The Permanence, Intensity and Seasonality of Early Crop Cultivation in Western-Central Europe

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Volume 1
Text

Thesis submitted in fulfilment of the Degree of Doctor of Philosophy

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October, 2002

Table of Contents

Volume 1

Volume 2

Acknowledgements

Glynis Jones (supervisor) has been an exceptional teacher and guide throughout this project. Paul Halstead (advisor) answered many questions about farming and made his extensive ethnographic field notes available.

Of the many archaeobotanists who provided advice and information, I would particularly like to thank the following people for generously allowing me access to their unpublished data: Corrie Bakels, Stefanie Jacomet and her colleagues in Basel, Sabine Karg, Ursula Maier, Ulrike Piening, Simone Riehl, Manfred Rösch and Hans-Peter Stika.

I am grateful to John Hodgson for his expert advice on field identifications and plant ecology and for access to unpublished botanical survey data from the Sheffield region. Andrew Askew, Stuart Band and Ken Thompson of the Unit of Comparative Plant Ecology also provided various forms of assistance.

I would like to thank Rüdiger Krause and Manfred Rösch of the Landesdenkmalamt Baden-Württemberg for allowing me to work on the archaeobotanical material from Vaihingen. Rüdiger Krause also provided unpublished information on the site of Vaihingen. I would also like to thank Jutta Meurers-Balke, Jens Lüning and Wilhelm Lohmeyer for the opportunity to analyse unpublished data from the Hambach Forest experiment.

Funding for this project was provided by a doctoral fellowship from the Social Sciences and Humanities Research Council of Canada, a tuition grant from the Overseas Research Fund and a grant to cover remaining tuition fees from the University of Sheffield. The John Ray Trust provided additional funding for travel/fieldwork.

Equally critical for this project was the encouragement and support of my family and friends. Mike played multiple supporting roles (chauffeur, chef, consultant etc.) with patience and kindness. My parents, Mary and Paul, and sister, Anna, have been great listeners and travel companions along the way. I would also like to acknowledge all of the excellent teachers – in Sackville, Bryn Mawr and Sheffield – who made me want to learn more.

Summary

The aim of this project is to assess competing models of neolithic-bronze age crop husbandry (shifting cultivation, extensive ard cultivation, floodplain cultivation, intensive garden cultivation) in the loess belt of western-central Europe and the Alpine Foreland by analysing archaeobotanical weed assemblages. Modern weed survey studies relating to three key variables (permanence, intensity, seasonality) distinguishing these models are used as 'controls' to which the archaeobotanical weed data are compared on the basis of their weed ecological characteristics. Data on the ecology of the archaeobotanically attested weed taxa are assembled by measuring the 'functional attributes' (ecologically meaningful morphological and behavioural traits) of robust present-day specimens. This method was previously used to analyse the modern weed survey studies of traditional crop husbandry regimes, with the result that weed species characterising different regimes could be distinguished on the basis of their functional attributes.

Archaeobotanical samples most likely to contain crop and weed material from the same arable source are identified by considering the influence of various taphonomic factors on sample composition. Of the thousands of archaeobotanical samples available from the study area, 130 samples, mostly neolithic (especially early neolithic) in date, are selected as offering the best evidence of crop growing conditions.

Direct comparison of the modern and archaeobotanical weed data indicate that cereals (mostly glume wheats) were grown in fixed plots sown in the autumn and managed using intensive methods (e.g. careful tillage and weeding, manuring or middening). While the shifting, extensive ard and floodplain cultivation models can be excluded based on these results, intensive garden cultivation emerges as the most plausible model of crop husbandry, with a series of implications for the mobility, productivity and long-term sustainability of early crop cultivation in western-central Europe. Exploration of internal variation in weed composition among archaeobotanical samples reveals ecological trends and hence differences in crop husbandry practices between archaeological sites as well as within the best-represented site, LBK Vaihingen. Inter-site differences appear to reflect the existence of regional crop husbandry traditions, while intra-site variability in cultivation intensity at Vaihingen may relate to the unusually high degree of nucleation at this enclosed LBK site.

1 The archaeological problem: approaches to the recognition of early crop husbandry in western-central Europe

1.1 Aim and structure of the thesis

Current perceptions of crop cultivation in western-central Europe during the Neolithic and Bronze Age vary widely, including models of transient and permanent cultivation, small-scale hand cultivation and large-scale production with the ox-drawn ard, cultivation of floodplain alluvium and higher ground. Debate over crop husbandry reflects conflicting views of the way in which farming spread to temperate Europe, the mobility of early farming communities, the extent of social differentiation among households and the aims of crop production.

The goal of this project is to address these conflicting views of early crop husbandry by analysing the extensive archaeobotanical dataset available from neolithic-bronze age sites across western-central Europe. Archaeobotanical data on the arable weed floras from ancient crop fields can form the basis of a detailed reconstruction of the crop husbandry practices carried out by early farmers. These practices are of interest as an aspect of everyday life and as a cause or consequence of long-term transformations in society.

The remainder of this chapter discusses the interpretation of archaeobotanical weed evidence, models of neolithic-bronze age crop husbandry practices in western-central Europe and modern weed survey studies of particular relevance to these models. Chapter 2 sets out the methods used to select useful archaeobotanical data from the study area, to measure 'functional attributes' (ecologically meaningful morphological and behavioural traits) for the archaeobotanically attested weed species, to assess taphonomic processes affecting the composition of archaeobotanical samples and to analyse the relevant modern weed survey and archaeobotanical data. Chapter 3 summarises results from previous analyses of the modern weed studies using the FIBS (Functional Interpretation of Botanical Surveys) method, including analyses carried out with a view to direct comparison with the archaeobotanical data. The aim of Chapter 4 is to analyse the taphonomy (origin and formation) of the archaeobotanical material, to select samples suitable for ecological analysis and to present initial multivariate analyses of these samples that explore the extent and nature of floristic variation in their weed composition. Chapter 5 presents the results of statistical analyses comparing the selected archaeobotanical samples directly with modern weed floras developed under different husbandry regimes on the basis of their functional attribute values. The aim of Chapter 6 is to identify specific ecological trends – and hence differences in individual husbandry practices – underlying floristic variation in weed composition among the archaeobotanical samples. Finally, Chapter 7 discusses the wider archaeological implications of the results presented in Chapters 5 and 6 in terms of the models of crop husbandry reviewed in Chapter 1 and the wider social context of the crop husbandry regimes and practices reconstructed.

1.2 Methodological background

1.2.1 Crop husbandry in archaeology

Crop husbandry refers to the methods farmers use to grow crops, including the timing and method of tillage and sowing, weeding and watering of crops, middening or manuring and also longer-term rhythms of fallowing and rotation. These practices largely determine the productivity, labour demands, reliability and long-term sustainability of crop growing. While attempts have been made to understand husbandry regimes and their transformation as a function of single factors such as population pressure (e.g. Boserup 1965), environment (e.g. Vita-Finzi and Higgs 1970; Higgs and Vita-Finzi 1972) or the spread of technological innovations (e.g. Sherratt 1981), studies of farming societies around the world attest to the complex cultural specification of such basic parameters as carrying capacity, resource use, response to environmental change and the adoption of technological innovations (Sahlins 1972: 49; Grigg 1982; Halstead 1995; Charles and Halstead 2001). Ethnographic and historical studies have identified links between crop husbandry regime and many other aspects of farming communities, including settlement pattern, land ownership, social stratification and animal husbandry (e.g. Goody 1976; Sherratt 1981; Fleming 1985; Hodkinson 1988; Halstead 1987, 1990, 1995; Williamson and Bellamy 1987; Palmer 1998b; Forbes 2000a, b). Crop husbandry is thus of central importance for understanding past agricultural societies and, despite various shifts of theoretical outlook, has been a consistent theme of synthetic works on later European prehistory (Childe 1929, 1957; Clark 1952; Piggott 1965; Dennell 1983; Barker 1985; Hodder 1990; Whittle 1996a).

In terms of current theoretical perspectives, archaeologists have increasingly looked to "habitual action" (Gosden 1995: 188) or "the 'dull compulsion' of routine experience" (Edmonds 1999: 486) as the context in which social identities and institutions emerge and are reproduced over the long term (e.g. Barrett 1994, 1999; Gosden 1995; Edmonds 1999). In agricultural societies, crop husbandry can offer insights into these social processes as it represents a whole series of 'routines' or tasks taking place on a series of timescales (daily through seasonal, annual and inter-annual). By combining these varying timescales with the spatial dimension of arable land use, crop husbandry is of obvious relevance to recent emphasis on inhabited landscapes or 'taskscapes' as a context for archaeological discourse (e.g. Ingold 1993). An understanding of past crop husbandry regimes is also needed in order to assess the enduring effects of farming on the landscape (e.g. Acheson 1997; Halstead 2000).

1.2.2 The importance of middle range theory

Recent interest in routine practice highlights the need to broaden the range and resolution of inferences that archaeologists can make about the past (cf. Edmonds 1999). Different forms of archaeological data have been used to make inferences about past crop husbandry, including settlement distribution and artefactual/representational data. For example, Andrew Sherratt's theory of a 'Secondary Products Revolution' in the later neolithic of temperate Europe, including the transformation of crop husbandry through the introduction of the ox-drawn ard, is based largely on these forms of evidence (Sherratt 1981). Potentially the most informative source of archaeological evidence for crop husbandry practices – the seeds of arable weeds associated with crop material in archaeological deposits (below, 1.2.3) – has been under-utilised, however, or even misinterpreted, largely because the theory needed to link weed evidence with husbandry practices has been inadequate. In other words, archaeological inference has been limited by weaknesses and inconsistencies in the linking arguments or 'middle range theory' (Binford 1977, 1981: 23; see also Raab and Goodyear 1984) needed to interpret archaeobotanical weed assemblages as evidence of crop husbandry practices.

Binford (1981: 25-30) characterised good middle range theory as unambiguous, based on clear cause and effect rather than simple correlation, applicable to the past (i.e. based on plausible uniformitarian assumptions) and intellectually independent of "general theory". Hodder (1982) has discussed a similar concept of 'relational analogy' as analogy based not on mere superficial similarity ('formal analogy') but on "some natural or cultural link between the different aspects of the analogy" (Hodder 1982: 16) – that is, on similarity of causal mechanisms (Wylie 1985: 95). Criticism of middle range theory as construed by Binford has tended to focus on the notion of its theoretical independence: if all observation is 'theory-laden', the independence of middle range theory is illusory and arguments based upon it are circular (Hodder 1986: 107; Shanks and Tilley 1987: 122; Barrett 1990, 1994: 171 n. 1). Fortunately, however, not all forms of 'theory-ladeness' are equally problematic (Kosso 1991; Wylie 1986, 1992, 1993, 1995, 1996, 1998); thus, for example, plant ecological theory relating to the behaviour of weeds under different crop husbandry regimes is based on a set of assumptions with no direct relation to broader theories of human behaviour (cf. Charles and

Halstead 2001). On the other hand, middle range theory developed by Binford himself (1978: 458-497) incorporates assumptions of human rationality and optimising behaviour and so offers a useful *heuristic* tool rather than a set of 'innocent' linking arguments between the static record and dynamic past (Wylie 1989a; Halstead 1998; Charles and Halstead 2001). Another focus for criticism is Binford's claim that middle range theory provides "Rosetta Stones" for the past (Binford 1981: 25), with the implication that all aspects of past human behaviour are susceptible to reconstruction, provided the necessary middle range theory is developed (Wylie 1989b). The claim is clearly false, but useful middle range theory can be developed on the basis of physical, chemical and biological properties of humans, other organisms or artefacts that are plausibly extrapolated to the past and largely independent of assumptions about human behaviour (Wylie 1985, 1986, 1993, 1995; Shennan 1993; Charles and Halstead 2001). Middle range theory is an indispensable tool for archaeology (Cowgill 1993; Stark 1993; Trigger 1995; Wylie 1998; cf. Hodder 1991) and its use in the writing of Binford's own critics has been highlighted by Kosso (1991) and Tauschner (1996). The development of useful middle range theory not only broadens the limits of archaeological inference but also constrains what we can claim about the past.

1.2.3 Approaches to the interpretation of archaeobotanical weed assemblages as evidence of crop husbandry

A given species of crop can generally tolerate a range of growing conditions and may be grown using a variety of different husbandry practices (e.g. Behre and Jacomet 1991). Archaeobotanical crop remains, therefore, do not offer detailed insight into crop husbandry, though carbon isotope studies of ancient grain have been used to detect irrigation (e.g Araus *et al.* 1997) and ancient crop DNA may eventually permit the identification of ecotypes adapted to specific growing conditions (cf. Davies and Hillman 1988). At present, the most useful archaeological evidence of crop husbandry is provided by the seeds of arable weeds found in association with crop material in archaeological deposits (e.g. Knörzer 1971b, 1973, 1979a, 1984; Willerding 1980, 1981, 1983a, 1986; Hillman 1981, 1991; M. Jones 1981, 1988; Wasylikowa 1981; Greig 1988; Behre and Jacomet 1991; Küster 1991c; G. Jones 1992, in press; van der Veen 1992). Archaeobotanists have observed that ancient weed assemblages are often quite different to those of recent times and that this is likely to reflect differences in crop husbandry practices (e.g. Knörzer 1973; Willerding 1980, 1981, 1983a, 1986; Behre and Jacomet 1991; G. Jones 1992; Kroll 1997). Weed species have different ecological requirements and preferences (e.g. Holzner and Numata 1982; Ellenberg 1996: 870-888); hence, the prominence of certain weed species at a particular time and place should reflect the nature of the crop husbandry regime under which they thrived.

While the significance of ancient weed assemblages for the reconstruction of crop husbandry is widely acknowledged, approaches to the interpretation of this evidence vary, with the result that the same data can be interpreted in radically different ways (Charles *et al.* 1997) (see also below, 1.4.1-1.4.5). Two of the main approaches that have been used – phytosociology and Ellenberg numbers – are discussed below, before presenting an alternative approach that overcomes the major weaknesses of previous methods.

1.2.3.1 Phytosociology

Phytosociology classifies stands of vegetation into communities or 'syntaxa' based mainly on the occurrence of 'character species', which are more or less restricted to a certain syntaxon (Westhoff and van der Maarel 1973). An approach seeking to identify modern syntaxa in archaeobotanical assemblages is of limited usefulness in archaeology due to the historical contingency of plant communities and their instability through time (Holzner 1978; M. Jones 1984; Behre and Jacomet 1991; Hillman 1991; Küster 1991c; G. Jones 1992). Other problems with the identification of weed communities in archaeobotanical samples are that samples may not represent a single field and that the original field weed flora is only partially represented (M. Jones 1988; Küster 1991c; G. Jones 1992). These problems also apply to attempts to reconstruct ancient weed associations that no longer exist (e.g. the Bromo-Lapsanetum praehistoricum association of Knörzer 1971b).

An alternative use of phytosociology has been to interpret the occurrence of character species in archaeobotanical assemblages as indicators of habitat conditions rather than to identify syntaxa *per se*. The more general groupings of species (e.g. at the highest syntaxonomic level of 'class') can be applied to archaeobotanical weed assemblages with some confidence (Behre and Jacomet 1991; Küster 1991c; G. Jones 1992) and the occurrence of character species belonging to these general groupings can be used as indicators of the habitat conditions under which the group as a whole occurs. Even with this alternative use, however, there remains the underlying problem that plant communities are linked to field observations of growing conditions without distinguishing between ecological requirements and tolerances; for example, the species in a community growing in moist conditions might be assumed to indicate moisture generally, even though some or all of them merely tolerate a certain level of moisture but have a specific set of requirements for fertility or light etc. In other words, field observations linking phytosociological communities with growing conditions do not reveal which aspects of the environment cause certain species to grow in certain locations (Charles *et al.* 1997).

Phytosociology has been widely used in archaeobotany to infer habitat conditions and crop husbandry practices (e.g. van Zeist 1974; Wasylikowa 1978, 1981; Willerding 1979, 1983a; Jacomet *et al.* 1989: 128-144; Behre and Jacomet 1991; Karg 1995; Rösch 1998c; G. Jones in press). Some archaeobotanists have identified a greater prevalence of character species of the class Chenopodietea (root/row-crop or 'garden' weeds and ruderals) in archaeobotanical assemblages of cereals and pulses compared with modern phytosociological studies of winter cereals (Knörzer 1971b; Willerding 1979, 1981, 1983a; Behre and Jacomet 1991; G. Jones 1992). For example, G. Jones (1992) has noted that the weed assemblage associated with charred crop stores from late bronze age Assiros Toumba in Greek Macedonia is particularly rich in character species of the Chenopodietea compared with modern winter cereals and pulses. G. Jones (1992) argues that this could reflect the use of garden-like methods of crop husbandry such as manuring, hand weeding or hoeing and watering of crops but notes that three other explanations are also possible. First, character species of this group tend to be spring-germinating and so to characterise spring-sown crops, suggesting perhaps that archaeobotanical cereals/pulses associated with Chenopodietea are spring-sown (e.g. Groenman-van Waateringe 1979; Gluza 1983; Behre 1990) or that Chenopodietea-rich assemblages are derived specifically from (spring-sown) millet cultivation (e.g. Wasylikowa 1978; Kroll 1979, 1997). Second, the Chenopodietea group also includes many species that grow as ruderals (that is, in non-arable disturbed habitats), and so a further possibility is that the assemblages rich in Chenopodietea are contaminated by material of ruderal (non-arable) origin. A third explanation for the occurrence of Chenopodietea species in archaeobotanical assemblages, first proposed by Willerding (1980, 1981, 1983a, 1985, 1986: 335, 1988a, b), is that Chenopodietea species reflect an 'open' stand of autumn-sown crops allowing root/row-crop weeds to germinate in the gaps and compete with established plants (see also below, 1.4.2.1, 1.4.4-1.4.5).

1.2.3.2 Ellenberg numbers

Ellenberg (1950, 1979; Ellenberg *et al.* 1992) developed a series of scales for major environmental variables (light, temperature, continentality, soil moisture, soil pH, soil nitrogen content etc.) and scored a large number of central European plant species on each of these scales. Ellenberg numbers or "indicator values" have been widely used in archaeobotanical interpretation in order to infer fertility, moisture level, shadiness etc (e.g. Wasylikowa 1978, 1981; Willerding 1980, 1983a; Jacomet *et al.* 1989: 145-153; van der Veen 1992: 108-109). Ellenberg numbers were subjectively determined for use in central Europe, though they have been shown to correspond very well to more objective measures of species behaviour in Britain (Thompson *et al.* 1993). A more serious problem is that they are based on field observations of species' behaviour that, as noted above in connection with phytosociology, do not distinguish between species' ecological tolerances and requirements and so cannot disentangle which ecological factor(s) determine the occurrence of species in certain locations (Charles *et al.* 1997).

1.2.3.3 A new approach: the Functional Interpretation of Botanical Surveys

The Functional Interpretation of Botanical Surveys (FIBS) provides a means of relating the behaviour of individual plant species to specific ecological variables, thus overcoming the limitations of previous approaches based on field observations (Charles *et al.* 1997; G. Jones in press). This approach was developed at the Unit of Comparative Plant Ecology, University of Sheffield for investigating the impact of ecological processes on species' distribution within a wide range of habitats (Hodgson 1989, 1990, 1991; Hodgson and Grime 1990; Hodgson *et al.* 1999). FIBS is based on the measurement of 'functional attributes' – morphological and behavioural traits that measure species' potential in relation to major variables such as fertility, disturbance and moisture. Species sharing the same habitat also tend to share ecological characteristics and thus belong to a distinct 'functional type' (Grime 1979; Grime *et al.* 1988). In a vegetation survey of contrasting habitats, for example, the importance of specific ecological variables can be assessed by comparing functional attribute values of species associated with the different habitats.

FIBS has been applied to a series of modern weed survey studies of traditional husbandry regimes in Europe and the Near East. While the weed floras associated with these different husbandry regimes (e.g. irrigation versus dry farming, intensive versus extensive cultivation, different rotation regimes etc.) can be distinguished from each other on a floristic basis alone (G. Jones *et al.* 1995, 1999; Palmer 1998a; Bogaard *et al.* 2001; Charles and Hoppé in press), the modern weed floras may overlap only partially or not at all with archaeobotanical weed assemblages. A method that links species characteristics rather than species *per se* with particular traditional crop husbandry practices, therefore, is essential to the reconstruction of ancient husbandry regimes. Using FIBS, it has been demonstrated that the modern husbandry regimes can be distinguished on the basis of the functional attribute values of weed species associated with different husbandry practices (Charles *et al.* 1997, 2002, in press; Bogaard *et* *al.* 1999, 2000, 2001; G. Jones *et al.* 2000). Moreover, the use of functional attributes makes it possible to disentangle the effect of multiple ecological factors (e.g. fertility and disturbance, both of which may contribute to cultivation intensity – G. Jones *et al.* 2000).

The two main advantages of FIBS in archaeobotany, therefore, are that (1) it provides a means of comparing modern weed floras developed under known husbandry conditions with ancient weed assemblages and (2) it allows distinct ecological factors to be monitored independently (Charles *et al.* 1997; G. Jones in press). Thus, if functional attribute data are assembled for weed species in an archaeobotanical assemblage, FIBS makes it possible to construct a relational analogy (incorporating causal mechanisms – Hodder 1982: 11-27; Wylie 1985; cf. Binford 1981: 25-30) between the archaeobotanical weed assemblage and modern weed floras developed under particular husbandry regimes. Because the terms of the comparison – the functional attributes – are inherently meaningful ('functional'), there is also potential to reconstruct ancient husbandry regimes for which no close modern analogue exists.

In any ecological approach to archaeobotanical weed assemblages, the uniformitarian assumption that the ecology of weed species has remained stable through time is problematic (Behre and Jacomet 1991; G. Jones 1992, in press). The use of multiple weed species reduces the potential for erroneous conclusions due to major changes in the behaviour of individual species (G. Jones 1992, in press; Charles and Halstead 2001). Since functional attributes can be measured rapidly for any species in an archaeobotanical weed assemblage, FIBS promotes the use of suites of associated species to infer past growing conditions.

As a form of 'good' middle range theory, therefore, FIBS satisfies three of Binford's criteria (above): the relation of functional attributes to husbandry practices is one of cause and effect, plausible uniformitarian assumptions can be made based on suites of associated weed species and assumptions about plant ecology bear no direct relation to assumptions about human behaviour. FIBS also goes a long way towards satisfying the fourth criterion: while the relation of functional attributes to husbandry practices is not entirely unambiguous (i.e. there is potential for problems of equifinality since different husbandry measures may have similar ecological effects), the use of functional attributes permits this ambiguity to be identified and assessed.

1.3 The study area and its archaeological background

Two broad regions in western-central Europe have been the subject of debate over the nature of early crop husbandry (1.1) and are particularly well investigated from an archaeobotanical point of view: the loess belt, where hundreds of early-middle neolithic settlements (of the LBK and its immediate successors) have been excavated and well over 150 sampled for plant remains (e.g. Willerding 1980; Lüning 1988; Kreuz 1990; Knörzer 1997), and the Alpine Foreland, where lakeshore settlements dating from the Later Neolithic to the Bronze Age have long been the subject of intensive archaeobotanical as well as archaeological study (e.g. Heer 1866; Neuweiler 1905; Schlichtherle 1983, 1997a; Jacomet *et al.* 1989; Brombacher and Jacomet 1997). Together these adjacent regions of western-central Europe form a very broad study area (Fig. 1.1) bounded by the coastal plains of Europe to the north and west and the Alps to the south. To the east, the study area includes the loess belt of southern Poland, Slovakia and Hungary. LBK settlement did extend further east along with loess soils, into Romania (Transylvania, north-east Wallachia), south into Croatia and, to the north and east of the Carpathians, into the Ukraine and Moldavia, but available archaeobotanical data from these regions are very limited (Dergachev *et al.* 1991; Wasylikowa *et al.* 1991; Tezak-Gregl 1993; Cârciumaru 1996; Pashkevich 1997; Larina 1999). Similarly, extension of the study area to include LBK settlement well beyond the loess, in the North European plain, would be unproductive because of the poverty of archaeobotanical data (Bogucki 1982: 97; Heußner 1989; Nalepka *et al.* 1998).

In terms of chronological boundaries, the Neolithic (ca. 5500-2200 B.C.) has clearly been the focus of greatest interest for the recovery of plant remains in western-central Europe (e.g. Willerding 1980; Jacomet and Kreuz 1999: 293-308). The LBK (ca. 5500-5000 B.C.) is the earliest Neolithic culture across most of the loess belt but in the Hungarian Plain Starcevo-Körös sites (ca. 6000-5500 B.C.) represent the earliest neolithic period (Whittle 1996a: 150). Though archaeobotanical investigations are currently underway at sites of this earliest neolithic phase in the Hungarian Plain (e.g. Whittle 2000), very few archaeobotanical datasets are available, and so the LBK is the earliest period under investigation in this region.

While in the Alpine Foreland there is continuity of lakeshore settlement from the Neolithic through the Bronze Age (e.g. Schlichtherle 1995; Gross-Klee 1997), in the loess belt relatively few archaeobotanical datasets are available from the Early and Middle Bronze Ages due to the greater richness and visibility of burial compared with settlement sites (Rieckhoff 1990: 63; Bogucki 1999: 276). The situation is somewhat improved for the late bronze age Urnfield culture, with settlements across the loess belt as well as in the Alpine Foreland (Rieckhoff 1990: 71; Seidel 1995: 89). This project, therefore, will consider the entire Neolithic and Bronze Age (ca. 5500-750 B.C.). The major chronological terms and calibrated ^{14}C dates used in this project follow the scheme proposed by Lüning (1996: Fig. 1) for central Europe. Table 1.1 summarises the periods and culture-historical groupings considered.

1.3.1 The Early-Middle Neolithic (ca. 5500-4400 B.C.)

The early-middle neolithic archaeology considered here comprises the LBK (ca. 5500-5000 B.C.) and subsequent 'LBK-related' (i.e. Rössen, Lengyel, SBK, Oberlauterbach etc.) cultures of the Middle Neolithic (ca. 5000-4400 B.C.) in the loess belt – what Bogucki (1988) calls the "Primary Neolithic" of central Europe, a period of over one thousand years. Early-middle neolithic sites are 'flat' (non-tell) accumulations of post-holes and trenches of longhouses and associated pits; erosion and disturbance have destroyed floor surfaces and occupation layers, leaving only 'negative features' filled with archaeological deposits (Whittle 1996a: 160). LBK longhouses tend to have a tripartite organisation, with front, central and back sections divided by transverse rows of posts, though two- and perhaps one-section longhouses also occur and structures vary considerably in overall length, from ca. 10 to 40 m (Modderman 1988; Coudart 1998: 19, 27-28, 53-54). Middle neolithic longhouses often lack the internal tripartite division and tend to be trapezoidal in shape rather than rectangular (Coudart 1998: 51, 54, 56).

The concept of the longhouse as 'farmstead' (*Hofplatz*) with its surrounding 'yard' was developed in the course of extensive rescue excavations of LBK sites in the Rhineland, including the complete excavation of a 1.3 km stretch of the Merzbach valley in the Aldenhoven Plateau, which suggested that each longhouse was accompanied by a characteristic set of pits (Lüning 1982b, 1988, 1997; Stehli 1989). It was suggested further that the sequential replacement of longhouses over time resulted in a lateral 'drift' of structures (Lüning 1982b). This view is supported by seriation of finds (especially ceramics) from pits associated with individual longhouses, allowing the sequential replacement of longhouses to be traced through many 'generations' (Lüning 1988, 1997).

Since early-middle neolithic sites represent the palimpsest of drifting longhouses through time, what appear to be dense concentrations of longhouses may represent the replacement of a single structure over time or include very few contemporary longhouses separated by considerable distances, from 10-20 m to 100 m or more (Hamond 1981; Milisauskas 1986: 3-4; Whittle 1996a: 151). While many LBK settlements appear to consist of one to a few longhouses at any one time, large sites with a number of contemporary longhouses are also known: at Langweiler 8 in the Merzbach valley (Aldenhoven Plateau), for example, 11 contemporary longhouses covering ca. 7 ha are attested in one phase (Lüning 1988, 1997). Population estimates for early-middle neolithic sites range from less than ten (single families) to several hundred or more (e.g. Modderman 1970: 205-207; Milisauskas 1986: 219-220; Milisauskas and Kruk 1989a; Coudart 1998: 91). Most, if not all, settlements would not be demographically viable (Wobst 1974), and recent isotope work on human bone from LBK sites in the Rhineland suggests movement between communities in different regions (e.g. intermarriage) (Price *et al.* 2001).

Lüning (1997) has argued that even large sites such as Langweiler 8 were not 'true villages', with an emphasis on communal, supra-household organisation, but 'loose' groupings of farmsteads (*Streusiedlungen*). The newly excavated LBK settlement of Vaihingen/Enz in southwest Germany, however, was encircled in one phase by a ditch containing burials and appears to reflect a more cohesive, village-like community (Krause 1998). In some regions at least, sites appear to become more nucleated (i.e. fewer, larger sites in the Rhineland) and 'village-like' (i.e. a greater proportion with enclosures) in the Middle Neolithic (Lüning 1982b, 2000: 16; Starling 1985, 1988; Pavuk 1991; Hodder 1990: 122-129). The length of early-middle neolithic site occupations varies but is often of the order of several centuries; some large settlements were occupied for more than 400 years (Lüning 1997, 2000: 15).

Early-middle neolithic sites tend to occur in clusters of around five to nine within a radius of three to eight km (Hamond 1981; Bogucki 1988: 74; Lüning 1997). These clusters often consist of sites strung out along small to medium-sized river valleys. In some cases these clusters have been shown to include a single large site plus a number of smaller ones (Lüning 1997). These clusters, in turn, occur within broader concentrations of sites apparent on a continental scale, referred to as *Siedlungskammern* ("settlement cells") and often circumscribed by topographical features such as hills surrounding basins (Hamond 1981; Bogucki 1988: 72-73).

It is well known that sites tend to occur in areas of loess (silt-like material deposited by wind to the south of the Pleistocene ice sheets), though there are many exceptions to this in the LBK (e.g. Paris Basin, lower Oder, Kujavia), and middle neolithic settlement expanded into the moraine landscapes of the North European Plain and the Alpine Foreland (Lüning 2000: 17). The association with loess has usually been interpreted as a preference for the high fertility of loess soils, though other factors may have been of greater importance, such as location in flat areas near the conjunction of river valleys and watersheds (Bogucki 1988: 77; Bogucki and Grygiel 1993). This position enabled access to floodplains providing seasonal grazing for livestock and/or fertile alluvium for cultivation (Kruk 1973, 1980: 26-27, 50-54, 63-64, 1988; Bakels 1978: 139; Wasylikowa 1989) (see also below, 1.4.3).

Closed deciduous woodland is generally considered to have been the dominant vegetation across western and central Europe in the Neolithic (Küster 1995a: 69-70, 74-75; Jacomet and Kreuz 1999: 231-240; Lüning 2000: 25-27). Some ecologists have recently argued that open parkland rather than closed woodland is the 'natural' vegetation of western-central Europe in the absence of human influence (Geiser 1992; May 1993), an idea that harks back to Gradmann's (1898) *Steppenheide Theorie*. Zoller and Haas (1995) have argued convincingly, however, that mixed deciduous woodland is the 'natural' climax vegetation of much of western-central Europe, while emphasising also that this woodland would likely exist in a mosaic of regeneration states at any one time (only in the optimal phase of regeneration is the canopy truly 'closed') (see also Küster 1995a: 69-70, 74-75; Jacomet and Kreuz 1999: 239; Lüning 2000: 25-27). Pollen diagrams showing low amounts of non-arboreal pollen (often less than 5% of the pollen sum) indicate woodland in the Mesolithic as well as in previous interglacials (Zoller and Haas 1995). Zoller and Haas (1995) conclude that the location of early-middle neolithic sites along river valleys – like the later emergence of lakeshore settlement in the Alpine Foreland (below) – reflects a preference for more open vegetation, the dominant form elsewhere being more or less closed woodland.

The visibility and often dispersed distribution of early-middle neolithic longhouses has fostered interest in the household as the fundamental unit of decision-making (e.g. Bogucki 1988: 214-215; Lüning 1988: 86; Halstead 1989b; Bogucki and Grygiel 1993; Lüning 2000: 180) by analogy with ethnographic and historical studies of small-scale agrarian societies (e.g. Sahlins 1972; Netting *et al.* 1984). A crucial implication of the 'household perspective' is that crop husbandry practices reflect the aspirations and motivations of individual households (cf. Bogucki 1988: 215). Moreover, it is in the relationships between households and their differential success that the origins of social hierarchy have been sought (Halstead 1989a, b; Bogucki 1993, 1999: 210-218). There is disagreement, however, over the degree of social differentiation among households in the Early-Middle Neolithic (below, 1.4.6).

In contrast to later neolithic settlement in the North European Plain and the Alpine Foreland, the LBK has often been treated as a 'textbook case' of migration (e.g. Clark 1952: 95-98; Piggott 1965: 50-52; Ammerman and Cavalli-Sforza 1971, 1984: 61, 63-64; Vencl 1986; Bogucki 1987, 1996; Price *et al.* 1995). Recent emphasis on continuity with the Mesolithic in some aspects, however, especially in lithic assemblages (e.g. Tillmann 1993), as well as heterogeneity within the LBK (e.g. Lüning 2000: 110) and possible evidence for 'mesolithic agriculture' (Erny-Rodmann *et al.* 1997), has been used to support claims that the LBK represents a complex pattern of indigenous adoption and acculturation, with limited migration from the 'homeland' of LBK material culture in the Hungarian Plain (Dennell 1983: 176; Modderman 1988; Whittle 1996a: 363-364, 1996b, 1997; Kind 1998; Gronenberg 1999; Bogucki 2000; Jochim 2000; Zvelebil 2000; Price *et al.* 2001).

1.3.2 The Later Neolithic-Bronze Age (ca. 4400-750 B.C.)

The transition from the Middle to the Later Neolithic represents the end of the 'longhouse' tradition in western-central Europe. Subsequent neolithic settlement extended well beyond the loess belt (e.g. to the Alpine Foreland, which forms part of the study area – above, 1.3) and continued a trend towards increasing regionalisation of material culture. Later neolithic sites vary considerably in location (e.g. on and off loess; lakeshores and interfluves as well as valley margins), size (from large settlements surrounded by palisades and ditches to dispersed farmsteads) and duration (from long-lived settlements lasting several centuries to dendrochronologically dated lakeshore villages of less than 20 years' occupation).

The later part of the Neolithic (ca. 4400-2200 B.C.) has been characterised as a period of profound changes. Sherratt (1981, 1997) proposed a "secondary products revolution" or "complex" based on the intensive use of renewable resources from domesticated animals (traction, milk and wool/hair) in the fourth and third millennia B.C. The temporal and geographic coherence of this 'horizon' has been questioned, as has the extent and nature of its impact on societies across Europe (Chapman 1982; Rowley-Conwy 1987; Glass 1991: 77; Halstead 1995; Lüning 2000: 12). Recently, however, Bogucki (1993, 1999: 227-230) has advocated an "animal traction revolution", arguing that ox-drawn ard cultivation and wheeled transport freed later neolithic households from their inherent labour limitations, and that differential access to traction promoted economic differentiation between households (see also below, 1.4.2.2).

Another potential cause of changes in settlement and society in the Later Neolithic is the 'fusion' of indigenous hunter-gatherer and existing agricultural (i.e. LBK-related) communities, particularly in the North European Plain and the Alpine Foreland (Kruk 1988; Bogucki 1987, 1988: 107-109, 1996, 2000; Sherratt 1997). The exclusive association of 'indigenous' agricultural societies with the Later Neolithic, however, has also been called into question (above, 1.3.1). Nevertheless, contrasting neolithic traditions supposedly founded by 'immigrant' farmers versus 'indigenous' farmers have been linked directly to contrasting crop husbandry regimes (Bogucki 1996), as discussed further below (1.4.6).

Within the loess belt, regional survey of neolithic sites in southern Poland (Kruk 1973, 1980: 28-29, 54-57, 64, 1988) documented a shift of later neolithic TRB (*Trichterbecherkultur* or Funnel Beaker culture) sites (ca. 3950±170 – 3150±125 B.C.) away from the margins of river valleys, into the 'interfluves'. Another regional study of neolithic settlement, in the Elbe-Saale area (Starling 1985, 1988) detected a similar shift of larger sites (hilltop enclosures or *Hohensiedlungen*) to the interfluves but also greater continuity of settlement on valley margins. While Kruk (1973, 1980: 28-29, 54-57, 64, 1988) interprets the shift to interfluves as evidence for shifting cultivation in the TRB, other authors infer a greater emphasis on animal husbandry, including animal-drawn ard cultivation (Bogucki 1988: 176-177; Howell 1989) (below, 1.4.1.2, 1.4.2.2). Subsequent settlement evidence of the Baden culture (ca. 3150±125 B.C.) in southern Poland also extends into the interfluves, and an emphasis on stockbreeding and plough cultivation has been inferred (Sherratt 1981, 1997; Kruk 1988; Milisauskas and Kruk 1989a; Lüning 2000: 189) (below, 1.4.2.2). Bronocice, a TRB-Baden site on a loess ridge above a tributary of the Vistula in southeast Poland, is a large site of this period in the eastern loess belt, containing extensive spreads of pits and enclosure ditches but no detailed evidence of settlement or house layout (Milisauskas and Kruk 1993; Whittle 1996a: 222-223). This site has yielded possible evidence for animal traction and wool production (Milisauskas and Kruk 1989a; Milisauskas and Kruk 1991).

Archaeological evidence of later neolithic settlement from the western part of the loess belt is variable; here again, settlement remains are often confined to pits and ditches, without any clear evidence of settlement layout. The proliferation of monumental earthworks and hilltop enclosures in various regions suggests increasing concern with communal defence (Hodder 1990: 158-161). Sites of the Michelsberg culture (ca. 4100-2800 B.C.) – extending from the lower Rhine to the Swabian Alb and from eastern France to Bohemia and Moravia – consist of substantial earthworks, in some cases with evidence of settlement in the enclosed area (Keefer

1993: 149). Well-preserved settlements of the Aichbühl (ca. 4400-4100 B.C.) and Schussenried (ca. 4100-3800 B.C.) cultures of southwest Germany (the latter with close links in ceramic tradition to Michelsberg) have been excavated on loess (e.g. Hochdorf) as well as under waterlogged conditions off loess (e.g. Ehrenstein), revealing closely spaced, post-built houses, of smaller dimensions than the earlier longhouses, each containing a hearth and baking oven (Keefer 1993: 128-145). In lower Bavaria, settlements of the Altheim culture (ca. 3800-3500 B.C.), some with enclosures, have a similar layout (Ottaway 1999: 250). Settlements of related ceramic tradition are also known further south, in lakeshore sites of the Alpine Foreland (below).

Settlement evidence from the final phases of the Neolithic (ca. 3500-2200 B.C., e.g. Horgen, Cham, Baden, Globular Amphora, Corded Ware and Bell Beaker cultures) is limited in the loess belt (Rieckhoff 1990: 48-62; Keefer 1993: 161; Ottaway 1999: 251-258; Lüning 2000: 19-20). Waterlogged settlements of the Alpine Foreland provide the best evidence of house and settlement layout for this vast period (below). The Corded Ware and Bell Beaker complexes occur over large areas of eastern and western Europe, respectively (Lüning 2000: 20). Together with the Globular Amphora culture, these traditions have been associated with 'pastoral nomadism' due to the predominance of burial sites and lack of settlement evidence (e.g. Kruk 1973, 1980: 58-61, 1988), but there is no positive evidence for reliance on herding (Milisauskas and Kruk 1989a, b; Keefer 1993: 169-170). 'Migrationist' interpretations have to some extent been replaced by the concept of deliberate homogenisation of material culture (Shennan 1986; Hodder 1990: 175; Rieckhoff 1990: 48-57).

South of the loess, in the Alpine Foreland, the sequence of lakeshore settlements preserved by waterlogging begins ca. 4300 B.C. and continues in some areas through to the Corded Ware phase (ca. 2400 B.C.) (Schlichtherle 1995; Whittle 1996a: 216-219; Pétrequin *et al.* 1998; Gross-Klee 1997; Schibler and Jacomet 1999). Rather than an 'edge effect' of settlement concentrated on dry mineral soils, lakeshore settlement appears to reflect a real preference for wet areas (lake and marsh edges) in the Later Neolithic, along with houses that are smaller/lighter than the earlier longhouses and 'proper villages', often surrounded by fences or palisades, rather than loose groupings. High resolution dating by dendrochronology shows that the occupation of these villages was relatively brief, ranging from less than 20 years up to 80 years.

Conceptualisation of farming households as the fundamental productive units has been applied to the Later Neolithic as for the Early-Middle Neolithic (Bogucki 1988: 176, 1993, 1999: 211-218; Halstead 1989b). The good preservation and temporal resolution of lakeshore settlements in the Alpine Foreland appears to demonstrate household self-sufficiency at some sites. At Hornstaad-Hörnle 1A, for example, an early lakeshore settlement on Lake Constance, each house appears to have had its own crop stores (charred in the destruction of the settlement by fire) and a standard 'tool kit' (including wooden 'hand ards' (*Fürchenstöcke*) as well as polished stone axes, flint points and fishing equipment) (Dieckmann *et al.* 1997). At others sites, crop stores were located away from houses, in separate structures outside the village proper, in part perhaps as protection from fire (Pétrequin and Pétrequin 1995). The small size of houses in Goldberg III sites (Alleshausen-Täschenwiesen and -Grundwiesen) in the Federsee region, dated to the end of the Neolithic, appears to preclude household crop storage (Schlichtherle 1995, 1997b). Furthermore, botanical analyses at Alleshausen-Grundwiesen appear to indicate site specialisation in flax production (Maier and Schlichtherle 1993; Schlichtherle 1997b). These developments at the end of the Neolithic have been interpreted as evidence that 'independent' household production was being eroded (Schlichtherle 1995, 1997b).

Mortality curves for cattle assemblages from the Alpine Foreland suggest dairying in the Later Neolithic (Higham 1967; Becker 1981; Jacomet and Schibler 1985; Halstead 1989b; Gross *et al.* 1990; Hüster-Plogmann and Schibler 1997), though the lack of large-scale pasture and the labour intensity of fodder collection would have limited the scale of animal husbandry (Hüster-Plogmann *et al.* 1999). Later neolithic lakeshore settlements have provided the first direct evidence of stalling in the study area (above, 1.3.1). Such management practices would have increased the availability of milk for human consumption by encouraging the let down of milk (Halstead 1998). Modelling of the human diet suggests, however, that crops remained the chief food source (Gross *et al.* 1990; Schibler and Brombacher 1995). Evidence for a 'crisis' in food production in the 37th century B.C. at various lakeshore settlements (Lake Zurich, Lake Biel) suggests that declining crop yields were supplemented not by intensification of animal husbandry but by higher levels of hunting and foraging (Schibler *et al.* 1997a, b; Hüster-Plogmann *et al.* 1999).

In the Horgen levels (ca. 3300-2800 B.C.) of lakeshore settlements at Lake Zurich, age/sex data for cattle show evidence of use as work animals, coinciding with the first evidence of wheeled vehicles and yokes in the region (Hüster-Plogmann and Schibler 1997; Schibler and

Jacomet 1999); as discussed further below (1.4.2.2), this evidence has been associated with more extensive arable cultivation and greater availability of land for grazing. While cows and bulls may have been used for traction in the Horgen period, osteological data from Corded Ware (ca. 2800-2600 B.C.) and Early Bronze Age (ca. 1700-1600 B.C.) contexts at Lake Zurich suggest increased use of oxen (Hüster-Plogmann and Schibler 1997). Furthermore, sheep mortality data from Corded Ware contexts at Lake Zurich are consistent with milk production (Hüster-Plogmann and Schibler 1997).

Social organisation in the Later Neolithic has been characterised as 'transegalitarian', without hereditary elites, whereas full-blown chiefdoms have been inferred for the Bronze Age (ca. 2200-750 B.C.) (Gilman 1981; Rieckhoff 1990: 59, 184-212; Seidel 1995: 29; Fokkens 1997). This is largely based on the proliferation of rich burials in the Bronze Age rather than on settlement analysis; the number of well-investigated sites is relatively low (Bogucki 1999: 273-275). Early Bronze Age settlement hierarchy and evidence of political centralisation at fortified sites has been identified in southwest Slovakia (Shennan 1986) but bronze age candidates for 'chiefly residences' are generally lacking outside the Carpathians (Bogucki 1999: 274-275). Otherwise, evidence of bronze age settlement layout from the loess belt is scanty; most hilltop sites (*Hohensiedlungen*) are badly eroded (Seidel 1995: 56). A relatively well-preserved hilltop site of the Late Bronze Age (Urnfield culture, ca. 1200-750 B.C.) at "Der Runder Berg" near Urach in south-west Germany was occupied for ca. 400 years and contained abundant evidence for bronze working (Seidel 1995: 115). These hilltop sites are generally considered to have functioned as focal points of ritual, exchange and protection for their surrounding regions (Rieckhoff 1990: 200).

Waterlogged settlements of the Bronze Age occur in the lakeshore areas of the Alpine Foreland (Schlichtherle 1995; Gross-Klee 1997). The orderly, planned layout of bronze age settlements may reflect increasingly collective/communal economic strategies (Schlichtherle 1995), though household storage of a variety of crops is apparent at the late bronze age site of Zug-Sumpf (Jacomet and Karg 1996; Jacomet *et al.* 1998). There is evidence of elaborate defensive constructions at some bronze age sites and this has been linked to the rise of chiefly elites (Schlichtherle 1995).

A trend towards increased stalling and foddering of animals has been traced through the Bronze Age, along with pollen evidence for increased availability of grassland for pasture and/or hay cutting (Knörzer 1975; Behre 1996, 1998; Jacomet *et al.* 1998). Mortality data for cattle from some bronze age sites in western-central Europe suggest dairying (Benecke 1994a: 131-132). In the Alpine Foreland, however, bronze age mortality data for cattle appear to reflect meat production (Legge 1981), in contrast to later neolithic evidence for milking (above). The use of cattle for traction in the Bronze Age is suggested by horn-cores with signs of wear from southern Germany and the Alpine Foreland as well as by finds of ploughs, yokes and plough-marks in various parts of Europe (Benecke 1994a: 132-133; Tegtmeier 1993).

1.4 Models of crop husbandry in neolithic-bronze age western-central Europe

Crop husbandry models previously applied to the Neolithic-Bronze Age in the study area are summarised and discussed below. Crop husbandry regimes are often characterised as 'intensive' or 'extensive' in the archaeological literature, but it should be noted that the definition of these terms varies (Halstead 1992). In this project, 'intensive' husbandry refers to regimes involving high inputs of labour per unit area, resulting in high area yields; 'extensive' regimes involve smaller inputs of labour per unit area, resulting in smaller area yields (Slicher van Bath 1963: 240-243; Upton 1976: 196; Grigg 1984: 49, 174).

1.4.1 Shifting cultivation

Shifting cultivation refers to the use of newly cleared, and usually burned, woodland areas for short-term crop growing (ca. 1-5 years), followed by a 'shift' of cultivation to other newly cleared areas, and woodland regeneration (over ca. 20 or more years) on old plots. This system, also known as slash-and-burn, swidden, long-fallow or forest-fallow, is distinguished from cultivation regimes involving shorter fallow periods by the type of vegetation – primary or secondary woodland – cleared to create new fields (Dennell 1978: 37). Burning releases nutrients from organic material into the soil, promoting high crop yields for a short period, and may damage the viability of potential 'weed' seeds, rhizomes etc. present in the soil (Ellenberg 1996: 770), reducing the need for tillage and weeding (Sigaut 1975: 18-29, 99). Shifting cultivation is attested historically in parts of Europe and North America (e.g. Manninen 1932; Mead 1953; Montelius 1953; Grigg 1974: 62-63; Sigaut 1975: 18-29; Steensberg 1955, 1993: 15-16, 98-153; Larsson 1995; Lüning 2000: 52-54). It is also widely practiced in tropical regions, where such techniques counteract the rapid leaching of soil nutrients by very high rainfall (Grigg 1974: 57-74; Bayliss-Smith 1982: 25-36; Steensberg 1993: 16-98).

While shifting cultivation is generally characterised as an extensive husbandry regime, with low labour inputs per unit area (Boserup 1965: 24, 29), clearance work may be considerable (Lüning 2000: 52-54) and high yields have generally been assumed. In his description of pioneer farming in southern Ontario, Canada, Schott (1936: 169) reports area yields of ca. 1500-3400 kg/ha (60-100 bushels per hectare) for the first wheat crop sown on newly cleared forest soil, with little tillage and no weeding or manuring (Table 1.2). More often, historical yields are reported as seed-yield ratios – e.g. 20-50:1 or even 100:1 (Soininen 1959) (Table 1.2). As various authors (Sigaut 1975: 119-120; Rowley-Conwy 1981; Halstead 1990) have pointed out, however, these seed-yield ratios must be interpreted in light of the sowing techniques used and amount of seed sown. Historical descriptions of shifting cultivation often specify dibbling (i.e. dropping a few seeds into individual holes), which uses much less seed corn than broadcasting and tends to produce much higher seed-yield ratios (see also below, 1.4.5). Where area yield figures are unavailable, therefore, it is unclear to what extent high seed-yield ratios translate into high area yields, or whether high seed-yield ratios were caused primarily by the efficiency of dibbling rather than the quality of growing conditions *per se*. The results reported from the Draved (Steensberg 1979) and Butser (Reynolds 1977) experiments do not suggest spectacular area yields compared with intensive permanent cultivation (see also below). Rösch *et al.* (2002) report high area yields of up to 2500 kg/ha and 4000 kg/ha in the first cultivation season after clearance and burning from two sites near Stuttgart where experimental shifting cultivation was conducted (Table 1.2).

Archaeobotanical weed evidence has played a limited role in debate over the role of shifting cultivation in neolithic Europe (cf. Engelmark 1989; Dennell 1992). The usefulness of weed assemblages for distinguishing the cultivation of shifting versus permanent fields has been limited by the lack of comparative data on modern arable weed floras developed under a shifting cultivation regime. Descriptions of historical shifting cultivation in Europe and North America provide few observations on the weed floras growing with crops in shifting fields. There are indications that weed growth can be severely limited by burning and/or by exuberant crop growth in the first cultivation season of a shifting regime but that weed growth increases in the second and third cultivation seasons (Sigaut 1975: 18-29, 99; Engelmark 1995). Very little information on the floristic composition of these weed floras is available from historical accounts. Moreover, most of these accounts relate to coniferous woodland areas on poor soils; the weed floras of shifting cultivation in deciduous woodland – the dominant vegetation of the loess belt and Alpine Foreland through the Neolithic and Bronze Age (Zoller and Haas 1995) – may be quite different (Engelmark 1995).

1.4.1.1 Early-Middle Neolithic

Childe (1929: 45-46) first suggested shifting cultivation to explain the 'spread' of LBK farming communities across central and western Europe. The model was widely accepted for the LBK (e.g. Clark 1952: 92-98; Piggott 1965: 51-52) until the 1970s, when the alternative model of permanent fields cropped on a regular basis began to find favour (e.g. Modderman 1971; Kruk 1973). Nevertheless, shifting cultivation has continued to influence more recent discussion of early-middle neolithic cultivation in the loess belt of western-central Europe (Sangmeister 1983; Ammerman and Cavalli-Sforza 1984: 43, 114; Wasylikowa *et al.* 1985; Beranova 1987, 1989; Godlowska *et al.* 1987; Kruk 1988; Milisauskas and Kruk 1989a; Wasylikowa 1989; Rösch 1990d; Rulf 1991; Whittle 1996a: 160-162, 1996b, 1997; Gerht *et al.* 2002), despite sustained criticism of the model over several decades (e.g. Modderman 1970: 208-211, 1971; Kruk 1973; Lüning 1980, 2000: 49-50, 187-189; Sherratt 1980, 1981; Rowley-Conwy 1981; Dennell 1983: 172; Barker 1985: 141-143; Bogucki 1988: 79-82). Interestingly, it has evolved from a model explaining the spread of neolithic 'farmer-pioneers' across Europe (Childe 1929) into one that emphasises the indigenous, 'Mesolithic' (and hence 'mobile') identity of Europe's first farmers; the latter position appears to underlie Whittle's (1996a, b) recent characterisation of LBK communities as both more indigenous and more mobile than previously thought (see also below, 1.4.6.1).

Key arguments in support of early-middle neolithic shifting cultivation have included the lack of tell formation (Childe 1929: 45-46, 1957: 105-106) and apparent evidence for discontinuity in settlement occupation (Soudsky and Pavlu 1972), the supposed rapid exhaustion of soils (Childe 1929: 45-46, 1957: 105-106), the occurrence of sites in areas of relatively poor soils (Kruk 1973, 1980: 54-57, 1988) and pollen evidence for changes in woodland composition associated with clearance and burning (Wasylikowa *et al.* 1985; Wasylikowa 1989; Godlowska *et al.* 1987; Rösch 1990d). All of these arguments are open to question. First, the absence of tells is easily explained by the lack of mud brick architecture (Sherratt 1981). Second, the tendency of longhouses to 'drift' over time (versus superimposed rebuilding) can explain apparent discontinuity in settlement occupation (Modderman 1970: 208-211, 1971). Third, the claim of soil exhaustion in regions with relatively good soils (e.g. loess-based soils) is contradicted by experimental evidence from Britain and Germany for the long-term stability of crop yields over decades of continuous cultivation (Lüning 1980, 2000: 174; Rowley-Conwy 1981; Reynolds 1992). Fourth, the relationship between basic soil quality and crop growing conditions may not be straightforward: intensive manuring, watering and weeding of cultivation plots, for example, can create a highly fertile garden soil (e.g. G. Jones *et al.* 1999).

Fifth, in addition to the fundamental issues of adequate dating and calculation of pollen diagrams (Rowley-Conwy 1981; Kalis and Meurers-Balke 1998), changes in woodland composition associated with clearance and burning do not necessarily reflect past *arable* land-use. These changes could, for example, relate to the management of separate woodland or grazing areas (e.g. Rowley-Conwy 1981; Brombacher and Jacomet 1997; Kalis and Meurers-Balke 1997, 1998).

Critics of the slash-and-burn model for the Early-Middle Neolithic have emphasised differences between the environmental context of tropical swidden cultivators (e.g. thin, rapidly leached soils and high rainfall) and that of early farmers in western-central Europe (e.g. Modderman 1971; Jarman and Bay-Petersen 1976). A contrast can also be drawn between the loess belt and areas of northern Europe where historical shifting cultivation was associated with marginal soils and limited availability of good arable land (Sherratt 1980; Rowley-Conwy 1981). Furthermore, shifting cultivation was often a form of 'outfield' cultivation in marginal areas of northern Europe, practiced alongside a more intensive form of 'infield' cultivation (Rowley-Conwy 1981).

In the absence of modern comparative data on the sorts of weed floras that develop under a shifting cultivation regime, the same archaeobotanical evidence has been interpreted in different ways. The repeated occurrence of a narrow range of weed species (the so-called Bromo-Lapsanetum praehistoricum weed community) in charred crop material from LBK-Rössen sites in the Rhineland, for example, has been interpreted by Knörzer (1971b) as evidence for permanent fields cultivated using the same methods each year. Bakels (1978: 69), on the other hand, has argued that the repetition of weed species could reflect fixed cultivation or a shifting cultivation regime in which areas chosen for clearance, methods of clearance and sowing etc. were consistent. Another example of conflicting interpretations is represented by *Lapsana communis*, which constitutes one element of the so-called Bromo-Lapsanetum assemblages. It has been suggested that *Lapsana communis* indicates long-fallow cultivation by virtue of its shade tolerance and hence its ability to grow in heavily shaded shifting plots in woodland (Beranova 1987; cf. Whittle 1997). Other authors, however, have interpreted *Lapsana communis* as an indicator of permanent cultivation plots shaded by surrounding hedges (e.g. Knörzer 1967b, 1971b, 1988; Groenman-van Waateringe 1971) (see also below, 1.4.4.1). While recent archaeobotanical studies of early-middle neolithic crop husbandry in western-central Europe have tended to favour a permanent field model (e.g. Kreuz 1990, Stika

1996), the difficulty of excluding shifting cultivation based on weed evidence has also been acknowledged (e.g. Brombacher and Jacomet 1997).

A different line of evidence used to infer shifting cultivation – or at least the cultivation of newly cleared plots on virgin forest soil – is to use the absence of weed seeds in archaeobotanical crop samples as indicative. This is based on the observation that weeds may be suppressed in the first cultivation season following woodland clearance (above). Bakels (1991b) has suggested that weed-poor crop samples tend to derive from LBK sites established in new areas (i.e. without previous cultivation) whereas samples from sites in established settlement areas tend to contain more weed seeds, reflecting the continuous cultivation of plots. An obvious problem with this line of reasoning is that crop material may be free of weed seeds for a variety of reasons (e.g. crop processing, hand weeding of crops, preservation etc.) apart from recent woodland clearance. Furthermore, as Bakels (1991b) makes clear, initial woodland clearance would be necessary under any cultivation regime.

1.4.1.2 Later Neolithic

It has recently been claimed that shifting cultivation formed the principal crop husbandry regime of later neolithic lakeshore communities in the Alpine Foreland (Bocquet *et al.* 1987; Rösch 1987, 1989, 1990d, e, 1996b, 2000; Pétrequin 1996; Bailly *et al.* 1997; Pétrequin *et al.* 1998; Rösch *et al.* 2002; see also Schlichtherle 1989, 1992, 1995, 1997a; Whittle 1996a: 216-222), though the actual weed assemblages accompanying charred crop stores from lakeshore sites have been interpreted as evidence of fixed-plot cultivation (Jacomet *et al.* 1989: 234; Brombacher and Jacomet 1997; Maier 1999) (below, 1.4.4.2). The main arguments in favour of shifting cultivation are based on more indirect forms of evidence. Rösch interprets pollen and microscopic charcoal sequences from the Lake Constance area as evidence of cyclical changes in woodland composition and burning, respectively, and argues that shifting cultivation was dominant through to the end of the Neolithic (Rösch 1990e) or at least during the earlier part of the Later Neolithic (Rösch 1996b, 2000). He reasons that shifting cultivation in the Later Neolithic was necessitated by the deterioration of soils as a result of fixed cultivation without manuring or fallow in the Early-Middle Neolithic (below, 1.4.4.1) and argues further that shifting cultivation contributed to poor soil conditions in the Bronze Age (Rösch 2000). Pétrequin (1996; see also Bailly *et al.* 1997; Pétrequin *et al.* 1998) infers shifting cultivation prior to ca. 3000 B.C. for lakeshore settlement in the French Jura, mainly on the basis of the age and species composition of house timbers from sites on the shores of the Clairvaux and Chalain lakes. Both approaches are open to criticism since the link between the evidence cited and *arable* land use is tenuous; instead, woodland management practices related, for example, to animal husbandry may be represented (Rowley-Conwy 1981; Kalis and Meurers-Balke 1998; Lüning 2000: 50-52; Rösch *et al.* 2002).

Shifting cultivation has also been suggested as the major form of later neolithic crop husbandry in loess areas such as southern Poland (TRB culture – Kruk 1973, 1980: 54-57, 1988) and the Paris basin (Seine-Oise-Marne culture – Howell 1983). This is based on the association of settlement in this period with interfluves (above, 1.3.2) and the (untested) assumption that hand cultivation of fixed plots on the drier upland loess would be impractical (see also below). In addition, Howell (1983) cites the occurrence of charcoal layers as evidence of slash-and-burn cultivation in north-west France, though initial clearance by burning could relate to other forms of cultivation, or possibly to animal husbandry.

1.4.2 Extensive ard cultivation

Compared to cultivation by hand, cultivation with the animal-drawn ard requires less human labour per unit area (e.g. Halstead 1995; Lüning 2000: 181). Ethnographic evidence indicates that ard cultivation also results in less thorough tillage, unless it is accompanied by hoeing (G. Jones *et al.* 1999; cf. Halstead 1995; *contra* Jacomet *et al.* 1989: 155; Kohler-Schneider 2001: 185), contributing to lower area-yields compared with hand cultivation regimes (Gallant 1991: 51; Halstead 1995) (Table 1.2). Particularly when specialised plough oxen are used, however, the total area under cultivation is considerably larger than that worked under a hand cultivation regime, allowing the production of surplus on a large scale (Goody 1976; Halstead 1995).

1.4.2.1 Early-Middle Neolithic

According to Lüning (1979/80, 1980, 2000: 160-161, 163, 181), Lüning and Stehli (1989) and Tegtmeier (1993: 5), LBK cereal production must have taken place on a relatively large scale, with the help of an ox-drawn ard, in order to provide the staple food source. Lüning (1979/1980) has calculated that a family of six would need to cultivate 2.5 ha of cereals. This is based on an annual requirement of 250 kg of cereals per person and cereal yields of 900 kg/ha, of which 300 kg is reserved for seed corn (Table 1.2). If fields were left fallow every third year as in a medieval three-field system, the total cultivation area per family would be 3.75 ha (a bare fallow is apparently assumed here – cf. Lüning 1980). Lüning (1979/1980) claims that a household would need an ard to cultivate this area: with a conservative work rate for ard cultivation of 500-1000 m^2 per day, it is argued, at least 30 work days would be needed to cultivate 3.75 ha (cropped plus bare fallow area) once, and in fact two to three 'cross-ploughings' with the ard would be likely. The cultivation area could easily be accommodated within the 10 ha estimated to have been available for each LBK longhouse in the Merzbach valley of the Aldenhoven Plateau (Lüning 1979/80; Stehli 1989).

Lüning (1979/1980) finds further support for cultivation with the ox-drawn ard in osteological evidence (horn cores, metapodia) for bull castration in the LBK (Müller 1964, 1998; Benecke 1994a: 100-101, 1994b: 176), suggesting that oxen were available for traction. Other more ambiguous arguments in favour of ard cultivation include the standardisation of LBK growing conditions based on the repeated occurrence of a narrow range of weed species in LBK-Rössen sites in the Rhineland (Knörzer 1971b, 1977), the evident 'success' of LBK agriculture in its rapid spread across Europe and the combination of cereal production with a general emphasis on cattle husbandry in the LBK (Tegtmeier 1993: 5).

A further element of this model is that cereal fields were not manured. Lüning (1980) argues on the basis of yield data from the Rothamsted Experimental Station that cereals grown continuously without manure on reasonably good soils show only a gradual decrease in yield over a number of decades. Furthermore, the loess soils of western-central Europe are thought to have undergone considerable degradation since the Neolithic and, therefore, would have been even more fertile in the Early-Middle Neolithic (see also Willerding 1983a; Rösch 2000). Lüning (2000: 182) notes the possibility that pulses were grown more intensively and on a smaller scale than cereals, with the implication that cereal-pulse rotation was not practised.

Willerding (1983b, 1988b) has argued that LBK archaeobotanical data from Lower Saxony, Germany support the model of ard cultivation. He observes that a variety of weeds species occur in LBK assemblages – typical winter cereal weeds (i.e. of the phytosociological class Secalinetea) as well as root/row-crop weeds or ruderals (Chenopodietea), perennials (mostly hemicryptophytes, with buds at soil level) and possible woodland 'relic' species. This ecological variety, Willerding argues, could be accommodated by a system of ard-ploughing in which furrows were quite widely spaced (e.g. 30 cm apart) and cereals were row-sown in the furrows. In the 'open' spaces between the furrows, weeds could grow that are not typical of winter cereals, including species tending to germinate in spring (root/row-crop weeds) and those unable to tolerate severe disturbance (hemicryptophytes).

There are a number of problems with the extensive model of cultivation for the Early-Middle Neolithic. First, the argument that the ox-drawn ard would be necessary to support an early-middle neolithic household is questionable. Ethnographic data suggest that a farming family can cultivate ca. 2-4 ha by hand and harvest up to 4 ha (Halstead 1987, 1995). Based even on the conservative area yield and seed-yield ratio figures used by most commentators on prehistoric agriculture in the study area (Table 1.2), estimates of the cultivated area needed per household (ca. 2-3 ha), therefore, tend to fall within the labour-capacities of ethnographic farming families practising hand cultivation. Second, the assumption of bare fallow is unwarranted. This is a method of reducing weed infestation that makes efficient use of plough animals and scarce human labour in an extensive farming regime (Halstead 1987; Palmer 1998a); in a small-scale intensive regime, other techniques of weed control such as hand weeding of crops are arguably more probable (Halstead 1987) (below, 1.4.5). Third, extensive farming is generally associated with the 'loss' of manure through transhumance, a practice associated with herding on a large scale (Halstead 1987, 1989a). It is unlikely, however, that small-scale arable and livestock husbandry would be completely divorced (Halstead 1987, 1989b, 2000) (below, 1.4.5). Fourth, the osteological evidence for bull castration may be unrelated to traction since this practice can form part of a meat strategy in which the goal is to encourage weight gain and good condition (Arbogast 1994: 95). In this connection, it is worth noting that a rare find of an LBK cattle bone with signs of wear from traction (from Eilsleben, central Germany) belongs to a cow, not an ox (Döhle 1997). If cows were used for ard traction, this practice would spare human labour but would not greatly increase the area a farming family could cultivate (Halstead 1995) (below, 1.4.2.2). Fifth, the archaeobotanical weed evidence presented by Willerding (1983b, 1988b) – in particular the combination of Secalinetea and Chenopodietea species in LBK assemblages – has been interpreted in other ways, including intensive cultivation (Lundström-Baudais 1984, 1986; Bocquet *et al.* 1987; Halstead 1989b; G. Jones 1992) (below, 1.4.5).

1.4.2.2 Later Neolithic-Bronze Age

Cultivation with the ox-drawn ard is widely assumed for the Later Neolithic and Bronze Age based on the appearance of plough-marks, artefactual evidence for the ard and animal traction (e.g. remains of ards, yokes, wheeled vehicles; representational evidence) and various forms of osteological evidence linked with the use of cattle for traction (maintenance of mature animals, evidence for castration, cattle burials, pathologies associated with traction) in various parts of Europe from the fourth millennium B.C. onwards (Sherratt 1981, 1997; Niesiolowska-Sreniowska 1999; Tegtmeier 1993). The emergence of ox-drawn ard cultivation has been associated with increasing social complexity (e.g. Gilman 1981; Sherratt 1981; Bogucki 1993) based on cross-cultural links between plough cultivation and social stratification (Goody 1976) (below, 1.4.6.2).

The earliest widely accepted use of the ard is in the TRB and coincides with a shift of settlement away from valley margins and further into the interfluve or watershed zone (Kruk 1980: 28-29, 1988; Sherratt 1981; Bogucki 1988: 175-177, 1993, 1999: 227-230; Milisauskas and Kruk 1989a). In fact, some authors assume that cultivation of the loess uplands would *require* a plough (e.g. Bogucki 1988: 176-177; Howell 1989); thus, Bogucki (1988: 176-177) argues that the plough "freed [later neolithic] households from their dependence on energy-subsidized floodplain habitats, enabling the occupation of interfluves". Plough cultivation is generally assumed for subsequent Baden period settlement of interfluve areas as well (Sherratt 1981, 1997; Kruk 1988; Milisauskas and Kruk 1989a; Lüning 2000: 189). The TRB-Baden site of Bronocice has yielded possible evidence for animal traction dating to ca. 3500-3000 B.C. – osteological evidence for a predominance of mature cattle (including some oxen), a vessel decorated with a wagon motif and a horn core with cord impressions, possibly from yoke-wear – with the implication that the ox-drawn ard was used for cultivation (Milisauskas and Kruk 1991, 1993).

While there are no archaeobotanical weed studies of later neolithic sites in the loess belt that have been interpreted as evidence of extensive ard cultivation, later neolithic pollen spectra in the Rhineland show higher levels of herb and grass pollen than in earlier periods (Kalis and Meurers-Balke 1997). Kalis and Meurers-Balke (1997) suggest that this reflects greater consolidation of cultivation areas if not a major increase in cultivated areas *per se*, and they infer plough cultivation as the cause.

Bogucki (1993, 1999: 227-230) has recently argued that plough cultivation 'revolutionised' household production in the Later Neolithic: the cultivated area could be increased, thus offsetting the lower area yields associated with ard cultivation, and farming families would be freed from the "labour bottlenecks" of tillage and transport. Bogucki (1993) cites data on household farming in West Africa and Ethiopia indicating that cultivation with plough oxen is up to five times as fast as cultivation without, and that households with animal traction cultivate almost twice the area of those without. He argues that unequal access to plough oxen in the Later Neolithic promoted asymmetrical relationships (dependency relationships) between households; augmented by trade in exotic materials and by mortuary ceremonialism, this differentiation would result in marked inequality (Bogucki 1993, 1999: 227-230).

A problem with this argument is that harvesting poses a further 'labour bottleneck': ethnographic data indicate that the harvesting capacity of a farming family barely matches the normal area that can be cultivated with oxen (Halstead 1995). Thus, if the cultivated area were doubled as Bogucki suggests, labour outside the household would be needed to keep up with harvesting. The need to mobilise labour outside the household, in turn, would require modification of the household model of agricultural production, which Bogucki himself (1993, 1999: 211-218) applies to the Later Neolithic. Large farming families with several adults might be able to harvest extensive ox-ploughed fields, but a large number of consumers would also tend to use up the surplus harvest (Halstead 1995).

While plough oxen can 'displace' human labour to some extent, extensive cultivation with specialised oxen is generally associated with large estates producing for a market, and not with household farming (Halstead 1995). This is because specialised plough oxen are 'expensive' to maintain (e.g. high fodder requirements) (Barker 1985: 258; Halstead 1995). Though ard-ploughing may have been prestigious in the Late Neolithic – perhaps even of ritual significance (cf. Rowley-Conwy 1987) – this does not mean that it was necessarily used to perpetuate large-scale extensive agriculture. A further possibility, which Bogucki does not consider, is that late neolithic plough animals were relatively unspecialised oxen or even cows, which would allow lower human labour inputs per unit cultivated area, without a 'quantum leap' in the scale of household cultivation. Halstead (1995) reports that the quality and rate of ploughing with unspecialised oxen (e.g. oxen used for transport as well as ploughing) or cows is much lower than for specialised plough oxen. Moreover, sharing or lending of plough oxen, which Bogucki advocates as a mechanism for social differentiation, would also tend to limit the area cultivated (Halstead 1995; Forbes 2000a).

Burials of cattle in later neolithic (ca. 3500-2200 B.C.) eastern-central Europe have been cited as evidence for animal traction in relation to ploughing and wheeled transport (Benecke 1994a: 100, 1994b: 147). It is worth noting that, of the six paired cattle burials for which sex has been determined, only one consists of two oxen; the remaining pairs include two cows and various combinations of cows, bulls, and oxen (Pollex 1999). Of the five single cattle burials of known sex, three are female, or too young to pull a wagon (Pollex 1999). If these burials do generally represent traction animals, it is clear that they do not correspond to the specialised teams of oxen that are often assumed for later neolithic ploughing.

A combination of archaeobotanical, archaeozoological, artefactual and palaeoecological evidence has been used to suggest relatively extensive cultivation with the animal-drawn ard during the Horgen and Corded Ware occupations (ca. 3200-2400 B.C.) of the Lake Zurich sites. As noted above (1.3.2), osteological data for cattle in the Horgen levels at Lake Zurich suggest that cows and bulls were maintained for traction, and this coincides with the earliest evidence in the region for wheeled transport and yokes; in the Corded Ware levels, there is increased evidence of bull castration and hence ox-traction. Archaeobotanical data (waterlogged and charred) from Horgen-Corded Ware lakeshore occupation at Lake Zurich as well as Lake Biel indicate a denser crop stand compared with earlier periods (suggested by a decrease in summer annuals) and so perhaps the onset of broadcast sowing, short grazed fallow breaks (suggested by an increase in tread-resistant pasture indicators), greater field size and/or consolidation (suggested by a decrease in woodland edge species) and, to some extent, growing conditions of relatively low fertility (e.g. occurrence of stress-tolerant weeds such as *Euphorbia exigua* – cf. Bogaard *et al.* 1998) (Jacomet *et al.* 1989: 155; Brombacher 1995; Brombacher 1997; Brombacher and Jacomet 1997; Schibler and Jacomet 1999). Pollen evidence from this period shows an increase in grassland species (Brombacher and Jacomet 1997). In terms of artefactual evidence, the emergence of a new type of harvesting knife in the Horgen period may reflect a new harvesting technique adapted to denser stands of crops sown by broadcasting (Schlichtherle 1992). The first evidence of yokes and wheeled vehicles appears in the Horgen period, and implements associated with hand cultivation (*Hacken, Fürchenstöcke*) are absent from Corded Ware levels of lakeshore settlements (Brombacher and Jacomet 1997; Schibler and Jacomet 1999). Combining all of this evidence, Schibler and Jacomet (1999) suggest a system of ard cultivation with grazed short fallow breaks (*Feld-Graswirtschaft*) for the Horgen-Corded Ware phases, the increased availability of grazing allowing an expansion of animal husbandry.

Cultivation with the cow or bull-drawn ard as inferred for the Horgen period would represent a lower input of human labour per unit area than cultivation by hand but, as noted above, would not greatly increase the total area a farming household could potentially cultivate. With more oxen in the Corded Ware period, tillage rates may have increased, though it is questionable whether the full potential of specialised plough oxen was used to cultivate much larger areas than could be worked by hand or cow-drawn ard (above). Ard cultivation in the Horgen-Corded Ware periods may have been relatively extensive, with low labour inputs and yield per unit area, but whether or not it represents a 'revolution' (*sensu* Bogucki 1993, 1999: 227-230) in household productivity is open to question.

While the date of ca. 3000 B.C. (i.e. in the Horgen period) is often cited for the onset of ard cultivation in the Alpine Foreland (e.g. Schlichtherle 1992: Fig. 18), archaeobotanical weed evidence from western Switzerland has been interpreted to suggest that the plough was absent prior to the Bronze Age. Lundström-Baudais (1984) compared waterlogged weed assemblages from a neolithic site (Brise-Lames – ca. 2800 B.C.) and a late bronze age site (Auvernier Nord – ca. 800 B.C.) located ca. 200 m apart on the shore of Lake Neuchâtel in western Switzerland. Weed assemblages from both sites contained Chenopodietea species, but the late bronze age weed flora also included weed species typical of winter cereals, as well as a few species indicative of relatively low fertility. Lundström-Baudais (1984: 172) suggests that this contrast may reflect "the introduction of new faming techniques such as winter sowing and the use of the plough", and associates this change with the prominence of spelt wheat (generally considered a winter-sown crop) in the Bronze Age.

Archaeozoological and archaeobotanical evidence from other bronze age sites in the Alpine Foreland has also been interpreted to suggest extensive ard cultivation. The predominance of adult cattle and occurrence of pathologies in cattle bones at some bronze age sites appear to reflect the intensive use of cattle as draught animals (Schibler 1996). Archaeobotanical analysis of the late bronze age charred weed assemblages from Zug-Sumpf suggests relatively "extensive" tillage and weedy fallow based on the occurrence of perennial meadow and ruderal species (Jacomet and Karg 1996). The waterlogged weed assemblage from the late bronze age site of Hauterive-Champréveyres on Lake Neuchâtel is interpreted as evidence of a grazed or mowed fallow regime (*praire-jachère*), and the predominance of mature cattle is consistent with their use for traction as well as dairying (Jacquat and Studer 1999).

Bronze age archaeobotanical data from the tell site of Feudvar (Vojvodina) in the southeast corner of the Hungarian Plain, just outside the study area, has been used to support the case for extensive cultivation of autumn-sown einkorn in the Early Bronze Age, coinciding with the maximum nucleation of population at the site (Kroll 1997). It is suggested that einkorn was cultivated extensively on moderately fertile upland loess without manuring (Kroll and Borojevic 1988). Kroll (1997) contrasts the winter cereal flora (Secalinetea character species) associated with stored einkorn in the Early Bronze Age with more 'mixed' weed floras containing both Secalinetea (winter cereal weeds) and Chenopodietea (root/row-crop weeds and ruderals) species associated with crop stores in the Late Bronze Age (Urnfield culture) and Iron Age. He argues that late bronze age and iron age weed floras reflect the diversification of the crop spectrum (e.g. the introduction of spring-sown crops such as millet), the rotation of spring- and autumn-sown crops and the combination of intensive infield/extensive outfield cultivation. This intensification and diversification of agriculture coincided with more a dispersed settlement pattern.

Archaeobotanical evidence of extensive cultivation methods in the Late Bronze Age (Urnfield culture) has been discussed by Rösch (1990e, 1993b, 1995b, 1998c, 2000). He infers extensive *Feld-Graswirtschaft* (alternation of cultivation with grazed short fallow periods) based on archaeobotanical weed evidence from sites such as Knittlingen (Rösch 1995b), a late bronze age site on loess in southwest Germany. Rösch (1995b) interprets the weed assemblage as evidence of non-intensive tillage and/or short fallow breaks and insufficient manuring (low-moderate fertility), though he has also argued that a general increase in evidence for stalling in the Bronze Age suggests greater manuring (Rösch 2000). The implication appears to be that archaeological evidence for stalling and the intensity of manuring per unit area may not be directly correlated.

In conclusion, evidence of ard cultivation in the Later Neolithic has been interpreted in radically different ways – as a widespread development with a revolutionary social and agricultural impact (e.g. Sherratt 1981; Bogucki 1993) and as an innovation of limited significance, assuming that specialised plough animals were not widely used (Halstead 1995). While artefactual evidence for the ard in the Later Neolithic clearly reflects some awareness of its use and potential, the appearance of this evidence cannot be assumed to reflect a widespread change of agricultural practice. Moreover, even if some form of animal-drawn ard cultivation were practiced (e.g. with cows, bulls or unspecialised oxen), it may or may not have led to a considerable increase in cultivated area compared to that which a household could cultivate by hand.

1.4.3 Floodplain cultivation

In terms of human labour per unit area, hand cultivation is inherently more intensive than cultivation with the animal-drawn ard (above). To this extent, hand cultivation of plots, even if no further labour-intensive inputs such as weeding and manuring were applied, can be characterised as more intensive than plough cultivation. The majority of authors describing LBK hand cultivation assume that no other intensive husbandry practices were applied (below, 1.4.4). The most coherent model of 'relatively low intensity hand cultivation' is that of floodplain cultivation.

1.4.3.1 Early-Middle Neolithic

This model was first proposed by Kruk (1973) based on survey data from southern Poland. In the survey area, LBK sites tend to be located on the lower slopes of river valleys, where the deep alluvial soils are cyclically enriched by floods and colluvium. Kruk (1973) suggested that small plots in the valley bottoms and margins were cultivated continuously without manuring, though the crops he envisioned in these plots were "vegetables" (e.g. root/leaf-crops not attested archaeobotanically) rather than cereals. Subsequently, Kruk (1980: 51-52, 63) suggested that cereals were also grown in these horticultural plots but drew a distinction between cereals, on the one hand, and pulses and "vegetables", on the other, the latter requiring almost individual care and so more closely linked with horticultural methods. In a later publication, Kruk (1988) suggested that cereals were grown in drier forested areas and *Gartenpflanzen* (presumably pulses and unknown root/leaf-crops) on the moist valley bottom soils while, in yet another paper, the suggestion of cereal cultivation in valley bottoms "during periods of low water table" is renewed (Milisauskas and Kruk 1989a: 410). Kruk (1988) has also introduced the idea of 'forest-fallow' as a response to eventual weed-infestation and soil degradation in the cultivation plots (above, 1.4.1.1), emphasising the lack of manuring and weeding in his cultivation model. Finally, Kruk (1973, 1980: 50-54, 1988) has suggested that there was continuity of floodplain cultivation from the LBK to the Lengyel period (Early-Middle Neolithic), though with a possible increase in slash-and-burn cultivation in interfluve areas during the Lengyel period (above, 1.4.1.1).

Support for aspects of Kruk's floodplain cultivation model has been inferred from archaeobotanical and palynological studies at the sites of Pleszów and Mogila 62 in the Vistula valley near Krakow, southern Poland. Gluza (1983) studied a rich sample of crop and weed remains from a Lengyel pit at Mogila 62 and concluded that the cereals were spring-sown because of an abundance of spring-germinating weed species in the assemblage. The inference of spring sowing offers some indirect support for Kruk's model, since cereals grown on the valley floor would be spring-sown in order to avoid winter-early spring flooding (Milisauskas and Kruk 1989a; Wasylikowa 1989). Based on ecological indicator values (e.g. Ellenberg numbers) for the weeds from Mogila 62, however, no additional evidence was found for valley bottom cultivation (Gluza 1983; Wasylikowa *et al.* 1985; Wasylikowa 1989). On the other hand, Lengyel period cereal pollen and waterlogged macroremains of einkorn and emmer from a peat-filled palaeochannel below the site of Pleszów have been interpreted to suggest local cereal cultivation in the valley floor (Wasylikowa *et al.* 1985; Godlowska *et al.* 1987; Wasylikowa 1989). It is worth noting that Wasylikowa (1989) mentions dibbling and weeding as possible aspects of cultivation and thus appears to support a more intensive model of cultivation than Kruk; she does not, however, mention any direct archaeobotanical evidence for such practices.

Kruk's floodplain cultivation model was elaborated by Sherratt (1980, 1981, 1997), who argued that small-scale horticulture adapted to alluvial, lake-edge, riverine or springside conditions – that is, supplemented by high ground-water and flooding – characterised early crop agriculture from the Near East to central Europe. Though he describes this regime as 'horticulture', Sherratt (1980: 318) emphasises that it would *not* be labour-intensive:

> "The technology which such a horticultural system would require is of the simplest. In most cases forest clearance would not be needed. The seed would be broadcast, and relatively little weeding would be necessary. Virtually no preparation of the soil would be required, which in many cases would hardly rank even as hoe- or digging-stick cultivation. Where soils are subject to winter flooding and summer desiccation, the deep cracking caused by drying-out would provide natural aeration and make them practically self-cultivating. The labour-costs would thus have been trivial" (Sherratt 1980: 318).

Like Kruk's model, therefore, Sherratt's model is not intensive in terms of labour inputs, even to the point where doubt is cast on the necessity of hand cultivation itself. Sherratt (1980) also assumes spring sowing of cereals to avoid earlier flooding. According to Sherratt (1980: Fig. 2), "horticulture on alluvial soils" was practiced throughout the Early and Middle Neolithic in western-central Europe, to be replaced by "rainfed horticulture" in the later Neolithic and Bronze Age.

Bogucki (1982: 40, 1988: 76-84, 1996) has also adopted the idea of floodplain cultivation, arguing that the location of LBK sites near the conjunction of river valleys and loess-covered uplands may have been conditioned as much by a horticultural focus on river valley alluvium as on the fertility of loess soils. Like Kruk and Sherratt, Bogucki (1996: 247) asserts that this cultivation regime was relatively non-intensive, thanks to the rich, self-renewing conditions in the river valleys:

> "Spring flooding and groundwater from the watersheds would have recharged the soil nutrients in the narrow floodplains of the small central European streams. As a result, the fertility of these regions was sustained for years despite continuous cultivation" (Bogucki 1996: 247).

Bogucki (1996) sees the spring-sowing of cereals as integral to this cultivation model and, more generally, to the spread of farming across Europe: whereas cereals were autumn-sown in the eastern Mediterranean to exploit winter rain and avoid summer drought, wetter summers and colder winters in temperate Europe made spring sowing viable and, in the context of floodplain farming, necessary.

As noted above, the floodplain cultivation model of Kruk, Sherratt and Bogucki does not refer to truly intensive horticultural practices such as thorough tillage, weeding and manuring but rather describes situations in which garden-like conditions are almost 'naturally' present. From this perspective, the floodplain cultivation model is rather similar to the shifting cultivation model, where the cultivation of virgin forest soil is seen to offer 'garden-like' conditions (high fertility, low levels of weed growth) without any manuring, soil preparation or weeding (above, 1.4.1). It is not surprising, therefore, that floodplain cultivation is sometimes combined with shifting cultivation in the same model (Kosse 1979: 140-144; Kruk 1988).

Various authors have criticised the model of floodplain cultivation. Some have pointed out that many LBK sites are located near small streams without major flooding and silt deposition and with little room for floodplain farming; they argue that cultivation was located on higher river terraces or upland plateaux (Chapman 1982; Lüning 1982a, 1988; Stehli 1989). Furthermore, in the Middle Neolithic especially, a considerable proportion of sites are located well away from valley margins, in interfluve areas (Chapman 1982; Kruk 1973, 1980: 26-27, 1988; Whittle 1996a: 161). According to Bakels (1978: 67-68, 1988), the ecological preferences of weed species in LBK weed assemblages could be compatible either with valley floor or loess upland cultivation. A number of authors do infer spring sowing of cereals due to an abundance of spring-germinating species in early-middle neolithic weed assemblages (Groenman-van Waateringe 1979; Bakels and Rouselle 1985; Rösch 2000), which would be consistent with the avoidance of winter-early spring floods in valley bottoms, but others interpret the consistent presence of a few autumn-germinating species in weed assemblages as evidence of autumn sowing (Knörzer 1967b, 1971b, 1988, 1991; Willerding, 1980, 1983a, 1985, 1988a; Halstead 1989b). The lack of cereal pollen in several cores from river valleys adjacent to LBK settlements has been used to suggest that cultivation plots were located further away in upland areas (Bakels 1988, 1992a; Kalis and Zimmerman 1988; Lüning 2000: 184). Where cereal pollen has been found in cores from river valleys, it can be argued that it was washed in from the upper slopes with colluvium (Kalis and Zimmerman 1988; Bakels 1992a).

1.4.3.2 Later Neolithic

According to Kruk (1973, 1980: 54-57, 1988), floodplain cultivation of the type practiced in southern Poland during the Early-Middle Neolithic (above) continued during the TRB period alongside upland shifting cultivation (above, 1.4.1.2). As evidence of continued valley bottom 'horticulture', he cites the occurrence of small sites in the valley margin zone in addition to the larger sites of the interfluve.

1.4.4 Other forms of 'relatively non-intensive' hand cultivation

Hand cultivation of crops without intensive practices such as manuring and weeding has also been suggested without invoking the 'natural' fertility of floodplains or forest soil. A number of archaeobotanists publishing neolithic material from the study area appear to support more or less permanent hand cultivation of cereals and pulses, but without other intensive husbandry practices.

1.4.4.1 Early-Middle Neolithic

Gregg (1988: 65, 94, 97, 99, 166-167) suggests hand cultivation of cereals without manuring in the LBK, citing evidence for the maintenance of cereal yields around 1000 kg/ha without manuring. Gregg does imply some addition of manure, however, by proposing weedy fallow periods of at least one year to provide grazing for livestock (see also Stika 1996). Gregg infers the practice of fallowing by reasoning that LBK weed assemblages do not reflect coherent phytosociological communities in a modern sense and so cannot derive from continuously cultivated fields. Given the historical contingency of phytosociological communities (above, 1.2.3.1), however, this argument is problematic. Gregg (1988: 98, 167) also mentions the possibility of "gardens plots" for the non-cereal crops (peas, lentils, poppies and flax) but without referring in any more detail to the husbandry methods used; some weeding of crops is implied in Gregg's (1988: Fig. 4) cultivation and harvest schedule.

Kreuz's (1988a, 1990: 173-182) interpretation of archaeobotanical data mostly dating from the earliest LBK phase (*älteste Linearbandkeramik*) includes the suggestion of fairly intensive soil disturbance based on the dominance of annual weed species. Otherwise, no intensive measures are inferred and it is argued that manuring would be unnecessary to maintain reasonable yields.

Other archaeobotanists appear to assume hand cultivation in the Early-Middle Neolithic but infer poor growing conditions attributed to a lack of intensive tillage and manuring. Knörzer (1988) has emphasised the occurrence of the perennial grass *Phleum pratense* in many LBK samples, arguing that it reflects relatively poor tillage (cf. Willerding 1980, 1983b, 1988b).

Knörzer (1986) also argues that weed species indicative of low nutrient status (e.g. *Rumex acetosella*) indicate the degradation of unmanured soils in the LBK. According to Rösch (1998b, 2000), cultivation of highly fertile loess soils by LBK farmers without manuring or fallow breaks resulted in decreasing soil productivity and crop yields. As a result, cultivation of barley (claimed to be more tolerant of poor soils than einkorn and emmer) increased and/or larger areas were cultivated. As evidence for soil degradation, Rösch (1998b, 2000) compares early and late LBK samples from Vaihingen/Enz in the Neckar valley: barley occurs in a larger proportion of late LBK samples, and weed species of acid soils make up a larger proportion of the total seeds from wild taxa in the late LBK samples. As Rösch (1998b, 2000) admits, these data are not sufficient to support this wide-ranging theory. There are also problems with his use of 'presence/absence' for barley (no attempt is made to amalgamate samples from the same context) and with the amalgamation of all wild seeds from the early and late LBK (cf. G. Jones 1991). In contrast to Rösch, Willerding (1980, 1983a) has argued that there is no evidence for soil exhaustion in the LBK.

Authors inferring small-scale hand cultivation often cite the presence of shade-tolerant species such as *Lapsana communis* in LBK weed assemblages as evidence that cultivation plots were small and surrounded by hedges or woodland (Knörzer 1967b, 1971b, 1988; Groenman-van Waateringe 1971; Willerding 1980; Gregg 1988: 91; Milisauskas and Kruk 1989a; Heim and Jadin 1998). Shaded crops imply small-scale cultivation, while hedges would suggest permanence. It has been argued, however, that shade could be cast by trees left standing in and around cultivation plots rather than by hedges surrounding small plots (Bakels 1978: 68; Bakels and Rouselle 1985). Kreuz (1990: 193) has also pointed out that possible 'hedge species' in archaeobotanical assemblages tend to grow in a range of habitats and so cannot be used as 'hedge indicators'. Furthermore, the presence of *Lapsana communis* has also been interpreted as evidence for slash-and-burn fields in woodland (above, 1.4.1.1). In fact, species like *Lapsana communis* do grow successfully in open situations (i.e. they are shade-tolerant, not shade-requiring – Knörzer 1988; Brombacher and Jacomet 1997; Lüning 2000: 185-186) and could in any case be shaded by the crop itself rather than by trees or hedges (Willmans 1988).

On the other hand, the existence of hedges at a number of LBK sites has also been inferred from the analysis of macroscopic wood charcoal (from settlement pits), and it has been suggested further that the hedges protected cultivation plots from animals, wind etc. (Kreuz 1988b, 1990: 192-196, 1992; Castelleti and Stäuble 1997). In contrast to these results, potential hedge or 'border vegetation' species (*Kernobstgewächse*) are rare in middle neolithic charcoal samples from the Aldenhoven Plateau (Castelleti and Stäuble 1997), an observation that has been interpreted to suggest that cultivation plots were more consolidated in this period, possibly as part of more 'village-like', communal settlement (Lüning 2000: 40).

Though intensive practices such as manuring and weeding are rarely mentioned in the models of small-scale hand cultivation reviewed above, cereal-pulse rotation is suggested by some authors (Hamond 1981; Bogucki 1988: 82; Stika 1996; Willerding 1983b, 1988b). Cereal-pulse rotation is more labour-intensive than rotation with fallow (whether weedy or bare fallow) (Halstead 1987). Knörzer (1971b) argues against cereal-pulse rotation, however, on the basis of the repeated occurrence of Bromo-Lapsanetum in LBK-Rössen crop assemblages in the Rhineland, arguing that this indicates consistent growing conditions from year to year. Knörzer (1977) suggests further that pulses were cultivated in 'gardens' as opposed to fields – so on a smaller scale (and presumably more intensively) than cereals (cf. Kruk 1980: 63). The idea of pulse 'gardens' also underlies the interpretation of 'fences' near or attached to LBK longhouses as garden enclosures (Kind 1989: 84; Lüning 2000: 182). This dichotomy between 'infield' pulse cultivation and 'outfield' cereal cultivation, however, derives from a specific historical context – nucleated settlement and the extensive cultivation of distant cereal fields in the recent past (Halstead 1981a, 1987; Hodkinson 1988) and so should not be automatically extrapolated to prehistory. In fact, pulse crops can be grown on a large (field) scale (e.g. Gill and Vear 1980: 177, 182), while cereals can be grown on a small or garden scale (Charles *et al.* 2002).

1.4.4.2 Later Neolithic

Various authors describing crop cultivation in the Alpine Foreland in the earlier part of the Late Neolithic (ca. 4300-3500 B.C., prior to the Horgen period) appear to assume hand cultivation of crops but do not specify the use of other intensive husbandry methods (e.g. manuring or hand weeding/hoeing during the crop growing season). As for the Early-Middle Neolithic (above), some authors note the presence of Chenopodietea character species (root/row-crop weeds and ruderals) in later neolithic weed assemblages but do not interpret this as evidence of 'truly' intensive husbandry. Thus the higher frequency of Chenopodietea/summer annuals in pre-Horgen (charred and waterlogged) weed assemblages at Lake Zurich sites are interpreted as evidence of an 'open' crop stand, possibly as a result of row-sowing, and intensive hand weeding/hoeing between the rows is not considered (Jacomet *et al.* 1989: 144, 155; Brombacher and Jacomet 1997). In fact, it is suggested that little soil disturbance took place between the sown rows of crop, allowing perennial weeds to flourish as well (Jacomet *et al.* 1989: 155; Brombacher and Jacomet 1997). The occurrence of tread-resistant pasture species is interpreted as evidence of grazed fallow, while woodland edge species are interpreted as evidence that fields were small and surrounded by woodland. Overall, a sort of *Feld-Graswirtschaft* (cultivation with grazed short fallow breaks) is suggested (Schibler and Jacomet 1999), but with hand cultivation, smaller cultivation plots and a more 'open' crop stand than in later periods (above, 1.4.2.2).

A somewhat different interpretation is presented by Maier (1999) for the weed assemblages associated with charred crop stores at Hornstaad-Hörnle IA, an early lakeshore settlement (ca. 3915 B.C.) on Lake Constance destroyed by fire after ca. 10 years of occupation. She notes that weed levels overall are low in the stores, that perennials are infrequent, indicating thorough tillage, and that manuring would be unnecessary given the high fertility of local soils. She also argues, based on a relatively low frequency of woodland edge species, that cultivated plots were consolidated rather than scattered. In contrast to Rösch's (1990e, 1996b, 2000) interpretation of pollen and plant macrofossil evidence from Lake Constance, Maier (1999) detects no evidence for shifting cultivation.

Modest area yield estimates of ca. 600 or 650 kg/ha have been used to model the economies of the Lake Zurich sites and Hornstaad-Hörnle (Table 1.2), underlining the relatively low intensity of husbandry (Jacomet *et al.* 1989: 90-91; Gross *et al.* 1990; Billamboz *et al.* 1992; Dieckmann *et al.* 1997; Maier 1999). Gross *et al.* (1990) conclude, based on an area yield figure of 650 kg/ha, that the late neolithic economy in the Lake Zurich area was marginal and subject to imbalance. Their use of a fairly low area yield (650 kg/ha, of which ca. 520 kg/ha would be available for consumption) also contributes to the inference that cereal cultivation provided no more than 50% of the human diet (Table 1.2).

For later neolithic sites in the loess belt, Küster (1985: 52) and Stika (1996) infer intensive tillage at Hochdorf (Schussenried culture) and Heilbronn-Klingenberg (Michelsberg culture), respectively, based on the dominance of annual weed species. No other intensive husbandry measures are inferred, though both authors mention the possibility that livestock grazing stubble/fallow would provide some manure.

1.4.5 Intensive garden cultivation

A truly intensive model of cultivation has been constructed based on the practices of recent farmers pursuing small-scale crop and animal husbandry for domestic consumption (Halstead 1987, 1989b, 2000). Intensive garden cultivation is characterised by high inputs of human labour per unit area through practices such as dibbling or row sowing, hand weeding or hoeing of crops, manuring and watering, and involves close integration of crop and animal husbandry (Halstead 1987, 1989b, 2000; G. Jones 1992; G. Jones *et al.* 1999). Sowing crop seed by dibbling or row-sowing rather than broadcasting makes more efficient use of the seed corn, requiring much less seed than broadcasting and so allowing much higher seed-yield ratios (e.g. at least 10:1) than those associated with extensive cereal cultivation (e.g. 5:1 or less) (Sigaut 1975: 219-221, 1992; Halstead 1987, 1990, 1995). Low seed-yield ratios derived from extensive farming (e.g. 3:1, 4:1 or 5:1) have sometimes been applied to prehistoric agriculture in the study area (Table 1.2; above, 1.4.2, 1.4.4), with the result that significant deductions for seed corn are made when estimating area yields available for consumption. In a row-sowing or dibbling regime, however, such deductions would be very low or negligible. Dibbling and row sowing also facilitate weeding of the crop (Halstead 1987). Weeding not only improves yields but can also supplement the human and animal diet (Gallant 1991: 49-50; Forbes 1998; Foxhall 1998; Palmer 1998b).

While the benefits of dibbling versus broadcasting on seed-yield ratios are fairly well known, empirical data on *area yields* for intensive cereal cultivation have been lacking because intensive cereal cultivation using traditional methods is extremely rare today. A study of intensive spelt cultivation in Asturias, north-east Spain indicates that spelt yields of 1700-1900 kg/ha (down to 800 kg/ha in bad years) are achieved using intensive husbandry methods such as manuring and hand weeding (Charles *et al.* 2002) (Table 1.2; see also below, 1.5.2). These yields are comparable with high average yields recorded over 15 years in the Little Butser field trials, where row-sown emmer and spelt plots were thoroughly hoed three times during the growing season but no manure was applied (Reynolds 1992) (Table 1.2). As noted above, calculations of the areas required to support farming families have tended to use low seed-yield ratios and/or modest area yields (Table 1.2), sometimes resulting in the conclusion that ard cultivation was necessary (above, 1.4.2.1) or that households were surviving 'on the breadline' (above, 1.4.4.2). While 'bad years' due to poor weather conditions etc. are inevitable under any husbandry regime, intensive cereal husbandry would reduce the amount of land a household needs to cultivate by helping to ensure high yields per unit area. The effect of varying area yield figures on the cultivated area necessary to supply a household of five with

1500 kg cereals per year is shown in Table 1.3. As area yields approach the levels reported for the Asturias spelt (ca. 1500+ kg/ha), the area cultivated falls to 1 ha per household or less (Table 1.3). The annual requirement of 1500 kg per household (300 kg cereals per person per year) is based on the assumption that wheat provides the bulk (ca. 80%+) of the diet, allowing ca. 2500 kcal per person per day given that 1 kg wheat provides ca. 3000 kcal (Gregg 1988: Table 1, 73). Other authors arguing for less intensive forms of hand cultivation and lower area yields have arrived at low area estimates (e.g. 1 ha per household or less) by assuming that cereals provided no more than ca. 50% of the diet, estimated to amount to as little as 100 kg per person per year (e.g. Gross *et al.* 1990; Billamboz *et al.* 1992) (Table 1.2; above, 1.4.4.2).

The question of manuring depends partly on the yields farmers aimed to achieve. It has been argued that wheat yields of around 1000 kg/ha can be achieved without manuring over the long-term (Loomis 1978; Gregg 1988: 65; Lüning 2000: 174). Yields of unmanured wheat in the Broadbalk experiment at Rothamsted, cultivated continuously since 1843, have stabilised at ca. 1200 kg/ha (Rothamsted Experimental Station 1991); average yields of unmanured barley and wheat in the Woburn experiment (1877-1927) are of a similar order (Russell and Voelcker 1936) (Table 1.2). Of course, the Rothamsted and Woburn results are influenced by modern conditions, including improved cereal varieties and widespread use of herbicides. The high yields reported by Reynolds (1992) for unmanured emmer and spelt cultivated continuously over 15 years in the Little Butser field trials must also to some extent reflect the modern context of the experiment (Dark and Gent 2001), though these yields also reflect row-sowing and intensive hoeing between the rows of cereals during the growing season (Lüning 2000: 174) (Table 1.2). It should also be admitted that area yields reported from plots or fields of differing size and evenness of sowing are not, strictly speaking, fully comparable (Sigaut 1992).

Though average yields for unmanured cereals in modern experiments appear reasonably high (ca. 1000 kg/ha), experimental evidence also shows that yields on unmanured plots tend to decline in the medium-term before stabilising and that manuring can maintain higher yields over many years (Russell and Voelcker 1936: 236, 239; Rowley-Conwy 1981) (Table 1.2). Moreover, ethnographic observation indicates that it is the *poor* crop yields that are the most critical for subsistence farmers, not the maximum or average yields, since poor yields resulting from adverse weather conditions, scarcity of labour etc. must be sufficient to feed the household (Forbes 2000b). Thus, even if the average yields of unmanured neolithic-bronze age fields matched the ca. 1000 kg/ha reported from modern experiments, the poor yields would be substantially less (e.g. 500 kg/ha or less – Table 1.2). If households depended on quite high area yields – a likely possibility given the limited area a household could hand cultivate and harvest (above, 1.4.2.1) – manuring would be one way of ensuring that relatively poor yields remained adequate.

Heavy manuring of cereal plots may cause cereal plants to lodge, but ethnographic evidence suggests that allowing sheep or goats to graze unripe crops counteracts this effect (Forbes 1998; P. Halstead, field notes from Asturias and Greece). A range of factors other than manuring also affects lodging (weed infestation, weather, straw-length of cereal variety). Farmers in Asturias growing spelt (a particularly tall cereal crop) using intensive methods (below, 1.5.2) have reported that the long-term benefits of manuring on spelt yields outweigh the short-term disadvantages of a greater tendency to lodge (P. Halstead, field notes from Asturias).

1.4.5.1 Early-Middle Neolithic

As noted earlier, early-middle neolithic weed assemblages tend to contain a mixture of character species of the Chenopodietea and Secalinetea. Willerding (1980, 1981, 1983a, 1985, 1986: 335, 1988) has argued that the association between Chenopodietea and cereals, which he considers to have been autumn-sown (as in the Near East), indicates an open crop stand enabling the root/row-crop weeds to germinate in the spring and compete with established plants. This explanation has been widely accepted among archaeobotanists (Gluza 1983, Jacomet *et al.* 1989: 144, 155; Wasylikowa 1989; Stika 1991; Brombacher and Jacomet 1997) (above, 1.4.4.2). Late ripening of einkorn and emmer has also been cited as a possible cause (Gluza 1983; Wasylikowa 1989). Alternatively, archaeobotanists have associated the occurrence of spring-germinating annuals (including Chenopodietea character species) as evidence that cereals were spring-sown (Groenman-van Waateringe 1979; Bakels and Rouselle 1985; Rösch 2000; cf. Willerding 1981).

The presence of Chenopodietea species in early-middle neolithic weed assemblages, however, may also offer support for a model of intensive garden cultivation in the LBK – that is, one involving high inputs of labour per unit area over and above the task of hand cultivation itself. Halstead (1989b: 34) has suggested that the occurrence of Chenopodietea character species in LBK crop samples could indicate labour-intensive practices such as "manuring or midenning and weeding or hoeing" by analogy with work by G. Jones (1992) on late bronze age weed assemblages from Assiros Toumba in Greek Macedonia. G. Jones (1992) interpreted high proportions of Chenopodietea character species in crop samples from Assiros as evidence of intensive garden cultivation, citing other weed assemblages containing mixtures of Chenopodietea and Secalinetea in Europe (Roman Neuss in Germany, medieval Poland) as possible evidence that intensive cultivation was widespread in the past. For the Early-Middle Neolithic, the interpretation of the Chenopodietea component of LBK weed assemblages in terms of intensive husbandry (Halstead 1989b; cf. G. Jones 1992) is the only explicit argument that has been made for an intensive garden cultivation model of crop husbandry.

A recent study of the weed floras associated with intensive and extensive cultivation of winter-sown pulses in Greece shows that Chenopodietea character species are associated with intensively managed plots (G. Jones *et al.* 1999) (see also below, 1.5.2). Furthermore, an ongoing study of the effect of late harvesting of einkorn on weed floras in southern France (G. Jones *et al.* in prep) shows that late harvesting does not encourage floras rich in Chenopodietea character species. Personal observations made by the author in Evvia, Greece suggest that thinly-sown cereal fields, with an 'open' crop stand, do not tend to contain Chenopodietea character species growing in the gaps. Similar observations have been made by M. Charles, G. Jones and P. Halstead in Borja, Spain, where Chenopodietea species tend to occur in irrigated fields with a dense crop stand rather than in more open, unirrigated fields. The implication is that intensive husbandry, rather than late harvesting or the reduction of competition by the (winter) crop in an 'open' crop stand, may be responsible for the occurrence of Chenopodietea character species in prehistoric weed assemblages. A significant complication to the link between Chenopodietea and intensive garden cultivation, however, is crop sowing time, since Chenopodietea are also associated with spring-sown crops (G. Jones 1992; G. Jones *et al.* 1999). A further, 'non-husbandry' explanation for the presence of Chenopodietea in archaeobotanical weed assemblages is contamination by ruderal vegetation (G. Jones 1992) (above, 1.2.3.1). This is a distinct possibility for some early-middle neolithic weed assemblages dominated entirely by *Chenopodium album*, a Chenopodietea character species (Oberdorfer 1994) that may have been collected as a food plant as well as being harvested as an arable weed with crops (e.g. Knörzer 1967b, 1988, 1997; Bakels 1979, 1983/4, 1991b; Stokes and Rowley-Conwy 2002) (see also below, 4.5.1).

Manuring in the Early-Middle Neolithic is considered unlikely by many authors on the grounds that it would be unnecessary, though a few authors do suggest that fallow breaks provided grazing for livestock and so imply that plots received some manure (Gregg 1988: 94, 99, 167; Stika 1996) (see also above, 1.4.1-1.4.4). Based on a study of LBK buried soils in Luxembourg and Lorraine, Fechner *et al.* (1997) have argued that high-yielding cereal cultivation could only be carried out in the long-term with regular manuring and the addition of fertilizers such as ash. Manuring may have caused high phosphate levels at some sites, though the phosphate could have entered the soil after the Neolithic (Fechner *et al.* 1997). Compared with early neolithic sites, middle neolithic sites tend to occur more frequently on relatively poor, non-loess soils, with the implication that manuring would be necessary (Lüning 1982b; Kooijmans 1993).

An obvious factor affecting the practice of manuring in the Early-Middle Neolithic would be the availability of manure. The spreading of animal dung collected in pens or stalls on arable fields or the provision of dung by animals grazing stubble or fallow can replenish the nutrients taken up by the crop and weeds (e.g. Halstead 1987; Forbes 1998; Williamson 1998). Cattle – the dominant domesticate in most early-middle neolithic animal bone assemblages from the study area (Lüning 2000: 110) – provide about 12 tons of manure per animal per year (Rowley-Conwy 1981). Slicher van Bath (1963: 260) summarises 18th-19th century sources on manuring in western Europe and suggests that, on average, about 10 tons of manure were required (per harvest) per hectare. Alcock *et al.* (1994) suggest heavier manure requirements (of 16-34 tons per hectare) as minimal rates for classical farmsteads. Heavy manuring is also indicated by ethnographic data from Asturias, Spain relating to small-scale intensive cultivation of maize and potatoes in rotation with spelt (P. Halstead, field notes): here, a small herd of around ten cows is reported to provide enough manure for the area cultivated intensively by one household (ca. 1 ha). While manure was probably in chronic shortage in the Early-Middle Neolithic as in more recent times (Barker 1985: 52-54; Alcock *et al.* 1994), it appears plausible that a household keeping a few cattle each for meat and perhaps milk (see also below) as well as a few sheep/goat and pigs (cf. household livestock estimates by Suter and Schibler 1996) could, by strategic folding of animals on stubble and spreading of stall manure or household refuse, manage to replenish nutrients in intensively cultivated plots.

The predominance of cattle in early-middle neolithic bone assemblages has been linked to their grazing ecology: they browse more than sheep, can reach higher vegetation and can tolerate a poorer diet, and so are better suited to browsing woodland (Halstead 1989b). While sheep are better at picking up fallen grains in stubble fields and grazing sprouting weeds close to the ground, cattle can also convert stubble to manure (Rowley-Conwy 1981; Halstead 1989a, b). The different grazing habits of cattle and sheep could have been used in combination: cattle may have been allowed to graze the stubble first, thinning it out before the sheep were allowed to graze (cf. Bell 1971). Overall, therefore, cattle would be suitable for grazing the full range of available habitats (woodland, stubble, fallow) and producing manure to replenish nutrients lost from cultivation plots each year.

The antiquity of manuring has been linked with that of stalling animals for draught or milking (Bakels 1997) (see also below, 1.4.5.2). Available mortality data for cattle and sheep/goat assemblages from early-middle neolithic sites are generally too limited to infer herd management strategies *sensu* Payne (1973) reliably (Halstead 1989b; Glass 1991: 69; Arbogast 1994: 91), but they appear to reflect predominant meat use for cattle and sheep/goat (Arbogast 1994: 93; Benecke 1994a: 95, 1994b: 122-123). Benecke (1994a: 96) has argued that a high proportion of adult females among cattle and sheep/goat remains at the middle neolithic (Rössen) site of Künzing-Unternberg in Lower Bavaria indicates a combined meat/milk strategy. Ceramic sieves from LBK sites have been interpreted as cheese strainers for separating curds and whey (Bogucki 1982, 1984, 1986) and have been used to suggest that cattle were exploited for their dairy products, perhaps as part of a more generalized milk-meat-blood use strategy (cf. Glass 1991: 75). There is little evidence for the use of cattle for traction (above, 1.4.2.1). Morphological evidence for bull castration has been identified at some LBK sites (Müller 1964, 1998; Benecke 1994b: 176) but need not indicate ox-traction *per se*, in any case (above, 1.4.2.1). Firm evidence for draught animals or specialised dairying in the Early-Middle Neolithic is, therefore, lacking, though there are some indications of milk use.

The 'north' (or rear) section of LBK longhouses has sometimes been interpreted as a byre (Startin 1978; cf. Sherratt 1981) but this has been considered unlikely for three reasons: first, the size of this section varies greatly (Modderman 1988; Coudart 1998: 105); second, the probable location of the main house entrance is at the southern end (Coudart 1998: 71, 105; Bradley 2001); and third, phosphate surveys of a small number of longhouses suggest – with one possible exception (House 35 at Vaihingen) – that animals were not kept inside (Lienemann 1998; Stäuble and Lüning 1999). The remains of fences in and around some LBK sites (Lüning 2000: 159), however, could represent animal enclosures where manure would be concentrated. Furthermore, charcoal evidence for the collection of firewood from hedge-like habitats (Kreuz 1988b, 1990: 192-196, 1992; Castelleti and Stäuble 1997) may hint at the existence of hedge-enclosures (above, 1.4.4.1) and hence the potential for enclosed grazing of stubble/fallow and/or manure collection for spreading.

All in all, there is no firm evidence for stalling of animals in the Early-Middle Neolithic or for dairying or animal traction. Even if it is assumed that animals were not generally stalled, however, the use of pens or enclosures and/or grazing of stubble and fallow may have played an important role in crop and animal husbandry.

1.4.5.2 Later Neolithic

Lundström-Baudais (1984, 1986) and Bocquet *et al.* (1987) consider the possibility that the predominance of Chenopodietea character species (root/row-crop weeds and ruderals) in later neolithic assemblages from lakeshore sites (Brise-Lames, Charavines-les-baigneurs, Clairvaux) in the French Jura reflects intensive garden cultivation. According to this interpretation, crops were autumn-sown and the abundance of spring-germinating Chenopodietea species reflects hand weeding or hoeing (*sarclage*) of crops during the growing season. Manuring is not explicitly mentioned, but the overall husbandry regime is described as resembling modern gardening rather than modern cereal cultivation. The high nutrient requirements of weeds in the later neolithic assemblage from Twann on Lake Biel may, according to Ammann *et al.* (1981: 91), indicate manuring.

Bakels (1997) has recently argued that manuring with animal dung forms part of the 'secondary products complex' of the Later Neolithic (above, 1.3.2), when the first direct evidence of stalling and manured fields appears. It is likely, Bakels (1997: 444) argues, that "the practice of collecting dung for use as manure was a consequence of the confining of animals for the purpose of milking or of the stalling of draught animals". The earliest evidence for stalling and manuring has been identified at the lakeshore site of Thayngen-Weier (Pfyn culture). A layer of organic material washed into the lake adjacent to the settlement was found to contain fly puparia and parasite eggs characteristic of faecal material as well as probable fodder remains and has been interpreted as material from a manured plot (Nielsen 1989; Robinson and Rasmussen 1989). One of the structures in the Weier II settlement, Building 3, contains layers of dung between three successive wooden floors and has been interpreted as a byre (Nielsen *et al.* 2000). The dung includes probable fodder remains (Robinson and Rasmussen 1989) and an insect fauna associated with dung and decaying matter (Nielsen *et al.* 2000). Evidence for animal stalling has been identified at only one other site in the late neolithic Alpine Foreland – Pestenacker, with leafy hay remains in a possible 'stall section' of a house and accumulated dung in an associated yard (Hilbig and Neef 1992) – but animal dung has been noted more widely at lakeshore sites (e.g. Gross *et al.* 1990), and the ubiquity of twigs and branches points to leaf and/or branch foddering (Lüning 2000: 147) (see also 2.6.2). Evidence for the presence and foddering of animals in settlements coincides with evidence for dairying from the mortality curves of cattle in the region (Higham 1967; Becker 1981; Jacomet and Schibler 1985; Halstead 1989b; Gross *et al.* 1990; Hüster-Plogmann and Schibler 1997) (above, 1.3.2). In addition to manure from stalled animals, some authors (Küster 1985: 52; Stika 1996) have mentioned the possibility of manuring as a by-product of stubble/fallow grazing (above, 1.4.4.2).

It should be emphasised that the 'sudden appearance' of evidence for stalling and for an abundance of dung and fodder in settlements coincides with the appearance of lakeshore settlements of the Alpine Foreland where organic remains are preserved by waterlogging. In non-waterlogged 'dry' conditions, (uncharred) plant and insect remains associated with manure layers or sheep/goat pellets would not be preserved, and the uncharred dung/manure itself might be very difficult to detect. With some rare exceptions (LBK well deposits – Knörzer 1998, traces of Rössen settlement in the Federsee region Schlichtherle 1995), waterlogged conditions are lacking for the Early-Middle Neolithic. Like the secondary products complex in general (Chapman 1982; Rowley-Conwy 1987; Glass 1991: 77; Halstead 1995; Lüning 2000: 12) (above, 1.3.2), therefore, Bakels' (1997) 'manure revolution' may well be a false horizon.

1.4.6 The key variables of permanence, intensity and seasonality and their wider implications

Four models of crop husbandry, each representing distinct 'extremes' in growing conditions, have been suggested for the study area in the archaeological literature: shifting cultivation, extensive ard cultivation, floodplain cultivation and intensive garden cultivation. As noted in the discussion above, the strength of evidence cited in support of these models is variable, and an attempt has been made to identify clear weaknesses and problems. The aim of this project is to reconstruct crop husbandry practices of the Neolithic-Bronze Age in western-central Europe, and in particular to see what light the large archaeobotanical dataset available for this region/period can shed on the relative validity of these models.

Table 1.4 shows how the four crop husbandry models can be distinguished by three key variables: permanence, intensity and seasonality. Permanence separates shifting cultivation on the one hand and fixed-plot cultivation (whether extensive or intensive) on the other. Intensity distinguishes between extensive ard cultivation and small-scale intensive cultivation. Finally, seasonality (autumn versus spring sowing) can potentially distinguish between floodplain cultivation, in which crops would be spring-sown to avoid earlier flooding, and intensive garden cultivation, in which crops could be autumn- or spring-sown; it should be noted, therefore, that seasonality can only distinguish between floodplain and intensive garden cultivation where the latter involves autumn sowing.

The broad social implications of each of these variables are considered below.

1.4.6.1 Permanence (shifting versus fixed-plot cultivation)

A broad implication of shifting cultivation for early farmers in western-central Europe is that it would involve a higher degree of mobility than fixed-plot cultivation. Whittle (1996a: 160-162, 176-177, 363-364, 1996b, 1997) has suggested that LBK longhouses acted as 'tethers' in a mobile way of life associated with cattle herding, limited cultivation, gathering and hunting. For Whittle, neolithic 'mobility' suggests continuity with the Mesolithic and hence that early farmers were descended from local hunter-gatherers (cf. recent writing on shifting cultivation and Mesolithic-Neolithic continuity in Britain – Barrett 1994: 143-148, 1999; Whittle 1997; Thomas 1999: 23-32):

> "Contrary to its usual characterisation as the classic example of colonisation, the LBK . . . can be seen as the result of the extension of [a mobile strategy] by indigenous inland foragers. Taking advantage of new staples, but retaining mobility and initially a broad resource spectrum, they anchored a lifestyle of moving around the river valleys and woodlands on groupings of larger timber longhouses . . . occupations fluctuated in size and duration; rather few were in continuous use" (Whittle 1996a: 363-364).

Whittle (1996b: 16-17) has also suggested that "foragers could easily and rapidly adopt (and easily abandon again) new subsistence techniques" and that "cultivation could be incorporated into mobile annual cycles". It is interesting to note, however, that the cultivation practices of the Penobscot of Maine – the ethnographic example cited by Whittle (1996b) for the integration of cultivation into mobile annual cycles – do not resemble shifting cultivation: cultivated plots (termed "gardens") were located at the permanent villages, near the wigwams of individual families (Speck 1940: 35, 91). Furthermore, intensive practices were associated with these gardens in the past: "They say that in ancient times the ground was turned over with sharpened sticks, and when the seeds had been planted dead fish and refuse were put on top as fertilizer" (Speck 1940: 91-92).

The assumption that indigenous farmers in the Neolithic would have easily 'picked up' a mobile form of cultivation is open to question on several grounds. First, as Whittle (1996b) himself has noted, the general perception of mesolithic hunter-gatherer groups in central Europe as small, simply structured and residentially mobile – in opposition to large, sedentary groups of logistically mobile hunter-gatherers in northern Europe – may be exaggerated (Zvelebil 2000; cf. Gronenberg 1999: 137). Zvelebil (2000) has identified major taphonomic biases against the detection of residential hunter-gatherer sites in central Europe and in favour of peripheral sites such as caves. Forms of mobility among mesolithic hunter-gatherers in central Europe probably varied, and residential mobility *per se* may not have predominated. Second, even if residential mobility from season to season is assumed for mesolithic hunter-gatherers in central Europe (Kind 1998), this form of mobility takes place on a different time-scale to the supra-annual mobility of a shifting cultivation regime (cf. G. Jones 2000). Third, Zvelebil and Rowley-Conwy (1986) have argued that pursuit of a 'half-and-half economy', incorporating some limited form of cultivation along with continued hunting and gathering, would be unsustainable due to scheduling conflicts (see also Rowley-Conwy 2000). The autumn, a period of maximum plant productivity, would represent the main period for collection and preparation of wild plant foods (nuts etc.) for storage; ungulates would be in prime condition as well. If agriculture were also practised, however, cereals would require harvesting in the autumn, and animal fodder would also be collected at this time. It could be argued, therefore, that shifting cultivation, as a 'transitional' form of cultivation permitting continued foraging and hunting strategies by hunter-gatherers in central Europe, would simply not be viable. Moreover, autumn sowing of crops (i.e. seasonality of cultivation – below, 1.4.6.3) would only add to the scheduling conflicts noted by Zvelebil and Rowley-Conwy (1986) (cf. Jacomet *et al.* 1989: Fig. 74, 223-225).

Like shifting cultivation, high levels of hunting in neolithic contexts have sometimes been linked to direct continuity with the Mesolithic (e.g. Benecke 1994a: 85), though the assumed relationship between hunting and indigenous people has been criticised (Uerpmann 1977; Gronenberg 1999: 164). Until recently, hunting was considered an activity of negligible importance in the LBK (e.g. Müller 1964), but there is growing evidence that levels of hunting varied (Döhle 1993, 1994; Lüning 2000: 113-116; Tresset and Vigne 2001). Tresset and Vigne (2001) have noted that relatively high levels of hunting and pig husbandry in the LBK tend to occur in regions (e.g. lower Bavaria, Baden-Württemberg) where the association of settlement with loess is particularly strong (cf. Döhle 1993, 1994). They suggest that heavy reliance on arable production (reflected in the preference for loess) was associated with settlement in densely forested areas, and hence with a greater emphasis on hunting and pigs versus ruminant husbandry (cattle and sheep/goat). They consider that this complex of features could reflect a particular adaptation of a predominantly 'mesolithic' population – one quite different to that envisioned by Whittle (above) – though the correlation with ceramic traditions widely interpreted as mesolithic in origin (La Hoguette, Limburg – Lüning *et al.* 1989) is not very close.

Some neolithic faunal assemblages from the Alpine Foreland, a region where the indigenous adoption of farming is widely assumed, indicate significant levels of hunting (e.g. Bogucki 1996). Here also, there is controversy over the permanence of agricultural plots (above, 1.4.1.2, 1.4.4.2). High levels of wild fauna at some lakeshore sites – particularly early sites (ca. 4400-3900 B.C.) as well as later Pfyn-period sites (latter part of the 37th century B.C.) – have been related to their 'mesolithic' heritage and used as an indirect argument for mobility (Whittle 1996a: 216-222). High levels of wild fauna in these periods, however, coincide with climatic evidence for short cold phases and perhaps also with failing crop production (Schibler *et al.* 1997a, b; Hüster-Plogmann *et al.* 1999; Lüning 2000: 128-130). It is also worth noting that changes in hunting levels in neolithic Greece have been interpreted in a completely different manner, by reference to greater obligations to share wild versus domesticated foods (Halstead 1999).

Clearly, the link between shifting cultivation and 'indigenous' farming – like that between hunting and 'indigenous' farming – is tenuous at best; in fact, the shifting cultivation model was originally linked to neolithic colonisation (above, 1.4.1.1). Equally, the assumption that other forms of crop husbandry reflect the cultivation practices of 'immigrant' farmers is questionable (below, 1.4.6.3).

The issue of permanence may have implications for tenurial claims on land and social ranking (Boserup 1965: 79-81; Goody 1976: 20-22; Wilk and Netting 1984; Barrett 1994: 143-145). Halstead (1989a) has noted that sustained imbalances in production are unlikely to develop under a shifting cultivation regime: land tends to be owned communally in such a regime because a given plot may only be cultivated once every ca. 15-20 years, making individual 'ownership' of specific plots meaningless (Grigg 1974: 58, 74; Brown 1978: 70, 109-111, 113-143; Bayliss-Smith 1982: 29). Similarly, Gilman (1981) has argued that neolithic shifting cultivation, as a form of 'low investment' (extensive) husbandry, would encourage fissioning and prevent the emergence of social ranking. Thus, it could be argued that shifting cultivation would promote relative equality among households.

Some authors support a model of more or less egalitarian social structure (without formalised, inherited social rank) for the LBK and, indeed, much of the Neolithic (e.g. Bogucki 1988: 122-128, 1999: 209; Coudart 1998: 104, 110-111) (below, 1.5.2). A lack of social ranking, however, can also be consistent with fixed-plot farming. Halstead (1989a) has argued that consistent inequalities among households farming fixed plots are unlikely to emerge if there are general threats to crop production affecting all producers. Prior to the development of crop strains adapted to climatic conditions in temperate Europe, where winter cold and summer rainfall posed the main crop hazards rather than summer drought as in the Mediterranean, crop failure may have posed such a 'general threat' to early cultivators in western-central Europe (Bogucki 1988: 92; Gregg 1988: 5; Halstead 1989b). Recent claims for pre-LBK cultivation in central Europe (Haas 1996; Erny-Rodman *et al.* 1997; Price *et al.* 2001) may imply a longer period for the development of temperate crop strains than previously thought, but the relatively narrow range of LBK cereals/pulses compared with neolithic crop spectra in Greece and the Balkans suggests that early neolithic crop production in the study area was especially prone to risk (Halstead 1989b).

Halstead (1989b) has pointed to other indications of high risk in the LBK. First, dispersed settlement and unpainted pottery in the LBK contrasts with 'village settlement' and painted pottery in the Neolithic of the southern Balkans and Greece, suggesting that sharing between neighbours was less important in the LBK due to the widespread unreliability of crop production. Second, the prominence of cattle in the LBK is consistent with extensive grazing of available habitats (woodland, stubble and fallow) and, together with dispersed settlement, could indicate that stock played a key role in the diet, perhaps reflecting the heightened risk of crop failure. Third, long-distance contacts are reflected in the overall homogeneity of LBK material culture and the far-flung distribution of exotic items such as *Spondylus* shell ornaments. *Spondylus* shell ornaments could represent the 'social storage' of food (Halstead 1981b; O'Shea 1981; Halstead and O'Shea 1982; Halstead 1989a, b), allowing exchanges in times of extreme need over large temporal, social or spatial distances. Social storage systems tend to be inflationary, as tokens are consumed at a slower rate than food (O'Shea 1981: 178); the deposition of *Spondylus* shell ornaments in burials (e.g. Jeunesse 1996) could reflect a mechanism for reducing this tendency by removing tokens from circulation.

A general increase in the reliability of crop production in western-central Europe may be suggested by broadening crop spectra from the Middle Neolithic onwards (Bakels 1991a), by a tendency towards increasing regionalisation of material culture through the Neolithic (Lüning 1988, 1997, 2000: 16-20; Hodder 1990: 135-136; Keefer 1993: 94, 110, 123; Coudart 1998: 101, 114), by increased site nucleation in the Middle and Later Neolithic (Lüning 1982b, 2000: 16; Starling 1985, 1988; Pavuk 1991; Hodder 1990: 122-129) (above, 1.3.1) and by the reduced circulation of *Spondylus* shell ornaments in the Later Neolithic (Bogucki 1988: 198). Following Halstead's reasoning, these tendencies suggest that, along with the development of crop strains adapted to local conditions, the importance of long-distance social storage was reduced and local support networks developed along with the emergence of 'true villages' in the Later Neolithic (above).

If fixed-plot cultivation was generally practiced in the Middle and Later Neolithic, inequalities between households might develop as some farming families tended to succeed and others to fail in their productive efforts. On the other hand, if shifting cultivation were the norm, it would tend to dampen any such tendencies by discouraging individual ownership of particular plots of land and by spreading the impact of crop failure across the community. In fact, various authors have inferred the development of greater social inequality after the LBK. Coudart (1998: 114) has argued that the emergence of leaders ('Big Men') is more plausible in the Middle Neolithic than the Early Neolithic: increasing regionalisation of architecture and evidence of conflict and territoriality (e.g. ditches surrounding settlements or 'ceremonial areas') in the Middle Neolithic could reflect increasing inter-group competition, though probably without formal social stratification. Milisauskas and Kruk (1989a, 1991, 1993) have identified a two-tiered site hierarchy in the TRB-Baden periods in southeast Poland. Bogucki (1999: 208-230) has recently applied the anthropological concept of 'transegalitarian' societies to the Later Neolithic and argues that 'residual elites' did emerge but without the development of formalised political authority. More evidence of social differentiation has been identified for the Bronze Age (above, 1.3.2).

1.4.6.2 Intensity (intensive versus extensive cultivation)

Goody (1976) proposed a causal relationship between extensive plough agriculture and social stratification: the ox-drawn plough allows large-scale surplus production to support non-producers and promotes land shortage and unequal access to land. Halstead (1995) has argued convincingly that large-scale surplus production also requires the availability of landless or dependent workers at harvest time (see also above, 1.4.2.2). The need for harvesting labour, high-maintenance (specialised) plough oxen and access to land under conditions of land shortage suggests that social stratification is a precondition as well as a consequence of ox-based plough cultivation (Halstead 1995). Thus, large-scale plough cultivation with oxen, as argued by Lüning (1979/80, 1980, 2000: 160-161, 163, 181), Lüning and Stehli (1989) and Tegtmeier (1993: 5) for the Early-Middle Neolithic and by other authors (Sherratt 1981, 1997; Kruk 1988; Milisauskas and Kruk 1989a, 1991, 1993; Lüning 2000: 189; Bogucki 1993, 1999: 227-230) for the Later Neolithic and Bronze Age, would imply considerable social stratification *as a cause as well as an effect.* By contrast, intensive cultivation involves the production and storage of a "normal surplus", which could potentially be deployed to promote inequality between households (Halstead 1989a), but social stratification is not a prerequisite.

Some authors have inferred considerable social differentiation among households in the Early-Middle Neolithic, thus increasing the plausibility of extensive plough cultivation. Lüning (1988, 1997, 2000: 202) has argued that the so-called *Großbau* type of longhouse – that is, with three sections, including a 'south-east' (or front) section thought to contain crop storage facilities on an upper floor, may have had control or 'possession' (*Besitz*) of the cereal harvest, which was redistributed to other households lacking their own crop stores. The presumption of a storage function for the front section of the longhouse is based on the occurrence of double post-holes in this part, suggesting double posts to support both the roof and an upper storey (Modderman 1988; Coudart 1998: 72, 76, 104; Gronenberg 1999). Roof space would provide warm, dry conditions for cereal storage (Rowley-Conwy 2000). Evidence of a connection between houses with a 'south-east section' and cereal production has been claimed at the LBK site of Langweiler 8 based on the observation that a greater quantity of glume wheat glume bases and weed seeds occurs in pits associated with three-part longhouses than in pits associated with smaller, two- or one-part longhouses (*Bau* and *Kleinbau* types) (Boelicke 1982). Boelicke's (1982) calculations are based on the proportion of total glume bases (or weed seeds) from the site found in pits associated with three-part longhouses versus smaller house types. In his full analysis of the plant remains from Langweiler 8, Knörzer (1988) similarly concludes that more glume wheat processing took place at the three-part longhouses than at two- or one-part houses because the overall density of glume wheat glume bases and weed seeds is higher in the *Großbauten*. Knörzer's (1988) calculation is based on amalgamated counts of glume bases and weed seeds per longhouse type, divided by the total amount of soil sampled. The association between material interpreted as 'processing waste' (glume wheat chaff, weed seeds) and three-part longhouses is interpreted to suggest that the crops were processed there before cleaned grain was redistributed. There is no greater association of cereal grains with three-part longhouses (whether based on overall percentage – Boelicke 1982, or density – Knörzer 1988), suggesting that the cleaned crop was consumed in all households. Animal bone data from the Paris basin have also been interpreted as evidence of 'economic' differentiation between longhouse types – high levels of hunting are associated with the smallest type and more livestock keeping with the three-part type (Hachem 2000; Lüning 2000: 102, 202). A greater frequency of decorated sherds and finished flint tools in pits associated with three-part longhouses adds further support to the idea that their inhabitants not only carried out distinct activities but also enjoyed a special social status (Boelicke 1982; Lüning 1997; cf. Gronenberg 1999).

Modderman (1988), van de Velde (1990) and Jeunesse (1996) have discussed social and economic differentiation between longhouses based on inherited status and associate potential evidence of intra- and inter-site hierarchy with differential distribution of 'wealth' in burials. Jeunesse (1996), in particular, has made the case for inherited wealth and status based on the occurrence of small groups of 'rich' burials – including those of children – in the middle-late LBK and Middle Neolithic. Based on this evidence, together with the presumed special role of the *Großbauten* in settlements and indications of inter-site hierarchy, van de Velde (1990) and Jeunesse (1996) argue that social organisation in the later LBK and Middle Neolithic involved inherited status and some form of domination or even exploitation by elite households. In a similar vein, Modderman (1988: 130) suggests that the end of the Bandkeramik tradition, associated with evidence of violent conflict, was a result of "revolt against a social system based on an economy in which a few people controlled the distribution of food".

Other authors (Bogucki 1988: 122-128, Coudart 1998: 104, 110-111) have challenged the interpretation of variability in longhouse size or type as evidence of social ranking. Coudart (1998: 104, 110-111) accepts the notion of functional differences between longhouses (i.e. the presence of a front storage section in tripartite houses) but argues that these differences do not amount to social ranking; she emphasises the apparent position of storage in the most public (front) part of the longhouse and suggests that those responsible for storage were fully accountable to other households. In fact, the archaeobotanical evidence for a contrast between *Großbauten* and other structures is unconvincing in its calculation (e.g. based on the amalgamation of plant remains from different contexts). Even if it is assumed that glume wheat chaff and weed seeds are particularly associated with the *Großbauten*, this could simply reflect greater household size (below).

According to Bogucki (1988: 122-128), the interpretation of 'large' early-middle neolithic longhouses as indicators of high status is implausible for several reasons. First, in comparison with 'Big Man' economies of highland New Guinea (where aspiring leaders aim to mobilise labour beyond their immediate household), for example, widespread risk and uncertainty would have been much more prominent in the Early-Middle Neolithic and would "cut short any sort of aggrandising behaviour involving labour control" (cf. Halstead 1989a, b). Second, settlement fissioning (effectively redistributing labour within a region) would further dampen intra- and inter-community tendencies towards social hierarchy (cf. Gilman 1981). Third, like Halstead (1989a) (above, 1.4.6.1), Bogucki interprets long-distance exchange (e.g. *Spondylus* shell ornaments) as evidence of the support networks needed for survival in unfamiliar environments. While Bogucki's second point (fissioning) is linked with a migrationist view of the spread of farming to Europe (Price *et al.* 2001), the importance of widespread risk and uncertainty as well as the prominence of long-distance support networks could equally apply to an indigenist view of neolithic communities.

If variability in the form and size of longhouses cannot be equated with social ranking and political authority, it may reflect other forms of social difference between households. Bradley (2001) has recently suggested that the tripartite longhouse form reflects the composition of the household itself, the front and rear sections being added to the central section as the household increased in size or in the number of generations included (cf. Coudart 1998: 110). He suggests that the rear section of the longhouse – the last to be constructed – functioned as a shrine or mortuary and that structures were abandoned and replaced after the death of an occupant. This perspective on longhouse development and replacement is linked to patterning in longhouse orientation across Europe (N-S in central/eastern Europe, E-W in western Europe). Bradley suggests that longhouse orientation relates to the areas from which LBK colonists in different regions emanated; the longhouse door and adult LBK burials tend to face this same direction. *Spondylus* shell ornaments are also drawn into this model as tangible links between newly colonised areas and regions settled long before.

Evidence for social stratification in the Later Neolithic and Bronze Age has already been summarised (above, 1.3.2). While Milisauskas and Kruk (1991, 1993) relate animal traction including the use of plough oxen to evidence for a two-tiered settlement hierarchy in the Bronocice region in the TRB-Baden periods, other authors supporting extensive ard cultivation from the TRB period onwards have recently emphasised that the evidence for social stratification is limited. Sherratt (1991, 1997) has recently argued that the major impact of plough cultivation was not in the TRB as previously suggested (Sherratt 1981) but emerged in the Corded Ware period, along with a shift from communality in mortuary ritual to a concern for personal possession (cf. Shennan 1986). Similarly, Bogucki (1993: 1999: 227-230) argues that animal traction in the latter half of the fourth millennium B.C. was 'revolutionary' but notes that the expected effect – hereditary elites – was delayed (Bogucki 1999: 230); even in the Bronze Age, the evidence for hereditary elites is variable (above, 1.3.2). These admissions of 'delay' from authors advocating the 'revolutionary' impact of ard cultivation suggest that the social significance of early ard cultivation may have been limited (see also above, 1.4.2.2).

1.4.6.3 Seasonality (floodplain cultivation versus intensive garden cultivation)

A particular implication of the floodplain model, according to Bogucki (1996: 253, 1999: 181), refers to the debate over neolithic colonisation versus indigenous adoption of agriculture:

> "Perhaps eventually the generalisation can be made that a clear preference for floodplain and alluvial habitats is a hallmark of agricultural colonisation" (Bogucki 1996: 253).

A link between floodplain cultivation and colonisation also underlies Sherratt's (1980) version of the floodplain cultivation model: the spread of farming populations from the Near East to the Balkans and central Europe was facilitated by continuity in the farming of alluvial soils using the same methods. The assumed link between floodplain cultivation and immigrant farmers, however, is weak: given the argument by Kruk, Sherratt and Bogucki (above, 1.4.3) that floodplain cultivation could be implemented with little labour input, it could perhaps more readily be adopted by indigenous hunter-gatherers. Furthermore, scheduling conflicts arising in the autumn between hunting/foraging and cereal cultivation would be eased somewhat by sowing crops in spring (above, 1.4.6.1), as required in a floodplain cultivation regime.

The distinction between floodplain and intensive garden cultivation has more direct implications for time and labour investment in cultivation, integration of plant and animal husbandry and the scheduling of agricultural tasks. The labour requirements (e.g. thorough tillage, weeding and manuring) of intensive garden cultivation would be greater than for floodplain cultivation (above, 1.4.5). The collection and spreading of manure to maintain fertility levels in intensively cultivated garden plots would require close integration with animal husbandry – for example, grazing of cattle and sheep/goat on stubble and fallow and/or the use of pigs to clear fallow. This need for integration would limit potential for economies with 'separate' horticultural and pastoral components (Halstead 1987, 2000). In terms of scheduling, crops could be autumn- or spring-sown in an intensive garden cultivation regime. Autumn sowing of cereals would allow longer growing seasons and hence bigger crop yields (Gregg 1988: 132); it would also exacerbate scheduling conflicts with hunting and wild plant collection in the autumn (above, 1.4.6.1) and so discourage the balanced pursuit of gathering and hunting alongside cultivation.

1.5 Modern weed studies relevant to the key variables

Modern weed survey studies that encompass the extremes of permanence, intensity and seasonality are required for comparison with the archaeobotanical weed assemblages in order to assess the relevance of the four archaeological husbandry models. Modern studies meeting these requirements are introduced below.

1.5.1 Permanence

While shifting cultivation is unknown as a traditional husbandry regime in the study area today, a number of archaeologically-motivated experiments have included short-term cultivation of newly cleared fields in woodland areas: the Draved Forest experiment in southern Jutland, Denmark (Iversen 1956; Steensberg 1957, 1979), the Butser slash-and-burn experiment in Hampshire, England (Reynolds 1977), the Hambach Forest experiment near Cologne, Germany (Lüning and Meurers-Balke 1980, 1986; Meurers-Balke 1985; Meurers-Balke and Lüning 1990), the Chassemy experiment in the Aisne Valley, France (Firmin 1981, 1984) and the Umeå experiment in northern Sweden (Engelmark 1989, 1995, Viklund 1998: 27-28, 36-38). In addition, a new set of experiments was begun in 1994 near Stuttgart (Rösch 1996b, 1998a, 2000; Rösch *et al.* 2002). Of the completed experiments, the Hambach Forest experiment is particularly relevant to the interpretation of LBK and later weed assemblages in the loess regions of western-central Europe: the plots were laid out on newly-cleared, loess-based soil that had supported mixed oak woodland since early medieval times. Furthermore, the weed floras growing in experimental plots were surveyed just prior to harvest time over multiple cultivation seasons. Experimental conditions differed in some ways from those of the Neolithic (e.g. oak-hornbeam woodland rather than the lime-dominated woodland of the Atlantic period – Meurers-Balke and Lüning 1990). Nevertheless, the weed surveys conducted during the experiment provide comparative data of direct relevance to the interpretation of archaeobotanical weed assemblages. Three general observations on the development of the Hambach weed floras (Meurers-Balke and Lüning 1990; J. Meurers-Balke pers. comm.) deserve emphasis: 1. weed growth on the newly cleared soil was abundant, even by harvest time in the first cultivation season; 2. burning increased the vigour of both crop and weed growth; 3. floristically, the weed floras did not resemble the typical archaeobotanical weed assemblages known from LBK-Rössen sites in the Rhineland.

The detailed weed survey data collected in the course of the Hambach Forest experiment have been made available to the author for analysis. The aims of this new analysis are to investigate how the weed floras on freshly cleared experimental plots developed over the first six years of cultivation and to compare the Hambach weed floras in ecological terms with the archaeobotanical weed dataset available from the study area. If the Hambach floras differ not only floristically but also ecologically from the archaeobotanical weed assemblages, the relevance of shifting cultivation to neolithic farming in the loess belt should be seriously questioned.

1.5.2 Intensity

A weed survey study of traditional pulse cultivation on the Greek island of Evvia by G. Jones *et al.* (1999) focused on the variable of cultivation intensity. The weed floras growing on 60 cultivation plots were surveyed immediately prior to harvest time. These plots ranged from intensively managed 'gardens', which tended to be hoed, weeded, manured and watered, through to extensively managed 'fields', which tended to be ard-ploughed and not to receive manure, weeding and watering. G. Jones *et al.* (2000) applied the FIBS method (above, 1.2.3.3) to the weed data from this study and found that functional attributes relating to the response of the weed species to fertility and disturbance could be used to distinguish intensively and extensively cultivated plots. More recent analysis of these data (Charles *et al.* 2002) opens the way for direct comparison between the modern weed floras of 'gardens' versus 'fields' with archaeobotanical data from the study area in the current project.

A further weed survey study of 65 plots of intensively cultivated spelt wheat in Asturias, northeast Spain was conducted by Charles *et al.* (2002). This study does not encompass a continuum of cultivation intensity like the Evvia study but offers valuable comparative data on the weed floras of intensively cultivated *cereals* rather than pulses. Recent analysis of this dataset by Charles *et al.* (2002) included comparison of the Asturias and Evvia data relating to cultivation intensity.

1.5.3 Seasonality

Hüppe and Hofmeister (1990) have synthesised available phytosociological data (ca. 9000 relevées, or phytosociological samples, dating from the 1940s through the 1980s) for segetal and annual ruderal associations from different parts of Germany. In order to facilitate the archaeobotanical recognition of autumn versus spring sowing on the basis of weed seeds associated with ancient crop remains, Bogaard *et al.* (2001) analysed this dataset using the FIBS method (above, 1.2.3.3) and found that functional attributes relating to the seasonality of the weed species could be used to distinguish the two sowing regimes. More recent analysis of these data (Charles *et al.* 2002) opens the way for direct comparison between modern weed associations from autumn- versus spring-sown crops with archaeobotanical data from the study area.

2 Methods

2.1 Selection of suitable samples

Table 2.1 lists all of the available archaeobotanical reports on plant remains from neolithic-bronze age sites in the study area (published by the end of 1999 or made available to the author in unpublished form). This list excludes reports dealing only with wood charcoal or pottery/daub impressions of plant remains. Archaeobotanical data from all of these reports were considered and their suitability for selection assessed based on the requirements outlined below.

The selection of archaeobotanical samples was concerned with two main requirements: the need to minimise any mixing of plant remains from different sources and the need for a reasonable level of 'weed seed' content in each sample, so that samples could ultimately be compared on the basis of weed species composition alone. A decision affecting both of these considerations was whether or not to include waterlogged as well as charred plant remains.

2.1.1 Charred versus waterlogged preservation

While the plant remains recovered from LBK and later sites in the loess belt of Europe are almost always preserved by charring, the lakeshore sites of the Alpine Foreland have produced a huge amount of data on waterlogged plant remains (Jacomet and Kreuz 1999: 293-300). The interpretation of waterlogged remains, however, is in some ways more problematic than that of charred remains. Since waterlogging preserves any plant material present in an ancient settlement (including *in situ* vegetation), the range of potential sources (e.g. arboreal, arable, ruderal etc.) is very wide (Green 1982). This is a particular problem for the interpretation of 'weed' seeds since many potential arable weeds also grow in non-arable habitats or are edible and so may have reached the site by a variety of routes. Indeed, analyses of weed spectra from lakeshore sites tend to focus on charred weed seeds associated with charred crop remains (e.g. Jacomet *et al.* 1989: 132-134; Maier 1991; Brombacher 1997; Brombacher and Jacomet 1997).

Added to this is the difficulty of defining discrete 'contexts' that are meaningful in archaeobotanical terms given the virtually continuous preservation of plant materials in a lakeshore settlement (cf. Bogaard and Halstead 2000). The most obvious cases of 'discrete events' in the deposition of plant remains in lakeshore settlements are in fact caches of charred cereal remains representing stored material (e.g. Jacomet *et al.* 1989: 58; Maier 1991; Brombacher and Jacomet 1997). Stores of waterlogged crops are more difficult to recognise

(Brombach and Jacomet 1997) and few have been securely identified (e.g two uncharred flax stores from Port-Stüdeli – Brombacher and Jacomet 1997: Tables D353-354). Finally, as they have not undergone charring, waterlogged plant remains may be difficult to distinguish from recent plant material contaminating archaeological deposits. For all of these reasons, therefore, this project is concerned only with charred plant remains.

2.1.2 Sample contamination

A basic concern of this project is to interpret the co-occurrence of wild/weed species in archaeobotanical samples. It is important, therefore, to limit the potential for 'spurious' combinations of species due to mixing of plant remains from different sources – that is, from different habitats, contexts of use, depositional events etc. An extreme solution to this problem might be to consider only samples from 'closed contexts' (*sensu* Jacomet *et al.* 1989: 37; Brombacher and Jacomet 1997; Jacomet and Kreuz 1999: 77-79), that is, from deposits with a very high density of plant remains likely to have been deposited as one discrete event such as crop stores. In such samples, all crop and wild/weed remains are likely to derive from harvested fields, possibly even from the same field or cluster of fields. Unfortunately, such samples are rare and often contain very little or no wild/weed seeds because they have been fully processed and cleaned. Furthermore, crop stores sometimes contain other edible 'contaminants' (e.g. apple seeds, hazelnuts etc.) that are unlikely to have been harvested with the crops themselves (e.g. Jacomet *et al* 1989: 132). On the other hand, the residues or by-products from crop cleaning are often rich in wild/weed seeds and so may also provide useful information on past weed floras (Hillman 1981, 1984a; G. Jones 1984). Residue material, however, is usually found in 'open' contexts (i.e. deposits containing relatively low densities of plant material and built up over a period of time). While the association of crop and 'weed' material from residues – let alone their derivation from a single field or field cluster – is less certain than for crop stores, such material inevitably represents a very important source of archaeobotanical weed data. Furthermore, an important methodological concern of this project is to 'factor out' the systematic effects of crop processing on archaeobotanical weed assemblages in order to accurately reconstruct crop husbandry practices (cf. G. Jones 1987, 1992). To do this, it is useful to examine weed evidence from as many stages in the crop processing sequence as possible. For this project, therefore, both 'open' and 'closed context' samples were considered for selection.

A recurring problem in assessing the possible contamination of samples (mixing of material from different sources) was the lack of comment in archaeobotanical reports on sampling methods. If it seemed that a sample derived from more than one feature (usually pits), it was excluded automatically from consideration. Similarly, if a sample clearly combined distinct deposits in the same pit or feature, it was excluded. There were a number of samples, however, that came from a single feature but little or no comment was made about the make-up of the pit fill (whether the pit contained different layers or appeared homogeneous etc.). Sometimes these samples were actually made up of a number of smaller samples (e.g. taken at arbitrary depth intervals in the pit) amalgamated in the publication. Where possible the author of the relevant archaeobotanical report was contacted to check the homogeneity of the pit fill (e.g pit samples from Ditzingen – Piening 1998). In other cases, the nature of the sample (high density of cereal grain) suggested that it represented an unusual find of visible material taken as a one-off sample by the excavator and thus not mixed with other deposits (e.g. cereal grain sample from Kamenin – Hajnalová 1989).

Often the contents of a number of samples from the same pit or feature were reported separately. In these cases, the question was whether or not to amalgamate adjacent samples. The goal here was to avoid the two extremes of amalgamating separate deposits (potentially derived from different sources) or of allowing over-representation of a single deposit. This was addressed by balancing similarity in botanical composition against stratigraphic and spatial evidence. If adjacent samples were very similar in composition and appeared to come from the same deposit, they were amalgamated; if either of these conditions was lacking, they were not.[1] In one case, only the richest and most dense sample was selected from a site lacking detailed contextual information (Korntal-Münchingen – Stika unpublished).

In the case of Vaihingen/Enz, an early neolithic (LBK) site in the Neckar valley, pit stratigraphy was often difficult to define during excavation and so a systematic sampling strategy had been pursued: samples were taken as arbitrary units, each ca. 20 cm deep, in a 'column' through the section of a pit (Rösch 1998b). Once sample sorting and identification were completed, the similarity of adjacent samples within a 'column' was assessed (Bogaard unpublished). Adjacent samples were not amalgamated if there were abrupt changes in botanical composition and/or density between them; in such cases only one weed-rich sample or group of samples from the same column were selected for further analysis. In many cases, some or all of the adjacent samples in a column could be amalgamated. Further 'horizontal'

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[1] In a small number of cases, similar samples apparently from the same pit or pit complex were not amalgamated because the stratigraphy of the pit and the exact relation of the samples were unknown: Laurenzberg 7 (context 202) (Knörzer 1997), Langweiler 8 (context 3930) (Knörzer 1988), Hilzingen (contexts 348e, 348g, 348f – these may actually be separate pits) (Stika 1991).

amalgamation of columns within the same large pit or pit complex was not carried out because columns were usually at least one metre apart.

While most decisions about amalgamation involved relatively discrete features such as pits, several Alpine Foreland sites contained layers of burned material covering part or all of the settlement. These layers represented the catastrophic destruction of settlements by fire and tended to preserve large quantities of crop remains. At these sites many samples were taken at intervals across the burned layer. For Hornstaad-Hörnle (Maier 1991, 1996, 1999, unpublished), maps could be produced from the available data with pie charts showing the crop content of each sample. Clusters of adjacent samples similar in crop composition were defined and samples within these clusters were amalgamated. At a second site, Uerschausen (Feigenwinter unpublished), clusters of similar samples were again defined for potential amalgamation. The weed content of these samples tended to be higher than that of the Hornstaad samples, and in several cases a large assemblage of weed seeds (ca. 100 or more) could be achieved with minimal or no amalgamation of the densest and richest samples in each cluster. In such cases, ca. 100 weed seeds was considered sufficient, and no amalgamation beyond this was carried out (i.e. only the densest/richest sample in the cluster was selected) (cf. G. Jones 1983: 28-29). For two further sites, Ehrenstein (Hopf 1968) and Zug-Sumpf (Jacomet and Karg 1996, unpublished), no detailed site plans were available, but it was at least clear that the weed-rich samples were not from immediately adjacent locations in the same charred layer.

2.1.3 Weed richness

In order to meet the requirement for weed-richness, only those samples containing at least 30 charred seeds of wild/weed taxa identified more or less to species (including 'cf.' identifications), or to two or three species within a genus, were selected. Identifications to a species 'type' were accepted if it was clear that the type included a maximum of three species within a genus. Other more general identifications (e.g. genus- or family-level) were disregarded in the assessment of weed-richness. Certain taxa with edible fruits were also excluded. These include fruit-bearing trees and shrubs (*Cornus sanguinea, Corylus avellana, Malus sylvestris, Prunus padus, Prunus spinosa, Pyrus communis, Rosa* spp., *Rubus* spp., *Sambucus nigra, Sambucus racemosa*), plus a few edible herbaceous species (*Anethum graveolens, Apium graveolens, Fragaria* spp., *Petrosilenum crispum*) that may have been cultivated (Küster 1985; Brombacher 1997; Brombacher and Jacomet 1997). Opium poppy (*Papaver somniferum*) was also excluded since there is good evidence that it was cultivated in at least the Later Neolithic (e.g. Brombacher and Jacomet *et al.* 1997; see also Knörzer 1998 for a high concentration of waterlogged opium poppy seeds in the LBK well at Erkelenz/Kückhoven). Any of these species could probably invade crop fields and thus occur as arable weeds but their status as weeds in the past is always open to question due to their edibility. Furthermore, most of the excluded species are woody perennials unlikely to set seed as weeds of annual crops; three other woody perennials were excluded for this reason alone (*Alnus glutinosa, Sorbus aria, Viscum album*). Of course, there are other edible species such as fat hen (*Chenopodium album*) and black bindweed (*Fallopia convolvulus*) that occur mainly or exclusively in ruderal or arable habitats (e.g. Jacomet *et al.* 1989: Table 80), but excluding all edible taxa *a priori* was considered undesirable due to the potential loss of ecological information. In addition, certain samples from the charred crop stores at Hornstaad-Hörnle (Maier 1991, 1996, 1999, unpublished) were excluded because they contained very large amounts of edible wild seeds of ambiguous status (e.g. *Brassica rapa*), in contrast to a low wild seed frequency elsewhere in the 'charred store' layer. Finally, *Schoenoplectus lacustris*, a species of wet habitats and character species of the phytosociological alliance Phragmiteon (littoral vegetation), was excluded as an unlikely arable weed.

Usually the 'minimum number' of wild/weed seeds represented in a sample had been counted, and so determining whether a sample met the criterion for weed-richness (at least 30 weed seeds identified more or less to species) was straightforward (after the 'non-weed'/'ambiguous' taxa mentioned above were excluded). One exception to this was a rich sample from a pit at Mogila 62 (Gluza 1983), in which large-type *Bromus* caryopses had been quantified by volume (cm^3). This volume was 'translated' into an approximate seed count using an estimated *Bromus* seed/cm^3 ratio. Fragment counts were also encountered occasionally and were ignored where redundant; in the assemblage from Hilzingen (Stika 1991), for example, both 'shell' fragment counts and seed 'kernel' counts were given for *Fallopia convolvulus* but only kernel counts were used (as one kernel occurs in each whole seed). Counts of seed 'halves' were divided by two (e.g. Ditzingen – Piening 1998). Fragment counts for Mogila 62 (Gluza 1983) were halved to estimate the number of seeds represented.

2.1.4 Recovery techniques

A further possible criterion for sample selection involves the techniques employed for the recovery of charred plant remains at the various sites. Though it is usually clear that some form of wet sieving or flotation was used to extract the plant remains, the minimum mesh size used to retain them is not always stated. Miminum mesh size is important because it will obviously affect the final assemblage recovered. Very small weed seeds will tend to be missed by mesh sizes greater than ca. 0.5 mm. Even variation between 0.5 mm and 0.25 mm may affect the recovery of extremely small seeds such as *Agrostis*, *Verbascum* and *Juncus* (e.g. Jacomet *et al.* 1989: 70; Kreuz 1990: 61).

When minimum mesh size is mentioned, it is usually 0.5 mm or smaller. The major exception to this is Langweiler 8 in the Aldenhovener Platte (Knörzer 1988), a very significant, widely sampled LBK site (over 230 samples in total), where the minimum mesh size was 0.9 mm. To exclude Langweiler 8 and/or other sites where the mesh size is not given would severely reduce the dataset available. Furthermore, the archaeobotanical assemblage recovered at Langweiler 8 includes very small seeds such as those of timothy grass (*Phleum pratense*), indicating that these were not entirely missed. It was decided, therefore, that sites would not be excluded on the basis of minimum mesh size.

2.2 Selection of wild/weed taxa for functional attribute measurements

A total of 323 samples from 87 sites were found to meet the criteria outlined above. Once the 323 weed-rich samples had been identified, the selection of potential weed species for functional attribute data (i.e. for inclusion in FIBS analysis – below, 2.4) could begin. This selection of species was based on their frequency of occurrence in the weed-rich samples. Very rare species are not only difficult to interpret (i.e. they are more likely than common species to be 'chance occurrences'), they also cause problems for analytical methods such as correspondence analysis that emphasise their importance (Gauch 1982: 213-214; Jongman *et al.* 1987: 109-111; G. Jones 1991). On the other hand, as many species as possible needed to be included for functional attribute measurements in order to maximise the amount of ecological information available in the archaeobotanical data. It was estimated that ca. 75 wild/weed species occurred in at least five weed-rich samples (so ca. 1.5 % of the total 323). In addition, ca. 20 species were estimated to occur in at least three neolithic or three bronze age samples (so in ca. 1% of the total 323) but in fewer than five samples overall. It was decided that all species occurring in at least five weed-rich samples overall, or in at least three neolithic or three bronze age samples, represented a generous but feasible number of species (ca. 95 total) for functional attribute measurements. This total of ca. 95 includes all species in amalgamated categories (i.e. all three species in an amalgamated category such as *Bromus arvensis/hordeaceus/secalinus* – below, 2.2.1). In order to determine the final list of species for FIBS measurements, however, conflicting and overlapping identifications needed to be resolved.

2.2.1 Standardisation of wild/weed seed identifications

The weed-rich samples available represent the work of many archaeobotanists working in a range of contexts over a period of several decades. Different workers may be more or less 'optimistic' in their identifications, and later work has benefited from earlier work. The archaeobotanical dataset, therefore, needed to be standardised to enable meaningful comparison of samples identified by different archaeobotanists over a long period (cf. Colledge 2001: 183). The standardised identifications described below are not intended as necessarily 'better' than the originals, but rather as part of a consistent system devised with a view to comparative analysis on a species basis (e.g. correspondence analysis).

An obvious preliminary step towards standardisation was the amalgamation of 'cf.' identifications (and accepted 'type' identifications – 2.1.3) with their unqualified counterparts (e.g. amalgamation of *Galium* cf. *aparine* with *Galium aparine*). For taxa otherwise identified with variable specificity in the literature (e.g. sometimes to species, sometimes to species groups), a more complex step was to decide on the level of identification appropriate for those taxa in charred form. All such taxa for which identifications were altered in accordance with their usual charred state are listed below along with the rationale for the alteration. All botanical nomenclature follows Tutin *et al.* (1964-1993).

<u>*Bromus arvensis/hordeaceus/secalinus*</u> – Identifications to *Bromus arvensis*, *B. hordeaceus* or *B. secalinus* were changed to this more general category. Though caryopses of this type of *Bromus* with a rounded apex have often been identified to species, the criteria used by different authors are somewhat contradictory (e.g. Bakels 1978: 179-180; Küster 1985: 36-38; Piening 1986b). Ideally, the orientation and shape of the fruit wall cells, which are usually destroyed or obscure in charred material, should be used to make a secure identification to species (Körber-Grohne 1991). The difficulty of distinguishing these species in charred form is underlined by the recent work of Knörzer (1995, 1998) on waterlogged material from an LBK well at Erkelenz/Kückhoven. Many caryopses of this type of *Bromus* were recovered with their fruit wall cells intact and could thus be identified as *B. arvensis*. As Knörzer has noted (1997), this evidence casts doubt on his own previous identifications of similar charred *Bromus* caryopses from LBK sites as *B. secalinus*.

There seems to be disagreement over the feasibility of distinguishing between *B. arvensis/hordeaceus/secalinus* on the one hand and *B. commutatus/racemosus* on the other, in charred form (e.g. Gluza 1983; Knörzer 1970; Körber-Grohne 1991). For the purpose of this project, *B. commutatus* and *B. racemosus* were not amalgamated with the other species. Some support for this is provided by waterlogged *Bromus* material from the Alpine Foreland (e.g. Jacomet *et al.* 1989: 318; Brombacher and Jacomet 1997) and from the LBK well at Erkelenz/Kückhoven (Knörzer 1995, 1998), all of which apparently consists of *B. arvensis* or *B. hordeaceus*, and not of *B. commutatus* or *B. racemosus*.

Bromus sterilis/tectorum – Identifications to *Bromus sterilis* or *B. tectorum* were changed to this amalgamated category. As in the previous *Bromus* category, the form and arrangement of fruit wall cells can be used to separate these two species (Körber-Grohne 1991) but these features are often obscure in charred material. Caryopses of *B. tectorum* may also be distinguishable from *B. sterilis* based on their shorter length (e.g. Knörzer 1971a; Piening 1998), but it is often unclear whether or not identifications to species were based on whole caryopses.

A third species with similar caryopses, *Bromus erectus*, has been considered a late arrival (perhaps no earlier than the Roman period) in central Europe and so eliminated from consideration for neolithic-bronze age material (Kreuz 1990: 207; cf. Körber-Grohne 1993; but note Piening 1998).

Carex vesicaria/rostrata – Seeds identified as *C. vesicaria* or *C. rostrata* were amalgamated since they are very difficult to separate (Jacomet *et al.* 1989: 316).

Chenopodium album group – Seeds identified to species within the *Chenopodium album* group (*C. album*, *C. giganteum*, *C. jenissejense*, *C. opulifolium*, *C. strictum*, *C. suecicum* – Tutin *et al.* 1964-1993) were placed in this amalgamated category. Many authors do not attempt to separate the species in this group (e.g. Jacomet *et al.* 1989: 301).

Galeopsis angustifolia/ladanum/segetum – Seeds identified as any of these three species were amalgamated to form a group. Modern seeds of these species are variable and cannot be distinguished from one another reliably (Jacomet *et al.* 1989: 306).

Galeopsis bifida/speciosa/tetrahit – As in the previous case, the seeds of these species cannot be separated reliably (Jacomet *et al.* 1989: 306). Identifications of seeds as any of these three species, therefore, were amalgamated.

Lotus corniculatus group – Seeds identified to *L. corniculatus*, *L. tenuis* or *L. uliginosus* were placed in this amalgamated category (Tutin *et al.* 1964-1993) since they are difficult or impossible to distinguish (Anderberg 1994: 62), particularly in charred form.

Phleum pratense – Identifications of *Phleum pratense* caryopses as subsp. *pratense* or subsp. *bertolonii* were changed to this category since the subtle difference in their average lengths (Knörzer 1973) is not a reliable criterion. Furthermore, identifications to the genus level (*Phleum*) were also changed to *Phleum pratense*, for two reasons: 1. this common type is only ever identified to species as *P. pratense* and 2. the other species of *Phleum* most closely resembling *P. pratense*, *P. arenarium*, grows on sand dunes (Tutin *et al.* 1964-1993) and is thus unlikely to be represented in the archaeobotanical material.

Poa compressa/nemoralis/palustris – Identifications to species within this group were changed to this amalgamated category, which shares a similar caryopsis and hilum size/shape and is, therefore, very difficult to separate in charred material (Jacomet *et al.* 1989: 319). The amalgamated category is also similar to other *Poa* species, especially *P. trivialis* and *P. pratensis* (see below) (Körber-Grohne 1991). In well-preserved charred material, however, caryopses of *P. pratensis* group/*trivialis* differ from this group in several respects (apex shape, overall size and/or hilum form – e.g. Knörzer 1980b; Küster 1985: 37; Jacomet *et al.* 1989: 319; cf. Körber-Grohne 1991: Fig. 5) and so they were treated separately.

Poa pratensis group/trivialis – Identifications to *P. trivialis* or *P. pratensis* (=*Poa pratensis* group in Tutin *et al.* (1964-1993) – *Poa angustifolia, P. pratensis, P. subcaerulea*) were transferred to this amalgamated category since the caryopses of these species are very similar and not always separable even in uncharred material (e.g. Jacomet 1986b; Jacomet *et al.* 1989: 319; Körber-Grohne 1991, 1993).

Polygonum aviculare group – All seeds identified as any species within the *Polygonum aviculare* group (Tutin *et al.* 1964-1993) – *P. arenastrum, P. aviculare, P. boreale, P. rurivagum* – were placed in this amalgamated category. While differences in the size and surface pattern of some of these species have been noted (e.g. Berggren 1981: 27-28; G. Jones 1983: 45), these are rather subtle and some authors have not attempted to distinguish between them (e.g. Jacomet *et al.* 1989: 302).

Rumex conglomeratus/sanguineus – Identifications of *Rumex* seeds as *R. conglomeratus* or *R. sanguineus* were changed to this amalgamated category. The perianth must be present in order to distinguish between the two species (Jacomet *et al* 1989: 303; Berggren 1981: 22) but is normally absent in charred form. Identifications to species appear to have been made where the perianth was definitely lacking.

Rumex crispus/obtusifolius – As in the previous case, the perianth is required in order to separate these species reliably (Jacomet *et al.* 1989: 302-303; Berggren 1981: 22) but it is usually absent in charred material. Therefore, identifications of *R. crispus* or *R. obtusifolius* were amalgamated.

Rumex acetosa/thyrsiflorus – Here again, the seeds of these *Rumex* species without the perianth are very similar (Berggren 1981: 24-25) and so cannot normally be distinguished in charred material.

Setaria viridis/verticillata – Caryopses identified as one or other of these species were changed to the amalgamated category. These species are not generally considered to be separable in charred form (e.g. Bakels 1978: 180; Stika 1991; cf. Körber-Grohne 1991).

Stellaria graminea/palustris – The seeds of these species cannot reliably be separated in charred form (e.g. Jacomet *et al.* 1989: 300) as they differ only in colour and (slightly) in size (Berggren 1981: 56-57). Identifications of either species, therefore, were amalgamated.

Trifolium fragiferum/hybridum – Seeds identified as either of these species were placed in this amalgamated category since they are very similar (Anderberg 1994: 59-60) and difficult to distinguish in charred form.

In addition to assessing the identifiability of taxa in charred form, differences in the specificity of identifications due to variable preservation were also considered. Sometimes distinct species categories, which are potentially separable in charred form, have been amalgamated by archaeobotanists to form a more general category for the identification of poorly preserved seeds. Variation between samples in the use of amalgamated and species identifications is not a problem for analytical methods based on characteristics of species, where species' counts are combined and used to represent these characteristics (e.g. discriminant analysis based on weed seed types – below, 2.5.3, 2.8.2.1). For analytical methods based solely on compositional data (e.g. correspondence analysis – below, 2.8.1), however, this variation is problematic since overlapping taxonomic categories would be treated as independent taxa. Such overlapping taxonomic categories, therefore, had to be resolved. In assessing overlapping categories, a balance needed to be struck between preserving individual species identifications (and thus also their potential ecological specificity) and allowing as many taxa as possible to be included in analyses.

Table 2.2 shows the amalgamated categories encountered and indicates their frequency of occurrence in weed-rich samples relative to identifications of component species. Only those cases are shown that potentially (if all added together) met the criteria for the selection of taxa for functional attribute measurements (above, 2.2).

Three sorts of decision were made on the basis of Table 2.2. First, where at least one individual species identification met the criteria for inclusion in analyses using functional attribute data, the number of samples in which amalgamated categories occurred relative to those with species identifications was assessed in order to determine which should be used (Table 2.2 group (a)). As the frequency of amalgamated categories was always small compared to individual species identifications, individual species identifications were used and amalgamated categories disregarded. Second, where there were too few individual species identifications to meet the criteria for inclusion in analyses, these identifications were amalgamated so that the amalgamated category could be included (Table 2.2 group (b)). Third, where only one of the component species in an amalgamated category had been identified definitively, it was assumed that the amalgamated category represented the definitely identified species (Table 2.2 group (c)).

A final form of standardisation employed was the change from a genus identification to a species identification. This was done in cases where a given genus, when identified to species level, was always identified as the same species. The genera altered in this way are: *Aphanes* (to *A. arvensis*), *Atriplex* (to *A. patula/prostrata*), *Phleum* (to *P. pratense* – see also above) and *Solanum* (to *S. nigrum*).

2.2.2 The selected wild/weed taxa

After standardisation, 80 wild/weed taxa were found to occur in at least five weed-rich samples overall or in at least three neolithic or three bronze age samples (Table 2.3). Since some taxa are made up of several species (e.g. *Galeopsis bifida/speciosa/tetrahit*) and some of the species contain multiple subspecies, however, the number of species/subspecies requiring functional attribute measurements was greater.

Table 2.4 lists all of the species included in the selected archaeobotanical taxa and thus requiring functional attribute measurements. In the majority of cases, the selected archaeobotanical taxa include up to three species (without subspecies) requiring functional attribute measurements. In a few cases, the archaeobotanical taxon potentially also includes multiple subspecies within each species. Where only one subspecies is geographically relevant to the study area and/or is much more common than the other subspecies (e.g. *Arenaria serpyllifolia* subsp. *serpyllifolia*), only this single subspecies was included in the collection of functional attribute measurements (Table 2.4). In fact, *Phleum pratense* is the only species within which two subspecies were considered to require measurement. This is because both subspecies (P. *pratense* subsp. *pratense* and subsp. *bertolonii*) are geographically relevant and common.

A similar scenario involves those archaeobotanical taxa corresponding to species 'groups' in Tutin *et al.* (1964-1993) (e.g. *Polygonum aviculare* group). For some of these groups, all relevant member species were considered to require FIBS data because they are all widespread in the study area (e.g. the three species in the *Poa pratensis* group). In other cases, only one species in a group is geographically relevant (e.g. *G. mollugo* in the *Galium mollugo* group). For the *Chenopodium album* group, four species are geographically relevant (*C. album, C. opulifolium, C. strictum, C. suecicum*) but *C. album* is far more widespread and common than the other members of the group and so it was selected for functional attribute measurements.

In total, Table 2.4 lists 102 'species' (including two subspecies of *Phleum pratense*) requiring functional attribute measurements. It should be noted that one taxon (*Eleocharis palustris*) lacking leaves was excluded from the collection of FIBS measurements, many of which are based on leaves.

2.3 Final selection of samples

Of the 323 weed-rich samples available (above, 2.2), all but seven contain at least 30 seeds of the selected wild/weed taxa requiring functional attribute measurements. The seven samples containing fewer than 30 seeds of these taxa were excluded from further consideration. The 316 remaining samples derive from a total of 85 sites. These sites are listed, together with the number of weed-rich selected samples per site, in Table 2.5. Table 2.5 shows that most sites are concentrated in the Lower Rhine-Meuse basin (which includes the intensively studied Aldenhoven Plateau – Knörzer 1997), the Neckar valley, north-central Switzerland (including Lake Zurich) and Lower Bavaria. There are relatively few sites in the eastern part of the study area (Poland, Hungary, Slovakia).

Table 2.6 summarises the numbers of samples and sites available and selected for each major period. It should be noted that the numbers of available samples given in Table 2.6 represent an overestimate of the individual contexts sampled due to multiple sampling of single deposits, whereas the numbers selected were determined after any justified amalgamations of samples from the same deposit had been carried out. Even so, the number of selected samples is a mere fraction of the number available: overall, 4 % of the available number of samples was selected (Table 2.6). The 85 sites with selected samples represent 21% of total sites with available data (Table 2.6). Fortunately, despite such a significant reduction, the number of samples selected (316) is still large.

The broad chronological and geographical scope of this project (defined in section 1.3) is partly due to the small proportion of archaeobotanical samples potentially suitable for the reconstruction of crop husbandry practices (Table 2.6). This breadth, however, also provides increased potential for comparison of crop husbandry practices at different times and in different places.

2.4 Collection of functional attribute measurements for archaeobotanical wild/weed species

As discussed in section 1.2.3.3, the FIBS method of interpreting botanical data – in this case, archaeobotanical weed data – is based on the measurement of functional attributes. In the course of FIBS studies of modern weed survey data (Charles *et al.* 1997, 2002; Bogaard *et al.* 1999, 2001; G. Jones *et al.* 2000), the authors used a series of functional attributes as measures of major ecological gradients (e.g. fertility, disturbance/seasonality, water availability) relevant to crop husbandry practices. The functional attributes used in the present project and their relationship to habitat conditions are described in Table 2.7.

2.4.1 General strategy for the measurement of functional attributes

For most functional attributes, the collection of measurements involves locating robust, well-established specimens of plants (i.e. those flowering or setting seed) growing in arable fields, field margins, ruderal habitats etc. (Charles *et al.* 1997, 2002; Bogaard *et al.* 1999, 2001; G. Jones *et al.* 2000). In order to enhance the reliability of these measurements, specimens of each species should be collected at multiple locations. An attempt was made, therefore, to measure functional attributes on specimens collected from at least three separate locations (see below, 2.4.2, on specific methods for each attribute).

The extent to which functional attribute values for the same species vary between different climatic zones within Europe is unclear (J. Hodgson pers. comm.). The study area of this project falls within the atlantic-continental zones of Europe (temperate with year-round rainfall) and does not extend into mediterranean Europe (temperate with dry summers, lack of frost) (cf. Oberdorfer 1994: Fig. 2). A further aspect of measurement strategy, therefore, was to obtain at least two collections of each species within atlantic-continental Europe as far as possible.

Some of the functional attribute data used in this project derive from a database accumulated during FIBS studies of modern weed survey data (Charles *et al.* 1997, 2002; Bogaard *et al.* 1999, 2001; Wilson *et al.* 1999; G. Jones *et al.* 2000). These previous measurements were collected in different areas across Europe in both mediterranean and wetter temperate zones. In cases where there were at least three collections of specimens (and so at least three sets of functional attribute measurements) as a result of this previous work, including at least two sets from atlantic/continental Europe, species were considered 'complete' in terms of functional attribute data for the current project. The majority of species selected from the archaeobotanical data, however, lacked the full complement of measurements (due to the addition of 'new' attributes in the course of previous work), lacked sufficient measurements from atlantic/continental Europe, had been collected/measured less than three times or had never been measured before.

For the sake of convenience, the Sheffield region was the major area in which species collections were made for this project. Some of the species selected, however, do not occur in this region, and so collection also took place further afield in areas where the required species could be found. In Britain, a number of collections were made in East Anglia, where 'continental' species occur in the relatively warm, dry climate of the Breckland (Fitter 1978: 15). Several other collection areas in France (Normandy, Provence) and Spain (Asturias) were selected to target species that are very rare or absent in the UK. In Provence, all collections were made north of the Lubéron, which forms the approximate east-west boundary between (sub)atlantic and mediterranean zones. The mountainous province of Asturias falls within the atlantic climate zone (Oberdorfer 1994: Fig. 2).

A small number of the selected weed species are now so rare in the UK and western Europe that even one location for the collection of specimens was difficult to find. In order to maximise the functional attribute data available, specimens of these species were grown on in Sheffield. Where possible, specimens were grown from seed in two contrasting situations: in 'growth chambers' at the Department of Animal and Plant Sciences, University of Sheffield, and in protected conditions outdoors. In this way, two independent 'collections' of a species could be obtained.

2.4.2 Measurement procedures for functional attributes

The ecological rationale and measurement procedures for the functional attributes in Table 2.7 are set out below. These methodological descriptions were largely abstracted from previous publications on FIBS study of modern husbandry regimes (see references for each attribute, below), though the measurement procedures for some attributes have been somewhat revised.

2.4.2.1 Attributes relating to the duration and quality of the growth period

It is expected that weeds with high values for these attributes (canopy size, leaf size, leaf 'density') will be associated with highly fertile habitats such as manured (and well watered) cultivation plots.

Canopy size attributes (G. Jones *et al.* 2000; see also Charles *et al.* 1997, in press; Bogaard *et al.* 1999, 2001)

Weeds with potentially large canopy height and/or diameter are characteristic of productive sites where disturbance is relatively infrequent (Bogaard *et al.* 1998). By contrast, those consistently exhibiting smaller canopy dimensions are indicative of one of two situations. Some weeds are inherently smaller because they exploit less productive conditions where factors such as nutrients, water, light and even temperature limit the quality or length of the growing period. They attain their size by prolonged but relatively slow growth. This can only be achieved if disturbance is infrequent. The other group of smaller weeds exploits highly productive but severely disturbed sites. Although fast-growing, such plants achieve at best medium size at maturity. This enables them to complete their life-cycle before the next disturbance event. It is anticipated, therefore, that species capable of attaining a large canopy height and/or diameter will be characteristic of highly fertile sites with relatively low levels of disturbance. Where disturbance is more severe, or sites less fertile, smaller species should be especially successful.

For each species, canopy dimensions (or, for climbing species, maximum stem length – see below) were measured at one to five locations. For semi-basal species, canopy height was measured as described in Bogaard *et al.* (1998). Maximum plant heights for more or less free-standing/erect species were abstracted from Tutin *et al.* (1964-1993) and from Rothmaler (1995). The most plausible published Flora height (J. Hodgson pers. comm.) was used to calculate maximum canopy height as follows:

$$\text{mean of } \frac{\text{measured canopy height}}{\text{measured plant height}} \times \text{ max plant height (from Flora)}$$

and this was used if it exceeded the maximum canopy height measured in the field. Canopy height for climbing species (with tendrils, twining stems etc.) was defined as the height of the stem at an angle of 45°. Maximum stem length measured in the field was compared with maximum stem length from Tutin *et al.* (1964-1993) and the larger value was used to calculate maximum canopy height. The mean of maximum canopy height and maximum canopy diameter (mean canopy dimension) was also calculated for each species because these two attributes may act as alternative methods of attaining high biomass.

Leaf size attributes (G. Jones *et al.* 2000; see also Bogaard *et al.* 1999, 2001; Charles *et al.* in press)

Plants with many and/or large leaves per node require a major investment of resources (both of carbon and nutrients) for each nodal growth increment. Thus weed species with large quantities of leaf per node – measured as maximum leaf weight per node and maximum leaf area per node – should be consistently associated with productive conditions. Conversely, species with small quantities of leaf per node would be expected in less productive habitats. Leaf thickness tends to be plastic (Dale 1982) and high values are associated either with small leaves in unproductive conditions or with very large leaves in productive conditions. Thus, by itself, leaf thickness is an ecologically ambiguous character. The ratio of leaf area per node to leaf thickness, however, should distinguish between species of productive habitats (with small, thin leaves or large, thick leaves) and those of unproductive habitats (with small, thick leaves).

Robust specimens of each species were collected at one to three locations. First, the area of five mature leaves from each collection was measured using the Aequitas Image Analysis program (Dynamic Data Links 1993-1996) and the maximum individual leaf area for each species was multiplied by the typical number of leaves per node. Secondly, this maximum leaf area per node was divided by mean specific leaf area (see below) to calculate maximum leaf weight per node. Thirdly, the inter-venal leaf thickness was measured (to the nearest 0.01 mm) using a dial thickness gauge (which applies very little force to the leaf surface). One reading was taken for each of five fresh leaves from each collection. The ratio of maximum leaf area per node to average leaf thickness was calculated for each species.

Weed size index (Bogaard *et al.* 1998; G. Jones *et al.* 2000)

A 'weed size index' combining canopy size attributes (canopy height and diameter) and leaf size (leaf weight per node) reflects the productivity of habitats with which species are associated and predicts the type of ruderal strategy *sensu* Grime (1979) (Bogaard *et al.* 1998). The first strategy class comprises competitive ruderals (CR), large competitive species of productive, relatively undisturbed habitats. The second strategy class, 'ruderals' *sensu lato*, is a composite group of medium-sized species comprising (a) ruderals (R) in the strict sense of Grime (1979), which are characteristic of highly fertile/highly disturbed conditions, and (b) weeds of sites of intermediate fertility and less disturbance (R/CSR). The third class comprises stress-tolerant ruderals (SR), small species of unproductive habitats.

For each species, maximum canopy height, maximum canopy diameter and maximum leaf weight per node values (see above) were scored on a 1 to 5 scale (using categories given in Bogaard *et al.* 1998). The three attribute scores were then added together to give index values with a potential range of 3 to 15. Index values were 'translated' into Grime's ruderal strategies as follows: 3-5 = SR, 6-7 = R/SR, 8-10 = R and R/CSR, 11-13 = R/CR, 14-15 = CR. For perennial species with horizontal root systems (rhizomes, stolons), the maximum canopy diameter of an individual ramet was used rather than the maximum diameter of a clonal patch since this is a better measure of strategy *sensu* Grime (1979) (J. Hodgson pers. comm.).

Leaf 'density' attributes (G. Jones *et al.* 2000; see also Charles *et al.* 1997, in press; Bogaard *et al.* 1999, 2001)

A high specific leaf area (SLA, leaf area/dry leaf weight) is generally indicative of a fast growth rate, which is of necessity associated with a productive habitat. By contrast, a low specific leaf area is found in plants from less fertile situations with slower growth. Dense shade, however, may complicate these expectations. Under these conditions, rates of photosynthesis will be low. As a result there is a low production of carbohydrates, including structural ones such as cellulose and lignin and, since the plant has a requirement to maximise leaf area for light capture, this results in the formation of thin leaves (see Dale 1982). Thus, irrespective of other habitat factors, leaves of shade-tolerant species will tend to have high SLA.

Leaf dry matter content (DMC, dry leaf weight/fresh leaf weight) similarly assesses growth rate and the exploitation of productive conditions, because slow-growing plants invest more heavily in dry matter content and *vice-versa* (Garnier and Laurent 1994; Ryser 1996). Low values indicate fertile and high values infertile conditions. In shaded habitats, however, DMC is beset by identical problems to those of SLA: the low production of carbohydrates (dry matter) in shade-tolerant species means that they will tend to have low DMC values irrespective of other habitat factors.

About 1g fresh weight of leaves from each collection of specimens was enclosed within moistened paper towel and kept refrigerated overnight in a sealed polythene bag. The fully turgid leaves were quickly dabbed dry with paper tissues and weighed. The leaf area of a subset of five whole leaves from each collection was measured using the Aequitas Image Analysis program (Dynamic Data Links 1993-1996) and both samples were then put in an oven at 80°C for two days before weighing. SLA is expressed as leaf area (mm^2) per unit of dry weight (mg) and DMC as a percentage (dry weight x 100/fresh weight). In both cases, the average value was calculated from the results for the different collections of each species. DMC tends to be higher in monocotyledonous species than in dicotyledonous species and so needs to be considered separately for each group.

2.4.2.2 Attributes relating to seasonality and/or the ability to regenerate rapidly following disturbance

It is expected that weeds with attributes enabling them to regenerate rapidly following soil disturbance (i.e. long flowering period, vegetative spread) will be associated with high levels of soil disturbance, such as well tilled and weeded cultivation plots. Seasonality attributes (i.e. germination time and life history, flowering onset/length, epidermal cell endopolyploidy), on the other hand, can be used to determine the sowing regime (autumn or spring) of the crops with which weeds are associated.

Germination time and life history (Bogaard *et al.* 2001; see also Charles *et al.* 1997)

Annual species germinating primarily in the autumn are unlikely to flourish in spring-sown crops since they will have little ability to establish themselves after the spring ploughing. Annuals germinating mainly in the spring or early summer will be successful in spring-sown crops, but at a serious disadvantage (due to the closure of the crop-weed canopy) in autumn-sown crops (Ellenberg 1950). Modern weed survey data indicate that species germinating in both autumn and spring tend to be associated with autumn-sown crops, presumably because they tend to germinate mainly in this period (Bogaard *et al.* 2001). In life history terms, therefore, winter annuals, which germinate in autumn, and, to a lesser extent, winter/summer annuals should be particularly associated with autumn sowing; summer annuals, which germinate in spring, should be particularly associated with spring sowing. These links between germination time and sowing time should also apply to those perennials regularly regenerating from seed.

Germination times were taken from the *Ciba-Geigy Weed Tables* (Häfliger and Brun-Hool, 1968-77) or, for species not included in this source, from Fitter (1987). Life history data were taken from Rothmaler (1995).

The onset and length of the flowering period (Bogaard *et al.* 2001; see also Bogaard *et al.* 1999; G. Jones *et al.* 2000)

For the most opportunistic annual weeds that can germinate over a wide range of temperatures and that reach maturity rapidly (e.g. *Stellaria media*), the period over which flowering may be observed is prolonged. This tendency for some annuals to flower rapidly and for a protracted period also extends to perennials regenerating from seed (e.g. *Lolium perenne*). These long-flowering species should do particularly well in fields disturbed during the growing season – by repeated weeding, for example. Conversely, species flowering over a more restricted period will be less able to produce multiple generations in a single growing season in response to disturbance.

Prolonged flowering should also enable species to recover from spring ploughing, as in a spring sowing regime. In addition, species with a late onset of flowering (July or later) should tend to be associated with spring sowing since, as species that exploit best the warmer summer growth period, they are at a competitive disadvantage in the autumn-sown crops. On the other hand, weed species with an early (January-March) or intermediate (April-June) onset of flowering and a brief flowering period (1-3 months) are likely to have germinated and become vegetatively well-developed prior to spring ploughing. Such species will lack the ability to recover and set seed following spring ploughing and, therefore, should be more abundant in autumn-sown crops.

Data on the onset and length of the flowering period were taken from Rothmaler (1995). Flowering onset/length categories have been defined as shown in Table 2.8. Unlike germination times, flowering data are available for all species and more accurate dates are available (e.g. April-June), allowing more flexibility in the categorisation of species.

Estimated epidermal cell endopolyploidy (Bogaard *et al.* 2001)

Plant growth involves two critical processes, cell division, which is generally slow and requires warmer temperatures, and cell expansion, which can take place rapidly at a wide range of temperatures (Bennett 1971). Thus, cell division is generally a rate-limiting step, particularly for the growth of cool-season plants. One solution to this problem is for cool-season species to generate 'stored growth'. There is a positive correlation between the size of an individual cell and the size of its nucleus. Some perennials tend to have large nuclei and large cells. These are laid down during the previous warm season and grow rapidly through cell expansion in the cool season. This strategy is not an option for cool-season annuals, however, which would have existed as seeds for much of the previous warm season and which generally have small nuclei and small cells (Grime *et al.* 1988). Nevertheless, it is suspected that the growth of winter annuals parallels that of perennials but is highly opportunistic and depends on the exploitation of unseasonably warm days and sunny locations. During these warm winter periods nuclear division may occur in some cells with a successive doubling of the chromosome number (endopolypoidy) resulting in larger nuclei. When cell expansion resumes, these cells are able to expand to a much greater size than the normal diploid cells, resulting in rapid growth. Indeed, high levels of endopolyploidy have been observed in the winter annual *Arabadopsis thaliana* (Melaragno *et al.* 1993). The unspecialised epidermal cells surrounding the stomatal guard cells tend to remain diploid (Melaragno *et al.* 1993), however, and are hence the smallest; polyploid cells are further away from stomata. It is predicted that winter annuals, particularly those that complete their life cycle early, will exhibit endopolyploidy and a wide range of epidermal cell size, while for summer annuals cell size will be more uniform.

The area of one cell adjacent to a guard cell and of one cell as far as possible from any guard cell were measured on each of three acetate impressions of the upper leaf surface for each collection of a species. The average area of both cell types ('adjacent to guard cells' and 'not adjacent') was calculated per collection and then per species. Epidermal cell endopolyploidy was calculated for each species as follows:

$$\frac{\text{mean area of cell furthest from any guard cell}}{\text{mean area of cell adjacent to a guard cell}} \times 100$$

This index was calculated for each species as an estimate of endopolyploidy.

Vegetative spread (Bogaard *et al.* 1999; see also G. Jones *et al.* 2000)

The capacity to regenerate rapidly from fragments of stem or root is advantageous to perennial species under conditions of high disturbance (Leakey 1981; Håkansson 1982; Hodgson and Grime 1990). A common feature of many of the most successful perennial weeds is the presence of an extensive network of horizontal rhizomes, stolons or even roots (see Holm *et al.* 1991) that, when cut into fragments, regenerate freely, allowing effective vegetative spread over a wide area (Håkansson 1982; Mortimer 1990). By contrast, perennial species with more vertical roots lack this capacity for rapid vegetative spread under conditions of high soil disturbance. It should be noted, however, that not all perennials possessing rhizomes and/or stolons regenerate rapidly from fragments. For example, rhizomatous species of relatively undisturbed habitats such as *Urtica dioica* and *Phragmites australis* can develop extensive clonal patches but are not generally invasive in disturbed habitats (Grime *et al.* 1988).

Perennial species were classified as with horizontal spread (stoloniferous and/or rhizomatous) or without horizontal spread (other root types lacking rhizomes and/or stolons) based on field observations and collected root material.

2.4.2.3 Attributes relating to water use

It is expected that weed species of dry habitats will tend to possess attributes reflecting drought-avoidance such as a deep tap-root and that their stomatal and cell characteristics will reflect efficient water use (e.g. numerous small stomata, small, straight-walled epidermal cells). Weed species growing in habitats with adequate moisture, by contrast, will tend to have shallow tap roots and stomatal and cell characteristics that reflect adequate water availability (e.g. few, large stomata; large cells with undulating walls), enabling them to grow successfully in these conditions.

Rainfall in the study area is fully adequate for cereal and pulse production and so watering/irrigation of crops is not an important issue, though there are occasional examples of irrigation in central Europe today due to exceptional local dryness (e.g. Valais region of Switzerland). On the other hand, soil moisture contributes directly to site productivity since it promotes the absorption of nutrients by plants (Peregrine *et al.* 1966: 52-54). The addition of manure to cultivated land increases the formation of humus, which in turn promotes a crumb structure in the soil, allowing water and air to penetrate (Peregrine *et al.* 1966: 67-68). Manuring, therefore, facilitates the supply of water required by plants. It is to be expected, therefore, that the highest availability of water will coincide with the highest fertility.

Stomatal density and size (G. Jones *et al.* 2000; see also Charles *et al.* 1997, in press; Bogaard *et al.* 1999)

Stomatal size and density are inversely related (Carpenter and Smith 1975) but there is no universal agreement on what constitutes the optimal size and density of stomata for maximum water use efficiency. Cowan and Milthorpe (1968) suggested that smaller pores are more efficient but this may not always be the case (Abrams *et al.* 1994) and the fact that stomatal pores may operate when partially closed further complicates the problem. Nevertheless, despite exceptions (e.g. Abrams *et al.* 1994), plants from dry habitats tend to have smaller, more numerous stomata (Salisbury 1927; Carpenter and Smith 1975; Donselman and Flint 1982).

The method of Beerling and Chaloner (1992) was used to take acetate impressions from the upper and lower surfaces of each of three replicate leaves per species collection. Stomatal density (no. per mm^2) was measured at three points on each upper and lower leaf surface impression. The lengths (μm) of three closed stomata (i.e. the two guard cells together) were measured where possible for each of three upper leaf surface impressions using the Aequitas Image Analysis program (Dynamic Data Links 1993-1996). Mean stomatal density and length were calculated per collection, then per species.

Epidermal cell size (G. Jones *et al.* 2000; see also Charles *et al.* 1997, in press)

Cell turgor is maintained more readily in small cells than in larger ones at times of water shortage (Cutler *et al.* 1977). Thus, theoretically, small cell size may be advantageous in droughted conditions.

The area (μm^2) was measured of one cell furthest away from stomata (as this tends to be the largest) for each of three replicate acetate impressions of the upper leaf surface of each collection using the Aequitas Image Analysis program (Dynamic Data Links 1993-1996). Mean cell size was calculated per collection, then per species. Epidermal cell size tends to be higher in monocotyledonous species than in dicotyledonous species and so needs to be considered separately for each group.

Epidermal cell wall undulation (G. Jones *et al.* 2000; see also Bogaard *et al.* 1999; Charles *et al.* in press)

Cell wall undulation may relate to habitat moisture: under conditions of high turgor, undulating cell walls confer greater tensile strength on leaves with little specialised support tissue (cf. Linsbauer, 1930). This structural support may be advantageous in conditions of adequate water supply. It should be noted, however, that this attribute may be quite plastic within species.

Cell wall undulation was assessed by measuring the perimeter and maximum diameter (μm) of one cell furthest away from stomata using the Aequitas Image Analysis program (Dynamic Data Links 1993-1996) for each of three replicate acetate impressions of the upper leaf surface of each collection. The ratio of mean cell perimeter to mean diameter was calculated for each species as an estimate of cell wall undulation. Cell wall undulation does not occur in monocotyledonous species, and so this attribute applies only to dicotyledonous species.

Root diameter at 10 cm depth (G. Jones *et al.* 2000; see also Charles *et al.* 1997, in press; Bogaard *et al.* 1999)

Weed species, particularly those associated with droughted conditions, may access subsoil water by means of deep roots. Root diameter at 10 cm is positively correlated with rooting depth (Charles *et al.* 1997) and is used here to provide an approximate indication of rooting depth.

A root collection was made for each species at one to three locations, and the diameter (mm) of the main root at 10 cm depth was measured using callipers. This attribute applies only to species with a tap root.

2.4.2.4 Attribute relating to shade tolerance

It is expected that weed species of unshaded habitats will tend to be amphistomatous and that species growing in shaded conditions will be tend to have stomata restricted to one leaf surface.

Stomatal distribution (G. Jones *et al.* 2000; see also Bogaard *et al.* 2001)

In their definitive study using British data, Peat and Fitter (1994) associate the restriction of stomata to a single leaf surface with species of shaded habitats and the equal distribution of stomata on both surfaces (amphistomaty) with unshaded habitats. They conclude that amphistomaty, which enables carbon dioxide (CO_2) intake from both leaf surfaces, may allow better exploitation of unshaded habitats where CO_2 may limit photosynthesis, but that the opposite prevails in situations where CO_2 is unlikely to limit photosynthesis (e.g. in shaded habitats). In species of shaded habitats, where light limits photosynthesis, leaves tend to be thin, with stomata more restricted to one leaf surface, in order to maximise light capture (Peat and Fitter 1994).

Stomatal density was measured at three points on each upper and lower leaf surface impression. Using mean stomatal densities for upper and lower leaf surfaces per species, stomatal distribution was assessed as the percentage of total stomata occurring on the surface with the most stomata (the lower surface of most species but the upper surface of grasses). Species with 45% to 55% of stomata on both surfaces were classified as amphistomatous and species with >55% of stomata on one surface as non-amphistomatous.

2.4.2.5 Attribute relating to habitat stability

Presence of a persistent seed bank (G. Jones *et al.* 2000; see also Charles *et al.* 1997, in press; Bogaard *et al.* 1999)

A persistent seed bank allows species to survive below ground the catastrophic disturbance events such as ploughing and weeding that would kill a vegetative plant. Thus most species of arable land have the capacity to form a persistent seed bank in the soil but seed persistence is particularly crucial in habitats where stability of conditions from year to year is uncertain – whether due to disturbance or variable site productivity – as it enables species to survive dormant in the soil in unfavourable years.

Using the method of Bekker *et al.* (1998), seed size and shape were combined in the formula, log (seed weight x √seed shape), to predict persistence. Seed shape is measured as the mean variance of seed dimensions (length, breadth and thickness) for five dispersules of each species. This index is negatively correlated with seed persistence. Index values were subdivided into five equal size classes (quintiles). Species with hard seed coats (Cistaceae, Convolvulaceae, Geraniaceae, Leguminosae, Malvaceae) generally have a persistent seed bank and, therefore, were placed in the lowest quintile regardless of their calculated index value.

2.4.3 The functional attribute data assembled

Table 2.9 outlines the functional attribute data collected for the 102 selected species, showing the total number of collections made for each species, the number of collections from different sources (i.e. from collections in atlantic/continental or mediterranean Europe, from material grown on in Sheffield) and the number of collections providing plant (canopy size, plant height etc.), leaf (SLA, leaf area per node etc.) and root (tap root diameter) data. It should be noted that many of the individual collections – particularly those from previous FIBS-related work – were incomplete in terms of functional attributes, often because slightly different sets of attributes were measured in earlier work. Thus some collections do not provide, for example, both plant and leaf measurements.

At least three sets of plant and leaf measurements plus (where applicable) at least two tap root measurements were obtained for 83 of the 102 species selected (ca. 81% of species) (Table 2.9). At least two sets of field and leaf measurements and one or two tap root measurements were obtained for a further nine species. Of the remaining ten species, at least one set of all measurements was obtained for six species. No measurements were obtained for four species (*Fallopia dumetorum*, *Galeopsis ladanum*, *Polygonum minus, Stellaria palustris*). These species were not found in any of the collection areas and were also not grown on successfully due to the failure of their seeds to germinate under a variety of conditions. Two of these species (*Galeopsis ladanum*, *Stellaria palustris*) are included in amalgamated taxa (Table 2.4) also containing one or two other species; in these cases, therefore, the partial FIBS data available were used to represent the amalgamated category. The other two species (*Fallopia dumetorum, Polygonum minus*) do not occur very frequently in the samples selected (Table 2.3). They were eliminated from all subsequent analyses using functional attribute data based on field or laboratory measurements but were included in ecological analyses using Flora-based data (i.e. comparison with Hambach experimental data, discriminant analyses of sowing regimes – below, 2.7.1, 2.8.2.2). Similarly, *Eleocharis palustris*, which lacks leaves and so was excluded from the collection of FIBS measurements (above, 2.2.2), was included in ecological analyses based on data from Floras.

While collections from mediterranean Europe were used for 22 of the species, at least two collections from atlantic/continental Europe were also used for all but *Galium spurium, Polygonum rurivagum* and *Setaria verticillata* (Table 2.9). Mediterranean collections were used along with available collections from atlantic/continental Europe because the latter did not provide three full sets of functional attribute data. In other words, it was considered more important to obtain full sets of functional attribute data than to exclude mediterranean data.

2.5 Methods for identifying the effects of crop processing and harvesting

Crop processing systematically alters both the crop and weed composition of harvested material and its effects have been investigated through ethnoarchaeological studies (Hillman 1981, 1984a, b, 1985; G. Jones 1983, 1984, 1987, 1992; Peña Chocarro 1996). Of particular interest for this project is the effect of crop processing on weed composition: the impact of crop processing needs to be assessed before interpreting differences (and similarities) in the weed composition of archaeobotanical samples as evidence of crop husbandry (G. Jones 1981, 1983, 1984, 1987, 1992). G. Jones (1992) has demonstrated that crop processing introduces ecological biases in the weed composition of harvested material at different processing stages: in particular, proportions of small-seeded weed species of the phytosociological class Chenopodietea (root/row-crop weeds and ruderals) tend to decrease through the processing sequence relative to large-seeded Secalinetea species, which tend to mimic the winter cereals with which they grow (see also 3.4).

Two methods were used to identify the processing stage(s) represented by the selected archaeobotanical samples: 1. classification of samples based on their crop content (that is, both the crop types – glume wheat, free-threshing cereal, pulse etc. – and the plant parts – grains, glume bases, rachis internodes etc. – represented) and 2. classification of samples based on the physical properties of the weed seeds they contain. The first, crop-based method makes use of the known proportions of plant parts (e.g. grains, rachis internodes, glume bases) in whole plants of each cereal species in order to identify crop processing stage; the mixing of processing stages can also be detected from mixing of crop parts in samples. The crop-based method also makes use of the overall proportion of weed seeds in samples in order to identify processing stage. The second method, based on weed seed types, focuses instead on the impact of crop processing on weed type composition, which may correspond to a single processing stage or to a mixture of processing stages. Thus, the two methods are complementary: they provide independent means of identifying the crop processing stage (or the mixture of stages) from which archaeobotanical samples derive. By combining the two lines of evidence, it is possible to decide whether the material in a sample derives from the same crop type, the same processing stage and hence potentially the same arable source (i.e. the same crop harvest or field).

Before discussing the methods used to identify the processing stage(s) represented by archaeobotanical material, previous work on crop processing techniques and harvesting methods must be reviewed as background.

2.5.1 Previous work on glume wheat processing techniques

An ethnoarchaeological study by G. Jones (1983, 1984, 1987) of traditional (non-mechanised) cereal processing on the Greek island of Amorgos provides data on the crop and weed composition of harvested material at various stages in the processing sequence. These modern comparative data play an important role in the identification of crop processing stage(s) in this project (below, 2.5.2-2.5.3). The Amorgos study is based on the processing of free-threshing cereals and pulses, in which threshing releases grains from chaff/pods (cf. Hillman 1981, 1984a, 1985). The major stages in free-threshing cereal/pulse processing (threshing, winnowing, coarse sieving, fine sieving) also occur in the processing of glume wheats, but with one significant difference: threshing breaks glume wheat ears into individual spikelets and does not release grains from chaff (Hillman 1981, 1984a, b). Thus, an additional processing sequence – beginning with spikelet pounding to release the grains from the glumes – must be applied to glume wheats. Once spikelets have been pounded, various combinations of winnowing, coarse sieving and fine sieving may be used to separate grains from chaff and weed seeds. In his ethnographic/historical account of glume wheat processing, Hillman (1984a: 13) notes that,

> "the dehusking (by pounding) of stored spikelets of glume wheats and the cleaning of the grain (by small-scale winnowing and sieving) occurs on a day-to-day basis . . . this work is generally done indoors, and, indoors, the most obvious place to sweep the winnowings and dump the cleanings is into the fire burning in the hearth" (Hillman 1984a: 13).

This model of daily spikelet processing and charring of cleaning residues in hearths, or in a specific manufacturing activity (Gregg 1991), is often cited in descriptions of the prevalent form in which charred plant remains occur on LBK and later sites in the study area of this project, namely glume wheat glume bases (e.g. Gregg 1989; Meurers-Balke and Lüning 1992).[2]

There is some controversy in the archaeobotanical literature, however, over the most effective method(s) of dehusking glume wheat spikelets and of subsequently separating grains from glumes (Nesbitt and Samuel 1996). Küster (1984, 1985) used a saddle quern to dehusk einkorn spikelets experimentally and found that subsequent winnowing alone separated glume material from grains. In another experimental study, Meurers-Balke and Lüning (1992) found that pounding in a large wooden mortar offered a more efficient method of dehusking than grinding with a saddle quern but, like Küster (1984, 1985), they suggest that winnowing is sufficient for the subsequent separation of glume and grain material. Hillman's (1981, 1984a, b) discussion of glume wheat processing based on ethnographic and historical evidence

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[2] Ancient sources seem to describe parching of spikelets as a stage in glume wheat processing and parching has often been cited by archaeobotanists as a context for accidental charring (Peña Chocarro 1996; Nesbitt and Samuel 1996). The role of parching, however, is doubtful given experimental evidence that it has little effect on ease of dehusking (Meurers-Balke and Lüning 1992; Nesbitt and Samuel 1996).

emphasises the use of a wooden mortar and mallet for pounding spikelets, followed by a combination of winnowing and sieving (both coarse sieving, in which cereal grains pass through the sieve, and fine sieving, in which cereal grains are retained by the sieve) to separate grains from chaff. Hillman (1981, 1984a, b) suggests that light chaff (e.g. lemmas) would be removed by winnowing of pounded spikelets, that unbroken spikelets and straw nodes would be removed by coarse sieving and that heavy fragments of chaff (e.g. glume bases) would be removed by fine sieving.

A question that arises from this experimental and ethnographic/historical evidence is whether archaeobotanical samples dominated by glume wheat glume bases represent the by-product primarily of winnowing, fine sieving or a combination of the two. Experimental work on the 'winnowability' of glume wheat glume material (see Appendix) suggests that samples dominated by glume bases could potentially represent the by-product of winnowing alone, while thorough cleaning of emmer or an einkorn/emmer maslin would probably require some fine sieving in addition to winnowing. Whether winnowing and fine sieving were both applied to pounded glume wheat material (as two stages in a process) or whether they were alternative means of cleaning grains in the past is unknown. In sum, therefore, it appears that samples dominated by glume bases potentially represent winnowing by-products, fine sieve by-products or a mixture of the two.

Another uncertain aspect of glume wheat processing is the extent to which weeds were separated from spikelets prior to dehusking (e.g. by winnowing, fine sieving) or afterwards or both. Cleaning prior to spikelet pounding would reduce the amount of weed material separated off in subsequent by-products. For example, winnowing prior to dehusking may remove most small free light weed seeds characteristic of winnowing by-products, so that subsequent winnowing of pounded spikelets would produce a by-product consisting mostly of chaff with very little weed material.

2.5.2 Classification of archaeobotanical samples based on crop content

The crop content of the selected archaeobotanical samples was used to classify them and subsequently to evaluate the crop processing stage(s) represented by samples dominated by a single crop type (below, 2.5.2.3, 2.5.3). Before classifying samples based on their crop content, however, the crop composition of samples needed to be standardised and simplified. The basic rationale for this simplication is that it is the crop types represented in the archaeobotanical samples, and not the crop species *per se*, which are of critical importance for the identification of crop processing stage. Moreover, crop species of the same type – that is, crops processed in a similar way (e.g. glume wheats, free-threshing cereals) – may be grown together as a mixed or 'maslin' crop (cf. Jones and Halstead 1995). It has often been argued, for example, that einkorn and emmer were grown together as a 'maslin' in the LBK and later neolithic periods in western-central Europe (e.g. Willerding 1980, 1983b; Knörzer 1997, 1998). In addition, like the wild/weed seed identifications (above, 2.2), crop identification methods vary among archaeobotanists, as do methods of quantification.

2.5.2.1 Standardisation of crop quantification

One problem to resolve was variation in the method of counting glume bases and spikelet forks of glume wheats. While many authors gave separate counts for these, or calculated the total number of glume bases (=individual glume bases + two glume bases in each spikelet fork) accurately, others did not distinguish between glume bases and spikelet forks in their counts. In the latter case, both glume bases and spikelet forks were counted as 'one' and amalgamated in the report. These amalgamated counts would tend to underestimate the actual number of glume bases represented, since the two glume bases in each spikelet fork were counted as one.

For some sites, clues are given about the form in which glume bases occurred (i.e. as separate glume bases or as spikelet forks). For the LBK site of Ulm-Eggingen, for example, Gregg (1989: 375) notes that spikelet forks "were often fragmentary, or broken into two halves". In the case of this site, therefore, the amalgamated glume base/spikelet fork count for each sample is probably not a gross underestimate of the actual number of glume bases.

In his report on the plant remains from Hochdorf, Küster (1985) appears not to differentiate between spikelet forks and glume bases in his counts, giving each a value of one. His comments on identification (Küster 1985: 27), however, suggest that material identified to species – as einkorn or as emmer chaff – was in the form of spikelet forks, whereas individual glume bases were placed in a general 'wheat glume' category. For this site, therefore, counts for einkorn and emmer chaff were doubled (because they represent spikelet forks) and counts of 'wheat glume' were taken unchanged as representing counts of individual glume bases.

For the remaining sites where spikelet forks and glume bases were not differentiated (Kleine Hafner, Mozartstraße, Mythenschloß – Jacomet *et al.* 1989, unpublished; Brombacher and Jacomet 1997; Uerschausen – Feigenwinter unpublished; Zug-Sumpf – Jacomet and Karg 1996, unpublished), no clues were available about the proportion of whole spikelet forks versus glume bases in the samples. Different hypothetical proportions (from 100% glume bases to 100% spikelet forks) were applied to see what effect these would have on the interpretation of the crop content of these samples. The overall interpretation of these samples in terms of processing is not significantly affected by these varying proportions.

Sometimes whole spikelets or "ear fragments" had been observed in samples and counted separately (e.g. Jacomet and Karg 1996, unpublished). While the spikelet counts could easily be 'translated' into grain and glume base counts for glume wheats, "ear fragments" contain an indeterminate number of spikelets, though presumably at least two (since individual spikelet counts were given separately). In order to translate the ear fragment counts into grain and chaff counts, the minimal assumption was made that each ear fragment contained two spikelets.

A further decision related to chaff quantification involved one sample from a site (Zug-Sumpf – Jacomet and Karg 1996, unpublished) where six-rowed barley rachis was quantified partly as rachis internodes (*Spindelglieder*) and partly as 'glume bases' (*Spelzenbasen*). The glumes of free-threshing cereals, especially barley, are flimsy and do not usually survive charring. The 'glume bases' were assumed to represent the upper glume-bearing portion of rachis internodes (cf. 'spikelet bases' in Knörzer 1971a) and so were added to the counts of whole rachis internodes.

For Hochdorf, barley and free-threshing wheat chaff was recorded as counts of *Spelzen*, a term normally referring to 'glumes' but which Küster (1985) also uses to include all forms of chaff at this site. Because there was no indication in the Hochdorf report that *Spelzen* referred literally to individual glumes of free-threshing cereals, therefore, these counts were assumed to represent the common form in which free-threshing cereal chaff occurs, namely rachis internodes.

A final issue of quantification encountered was that cereal grains were sometimes quantified by weight or volume rather than by grain counts. For one sample from Mogila 62 (Gluza 1983), a volume of 'indeterminate wheat' grain (in cm^3) was converted to an approximate grain count using the average glume wheat grain/cm^3 (ca. 40) also reported by Gluza (1983) (i.e. glume wheat grain in the sample was given as both grain counts and volumes). This grain/volume ratio was also used to convert the volume of 'indeterminate cereal' grain fragments in another sample from Mogila 62 (Gluza *et al.* 1988) into a grain count. In other cases, where grain was quantified by weight, or where no specific quantification of some or all crop material was provided, samples were placed in a 'not properly quantified' category (see also below, 2.5.2.3). Also, in one sample where fragment counts were given in addition to whole grain counts (Gluza 1983), counts of glume wheat and barley grain fragments were halved to estimate the number of grains represented.

2.5.2.2 Standardisation of crop identification

In addition to standardising counts of crop material, it was also necessary to simplify crop identification categories, partly to allow for the possibility that mixed or 'maslin' crops were grown and partly to make identifications by different authors comparable (see also above, 2.5.2). The amalgamated crop categories are defined and summarised in Table 2.10. Some of the decisions shown in Table 2.10 require justification. Indeterminate (wild/cultivated) barley grain (*Hordeum* indet.) occurs at only one site (Uerschhausen – Feigenwinter unpublished), where it is correlated with cultivated barley grain categories, and so this material is included with cultivated barley grains in 'free-threshing cereal grain'. Similarly, certain general millet-related categories (Paniceae, *Panicum/Setaria*) occur in significant numbers at two bronze age sites (Zug-Sumpf – Jacomet and Karg 1996, unpublished; Münchenwiler Im Loch 1 – Jacomet *et al.* unpublished) along with high counts of cultivated millets (*Panicum milliaceum, Setaria italica*). These general categories, therefore, were included in the amalgamated millet group. Grains of oat cannot be identified as cultivated or wild. With the exception of one sample from Hochdorf (pit 376 – Küster 1985), oat grains occur at (middle-)late bronze age sites. Since oat appears to have been cultivated from the Bronze Age onwards in western-central Europe (Zohary and Hopf 1994: 77), this material was classified as oat crop material.

Finally, it should be noted that some categories of (potential) crop material were disregarded in the amalgamation of crop types and in subsequent considerations of crop processing. Of the cereal material, all categories of cereal chaff that cannot be reliably quantified (e.g. awn fragments) or that cannot be assigned to the glume wheat or free-threshing cereal types (e.g. cereal indet./wheat indet. rachis or glume bases, culm nodes) were disregarded. This last group included culm nodes, which are potentially useful in assessing crop processing (e.g. Hillman 1981, 1984a, b, 1985; G. Jones 1990) but occurred very rarely and at low levels in the samples selected. Also, capsule and stem fragments of flax were ignored; in the selected samples these occurred only occasionally and at low levels alongside flax seeds. Unusually, millet chaff was reported at one site (Zug-Sumpf – Jacomet and Karg 1996, unpublished) but was ignored because it is not generally preserved by charring.

2.5.2.3 Classification scheme

Once crop quantification had been standardised and crop identifications amalgamated into crop types, samples were classified in terms of the crop types represented. Samples were classified as predominantly glume wheat, free-threshing cereal etc. if they comprised 70% or more of one crop type (Table 2.11). The percentages for this classification were based on the total of all crop items included in the amalgamated crop categories presented in Table 2.10.

Once the archaeobotanical samples had been classified based on their predominant crop type, the classification was further refined by assessing the *extent* to which samples dominated by one crop type were 'contaminated' by other crop types. Three categories relating to contamination were used:

1. Samples containing >90% one crop type (i.e. less than 10% of all other crop types combined) were classified as relatively 'uncontaminated'.

The remaining samples containing 70-90% one crop type plus 10-30% contamination were divided into two further groups:

2. Samples containing 70-90% one *cereal* type where the contamination is mainly indeterminate cereal grain (i.e. the contamination contains $\geq$70% indeterminate cereal grain) were classified as 'possibly contaminated' as these indeterminate grains may, in fact, belong to the dominant cereal type.
3. Samples containing 70-90% one cereal type where the contamination includes significant (>30%) quantities of material other than indeterminate cereal grains, and samples containing 70-90% non-cereal crop types, were classified as 'definitely contaminated'.

While the 70% and 90% crop type thresholds used in the classification of samples according to crop type is arbitrary, the definition of cereal grain:chaff ratios expected at different stages of processing can be based on the usual grain:glume base or grain:rachis internode ratios for whole spikelets/ears of each cereal species (Table 2.11). Of the glume wheats represented in the selected samples, emmer and spelt have a grain:glume base ratio of ca. 1.0 in whole spikelets, while the ratio for einkorn is ca. 0.5. Because glume wheat samples may contain mixtures of these species, samples of possible glume wheat spikelets were defined for the purposes of estimating crop processing stage as having grain:glume base ratios ranging from 0.3 to 1.5. This encompasses the expected einkorn ratio (ca. 0.5) and the expected emmer or spelt ratio (ca. 1.0) for whole spikelets with a little 'leeway' either side to allow for preservation differences. The upper limit of 1.5 is slightly more generous (further from 1.0 than the lower limit is from 0.5) because there may be a preservation bias against glume bases in charred material (Boardman and Jones 1990). The free-threshing cereals in the samples are barley (naked and hulled) and free-threshing wheat. The barley is apparently six-rowed (Zohary and Hopf 1994: 63) and so the grain:rachis internode ratio for whole barley ears is 3:1. Morphological study of free-threshing wheat rachis by Maier (1998) suggests that both hexaploid (e.g. LBK Erkelenz/Kückhoven) and tetraploid free-threshing wheats (e.g. Late Neolithic Alpine Foreland) are represented in the samples selected. Ears and ear fragments of tetraploid wheats from Hornstaad-Hörnle have been studied in detail and ears with 2 – 5 grains per spikelet have been observed (Maier 1998). Samples with a grain:rachis internode ratio of 2 to 5, therefore, were classified as possible unthreshed free-threshing cereals (Table 2.11).

For the 'uncontaminated' and 'possibly contaminated' glume wheat and free-threshing cereal samples, proportions of grains, chaff (glume bases for glume wheat samples, rachis internodes for free-threshing cereal samples) and weed seeds per sample were combined in triangular scatter plots as a further aid to the identification of crop processing stage. Triangular scatter plots showing proportions of grain, chaff and weeds have been used by M. Jones (1985) and others (e.g. van der Veen 1992: 92-99) to assess the processing stage of archaeobotanical samples. This approach has also been used by G. Jones (1990) with ethnoarchaeological samples of free-threshing cereals from Amorgos in order to demonstrate that different processing stages contain different proportions of weed seeds, rachis internodes and grains. G. Jones (1990) has pointed out that triangular plots of this type should not be used to determine the processing stage of samples containing a mixture of glume wheat and free-threshing cereal material: free-threshing cereal rachis and glume wheat glumes are separated at different stages in the processing sequence, and also the origin of the weed seeds with one or other crop type cannot be determined. For this reason, the method was applied only (and separately) to samples dominated by glume wheat or by free-threshing cereal material. Other factors to consider in the use of triangular plots are that any culm (straw) nodes in samples can not be included in the plot and that indeterminate cereal grains must be either omitted or assigned to 'glume wheat grain' or 'free-threshing cereal grain' (G. Jones 1990).

Triangular scatter plots were drawn up using Origin 6.1 (OriginLab Corporation 1991-2000) to show, for samples dominated by glume wheat, the proportions of weed seeds, glume bases and grains and, for samples dominated by free-threshing cereal material, the proportions of weed seeds, rachis internodes and grains. The triangular scatter plot of free-threshing cereal samples could then be compared with that of ethnoarchaeological samples from Amorgos (G. Jones 1990) as a further confirmation of crop processing stage. The ethnoarchaeological and archaeobotanical samples can be compared directly in this way because both are free-threshing and, indeed, include the same taxa (six-rowed barley and durum/bread wheat), which should, therefore, be similar in their original grain:rachis internode ratios. It should be noted that indeterminate cereal grains were omitted from the grain totals in the calculation of grain proportions; the amounts of indeterminate cereal grains in these samples is small because they are by definition dominated by glume wheat or free-threshing cereal material. Culm nodes were, of course, omitted from the diagrams, but are mostly absent from these samples in any case. In the calculation of proportions for the archaeobotanical samples, total 'weed seeds' per sample included all wild/weed taxa identified to species or genus except those taxa specifically excluded as 'potential weeds' in the original assessment of weed-richness (above, 2.1.3).

2.5.3 Crop processing analysis using weed seed types

This method, based entirely on weed composition, provides another way of comparing archaeobotanical data directly with ethnoarchaeological samples taken from a traditional cereal processing sequence on the island of Amorgos, Greece (G. Jones 1983, 1984, 1987) and can be applied to glume wheats and pulses as well as free-threshing cereals. G. Jones has demonstrated that the proportions of weed seeds of different physical types (big free heavy, small free light etc.) in ethnoarchaeological samples from the four main processing stages (winnowing by-product, coarse sieve by-product, fine sieve by-product, fine sieve product) can be used to distinguish these processing groups using discriminant analysis. The discriminant functions extracted were then able to reclassify the samples into the four original processing groups with a high degree of accuracy (84% success rate, based on square roots of percentages) (see also below, 2.8.2).

In order to combine the selected archaeobotanical samples with the ethnoarchaeological samples in a discriminant analysis, the archaeobotanical wild/weed taxa needed to be classified into the relevant physical types. This method was applied only to those 'uncontaminated' and 'possibly contaminated' archaeobotanical samples dominated by a single cereal type or by pulses (above, 2.5.2.3).

The classification of wild/weed taxa is based on three physical characteristics: the size of seeds, the 'lightness' of seeds (aerodynamic properties) and the ability of seed heads, pods etc. to retain their seeds despite threshing ('headedness') (G. Jones 1984; cf. Hillman 1984a). Weed seeds in the ethnoarchaeological samples from Amorgos were of six physical types: big free heavy (BFH), small free heavy (SFH), big headed heavy (BHH), small headed heavy

(SHH), small headed light (SHL) and small free light (SFL). Certain physical types were preferentially extracted from the crop product at specific processing stages (i.e. small free light by winnowing, headed types by coarse sieving and small free heavy by fine sieving), the big free heavy seeds tending to remain with the product and thus characterising the fine sieve product.

Wild taxa in the archaeobotanical samples, therefore, were divided into these physical types. Prior to classification, two criteria were used to select wild taxa for inclusion: 1. the likelihood that the taxa represented arable weeds harvested and processed with the crop, and 2. whether or not the taxa corresponded to a single physical type. All of the taxa excluded as 'potential weeds' in the original assessment of sample weed-richness (above, 2.1.3) were also excluded here except that genus-level identifications were included if all of the possible species in the genus belonged to the same physical type (e.g. all *Vicia* species are big free heavy); tentative genus-level identifications (i.e. 'cf.' identifications, genus 'types'), however, were excluded, as were family-level identifications. Finally, one sub-genus category, *Galium aparine/spurium*, was also excluded since *G. aparine* is classified as big free heavy and *G. spurium* as small free heavy.[3]

The physical type of each wild/weed taxon was determined using modern specimens from the seed reference collection of the Department of Archaeology and Prehistory, University of Sheffield. The size of seeds ('big', ≥1.5 mm diameter or 'small', <1.5 mm diameter) was determined by measuring them under a binocular microscope with an ocular graticule, while headedness was assessed by examining whole seed heads/pods. Seed lightness was determined initially by examining seed density, shape and structure (e.g. presence of persistent pappus etc.). Some of the wild taxa had already been classified by G. Jones as part of the Amorgos study or in the application of the method to archaeobotanical samples from late bronze age Assiros Toumba in Greek Macedonia (G. Jones 1983, 1984, 1987).

The results of an experiment in the measurement of seed lightness using a seed buoyancy machine (see Appendix) suggest that the light/heavy distinction relevant to processing is susceptible to objective measurement: species with low average velocities (<3.50 m/s) in the

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[3] *Galium aparine/spurium* occurs in four of the selected samples and makes up only a small proportion of the wild/weed seeds in these samples (up to c. 6% of wild/weed taxa identified to species). Modern seeds of *Galium spurium* are variable in size but often measure 1.5 mm or more in length (e.g. Lange 1979). Archaeobotanical *G. spurium* from the study area, however, is conspicuously smaller than modern material (e.g. Küster 1985; Stika 1991; Piening 1998; Bogaard unpublished). For this reason, *Galium spurium* has been classified as small free heavy rather than as big free heavy.

seed buoyancy machine had been classified as 'light' by G. Jones (1984) and species with high average velocities (>3.00 m/s) as 'heavy', with only a small region of overlap (3.00-3.50 m/s) between 'light' and 'heavy' species (Appendix Fig. 1).

In order to apply this result to the archaeobotanical taxa, velocities of wild species of uncertain lightness (i.e. excluding seeds that were clearly heavy) in the selected samples, 30 in all, were measured using the seed buoyancy machine. Five seeds of each species were dropped through the machine and the average velocity of each species was calculated. The results were used to classify the species as 'light' or 'heavy': species with velocities lower than 3.00 m/s were classified as 'light', those with velocities greater than 3.50 m/s as 'heavy'. A few taxa falling within the 'overlap zone' of ca. 3.00-3.50 m/s were classified as 'light' or 'heavy' depending on their morphological similarity to species falling within the definite 'light' and 'heavy' ranges.

The final classification of wild taxa into physical types is shown in Table 2.12. One of the seed types (big free light, *Agropyron caninum*) was not encountered in the original Amorgos study and was grouped together with small free light in subsequent analyses, as both types would tend to be separated from the crop product by winnowing.

In order to explore possible links between the effects of crop processing and the 'ecological composition' of archaeobotanical samples, weed taxa from three modern weed studies with available functional attribute data (Germany, Evvia and Asturias – below, 2.7.2-2.7.4; see also 1.5.2-1.5.3) were also classified into the weed physical types relevant to crop processing. Once classified into these groups, averages and standard deviations were calculated for six functional attributes (maximum canopy height, maximum canopy diameter, leaf area per node:thickness, specific leaf area, length of the flowering period, stomatal distribution). The Mann-Whitney U-test (non-parametric version of the t-test) was used to compare average attribute scores of two weed physical types, big free heavy (BFH) and small free heavy (SFH), which are characteristic of two 'late' processing stages – fine sieve by-product and fine sieve product, respectively. These two types were chosen for comparison since fine sieve by-product and fine sieve product are the most commonly represented sample types in the archaeobotanical dataset (4.1).

2.5.4 Identifying harvesting methods

Methods of harvesting cereals attested historically and ethnographically include ear-harvesting (i.e. harvesting of ears by plucking or stripping, the straw left unharvested or harvested separately), sickle-harvesting (cutting on the straw) and uprooting of cereal plants (Hillman 1981; Sigaut 1988). Variation in harvesting methods in the past would affect the composition of archaeobotanical weed assemblages: much more weed material tends to be harvested by sickle- than by ear-harvesting, for example, and different harvesting methods may also affect the range of weed species typically harvested (Hillman 1981). Differences in weed composition among archaeobotanical samples from different harvesting regimes, therefore, may obscure similarities or differences in crop husbandry. Unlike crop processing (above, 2.5.1-2.5.3; see also 3.4), however, there is no theoretical reason why harvesting method should introduce an ecological bias in the composition of the weed flora collected.

Study of probable harvesting tools from sites in the study area suggests that sickles (or knives with a 'finger extension', forming a 'sickle' shape) were used from the LBK onwards (Schlichtherle 1992). The artefactual assemblage is very small, in any case, and cannot rule out the use of techniques such as ear plucking without any surviving 'tool kit'.

Various archaeobotanists (e.g. Knörzer 1967b, 1971b, 1988, 1997; Willerding 1983b) have argued that the absence of culm (straw) nodes and low-growing weed species (e.g. <40 cm maximum height) in early neolithic (LBK) archaeobotanical samples points to ear-harvesting of einkorn and emmer, the predominant cereals. Hillman (1981, 1985) has suggested further that ear-plucking of glume wheats would leave the basal rachis internodes unharvested, since these remain attached to the straw. The widespread absence of culm nodes (and basal rachis internodes) in archaeobotanical samples of glume wheat material from the study area, however, may also relate to the separation of these items from the crop at early stages of processing, by winnowing and coarse sieving of glume wheat spikelets (Hillman 1981, 1984a; M. Jones 1985; G. Jones 1987, 1998). By contrast, glume bases – which dominate many LBK crop samples from the study area – are separated off in the final stages of glume wheat processing, by winnowing and/or fine sieving of pounded spikelets. Given that the separation of culm nodes and glume bases from the crop took place at opposite ends of the processing sequence and possibly at widely separated times of year, it is perhaps not surprising that samples rich in glume bases do not contain culm nodes. The absence of culm nodes could also reflect the fact that they do not survive charring as well as glume bases and grains (Boardman and Jones 1990; cf. Hillman 1981, 1984a). With regard to maximum weed heights, relatively 'short' weeds (e.g. <40 cm maximum height) are, in fact, frequent at some LBK sites (e.g. *Valerianella dentata*, with a maximum plant height of 30 cm, at LBK Vaihingen – Bogaard unpublished), suggesting harvesting relatively low on the straw. Low-growing weeds are also well-attested at various post-LBK sites in the loess belt: for example, in a rich find of glume wheat spikelets and barley grains from a middle neolithic (Lengyel) pit at Mogila 62 (Gluza 1983) and in crop samples from later neolithic Hochdorf (Küster 1985). Sickle-harvesting of cereals fairly high on the straw is attested at several neolithic sites in the Alpine Foreland in the form of charred stores of unthreshed cereal ears with attached straw (Schlichtherle 1992). At Hornstaad-Hörnle, for example, the cereals were cut c.10-20 cm below the ears (Maier 1999). Neolithic to bronze age archaeobotanical evidence from waterlogged sites around Lake Zurich – including the regular occurrence of low-growing weed species as well as the occasional recovery of whole cereal ears with associated straw – generally points to sickle-harvesting (Jacomet *et al.* 1989: 155-156; Brombacher and Jacomet 1997).

Another possible approach to distinguishing ear- and sickle-harvesting is to consider the amount of weed seeds relative to crop material in archaeobotanical samples (G. Jones 1998). Ethnohistorical and experimental evidence (Reynolds 1985, 1993; Sigaut 1988) suggests that ear-harvesting allows the reaper to avoid most weeds and so few weed seeds are present in the harvested crop. Experimental harvesting of emmer and spelt by ear-plucking (Reynolds 1981, 1985, 1993) has indicated that most weeds can be left unharvested, tall and especially climbing weeds being the most difficult to avoid.

No quantitative data are available on the crop and weed content of ear-harvested cereal material. Data on the weed and crop content of sickle-harvested free-threshing cereals, however, are available from the study by G. Jones (1983, 1984) of the crop processing sequence on Amorgos. These data can be compared with the archaeobotanical crop and weed data in order to assess whether the archaeobotanical material potentially derives from sickle-harvesting. The Amorgos study produced crop and weed data on paired fine sieve by-products and products from the same harvested crop assemblages. The grain counts for these pairs were re-amalgamated (with correction for subsampling) to determine the original grain amounts in the crop products prior to fine sieving. The cereals processed in the Amorgos study were free-threshing wheat and six-rowed barley, which tend to produce more grains per ear than emmer or einkorn (Percival 1974). If the amalgamated 'pre-sieve' grain counts from Amorgos are halved to take account of this, the approximate number of glume bases in an equivalent pre-sieved emmer spikelet sample can be determined (using the 1:1 grain:glume base ratio for emmer). If it is assumed that all glume bases in the 'pre-sieve' product would be separated off in the fine sieve by-product, the actual weed counts from the Amorgos fine sieve by-products can then be used to calculate hypothetical weed:glume base ratios for emmer fine sieve by-products. The weed:glume base ratios for einkorn fine sieve-products can be inferred by doubling the glume base counts in the 'pre-sieve' products based on the 1:2 grain:glume base ratio in einkorn. For the archaeobotanical samples, total 'weed seeds' per sample included all wild/weed taxa identified to species or genus except those taxa specifically excluded as 'potential weeds' in the original assessment of weed-richness (above, 2.1.3, 2.5.2.3).

Even if the archaeobotanical data generally derive from sickle-harvested crops, variation in actual harvesting height could introduce differences in the range of weed species represented (e.g. Schlichtherle 1992). As noted for ear- versus sickle-harvesting, however, differences in harvesting height between samples are unlikely to introduce clear ecological biases in the weed species harvested. The lowest maximum weed height represented in archaeobotanical samples was used to estimate the maximum height at which crops were cut. The maximum plant heights of wild/weed taxa included in the collection of functional attribute measurements (Table 2.4) were assessed using Floras (Tutin *et al.* 1964-1993; Rothmaler 1995) for free-standing/erect species. For other species (with leafy canopies and a 'non-erect' growth habit), maximum canopy height (above, 2.4.2.1) was used to approximate maximum plant height. Finally, wild/weed taxa were classified into the following maximum plant height categories: <40 cm, 40-70 cm, >70 cm.

2.6 Methods for identifying dung-derived archaeobotanical material

2.6.1 The identification of charred plant material from burned dung fuel

The possibility that charred plant remains from archaeological deposits represent the residues of animal dung burned as fuel has received increasing attention from archaeobotanists (Miller and Smart 1984; Charles 1998; Jacomet and Kreuz 1999: 65-66). Dung has mostly been considered in analyses of archaeobotanical material from arid regions, where wood fuel is scarce and manuring of crop fields less beneficial than in temperate Europe due to limited water availability. Gregg (1991) is unusual in acknowledging the possibility that LBK plant remains derive from animal dung fuel, though she dismisses the use of dung fuel on the grounds that wood was abundant. Ethnohistorical evidence shows that, even in regions of where wood fuel is readily available, dung may be a fuel of choice rather than of necessity (Anderson and Ertug-Yaras 1998; Charles 1998). Its potential relevance to western-central Europe in the Neolithic and Bronze Age, therefore, cannot be excluded. Dung could have played a role as a specialised fuel alongside firewood, which itself appears to have been carefully selected and managed in the LBK, for example (Kreuz 1988b, 1992; cf. Castelleti and Stäuble 1997). If dung did play a major taphonomic role in the formation of the assemblages under study, interpretation of the wild/weed taxa would be significantly altered. Wild taxa in dung fuel could potentially derive from habitats grazed by livestock, from habitats where fodder was collected or from other plant material used in the manufacture of 'dung cakes' (Anderson and Ertug-Yaras 1998; Charles 1998). Such material, therefore, would not provide direct evidence of crop field conditions and crop husbandry.

Charles (1998) has suggested criteria for the recognition of dung-derived charred plant remains. One criterion is the occurrence of recognisable charred dung (e.g. sheep/goat pellets) on archaeological sites. A second criterion is the mixture of crops and plant parts in archaeobotanical samples, especially those that cannot be the result of the processing of a maslin (mixed) crop (e.g. mixing of grain-rich barley material with chaff-dominated glume wheat material – Charles 1998). A third criterion is the biology and ecology of the wild taxa; Charles (1998) argues that the presence of taxa fruiting *after* the normal cereal harvest demonstrates that their seeds could not have been harvested with the crop.

2.6.2 Analyses of waterlogged animal dung from the Alpine Foreland

A related topic, which may also shed light on the identification of dung-derived material in this project, is the evidence of waterlogged animal dung from the lakeshore sites in the Alpine Foreland. Archaeobotanical studies of waterlogged animal dung are available from four neolithic lakeshore sites in the Alpine Foreland (Egolzwil 3 – Rasmussen 1993; Horgen-Scheller – Akeret and Jacomet 1997; Arbon-Bleiche 3 – Akeret *et al.* 1999; Thayngen-Weier – Robinson and Rasmussen 1989) and one Bronze Age site (Fiavè) in the foothills of the Italian Alps (Karg 1998; Haas *et al.* 1998). At Thayngen-Weier, an apparent manure layer contained fragments of free-threshing wheat ears and whole wheat grains, cereal bran, straw, leaf fragments and the seeds of various wild species, ranging from annuals of arable/ruderal habitats to *Rubus* and various tree species (Robinson and Rasmussen 1989) (see also 1.4.5.2). Robinson and Rasmussen (1989) suggest that this manure was derived from cattle based on experimental evidence that wheat grains tend to survive cattle digestion better than sheep/goat digestion. In addition to the 'manure layer samples', sheep/goat faeces from a probable byre in the settlement (see also 1.4.5.2) were found to contain mixtures of leaf, wood and cereal bran fragments (Robinson and Rasmussen 1989), interpreted as evidence that animals were stall-fed cereal material as well as leafy hay. This is the only published study to date clearly demonstrating the feeding of cereal material to livestock. Macroscopic plant remains from sheep/goat pellets at the other sites vary considerably, from Rosaceae prickles and *Rubus* seeds (Horgen-Scheller – Akeret and Jacomet 1997; Arbon-Bleiche 3 – Akeret *et al.* 1999), to mixtures of tree leaf fragments, anthers and/or wood (Egolzwil 3 – Rasmussen 1993; Arbon-Bleiche 3 – Akeret *et al.* 1999; Fiavè – Haas *et al.* 1998), sometimes together with seeds of a wide variety of herbaceous species (Karg 1998). All of these have been interpreted as various types of winter fodder – browsing of blackberry bushes (Horgen-Scheller, Arbon), twig or branch foddering (prior to full leaf emergence) (Egolzwil 3, Arbon-Bleiche 3, Fiavè) and, in the Bronze Age, herb and grass foddering (Fiavè).

This apparent variability in foddering practices suggests that a diverse range of plant resources were used for fodder and supports the general view that developed grassland habitats (as pasture and meadow) were lacking in the Neolithic and, to some extent, the Bronze Age (Rasmussen 1990; Behre 1996, 1998; Akeret *et al.* 1999; cf. Körber-Grohne 1990, 1993). It should be noted also that the byre structure at Thayngen-Weier represents the earliest unequivocal evidence for the stalling of livestock in the Later Neolithic (Schlichtherle 1995). A recent study of the arthropod assemblage from this building adds further support to its interpretation as a byre (Nielsen *et al.* 2000). While the longhouses of the Early and Middle Neolithic (LBK – Rössen/Lengyel) could have housed livestock as well as people, phosphate analyses of LBK longhouses have generally failed to register any clear evidence for stalling (Lienemann 1998; Stäuble and Lüning 1999) (1.4.5.1).

2.7 Modern weed studies used

Four modern weed studies are considered in this project (1.5). One of these consists of weed survey data from a cultivation experiment – the Hambach Forest experiment (Lüning and Meurers-Balke 1980; Meurers-Balke and Lüning 1990) – relating to shifting cultivation, whereas the other three studies provide weed survey data from 'traditional' husbandry regimes. The studies of 'traditional' regimes include one based on summarised weed data from autumn- and spring-sown crops in Germany (mostly pre-1945), another of intensive versus extensive pulse cultivation on the Greek island of Evvia (G. Jones *et al.* 1999, 2000) and a third of intensive cereal cultivation in Asturias, north-west Spain (Charles *et al.* 2002). All three studies of 'traditional' crop husbandry included the collection of functional attribute measurements for the weed taxa; the Hambach weed species have not been collected for functional attribute data since this was not part of the original experiment.

As noted in sections 1.5.2-1.5.3, analyses of the modern weed data (G. Jones *et al.* 1999, 2000; Bogaard *et al.* 2001; Charles *et al.* 2002) have been adapted for archaeobotanical application in this project (Chapter 3).

2.7.1 Shifting cultivation study (Hambach Forest experiment)

The layout of experimental plots in the Hambach Forest and the cereal crops grown on each plot are shown in Fig. 2.1. Husbandry techniques used and the timing of weed surveys are shown in Table 2.13. Weed survey data were collected immediately prior to harvest time by Lohmeyer (1980, unpublished) from 1979-1984. It should be noted that the seed corn used in the experiment was specially counted out for the calculation of seed yield ratios and thus virtually weed-free (J. Meurers-Balke pers. comm.). Soil disturbance measures — tillage prior to sowing and weeding during crop growth – varied over the course of the experiment, becoming more severe in response to increasing weed infestation (Table 2.13). Thus, while some plots received no tillage or weeding in the first year, all plots were tilled by rotavator (rotary hoe) prior to sowing and weeded during crop growth in the last two years (Table 2.13). One plot (21) was burned prior to sowing for two consecutive years, followed by tillage by rotavator in subsequent years (Table 2.13).

All surveys conducted on plots 1-21 (plots 22-24 were not surveyed) in 1979-1982 and 1984 (Table 2.13) were included in the new analysis. Weed species occurring in at least 5% (five or more) of these plot surveys were included in analyses. Trees and shrubs such as *Rubus* spp. were excluded because of their inability to set seed in disturbed conditions and so be harvested in seed; such species would not be present in archaeobotanical weed assemblages. Ferns and mosses were also left out because they do not produce seeds. In total, the analysis was based on 102 individual plot surveys (experimental plots surveyed in a given year) and 50 weed species. Lohmeyer (1980, unpublished) scored the weed species in each experimental plot survey on a phytosociological cover/abundance scale. In order to analyse these data, cover/abundance values were converted to a numerical scale as shown in Table 2.14.

In the new ecological analyses of the Hambach data presented in this thesis, the general habitat categories (based on groupings of phytosociological classes – Klassengruppen) presented by Ellenberg et al. (1992) were used to characterise species' habitats. Oberdorder's (1994) determination of phytosociological character species was used as an alternative means of estimating general habitat conditions. Life history information was taken from Rothmaler (1995). Two measures of the shade tolerance of species were used: the light index of

Ellenberg et al. (1992) and a light index based on survey data from the Sheffield region (J. Hodgson pers. comm.). Three other Ellenberg indices (soil pH, nitrogen and moisture – Ellenberg et al. 1992) were also used to estimate soil conditions. In order to compare the Hambach data in ecological terms with archaeobotanical data, these sources were used to gather the same ecological information for wild/weed taxa in archaeobotanical samples. This was not possible for the shade index derived from the Sheffield region, however, which is restricted to the species occurring in local surveys, including only a small number of the archaeobotanical wild/weed taxa.

The archaeobotanical taxa included in these comparisons were all 'potential weed' taxa. As in the original determination of sample weed-richness (2.1.3), 'potential weeds' included all taxa identified more or less to species except tree/shrub taxa, edible taxa and one species of wet habitats (*Schoenoplectus lacustris*). Standardised species identifications (2.2.1) were used except that all overlapping categories (e.g. *Galium aparine/spurium* as well as *G. aparine* and/or *G. spurium* – group (a) in Table 2.2) were included. Where overlapping categories occurred together in a sample, counts of taxa present in the sample did not include redundant categories (e.g. a sample containing *Galium aparine/spurium* and *G. aparine* would have a taxon count of one).

2.7.2 Sowing time study (Germany)

The sowing time data (from Hüppe and Hofmeister 1990: Table 1) consist of a number of studied phytosociological weed associations characterising different soil types (acidic versus basic) and sowing regimes (autumn versus spring sowing). The studied associations, collated from a large number of published and unpublished relevées, each include character species scored on a cover/abundance scale. This scale was converted to a numerical scale as shown in Table 2.15. Analyses of the sowing time study included all arable associations (as opposed to ruderal or vineyard associations) published by Hüppe and Hofmeister (1990: Table 1) and all character species occurring in more than one studied arable association (Bogaard *et al.* 2001). Analyses included 38 studied associations and 90 character species in total.

All 90 character species included in analyses have been measured for functional attributes (Bogaard *et al.* 2001). The precise methods used for the collection and measurement of species are given in Bogaard *et al.* (2001) and closely resemble the methods described in detail for the collection and measurement of the species represented archaeobotanically (above, 2.4).

2.7.3 Intensive and extensive pulse cultivation study (Evvia, Greece)

The Evvia study included surveys of weeds growing with winter-sown pulse crops in various plot types, ranging from intensively cultivated 'back gardens' and 'allotment gardens', which tended to be manured, weeded and watered and tilled by hoeing, through plots types of intermediate intensity ('vineyards', 'fenced fields') to 'unfenced fields', which tended to be lightly tilled (by ard-ploughing) and not to receive manuring, weeding and watering (G. Jones *et al.* 1999). The Evvia dataset consists of a species-by-plot matrix where weed species' scores indicate the number of $1m^2$ quadrats out of ten per cultivated plot in which they occurred; in the case of small plots in which five to nine quadrats had been recorded, the figures were adjusted accordingly (G. Jones *et al.* 1999). All weed taxa occurring in at least 10% (six or more) of the cultivated plots were included in analyses. In total, analyses included 60 cultivated plots and 84 taxa.

All 84 weed taxa included in analyses have been measured for functional attributes (G. Jones *et al.* 2000). The precise methods used for the collection and measurement of species are given in G. Jones *et al.* (2000) and closely resemble the methods described in detail for the collection and measurement of species represented archaeobotanically (above, 2.4).

2.7.4 Intensive cereal cultivation study (Asturias, Spain)

The Asturias study included surveys of weeds growing in intensively cultivated plots of winter-sown spelt wheat receiving high inputs of manure and disturbance (hoeing/harrowing after sowing, hand weeding etc.) (Charles *et al.* 2002). Like the Evvia dataset, the Asturias data consist of a species-by-plot matrix, with species' scores indicating the number of $1m^2$ quadrats out of ten per cultivated plot in which they occurred. All weed taxa occurring in at least 5% (three or more) of the cultivated plots were included in analyses. In total, analyses included 65 cultivated plots and 65 taxa.

All 65 weed taxa included in analyses have been measured for functional attributes (Charles *et al.* 2002). The methods used are identical to those described for the collection and measurement of species represented archaeobotanically (above, 2.4).

2.8 Methods of multivariate statistical analysis

2.8.1 Correspondence analysis

Correspondence analysis (CA) is a multivariate statistical technique used in fields such as ecology and archaeology to search for patterns in complex variable-by-sample data, including compositional data (e.g. species-by-sample data from vegetation surveys or archaeobotanical samples). In archaeobotany, for example, CA has been applied to species-by-sample data to generate hypotheses about causes of variation among archaeobotanical samples (e.g. Lange 1990; G. Jones 1991; Brombacher and Jacomet 1997; Colledge 1998, 2001: 183-191; Buurman 1999; Charles and Bogaard 2001). The following description of the method is summarised from a number of sources (Gauch 1982; ter Braak 1987, 1987-1992; Jongman *et al.* 1987; Lange 1990; G. Jones 1991, unpublished Sheffield Workshop notes) and focuses on the application of CA to compositional (species-by-sample) data. CA is a technique of 'ordination'- a term applied to multivariate techniques that arrange 'samples' (that is, the units whose characteristics have been measured) along axes on the basis of their combined characteristics (for compositional data, their species composition). Advantages of CA over other ordination techniques are that it is appropriate for data with many zeros (as species scores), that normal distribution is not assumed and that CA can simultaneously display both samples and species on the same axes. CA produces two-dimensional scatter plots in which samples and species are arranged along two axes representing trends in the data; often the first two axes, which by definition account for the most variation, are plotted together. CA axes are expected to represent the underlying causes of species variation among samples and so are used to generate hypotheses about these causes. Hypotheses about the causes of variation along axes can be explored by coding data points (for species or samples) according to extrinsic variables (e.g. species' ecology, sample origin) and observing how far these variables 'match' the arrangement of species and/or samples in the scatter plot (see also below).

There are various guidelines for assessing the arrangement of species and samples in the scatter plot (Lange 1990: 43-44; G. Jones unpublished Sheffield Workshop notes). First, the origin (0,0 coordinate) in the scatter plot is its "centre of gravity"; samples near the origin tend to be 'normal' or 'average' in their composition, while species near the origin tend to be common or ubiquitous.[4] Second, the direction in which data points diverge from the origin reflects their positive or negative association (i.e. divergence of samples and species in the same direction reflects positive association, in opposite directions reflects negative association). Third, the distance of data points from the origin indicates their 'degree of divergence' (i.e. how different a sample is from the 'usual' composition, or how restricted a species is to certain samples). Fourth, while the distance between sample points reflects their degree of similarity (or, for species, the degree to which they occur in the same samples), the distance between sample and

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[4] There is, however, no exact 'meaning' attached to location near the origin. Thus, a sample located near the origin is usually 'average' in its content but may not contain all species. Similarly, species near the origin are usually 'common' but may not occur in all samples.

species points is not a measure of their association – this can only be interpreted on the basis of their divergence from the origin.

Correspondence analysis was used to explore variation in weed composition for both archaeobotanical data and modern weed survey data. For the archaeobotanical data, correspondence analyses were carried out on seed counts (per sample) of standardised wild/weed taxa only (2.2.1); crop taxa and other 'non-weed' taxa (2.1.3) were excluded. For the modern weed survey data, correspondence analysis was based on the quantitative scores of weed taxa per cultivated plot, studied association or experimental plot survey (2.7). Correspondence analysis has already been applied to some of the modern weed survey data (G. Jones *et al.* 1999, 2000; Bogaard *et al.* 2001) and some of these analyses were re-used in the present project (3.1).

CANOCO for Windows (ter Braak and Smilauer 1997-1999) was used to carry out the correspondence analyses and CANODRAW (Smilauer 1992) to plot the results. Unless stated otherwise, axis 1 was plotted horizontally and axis 2 vertically in the correspondence analysis plots (occasionally, axis 1 is plotted against axis 3 (vertical) instead of axis 2). A problem with CA is that it emphasises rare species and samples (often containing a small number of items) dominated by rare species (Gauch 1982: 213-214; Jongman *et al.* 1987: 109-111; G. Jones 1991). These species and samples may be pulled out as outliers from the remaining samples and species, which are clumped together. To minimise such outliers (which are usually due to chance occurrences) in correspondence analysis, the rarest taxa (i.e. those occurring in very few archaeobotanical samples or cultivated plots) were left out of analyses (cf. Gauch 1982: 213-214; Lange 1990: 73-76; G. Jones 1984, 1991). Partly in anticipation of this problem, wild/weed taxa occurring very rarely in selected archaeobotanical samples were excluded from the collection of functional attribute measurements (above, 2.2). The minimum frequency used and actual taxa included depended on the content of the dataset entered into the analysis (4.6). Archaeobotanical samples entered into correspondence analyses contained a minimum of 25 seeds of the taxa included.

By coding data points in correspondence analysis plots of samples using symbols for extrinsic variables, a range of sample variables (e.g. crop processing stage or archaeological site for archaeobotanical samples; husbandry techniques for modern cultivated plots) were examined as possible factors underlying variation in weed composition. In order to identify any ecological aspects of variation in weed composition, taxa included in correspondence analyses were classified according to their functional attribute values or other ecological characteristics. For correspondence analyses of archaeobotanical wild/weed taxa, various decisions were made in order to classify taxa according to their functional attribute values. In the case of taxa comprising multiple species or subspecies (Table 2.4), functional attribute data for these species/subspecies were combined. For continuous variables (e.g. canopy height) and length of the flowering period (an ordinal variable), this was done by calculating the average for all species/subspecies values in the taxon. For seed persistence quintiles (an ordinal variable), the average seed longevity index value was calculated and this value then categorised as one of the five quintiles. Similarly, for the weed size index (an ordinal variable), average canopy height, canopy diameter and leaf weight per node were calculated for the taxon and these values were then categorised on a 1-5 scale for each attribute (2.4.2.1). For the few nominal variables among the functional attributes, different methods were used. For flowering onset/duration, two sorts of decision were made: 1. for taxa containing three species, a category represented by two of the species was used for the whole taxon, and 2. for taxa containing two species falling into different categories (Table 2.8), the 'neutral' category of 'medium-intermediate' was used for the taxon. For amphistomaty, the average percentage of stomata occurring on one surface was calculated and this value then categorised as amphistomatous or non-amphistomatous. For the remaining nominal variable, vegetative spread, categories were consistent for all members of amalgamated taxa, and so no 'decisions' were required.

There are several ways of illustrating variation in functional attribute values (and other ecological or crop processing data) in correspondence analysis plots of weed compositional data. The first, used in the FIBS study of modern weed data (Charles *et al.* 1997; Bogaard *et al.* 1999, 2001; G. Jones *et al.* 2000), is to code data points in a correspondence analysis plot of taxa with symbols indicating functional attribute categories (e.g. ranges of values) or other ecological categories. The second is to represent each sample in a correspondence analysis plot of samples as a pie-chart showing proportions of weeds in different functional attribute (or other ecological) categories. These pie-charts may be based on numbers of seeds, quadrats etc. for each taxon in the categories or on numbers of taxa in each category. Finally, the data points in a correspondence analysis plot of samples may be represented by symbols whose size varies according to the quantity of a particular ecological category, calculated either in terms of numbers of seeds/quadrats etc. or in terms of numbers of species in that category.

These different presentational 'styles' are more or less appropriate for different methods of quantification. Correspondence analysis determines trends in the data according to numbers of seeds of (in the case of the archaeobotanical data), cover/abundance scores for (in the case of the Hambach Forest experiment and the German phytosociological study), or quadrats containing (in the case of the modern quadrat surveys) different weed taxa. This is influenced both by the numbers of taxa contributing to the trends and by the numbers of seeds, values of scores or numbers of quadrats for each contributing taxon. Coding the data points in the taxa plot according to functional attribute (or other ecological) categories emphasises the number of taxa contributing to the trend. This is a good way of presenting the results of the modern quadrat surveys, where the maximum 'score' for a single taxon is ten, and so the trends are determined largely by the number of taxa contributing to each trend. This style of presentation is also appropriate for cover/abundance scores (for the same reason) and is, therefore, used here for the FIBS study of modern weed data based on quadrat counts and cover/abundance values (3.1.1.1, 3.1.2.1).

Representing the data points in the sample plot by pie-charts showing the proportions of 'items' (seeds, quadrats etc.) in different ecological categories emphasises the numbers of seeds (quadrats etc.) contributing to trends. This is unsuitable for data based on presence/absence in quadrats, or for cover/abundance scores, because pie-charts are based on percentages, and this type of data is not 'additive' (i.e. the data do not make up the constituent parts of a whole and so cannot be added together to arrive at a meaningful total). The same does not apply to pie-charts based on numbers of species present (where a meaningful total number of species can be calculated) and so this style of presentation is used for the Hambach data, as well as representing data points in the sample plot by symbols whose size varies according to a single ecological category, again calculated in terms of numbers of species.

For the archaeobotanical data, pie-charts based on numbers of seeds are a very good way of illustrating variation in the functional attribute values (or other ecological or crop processing data) because trends in the data are often due to high counts of a small number of taxa (and single seeds from a different taxon may be no more than chance inclusions). This style of presentation, therefore, is used for the archaeobotanical samples (Chapter 6). It should be noted, however, that the most reliable trends involve both the number of seeds and the number of taxa, but the latter is not apparent from the pie-charts. In addition, therefore, data points in sample plots are represented by symbols whose size varies according to the number of seeds of particular species, in order to explore their individual impact on the correspondence analyses.

2.8.2 Discriminant analysis

Discriminant analysis was used to find the most successful combination(s) of variables (the discriminant function(s)) for discriminating between predefined groups. The discriminant function(s) extracted by the analysis may then be used to classify the samples making up the original groups, as well as samples of unknown group, into the predefined groups. All discriminant analyses were carried out using SPSS for Windows Release 10.0.7 (SPSS Inc 1989-1999). For the (re-)classification of the samples making up the original groups, the 'leave-one-out' option was used, such that each sample was classified by the discriminant functions derived from all members of the groups except the one being classified.

2.8.2.1 Discrimination of crop processing groups

The classification of weed taxa into physical types relevant to crop processing (above, 2.5.3) formed the basis of a comparison of ethnoarchaeological samples from Amorgos with the archaeobotanical samples using discriminant analysis. The three discriminant functions extracted to distinguish the four processing groups represented by the ethnoarchaeological samples (i.e. winnowing by-product, coarse sieve by-product, fine sieve by-product, fine sieve product; G. Jones 1984) were used to classify the archaeobotanical samples. To calculate discriminating variables for the archaeobotanical samples comparable to those used for the ethnoarchaeological samples, the square root of the percentage of each weed taxon was calculated first, then values for taxa in each weed seed type category (BFH, SFH etc.) were summed for each sample.

2.8.2.2 Discrimination of modern husbandry regimes

Two of the modern weed studies (Germany, Evvia) use functional attribute data for contrasting husbandry practices (autumn versus spring sowing and intensive versus extensive cultivation of pulses, respectively) and so have been subjected to discriminant analyses of these predefined husbandry groups using average functional attribute scores per studied association (Germany) or cultivated plot (Evvia) as the discriminating variables (G. Jones *et al.* 2000; Bogaard *et al.* 2001; see also Charles *et al.* 2002). Discriminant analyses from these studies have been extended in the present project and the discriminant functions used to classify the archaeobotanical samples (3.1-3.3).

Average attribute scores per studied association or cultivated plot were calculated in two different ways:

1. using quantitative data (as in the original publications – G. Jones *et al.* 2000; Bogaard *et al.* 2001): the formula used for the calculation of average attribute scores per field (Charles *et al.* 1997) is as follows:

   $(a_1k_1 + a_2k_2 \ldots + a_nk_n)/k_1 + k_2 \ldots + k_n)$

   where k = numerical score for the species (so, for the sowing time study, the numerical equivalent of the cover/abundance score (Table 2.15) and, for the Evvia study, the number of quadrats out of ten), a = attribute value for the species and n = number of species recorded from the studied association or cultivated plot.
2. using semi-quantitative (presence/absence) data (as in Charles *et al.* 2002): in this calculation, the numerical score for each species ('k' above) is simply '1' for species present in a studied association or cultivated plot and '0' for absent species. Thus, in the numerator, the attribute values ('a' above) for all species present are simply added together; the denominator is the total number of species present.

Discriminant analyses were carried out using both quantitative and semi-quantitative (presence/absence) data. The discriminant functions derived to distinguish autumn- versus spring-sowing (Germany) and intensive versus extensive cultivation (Evvia) were used to classify cultivated plots from the Asturias study (Charles *et al.* 2002) and the archaeobotanical samples. For the calculation of (quantitative) average attribute scores for the archaeobotanical data, seed counts were used instead of the quadrat counts or cover/abundance scores used in the modern studies.

For the classification of archaeobotanical samples using the discriminant function extracted to distinguish autumn and spring sowing regimes (Germany), all 'potential weed' taxa identified more or less to species (as defined above, 2.1.3) were included, since the discriminant functions are based on ecological data from Floras (available for all species). For the classification of archaeobotanical samples using the discriminant function extracted to distinguish intensive and extensive cultivation (Evvia), only those taxa included in the collection of functional attribute measurements could be included, since the discriminant functions are based on functional attribute measurements of plants in the field and laboratory.

Variation between amalgamated and species identifications (e.g. *Galium aparine* versus *Galium aparine/spurium*) does not pose a problem for discriminant analysis based on quantitative data, as species' characteristics (e.g. weed seed types, functional attribute scores) are used rather than actual species (above, 2.2.1). The standardised archaeobotanical identifications determined for correspondence analysis (above, 2.2.1), therefore, are mostly unnecessary for discriminant analysis. The exceptions are the taxa shown as group 'c' in Table 2.2, where certain amalgamated categories have been changed to species identifications for all analyses.

In discriminant analyses based on semi-quantitative (presence/absence) data, however, the occurrence of overlapping (amalgamated plus species) identifications in the same sample must be resolved since the analysis uses taxon counts and the same taxon could be counted twice. In such cases (e.g. where seeds identified as *Galium aparine* and *Galium aparine/spurium* occur in the same sample), the overlapping taxa in samples were given a count of '1' in the calculation of mean attribute scores per sample, and attribute values for the definitely identified species were used.

A final methodological point relates to the functional attribute measurements used in discriminant analyses comparing the Asturias fields or archaeobotanical samples with the Germany or Evvia studies. In order to compare 'like with like', the range and ecological significance of functional attributes should be similar in these regions and, in particular, species common to both datasets should be represented by the same functional attribute values. As noted earlier (2.4.1), the precise nature and extent of variation in the functional attribute values of species between geographical regions is unclear, but there is little or no evidence of geographical bias in most attributes (G. Jones *et al.* in prep). This suggests that it is valid to combine functional attribute data gathered for the same species in a variety of geographical locations. Thus, functional attribute values used in discriminant analyses combining Germany or Evvia data with the Asturias fields or archaeobotanical samples were based on the full set of available measurements from across Europe (e.g. Mediterranean as well as temperate Europe) such that, for example, species common to more than one dataset were represented by the same functional attribute values. This is in contrast to the 'temperate European' functional attribute data used for the archaeobotanical data in other contexts (above, 2.4.1).

Attributes relating to the timing and duration of flowering (Table 2.7; 2.4.2.2) are an exception, however, since flowering times do show considerable variation from one region to another (G. Jones *et al.* in prep). In fact, the Germany study, the Asturias study and the archaeobotanical study share a similar climate and so flowering times were taken from the same regional Flora (Rothmaler 1995). For the Evvia study, however, flowering data were taken from a source more appropriate to this climatic region (Strid and Tan 1997; Strid pers. comm. – see G. Jones *et al.* 2000) and so, for example, the same species occurring in the Evvia study, on the one hand, and the Asturias study or the archaeobotanical samples, on the other, could be represented by somewhat different flowering times. While such differences may reflect a general difficulty with regard to flowering times in direct comparisons of weed data from distinct geographical regions, it can also be argued that the same plant species functions somewhat differently in separate geographical regions and is, therefore, associated with different growing conditions.

3 Models based on modern weed ecological studies

As discussed in section 1.2.3.3, modern weed data are essential to the construction of meaningful comparisons incorporating causal mechanisms ('relational analogies') between past and present-day crop husbandry practices (Hodder 1982: 11-27; Wylie 1985; cf. Binford 1981: 25-30). 'Traditional' husbandry regimes practiced today certainly do not encompass all combinations of husbandry practices of relevance to the past. The small range of regimes dealt with below, however, relate to three variables of critical importance to ongoing debate over the nature of cultivation in the study area during the Neolithic and Bronze Age: the permanence, intensity and seasonality of cultivation (1.5).

Section 3.1 describes previous FIBS studies of crop sowing time (Germany) and intensive versus extensive pulse cultivation (Evvia) (2.7.2-2.7.3). The subsequent sections 3.2-3.4 present further work on these datasets with a view to their use in archaeobotanical interpretation.[5] The final section (3.5) describes new work on an existing dataset from the Hambach Forest experiment (2.7.1), which relates to the archaeobotanical recognition of shifting cultivation.[6]

3.1 Results of previous analyses of modern weed data from Germany and Evvia

3.1.1 A FIBS study of crop sowing time (Germany)

Correspondence analysis of the Germany data has shown that autumn and spring sowing regimes are floristically distinct (Bogaard *et al.* 2001). In a correspondence analysis plot of the German phytosociological weed associations (Fig. 3.1a), each weed association is coded by soil pH and crop sowing time. In addition to the clear separation of weed associations of acidic and basic soils along axis 1 (horizontal), weed associations of autumn- and spring-sown crops are clearly separated along axis 2 (vertical): winter associations are at the positive (top) end of axis 2 and summer associations at the negative (bottom) end of the same axis. Moreover, this sowing time pattern appears to reflect the impact of sowing time *per se* rather than crop type or soil fertility, which may be correlated with crop sowing time. Coding of weed associations in the correspondence analysis plot by crop type and site nutrient level (plots not shown) indicates that these factors do not cause the floristic separation of summer and winter associations (Bogaard *et al.* 2001).

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[5] Some of this work has recently been published in Charles *et al.* (2002).

[6] A summary of this work has recently been published in Bogaard (2002).

3.1.1.1 The relationship of individual functional attributes to sowing time

Of the functional attributes relating to seasonality and/or the ability to regenerate rapidly following disturbance, the onset and length of the flowering period in combination show the clearest relationship to crop sowing time (Fig. 3.1b) (Bogaard *et al.* 2001). In Fig. 3.1b, short-flowering species with early to intermediate onset of flowering are confined to the positive (top) end of axis 2, where autumn-sown associations are located, whereas both late-onset and long-flowering species tend towards the negative (spring-sown) end of the same axis. Annual life history and germination time are more weakly related to sowing time, whereas epidermal cell endopolyploidy shows no obvious relationship (plots not shown).

In addition to attributes functionally related to sowing time by their seasonality and/or response to disturbance, certain other attributes relating to the quality and duration of the growth period, which normally indicate soil fertility, also appear to be influenced by sowing time. Species with the tallest canopies tend to be associated with spring-sown crops and those with the shortest canopies with autumn-sown crops (plot not shown). Similarly, for leaf size attributes and one leaf 'density' attribute (SLA), high values are associated with weeds of spring-sown crops and low values with weeds of autumn-sown crops, though not all species fit this pattern (plots not shown). Of all the functional attributes included in the study by Bogaard *et al.* (2001), however, flowering onset and length show the clearest relationship to sowing time in the correspondence analysis.

3.1.1.2 The ability of functional attributes to discriminate between autumn and spring sowing regimes

Functional attributes were also used as discriminating variables in discriminant analyses of weed associations from autumn- and spring-sown crops (Bogaard *et al.* 2001). A discriminant analysis incorporating the full range of attributes included in the study (onset and length of the flowering period, germination time, estimated endopolyploidy, canopy height, canopy diameter, leaf weight per node, leaf area per node:thickness, SLA, DMC) correctly reclassifies 97% of the weed associations (36 out of 37) as belonging to the sowing regimes (autumn or spring) from which they are known to derive. All the attributes are correlated with the discriminant function in the predicted way, except epidermal cell endopolyploidy, which is only weakly correlated with the discriminant function (diagrams not shown). Attributes relating to seasonality and/or the ability to regenerate rapidly following disturbance are strongly correlated with the discriminant function. Indeed, if three nominal variables derived from flowering onset/length (above, 3.1.1.1) – early-intermediate/short flowering, late flowering and long flowering – are used alone as discriminating variables, the percentage of studied associations correctly reclassified as autumn- or spring-sown is only slightly reduced. Fig. 3.2a shows the successful discrimination of autumn- associations and spring-sown weed associations: 95% of associations (35 out of 37) are correctly reclassified by the discriminant function.[7] Fig. 3.2b shows the correlation of the three variables with the discriminant function: as predicted, early-intermediate/short flowering is associated with autumn sowing and late and long flowering with spring sowing.

3.1.1.3 Summary of results

A FIBS study of the German phytosociological data from autumn- and spring-sown crops produced two important conclusions (Bogaard *et al.* 2001). First, the most useful attributes relating to sowing time are the onset and length of the flowering period; attributes previously used by archaeobotanists (life history and germination time of annuals) are more weakly linked to sowing time. Second, fertility attributes appear to be influenced by sowing time. Rather than indicating differential fertility *per se*, this phenomenon probably reflects mainly cool season growth (promoting relatively small, slow-growing species) in autumn-sown crops versus warm season growth (promoting larger, faster-growing species) in spring-sown crops. Importantly, this result suggests that sowing time should be assessed from weed data prior to assessing fertility, since an apparent difference in fertility may be caused by a difference in sowing time.

3.1.2 A FIBS study of cultivation intensity (Evvia)

Correspondence analysis of the Evvia data has shown that there are clear floristic differences between pulse plots of varying scale and cultivation intensity (G. Jones *et al.* 1999). Pulse plots ranged from intensively managed ‘gardens’, which tended to be hoe-cultivated, weeded, manured and watered, to extensively managed ‘fields’, which were ard-ploughed and tended not to be weeded, manured or watered. Fig. 3.3a shows the correspondence analysis diagram of pulse plots coded by plot type, with gardens towards the left (especially top left) of the diagram, unfenced fields to the right and intermediate plot types (vineyards, fenced fields) located centrally and extending from right to bottom left, respectively.

A detailed interpretation of the first two correspondence axes has been presented using the fertility and disturbance categories shown in Fig. 3.3b (G. Jones *et al.* 2000). Axis 1 emerges

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[7] Bogaard *et al.* (2001) report that the percentage of associations correctly reclassified remains 97% with the nominal variables derived from flowering onset/length as the only discriminating variables. This is the result of a discriminant analysis with late and long flowering only as discriminating variables. When early-intermediate/short flowering is included as a third discriminating variable, however, an additional association is misclassified, resulting in 95% correctly reclassified.

as primarily a fertility axis, with high fertility plots towards the negative (left) end and low fertility plots towards the positive (right) end, and axis 2 as a disturbance axis, with hoed plots towards the positive (top) end and ploughed plots towards the negative (bottom) end. Exceptions to these trends suggest that both fertility and disturbance may contribute to each axis. In particular, it appears that disturbance does play a role on axis 1: low fertility plots that are also hoed or ploughed/weeded (open triangles and open circle) are located towards the negative (left) end of axis 1 in Fig. 3.3b.

3.1.2.1 The relationship of individual functional attributes to cultivation intensity

As expected, both leaf size attributes (e.g. leaf area per node:thickness – Fig. 3.4a) and canopy size attributes (e.g. canopy height – Fig. 3.4b), as well as the weed size index incorporating canopy size and leaf size (plot not shown) (2.4.2.1), exhibit clear patterning along axis 1 (G. Jones *et al.* 2000): species with high leaf area per node:thickness values (>20000 mm – Fig. 3.4a) and tall canopies (>85 cm – Fig. 3.4b) are located towards the left of the correspondence analysis plot, at the negative ('fertile') end of axis 1. All of these attributes, therefore, reflect the predominant role of fertility along axis 1. While the relationship of leaf size to relative fertility level at either end of axis 1 is straightforward (Fig. 3.4a), however, canopy size (Fig. 3.4b) may also be affected by disturbance. The tendency of species with tall canopies (>85 cm) to occur towards the lower left of the plot (Fig. 3.4b) and the absence of these species from the upper left can be explained by the inability of species with very tall canopies to thrive under highly disturbed (e.g. hoed) conditions. Leaf 'density' attributes do not show a clear pattern along axis 1 (plots not shown), probably as a result of the dense shade cast by broad bean, the primary crop (G. Jones *et al.* 1999, 2000) (see also 2.4.2.1).

Attributes relating to the ability to regenerate rapidly following disturbance – length of the flowering period (Fig. 3.5a) and vegetative spread (plot not shown) – also show a pattern along axis 1: species with a relatively long flowering period (4 months or more) and/or a horizontal root system tend to occur towards the negative (left) end of axis 1, where hoed and weeded plots are located, while species with a relatively short flowering period (2 months or less) tend more weakly towards the positive (right) end of axis 1. These results confirm that the effects of disturbance (hoeing and hand weeding) do play a role along axis 1. The importance of disturbance along axis 2 is also confirmed: species of open habitats (with stomata evenly distributed on both leaf surfaces – 'amphistomatous') are absent from the top left of the plot, where hoed plots are concentrated (Fig. 3.5b). The relative absence of these shade-intolerant weeds from hoed plots apparently relates to the destruction of standing weeds by hoeing and the need for subsequently developing weeds to be tolerant of the dense shade cast by the crop. The effect of disturbance in hoed plots is also indicated by the absence of species with tall canopies from the top left of the plot (above, Fig. 3.4b). The attributes suggest that fertility plays no effective role along axis 2.

3.1.2.2 The ability of functional attributes to discriminate between intensive and extensive pulse cultivation

A highly successful discrimination of intensively cultivated gardens ('back gardens' and 'allotment gardens') and extensively cultivated fields ('unfenced fields') was carried out using the full suite of functional attributes (with the exception of vegetative spread) included in the study as discriminating variables (canopy height and diameter, leaf weight per node, leaf area per node:thickness, SLA, DMC, flowering period, stomatal density, stomatal size, epidermal cell size, cell wall undulation, root diameter, amphistomaty, seed persistence): 95% of plots (36 out of 38) are correctly reclassified as gardens or fields by the discriminant function (G. Jones *et al.* 2000).[8] The attributes are all correlated with the discriminant function in the predicted way, with the exception of tap root diameter (diagrams not shown). Several further discriminant analyses were also carried out using reduced sets of attributes as discriminating variables (G. Jones *et al.* 2000). The smallest set consisted of the six attributes (SLA, canopy height and diameter, leaf area per node:leaf thickness, flowering period, amphistomaty) most strongly correlated with the discriminant function (excluding water-related attributes), which successfully discriminated gardens and fields (Fig. 3.6a): 92% of plots (35 out of 38) are correctly reclassified.[9] The attributes are all correlated with the discriminant function in the predicted way (Fig. 3.6b).

For the purpose of the present project, so that the Evvia discriminant analysis can be used to classify the archaeobotanical samples from western-central Europe, functional attribute values for the Evvia species were recalculated using measurements taken at locations across Europe wherever possible (see also 2.8.2.2). Species' values for five of the six attributes (i.e. those most useful in the original discriminant analysis) were recalculated but local data on length of the flowering period were retained (see also 2.8.2.2). A discriminant analysis was carried out using these six attributes (Fig. 3.7a): 92% of plots (35 out of 38) are correctly classified, as in the analysis based on local data (above, 3.1.2.2) and the attributes are all correlated with the

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[8] G. Jones *et al.* (2000) report that 100% of plots were correctly reclassified with the full suite of functional attributes included in the study as discriminating variables. Using the leave-one-out classification option (2.8.2), however, this is reduced to 95%.

[9] G. Jones *et al.* (2000) report that 95% of plots were correctly reclassified with the six fertility and disturbance attributes as discriminating variables. Using the leave-one-out classification method (2.8.2), however, this is reduced to 92%.

discriminant function in the predicted way (Fig. 3.7b). This discriminant function, therefore, was used for all subsequent classifications in comparison with the Evvia study.

3.1.2.3 Summary of results

The FIBS study of the Evvia data enabled the investigators to disentangle the effects of fertility and disturbance along the first two correspondence axes (G. Jones *et al.* 2000). Attributes relating to a third ecological factor, water availability, do not show any patterning along the correspondence axes but some are strongly correlated with the discriminant function distinguishing fields and gardens. This discrimination, however, is very successful using only the six fertility and disturbance attributes, which suggests that watering is correlated with fertility and/or disturbance but was not a major determinant of floristic composition (G. Jones *et al.* 2000).

3.2 A semi-quantitative approach to the discrimination of husbandry regimes

The modern weed survey data discussed above (3.1) consist, in the Evvia study, of the number (0 – 10) of 1 m^2 quadrats per plot in which a given weed species was recorded (2.7.3) and, in the Germany study, of the phytosociological cover/abundance scores for each weed species in each weed association (Table 2.15; 2.7.2). Archaeobotanical weeds are quantified in a completely different manner, by counting the (minimum) number of seeds of each taxon per sample (2.1.3). These very different forms of quantification make direct comparison between modern and archaeobotanical weed data problematic.

One method for comparing archaeobotanical weed data directly with modern weed data is to use the discriminant functions extracted to distinguish the modern groups to classify the archaeobotanical samples (2.8.2.2). This approach is analogous to the method used by G. Jones (1983, 1984, 1987) for directly comparing archaeobotanical samples with ethnoarchaeological samples from different crop processing stages (2.8.2.1). The discriminant analyses discussed above (3.1) are all based directly on quantitative data from the weed surveys (i.e. quadrat counts per plot for Evvia, cover/abundance scores for Germany). Strictly speaking, therefore, discriminant functions extracted for distinguishing the modern studies are not directly applicable to archaeobotanical data based on weed seed counts. Furthermore, there is no reliable way of converting counts of seeds into numbers of quadrats per field or cover/abundance scores.

Simplification of both modern and archaeobotanical weed data to the level of species' presence/absence greatly enhances their comparability. In this approach, the calculation of functional attribute scores for modern 'units of analysis' (cultivated plots or weed associations) is the same as for archaeobotanical samples: the attribute values for all taxa present are simply added up and divided by the total number of taxa present (2.8.2.2). The resulting attribute scores can then be used as the discriminating variables in discriminant analyses of modern husbandry regimes and the discriminant function extracted used to classify the archaeobotanical samples.

The semi-quantitative approach has some disadvantages. The quantitative versions of both modern and archaeobotanical weed data potentially contain a good deal more useful information on the relative responses of individual species to environmental conditions, and so the discrimination of predefined groups may be less clear using semi-quantitative data. Furthermore, it has been argued that analysis of archaeobotanical data on the basis of species' presence/absence is problematic since small amounts of contamination may be present (G. Jones 1992). Nevertheless, the semi-quantitative approach provides a way of comparing archaeobotanical samples directly with modern weed data from different husbandry regimes. In order for this approach to be viable, however, it must be demonstrated that modern husbandry regimes can be discriminated successfully on the basis of semi-quantitative weed data.

3.2.1 Discrimination of autumn and spring sowing regimes

A discriminant analysis of autumn and spring sowing regimes based on semi-quantitative weed data was carried out using the three flowering onset/length attributes described above (3.1.1.2) as the discriminating variables (early-intermediate/short flowering, late flowering, long flowering) (Fig. 3.8a). The discrimination is successful: 89% of associations (33 out of 37) are correctly reclassified using the discriminant function extracted. This outcome is only slightly poorer than the discrimination using quantitative data and the same attributes as variables (95% correctly reclassified – above, 3.1.1.2), though a greater proportion of weed associations are reclassified with low probabilities (<0.90, Table 3.1). The attributes are correlated with the discriminant function in the predicted way (Fig. 3.8b).

3.2.2 Discrimination of intensive and extensive pulse cultivation

A discriminant analysis based on semi-quantitative weed data was carried out using the set of six fertility and disturbance attributes used in the quantitative discriminant analysis (above, 3.1.2.2) (Fig. 3.9a). The discrimination is successful: 90% of plots (34 out of 38) are correctly reclassified. This result is only slightly poorer than the discrimination using quantitative data and the same attributes as variables (92% correctly reclassified – above, 3.1.2.2) and very similar proportions of cultivated plots are reclassified with low probabilities (Table 3.1). The attributes are correlated with the discriminant function in the predicted way (Fig. 3.9b).

3.3 A test case: intensive cultivation of winter-sown spelt (Asturias)

The modern weed survey data from the spelt cultivation study in Asturias (2.7.4), for which both crop sowing time and cultivation intensity are known, can be used to 'test' the success of the sowing time and cultivation intensity models in application to cases of unknown husbandry regime (e.g. archaeobotanical samples) (Charles *et al.* 2002). Spelt cultivation in Asturias was intensive, with high inputs of manure and high disturbance during the crop growing season (in the form of hoeing/harrowing and/or hand weeding), and the spelt was sown in late autumn-winter. This combination of husbandry practices in a cereal-growing regime is of particular interest for two reasons. First, the intensive cultivation of spelt in Asturias differs from the usual extensive cultivation of modern cereals and there is some uncertainty about the applicability of the Evvia results to cereals since it relates to intensive pulse cultivation. In particular, the main pulse crop in the Evvia study, broad bean, casts a denser shade than cereal crops (G. Jones *et al.* 1999). Second, the weed floras of both spring-sown and intensively cultivated crops are rich in character species of the phytosociological class Chenopodietea (root/row-crop weeds and ruderals) (e.g. G. Jones 1992; G. Jones *et al.* 1999). The question thus arises, whether or not functional attribute data can distinguish between spring-sown crops, on the one hand, and intensively cultivated autumn-sown crops, on the other (cf. G. Jones 1992). To some extent, intensive cultivation would be expected to obscure the effects of autumn sowing and *vice-versa* in functional attribute terms: long-flowering species are promoted both by weeding and by spring sowing, while some short-flowering species (i.e. those with early-intermediate onset) are promoted by autumn sowing and, to some extent, by low disturbance as in an extensive cultivation regime (G. Jones *et al.* 2000; Bogaard *et al.* 2001) (2.4.2.2).

These issues were addressed by using the discriminant functions extracted to distinguish autumn versus spring sowing and intensive versus extensive pulse cultivation (from the Germany and Evvia studies, respectively) to classify the Asturias plots (Charles *et al.* 2002).[10]

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[10] Analyses comparing the Asturias data with intensive versus extensive pulse cultivation in Evvia (below, 3.3.2) differ slightly from those presented by Charles *et al.* (2002): the functional attribute data used in this comparison incorporate all available data for the Asturias and Evvia species from across Europe except for length of the flowering period (2.8.2.2).

In addition, by using discriminant analyses based both on quantitative and semi-quantitative weed data, the relative success of the two methods can be assessed.

While the same system of quantification was used for the Asturias and Evvia studies (quadrats counts out of ten per field), the sowing time study used cover/abundance scores to quantify species (2.7.2-2.7.4). The classification of Asturias plots by the discriminant function distinguishing autumn and spring sowing in Germany based on quantitative data, therefore, is somewhat dubious since different quantification systems were used. These differences, however, are more likely to obscure ecological patterning than to create spurious patterns (Charles *et al.* 2002).

3.3.1 Comparison of Asturias plots with autumn and spring sowing regimes (Germany)

In a discriminant analysis based on quantitative weed data, the Asturias spelt plots were classified using the discriminant function extracted earlier to distinguish autumn and spring sowing regimes (above, 3.1.1.2). The classification is successful: 91% of spelt plots (59 out of 65) are classified correctly as autumn-sown (Table 3.2; Fig. 3.10b). In a discriminant analysis based on semi-quantitative weed data, the results are less successful: 68% of spelt plots (44 out of 65) are classified correctly as autumn-sown (Table 3.2; Fig. 3.10d). This is, in fact, not inconsistent with the sowing time at Asturias, which starts in late autumn (November) and continuing into winter (January or, in one case, even February). Sowing in Asturias, therefore, is later than typical autumn sowing in Germany (September-October) and so it is not surprising that the classification of these plots as either autumn- or spring-sown is ambiguous (Charles *et al.* 2002). Late autumn/winter sowing may also explain the fact that, in both quantitative and semi-quantitative versions of the discriminant analyses, the Asturias plots are more variable in their discriminant scores than the weed associations from Germany (Fig. 3.10).

3.3.2 Comparison of Asturias plots with intensive and extensive pulse cultivation (Evvia)

In a discriminant analysis based on quantitative weed data, the Asturias plots were classified using the discriminant function extracted earlier to distinguish pulse gardens and fields using six fertility and disturbance attributes (above, 3.1.2.2). 100% of Asturias plots are classified correctly as gardens by the discriminant function (Table 3.3; Fig. 3.11b). In a discriminant analysis based on semi-quantitative weed data, 100% of Asturias plots are classified correctly as gardens (Table 3.3; Fig. 3.11d). In both discriminant analyses, the discriminant scores for the Asturias plots tend to be more extreme than those for the Evvia gardens (Fig. 3.11).

3.3.3 Discussion of Asturias results

The results have demonstrated the overall success of both quantitative and semi-quantitative discriminant analyses as methods of identifying the sowing regime and intensity of spelt cultivation in Asturias. It appears that the Evvia study of pulse cultivation is relevant to cereal cultivation despite the denser shade cast by broad beans. Moreover, it has proved possible to identify the combination of autumn/winter sowing and intensive cultivation, despite the opposite effects of these practices on the length of the flowering period.

The greatest discrepancy between quantitative and semi-quantitative versions of discriminant analysis was observed in the classification of Asturias plots as autumn- or spring-sown (Table 3.2). A higher proportion of plots is classified as spring-sown in the semi-quantitative analysis (32%) compared to the quantitative analysis (9%), while the proportion of plots classified at a low probability (<0.90) is also much higher (31%) in the semi-quantitative analysis than in the quantitative analysis (3%) (Table 3.1). As noted above (3.3.1), sowing in Asturias took place from late autumn through to winter, later than typical autumn sowing in Germany, and this difference may contribute to the higher proportion of spring classifications by the semi-quantitative analysis. Classification of Asturias plots as 'winter-sown' is, of course, impossible, since only autumn and spring sowing regimes were included in the Germany study. Late autumn/winter sowing in the Asturias study may also contribute to the greater spread of discriminant scores for Asturias plots compared with those for the weed associations in the Germany study (Fig. 3.10).

The discriminant scores for the Asturias plots tend to be more extreme than those for the Evvia gardens (Fig. 3.11). Contrasting growing conditions in Asturias and Evvia may contribute to these differences. Asturias is located in the atlantic-temperate climate zone, with year-round rainfall and cold winters, whereas Evvia is located in the mediterranean-temperate zone, with winter rainfall (and lack of frost) and hot, dry summers. Growing conditions in Asturias would tend to be wetter (and hence more productive) than in Evvia, even though some of the Evvia gardens were watered. It is hardly surprising, therefore, that the Asturias plots, though most similar to the Evvia gardens, tend to be more extreme in their discriminant scores.

The comparison of Asturias plots with the Germany and Evvia studies demonstrates that, while such comparisons can successfully identify the 'most appropriate' husbandry category for plots of 'unknown' husbandry regime, differences in discriminant scores between the original study (Germany, Evvia) and the unknown cases (Asturias) deserve attention. Such contrasts reflect the fact that the modern studies are themselves unique cases to some extent. The Evvia gardens and fields represent specific points along a broad potential continuum of cultivation intensity. Crop sowing time is also not straightforward; in fact, distinct autumn and spring sowing periods are specifically characteristic of central-northern Europe, where frost prevents sowing in winter, whereas in milder parts of atlantic and mediterranean Europe sowing can take place throughout the winter (cf. Silverside 1977: 8-9). Differences in discriminant scores, therefore, may provide a useful starting point in the reconstruction of past husbandry regimes having no exact analogue amongst the modern weed studies available (see also 5.2.1.5, 5.2.2.4).

3.4 The impact of crop processing on the modern weed data

The analyses of modern weed survey data described in the preceding sections (3.1-3.3) were based on all frequently occurring weed taxa (2.7). The weed composition of archaeobotanical samples, by contrast, is 'filtered' by a number of taphonomic processes. G. Jones (1992) has shown that one taphonomic factor, crop processing, may introduce biases in the ecology of weed species characteristic of different processing stages. As discussed in section 2.5.3, weed seeds with particular physical properties are removed at different stages in the crop processing sequence; importantly, these physical properties may to some extent be correlated with the ecological behaviour of weed species. G. Jones (1992) compared ratios of weeds of two phytosociological groupings in ethnoarchaeological samples from different stages in a traditional crop processing sequence. The two groupings are the phytosociological classes Secalinetea (winter cereal weeds), which tend to mimic cereals, and Chenopodietea (root/row-crop weeds and ruderals), which tend to be unspecialised. It was found that the ratio of Chenopodietia character species to those of Secalinetea decreased significantly through the processing sequence, whether calculated on the basis of species numbers or seed numbers (G. Jones 1992). To the extent that Secalinetea and Chenopodietea possess distinct ecological characteristics, therefore, the weed composition of crop products (rich in Secalinetea) and by-products (rich in Chenopodietea) may appear to reflect contrasting husbandry practices, even if they derive from the same harvested crop.

To some extent, the problem of ecological bias between processing stages can be addressed by comparing archaeobotanical samples from the same processing stage (G. Jones 1987, 1992). If crop processing introduces radical biases in the ecology of weeds characterising different processing stages, however, it may be difficult to infer husbandry practices accurately from weed material affected by crop processing. The purpose of this section is to explore the possibility that the physical weed types characteristic of different processing stages are biased in their functional attribute values.

The following sections (3.4.1–3.4.2) are concerned with weed species belonging to two weed seed types – small free heavy and big free heavy. Small free heavy and big free heavy species, respectively, characterise the most commonly represented sample types in the archaeobotanical dataset (4.1), fine sieve by-products and fine sieve products, respectively.

3.4.1 Bias in attributes relevant to crop sowing time

The correspondence analysis plot of weed species from the sowing time study (Germany) is shown in Fig. 3.12a, with species coded by big free heavy or small free heavy physical type; taxa of other physical types are not shown. There is no clear patterning of these groups in relation to axis 2 (the sowing time axis). Clearly, data points are mostly positioned according to their seasonality (e.g. flowering onset/length – Fig. 3.1b) rather than their crop processing category.

Table 3.4 considers the relationship between weed seed type (big or small free heavy) and flowering onset/length category. There is a strong tendency for early-intermediate/short-flowering taxa to be big free heavy and for late- and long-flowering taxa to be small free heavy. This suggests that there would be a tendency for fine sieve products (charaterised by big free heavy seeds) to indicate autumn sowing and for fine sieve by-products (characterised by small free heavy seeds) to indicate spring sowing. These relationships are not perfect, however: three late- or long-flowering taxa are big free heavy (*Fallopia convolvulus, Fumaria officinalis, Polygonum persicaria*) and four early-intermediate/short-flowering taxa are small free heavy (*Anthoxanthum puelli, Aphanes microcarpa, Rumex acetosella, Veronica triphyllos*).

Thus, while it is not inevitable that fine sieve products and by-products should indicate autumn and spring sowing, respectively, there is a definite bias in this direction. Clearly, archaeobotanical samples contradicting this bias (e.g. fine sieve by-products indicative of autumn sowing) would offer the best evidence for crop sowing time, though such samples may be rare.

3.4.2 Bias in attributes relevant to cultivation intensity

The correspondence analysis plot of weed taxa from the cultivation intensity study (Evvia) is shown in Fig. 3.12b, with taxa coded by big free heavy or small free heavy type. There is clearly no patterning in relation to either axis – neither axis 1 (primarily a fertility axis, with taxa indicative of high fertility at the negative end) nor axis 2 (primarily a disturbance axis, with taxa indicative of high disturbance at the positive end) relates to weed seed type. This suggests that there are no obvious biases in the occurrence of big versus small free heavy taxa at different levels of cultivation intensity.

Another approach, which incorporates a range of functional attributes, is to compare average functional attribute values of big free heavy and small free heavy taxa. Table 3.5 shows data from the three modern studies discussed above (3.1-3.3) for which functional attribute data are available (Germany, Evvia and Asturias). Averages and standard deviations are given for six attributes relating to cultivation intensity (i.e. the six attributes used in discriminant analyses of Evvia gardens and fields – above, 3.1.2.2, 3.2.2, 3.3.2). The Mann-Whitney U-test (non-parametric version of the t-test) was used to compare averages for big free heavy and small free heavy taxa. Table 3.5 suggests that there is a tendency for big free heavy taxa to have larger canopies, lower SLA and a shorter flowering period. There is possibly also a tendency for big free heavy taxa to have higher leaf area per node:thickness and a greater proportion of stomata on one leaf surface (i.e. less likely to be amphistomatous), though these tendencies are weaker and/or do not apply in all three studies.

These tendencies mostly contradict the expected bias, according to which small free heavy taxa (associated with the Chenopodietea and hence potentially with intensive cultivation) would have larger canopies, higher leaf area per node:thickness and SLA, longer flowering periods and greater proportions of stomata on one leaf surface than big free heavy taxa (associated with the Secalinetea and hence potentially with extensive cultivation). The large standard deviations suggest large variation within both big free heavy and small free heavy types and few of the differences are statistically significant (Table 3.5).

3.5 Analysis of weed data from the Hambach Forest experiment

As discussed in section 1.5.1, surveys conducted by Lohmeyer (1980, unpublished) of the weed vegetation in the Hambach experimental plots provide unique data on the growth of weeds with cereals on freshly cleared loess over a six-year period. Methods for analysing these weed survey data – mainly correspondence analysis – were described in section 2.7.1. The results of the correspondence analysis are presented below (see also Bogaard 2002). In the correspondence analysis diagrams (below), 'sample' data points represent experimental plots surveyed in a certain year (1979 to 1984 – see Table 2.13).

3.5.1 The impact of different husbandry measures on the Hambach weed floras

As noted in section 2.7.1, the methods used to till experimental plots prior to sowing became increasingly severe over the course of the Hambach Forest experiment, from no tillage or tillage by hand weeding only in 1979 through to tillage by rotavator in later years (see Table 2.13). In Fig. 3.13a, data points representing experimental plots are shown distributed along axes 1 (horizontal) and 2 (vertical), with symbols indicating the survey year. There is a clear trend along axis 1, from the earliest survey year (1979) at the negative (left) end through to the latest year (1984) towards the positive (right) end. In Fig. 3.13b, the same diagram is shown with symbols indicating method of tillage. A clear horizontal trend is evident, from no tillage (open circles) or tillage by hand weeding (open diamonds) towards the negative (left) end of axis 1, through tillage by ard (+ signs) in an intermediate position to tillage by rotavator (filled circles) at the positive (right) end. Fig. 3.13b suggests, therefore, that the spread of points along axis 1 represents a trend in the severity of disturbance more than a reflection of year *per se*.

In Fig. 3.14a symbols indicate the sequence of tillage methods on the same experimental plots (see Table 2.13). Fig. 3.14a shows that axis 1 relates to the cumulative effect of tillage methods over time. Thus, plots tilled by hand weeding for the first time occur closer to the negative (left) end of axis 1 than the same plots tilled by hand weeding for the second time. Similarly, plots that were ard-ploughed for three consecutive years tend to be arranged sequentially along axis 1; such a trend is less evident among the plots tilled by rotavator for three years. Axis 1, therefore, appears to reflect increasingly severe tillage methods from left to right, the effect of any method becoming more extreme when repeated through time. The major exceptions to the tillage trend along axis 1 are the surveys of plot 21 (asterisks in Figs. 3.13a-3.14a); this plot was tilled by rotavator in both survey years but had previously been burned prior to sowing (see Table 2.13).

In Fig. 3.14b, symbols indicate whether or not plots were weeded (by hand or hand plus hoe) during the crop growing season, and weeded and unweeded plots are clearly separated on axis

2. The separation becomes less clear towards the positive (right) end of axis 1, suggesting that the additional impact of weeding during the crop growing season becomes less marked as tillage method becomes increasingly severe (cf. G. Jones *et al.* 1999). A partial separation of hoed and unhoed plots is also seen along axis 1 but this pattern may be an artefact of the association between hoeing and tillage by rotavator (Table 2.13). The exceptions to the patterning along axis 2 are again the surveys of plot 21. This plot was weeded in one survey year (+ sign) but this plot survey occurs at the extreme negative (bottom) end of axis 2 with the unweeded plots.

To summarise, it appears that axis 1 reflects a trend in the severity of pre-sowing disturbance (tillage) whereas axis 2 relates to disturbance during the crop growing season (weeding). The surveys of plot 21 (burned in 1980-1981), however, do not conform to the tillage trend on axis 1 or to the weeding trend on axis 2 (Fig. 3.14). Field notes gathered during the experiment (J. Meurers-Balke pers. comm.) suggest that the release of nutrients by burning had a positive effect on crop and weeds alike, causing both to grow more vigorously on burned plots. The implication of these observations and of the position of plot 21 surveys in the correspondence analysis diagram (Figs. 3.13-3.14) is that burning reduced the effectiveness of disturbance measures (tillage and weeding).

No other husbandry variables (method of sowing, type of cereal grown – diagrams not shown) showed any clear relationship with axis 1 or 2.

3.5.2 The development of the weed floras

3.5.2.1 Annuals versus perennials

Fig. 3.15a shows the species diagram coded by annual versus perennial life history (a few biennials are included with the perennials). No patterning is evident in the distribution of annual or perennial species along either axis. In Fig. 3.15b, data points representing experimental plot surveys are shown as pie-charts indicating the relative proportions of annual and perennial species present in each plot survey (so based on species' presence, not cover/abundance scores – 2.8.1). It is evident that these proportions do not tend to change along either axis; throughout, perennial weeds dominate plots. In fact, based on all weed species in each plot survey (except trees, shrubs, ferns and mosses – 2.7.1), the percentage of perennial weeds ranges from 57-100% (average 80%). Furthermore, there is no clear trend in the *number* of annual species per plot along either axis (diagram not shown). Despite increasingly severe disturbance measures, therefore, conditions in the Hambach experimental plots remained favourable for perennials throughout the six-year period covered by the surveys. Annuals were able to colonise the plots from the first cultivation season onwards but were always outnumbered by perennials.

3.5.2.2 Habitat of perennial species

Fig. 3.16 shows the correspondence analysis diagram of species, with perennials coded by Ellenberg's general habitat categories and by phytosociological class. Along axis 1, which relates to tillage, woodland perennials (Fig. 3.16a; character species of Querco-Fagatea in Fig. 3.16b) tend to be located neutrally or towards the negative (left) end; perennials of frequently disturbed habitats (including pioneer, flooded and trampled communities – Isoeto-Nanojuncetea, Artemisietea, Agropyretea intermedio-repentis, Agrostietea stoloniferae and Plantaginetea majoris) tend to occur towards the positive (right) end (Figs. 3.16a, b). Perennials of other habitats, or of indeterminate habitat (non-character species in Fig. 3.16b), do not show any pattern along axis 1. Along axis 2, which relates to weeding, the woodland versus disturbed trend does not occur (Figs. 3.16a, b), though woodland species are absent from the bottom right area of both diagrams, perhaps due to the combined effects of tillage by rotavator and weeding.

The trends for perennials of woodland and disturbed habitats are shown in a different form in Fig. 3.17, based on Ellenberg's habitat categories (diagrams based on phytosociological class – not shown – are virtually identical). The size of points illustrates the number of woodland perennial species (Fig. 3.17a) or perennials from disturbed habitats (Fig. 3.17b) present in each experimental plot survey. In Fig. 3.17a, woodland perennials are seen to be most numerous in the earlier plots of the bottom left quadrant, which received the least soil disturbance (no tillage or light tillage by ard and no weeding during crop growth – Figs. 3.13b, 3.14b). The lowest numbers of woodland perennials occur in later plots of the top right quadrant, which received the most soil disturbance (tilled by rotavator, with hand weeding or hand weeding plus hoeing during crop growth – Figs. 3.13b, 3.14b). In terms of the number of woodland species per plot, therefore, the trend appears diagonal, decreasing from bottom left to top right. Fig. 3.17b, illustrating the number of perennials from disturbed habitats per plot survey, shows a diagonal trend in the opposite direction, with numbers tending to increase from bottom left to top right, so from the least to most disturbed plots.

3.5.2.3 Habitat of annual species

It has already been shown that neither the proportion (Fig. 3.15b) nor the number of annual species per plot increased as a result of increasingly severe disturbance or weeding (3.5.2.1).

The question remains, whether or not there is some trend in the habitat of annual species relating to soil disturbance level. In Fig. 3.18a, annual species are coded by Ellenberg's general habitat categories and in Fig. 3.18b annual character species are coded by phytosociological class. A single species (*Moehringia trinervia*) in Fig. 3.18a is classified as a woodland annual, and its location at the extreme negative (left) end of axis 1 suggests that it is particularly associated with the lowest levels of tillage (Figs. 3.13b-3.14a). The remaining annuals – all of more or less disturbed habitats – do not show any clear trend in relation to disturbance level. In Fig. 3.18b, annuals of arable habitats (root/row-crops and winter cereals – Chenopodietea and Secalinetea, respectively) occur towards the negative end of axis 1. Fig. 3.19 shows the presence of arable character species (Chenopodietea and Secalinetea) per plot survey, and the slight trend towards the negative (left) end of axis 1 is again evident. The appearance of 'arable-type' annuals in cereal plots during the first year of the experiment was particularly noted by Lohmeyer (1980: 323). These annuals were absent from the woodland flora prior to clearance and were probably brought in on car tires, shoes etc.; as noted in section 2.7.1, no weed seeds were present in the seed corn.

3.5.2.4 Shade tolerance of species

A major characteristic of woodland species is their ability to tolerate shade (Ellenberg 1996: 125). Two indices of shade tolerance are available based on the occurrence of species in the field: Ellenberg's light index and a light index provided by J. Hodgson based on the occurrence of species in different shade conditions in intensive vegetation surveys of the Sheffield region (2.7.1). Fig. 3.20 shows perennial species coded by these two indices. Both show a tendency of shade-tolerant perennials (filled symbols) to occur towards the negative (left) end of axis 1 or in a neutral position. There is also a tendency for the least shade-tolerant perennials (open symbols) to occur towards the positive (right) end of axis 1.

In Figs. 3.21-22, plot surveys are shown as circles indicating the number of perennial species present belonging to different light index categories. Figs. 3.21a and 3.22a show that perennials of heavily shaded habitats are most abundant in the bottom left quadrant and lowest in the top right quadrant. This trend among shade-tolerant perennials is very similar to the trend among woodland perennials (Fig. 3.17a). Figs. 3.21b and 3.22b show that perennials of the least-shaded habitats are most abundant in the top right quadrant and least abundant in the bottom left quadrant. This trend is very similar to that seen among perennials of disturbed habitats (Fig. 3.17b). Thus, the diagonal trends in perennial shade tolerance – like those in perennial habitat – appear to reflect the combined impact of tillage and weeding, which is lowest in plot surveys of the bottom left quadrant and highest in plots surveys of the top right (Figs. 3.13b-3.14b). It should be noted that perennial species in the 'most shaded' categories (i.e. those shown in Figs. 3.21a and 3.22a) are mostly 'woodland perennials' (whether defined by Ellenberg group or phytosociological class, as above) but include one perennial of disturbed habitats (*Mycelis muralis*) and one perennial without a specific habitat (*Oxalis acetosella*). Perennial species in the 'least shaded' categories (i.e. those shown in Figs. 3.21b and 3.22b) contain perennials from a mixture of open habitats, especially disturbed and grassland habitats.

Fig. 3.23 shows annual species coded by the two light indices. Only three annual species in total are classed as shade-tolerant (filled symbols): *Galeopsis tetrahit, Moehringia trinervia* and *Senecio sylvaticus*. They are located towards the negative (left) end of axis 1 and so, like the shade-tolerant perennials, may relate to low levels of tillage. Only one of these species (*Moehringia trinervia*) is a woodland annual (above, 3.5.2.3). In fact, among the ca. 20 'shade-tolerant' annual species listed in Ellenberg *et al.* (1992), several are character species of arable weed communities (Secalinetea and Chenopodietea). This suggests that shade-tolerant annuals are not suitable indicators of freshly cleared woodland soil as in a shifting cultivation regime.

3.5.2.5 Other ecological attributes

It was beyond the scope of this thesis to carry out functional attribute measurements on the species in the Hambach Forest experiment. Some functional attributes, such as annual life history (winter versus summer annual), germination time, vegetative spread and flowering times, however, are derived from Floras (2.4.2.2). Of these, annual life history, germination time and flowering onset/length – which relate to seasonality and hence to crop sowing time (Table 2.7) – are not directly relevant since spring sowing was carried out in each year of the experiment.

Vegetative spread and flowering period – which relate to the ability to regenerate rapidly following disturbance (Table 2.7) – might be expected to reflect increasing severity of tillage along axis 1 and/or weeding along axis 2. Neither of these attributes, however, showed any clear pattern (diagrams not shown). For vegetative spread, this may be due to the fact that not all perennials possessing rhizomes and/or stolons can regenerate rapidly from fragments, particularly species of relatively undisturbed habitats such as woodland (Bogaard *et al.* 1999). For flowering period, only three species in the Hambach study flower for a long period (>5 months).

Another attribute of potential relevance to the development of weed floras on freshly cleared soil is regenerative strategy *sensu* Grime *et al.* (1988). It has been suggested that species with wind-dispersed seeds would be particularly able to colonise bare soil immediately following clearance (Ellenberg 1996: 876). Wind-dispersed species, however, occurred throughout the six years covered by the surveys and do not show any pattern (diagram not shown).

In addition to Ellenberg's light index (above), the Ellenberg indices relating to nitrogen, soil pH and soil moisture were also used to code species in the correspondence analysis. No patterns emerged in relation to either axis (diagrams not shown).

3.5.3 Discussion of the Hambach Forest experiment

Correspondence analysis of the weed survey data has demonstrated that the weed floras of newly cleared plots receiving low-level soil disturbance, that is no/light tillage and no weeding, are rich in perennial taxa, particularly woodland (/shade-tolerant) perennials. The latter could regenerate from roots/rhizomes in the soil or from the local seed bank or recolonise the cleared ground from adjacent woodland areas. Recently cleared plots receiving higher levels of disturbance are also dominated by perennial weeds but are characterised particularly by perennials of disturbed (/unshaded) habitats. These may also derive, at least partly, from the local flora including the seed bank; Ellenberg (1996: 768) has noted that the seeds of perennials from non-woodland habitats are often present in woodland areas on the soil surface or in the seed bank and germinate following clearance. Annuals occur at low levels in relatively undisturbed and highly disturbed plots alike and derive partly from the local woodland flora but mostly from highly disturbed anthropogenic habitats elsewhere (brought in on shoes etc.). In a shifting cultivation regime, with little or no tillage and weeding, it appears that the weed flora would be dominated by perennials, including woodland perennials, though possibly with some non-woodland annuals present (that is, brought in from other anthropogenic habitats, possibly via the seed corn). This outline of the weed flora associated with shifting cultivation agrees with general observations from other experiments on the weed floras in newly cleared and burned fields (Engelmark 1995; Rösch 2000; Rösch *et al.* 2002). The least predictable influence on these floras is the proximity and character of non-woodland habitats from which plants could colonise plots, including any weed seeds in the seed corn (cf. Dierschke 1988; Engelmark 1989). The most predictable influence is the local woodland flora itself since, by definition, cultivation areas in a shifting cultivation regime are newly cleared of woodland (Dennell 1978: 37).

While this general model of a weed flora dominated by perennials, including woodland perennials, is readily applicable to archaeobotanical data, there are two caveats. First, in order to be 'visible' archaeobotanically, weeds must set seed and their seeds must be harvested with the crop. Perennial plants regenerating from seed or roots/rhizomes after clearance and burning, however, would vary in their ability to set seed in the first cultivation season after clearance. Indeed, the weed survey data from the Hambach Forest experiment (Lohmeyer 1980, unpublished) suggest that trees and woody shrubs such as *Rubus* remained vegetative throughout the experiment; for this reason, they were excluded from the correspondence analysis (2.7.1). Data on the length of the 'pre-reproduction period' of herbaceous perennials are few but it is clear that some — including woodland perennials such as *Epilobium montanum* (Grime *et al.* 1988: 246; cf. Ellenberg 1996: 768) — can set seed within a few months of germination (Rösch *et al.* 2002: Table 4). Other newly germinated biennial/perennial species normally require at least a year of vegetative growth before they flower and set seed (such as *Cirsium* spp. — Grime *et al.* 1988: 198, 200). The archaeobotanical 'visibility' of perennial weeds, therefore, would tend to increase in the second and later cultivation seasons of a shifting cultivation regime (cf. Steensberg 1979: 23; Engelmark 1995; Rösch 2000). Assuming that prehistoric shifting cultivation allowed more than one cultivation season in newly cleared areas, as suggested by Reynolds (1977) based on the Butser slash-and-burn experiment and attested in many accounts of historical shifting cultivation in Europe (e.g. Sigaut 1975: 121-124; Steensberg 1993: 98-153), an abundance of perennials weeds ought to register archaeobotanically. In fact, the weed composition of harvested cereals from the *first* cultivation season following clearance and burning in the ongoing Forchtenberg experiment near Stuttgart (Rösch *et al.* 2002: Table 4) reflects a dominance of perennials, including woodland perennials.

A second and related complication is the severity of burning on newly cleared plots. Very intensive burning of the soil surface could potentially lead to virtual sterilisation of the soil (Ellenberg 1996: 709), whereas less severe burning, as in the Hambach Forest experiment, increases the vigour of crop and weed growth alike. A similar 'positive' effect on weed growth has been observed to result from stubble burning in East Anglia (Evans 1969: 20). Clearly, the effects of burning on weed growth could have been variable in the past, sometimes resulting perhaps in virtually 'weedless' harvests, in other cases leading to abundant weed growth. In summary, it seems reasonable to expect that widespread shifting cultivation in the

Neolithic would have left some definite evidence behind in archaeobotanical weed assemblages, namely an abundance of perennial weeds, including woodland perennials.

4 Taphonomic analysis of the archaeobotanical data

The aim of this project is to interpret the wild/weed composition of archaeobotanical samples from the study area as evidence of crop husbandry (1.1). Ecological analysis of archaeobotanical wild/weed data with a view to crop husbandry reconstruction, however, can only proceed once the taphonomy of the archaeobotanical material (i.e. its origin and the processes that affect its composition) has been assessed. Among the 316 weed-rich samples available from the study area (Table 2.6), those containing crop and weed material from the same arable source (i.e. the same crop harvest or field) would provide the most reliable evidence of neolithic and bronze age weed floras in the study area and hence of crop husbandry practices. The purpose of this chapter is to consider the influence of various taphonomic factors on sample composition (4.1-4.5) and to identify which samples potentially derive from an arable source before exploring variation in wild/weed composition among samples and its possible causes (4.6).

4.1 The impact of crop processing on crop and wild/weed composition

Two lines of evidence are used in this project to identify the processing stage(s) represented by archaeobotanical samples (see also 2.5.2-2.5.3). First, relatively 'pure' samples dominated by a single cereal type (i.e. glume wheat or free threshing-cereal) are evaluated on the basis of their grain, chaff (glume bases for glume wheat samples, rachis internodes for free-threshing cereal samples) and weed seed proportions in order to identify the crop processing stage(s) represented (4.1.1). Second, relatively 'pure' samples dominated by a single cereal type or by pulses are compared with ethnoarchaeological samples from different processing stages on the basis of the proportions of different weed physical types in each sample (4.1.2). The results of the two methods are combined in order that samples containing material from one predominant crop type and from the same processing stage (and hence potentially from the same crop harvest or field) can be identified (4.1.3).

4.1.1 Results for approach based on crop (and total weed seed) content

4.1.1.1 Classification of samples based on their crop type composition

The classification of samples based on their crop type composition is shown in Table 4.1a. Of the samples dominated by a single crop type (for definition of crop types see 2.5.2), the largest group is dominated by glume wheat material (167 total, ca. 53% of samples), followed by samples dominated by free-threshing cereal material (7 total, ca. 2% of samples) and one sample dominated by each of millet, flax or pulses (Table 4.1a). The remaining samples contain mixed or indeterminate crop types (<70% of any one type, or samples containing

≥70% indeterminate cereal grain), had not been properly quantified in the original archaeobotanical reports or contain less than 50 crop items and so cannot be assessed in terms of crop type. These mixed, ambiguous or crop-poor samples were excluded from all subsequent taphonomic and ecological analyses.

Some of the samples dominated by one crop type (70%-90% one crop type) also contain a significant proportion (10-30%) of 'contamination' by another crop type or type(s). Table 4.1b shows the numbers of samples in each crop type category that are 'uncontaminated' (i.e. contain >90% one crop type), 'possibly contaminated' (i.e. cereal samples containing 70-90% one cereal type plus 10-30% 'contamination', the latter composed mainly (≥70%) of indeterminate cereal grain) or 'definitely contaminated' (i.e. all remaining samples containing 70-90% one crop type plus 10-30% 'contamination') (see also 2.5.2.3). The 'definitely contaminated' samples, like the mixed or ambiguous samples noted above, were excluded from all subsequent taphonomic and ecological analyses.

4.1.1.2 Assessing crop processing stage for glume wheat and free-threshing cereal samples

For the 'uncontaminated' and 'possibly contaminated' glume wheat and free-threshing cereal samples, crop processing stage was assessed using triangular scatter plots of samples showing, for glume wheat samples, the relative amounts of glume wheat grains, glume bases and weed seeds and, for free-threshing cereal samples, the relative amounts of free-threshing cereal grains, rachis internodes and weed seeds (see also 2.5.2.3).

Fig. 4.1 shows glume wheat grain, glume base and weed seed proportions for the glume wheat samples. Dotted lines drawn across the triangle indicate boundaries (discussed in section 2.5.2.3) between samples dominated by glume bases, samples with a possible spikelet ratio of glume wheat grains:glume bases and samples dominated by glume wheat grains. Weed seed proportions have not been used to define these processing stage categories because the stage(s) in the processing sequence at which weeds were separated from the crop is unknown (e.g. before and/or after spikelet pounding – 2.5.1). If, for example, weeds were separated from spikelets before pounding, subsequent separation of grains from glume bases would result in weed-poor chaff by-products; if spikelets were not cleaned of weeds, however, chaff by-products could be very rich in weed seeds, depending on the weediness of the original crop fields.

The largest processing category among the glume wheat samples consists of those dominated by glume bases (125 out of 154 glume wheat samples in Fig. 4.1, ca. 81%). A further 16 samples (ca. 10%) are dominated by glume wheat grains and 13 samples (ca. 8%) contain a possible spikelet ratio of glume wheat grains:glume bases. The glume base samples could represent the by-products of fine sieving and/or winnowing following spikelet pounding (2.5.1). The glume wheat 'spikelet' samples represent either spikelets prior to pounding or mixtures of chaff-rich by-products and grain-rich products. The glume wheat grain samples should represent cleaned products separated from chaff after spikelet pounding. Glume bases tend to be underrepresented due to charring bias (Boardman and Jones 1990), however, and it is possible that both 'spikelet' and grain samples are particularly affected by this bias.

Fig. 4.2 shows free-threshing grain, rachis internode and weed seed proportions for the ethnoarchaeological samples from Amorgos (Fig. 4.2a) and for the archaeobotanical free-threshing cereal samples (Fig. 4.2b). In Fig. 4.2b, samples are coded according to the grain:rachis proportions discussed in section 2.5.2.3 for defining grain-rich, possibly unthreshed (i.e. spikelet ratio) and rachis-rich free-threshing cereal samples. The inclusion of weed seed proportions in Fig. 4.2b makes it possible to evaluate how well grain:rachis proportions in the archaeobotanical samples agree with the weed seed proportions present at different processing stages in the samples from Amorgos. In particular, fine sieve products and by-products, both of which are characterised by high grain:rachis ratios, can only be differentiated on the basis of weed seed proportions (Fig. 4.2a) (G. Jones 1990). Both of the grain-rich samples in Fig. 4.2b fall within the zone occupied by the Amorgos fine sieve products (Fig. 4.2a).

4.1.2 Results for approach based on weed seed types

The processing stage represented by each of the relatively 'pure' cereal samples (i.e. 'uncontaminated' or 'possibly contaminated' glume wheat and free-threshing cereal samples in Table 4.1b) was investigated further on the basis of their weed seed type (big headed heavy, small free light etc.) composition (see also 2.5.3). Discriminant analysis of the ethnoarchaeological samples from Amorgos was used to classify the archaeobotanical samples. The archaeobotanical samples were classified as one of four processing groups (winnowing by-product, coarse sieve by-product, fine sieve by-product, fine sieve product) using the discriminant functions extracted to distinguish the ethnoarchaeological samples in these groups (see also 2.8.2.1).

In Fig. 4.3 the ethnoarchaeological samples from Amorgos are plotted on the first two discriminant functions – i.e. those with the highest eigenvalues and therefore the greatest ability to separate groups (G. Jones 1984). The circles shown in Fig. 4.3 are centred on the centroids for each processing group and enclose ca. 90% of the samples in each group. The archaeobotanical samples are plotted on these same discriminant functions in Fig. 4.4, which also shows the circles enclosing 90% of each Amorgos group. Fig. 4.4 shows that virtually all of the archaeobotanical samples are most similar to the fine sieve by-product or the fine sieve product groups from Amorgos. The classification of each sample and the probability attached to each classification are based on the position of each sample relative to the group centroids (in three dimensions, on the first, second and third discriminant functions). Samples classified with high probability (defined arbitrarily as $\geq$0.90) tend to be located well within the circle enclosing the relevant processing group or, as is the case for many classified as fine sieve by-products, outside the circle but closest to the fine sieve by-product centroid. Samples classified with low probability (<0.90) are located in areas where the Amorgos groups overlap (e.g. between the fine sieve by-product and product groups).

Samples classified as fine sieve by-products with high probability but located outside the Amorgos circles are more 'extreme' in their weed seed type content than the Amorgos samples themselves. Other applications of this method to archaeobotanical data have sometimes shown similar results (e.g. 'extreme' fine sieve by-product samples from late bronze age Assiros Toumba, northern Greece – G. Jones 1987 and iron age Rock Castle, northern England – van der Veen 1992: 86). A possible explanation for this phenomenon is that different crop fields contain different proportions of weed seed types (big free heavy, small free heavy etc.) to start with and so the weed seed type composition of crop processing by-products and products will not be identical in different locations, despite consistent tendencies for certain weed seed types to characterise certain stages (G. Jones pers. comm.). It is interesting that the fine sieve by-products in Fig. 4.4 are often 'extreme' whereas the samples classified as products at a high probability all lie within the Amorgos circle; similar results have been obtained with archaeobotanical material from late bronze age Assiros Toumba, northern Greece (G. Jones 1987). One possible explanation for this is that, irrespective of the precise composition of the original field weed flora, only big free heavy weeds tend to remain with the fine sieve product. Alternatively, this phenomenon may indicate that early crop fields tended to have more weed taxa with small free heavy seeds (characterising fine sieve by-products) than the Amorgos fields but that the amount of taxa with big free heavy seeds (characterising fine sieve products) was similar.

The two archaeobotanical samples classified as winnowing by-products with high probability appear to be very close to the centroid for fine sieve by-products in Fig. 4.4. Winnowing by-products from Amorgos, however, are mainly distinguished from the other processing groups on the third discriminant function (G. Jones 1984). Fig. 4.5 shows the Amorgos samples and the two archaeobotanical samples classified as winnowing by-products plotted on the first and third discriminant functions. The two archaeobotanical samples are separated out positively, with the most extreme Amorgos winnowing by-products (Fig. 4.5).

4.1.3 Combining crop- and weed-based approaches

The results of the crop- and weed-based methods of identifying crop processing stage (above, 4.1.1-4.1.2) were combined in order to identify the processing stage of each sample as securely as possible. To achieve this, the triangular scatter plots of glume wheat and free-threshing cereal samples discussed above (Figs. 4.1, 4.2b) were compared with the classification of samples by the discriminant analysis based on weed seed types. Samples with 'compatible' outcomes from the two approaches are those most likely to contain crop and weed material from the same processing stage and hence potentially from the same arable source (crop harvest or field).

4.1.3.1 Comparing crop- and weed-based outcomes for glume wheat samples

As noted above (4.1.1.2), the classification of glume wheat samples based on their glume wheat grain:glume base ratios provides one way of distinguishing processing stages: glume base samples should represent chaff-rich by-products of winnowing and/or fine sieving (following spikelet pounding), 'spikelet' samples should represent intact spikelets (which may or may not have been cleaned of weed seeds) or mixtures of products and by-products, and grain-rich samples should represent the crop product after spikelet pounding and the removal of chaff. These crop-based classifications can be compared with the classification of samples by the discriminant analysis based on weed seed types. It is expected that glume base samples would be classified as winnowing or fine sieve by-products on the basis of weed seed types, and glume wheat grain samples as fine sieve products. The expected classification of 'spikelet' samples depends on whether or not the spikelets were fine sieved prior to dehusking. Sieved spikelets would be expected to resemble fine sieve products in their weed content, whereas unsieved spikelets would resemble a mixture of fine sieve by-product and product – i.e. be classified with low probability as fine sieve by-products or products by the discriminant analysis based on weed seed types. These expectations are illustrated in triangular scatter plots of glume wheat samples classified as fine sieve by-products or products with high or low probability (Figs. 4.6-4.7) by highlighting the 'expected zones' defined by the crop-based classification (i.e. 'glume zone', grain:glume base <0.30; 'spikelet zone', grain:glume base 0.3-1.5; 'grain zone', grain:glume base >1.5).

Fig. 4.6 shows glume wheat samples classified by the discriminant analysis based on weed seed types as fine sieve by-products with high (≥0.90, Fig. 4.6a) and low (<0.90, Fig. 4.6b) probability, plotted according to their glume wheat grain/glume base/weed seed proportions. Fig. 4.6 shows that the majority of glume wheat samples classified as fine sieve by-products falls in the 'glume zone' (grain:glume base ratios of <0.3) of the triangular plot (112 out of 127, ca. 88%). Comparing Figs. 4.6a and b, proportionately more samples classified with high probability as fine sieve by-products (96 out of 106, ca. 91%) occur in the 'glume zone' than samples classified with low probability (16 out of 21, ca. 76%). In other words, the samples classified with low probability as fine sieve by-products on the basis of weed seed types tend also to contain more grain. This may indicate a mixed content for these samples, though the three samples in the 'spikelet zone' (grain:glume base ratios of 0.3-1.5) classified with low probability as fine sieve by-products (Fig. 4.6b) may be 'legitimate' unsieved spikelets. Samples falling outside the 'expected zones' of the triangular plots in Fig. 4.6 (i.e. glume wheat grain and spikelet samples classified with high probability and the glume wheat grain samples classified with low probability) presumably represent varying mixtures of fine sieve by-product and product material.

Fig. 4.7 shows glume wheat samples classified by the discriminant analysis based on weed seed types as fine sieve products with high (≥0.90, Fig. 4.7a) and low (<0.90, Fig. 4.7b) probability, plotted according to their glume wheat grain/glume base/weed seed proportions. In contrast to the samples classified as fine sieve by-products (Fig. 4.6), only a minority (12 out of 25, ca. 48%) of the samples classified as fine sieve products fall in the 'expected zone'. Of these, samples in the 'spikelet zone' may represent mixtures of fine sieve by-product and product material or may be 'legitimate' spikelets, fined sieved (high probability) and unsieved (low probability). Samples falling outside the 'expected zone', all classified with high probability (Fig. 4.7a), are dominated by glume bases and could result from mixing of fine sieve by-product material (glume bases) with big free heavy weed seeds picked out of product material by hand ('hand cleanings' – Hillman 1981, 1984a; G. Jones 1984). Given that glume wheat dehusking may well have taken place on a piecemeal day-to-day basis (2.5.1), it is not implausible that the by-products of various dehusking and subsequent cleaning stages were sometimes combined incidentally or for use as fodder, fuel etc.

It should be noted that the two glume wheat samples classified as winnowing by-products with high probability by the discriminant analysis (above, Figs. 4.4-4.5) are not included in Figs. 4.6-4.7. These samples are dominated by glume wheat grains and so could represent mixtures of winnowing by-product and fine sieve product material.

4.1.3.2 Comparing crop- and weed-based outcomes for free-threshing cereal samples

Fig 4.8 shows the free-threshing cereal samples plotted according to their free-threshing cereal grain/free-threshing cereal rachis/weed seed proportions and coded to indicate the classification of each sample by the discriminant analysis based on weed seed types. The sample classified as a fine sieve product with high probability is dominated entirely by free-threshing cereal grains and so occurs at the apex of the triangle, like the Amorgos fine sieve products (Fig. 4.2a). The sample classified as a fine sieve by-product with high probability, however, is also dominated by grains and so contains much less weed than the Amorgos fine sieve by-products (Fig. 4.2a), occurring instead at the apex of the triangle. This sample (from Zemplinske Kopcany, southern Slovakia – see Table 2.5) is also unique in its archaeological context: it is a sample interpreted as 'crushed barley grain' found in a ceramic vessel along with some seeds of wild taxa, mostly *Chenopodium album* (Hajnalová 1989). The author of the report on this sample suggested that the *C. album* was collected as food (Hajnalová 1989). The low weed content of this sample, combined with its archaeological context, makes it very unlikely to be a fine sieve by-product, the misclassification by weed type resulting from the deliberate addition of small-seeded *C. album*.

Two further free-threshing cereal samples, not shown in Fig. 4.8, derive from an extensive burned destruction layer at late neolithic Hornstaad-Hörnle, southern Baden-Württemberg (Table 2.5). This layer was found to contain thousands of intact cereal ears interpreted by Maier (1991, 1996, 1999, unpublished) as unthreshed cereal material. Though full chaff data are not available for these samples, their status as unthreshed cereal material is reasonably certain. The classification of these samples with low probability – one as a fine sieve by-product and one as a fine sieve product – is consistent with their 'unprocessed' state.

4.1.4 Summary of crop processing analysis

The comparison of crop- and weed-based methods of identifying processing stage above (4.1.3) indicates that the majority of relatively 'pure' ('uncontaminated' or 'possibly contaminated') glume wheat samples (127 out of 154, ca. 82%) and free-threshing cereal samples (3 out of 4) contain 'compatible' crop and weed material indicative of a single processing stage. The final crop processing classification of samples containing 'compatible' crop and weed material is shown in Table 4.2. Only these samples are considered in further taphonomic and ecological analyses. For the remainder of this chapter, they are referred to as the 'potentially unmixed' glume wheat and free-threshing cereal samples.

The location of sites with 'potentially unmixed' samples suitable for further analysis is shown in Fig. 4.9. Regions with more than one site are the Lower Rhine-Meuse basin, the Neckar valley, southern Baden-Württemberg, north-central Switzerland and Lower Bavaria. All 130 samples suitable for further analysis are listed in Table 4.3, together with context and date information (references to archaeobotanical reports for all of these sites are shown in Table 2.5).

The largest processing category among 'potentially unmixed' cereal samples are the glume base samples classified as fine sieve by-products (96 out of 130, ca. 74% – Table 4.2). It is worth emphasising that there is archaeological evidence for glume wheat spikelets in apparent storage contexts from neolithic-bronze age sites in the study area (e.g. Hopf 1968), including one of the 'spikelet' samples in Table 4.2 (sample myt001 in Table 4.3), which contains 65 whole emmer spikelets as well as abundant 'free' emmer grain and chaff. Spikelet storage is consistent with the dehusking of spikelets on a piecemeal basis throughout the year (i.e. not only at harvest time) and hence of the frequent charring of cleaning residues from this process (i.e. the glume base samples) (see also 2.5.1).

4.2 The impact of harvesting method on wild/weed composition

4.2.1 Ear- versus sickle-harvesting

Ear-harvesting has often been cited as a likely harvesting method for the Neolithic in the study area, especially the Early Neolithic (LBK) (2.5.4). Sickle-harvesting (cutting on the straw), however, is securely attested at various neolithic sites in the Alpine Foreland (2.5.4). Different harvesting methods may introduce differences in the weed material harvested; for example, ear-harvested material should contain few weeds, with the possible exception of climbing species (Reynolds 1985, 1993), whereas sickle-harvesting tends to be less selective. It is possible, therefore, that differences in weed composition among archaeobotanical samples from different harvesting regimes (e.g. sickle-harvested crops rich in weed species versus ear-harvested crops with few weed species) could obscure similarities or differences in crop husbandry. As already noted in section 2.5.4, however, there is no theoretical reason why harvesting method should introduce an ecological bias in the weed composition of the harvest, unlike crop processing.

The strength of arguments in support of ear-harvesting in the study area – a general lack of culm nodes (as well as basal rachis internodes) and low-growing weeds in archaeobotanical samples – has already been questioned (2.5.4). An alternative method of distinguishing sickle- versus ear-harvesting is to consider the 'weediness' of archaeobotanical samples (that is, the amount of weed relative to that of crop) (2.5.4). G. Jones (1998) has suggested that the relative abundance of weed seeds associated with glume wheat material may be the only way to determine whether glume wheats at a late stage of processing (i.e. after the removal of any straw with basal rachis internodes) were harvested by ear-plucking rather than by sickle-harvesting (cf. Hillman 1981; Reynolds 1985, 1993; Sigaut 1988). Data relevant to the weed seed:glume base content of sickle-harvested emmer fine sieve by-products have been derived from the Amorgos crop processing study, as described in section 2.5.4. The data for the 'potentially unmixed' glume base samples may be compared with the data derived from the Amorgos samples in order to see whether some or all of the archaeobotanical samples could derive from sickle-harvested crops, or whether they tend to be lower in their weed content, as expected for ear-harvested glume wheats.

It should be noted that the assumptions made in the calculation of hypothetical weed seed:glume base ratios (2.5.4) are more likely to overestimate than underestimate the quantity of weed seeds relative to glume bases. This is because conservative estimates were made of the numbers of grains/glume bases expected in glume wheat ears relative to weed infestation.

Fig. 4.10a shows the 'weed seed:glume base' ratios derived from the Amorgos data for hypothetical emmer fine sieve by-products. These ratios offer a rough estimate of the 'weediness' expected in sickle-harvested emmer fine sieve by-products from fields with similar levels of weed infestation to those in the Amorgos study. Fig. 4.10b shows weed seed:glume base ratios for the 'potentially unmixed' glume base samples. It is evident that the Amorgos and archaeobotanical samples have a similar range of values, though the archaeobotanical samples tend to have even greater quantities of weed seeds. Fig. 4.10c shows the ratios for the archaeobotanical samples with *Chenopodium album* removed; this species may have been collected separately and so may 'inflate' the apparent weediness of some fine sieve by-products (below, 4.5.1). In comparison with Fig. 4.10b, the weed seed:glume base ratios in Fig. 4.10c tend to be lower and more comparable with the Amorgos data (Fig. 4.10a).

Whether calculated with or without *C. album*, however, the lowest weed seed:glume base ratios for the archaeobotanical samples are within the range for the Amorgos samples, and the highest ratios exceed the highest Amorgos ratio. It appears, therefore, that the archaeobotanical samples could, on the basis of their 'weediness', derive from sickle-harvested crops. If ear-harvesting produces crop harvests containing few weed seeds, as experimental evidence suggests (Reynolds 1985, 1993), it seems unlikely that ear-harvesting was responsible for the weed assemblages under consideration.

4.2.2 Harvesting height

Even if sickle-harvesting was the prevalent method used, there could still be variation in actual harvesting height, which would affect the range of weed species harvested, though probably with no ecological bias. The lowest maximum weed height represented in archaeobotanical samples can be used to estimate the maximum height at which crops were cut (2.5.4). Table 4.4 shows the lowest maximum plant heights of wild/weed taxa selected for functional attribute measurements in the 'potentially unmixed' cereal samples. 26% of samples (34 out of 130), including early neolithic (LBK) samples, contain taxa with maximum heights of less than 40 cm, suggesting a fairly low harvesting height in at least these cases. Fig. 4.11 shows the lowest maximum plant heights for samples divided into broad chronological categories. It appears that a lower proportion of early neolithic samples contain taxa with low maximum plant heights (<40 cm) than samples from later periods (Fig. 4.11), suggesting perhaps that a relatively low harvesting height was more common in the later periods. Estimates for later periods are problematic, however, since only 23 of the 'potentially unmixed' cereal samples date to the Middle Neolithic onwards. In any case, Table 4.4 and Fig. 4.11 suggest that harvesting height could well have been variable, and the interpretation of variation in wild/weed composition among samples should include consideration of the lowest maximum plant height for each sample (below, 4.6.3.2).

4.3 The impact of weed fruiting times on wild/weed composition

The date at which weed species set seed – relative to crop harvesting time – will clearly affect their representation in the archaeobotanical record: species setting seed well before or after harvest will be under-represented relative to those setting seed at a similar time to the crop (cf. Charles 1998). In western-central Europe, most weeds flower and set seed before or during the time of the cereal harvest in July-August but many flower and set seed several months earlier (e.g. April-May) and so may be generally under-represented. The timing of flowering and seed set is linked to a number of other plant ecological characteristics, including ecological behaviour of direct relevance to crop husbandry: crop-mimicking weeds of the Secalinetea (winter cereal weeds) tend to set seed at a similar time to winter cereals, whereas root-/row-crop and ruderal weeds of the Chenopodietea tend to show a broader range of fruiting times (2.5, 3.4). Thus, the ecological bias linked with weed fruiting time is potentially as severe as that associated with the impact of crop processing on weed composition.

On the other hand, unlike crop processing, the ecological bias associated with variable weed fruiting times is unlikely to cause spurious *differences* in 'ecological composition' *between* archaeobotanical weed assemblages. This is because both weed fruiting and crop harvesting time are conditioned by macroclimatic variables and, therefore, should remain relatively consistent across the study area of this project. The under-representation of weed species setting seed well before (or after) the crop harvest, therefore, should apply to all of the archaeobotanical samples under investigation.

4.4 Summary of the impact of crop processing, harvesting method and weed fruiting times on weed composition

For various reasons, it appears unlikely that harvesting method and weed fruiting times will cause differences in the weed composition of the 'potentially unmixed' cereal samples that could be misinterpreted as differences in crop growing conditions and hence crop husbandry practices. The effect of crop processing on the weed composition of the 'potentially unmixed' cereal samples selected for further ecological analysis, however, has been demonstrated (4.1). Crop processing, in turn, is likely to cause ecological differences in the weed composition of archaeobotanical samples from different processing stages (2.5); these ecological differences could potentially be misinterpreted as crop husbandry differences, especially with regard to crop sowing time (3.4). Clearly, therefore, it is essential to take crop processing into account in the exploration of variation in wild/weed composition (below, 4.6) and in the ecological interpretation of this variation (Chapters 5 and 6). It is also necessary to consider the possibility that potential weed taxa may be derived from non-arable as well as arable sources (4.5).

4.5 Sources of wild/weed taxa

Despite careful selection of the 'potentially unmixed' cereal samples (Table 4.2) as those most likely to provide reliable information on neolithic-bronze age weed floras in the study area, it is possible that they contain wild/weed material that was not actually harvested with the associated crop material. Two alternative sources of wild/weed material are considered below: the separate collection of wild/weed seeds as useful resources (4.5.1) and the derivation of charred plant material from animal dung burned as fuel (4.5.2). The general ecological characteristics of the archaeobotanical wild/weed taxa – and hence their plausibility as arable weeds – are discussed in section 4.5.3.

4.5.1 Collection of wild/weed taxa

Many of the wild/weed taxa selected for functional attribute measurements (Table 2.3) were potentially collected in neolithic-bronze age western-central Europe as food or fodder or for some other use (e.g. Jacomet *et al.* 1989: 193-212; Brombacher and Jacomet 1997; Lüning 2000: 90-92). Waterlogged caches of seeds (*Ansammlungen*) from the lakeshore settlements at Lake Zurich, for example, suggest that *Chenopodium album* was collected (Jacomet *et al.* 1989: 206; Brombacher and Jacomet 1997). In more mixed waterlogged samples from the Zurich sites, high densities of *Brassica rapa* may reflect the collection of this species (Jacomet *et al.* 1989: 206; Brombacher and Jacomet 1997). Both *Chenopodium album* and *Brassica rapa* have also been recovered in charred form in stores of charred cereals from the Zurich sites and so are also attested as arable weeds (Jacomet *et al.* 1989: Table 39; Brombacher and Jacomet 1997: Tables D 353-354). Gregg (1989) has noted that *Chenopodium album* seeds at LBK Ulm-Eggingen are significantly correlated with glume wheat chaff, suggesting that *C. album* was harvested with the crop. *C. album* is the single most common wild/weed species among the 'potentially unmixed' cereal samples, occurring in ca. 95% (124 of 130 samples).

Historical and ethnographic sources attest to the use of the seeds and (young) leaves of *C. album* as food, and archaeobotanists have long recognised its potential as a food plant (Helbaek 1960; Bakels 1978: 60; Willerding 1986: 100; Stokes and Rowley-Conwy 2002). Large numbers of charred *Chenopodium* seeds have been found in more or less pure caches across Europe (e.g. Helbaek 1960; Kroll 1990). Within the geographical and chronological boundaries of this project, two sorts of charred evidence for the collection of *C. album* have been emphasised in the archaeobotanical literature: 1. the occurrence of samples entirely dominated by *C. album* seeds ('caches'), containing little cereal material and few seeds of other wild taxa (e.g. Knörzer 1967b, 1988, 1997; Bakels 1979, 1983/4, 1991b; Lüning 2000: 92), and 2. the occurrence in some of these samples of a large proportion of 'unripe' *C. album* seeds (e.g. Knörzer 1967b, 1973; cf. Bakels 1991b). Knörzer (1967b, 1973) has argued that unripe seeds point to the collection of immature plants for their leaves, the seeds being discarded as waste. This second criterion cannot be applied here since the proportion of unripe seeds in samples is often unknown; in any case, the presence of unripe seeds is of doubtful usefulness since the abundant seeds produced by individual *Chenopodium* plants tend not to ripen simultaneously and could be harvested with crops in a range of ripe and unripe states.

If a *C. album* 'cache' is defined (arbitrarily) as a sample containing at least 70% *C. album* seeds (of all identifiable charred items combined), four such samples are included among the 'potentially unmixed' cereal samples (samples 7lau430, 8lan136, ulm153/1 and vaih63 in Table 4.3), all of which are glume base samples classified as fine sieve by-products with high probability. The fact that these samples contain more *C. album* seeds than glume bases may suggest that they are not genuine 'crop and weed' samples. Though *C. album* may represent a harvested weed in many of the 'potentially unmixed' cereal samples, the positive evidence for its collection in the study area means that the identification of husbandry practices on the basis of this species must be extremely cautious (Chapters 5 and 6).

As noted above, there is some waterlogged evidence from the Lake Zurich sites for the collection of *Brassica rapa*. It occurs (in charred form) in two of the 'potentially unmixed' cereal samples (samples hor1 and hor2 in Table 4.3), both from Hornstaad-Hörnle in the Alpine Foreland, but does not dominate either and is regarded here as a harvested weed. Mention should also be made of a further wild/weed taxon regarded by some archaeobotanists as an important wild food plant or even a crop in the study area – *Bromus arvensis/hordeaceus/secalinus* (e.g. Knörzer 1967a, b; Bakels and Rouselle 1985; Lüning 2000: 91). This taxon has big free heavy seeds (Table 2.9) and is prominent in some of the 'potentially unmixed' fine sieve products, though it never dominates the total charred material in any sample. There is no positive evidence to suggest that this taxon was collected or grown separately (Knörzer 1998) and so it is regarded here as a harvested weed (cf. Wasylikowa 1989).

4.5.2 Dung-derived material

If the 'potentially unmixed' cereal samples do represent harvested crop and weed material, they may have become charred as cleanings from glume wheat dehusking (2.5.1) or in accidental burning events (e.g. large-scale destruction of unthreshed crops at Hornstaad-Hörnle – Maier 1999). There is an alternative suggestion for the charring of plant material, however: its derivation from the burning of animal dung fuel (2.6). Criteria suggested by Charles (1998) for identifying dung-derived material in archaeobotanical samples, summarised in section 2.6.1, were applied to the 'potentially unmixed' cereal samples.

With regard to the first criterion – the occurrence of recognisable charred dung (e.g. sheep/goat pellets) on archaeological sites – no such material has been reported from any of the sites with charred plant remains in the study area. It should be noted, however, that cattle bones often dominate bone assemblages from the study area (e.g. Lüning 2000: 108-139) and cattle dung would survive less well and be harder to recognise in charred form than sheep/goat pellets (cf. Charles 1998).

The second criterion – mixing of crops and plant parts in archaeobotanical samples – relates to the selection of 'potentially unmixed' cereal samples, which are by definition dominated by a single cereal type (glume wheat or free-threshing cereal) and contain proportions of plant parts (glume wheat grains:glume bases; free-threshing cereal grains:rachis internodes) corresponding to individual processing stages. The 'potentially unmixed' cereal samples, therefore, appear relatively unmixed in terms of the crop types and plant parts (grains and chaff) they contain.

A third criterion for recognising dung-derived material, the biology and ecology of the wild taxa, is based on the idea that wild taxa fruiting *after* the cereal harvest could not have been harvested with the crop. Unfortunately, this criterion is not really applicable to the study area of this project since most weeds in temperate Europe sets seed before or during the time of the cereal harvest in July-August (above, 4.3). If, instead, life history and regular reproduction by seed are used to assess the likelihood of their occurrence as arable weeds, it could be argued that trees and large woody shrubs are unlikely to 'behave as annuals' in arable fields and reproduce by seed when small seedlings. For this reason, such taxa were excluded from consideration as 'potential weeds' in the selection of archaeobotanical material for this project (2.1.3). The seeds of shrub/tree taxa (e.g. *Rubus, Prunus* etc.) do occur in some of the 'potentially unmixed' cereal samples under consideration (29 out of 130, ca. 22%) but usually at very low levels. Only one 'potentially unmixed' cereal sample contains more than 5% 'tree/shrub seeds' of the total charred plant remains (sample cha2 in Table 4.3, which contains 14% 'tree/shrub seeds').

It is worth noting that the small free heavy seeds characteristic of fine sieve by-products, the largest group of 'potentially ummixed' samples (Table 4.2), would also tend (by virtue of their small size and robusticity) to survive digestion (Anderson and Ertug-Yaras 1998). In fact, two of the frequent 'small free heavy' weed taxa in the 'potentially unmixed' cereal samples (*Chenopodium album, Setaria viridis/verticillata*) are known to survive well in animal dung and are promoted incidentally by manuring (Willerding 1986: 100-101; Gregg 1988: 81). Their presence in samples, therefore, could equally reflect intensive manuring of crop fields or the burning of dung.

The criteria presented by Charles (1998) were devised to identify the presence of dung-derived material and none have produced 'positive results' in favour of dung in the 'potentially unmixed' cereal samples. On the other hand, it is very difficult in general to devise criteria for excluding dung as a source of charred plant remains. The variable botanical composition of waterlogged dung from the lakeshore sites in the Alpine Foreland (2.6.2), however, contrasts with the repeated occurrence of samples dominated by charred glume bases and with the rather restricted range of wild taxa found repeatedly in association with crop material in the study area. The restricted nature of LBK 'weed flora', in particular, is well attested (e.g. Knörzer 1971b; Bakels 1999; Rösch 1998c, 2000). It seems unlikely, therefore, that the 'potentially unmixed' glume base samples are composed of the dung of livestock fed a monotonous diet of glume wheat chaff and/or specific wild/weed taxa. The remaining 'potentially unmixed' cereal samples appear to represent various sorts of product (unthreshed, glume wheat spikelets, grains) (Table 4.2). There is no *a priori* reason why at least some of these samples could not represent dung, though the high density and context of some of these samples (e.g. from major burned destruction layers) indicates that they represent accidentally charred stores.

4.5.3 The selected wild/weed as arable weeds

Of the 66 taxa included in the collection of functional attribute measurements and occurring in 'potentially unmixed' cereal samples, the majority grow predominantly in disturbed habitats (e.g. arable, ruderal, pioneer/mudbank habitats) according to the general habitat groupings used by Ellenberg *et al.* (1992) (Table 4.5). The second largest group of taxa consists of those occurring predominantly in grassland, though many of these can also occur in arable or ruderal habitats according to Oberdorfer (1994).

Phleum pratense is by far the most common perennial species, occurring in 62 out of 130 'potentially unmixed' cereal samples (ca. 48%). Its present-day occurrence is predominantly in grassland (Table 4.5), being grown extensively for grazing and hay production (Hubbard 1984: 319-321; Grime *et al.* 1988: 252-253) but it is also found in ruderal and arable habitats (Hegi 1935: 292; van Elsen 1994; Oberdorfer 1994: 256; Ellenberg 1996: 874). Seeds of *Phleum pratense* have been found in charred cereal stores dating from the Neolithic to the Medieval period (e.g. Jacomet *et al.* 1989: Table 39; Karg 1995; Kooistra 1996: Table 46; Brombacher and Jacomet 1997: Tables D 353-354; Stika 1999). According to Körber-Grohne (1990, 1993), *Phleum pratense* lacks a primary ('natural') habitat in western-central Europe and was brought to the area as an arable weed in the Early Neolithic (LBK). Tutin *et al.*

(1964-1993) recognise two subspecies (subsp. *pratense* and subsp. *bertolonii* – see Table 2.4), which are quite similar ecologically, though subsp. *pratense* is taller than subsp. *bertolonii* and is associated with somewhat more fertile and moist habitats (Grime *et al.* 1988: 252-253). These two subspecies cannot be distinguished in charred archaeobotanical material (2.2.1). Overall, there is no reason to assume that *Phleum pratense* represents animal dung or collected fodder rather than arable weed material.

4.5.4 Summary

Consideration of Charles' (1998) criteria, the evidence of waterlogged dung from the Alpine Foreland and the ecology of the selected wild/weed taxa has failed to produce any convincing evidence that the archaeobotanical material under investigation was derived from the burning of dung fuel. Notwithstanding the problems surrounding the interpretation of *Chenopodium album* as a separately collected resource (above, 4.5.1), therefore, the cautious interpretation of the wild/weed taxa as evidence – albeit fragmentary – of ancient arable weed floras appears justified.

4.6 Exploring variation in wild/weed composition among samples

The aim of correspondence analysis in application to the archaeobotanical sample data is to explore variation in wild/weed seed composition (2.8.1) and, using functional attribute data (Chapter 6), to assess how far these differences may be interpreted as variability in crop growing conditions and hence crop husbandry practices. By comparing samples containing crop material of the same type and processing stage, variation in crop husbandry can potentially be isolated from other possible causes of variation such as crop processing and the mixing of different processing stages. Since a large number of samples are available in this project, it is unnecessary to rely on samples that are likely to be affected by mixing of crop types and/or crop processing stages. Only the 'potentially unmixed' cereal samples (Table 4.2), therefore, were considered for inclusion in correspondence analyses.

4.6.1 Selection of samples for correspondence analysis

The largest group of 'potentially unmixed' cereal samples in this project are the glume base samples classified as fine sieve by-products (with high or low probability) by the discriminant analysis based on weed seed types (Table 4.2). Within this group, two 'levels' of contamination have been distinguished (Table 4.2): samples that are relatively 'uncontaminated' by other crop types (88 total) and 'possibly contaminated' samples (i.e. 'contaminated' mainly by indeterminate cereal grains – 24 total). The 'potentially unmixed' glume base samples, therefore, represent a large (112 total), relatively homogeneous group of samples appropriate for correspondence analysis to identify crop husbandry practices (below, 4.6.3-4.6.4).

While crop processing systematically alters weed content based on the physical characteristics of weed seeds, it may also introduce biases in the ecology of weed species characterising different processing stages, particularly in relation to the inference of crop sowing time (3.4). The 'potentially unmixed' glume wheat spikelet samples (8 total) and glume wheat grain samples (7 total) (Table 4.2), therefore, were included in a correspondence analysis with the glume wheat glume base samples in order to explore differences in wild/weed composition caused by crop processing (below, 4.6.2).

All but three of the 'potentially unmixed' cereal samples (Table 4.2) are dominated by glume wheat. It is not possible, therefore, to conduct a separate correspondence analysis exploring wild/weed variation among free-threshing cereal samples.

4.6.2 Exploring variation among glume wheat samples from different processing stages

A correspondence analysis was carried out on all 'potentially unmixed' glume wheat samples (127 samples) and all wild/weed taxa occurring in at least three of these samples (35 taxa). One 'potentially unmixed' glume wheat sample (sample cha2 – Table 4.3) was omitted because it contains <25 seeds of the wild/weed taxa included. In the initial analysis (plot not shown), two samples (bru283 and myt001 – Table 4.3) emerged as extreme outliers and so were removed in order to explore variation in the remainder, i.e. the analysis was repeated using the remaining data (124 samples/32 taxa) (Figs. 4.12-4.13).

In Fig. 4.12, samples are coded by crop processing category (combining the crop-based classification with the results of the discriminant analysis based on weed seed types as in Table 4.2). Axis 1 (horizontal) evidently reflects variation in wild/weed content due to processing: 'uncontaminated' grain samples classified as fine sieve products with high probability occur towards the positive (right) end of axis 1, whereas 'uncontaminated' glume base samples classified as fine sieve by-products with high probability occur towards the negative (left) end. 'Spikelet' samples are located towards the positive end of axis 1, with the grain-dominated fine sieve products, or occur (with the one grain sample classified with low probability) in this 'intermediate' area. Glume base samples classified as fine sieve by-products with low probability also tend to occur in the 'intermediate' area between high probability/'uncontaminated' grain products and glume base by-products. Glume base samples classified as fine sieve by-products with high probability but with 'possible contamination' either occur towards the negative end of axis 1 (with high probability/'uncontaminated' by-products) or in the 'intermediate' area. Not surprisingly, the samples classified as fine sieve by-products with low probability tend to be more 'intermediate' than high probability fine sieve by-products with 'possible contamination': both the discriminant analysis based on weed seed types and correspondence analysis relate directly to wild/weed composition, whereas 'contamination' is based on crop content. Those glume base samples that are both classified with low probability and possibly contaminated tend to be closest to the fine sieve products at the positive end of axis 1.

Crop processing appears to influence axis 2 as well, since fine sieve products are located at the extreme negative (bottom) end. The majority of variation along this axis, however, relates to differences among glume base samples classified as fine sieve by-products, and thus not to crop processing stage *per se*. There is also no clear trend in fine sieve by-product probability (high versus low) or contamination, though samples classified with low probability are lacking from the extreme positive (top) end of axis 2.

Fig. 4.13 shows the plot of taxa contributing to these trends and, in Fig. 4.14, samples are represented by pie-charts indicating the proportions of weed seed types (big free heavy, small free light etc.) in each sample. Here again, variation along axis 1 appears to be strongly linked to processing, with the highest proportions of big free heavy seeds towards the positive (right) end of axis 1 and the highest proportions of small free heavy seeds towards the negative (left) end of the same axis.

In Fig. 4.13, *Chenopodium album* is located at the extreme negative (left) end of axis 1, where the glume base samples are located and, in Fig. 4.15, samples are represented by circles showing the proportion of *C. album* seeds in each sample. Fig. 4.15 indicates that the cluster of samples at the extreme negative (left) end of axis 1 are dominated by this species. *C. album* content decreases towards the positive (right) end of axis 1. Samples located towards the positive (top) end of axis 2, although low in *C. album* content, are rich in the seeds of other small-seeded taxa (Fig. 4.14) such as *Phleum pratense* (Fig. 4.13). Fig. 4.16 shows that this species increases towards the positive (top) end of axis 2 and dominates a few samples at this end. *Bromus arvensis/hordeaceus/secalinus* is situated towards the positive end of axis 1 and negative end of axis 2 (bottom right) and this taxon, which is large-seeded, is seen to clearly dominate the fine sieve products in this area of the plot (Fig. 4.17).

4.6.3 Exploring variation among glume wheat samples from the same processing stage

Correspondence analysis of glume wheat samples from the same processing stage was used first to identify any residual variation in wild/weed composition related to crop processing (i.e. low-level contamination by other processing stages, variation due to the thoroughness of processing etc.) within the group (below, 4.6.3.1). Processing-related variation needs to be identified in order that variation due to other factors – such as differences in crop husbandry practices – can be distinguished. Other variables, therefore, were explored (below, 4.6.3.2) after a consideration of processing-related variation. A correspondence analysis was carried out on all of the 'potentially unmixed' glume base samples (110 total) used in the previous analysis and all wild/weed taxa occurring in at least three of these samples (30 taxa) (Figs. 4.18-4.19).

4.6.3.1 Variables related to crop processing

Fig. 4.18 shows a plot of samples coded by crop processing category. 'Uncontaminated' glume base samples classified as fine sieve by-products with high probability are concentrated in a dense cluster at the negative (left) end of axis 1 spreading towards the positive (top) end of axis 2. The remaining (more ambiguously classified) samples are (with one exception at the positive end of both axes, top right) dispersed among these or located towards the negative (bottom) end of axis 2 (and positive – right – end of axis 1). This suggests that these samples share some common characteristics in their wild/weed composition that may relate to their slightly uncertain status. In the correspondence analysis of glume wheat samples from different processing stages (Fig. 4.12), some of these samples tended to be intermediate between the unambiguously classified fine sieve products and by-products. It is possible, therefore, that glume base samples with 'possible contamination' and/or classified as by-products with low probability tend to be contaminated with product-type weeds (i.e. weed taxa with big free heavy seeds), either with products themselves or with weeds removed from products by hand sorting (see also above, 4.1.3.1).

The plot of taxa (Fig. 4.19) indicates that *Chenopodium album* dominates the negative (left) end of axis 1, and in Fig. 4.20 the high proportion of *C. album* seeds in the dense cluster of samples at this end of the axis is apparent (as in the analysis including processing products – Figs. 4.13, 4.15). *Bromus arvensis/hordeaceus/secalinus*, the big-seeded taxon characterising fine sieve products in the analysis including products (Figs. 4.13, 4.17), is located more neutrally in the plot of taxa for this analysis (Fig. 4.19). The highest proportions occur in samples slightly towards the negative (bottom) end of axis 2 (Fig. 4.21) but, while the proportions of this taxon are high (>50%) in some of the ambiguously classified samples in this location (shown as filled circles), it is much lower in others, including those nearer the negative end of the axis. Thus, *Bromus arvensis/hordeaceus/secalinus*, which may be an indicator of contamination by fine sieve product material, does not explain the overall tendency of ambiguously classified samples to occur towards the negative end of axis 2.

Another way of looking at possible product contamination is shown in Fig. 4.22, where samples are represented by pie-charts indicating the proportion of different weed physical types in each sample. The dense cluster of samples dominated by *Chenopodium album* (as seen in Fig. 4.20) is naturally dominated by small free heavy seeds since *C. album* is of this type; other samples located towards the positive (right) end of axis 1 mostly contain higher proportions of other seed types, especially the big free heavy type. On axis 2, however, no trend in the relative proportions of taxa with small free heavy and big free heavy seeds is evident. This confirms the suggestion (based on *Bromus arvensis/hordeaceus/secalinus* alone) (Figs. 4.19, 4.21) that the tendency of ambiguously classified samples to occur towards the negative (bottom) end of axis 2 is not due to contamination by taxa with big free heavy seeds. Indeed, Fig. 4.19 shows that a variety of taxa (*Silene vulgaris, Galeopsis segetum/ladanum/angustifolia, Setaria pumila*, *Sonchus asper* etc.) are located at the negative end of axis 2, only one of which (*Galeopsis segetum/ladanum/angustifolia*) has big free heavy seeds.

An important cause of patterning along axis 2 appears to be *Phleum pratense* which, in the plot of taxa, is located towards the positive (top) end of the axis (Fig. 4.19) where samples are characterised by a relatively high proportion of this species (Fig. 4.23), especially two samples at the extreme positive end in which it predominates. Thus, whereas axis 1 reflects decreasing *Chenopodium album* content from left to right, axis 2 is heavily influenced by decreasing *Phleum pratense* content from top to bottom.

It is worth noting, however, that the two samples rich in *Phleum pratense* at the extreme positive (top) end of axis 2 are not the sole cause of patterning along this axis. If these two samples are removed from the analysis (Fig. 4.24), *Phleum pratense* becomes more neutrally located but the arrangement of other taxa along axis 2 remains similar (though the axis is reversed – negative to positive): *Valerianella dentata* replaces *Phleum pratense* as the most influential species at one end of the axis, while the taxa at the other end remain essentially the same as in the analysis with the two *Phleum*-rich samples included (Fig. 4.19).

4.6.3.2 Other variables

Given that variation in wild/weed composition among glume base by-product samples cannot be explained by contamination from other crop processing stages, other factors need to be considered as possible causes. Fig. 4.25 shows samples coded according to the lowest maximum wild/weed plant height per sample, an estimate of maximum harvesting height (above, 4.2.2). No clear trend is evident along either axis. Fig. 4.26, with samples coded by number of identifiable charred items per litre, also shows no obvious patterning on either axis, suggesting that differences in depositional history do not explain major trends in the data. Fig. 4.27 shows samples coded by archaeological site. Site clustering is evident on both axes, but particularly on axis 2 (Fig. 4.27a): samples from Vaihingen entirely dominate the positive (top) end and Hochdorf samples are located towards the negative (bottom) end. Between these two extremes, some smaller site clusters (Hilzingen, Meindling, Ulm-Eggingen) are evident (Fig. 4.27b). Other sites (e.g. Langweiler 8, Laurenzberg 7) occur only in the dense cluster of samples at the negative (left) end of axis 1 (Fig. 4.27b), particularly towards the lower end of the cluster away from the Vaihingen samples.

The site clustering along axis 2 (Fig. 4.27) is clearer than the patterning of ambiguously and unambiguously classified samples along this axis (Fig. 4.18), which suggests that the patterning of these crop processing 'categories' may be an artefact of site patterning rather than the reverse. This accords well with the earlier observation that the tendency of ambiguously classified samples to occur towards the negative (bottom) end of axis 2 cannot be explained merely by contamination from crop processing products.

In a plot of axis 1 (horizontal) and axis 3 (vertical) (Fig. 4.28),[11] clearer site patterning is evident along axis 3 for some of the smaller site clusters seen in Fig. 4.27: samples from two sites (Hilzingen, Ulm-Eggingen) are located towards the negative (bottom) end of the axis.

Given that samples from different sites tend to have distinct wild/weed composition, a further possibility is that this site clustering relates to regional or chronological differences. In Fig. 4.29, with samples coded by region, samples from sites in the Lower Rhine-Meuse basin are located towards the negative (left) end of axis 1 while samples sites in Lower Bavaria are slightly towards the positive (right) end. Samples from the Neckar valley are distributed along both axes. Thus, regional patterning in Fig. 4.29 relates mainly to axis 1, and hence above all

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[11] In this plot an outlier emerges towards the positive (top) end of axis 3. In the plots of axes 1 and 3 shown in this chapter, therefore, only the main cluster of samples separated off from this outlier is shown (expanded), in order to explore variation within the main group.

to *Chenopodium album* content (see above, Figs. 4.19, 4.20). A plot of axis 1 and axis 3 (Fig. 4.30) shows additional patterning in relation to axis 3: samples from southern Baden-Württemberg are located towards the negative (bottom) end. These patterns cannot be explained by variation in general soil type (Figs. 4.31-4.32) as all but two of the sites (Hilzingen in southern Baden-Württemberg, Straubing in Lower Bavaria) are situated on or very near (ca. ≤0.5 km) loess soils. Moreover, the sample from Straubing (near the origin in Fig. 4.32) does not cluster with the samples from Hilzingen (towards the negative end of axis 3 in Fig. 4.32).

Fig. 4.33, coded by archaeological period, also shows some patterning along axis 2. This is due to the fact that the Hochdorf samples are later neolithic in date, whereas Vaihingen is an early neolithic (LBK) site. The three middle-later neolithic samples from other sites also tend, like Hochdorf, to be located towards the negative (bottom) end of axis 2 though the single bronze age sample is located in the overlap region between the LBK and later neolithic sites. This suggests that there may be some chronological component to axis 2 but it is difficult to say whether axis 2 is influenced more by chronological differences than by site origin *per se*.

4.6.4 Exploring variation among samples from the same processing stage without *Chenopodium album*

Chenopodium album is unique among the wild/weed taxa included in the previous correspondence analyses in that it is attested as a separately collected resource in the study area (above, 4.5.1). Thus, its status as an arable weed harvested with crop material, particularly in samples dominated by it, is in some doubt. A further correspondence analysis of fine sieve by-products, therefore, was carried out with this species removed. The aim was to determine whether *C. album* is an important component of patterns noted in the previous section (e.g. crop processing category, archaeological site etc.).

A correspondence analysis was carried out on 'potentially unmixed' glume base samples used in previous analyses and all wild/weed taxa except *C. album* (29 taxa) occurring in at least three samples; all samples containing at least 25 seeds of these taxa were included (67 samples) (Figs. 4.34-4.35). Comparison of Fig. 4.35 with the plot of taxa from the previous analysis (Fig. 4.19) shows that the trend previously along axis 2 has shifted to axis 1 in the new plot: thus, *Phleum pratense* and *Valerianella dentata* occurs at the positive (right) end of axis 1, with *Silene vulgaris, Galeopsis segetum/ladanum/angustifolia, Setaria pumila* etc. at the negative (left) end of the same axis. Axis 2 is determined by a large number of taxa at both ends.

4.6.4.1 Variables related to crop processing

Fig. 4.34, with samples coded by crop processing category, shows that differences between ambiguously and unambiguously classified samples persist: unambiguously classified samples tend to be located towards to the positive (right) end of axis 1, the ambiguously classified samples towards the negative (left) end.

4.6.4.2 Other variables

Variables other than crop processing category that exhibited patterning in the previous analysis (archaeological site, region, chronological period) were also applied to the analysis without *Chenopodium album*.

In Fig. 4.36, with samples coded by archaeological site, the strongest site distinction in the previous correspondence analysis (Fig. 4.27), between Vaihingen and Hochdorf, is still evident. Hochdorf samples are located towards the negative (left) end and Vaihingen samples towards the positive (right) end of axis 1; two other sites (Hilzingen, Ulm-Eggingen) are located towards the positive (top) end of axis 2 (Fig. 4.36), a separation seen most clearly along axis 3 in the previous analysis (Fig. 4.28). So, although the removal of *C. album* removes the first axis of variation, the site patterning evident in Fig. 4.36 indicates that the differences between sites are determined also by other taxa. As in the previous correspondence analysis (Figs. 4.18, 4.27), site clustering in Fig. 4.36 is much clearer than the patterning of crop processing categories in Fig. 4.34.

The pattern in Fig. 4.37, with samples coded by region, shows that the Lower Rhine-Meuse samples, previously associated with high *C. album* content (Fig. 4.29), are now located towards the negative ends of both axes (bottom left) with a host of other taxa (Fig. 4.35). Other region-specific clusters (southern Baden-Württemberg, Lower Bavaria) are relatively neutral on axis 1 but are located (to different degrees) towards the positive (top) end of axis 2. These trends relating to axis 2 in Fig. 4.37 were evident along axis 3 in the previous analysis (Fig. 4.30).

The chronological pattern seen in the previous analysis (Fig. 4.33) is a little less clear with *C. album* removed: Fig. 4.38 shows that some degree of separation between early neolithic (LBK, mostly Vaihingen) and later neolithic (mostly Hochdorf) samples persists, with later neolithic samples towards the negative ends of both axes (bottom left). The removal of *C. album* has brought some LBK samples closer to the later neolithic samples, suggesting perhaps that *C.*

album was less important after the LBK, whether as an arable weed or as a separately collected plant.

4.6.5 Summary of variation among glume wheat samples

In the correspondence analysis combining 'potentially unmixed' glume wheat samples from different processing stages, there is a clear separation of fine sieve products and by-products (Fig. 4.12). While the fine sieve products are all characterised by high proportions of *Bromus arvensis/hordeaceus/secalinus* (Fig. 4.17), there is considerable variation in wild/weed composition among by-products; in particular, there is a clear inverse relationship between the proportions of *Chenopodium album*, which dominates many samples (Fig. 4.15), and *Phleum pratense*, which dominates only a few samples but occurs at lower levels in a larger number (Fig. 4.16).

In the two correspondence analyses of glume wheat fine sieve by-products (with and without *Chenopodium album*), contamination from product material (especially *Bromus arvensis/hordeaceus/secalinus*) in ambiguously classified samples (Figs. 4.18, 4.34) appears to be of little importance compared to archaeological site (Figs. 4.27, 4.36) as a determinant of wild/weed composition. Furthermore, there is some clustering of sites according to region (Figs. 4.29, 4.37) and possibly chronological period (Figs. 4.33, 4.38). This suggests that site clustering on the basis of wild/weed taxa is not simply an artefact of site-specific taphonomic conditions (crop processing/contamination level, preservation, recovery, archaeobotanical methods etc.). Clustering of sites and regions does not appear to be a reflection of different soil type. Site, region and/or chronological patterning, therefore, may reflect differences in crop husbandry practices. It is particularly striking that, while most sites conform to a regional pattern, the two most strongly separated sites – Vaihingen and Hochdorf – are located only ca. 10 km apart but differ in date (early neolithic/LBK and later neolithic/Schussenried culture, respectively).

5 Comparison of the archaeobotanical data with modern weed data from different crop husbandry regimes

The aim of this chapter is to compare the wild/weed composition of the 'potentially unmixed' cereal samples identified in section 4.1.4, hereafter referred to simply as the 'archaeobotanical samples', with modern weed data from a range of crop husbandry regimes: shifting cultivation, autumn versus spring sowing and intensive versus extensive cultivation. The functional attributes and other weed ecological characteristics useful in distinguishing the present-day husbandry regimes (3.1-3.3, 3.5) were used to construct 'relational analogies' (Hodder 1982: 11-27; Wylie 1985; cf. Binford 1981: 25-30 – analogies, or comparisons, incorporating causal mechanisms) between the modern and archaeobotanical datasets (1.2.3.3). In this way, the ancient husbandry regimes from which the archaeobotanical samples derive can be described in terms of their similarity to extant traditional husbandry regimes.

5.1 Comparison of the archaeobotanical data with modern weed data from shifting cultivation (the Hambach Forest experiment)[12]

Weed ecological characteristics relevant to the recognition of shifting cultivation were discussed in section 3.5. Analysis of the Hambach data showed that weed floras in the recently cleared experimental plots were dominated by perennial species (in terms both of species numbers and relative presence). Furthermore, the initial years after clearance were particularly characterised by perennials of woodland and/or heavily shaded habitats; in later years, these perennials decreased in favour of perennials of disturbed and/or unshaded habitats. As discussed in section 2.7.1, the following analysis of the archaeobotanical data includes all 'potential weed' species in the samples (not only those taxa selected for functional attribute measurements).

Fig. 5.1 summarises the proportions of perennials in the archaeobotanical samples based on seed counts (Figs. 5.1a-b). These proportions are shown with and without *Chenopodium album* – an annual species that may not always be present as an arable weed (4.5.1). Both versions produce very similar results: most samples contain only annual taxa or are dominated by annual taxa. A very small proportion of samples (3% including *C. album*, 8% excluding *C. album*) contain at least 50% perennial taxa. Fig. 5.1 also shows the proportions of perennials, based on taxon counts, present in samples containing at least 10 taxa in total (Figs. 5.1c-d).

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[12] A version of this work has recently been published (Bogaard 2002), though in application to a somewhat different archaeobotanical dataset (i.e. all published weed-rich samples from the loess belt plus Vaihingen – Bogaard unpublished).

Whether calculated with or without *C. album*, none of these samples contains 50% or more perennial taxa. In contrast to the proportions of perennials based on taxon counts in the Hambach experimental plots (57%-100% of weed species present), therefore, the archaeobotanical samples are much richer in annual taxa.

As discussed in section 3.5, there may be a tendency for perennial weeds to be under-represented archaeobotanically, especially in the first cultivation year after clearance, since seed set may be delayed in some species. Even if a minority of perennial taxa in a sample were accepted as compatible with shifting cultivation, however, woodland and shade-tolerant perennials are very rare in the archaeobotanical samples. Only three woodland perennial species – defined by Ellenberg habitat category and/or as phytosociological character species of Querco-Fagatea by Oberdorfer (1994) – occur in only two samples (ca. 2% of samples) (Table 5.1). Two of these species (*Circaea lutitiana, Stachys sylvatica*) are also shade-tolerant. The extreme rarity of woodland and shade-tolerant perennials *per se* is unlikely to be due to slow perennial seed set since there should be no particular bias against seed set in these perennials as opposed to perennials from other habitats. Furthermore, Table 5.1 shows that only one sample (bed28) contains more than one woodland perennial species. The two samples in Table 5.1 are also unlike the Hambach plots in that neither contains 50% or more perennials (whether based on seed or taxon counts).

Woodland annuals are of more ambiguous status in relation to shifting cultivation since very few annuals of this type occurred in the Hambach experiment (3.5.2.3). Woodland annuals are also rare in the archaeobotanical samples: one woodland annual species (*Moehringia trinervia*, classified as a woodland species by Ellenberg *et al.* 1992) occurs in one sample also containing one woodland perennial species (Table 5.1). As noted in section 3.5.3, woodland annual species in general are few, though this cannot account for the rarity of their *seeds* in archaeobotanical samples. Furthermore, because of their annual life cycle, slow seed set cannot explain their rarity in the archaeobotanical samples.

Seeds of shade-tolerant annuals, on the other hand, are quite common in the archaeobotanical samples: in addition to *Moehringia trinervia, Lapsana communis* also has a low Ellenberg light index value and occurs in 55 samples. As noted in section 3.5.2.4, shade-tolerant annual species listed in Ellenberg *et al.* (1992) include character species of arable weed communities (e.g. *Buglossoides arvensis*, of the Secalinetea, and *Veronica polita*, of the Chenopodietea). Such species cannot be regarded as remnants of a woodland flora and are, therefore, poor indicators of freshly cleared woodland soil. *Lapsana communis*, which occurs frequently in neolithic samples from the study area (e.g. Knörzer 1971b; Bakels 1978), is a character species of ruderal (Artemisietea) rather than arable communities (Ellenberg *et al.* 1992; Oberdorfer 1994). It does commonly occur, however, in modern crop fields, including unshaded ones (Knörzer 1988; Willmans 1988; Oberdorfer 1994: 975; Brombacher and Jacomet 1997; Lüning 2000: 185-186; pers. obs.), as well as in hedges and along the edges of woodland (Oberdorfer 1994: 975). Furthermore, in the vast majority of cases (53 out of 55 samples), *Lapsana communis* does not co-occur with other shade-tolerant species (i.e. *Moehringia trinervia, Circaea lutitiana, Stachys sylvatica* – all of which are also woodland species). It has previously been suggested (Beranova 1987; cf. Whittle 1997) that *Lapsana communis* indicates shifting cultivation (1.4.1.1). The arguments presented above, however, suggest that *Lapsana communis* cannot be regarded as an indicator of shifting cultivation.

The dominance of annuals and rarity of woodland taxa and shade-tolerant perennials among the archaeobotanical samples strongly suggests that they do not derive from newly cleared fields as managed in a shifting cultivation regime, and that fallow periods, if in use, were not long enough for woodland vegetation to re-establish itself. Even the few samples containing woodland taxa are not very convincing as evidence of shifting cultivation and could, in any case, reflect early phases in the establishment of 'new' permanent fields.

It is interesting that one of the two samples containing woodland taxa (Table 5.1) derives from charred crop stores at the lakeshore site of Hornstaad-Hörnle (established ca. 3915 B.C.), the earliest settlement known on Lake Constance (Dieckmann *et al.* 1997). A second sample from this site was also included in ecological analyses but lacks woodland taxa. Crop husbandry at Hornstaad-Hörnle has been the subject of controversy: Maier (1999) has interpreted the charred weed assemblage as evidence of fixed-plot cultivation, while Rösch (1990e, 2000) has inferred shifting cultivation primarily on the basis of pollen and microscopic charcoal evidence from the region (1.4.1.2, 1.4.4.2). The fact that one sample from Hornstaad does include woodland species may reflect the relatively short occupation of the settlement (ca. 10 years) preceding the fire that preserved the crop stores (Maier 1999) rather than shifting cultivation *per se*.

5.2 Comparison of the archaeobotanical data with modern weed data from different sowing regimes and cultivation intensity levels

As discussed in section 3.2, discriminant analysis represents one method of comparing archaeobotanical wild/weed data directly with modern weed data. The method devised by G. Jones (1983, 1984, 1987) for identifying crop processing stage based on physical weed seed types illustrates this approach: the discriminant functions extracted to distinguish the modern processing groups on the basis of their weed type composition can be used to classify archaeobotanical samples according to the modern groups (4.1.2). Similarly, discriminant functions extracted to distinguish modern cultivation plots/weed associations from contrasting husbandry regimes (i.e. autumn versus spring sowing in the Germany study; intensive versus extensive cultivation in the Evvia study) on the basis of weed functional attributes can be used to classify cases of 'unknown' husbandry regime, such as archaeobotanical samples. Very different forms of quantification, however, were used for the modern weed ecological studies (quadrat counts, cover abundance scores) and archaeobotanical weed data (weed seed counts); discriminant functions extracted to distinguish the modern husbandry groups, therefore, are not directly applicable to archaeobotanical sample data based on weed seed counts. If both the modern and the archaeobotanical weed data are used in semi-quantitative form (counts of weed taxa), their comparability is greatly enhanced (3.2). Application of both semi-quantitative and quantitative discriminant analyses to a modern test case, the spelt plots in Asturias, demonstrated their overall success as methods for identifying sowing regime and cultivation intensity (Charles *et al.* 2002) (3.3).

The aim of this section is to apply both semi-quantitative and quantitative approaches to the archaeobotanical samples as a means of identifying the sowing regime and cultivation intensity of the cereal plots from which they derive. Though the classification of archaeobotanical samples by the analysis based on quantitative data is problematic, both semi-quantitative and quantitative approaches were used and their results compared in order to explore the effects of varying methods of quantification.

5.2.1 Comparison of the archaeobotanical data with autumn and spring sowing regimes (Germany)

The discriminant functions extracted to distinguish autumn and spring sowing regimes in Germany (3.1.1.2, 3.2.1) were used to classify the archaeobotanical samples as deriving from autumn- or spring-sown crops in the same way as the modern Asturias plots were classified as a 'test' case (3.3.1). The discriminating variables from which the discriminant functions were derived for Germany are three nominal variables based on flowering onset/length: early-intermediate/short flowering, late flowering and long flowering. The discriminant function extracted from semi-quantitative data (taxon counts) and that extracted from quantitative data (seed or quadrant counts) were used to classify both the archaeobotanical samples and the Asturias plots.

5.2.1.1 Discriminant analysis based on semi-quantitative data

Table 5.2 summarises the classification of archaeobotanical samples by the discriminant function based on semi-quantitative data. 81% of the samples are classified as autumn-sown and 94% of these 'autumn' samples are classified with high probability. The discriminant scores for each sample are plotted in Fig. 5.2c; discriminant scores for weed associations in the Germany study (Fig. 5.2a) and for spelt plots in Asturias (Fig. 5.2b) are also plotted. Clearly, the discriminant scores for the archaeobotanical samples show the most variation.

In section 3.4.1, it was shown that crop processing may introduce a bias in the weed composition of fine sieve by-products and products relating to the inference of crop sowing time: weed species with small free heavy weed seeds, associated with by-products, tend to be late- or long-flowering and so to indicate spring sowing, while weed species with big free heavy weed seeds, associated with products, tend to be early-intermediate/short-flowering and so to indicate autumn sowing. In Fig. 5.3, the discriminant scores of archaeobotanical samples from different processing stages are plotted separately. The two unthreshed free-threshing cereal samples and the unsieved glume wheat 'spikelet' samples are all classified as autumn-sown (Table 5.2; Fig. 5.3a). Unthreshed cereals would be completely unprocessed and unsieved spikelets would have undergone fewer processing stages than fine sieve by-products or products (see below); both, therefore, are 'closer' to the original cereal harvest than samples from other processing stages. Though the status of the unsieved 'spikelet' samples is somewhat uncertain (i.e. they may represent mixtures of product and by-product material rather than genuine spikelets – 4.1.3.1), it is worth emphasising that those samples that appear to be least affected by processing (i.e. the unthreshed cereal samples and possibly also the unsieved 'spikelet' samples) were all classified as autumn-sown.

The glume wheat fine sieve by-products (Fig. 5.3b) cover nearly the full range of discriminant scores for the archaeobotanical samples (Fig. 5.2c) and include the only samples classified as spring-sown (Table 5.2). The classification of some fine sieve by-products as spring-sown conforms to the expected bias caused by crop processing (i.e. the tendency of weed species with small free heavy seeds to be late- or long-flowering). The clear majority (78%) of fine sieve by-products, however, are classified as autumn-sown despite the inherent bias towards a spring-sown classification for this type of processing by-product.

All of the fine sieve product and sieved glume wheat 'spikelet' samples are classified as autumn-sown (Table 5.2; Fig. 5.3c), but this could be due to the inherent bias towards early-intermediate/short-flowering species present in this type of sample. These products also include a high proportion of extreme 'autumn' classifications (i.e. with very high discriminant scores), however, perhaps suggesting that they were originally derived from autumn-sown cereals and that their extreme composition results from further removal of long- and late-flowering species by crop processing.

The classification of the archaeobotanical samples by the discriminant function based on semi-quantitative data (Table 5.2; Figs. 5.2-5.3), therefore, strongly suggests that most (if not all) samples derive from autumn-sown crops. Despite the tendency, caused by crop processing, for fine sieve by-products to appear spring-sown, most were classified as autumn-sown. This result is further underlined by the classification of the unthreshed cereal samples (and unsieved 'spikelet' samples) as autumn-sown and by the fact that about half of the product samples are more extreme in their autumn characteristics than any of the autumn-sown associations from Germany. The samples classified as spring-sown are all fine sieve by-products and so their spring classification could be due to the effects of crop processing rather than spring sowing.

5.2.1.2 Discriminant analysis based on quantitative data

Table 5.2 summarises the classification of archaeobotanical samples by the discriminant function based on quantitative data. The proportion of samples classified as autumn-sown (ca. 93%) is even higher than in the semi-quantitative analysis, though this results in a lower proportion of 'autumn' samples classified with high probability (ca. 86%). The discriminant scores for each sample are plotted in Fig. 5.4c; discriminant scores for weed associations in the Germany study (Fig. 5.4a) and for spelt plots in Asturias (Fig. 5.4b) are also plotted. As in the semi-quantitative analysis, the discriminant scores for the archaeobotanical samples show the most variation.

In Fig. 5.5, the discriminant scores of archaeobotanical samples from different processing stages are plotted separately. As in the semi-quantitative analysis, the fine sieve by-products of glume wheats (Fig. 5.5b) cover nearly the full range of discriminant scores for the archaeobotanical samples (Fig. 5.4c) but the number of spring classifications is even lower:

some samples classified as spring-sown in the semi-quantitative analysis are classified as autumn-sown in the quantitative analysis, albeit with low probability (Table 5.2). The fine sieve product and sieved glume wheat 'spikelet' samples are classified as autumn-sown, mostly with extreme discriminant scores (Table 5.2; Fig. 5.5c). The two unthreshed free-threshing cereal samples, however, are classified as spring-sown (Table 5.2; Fig. 5.5a), whereas in the semi-quantitative analysis (Table 5.2; Fig. 5.3a) they are classified as autumn-sown. Fig. 5.6 compares the composition of these samples calculated on the basis of semi-quantitative (taxon counts, Fig. 5.6a) and quantitative (seed count, Fig. 5.6b) data. The major difference between the two methods of calculation is in the proportions of long-flowering taxa, which are higher for seed counts (quantitative) than for taxon presence/absence (semi-quantitative), and this would explain the difference in classification between the semi-quantitative and quantitative analyses. The unsieved glume wheat 'spikelet' samples are all classified as autumn-sown (Table 5.2) and include three samples with extreme discriminant scores (Fig. 5.5b).

The classification of the archaeobotanical samples by the discriminant function based on quantitative data (Table 5.2; Figs. 5.4-5.5) suggests that most (or all) of the archaeobotanical samples derive from autumn-sown crops. As in the semi-quantitative analysis, the strongest evidence for this is the classification of most fine sieve by-products as autumn-sown, despite a bias in the opposite direction potentially introduced by crop processing. Those fine sieve by-products classified as spring-sown could reflect the effects of crop processing rather than actual spring sowing. The classification of the two unthreshed cereal samples as spring-sown, however, cannot be explained by processing-related bias (see also below, 5.2.1.5).

5.2.1.3 Discriminant analyses without Chenopodium album

The discriminant functions based on semi-quantitative and quantitative data were also used to classify samples with *C. album* removed. This was done in order to see how the samples are classified when this species, which may be present in some samples as a collected food plant rather than an arable weed (4.5.1), is excluded. Its removal reduces the number of archaeobotanical samples containing at least 30 weed seeds from 130 to 74. Not surprisingly, given that it flowers late, an even greater proportion of samples are classified as autumn-sown in the semi-quantitative analysis or, in the quantitative analysis, are classified as autumn-sown with higher probability (Table 5.3). Overall, however, the results of the analyses with and without *C. album* are very similar: the vast majority of samples (81-93%) are classified as deriving from autumn-sown crops. Since *C. album* does not have a great effect on this overall outcome, the analyses including this species (and all samples) will be the focus of subsequent discussion.

5.2.1.4 The relationship between sample composition and classification

The classification of archaeobotanical samples by the discriminant functions generally 'matches' the composition of samples in terms of flowering onset/length: that is, the relative proportions of flowering onset/length categories used as discriminating variables (early/intermediate-short flowering, late flowering, long flowering) are consistent with the correlation between these variables and the discriminant function used to classify the samples (Figs. 3.2b, 3.8b). There is one curious exception to this: samples containing high proportions of late-flowering taxa (up to 100%) are classified as autumn-sown in the quantitative analysis, despite the association of late flowering with spring sowing (Fig. 3.2b). This apparently relates to the fact that long flowering is of greater importance to the discriminant function based on quantitative data than late flowering (Figs. 3.2b), making late flowering, by itself, less indicative of spring sowing. In the semi-quantitative analysis, samples with 100% late-flowering taxa were classified as spring-sown and it is worth noting that, in this analysis, the relative contribution of late flowering to the discriminant function is greater than in the quantitative analysis (Fig. 3.8b). The weakness of the link between late flowering *per se* (in the absence of long-flowering taxa) and spring sowing in the quantitative analysis should perhaps be expected. The quantitative discriminant analysis of the German weed associations indicates that (1) the weed floras of spring-sown crops contain a high proportion of both long- and late-flowering species, since both are encouraged by spring ploughing (Bogaard *et al.* 2001), and (2), through the weaker association of late flowering with spring sowing, late-flowering species are also present in autumn sown plots.

Thus, samples dominated by late-flowering taxa but lacking any long-flowering taxa may not represent genuine 'spring-sown' weed floras. Instead, they may reflect the impact of crop processing on sample composition: most of the samples with high proportions of late-flowering taxa, classified as autumn-sown in the quantitative analysis, are fine sieve by-products and so are dominated by small-seeded weed species. A possible explanation for the fine sieve by-product samples dominated by late-flowering taxa, therefore, is that the weed floras they derive from grew with autumn-sown cereals and were dominated by early-intermediate/short-flowering taxa but included some late-flowering taxa. Since late-flowering species usually have small seeds, however, these will tend to be removed by fine sieving and so be present in enhanced numbers in fine sieve by-products. If the removal of larger-seeded species is sufficiently thorough, this could, in some cases, result in samples from autumn-sown crops dominated by late-flowering taxa. If crop processing is the main cause of samples dominated by late-flowering taxa, its effect should be more pronounced in terms of seed counts than taxon counts, since processing affects weed *seeds*, not taxa *per se*. Fig. 5.7 shows that the association of high late-flowering content (75-100%) with fine sieve by-products is, in fact, more pronounced in terms of seed counts (quantitative data – Fig. 5.7b) than in terms of taxon counts (semi-quantitative data – Fig. 5.7a), lending further support to this explanation.

5.2.1.5 Discussion of results

Overall, agreement between semi-quantitative and quantitative analyses in the classification of samples is high: 77% of samples (100 out of 130) were classified into the same category (autumn- or spring-sown) in both analyses. The classification of fine sieve product and sieved 'spikelet' samples as autumn-sown is unanimous and, while the content of these samples may be biased by crop processing in favour of the early-intermediate/short flowering taxa indicative of autumn sowing, their tendency to have extreme discriminant scores is consistent with their derivation from autumn-sown cereals. Agreement in the classification of fine sieve by-product samples is also quite high (73% of samples classified consistently as autumn- or spring-sown) and the tendency for these samples to be classified as autumn-sown offers the strongest evidence for an autumn sowing time for most, if not all, cereals since it goes against the processing-related bias.

The two unthreshed cereal samples (Fig. 5.6) were classified by each analysis with high probability into different categories (Table 5.2). The more reliable classification is likely to be their classification as autumn-sown based on semi-quantitative data, since these data are inherently more justifiable as a basis on which to compare the archaeobotanical and modern weed samples (3.2). In this connection, it is worth noting that the classification of the unthreshed samples by the semi-quantitative analysis matches the classification of most other samples in both quantitative and semi-quantitative analyses.

Whereas some discrepancies in the classification of samples between the semi-quantitative and quantitative analyses relate to differences in the composition of samples expressed in seed counts or taxon counts (as for the unthreshed cereal samples – Table 5.2; Fig. 5.6), others are caused primarily by differences in the relative importance of the flowering onset/length variables between the two analyses. Importantly, the most significant 'anomaly' – the classification of samples dominated by late-flowering taxa (up to 100%) as autumn-sown in the quantitative analysis – is consistent with an autumn-sown cereal origin for most, if not all, of the archaeobotanical samples (above, 5.2.1.4). Overall, the classification of the archaeobotanical samples by both the semi-quantitative and quantitative discriminant functions points to the dominant role of autumn sowing in cereal husbandry.

While differences in precise sowing time between Asturias and Germany may account for the greater spread of discriminant scores among Asturias plots (3.3.3), the even greater spread of discriminant scores among archaeobotanical samples has been shown to relate, at least partially, to the effects of crop processing. The broad spread of discriminant scores among archaeobotanical samples from the same processing stage (glume wheat fine sieve by-products) perhaps suggests that differences in precise sowing time between the Germany study and the archaeological study area are also at work.

5.2.2 Comparison of the archaeobotanical data with intensive and extensive pulse cultivation (Evvia)

The discriminant functions extracted to distinguish intensive and extensive pulse cultivation in Evvia (3.1.2.2, 3.2.2) were used to classify the archaeobotanical samples as deriving from gardens or fields in the same way as the modern Asturias plots were classified as a 'test' case (3.3.2). The discriminating variables from which the discriminant functions were derived for Evvia are the six fertility and disturbance attributes most useful in the original discriminant analysis (3.1.2.2): SLA, canopy height and diameter, leaf area per node:leaf thickness, length of the flowering period and amphistomaty. The discriminant function extracted from semi-quantitative data (taxon counts) and that extracted from quantitative data (seed or quadrat counts) were used to classify both the archaeobotanical samples and the Asturias plots.

5.2.2.1 Discriminant analyses based on semi-quantitative data

Table 5.4 summarises the classification of archaeobotanical samples by the discriminant function based on semi-quantitative data. 97% of samples are classified as gardens and 98% of these 'garden' samples are classified with high probability. The discriminant scores for each sample are plotted in Fig. 5.8c; discriminant scores for cultivation plots in the Evvia study (Fig. 5.8a) and for spelt plots in Asturias (Fig. 5.8b) are also plotted. The discriminant scores for the archaeobotanical samples are more variable than those for the Evvia cultivated plots and include extreme 'garden' scores, though the scores tend to be less extreme than those for the Asturias plots.

As discussed in section 3.4, G. Jones (1992) has shown that crop processing tends to introduce a bias in weed composition that may relate to cultivation intensity: the ratio of Chenopodietea to Secalinetea character species decreases through the processing sequence. In relation to cultivation intensity, therefore, fine sieve by-products might appear to derive from gardens and fine sieve products from fields, even though they derive from the same crop harvest and/or husbandry regime. In terms of functional attributes relating to cultivation intensity, however, it has been shown that crop processing is unlikely to introduce a serious bias in the weed composition of fine sieve by-products and products (3.4.2). Nevertheless, in order to explore the possible impact of crop processing stage on the inference of cultivation intensity, in Fig. 5.9 the discriminant scores of archaeobotanical samples from different processing stages are plotted separately. The two unthreshed free-threshing cereal samples, which should be unaffected by processing, are classified as gardens, as are the unsieved glume wheat 'spikelet' samples (Table 5.4; Fig. 5.9a). All but three (97%) of the glume wheat fine sieve by-products are classified as gardens (Table 5.4; Fig. 5.9b). Of the eleven product samples (fine sieve products and sieved glume wheat 'spikelet' samples), ten are classified as gardens and one as a field (Table 5.4; Fig. 5.9c). Despite the possible bias towards 'field indicators' in the weed composition of product samples, therefore, most are classified as gardens. This result, together with the classification of relatively 'unprocessed' cereal samples (i.e. unthreshed cereal samples and possibly also the unsieved 'spikelet' samples) as gardens, suggests that intensive cultivation is generally represented, and that the classification of most fine sieve by-products as gardens is not merely a reflection of processing bias.

5.2.2.2 Discriminant analysis based on quantitative data

Table 5.4 summarises the classification of archaeobotanical samples by the discriminant function based on quantitative data. The proportion of samples (96%) classified as gardens is very similar to that in the semi-quantitative analysis and the proportion of 'garden' samples classified with high probability is again high (94%). The discriminant scores for each sample are plotted in Fig. 5.10c; discriminant scores for cultivation plots in the Evvia study (Fig. 5.10a) and for spelt plots in Asturias (Fig. 5.10b) are also plotted. The discriminant scores for the archaeobotanical samples are only slightly more variable than those for the Evvia gardens and less extreme than those for the Asturias plots.

In Fig. 5.11 the discriminant scores of archaeobotanical samples from different processing stages are plotted separately. The unthreshed free-threshing cereal samples and unsieved glume wheat 'spikelet' samples are again all classified as gardens (Table 5.4; Fig. 5.11a). 96%

of the glume wheat fine sieve by-products are classified as gardens (Table 5.4; Fig. 5.11b), as are all of the fine sieve product and sieved glume wheat 'spikelet' samples (Table 5.4; Fig. 5.11c). There is little evidence of a processing-related bias in these results, since all of the products (as well as most by-products) are classified as gardens.

The classification of the archaeobotanical samples by the discriminant function based on quantitative data (Table 5.4; Figs. 5.10-5.11) again suggests that most archaeobotanical samples derive from intensive cultivation. There is no evidence of processing-related bias, and so the classification of a few samples as fields cannot be explained in this way (see also below, 5.2.2.4).

5.2.2.3 Discriminant analyses without Chenopodium album

The discriminant functions based on semi-quantitative and quantitative data were also used to classify samples with *C. album* removed. As in the discriminant analyses of sowing regimes (above, 5.2.1.3), this was done in order to see how samples are classified without *C. album*, which may be present in some samples as a collected food plant rather than an arable weed (4.5.1). The results of analyses with and without *C. album* are very similar: the vast majority of samples (88-95%) are classified as gardens (Tables 5.4-5.5). Furthermore, the classification of most samples as gardens in the analyses without *C. album* – a character species of the Chenopodietea (root/row-crop weeds and ruderals) – shows that the samples contain other taxa indicative of intensive cultivation. Since *C. album* does not have a great effect on the overall outcome, the analyses including this species (and all samples) will be the focus of subsequent discussion.

5.2.2.4 Discussion of results

The overall agreement between semi-quantitative and quantitative analyses in the classification of samples is very high: 95% of samples (123 out of 130) are classified into the same category (garden or field) in both analyses. The classification of most samples as gardens in both analyses, therefore, appears genuinely to reflect intensive cultivation; extensive cultivation in a minority of cases, however, cannot be ruled out.

As discussed earlier (5.2.1.5), the effect of processing-related bias on the classification of samples according to sowing regime may contribute to the considerable spread of discriminant scores among the archaeobotanical samples, which is greater than that among the German weed associations or the Asturias plots. In the classification of samples according to cultivation intensity, however, processing-related bias does not appear to play an important role, though the discriminant scores of the archaeobotanical samples are somewhat more variable than those for the Asturias and Evvia plots.

In sections 3.3.2-3.3.3, the discriminant scores for Asturias plots were noted to be more extreme than those for the Evvia gardens, and it was suggested that certain contrasts between growing conditions in Asturias and Evvia (e.g. atlantic versus mediterranean climate) contribute to these differences. The fact that the Asturias scores also tend to be more extreme than the scores for the archaeobotanical samples (Figs. 5.8, 5.10) suggests that the latter derive from conditions that are less productive and/or less severely disturbed than the Asturias spelt plots. As noted previously (3.3.3), such contrasts between discriminant scores may provide a basis on which to reconstruct past husbandry regimes that have no exact analogue amongst the modern weed studies available.

5.2.3 Comparison of results from discriminant analyses based on semi-quantitative data

Results from semi-quantitative analyses are the focus of this final discussion for two reasons. First, it has been shown in the preceding sections (5.2.1-5.2.2) that classifications of archaeobotanical samples based on semi-quantitative and quantitative data largely agree, suggesting that results based on the two types of data reflect the same phenomena (i.e. past crop husbandry practices), despite the greater simplicity of presence/absence data. Secondly, semi-quantitative data offer a more justifiable basis of comparison between modern and archaeobotanical weed data than quantitative data (above and 3.2). Thus, where classifications of samples based on the two types of data disagree, the semi-quantitative version is likely to be more reliable.

Classifications of archaeobotanical samples using discriminant functions for modern autumn versus spring sowing regimes (Germany) and intensive versus extensive pulse cultivation (Evvia) based on semi-quantitative data are tabulated in Table 5.6. The clear majority of samples (78%) are classified as deriving from autumn-sown ‘gardens’. The next largest group (19%) consists of samples classified as deriving from spring-sown ‘gardens’. 3% of samples are classified as deriving from autumn-sown ‘fields’. No samples are classified as spring-sown ‘fields’. As discussed in connection with the classification of Asturias plots (3.3), the combination of autumn sowing and intensive cultivation (or spring sowing and extensive cultivation) could be particularly difficult to detect since one functional attribute (length of the flowering period) is positively associated with both spring sowing and intensive cultivation (high disturbance). The correct classification of Asturias plots as autumn-sown and intensively cultivated, however, has demonstrated that this problem is not so severe as to prevent the independent identification of sowing regime and cultivation intensity (3.3.3). The classification of 78% of archaeobotanical samples as autumn-sown and intensively cultivated also demonstrates the ability of functional attributes to distinguish the effects of sowing regime from those of cultivation intensity. On the other hand, the samples classified as autumn-sown and extensively cultivated or as spring-sown and intensively cultivated may be affected by the dual role of flowering period in the sowing regime and cultivation intensity models. Given that most or all samples derive from autumn-sown 'gardens', it is possible that the effect of autumn sowing on length of the flowering period (promoting weed species with short flowering periods that also begin flowering early) has occasionally resulted in the classification of samples as extensively cultivated (associated with short flowering periods); likewise, intensive cultivation (promoting species with long flowering periods) may occasionally have resulted in the classification of samples as spring-sown (also associated with long-flowering taxa).

Table 5.7 shows the combined sowing regime/cultivation intensity classification of samples from different processing groups. While the 'autumn garden' samples derive from all processing groups, 'spring garden' samples derive exclusively from fine sieve by-products, and the few 'autumn field' samples include one fine sieve product of glume wheats. These patterns suggest that crop processing accentuates the dual role of flowering period noted above. Thus, the association of long flowering with intensive cultivation, combined with the tendency of weed species with small free heavy seeds (associated with fine sieve by-products) to be long-flowering, may have contributed to the classification of some fine sieve by-products as 'spring gardens'. Similarly, the tendency of weed species with big free heavy seeds (associated with fine sieve products) to be short-flowering, combined with the association of short flowering periods with extensive cultivation, may have contributed to the classification of one fine sieve product as an 'autumn field'. These possible relationships cast doubt on the legitimacy of the 'spring garden' and 'autumn field' classifications. The 'spring garden' classifications could be due entirely to crop processing combined with the dual role of flowering period. One of the three 'autumn field' samples could also be affected by the combination of crop processing and the dual role of flowering period. Crop processing is unlikely to contribute to the two remaining 'autumn field' classifications (fine sieve by-product samples – Table 5.7), though the dual role of flowering period may play a role. The 'autumn garden' classifications, by contrast, override the expected biases – for fine sieve by-products to appear spring-sown and for autumn sowing to obscure the effects of intensive cultivation and *vice-versa* – and emerge, therefore, as secure identifications.

5.2.4 The relationship of husbandry regime to archaeological site, geographical region and chronological period

It remains to consider how the combined sowing time/cultivation intensity classification relates to the archaeological site, geographical region and chronological period from which samples derive. Tables 5.8-5.9 show the relationship between combined sowing regime/cultivation intensity classification and these other variables. Table 5.8 shows that 'spring garden' and 'autumn field' samples do not characterise any particular site with multiple samples, with the exception of Hilzingen, where all four samples were classified as 'spring garden'. Samples from the three well-represented sites (with at least 10 samples each – Langweiler 8, Hochdorf and Vaihingen) are all mostly (≥75%) classified as 'autumn garden'. These three sites occur in two of the three well-represented regions (with at least 10 samples each) – the Lower Rhine-Meuse basin and the Neckar valley – which are similarly dominated by 'autumn garden' samples. By contrast, half of the samples in the southern Baden-Württemberg, the third well-represented region (including Hilzingen), were classified as 'spring garden'.

Table 5.9 shows that 'autumn garden' samples dominate the two well-represented periods (with at least 10 samples each) – LBK and Later Neolithic. All of the 'spring garden' samples date to the LBK; most of these samples (72%) are from Vaihingen and Hilzingen, with one-two samples from each of six further sites. While the very different quantities of samples from different periods make comparisons difficult, the fact that eight sites contribute to the 'spring garden' group suggests that their LBK date may be significant. Furthermore, it is intriguing that two of the three bronze age samples are classified as 'autumn field'.

To summarise the comparison of sample classification and site/region/period, there is some evidence of an association between the 'spring garden' regime and the LBK and also between the 'spring garden' regime and one particular site, Hilzingen in southern Baden-Württemberg. There is slight evidence of a link between the 'autumn field' regime and the Bronze Age. One possible interpretation of these patterns is that cultivation intensity was greatest in the LBK, sometimes resulting in the dominance of weeds indicative of spring sowing, and lowest in the Bronze Age, resulting in the 'field' classifications (see also 7.2.2-7.2.3). The most secure conclusion, however, is that well-represented sites, regions and periods (with at least 10 samples per group) are dominated by 'autumn garden' samples.

5.3 Summary of results

The comparisons of archaeobotanical and modern weed data presented in this chapter suggest that the (mostly) neolithic archaeobotanical samples from western-central Europe studied here generally derive from long-established cereal plots that were autumn-sown and cultivated using intensive methods, resulting in relatively high levels of soil disturbance and productivity. While these results imply overall homogeneity, there remains considerable potential for variation in husbandry practices – for example, in the severity and timing of soil disturbance, level of soil productivity, impact of rotation with other crops and/or fallow periods etc. The reconstruction of husbandry regimes can be pursued further using correspondence analyses of archaeobotanical samples based on their wild/weed composition, which allow individual functional attributes (and hence potentially specific husbandry practices or aspects of husbandry) to be investigated (Chapter 6).

6 Identification of separate ecological gradients and specific husbandry practices

6.1 Introduction

While Chapter 5 was concerned with comparing the archaeobotanical samples to entire modern husbandry regimes, this chapter will explore specific aspects of husbandry (e.g. hoeing, hand weeding, manuring, watering etc.). The identification of different husbandry practices is particularly important for understanding differences in cultivation intensity, which involves multiple ecological factors (fertility, disturbance and water availability) (3.1.2). Most or all of the archaeobotanical samples were identified in Chapter 5 as deriving from intensively cultivated plots, but it remains to determine whether this intensity varied in terms of fertility, disturbance level or water availability etc. and so which intensive husbandry practices were applied to the neolithic-bronze age crops. In contrast to cultivation intensity, sowing regime is a single husbandry practice – time of sowing – and relates directly to only one ecological factor – seasonality. Sowing regime, therefore, does not need to be understood in terms of different husbandry practices and ecological factors. Several functional attributes potentially measure seasonality, however, and only flowering onset/length was used in the discriminant analysis of sowing regimes in Germany (3.1.1.2, 5.2.1). This chapter, therefore, will also explore variation in the other seasonality attributes relating to sowing regime. Likewise, all of the functional attributes measuring fertility, disturbance and water availability – including attributes not used in the discriminant analysis of cultivation intensity in Evvia (3.1.2.2, 5.2.2) – will also be considered.

In Chapter 4 (4.6), correspondence analysis was used to explore variation in wild/weed composition among glume wheat samples. Potential 'causes' of this variation, such as crop processing stage, archaeological site and chronological period from which the samples derive, were considered. It was shown that crop processing accounts for most variation in wild/weed composition among glume wheat samples as a whole (4.6.2), whereas variation within the fine sieve by-products of glume wheats (the largest crop processing group) relates primarily to archaeological site, and possibly also to geographical region and chronological period (4.6.3-4.6.4). The implication of this variation among samples from the same processing stage is that different crop husbandry methods were practiced at different sites, possibly as part of broader regional and/or chronological differences (4.6.5).

The aim of this chapter is to assess the extent and nature of differences in husbandry practices and two correspondence analyses of the wild/weed taxa in the glume wheat samples are used to assist this. The first correspondence analysis including all the glume wheat samples (described in section 4.6.2) is used to determine the extent to which crop processing introduces ecological biases. A further complicating factor in this analysis is *Chenopodium album*, which dominates many fine sieve by-product samples but may be present as a separately collected plant rather than as an arable weed harvested with the glume wheats (4.5.1). The second correspondence analysis including only the glume wheat fine sieve by-products (described in section 4.6.4) is used to assess the ecological significance of variation in wild/weed taxa among samples from the same processing stage, which can be interpreted in terms of crop husbandry differences. In this second analysis, *C. album* is excluded.

Crop processing biases are to be expected in the first correspondence analysis including all glume wheat samples. G. Jones (1992) has demonstrated that the ratio of Chenopodietea to Secalinetea character species decreases through the processing sequence (3.4). Secalinetea species tend to be harvested and dispersed with the seed corn. As such, they tend to be large-seeded and are retained, with the cereal grain, in the products from fine sieving. Conversely, Chenopodietea species tend to shed their seeds before (or after) the harvest and grow again *in situ*. They are generally small-seeded and so are removed with the by-products of fine sieving. Crop processing, therefore, imposes a general bias in the phytosociological classification of weed species.

A related bias may be expected in the seasonality of the weed species dominating the products and by-products of fine sieving. As Secalinetea species tend to flower early in the growing season, there may be a tendency for fine sieve products (where Secalinetea may be over-represented) to be dominated by species indicative of autumn sowing. Chenopodietea species, on the other hand, tend to flourish later in the growing season, so there may be a tendency for fine sieve by-products (where Chenopodietea predominate) to be dominated by species indicative of spring sowing. Such a bias in one seasonality attribute – flowering onset/length – was predicted from the study of modern weed associations of autumn- and spring-sown crops in Germany (3.4.1).

Similarly, a bias may be expected in the attributes relating to cultivation intensity – that is, those relating to disturbance level and soil productivity (including duration/quality of the growth period as well as water availability) – of weed species dominating the products and by-products of fine sieving: Secalinetea species are associated with extensive cultivation, while Chenopodietea species are associated with intensive cultivation. Chenopodietea species, characteristic of fine sieve by-products, therefore, may tend to have attributes associated with intensive cultivation practices and Secalinetea species,, characteristic of fine sieve products, to have attributes associated with extensive cultivation. Consideration of attributes relating to cultivation intensity for weed taxa in three modern weed studies (3.4.2), however, suggested that most of the attributes considered either contradicted the expected bias or at least were not strongly biased in the expected way.

Seed persistence may also be generally affected by crop processing: Secalinetea tend to mimic cereals and so are large-seeded and lack a seed bank in the soil, while Chenopodietea (root/row-crop weeds and ruderals) tend not to mimic cereals and are generally small-seeded, enhancing their persistence in the soil (2.4.2.5, 3.4). These relationships between seed dispersal, size and persistence in the soil suggest that small-seeded weed species characteristic of fine sieve by-products will tend to be persistent, whereas large-seeded weed species characteristic of fine sieve products will tend not to persist in the soil and to use the seed corn itself as an 'alternative seed bank'. Indeed, the method used here to estimate seed persistence (the seed longevity index) is partly based on seed size, as measured by weight.

Finally, it should be noted that, aside from the predictable relationships between seed dispersal and other aspects of weed ecology noted above, crop processing could also have unpredictable effects due to chance differences in the attributes of the large- and small-seeded taxa dominating the products and by-products of fine sieving, respectively.

Wild/weed taxa included in the correspondence analyses were classified according to their individual functional attribute values (e.g. canopy height, length of the flowering period etc. – 2.4.2), or phytosociological class, and these classifications were used to interpret the correspondence analysis plots (2.8.1). Since many glume wheat samples are dominated by a small number of wild/weed taxa, pie-charts of seed counts are used for assessing the importance of individual functional attributes (2.8.1). If there is a trend in the values of functional attributes (e.g. from low to high or *vice versa*) along the axes in the correspondence analysis plots, ecological causes of variation in wild/weed composition can be inferred. These ecological trends, in turn, can be related to differences in crop growing conditions and hence in husbandry practices. In the results presented below (6.3-6.9), plots for the two correspondence analyses (that using all glume wheat samples and that using fine-sieve by-products only) are shown in pairs (usually as a and b, respectively) for each functional attribute.

6.2 Summary of trends in non-ecological variables in correspondence analyses of glume wheat samples

The correspondence analysis of all glume wheat samples (including unsieved 'spikelet', fine sieve by-product, fine sieve product and sieved 'spikelet' samples) was introduced in section 4.6.2 (Figs. 4.12-4.17). It was shown that a few dominant wild/weed taxa largely determine the arrangement of samples in the plot. The product samples, towards the positive end of axis 1 and the negative end of axis 2 (bottom right), are dominated by the large-seeded taxon *Bromus arvensis/hordeaceus/secalinus* (Figs. 4.13, 4.17). The dense cluster of fine sieve by-product samples towards the negative (left) end of axis 1 is dominated by the small-seeded species *Chenopodium album* (Figs. 4.13, 4.15), while fine sieve by-product samples located towards the positive (top) end of axis 2 contain high proportions of the small-seeded species *Phleum pratense* (Figs. 4.13, 4.16) and three of them also contain particularly high proportions of *Valerianella dentata* (small-seeded). Thus, in addition to the primary distinction between products and by-products, there is considerable variation among by-products (dominated by small-seeded taxa), which cannot be explained by crop processing.

The correspondence analysis of fine sieve by-products of glume wheats (with *Chenopodium album* removed) was introduced in section 4.6.4 (Figs. 4.34-4.38). It was shown that axis 1 in this analysis relates especially to the contrast between Hochdorf (towards the negative or left end) and Vaihingen (towards the positive or right end) (Fig. 4.36); these two sites differ in date (later neolithic and LBK, respectively) but are located close together in the same region (the Neckar valley). Some regional clustering is also evident, with Lower Rhine-Meuse samples located towards the negative (left) end (Fig. 4.37). Along axis 2, samples from southern Baden-Württemberg (Hilzingen, Ulm-Eggingen) occur towards the positive (top) end, samples from Lower Bavaria more weakly so. In terms of dominant taxa in this analysis, *Phleum pratense* dominates the positive (right) end of axis 1 and negative (left) end of axis 2 (Fig. 4.35) and high proportions of *Valerianella dentata* also occur in some samples at the positive end of this axis. In the absence of *C. album*, therefore, axis 1 apparently takes over some of the role of axis 2 in the analysis including all glume wheat samples. The location of samples in other areas of the plot is largely determined by a range of different taxa.

6.3 Attributes relating to seasonality

Attributes relating to seasonality (life history, germination time, flowering onset/length, estimated cell endopolyploidy) are considered first since sowing regime may affect the interpretation of functional attributes relating to disturbance and the duration and quality of the growth period (3.1.1.1).

6.3.1 Life history

It is expected that summer annuals will be associated with spring sowing, whereas winter annuals and, to a lesser extent, winter/summer annuals, will be associated with autumn sowing (2.4.2.2).

Fig. 6.1a: The predominance of summer annuals at the negative (left) end of axis 1 is largely a reflection of the high proportions of *Chenopodium album*, a small-seeded species, in samples at this end of the axis. The predominance of winter/summer annuals in product samples at the positive end of axis 1 and negative end of axis 2 (bottom right) is largely due to high proportions of *Bromus arvensis/hordeaceus/secalinus*, a large-seeded taxon. This could be an effect of crop processing since summer annuals might be expected to be small-seeded and winter annuals to be large-seeded (6.1). Some of the pattern on axis 2 may genuinely reflect sowing time differences, however, as *Chenopodium album*, *Phleum pratense* and *Valerianella dentata* (the last two at the positive end of axis 2) are all small-seeded (and characteristic of by-products) but differ in their life histories. *V. dentata*, in particular, is an obligate winter annual and so may indicate samples derived from autumn-sown crops at the positive (top) end of axis 2. The concentration of perennials towards the positive (top) end of axis 2 is largely due to the dominance of *Phleum pratense* in these samples.

Fig. 6.1b: Samples at the positive (right) end of axis 1 are dominated by perennial taxa (especially *Phleum pratense*). This trend is not relevant to sowing regime and will be discussed in connection with soil disturbance (below, 6.4). Samples towards the negative (left) end of axis 1 are (with some exceptions) dominated by winter/summer annuals. Summer annuals predominate in samples towards the positive (top) end of axis 2 and winter annuals in samples towards the positive (right) end of axis 1. The predominance of summer annuals at the positive end of axis 2 could indicate that these samples are derived from spring-sown crops, though samples with the winter annual *Valerianella dentata* are also located in this general part of the plot, suggesting that sowing time is not a major axis of variation.

6.3.2 Germination time

It is expected that spring-germinating weed species will be associated with spring sowing and that autumn-germinating species and, to a lesser extent, autumn/spring-germinating species, will be associated with autumn sowing (2.4.2.2).

Fig. 6.2a: The dominance of spring-germinating taxa at the negative (left) end of axis 1 is again due to *Chenopodium album* and the predominance of autumn/spring-germinating taxa at the positive end of axis 1 and negative end of axis 2 (bottom right) to *Bromus arvensis/hordeaceus/secalinus*. As before, this contrast may be due to crop processing as spring-germinating species might be expected to be small-seeded and autumn-germinating species large-seeded (6.1). The predominance of autumn-germinating taxa at the positive (top) end of axis 2 may genuinely reflect some sowing time differences, however, as *Chenopodium album* (spring-germinating), *Phleum pratense* (autumn-germinating) and *Valerianella dentata* (autumn-germinating) are all small-seeded.

Fig. 6.2b: Samples at the positive (right) end of axis 1 are dominated by autumn-germinating taxa (especially *Phleum pratense* and *Valerianella dentata*) while those towards the negative (left) end are (with some exceptions) dominated by autumn/spring-germinating taxa. This pattern is probably not caused by sowing time since both autumn-germinating taxa and autumn/spring-germinating taxa tend to be associated with autumn sowing. Spring-germinating taxa predominate in samples towards the positive (top) end of axis 2, which could indicate that these samples derive from spring-sown crops, while those at the negative end derive from autumn-sown crops.

6.3.3 Flowering onset/length

It is expected that late- and long-flowering weed species will be associated with spring sowing and early-intermediate/short-flowering species with autumn sowing (2.4.2.2, 3.1.1). Flowering onset/length was the best attribute for distinguishing autumn- and spring-sown crops in the correspondence analysis of weed associations in Germany (3.1.1.1) and was used in the discriminant analysis of sowing regimes in Germany (3.1.1.2, 5.2.1).

Fig. 6.3a: Late-flowering taxa predominate in samples at the negative (left) end of axis 1, while early-intermediate/short- or intermediate/medium-flowering taxa predominate towards the positive (right) end. This pattern may be partly due to crop processing, since early-intermediate/short-flowering species tend to be large-seeded and late- or long-flowering species tend to be small-seeded (6.1). There is no trend along axis 2, however – early-intermediate/short-flowering taxa predominate at both ends – so the predominance of early-intermediate/short-flowering species at the positive (top) end of this axis cannot be due to crop processing as these taxa are small-seeded (*Phleum pratense* and *Valerianella dentata*). Variability amongst the fine sieve by-products, therefore, may genuinely reflect differences in sowing regime.

Fig. 6.3b: There is no trend along axis 1: early-intermediate/short-flowering taxa predominate at both ends. Late- and long-flowering taxa predominate in samples towards the positive (top) end of axis 2 and early-intermediate/short-flowering taxa in samples towards the negative (bottom) end of axis 2. This could indicate that samples at the positive end are derived from spring-sown crops and those at the negative end from autumn-sown crops.

6.3.4 Epidermal cell endopolyploidy

It is expected that epidermal cell endopolyploidy – the development and expansion of polyploid epidermal cells as a method of cool season growth – will be positively associated with autumn sowing (2.4.2.2).

Fig. 6.4a: Taxa with low endopolyploidy (<200% diploid cell size) predominate in samples at the negative (left) end of axis 1, while taxa with high endopolyploidy (>200% diploid cell size) predominate in samples at the positive (right) end. This pattern may be partly due to crop processing, since cool-season species (with high endopolyploidy) might be expected to be large-seeded and warm-season species (with low endopolyploidy) to be small-seeded (6.1). There is no trend along axis 2, however – taxa with high endopolyploidy predominate at both ends – so the predominance of taxa with high endopolyploidy at the positive (top) end of this axis cannot be due to crop processing as these are mostly small-seeded.

Fig. 6.4b: There is no trend along axis 1: taxa with high endopolyploidy predominate at both ends. Taxa with low endopolyploidy tend to predominate in samples near the positive (top) end of axis 2, while taxa with high endopolyploidy tend to predominate in samples towards the negative (bottom) end, though the trend is much less clear than for the previous seasonality attributes.

6.3.5 Summary of seasonality attributes

Two important observations emerge from the application of seasonality attributes to the correspondence analyses of glume wheat samples. First, in the analysis of all glume wheat samples, all of the seasonality attributes exhibit similar trends, with high proportions of taxa indicative of autumn sowing in product samples and high proportions of taxa indicative of spring sowing in some of the fine sieve by-products. It appears, therefore, that all of the seasonality attributes are similarly affected by crop processing. Indeed, this supports the suggestion made earlier (5.2.1, 5.2.3) that crop processing, together with intensive cultivation, causes some fine sieve by-products from autumn-sown crops to appear as though they derived from spring-sown crops.

The second important observation is that differences in sowing regime do not explain the major axis of variation in wild/weed composition among fine sieve by-products: samples at both ends of axis 1 tend to be dominated by taxa with attributes indicative of autumn sowing. It appears, therefore, that the major contrast along axis 1 – between LBK Vaihingen and later neolithic Hochdorf (Fig. 4.36) – is unrelated to differences in sowing regime. Axis 2, on the other hand, may reflect a contrast between autumn- and spring-sown glume wheats: samples located towards the positive end of the axis (e.g. samples from LBK sites in southern Baden-Württemberg – see Fig. 4.37) tend to be rich in spring-sowing indicators, while samples towards the negative end (e.g. samples from LBK-middle neolithic sites in the Lower Rhine-Meuse basin and later neolithic Hochdorf plus some LBK Vaihingen samples – see Fig. 4.36) are rich in autumn-sowing indicators (see also Tables 5.8-5.9; 5.2.4).

6.4 Attributes relating to the ability to regenerate rapidly following disturbance

Two attributes – length of the flowering period and vegetative spread – are related to the ability to regenerate rapidly following soil disturbance. Length of the flowering period is also a component of the flowering onset/length attribute relating to seasonality (above, 6.3.3) but is considered here in more detail (late-flowering taxa may flower for a short or medium period – 2.4.2.2) and in isolation from time of flowering onset.

6.4.1 Length of the flowering period

It is expected that weed species flowering for an extended period of time will be associated with high levels of disturbance (e.g. hoeing and hand weeding) whereas species flowering for a short period will be associated with lower levels of disturbance (2.4.2.2, 3.1.2).

Fig. 6.5a: Taxa with a flowering period of medium-long duration (four months or more) predominate in samples at the negative (left) end of axis 1, while short-flowering taxa (three months or less) predominate in samples towards the positive (right) end. This pattern may be partly due to crop processing since short-flowering species might tend to be large-seeded and medium- or long-flowering species to be small-seeded (6.1). There is no trend along axis 2, however – short-flowering taxa predominate at both ends – so the predominance of short-flowering taxa at the positive (top) end of this axis cannot be explained by crop processing as these taxa are mostly small-seeded.

Fig. 6.5b: There is no trend along axis 1: short-flowering taxa predominate at both ends. Medium- and long-flowering taxa tend to predominate in samples towards the positive (top) end of axis 2 and short-flowering taxa in samples towards the negative (bottom) end, suggesting that samples at the positive end are derived from the most disturbed conditions.

6.4.2 Vegetative spread

It is expected that perennials spreading horizontally through rhizomes or stolons will be associated with higher levels of disturbance than perennials without vegetative spread (2.4.2.2, 3.1.2.1). This 'perennial' attribute is combined here with perennial versus annual life history, which also relates to disturbance: annuals can generally tolerate higher levels of disturbance than perennials (e.g. Ellenberg 1996: 872).

Fig. 6.6a: There is no trend along axis 1: annuals predominate at both ends. Along axis 2, perennials (especially *Phleum pratense*) predominate in samples at the positive (top) end. This trend cannot be explained by crop processing since *Phleum pratense* is small-seeded like the other (mostly annual) weed taxa characterising the fine sieve by-products.

Figs. 6.6b: Perennial taxa without vegetative spread predominate in samples at the positive end of axis 1 and negative end of axis 2 (bottom right, mostly due to *Phleum pratense*) and in some samples at the negative end of both axes (bottom left, especially *Rumex conglomeratus/sanguineus* and *Silene vulgaris*). The few perennials with vegetative spread also occur at low levels in samples towards the negative end of both axes (bottom left). Annuals predominate at the positive (top) end of axis 2. Axis 2 could, therefore, reflect a trend from relatively high disturbance at the positive end to relatively low disturbance at the negative end, where perennials (especially those without vegetative spread) are concentrated. There is some indication of differences in disturbance level along axis 1 also: perennials with vegetative spread (bottom left) indicate higher disturbance than perennials without vegetative spread (especially bottom right). Annuals also predominate in samples towards the bottom left, again indicating higher levels of disturbance than samples towards the bottom right.

6.4.3 Combining flowering period and vegetative spread

Fig. 6.7a-b: Length of the flowering period (above, 6.4.1) was combined with vegetative spread and annual/perennial life history (above, 6.4.2) in order to summarise disturbance-related trends among the fine sieve by-products. While perennials without vegetative spread (indicative of the lowest disturbance) are particularly concentrated in samples towards the positive end of axis 1 and negative end of axis 2 (bottom right), samples towards the negative end of both axes (bottom left) are characterised by perennials with and without vegetative spread as well as by short-flowering annuals (categories indicative of moderate levels of disturbance). The predominance of mainly medium- to long-flowering annuals at the positive (top) end of axis 2 suggests that axis 2 represents increasing disturbance from bottom to top. The role of disturbance on axis 1 is more ambiguous since samples deriving from the most disturbed conditions are located mid-way along the axis.

6.4.4 Summary of disturbance attributes

In the analysis of all glume wheat samples, crop processing appears to introduce a bias in the length of the flowering period (short-flowering taxa being associated with products as predicted) but not in vegetative spread or annual/perennial life history.

In the analysis of fine sieve by-products alone, it appears that the major site (and chronological) contrast along axis 1 (Fig. 4.36) cannot easily be explained by differences in the level of disturbance. While samples at the negative end (e.g. from later neolithic Hochdorf) do appear to derive from more disturbed conditions than those at the positive end (e.g. from LBK Vaihingen) on the basis of perennial vegetative spread and annuals versus perennials generally, the samples towards the middle of the axis (including some Vaihingen samples) appear to derive from the most highly disturbed conditions on the basis of annual flowering period. Axis 2, on the other hand, may represent a disturbance axis: there is a trend from indicators of high disturbance at the positive end of the axis (e.g. in samples from LBK sites in southern-Baden-Württemberg – Fig. 4.37) to those of medium to low disturbance at the negative end (e.g. in samples from LBK-middle neolithic sites in the Lower Rhine-Meuse basin – Fig. 4.37 and later neolithic Hochdorf plus some LBK Vaihingen samples – Fig. 4.36).

While trends in seasonality attributes along axis 2 may be explained by a sowing time contrast along this axis (above, 6.3), disturbance in the form of hoeing and/or hand weeding during the growing season could also cause these trends. Intensive disturbance of autumn-sown crops during the growing season could reduce weed taxa indicative of autumn sowing while promoting taxa indicative of spring sowing. In fact, disturbance offers a better explanation for trends along axis 2: differences in sowing regime cannot explain the differences in the proportion of perennials (versus annuals) along this axis (Figs. 6.1b, 6.6b) since perennial weeds should be no more prevalent in autumn than spring-sown crops (J. Hodgson pers. comm.; cf. Bogaard *et al.* 2001). Thus, while spring sowing still cannot be excluded as a contributing factor, it appears that axis 2 in the analysis of fine sieve by-products primarily reflects a trend in disturbance level.

6.5 Attributes relating to the duration and quality of the growth period

Three types of attributes relate to duration and quality of the growth period: those measuring canopy size, leaf size and leaf 'density'. One attribute, the weed size index, combines plant size and leaf size attributes.

6.5.1 Canopy size

It is expected that weed species with large canopy size will be associated with highly fertile sites where disturbance is relatively low, whereas species with small canopies will be associated with low fertility or high disturbance (2.4.2.1, 3.1.2.1).

6.5.1.1 Canopy height

Fig. 6.8a: There is a gradient in canopy height from samples with tall canopied taxa (>90 cm) at the negative (left) end of axis 1, extending to the negative end of axis 2 (bottom right), with increasing proportions of taxa of medium canopy height (50-90 cm) in samples towards the positive (top) end of axis 2 (including *Phleum pratense*), terminating with a few samples with short canopied taxa (<50 cm, especially *Valerianella dentata*). Both products and most by-products of fine sieving are dominated by tall canopied taxa, indicating that crop processing has had little effect on this attribute. Moreover, the contrast between the products (bottom right) and some by-products (top) is the reverse of the general bias that crop processing might be expected to introduce (6.1).

Fig. 6.8b: Taxa with tall canopies predominate in samples towards the negative (left) end of axis 1 with increasing proportions of medium canopy height in samples towards the positive (right) end of the same axis. Taxa with short canopies (especially *Valerianella dentata*) also occur in a restricted number of samples at the positive end of this axis. This suggests that there is a gradient of increasing fertility from right to left along axis 1.

6.5.1.2 Canopy diameter

Fig. 6.9a: Along axis 2, taxa with narrow canopies (<40 cm, especially *Phleum pratense* and *Valerianella dentata*) predominate in samples towards the positive (top) end of axis 2. As for canopy height, there is no evidence of a bias that crop processing might be expected to introduce: both products (bottom right) and most by-products of fine sieving (left) are dominated by taxa with medium-width (40-70 cm) canopies. Here also, the contrast between the products (bottom right) and some by-products (top) is the reverse of the expected crop processing bias (6.1).

Fig. 6.9b: Taxa with narrow canopies (*Phleum pratense* and *Valerianella dentata*) predominate in samples at the positive (right) end of axis 1. Taxa with wider canopies predominate in samples towards the negative (left) end of axis 1 and taxa with the widest canopies at the positive (top) end of axis 2. This could suggest that taxa in the samples at the positive (right) end of axis 1 are derived from the least fertile habitats. Since it has already been argued that axis 2 represents a trend of increasing disturbance from the negative (bottom) to positive (top) end, the predominance of the widest canopies in samples at the positive end of this axis may either reflect greater fertility or some effect of disturbance. The prominence of climbing taxa (e.g. *Fallopia convolvulus, Galium spurium*) with wide canopies in samples at this end of axis 2 could reflect the difficulty of eradicating such species by hand weeding or hoeing, particularly later in the growing season when the crop is at its most tall and dense.

6.5.1.3 Mean canopy dimension

Fig. 6.10a: As for canopy height and diameter, taxa with small mean canopy dimension (<70 cm) predominate in samples at the positive (top) end of axis 2. Here again, there is no evidence of a general difference between products and by-products introduced by crop processing since both are mostly dominated by taxa with large mean canopy dimension (>70 cm). The contrast between the products (bottom right) and some by-products (top) is again the reverse of the general bias expected for crop processing (6.1).

Fig. 6.10b: When canopy height and diameter are combined in mean canopy dimension a clear trend from high through medium to low is apparent from the negative (left) to positive (right) end of axis 1. This suggests a gradient of increasing fertility from right to left along axis 1, though given the role of disturbance on axis 2, the predominance of medium-sized canopies at the positive (top) end of this axis (which is also the mid-section of axis 1) may reflect high fertility combined with high levels of disturbance.

6.5.2 Weed size index

It is expected that weed species with high index values (14-15, Competitive Ruderals) will be associated with productive, relatively undisturbed habitats, species with medium index values (6-13) with either highly fertile/highly disturbed conditions (Ruderals) or relatively undisturbed conditions of medium fertility (Ruderals/intermediate Competitive-Stress tolerant-Ruderals) and species with low index values (<6, Stress-tolerant Ruderals) with undisturbed conditions of low fertility (2.4.2.1). There were, in fact, no taxa with values of <8 in the archaeobotanical samples, which itself suggests either disturbed or fertile conditions (or both).

Fig. 6.11a: Along axis 2, taxa with medium index values (8-13, a variety of taxa including *Phleum pratense* and *Valerianella dentata*) predominate in samples at the positive (top) end. As noted previously for the canopy size attributes, there is no evidence of a general difference introduced by crop processing since both products and by-products are dominated with taxa with high index values (14-15). The contrast between the products (bottom right) and some by-products (top) is again the reverse of the general bias expected for crop processing (6.1).

Fig. 6.11b: A clear trend from high to medium index values is evident along axis 1 from the negative (left) to positive (right) end. This pattern may suggest that there is a gradient of increasing fertility from right to left along axis 1 though, as noted for canopy dimension, disturbance may also play a role, with the medium-sized taxa at the positive (top) end of axis 2 possibly reflecting high fertility combined with high disturbance.

6.5.3 Leaf size

It is expected that weed species with large amounts of leaf per node (and/or large, thin leaves) will be associated with highly fertile conditions, whereas species with small amounts of leaf per node (and/or small, thick leaves) will be associated with less fertile conditions (2.4.2.1, 3.1.2).

6.5.3.1 Leaf area per node

Fig. 6.12a: Along axis 2, taxa with small leaf area per node (<1500 mm^2, especially *Phleum pratense* and *Valerianella dentata*) predominate in samples towards the positive (top) end. Both products and most by-products of fine sieving are dominated by taxa with medium leaf area per node (1500-5000 mm^2), indicating that crop processing has had little effect on this attribute. Moreover, the contrast between the products (bottom right) and some by-products (top) is the reverse of the general bias that crop processing might be expected to introduce (6.1).

Fig. 6.12b: Taxa with small leaf area per node (especially *Phleum pratense* and *Valerianella dentata*) predominate in samples located at the positive (right) end of axis 1. Taxa with medium leaf area per node predominate in samples towards the negative (left) end of axis 1 and the positive (top) end of axis 2. Proportions of taxa with the highest leaf area per node (>5000 mm^2) tend to increase towards the negative (left) end of axis 1. These patterns suggest that there is a gradient of increasing fertility from right to left along axis 1.

6.5.3.2 Leaf area per node:thickness

Fig. 6.13a: Along axis 2, taxa with low values (<10000 mm, especially *Phleum pratense* and *Valerianella dentata*) predominate in samples at the positive (top) end. As for leaf area per node, there is no evidence of a general bias caused by crop processing: both products (bottom right) and by-products (left) are dominated by taxa with high values (>10000 mm). Also as for leaf area per node, the contrast between the products (bottom right) and some by-products (top) is the reverse of the general bias that crop processing might be expected to introduce (6.1).

Fig. 6.13b: Taxa with low values (especially *Phleum pratense* and *Valerianella dentata*) predominate in samples located at the positive (right) end of axis 1 and those with high values at the negative (left) end. This suggests that there is a gradient of increasing fertility from right to left along axis 1.

6.5.3.3 Leaf weight per node

Fig. 6.14a: Taxa with high leaf weight per node (>125 mg) predominate in samples at the negative (left) end of axis 1, largely due to the high proportions of *Chenopodium album* in these samples. Taxa with low leaf weight per node (<125 mg) predominate at both ends of axis 2; at the negative end (bottom right), this is largely due to high proportions of *Bromus arvensis/hordeaceus/secalinus*. While the contrast between the by-products at the negative (left) end of axis 1 and the products (bottom right) does conform to the general bias that crop processing might be expected to impose, the predominance of low leaf weight per node in by-products at the positive (top) end of axis 2 cannot be explained by crop processing.

Fig. 6.14b: There is no clear trend on either axis: taxa with low leaf weight per node tend to predominate in samples at both ends of each axis. A fertility pattern comparable to that observed for the previously described leaf size attributes, therefore, is lacking.

6.5.4 Leaf 'density' (specific leaf area)

Both leaf dry matter content (DMC) and specific leaf area (SLA) assess growth rate but DMC tends to be higher in monocotyledonous species than in dicotyledonous species (2.4.2.1) and so needs to be considered separately for each group. Though the majority of wild/weed taxa in the correspondence analyses of glume wheat samples are dicotyledonous, the seeds of monocotyledonous taxa (e.g. *Bromus arvensis/hordeaceus/secalinus*, *Phleum pratense*) are abundant in a large number of samples. This means that it is difficult to assess any trends in DMC for each group separately and, for this reason, only specific leaf area (SLA) is considered here.

It is expected that weed species with a high SLA will be associated with highly fertile habitats, whereas species with a low SLA will be associated with less fertile situations (2.4.2.1, 3.1.2).

Fig. 6.15a: Taxa with low SLA (<20 mm^2/mg) predominate in samples towards the negative (left) end of axis 1. This is again largely a reflection of the high proportions of *Chenopodium album* at this end of the axis. Taxa with high SLA (>20 mm^2/mg) predominate at the positive end of axis 1 and negative end of axis 2 (bottom right), largely due to high proportions of *Bromus arvensis/hordeaceus/secalinus*. The contrast between products and by-products of fine sieving, however, is the reverse of that which crop processing might be expected to introduce (6.1).

Fig. 6.15b: Taxa with low SLA (especially *Phleum pratense*) predominate in samples at the positive end (right) of axis 1 and those with high SLA at the negative (left) end. This suggests that there is a gradient of increasing fertility from right to left along axis 1.

6.5.5 Summary of fertility attributes

As noted earlier (6.1), crop processing might be expected to introduce a bias in the fertility attributes of weed species such that the by-products of fine sieving would appear to derive from more intensively cultivated conditions than the products. In fact, where differences between products and by-products have been noted for some fertility attributes, they virtually all work in the *opposite* direction to that expected (i.e. product samples appear to derive from more productive conditions than some of the by-products). Overall, these results support the suggestion made earlier (3.4.2) that crop processing does not introduce a general bias in fertility attributes.

As noted in section 3.1.1.1, attributes relating to the duration and quality of the growth period are affected by the season of growth and hence by sowing regime: species germinating and developing in spring/summer (e.g. after tillage in a spring sowing regime) tend to have higher values for fertility attributes (i.e. canopy size, leaf size, specific leaf area) than species germinating and developing in autumn/winter (e.g. after tillage in an autumn sowing regime). In addition, the severity of disturbance during the growing season affects canopy size: species with large canopies are characteristic of productive sites where disturbance is relatively infrequent, whereas species of highly productive and disturbed conditions tend to have medium-sized canopies, enabling them to complete their life-cycle between disturbance events (2.4.2.1, 3.1.2.1). Leaf size and 'density' attributes, however, should be relatively unaffected by disturbance level.

The patterning of fertility attributes along axis 1 in the analysis of fine sieve by-products generally suggests increasing fertility from the positive (right) to negative (left) end. The contrast between samples at the positive and negative ends of this axis cannot be an artefact of differential sowing time or disturbance level: both groups of samples are also at the negative (bottom) end of axis 2 where, it was argued above, samples are from the least disturbed conditions (6.4.4) and are securely identified as autumn-sown (6.3.5). The apparent fertility differences, therefore, appears genuine.

The interpretation of samples towards the middle of axis 1 and positive (top) end of axis 2 is more complicated. It was argued above that these samples derive from the most highly disturbed conditions. This agrees with the predominance of taxa with medium canopy dimension and weed size index in these samples: species of medium size are expected to characterise highly fertile, yet highly disturbed, conditions. These samples, however, also appear intermediate in terms of leaf size and leaf 'density' attributes, which should be unaffected by disturbance level. The implication is that these samples derive from highly disturbed conditions that are somewhat less fertile than those represented by samples at the negative end of both axes (bottom left).

If axis 1 is, therefore, primarily a fertility axis, and axis 2 a disturbance axis, some of the samples from LBK Vaihingen (bottom right) appear to derive from the least fertile, least disturbed conditions, while samples from LBK sites in southern-Baden-Württemberg plus the other samples from LBK Vaihingen (towards the positive or top end of axis 2) appear to represent conditions of higher fertility and high disturbance. Samples from LBK-middle neolithic sites in the Lower Rhine-Meuse basin and later neolithic Hochdorf (bottom left) appear to derive from the most fertile conditions, with moderate disturbance (Figs. 4.36-4.38).

6.6 Attributes relating to water use

As noted in section 2.4.2.3, rainfall in the study area is variable but on the whole fully adequate for cereal and pulse production, and so it is unlikely that watering/irrigation of crops was ever important. On the other hand, soil moisture contributes directly to site productivity since it allows the absorption of nutrients by plants. The addition of manure promotes a crumb structure in the soil, allowing water and air to penetrate. Manuring, therefore, increases the availability of water required by plants.

The water use attributes considered below are stomatal size and stomatal density. Of the other attributes relating to water use, epidermal cell size applies differently to monocotyledonous and dicotyledonous species (the former tend to have very large cells), while cell wall undulation applies only to dicotyledonous species (since cell wall undulation does not occur in monocotyledonous species) and root diameter applies only to species with tap roots (2.4.2.3). Though the majority of wild/weed species in the correspondence analyses of glume wheat samples are dicotyledonous, the seeds of monocotyledonous species (e.g. *Phleum pratense*) are abundant in a large number of samples. This means that it is difficult to assess any trends in cell size for each group separately or, in the case of cell wall undulation, for dicotyledonous taxa only. Similarly, taxa without tap roots occur in many glume wheat samples and so it is difficult to assess any trends in tap root diameter for these taxa. These attributes, therefore, are not considered here.

6.6.1 Stomatal size and density

It is expected that weed species with few, large stomata will be associated with high water availability, whereas species with many, small stomata will be associated with low water availability (2.4.2.3, 3.1.2.2).

6.6.1.1 Stomatal size

Fig. 6.16a: There is a clear trend along axis 2, from a predominance of taxa with small stomata (length of guard cells <32 µm, especially *Phleum pratense* and *Valerianella dentata*) in samples at the positive (top) end, through samples dominated by taxa with medium stomata (length of guard cells 32-38 µm) to those dominated by taxa with large stomata (length of guard cells >38 µm) at the negative (bottom) end. The predominance of taxa with large stomata in product samples at the positive end of axis 1 and negative end of axis 2 (bottom right) is mostly due to high proportions of *Bromus arvensis/hordeaceus/secalinus*, while the predominance of taxa with medium stomata in samples at the negative (left) end of axis 1 is largely due to the dominance of *Chenopodium album*. This contrast between products and by-products may be a chance effect of crop processing acting on these two particular taxa (it is the reverse of the *expected* crop processing bias – 6.1) but the overall trend on axis 2 suggests that something more than crop processing is involved as *Phleum pratense* (with small stomata), *Valerianella dentata* (with small stomata) and *Chenopodium album* (with medium stomata) are all associated with by-products.

Fig. 6.16b: Taxa with large stomata predominate at the negative end of both axes (bottom left) but taxa with medium and small stomata are present in samples all along axis 1, with a slight tendency for taxa with small stomata to predominate at the positive (right) end. This may suggest that samples tend to derive from increasingly moist habitats from right to left along axis 1.

6.6.1.2 Stomatal density

Fig. 6.17a: A trend is evident along axis 2, from a predominance of taxa with high stomatal density (>250 per mm^2, especially *Phleum pratense* and *Valerianella dentata*) in samples at the positive (top) end, through samples dominated by taxa with medium stomatal density (150-250 per mm^2) to those dominated by taxa with low stomatal density (<150 per mm^2) at the negative (bottom) end. Again, the predominance of taxa with low stomatal density in the product samples (bottom right) reflects high proportions of *Bromus arvensis/hordeaceus/secalinus*, while the predominance of taxa with medium stomatal density in by-products at the negative (left) end of axis 1 is largely due to the dominance of *Chenopodium album*. As stomatal size and density tend to be negatively correlated (2.4.2.3), this contrast may again be due to the same chance effect of crop processing acting on these two taxa but, for the same reason as for stomatal size, the overall trend on axis 2 suggests variation due to other factors within the crop processing by-products.

Fig. 6.17b: Taxa with high stomatal density predominate in samples at the positive end of axis 1 and the negative end of axis 2 (bottom right). Taxa with low stomatal density predominate in samples at the negative end of both axes (bottom left). This trend is clearer than that for stomatal size and may again suggest that samples tend to derive from increasingly moist habitats from right to left along axis 1.

6.6.2 Summary of water use attributes

Crop processing may introduce a bias in the stomatal size and density of some of the predominant taxa in fine sieve products and by-products but, if so, it does not conform to the *expected* processing bias (6.1) and other reasons must be sought for the overall trend in these attributes.

While artificial watering of crops in the study area is unlikely, water does contribute to site productivity, and manuring enhances water as well as nutrient availability. It is not surprising, therefore, that stomatal size and, rather more clearly, stomatal density indicate a gradient of increasing water availability from right to left along axis 1 in the analysis of fine sieve by-products. This trend is similar to trends seen previously in the fertility attributes and suggests that axis 1 should be interpreted as primarily a productivity axis.

6.7 Attribute relating to shade tolerance (stomatal distribution)

It is expected that amphistomatous species, with an equal distribution of stomata on the upper and lower leaf surfaces (50-55% on one leaf surface), will be associated with unshaded conditions, whereas species with stomata mostly restricted to one or other leaf surface (95-100% on one surface) will be associated with shaded conditions (2.4.2.4, 3.1.2).

Fig. 6.18a: There is no trend on either axis and so no evidence of a general contrast between crop processing products and by-products: taxa with medium stomatal distribution (55-95% stomata on one surface) predominate at both ends of both axes.

Fig. 6.18b: There is no clear trend on either axis: taxa with medium stomatal distribution predominate at both ends of axis 1, while both amphistomatous taxa and taxa with stomata largely restricted to one leaf surface tend to reach their highest levels towards the positive (top) end of axis 2, suggesting that degree of shade does not play a major part in species composition.

6.8 Attribute relating to habitat stability

6.8.1 Seed persistence

It is expected that weed species with high seed persistence (i.e. low values for the seed longevity index) will be associated with conditions that are variable from year to year, whereas species with low seed persistence (i.e. high values for the seed longevity index) will be associated with more stable conditions (2.4.2.5, 3.1.2.2).

Fig. 6.19a: The predominance of taxa with the greatest seed persistence (longevity index < -1.0 and/or hard seed coats) in most by-products, at the negative (left) end of axis 1 as well as at the positive (top) end of axis 2, is due to the predominance, respectively, of two small-seeded species, *Chenopodium album* and *Phleum pratense*. The predominance of taxa with the least seed persistence (longevity index > -0.5) in products at the positive end of axis 1 and negative end of axis 2 (bottom right) reflects high proportions of the large-seeded taxon *Bromus arvensis/hordeaceus/secalinus*. This is hardly surprising as seed size (measured by weight) contributes to the calculation of the seed longevity index: large seeds (which tend to be heavy) have a higher longevity index than small seeds of the same shape (which tend to be lighter). Small-seeded taxa, therefore, are likely (more or less by definition) to have a persistent seed bank, though large-seeded taxa may also have a persistent seed bank if they are hard-coated.

Fig. 6.19b: Taxa with the greatest seed persistence are most abundant in samples towards the positive (right) end of axis 1 and taxa with the least seed persistence at the negative (left) end, suggesting a trend of increasingly stable conditions from right to left along axis 1.

6.8.2 Summary of seed persistence

As expected, crop processing introduces a bias in the weed content of fine sieve products and by-products in terms of seed persistence.

As noted in section 2.4.2.5, seed persistence tends to be high in most arable weed species since arable habitats are relatively disturbed, but it is particularly crucial where habitat conditions are variable from year to year, whether in terms of water availability, soil productivity or some other ecological factor affecting survival. The trend of decreasing seed persistence from right to left along axis 1 in the analysis of fine sieve by-products coincides with increasing productivity (fertility and water availability – above, 6.5-6.6) and suggests that the most productive conditions (represented by samples in the bottom left area of the plot) were also the most stable.

6.9 Phytosociological class

Phytosociological class was considered as a way of exploring variation in terms of broad habitat classifications (arable, ruderal, grassland etc.). A number of authors have suggested that past arable weed floras included species now considered typical of other habitats (e.g. grassland and ruderal habitats) (e.g. Körber-Grohne 1990, 1993; Pott 1992; Karg 1995; Stika 1999). Assuming that the wild/weed taxa in the archaeobotanical samples represent arable weeds, the presence of 'non-arable' taxa may indicate a wider range of growing conditions (e.g. less fertile and/or disturbed) than strictly 'arable' taxa.

Fig. 6.20a: The predominance of character species of the Chenopodietea in samples at the negative (left) end of axis 1 is largely due to *Chenopodium album*. The predominance of the category 'unknown class/non-character species' at the positive end of axis 1 and negative end of axis 2 (bottom right) reflects high proportions of *Bromus arvensis/hordeaceus/secalinus*. It is impossible to say whether or not this taxon is a character species of any single class since it is not accurately identified and the possible identifications are differently classified (*B. secalinus* Secalinetea; *B. arvensis* Chenopodietea; *B. hordeaceus* not a character species of any class). Along axis 2, character species of the two grassland classes, Molinio-Arrhenatheretea (*Phleum pratense*) and Sedo-Scleranthetea (*Valerianella dentata*), predominate in samples towards the positive (top) end, a trend that cannot be explained by crop processing.

Fig. 6.20b: Character species of the two grassland classes, Molinio-Arrhenatheretea (*Phleum pratense*) and Sedo-Scleranthetea (*Valerianella dentata*), predominate in samples towards the positive (right) end of axis 1. Character species of the Secalinetea and Chenopodietea are most abundant towards the positive (top) end of axis 2. Character species of ruderal communities (Artemisietea, Bidentetea, Plantaginetea) are concentrated in samples at the negative (left) end of axis 1, though taxa in the category 'unknown class/non-character species' are mostly dominant.

6.10 Summary of the effect of crop processing

Crop processing has a variable impact on the ecological conditions represented by products and by-products. Table 6.1 outlines the effect of crop processing on the different functional attributes. Seed persistence is the strongest case of a crop processing bias: the contrast between products and by-products conforms to the expected bias and, with regard to the by-products, is not based solely on the dominance *Chenopodium album*. The expected effect of crop processing on seasonality is more weakly expressed: the products do conform to expectations (dominated *Bromus arvensis/hoedeaceus/secalinus*, an autumn sowing indicator) but only the by-products dominated by *Chenopodium album* agree with predictions (i.e. appearing to derive from spring-sown crops). The expected effect of crop processing on length of the flowering period (a disturbance attribute) is similarly weak: products are dominated by short-flowering *Bromus arvensis/hordeaceus/secalinus* but the by-products are variable. Finally, attributes relating to fertility, water availability and shade do not conform to the expected crop processing biases; in fact, where differences between products and by-products are apparent, they tend to be in the opposite direction to the expected bias.

6.11 Synthesis of trends in husbandry practice

It has been demonstrated (6.3-6.9) that various ecological trends occur among glume wheat fine sieve by-products and so cannot be accounted for by crop processing bias. These trends are represented schematically in Fig. 6.21: axis 1 reflects increasing productivity from right to left and axis 2 reflects increasing disturbance from bottom to top. While spring sowing may contribute to axis 2, overall disturbance level appears to be the main cause of variation along this axis.

It is worth noting that those taxa most characteristic of 'low productivity and low disturbance' at the positive (right) end of axis 1 – *Phleum pratense* and *Valerianella dentata* – are more usually associated with grassland habitats, which tend to be less disturbed than arable land (Fig. 6.20b). Taxa characteristic of 'very high productivity and moderate disturbance' at the negative (left) end of axis 1 are associated with ruderal habitats, which tend to be affected by periodic disturbance (e.g. trampling) and may be highly fertile (Fig. 6.20b). Finally, taxa characteristic of 'high productivity and high disturbance' are associated with arable (highly disturbed) habitats (Fig. 6.20b).

The ecological trends summarised in Fig. 6.21 may explain the patterning in terms of archaeological site, region and chronological period noted in Chapter 4 (Figs. 4.36-4.38; 4.6.4-4.6.5). The major site contrast along axis 1 (Fig. 4.36), between Vaihingen (right) and Hochdorf (bottom left), clearly relates to differences in productivity. Samples from the Lower Rhine-Meuse basin are located along with those from Hochdorf in the bottom left area of the plot (Fig. 4.37), indicating very productive, moderately disturbed conditions. Samples from southern Baden-Württemberg (Hilzingen, Ulm-Eggingen) reflect higher levels of disturbance (Figs. 4.36-4.37). Samples from sites in Lower Bavaria also tend towards high levels of disturbance, though two samples from one site in this region (Meindling) occur in the bottom left area of the plot, suggesting higher productivity and more moderate disturbance (Figs. 4.36-4.37).

Fig. 6.22 shows the distribution of sites and their crop growing conditions within the study area. The Neckar Valley appears to be the most variable region in terms of growing conditions. Southern Baden-Württemberg and Lower Bavaria tend towards the category of 'high productivity/high disturbance', while the Lower Rhine-Meuse sites all fall within the 'very high productivity/moderate disturbance' group. Most of these sites are LBK in date, and the regional patterning of growing conditions may point to the existence of regional crop husbandry traditions (see also 7.1.2).

In terms of chronological patterning, the majority of samples in the correspondence analysis are of LBK date and occur in all areas of the plot; middle neolithic samples (i.e. one sample each from Endersbach and Maastricht-Randwijck) and later neolithic samples (i.e. those from Hochdorf) all occur in the bottom left area of the plot, where highly productive, moderately disturbed conditions are indicated (Fig. 4.38). Though the clustering of post-LBK samples may reflect chronological differences, the number of later samples is relatively small (12) (Table 6.2) and their proximity to LBK samples (e.g. those from the Lower Rhine-Meuse basin) suggests that any chronological change in husbandry practice was not great.

It remains to interpret ecological variation between sites, regions and periods (Figs. 6.21-6.22; Table 6.2) in terms of specific husbandry practices (Table 6.3). It was shown in Chapter 5 that the glume wheat samples generally derive from fixed cultivation plots that were intensively cultivated and autumn-sown. This suggests that ecological trends in the correspondence analysis should be interpreted within this overall context. For example, samples indicating 'low productivity/low disturbance' in Fig. 6.21 are only 'low' in comparison to the other samples in the analysis. In terms of the comparison with the Evvia pulse gardens (5.2.2-5.3), virtually all of the archaeobotanical samples derive from intensive cultivation, and so the 'low productivity/low disturbance' samples reflect *relatively* poor growing conditions within an overall intensive regime.

A range of factors could contribute to the relatively low levels of disturbance (tillage, weeding) and manuring indicated for these samples. These include low availability of human labour, low availability of manure or limited time for tillage, which needs to be carried out after autumn rains (though not following very heavy rain) but before the ground freezes (cf. Halstead 1987; Forbes 2000a, b). Crops grown under these conditions might give poor returns but provide grazing and/or fodder (P. Halstead pers. comm.).

A further possibility, suggested by the 'grassland' classification of prominent taxa in this area of the plot (Fig. 6.20), is that these growing conditions were created by some form of rotation between arable and short-term grassy fallow, perhaps on the order of one to two years' duration (cf. Karg 1995). Short fallow, even if untilled, can promote weed control by encouraging non-arable vegetation that is more easily eradicated by subsequent cultivation (cf. Ellenberg 1996: 901-902); it also provides grazing for livestock (Forbes 1976; Brombacher and Jacomet 1997). There are, however, several problems with this hypothesis. First, weedy fallow would not account for growing conditions of *low productivity* as well as low disturbance – if the land were not being cropped for up to several years, this would tend to restore productivity. Second, a 'grass' fallow would make subsequent tillage difficult (i.e. the root mat would be difficult to cut through), particularly if the ard was not used (cf. Boserup 1965: 24). Third, such a rotation/fallow regime would be likely to involve fallow grazing. Brombacher and Jacomet (1997) and Schibler and Jacomet (1999) infer the use of short grazed fallows on arable land in the neolithic Alpine Foreland from the occurrence of 'tread-resistant' perennials characteristic of pasture as weed seeds in charred crop stores (e.g. *Prunella vulgaris*, *Potentilla reptans* and *Trifolium repens*). These species are low-growing (thus avoiding grazing) and spread horizontally through rhizomes or stolons (enabling them to recover from disturbance, including trampling). By contrast, *Phleum pratense* – the primary indicator of 'low productivity/low disturbance' in the samples studied here – is a perennial lacking a procumbent growth form and vegetative spread. It appears that *Phleum pratense* does tolerate winter/early spring grazing due to its winter growth habit but that it grows poorly under summer grazing and is relatively intolerant of trampling (Grime *et al.* 1988: 252; cf. Körber-Grohne 1990). Overall, therefore, is seems unlikely that short 'grassy' fallow breaks are indicated by the 'low productivity/low disturbance' samples.

A case for grazed short-term fallow could perhaps be made for the 'very high productivity/moderate disturbance' group, which includes low-growing perennials with horizontal root systems such as *Trifolium repens*. 'Very high productivity/moderate disturbance' also suggests a greater emphasis on manuring than the previous category, along with more thorough tillage and possibly some weeding. Perhaps the high soil productivity of this category resulted from a combination of manure from livestock grazing short-term fallow and further application of manure in cultivation years.

'High productivity/high disturbance' suggests relatively intensive cultivation including high levels of soil disturbance as well as some manuring. This would involve thorough tillage – presumably by a hoe-like implement of wood or antler, possibly as a follow-up to ard ploughing – as well as weeding during crop growth. Productivity would presumably be maintained by direct applications of stall manure/household refuse and/or by manure from livestock grazing stubble.

While most of the sites in this study are associated with one particular set of ecological conditions, samples from Vaihingen – the best-represented site – show considerable variation, from the low productivity/low disturbance 'extreme' (bottom right) towards high productivity/high disturbance (the positive end of axis 2). Thus, samples from Vaihingen reflect intra-site variation in growing conditions. One possibility is that this variation relates to changes in cultivation intensity through time; such changes, however, appear unlikely according to currently available sample phasing (i.e. samples from relatively early and late phases overlap in the correspondence analysis plot – not shown). Perhaps the most plausible explanation for intra-site variation at Vaihingen is that the intensity of cultivation varied from year to year according to the needs of the community, the labour force available, manure available and time constraints imposed by the weather (Halstead 1987; Forbes 2000a, b). Perhaps this 'inevitable' variability was exaggerated by the nucleated layout of the settlement at LBK Vaihingen, promoting relatively low intensity cultivation on the 'periphery' of the cultivated area (cf. G. Jones *et al.* 1999; Forbes 2000a, b) (see also 7.1.1).

The implications of these husbandry practices with reference to specific sites, regions and periods, as well as the more general implications of permanent cultivation plots, autumn sowing and intensive cultivation (Chapter 5) for understanding early farming societies in the study area, are considered in Chapter 7.

7 Conclusions

The aim of this chapter is to draw out the wider archaeological implications of the results presented in Chapters 5 and 6. Regional and chronological variation in crop husbandry practices is discussed (7.1) before the four major models proposed for crop husbandry in the study area (1.4) are re-considered (7.2). Section 7.3 considers the implications of these results for the Mesolithic-Neolithic transition in western-central Europe.

7.1 Interpretation of variability in husbandry practices

The general identification of samples as deriving from long-lived, intensively cultivated plots sown in the autumn (Chapter 5) does not necessarily indicate that husbandry practices were totally uniform across the study area and through time. Ethnographic observations indicate that the aims and means of crop production vary in accordance with the lives of individual households (e.g. varying ratio of producers:consumers) as well as with prevailing social and environmental conditions (e.g. Halstead 1989a, b; Sahlins 1972: 101-148). It is inherently unlikely, therefore, that crop husbandry regimes were utterly fixed and unchanging.

Indeed, interpretable ecological trends in functional attribute values in the correspondence analysis demonstrate variation in the precise nature of husbandry regimes, with differing emphasis on practices related to soil disturbance and productivity (6.11). Variation in husbandry practices has been demonstrated both within and between sites. The best example of intra-site variation is Vaihingen (below, 7.1.1), while regional differences within the LBK may contribute to inter-site trends (below, 7.1.2). Finally, the major contrast between LBK Vaihingen and later neolithic Hochdorf may relate to chronological differences (below, 7.1.3).

7.1.1 Intra-site variability and settlement layout

Vaihingen is unique among the sites considered here in two respects. First, it is by far the best-represented in terms of numbers of samples. Second, almost complete excavation of the site has revealed a settlement layout that is quite different to the loose groupings of LBK longhouses (*Streusiedlungen*) known from large-scale excavation of the Merzbach valley in the Aldenhoven Plateau (1.3.1). A ditch and 'palisade' enclosed settlement at Vaihingen for a brief period in the earlier LBK (Flomborn phase); the ditch was subsequently filled in and used for burial (Krause 1998). The enclosure is associated with high nucleation by LBK standards: it is estimated that as many as 10-15(-20) contemporary longhouses occurred within the ca. 2 ha enclosed area or its immediate vicinity (R. Krause pers. comm.).

Several factors may contribute to the observed variability in husbandry practices at Vaihingen. First, the variation could be a simple function of the relatively high number of samples available. On the other hand, ten samples from ten different sites in a single region (the Lower Rhine-Meuse basin) show less variability in weed functional attributes than Vaihingen, suggesting that husbandry practices at Vaihingen were more variable. A second factor may be the relatively high degree of nucleation at Vaihingen and a corresponding tendency for intensive husbandry practices to decrease with distance from home: in more nucleated settlements, farmers might tend to cultivate plots at varying distances from home, perhaps resulting in greater variability in cultivation intensity (cf. Halstead 1987; Chapman 1990; Alcock *et al.* 1994; G. Jones *et al.* 1999; Kotsakis 1999). A complication here is that the layout of the settlement – especially its overall size – appears to have changed over time (R. Krause pers. comm.). A third possible factor is chronological change in husbandry practices during the occupation of the site, though this appears unlikely given the sample phasing currently available (6.11).

The relative uniformity of husbandry practices among sites in the Lower Rhine-Meuse basin coincides with a dispersed settlement pattern (loose groupings of longhouses – *Streusiedlungen*) and husbandry practices encouraging particularly high productivity. The largest LBK site excavated in the Merzbach valley of the Aldenhoven Plateau (within the Lower Rhine-Meuse basin) is Langweiler 8, with 11 contemporary longhouses spread over 7 ha (1.3.1), reflecting a much more dispersed layout than at Vaihingen. It could be argued that farmers in small settlements of dispersed households would be most likely to cultivate land directly adjacent to their homes, perhaps encouraging more consistently intensive husbandry.

According to this reasoning, relatively nucleated versus dispersed settlement may relate to the contrast in ecological variability between Vaihingen and the Lower Rhine-Meuse basin (with samples mainly from the Aldenhoven Plateau), while the greater productivity of cultivation plots in the Lower Rhine-Meuse basin may reflect a greater intensity of middening and manuring of cultivation plots closer to home. P. Halstead (field notes) reports, for example, that direct manuring of fields (by spreading carted stall manure) around the village of Assiros in Greek Macedonia was restricted to a ca. 500 m radius of the settlement; beyond this point, manuring was carried out indirectly, by allowing sheep to graze on stubble/fallow.

The layout of other LBK sites with multiple samples is not known in detail. At Ulm-Eggingen, the numbers of contemporary structures and full extent of the settlement is unclear, though the distance between contemporary longhouses appears to have been smaller than at Langweiler 8 (Strien 1990: 12). At Hilzingen, the phasing of longhouses is problematic due to a lack of find-rich pits associated with particular structures, and the extent of settlement is also unclear (Dieckmann and Fritsch 1990). Finally, the layout and extent of the site at Meindling in Lower Bavaria could not be determined in detail (Modderman 1992).

The houses at later neolithic Hochdorf were small, post-built structures typical of this period (1.3.2), but the density and extent of settlement are unclear (Keefer 1988: 42-43). The small size of the Schussenried houses at Hochdorf compared with LBK longhouses has been interpreted to suggest that more activities tended to take place in communal areas or structures (Keefer 1988: 42-47; Last 1996). Perhaps cultivation plots tended to be organised more communally as well (e.g. consolidated blocks of plots rather than dispersed plots) (see also below, 7.1.3.3). In view of the close spacing of houses at other later neolithic sites (Keefer 1993: 128), the layout of the Hochdorf site may have been much more nucleated than that of the Lower Rhine-Meuse sites, though weed functional attributes indicate that crop husbandry practices were similar. There is a slight indication that husbandry practices were more variable at Hochdorf than in the Lower Rhine-Meuse basin, however, which could be a function of greater nucleation at Hochdorf.

7.1.2 Regional differences within the LBK

Regional differences in ceramic decoration emerged during the LBK period and became increasingly accentuated in the later phases (Lüning 1988; Modderman 1988; Kneipp 1995). Regional differences in 'economy' may also have existed during the LBK. An early attempt to distinguish regional economic strategies was made by Sielmann (1971, 1972). He defined two ecological zones of LBK settlement in western Germany (an agriculturally favourable low precipitation zone 'A' and a less favourable higher precipitation zone 'B') and related them to stylistic differences in ceramic decoration. More recently, regional differences in crop spectra (Willerding 1980, 1983b; Willms 1991; Küster 1995b: 81-86; Heim and Jadin 1998; Lüning 2000: 60), weed assemblages (Bakels 1992; Küster 1995b: 86-87) and faunal spectra (Döhle 1993, 1994; Arbogast and Jeunesse 1996; Tresset and Vigne 2001) have been identified.

Functional ecological differences in weed taxa appear to reflect regional differences during the LBK: samples from multiple LBK sites in the Lower Rhine-Meuse basin, Lower Bavaria and southern Baden-Württemberg share weeds with similar functional attributes. On the other hand, the Neckar valley sites are dominated by the contrast in weed functional attributes between LBK Vaihingen and later neolithic Hochdorf (below, 7.1.3) and, to a lesser extent, diversity within Vaihingen itself (ranging from 'low productivity/low disturbance' to 'high productivity/high disturbance'). The only other LBK site in the Neckar valley included in ecological analyses in Chapter 6 is Ditzingen, represented by a single sample in the 'high productivity/high disturbance' group.

Differences in weed functional attributes between regions cannot be explained simply by regional 'economic independence' (i.e. lack of seed corn circulation between regions), a suggestion put forward by Küster (1992d, 1995b: 86-87). If husbandry practices were uniform between regions, lack of seed corn circulation by itself would not create distinctive regional weed floras. Instead, regional differences imply both differences in husbandry practices and a lack of seed corn circulation between regions.

Table 7.1 lists a number of variables that could relate to differences in LBK husbandry practices between regions. Each of these variables is considered below.

7.1.2.1 Crop spectra

Of the various differences in crop spectra that have been observed over the whole zone of LBK settlement, the occurrence of barley offers the only obvious contrast between the regions in Table 7.1; otherwise, the same crops are attested in each region, though of course their relative importance may have varied. It should be emphasised that mixtures of einkorn and emmer – the glume wheats on which the ecological analysis was based – are by far the most abundantly and consistently found crops, usually in the form of chaff (2.5.1). Furthermore, 'rich' finds of barley (e.g. more than 100 items per sample) are generally rare even in the regions where barley is attested, and so its significance is uncertain. It has also been suggested that the importance of barley varied through time within the LBK period (Rösch 1998b).

Barley is considered by some archaeobotanists to be more tolerant of poor growing conditions than einkorn or emmer (e.g. Heim and Jadin 1998; Rösch 1998b), though it is questionable whether barley is truly more stress-tolerant than einkorn (cf. Percival 1974: 171). It is interesting to note that the lack of barley in the Lower Rhine-Meuse basin coincides with the highest soil productivity. Barley is also lacking in Lower Bavaria (the next most productive region) but present in southern Baden-Württemberg and the Neckar valley, where it may relate to slightly less productive growing conditions (especially at Vaihingen). It should be emphasised, however, that no 'rich' barley finds are known from the sites in question (Hilzingen, Ulm-Eggingen, Vaihingen, Ditzingen).

7.1.2.2 Faunal spectra

Animal husbandry may affect both productivity (e.g. through manuring) and soil disturbance levels (e.g. weedy fallow for grazing reducing disturbance or hand weeding for fodder increasing disturbance) in cultivation plots. Animal bone assemblages from LBK sites in the Neckar valley, southern Baden-Württemberg and Lower Bavaria are generally characterised by relatively high proportions of pig (the second most important domesticate after cattle) and wild fauna. High proportions of pig in these regions may generally relate to intensive disturbance and manuring of cultivation plots: pigs are known to break up soil effectively and clear plots of weeds while also providing manure (Rowley-Conwy 1981; Brombacher and Jacomet 1997).

Bone preservation at LBK sites in the Lower Rhine-Meuse basin is poor, but Tresset and Vigne (2001) have argued that animal husbandry there was similar to that in the Paris Basin and Hungarian Plain, where cattle are strongly predominant and levels of pig and wild fauna are low. It could be argued, therefore, that growing conditions of high productivity and moderate disturbance associated with the Lower Rhine-Meuse basin correspond to animal husbandry focussed on cattle – bulk manure providers (Rowley-Conwy 1981) but without the thorough soil disturbance provided by pigs. By contrast, growing conditions at sites in southern Baden-Württemberg (Hilzingen, Ulm-Eggingen), Lower Bavaria (Meindling etc.) and to some extent the Neckar valley (Ditzingen, some samples from Vaihingen) tend towards high productivity and high disturbance – conditions that could be promoted by pigs. The lack of adequate bone evidence from the Lower Rhine-Meuse basin, however, means that this hypothesis remains speculative.

7.1.2.3 Ecological zone

Sielmann's (1972) study of ecological zones of LBK settlement classified the Neckar valley and Lower Bavaria in the wetter zone 'B' (Table 7.1). By contrast, the middle Rhine (adjacent to the Lower Rhine-Meuse basin) falls within the drier zone 'A' (Table 7.1). This suggests that husbandry differences between Lower Bavaria and the Lower Rhine-Meuse basin could relate to general environmental differences. Sielmann (1972) suggested on the grounds of general environmental favourability that barley cultivation would have been more important in the 'B' zone; it is lacking, however, from LBK sites in Lower Bavaria (Table 7.1). In addition, there is no evidence from the functional attributes for drier growing conditions in the Lower Rhine-Meuse basin: in fact, habitat moisture as a component of site productivity appears to have been higher in the Lower Rhine-Meuse basin than in the 'wetter' regions of the Neckar valley and Lower Bavaria (6.6, 6.11).

It should be noted that general soil type (loess versus non-loess) has also been excluded as a cause of floristic differences (4.6.3.2).

7.1.2.4 Material culture

It remains to consider whether differences in husbandry practices coincide with differences in material culture. Flint source varies among sites and regions (e.g. Lüning 1988), but this is affected by logistical considerations (i.e. the proximity and quality of flint sources). Regional coherence in ceramic decorative style, on the other hand, appears to reflect social links and interaction. Groupings based on LBK ceramic decoration have been defined on a broad regional scale (Lüning 1988; Strien 1990). In very intensively studied areas such as the Aldenhoven Plateau, micro-regional differences among sites have also been investigated, revealing variability in ceramic decoration even among longhouses in the same settlement (Lüning 1988, 1997; Fridrich 1994).

The four regions discussed here correspond to three groups that are stylistically distinct in terms of ceramic decoration (Lüning 1988) (Table 7.1). Differences in ceramic decoration, therefore, coincide to some extent with differences in husbandry practices.

Another aspect of LBK material culture that appears to reflect broad regional differences relates to funerary practice. Jeunesse (1996) has proposed two regional traditions in funerary practice for the western part of the LBK settlement zone (Germany, France, The Netherlands). In Tradition I, bodies are buried facing east and covered with red ochre powder; shell ornaments (especially *Spondylus*) are prominent among grave goods. In Tradition II, bodies are often buried facing west and covered in red ochre fragments (as opposed to powder); stone tools (including grinding stone fragments) and ceramics are prominent among grave goods. The Lower Rhine-Meuse basin and the Neckar valley are included in Tradition I, Lower Bavaria in Tradition II (Table 7.1); LBK funerary practices in southern Baden-Württemberg have not been classified by Jeunesse (1996). Clearly, differences between the Lower Rhine-Meuse basin and the Neckar valley in husbandry practices do not reflect their similarity in funerary practice.

7.1.2.5 Summary

Regional differences in husbandry practices in the LBK do not obviously correspond to differences in crop or faunal spectra, though this may be due to taphonomic factors such as poor preservation (e.g. lack of bone assemblages from the Lower Rhine-Meuse basin, lack of 'rich' barley finds). Furthermore, differences in ecological zone – or general soil type (4.6.3.2) – also do not appear to explain regional variation in husbandry practices among LBK sites. Regional differences in husbandry practices, however, do coincide to some extent with broad regional differences in ceramic decoration.

Attempts to link regional ceramic styles with differences in crop or faunal spectra in the Neolithic have been criticised by Lüning (2000: 209, 212). He points out that some differences in faunal spectra (e.g. tendency towards high pig levels in south-west Germany) and crop spectra (e.g. lack of barley in Lower Bavaria) transcend the LBK and persist over long periods. In other cases, faunal and crop spectra appear to have changed over a short period, perhaps in response to short-term climatic fluctuations (Schibler *et al.* 1997a, b; Hüster-Plogmann *et al.* 1999) (1.3.2).

Crop husbandry routines may have contributed to social cohesion on a regional scale, as reflected in shared ceramic styles. 'Social' considerations influencing husbandry practices could include obligations to share surplus food with kin in other settlements whose crops had failed and/or commitments to cycles of ritual activity. Close similarity in crop husbandry practices among sites in some regions (the Lower Rhine-Meuse basin, southern Baden-Württemberg, Lower Bavaria) is consistent with shared aims and expectations regarding crop production and also a close synchronisation of activity cycles. Though small-scale intensive cultivation is essentially designed for the ideal of independent household production (cf. Sahlins 1972: 95-97), it appears that crop husbandry regimes were also responsive to the wider social obligations of each household, both within the immediate community and on a wider regional scale. The diversity of crop husbandry practices at Vaihingen, on the other hand, may relate to its unusually nucleated character (above, 7.1.1).

7.1.3 Chronological differences (LBK Vaihingen versus LN Hochdorf)

The chronological trend in weed functional attributes is not very clear: all of the post-LBK samples (two middle neolithic plus ten later neolithic samples from Hochdorf) indicate very high productivity and moderate disturbance, but so do LBK samples from the Lower Rhine-Meuse basin (6.11). The contrast between LBK Vaihingen and Ditzingen and later neolithic

Hochdorf, however, may relate to genuine chronological differences in crop husbandry practices within the Neckar valley. Because Ditzingen is represented by a single sample in the ecological analysis (Chapter 6), the following discussion will focus on the contrast between Vaihingen and Hochdorf.

Table 7.2 lists a number of variables that could relate to chronological differences in husbandry practice between Vaihingen and Hochdorf. Each of these variables is considered below.

7.1.3.1 Crop spectra

The later neolithic Schussenried culture to which Hochdorf belongs is associated with a wider crop spectrum than the LBK, and it has been suggested that new husbandry methods allowed the spread of Schussenried settlement to less fertile, non-loess soils and poorly drained areas (e.g. the Federsee) (Keefer 1993: 123). While Hochdorf itself, like Vaihingen, is located on loess soils, crop spectra at the two sites do differ (Küster 1985; Rösch 1998b; Bogaard unpublished). Einkorn and emmer (which always occur as mixtures) are the only richly attested cereal crops at Vaihingen; hulled barley grains occur at low levels in a restricted number of samples. By contrast, naked barley is well attested at Hochdorf in addition to einkorn/emmer mixtures; free-threshing wheat (grain and rachis) also occurs at low levels. With regard to pulses, common pea occurs at moderate levels at both sites and lentil is attested at low levels only at Vaihingen; for oil-seed crops, opium poppy seeds occur at low levels at both sites along with flax (the latter a single seed at Hochdorf).

Wider cereal diversification at Hochdorf may have allowed more reliable cereal production than at Vaihingen. Perhaps greater reliability also relates to higher soil productivity at Hochdorf as indicated by weed functional attributes, which could reflect a combination of manuring and stubble/fallow grazing (6.11). These practices could reflect a closer integration of animal and plant husbandry fostered by the development of local crop strains and the wider of the cereal spectrum: perhaps the broader range of crops enhanced their potential as both food and fodder. This link between a broader crop spectrum and more productive growing conditions, however, is admittedly speculative.

7.1.3.2 Faunal spectra

Faunal assemblages from south-west Germany tend to maintain the same frequency-order of domesticates from the Early through to the Later Neolithic, with cattle predominating, followed by pig, and sheep/goat least frequent (Döhle 1993: 119; Benecke 1994a: 89). The faunal assemblages from both Vaihingen (Argobast 1998) and Hochdorf (Makovicz-Poliszot

1988) exhibit this tendency. Detailed age/mortality data for these assemblages are not available, and so the degree to which they resemble optimal meat or dairying strategies for cattle or sheep/goat cannot be compared. Proportions of wild fauna at the two sites differ only slightly (16% at Vaihingen, 7% at Hochdorf based on total numbers of identified specimens). Obvious differences between the two sites in animal husbandry and hunting levels, therefore, are lacking.

7.1.3.3 Material culture

As noted above (7.1.1), the LBK and Schussenried cultures differ in house form: the one- to two-roomed houses known from Schussenried sites are smaller than LBK longhouses. The Hochdorf houses (average ca. 5.5 x 3.5 m – Keefer 1988: 44) are much smaller than the Vaihingen longhouses, which tend to be 7 m wide and usually ca. 20+ m long (Krause 1998). The difference in house size may indicate that residential units were smaller in the later period and/or that certain activities confined to individual longhouses in the LBK took place in more communal spaces or buildings. Communality is also suggested by the closer spacing of houses in well-preserved later neolithic settlements compared with those of the LBK (Keefer 1993: 128). As noted above (7.1.1), however, longhouses at Vaihingen were also closely built and so the main distinction in settlement form between Hochdorf and Vaihingen is likely to have been house form/size.

It is unclear how smaller house (and household?) size at Hochdorf, and perhaps a more communal organisation of crop production, might relate to more productive growing conditions than at Vaihingen. One could speculate that greater communality encouraged greater consolidation of cultivation plots (without any significant expansion in the total cultivated area) and perhaps also systematic stubble/fallow grazing and manuring.

7.1.3.4 Summary

Differences in crop husbandry between LBK Vaihingen and later neolithic Hochdorf may coincide with differences in the reliability and/or communality of arable farming, as suggested by a wider cereal spectrum and smaller houses at Hochdorf, respectively. The tentative explanations suggested above, however, are speculative. Perhaps the most secure conclusion is that crop husbandry differences between Vaihingen and Hochdorf probably relate to other fundamental differences (e.g. household form and size) between the LBK and Schussenried cultures.

7.2 Reconsideration of the four major husbandry models

7.2.1 Shifting cultivation

Shifting cultivation can be rejected as a model for the Neolithic of western-central Europe based on the ecological comparison between the weed floras of experimental plots in the Hambach Forest experiment and the archaeobotanical wild/weed data (5.1). Previous arguments against early shifting cultivation in western-central Europe have tended to emphasise that it would be ecologically *unnecessary* (e.g. Modderman 1971; Lüning 1980; Rowley-Conwy 1981; Barker 1985: 141-143). Thus, Jarman and Bay-Petersen (1976: 180-181) assert that, "on the basis of the site territories [of LBK sites on loess] and an estimate of their exploitation potential . . . shifting cultivation would not have been necessary and would probably have been wasteful of resources". Such arguments, however, leave room for manoeuvre to archaeologists seeking continuity in mobile lifestyle between the Mesolithic and Neolithic (Barrett 1994: 143-148, 1999; Whittle 1996a: 160-162, 176-177, 363-364, 1996b, 1997; Thomas 1999: 23-32) – a scenario in which the 'ecological necessity' and 'wastefulness' of shifting cultivation is arguably irrelevant. The direct archaeobotanical evidence for crop husbandry analysed here, however, points unambiguously to the cultivation of long-established fixed plots.

Shifting cultivation has recently been associated with a mobile lifestyle and hence with Mesolithic-Neolithic continuity in western-central Europe (1.4.1, 1.4.6.1). The assumption of mobility as a necessary corollary of 'indigenous' farming, however, is problematic, as discussed earlier (1.4.6.1). The corresponding expectation of an 'intrusive' form of crop husbandry facilitating colonisation (i.e. floodplain cultivation – 1.4.6.3) is also questionable (see below, 7.2.3).

Fixed-plot cultivation implies that at least part of the community was more or less sedentary, tending crops and stores of grain at the 'home base' (cf. G. Jones 2000). On the other hand, rejection of shifting cultivation does not necessarily imply a rejection of the 'egalitarian' social structure generally associated with it: fixed-plot cultivation – particularly when it involves widespread uncertainty – is consistent with a lack of social ranking (1.4.6.1). Equally, however, fixed-plot cultivation harbours the potential to promote inequality between households once widespread risks have diminished (i.e. with the development of local crop strains) (1.4.6.1).

7.2.2 Extensive ard cultivation

Extensive ard cultivation of cereals is unlikely for all but a minority of samples given their overwhelming classification as deriving from intensive cultivation (Table 5.6; 5.2.3). While this does not exclude the possibility of ard cultivation *per se*, it implies that, if the ard did come into widespread use during the Neolithic in the study area, it was generally used to perpetuate *intensive* agriculture rather than to introduce extensive regimes. The immediate effect of the ard in this case would not have been to cultivate considerably larger areas than could be managed intensively with practices such as manuring and weeding. This result adds further support to the idea, discussed in section 1.4.2, that large-scale extensive cultivation with specialised plough oxen is unlikely to have developed in the study area in the Neolithic.

It should be emphasised that the bulk of samples included in ecological analyses (107 out of 130, ca. 82 %) date to the Early Neolithic (LBK). These results are particularly relevant, therefore, to Lüning's (1979/80, 1980, 2000: 160-161, 163, 181) model of extensive ard cultivation from the LBK onwards (1.4.2.1). The possibility of extensive cultivation in the Later Neolithic has not been thoroughly assessed since only 16 out of 130 samples included in ecological analyses date to this period (Table 5.9). Nevertheless, of the later neolithic samples, only one (from Grossachsenheim, Schussenried culture – Table 4.3) was classified as deriving from extensive cultivation (Tables 5.8-5.9). Samples classified as deriving from intensive cultivation include the only Baden (Later Neolithic period) sample (from Kamenin, southern Slovakia – Table 4.3) (Table 5.8), a result that conflicts with Sherratt's (1981, 1997) arguments for extensive plough cultivation in this particular period (1.3.2, 1.4.2.2). The single sample of the Corded Ware culture (Later Neolithic period) (from Mythenschloß, Lake Zurich – Table 4.3) was also classified as deriving from intensive cultivation (Table 5.8), a result that does not support the case for extensive cultivation in this period in the Alpine Foreland, as argued previously by Schibler and Jacomet (1999) (1.4.2.2).

As noted in section 5.2.4, it is intriguing that two of the three bronze age samples were classified as fields (Table 5.9). Perhaps this reflects a genuine trend towards extensive ard cultivation in the Bronze Age in some areas, but clearly a much larger dataset is needed to assess such a trend properly.

In terms of the broad social implications of cultivation intensity discussed in section 1.4.6.2, the general rejection of extensive ard cultivation for the Neolithic does not remove the possibility that social ranking developed; rather, social ranking is removed as a *precondition* of cultivation. The case for inherited social status in the LBK, for example, can no longer be supported by the argument that ranking was fundamental to the agricultural success of LBK communities. Furthermore, intensive cultivation would be unlikely to foster the emergence of social differentiation under conditions of widespread risk and uncertainty (1.4.6.1).

7.2.3 Floodplain cultivation

Horticultural plots in river floodplains or alluvium – as envisioned by Kruk (1973, 1980: 51-54, 63; 1988), Sherratt (1980, 1981, 1997) and Bogucki (1982: 40, 1988: 76-84, 1996) for the Early-Middle Neolithic in particular – would require a spring sowing regime in order to avoid destruction of crops by earlier flooding (1.4.3). In fact, the vast majority of samples have been identified as autumn-sown (Table 5.6; 5.2.3), a result that excludes the possibility of cultivation within the flooding zone of watercourses.

Even where samples appear spring-sown, this may be a result of taphonomic processes and/or high cultivation intensity. The probable impact of crop processing is to exaggerate the abundance of spring sowing indicators in fine sieve by-products (3.4.1, 5.2.1, 5.2.3, 6.10). Intensive soil disturbance would also encourage high levels of spring sowing indicators in the weed flora generally (6.4.4). If such interpretations are correct, 'spring-sown' samples do not reflect a degree of floodplain cultivation but rather a combination of taphonomic processes (crop processing, possibly also contamination by collected *Chenopodium album* – see 4.5.1) and/or high levels of soil disturbance due to thorough tillage and weeding.

Floodplain farming cannot be excluded for the minority of (LBK) samples identified as spring-sown, though these tend to derive from sites where its extent would at least be limited for topographical reasons (Table 5.8): Vaihingen, Ditzingen, Ulm-Eggingen, Aiterhofen, Meindling, Langweiler 2 and Langweiler 8 are all located near streams/stream beds with narrow floodplains (Lüning 1982a, 1988, 2000: 184; Kind 1989: 19, 23; Stehli 1989; Bakels 1992b; Krause 1998; Piening 1998). The situation of Hilzingen is more ambiguous due to erosion, colluviation and drainage around the site since the Neolithic (Dieckmann and Fritsch 1990). Hilzingen is also the only site with multiple samples associated exclusively with spring sowing (Table 5.8; 5.2.4).

While it is clear that floodplain cultivation was not widely practiced in the LBK, river/stream valleys may instead have provided an important form of seasonal pasturage for livestock (Bakels (1978: 139; Wasylikowa 1989; cf. Brombacher and Jacomet 1997) (1.3.1). The need for relatively open grazing areas in a heavily wooded environment may have influenced the location of early-middle neolithic settlements.

As discussed in section 1.4.6.3, floodplain cultivation has been associated with LBK colonisation, but the assumed link with 'immigrant' farming is open the question. The rejection of floodplain cultivation, therefore, should not be used to suggest that early neolithic farmers were of indigenous origin. The evidence of widespread autumn sowing of cereals also suggests that opportunities for intensive foraging and hunting in the autumn, when wild plant and ungulate productivity is particularly high in temperate Europe, were limited by the need to sow as well as harvest crops (1.4.6.1, 1.4.6.3).

7.2.4 Intensive garden cultivation

The intensive garden cultivation model proposed by Halstead (1989b) for the LBK period emerges as the most plausible and widespread form of crop husbandry in the study area. The classification of most samples as deriving from 'autumn-sown gardens' (Table 5.6; 5.2.3) suggests that cereals tended to be cultivated intensively with high inputs of human labour, outside the 'naturally fertile' conditions that floodplains may have offered. Indeed, intensive cultivation (thorough tillage and weeding) itself may have caused the obliteration of weeds indicative of autumn sowing in some cases, resulting in the classification of some LBK samples as spring-sown (above, 7.2.3).

As discussed in section 1.4.5, intensive garden cultivation implies a substantial time/labour commitment to crop cultivation as well as some degree of integration between plant and animal husbandry (e.g. manuring of crops, grazing of stubble/fallow). It is unlikely, therefore, that a separate pastoral component of the economy developed during the period analysed (cf. Halstead 1987, 1989b, 2000). Intensive garden cultivation also suggests high area yields and hence smaller cultivation areas per household than commonly assumed (see Table 1.1). Given yields of ca. 1500 kg/ha (cf. ethnographic data from intensive spelt cultivation in Asturias – Table 1.2), for example, a household of 5 individuals (each requiring ca. 300 kg/year – assuming that cereals provided the bulk of the diet) would need to cultivate ca. 1 ha (Table 1.3) rather than the 2-4 ha sometimes inferred for the study area (Table 1.2). Such a cultivation area falls well within the labour capacity of ethnographic farming families (1.4.2.1). The likelihood of such small cultivation areas is also relevant to the minimal signs of neolithic cultivation in pollen diagrams from the study area (pollen of cereals, ruderals etc.) (Kalis and Meurers-Balke 1988, 1997; cf. Halstead 2000), which have previously been used to question the economic importance of cultivation in the LBK, for example (Whittle 1997). Finally, the recognition of early cultivation as intensive demands a reassessment of perspectives on the Mesolithic-Neolithic transition (below).

7.3 LBK crop husbandry and the Mesolithic-Neolithic transition

A fundamental question surrounding the 'spread' of the LBK is whether it represents the movement of communities from south-east Europe (the Hungarian Plain), the adoption of new practices by local hunter-gatherers or some combination of the two (e.g. Dennell 1983: 176; Zvelebil 1986, 2000; Modderman 1988; Whittle 1996a: 160-162, 176-177, 363-364, 1996b, 1997; Gronenberg 1999; Bogucki 2000; Price *et al.* 2001) (1.3.1, 1.4.6.1). While both shifting cultivation and floodplain cultivation have been rejected as models of neolithic crop husbandry (above, 7.2), the assumed link between these husbandry regimes and indigenous versus immigrant identity has also been called into question (1.4.6.1, 1.4.6.3). Though crop husbandry may not provide a useful way of determining the *origin* of Europe's first farmers, husbandry routines do have important implications for the *role of crop growing* in early neolithic communities, a critical aspect of the Mesolithic-Neolithic transition.

A major conclusion of this project is that crop husbandry in the LBK period tended towards intensive garden cultivation of fixed plots that were sown in the autumn. This reconstruction has three major implications for the Mesolithic-Neolithic transition.

First, intensively cultivated plots could be maintained and used productively for extended periods of time, from one generation to the next. With the continual replacement of soil nutrients through manuring or middening, carefully managed plots could potentially be cultivated for centuries without exhaustion. The 'spread' of LBK settlements across Europe, therefore, cannot be regarded as a function of soil exhaustion, even on a generational or longer time scale. Furthermore, the long-term benefits of manuring on soil productivity, along with the short-term damage it can cause by encouraging the crop to lodge (1.4.5), underline its role as an essentially *long-term investment* in a fixed plot of land. Established cultivation plots would be a valuable asset to households and communities; though potentially cultivatable land was plentiful, established cultivation plots could not be easily 'replaced', as in a shifting cultivation or floodplain cultivation regime, but would have to be created 'from scratch'.

Intensive garden cultivation, therefore, would not be particularly conducive either to adoption by a hunter-gatherer population *or* to the movement of immigrant groups, so there is no reason to believe that the 'spread' of the LBK settlement was in any way prefigured in the husbandry regime itself. In other words, our understanding of the Mesolithic-Neolithic transition in western-central Europe can no longer rely on an assumption of a crop husbandry regime 'pre-adapted' to rapid assimilation and/or immigration, as it has tended to do since Childe (1929). Rather, the 'spread' of farming took place *despite* the stationary and intensive nature of the husbandry regime and the inertia generated by plots tended carefully over many years.

Second, high cultivation intensity has been linked in a number of ways to risk-buffering in the context of small-scale household production (Halstead 1987, 1989a, b). Husbandry practices such as dibbling or row-sowing, manuring, hand weeding and hoeing promote high seed-yield ratios and area yields, enabling households to cultivate a manageable area (1.4.2.1, 1.4.5) and to produce a surplus in good years to supplement poor returns in bad years. A particular risk of crop failure that may have threatened farmers in the LBK is the poor adaptation of 'foreign' crop strains to local conditions in western-central Europe (1.4.6.1). Risk-buffering may also be reflected in dispersed settlement patterns and the long-distance exchange of exotic items such as *Spondylus* shell ornaments (1.4.6.1). Risk minimisation would only become a paramount concern if the survival of the household and wider community depended on the success of crop production.

Though labour-intensive cultivation implies that crops were grown on a relatively small scale (without substantial surplus production), its restricted scale does not mean that it reflects a limited form of 'experimental' cultivation. Rather, intensive garden cultivation indicates substantial labour investment in crop production and implies that crops did not play a minor supplementary role alongside cattle herding, as has been suggested for the LBK generally (Whittle 1996a: 162, 1997) or for certain regions where cattle are strongly predominant (Tresset and Vigne 2001). Instead, intensive garden cultivation suggests that crop production played a central role and may have provided the bulk of the human diet.

This point is underlined further by widespread autumn sowing of cereals, which would exacerbate the "scheduling crisis" in autumn for communities pursuing intensive foraging and hunting alongside agriculture in temperate Europe (Zvelebil and Rowley-Conwy 1986; see also Rowley-Conwy 2000) (above, 7.2.3). Following the cereal harvest in July-August, autumn sowing in September-October would coincide with the collection period for storable, calorie-rich wild plant foods such as hazelnuts, acorns and wild apple (Jacomet *et al.* 1989: Fig. 74, 223-225). Ungulates are also in prime condition in the autumn (Zvelebil and Rowley-Conwy

1986). By contrast, spring sowing in March-April would not coincide with marked peaks in the productivity of wild plant foods (Jacomet *et al.* 1989: Fig. 74, 223-225) or hunted fauna (Suter and Schibler 1996: Fig. 7). Though cereal growing, the collection of nuts etc. and hunting in autumn are by no means mutually exclusive, the decision to sow cereals in autumn rather than in spring implies that cereal cultivation displaced these other activities to some extent. Cereals may have been autumn-sown in order to produce higher yields and/or to divide the labour of soil preparation and sowing over two seasons, other crops (pulses, flax, poppy) potentially being sown in spring (Gregg 1988: 76-78, 132; Jacomet *et al.* 1989: 142; Kreuz 1990: 173; Brombacher and Jacomet 1997: 264). It is worth noting here that an apparent episode of climatic deterioration and failure in the production of autumn-sown cereals during the 37th century B.C. (later Pfyn period) in the Alpine Foreland coincided with a sharp rise in red deer hunting and wild plant gathering (Brombacher 1995; Brombacher and Jacomet 1997; Schibler *et al.* 1997a, b; Hüster-Plogmann *et al.* 1999).

A third implication is that the technology of intensive garden cultivation – unlike that of extensive ard cultivation (requiring both the ard and animal traction) – would consist of elements that were arguably present and used for plant husbandry in the Mesolithic of temperate Europe (e.g. soil digging implements, manure, harvesting equipment) (Zvelebil 1994; cf. Gronenberg 1999: 137); recent pollen analyses from the Lake Zurich area may even suggest "pre-neolithic" cultivation of cereals (Haas 1996; Erny-Rodmann *et al.* 1997). It can be argued, therefore, that, on a basic technological level, LBK horticulture did not represent a radically new way of manipulating plant resources in western-central Europe. On the other hand, the adoption of agriculture by indigenous hunter-gatherers could represent a fundamental change in the social organisation of production, as well as in the level of commitment to plant husbandry (cf. Gronenberg 1999: 142-143). This interpretation, however, depends on the extent of residential mobility among hunter-gatherers in the loess belt; a high degree of mobility is generally assumed (e.g. Jochim 1976: 180-181, 2000; Gregg 1988: 29) but this has recently been questioned (Zvelebil 2000) (1.4.6.1). Horticulturalist households tend to be organised as productive groups, whereas residentially mobile hunter-gatherer households are associated with distributive and reproductive activities (Wilk and Netting 1984: 20; Gregg 1988: 23-29). The transition to farming, therefore, may resemble "a process of transition from band or individual production and household pooling, to a system of household production and exchange among households" (Wilk and Netting 1984: 20). Whether or not LBK farmers were immigrants or indigenous people, intensive garden cultivation – like the prominence and even monumentality of the longhouse itself (cf. Hodder 1990) – attests to the importance of the household as the fundamental social and economic unit (cf. Sahlins 1972: 95-97).

7.4 Final summary

This project has demonstrated how archaeobotanical wild/weed data can be used to reconstruct crop husbandry practices and directly evaluate competing models. In so doing, it has overturned some long-held ideas about neolithic crop husbandry in western-central Europe. Intensive cultivation of fixed, autumn-sown plots emerges as the most plausible model of crop husbandry, with some evidence of variation in crop husbandry routines within and between sites. While the intensive garden cultivation model does not directly address the two extremes of colonisation versus indigenous adoption as explanations for the Mesolithic-Neolithic transition, they do clarify the value of established plots and difficulty of creating new ones 'from scratch', the central role of crop cultivation in the LBK and the radical emphasis on the household as the fundamental social and production unit.