for the first analyses of layer 13, and they were only properly quantified for layer 14 (and in the second phase of analyses of layer 13).

Flax could have been mostly used to gain oil, according to some researchers who observe a correlation between the finding of capsule fragments and seeds. This type of assemblage would be the residue of oil production that could have potentially been given to animals as fodder. The use of plant oil (likely from opium poppy and probably also from flax) to treat antler tools was proven by organic residue analysis ZHOPE (Spangenberg et al. 2014). At Arbon Bleiche 3, a site dated to ca. 3400 cal. BC and located at the southwestern shore of Lake Constance, it seems that, in addition to their use for production of oil, also seeds would have been consumed on their own, since large accumulations of capsule fragments were found in intervening spaces between houses (Hosch and Jacomet 2004). Spindle whorls were found in most houses at Arbon Bleiche 3, so it is assumed that weaving took place in all of them, but probably not from flax, which requires a very intensive processing. Most of the textile fragments found at the site come from lime bast fiber (Hosch and Jacomet 2004).

The importance of flax and opium poppy during this phase, together with the increase of importance of emmer in relation to naked wheat, has been connected to an impoverishment of the soils. There are further hints for this, such as the weed spectra of some of the investigated sites in lake Zürich, including taxa such as *Vicia tetrasperma, Euphorbia exigua,* and *Trifolium arvense* (Brombacher and Jacomet 1997). Other possibilities have also been proposed, such as a lower influence of southwestern groups on the economy of the Horgen Culture. This could also eventually explain the lower amounts of naked wheat found towards the end of this period, in favour of emmer and flax (Jacomet 2006), considering the fact that naked wheat does not seem to be an important crop further east (Kohler-Schneider 2007; Kohler-Schneider and Caneppele 2009). It must be noted, though, that an increase in hulled wheat agriculture is also observed in the Jura region (Schaal and Petrequin 2015) and in other regions of particularly northern France (Martin et al. 2016). At the same time, there is indication of an intensification of farming in this area, with more weeds typical of winter-sown fields that would be kept fertile over long periods (Jacomet et al. 1989).

Regarding edible wild plants, the large amounts of diaspores recovered in lakeshore sites has been the basis to propose that gathered plants made an important contribution to human diet in the Neolithic. Previous modelling work concluded that between 20 and 50 per cent of the daily calories were obtained from wild plant resources (Gross et al.

1990). Calculations from the site of Arbon Bleiche 3 based on the total amount of remains found in the analysed samples, concluded that up to ca. 50 per cent of the caloric intake from plant resources would come from wild plants. For these calculations hazelnuts (*Corylus avellana*) and acorns (*Quercus* sp.) were used (Hosch and Jacomet 2004). The TKG (thousand grain weight or *Tausendkorngewicht*) was used to calculate the total amount of weight (and therefore calories) represented by the different taxa in Arbon Bleiche 3. The results were as follows: barley: 1 per cent; emmer: 8 per cent; naked wheat: 22 per cent; flax: 28 per cent and opium poppy 1 per cent; hazelnuts 35 per cent; and acorns 2 per cent.

Other important gathered plants could have been wild apples/pears (Maloideae) and bramble/raspberry (*Rubus fruticosus/idaeus*), among others. Large concentrations of hazelnut shells have been found in several sites, such as in House 14 in Arbon Bleiche 3 (Hosch and Jacomet 2004) or in Horgen Scheller, a site located south of Zürich, on the western shore of Lake Zürich (Favre 2002). Similarly important concentrations of crab-apples are known from the Horgen layer 3 of Mozartstrasse (Jacomet et al. 1989), in Lake Zürich. Some taxa could have been favoured by a higher human impact on the landscape during the Late Neolithic, and this could explain the increase of sloe fruits (*Prunus spinosa*) (Brombacher 1995, 1997). Hazelnuts and crab-apples have also been reported as being extremely abundant further east (Kohler-Schneider 2007). The role of some of these plants in human diet is not clear though, particularly for acorns and achenes of beech (*Fagus* sp.), although it seems plausible that they were gathered and stored for human consumption (see discussion in Hosch and Jacomet 2004). A significant negative correlation between acorns and hazelnuts in Horgen Scheller was also interpreted as evidence of the use of acorns as fodder at the site (Favre 2002).

This paper will present some of the most relevant outcomes of the ZHOPE project so far, and some of the fields in which current and future research at the site will focus:

- Basic methodological aspects: sample volume, sieving strategies, quantification methods, etc.
- Approach to the role of certain resources that had been to date underrepresented in the studies: large-seeded wild plants in general and domesticated pulses
- Use of GIS for the identification of activity areas at the site
- Detailed dietary analysis based on the total number of fruit remains from the full range of crops and edible wild plants present at the site.

The aim of this paper is to share some of our experiences regarding these aspects, without aiming to demonstrate each of the statements proposed, since most of them have been treated in other publications that will be quoted as a guideline for further research on each topic.

The site of Zürich-Parkhaus Opéra. The sampling and sieving strategy

Zürich-Parkhaus Opéra (ZHOPE) is located in the northern shore of lake Zürich (Switzerland) (Figure 1). It was a large excavation of over 3000 m^2 that took place during 2010 and 2011 (Bleicher and Harb 2015). Up to 8 settlement phases were detected in this area. This study is based on the samples from the two Horgen layers number 13 (dendrodated to 3176–3153 BC, representing one settlement phase of no more than 25 years) and number 14 (dendrodated to ca. 3090 BC, of unknown duration) (Bleicher and Burger 2015). The preservation of both layers was not comparably good, being layer 13 better preserved over a larger surface, while layer 14 was well preserved in a smaller area (Figure 2). This was tested through a taphonomic analysis of plant macroremains as indicators of layer formation processes (Antolin, et al. 2017). Both layers are strongly organic and contain large amounts of plant remains, including lignified and non-lignified tissues such as leaf blades. A total number of 27 constructed features and a fence were identified for layer 13 and 9 constructed features for layer 14 through dendrochronological analyses (Bleicher and Burger 2015).

Having a multi-phase lakeshore site representatively sampled involves more revision and controlling than most of dry sites. In this particular case, house plans cannot be defined during fieldwork or soon after it. They require dendrochronological analyses, which may take several months, if not years, to be conducted. In the meantime, all the information that is available for archaeobotanists is the information connected to the sample, if the samples were recorded in a database, and the sample in itself. For this reason, the nature of the sediment samples was described before sieving and they were later assigned to the part of the layer from which they had been obtained (base, intermediate or top position), relying on the field documentation. Following previous research, it was the aim of our sampling strategy to obtain up to 8 samples per habitation unit or construction unit (Hosch and Jacomet 2001), a reasonable number of samples from intervening spaces between houses, as well as from different types of sediments (loam-rich, organic-rich, sandy-rich) and special features such as burnt layers (for the latter, for instance, it was established that 10–20 samples were enough to characterise their homogeneity/heterogeneity (Jacomet et al. 1989). Deciding which samples had to be analysed was therefore a multi-step process that started with a systematic type of interval sampling (1 sample every second meter from the parts of the site that were excavated in detail), and it was continued with a more targeted sampling oriented to the obtention of enough samples per constructed unit and particularly enough samples from the intervening spaces between houses and the burnt layer. This strategy was only possible because ca. 2000 samples were taken during fieldwork, systematically, every second meter. Those samples are still today stored in a dark storage facility under constant fresh conditions in case some further sampling is needed. Had it been organised otherwise, there would not have been any chance to go back and expand the sampling strategy upon request.

The sampling and sieving strategy was described in previous publications (Antolín et al. 2017a,c, 2015; Steiner et al. 2015, 2017). Its main goal was overcoming two traditional limitations in most previous investigations. Firstly, having the whole surface of the site sampled and that the volume

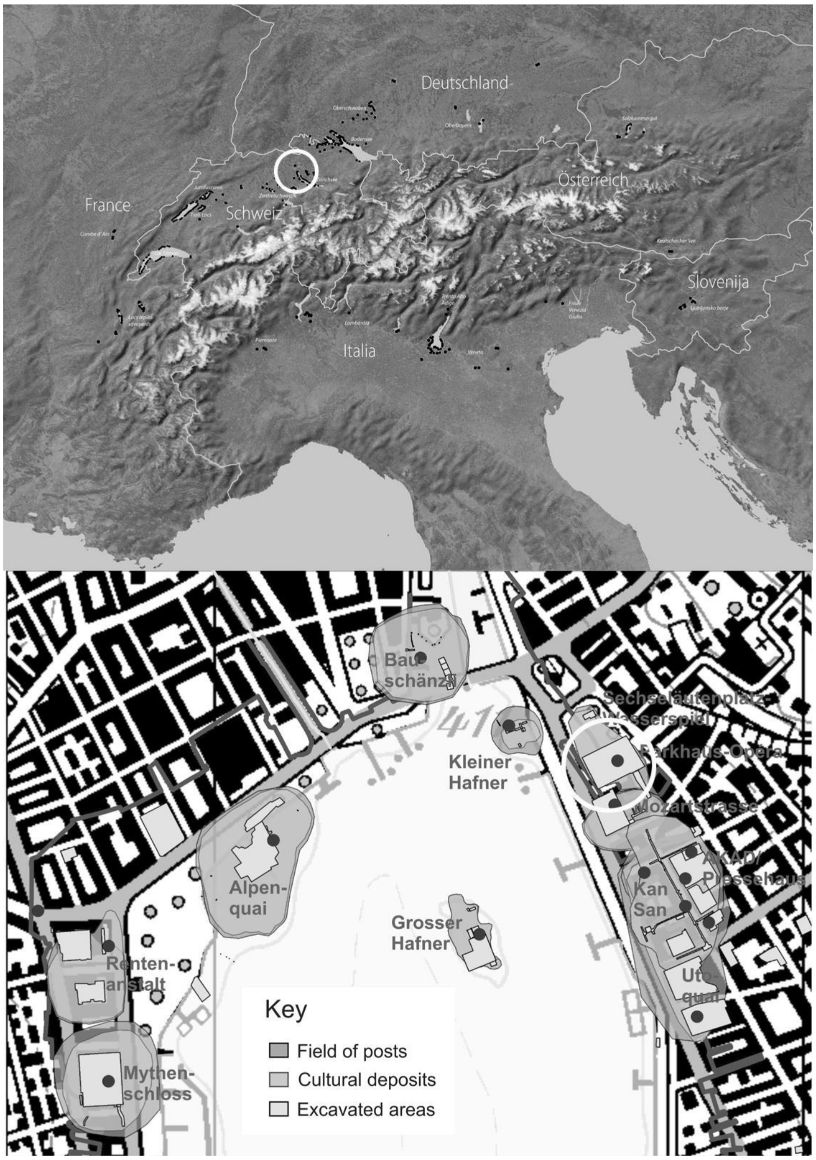


Figure 1: Location of the site at a wider scale (above) and in the northern shore of Zürich lake (below) (Antolín, et al. 2016).

of the samples was enough to have not only small-size plant remains (such as cereal chaff or flax seeds) but also large-size seeds and fruits (such as acorns, hazelnuts, and charred grain) in a representative number. Secondly, it was our aim to establish a methodology that could be used in other similar sites with good preservation and not particularly thick cultural layers (i.e. less than 40 cm). This methodology should aim for excellent results in the shortest time span possible. Several tests were performed to improve our methods (Antolín et al. 2017a,c, 2015; Steiner et al. 2015, 2017). The wash-over technique combined with a freeze-thaw pre-treatment (Vandorpe and Jacomet 2007) was used in order to recover plant diaspores, including the most fragile ones which can get destroyed during regular water sieving (Hosch and Zibulski 2003). Each master sample was subdivided into two sub-samples: one of ca. 3 L (the so-called A-samples) for large-seeded remains, to be sieved down to 2 mm; and one of ca. 0.3 L (the so-called B-samples) for the small seeded remains, to be sieved down to 0.35 mm. Despite the risk of obtaining slightly biased re-

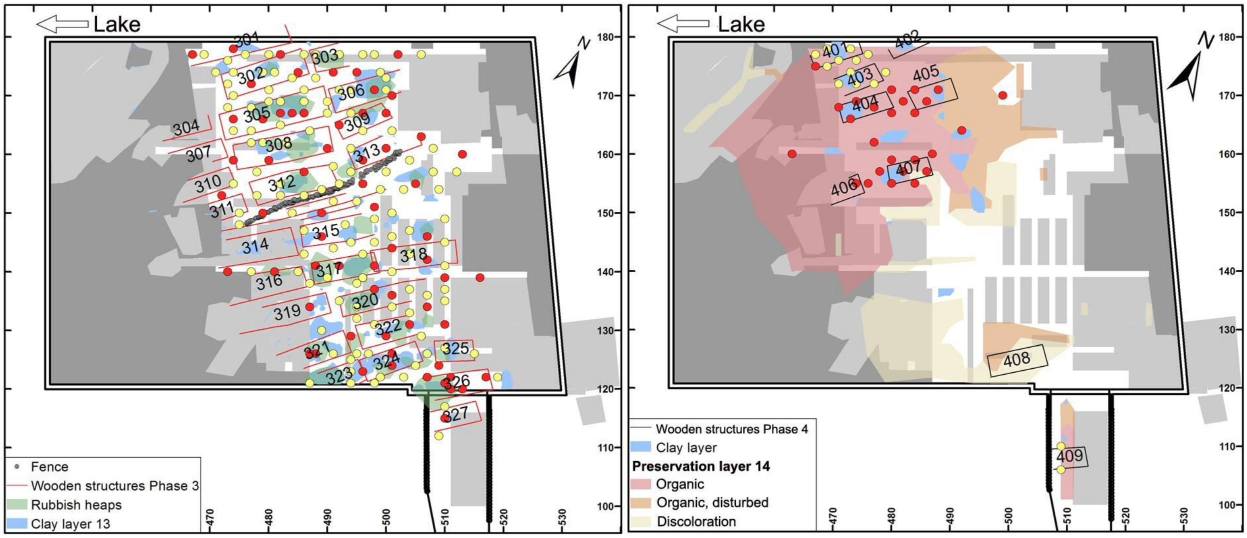


Figure 2: Samples taken at ZHOPE. Red dots indicate A-samples, yellow dots A- and B-samples (Antolín, et al. 2017).

sults in the smallest subsample, this allowed reducing the sieving time for large samples and as well as deciding which samples were needed in order to record small-sized remains representatively. In total, 256 samples (123 of which were sieved down to 0.35 mm) of layer 13 with a total volume of almost 1000 L were investigated until 2016 (average sample volumes of 3.8 L), while new analyses are still unpublished (ca. 60 additional A- and B- samples). The data regarding large-seeded plant remains refers to the total number of samples, small-seeded plant remains were exclusively analysed in the 123 samples mentioned above. Regarding layer 14, 53 samples were sieved and 33 of them down to 0.35 mm.

ArcGis (ESRI 2010) was used to represent on the site plan the densities of plant remains obtained per sample by means of graduated symbols with sizes defined by the Jenks natural breaks classification method (Jenks and Caspall 1971).

Methodological observations towards a better comparability of the data

It was observed during research at ZHOPE that instruction files for all the steps in the sample preparation and process of analysis need to be written before the project starts. This is the only way to provide the same detailed instructions to the whole team. Even in these ideal conditions, inconsistencies take place and for this reason sieving tests need to be carried out when multiple operators work in parallel (Steiner et al. 2015). It was repeatedly observed that what is quantified in each fraction is of major importance for the comparability of the data and different tests (Antolín et al. 2017c; Steiner et al. 2015, 2017) allowed defining a set of counting units in each fraction (Table 1). This is only to be applied in similar large-scale studies, and not for the most common monolith samples or profile samples.

Table 1: Recommended guidelines for the recording of botanical macroremains (currently used in the analysis of Parkhaus-Opéra) (Antolín et al. 2017c). p/a stands for presence/absence.

Taxa/type of remain	**State of preservation**	**Counting unit**	**Quantification (2mm fraction)**	
			A-samples	**B-samples**
Cereal grains	charred	with embryo	full	full (only when no A-Sample is analysed)
Cereal bran	waterlogged	>2mm with hilum	full	full (only when no A-Sample is analysed)
Cereal chaff	waterlogged and charred	glume bases (glume wheat) or rachis segments (naked wheat and barley)	full	full
Flax (*Linum usitatissimum*) capsules	waterlogged and charred	≥2 capsule fragments, with apical ending	full	full; single capsule fragments with apical ending
Flax (*Linum usitatissimum*) seeds	waterlogged and charred	with hilum	semi (only when no 0.35mm fraction is analysed)	full
Opium poppy (*Papaver somniferum*) seeds	waterlogged and charred	whole seeds or halves	p/a (only when no 0.35mm fraction is analysed)	full
Amorphous charred objects	charred	>5mm	full	full
Rubus fruits	waterlogged and charred	whole seeds	semi (present, some, many)	full
Corylus/*Fagus*/*Quercus* pericarp	waterlogged and charred	5x5mm	full	full (only when no A-Sample is analysed)
Malus/*Pyrus* pericarp	waterlogged and charred	3x4mm	full	full (only when no A-Sample is analysed)
Large seeds/fruits (incl. *Najas* and *Aethusa cynapium*)	waterlogged and charred	whole or >1/2	full	full (only when no A-Sample is analysed)
needles of coniferous trees	waterlogged and charred	needles with apical ending	semi (present, some, many)	semi (present, some, many)
Smaller seeds/fruits	waterlogged and charred	whole or >1/2	p/a (only when no 0.35mm fraction is analysed)	full

We do not want to introduce the study of taphonomic variables in this paper, but guidelines for their recording and study were also developed and published elsewhere (Antolín et al. 2017b).

The recording of the data was done on pre-designed paper sheets, where all the variables and commonly found taxa were already introduced to minimise writing time during analysis. The data were stored in an Access database called ArboDat (© Kreuz and Schäfer, 2017), which facilitated their systematic recording. Specific effort was put so that identifications by all project collaborators were homogenised, providing the codes and rest types to be introduced in the program beforehand (see Anhang 1 in Antolín et al. 2017a).

General results of the archaeobotanical analyses at ZHOPE

Archaeobotanical analyses at the site allowed for the identification of around 225,000 plant macroremains (mostly seeds and fruits) from layer 13 and 40,000 for layer 14. Cultivated plants were well represented in the record, particularly cereals and oil plants. Among the cereals, emmer (*Triticum dicoccon*), and naked wheat (*Triticum aestivum/durum/turgidum*, mostly belonging to the *durum/turgidum* group) are better represented in the uncharred record, while barley (*Hordeum vulgare*, multi-rowed and mainly of the naked type) is one of the most important cereals when considering the remains preserved by charring. Oil plants, including flax (*Linum usitatissimum*) and opium poppy (*Papaver somniferum*) were found in very large amounts, as is typical for lakeshore sites (Billamboz et al. 2010; Jacomet et al. 1989; Maier 2001; Maier and Vogt 2004; Rösch 1985). The spectrum of cultivated plants in both phases is very similar, although it seems that naked wheat and flax gain importance in layer 14 (Antolín et al. 2017a). Pulses were underrepresented in the samples of layer 13 due to difficulties during the identification process. Pea (*Pisum sativum*) was identified and it seems to have been an important crop, considering the average densities in layer 14 (ca. 80 r/L). Large seeded wild fruits (such as hazelnuts, acorns, and wild apple/pears) have also been observed to play a very significant role in the economy of the settlement (Antolín et al. 2016, 2017a).

The evaluation of the weeds accompanying crop plants has not yet been done in detail, and further work will focus on the charred layer of stored grain in order to identify charred seeds of weeds. In general, it seems that the weed spectrum is similar to that observed in other Horgen sites and briefly presented above, such as typical winter annuals (*Aphanes arvensis, Valerianella dentata, Cuscuta epilinum* or *Fallopia convolvulus*) and summer annuals (*Arenaria serpyllifolia, Cerastium pumilum, Potentilla argentea, Chenopodium album, Galeopsis tetrahit, Polygonum persicaria* or *Sonchus asper*). This spectrum would not fit with the usual spectrum of burnt fields in a shifting system (Bogaard 2002) but with that of permanent fields, maybe with the use of fallowing (for further details see Antolín et al. (2017a).

Some thoughts about the spatial distribution of the main economic taxa

Interpreting the palaeoeconomic meaning of plant remains, even under the best preservation conditions, is not straightforward. Plant remains may arrive into lakeshore villages through a number of different paths, including construction material, animal dung, etc. Besides, one needs to be sure that the postdepositional processes have not affected either their preservation — in a way that comparisons between different areas or parts of the stratigraphy are not any more possible — or their location at the moment of being discarded — since e.g. wave action could influence their final distribution.

Taphonomic evaluation of plant remains (Antolín et al. 2017a,b), as well as of multiple other proxies (Bleicher, et al. submitted; Bleicher et al. 2017) have shown that the uppermost part of the archaeological layer of ZHOPE had experienced intense erosion in the northern half of the site, and significant reworking due to site abandonment and subsequent natural dynamics in the rest of the site. It was, however, concluded on the basis of several example calculations, that comparisons across the site were only possible if samples from the lowermost part of the layer were used.

The observation of the distribution of certain plant remains should help us to identify areas of cereal processing (observed in the accumulation of chaff remains) or the type of uses of flax (through the observation of the distribution of seeds and capsules (i.e. if the distribution is similar, they could be interpreted as resulting from the production of oil, as stated above). The spatial evaluation of the botanical data (including a detailed comparison between houses) will be done in the future.

We selected some examples of layer 13 at ZHOPE to show the potential of this type of approach (Figure 3): cereal bran, free-threshing cereal chaff, flax seeds and capsule fragments, and seeds of opium poppy. The large accumulations of cereal bran, sometimes within house limits but often close to the edges might indicate grinding areas, since bran is one of the by-products of grinding (see e.g. Alonso et al. 2014). Findings of bread-like objects have been identified at the site (Heiss et al. 2017), which suggests that grinding and baking could have taken place at a household scale. Smaller accumulations of bran could also reflect the presence of dung, since it usually survives digestion. The distribution of the largest accumulations of chaff of free-threshing cereals shows that threshing must have taken place, at least to some extent, in open areas and not inside. Similar interpretations regarding free-threshing wheat were reached at the site of Torwiesen II (Maier and Harwath 2011). Smaller accumulations within loam lenses or rubbish heaps might respond to the use of chaff as animal fodder. Regarding the distribution of flax seeds and capsule fragments, concentrations mainly consisting of seeds were found in several buildings (mostly inside them). This could indicate the consumption of seeds. At the same time, the finding of capsule-rich samples could correspond to observations done in other sites of this period, referring to the use of capsules to gain oil. One also needs to take into account that capsule fragments discarded between buildings could have been accumulated landwards by wave action. Opium poppy seeds were found in very large amounts, particularly within building limits. This latter observation was also similar at Torwiesen II (Maier and Harwath 2011).

For further distribution plans and discussion on the distribution of plant remains see Antolín et al. (2017a).

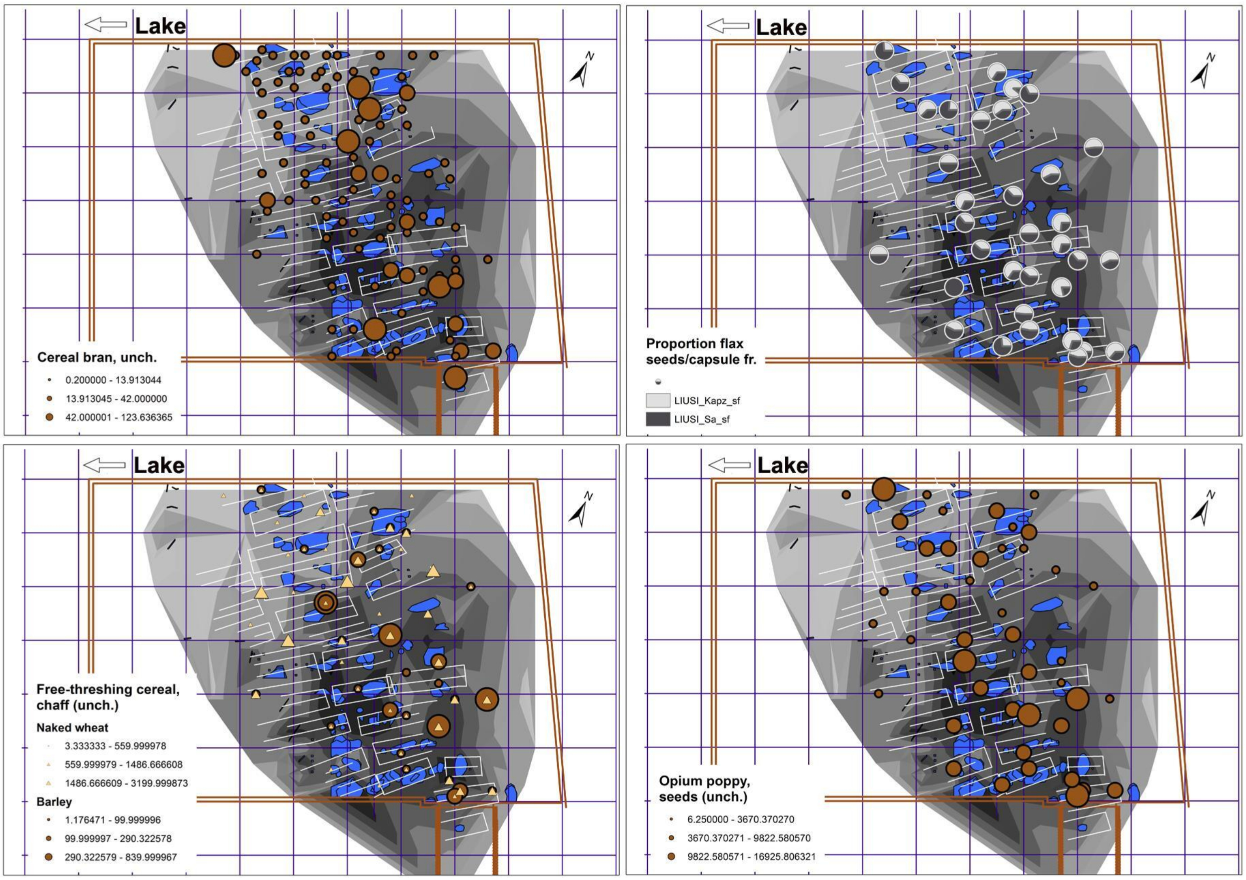


Figure 3: Site plans of ZHOPE showing the density of plant remains obtained per sample. Only samples at the base of the stratigraphy have been represented to allow a more direct comparison across the site's surface. The scale of greys in the background indicates layer thickness (from ca. 5 in the lightest spots to ca. 30 cm in the darkest ones). Areas in blue indicate loamy sediment, which is well connected with the groundplans of the houses.

Towards a diet reconstruction at a site scale in ZHOPE

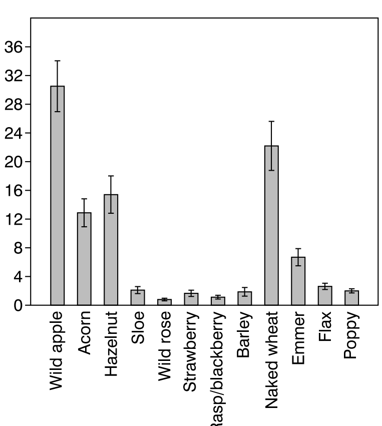


Figure 4: Barcharts showing the mean and standard error obtained from the proportion of calories represented by each ressource in each of the 53 samples located at the basis of the stratigraphy of ZHOPE.

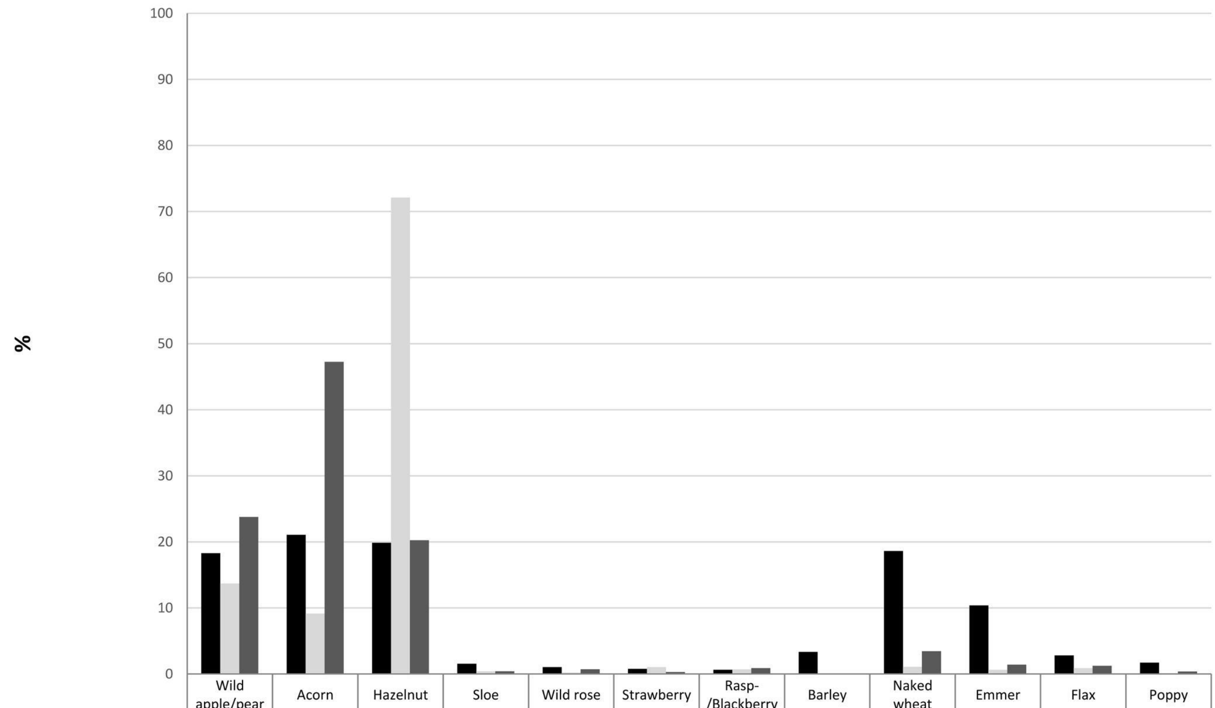
The quantification units used in archaeobotany do not always directly allow the quantification of the minimum number of seeds/fruits in a sample. This would be useful as a basis to infer weight and calories, with the limitations that we need to take into account (we do not have references for the weight of prehistoric wild apples, for instance). This, together with the diverse taphonomic processes that affect plant remains in most dry sites, usually results in a very limited (or mostly absent) approach to the diet (the relative contribution of cereals, legumes, oil plants, and wild plants to the diet) of the inhabitants of the studied sites. Only in wet sites can one assume that uncharred plant remains (particularly those found in greater abundance) are a more or less reliable proxy for consumed plant resources. Most of the previous attempts on this field are therefore only found in the Alpine Foreland.

At ZHOPE, plant remains are quantified in a manner that they roughly express a minimum number of individuals (MNI) in most cases. In other cases, easy formulas can be applied to calculate the minimum number of fruits (e.g. apple pericarps/10= 1 apple). There are formulas to calculate MNI for different taxa (Antolín and Buxó 2011; Antolín and Jacomet 2015;

Berihuete and Antolín 2012), but they are time-consuming and mostly proposed for charred assemblages, where the time investment is significantly lower than in wetland sites. We can in any case present an approach to human diet at layer 13 in ZHOPE on the basis of the 53 samples that were completely analysed (A- and B-samples of the same master sample) and that were located at the basis of the stratigraphy, thus presenting optimal preservation conditions. The values used for the calculations are presented in Table 2 and obtained from several bibliographical sources (Antolín et al. 2016, and references therein; Elmadfa et al. 2014; Kuhnlein et al. 2006). It is clearly observed that wild resources add up to about 65 per cent of the total calorific input, while domestic resources (cereals and oil plants) add up to 35 per cent (cereals yielding most of it, around 30 per cent of the calories) (Figure 4). One should still add the role of legumes (green pea). This was done on a theoretical basis, using the data from layer 14 of ZHOPE, where the pea pod fragments of peas were correctly identified and quantified. Considering that pea pods were found in an average density of 81.1 r/L, and that each pea weights about 0.15 gr and has ca. 0.84 calories/gr, one would obtain an average hypothetical percentage of 1.2 per cent of the total calories represented. It is not a neglectable amount, since peas are particularly important due to their high protein content and particularly as a daily complement to cereals in order to allow the absorption of those proteins (e.g. Rosenstock et al. 2015, and references therein). In any case, it does not change the general picture: wild plants contributed with a major role to everyday diet at Parkhaus Opéra. It is also possible that the large number of unidentified cereal chaff might reduce the representation of cereals in the graph. If we increased the calorific contribution of cereals in 1/3, which is a common proportion of unidentified cereal chaff in most samples, the overall calorific contribution of cereals in the diet would be ca. 38–40 per cent, while gathered plants would add up to ca. 57 per cent of the total calorific input. These results are similar to those obtained at Arbon Bleiche 3 (Hosch and Jacomet 2004).

Is this a single case in lakeshore settlements? Due to inappropriate sampling strategies (too few samples of a low volume, much below 1 L in average), we cannot compare our data with many other sites dating to the second half of the 4th millennium cal. BC, but we can compare them with Arbon Bleiche 3 and Horgen Scheller, Layer 3 (probably a seasonal site where wild resources make the greatest part of the archaeobotanical and archaeozoological record). The results show that, if anything, the results of ZHOPE are the ones that allow a better representation of cultivated plants in the diet (Figure 5). In front of these results, one can only wonder if cultivated plants could be underrepresented in our records, which would be completely unexpected given the fact that the spatial distribution of these remains shows the regular practice of household processing. In our opinion, current results indicate that the role of wild plants in the diet of early farming populations is regularly underestimated and that too much focus had been put on the importance of cultivated plants, which make up a very significant part of the diet, but not the largest amount, when one considers the calorific input. Further discussion could follow on the significance of each of the resources in each site, but this is not the aim of this paper.

When looking at the significance of wild plant gathering in the economy of ethnographical case studies in the *Ethnographic atlas* of Murdock (see a



	Wild apple/pear	Acorn	Hazelnut	Sloe	Wild rose	Strawberry	Rasp-/Blackberry	Barley	Naked wheat	Emmer	Flax	Poppy
ZHOPE	18.3	21.1	19.9	1.5	1.0	0.8	0.6	3.3	18.6	10.4	2.8	1.7
Arbon Bleiche 3	13.7	9.1	72.1	0.4	0.2	1.0	0.7	0.1	1.1	0.6	0.9	0.1
Horgen Scheller, Layer 3	23.8	47.2	20.2	0.4	0.7	0.3	0.9	0.0	3.4	1.4	1.2	0.4

Figure 5: Percentages of calories obtained from each plant food resource at ZHOPE, Arbon Bleiche 3 and Horgen Scheller. For the calculations, the same values presented in Table 2 were used.

synthesis in Antolín and Berihuete 2017, and references therein) it seems a rare case that a farming population puts such a big effort in wild plant gathering. Such a case is more often found in small-scale societies with a low social stratification where agriculture (either intensive or shifting agriculture) does not play a preponderant role in the economy (Antolín and Berihuete 2017). It is therefore of major interest to pursue further this line of research.

Table 2: General results of layer 13 in ZHOPE with the main taxa recovered in the archaeobotanical record presented in average density of the MNI (53 completely analysed samples from the basis of the stratigraphy were used), with additional information on the weight per seed/fruit, calories per gram and the overall resulting calories per taxon, as well as the percentage of the total amount of calories and the corrected percentage when taking unidentified cereal chaff into account as mentioned in the text (see references in the text and in Antolín et al. 2016).

	Average density (MNI)	**Weight per seed/fruit (gr)**	**Calories/gr**	**Total calories**	**per cent of the total calories**	***corrected per cent of the total calories**
Wild apple/pear	10.3	20	0.76	156.5	18.3	16.5
Acorn	13.0	6.33	2.191.6	180.2	21.1	19.0
Hazelnut	26.4	1	6.44	169.9	19.9	17.9
Sloe	3.9	7	0.48	13.2	1.5	1.4
Wild rose	5.4	3	0.55	8.8	1.0	0.9
Strawberry	12.1	1	0.54	6.5	0.8	0.7
Rasp-/Blackberry	9.4	1.3	0.44	5.4	0.6	0.6
Barley	356.6	0.023	3.48	28.5	3.3	4.0
Naked wheat	1953.1	0.027	3.02	159.3	18.6	22.4
Emmer	1223.1	0.024	3.02	88.6	10.4	12.6
Flax	1279.8	0.005	3.76	24.1	2.8	2.5
Poppy	5129.0	0.0006	4.77	14.7	1.7	1.6

Conclusions

Recent research at Zürich-Parkhaus Opéra proved that archaeobotanical investigations in lakeshore settlements can still (after intensive research in the past decades) bring important information about prehistoric communities living on the shores of the lakes found north of the Alps, if the full potential is used employing latest methodologies. It was shown how the latest methodological improvements, following previous developments, increase the representativeness and comparability of the data produced and how it has been possible to better document some important plant resources, particularly those of most fragile nature, but also large-seeded wild plants.

Having produced high-quality data for the site, and after having done the necessary taphonomic research for establishing the representativeness of the data across the stratigraphy and the site's surface, it will now be possible to move forward to largely unexplored areas of research such as diet. It is our hope to be able to start defining household units (with integrative methods) and later characterise their economy and nutrition in a more detailed way than ever before in the past.

Acknowledgements

This study was funded by the Swiss National Science Foundation, project number CR30I2_149679/1 (main project leader Philippe Rentzel) and the canton and town of Zürich.

References

Alonso, N., F. Cantero, R. Jornet, D. López, E. Montes, G. Prats, and S. Valenzuela (2014). 'Milling wheat and barley with rotary querns: the Ouarten women (Dahmani, El Kef, Tunisia)'. In: *Seen through a millstone*. Ed. by L. Selsing. Bergen: Museum of Archaeology, University of Stavanger, pp. 11–30.

Antolín, F. and M. Berihuete (2017). 'De tal palo tal astilla: la etnografía como herramienta de la arqueobotánica para el estudio de la gestión de los recursos silvestres comestibles en el pasado'. In: *Miscelánea en homenaje a Lydia Zapata Peña (1965-2015)*. Ed. by F. Eraso, J. Alustiza, A. Valbuena, and M. Díez. Bilbao: Universidad del País Vasco, pp. 107–30.

Antolín, F., N. Bleicher, C. Brombacher, M. Kühn, B. Steiner, and S. Jacomet (2016). 'Quantitative approximation to large-seeded wild fruit use in a late Neolithic lake dwelling: New results from the case study of layer 13 of Parkhaus Opéra in Zürich (Central Switzerland)'. In: *Quaternary International* 404 (Part A), pp. 56–68.

Antolín, F., C. Brombacher, M. Kühn, B. Steiner, and S. Jacomet (2017a). 'Archäobotanik (Makroreste): Ergebnisse der Untersuchungen der Flächenproben im Hinblick auf Taphonomie, Ackerbau, Sammelwirtschaft und Umwelt'. In: *Zürich-Parkhaus Opéra. Eine neolithische Feuchtbodensiedlung. Band 3: Naturwissenschaftliche Untersuchungen*. Ed. by N. Bleicher and C. Harb. Zürich und Egg: Photorotar, pp. 50–92.

Antolín, F. and R. Buxó (2011). 'Proposal for the systematic description and taphonomic study of carbonized cereal grain assemblages: a case study of an early Neolithic funerary context in the cave of Can Sadurní (Begues, Barcelona province, Spain)'. In: *Vegetation History and Archaeobotany* 20, pp. 53–66.

Antolín, F. and S. Jacomet (2015). 'Wild fruit use among early farmers in the Neolithic (5400–2300 cal bc) in the north-east of the Iberian Peninsula: an intensive practice?' In: *Vegetation History and Archaeobotany* 24, pp. 19–33.

Antolín, F., B. Steiner, Ö. Akeret, C. Brombacher, M. Kühn, P. Vandorpe, N. Bleicher, E. Gross, G. Schaeren, and S. Jacomet (2017b). 'Studying the preservation of plant macroremains from waterlogged archaeological deposits for an assessment of layer taphonomy'. In: *Review of Palaeobotany and Palynology* 246, pp. 120–45.

Antolín, F., B. Steiner, and S. Jacomet (2017c). 'The bigger the better? On sample volume and the representativeness of archaeobotanical data in waterlogged deposits'. In: *Journal of Archaeological Science: Reports* 12, pp. 323–33.

Antolín, F., B. Steiner, W. Vach, and S. Jacomet (2015). 'What is a litre of sediment? Testing volume measurement techniques for wet sediment and their implications in archaeobotanical analyses at the Late Neolithic lake-dwelling site of Parkhaus Opéra (Zürich, Switzerland)'. In: *Journal of Archaeological Science* 61, pp. 36–44.

Berihuete, M. and F. Antolín (2012). 'A les avellanes, foc i flames: Tafonomia i quantificació de closques d'avellana recuperades en contextos arqueològics. Revisió del registre documentat a la Península Ibèrica.' In: *Cypsela* 19, pp. 281–94.

Billamboz, A., U. Maier, and I. Matuschik (2010). 'Die jung- und endneolithischen Seeufersiedlungen von Sipplingen „Osthafen" am Bodensee: Besiedlungs- und Wirtschaftsdynamik im eng begrenzten Naturraum des Sipplinger Dreiecks'. In: *Vernetzungen*. Freiburg i. Br: Lavori-Verlag, pp. 253–286.

Bleicher, N., F. Antolín, O. Heiri, S. Häberle, H. Hüster Plogmann, S. Jacomet, C. Pümpin, P. Rentzel, M. Schäfer, J. Schibler, and P. Wiemann (2017). 'Taphonomie und Schichtgenese'. In: *Zürich-Parkhaus Opéra: eine neolithische Feuchtbodenfundstelle. Band 3: Naturwissenschaftliche Analysen und Synthese*. Ed. by N. Bleicher and C. Harb. Zürich und Egg: Photorotar, pp. 215–25.

Bleicher, N. and M. Burger (2015). 'Dendroarchäologie und Pfahlfeldanalyse'. In: *Zürich- Parkhaus Opéra. Eine neolithische Feuchtbodenfundstelle. Band 1: Befunde, Schichten und Dendroarchäologie*. Ed. by N. Bleicher and C. Harb. Zürich und Egg: Photorotar, pp. 100–46.

Bleicher, N. and C. Harb, eds. (2015). *Zürich-Parkhaus Opéra. Eine neolithische Feuchtbodensiedlung. Band 1. Befunde, Schichten und Dendroarchäologie*. Zürich und Egg: Photorotar.

Bogaard, A. (2002). 'Questioning the relevance of shifting cultivation to Neolithic farming in the loess belt of Europe: evidence from the Hambach Forest experiment'. In: *Vegetation History and Archaeobotany* 11, pp. 155–68.

Brombacher, C. (1995). 'Wirtschaftliche Entwicklung aufgrund archäobotanischer Daten'. In: *Neolithikum*. Ed. by E. Stöckli, U. Niffeler, and E. Gross-Klee. Basel: SGUF, pp. 86–96.

– (1997). 'Archaeobotanical investigations of Late Neolithic lakeshore settlements (Lake Biel, Switzerland)'. In: *Vegetation History and Archaeobotany* 6, pp. 167–86.

Brombacher, C. and S. Jacomet (1997). 'Ackerbau, Sammelwirtschaft und Umwelt: Ergebnisse archäobotanischer Untersuchungen'. In: *Ökonomie und Ökologie neolithischer und bronzezeitlicher Ufersiedlungen am Zürichsee. Ergebnisse der Ausgrabungen Mozartstrasse, Kanalisationssanierungen Seefeld, AKAD/Pressehaus und Mythenschloss in Zürich*. Ed. by H.-P. Schibler, S. Jacomet, C. Brombacher, E. Gross-Klee, and A. Rast-Eicher. Zürich und Egg: Direktion der öffentlichen Bauten des Kantons Zürich, pp. 220–79.

Elmadfa, I., W. Aign, E. Muskat, and D. Fritzsche (2014). *Die große GU Nährwert Kalorien Tabelle*. München: Gräfe und Unzer Verlag.

ESRI (2010). *ArcGIS 10.0*. Environmental System Research Institute, Inc., Redlands, California.

Favre, P. (2002). 'Archäobotanik'. In: *Die Seeufersiedlungen in Horgen. Die neolithischen und bronzezeitlichen Fundstellen Dampfschiffsteg und Scheller*. Ed. by C. Achour-Uster, U. Eberli, R. Ebersbach, and P. Favre. Zürich / Egg: Fotorotar, pp. 150–80.

Gross, E., S. Jacomet, and J. Schibler (1990). 'Stand und Ziele der wirtschaftsarchäologischen Forschung an neolithischen Ufer- und Inselsiedlungen im Unteren Zürichseeraum (Kt. Zürich, Schweiz)'. In: *Festschrift für Hans R. Stampfli. Beiträge zur Archäozoologie, Archäologie, Anthropologie, Geologie und Paläontologie. Basel*. Ed. by J. Schibler, J. Sedlmeier, and H. Spycher. Basel: Helbing & Lichtenhahn, pp. 77–100.

Heiss, A., F. Antolín, N. Bleicher, C. Harb, S. Jacomet, M. Kühn, E. Marinova, H.-P. Stika, and S. Valamoti (2017). 'State of the (t)art: Analytical approaches in the investigation of components and production traits of archaeological bread-like objects, applied to two finds from the Neolithic lakeshore settlement Parkhaus Opéra (Zürich, Switzerland)'. In: *PLOS ONE* 12.

Hosch, S. and S. Jacomet (2001). 'New aspects of archaeobotanical research in central European Neolithic lake dwelling sites'. In: *Environmental Archaeology* 6, pp. 59–71.

– (2004). 'Ackerbau und Sammelwirtschaft. Ergebnisse der Untersuchung von Samen und Früchten'. In: *Die neolithische Seeufersiedlung Arbon Bleiche 3: Wirtschaft und Umwelt*. Ed. by S. Jacomet, J. Schibler, and U. Leuzinger. Frauenfeld: Amt für Archäologie des Kantons Thurgau, pp. 112–57.

Hosch, S. and P. Zibulski (2003). 'The influence of inconsistent wet-sieving procedures on the macroremain concentration in waterlogged sediments'. In: *Journal of Archaeological Science* 30.7, pp. 849–857. DOI: 10.1016/S0305-4403(02)00263-7.

Jacomet, S. (2006). 'Plant economy of the northern Alpine lake dwellings - 3500-2400 cal. BC'. In: *Environmental archaeology* 11, pp. 65–85.

– (2007). 'Neolithic plant economies in the northern alpine foreland from 5500-3500 BC cal'. In: *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*. Ed. by S. Colledge and J. Conolly. U.S.A.: Left Coast Press, pp. 221–58.

– (2009). 'Plant economy and village life in Neolithic lake dwellings at the time of the Alpine Iceman'. In: *Vegetation History and Archaeobotany* 18, pp. 47–59.

– (2013). 'Archaeobotany: Analyses of Plant Remains from Waterlogged Archaeological Sites'. In: *The Oxford Handbook of Wetland Archaeology*. Ed. by F. Menotti and A. O'Sullivan. Oxford: Oxford University Press, pp. 497–514.

Jacomet, S. and C. Brombacher (2005). 'Reconstructing intra-site patterns in Neolithic lakeshore settlements: The state of archaeobotanical research and future prospects'. In: *WES'04 - Wetland Economies and Societies. Proceedings of the International Conference in Zurich, 10-13 March 2004*. Ed. by P. Casa and M. Trachsel. Zürich: Chronos, pp. 69–94.

Jacomet, S., C. Brombacher, and M. Dick (1989). *Archäobotanik am Zürichsee. Ackerbau, Sammelwirtschaft und Umwelt von neolithischen und bronzezeitlichen Seeufersiedlungen im Raum Zürich. Ergebnisse von Untersuchungen pflanzlicher Makroreste der Jahre 1979-1988*. Zürich: Orell Füssli Verlag.

Jacomet, S., R. Ebersbach, Ö. Akeret, F. Antolín, T. Baum, A. Bogaard, C. Brombacher, N. Bleicher, A. Heitz-Weniger, H. Hüster-Plogmann, E. Gross, M. Kühn, P. Rentzel, B. Steiner, L. Wick, and J. Schibler (2016). 'On-site data cast doubts on the hypothesis of shifting cultivation in the late Neolithic (c. 4300–2400 cal. BC): Landscape management as an alternative paradigm'. In: *The Holocene* 26.11, pp. 1858–1874.

Jenks, G. and F. Caspall (1971). 'Error on Choroplethic maps: definition, measurement, reduction'. In: *Annals of the American Association of Geographers* 61, pp. 217–44.

Kohler-Schneider, M. (2007). 'Early agriculture and subsistence in Austria: a review of neolithic plant records'. In: *The origins and spread of domestic plants in Southwest Asia and Europe*. Ed. by S. Colledge and J. Conolly. U.S.A.: Left Coast Press, pp. 209–20.

Kohler-Schneider, M. and A. Caneppele (2009). 'Late Neolithic agriculture in eastern Austria: archaeobotanical results from sites of the Baden and Jevišovice cultures (3600–2800 b.c.)' In: *Vegetation History and Archaeobotany* 18, pp. 61–74.

Kuhnlein, H., S. Smitasiri, S. Yesudas, L. Bhattacharjee, L. Dan, and S. Ahmed (2006). *Documenting Traditional Food Systems of Indigenous Peoples: International Case Studies. Guidelines for Procedures*. Ste. Anne de Bellevue: Centre for indigenous peoples' nutrition and Environment, McGill University.

Maier, U. (2001). 'Archäobotanische Untersuchungen in der neolithischen Ufersiedlung Hornstaad-Hörnle IA am Bodensee'. In: *Siedlungsarchäologie im Alpenvorland VI. Botanische und pedologische Untersuchungen zur Ufersiedlung Hornstaad-Hörnle IA*. Ed. by U. Maier and R. Vogt. Stuttgart: Konrad Theiss Verlag, pp. 9–384.

Maier, U. and A. Harwath (2011). 'Detecting intra-site patterns with systematic sampling strategies. Archaeobotanical grid sampling of the lakeshore settlement Bad Buchau-Torwiesen II, southwest Germany'. In: *Vegetation History and Archaeobotany* 20, pp. 349–65.

Maier, U. and C. Herbig (2011). 'Archäobotanische Flächenuntersuchungen in der endneolithischen Feuchtbodensiedlung Torwiesen II'. In: *Die endneolithische Moorsiedlung Bad Buchau-Torwiesen II am Federsee. Band 1: Naturwissenschaftliche Untersuchungen*. Ed. by H. Schlichtherle and J. Köninger. Freiburg i. Breisgau: Janus-Verlag, pp. 81–280.

Maier, U. and R. Vogt (2004). 'Archäobotanische Untersuchungen in jung- und endneolithischen Moorsiedlungen am Federsee'. In: *Ökonomischer und ökologischer Wandel am vorgeschichtlichen Federsee. Archäologische und naturwissenschaftliche Untersuchungen. Hemmernhofener Skripte 5*. Ed. by J. Köninger and H. Schlichtherle. Freiburg i. Br.: Janus Verlag, pp. 71–159.

Martin, L., L. Bouby, P. Marinval, M.-F. Dietschi-Sellami, O. Rousselet, M. Cabanis, F. Durand, and I. Figueiral (2016). 'L'exploitation des ressources végétales durant le Chasséen: un bilan des données carpologiques en France entre 4400 et 3500 avant notre ère'. In: *Le Chasséen, des Chasséens... Retour sur une culture nationale et ses parallèles, Sepulcres de fossa, Cortaillod, Lagozza. Colloque international de Paris, 18-20 novembre 2014*. Ed. by T. Perrin, P. Chambon, J. Bao, and G. Goude. Toulouse: Archives d'Écologie Préhistorique, pp. 259–72.

Rösch, M. (1985). 'Die Pflanzenreste der neolithischen Ufersiedlung von Hornstaad-Hörnle I am westlichen Bodensee: 1. Bericht'. In: *Berichte zu Ufer- und Moorsiedlungen Südwestdeutschlands : 2*. Stuttgart: Theiss, pp. 164–199.

Rosenstock, E., M. Gross, A. Hujic, and A. Scheibner (2015). 'Back to good shape: biological standard of living in the Copper and Bronze Ages and the possible role of food'. In: *The Third Food Revolution? Setting the Bronze Age table: common trends in economic and subsistence strategies in Bronze Age Europe*. Ed. by J. Kneisel, M. Corso, W. Kirleis, H. Scholz, N. Taylor, and V. Tiedtke. Bonn: Verlag Dr. Rudolph Habelt GmbH, pp. 121–51.

Schaal, C. and P. Petrequin (2015). 'Approche archéobotanique du Néolithique moyen de Clairvaux'. In: *Néolithique Moyen Bourguignon*. Ed. by P. Petrequin and A.-M. Petrequin. Besançon: Presses universitaires de Franche-Comté, Centre de Recherche Archéologique de la Vallée de l'Ain, pp. 1193–278.

Spangenberg, J., M. Ferrer, S. Jacomet, N. Bleicher, and J. Schibler (2014). 'Molecular and isotopic characterization of lipids staining bone and antler tools in the Late Neolithic settlement, Zurich Opera Parking, Switzerland'. In: *Organic Geochemistry* 69, pp. 11–25.

Steiner, B., F. Antolín, and S. Jacomet (2015). 'Testing of the consistency of the sieving (wash-over) process of waterlogged sediments by multiple operators'. In: *Journal of Archaeological Science: Reports* 2, pp. 310–20.

Steiner, B., F. Antolín, W. Vach, and S. Jacomet (2017). 'Subsampling of large-volume samples in waterlogged sediments. A time-saving strategy or a source of error?' In: *Review of Palaeobotany and Palynology* 245, pp. 10–27.

Vandorpe, P. and S. Jacomet (2007). 'Comparing different pre-treatment methods for strongly compacted organic sediments prior to wet-sieving: a case study on Roman waterlogged deposits'. In: *Environmental archaeology* 12, pp. 207–14.