The bigger the better? On sample volume and the representativeness of archaeobotanical data in waterlogged deposits

Ferran Antolín, Bigna Steiner, Stefanie Jacomet

Crossreferences

Abstract

This paper provides a reference to estimate the representation of large-sized items (seeds and fruits, mainly) in samples of larger and smaller volume in wetland sites with the aim of proposing a minimum sample size to recover these remains in a representative way. For this, almost 100 samples from a late Neolithic settlement phase found at the lakeshore site of Parkhaus Opéra (Zürich, Switzerland) were subsampled into one larger subsample (A-sample, of ca. 3 litres of volume) and one smaller subsample (B-sample, of ca. 0.3 l of volume). We compared how large and small-sized items were represented in the different fractions of large and small subsamples on the basis of ubiquity, concentration and proportions between the taxa. Large-sized remains (like *Prunus spinosa* or charred fragments of *Corylus avellana*) and some medium-sized remains (*Najas*, *Aethusa cynapium*) were more often represented in larger subsamples and therefore are considered to be underrepresented in smaller samples. Average concentration values were similar in both groups of samples (and therefore comparable) but large differences were observed on a one-to-one sample basis, finding no positive monotonic correlation between them. Our observations also prove that in order to obtain data that are comparable to dryland sites concerning charred remains (including cereals and large-seeded wild fruits), large volume samples of at least ca. 3 l are needed. Counting units per taxon in each fraction were re-defined on the basis of the results obtained. Finally, some clues to interpret results concerning large-sized items in sites with samples of small volume are also proposed following our observations.

Key-words: lakeshore settlement, methodology, sample size, quantification

1. Introduction

Sampling in archaeobotany is a major issue, playing a key role in the interpretation of botanical assemblages. When designing a sampling strategy, one needs to take into consideration which contexts are sampled, their potential richness in botanical macroremains, the size of the samples and the number of contexts sampled per site, in order to have a dataset that can be considered representative of the total amount of botanical macroremains preserved until today. Above all, the scientific questions that are aimed for should be clearly stated beforehand in order to plan the sampling strategy accordingly (see overviews on this issue in e.g. d'Alpoim Guedes and Spengler, 2014; Filipović and Marić, 2013; Jones, 1991; Lennstrom and Hastorf, 1992; Pearsall, 2015; van der Veen, 1985). Archaeobotanical research in waterlogged deposits of prehistoric lakeshore settlements has some specificities. To start with, sampling is usually performed before any archaeological structure is identified with certainty, since this is mostly done at a second stage, after the conduction of dendrochronological analyses. This means that systematic or random sampling (see e.g. Hosch and Jacomet, 2001) is absolutely necessary to have different

structures properly represented in the samples. Secondly, sample size is another important issue. When preservation conditions are good, plant macroremains appear in extremely high numbers (thousands in each sample). For this reason, a balance needs to be found between having samples large enough to have all kinds of fruits well-represented in them, and at the same time trying to analyse them in the most efficient way possible (Jacomet and Brombacher, 2005; Kenward and Hall, 1995: 454-455; Steiner et al. in press).

Most of the research in (mostly Neolithic) lakeshore settlements done in the seventies and the eighties of the XXth century was based on profile (monolith) samples (e.g. Jacomet, 1980; Jacomet et al., 1989; Maier, 1988; Schlichtherle, 1985), although there were some early exceptions of surface sampling (Jacomet, 1981). Profile sampling yielded samples of a relatively small volume (mostly below 0.3 l) and recommendations were done to take, in parallel, a certain amount of bulk samples (10-20 samples of more than 0.7 l per settlement phase) in order to record the large-sized items in a representative way (Jacomet et al., 1989: 82). The large research project carried out at Arbon Bleiche 3 in the early nineties made it possible to recover samples of a larger volume to test if large-sized items (those taxa with seeds of well above 2 mm in size or other items like spikelets or capsules) were better represented in them. It was soon observed that samples of ca. 0.3 l only allow a representative evaluation of small-sized items (below 2 mm) and that samples of at least 2 l were recommended for a fully representative analysis (Brombacher and Jacomet, 1997: 222). The goal was to reach a statistically representative amount of remains for a sample (*sensu* Van der Veen and Fieller, 1982). It was observed that ca. 400 remains per fraction (2mm and 0.35mm) were needed for a representative analysis of a sample, so that large-sized items were also representatively recorded (Hosch and Jacomet, 2001). This made it clear that larger samples were needed to reach this amount of large-sized remains in the 2mm fraction. As methodological conclusions of the Arbon Bleiche 3 project, it was recommended (parallel to profile sampling, which remains as the optimal strategy to target layer formation processes in lakeshore settlements) to take large-volume samples (ca. 3 l, and a maximum of ca. 8 l) in a systematic way over the excavated surface of the settlement. From these large samples, small-volume subsamples (ca. 0.3 l) could be produced in a way that large samples only needed to be investigated for large-sized items (and therefore sieved with a mesh of 2mm) and smaller samples for small-sized items (sieved with a mesh of 0.35mm) (Hosch and Jacomet, 2001; 2004: 116). This time-saving strategy was finally applied to the recently excavated multi-phase site of Zürich-Parkhaus Opéra, our case study (Antolín et al., 2015; 2016; 2017; Bleicher and Harb, 2015) and recently also critically revised (Steiner et al., in presss).

In parallel to this line of research developed at the IPAS (Integrative Prehistory and Archaeological Science, University of Basel), other researchers developed alternative sampling strategies, like systematic coring (every meter). This type of sampling was usually performed within scientific research projects (not rescue excavations) and resulted in a large amount of samples of less than 0.3 l of volume in average, or occasionally more, like at Sipplingen (0.7 l in average) (Baudais et al., 1997; Maier, 2001; Maier and Herbig, 2011; Riehl, 2004). Sometimes, this type of sampling was combined with extensive coarse-sieving, which allowed observing some of the biases of small-volume samples (Maier, 2001).

The main reason why large-volume samples are rarely taken in wetland sites is that the archaeobotanical evaluation of the samples is very time consuming. Furthermore large-volume samples can pose problems in sites with very thick (superimposed) cultural layers that might respond to more than one settlement phase, since these samples are difficult to

ascribe to a particular phase if this was not possible to identify during fieldwork (such a case was observed at Pfäffikon-Burg in Zibulski, 2010). On a more practical scale, large samples also involve storage difficulties, since they need to be stored in cool dark rooms (or even deep frozen) to avoid the degradation of the plant material present in them. Most sites where large samples were investigated usually had to reduce the number of samples analysed (see Fig. 1). Sites where small-volume samples were taken rarely reached 50 liters of sediment sieved in total. For this reason, the sampling strategy applied at Zürich-Parkhaus Opéra (with ca. 1000 l of sediment processed) represents a milestone in archaeobotanical research in prehistoric lakeshore research and can be used as a reference point to review previous research.

The goals of this paper are:

1. testing the comparability of the ubiquity, the concentration values (density values), the proportion (relative percentage) and the spatial analysis (using GIS) of large-sized items obtained in the 2mm fraction of subsamples of different volume taken from the same original sample;
2. assessing which taxa are more often represented in the 2 mm and the 0.35 mm fraction in large and small-volume subsamples taken from the same samples;
3. comparing the results of our test with those obtained from roughly contemporary investigated lakeshore settlements with different sampling strategies;
4. providing guidelines for the optimal procedures to efficiently record these plants in wetland sites and some final thoughts on the reliability of data obtained from samples of small volume (< 0.5 litres of sediment).

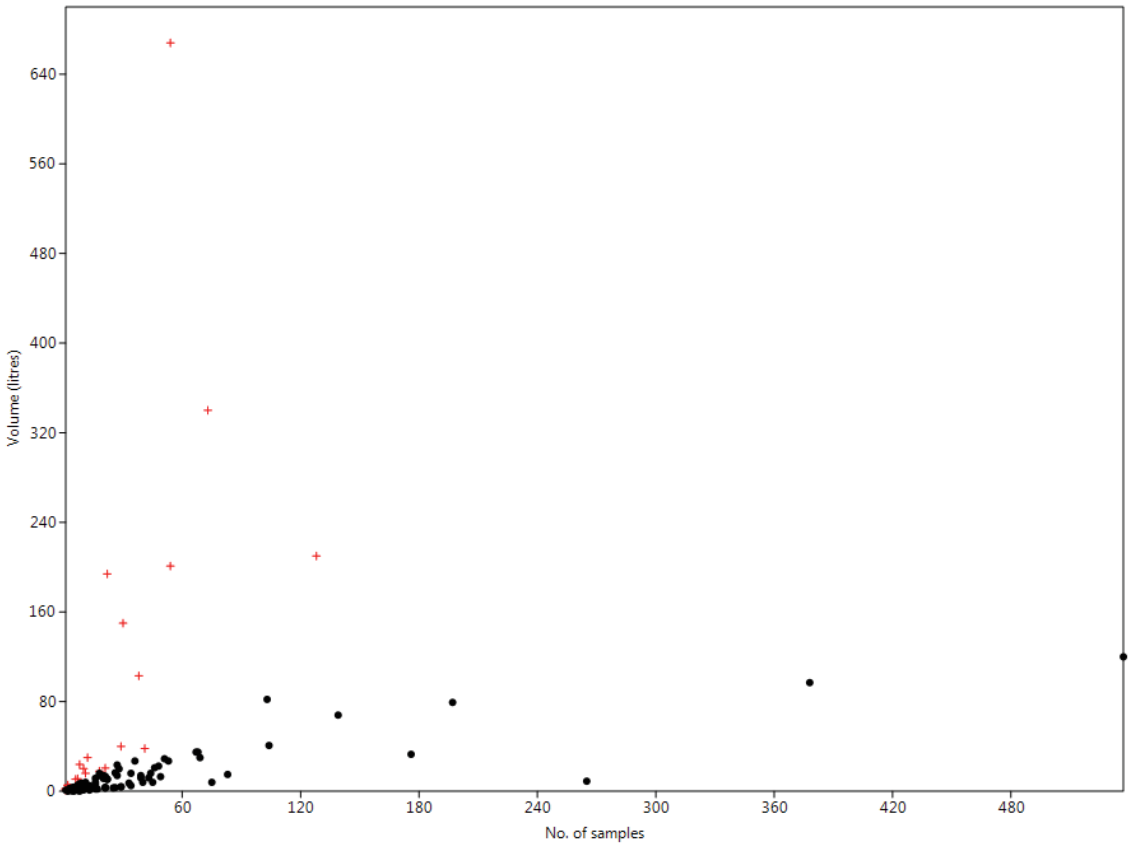


Fig. 1. Total volume of sediment (in litres) and number of samples sieved per settlement phase of Neolithic lakeshore sites in the Alpine Foreland. Crosses refer to sites where the average volume per sample was above 0.9 L. Data compiled by S. Jacomet (ESM 1).

2. Materials and methods

Zürich–Parkhaus Opéra (Zürich, Switzerland) is a lakeshore site with several settlement phases which was excavated during 2010 and 2011 (Bleicher and Harb, 2015). This paper focuses on the methodological research carried out with samples from one settlement phase, layer 13 (Horgen culture, dendrodated to c. 3160 BC, of ca. 20 years of duration (Bleicher and Burger, 2015)). The sampling strategy applied at the site has been explained in previous publications (Antolín et al., 2015; 2017; Steiner et al., 2015; Steiner et al., in press). Large-volume surface samples (5–7 l, the master samples) were taken in a systematic way. These were subsampled before processing in the laboratory into two subsamples: the so-called A- and B-samples. B-samples were of smaller-volume (of 0.3 l), were taken using the grid method taking sediment systematically from each square of the grid (see Steiner et al., in press) and sieved with meshes of 2 and 0.35mm size. All B-samples yielded many more remains than those that we aimed to recover for a representative evaluation of small-sized items (ca. 400 remains, following Van der Veen and Fieller (1982) modified by Hosch and Jacomet (2001)). For this reason, the 0.35mm fraction was always subsampled using the grid method (like for master samples) and sub-samples of ca. 5 ml were analysed until the target population was reached. In order to see what volume was necessary to sieve concerning A-samples to recover a sufficient amount of large-sized remains (ca. 400) in the 2mm fraction, we performed an early evaluation of the data (unpublished). This volume was observed to be around 3 litres. In consequence, A-samples were either the amount of sediment that remained after the subsampling process to obtain the B-sample or, if this was above 4 l of sediment, a subsample of it (always of above 3 l of volume). Therefore, A-samples usually had a larger volume of sediment (ca. 3-5 l). They were sieved with meshes of 8 and 2 mm size. The wash-over technique with freezing as pre-treatment was used for processing all samples (Kenward et al., 1980; Vandorpe and Jacomet, 2007). Over 250 A-samples and 120 B-samples were analysed completely. The 2 mm fraction was analysed in both A- and B-samples in 96 samples (see location in Fig. 2). This allowed a unique possibility to compare the results obtained in both. Nevertheless, since sediment was removed from the original sample to obtain the B-sample, we cannot exclude a sequencing effect in our test. We need to assume that since B-samples usually comprised less than 1/20 of the total amount of the master sample (of usually ca. 6 litres of sediment), the impact should be of very low significance.

Quantification criteria were established in previous publications, so that certain remains were only quantified in one of the fractions (Hosch and Jacomet, 2004; Steiner et al., 2015) (Fig. 3). The aim of this was to restrict the number of remains to be counted in the 2 mm fraction to those taxa that are not found in the 0.35 mm fraction because of their larger size. This is an efficient time-saving strategy in the analysis of the 2 mm fraction and it is based on the assumption that the rare finding of smaller-size taxa in the 2 mm fraction (due to the sieving process, which does not perfectly separate both fractions) does not have a significant effect on the overall results for the sample. Taxa that were not to be counted in A-samples (that is to say, small-sized items) were described as present or absent in order to at least have their

presence recorded in the fraction. This was particularly of interest for those samples for which no B-sample was analysed due to time and budgetary restrictions.

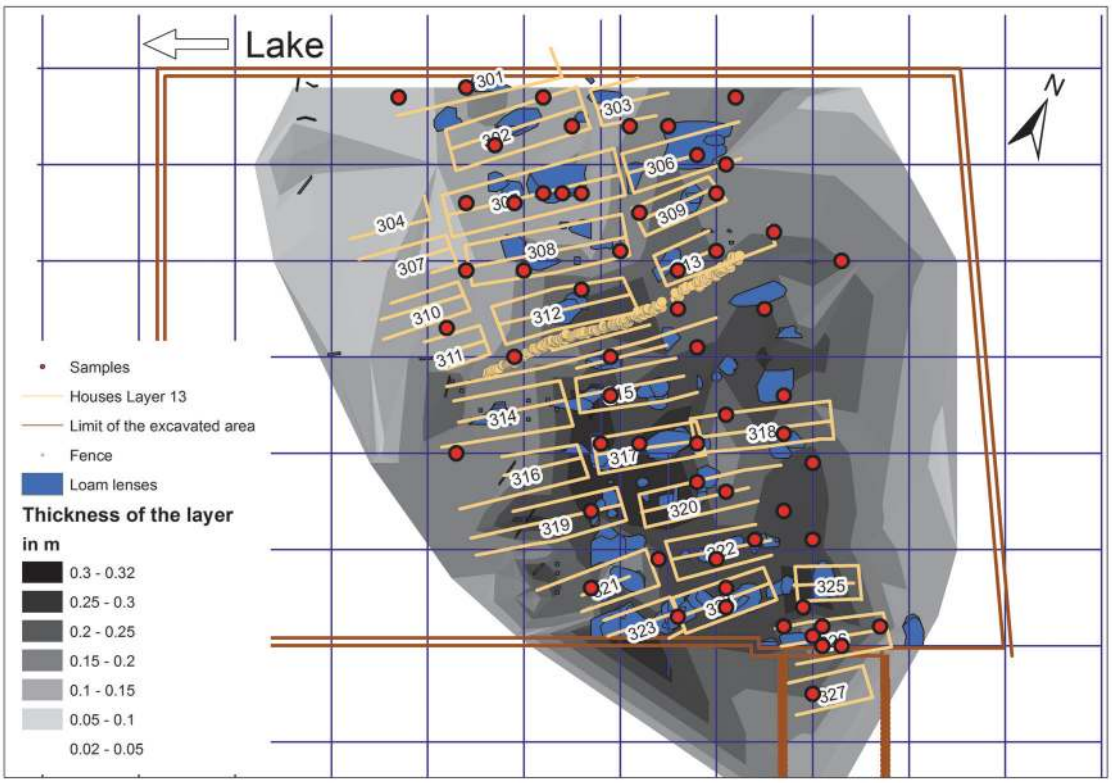


Fig. 2 Distribution of the points where both A- and B-samples from layer 13 at Zürich-Parkhaus Opéra. In several cases, more than one sample from the same square was analysed, representing different parts of the inner stratigraphy of the cultural layer.

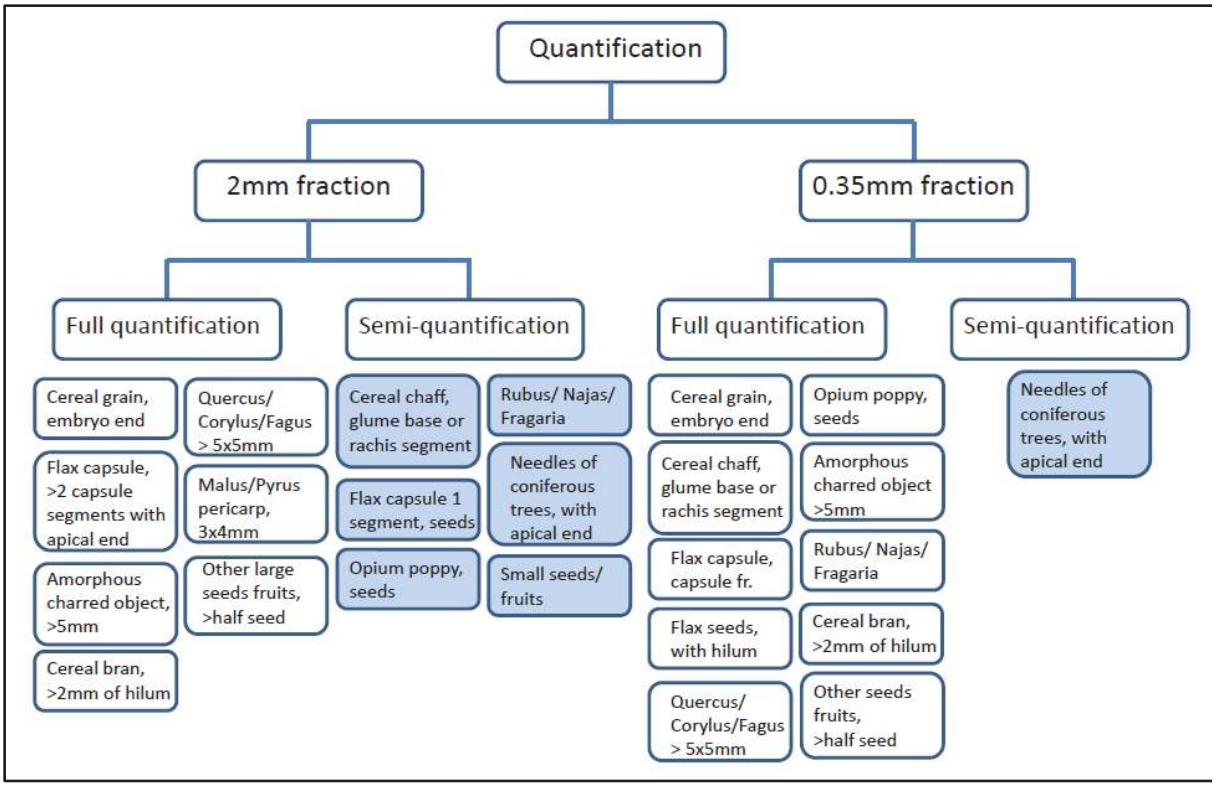


Fig. 3 Guidelines for the recording of botanical macroremains used in the analysis of Parkhaus-Opéra (Steiner et al., 2015).

All sediment volume measurements presented in this paper refer to the displacement volume (Antolín et al., 2015). Nomenclature of scientific plant names follows the National Data and Information Center of the Swiss Flora (http://www.infoflora.ch).

We calculated the ubiquity values (number of samples in which one taxon was found) for large- and small- sized items per fraction in both kinds of subsamples in order to compare how samples of different volumes affect their representation in the record. The results of large-sized items found in the 2 mm fraction of A- and B-samples were represented in scatterplots with concentration values (number of remains per litre of sediment) and proportions (relative frequency or percentage of a taxon in relation to the total of remains of the sample) of objects counted in the 2 mm fraction in both kinds of subsamples. The software R (R CORE TEAM, 2016) was used for this. In addition to this we integrated both ubiquity and concentration of large-sized items by producing GIS Plans with ArcGis (ESRI, 2010) with the data obtained from both sets of subsamples. The size of the symbols was established with the Jenks natural breaks classification method (Jenks and Caspall, 1971). Anselin Local Morans I was used to calculate the clusters (Anselin, 1995).

3. Results

3.1. General results

Around 80.000 plant macroremains were found in the 8 and 2 mm fractions of the 96 A-samples included in this evaluation (in total, 371.75 l of sediment, av. volume of sample 3,7l; av. density: 209.8 r/l), and around 7.000 in the 2 mm fraction of the B-samples (29.38 l; av. volume of sample around 0.3 l; av. density: 236.25 r/l). Over 45 taxa with large-sized

diaspores were recovered in both types of subsamples. Only 5 taxa were found in one of the sample types exclusively. *Prunus padus, Rhamnus cathartica* and *Crataegus laevigata* were only recovered in A-samples, while *Tilia platyphyllos* and *Laserpitium siler* only in the B-samples[1]. Among the best-represented large-sized items in both types of samples one can find *Arctium* sp., *Corylus avellana*, *Galeopsis tetrahit, Linum usitatissimum* (large capsule fragments), *Malus sylvestris*, Maloideae (pericarp)*, Prunus spinosa, Quercus* sp., *Rosa* sp. and *Viburnum lantana*. Common small- to medium-sized items found in both samples are *Najas intermedia/marina, Potentilla* sp., *Fragaria vesca,* chaff remains of *Triticum aestivum/durum/turgidum (*or *T. "nudum*")*, Triticum dicoccon* and *Hordeum vulgare,* as well as other taxa like *Chenopodium album, Polygonum persicaria* or *Sonchus asper.*

3.2. Ubiquity

All of the large-sized items were found in higher ubiquity values in A-samples (Table 1). For some taxa, the differences were not qualitatively significant, because they were present in almost all samples. This would be the case of *Corylus avellana*, *Linum usitatissimum* (large capsule fragments), *Malus sylvestris* and pericarp fragments of Maloideae. On the other hand, large differences of above 30 samples (ca. 1/3 of the total) were found for other taxa like *Agrimonia eupatoria, Fallopia convolvulus*, charred grains of *Hordeum vulgare*, *Prunus spinosa, Rosa* sp. and *Viburnum lantana*.

Small-sized items were semi-quantified or only indicated as present in A-samples (see section 2). We also compared the ubiquity values obtained in both types of subsamples to check if this semiquantification provided relevant information (Table 2). It was observed in several cases that taxa that were found in the 2 mm fraction of A-samples were more rarely found in the 2 mm fraction of B-samples and, instead, they were mostly recovered in the 0.35 mm fraction. This is the case of many taxa like: *Carex* sp., rachis fragments of *Hordeum vulgare*, charred seeds of *Linum usitatissimum*, seeds of *Papaver somniferum*, *Valerianella dentata, Brassica rapa, Chenopodium album, Malva sylvestris, Polygonum aviculare, Polygonum persicaria* and *Ranunculus repens.* Other (clearly small-sized) taxa were found only rarely in the 2 mm fraction of both kinds of subsamples and mostly in the 0.35 mm fraction of B-samples: *Potentilla* sp., *Lycopus europaeus,* seeds without wings of *Betula pendula/pubescens*, among others. There were only a few cases of very abundant taxa which were found to show similar ubiquity values in all fractions of all subsample types: uncharred chaff remains of *Hordeum vulgare, Triticum dicoccon, Triticum durum/turgidum* and seeds of *Linum usitatissimum*. Unexpectedly, a few other medium-sized items were more often found in A-samples. These include: *Najas marina/intermedia* (complete and half seeds), charred chaff remains of *Triticum dicoccon* and *Triticum durum/turgidum* and seeds of *Aethusa cynapium* as well as *Ranunclus repens.*

	A-Samples	B-Samples
Abies alba	32.3	11.5
Acer spec.	21.9	14.6
Agrimonia eupatoria	57.3	16.7
Alnus glutinosa, Catkin	11.5	2.1
Arctium spec.	94.8	68.8
Asteraceae, Flower	29.2	17.7

[1] We would like to note that these taxa were found in other A-samples of the same settlement phase not included in this evaluation.

Betula pendula/pubescens, Cone scale	43.8	25
Ceratophyllum demersum	14.6	1
Cerealia indet., Bran frag. (unch)	66.7	37.5
Cerealia indet., Grain (ch)	53.1	22.9
Clematis vitalba	36.5	9.4
Cornus sanguinea	26	5.2
Corylus avellana (ch)	31.3	8.3
Corylus avellana (unch)	100	88.5
Fagus sylvatica, Cupule	26	4.2
Fagus sylvatica, Pericarp	45.8	22.9
Fallopia convolvulus	57.3	20.8
Frangula alnus	16.7	2.1
Galeopsis tetrahit	81.3	52.1
Hordeum vulgare undiff., Grain (ch)	60.4	28.1
Linum usitatissimum, Capsule fr. (unch)	97.9	88.5
Malus sylvestris, seed	100	86.5
Malus/Pyrus, Pedicel (unch)	43.8	21.9
Malus/Pyrus, Pericarp (unch)	99	91.7
Malva sylvestris	26	2.1
Papaver somniferum, Capsule fr. (unch)	12.5	2.1
Prunus spinosa	86.5	53.1
Quercus spec.	52.1	24
Quercus spec., Pericarp (unch)	89.6	62.5
Rosa spec.	87.5	50
Sambucus nigra/racemosa	16.7	1
Triticum aestivum s.l./*durum/turgidum,* Grain (ch)	35.4	11.5
Triticum dicoccon, Grain (ch)	36.5	11.5
Viburnum lantana	79.2	32.3
Viscum album s.l.	25	14.6

230 Table 1. Ubiquity (percentage of samples) in which the large-sized items appear in A- and B-
231 samples. Dark grey-shadowed taxa showed similarly high ubiquity values in both types of
232 subsamples. If no indication is given, remains are preserved in an uncharred state.

			A-samples (2mm fraction)	B-samples (2mm fraction)	B-samples (0.35mm fraction)
Hordeum vulgare undiff.	Rachis segment	unch	72.9	59.4	66.7
Aethusa cynapium	Seed/fruit	unch	19.8	3.1	0
Alnus sp.	Seed/fruit	unch	19.8	0	16.7
Arenaria serpyllifolia agg.	Seed/fruit	unch	2.1	0	80.2
Betula pendula/pubescens, seeds with wings	Seed/fruit	unch	16.7	2.1	57.3
Betula pendula/pubescens, seeds without wings	Seed/fruit	unch	25	0	22.9
Brassica rapa	Seed/fruit	unch	17.7	0	22.9
Carex spec. bicarpellat	Seed/fruit	unch	11.5	3.1	19.8
Carex spec. tricarpellat	Seed/fruit	unch	40.6	4.2	52.1
Cerastium spec.	Seed/fruit	ch	1	0	1
Cerastium spec.	Seed/fruit	unch	1	0	40.6
Chenopodium album	Seed/fruit	unch	22.9	3.1	39.6
Fragaria vesca	Seed/fruit	unch	41.7	7.3	92.7
Hypericum perforatum	Seed/fruit	unch	2.1	2.1	1
Lapsana communis	Seed/fruit	unch	16.7	4.2	45.8
Linum usitatissimum	Seed/fruit	ch	18.8	2.1	15.6
Linum usitatissimum	Seed/fruit	unch	93.8	80.2	95.8
Lycopus europaeus s.l.	Seed/fruit	unch	14.6	2.1	44.8
Malva sylvestris	Seed/fruit	unch	26	2.1	13.5
Najas intermedia/marina	Seed/fruit	unch	77.1	58.3	35.4
Najas intermedia/marina	Fruit	unch	65.6	46.9	30.2
Origanum vulgare	Seed/fruit	unch	4.2	0	60.4
Papaver somniferum	Seed/fruit	unch	66.7	14.6	94.8
Physalis alkekengi	Seed/fruit	unch	63.5	14.6	66.7
Polygonum aviculare agg.	Seed/fruit	unch	37.5	0	59.4
Polygonum hydropiper	Seed/fruit	unch	16.7	3.1	13.5
Polygonum lapathifolium/persicaria	Seed/fruit	unch	2.1	3.1	11.5
Polygonum persicaria	Seed/fruit	unch	52.1	8.3	43.8

Potentilla spec.	Seed/fruit	unch	14.6	4.2	81.3
Prunella vulgaris	Seed/fruit	unch	24	5.2	50
Ranunculus cf. *repens*	Seed/fruit	unch	62.5	11.5	43.8
Rubus fruticosus agg.	Seed/fruit	unch	13.5	44.8	75
Rubus fruticosus/idaeus	Seed/fruit	unch	87.5	15.6	68.8
Rubus idaeus	Seed/fruit	unch	17.7	8.3	51
Rumex spec.	Seed/fruit	unch	10.4	3.1	24
Sambucus ebulus	Seed/fruit	unch	24	3.1	5.2
Schoenoplectus lacustris	Seed/fruit	unch	33.3	7.3	25
Solanum nigrum	Seed/fruit	unch	8.3	4.2	20.8
Sonchus asper	Seed/fruit	unch	25	3.1	65.6
Stellaria media agg.	Seed/fruit	unch	18.8	2.1	32.3
Torilis japonica	Seed/fruit	unch	9.4	2.1	5.2
Triticum dicoccon	Glume base	ch	30.2	6.3	7.3
Triticum dicoccon	Glume base	unch	85.4	74	84.4
Triticum durum/turgidum	Rachis segment	ch	17.7	9.4	6.3
Triticum durum/turgidum	Rachis segment	unch	76	67.7	85.4
Urtica dioica	Seed/fruit	unch	11.5	2.1	70.8
Valerianella dentata	Seed/fruit	unch	15.6	4.2	21.9
Verbena officinalis	Seed/fruit	unch	18.8	2.1	86.5

Table 2. Ubiquity (percentage of samples) in which the (small-sized) taxa that were semi-quantified in A-samples appear in A- and B-samples (2mm and 0.35mm fractions separately). Light grey-shadowed taxa showed higher ubiquity values in one of the fractions or subsample types. **Rubus* species were usually not identified to species level in the A-samples

3.3. Concentration values and proportions

Differences between A- and B-samples in the mean concentration of large-sized items were not significant (Table 3).

	A-SAMPLES	B-SAMPLES
Hordeum vulgare undiff., Grain (ch)	1.8	2.2
Triticum aestivum s.l./*durum/turgidum,* Grain (ch)	0.4	0.6
Triticum dicoccon, Grain (ch)	0.4	0.4
Cerealia indet., Grain (ch)	1.0	0.9
Cerealia indet., Bran frag. (unch)	5.8	3.5
Linum usitatissimum, Capsule fr. (ch)	3.7	2.1
Linum usitatissimum, Capsule fr. (unch)	44.2	30.7
Papaver somniferum, Capsule fr. (unch)	0.1	0.1
Asteraceae (flower)	0.3	0.9
Abies alba	0.1	0.9
Acer spec.	0.1	0.5
Agrimonia eupatoria	0.3	0.6
Alnus glutinosa (catkin)	0.1	0.3
Arctium spec., seeds	5.9	8.1
Betula pendula/pubescens (cone scale)	0.4	1.2
Ceratophyllum demersum	0.1	0.0
Clematis vitalba	0.3	0.5
Cornus sanguinea	0.1	0.2
Corylus avellana (ch)	0.2	0.3

Corylus avellana (unch)	23.9	27.9
Fagus sylvatica, Cupule	0.1	0.1
Fagus sylvatica, Pericarp	1.8	1.7
Fallopia convolvulus	0.8	0.8
Frangula alnus	0.0	0.1
Malus sylvestris, seed	16.2	14.3
Malus/Pyrus, Pericarp (unch)	76.4	89.3
Malus/Pyrus, Pedicel (unch)	0.5	1.3
Malva sylvestris	0.4	0.1
Prunus spinosa	4.8	4.6
Quercus spec.	1.2	2.4
Quercus spec., Pericarp (unch)	13.1	18.8
Ranunculus repens	0.2	1.1
Rosa spec.	4.3	4.9
Sambucus nigra/racemosa	0.1	0.0
Viburnum lantana	1.0	1.4
Viscum album s.l.	0.1	0.8

Table 3. Mean concentrations of large-sized items in A- and B-samples (2mm fraction).

Scatterplots were produced in order to show the relationship (on a one-to-one basis) between A- and B-samples concerning the density of the most-commonly-found taxa in A-samples (Fig. 4). Secondly, the proportion of these taxa in relation to the total of the sample were also plotted for comparison (ESM 2). All scatterplots are much skewed. In both cases (Fig. 4 and ESM 2), at least two different patterns were observed. A few taxa yielded a better distribution of a part of the samples along the line, indicating perfect match between both subsample types, while a number of outliers is always present. This is the case of shell fragments of *Corylus*, seeds of *Malus sylvestris*, pericarp fragments of Maloideae and large capsule fragments of *Linum usitatissimum*. The rest of the taxa showed no clear pattern.

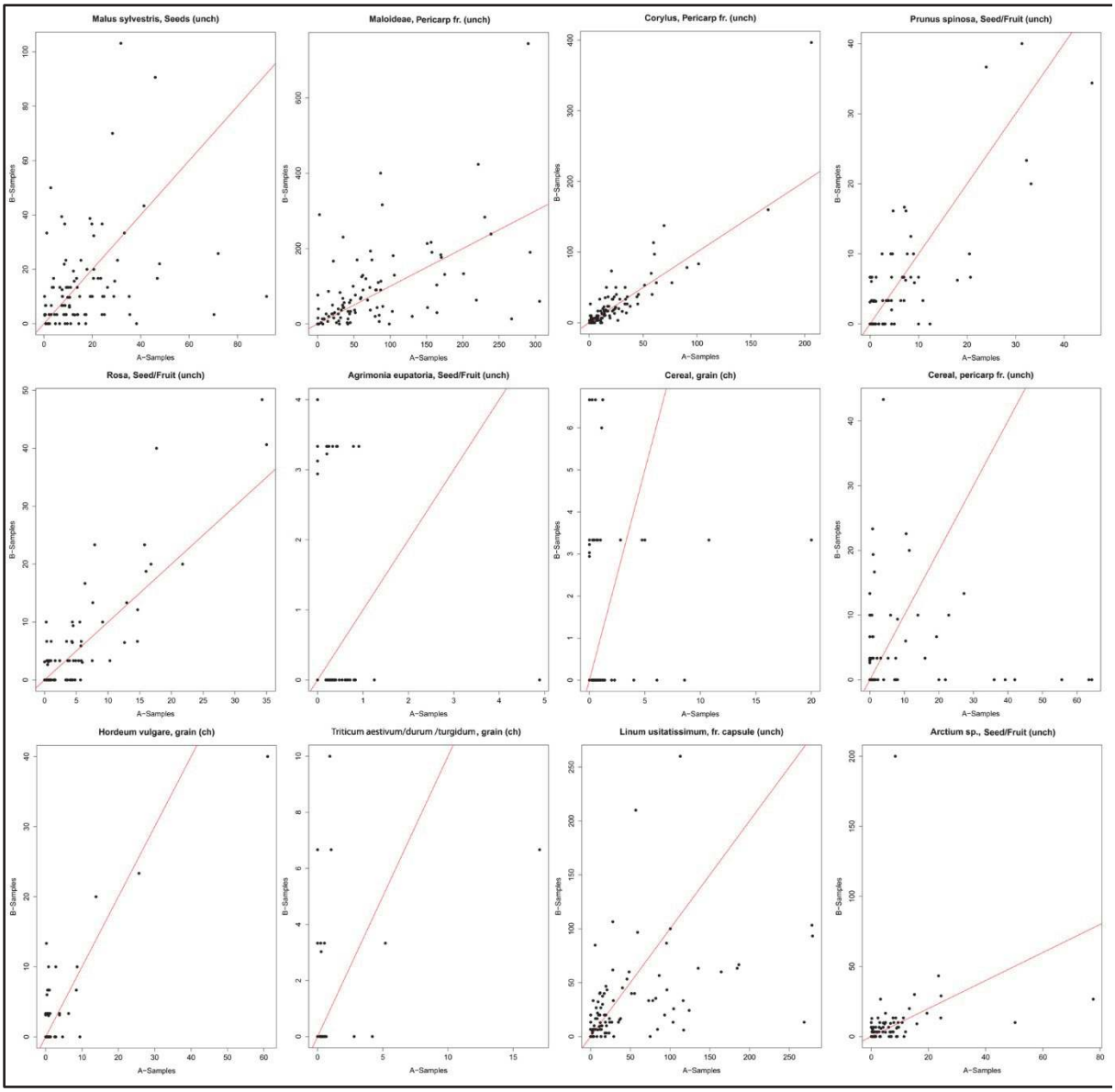


Fig. 4 Concentration values obtained for selected large-sized taxa in A- and B-samples. The red line shows perfect match

A Spearman's correlation was run to determine the relation between the values per taxon of A and B subsamples both using concentration values and proportions and a strong positive correlation was only determined for two taxa in both cases: *Agrimonia eupatoria* and *Ranunculus repens* (Table 4).

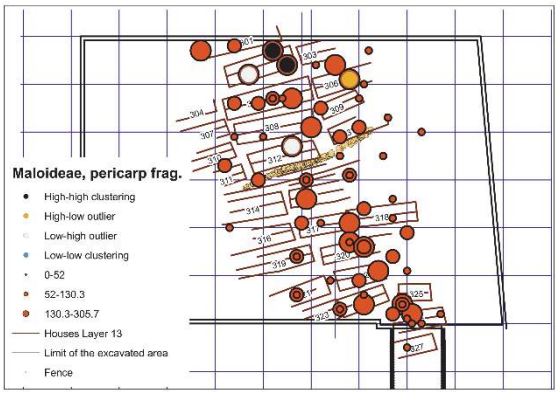
P: Spearman's Correlation	Concentration	Proportions
Triticum aestivum s.l./*durum/turgidum,* Grain (ch)	0.004	0.013
Triticum dicoccon, Grain (ch)	0.000	0.000
Cerealia indet., Grain (ch)	0.006	0.011
Cerealia indet., Bran frag. (unch)	0.052	0.162
Hordeum vulgare undiff., Grain (ch)	0.000	0.000
Linum usitatissimum, Capsule fr. (unch)	0.000	0.000
Agrimonia eupatoria	0.661	0.876
Arctium spec.	0.000	0.000

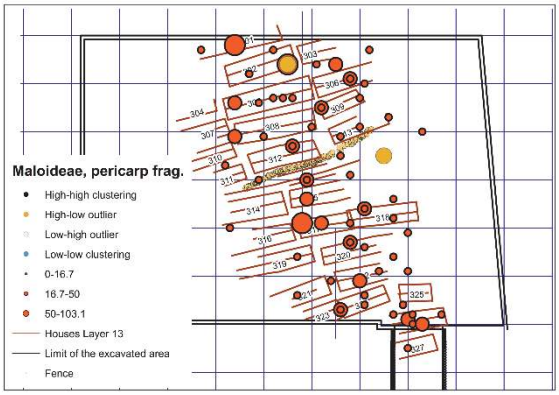
Corylus avellana (unch)	0.000	0.000
Galeopsis tetrahit	0.000	0.000
Malus sylvestris, seed	0.000	0.000
Malus/Pyrus, Pericarp (unch)	0.000	0.000
Prunus spinosa	0.000	0.000
Quercus spec., Pericarp (unch)	0.000	0.000
Ranunculus repens	0.748	0.641
Rosa spec.	0.000	0.000
Viburnum lantana	0.041	0.126

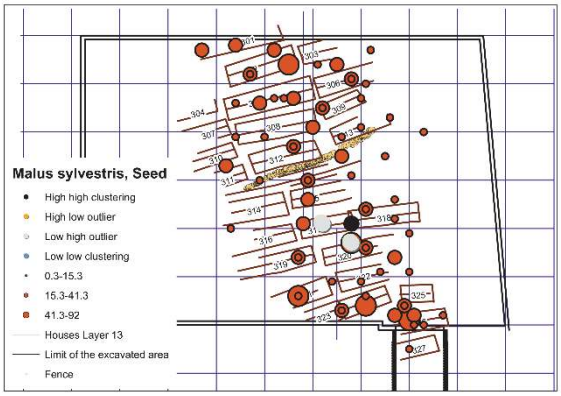
Table 4. Pearson's correlation, p-value. Strong correlations shaded in dark grey.

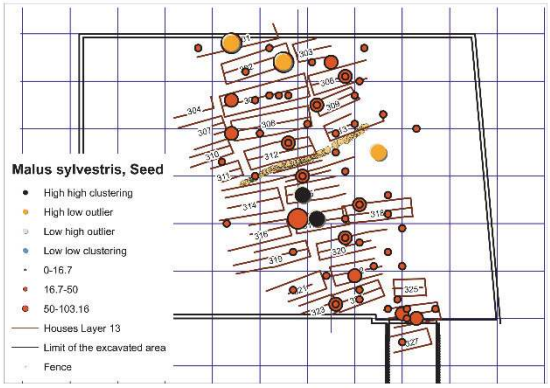
3.3. GIS mapping of concentration values

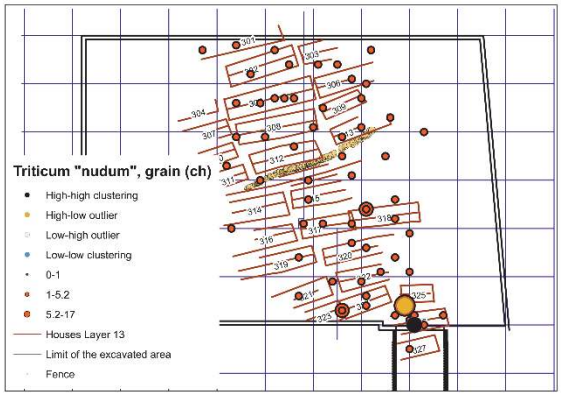
Taxa that were fully quantified in A- and B- samples were represented in GIS maps using the Jenks natural breaks to define the size of the circles to avoid taking differences on a sample-to-sample basis, and focus on the trends observed of samples with "low", "medium" or "high" density, and, in addition to this, pointing out statistically significant clusters to compare the information provided by both datasets (see a summary of selected taxa in Fig. 5 and a more complete list of taxa in ESM 2). For some large-seeded taxa, like pericarp fragments of Maloideae, higher densities were found to be more widespread in the A-samples, and therefore clustering was better identified (instead of outliers, which were detected in the B-samples). Clustering was also better identified for *Arctium* seeds and *Viburnum lantana* in the A-samples. On the other hand, charred grain of *Triticum "nudum"* and large capsule fragments of *Linum usitatissimum* yielded similar distributions and clustering patterns.

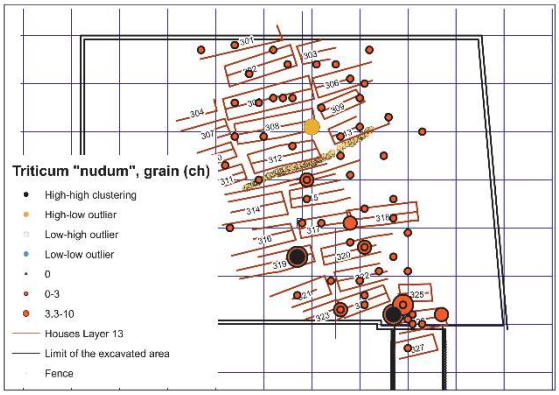












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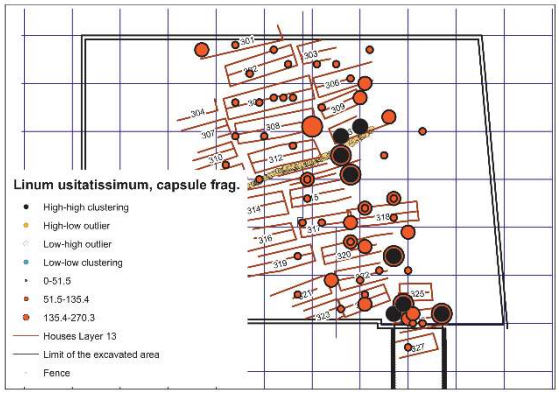

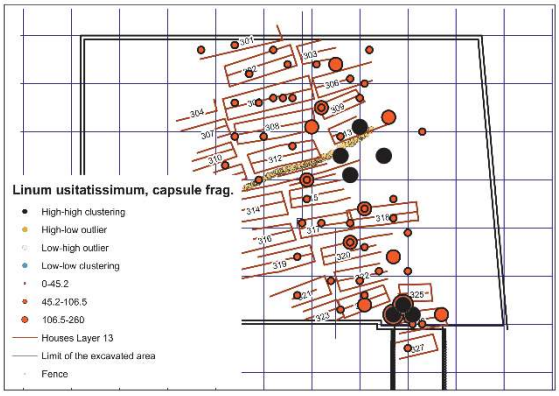

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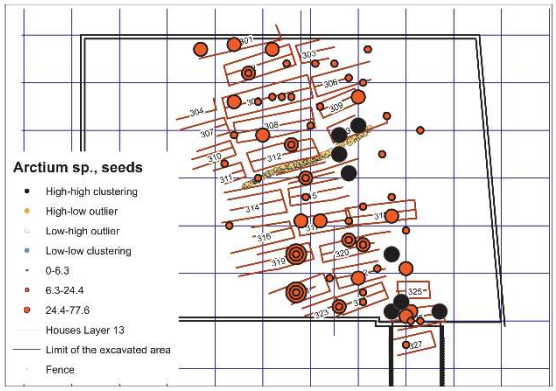

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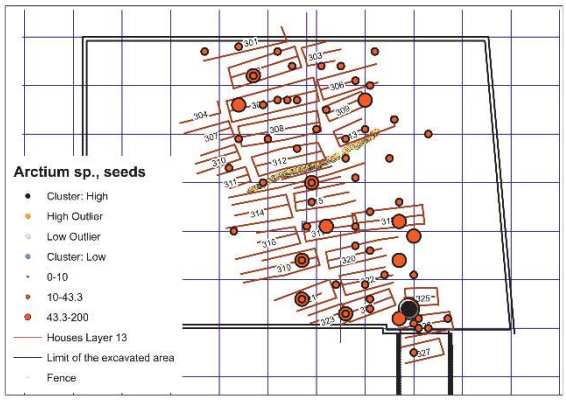

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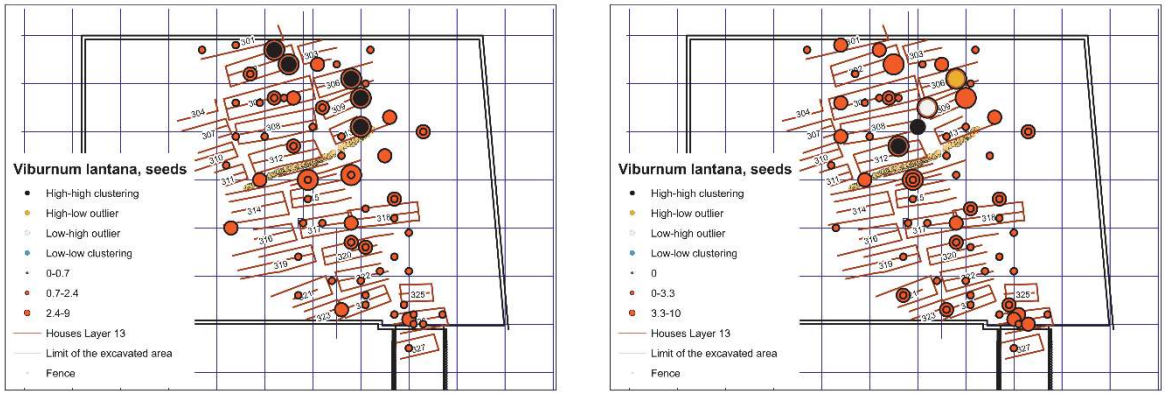

Fig. 5. GIS plans for different taxa quantified in A- (left column) and B-samples (right column) showing the density of remains per sample using Jenks natural breaks to define symbol size and Anselin Local Morans I to identify clusters and outliers.

4. Discussion

4.1. Limitations of this work

The results presented in this paper are of high relevance for archaeobotany in wetland contexts, particularly taking into account the insufficient amount of methodological research done to date in this field, mostly due to the fact that most of the research is carried out in the framework of commercial archaeology, which does not allow the time nor the financial support for methodological evaluations.

The comparison presented above is aimed to make a final statement about the need of large-volume samples from well-preserved waterlogged archaeological deposits in order to have a full representation of all seed and fruit remains (possibly also other types of remains recovered in these samples, like insect or fish remains). This was a necessary work given that profile and core sampling are still very commonly used in similar contexts to the ones investigated in this paper. This kind of sampling is most useful to target layer formation processes, but not representative enough for a full reconstruction of the economy (particularly regarding the relative importance of different plant foods in diet) at a site scale.

There are some methodological limitations in our work that need to be taken into consideration. The samples we studied need to be understood as subsamples of different volume of the same master sample, which is not fully comparable to the type of samples that one would obtain by sampling profiles (monolith sampling), using cores scattered through the site. At most, it could be compared to taking small surface samples because our samples were taken from a surface of a square metre (so called scatter samples according to Lennstrom & Hastorf 1992) and not just at a random point. One should assume that profile sampling or core sampling would tend to give even more biased results than the ones presented here, since the chances of not having a good representation of the whole surface of the site are larger. In addition to this, taking a sub-sample from the master sample introduced a sequencing effect and an error (due to the process of subsampling a clumpy sediment) that we have recently tried to calculate (Steiner et al., in press). Ideal case studies or test studies do not generally exist in archaeology. One cannot take a large and a small sample from a context without introducing this sequencing effect in some form. For this reason we still find our analysis a powerful tool to judge the representativeness of different sampling strategies in wetland sites with similar preservation conditions.

4.2. How comparable are ubiquity, concentration and proportions obtained in A- and B- samples for large-sized items?

We observed that the results obtained for large-sized items in A- and B-samples tend to diverge considerably, depending on the method used to compare the samples. From the most common taxa, only one was comparably well recorded in both kinds of subsamples: large capsule fragments of *Linum usitatissimum* (Table 5). Some taxa never yielded comparable results like charred grains, bran fragments of Cerealia or fruits of *Agrimonia eupatoria.* Other plant macroremains, like pericarp fragments of Maloideae and nutshell fragments of *Corylus avellana* gave roughly similar results for ubiquity, concentration and proportions, but not in the GIS plans. Other taxa yielded similar GIS-plan distributions despite dissimilarities in other parameters, like charred grains of *Hordeum vulgare* and *Triticum aestivum/durum/turgidum.* Large-sized items seem to be systematically underrepresented in small-sized samples except the most abundant and frequent ones (with the exception of large capsule fragments of flax) (Steiner et al., 2015).

Regarding ubiquity values, on the basis of what we have observed (Table 1), very important large-sized items present in almost all samples (97-100%) are equally recovered in almost all smaller sub-samples (88-92%), but a few taxa with somewhat lower ubiquity values (75-95%), which are also economically important, presented clearly lower values in smaller samples (30-60%), showing poorer chances to be detected with this type of sampling. Therefore, under the pre-condition that a relatively large number of small-volume samples have been investigated, large-sized items found in small-volume samples in ubiquities above 50% should be considered as important resources, since it is unlikely that these values are higher for most taxa when small samples are taken. Ubiquity values are, therefore, in general, not directly comparable to other sites where large-volume samples have been investigated.

Regarding concentration, we have observed that average concentration values are similar using both datasets and therefore are fully comparable, which is a very important result for large-scale comparisons between different sites with different sample sizes. A relatively large number of samples and a large-scale surface sampling (from multiple parts of the settlement) is also required in any case so that these average values are representative for the site. On the other hand, comparisons on a sample-to-sample basis do not seem possible either relying on concentration values or on proportions. Only two taxa (*Ranunculus repens* and *Agrimonia eupatoria*) seemed to show a positive monotonic correlation, which is what one would expect if B-samples provided a proportional amount of remains of those found in A-samples. In addition to this, a qualitative observation of the scatterplots in Fig. 4 and ESM 2 also allowed the observation that the taxa which have the highest ubiquity values in B-samples are the ones which also yielded more similar results in concentration on a one-to-one basis to A-samples. This could be interpreted as an indication that concentration values at a sample scale are in general not reliable in small samples as a direct comparison to large samples except for the most ubiquitous taxa.

Qualitative comparisons (combined with clustering analysis) between GIS plans produced with concentration values of A- and B-samples also showed divergences between A- and B-samples, particularly among clearly large-sized items. For this reason, direct comparison does not seem possible.

	Ubiquity	Concentration	Proportion	GIS Plan
Malus sylvestris, seed	✓	✓	✓	
Maloideae, pericarp fragment	✓	✓	✓	
Corylus avellana, shell fragments	✓	✓	✓	
Prunus spinosa, seed			✓	✓
Rosa sp., seed		✓	✓	
Agrimonia eupatoria, fruit				
Cerealia, grain (charred)				
Cerealia, bran fragment (uncharred)				
Hordeum vulgare, grain (charred)				✓
Triticum “nudum”, grain (charred)				✓
Linum usitatissimum, large capsule fragment	✓	✓	✓	✓
Arctium sp., seed		✓	✓	

Table 5. Ticks mark an “acceptable” agreement in the results obtained in A- and B- samples.

4.3. Which taxa appear in which fractions? Does sample volume make a difference?

Two different aspects were to be considered regarding the type of remains found in each fraction: first of all, do large-sized remains appear in the 2 mm fractions independently of sample size? Secondly, are large- and small-sized items equally separated in the two fractions that we used in large and small samples? In consequence, were our counting units adequate for our case study and are they valid for other case studies with independence of the volume of the samples?

We had defined our **counting units** on the basis of previous work in Arbon Bleiche 3 (Hosch and Jacomet, 2004) and adapted them after performing some initial tests (Jacomet, unpublished) and further sieving tests (Fig. 3, Steiner et al. 2015). With the present work, we identified some other plant macroremains that were not quantified in the 2 mm fraction of A-samples but should be included in the quantification list in future analyses (these concern mainly middle-sized seeds and other items): *Najas marina/intermedia* (complete and half seeds), charred chaff remains of *Triticum dicoccon* and *Triticum durum/turgidum* and seeds of *Ranunculus repens* and *Aethusa cynapium* (ESM 4). It is particularly important to emphasize that charred chaff remains of cereals must be counted in this fraction in order to obtain comparable results to dry sites.

What about small-sized items? As already mentioned, smaller-sized items were semi-quantified in A-samples. In the case that the 0.35 mm fraction had not been analysed, how much could one rely on the semiquantifications performed in A-samples? Could one use the presence/absence of these taxa as a reliable indicator in, for instance, preliminary evaluations for a site under study? In this test, the recording of presence of the taxa proved to be reliable for a lot of taxa (including uncharred chaff remains of the main cereals and flax

seeds) except those with clearly small seeds like *Potentilla* sp., *Lycopus europaeus, Betula pendula/pubescens, Fragaria vesca, Origanum vulgare, Prunella vulgaris,* etc. These taxa would have always been underestimated in terms of ubiquity in the values produced by the 2 mm fraction of A-samples. One final remark is needed: our results are only valid for other sites where the sieving method was equally gentle (the so-called wash-over technique). Otherwise, much less small-sized material would have been recovered in A-samples.

4.4. Comparison with other contemporary lakeshore settlements

The results presented above indicate two main guidelines for the comparison of values regarding large-seeded taxa between sites where different sample sizes have been taken. The first one is that only the global concentration values (and not at a sample basis) can be compared if a relatively high number of samples has been studied. The second one is that only the most ubiquitous taxa will have a reliable ubiquity in sites where small samples were taken. Otherwise, taxa with ubiquities of 30-70% should be considered as very ubiquitous (=75-95%).

In order to see how useful these guidelines are, we compared our results with other roughly contemporaneous lakeshore sites investigated in the region and for which the necessary data were available: Arbon Bleiche 3 (Hosch and Jacomet, 2004), Horgen Scheller (Horgen layers) (Favre, 2002), Bad Buchau-Torwiesen II (Maier and Herbig, 2011) and Zürich-Kanalisationssanierung Seefeld (abbreviated as “KanSan”) (Layer 3) (Brombacher and Jacomet, 1997). These sites were sampled in different ways. From Arbon Bleiche 3 we could include profile samples (av. volume of 0.13 litres per sample, 49 samples from 12 places along a lake-land transect) and surface samples (33 samples of 2 litres of volume in average); the latter came from different locations than the profile samples. From Horgen Scheller, scatter samples (see section 4.1) of small volume (ca. 0.6 litres) were taken, while from Zürich-KanSan only profile samples from 13 locations (ca. 0.7 litres of volume per sample in average) were studied. We selected a number of taxa that appeared in our test study and, in order to avoid comparing very poor samples, only samples that presented more than 100 remains per litre of sediment of these taxa were kept for the evaluation. The synthesis of the data produced can be observed in Table 6.

It can soon be observed that the lowest density and ubiquity values were obtained mostly in the profile samples of Arbon Bleiche 3 and the coring program at Torwiesen II, which also presented the smallest volumes per sample, as well as in Horgen-Scheller, where the average volume was below 1 litre per sample. It is particularly clear how charred cereal remains were found in much lower ubiquities in all sets of samples except the surface samples of Arbon Bleiche 3. These trends confirm the results observed in our test. The large differences in concentration values between small- and large-volume samples observed in Table 6 (particularly for Arbon Bleiche, where both types of samples were taken) might be due to the fact that small-volume samples come from profile columns or cores (in Bad Buchau). In both cases, the sample is taken from a specific point, instead of aiming to have represented a larger surface as with scatter samples. As already noted in the comparison performed by Jacomet between profile and surface samples at Arbon Bleiche 3, the average concentration values of small-volume samples taken from a small number of spots (<20) cannot provide reliable estimations (Jacomet et al. 2004, 413-414)

	Arbon Bleiche 3, Profile samples (49 samples from 12 columns, av. Vol. 0.13 litres)		Bad Buchau-Torwiesen II, coring program (537 Samples, av. Vol. 0.225 litres)		Horgen-Scheller, Layer 3, surface samples (41 samples, av. Vol. 0.6 litres)		Horgen-Scheller, Layer 4, surface samples (21 samples, av. Vol. 0.7 litres)		Zürich-KanSan, profile column (18 Samples from 13 columns, av. Vol. 0.7 litres)		Arbon Bleiche 3, Surface samples (33 Samples, av. Vol. 2 litres)	
	average density	ubiquity	average density	ubiquity	average density	ubiquity	average density	ubiquity	average density	ubiquity	average density	ubiquity
Malus sylvestris, seed	100.1	93.9	1.5	5	69.5	92.7	14.3	95.2	61.2	100	179.4	100
Malus sylvestris, pericarp frag.	284.6	100	0.6	<1	363.3	100	37.8	100	124.5	100	220.1	100

Quercus spec., pericarp frag.	5.0	26.5			79.2	95.1	32.0	100	104.0	77.8	16.1	87.9
Corylus avellana, shell frag.	183.0	95.9	0.1	<1	73.1	92.7	42.6	100	38.0	100	273.5	97.0
Prunus spinosa, stone	2.0	16.3	0.0	<1	2.7	53.7	3.8	47.6	6.5	83.3	2.9	75.8
Rosa spec., stone	2.3	14.3	0.0	<1	9.8	82.9	6.8	85.7	14.9	88.9	3.2	72.7
Cerealia indet., grain (ch)	3.2	14.3	0.0	<1	8.7	80.5	0.9	33.3			1.5	63.6
Hordeum vulgare undiff., grain (ch)	13.7	26.5	2.0	15.0	0.9	36.6	0.8	33.3	1.3	33.3	1.8	78.8
Triticum „nudum“, grain (ch)	1.7	12.2	0.4	6.0	0.8	36.6	0.3	14.3	0.9	22.2	1.2	69.7
Linum usitatissimum, capsule frag.	239.0	91.8	76.0	79	1014.1	100	2508.4	100	984.4	100	1136.7	100

Table 6. Average density and ubiquity of some selected large-seeded taxa from lakeshore sites in the Alpine Foreland that are roughly contemporary to Zürich-Parkhaus Opéra, ordered from left to right according to the mean sample volume. The lowest values per taxon are shaded in grey. Volume measurements of Arbon Bleiche 3, Zürich-KanSan and Horgen-Scheller were converted to displacement volume by applying a factor of 1.5 as suggested in Antolín et al., 2015. See references to the bibliographical sources in the text.

Regarding the number of places that should be sampled if only profile columns or cores with samples of less than 1 litre of volume in average are a viable option or in order to consider this type of approach as representative, 20 sampling spots have been mentioned in previous research (Jacomet et al. 2004, 414). We would now even suggest 40 spots as a minimum, taking into consideration the results of layer 3 in Horgen Scheller (Table 6). This number remains to be tested, since the work presented here does not allow stating a minimum number of samples.

4.5. Which is the appropriate volume of sediment to make a reliable evaluation of large-sized items in wetland sites? Which are the implications for research carried out to date in wetland sites?

The analysis of ubiquity showed that some plant macros were clearly underrepresented in samples of small size like charred cereal grains, and wild plants with a secondary importance (not regularly consumed and processed, but economically important) like *Viburnum lantana, Rosa* sp. or *Prunus spinosa*. In this case, only very frequent and abundant taxa like *Corylus avellana* or *Malus sylvestris* produced similar patterns for large- and small-volume samples.

On the other hand, the mean concentration per taxon seems to not be significantly different between subsample types, which is probably not comparable to sites where profile or core samples were taken because these only reflect very specific areas of the surface of the site. Therefore, if a large number of small samples (above 40) is taken and the spatial patterning of each plant taxon is not a main question of the project, a reliable average density can be obtained for a settlement phase and reliable ubiquity values for all those taxa that appear in high densities and extremely high ubiquities. For large-sized taxa that do not appear in most samples and particularly taxa that appear in low densities, small-sample volumes are not appropriate. This implies, for instance, that charred grains (probably excluding those in burnt layers) were not representatively recorded in sites where only samples of small volume were taken.

From the results obtained at Zürich-Parkhaus Opéra, we can infer that samples of 3 l of sediment volume (that is to say 4.5 l if measuring the classical volume) are needed for a representative recovery of large-sized plant remains. This confirms the estimations done in previous work, but tests should be carried out in other sites to prove the applicability of this value (it can vary if this amount is not enough to recover ca. 400 large-sized items, for instance).

This result implies that more human and financial efforts need to be put in the archaeobotanical research of sites with waterlogged preservation, and that more

methodological critique needs to be included in the interpretation of archaeobotanical assemblages coming from samples of small volume in this type of archaeological deposits.

5. Conclusions

In this study we could perform a test analysis that finally proves that large-volume samples are needed for the representative recording of large-sized items (including charred cereal grain) in wetland sites, especially if the economy of a site is targeted. This is an important result given that sample sizes are usually very small (below 1 litre) in these sites, which renders the results of these unique contexts (regarding charred remains) almost incomparable to the archaeobotanical data obtained from dry sites. We therefore recommend the use of samples of around 3 l of sediment, at least, for well-preserved Neolithic settlement layers (with average concentration values per sample of around 10.000 mostly uncharred remains per litre of sediment).

We could also show that average density values obtained from small-volume samples might be comparable to those obtained from large-volume samples. This facilitates inter-site comparisons of wetland sites, although caution is always recommended in interpretations. Ubiquity values of large-sized items will probably be underestimated in sampling programs based on samples of small volume. In this case, ubiquity values above 30% and particularly above 50%, need to be considered as very high. Site plan distributions of large-sized items based on samples of small volume are prone to a large bias and should not be performed or interpreted as representative (particularly the absence of remains cannot be interpreted in these cases).

Since the number of remains to be counted per sample are independently treated for each fraction (ca.400 remains are needed per fraction), counting units need to be clearly pre-defined to avoid counting remains twice and our proposal can be used as a reference. A proposal is included in the ESM 4 of this paper.

Finally, we recommend the conduction of tests at a site scale to check the suitability of these standards to each case study.

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