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)

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Abstract

A specific sediment sampling strategy was applied to a late Neolithic settlement phase (dendrodated to around 3160 BC) in the pile-dwelling site of Parkhaus Opéra (Zürich, Switzerland). It consisted in a systematic collection of over 2100 large-volume samples (3-10 litres) in an area of ~3,000 m², of which 255 were selected for archaeobotanical analysis. Over 80,000 plant macroremains of large size (>2 mm) were recovered and a rich assemblage of large-seeded wild fruits was evaluated. Hazelnuts (*Corylus avellana* L.), acorns (*Quercus* sp.), apples/pears (*Malus/Pyrus*), sloes (*Prunus spinosa* L.), wild rose fruits (*Rosa* sp.), beech nuts (*Fagus* sp.) and wayfaring tree fruits (*Viburnum lantana* L.) were among the most frequently and abundantly gathered and consumed wild fruits at the settlement. Three methods of quantification were used to evaluate their importance in the economy taking into account the samples retrieved from 16 fully excavated structures: total average density of fruit items, total estimated amount of fruits, and their calorific contribution. The estimation of the caloric importance of large-seeded wild fruits depends on assumptions on taphonomic biases. A first estimation suggested that they probably provided between 1.5% and 15% of the total calorific input by the settlement's inhabitants.

Keywords: *Archaeobotany, palaeoeconomy, subfossil plant macroremains, diet, GIS*

1. Introduction: The lakeshore site of Parkhaus Opéra

The site of Parkhaus Opéra is located at the north-eastern shore of lake Zürich (Switzerland) and was documented during a rescue excavation in 2010 and 2011 under the scientific direction of Niels Bleicher. The evaluation of the structures, artefacts and ecofacts has been running since then under the direction of Niels Bleicher (Office for Urbanism, City of Zürich) and Christian Harb (Cantonal Archaeology of Zurich) (Bleicher and Harb, 2015). The site is close to other previously investigated archaeological sites like Kleiner Hafner, Mozartstrasse, AKAD/Pressehaus or Kanalisationssanierung (KanSan), making this a privileged region in terms of richness in archaeological settlements with waterlogged deposits with good preservation of organic remains dated to the Neolithic period (ca. 4500-2500 cal BC) (Fig. 1). Eight settlement phases were uncovered at Parkhaus Opéra, dendro-dated between 2727 and 3234 BC. For this paper, we focused on the results of layer 13 (of ca. 20 years duration between 3175BC and 3157 BC), which is the third settlement phase found at the site and the one that was best preserved in a larger surface (~3,000 m²). This so-called cultural layer consisted of different sediment types (mostly organic sediments, but also clay-rich sediments as well as sandy ones or thin layers of lake marl) of varying thickness (Fig. 2). The maximum thickness of the layer was 32 cm. A total number of 27 houses and a footbridge were identified (Fig. 2) through dendrochronological analyses (Bleicher and Harb, 2015).

According to the dating and the material evidence found at the settlement, this settlement phase belongs to the Horgen culture (ca. 3500-2780 cal BC), more precisely to the developed Horgen culture (ca. 3250-3150 BC) (see Hafner and Suter, 2003). Plant economy during this period was founded on a combination of agriculture and plant gathering. Agriculture was based on the cultivation of cereals, especially tetraploid naked wheat (*Triticum durum* Desf./*turgidum* L.), emmer (*Triticum dicoccon* Schrank), einkorn (*Triticum monococcum* L.) and barley (*Hordeum vulgare* L.); legumes, especially green pea (*Pisum sativum* L. s.l.), and oil plants, including flax (*Linum usitatissimum* L.) and opium poppy (*Papaver somniferum* L.) (Jacomet, 2006, 2014). The most important collected plants were hazelnut (*Corylus avellana* L.), crab apple (*Malus sylvestris* (L.) Mill.), sloe (*Prunus spinosa* L.),

acorns (*Quercus* sp.), blackberry and raspberry (*Rubus* sp.), wild strawberry (*Fragaria vesca* L.) and rose (*Rosa* sp.) (Jacomet, 2006, 2014).

Fig. 1. Location of Lake Zürich within the Alpine region (above) and plan of Parkhaus Opéra and other prehistoric pile dwellings around lake Zürich (below) (Author: Office for Urbanism, City of Zürich).

The aim of this paper is to present the methods used for a representative recovery of large-seeded taxa at layer 13 of the site of Parkhaus Opéra, to compare different quantitative methods available to describe the data and then use the data obtained to provide a first approach to the importance of large-seeded wild fruits in the diet and the economy of the settlement. There are few other attempts to model the role of plant gathering at a site level based on representative data obtained from a site with excellent preservation of organic remains. The closest example to our case study would be the site of

Arbon Bleiche 3, where it was suggested that gathered plants could represent up to 40% of the calorific input of plant origin (Hosch and Jacomet, 2004).

2. Materials and methods

The excavated area was dug in trenches of 1 metre width, in general. The largest part of the settlement was excavated in detail (Fig. 3). This strategy provided a dense network of documented profiles (1.9 km have been documented photogrammetrically) and well-excavated trenches all over the excavated surface, as well as to proceed faster with the work in areas that were coarsely excavated. Samples (>2100) were mostly taken every second square meter in fine-excavated trenches and, whenever several sublayers were observed, samples from more than one sublayer were taken in the same square. Areas with clay structures (defined as an area where stratified loam was present among the organic remains over several square metres) with a particularly complex stratigraphy were usually more thoroughly sampled. Afterwards a selection of 255 of these samples was done (Fig. 3) with the aim of having represented in a systematic way as much of the surface of the settlement as possible, as well as its inner stratigraphy (for a review of sampling methods for lakeshore settlements see Jacomet and Brombacher (2005)). The reason for this strategy was that the sampling and analysis was done before the origin of the samples, the location of archaeological features and house plans were known. This is almost always the case in lakeshore settlements because such features can only be identified by dendrological analyses.

The goal of the archaeobotanical investigations at the site was to obtain reliable data for a palaeoeconomic reconstruction not only at a site level but, if possible, at a feature level (a house, a street, etc.). For this, it was intended to obtain ~400 remains of large size (well above 2 mm) and ~400 remains of small size (2 mm or less) (following van der Veen and Fieller (1982) modified in Hosch and Jacomet (2001)) in each sample. Archaeobotanical investigations at the site of Arbon Bleiche 3 indicated that 8 samples per house were enough to get a good representation of the 18 most important useful plants found (Hosch and Jacomet, 2001). This amount of samples was analysed for

10 of the houses, while 6-7 samples were studied for 6 further houses (Table 1). Some houses were not excavated or defined in their entirety (Fig. 3), and hence comparisons between them were only partly possible. An accurate extrapolation of a total number of fruits per house was not possible for 9 houses (Table 1).

Number of houses	Number of samples analysed and reliability	Houses
10	8 or more (high)	H302, H305, H306, H308, H312, H313 , H318, H320, H324, H326
6	6 or 7 (medium)	H303 , H309, H315, H321 , H323, H325
5	3 to 5 (low)	H301 , H316, H319 , H322, H327
4	1 or 2 (very low)	H310 , H311 , H314 , H317

Table 1. Number of samples analysed per house and reliability of the results obtained for each house.

In bold, incompletely excavated houses. For the location of the houses see Fig. 2.

Previous work demonstrated that sediment samples of a large volume are needed in order to have a good representation of large-sized remains (e.g. Jacomet, 2013). For this reason, surface samples of ~ 3-10 litres were taken. Nevertheless, it is also known that small samples (~0.3 litres of sediment) are enough to recover the required amount of small-sized remains. Therefore, in order to make the work as efficient as possible, it was decided to split large samples into an A-sample (ca. 3-5 litres) and a B-sample (0.3 litres) using the grid method in order to ensure a random subsampling (van der Veen and Fieller, 1982). All samples were sieved using the wash-over method (Hosch and Zibulski, 2003; Steiner et al., 2015) after a freeze-thaw pre-treatment (Vandorpe and Jacomet, 2007), which are the most adequate methods for the recovery of fragile plant macroremains with the minimum damage possible. Sieves of 8mm and 2mm mesh size were used for A-samples, which allowed speeding the sieving process, while B-samples were sieved with sieves of 2mm and 0.35mm mesh sizes. B-samples were not included in this paper, as the focus here was on the analysis of the large-seeded taxa. The 8mm fraction of the A-samples was analysed in its entirety but subsamples of the 2mm fraction were always carried out using the grid method. The aim was to obtain, in total, ~ 400 remains of more than 2mm. One would start with the first subsample and continue with more subsamples until this amount of remains was reached, or until more than 12 hours had been invested and the sample was considered to be too poor. When 5 or more remains of a taxon were found, a multiplying factor obtained from the

number of subsamples analysed was used to extrapolate the total amount of items that should be present in the sample. This threshold was established in order to avoid large errors with rare finds.

This is the largest ever investigated number of voluminous samples for a waterlogged settlement, where samples were sieved in an appropriate way and fully-quantitatively analysed. The total volume of sediment investigated was 978.5 litres. An average volume of 3.8 litres of sediment per sample were sieved. All references to volumes of sediment in this paper refer to the displacement volume (see definitions in Jacomet and Kreuz, 1999; Antolín et al., 2015; Steiner et al., 2015).

The identification of seed and fruit remains was done by comparison to the reference collection from the IPAS, as well as using atlases of identification (e.g. Cappers et al., 2006) and specific seed catalogues for lake dwelling sites of the region (Jacomet, 1986; Jacomet et al., 1989). The data were introduced into the database ArboDat (© Kreuz and Schäfer 2013). The nomenclature of scientific plant names follows the National Data and Information Centre of the Swiss Flora (<http://www.infoflora.ch>). The classification of taxa into ecological groups is based on previously published work (Brombacher and Jacomet, 1997).

Fig. 2. House plans and thickness of layer 13 of Parkhaus Opéra, with two photographs showing the difference in thickness of the layer in different parts of the settlement (Office for Urbanism, City of Zürich).

Fig. 3 Distribution of the analysed A-samples from layer 13 of Parkhaus Opéra with indication to finely and coarsely-excavated sectors. In several cases, more than one sample from the same square was analysed, representing different parts of the cultural layer.

As no 0.35 mm sieve was used for A-samples, there was a risk of counting particularly fragile or small items that were differentially recovered in the 2 mm fraction depending on the operator who sieved the sample or due to other (mainly human) factors. For this reason, a test was carried out and counting units were defined accordingly (Steiner et al., 2015). Only remains of a size well above 2 mm that could not randomly disappear due to a slightly more intensive sieving were taken into consideration (for instance, seeds of flax were not counted but fragments of capsules with two or more segments were counted). Some of these counting units were also defined according to previous work (Hosch and Jacomet, 2004).

This paper focuses on edible large-seeded fruits. Edibility was established by checking two main sources: the Plants for a Future Database (www.pfaf.org), with a worldwide ethnographic perspective; and the *Enzyklopädie Essbare Wildpflanzen* (Fleischhauer et al., 2013), focused on central Europe.

In order to extrapolate the obtained data and reach an ideal absolute number of fruit items (meaning e.g. apple pericarps, hazelnut shells, etc.) per house, some decisions were made. Only those squares inside house limits were taken into account, even though these limits cannot be considered as actual

walls (most probably, houses stood on wooden piles). This means that our results in terms of number of fruits gathered per house must be considered as a minimum number and not a maximum. Secondly, some squares were shared by houses 316 and 317 and it was not possible to know to which house they belonged to. For this reason, both houses were treated as one in studies of concentration of remains per house. But for the comparison of the absolute number of remains per house it was decided to assign those shared samples to both houses, which means that they were counted twice. Thirdly, in order to extrapolate the number of fruit items found per square metre, the total amount of litres excavated was taken into consideration, as well as the number of samples studied when more than one was available. In the latter case, the average density between the samples of the same square was used to extrapolate the total fruit items. From the total amount of fruit items of the investigated squares, a total amount of fruit items was extrapolated per house. The number of years in which the fruits found at Parkhaus Opéra were gathered and consumed was considered to be 20 (19 years documented with dendrochronology plus one extra during which construction activities might not continue but the settlement could have been dwelled on). This number is actually a maximum, as ongoing work indicates that some houses were built at a later stage and it is in general difficult to know the exact period of occupation of each house in the current state of research.

As a final step, the number of fruits recovered per house was converted into calories. This is a controversial step, as it is difficult to know the size and weight of fruits in the Neolithic, and therefore their calorific content. Furthermore, data on the calorific or mineral content of wild fruits in Europe is not easily available, as well as average weight values per fresh fruit. But as a modelling attempt, we have tried to produce some hypothetical calculations based on an average weight per seed or fruit and an estimation of the calories. As literature reference, we mainly used *Traditional plantfoods of Canadian indigenous people* (Kuhnlein and Turner, 1991) and *Die große GU Nährwert-Kalorien-Tabelle* (Elmadfa et al., 2014). Not all taxa were found, so alternative species from the same taxon were sometimes used. The errors introduced were probably low at this scale of analysis.

Site plans were produced with ArcGIS (ESRI, 2010). The size of the symbols showing densities or absolute number of remains were presented in three different dimensions and the gradients were

established automatically by ArcGIS using the Jenks natural break classification method (Jenks and Caspall, 1971).

3. Results

3.1. Taxa and ecological groups

In total, 86,450 items (over 200,000 after extrapolation) of 49 large-seeded taxa were recovered and fully quantified. The large majority of items were fruit remains of wild plants. These belonged to several ecological groups, including water plants (2 taxa), plants from woodland edges and clearings (2 taxa), weeds and ruderals (8 taxa) and woodland plants (29 taxa) (Table 2). Two ecological groups of wild plants were present in almost all samples and provided the edible taxa: weeds and ruderals and woodland plants. Within the latter group, 69% of the remains and the majority of edible plants (17 taxa) were found (Table 2).

	Number of taxa	Number of taxa with edible fruits	Number of remains after extrapolation	% of total remains	% ubiquity
Water plants	2	0	90	0.04	15.3
Woodland edges and clearings	2	0	303	0.14	56.5
Weeds and ruderals	8	3	10,071	4.56	97.6
Cultivars	9	9	56,741	25.68	98
Woodland	29	17	153,751	69.58	99.6

Table 2. Number of taxa and of remains per ecological group.

A summary of the results obtained for edible plants is presented in Table 3. Most remains were preserved in a subfossil state. Only 441 remains (0.3%) were charred, mostly found in concentrations below 1 r/l. Significant numbers (>100) of charred items per sample were only found for two taxa: hazelnuts (*Corylus avellana* L.) and fruit flesh fragments of wild apple (*Malus sylvestris* Miller).

Concerning the absolute number of subfossil remains, the apple/pear (*Malus/Pyrus*) group yielded the largest majority, around 50% of the total remains. Hazelnut shells were also abundant. Ubiquity values were very high for both taxa, as well as for other taxa, including burdock (*Arctium* sp.), sloe (*Prunus spinosa* L.), acorns (*Quercus* sp.), wild rose (*Rosa* sp.), and wayfaring tree (*Viburnum lantana* L.).

Several taxa appeared in quantities of over 100 remains in one sample, but only four taxa appeared in these amounts in more than 25 samples (10% of the total): hazelnuts, apples, sloes and acorns. High densities of remains at a sample level were observed. In fact, 85 samples yielded over 100 r/l each. In most cases, these concentrations were of wild apples/pears (69), but also of acorns (6) and hazelnuts (7), as well as common beech (2) and sloe (1). Taxa that were present in less than 5% (see Table 3) of the samples were not considered further.

	Type of remain	Preservation type	Total layer 13	% of total	% ubiquity (total 255 samples)	No. samples with more than 100 remains	Average density	Maximum density	No. samples >100r/l
Weeds and ruderals									
<i>Arctium spec.</i>	seed/fruit	sf	6,293	4.00	94.1	12	6.0	77.6	0
<i>Polygonum convolvulus</i>	seed/fruit	ch	2	0.00	0.8		0.0	0.2	0
<i>Polygonum convolvulus</i>	seed/fruit	sf	831	0.53	58.8	1	0.8	29.8	0
<i>Vicia hirsuta</i>	seed/fruit	ch	3	0.00	1.2		0.0	0.3	0
Woodland									
<i>Cornus sanguinea</i>	seed/fruit	sf	156	0.10	21.2		0.1	14.4	0
<i>Corylus avellana</i>	seed/fruit	ch	148	0.09	29.8		0.2	9.4	0
<i>Corylus avellana</i>	seed/fruit	sf	22,779	14.47	99.2	66	25.3	569.1	7
<i>Crataegus laevigata</i>	seed/fruit	sf	4	0.00	1.6		0.0	0.5	0
<i>Crataegus monogyna</i> agg.	seed/fruit	sf	26	0.02	7.1		0.0	1.0	0
<i>Fagus sylvatica</i>	cupule fr.	sf	65	0.04	19.2		0.1	1.6	0
<i>Fagus sylvatica</i>	pericarp fr.	sf	1,802	1.14	46.3	3	1.6	115.0	2
<i>Malus sylvestris</i>	seed/fruit	ch	25	0.02	8.2		0.0	1.2	0
<i>Malus sylvestris</i>	seed/fruit	sf	17,336	11.01	95.7	53	17.5	196.2	2
<i>Malus sylvestris</i>	fruit flesh	ro/ch	239	0.15	14.1		0.3	33.4	0
<i>Malus sylvestris</i>	fruit flesh	sf	18	0.01	5.1		0.0	1.2	0
<i>Malus/Pyrus</i>	seed/fruit	ch	6	0.00	1.2		0.0	1.0	0
<i>Malus/Pyrus</i>	seed/fruit	sf	1,981	0.00	5.9	3	2.6	217.3	2
<i>Malus/Pyrus</i>	pericarp fr.	sf	79,560	50.52	96.5	174	78.3	523.7	67
<i>Malus/Pyrus</i>	pedicel	ch	5	0.00	1.2		0.0	0.6	0
<i>Malus/Pyrus</i>	pedicel	sf	795	0.50	39.2	1	0.7	30.2	0
<i>Prunus avium</i>	seed/fruit	sf	1	0.00	0.4		0.0	0.3	0
<i>Prunus padus</i>	seed/fruit	sf	3	0.00	1.2		0.0	0.3	0
<i>Prunus spinosa</i>	seed/fruit	ch	1	0.00	0.4		5.3	104.1	1
<i>Prunus spinosa</i>	seed/fruit	sf	5,298	3.36	81.6	9	0.0	0.2	0
cf. <i>Pyrus spec.</i>	seed/fruit	sf	2	0.00	0.8		0.0	0.5	0
<i>Quercus spec.</i>	base	ch	5	0.00	1.2		0.0	0.6	0
<i>Quercus spec.</i>	base	sf	1,096	0.70	53.7	2	1.0	41.4	0
<i>Quercus spec.</i>	cotyledon	ch	2	0.00	0.4		0.0	0.4	0
<i>Quercus spec.</i>	cupule fr.	sf	16	0.01	4.7		0.0	1.4	0
<i>Quercus spec.</i>	pericarp fr.	ch	1	0.00	0.4		0.0	0.2	0
<i>Quercus spec.</i>	pericarp fr.	sf	14,916	9.47	86.3	29	15.0	481.7	6
<i>Rosa spec.</i>	seed/fruit	ch	4	0.00	1.6		0.0	0.4	0
<i>Rosa spec.</i>	seed/fruit	sf	4,449	2.83	88.6	7	4.5	69.1	0
<i>Sambucus nigra/racemosa</i>	seed/fruit	sf	79	0.05	14.9		0.1	7.5	0
<i>Taxus baccata</i>	seed/fruit	sf	15	0.01	4.9		0.0	0.7	0
<i>Viburnum lantana</i>	seed/fruit	sf	1,252	0.80	78.4		1.3	17.3	0
<i>Viburnum opulus</i>	seed/fruit	sf	11	0.01	3.9		0.0	0.5	0
<i>Viscum album</i> s.l.	seed/fruit	sf	222	0.14	22.4		0.2	22.7	0

Table 3. Number of remains, ubiquity, and average and maximum density of remains per taxon. Only edible taxa shown densities (ch: charred; sf: subfossil; ro: roasted).

3.2. Ubiquity and concentration of remains per sample: inside or outside house limits

In terms of ubiquity, the edible large-seeded taxa identified in layer 13 of Parkhaus Opéra were found in a similar proportion of samples both inside and outside house limits (Table 4). In contrast, the average concentration of remains for most of these taxa is higher (usually twice as high) in samples inside house limits. The differences were even higher when comparing the maximum concentration found in each group of samples. All taxa had a much higher maximum concentration inside house limits except for two: common beech (cupule fragments) and elderberry (*Sambucus nigra* L./*racemosa* L.). Most of the high concentrations per sample (samples with >100 r/l) were found inside house limits. Only 12 (14%) were found outside house limits: 11 were concentrations of apple/pear pericarp fragments and one of common beech fruits. Only samples found within the house limits were considered in further analyses.

	SAMPLES INSIDE HOUSE LIMITS					SAMPLES OUTSIDE HOUSE LIMITS				
	No. OF SAMPLES	% SAMPLES (TOTAL 190)	Average concentration	Maximum concentration	No. SAMPLES >100 r/l	No. OF SAMPLES	% SAMPLES (TOTAL 47)	Average concentration	Maximum concentration	No. SAMPLES >100 r/l
<i>Arctium</i> sp.	177	93.2	6.5	77.6	0	44	93.6	5.3	38.7	0
<i>Fallopia convolvulus</i>	109	57.4	0.8	29.8	0	30	63.8	0.9	10.0	0
<i>Cornus sanguinea</i>	42	22.1	0.2	14.4	0	10	21.3	0.1	0.7	0
<i>Corylus avellana</i> (sf)	186	97.9	30.3	569.1	7	47	100.0	11.7	38.1	0
<i>Corylus avellana</i> (ch)	63	33.2	0.2	9.4	0	11	23.4	0.1	0.5	0
<i>Crataegus monogyna</i> agg.	14	7.4	0.0	1.0	0	1	2.1	0.0	0.3	0
<i>Fagus sylvatica</i> , cupule	32	16.8	0.1	0.9	0	13	27.7	0.1	1.6	0
<i>Fagus sylvatica</i> , peric.	87	45.8	1.4	115.0	1	21	44.7	2.6	109.5	1
<i>Malus/Pyrus</i> , peric.	182	95.8	84.5	523.7	54	47	100	58.9	170.5	11
<i>Malus/Pyrus</i> , pedic.	78	41.1	0.8	30.2	0	14	29.8	0.5	6.8	0
<i>Malus sylvestris</i> , seed	180	94.7	19.0	196.2	2	46	97.9	13.7	50.5	0
<i>Prunus spinosa</i>	154	81.1	6.3	104.1	1	38	80.9	2.2	13.6	0
<i>Quercus</i> sp., peric.	161	84.7	15.7	310.6	5	43	91.5	6.2	32.3	0
<i>Quercus</i> sp., base	104	54.7	1.2	41.4	0	22	46.8	0.2	1.4	0
<i>Rosa</i> sp.	168	88.4	4.7	69.1	0	39	83.0	2.9	34.3	0
<i>Sambucus nigra/racemosa</i>	26	13.7	0.0	0.8	0	10	21.3	0.2	7.5	0
<i>Viburnum lantana</i>	148	77.9	1.4	17.0	0	36	76.6	1.0	5.0	0
<i>Viscum album</i> s.l.	40	21.1	0.3	22.7	0	13	27.7	0.1	0.9	0

Table 4. Ubiquity, and average and maximum density of the edible taxa in samples found inside (left part of the table) or outside (right part of the table) house limits (subfossil preservation unless indicated, sf: subfossil, ch: charred).

3.3. Average and maximum concentration of remains in samples found within the limits of houses

The average concentration of large-seeded fruit items per house (calculated from those samples found within the limits of house plans) is between 57.1 r/l (House 314) and 471 r/l (House 311). These extreme values were only obtained in houses for which one single sample was analysed. In average, 172.7 remains per litre of sediment were found in each house. Besides House 311, two other houses had high average densities: houses 302 and 308. Both were located at the north-western part of the settlement (Fig. 3) and they were intensively sampled (Table 1). On the other hand, several houses presented low densities, other than house 314. These were houses 309, 313, 315 and 327. Most (except for house 327, the southernmost one) were in the central part of the settlement, either to the south of the footbridge (houses 313, 314 and 315) or in the area where a gravel line was identified (house 309) (Fig. 4).

Fig. 4. Site plan with the representation of the average density of edible large-seeded taxa per house.

3.4. Extrapolation of the number of edible fruit items per house

By taking into account the density of remains of each taxon per litre of sediment of a sample connected to a particular square metre within the excavation, it was possible to extrapolate the number

of fruit items that could have been found in each square meter and consequently within the limits of each house plan. All houses but ten yielded more than 100,000 fruit items (Table 5). Nine of these ten houses with a lower amount of fruit remains were among the incompletely excavated houses. Therefore, all the completely excavated houses but one (house 309) yielded between 120,000 and 320,000 fruit items. Considering the richness of fruit items per house (Fig. 5), it was observed that there were houses rich in edible fruit items all over the excavated area. In only taking completely excavated houses into account, this was observed as well (graph not shown). The total number of fruit items per house seemed to have no relation with the thickness of the archaeological layer or the average density of remains per house (Fig. 4 and Fig. 5).

	Total excavated litres of sediment	Arctium sp.	Polygonum convolvulus	Cornus sanguinea	Corylus avellana	Fagus sylvatica	Malus sylvestris, seed	Malus/Pyrus, pericarp	Malus/Pyrus, pedicel	Prunus spinosa	Quercus sp., base	Quercus sp., pericarp	Rosa sp.	Viburnum lantana	Viscum album	Total large-seeded edible fruits per house
House 301	290	899	103	0	3679	14	8105	27890	116	2001	760	1235	1286	89	0	46177
House 302	870	11283	3775	122	20709	50	27958	127947	217	13335	1153	56958	16581	2489	2420	284998
House 303	470	1838	540	36	8977	223	12078	29512	826	920	811	10368	831	800	18	67778
House 305	1040	10169	521	165	31770	127	34250	80078	846	12526	2819	19871	5843	2699	43	201728
House 306	860	1380	250	118	47352	235	21558	92160	51	3867	65	3919	5224	809	0	176989
House 308	750	3143	231	0	51026	37	14146	122757	706	10004	207	4500	7805	3787	110	218459
House 309	560	5830	821	0	18329	28	8334	31967	1556	1316	0	1493	713	935	142	71465
House 310	160	270	27	28	2794	28	4538	17328	81	139	82	1959	110	82	0	27468
House 311	90	60	30	0	390	0	6720	32040	90	2790	0	120	90	30	0	42360
House 312	1230	10362	521	776	30178	323	19039	71972	909	3619	916	15294	3020	3341	84	160354
House 313	940	1238	271	154	8608	716	7173	40308	553	3266	85	3049	2858	1712	78	70069
House 314	120	247	124	0	322	74	1064	3711	25	297	25	445	198	223	0	6755
House 315	1310	5646	633	0	13359	48	9701	68624	70	3571	373	9801	3051	2306	50	117233
House 316	1920	27380	902	119	94179	7184	24933	131332	690	6587	1074	25248	5604	782	212	326226
House 317	1500	24295	838	119	83946	6965	24000	124252	474	6559	450	19442	5590	735	183	297849
House 318	1220	5944	1089	85	22946	2663	18073	197433	47	7142	143	8774	7273	2279	0	273891
House 319	250	5930	682	65	10042	161	2710	11196	103	902	51	1354	1574	99	58	34927
House 320	1520	7224	174	146	21012	2321	34135	119367	597	4466	1598	26791	4049	1140	488	223508
House 321	470	7881	106	0	8636	140	10755	41597	406	2253	282	7207	1627	305	0	81196
House 322	1140	3989	451	43	15500	25807	10809	117233	300	2321	598	16942	1959	131	152	196234
House 323	1120	4228	611	130	162269	42	12936	44904	8136	2027	553	6492	2414	1061	552	246356
House 324	1360	11664	1764	1722	16481	199	28295	112219	1171	4144	192	10192	5980	637	247	194907
House 325	950	8780	83	224	12700	1303	12247	105919	833	12354	174	6849	757	370	722	163316
House 326	990	7231	143	120	11650	3815	12907	68348	809	9129	6306	30249	4004	505	248	155465
House 327	430	396	45	0	3234	30	5399	31534	120	414	45	378	447	0	27	42070

Table 5. Volume of sediment excavated per house and extrapolated number of fruit items found per house. Grey-shaded rows belong to houses that were completely excavated (only subfossil preservation).

Fig. 5. Site plan with a graphic representation of the extrapolated total number of fruit items found per house.

3.6. Calorific contribution of the large-seeded wild fruits to the diet

In order to compare the role of the main fruits in the diet, fruit numbers were converted into fruit units and calories per year (Table 6). The possible calorific contribution from the most important large-seeded wild fruits was dominated by the most abundant fruits: hazelnuts (32670 fruits per year and 39% of the calories), acorns (13141 fruits per year and 34% of calories) and apples/pears (8083 fruits per year and 23% of the total amount of calories). Sloe fruits provided 3% of the calories.

	Type of remain	Preservation type	Extrapolated total gathered fruit items	Total gathered fruits	Fruits per year (20 years max.)	Weight/year (gr)	Calories/year
<i>Corylus avellana</i>	seed/fruit	sf	653407	653407	32670	32690	210397
<i>Fagus sylvatica</i>	pericarp fr.	sf	51148	51148	2557	742	4213
<i>Malus/Pyrus</i>	pericarp fr.	sf	1616513	161651	8083	161651	122855
<i>Prunus spinosa</i>	seed/fruit	sf	102966	102966	5148	36038	17298
<i>Quercus spec.</i>	pericarp fr.	sf	262816	262816	13141	83181	182167
<i>Rosa spec.</i>	seed/fruit	sf	79867	79867	3993	11980	6589
<i>Viburnum lantana</i>	seed/fruit	sf	24007	24007	1200	576	225

Table 6. Ubiquity, average density, maximum density, spatial distribution, total number of fruits and calories obtained per year for the more relevant taxa. Only the data from the 16 completely excavated

houses was used to calculate the total number of fruits and calories obtained per year. In general, fruit items were considered as fruit units, but apple/pear pericarps were divided by 10. Weight of one seed/fruit of each taxon (Englund, 1993; Holst, 2010; Kaliniewicz et al., in press; Rodríguez-Estévez et al., 2009; Schweingruber, 1979; Szentmihályi et al., 2002): hazelnut = 1 gr; beech nut= 0.29 gr; apple/pear= 20 gr; sloe= 7 gr; acorn = 6.33 gr; wild rose= 3 gr; wayfaring tree fruit = 0.48 gr. Calories per 100 gr of each fruit (Elmadfa et al., 2014; Kuhnlein and Turner, 1991): hazelnut = 644 kcal; beech nut= 568kcal; apple/pear= 76 kcal; sloe= 48 kcal (data from cherry, *Prunus avium* (L.) L.); acorn= 219 kcal (data from white oak, *Quercus alba* L.); wild rose= 55 kcal (data from *Rosa acicularis* Lindl.); wayfaring tree= 39 kcal (data from guelder rose, *Viburnum opulus* L.).

4. Discussion

4.1. Methodological discussion: brief comment on the sampling strategy in comparison to other lakeshore settlements with similar chronology

The sampling strategy applied at Parkhaus Opéra was very successful in the recovery of large-seeded wild plants. An average of ~340 large-seeded items per sample was obtained. This is slightly below our target (~400) but it is certainly a unique case in the research of lakeshore settlements to have such a high amount of large-volume samples investigated in a methodologically thorough way. The high ubiquity values (usually close to 100%) and average densities demonstrate that large-volume samples allow a good representation of this type of remains. Furthermore, 16 houses were optimally or close to optimally sampled for our purposes, to get a good representation of the most important taxa. This offers an excellent opportunity to perform comparative analyses at a site level between houses, which will be carried out in future work.

Fig. 6 Average concentration (remains/litre) and ubiquity (%) values for the most important large-seeded wild fruits at Parkhaus Opéra in comparison to other sites in the region with a similar chronology.

The results obtained at Parkhaus Opéra were compared with those of more or less contemporary lakeshore settlements in Lake Zürich (Mozartstrasse 3, KanSan 3), and Lake Constance (Arbon Bleiche 3) (Fig. 6). In order to compare the concentration of remains with other settlements, where classical volume instead of the displacement volume was measured, a correction factor of 1.5 was applied (following Antolín et al., 2015). The results at a site level were not very different. Sometimes higher average concentration values were obtained at Arbon Bleiche (where ~240 litres of sediment were investigated) or in KanSan 3, where only 13.3 litres of sediment were investigated. Mozartstrasse 3 usually yielded lower concentration values. A similar pattern was observed in the ubiquity values. These were usually higher at Parkhaus Opéra than in Mozartstrasse 3 or KanSan 3, but similar to the

site of Arbon Bleiche 3. One can thus conclude that the sampling carried out at Arbon Bleiche 3 (73 samples and 243 litres of sediment investigated) was probably enough to get a good representation of large-seeded wild fruits at the site. Mozartstrasse 3 gave the poorest results in this sense, which might be due to a sampling strategy based only on profile columns, which resulted in small-volume samples (<1 litre). Similar absences were observed in other settlements with waterlogged deposits with excellent preservation as in Torwiesen II, Federsee (southwest Germany), dendrodated to 3283-3279 BC (Maier, 2011, Maier and Harwath, 2011). Systematic sampling with samples of large volume is necessary for a proper investigation of large-seeded wild fruits at a site level. If representative data at a house scale is the aim, the sampling strategy should be dense enough to provide at least 8 samples per house (Hosch and Jacomet, 2004).

4.2. Methodological discussion: comparison between different techniques of numerical description of the results

Two techniques of numerical description were used in this paper in order to establish the importance of the different taxa: average concentration of remains per litre of sediment and extrapolated absolute number of fruits per house. Besides, the number of fruits per house was used to calculate the calorific contribution of each taxon. The potential of each technique is different, as well as the information that they provide. Average concentration of remains was calculated for all houses, even for those that were not completely excavated (Fig. 4). The largest drawback for this technique is the number of samples available per house. The lower the amount of samples, the less reliable the average concentration of remains can be considered. Concentration of remains might be affected by several taphonomic factors. The thickness of the layer is not homogeneous over the excavated surface of the settlement (see Fig. 3). It is thicker in the southern half and it thins towards the north/north-west. It might therefore be misleading to interpret high average densities of remains as indicators for the importance of gathering at a house level. They can only be interpreted as signs of presence of accumulations at a sample level, which is informative in terms of more or less intensive gathering and processing practices.

On the other hand, it is not possible to compare which houses gathered more fruits and which fruits were more often gathered in each house until an extrapolation of the total amount of fruits per house is

calculated. The potential error produced in these calculations is high and future, more detailed investigations on this issue would be very welcome. Nevertheless, as no better results are available, these have to be considered as the closest approach conducted to the present. The drawback of this technique of analysis is that incompletely excavated houses (or houses that cannot be identified in their entirety with dendrological analyses) cannot be compared to other houses because the total amount of sediment per house is unknown. In our case study, 9 houses out of 25 (and their corresponding 38 samples) had to be left out of our calculations. The positive aspect of this technique is that houses can be compared, always keeping in mind that total numbers are estimations and that they can be affected by several taphonomic processes, starting with the real duration of each of the houses and the number of people that inhabited them. Looking at the differences in the patterns shown by Fig. 4 and 5, average densities per house produced a misleading image of the importance of gathering at a house level (higher densities were found in houses at the north-western half of the settlement). Houses with high amounts of large-seeded gathered plants were present all over the excavated surface, once the absolute number of fruit items was calculated. The absolute number of fruit items found per house allows further discussion on the role of wild plants in the economy at a house level, as fruit numbers can be converted into fruit units gathered per year and calories obtained. For details on how they were processed (in bulk or not), it is more useful to observe maximum densities.

The results obtained using each technique show important differences when looking at the proportion between the main gathered taxa (Fig. 7). According to the average density of remains, apple/pear would be the main gathered plant at the site, which would agree with the ubiquity of this taxon (Table 3). When calculating the number of gathered fruits, hazelnuts and acorns become much more relevant and apple/pears show a much lower percentage. This is because apple/pears might be overrepresented by the fact that each fruit contains 10 pericarps. The calorific contribution of each taxon allows a better comprehension of the role of each taxon in the diet. Hazelnuts, acorns and apples/pears were the fruits that contributed more calories to the diet.

Fig.7. Proportion of the main gathered large-seeded taxa at Parkhaus Opéra according to average density, total estimated number of fruits and total estimated calories.

In summary, for a complete evaluation of the role of wild plants in wetland settlements, it is necessary to apply all these techniques of numerical description. If the total amount of fruits per house cannot be estimated for whatever reason, only relative approaches to the importance of wild plants on the basis of ubiquity and density of remains per sample are possible, rendering the role of wild plants difficult to quantify. The use of clear counting units for each taxon and the calculation of a minimum number of fruits (e.g. (Antolín and Jacomet, 2015)) might also help to avoid the overrepresentation of some taxa.

4.3. Important large-seeded wild plants at the site of Parkhaus Opéra: their role in the diet and the economy at the site: new data and interpretative limitations

The basis to establish the importance of large-seeded wild plants at Parkhaus Opéra is the representation of their seeds/pericarps in the record (Table 6). Of the 20 edible taxa within this group of plants, 7 taxa were recovered in sufficiently large amounts to be considered as important resources: hazelnuts, common beech nuts, apples/pears, sloes, acorns, wild rose fruits and wayfaring tree fruits.

More than a thousand fruits per year were gathered from each taxon (Table 6), and in some cases several thousands of fruits per year were gathered (e.g. hazelnuts, acorns or apples/pears). Their finding in all houses indicates that their consumption was part of the economic strategies of the settlement, and not a random opportunistic behaviour. This may indicate tending of these species in the surroundings of the settlement, as known from ethnographic sources like those from North-American woodland aboriginal peoples (Smith, 2001, 2009). The presence of samples with higher densities of remains could suggest processing in bulk. This could be due to the preparation of fruits for storage. The fact that higher concentration values were found for charred hazelnuts and apples (Table 3) suggests that these could have been roasted to facilitate their storage (Berihuete and Antolín, 2012; Holst, 2010; Zapata, 2000). As concentrations were found in most houses in the settlement, one can suggest a household scale of processing of these fruits. The accumulation of finds within the limits of houses would point to the existence of a trap-door in the floor, through which garbage could have been disposed, as observed for other lakeshore settlements (like in Chalain station 3 (Baudais et al., 1997)). The importance in the economy of other frequent plants is difficult to discern. Burdock (*Arctium* sp.) seeds were frequent in the record but they were almost equally well represented both inside and outside house limits. This was not the case of clearly gathered plants. Achenes of *Arctium* sp. could have also arrived to the settlement attached to the hairs of animals or to the clothes of humans, or even grown locally. Their role in the economy of the settlement remains unknown until further investigations (a more detailed identification to species level) are done. Some fruits could have acted as food resources in certain moments (due to food shortages?). This would be the case of fruits such as common dogwood, which appear in greater densities in just one sample in one house. Other fruits do not often appear inside houses, but mostly outside, such as elderberry. Their consumption by humans remains therefore in question.

When attempting to calculate how much of the diet large-seeded wild fruits would account for in this model, we needed to introduce some assumptions. First of all, one needs to assume that houses were always inhabited during the duration of the settlement and that the number of inhabitants per house was comparable for this period. Secondly, we calculated that the members of a house could consume in average an amount of calories equivalent to a maximum of four adults (perhaps with two adults and

4-5 children) and the average calorie income per person and per day was considered to be 1,800 kcal/day (found to be a minimum in ethnographic research among traditional farming villages (Ebersbach, 2002). Under these parameters, large-seeded wild fruits would be at least 1.3% of the total calorific input in average (Table 7). However, samples from outside of house limits (n: 47, ~18% of the total) were not included in the calculations, which means that this percentage could be higher (perhaps around 1.5-1.75%). However, it is also possible that the average calories consumed per day and per house was higher. This total percentage should in any case be revised once the total amount of calories out of the food resources (both of plant and animal origin) recovered at the settlement is calculated. How sensible would it be to expect to reach 75 or 90% of the total of calories needed for 16 houses that consume ~7,200 kcal per day during 20 years after adding up all the bioarchaeological information recovered from the site? Or should this proportion be much lower? The problem here is that we do not know how much of the foodstuffs present once in the settlement have survived, and if the cultural layer is the result of the accumulation of all these foodstuffs during the period that the settlement was active or if there were postdepositional factors that could have affected the layer on a seasonal basis or at particular points during the settlement history. There are some calculations in this sense from the zooarchaeological data of other lakeshore settlements, as at Arbon Bleiche 3 (Deschler-Erb and Marti-Grädel, 2004; and see more references therein), and they considered that the proportion of the assemblage preserved is around 10%. If this was the case for edible plants at Parkhaus Opéra, large-seeded wild plants could be 15% of the caloric input of its inhabitants. We plan to perform such estimations in the near future, as the comprehensive sampling, the already performed reconstruction of the houses of layer 13 of Parkhaus Opéra and the type of analysis that has been carried out allow us to do reliable estimations for the first time.

In any case, similar percentages (<5%) of the role of fruits (including small-seeded plants, which were not included in our evaluation) in the diet were observed in ethnographic research among traditional and self-sufficient villages (Ebersbach, 2002, Abb. 94). As Ebersbach remarks, despite the low calorific contribution from these food plants, they were a major source for vitamins and minerals (see also Kreuz, 2012). Furthermore, one should take into account all those “missing foods” that were not possible to enter into our calculations: plants from which leaves, flowers, shoots, tubers, etc., were

consumed (Hillman et al., 1989). Palynological studies showed for instance an important role of wild garlic (*Allium ursinum* type) pollen, pointing towards an intense use of its leaves in early spring (see discussions and citations in Brombacher and Jacomet (1997)). However, the calorific contribution of these plants would have been rather low in comparison to crops and animal resources.

Total calories from L-S WP at the site in one year	543,744
Total calories per house (16) in one year	33,984
Total calories per person (4 per house) in one year	8,496
% annual calories from L-S WP per person (1800cal/day)	1.3

Table 7. Estimation of the calorific contribution of large-seeded wild plants (L-S WP) in human diet at Parkhaus Opéra, under the assumptions that a large part of the remains has survived and that most of that found within the limits of houses was consumed by humans.

Our results might show some contradiction with earlier modelling attempts to quantify the calorific contribution of gathered plants to the diet. For instance, it is possible that the role of apples/pears has been underestimated in previous studies of prehistoric diet in the region of Zürich (Jacomet and Schibler, 1985; Gross et al., 1990). In previous calculations for the site of Arbon Bleiche 3 (Hosch and Jacomet, 2004) it was suggested that one third of the plant diet at the site could come from wild plants. We must clarify, though, that this result was based on the comparison between the calorific contribution of crops and gathered plants (which has not yet been done for Parkhaus Opéra due to the ongoing research), that only hazelnuts and acorns were included in the calculations and that the absolute number of remains per house or for the layer was not calculated.

To summarize, as long as we do not know the total proportions of calories represented by all the plant remains in a given layer, we are not able to accurately estimate the contribution of large-seeded gathered food plants or other calorie sources to the diet. In the case of the large seeded wild fruits it probably lies at around 1.5% as a minimum but it may be much higher if only a small proportion of the remains once present have survived.

5. Conclusions

A specific sampling strategy designed for a representative recovery of large-seeded wild fruits at a late Neolithic settlement phase of the lakeshore site of Parkhaus Opéra allowed the recovery of a large

amount of novel information. This resulted in a good degree of representativeness of the data both at a site scale and at a household scale. High average concentration values and high ubiquity percentages were used to establish the most important gathered taxa, which were: apples/pears, hazelnuts, acorns, sloes, beech nuts, wild rose fruits, and wayfaring tree fruits. Concentration values per sample were used to extrapolate the data and calculate the number of fruits gathered per house during a maximum of 20 years of occupation of the settlement.

Large-seeded wild fruits could have had a calorific contribution to the diet of around 1.5% as a minimum (assuming that each house would consume around 7,200 kcal per day during the same amount of time). This percentage could be much higher both due to the lack of similar information for crops and animal resources, as well as taphonomic biases that are difficult to quantify. Among the important gathered large fruits, hazelnuts, acorns and apples/pears made the largest contribution to the diet at the settlement. This was the first time that similar calculations were possible for such a large surface in a lakeshore settlement in the region.

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