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CHAPTER 29

ARCHAEOBOTANY

Analyses of Plant Remains from Waterlogged Archaeological Sites

STEFANIE JACOMET

Introduction and aims

The main focus of archaeobotanical research is the study of past people–plant relationships. This includes a reconstruction of the diet, subsistence, agricultural strategies, the social and cultural role of food, the exploitation of wild resources, the procurement of fodder, aspects of seasonality, and the reconstruction of the environment in which people and their animals dwelt. The accuracy of archaeobotanical reconstructions, however, depends on the quality of the botanical data recovered from excavations. The first responsibility for an archaeobotanist is therefore to consider all the factors that influence the making of the record (e.g. taphonomy). This was highlighted already by many archaeobotanists (for a recent overview see Van der Veen 2007: 979).

Preservation by waterlogging (anaerobic conditions) allows a much greater insight into the diversity of plant use based on plant macroremains (seeds, fruits, chaff, etc.; Jacomet 2007a), simply because much more remains are preserved. An investigation of such well-preserved findings allows us also to estimate what might be absent in the 'usual' record when preservation is bad (aerobic conditions in temperate regions). This may prevent biased interpretations. In this chapter I will concentrate on 'seedy' macroremains. Nevertheless, I will mention (where necessary) other lines of evidence such as microremains (pollen, phytoliths, etc.).

The interpretation of archaeological plant material is not straightforward in a biological sense. Plant remains in archaeological sites have to a very large extent to be considered as ecofacts, i.e. archaeological materials, which happen to be biological (Wilkinson and Stevens 2003). Therefore, in interpreting archaeological plant remains we have to consider both biological and archaeological facts.

The main aim of this chapter is to discuss how both preservation and research methodology affect our interpretation. Besides the possible routes of entry of plant remains into the deposits, we will emphasize the loss of evidence due to poor preservation conditions. Finally, several case studies will underline the potential of waterlogged preservation, demonstrating at the same time that a failure to understand the taphonomical processes can lead to inaccurate and biased interpretations of the data.

METHODOLOGICAL CONSTRAINTS: THE INFLUENCE OF TAPHONOMY ON THE INTERPRETATION OF ARCHAEOLOGICAL PLANT REMAINS

Routes of entry of plant remains into archaeological deposits

Most macroremain assemblages in settlement layers are normally made up of secondary refuse, such as material discarded away from its location of use (so-called mixed deposits). More rarely, there is also evidence of primary refuse, which reflects discrete and/or single activities or 'snapshots' of human or animal activity (see e.g. Schiffer 1991; 2002; 1991; Jacomet and Kreuz 1999: 76–9).

The different possible routes of entry of plant macroremains into mixed deposits were recently compiled by Van der Veen (2007). Residues of crop processing like cereal chaff, cereal pollen, flax capsule fragments, and weeds are encountered at most settlements, either because the crop processing took place there or because such byproducts were brought in on purpose, for instance fodder, bedding, fuel, or building material (temper and insulation materials). However, the most important sources of plant remains are leftovers of food preparation and kitchen waste. These typically include dehusking residues of cereals and pulses, testa fragments of cereal grain (bran) and pulses, flavourings, the shells of nuts, or fruit remains. They may also be stored food/fodder in mixed settlement layers. Also likely to be encountered in mixed assemblages are remains of table waste and snack foods. Both may be discarded casually and dispersed across the site; however, they also may be deposited in batches, and in specific locations. There may also be leftovers of handicrafts such as dyeing (e.g. Hall 1996) or plants used for medicinal purpose or as drugs (e.g. Merlin 2003). Finally, there may also be remains of plants used in rituals (e.g. Robinson 2002).

In the past (and in some parts of the world even today) animals wandered freely through the settlement, and rooms in houses were sometimes given over to animal stalling. Consequently, animal dung and droppings are regularly incorporated into refuse created by the human occupants. The same is true for fodder and bedding material. From many studies it is clear that seeds, grains, and chaff fragments but also microremains such as pollen and spores or parasite eggs survive the digestive tract of animals (see e.g. Charles 1998; Hall and Kenward 1998; and for the Circum-Alpine lake-dwellings the recent compilation by Kühn et al. in press).

Another important source of entry of plant materials, seeds, or fragments of them (microremains) is human faecal material. Such remains are characterized on the one hand by the presence of small seeds, which were swallowed when eaten (for examples see Maier 2001: 142–453; Knörzer 1984), and on the other hand by cereal remains, mainly bran (e.g. Dickson 1989). It may, however, happen that also animals have eaten fruits, such as figs (e.g. Valamoti and Charles 2005).

Decaying wall plaster, insulation, and roofing material may be important additional sources of plant remains. Such materials are often composed of cereal straw and cereal chaff, but also of other plant material, such as moss pads or fragments of wooden shingles. There may also be deposits of rodents.

Finally, we can find remains of the local vegetation of a site. They may have been blown in there by wind (mainly microremains, e.g. pollen) or just deposited where they grew.

Waterlogged vs charred preservation

Waterlogging occurs when an archaeological deposit is preserved under the groundwater table. For a good preservation the groundwater level should remain stable, thus ensuring anaerobic conditions and preventing the decay of the organic compounds. Low temperatures also play an important role (Retallack 1984). Examples of such preservation are found in the Circum-Alpine region (the lake-dwellings), the *wurten* or *Terpen* on the North Sea coast (e.g. Behre 2008), medieval settlement layers as in York (e.g. Kenward and Hall 1995), and the crannogs in Scotland and Ireland (e.g. Dickson and Dickson 2000) (see also Parts 1 and 2 above). In addition, waterlogged preservation may occur in usually dry temperate regions when structures such as pits, wells, or ditches reach the groundwater level (see Jacomet and Kreuz 1999: 82–8).

The modes of preservation most commonly encountered in plant macroremains are—in a temperate climate—waterlogging and charring (carbonization). Under waterlogged conditions plant remains are preserved in a fairly unaltered state (McCobb et al. 2001), also called subfossil. In contrast, carbonized remains are fossilized through charring under oxygen-poor conditions. When preservation is waterlogged, usually >90 per cent of the plant macroremains in mixed deposits are preserved in subfossil state. Carbonized macroremains and taxa are not very numerous, but occur regularly (Jacomet and Kreuz 1999: 55; Jacomet 2007a).

Each mode of preservation tends to favour particular types of plants. During food preparation there is a good chance for plant remains to become charred because they might have been used as fuel, or their preparation (baking, cooking, roasting) may have required the use of fire. Broadly speaking, beside charcoal, cereal grain, cereal chaff, and to a lesser extent pulses, nut shells and some wild plants (mostly field weeds) are the categories with the highest proportions of carbonized remains in mixed deposits (see Van der Veen 2007). In contrast, fruits, vegetables, and crops with oil-rich seeds as well as most of the wild plants are much less likely to become charred and tend therefore to be underrepresented. Thus, in the 'usual' mixed charred plant assemblages we are concerned with a relatively limited range of plant species, and charred assemblages (except accidental burning events, see below) are remarkably similar in composition across chronological periods and geographical regions (Van der Veen 2007). The reconstruction of food consumption and environment, using charred assemblages only, is generally restricted to a record of the major staples and the field weed flora, while other foods or plant groups are only occasionally preserved in this mode. Most charred assemblages are therefore only suited for a reconstruction of agricultural practices.

The formation processes of charred macro-remain assemblages are reasonably well understood; there is also consensus that only dense (often small) and often lignified items are likely to survive (see Van der Veen 2007: 978–9). These facts were already established in the early

1970s, especially by Willerding (1991), and were corroborated later by many archaeobotanical data. As charring is the 'usual' preservation mode under unfavourable aerobic conditions, the (few) carbonized remains in waterlogged layers may therefore reflect what is 'normally' preserved in dry condition. As a result, a determination of the degree of loss in carbonized mixed assemblages becomes possible.

Only when accidental burning occurs (e.g. the settlement is destroyed by fire) are fruits, oil-rich seeds, herbs, and vegetables as well as many wild plants are represented in carbonized assemblages (Van der Veen 2007: 979 and cited literature). The conflagration also preserves charred stores, roofing materials (e.g. shingles or thatch), wattle and daub, and charred dung.

Characteristics of waterlogged plant assemblages

Unaltered plant materials preserved under waterlogged conditions are usually excellently preserved (Fig. 29.1). Macro-remains may also contain fragile, perishable plant tissues such as cereal chaff or calyces and petals of *Trifolium* (clover). Basically, almost all plant parts may be preserved. Waterlogged deposits are therefore generally very rich in unaltered, subfossil

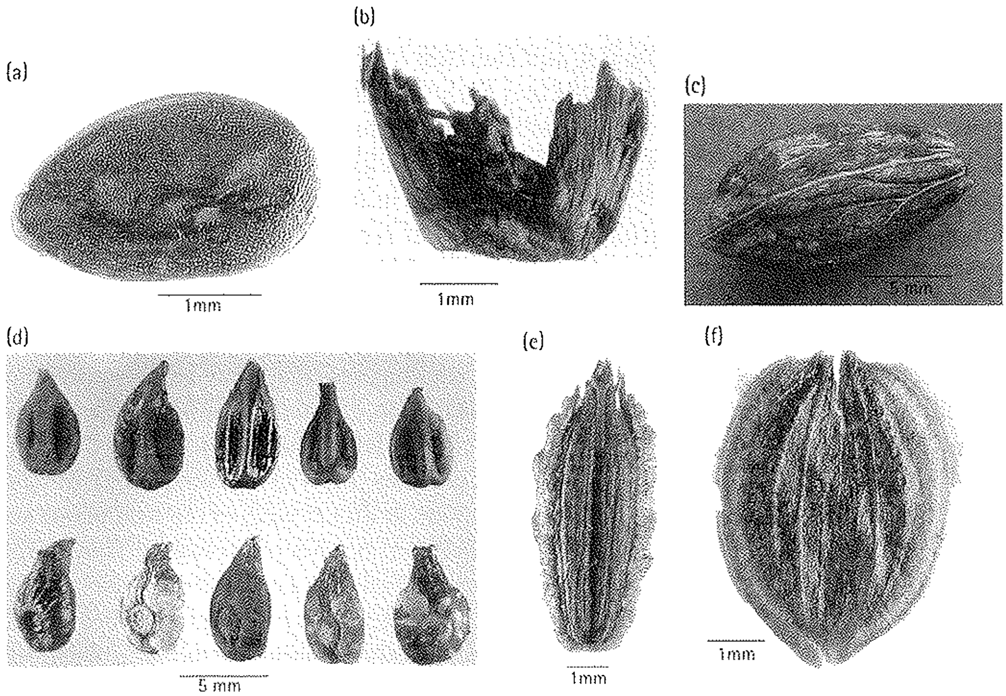

FIGURE 29.1 Examples of subfossil plant remains from waterlogged layers: (a) flax (*Linum usitatissimum*) seed (Arbon Bleiche 3, Neolithic, 3380 BC, Canton of Thurgau, Switzerland); (b) spelt (*Triticum spelta*) chaff; (c) olive (*Olea europaea*) stone; (d) grape (*Vitis vinifera*) seeds; (e) mericarp of *Caucalis daucoides*; (f) mericarp of *Orlaya grandiflora* ((e) and (f) are field weeds). (b–f: Oedenburg, Biesheim-Kunheim, Alsace, France, Roman, 1st–2nd centuries AD). (Photographs: Georges Haldimann, La Chaux-de-Fonds, © IPNA, Basel University.)

plant remains, and the scores for densities of macro-remains (seeds/chaff) may reach several thousand items per litre (see e.g. Jacomet et al. 1989: 62–70). Fruits, oil-rich plants, and condiments as well as several ecological groups of wild plants are recorded in high amounts too. When we are dealing with cereal growing communities, the proportion of subfossil cereal chaff is high in waterlogged mixed deposits (for examples of the Late Neolithic period see Jacomet 2006; 2009; Jacomet 2007b and cited literature; for later periods see Jacomet and Brombacher 2009). Cereal pollen—including autogamous cereals such as wheat or barley—also occurs in high amounts. This pollen derives from cleaning activities in the site (see e.g. Robinson and Hubbard 1977).

In addition, waterlogged assemblages are usually very species-rich. The number of species—in the case of plant macro-remains—is usually over 100. Micro-remain spectra may also be extremely diverse (see e.g. pollen from Neolithic and Bronze Age ruminant dung, Kühn et al., in press).

Charred remains occur in waterlogged mixed assemblages too, although usually in very low amounts (under 10 items per litre of sediment and only a limited range of taxa—often under 10). Worth mentioning is the fact that they are often much better preserved than under 'usual' conditions in well-drained soils. When there are burnt layers they may be present in larger numbers and extraordinarily well preserved, like cereal ears in lake-dwellings (Jacomet et al. 1989; Maier 1996) or the large amounts of carbonized materials (over 90,000 plant remains from 142 taxa) from the Upper Palaeolithic submerged site of Ohalo II (23,000 cal BP) (Weiss et al. 2004). The latter allowed completely new insights into plant use and advanced our ability to understand better the basis for the transition to farming.

Recovery and identification

In general, the methods applied to the recording of small (usually <10 mm) biological remains (plant macro-remains, remains of small animals) of waterlogged mixed deposits is rather heterogeneous and therefore results are often hardly comparable. A lot of information is scattered in site reports (Körber-Grohne 1999). Only some of it has been incorporated into textbooks (see e.g. Jacomet and Kreuz 1999; Pearsall 2000; van Zeist et al. 1991), or internet-based instructions (developed for teaching) such as at IPAS Basel (*http://ipna.unibas.ch/archbiol/ArchBiol_Feldkurs_2009_Skript_mBeil.pdf*) or at Sheffield University (Sheffield Centre for Archaeobotany and ancient Land-usE—Research SCALE: *http://archaeobotany.dept.shef.ac.uk/wiki/index.php/Main_Page*).

Sampling strategies, sample volumes

Sampling strategies for macroremains in extensive waterlogged settlement layers—with a special emphasis on lake-shore settlements—were compiled by Jacomet and Brombacher (2005) and M. Jones (1991). It should be emphasized that one type of sample should be usable for all different types of remains. Different people working on samples should correlate the research, because the various biological remain types may require different sample preparation.

Samples should be representative of the ancient situation at the site. They should make it possible to draw inferences relevant to nutrition, agricultural practices, gathering, fishing, hunting, foddering, the use of wood, and finally the environment in which animals and humans live. In addition, information is needed on intra-house and intra-site patterns, the disposal of rubbish, and genesis of the layers. While sampling, the following five important facts have to be considered:

1. The density of the sampling should be high enough to enable a reconstruction of intra-site patterns. The sampling should be as systematic as possible, from for instance every square metre (for further details see e.g. Jacomet and Kreuz 1999: 97–100; Fig. 29.2).

One possibility is to fill strong bags or (better) buckets with sediment during the excavation of a layer. Such samples are called surface samples (*Flächenproben*). The sample should contain material from all parts of the excavated area (e.g. the quadrant [$1m^2$] in which the sample is taken). In sampling one has to be careful not to mix up layers. Therefore, such a surface sampling strategy can be applied only when a cultural layer has a very simple structure, representing most probably a single-phase settlement. If there are thicker layers or more complex stratigraphies, a systematic surface sampling only makes sense when a detailed excavation is carried out and the single layers can be differentiated properly.

Another possibility is to sample the layer(s) with a dense network of profile columns. This type of sampling strategy is always suggested, but above all when there are thick organic layers without visible internal stratigraphy, or when there are other 'complicated' situations, such as complex sequences of many settlement phases. In order to be able to make some interpretations about intra-site patterns, it is necessary to take at least one column per square metre (see Maier and Harwath 2011). The diameter of the columns should be as large as possible (>10–15cm) so that samples are large enough (see sample volumes below).

The density of sampling may have a large influence on the results, as shown during work on the Neolithic settlement of Arbon-Bleiche 3 (Jacomet et al. 2004). For instance, densities of large seeded items, such as hazelnut shellss and sloe and apple remains, were much lower in the small samples from the few profile columns than in the bulky and more surface-covering surface-samples. The reason for this is that many remains are not evenly distributed across the settlement. Their real value is therefore not detectable with only a few broadly spaced samples (for details see Jacomet and Brombacher 2005). The difference between densely taken profile columns (which represent small samples of a few hundred ml in average) and regularly taken surface samples (of over 5 litres volume each) has only been evaluated recently (see sample volumes below).

If a settlement layer is not extensive (for instance a well-fill), the sampling strategy has to be modified (see e.g. Maier, in press).

2. The volume of the samples should be large enough for recording the totality of biological remains and their diversity at the place where the sample was taken. For recording properly also large-seeded taxa, cereal ears, twigs, dung and remains of small animals (and small archaeological artefacts such as beads) large bulk samples are needed. The volume of these samples should not be less than 5–10 litres.

A surface sampling with such bulk samples entails large amounts of material: their transport and storage may cause problems, because waterlogged sediments have to be stored under cool (if possible below 5°C, or even deep frozen) and dark conditions to prevent infestation by fungi or algae.

Because a large sample volume is only necessary for the larger items (see below), we suggest taking a maximum one-litre subsample before coarse-sieving in order to record smaller

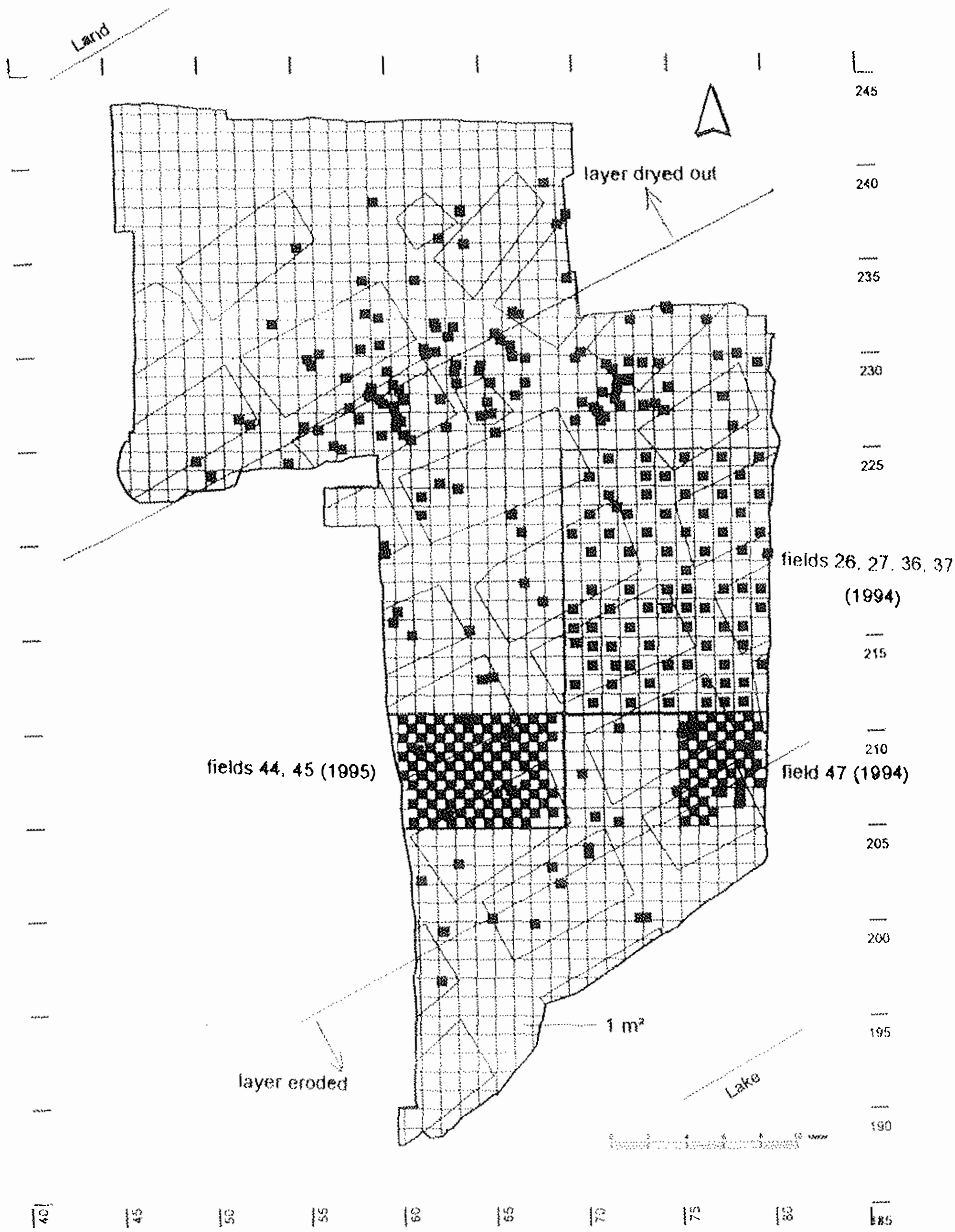

FIGURE 29.2 Distribution of the bulky surface samples (black squares) taken from the cultural layer of Arbon-Bleiche 3, Switzerland. (After Hosch and Jacomet 2001.)

items such as flax, berry seeds, poppy seeds, and cereal chaff. Then it is possible to sieve the larger part of the sample only with a coarse sievemesh size (e.g. 4 or 2mm). This saves time, because only the subsamples have to be sieved with smaller mesh sizes (see below). In a sample of 500ml of an organic layer, there are in fact more than enough small remains (numbers required see below).

In the case of profile columns the sample volumes will not be large enough for a representative recording of larger biological items. This disadvantage is to some extent compensated for by dense sampling.

Samples for microremains such as pollen are usually very small (1cm³);
from bulky samples or profile columns, before they are sieved (see Dimbleby 1985).

3. It is also crucial to note the type of the sample. Beside the above-mentioned samples, which represent materials that became part of a mixed deposit during the daily routine practice, it is important to take judgement samples, as they may represent a very short-term, single event (e.g. a coprolite, a moss pad, or a burnt store). Sample type plays a decisive role when interpreting the data.

4. Also important is the type of sediment that is sampled, because it has a major effect on the taxa represented and therefore on the interpretation (Jacomet et al. 1989: 40–41, 54–85). For instance, in lake-shore and bog settlements there are, on the one hand, layers consisting mainly of subfossil organic materials and, on the other, burnt layers with mainly carbonized items, as well as places where inorganic materials like clay or stones (resulting from wall constructions or hearths) predominate (see Ebersbach, Chapter 17 this volume).

5. Finally, the stratigraphy should be documented properly by samples. This is only possible with the help of profile columns. These can be divided (in a very detailed way) into samples, in order to reconstruct the history of the layer formation. This may be important because horizontal differences (e.g. in lakeshore settlement layers) can be due to human activities, but also to lake level fluctuations or erosion from the landward side. Therefore, it is always necessary, even when the sampling is mainly done by surface sampling, to take at least some profile columns along a lake–land transect (see also Jacomet and Brombacher 2005).

Processing and further treatment

Further treatment of samples is not very much standardized in macroremain research, in contrast to the treatment(s) of microremain (pollen) samples (see e.g. Faegri and Iversen 1989). This could have severe consequences, because the processing method has a strong influence on the representation of plant macroremains. Very fragile items like the remains of subfossil cereal chaff are totally eliminated when processing is rough (Hosch and Zibulski 2003).

A suitable processing method—the wash-over technique—to treat waterlogged samples was already known in the 1980s (see 'wash-over' in Kenward et al. 1980); however, it is still not regularly used. If, for instance, we wish to record fragile plant remains and/or fish-scales, the wash-over method is relevant, and should be applied also during coarse-sieving programmes on excavations (see above; Fig. 29.3 – and the link: http://ipna.unibas.ch/archbot/ChaineOperatoire_Feuchtboden.pdf).

If the organic sediment is compacted, it should be pre-treated, for instance by freezing and subsequent slow thawing (Vandorpe and Jacomet 2007). If only some parts of the sample consist of strongly compacted remains, these may be ruminant dung. Whereas dung of small ruminants (sheep, goat) is easily recognizable, larger pieces of such compacted remains can derive from cattle dung (see Akeret and Rentzel 2001). Such pieces should remain intact for a special investigation; they should be taken out of the sample before (or during) sieving.

In some instances it is important to use small sieve mesh size (e.g. 0.5 or 0.35mm). This size is small enough to record economically important taxa, such as the small seeds of opium poppy. If the focus is on local vegetation, the sieve mesh size should be 0.25mm. If we follow

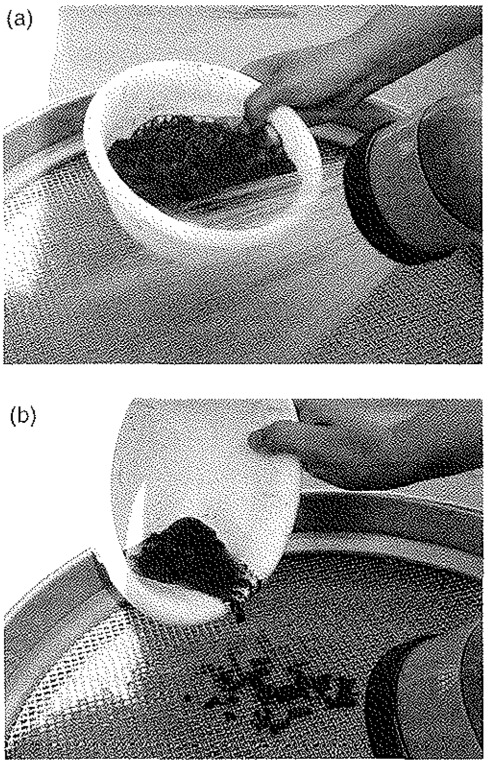

FIGURE 29.3 Sieving with the wash-over technique (Roman waterlogged layers in Eschenz, Canton of Thurgau, Lake Constance, Switzerland). A small portion of the sediment is put in a small bowl, then mixed with water (a). All the swimming parts are emptied to the sieve (b). The inorganic parts remain in the bowl. (Photographs: T. Nerini and S. Lutz, students, Basel University.)

the strategy of sieving bulk samples for recording larger items on the one hand and smaller subsamples on the other (see above), the former should be sieved with a 4mm or 2mm sieve only, and the latter with a 4–2mm and 0.5–0.35mm one (for the operational sequence see the above-mentioned internet links).

It should be emphasized that waterlogged samples as well as the fractions obtained after sieving should never be dried. This has fatal effects on the representation of fragile items (see Tolar et al. 2009). All subfossil items should be picked out of the fractions in water, and stored wet (e.g. in a conserving agent). Only carbonized items may be dried.

Because in waterlogged material the density of plant remains is mostly extremely high, we cannot count the totality of the remains. The statistical basis for determining the amount of items to be counted was developed by Van der Veen and Fjeller (1982) (e.g. counting 341 items). For waterlogged material it is appropriate to count this number in every fraction (Hosch and Jacomet 2001). It is therefore crucial to work with not more than two fractions, for instance 4mm or 2 mm and 0.5mm or 0.35 mm. For the recording of rare taxa, which might be of great importance, see Jacomet and Brombacher (2005).

Also very important is the definition of units that are counted (this will avoid counting the various items several times--see G. E. M. Jones (1991); or, as an example for lake-shore settlements Hosch and Jacomet (2004). However, consensus has so far not been reached on such counting units. Counts of macro-remains from waterlogged layers, therefore, remain difficult to compare directly. Finally, the state of preservation should also be noted (Jones et al. 2007). It gives hints on the preservation conditions.

Case studies

Neolithic: how many plants were used as crops?

How large was the importance of cereal cultivation in Neolithic Europe? Were cereals 'the' important staple foods, or was the Neolithic economy relying on a broad spectrum of plants, cultivars, and taxa collected from the wild (and maybe also cultivated or simply tended)? Were people in Neolithic central Europe 'low-level food producers' (Smith 2001)? This is a highly debated issue. 'Some have argued that the Neolithic economy remained essentially Mesolithic, and that cereals were "special" foods, consumed only rarely and in "ritual" contexts. Others have argued that cereals were more widely consumed, and formed the basis of the domestic economy' (Jones and Rowley-Conwy 2007: 399). Below, this and similar other problems will be discussed for different regions. The data considered come from sites on well-drained soils as well as waterlogged environments. We will especially consider taphonomy as a crucial factor in the debate.

Early Neolithic

There are clear hints from Early Neolithic sites in the Near East that besides cereals (and other cultivars), plants gathered in the wild also played an important role in the economy. For one example see Fairbairn et al. (2002), dealing with burnt stocks of gathered plants in Catal Hüyük (Turkey).

Interesting new insights were also afforded by the investigations of an Early Neolithic (PPNC) submerged well at Atlit-Yam on the Mediterranean coast of Israel (Kislev et al. 2004). There, thousands of waterlogged seeds of over 90 taxa—including many gathered plants—were preserved. Amongst them, a poppy (*Papaver somniferum* s.l.) seed was found (the first ever found in the eastern Mediterranean). It had until then been believed that poppy cultivation originated in the western Mediterranean region. Perhaps this view has to be reconsidered (for an overview see Zohary et al. 2012).

In Italy it is also possible to compare plant spectra of Early Neolithic waterlogged settlements (e.g. the lake-dwelling of La Marmotta near Rome, dated to approx. 5400 cal BC: Rottoli 1993) with dryland sites from northeastern Italy such as Sammardenchia (Rottoli and Pessina 2007), where the seed concentrations deriving from well-drained pits (therefore poorly preserved) is low. In La Marmotta, many fruits and oil plants were found which are (not surprisingly) lacking in the northern Italian sites. Even when differences of the natural environment are considered, this is much more likely to be a typical taphonomical 'artefact'.

Other good examples are the plant spectra of the Early Neolithic Linearbandkeramik (LBK) culture (*c*.5500–5000 cal BC). There are many sites investigated (Kreuz et al. 2005; Kreuz 2007). With a very few exceptions, the data come from sites whose remains lie above the groundwater level on well-drained soils. There, only carbonized plant remains are preserved. Their density is often quite low and depends on feature type. The plant remains were usually found in pits (single pits or the so-called house accompanying pits). Their final function was for the deposition of settlement waste. The former layers (*Gehhorizont*) are not preserved.

Waterlogged structures from LBK times are rare. In the past three decades several wells have come to the light (one in the Rhineland Erkelenz-Kückhoven, western Germany (Knörzer 1998), and five near Leipzig (eastern Germany); see contributions and citations in Maier, in press). They date to the 53rd to 51st centuries cal BC. Since the fills of the wells seem to contain also refuse, to some degree the spectra are comparable to the 'usual' pit-fills.

Based on the data of carbonized remains, during LBK only a very limited range of crops (domesticates) was cultivated (Kreuz et al. 2005). The assemblages of edible plants in the sites on well-drained soils are dominated (to a large extent) by cereals, mainly einkorn (*Triticum monococcum*) and emmer (*T. dicoccum*). But pea (*Pisum sativum*), lentil (*Lens culinaris*), and flax (*Linum usitatissimum*) are also found regularly. These five taxa are seen as the main crops of the LBK Culture. Some rather rare finds of poppy are present from LBK phase II, onwards. There may however be regional and/or chronological differences, with a certain importance of barley (*Hordeum distichon/vulgare*) and rare hints of other cultivars (Kreuz et al. 2005; Kreuz 2007).

Besides these domesticates (in the case of the poppy this is not totally clear!), there are also plants which were collected in the wild. Hazelnut (*Corylus avellana*) shells and brome grass caryopses (*Bromus secalinus* mainly) are regularly present, followed by some finds of crab apple (*Malus sylvestris*) and sloe (*Prunus spinosa*). Only very rarely are there larger amounts of other probably gathered plants in a carbonized state (e.g. *Chenopodium album* seeds; see Kreuz 2007: 68). In most cases, however, gathered plants are very rare. The densities of collected taxa, even of the readily carbonizing remains such as hazelnut shells, are very low (hardly 0.1 per 10 litres).

Looking at the fills of the different LBK wells we see clearly the above-described 'typical' differences between waterlogged and charred preservation. Cereals are preserved in the wells, too, and the 'typical' LBK cereals, einkorn and emmer, prevail. However, only a limited number of the cereal remains (mostly chaff) are present in charred state, most of them preserved in subfossil state (similarly also in the lake-shore settlements, see below). In addition, there were considerable amounts of other cereals like hexaploid naked wheat (*Triticum aestivum*; Maier, 1996). Subfossil remains of flax and poppy were found often in large numbers in the wells. Concerning the latter two taxa, more remains came to the light in the first of the wells excavated (Erkelenz-Kückhoven in the Rhineland, Germany) than in all the other LBK sites. The most important LBK pulses, pea and lentil, are also present in the wells, but mostly in carbonized state. Pea pods in subfossil state were only found in the well fills (Maier, in press).

The remaining 'non-cultivar' useful plants are, not surprisingly, much better represented under waterlogged conditions in the wells. However, there seem to be large differences between the wells, with some containing a significant number of such taxa, including *Fragaria vesca*, *Rubus*, and *Sambucus*, others nothing at all (see Maier, in press). Other wild plants are often found in very large numbers (e.g. chenopods, which may also be collected crops). In the well fills, the spectrum of 'other' wild plant taxa is extremely diverse (usually >140 taxa per well—see Maier, in press). Plants from ruderal areas, woodland and woodland edges, grassland and wetlands are very well represented. In contrast, in LBK sites on well-drained soils, the wild plants in a carbonized state are often only field weeds (see Kreuz et al. 2005: 247–8, table 7—85 taxa from over 30 sites).

All in all, the few known waterlogged contexts from the LBK in central Europe mirror very well the evidence from dry ground sites. At the same time, they give some hints as to how the importance of some crops may have been underestimated, and suggest that collecting a broad range of taxa in the wild may have been more important than thought previously. In addition, the diversity of the environment becomes much clearer. However, it is still not fully understood whether the same type of material deposited in the wells is also found in the pits. Very similar results are also reported by Kroll (2007) concerning Funnel Beaker sites in northern Germany.

Late Neolithic

During the Late Neolithic—from around 4300 until around 2400 cal BC—there were many lake-dwellings in the surroundings of the Alps which have been excellently preserved in waterlogged conditions. For a summary of the genesis of the layers of these wetland sites, see Jacomet and Brombacher (2005).

Between the cereals, different types of wheat (*Triticum* div. spec.) and barley (*Hordeum vulgare*) are well represented in dry-ground and waterlogged sites. There are a few waterlogged settlement layers where the entire storages burnt down. One of the best examples is probably that of Hornstaad Hörnle I on Lake Constance where, around 3910 cal BC, the entire village was destroyed shortly after the harvest (Maier 1996; 2001). The site yielded thousands of very well-preserved carbonized cereal ears. Totally cleaned grain stocks which became carbonized during accidental conflagrations are also to be found in other parts of the Circum-Alpine region (e.g. Zürich Kleiner Hafner: Jacomet et al. 1989). The regular occurrence of such findings clearly shows the high importance of cereals in the economy of Neolithic lake-dwellings.

Other cultivars in the Late Neolithic were pulses, but only the pea is relatively well represented. Important domesticates during the Late Neolithic of central Europe were also poppy and flax. Large amounts of these taxa are preserved under waterlogged circumstances, and over 90 to even 100 per cent of the remains of poppy and flax are found in subfossil state. There may be concentrations of over 3,000 waterlogged poppy seeds per litre, and no carbonized finds at all (see e.g. Jacomet et al. 1989: 115, table 32 and fig. 49; and fig. 50, p. 119; Hosch and Jacomet 2004: 117, fig. 84). Only a few remains of these taxa are found in contemporaneous sites on mineral soils.

The same holds for larger parts of plants collected in the wild. In Arbon-Bleiche 3 (Hosch and Jacomet 2004: 118, fig. 85), where a surface sampling strategy with large bulk samples was applied, there were only four carbonized seeds of wild strawberry (*Fragaria vesca*) as opposed to 5,462 in waterlogged state. The only important collected plant for human consumption which appears more often in carbonized state is hazelnut. This is in complete agreement with observations of other colleagues from dry-land sites, (e.g. in the British Neolithic—Jones and Rowley-Conwy 2007). In the lakeshore settlement of Arbon-Bleiche 3 we found only 35 fragments of charred hazelnut shells, contrasting with the high number of 9,605 in subfossil state (Hosch and Jacomet 2004: 118, fig. 85). Nevertheless, the density of carbonized hazelnut shells was 8 per 10 litres—many times higher than in the above-mentioned settlement pits of well-drained soils; there, carbonized remains of strawberry reach only 9 per cent, and hazelnut 30 per cent in frequency (in waterlogged state both reach 100 per cent). Some of the plants gathered in the wild have also been found encrusted inside pots, proving that they were cooked (see Martinez Straumann 2004).

The above-mentioned examples allow the conclusion that in sites on well-drained soils most of the crop diversity is underrepresented. There are, however, exceptions. For instance, diversity can be rather high in the spectrum of carbonized plants, if the settlement happened to have been burnt down. This is particularly clear at Heilbronn-Klingenberg (Stika 1996), where the amounts of collected plants are larger and their diversity is higher than 'usual'.

Iron Age and Roman Period: plant assemblages from waterlogged structures vs those from well-drained terrains

One very good example of the difference between waterlogged and well-drained soil preservation is found in the southern Netherlands (excavations at Oss, location Ussen: Bakels 1998). Excavated farms dating from the middle phase of the Late Iron Age (500–250 cal BC) to the Roman Iron Age (12 BC–AD 200) yielded pits in their yards filled with waste, and there were also wells filled with waste after abandonment.

In the waterlogged sediments of wells, far more species were preserved than in the dry contents of the pits. For instance, during the Roman Iron Age the difference between well-drained and waterlogged structures is extraordinary (37 taxa from 38 dry features, vs 144 taxa from 18 wells). Furthermore, while cereals are well represented in both contexts, oil-containing seeds, condiments, and fruits are much more numerous in the waterlogged contexts.

Other very good examples from the Late Iron Age showing the much greater potential of waterlogged sources come from the salt-producing facility at Bad Nauheim, Hesse (Germany) (Kreuz and Boenke 2003). Here, most surprisingly, some cultivars such as coriander (previously thought to have been introduced by the Romans) were found in waterlogged pits. Such finds are completely underrepresented in the carbonized record.

Another site which provided extremely interesting waterlogged features is the site of Fellbach-Schmiden in Baden-Württemberg (Germany), where deep pits in a structure called *Viereckschanze* were excavated. The archaeobotanical investigations did not corroborate the theory that these pits were used for human sacrifice. In contrast, waterlogged preservation allowed the identification of a large number of plants (around 200 taxa—Körber-Grohne 1999) as well as animal dung (including that of chickens). Mainly taxa of grassland species were represented. The conclusion was that the *Viereckschanzen* must have been agricultural settlements. There were no hints which suggested ritual activity, at least in the botanical material.

In the region of Basel, in the last decades many Roman period sites have been investigated (Jacomet and Brombacher 2009). Most of the materials come from two larger town-like settlements, the *colonia Augusta Raurica* (Augst-Kaiseraugst, (northwestern Switzerland) and the somewhat smaller town of *Argentovaria* (Oedenburg, Biesheim-Kunheim, eastern France), 70km to the north. From Augst, only structures above the groundwater level with carbonized and rarely mineralized material came to light, whereas in Oedenburg a number of features were preserved in waterlogged conditions (Vandorpe and Jacomet 2011). The excavated structures of both settlements were sampled in a systematic way, with bulk samples of around 10 litres each.

Under both preservation conditions, cereals are well represented. The most important taxa are a multi-rowed hulled barley and spelt, but naked wheat, oats, and millet (*Panicum* *miliaceum*) are also present. Shell fragments of walnut (*Juglans regia*) and hazelnut are also well preserved in both carbonized and waterlogged conditions.

Much larger differences in the spectra arise with taxa groups which do not survive carbonization or have fewer chances of being carbonized. These include oil and fibre plants like hemp (*Cannabis sativa*), flax, and poppy. Almost all remains of these taxa are preserved in waterlogged state and in features under the groundwater level. We would, for instance, have no idea about the presence of hemp in the Basel region during the Roman period if no waterlogged features had been analysed.

This picture is mirrored exactly by the remains of fruits, vegetables, and spices (and also by a large part of wild plant spectra). Before analysing material from waterlogged structures, we had only a limited idea of the use of the above-mentioned groups of plants.

Conclusions

The case studies from different periods and different regions clearly show how crucial it is to consider taphonomical circumstances when interpreting archaeobotanical macroremain spectra. Many plants may be completely underrepresented or even lacking if preservation is not favourable. When building theories based on the results of archaeobotanical analyses, it has to be kept in mind that many taxa may be lacking if only the 'usual' charred remains are taken into account; only cereals and field weeds are well represented. In order to obtain more comprehensive results based on charred plant remains from burnt layers of well-drained soils, single episodes of catastrophic conflagrations have to be taken into account. These may, however, reflect only a very brief period. When such material is not available, even the sieving of many large bulk samples does not provide a full spectrum with reliable proportions of the taxa. However, analyses of sites on well-drained soils are by no means valueless. In fact, important parts of the economy (cereal cultivation) and agricultural practices (based on weed spectra) are still reconstructable. In considering such taphonomical aspects it becomes clear that the largest part of wetland sites is by no means a 'special case' (see Ebersbach, Chapter 17 this volume).

Waterlogged samples are extremely rich in organic remains. At first glance this is an advantage. However, there are also some disadvantages. The investment of time and labour is much greater, and treatment and storage much more complex, than in more common dryland sites. Therefore, we have to manage the situation carefully (as in the evaluations in York—Kenward and Hall 1995; see also Jacomet and Brombacher 2005), making sure that appropriate and standardized methods are applied.

A scientific examination of wetland sites is an extremely powerful instrument to reconstruct diet, subsistence, agricultural strategies, social and cultural role of food, exploitation of wild resources, fodder production, seasonality, and finally the environmental setting of a site. Interdisciplinary research is germane in wetland studies. Samples collected for archaeobotanical analyses can for instance also be used for other scientific investigation, such as those of small zoological items, and—in the case of profile columns—also for geoarchaeological studies. Because waterlogged settlement layers can be precisely dated by dendrochronology, short-term economical fluctuations can also be detected, as clearly demonstrated by the above-mentioned Neolithic site of Arbon-Bleiche 3 (Jacomet et al. 2004).

References

Akeret, O. and Rentzel, P. (2001) Micromorphology and plant macrofossil analysis of cattle dung from the Neolithic lake shore settlement of Arbon-Bleiche 3. *Geoarchaeology* 16.6: 687–700.

Bakels, C. C. (1998) Fruits and seeds from the Iron Age settlements at Oss-Ussen. *Analecta Praehistorica Leidensia* 30: 337–67.

Behre, K.-E. (2008) *Landschaftsgeschichte Norddeutschlands: Umwelt und Siedlung von der Steinzeit bis zur Gegenwart*. Neumünster: Wachholtz.

Charles, M. (1998) Fodder from dung: the recognition and interpretation of dung-derived plant material from archaeological sites. *Environmental Archaeology* 1: 111–22.

Dickson, C. (1989) The Roman army diet in Britain and Germany. In U. Körber-Grohne and H. Küster (eds), *Archäobotanik: Symposium der Universität Hohenheim (Stuttgart) vom 11.-16-Juli 1988*: 135–54. Berlin: Cramer.

Dickson, C. and Dickson, J. (2000) Late Bronze Age and Iron Age: brochs and crannogs. In C. Dickson and J. Dickson (eds), *Plants and People in Ancient Scotland*: 86–113. Gloucester: Tempus.

Dimbleby, G. W. (1985) *The Palynology of Archaeological Sites*. London: Academic Press.

Faegri, K. and and Iversen, J. (1989) *Textbook of Pollen Analysis*. Chichester: Wiley.

Fairbairn, A. S., Asouti, E., Near, J. and Martinoli, D. (2002) Macro-botanical evidence for plant use at Neolithic Catalhöyük, southern-central Anatolia, Turkey. *Vegetation History and Archaeobotany* 11.1–2: 41–54.

Hall, A. R. (1996) A survey of palaeobotanical evidence for dyeing and mordanting from British archaeological excavations. *Quaternary Science Reviews* 15: 635–40.

—— and Kenward, H. (1998) Disentangling dung: pathways to stable manure. *Environmental Archaeology* 1: 123–6.

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

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

Hosch, S. and Zibulski, P. (2003) The influence of inconsistent wet-sieving procedures on the macroremains concentration in waterlogged sediments. *Journal of Archaeological Science* 30: 849–57.

Jacomet, S. (2006) Plant economy of the northern Alpine lake dwelling area: 3500–2400 BC cal. *Environmental Archaeology* 11.1: 64–83.

—— (2007a) Plant macrofossil methods and studies: use in environmental archaeology. In S. A. Elias (ed.), *Encyclopedia of Quaternary Science*: 2384–2412. Oxford: Elsevier.

—— (2007b) Neolithic plant economies in the northern alpine foreland from 5500–3500 BC cal. In S. Colledge and J. Conolly (eds) *The origins and Spread of Domestic Plants in Southwest Asia and Europe*: 221–58. Walnut Creek CA: Left Coast Press.

—— (2009) Plant economies and village life in Neolithic lake dwellings at the time of the Alpine Iceman. *Vegetation History and Archaeobotany* 18: 47–59.

—— and Brombacher, C. (2005) Reconstructing intra-site patterns in Neolithic lakeshore settlements: the state of archaeobotanical research and future prospects. In P. Della Casa and M. Trachsel (eds), *WES '04: Wetland Econom*

tional Conference in Zurich, 10–13 March 2004: 69–94. Zurich: Chronos.

——— (2009) Geschichte der Flora in der Regio Basiliensis seit 7500 Jahren: Ergebnisse von Untersuchungen pflanzlicher Makroreste aus archäologischen Ausgrabungen. *Mitteilungen der Naturforschenden Gesellschaften beider Basel* 11: 27–106.

——— and Dick, M. (1989) *Archäobotanik am Zürichsee: Ackerbau, Sammelwirtschaft und Umwelt von neolithischen und bronzezeitlichen Seeufersiedlungen im Raum Zürich. Ergebnisse von Untersuchungen pflanzlicher Makroreste der Jahre 1979–1988.* Zurich: Füssli.

——— and Kreuz, A. (1999) *Archäobotanik: Aufgaben, Methoden und Ergebnisse vegetations- und agrargeschichtlicher Forschungen.* Stuttgart: Ulmer.

——— Leuzinger, U. and Schibler, J. (eds) (2004) *Die jungsteinzeitliche Seeufersiedlung Arbon Bleiche 3. Umwelt und Wirtschaft.* Frauenfeld: Kanton Thurgau.

Jones, G. E. M. (1991) Numerical Analysis in Archaeobotany. In W. van Zeist, K. Wasylikowa and K.-E. Behre (eds) *Progress in Old World Palaeoethnobotany*: 63–80. Rotterdam: A. A. Balkema.

Jones, M. (1991) Sampling in Palaeoethnobotany. In W. A. van Zeist, K. Wasylikowa and K.-E. Behre (eds) *Progress in Old World Palaeoethnobotany*: 53–62. Rotterdam: A. A. Balkema.

Jones, J., Tinsley, H. and Richard, B. (2007) Methodologies for assessment of the state of preservation of pollen and plant macrofossil remains in waterlogged deposits. *Environmental Archaeology* 12.1: 71–86.

Jones, G. and Rowley-Conwy, P. (2007) On the importance of cereal cultivation in the British Neolithic. In S. Colledge and J. Conolly (eds) *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*: 391–420. Walnut Creek CA: Left Coast Press.

Kenward, H. K. and Hall, A. R. (1995) *Biological Evidence from 16–22 Coppergate.* York: Council for British Archaeology for York Archaeological Trust.

——— and Jones, A. K. G. (1980) A tested set of techniques for the extraction of plant and animal macrofossils from waterlogged archaeological deposits. *Science and Archaeology* 22: 3–15.

Kislev, M., Hartmann, A. and Galili, E. (2004) Archaeobotanical and archaeoentomological evidence from a well at Atlit-Yam indicates colder, more humid climate on the Israeli coast during the PPNC period. *Journal of Archaeological Science* 31: 1301–10.

Knörzer, K.-H. (1984) Aussagemöglichkeiten von paläoethnobotanischen Latrinenuntersuchungen. In W. A. van Zeist and W. A. Casparie (eds), *Plants and Ancient Man*: 331–9. Rotterdam: Balkema.

——— (1998) Botanische Untersuchungen am bandkeramischen Brunnen von Erkelenz-Kückhoven. In H. Koschik (ed.) *Brunnen der Jungsteinzeit. Internationales Symposium Erkelenz 27. bis 29. Oktober 1997 (Materialien zur Bodendenkmalpflege im Rheinland 11*: 229–46. Köln und Bonn: Landschaftsverband Rheinland.

Körber-Grohne, U. (1999) Der Schacht in der keltischen Viereckschanze von Fellbach-Schmiden (Rems-Murr-Kreis) in botanischer und stratigraphischer Sicht. In G. Wieland (ed.), *Die keltischen Viereckschanzen von Fellbach-Schmiden und Ehningen*: 85–149. Stuttgart: Theiss.

Kreuz, A. (2007) Archaeobotanical perspectives on the beginning of agriculture north of the Alps. In S. Colledge and J. Conolly (eds) *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*: 259–94. Walnut Creek CA: Left Coast Press.

——— and Boenke, N. (2003) Hirsebrei, Feigen und . . . : Landwirtschaft, Umwelt und Ernährung im Bad Nauheimer Raum. In B. Kull (ed.), *Sole und Salz schreiben Geschichte: 50 Jahre Landesarchäologie–150 Jahre Archäologische Forschung Bad Nauheim*: 249–55. Mainz am Rhein: von Zabern.

Kreuz, A., Marinova, E., Schäfer, E. and Wiethold, J. (2005) A comparison of early Neolithic crop and weed assemblages from the Linearbandkeramik and the Bulgarian Neolithic cultures: differences and similarities. *Vegetation History and Archaeobotany* 14.4: 237–58.

Kroll, H. (2007) The plant remains from the Neolithic Funnel Beaker site of Wangels in Holsatia, Northern Germany. In S. Colledge and J. Conolly (eds) *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*: 349–58. Walnut Creek CA: Left Coast Press.

Kühn, M., Wick, L., Perego, R., Heitz, A. and Jacomet, S. (forthcoming) Animal husbandry regimes in Late Neolithic and Bronze Age lake dwellings in the Alpine foreland. *Vegetation History and Archaeobotany*.

Maier, U. (1996) Morphological studies of free-threshing wheat ears from a Neolithic site in southwest Germany, and the history of the naked wheat. *Vegetation History and Archaeobotany* 5: 39–55.

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

—— (in press) Der bandkeramische Brunnen von Leipzig-Plaußig: archäobotanische Untersuchungen. Dresden: Veröffentlichungen des Landesamtes für Archäologie mit Landesmuseum für Vorgeschichte.

—— and Harwath, A. (2011) Detecting intra-site patterns with systematic sampling strategies: archaeobotanical grid sampling in the lakeshore settlement Bad Buchau-Torwiesen II, southwest Germany. *Vegetation History and Archaeoabotany*.

MartinezStraumann, S. (2004) Makro- undmikroskopische Untersuchungen von Speisekrusten aus Keramikgefässen. In S. Jacomet, U. Leuzinger and J. Schibler (eds) *Die neolithische Seeufersiedlung Arbon Bleiche 3. Umwelt und Wirtschaft*: 277–82. Frauenfeld: Amt für Archäologie des Kantons Thurgau.

McCobb, L. M. E., Briggs, D. E. G., Evershed, R. P., Hall, A. R. and Hall, R. A. (2001) Preservation of fossil seeds from a 10th century AD cess pit at Coppergate, York. *Journal of Archaeological Science* 28.9: 929–40.

Merlin, M. D. (2003) Archaeological evidence for the tradition of psychoactive plant use in the old world. *Economic Botany* 57.3: 295–323.

Pearsall, D. M. (2000) *Paleoethnobotany: A Handbook of Procedures*. San Diego, Calif.: Academic Press.

Retallack, G. (1984) Completeness of the rock and fossil record: some estimates using fossil soils. *Paleobiology* 10/11.1: 59–78.

Robinson, D. E. (2002) Domestic burnt offerings and sacrifices at Roman and pre-Roman Pompeii, Italy. *Vegetation History and Archaeobotany* 11.1–2: 93–9.

Robinson, M. and Hubbard, R. N. L. B. (1977) The transport of pollen in the bracts of hulled cereals. *Journal of Archaeological Science* 4: 197–9.

Rottoli, M. (1993) La Marmotta, Anguillara Sabazia (RM): Scavi 1989. Analisi paletnobotaniche: prime risultanze. *Bullettino di paletnologia italiana* 84: 305–15.

—— and Pessina, A. (2007) Neolithic agriculture in Italy: an update of archaeobotanical data with particular emphasis on northern settlements. In S. Colledge and J. Conolly (eds) *The Origins and Spread of Domestic Plants in Southwest Asia and Europe*: 140–54. Walnut Creek CA: Left Coast Press.

Schiffer, M. B. (1991) *Formation Processes of the Archaeological Record*. Albuquerque, NM: University of New Mexico Press.

—— (2002) *Behavioural Archaeology*. New York: Percheron Press.

Smith, B. D. (2001) Low-level food production. *Journal of Archaeological Research* 9.1: 1–43.

Stika, H.-P. (1996) *Vorgeschichtliche Pflanzenreste aus Heilbronn-Klingenberg: Archäobotanische Untersuchungen zum Michelsberger Erdwerk auf dem Schlossberg (Bandkeramik, Michelsberger Kultur, Späthallstatt/Frühlatène).* Stuttgart: Theiss.

Tolar, T., Jacomet, S., Veluscek, A. and Cufar, K. (2009) Recovery techniques of waterlogged archaeological sediments: a comparison of different treatment methods of samples from Neolithic lake shore settlements. *Vegetation History and Archaeoabotany* 19.1: 53–67.

Valamoti, S. M. and Charles, M. (2005) Distinguishing food from fodder through the study of charred plant remains: an experimental approach to dung-derived chaff. *Vegetation History and Archaeoabotany* 14.4: 528–33.

Van Der Veen, M. (2007) Formation processes of desiccated and carbonized plant remains: the identification of routine practice. *Journal of Archaeological Science* 34: 968–90.

—— and Fjeller, N. R. J. (1982) Sampling seeds. *Journal of Archaeological Science* 9: 287–98.

Vandorpe, P. and Jacomet, S. (2007) Comparing different pre-treatment methods for strongly compacted organic sediments prior to wet-sieving: a case study on Roman waterlogged deposits. *Environmental Archaeology* 12.2: 207–14.

——— —— (2011) Plant economy and environment. In M. Reddé (ed.), *Oedenburg II-2: Fouilles Françaises, Allemandes et Suisses à Biesheim et Kunheim, Haut-Rhin, France*: 3–72. Mainz: Römisch-Germanisches Zentralmuseum.

van Zeist, W. A., Wasylikowa, K. and Behre, K.-E. (eds) (1991) *Progress in Old World Palaeoethnobotany: A Retrospective View on the Occasion of 20 Years of the International Work Group for Palaeoethnobotany.* Rotterdam: Balkema.

Weiss, E., Wetterstrom, W., Nadel, D. and Bar-Yosef, O. (2004) The broad spectrum revisited: evidence from plant remains. *Proceedings of the National Academy of Sciences of the United States of America* 101.26: 9551–5.

Willerding, U. (1991) Präsenz, Erhaltung und Repräsentanz von Pflanzenresten in archäologischem Fundgut. In W. A. van Zeist, K. Wasylikowa and K.-E. Behre (eds) *Progress in Old World Palaeoethnobotany*: 25–51. Rotterdam: A. A. Balkema.

Wilkinson, K. and Stevens, C. (2003) *Environmental Archaeology: Approaches, Techniques and Applications.* Stroud: Tempus.

Zohary, D., Hopf, M. and Weiss, E. (2012) *Domestication of Plants in the Old World: The Origin and Spread of Cultivated Plants in West Asia, Europe and the Nile Valley.* Oxford: Oxford University Press.