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Wild plant use in European Neolithic subsistence economies: a formal assessment of preservation bias in archaeobotanical assemblages and the implications for understanding changes in plant diet breadth

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ABSTRACT

In this paper we estimate the degree to which the range and proportion of wild plant foods are under-represented in samples of charred botanical remains from archaeological sites. We systematically compare the differences between central European Neolithic archaeobotanical assemblages that have been preserved by charring compared to those preserved by waterlogging. Charred archaeobotanical assemblages possess on aggregate about 35% of the range of edible plants documented in waterlogged samples from wetland settlements. We control for the ecological availability of wetland versus terrestrial wild plant foods on assemblage composition and diversity, and demonstrate that the significantly broader range of wild plant food taxa represented is primarily a function of preservation rather than subsistence practices. We then consider whether observed fluctuations in the frequency of edible wild taxa over time can also be attributed to preservation, and demonstrate that it cannot; and thus conclude that there are significant changes in plant food diets during the Neolithic that reflect different strategies of land use and, over time, a decreasing reliance on foraging for wild plant foods. The wild species included in our analyses are not spatially restricted—they are common throughout central Europe. We maintain, therefore, that our results are relevant beyond our study area and more generally illustrate the challenges of attempting to reconstruct the relative importance of wild plant foods—and thus plant diet breadth—in Neolithic archaeobotanical assemblages from charred data alone.

1. Introduction: charred plant remains, missing plant foods, and Neolithic subsistence economies

The disparity between the quantity and range of remains preserved in waterlogged and charred form has long been recognised. This is apparent with regard to both crops and wild taxa and, for example, records of waterlogged specimens can outnumber those of charred specimens by hundreds, or even thousands (Brombacher and Jacomet, 1997, Tables 36 and 37; Heer 1865; Jacomet, 2013, 501; Jacomet et al., 1989, Tables 32–34, Figs. 49 and 50; Jacomet et al., 2004, Figs. 84 and 85). Despite this, reconstructions of European Neolithic plant-based diets have unavoidably tended to use the more durable macrofossils, mainly charred seeds and grains of domestic crop species, to make inferences about food choices that emphasise the contribution of cultivars to total diet. Bogucki (2000, 204), for example, states: "The earliest farming communities in north-central Europe grew a suite of crops, including emmer and einkorn wheat, barley, peas, flax and poppy… A recurring set of weeds of cultivation occurs among the carbonized seed samples, but otherwise no wild plants figure prominently in the subsistence of the early farmers." (for further examples see papers in: Colledge and Conolly, 2007; Douglas Price, 2000; Fairbairn, 2000; Milles et al., 1989; Van Zeist et al., 1991). However charred remains represent only a small and biased sample of the edible plant taxa used by Neolithic societies. Our ability to establish the composition and overall contribution of plant-based diets in subsistence is thus biased and inherently limited because of this largely unavoidable reliance on charred macrofossils. Hillman refers to the undetectable component of the diet as the 'missing foods' (Hillman, 1989), and we here present our attempt to identify the extent to which our reconstructions of food choices are biased on the basis of a comparative analysis of waterlogged versus charred plant assemblages from central European Neolithic sites.

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1.1. Formation and interpretation of archaeobotanical samples

In comparison to charring, preservation by waterlogging in anoxic or anaerobic conditions results in less taphonomic bias and the composition of waterlogged samples is likely to resemble more closely the original suites of plants utilised (Jacomet, 2013, 500; Willerding, 1971, 181). There is little or no discrimination (e.g., on the basis of robustness of plant components) as to what is preserved: soft fruits, underground storage organs and leafy vegetables, together with more fragile plant parts, such as pericarp, leaves, flowers, catkins, etc., that rarely survive after exposure to heat remain intact and, by comparison, overall losses are relatively small.

Pétrequin's ethnographic accounts of the deposition and accumulation of debris from daily activities at the pile-dwelling villages of the Toffinu on Lake Nokoué in the Republic of Benin are pertinent to the present study (Pétrequin, 1986). The Toffinu ("men of the water") were previously dryland farmers who subsequently adapted to living on marshes and lakes in pile-dwellings. Pétrequin notes that food waste (including nuts, seeds, grains, shells and fish bones) was thrown into the water through trap doors in floors in the kitchen areas (Pétrequin, 1986, 65). Likewise, human excrement was discharged via openings in houses directly onto the waterlogged sediments below. Rubbish accumulated into dumps that formed artificial islands and use was made of these as small livestock pens. Waste from several families would often form larger islands that provided shelter for larger animals such as cattle. There was a process of sorting on/in the sediments according to density or size of the organic elements ejected from the houses. Pétrequin describes patterns of deposition in layered lenses of a variety of anthropogenic debris at different depths of water such that heavier items (logs, branches) settled further out into the lake and lighter ones closer to the shore (Pétrequin, 1986: Fig. 14). The cycle of deposition of organic materials, accumulation and incorporation in waterlogged sediments continued after houses were abandoned and had collapsed into the water, contents (e.g., tools that were hung from walls) often settled in exactly in the same place as they had done when the houses were occupied.

Changes in the chemical balance of the water or waterlogged sediments (e.g., addition of chemical contaminants, changes in the availability of oxygen or increased acidity or alkalinity) can, however, initiate the decomposition process and also create conditions in which bacteria that cause organic decay are activated (Brinkkemper, 2006; Caple and Dungworth, 1998; Holden et al., 2006). Decomposition of plant materials may be accelerated in near surface sediments, which are more prone to periodic drying-out and higher rates of oxygen diffusion than those at greater depths, however there appears to be no consensus as to whether or not this is the case for all sites (e.g., urban versus rural settlements; Caple and Dungworth, 1998, Section 3.7; Carrott et al., 1996, 7; Jones et al., 2007, 83; Kenward and Hall, 2000; Willerding, 1991, 31). Moreover, waterlogged deposits of plant remains are relatively rare across Neolithic Europe and are restricted to the Alpine lakes and very few other wetland areas in northern Europe (e.g., northern Germany: Kirleis et al., 2012; Kroll, 2007; Netherlands: Kubiak-Martens, 2006, 2012; Out, 2009; Raemaekers et al., 1997; Van Haaster, 2001). Neolithic wells are as rare in central Europe but several structures have been found with stratified waterlogged deposits (e.g., below the water table) and from which diverse assemblages of plant remains have been recovered (Zerl and Herbig, 2012).

Plant materials used as fuels are a common source of charred remains, as are stored products that are destroyed in accidental or deliberate fires (e.g., to dispose of infested crops, or as a result of acts of violence; Van der Veen, 2007, 979). In addition, charred remains typically derive from the unintentional burning of plant foods and plant materials during preparation, processing or cooking (Hillman, 1981, 139–140). Modern charring experiments have demonstrated that the ability of plants to survive is dependent on their morphology (i.e., both physical and chemical) and on the construction, temperature and duration of the fires (Boardman and Jones, 1990; Guarino and Sciarrillo, 2004; Gustafsson, 2000; Märkle and Rösch, 2008; Wilson, 1984; Wright, 2003). Dry seeds with low densities combust more readily when heated and are more likely to survive intact than those that are fresh and have higher densities. Equally likely to survive are specimens with low oil content (Wilson, 1984, 204–205; Wright, 2003, 578). The experiments also demonstrate that plant materials burned in a reducing atmosphere (e.g., buried in the deposits underlying the fire or completely embedded within its fabric) can withstand higher temperatures for longer than under oxidising conditions and that exposure to intense heat over long periods results in the greatest losses (Boardman and Jones, 1990, Fig. 1; Wilson, 1984, Table 6; Wright, 2003, 578). Cereal chaff was shown to be less durable than grains at high temperatures (Boardman and Jones, 1990, 4–6 and Fig. 1); other less robust plant parts, such as soft fruits, leaves, roots/rhizomes/bulbs (etc.), are rarely preserved in charred assemblages (Willerding, 1971, 1991).

The seeds of some species are able to withstand considerable additional heat after charring and prior to total destruction whereas others have a much narrower range of survival and are thus more fragile in charred form. In oxidising conditions, for example, cereals tolerate greater increases in temperature than oil rich seeds such as *Linum usitatissimum* (domestic flax) and *Papaver somniferum* (opium poppy) before being reduced to ash (Boardman and Jones, 1990, 4–5; Märkle and Rösch, 2008, S260–261). The fragility of the plant components is highlighted by the fact that proportional losses after burning have been shown to be great: in experimental firing of hearths and houses between 60 and 80% of cereal grains failed to survive and there were similar, if not greater losses for seeds of wild species (Guarino and Sciarrillo, 2004, Figs. 3, 6 and 11; Gustafsson, 2000, Figs. 3 and 6). Archaeological samples after burning are therefore likely to comprise species with more resilient seeds and the probability is low that their overall composition bears direct relationship to the original taxa proportionality or diversity. Incomplete burning resulting in charring is a means by which only a subset of the plants originally used at a settlement survives and partial destruction is a more apt description of the process than preservation (cf. Wilson, 1984, 201).

In spite of these taphonomic limitations the analytical scope of charred assemblages is considerable. Charred remains dominated by crops (e.g., cereals and pulses) and wild plant species (e.g., mostly those common to cultivated fields) are ubiquitous on Neolithic and later sites across Eurasia (Hillman, 1981; M. Jones, 1984, 1988; Knörzer, 1971, 90–91; Van der Veen, 1992, 77). Their great interpretative strength hinges on the overall representational consistency of crops and wild species, thus facilitating spatial and temporal comparisons between sites or groups of sites (for example, see papers in Colledge and Conolly, 2007). The frequency with which the charred assemblages occur has enabled the development of sophisticated models concerning all aspects of arable farming systems: from the apportioning of responsibilities for production (at inter- and intra-site levels), the type of cultivation systems implemented, the organisation and scheduling of labour, the pre- and post-harvest tending of fields and crops, and the storage, processing and preparation of crops prior to consumption (whether by humans or animals). The basis for the interpretative models is the quantitative assessment of inter-assemblage compositional variability in the proportions of grains, chaff and seeds of wild plants.

The similarity was noted at early Neolithic Bulgarian sites, in terms of the ratios of grains to chaff and grains to weed seeds, between archaeobotanical samples and the various stages in the sequence of crop processing leading up to and including storage and cooking (Dennell, 1972, 1974). The significance of being able to identify the type of processing activities that took place was recognised, as was the necessity to take into account the effect of taphonomic filtering (e.g., as crops are cleaned and chaff and weed contaminants are removed by winnowing, sieving, etc.) prior to reconstructing subsistence economies (Dennell, 1974, 283). Hillman's seminal works in the 1970s, 1980s (Hillman, 1973, 1981, 1984), based on his ethnographic studies at agricultural settlements in the Aşvan region (Elâziğ province) in Turkey, strengthened this comparative approach by establishing a direct association between the modern crop processing discard recorded at the village farms and the archaeological samples. More specifically the uniqueness in composition of crop processing products and by-products enabled accurate categorisation of the archaeobotanical assemblages and the cultivation methods from which they derived, for example, including details of tillage and harvesting techniques, sowing times and post-harvesting processing stages prior to the final preparation of the crops for consumption (Hillman, 1984; G. Jones, 1984; Jones et al., 2005). The potential to classify ancient farming systems in terms of arable versus pastoralist economies, or producer versus consumer settlements, and to distinguish between intensive and extensive forms of agricultural production was realised by the use of ecological methods to assess the composition of weed species in charred assemblages (Bogaard, 2004; Jones, 1988; Van der Veen, 1992; see also Stevens, 2003; Van der Veen and Jones, 2006). In areas where woodlands are sparse and fires are of necessity fuelled by animal dung it has also been possible on the basis of charred seeds and cereal chaff preserved within matrix of the dung to gain insights into aspects of animal husbandry (e.g., livestock diets, mobility and seasonality of herding) and to what extent arable and pastoral economies are integrated to ensure sustainable systems of production for both crops and livestock (Bottema, 1984; Charles, 1998; Miller, 1984, 1999; Miller and Smart, 1984; Wallace and Charles, 2013).

1.2. Problem definition

We seek to quantify and to understand the source of variation in the range of wild plant use at Neolithic sites in central Europe. In particular, we wish to establish the degree to which samples of charred remains are correlated with low wild plant taxa diversity and samples of waterlogged remains with high plant taxa diversity and whether or not any correlations can be explained either by taphonomy or as a function of different types of foraging opportunities. To answer this question we compare taxonomic similarities and differences at a representative sample of Neolithic sites at which preservation of plant materials by both charring and waterlogging is recorded. We attempt to control for variation in foraging opportunity by selecting sites that are all adjacent to water or wetlands (e.g., settlements on or near lakes, watercourses and marshes) so we can a priori anticipate that they share a similar range of available plant species.

1.2.1. Context

The tradition of constructing waterside pile-dwelling settlements ('*Pfahlbauten*') is common in the Alpine region between c.4300 and 700 cal BC and approximately 750 sites are known from six countries bordering the Alps, of which c.450 are in Switzerland (Hafner and Schlichtherle, 2006/2007, 175; UNESCO Welterbe Prähistorische Pfahlbauten; UNESCO World Heritage Candidature 'Prehistoric Pile Dwellings around the Alps'). House construction at these sites was modified to facilitate habitation in wetland environments, floors were elevated either on a framework of wooden supports over waterlogged sediments, or raised much higher on stilts above open water, and sometimes they were built directly on to the ground surface, covered in a waterproof layer of clay with added insulation of various plant materials (Hofmann, 2013, 199; Menotti, 2012, 134).

Densities of settlement at the lakes fluctuated, the most populated periods were when lake levels were low, and vice versa (Arbogast et al., 2006). Regional scale synchroneity of settlement patterns is cited in support of arguments that favour climate as the underlying cause for the changes in occupancy at the lakesides (i.e., warm/dry phases coincidental with low lake levels, cold/wet phases with high lake levels; for contrary argument see Bleicher, 2013). However, on the basis of exceptions, e.g., sites that are occupied during periods of elevated lake levels, some authors doubt that climate is the sole cause and suggest that the oscillations in population size had sociological origins (Pétrequin and Bailly, 2004, 44). Using the example of the population dynamics at Lakes Chalain and Clairvaux (in the French department of Jura) Pétrequin proposes that displacements between the two were part of *les modalités normales* during the later phases of the Neolithic (with evidence of five population displacements between c.3800-2200 cal BC; Pétrequin, 2005, Fig. 7) and were in response to depletion of local resources at one lake in favour of plentiful supplies at the other (Pétrequin, 2005, 798–799). High population densities therefore alternated between Chalain and Clairvaux and were not necessarily linked to lake levels. There is no doubt, however, that at various times during Jungneolithikum (younger Neolithic) and Spätneolithikum (late Neolithic) many sites on the lakes in southern Germany and Switzerland were abandoned and/or occupation deposits lost or truncated due to water erosion (in particular for the period between 3550 and 3250 cal BC) and thus settlement evidence is scarce (Arbogast et al., 2006, 408–409).

1.2.2. Neolithic plant representation: wetland versus dryland preservation

Preservation conditions at wetland settlements are optimal for all discarded organic materials that fall into the water and become embedded within waterlogged sediments (see Jacomet and Kreuz, 1999, 102–3; Willerding, 1991, 32–33 and Tables 3 and 5). For example, at Arbon Bleiche 3 it is estimated that about 800,000 waterlogged remains would have been recovered if the whole site had been excavated (extrapolated from around 21,000 items sorted from a 20 m^2 section; Jacomet et al., 2004, 416) and with preservation conditions in the cultural deposits that are described as 'near optimal' the average number of items per litre of sediment is 10,000 (Jacomet et al., 2004, 384). Equally large quantities are recorded at other sites: at Horgen Scheller 495,108 items are identified in layers 3 and 4, and seed concentrations per litre are approximately 10,000 and 7,000, respectively for the two layers (Favre, 2002, Fig. 180); at Pfäffikon Burg 122,469 plant remains are recorded in 54 samples with an average concentration of 11,700 items per litre (Zibulski, 2010, 239); and at Bad Buchau-Torwiesen II 429,734 remains were sorted from 537 samples with an average density of c.12,000 items per litre (Maier and Harwath, 2011, 351).

The quantities of charred remains found on dryland sites are, in contrast, small and the densities are much lower (see Jacomet and Kreuz, 1999, 102–103). To highlight how extreme the differences can be we here refer to sites at which preservation is by charring (i.e., no waterlogged remains have been found), as is the case for the vast majority of Neolithic sites in central Europe. On wetland settlements, where there is evidence of burning episodes (either small scale, e.g., domestic hearths and ovens, or at a larger scale, e.g., catastrophic conflagration events), charred remains are much

Table 1
Sites and samples used in the analyses (sample details checked against Brombacher and Jacomet, 1997, Table 36; Jacomet and Brombacher, 2005, Table 1).

	Culture (date cal BC)	Site	Samples included in the study					Sample details
			∑ Samples	∑ Volume[a]	∑ Charred taxa	Systematic sampling (e.g., profile, surface grid)	Other (e.g., random, single samples)	
Endneolithikum	Corded ware (2700–2400)	Zürich, Mozartstrasse[1]	73	36	12	x		Profile samples taken from layer 2
		Hegne-Galgenacker[2]	13	Not known	1	x		Borehole samples
		Zürich, Mythenschloss[1]	14	28	12	x		Profile samples taken from layer 2
		Zürich-Seefeld (Kansan)[1]	57	45	38	x		Profile samples taken from layers A, B/C, D, E/F
Spätneolthikum	Late Horgen/ Goldberg III Group (2900–2800)	Alleshausen-Grundwiesen[3]	28	20	11	x		Samples taken across the site from a range of contexts (e.g., floors, fireplaces, peat layers, remains of animal feed, etc.)[f]
		Seekirch-Achwiesen[3]	9	6	13	x		1999 samples: profile P1(layers 2, 3a, 4, 5a, 5b) and single samples from layers in profile: E1 (detritus layer: wood fragments, seeds, bark, coprolites, etc.), E2 and E3 (clay layer: animal bones, charcoal, coprolite fragments, seeds, etc.)[f]
		Seekirch-Stockwiesen[3]	25	8	6	x		Samples from houses 1, 3, 4, 6 and 8 (internal and external contexts)[f]
	Middle Horgen (3200–3000)	Zug-Vorstadt 26[4]	1	3	15		x	Sample taken from excavation trench section III
		Pfäffikon-Burg[5]	43	188	27	x		Samples taken across the site (on a m^2 grid plan) from A (earliest) and B (middle) phases
		Horgen-Scheller[6]	62	59	25	x		Samples taken across the site (on a m^2 grid plan) from layers 3 and 4
		Sipplingen-Osthafen[7]	19	Not known	17	x		Profile samples from layers 11–15
		Zürich, Mozartstrasse[1]	68	37	23	x		Profile samples taken from layer 3
		Zürich-Seefeld (Kansan)[1]	64	53	37	x		Profile samples taken from layers 2, 2A, 3, 4
		Sutz-Lattrigen (Lattrigen Hauptstation VII)[8]	69	30	24	x		Gridded samples taken from the earlier occupation phase (layers 1–3)
	Early Horgen (3400-3200)	Bad Buchau-Torwiesen II[9]	46	21	21		x	Samples taken from a cultural layer (refuse areas in and around houses) on the basis of subjective assessment of relative density of plant remains
		Arbon Bleiche 3[10]	33	185	35	x		Samples taken across the site (on a m^2 grid plan) from the cultural layer
		Nidau-Schlossmatte/ BKW[8]	30	24	15	x		Gridded samples taken from cultural layer 5
Jungneolithikum	Pfyn/Altheim/ Cortaillod (3900–3400)	Pestenacker[11]	72	18	10	x		Samples taken from section 15 (layers 6.5–6.84); volume calculated on the basis of 72 samples (33 layers) of c. 250 ml each
		Ergolding-Fischergasse[12]	22	[b]155	7	x		Samples taken from cultural layers in sections 1–5; volume based on total weight of 22 samples of 194 kg (weight of 1 L of soil c. 0.8 kg)
		Delémont-En La Pran[13]	14	[b]18	1	x		Samples taken from dated sequence of layers (3.601–3.703) in area D; volume based on total weight of 14 samples of 14.7 kg (weight of 1 L of soil c. 0.8 kg)
		Niederwil[14]	4	Not known	2		x	Bulk sampling of cultural layer
		Port Stüdeli[15]	16	7	32		x	Samples taken from upper and lower cultural layers within burnt levels on the basis of subjective assessment of relative density of plant remains; volume based on 16 samples with total volume of 6.99 L
		Zürich, Mozartstrasse[1]	51	30	23	x		Profile samples taken from layer 4
		Ödenahlen[16]	8	Not known	25	x		1982 samples taken from profiles G20-24, G41, G50 and E1
		Sipplingen-Osthafen[17]	57	Not known	24	x		Layers 7–9 sampled in 18 profiles located at regular intervals across the excavation area
		Thayngen-Weier[18]	10	Not known	12	x		Samples taken from layers 1–8 in transect through the site; single sample taken from a byre context
		Zürich-AKAD/ Pressehaus[1]	128	210	17	x		Profile samples taken from layer J
		Zürich-Seefeld (Kansan)[1]	33	18	31	x		Profile samples taken from layers 5 and 9
		Seeberg Burgäschisee-Süd[19]	35	Not known	12	x		Profile samples taken from cultural layer in sector 34D (including lowest level comprising burnt debris) and also several bulk samples
		Zürich, Mozartstrasse[1]	45	c	19	x		Profile samples taken from layers 5 and 6
	Egolzwil/ Schussenried/ Older Cortaillod (4400–3900)	Zürich, Kleiner Hafner[1]	17	d	17	x		Profile samples taken from layer 4E/F
		Alleshausen-Hartöschle[3]	39	12	33	x		Samples taken from houses 1 and 2 (internal and external contexts)[f]
		Zürich, Kleiner Hafner[1]	16	e	11	x		Profile samples taken from layer 4A/B
		Egolzwil 3[20]	103	82	21	x		Samples taken from a profile (dug through cultural layer 86/87) and also across the site (on a m^2 grid plan)
		Zürich, Kleiner Hafner[1]	16	6	12	x		Profile samples taken from layer 5A/B

Site references: [1]Brombacher and Jacomet 1997; [2] Rösch 1990; [3]Maier 2004; [4]Jacomet and Wagner 1987; [5]Zibulski 2010; [6]Favre 2002; [7]Jacomet 1990; [8]Brombacher 1997; [9]Herbig 2006; [10]Jacomet et al., 2004; [11]Neef 1990; [12]Hinton 1995; [13]Brombacher and Klee 2009; [14]Van Zeist and Casparie 1974; [15]Brombacher and Jacomet 2003; [16]Maier 1995; [17]Riehl 2004; [18]Robinson and Rasmussen 1989; [19]Villaret-von Rochow 1967; [20]Bollinger 1994.

[a] To the nearest litre.

[b] Approximate volume only.

[c] Jacomet and Brombacher (2005) record total volume of 26 L for profile, judgement and surface samples. [d] Jacomet and Brombacher (2005) record total volume of 8 L for profile, judgement and surface samples. [e] Jacomet and Brombacher (2005) record total volume of 5 L (for layers 4A-C/D) for profile, judgement and surface samples. [f] See note in Maier 2004 (77, Section 1.4).

better preserved than on dryland sites (Jacomet, 2013, 501); therefore, in comparison with waterlogged samples from the same sites the disparity in quantities of remains is not as great. For example, at Hornstaad-Hörnle 1A (a pile dwelling dated to the Pfyn culture and located on Lake Constance) over 150,000 charred remains were recovered from the 20-cm-thick burnt layer (fire horizon AH2) that represented destruction by fire of the entire village (Maier, 2001, 26).

Based on data recorded from 80 phases at 51 Neolithic sites (dated from the early to final Neolithic) in western central Europe, where preservation of plant remains is predominantly by charring (e.g., 0.14% of the total number of identified specimens is mineralised), the average number of charred seeds and fruits per phase is 6154 with a density of 14 per litre (Kreuz, 2012; see Tables 3 and 4). For 210 Neolithic sites (comprising 246 phases; date range: 6000–2500 cal BC) located in central and northwestern Europe, and at which only charred plant remains are recorded, there is an even lower average value of c.2800 specimens per phase, for 63% ($n = 156$) of the 246 phases there are data on volumes processed and the average number of specimens per litre is c.10 (for 37% of phases, $n = 90$ volumes are either not provided, are incomplete or are imprecise; data taken from the EUROEVOL database). There are also marked differences between the two preservation forms in terms of the numbers of individual taxa identified and far fewer charred than waterlogged taxa are recorded; for example, on average less than ten, or in some instances five, species are identified in charred form in comparison with over 100 species in waterlogged form (Jacomet, 2013, 501; Jacomet et al., 1989, 75 and Fig. 33; see also Willerding, 1991, Table 3).

1.3. Hypotheses

Our primary focus is on the composition of the wild plant food diet, as this is the obvious missing component from most charred assemblages that preferentially record domestic cereals and pulses. Our three hypotheses address the representativeness of edible wild plants preserved in waterlogged and charred form, and also the significance or otherwise of changes over time in the frequency of use of wild plant foods.

1. Charred archaeobotanical samples under-represent the range of wild plant foods used by central European Neolithic populations;
2. Observed higher wild taxa diversity at wetland versus dryland sites is a product of better preservation not broader-spectrum subsistence strategies or wider local taxa availability;
3. Observed fluctuations in the frequency of edible wild plant use over time are driven by preservation bias rather than behavioural changes in subsistence practices.

2. Materials and methods

2.1. Sites and samples

Our study is based on published archaeobotanical reports from 27 sites dated between 4400 and 2400 cal BC located in southern Germany (in Bavaria and Baden Württemberg) and Switzerland (in the cantons of Berne, Jura, Luzern, Neuchâtel, Schaffhausen, Thurgau, Zug and Zürich) (Table 1, Fig. 1). The sites comprise 35 phases representing Egolzwil, Schussenried, Cortaillod, Pfyn, Altheim, Horgen, Goldberg III group and Corded Ware cultures of the Jungneolithikum (younger Neolithic), Spätneolithikum (late Neolithic) and Endneolithikum (final Neolithic; for cultural designations and date ranges see: Manning et al. in press). The relative order of sites and phases is according to the earliest and latest dates of occupation shown in Jacomet and Brombacher 2005, Table 1. All but one of the sites, Delémont-En La Pran (canton of Jura), are recorded as pile-dwellings; samples for analysis at Delémont-En La Pran were taken from the former meander of a stream and the authors comment that the site was probably located in the vicinity of the earlier watercourse (Brombacher and Klee, 2009, 77).

Details of samples and sampling methods for the sites in the study are given in Table 1. At most sites recovery of environmental materials was a priority and sampling strategies devised to maximise retrieval of plant remains were implemented from the outset of the excavations. Size of samples as well as scope of sampling (e.g., in terms of spatial coverage) were adapted with the aim of recovering suites of taxa that as closely as possible typified the range of plants originally present (i.e., representative samples; Van der Veen and Fieller, 1982). Sampling methods were also designed to encompass the various depositional environments represented by waterlogged plant remains (Jacomet and Brombacher, 2005; Jacomet and Kreuz, 1999, 96–102). Subjective or judgement samples refer to those taken where there are visible clusters of remains, e.g., stores of crops, threshing waste, latrine deposits, etc. (referred to as closed assemblages '*geschlossenen Fundkomplexen*'; Brombacher and Jacomet, 1997, 220), which correspond to discrete zones of activity probably relating to routine, repeated domestic processes. Less well defined deposits (open assemblages: '*offenen Fundkomplexen*'), which are typically representative of disparate activities carried out over longer periods of time, are more appropriately sampled in a gridded system with samples taken at regular intervals across a site, or in profiles to give an indication of diachronic changes in layer composition. Systematic sampling is more likely to produce a greater diversity of taxa than judgement sampling, but the latter provides information about routine activities involving plants and plant products that contribute to intra-site studies, e.g., how internal space is used on settlements (see Maier and Harwath, 2011). Our intention was to investigate inter-site rather than intra-site variations in composition and therefore, where possible, it was considered more appropriate to use data derived from systematic sampling methods (e.g., that are likely to reflect mixed deposits of plant debris; Jacomet pers. comm.; Hosch and Jacomet, 2001, 62).

The large number of samples taken at many of the sites (the average per site/site phase is 40) is an indication of the effort expended in an attempt to optimise recovery of plant materials. Corresponding volumes are relatively small (average per sample: 1 L) but because of the excellent preservation of plant materials in sediments on wetland settlements it has been found necessary to process only small amounts in order obtain representative samples (see Van der Veen and Fieller, 1982): 5–15 L are suggested for most sites where there is good preservation of organic remains, and even smaller volumes have been shown to be sufficient for deposits with very high densities (Greig, 1989, 25; Jacomet and Kreuz, 1999, 103; Jacomet and Brombacher, 2005, 83). In contrast, sampling for charred remains on dryland sites where preservation is poor requires much larger samples, typically 20–75 L (Campbell et al., 2011, 34; Greig, 1989, 22–23; Jacomet and Kreuz, 1999, 103).

The data used in our analyses are the amalgamated records of taxa from multiple samples taken from each site and phase in which both charred and waterlogged remains are identified (with the exception of Zug-Vorstedt 26, where a single sample only is reported). At a majority of the 35 phases (89%, $n = 31$) the sampling was systematic (e.g., samples were taken either from profiles or on the basis of gridded surface collections, see Table 1) and at only 11% ($n = 4$) were samples collected on the basis of subjective assessment of the relative density of plant remains in the occupation deposits (e.g., at Port Stüdeli, Bad Buchau-Torwiesen II, Zug-Vorstedt 26 and Niederwil). It is important to note that for 31%

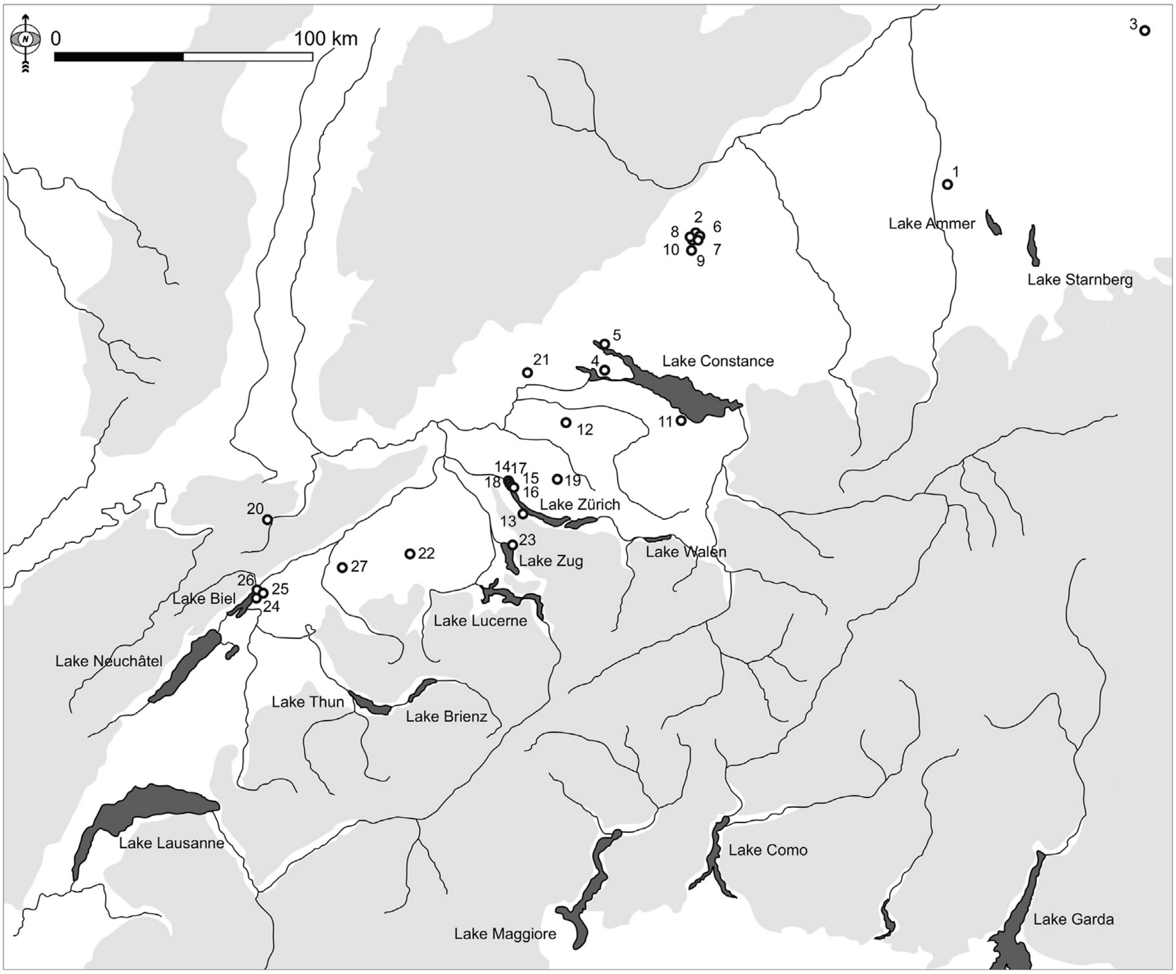

Fig. 1. Map of the study area showing location of sites. Key: 1: Pestenacker; 2: Ödenahlen; 3: Ergolding-Fischergasse; 4: Hegne-Galgenacker; 5: Siplingen-Osthafen; 6: Seekirch-Stockwiesen; 7: Seekirch-Achwiesen; 8: Alleshausen-Grundwiesen; 9: Bad Buchau-Torwiesen II; 10: Alleshausen-Hartöschle; 11: Arbon Bleiche 3; 12: Niederwil; 13: Horgen-Scheller; 14: Zürich, Kleiner Hafner; 15: Zürich-AKAD/Pressehaus; 16: Zürich-Seefeld (Kansan); 17: Zürich, Mozartstrasse; 18: Zürich, Mythenschloss; 19: Pfäffikon-Burg; 20: Delémont-En La Pran; 21: Thayngen-Weier; 22: Egolzwil 3; 23: Zug-Vorstadt 26; 24: Nidau-Schlossmatte/BKW; 25: Port Stüdeli; 26: Sutz-Lattrigen (Lattrigen Hauptstation VII); 27: Seeberg Burgächisee-Süd.

(n = 11) of the phases the volumes sampled are less than the minimum suggested (e.g., 20 L, see previous paragraph) to ensure recovery of representative numbers of taxa from charred assemblages (between 20 and 210 L have been sampled for 49% [$n = 17$] of the phases; and for 20% [$n = 7$] the sample volumes are not known; the average volume per phase is 48 L). For just under a third of the 35 phases there is the possibility therefore that the validity of our comparisons of different forms of preservation is undermined because of the under-representation of charred remains due to insufficient sample sizes. However, a linear regression analysis of the relationship between sample size and number of identified taxa shows virtually zero correlation; in other words, with regards to charred remains wetland sites are subject to less sample size effects than dryland sites. We are therefore confident that our use of amalgamated records from small volume samples does not compromise our comparisons of taxa diversity within charred versus waterlogged samples.

All waterlogged and charred plant remains that are listed and described in published reports for the 27 sites were recorded in a database according to chronological phase (as shown in Table 1); database records include identifications of whole and fragmentary seeds/fruits, whole and fragmentary cereal chaff, fragments of pericarp, whole and fragmentary storage organs (roots/rhizomes/bulbs), fragments of leaves, stems, catkins and flowers (total number of records: 2269). Our analyses are based on presence records and ubiquity scores (i.e., the number of samples in which a taxon is present as a percentage of the total number of samples per phase).

2.2. Edibility score

Vegetal refuse that accumulates in living spaces at settlements is not exclusively food or food waste but also comprises floor sweepings, cleanings from hearths and ovens, crop processing debris, human and animal faecal matter, artefacts such as baskets and textiles, insulation and building materials (Jacomet and Brombacher, 2005, 87; see also Willerding, 1991, Tables 2 and 5). Moreover, the distinction between edible and non-edible wild taxa in archaeobotanical samples is far from straightforward and particularly so for waterlogged remains that consist of large quantities of plants and plant products from diverse domestic activities. Several authors comment on the problems of identifying potential food plants and note there are possibly many more than are included in published lists of gathered species but that this is difficult to prove (Jacomet 2009, 53; Jacomet et al., 2004, 394; Kirleis et al., 2012, 235; Out 2012, 207–9; Robinson and Harild 2002, 93; Tolar et al., 2011, 212; see also Kreuz 2012, 116–117, who identifies 75 wild plant foods common on LBK (Linearbandkeramik) sites, including species with edible parts other than seeds/fruits). Dietary reconstructions are often based on those referred to as "obviously gathered plants" (Jacomet, 2009, Table 2; Jacquat, 2005, 121–122) and for which edibility is beyond doubt, including mainly species whose fruits and nuts are consumed (see also lists of taxa in: Karg and Märkle, 2012; Tolar et al., 2011). These still represent only a small proportion of the taxa identified on wetland settlements. Remains of wild plants found in human coprolites or embedded in residues inside cooking pots, and their co-occurrence in samples with other non-plant foods provide further confirmation of the edible status of certain taxa (Jacomet et al., 2004, 395; Jacquat, 2005, 126; Out, 2012, 207). For example, a recent publication cites the presence of *Alliaria petiolata* (garlic mustard) phytoliths embedded in Danish Ertebølle and Funnel Beaker culture ceramics as proof that at an early date the plant was used as a spice (Saul et al., 2013).

For our analyses we required a more systematic means of identifying edible wild taxa than context alone. We thus adopted a classification system that could be applied generally to sites, regardless of quality of preservation, settlement type or geographic region. The 'Plants For A Future' (PFAF) database (http://www.pfaf.org/) has records of about 7000 species in which each is given an edibility and medicinal rating on a 1-5 scale (5 being the most edible), together with details of plant parts that are edible (or used as spices, flavourings, infusions, etc.), how to prepare for consumption, nutritional details (calorific content, protein, mineral, vitamins, etc.), toxicity, and also growth habit, ecology, and other non-culinary uses. For each entry there is a full list of references drawn from an extensive bibliography of about 300 publications.

Of 378 wild taxa identified to family or lower rank represented at the 27 sites 61% ($n = 230$) could be assigned an edibility rating of between 1 and 5 in the PFAF database and for the remaining 39% ($n = 148$) there were either no known uses or no entries in the database (Table 2). Parts of many of the 1–2 rated wild taxa (35%, $n = 134$) are noted as being mildly or highly toxic and so we excluded these from our analyses on the basis that their edibility is considered questionable. We included only taxa rated 3–5 (25%, $n = 96$) in our data set for this study (hereafter referred to as the edible wild taxa). A majority (74%, $n = 71$) of these are classified as having more than one part that can be eaten. For 73% ($n = 70$) the leaves, stems, young shoots, seedpods are eaten (or used as spices, flavourings, infusions, etc.); 63% ($n = 60$) have seeds and fruits (including nuts: fruits with a hard shell enclosing a seed) that can be consumed; for 28% ($n = 27$) the underground storage organs (roots, rhizomes, bulbs) are commonly gathered for use; 24% ($n = 23$) have edible flowers/flower buds; and taxa with other useful parts (e.g., oils, sap, bark, pollen) constitute 16% ($n = 15$) of the total.

2.3. Ecological rating

Reconstruction of where in the surrounding landscape edible wild resources were collected is far from straightforward (e.g., uniformitarianism cannot necessarily be assumed; Cappers, 1995). Most settlement contexts (e.g., cultural layers, pits fills, middens, latrines, wells, etc.) are composed of mixed deposits that contain plant materials derived from a wide range of habitats; these are referred to by Willerding as thanatocoenoses—collections of species from different plant communities that are amalgamated as a result of secondary deposition (Willerding, 1991, 34–36 and Table 5). Less common are deposits that comprise palaeobiocoenoses—naturally co-occurring groups of species that decayed in situ (see Penney et al., 2012). The latter includes what Willerding defines as autochthonous plants, which are found in the immediate vicinity of lake settlements, e.g., marshland, peat and floodplain species.

To determine the habitats, and thus the likely collection source, the edible wild taxa represented at the 27 sites were classified according to the vegetation units described by Ellenberg (1988). Our method follows that used in many of the archaeobotanical analyses of the Swiss lake settlements (e.g., including Brombacher and Jacomet, 1997; Favre, 2002; Hosch and Jacomet, 2001, 2004; Zibulski, 2010). Taxa are grouped into eight vegetation units as described in Table 3.

3. Results

3.1. Hypothesis 1

The data set for the 27 sites includes 1068 records by presence of the 96 edible wild taxa. A majority of records (87%, $n = 924$) are in waterlogged form and only 13% of records ($n = 144$) are in charred form (see Table 4 for list of the most frequently occurring taxa in the samples). All 96 edible wild taxa are represented in the waterlogged remains and 34 are present in the charred remains. Our first hypothesis is thus supported: assemblages from non-waterlogged sites, on aggregate, represent 35% of the suite of edible wild taxa, versus the 100% representation on wetland sites. We conclude that reconstructions of total plant diet based on charred remains alone are undoubtedly misleading as a majority of the exploitable taxa is missing.

Note, however, that for domestic cereal grains (e.g., individual specimens and those enclosed within whole spikelets) of which there are 230 records by presence, a majority are in charred form (85%, $n = 195$) and only 15% ($n = 35$) are waterlogged; similarly, for pulses (e.g., domestic pea) a greater proportion is preserved in charred (67%) than in waterlogged form (33%; total number of records: 27). This suggests that charring is the primary vector by which domestic cereal grains and pulses enter the archaeological record. The former are more commonly represented in waterlogged form by fragments of bran—the cellular layers that comprise the testa and pericarp, which is problematic to identify, and this can result in an apparent under-representation in quantified lists of cereal taxa (Dickson, 1987; Greig, 1981, 271, 280; Holden, 1990; Jacomet et al., 2004, 392; Jacomet and Brombacher, 2005, 88). In contrast, spikelet forks, glume bases, rachis fragments, glumes, culm fragments, indeterminate threshing waste, etc., are better represented in waterlogged form and in our data set of the 392 records by presence, 50% of chaff specimens are waterlogged and 50% are charred. In waterlogged samples the possibility exists therefore that there is an under-representation of cereals—in the absence of evidence for chaff, and pulses.

3.2. Hypothesis 2

To test the second hypothesis we first established habitats for 96 edible wild taxa represented at the 27 sites. We amalgamated

Table 2
Classification of wild taxa (identified to species, genus, family) represented at the 27 sites included in the study according to edibility ratings in 'Plants for a Future' database (http://www.pfaf.org).

Edibility rating	Numbers of taxa
1–2	134
3–5	96
No known uses	37
No records available	111
	378

records for vegetation in units 3–5 to represent open herbaceous and grassland landscapes subject to disturbance by humans and animals, and also those in units 7–8 to include both the broad-leaved and needle-leaved (coniferous) woodlands, and related communities.

A minority of both waterlogged (8%, $n = 73$) and charred (3%, $n = 5$) records are classified under vegetation unit 1: plants that live in permanently waterlogged habitats (e.g., belonging to rooted water plant communities and reed and tall sedge swamps, Ellenberg, 1988, 665; Table 5). Taxa that grow in non-aquatic habitats dominate both the waterlogged and charred assemblages. Almost half the records for waterlogged remains ($n = 460$) are of taxa common in woodland edges/clearings and woodlands/woodland communities (units 6 and 7–8), with just over a third (37%, $n = 338$) representative of more open landscapes belonging to vegetation units 3–5. The same trend is apparent for the charred remains: 67% of records ($n = 97$) are for taxa found in units 6 and 7–8 and only 25% ($n = 36$) are present in the plant communities of units 3–5. Of the 96 edible wild taxa the highest proportion grow in habitats classified under vegetation units 3–5 (43%, $n = 41$; Table 6), with slightly fewer common to woodland edges/clearings and woodlands/woodland communities of units 6, 7–8 (41%, $n = 39$). Table 7 presents examples of the calorific values (kcal/100g) of commonly occurring taxa (all of which are represented at the study sites) by vegetation units. Of the seeds and fruits listed (i.e., the plant food types that predominate in both waterlogged and charred records, see Table 4) those common in woodlands have the highest values (with the exception of mustard seeds in units 3–5 that are not considered likely to have contributed greatly to the diet).

The waterlogged samples in our analysis do not reflect a wetland-focused gathering strategy but instead, like the charred remains, indicate foraging in woodlands and woodland edges/clearings, or open habitats. We thus conclude that this foraging strategy is not specific to the sites we have used in our analysis and was practiced throughout the region during the Neolithic. Our hypothesis that higher taxa diversity in waterlogged samples from wetland sites versus charred samples from dryland sites is a function of preservation, not foraging strategies, is thus upheld.

3.3. *Hypothesis 3*

To assess change over time in the frequency of edible wild taxa representation (i.e., those preserved in waterlogged form only), the sites and phases were grouped chronologically by culture (as listed in Table 1). Mean ubiquity scores were calculated for taxa within these groups according to vegetation units 3–5, 6 and 7–8. Fig. 2 is a comparison of mean ubiquities for the six cultural groups (see also Table 8). As can be seen, mean ubiquity varies by period but values for taxa of woodland edges/clearings and woodlands/woodland communities (units 6, 7–8) are consistently higher than those for the more open landscapes (of units 3–5; cf. hypothesis 2 results). There are periods of high mean ubiquities (i.e., greater use) in the earlier part of the younger Neolithic (c.4400-3900 cal BC) when it is thought by some authors there was expansion of cultivable land into forests using slash-and-burn (swidden) agriculture (Rösch, 1993; Schier, 2009; Schier et al., 2013; for contrary arguments see: Jacomet et al., 2004, 399; Maier, 1999, 90–91; see also Bogaard, 2004, 96–99). Similarly high values, most notably for taxa of woodland edges/clearings, occur in the early late Neolithic (c. 3400–3200 cal BC), which are interpreted as indicating greater exploitation of the ‘hinterlands’ (literally: the land behind) during periods of elevated lake levels and when population densities are low (Arbogast et al., 2006, 408–409; Jacomet et al., 2004, 387; Schibler and Jacomet, 2010). Low mean ubiquities are recorded at the end of the late Neolithic (i.e., after 3000 cal BC), which are coincidental with the earliest systematic use of ards and cattle traction for ploughing that facilitated a significant increase in the extent of cultivable land (Pétrequin, 2005, 799–801; Schlichtherle, 2006).

Aquatic plants are rare in samples recovered from wetland settlements, which suggests, as has been argued under hypothesis 2, that a majority of the assemblages represents the edible wild plants collected from areas beyond the immediate environs, in the open landscapes and bordering woodlands (Hosch and Jacomet, 2001, 65; Jacomet and Brombacher, 2005, 75; Jacomet et al., 2004, 387–397; see also reconstruction of landscape around Hornstaad Hörnle IA on Lake Constance, Menotti, 2012, 107, citing Maier, 2001, 166, Fig. 106). Changes in the frequency of use of the edible wild plants could therefore be related to changes in the mosaic of vegetation communities around the settlements and to the relative availability of certain taxa. Pollen data from cores taken at the Alpine lakes show that until the beginning of the younger Neolithic the surrounding areas were heavily forested with little sign of human impact other than small-scale clearance events (Lechterbeck et al. in press; Rösch, 1993, 2013). Spectra from higher in the profiles indicate that shrubs and coppiced woodland of hazel and birch dominated, and a corresponding increase in micro-charcoal is thought to be associated with the management of woodland by burning (Jacomet et al., 2004, 391; Rösch, 1993; Schier, 2009; Schier et al., 2013).

We conclude that changes in the frequency of use of edible wild taxa during the period c.4400-2400 cal BC are not caused by preservation bias, but instead are behavioural and correlate with major changes in land use. Hypothesis 3 is thus rejected. Increased use of wild plant foods of woodlands and associated habitats relates to foraging beyond the immediate surroundings of the lake settlements, as in the earlier part of the younger Neolithic when there was systematic clearance to increase cultivable land and in the early late Neolithic when woodlands were managed, for example, for the use of timber, fodder and firewood. Decreased use at the end of the late Neolithic is coincidental with the beginning of extensive agriculture, when there was large-scale production of domestic grain crops and seemingly a decreased dependence on wild plant foods.

Table 3
Descriptions of vegetation units (Ellenberg, 1988, 664–674).

Vegetation units	Description
1	Freshwater and mire vegetation
2	Saltwater and sea coast vegetation
3	Herbaceous vegetation and frequently disturbed sites
4	Stony sites and Alpine grasslands
5	Heaths and grasslands determined by human and animal activity
6	Woodland-related herbaceous perennial and shrub communities
7	Needle-leaved woodland and related communities
8	Broadleaved woodland and related communities

4. Discussion

4.1. *Charred versus waterlogged preservation*

There has been a long history of research into preservation conditions on Alpine lake settlements and the disparity between quantities of waterlogged and charred plant remains are particularly well documented at these sites (Brombacher and Jacomet, 1997, Tables 36 and 37; Heer 1865; Jacomet, 2013, 501; Jacomet et al., 1989, Tables 32–34, Figs. 49 and 50; Jacomet et al., 2004,

Table 4
Edible wild taxa represented in over 50% of waterlogged and charred records (in descending order of frequency of occurrence), together with details of parts of the plants that are edible.

	Common names	Numbers of records		Edible part/s (as listed in: http://www.pfaf.org/)
		Waterlogged	Charred	
Malus sylvestris	Crab apple	57	27	Fruit, oil
Corylus avellana	Hazel/nut	33	15	Nut/oil
Fragaria vesca	Strawberry	31		Fruit/leaves
Rubus fruticosus	Blackberry	30		Fruit/leaves/root
Rubus idaeus	Raspberry	30	11	Fruit/leaves/root
Fagus sylvatica	Beech/nut	28		Nut/leaves/oil
Urtica dioica	Common nettle	28		Leaves/oil
Quercus spp.	Oak/acorn	26		Nut
Physalis alkekengi	Bladder cherry	26		Fruit/leaves
Rubus caesius	Dewberry	25		Fruit
Sambucus spp.	Elder/berry	23		Fruit
Rosa spp.	Rosehip	23		Seeds/fruit/flowers
Brassica rapa	Turnip/rape	23	10	Leaves/root
Chenopodium album	Fat hen	23	9	Seeds/leaves/flowers
Phragmites australis	Common reed	22		Seeds/leaves/stem/rhizome
Origanum vulgare	Oregano	21		Leaves
Sambucus nigra	Elder/berry	19		Fruit/flowers
Arctium minus	Lesser burdock	19		Seeds/leaves/stems/roots
Prunus spinosa	Blackthorn/sloe	19		Seeds/fruit/flowers
	Total number of records	506	72	

Table 5
Proportional representation of records for wild edible taxa in waterlogged and charred form classified according to Ellenberg's vegetation units.

Units		Numbers of records		% of total	
		Waterlogged	Charred	Waterlogged	Charred
1	Freshwater and mire vegetation	73	5	8	3
2	Saltwater and sea coast vegetation	9	0	1	0
3–5	3: Herbaceous vegetation of frequently disturbed sites; 4: stony sites and alpine grassland; 5: heaths and grasslands determined by human and animal activity	338	36	37	25
6	Woodland-related herbaceous perennial and shrub communities	197	41	21	28
7–8	7: Needle-leaved woodland and related communities; 8: broadleaved woodland and related communities	263	56	28	39
	Unassigned taxa	44	6	5	4
	Total number of records	924	144		

Figs. 84 and 85). For example, relative proportions of waterlogged and charred specimens have been calculated for several of the settlements on Lake Zürich and range from between about 80% waterlogged to 20% charred and 95% waterlogged to 5% charred (e.g., see Brombacher and Jacomet, 1997, Table 37; see also Willerding, 1991, Table 3 in which the ratios of waterlogged to charred taxa at Neolithic and Bronze Age sites are comparable). Differences are as exaggerated in samples taken from basal deposits within the shafts of two LBK wells in central Europe, at Erkelenz-Kückhoven (North Rhine-Westphalia) 84% of all cultivated plants are uncharred and only 16% are charred and a comparable trend is noted in samples from the well at Brodau (Saxony; Zerl and Herbig, 2012, 4–5). The authors also note that cereal grains are only found in charred form in both wells whereas the chaff is both charred and uncharred, the latter being far more common (Zerl and Herbig, 2012, Figs. 3 and 4). Pulses are also found with greater frequency in charred form, as has been noted at several of the Lake Zurich sites (Jacomet et al., 1989, 60, Tables 11 and 36; see also Knörzer, 1971, 90). Similar proportional disparity is noted in a study of formation processes at four Libyan and Egyptian sites in which Van der Veen calculates that assemblages comprise about 80% desiccated and 20% charred remains (Van der Veen, 2007, Table 1). Our results for edible wild taxa are in accordance with these data and confirm that overall losses in taxa diversity due to charring are likely to be in the order of 65%. It follows that the spectrum of edible resources is incomplete on most dryland sites (i.e., in the absence of preservation by desiccation) and that the chances of being able to reconstruct dietary diversity are inherently limited (Tolar et al., 2012, 54).

4.2. Use of wild plant foods

The range of wild plant foods used at many central European Neolithic settlements is greatly underestimated, largely because of the difficulty of proving edibility (Jacomet, 2009, 53; Jacomet et al., 2004, 394; Out, 2012, 207–9; Tolar et al., 2011, 212). Interpretations

Table 6
Classification of the 96 edible wild taxa (i.e., with edibility rating 3–5) included in the study according to Ellenberg's vegetation units.

Units:	1	2	3–5	6	7–8	Un/ass	Total
No. taxa per unit	12	1	41	14	25	3	96

Table 7
Dietary contribution: calorific values by vegetation unit for selected plant food groups (cultivated crops also included for comparison) [all data from: http://www.nutritionvalue.org Accessed: 14 July 2013].

		kcal/100g
Units 3–5		
Leafy vegetables	e.g., Mustard greens turnip greens, nettles	33
Oils	e.g., Mustard oil	884
Root vegetables	e.g., Turnips, parsnips	52
Spices – leaf	e.g., Mint, thyme	86
Spices – seed	e.g., Mustard seed	508
Fruits – soft	e.g., Blueberries	57
Unit 6		
Fruits – soft	e.g., Strawberries, blackberries, raspberries, elder berries	50
Spices – leaf	e.g., Basil, oregano	144
Units 7–8		
Fruit	e.g., Cherries, apples, crabapples, rose-hips	88
Nuts	e.g., Pine nuts, acorns, beechnuts, hazelnuts	560
Spices	e.g., Wild garlic	149
Cultivated fields		
Cereals – bread		270
Cereals – cooked grain	e.g., Bulgur	105
Cereals – flour	e.g., Wheat, barley, millet	353
Cereals – grains	e.g., Wheat, barley, millet	344
Peas – raw		81
Peas – dried		341
Flax – seeds		534
Poppy – seeds		525
Oils	e.g., Poppy seed oil, flaxseed oil, grapeseed oil	884
Fruits – soft	e.g., Grape	57

of diet-breadth are consequently based on a much-reduced number of taxa. Leafy greens/vegetables and root foods, for example, are rarely considered as having any dietary significance and are absent from most published lists of gathered plants, even though they are represented in archaeological samples.[2] If these missing components are taken into account the potential calorific contribution to the diet of edible wild plants is estimated as being between 30–40% (Arbogast et al., 2006, 410; Jacomet, 2009, 54; Jacomet et al., 2004, 396). At Arbon Bleiche 3 calorific yields are calculated using standardised "grain units" and, on the basis of the proportional contribution of each of the major plant food types, gathered plants (37%) are higher than both cereals (34%) and oil plants (29%; Jacomet et al., 2004, 396).

More generally, we propose that studies of Neolithic land use should consider the significant contribution that foraging for wild resources makes to diets of even more recent 'agricultural' societies (cf. Jacquat, 2005, 122). For many indigenous societies who exploit multiple animal and plant species, including domesticates, the status of wild foods is elevated. For example, it was shown in a recent survey of agricultural and forager communities in 22 Asian and African countries that an average of 120 wild species per community is used (Bharucha and Pretty, 2010). Many of the edible wild plants are managed to enhance yields (e.g., by sowing seeds, irrigation of wild stands, burning to encourage new growth, replanting root foods, etc) and there is, therefore, often far less significance associated with the connotations of wild and cultivated (or wild and domesticated). The assumed dichotomy between forager and farmer is, to a large extent, invalid (Bharucha and Pretty, 2010, 2914–2915). Wild plants can have varied uses

[2] In most instances for taxa with edible plant parts that are less durable, e.g., leaves, stems, roots/rhizomes, bulbs, etc., which occur infrequently in archaeological deposits, we only have indirect evidence of their use in the form of seeds/fruits.

Table 8
Comparison of mean ubiquities of waterlogged edible wild taxa by vegetation units (refer to Table 1 for sites/site phases included in the cultural groups).

Cultural groups [number of sites/site phases]	cal BC	Ellenberg's vegetation units:		
		3–5	6	7–8
Egolzwil/Schussenried/ Older Cortaillod [5]	4400–3900	23.85	48.68	37.72
Pfyn/Altheim/Cortaillod [13]	3900–3400	19.57	38.21	24.27
Early Horgen [3]	3400–3200	28.80	54.23	32.07
Middle Horgen [7]	3200–3000	24.37	45.34	46.38
Late Horgen/Goldberg III Group [3]	2900–2800	18.81	39.00	35.80
Corded Ware [4]	2700–2400	16.17	49.96	39.40

(e.g., 80% of the 62 edible wild species used in Nepal are recorded as having multiple uses; Bharucha and Pretty, 2010, 2916 and Tables 3–5) and, as is emphasised in ethnobotanical and ethnohistorical accounts, their value is not always necessarily measured in terms of overall calorific return (e.g., high carbohydrate/starch content) but equally important for a balanced diet is the nutrient content (e.g., minerals and vitamins; Bharucha and Pretty, 2010, 2917; Ertuğ, 2009, 67; Grivetti and Ogle, 2000; Jacquat, 2005, 126). Grivetti and Ogle describe many instances in village communities where malnutrition and deficiency diseases are prevented by eating wild plant foods with high mineral and vitamin contents (e.g., in eastern Niger where over 93% of families are recorded as using more than 80 wild species with high levels of copper, iron, magnesium and zinc; and, similarly, the surveys report 280 wild herbs and vegetables used in Korea and 241 wild plants in Zambia that provide vital mineral and vitamin supplements; Grivetti and Ogle, 2000, 36–37). Recognition that wild greens/vegetables in particular are an important source of nutrients is apparent from the ethnobotanical studies of three regions in central and southwest Turkey (Aksaray, Bodrum and Buldan) where proportional use of species for their leaves and shoots is high (e.g., more than is recorded for any other edible plant part); raw or cooked shoots of the young plants provide important nutrient supplements when cultivated varieties aren't available, i.e., between harvests: from October to May (Ertuğ, 2009, 65–67 and Tables 8.2 and 8.3). Ertuğ stresses that wild plants are thought of not only as food substitutes in times of scarcity, for example, when crops fail, but many are chosen for their health-giving properties and superior taste (Ertuğ, 2009, 67–68). Gathering and preparation of wild plants as ingredients for meals on special occasions are also a means by which local customs and cultural identities are maintained (Ertuğ, 2009, 68–69).

4.3. Land use and availability of wild plant foods

Domestic cereals are the staple crops at all sites throughout the study period but at certain times and to varying degrees it is suggested that wild gathered foods provide important dietary supplements. Use of woodland/forest resources is emphasised at several Horgen Culture sites; for example, on the basis of proportions of wild taxa classified according to ecology those found in forests occur most frequently in the samples from the four occupation phases at Pfäffikon-Burg and together with taxa common to clearings they dominate the assemblages (Zibulski, 2010, Fig. 399). Similarly at Arbon Bleiche 3, the plant remains provide evidence of collection strategies focussed on the forest/forest edges, and the authors comment it was likely that "an array of different management practices was employed in order to benefit most from this landscape" (Jacomet et al., 2004, 387). The age ranges of waterlogged timber and branches at the site

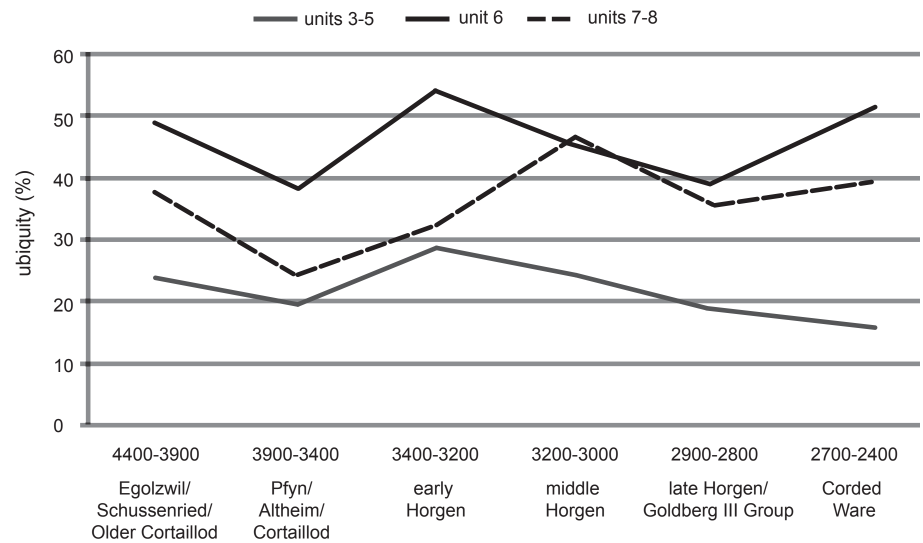

Fig. 2. Comparison of mean ubiquities of waterlogged edible wild taxa in vegetation units 3–5, 6 and 7–8 for the six cultural groups (dates in cal BC; see Table 8 for details).

are indicative of careful management of tree species, such that those with better quality wood for construction purposes or with plentiful fodder for livestock (e.g., oaks) were preferentially left, whereas other species were felled for firewood and leafy hay, thereby opening up woodland to enhance areas for grazing and foraging (Jacomet et al., 2004, 391; see also Schibler, 2006, 60). On the basis of the identification and measurement of the diameters of wood charcoal from the late Neolithic site of Chalain 4 Dufraisse also concludes that trees used for building materials, fodder and for their edible fruits/seeds were preserved at the expense of those that were selectively cut down for use as fuel (Dufraisse, 2008). Reduction of density of trees/tree canopy in this way would have favoured more light-demanding, fruit-bearing trees, shrubs and herbaceous species including: hazel, hawthorn, blackthorn, crab apple, elder, raspberry, blackberry (brambles), and strawberries, which would have attracted human and animal foragers. These more open areas in the woodlands would thus have become the focus for collecting and hunting of wild resources. In North American Aboriginal societies, mixed economies were common, as management of woodlands through burning and selective felling to increase foraging productivity particularly for nuts and deer (Delcourt and Delcourt, 2008).

5. Conclusion

Our work emphasises the importance of taphonomic biases in the reconstruction of Neolithic plant economies. That waterlogged remains provide more robust samples for full spectrum dietary reconstruction is not a new finding, but the significance of our work is that we have been able to demonstrate that waterlogged samples provide insight into the wild plant food foraging component of the diet that is otherwise under-represented in charred samples. Furthermore, the differences in taxa representation between contemporaneous sites with waterlogged assemblages versus those where there are only charred remains are, we maintain, principally a result of preservation: the differences do not derive from different plant use strategies. In order to build more complete understanding of plant food economies it is thus essential to integrate both waterlogged and charred samples—the former offer insight overall plant diet breadth, whereas the latter are the foundation for reconstructions of crops and arable farming systems. The results of our comparative study of wild plant foods can be extrapolated more widely to make predictions about plant use in Neolithic contexts in areas where only dryland sites exist. Similar comparative studies on preservation bias are needed for the Bronze and Iron Ages; but we suspect diets were similarly broader than those that can be reconstructed from study of charred assemblages alone.

The focus of most past and recent research has been on cultivation strategies, as in the early Neolithic Linearbandkeramik cultures of central Europe where, for example, assemblages of crop and weed species have been used to differentiate between intensive versus extensive techniques, to identify sowing times and harvesting methods, and to infer possible spheres of influence with neighbouring cultural groups and thus the derivation of the farming system (Bogaard, 2004, 2012; Kreuz, 2012, 78–90). However, wild plants obtained from foraging activities were also a component of subsistence economies and diets throughout the Neolithic and the recognition of their value to Neolithic societies has some significant implications for how we interpret subsistence behaviour. Building understanding of Neolithic diet breadth and wild plant food foraging behaviour can provide complementary insights into land use and mobility, as we have demonstrated in this study. Central place foraging models (e.g., Bird, 1997; Zeanah, 2004) may in this regard be useful for examining shifts in composition of wild plant food diets, as such models provide robust frameworks for predicting the circumstances in which foragers will increase or decrease diet breadth. Although beyond the scope of this present study, we believe exploring Neolithic diets from a central place foraging perspective to be a source of considerable insight. To realise these objectives, however, requires a more complete record of plant use than is typically available for most study areas and is only likely to be an achievable goal in specific preservational contexts.

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