NEOLITHIC FARMING IN CENTRAL EUROPE

An archaeobotanical study of crop husbandry practices

Amy Bogaard

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Neolithic Farming in Central Europe examines the nature of the earliest crop cultivation, a subject that illuminates the lives of Neolithic farming families and the day to day reality of the transition from hunting and gathering to farming.

Debate surrounding the nature of crop husbandry in Neolithic central Europe has focused on the permanence of cultivation, its intensity and its seasonality, variables that carry different implications for Neolithic society. Amy Bogaard reviews the archaeological evidence for four major competing models of Neolithic crop husbandry – shifting cultivation, extensive plough cultivation, floodplain cultivation and intensive garden cultivation – and evaluates charred crop and weed assemblages. Her conclusions identify the most appropriate model of cultivation, and highlight the consequences of these agricultural practices for our understanding of Neolithic societies in central Europe.

Amy Bogaard is Lecturer in Archaeological Science at the Department of Archaeology, University of Nottingham. Her main research interests are early farming practices and archaeobotany.

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INTRODUCTION

This book is concerned with the nature of early farming in central Europe – in particular the methods used to grow crops. Current perceptions of crop cultivation in central Europe during the Neolithic vary widely and include models of transient and permanent cropping, small-scale hand tillage and large-scale cultivation with the ox-drawn ard, farming of floodplain alluvium and higher ground. Debate over crop husbandry reflects conflicting views of the way in which farming spread from the Near East to Mediterranean and temperate Europe, the mobility of early farming communities, the extent of social differentiation among households and the goals of crop production. The aim of this book is to address these conflicting views of early crop husbandry by analysing the extensive archaeobotanical dataset available from Neolithic sites (*c.* 5500–2200 BC) across central Europe, in particular the loess belt and Alpine Foreland.

The general intention of this book, therefore, is to bring a substantial archaeobotanical record from central Europe into the mainstream of archaeological discourse on European prehistory. The approach used is to interpret the archaeobotanical data in terms of an explicit methodology for reconstructing crop husbandry practices, and to evaluate previously suggested models of crop husbandry in light of the archaeobotanical evidence. Non-specialists may be surprised to find that this analysis is not based on the crop species themselves, but rather on close attention to the arable weeds that grew and were harvested with certain crops. It is this 'weed' evidence that reflects the fundamental 'agency' of crop growing – the time chosen to sow crops, measures taken to encourage growth, the permanence of cultivation areas in the landscape, and so on. These choices, in turn, provide a rich source of evidence for the everyday life and longer-term transformations of past societies.

Archaeologists seeking to refine their accounts of agricultural practice beyond the listing of domesticated species from archaeological sites soon face a real methodological problem. Explicitly constructed models based on relevant features of plant and animal ecology are needed in order to relate bioarchaeological assemblages back to management regimes, and such models are still being developed (e.g. Charles *et al.* 1997; Halstead 1998; Mainland 1998; Balasse and Tresset 2002).

An overriding concern with methodology and model-building is often associated with the New Archaeology and related approaches of the 1960s and 1970s (Binford 1972; Higgs 1975), which focused on subsistence and technology and emphasized human adaptation to the environment. A problem with this approach is that it sometimes made the diversity of human culture seem redundant (Barker and Gamble 1985; Shanks and Tilley 1987). By contrast, post-processual archaeology (Hodder 1986, 1991; Shanks and Tilley 1987; Barrett 1990, 1994) has rejected these preoccupations, emphasizing the interpretation of meaning and symbolism in the form and functioning of houses, settlements and landscapes, in artefact styles or in mortuary practices. Recent accounts of the Mesolithic–Neolithic transition in Europe (e.g. Hodder 1990; Thomas 1999; Barrett 1994; Whittle 1996a; Bradley 1998) have focused on these forms of evidence, with only generalized consideration of the nature of agricultural practices themselves.

To the extent that post-processualism is not a call for methodological rigour but for a radical change in perspective, the construction of models relating bioarchaeological assemblages to husbandry regimes might be seen as a relatively low priority. Such an anti-methodological stance is, however, self-defeating: any revolution in archaeological theory is meaningless if it fails to formulate alternative interpretations based on 'rationally decisive' archaeological evidence (Wylie 1992, 1996).

The remainder of this introductory section discusses the significance of crop husbandry practices in archaeology, the role of middle range theory and the interpretation of archaeobotanical weed evidence. Chapter 1 provides a brief archaeological summary of the Neolithic in the loess belt and Alpine Foreland. Chapter 2 sets out previously suggested models of Neolithic crop husbandry practices in central Europe and the evidence on which they are based. Chapter 3 considers the key ecological variables that distinguish the main crop husbandry models and their broader social and economic implications. The methods used to select and analyse archaeobotanical data from the study area and relevant modern weed survey data are the focus of Chapter 4. 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 weed ecological characteristics. The aim of Chapter 6 is to identify and interpret specific ecological trends in weed species composition among the archaeobotanical samples, and hence differences in individual aspects of crop husbandry. 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 Chapters 2 and 3. Brief chapter summaries are provided at the end of Chapters 1 through 6.

Crop husbandry and middle range theory 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 (Boserup 1965), environment (Higgs and Vita-Finzi 1972) or the spread of technological innovations (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 (Netting 1971; Goody 1976; Sherratt 1981; Fleming 1985; Halstead 1987, 1990, 1995; Hodkinson 1988; Williamson and Bellamy 1987; Palmer 1998b; Forbes 1982, 2000a, 2000b). Crop husbandry is thus of central importance for understanding past agricultural societies (see also Chapters 2–3) 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).

Anthropologists such as Bourdieu (1977, 1990) have demonstrated that social reproduction takes place in the everyday habits of living. Archaeologists have increasingly looked to 'habitual action' (Gosden 1994: 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 (Barrett 1994, 1999; Gosden 1994; 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). Since it combines 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 (Ingold 1993). An understanding of past crop husbandry regimes is also needed in order to assess the enduring effects of farming on the landscape (Acheson 1997; Halstead 2000).

Recent interest in routine practice highlights the need to broaden the range and resolution of inferences that archaeologists can make about the past. 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 later Neolithic 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 – has been under-utilized, 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) characterized 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 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-ladenness' 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: 458–97) incorporates assumptions of human rationality and optimizing 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 has been 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); Kosso (1991) and Tschauner (1996) have highlighted its use in the writings of Binford's own critics. The development of useful middle range theory not only broadens the scope of archaeological inference but also constrains what we can claim about the past.

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

A given species of crop can generally tolerate a range of growing conditions and may be grown using a variety of different husbandry practices (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 (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 (Knörzer 1971, 1973, 1979, 1984; Willerding 1980, 1981, 1983a, 1986; Hillman 1981, 1991; M. Jones 1981, 1988; Wasylikowa 1981; Greig 1988; Behre and Jacomet 1991; Küster 1991; G. Jones 1992, 2002; van der Veen 1992). Archaeobotanists have observed that ancient weed assemblages are often quite different from those of recent times and that this is likely to reflect differences in crop husbandry practices (Knörzer 1973; Willerding 1980, 1981, 1983a, 1986; Behre and Jacomet 1991; G. Jones 1992; Kroll 1997). Weed species have different ecological requirements and preferences (Holzner and Numata 1982; Ellenberg 1996: 870–88); 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). Two of the main approaches that have been used – phytosociology and Ellenberg numbers – are discussed below, before presenting a third approach that overcomes the major weaknesses of previous methods.

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 1991; G. Jones 1992). Other problems with the identification of weed communities in archaeobotanical samples are that samples may not derive from a single field and that they do not fully reveal the original field weed flora (M. Jones 1988; Küster 1991; 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 1971).

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 1991; 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, 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 (van Zeist 1974; Wasylikowa 1978, 1981; Willerding 1979, 1983a; Jacomet *et al.* 1989: 128–44; Behre and Jacomet 1991; Karg 1995; Rösch 1998b; G. Jones 2002). 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 1971; 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 tend to characterize spring-sown crops, suggesting perhaps that archaeobotanical cereals/pulses associated with Chenopodietea are spring-sown (Groenman-van Waateringe 1979; Gluza 1983; Behre 1990) or that Chenopodietea-rich assemblages are derived specifically from (spring-sown) millet cultivation (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, 1988b), 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.

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' (*Zeigerwerte*), have been widely used in archaeobotanical interpretation in order to infer fertility, moisture level, shadiness, etc. (Wasylikowa 1978, 1981; Willerding 1980, 1983a; Jacomet *et al.* 1989: 145–53; van der Veen 1992: 108–9). 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).

FIBS in archaeobotany

A new approach to the ecological interpretation of archaeobotanical data is known as 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 2002). 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. 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. 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).

FIBS has been applied to a series of modern weed survey studies of traditional crop 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 2003), 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, 2003; Bogaard *et al.* 1999, 2000, 2001; G. Jones *et al.* 2000a). 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.* 2000a).

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 2002). 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. Critically, 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, 2002). 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, 2002; 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 set out above: the relation of functional attributes to crop 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 crop husbandry practices is not entirely unambiguous since different husbandry measures may have similar ecological effects, the use of functional attributes permits this ambiguity to be identified and assessed.

1

THE STUDY AREA AND ITS ARCHAEOLOGICAL BACKGROUND

Definition of the study area

Two broad regions of central Europe have been the subject of debate over the nature of Neolithic crop husbandry and are particularly well investigated from an archaeobotanical point of view. The first region is the loess belt, a series of upland basins where silt-like, wind-deposited material (loess) accumulated to the south of the Pleistocene ice sheets, forming a discontinuous band across Europe. Excavation has taken place at hundreds of Neolithic settlements in the loess belt, with sampling for plant remains at early Neolithic (*Linearbandkeramik* or LBK) sites in particular (Willerding 1980; Lüning 1988; Kreuz 1990; Knörzer 1997). The second region is the Alpine Foreland, where intensive bioarchaeological study has long formed part of

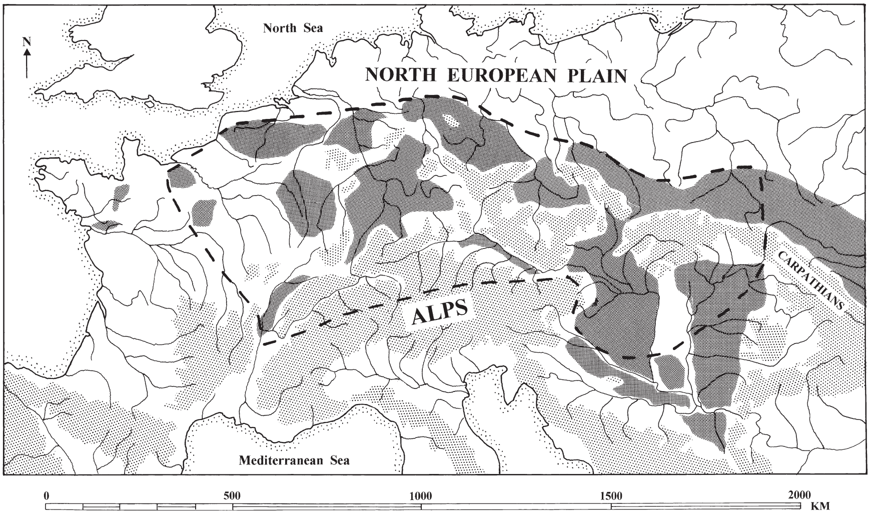

Figure 1.1 Map showing the study area (dashed line), which encompasses much of the loess belt (dark shading) and the Alpine Foreland

excavation at lakeshore settlements dating from the later Neolithic onwards (Heer 1866; Neuweiler 1905; Schlichtherle 1983, 1997a; Jacomet *et al.* 1989; Brombacher and Jacomet 1997; Maier 2001). Together, the loess belt and Alpine Foreland form a very broad study area bounded by the coastal plains of Europe to the north and west and the Alps to the south (Figure 1.1). 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 Moldova, but available archaeobotanical data from these regions are as yet 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 north of the loess belt, in the North European Plain, was considered unproductive because of the restricted archaeobotanical dataset available (Bogucki 1982: 97; Heußner 1989; Nalepka *et al.* 1998).

The chronological framework used in this book follows the scheme proposed by Lüning (1996: Figure 1) for central Europe. Table 1.1 summarizes the relevant periods and culture-historical groupings.

The early–middle Neolithic (*c.* 5500–4400 BC)

The early–middle Neolithic archaeology considered here comprises the *Linearbandkeramik* or LBK (*c.* 5500–5000 BC) and subsequent LBK-related cultures (i.e. Rössen, Lengyel, *Stichbandkeramik* or SBK, Oberlauterbach, etc.) of the middle Neolithic (*c.* 5000–4400 BC) 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' palimpsests 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 organization, 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 *c.* 10 to 40 m (Modderman 1988; Coudart 1998: 19, 27–8, 53–4). 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 a farmstead situated within its own yard (the *Hofplatz* model) was developed in the course of extensive rescue excavations of LBK sites in the lower Rhine basin, including the complete excavation of a 1.3 km stretch of the Merzbach valley in the Aldenhoven Plateau, which suggested that each longhouse was surrounded 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

Table 1.1 The chronological framework followed in this book, with culture-historical groupings for each region listed in approximate chronological order (LBK = *Linearbandkeramik*, SBK = *Stichbandkeramik*, TRB = *Trichterbecherkultur*)

Major periods *^{14}C cal.* BC	*Early Neolithic* *5500–5000*	*Middle Neolithic* *5000–4400*	*Later Neolithic* *4400–3500*	*3500–2800*	*2800–2200*
N France, Belgium	Rubané récent	Cerny/Blicquy	Chasséen	Seine–Oise–Marne	Corded Ware Bell Beaker
Lower Rhine–Meuse basin	LBK	Rössen	Michelsberg		
Southern Germany, Switzerland		Hinkelstein, Großgartach, Rössen/Lengyel/SBK/Oberlauterbach, Bischheim	Aichbühl, Michelsberg, Schussenried, Altheim, Pfyn-Cortaillod	Horgen/Cham/Wartberg	
Central Germany, Bohemia, Southern Poland		SBK	Late Lengyel, TRB	Bernburg, Baden, Globular Amphora	
Austria, Hungary, Slovakia, Moravia		Lengyel	Late Lengyel	Baden	

Sources: The overall structure and ^{14}C dating follows Lüning (1996: Figure 1). Supplementary sources are Keefer (1993: 171), Kooijmans (1993: Figure 9), Whittle (1996a: Figure 6.3), Preuß (1998: supplement 1).

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). As new longhouses were constructed, there appears to have been a tendency to avoid overlap with earlier structures (Pavlů 2000: 243).

Since early–middle Neolithic sites represent palimpsests 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 *c.* 7 ha are attested in one phase (Lüning 1988, 1997). Population estimates for early–middle Neolithic sites range from less than ten (a single longhouse) to several hundred or more (Modderman 1970: 205–7; Milisauskas 1986: 219–20; Milisauskas and Kruk 1989a; Coudart 1998: 91). Most, if not all, settlements would not be demographically viable (cf. Wobst 1974), and recent strontium isotope work on human bone from LBK sites in the Rhineland suggests movement of women in particular between communities in different regions, perhaps as a result of intermarriage and patrilocality (Price *et al.* 2001; Bentley *et al.* 2002, 2003).

Lüning (1997) has argued that even large sites such as Langweiler 8 were not true 'villages', with an emphasis on communal, supra-household organization, but 'loose' groupings of farmsteads (*Streusiedlungen*). The newly excavated LBK settlement at Vaihingen in south-west Germany, however, was enclosed in one phase by a ditch containing burials and appears to reflect a more cohesive, village-like community (Krause 2000). In some regions at least, sites appear to become more nucleated in the middle Neolithic (e.g. fewer, larger sites in the lower Rhine–Meuse basin), and greater cohesion may also be indicated by the construction of enclosures at some sites, implying communal cooperation (Lüning 1982b, 2000: 16; Starling 1985, 1988; Pavuk 1991; Hodder 1990: 122–9). 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 four hundred years (Lüning 1997, 2000: 15).

Early–middle Neolithic sites tend to occur in clusters, often strung out along small- to medium-sized river valleys (Hamond 1981; Bogucki 1988: 74; Lüning 1997). 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 'settlement cells' (*Siedlungskammern*) and often circumscribed by topographical features such as hills surrounding basins (Hamond 1981; Bogucki 1988: 72–3).

It is well known that early Neolithic sites tend to occur in areas of loess, though there are many exceptions (e.g. Paris basin, lower Oder, Kuyavia), 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: 26–7, 50–4, 63–4, 1988; Bakels 1978: 139; Wasylikowa 1989).

Mixed deciduous woodland is generally considered to have been the dominant vegetation in the Neolithic (Küster 1995a: 69–70, 74–5; Jacomet and Kreuz 1999: 231–40; Lüning 2000: 25–7). Some authors, however, have suggested that the 'natural' vegetation of central Europe is open parkland or wood pasture due to the impact of large native herbivores (Geiser 1992; May 1993; Vera 2000). Zoller and Haas (1995) argue in favour of mixed deciduous woodland but emphasize that it would exist in a mosaic of regeneration states at any one time. The location of early–middle Neolithic sites along river valleys – like the later emergence of lakeshore settlement in the Alpine Foreland (pp. 18–19) – may reflect a preference for relatively open vegetation (Zoller and Haas 1995).

The visibility and often dispersed distribution of early–middle Neolithic longhouses has fostered interest in the household as the fundamental unit of decision-making (Bogucki 1988: 214–15; Lüning 1988: 86; Halstead 1989a; Bogucki and Grygiel 1993; Lüning 2000: 180) by analogy with ethnographic and historical studies of small-scale agrarian societies (Sahlins 1972; Netting *et al.* 1984). This perspective implies that agricultural practices reflect the aspirations and motivations of individual households (cf. Bogucki 1988: 215). The origins of social hierarchy have been sought in the relationships between households and their differential success (Halstead 1989a, 1989b; Bogucki 1993, 1999: 210–18). There is disagreement, however, over the degree of social differentiation among households in the early–middle Neolithic (see Chapter 3).

The crop spectrum of the early Neolithic consists of emmer and einkorn wheat, common pea, lentil and flax, with the addition of opium poppy (in the western LBK) and barley (among other rare cereals and pulses) at some sites, though some or all of these additional species may have grown as weeds of the major crops. (Willerding 1980; Jacomet and Kreuz 1999: 294–7). It has been suggested that emmer and einkorn were grown together as a mixed or 'maslin' crop based on the ubiquitous mixture of these species in archaeobotanical samples (Willerding 1980, 1983b; Bakels 1991b; Knörzer

1997, 1998), though the lack of clear *in situ* storage contexts makes this difficult to demonstrate conclusively (Jacomet and Kreuz 1999: 295). Recent work on the morphology of glume wheat remains at the LBK site of Vaihingen (Bogaard unpublished data) suggests that a third type of glume wheat, recently described in Neolithic assemblages from Greece and resembling modern *Triticum timopheevi* Zhuk (G. Jones *et al.* 2000b), was also grown. The LBK spectrum of cereals and pulses is narrow compared to that known from the Neolithic in the southern Balkans and Greece (Halstead 1989a), which notably includes pulses such as bitter vetch, chick pea and grass pea that are mostly Mediterranean crops in Europe today (Zohary and Hopf 2000: 108, 116, 119). Free-threshing wheat and naked barley emerged as common crops in the study area during the middle Neolithic (Bakels 1991a, 1997a).

Cattle dominate most early–middle Neolithic animal bone assemblages from the study area, while the relative importance of pig and sheep/goat appears to vary (Lüning 2000: 110). The prominence of cattle throughout the Neolithic may reflect their suitability for browsing in woodland as well as their greater reliability compared with smaller stock as indirect 'banks' for surplus crops (Halstead 1989a, 1992b; cf. Bogucki 1988: 91). Available mortality data for cattle and sheep/goat assemblages from early–middle Neolithic sites are generally too limited to infer herd management strategies reliably (Halstead 1989a; Glass 1991: 69; Arbogast 1994: 91), but they appear to reflect predominant juvenile mortality and hence meat use (Arbogast 1994: 93; Benecke 1994a: 95, 1994b: 122–3). 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, interpreted as cheese strainers for separating curds and whey (Bogucki 1982, 1984, 1986), 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).

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 (Clark 1952: 95–8; Piggott 1965: 50–2; Ammerman and Cavalli-Sforza 1971, 1984: 61, 63–4; Vencl 1986; Bogucki 1987, 1996; Price *et al.* 1995). Continuity with the Mesolithic in some aspects, however, especially in lithic assemblages (Tillmann 1993), as well as heterogeneity within the LBK (Lüning 2000: 110) and possible evidence for 'Mesolithic agriculture' (Erny-Rodmann *et al.* 1997), has been used to argue that the LBK represents a complex pattern of indigenous adoption, with limited migration or no movement at all from the 'homeland' of LBK material culture in the Hungarian Plain (Dennell 1983: 176; Modderman 1988; Whittle 1996a: 363–4, 1996b, 1997; Kind 1998; Gronenborn 1999; Bogucki 2000; Jochim 2000; Zvelebil 2000a, 2000b; Price *et al.* 2001; Bentley *et al.* 2002, 2003).

The later Neolithic (*c*. 4400–2200 BC)

The transition from the middle to the later Neolithic represents the end of the *Bandkeramik* tradition of longhouses in central Europe. Subsequent Neolithic settlement extended well beyond the loess belt – including the Alpine Foreland, which forms part of the study area (Figure 1.1) – and continued a trend towards increasing regionalization of material culture. Later Neolithic sites vary considerably in location (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 twenty years' occupation).

The later part of the Neolithic (*c*. 4400–2200 BC) has been characterized as a period of profound changes. Sherratt (1981, 1997) proposed a 'secondary products revolution' based on the intensive use of renewable resources from domesticated animals (traction, milk and wool/hair) in the fourth and third millennia BC. 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, 2000a; Glass 1991: 77; Halstead 1995; Lüning 2000: 12). Recently, however, Bogucki (1993, 1999: 227–30) has advocated an 'animal traction revolution', arguing that ox-drawn ard (scratch plough) 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 Chapter 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: 107–9, 1996, 2000; Sherratt 1990, 1995). 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 in Chapter 2.

Within the loess belt, regional survey of Neolithic sites in southern Poland (Kruk 1973, 1980: 28–9, 54–7, 64, 1988) documented a tendency for later Neolithic TRB (*Trichterbecherkultur* or Funnel-necked Beaker culture) sites to be located in the interfluve (or watershed) zone, away from the margins of river valleys. Another regional study of Neolithic settlement, in the Elbe–Saale area (Starling 1985, 1988), detected a similar trend for larger sites (hilltop enclosures or *Hohensiedlungen*) in the interfluves but also greater continuity of settlement on valley margins. Kruk (1973, 1980: 28–9, 54–7, 64, 1988) interprets the focus on interfluves, characterized by poorer, non-loess soils, as evidence for shifting cultivation in the TRB, while other authors infer a greater emphasis on animal husbandry, including animal-drawn ard cultivation

(Bogucki 1988: 176–7; Howell 1989). Subsequent settlement evidence of the Baden culture 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). Bronocice, located on a loess ridge above a tributary of the Vistula in south-east Poland, has produced settlement evidence for the TRB and Baden periods in the eastern loess belt, comprising extensive spreads of pits and enclosure ditches but no detailed evidence of settlement or house layout (Milisauskas and Kruk 1993).

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 house or settlement layout. The proliferation of monumental earthworks and hilltop enclosures in various regions suggests increasing concern with communal defence (Hodder 1990: 158–61). Sites of the Michelsberg culture – 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 and Schussenried cultures of south-west 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: 128–45). In lower Bavaria, settlements of the Altheim culture, 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 (see p. 18).

Settlement evidence from the final phases of the Neolithic (*c.* 3500–2200 BC, 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: 251–8; Lüning 2000: 19–20). Waterlogged settlements of the Alpine Foreland provide the best evidence of house and settlement layout for this vast period (see below). Together with the Globular Amphora culture, the Corded Ware and Bell Beaker complexes have been associated with pastoral nomadism due to the predominance of burial sites and lack of settlement evidence (Kruk 1973, 1980: 58–61, 1988), but there is no positive evidence for reliance on herding (Milisauskas and Kruk 1989a, 1989b; Keefer 1993: 169–70). More recently, the concept of deliberate homogenization of material culture has to some extent replaced migrationist interpretations (Shennan 1986; Hodder 1990: 175; Rieckhoff 1990: 48–57).

Bioarchaeological evidence from later Neolithic sites in the loess belt indicates essentially the same range of crops as that attested in the middle

Neolithic (Lüning 2000: 66–7). Cattle bone assemblages from Michelsberg and Chasséen sites in the western loess belt suggest a general increase in the maintenance of older animals compared with the earlier Neolithic, possibly a reflection of dairying and/or use for traction (Arbogast 1994: 96). Nitrogen isotope analysis of cattle teeth from the Chasséen site of Bercy (early fourth millennium BC) is consistent with early weaning to increase the amount of milk available for human consumption (Balasse and Tresset 2002). To the east, the TRB-Baden site of Bronocice has yielded possible evidence for cattle traction and wool production (Milisauskas and Kruk 1989a, 1991).

South of the loess, in the Alpine Foreland, the sequence of lakeshore settlements preserved by waterlogging begins *c.* 4300 BC and continues in some areas through to the Corded Ware phase (*c.* 2400 BC) (Schlichtherle 1995; Whittle 1996a: 216–19; Pétrequin *et al.* 1998; Gross-Klee 1997; Schibler and Jacomet 1999). Rather than an 'edge effect' of settlement concentrated on dry 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 than the earlier longhouses and 'coherent 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 twenty years up to eighty years.

The good preservation of lakeshore settlements in the Alpine Foreland appears to demonstrate independent household production at some sites. Such evidence is particularly clear at Hornstaad-Hörnle IA, an early lakeshore settlement on Lake Constance (dendrochronologically dated to 3915 BC), where each house had its own crop stores (charred in the destruction of the settlement by fire) and a standard 'tool kit', including wooden 'hand ards' (*Fürchenstöcke*), polished stone axes, flint points and fishing equipment (Dieckmann 1991; Dieckmann *et al.* 1997). At other 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 Alleshausen-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 specialization 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).

The crop spectrum of Neolithic lakeshore settlements resembles that of the later Neolithic in the loess belt, but with notable emphasis on free-threshing wheat prior to the Horgen period in contrast to the focus on emmer and einkorn wheat in the loess belt from the early Neolithic onwards (Jacomet and Kreuz 1999: 302). Mortality curves for cattle assemblages from the Alpine Foreland suggest dairying at sites of the Pfyn-Cortaillod cultures (Higham 1967; Becker 1981; Jacomet and Schibler 1985; Halstead 1989a; 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).

The lakeshore settlement at Weier (Pfyn period) has provided the earliest direct evidence of stalling in the study area (Rasmussen 1989; Robinson and Rasmussen 1989; Overgaard Nielsen *et al.* 2000). 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 *c.* 3700–3600 BC (Pfyn period) at various lakeshore settlements (e.g. at Lake Zurich and 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, 1997b; Hüster-Plogmann *et al.* 1999).

In the subsequent Horgen levels 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 in Chapter 2, this evidence has been associated with more extensive arable cultivation and greater availability of land for grazing. It appears that cows and bulls were used for traction in the Horgen period, whereas osteological data from Corded Ware (and Early Bronze Age) contexts at Lake Zurich suggest increased use of oxen (Hüster-Plogmann and Schibler 1997). Sheep mortality data from Corded Ware contexts at Lake Zurich are consistent with milk production (Hüster-Plogmann and Schibler 1997).

Summary

- The study area consists of two adjacent regions with extensive Neolithic (*c.* 5500–2200 BC) archaeobotanical datasets: the western–central portions of the loess belt (extending from the Low Countries in the west to Poland, Slovakia and Hungary in the east) and the Alpine Foreland.
- Residential household groups are 'visible' throughout the period under consideration, from the longhouses of the early–middle Neolithic (which vary considerably in size and form) through to smaller, one- or two-room structures of the later Neolithic. Exceptional preservation at the later Neolithic lakeshore settlement of Hornstaad-Hörnle IA provides clear evidence for household-level production and consumption.
- In general, Neolithic settlements were too small to be demographically viable, and the importance of interaction between settlements is borne out by regional similarities in material culture and long-distance trade in materials such as *Spondylus* ornaments.

- The early Neolithic crop spectrum, dominated by emmer and einkorn wheat, is narrow compared with that known from Neolithic sites in south-east Europe. Crop spectra of the middle and later Neolithic were broadened by the addition of other cereal species. Cattle generally dominate animal bone assemblages throughout the Neolithic in the study area, with variability in the relative importance of pig versus sheep/goat.
- According to the secondary products revolution model, the general expansion of later Neolithic settlement beyond the loess was conditioned by use of animal traction and the ard (scratch plough), as well as by the emergence of milking and wool production.

2

MODELS OF CROP HUSBANDRY IN NEOLITHIC CENTRAL EUROPE

Introduction

The aim of this chapter is to summarize and discuss crop husbandry models previously applied to the Neolithic in the study area. Crop husbandry regimes are often characterized as 'intensive' or 'extensive' in the archaeological literature, but the definition of these terms varies (Halstead 1992a). In this book, '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: 240–3; Upton 1976: 196; Grigg 1984: 49, 174).

Shifting cultivation

Shifting cultivation (also known as slash-and-burn, swidden, long-fallow or forest-fallow) involves the clearance of primary or secondary woodland, usually by burning, and cropping of the newly cleared soil for one to five years. While new plots are cleared and cultivated, old plots are left to regenerate for twenty years or more. Burning both reduces the need for tillage and weeding by damaging the viability of seeds or rhizomes in the soil (Ellenberg 1996: 770) and mobilizes nutrients from organic material, resulting in high crop yields over the short term (Sigaut 1975: 18–29, 99). In tropical regions, with high rainfall and rapid leaching of soil nutrients, shifting cultivation is widely attested (Grigg 1974: 57–74; Bayliss-Smith 1982: 25–36; Steensberg 1993: 16–98). There is also historical evidence for shifting cultivation in parts of Europe and North America (Manninen 1932; Mead 1953; Montelius 1953; Grigg 1974: 62–3; Sigaut 1975: 18–29; Steensberg 1955, 1993: 15–16, 98–153; Larsson 1995; Lüning 2000: 52–4).

While shifting cultivation is generally characterized as an extensive husbandry regime, with low labour inputs per unit area (Boserup 1965: 24, 29), clearance work may be considerable (Lüning 2000: 52–4) and high yields have generally been assumed. In his description of pioneer farming in southern Ontario, Canada, Schott (1936: 169) reports area yields of *c.* 1500–3400 kg/ha for the first wheat crop sown on newly cleared forest soil, with little tillage and no weeding or manuring (Table 2.1). More often, historical yields are reported as seed-yield ratios – for example, 20–50:1 or even 100:1 (Soininen 1959) (Table 2.1). As various authors (Sigaut 1975: 119–20; 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. Where area yield figures are not available, 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 experiments at Draved (Steensberg 1979) and Butser (Reynolds 1977) do not suggest spectacular area yields compared with intensive permanent cultivation (Table 2.1). On the other hand, 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 (Wackershofen, Forchtenberg) where experimental shifting cultivation was conducted (Table 2.1).

Archaeobotanical weed evidence has played a limited role in debate over the importance of shifting cultivation in Neolithic Europe (cf. Engelmark 1989; Dennell 1992), in part due to the lack of modern comparative data on the arable weed floras that develop under a shifting cultivation regime. Few observations on the weed floras growing with crops in shifting fields are found in historical descriptions of shifting cultivation in Europe and North America. Though weed growth may be limited by burning and/or by luxuriant crop growth in the first cultivation season, there are indications that weed growth increases in the second and third cultivation seasons (Sigaut 1975: 18–29, 99; Engelmark 1995). Historical accounts provide very little information on the actual composition of these weed floras, and most relate to shifting cultivation on poor soils in coniferous woodland areas; weed floras in deciduous woodland may be quite different (Engelmark 1995).

Shifting cultivation in the early–middle Neolithic

Childe (1929: 45–6) invoked shifting cultivation to explain the dispersal of LBK farming communities across central Europe. Despite the emergence of an alternative model of permanent fields cropped on a regular basis (Modderman 1971; Kruk 1973; Lüning 1980, 2000: 49–50, 187–9; Sherratt 1980, 1981; Rowley-Conwy 1981; Dennell 1983: 172; Barker 1985: 141–3; Bogucki 1988: 79–82), the shifting cultivation model has continued to influence discussion of early–middle Neolithic cultivation in the loess belt (Sangmeister 1983; Ammerman and Cavalli-Sforza 1984: 43, 114; Wasylikowa

Table 2.1 Experimental, historical and ethnographic data on cereal yields and archaeological estimates of crop and cultivated area requirements

Source	*Reference*	*Crop husbandry*	*Area yield (kg/ha)*	*Seed-yield ratio*	*Kg/person (% diet)*	*No. people/ household*	*ha/household*
Experimental data – shifting cultivation:							
Draved experiment	Steensberg (1979)		±no return				
Butser experiment	Reynolds (1977)		1600 year 1, 1400 year 2, 900 year 3				
Wackershofen and Forchtenberg experiments	Rösch (2000a), Rösch *et al.* (2002)		up to 2500 and 4000 (year 1), minimal-zero yield in later years	>20:1			
Experimental data – continuous cereals:							
At Woburn 1877–1920	Russell and Voelcker (1936)*	Wheat, no manure	480–1630 (mean 820)				
		Wheat, manured	840–2750 (mean 1640)				
		Barley, no manure	114–1950 (mean 930)				
		Barley, manured	1100–3560 (mean 2150)				

Table 2.1 continued

Source	*Reference*	*Crop husbandry*	*Area yield (kg/ha)*	*Seed-yield ratio*	*Kg/person (% diet)*	*No. people/ household*	*ha/household*
Experimental data – continuous barley:							
At Rothamsted 1852–1962	Rothamsted Experimental Station (1970)[†]	No manure	450–1500 (mean 928)				
		Manured	1880–3510 (mean 2960)				
Experimental data – wheat/bare fallow:							
At Rothamsted 1852–1964	Rothamsted Experimental Station (1970)[†]	No manure	800–2380 (mean 1410)				
		Manured	1870–3550 (mean 2840)				
Experimental data – row-sown cereals:							
Grown for 15 years at Little Butser	Reynolds (1992)	No manure, 3x hoeing during crop growth	Emmer: 360–3030 (mean 1650); Spelt: 670–2610 (mean 1490)	30:1			
		As above, emmer rotated with broad beans	780–3110 (mean 2080)	30:1			
Historical data – shifting cultivation:							
Forest farming in Canada	Schott (1936)		1500–3400 in first year				
Shifting cultivation in Finland	Soininen (1959)			20–50:1, up to 100:1			

Historical data – extensive cereal cultivation:							
Medieval Europe (800–1150 AD)	Henning (1994)		450–550	2.5–3:1			
Historical data from central Europe (medieval period, 18th century)	Lüning (1979/1980), Tegtmeier (1993: 5)		900	3:1	250	6	*c*. 2.5, or 3.75 with bare fallow
Statistisch-Topographisches Bureau for 1850–1905	Gregg (1988)		800 (range 650–1050)	4:1	≤200 for male adult (55–65% of diet)	4–8	1.6–3.2
Ethnographic data – intensive cereal cultivation:							
Asturias, NW Spain	P. Halstead, field notes	Manuring, hand weeding	(800–)1700–1900				
Other estimates for prehistoric cereal cultivation:							
	Halstead (1981a, 1987)		800–1000				
	Bakels (1982)		800		65–80% diet	6–10	1.5–3
	Milisauskas and Kruk (1989b)		500		200 (80% diet)	5	2
	Jacomet *et al*. (1989: 90–1)		600	5:1	150 (65% diet)	5–6	1.5–2
	Gross *et al*. (1990)		650	5:1	100 (52% diet)	5	1
	Billamboz *et al*. (1992)		600, 800		100, 150 or 200 (50–100% diet)	5	1–2
	Halstead (1995)		1000		300	5	2–3

Notes: *Run of bad years in 1920s at Woburn omitted.
[†] Yield data reported as ten-year averages.

et al. 1985; Beranova 1987, 1989; Godlowska *et al.* 1987; Kruk 1988; Milisauskas and Kruk 1989a; Wasylikowa 1989; Rösch 1990a; Rulf 1991; Whittle 1996a: 160–2, 1996b, 1997; Gerht *et al.* 2002). Though Childe (1929) originally linked shifting cultivation with the spread of migrant farmers across Europe, it has come to be associated with the indigenous, Mesolithic (and hence mobile) identity of Europe's first farmers; the latter association appears to underlie Whittle's (1996a, 1996b) recent characterization of LBK communities as both more indigenous and more mobile than previously thought.

Arguments advanced in support of early–middle Neolithic shifting cultivation have included the lack of tell formation (Childe 1929: 45–6, 1957: 105–6) and apparent evidence for discontinuity in settlement occupation (Soudský and Pavlů 1972), the assumption that relatively good soils would be rapidly exhausted (Childe 1929: 45–6, 1957: 105–6) whereas relatively poor soils could not be improved (Kruk 1973, 1980: 54–7, 1988) and pollen evidence for changes in woodland composition linked with clearance and burning (Wasylikowa *et al.* 1985; Wasylikowa 1989; Godlowska *et al.* 1987; Rösch 1990a). All of these arguments are open to question. First, the absence of tells is easily explained by the lack of mudbrick architecture (Sherratt 1981). Second, the tendency of longhouses to 'drift' horizontally, avoiding overlap with earlier structures, can explain apparent discontinuity in settlement occupation (Modderman 1970: 208–11, 1971). Third, assumptions of soil exhaustion appear unwarranted given experimental evidence from Britain and Germany for the long-term stability of crop yields over decades of continuous cultivation on relatively good soils (Lüning 1980, 2000: 174; Rowley-Conwy 1981; Reynolds 1992); at the same time, manuring, watering and weeding of cultivation plots can greatly enhance crop-growing conditions (G. Jones *et al.* 1999). Fourth, in addition to the need for adequate dating and appropriate calculation of pollen diagrams (Rowley-Conwy 1981; Kalis and Meurers-Balke 1998), apparent clearance and burning episodes do not necessarily reflect past arable land use. These changes could, for example, relate to the management of separate woodland or grazing areas (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 also emphasized differences between the environmental context of tropical swidden cultivators (e.g. thin, rapidly leached soils and high rainfall) and that of early farmers in central Europe (Modderman 1971; Jarman and Bay-Petersen 1976). A further contrast can 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). Moreover, shifting cultivation was often a form of 'outfield' cultivation in marginal areas of northern Europe, practised alongside a more intensive form of 'infield' cultivation (Rowley-Conwy 1981).

In the absence of modern comparative data on the sort of weed flora that develops under a shifting cultivation regime, the same archaeobotanical evidence has been used to support different conclusions. Knörzer (1971) interpreted the repeated association between a narrow range of weed species (the so-called Bromo-Lapsanetum praehistoricum weed community) and charred crop material on LBK-Rössen sites in the lower Rhine basin as evidence for permanent fields cultivated each year using the same methods. Bakels (1978: 69), on the other hand, has argued that repetition of the same weed assemblage could reflect a shifting cultivation regime in which areas chosen for clearance, methods of clearance and sowing, etc. were consistent. A particular focus of conflicting interpretations is Nipplewort (*Lapsana communis* L.), which constitutes one element of the 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 this species as an indicator of permanent cultivation plots shaded by surrounding hedges (Knörzer 1967, 1971, 1988; Groenman-van Waateringe 1971) (see also p. 39). While a permanent field model has tended to find favour in recent archaeobotanical studies of early–middle Neolithic crop husbandry in central Europe (Kreuz 1990; Stika 1996), there has also been acknowledgement of the difficulty of excluding shifting cultivation on archaeobotanical grounds (Brombacher and Jacomet 1997).

A different approach to the inference of cultivation on newly cleared forest soil is to treat 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 (p. 22). 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 other reasons (e.g. crop processing, hand-weeding of crops, preservation, etc.). Furthermore, as Bakels (1991b) makes clear, initial woodland clearance would be necessary under any cultivation regime.

Shifting cultivation in the 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, 1990a, 1990b, 1996, 2000a; Pétrequin 1996; Bailly *et al.* 1997; Pétrequin *et al.* 1998; Rösch *et al.* 2002; see also Schlichtherle 1989, 1992, 1995, 1997a; Whittle 1996a: 216–22), 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, 2001: 78–109) (see also pp. 40–41). 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 1990b), or at least during the earlier part of the later Neolithic (Rösch 1996, 2000a). 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 fallowing in the early–middle Neolithic and argues further that shifting cultivation contributed to poor soil conditions in the Bronze Age (Rösch 2000a). Pétrequin (1996; see also Bailly *et al.* 1997; Pétrequin *et al.* 1998) infers shifting cultivation prior to *c.* 3000 BC 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; the pollen and timber evidence may instead reflect woodland management practices related to animal husbandry, for example (Rowley-Conwy 1981; Kalis and Meurers-Balke 1998; Lüning 2000: 50–2; Rösch *et al.* 2002).

Shifting cultivation has also been identified as the major form of later Neolithic crop husbandry in loess areas such as southern Poland (TRB culture – Kruk 1973, 1980: 54–7, 1988) and the Paris basin (Seine–Oise–Marne culture – Howell 1983). This is based on the association of settlement in this period with interfluves (see Chapter 1) and the assumption that hand cultivation of fixed plots on the drier upland loess would be impractical. 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 land use.

Extensive ard cultivation

Cultivation with the animal-drawn ard (scratch-plough) requires less human labour per unit area than cultivation by hand (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). Area yields are low compared with hand cultivation regimes (Gallant 1991: 51; Halstead 1995) (Table 2.1). Particularly when specialized 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).

Extensive ard cultivation in the early–middle Neolithic

According to Lüning (1979/80, 1980, 2000: 160–1, 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 2.1). 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, or cultivated, fallow is apparently assumed here – cf. Lüning 1980). Lüning (1979/1980) claims that a household would need an ard to cultivate this area: given a conservative work rate for ard cultivation of 500–1000 square metres per day, at least thirty 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 (measurements of horn cores and metapodia) for bull castration in the LBK (Müller 1964, 1998; Benecke 1994a: 100–1, 1994b: 176), suggesting that oxen were available for traction. Other arguments in favour of ard cultivation include the standardization of LBK growing conditions based on the repeated occurrence of a narrow range of weed species in LBK-Rössen sites in the lower Rhine basin (Knörzer 1971, 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 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 2000a). 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 extensive 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 arguments supporting extensive ard cultivation for the early–middle Neolithic. First, the claim that the ox-drawn ard would be necessary to support an early–middle Neolithic household is highly questionable. Ethnographic data suggest that a farming family can cultivate *c.* 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 2.1), estimates of the cultivated area needed per household (*c.* 2–3 ha), therefore, tend to fall within the labour capacities of ethnographic farming families practising hand cultivation. Second, the osteological evidence for bull castration may be unrelated to traction since this practice can form part of meat-oriented herd management in which the goal is to encourage weight gain and good condition (Bogucki 1988: 87; 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 (a pelvic socket with conspicuous 'polishing' from Eilsleben, central Germany) apparently 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) (see pp. 32–4). Third, 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 1989a; G. Jones 1992) (see pp. 44–5).

Other aspects of the model are also problematic. The assumption of bare fallow – which effectively increases the area requiring cultivation – 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 family farming regime, other techniques of weed control such as hand-weeding of crops are arguably more probable (Halstead 1987) (see pp. 41–2). Furthermore, the extensive ard cultivation model assumes that manuring was not practised. Historical and ethnographic data suggest that extensive farming is associated with the 'loss' of manure as a result of transhumance, a practice associated with herding on a large scale (Halstead 1987, 1989b). Metrical data on early–middle Neolithic cattle and pigs, however, appear to reflect small-scale herding of animals kept close to settlements (cf. Halstead 1996); whereas extensive herding would result in regular cross-breeding and a blurring of the distinction between wild and domesticated animals, domesticated cattle and pigs remain distinctly smaller than their wild counterparts throughout this period (Benecke 1994a: 48–55; Döhle 1997; Lüning 2000: 105). It is unlikely that such small-scale livestock husbandry would be divorced from arable cultivation (Halstead 1987, 1989a, 2000).

Extensive ard cultivation in the later Neolithic

Cultivation with the ox-drawn ard is widely assumed for the later Neolithic based on the appearance of ard-marks, artefactual evidence for the ard and animal traction (e.g. remains of 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 BC onwards (Sherratt 1981, 1997; Niesiolowska-Sreniowska 1999; Tegtmeier 1993). The emergence of ox-drawn ard cultivation has been associated with increasing social complexity (Gilman 1981; Sherratt 1981; Bogucki 1993) based on cross-cultural links between plough cultivation and social stratification (Goody 1976).

The earliest widely accepted use of the ard is in the TRB period and coincides with a shift of settlement away from valley margins and further into the interfluve zone (Kruk 1980: 28–9, 1988; Sherratt 1981; Bogucki 1988: 175–7, 1993, 1999: 227–30; Milisauskas and Kruk 1989a). In fact, some authors assume that cultivation of the loess uplands would require the ard (Bogucki 1988: 176–7; Howell 1989); thus, Bogucki (1988: 176–7) argues that the ard cultivation 'freed [later Neolithic] households from their dependence on energy-subsidized floodplain habitats, enabling the occupation of interfluves'. Ard 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 site of Bronocice has yielded possible evidence for animal traction dating to *c.* 3900–2600 BC – 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).

There are no archaeobotanical weed assemblages from later Neolithic sites in the loess belt that have been interpreted as evidence of extensive ard cultivation. Ard cultivation, however, has been linked with higher levels of herbs and grasses in later Neolithic pollen spectra in the Rhineland compared with earlier periods. Kalis and Meurers-Balke (1997) argue that this evidence points to the impact of ard cultivation, allowing a major increase in the size of cultivation areas.

Bogucki (1993, 1999: 227–30) has recently argued that animal traction combined with ard cultivation 'revolutionized' 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 dependency relationships between households; augmented by trade in exotic materials and by mortuary ceremonialism, this differentiation would result in marked inequality (Bogucki 1993, 1999: 227–30).

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 mobilize labour outside the household, in turn, would require modification of the household model of agricultural production, which Bogucki himself (1993, 1999: 211–18) 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 specialized oxen is generally associated with large estates producing for a market, and not with household farming (Halstead 1995). This is because specialized 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 later 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 unspecialized 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 unspecialized oxen (e.g. oxen used for transport as well as ploughing) or cows is much lower than for specialized 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 2000b).

Burials of cattle in later Neolithic (*c.* 3500–2200 BC) eastern–central Europe have been cited as evidence of animal traction for ploughing and wheeled transport (Sherratt 1981; Benecke 1994a: 100, 1994b: 147). 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). Clearly, these burials do not correspond to the specialized teams of oxen that are often assumed for later Neolithic ploughing. While it can be argued that plough oxen were too valuable to sacrifice (Sherratt 1981), an alternative interpretation is that cattle burials do not actually reflect a revolutionary shift towards extensive ard cultivation in the later Neolithic.

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 (*c.* 3200–2400 BC) of the Lake Zurich sites. As noted in Chapter 1, 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 (Hüster-Plogmann and Schibler 1997). 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 plants), greater field size and/or consolidation (suggested by a decrease in woodland-edge species) and growing conditions of relatively low fertility (suggested by the occurrence of stress-tolerant weeds such as Dwarf Spurge, *Euphorbia exigua* L.) (Jacomet *et al*. 1989: 155; Brombacher 1995, 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, 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 specialized plough oxen was used to cultivate much larger areas than could be worked by hand or cow-drawn ard. Ard cultivation in the Horgen-Corded Ware periods may have been relatively extensive, with lower labour inputs and yields per unit area compared with earlier phases, but the assertion that it represents a 'revolution' (Bogucki 1993, 1999: 227–30) in household productivity is open to question.

While the date of *c.* 3000 BC (i.e. in the Horgen period) has been cited for the onset of ard cultivation in the Alpine Foreland (Schlichtherle 1992: Figure 18), archaeobotanical weed evidence from western Switzerland has been interpreted to suggest that the ard was absent prior to the Bronze Age. Lundström-Baudais (1984) compared waterlogged weed assemblages from a Neolithic site (Brise-Lames – *c.* 2800 BC) and a late Bronze Age site (Auvernier Nord – *c.* 800 BC) located 200 m apart on the shore of Lake Neuchâtel in western Switzerland. Weed assemblages from both sites contained Chenopodietea species (root/row-crop weeds and ruderals), 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 farming 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.

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 (Sherratt 1981; Bogucki 1993) and as an innovation of limited significance, assuming that specialized 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, if some form of animal-drawn ard cultivation were practised with cows, bulls or unspecialized oxen it would not have led to a major increase in cultivated area compared to that which a household could cultivate by hand.

Floodplain cultivation

In terms of human labour per unit area, hand cultivation is inherently more intensive than cultivation with the animal-drawn ard. To this extent, hand cultivation of plots, even if no further labour-intensive inputs such as weeding and manuring were applied, can be characterized as more intensive than ard cultivation. The majority of authors describing early hand cultivation assume that no other intensive husbandry practices were applied. The most coherent model of this sort is that of floodplain cultivation.

Floodplain cultivation in the early–middle Neolithic

This model was first proposed by Kruk (1973) based on survey data from southern Poland. In the survey area, LBK sites tended 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: 51–2, 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 ‘garden plants’ (presumably pulses and 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, emphasizing the lack of manuring and weeding in his cultivation model. Finally, Kruk (1973, 1980: 50–4, 1988) has suggested that there was continuity of floodplain cultivation from the LBK to the Lengyel period (early–middle Neolithic), but with a possible increase in shifting cultivation in interfluve areas during the Lengyel period.

Aspects of Kruk’s floodplain cultivation model have found support in 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 charred crop and weed remains from a pit of the Lengyel period 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 is consistent with 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, cereal pollen and waterlogged macroscopic remains of emmer and einkorn wheat from a peat-filled palaeochannel below the site of Pleszów have been interpreted as evidence of local cereal cultivation in the valley floor during the Lengyel period (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 groundwater and flooding – characterized early crop agriculture from the Near East to central Europe. Though he describes this regime as 'horticulture', Sherratt (1980: 318) emphasizes 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: Figure 2), 'horticulture on alluvial soils' was practised throughout the early and middle Neolithic in central Europe, to be replaced by 'rainfed' cultivation on higher ground in the later Neolithic.

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 '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 productive growing conditions (high fertility, low levels of weed growth) without any manuring, soil preparation or weeding (see pp. 21–2). It is not surprising, therefore, that floodplain cultivation is sometimes combined with shifting cultivation in the same model (Kosse 1979: 140–4; Kruk 1988).

Various authors have criticized the model of floodplain cultivation for the early–middle Neolithic. 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: 26–7, 1988; Whittle 1996a: 161). According to Bakels (1978: 67–8, 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 2000a), 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 1967, 1971, 1988, 1991; Willerding, 1980, 1983a, 1985, 1988a; Halstead 1989a). 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, 1992b; 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 1992b).

Floodplain cultivation in the later Neolithic

According to Kruk (1973, 1980: 54–7, 1988), floodplain cultivation of the type practised in southern Poland during the early–middle Neolithic continued during the TRB period alongside upland shifting cultivation (see p. 28). 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.

Other forms of 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 newly cleared 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.

Other forms of non-intensive hand cultivation in the early–middle Neolithic

Gregg (1988: 65, 94, 97, 99, 166–7) suggests hand cultivation of cereals without manuring in the LBK, citing modern evidence for the maintenance of cereal yields around 1000 kg/ha without manuring. Some addition of manure, however, is implied by the suggestion that weedy fallow periods of at least one year provided grazing for livestock (see also Stika 1996). Gregg infers the practice of fallowing by reasoning that LBK weed assemblages do not reflect coherent plant communities in a modern sense and so cannot derive from continuously cultivated fields. Given the historical contingency of phytosociological communities (see Introduction), 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: Figure 4) cultivation and harvest schedule.

Kreuz's (1988a, 1990: 173–82) 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 reasonable yields could be maintained without manuring.

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 emphasized the occurrence of Timothy Grass (*Phleum pratense* L.) 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. Sheep's Sorrel, *Rumex acetosella* L.) reflect the degradation of unmanured soils in the LBK. According to Rösch (2000a, 2000b), 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 emmer and einkorn) increased and/or larger areas were cultivated. As evidence for soil degradation, Rösch (2000a, 2000b) compares early and late LBK samples from Vaihingen 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 (2000a, 2000b) admits, these data are not sufficient to support this wide-ranging theory. 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 Nipplewort (*Lapsana communis* L.) in LBK weed assemblages as evidence that cultivation plots were small and surrounded by hedges or woodland (Knörzer 1967, 1971, 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 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 strong evidence for the existence of hedges. Furthermore, the presence of *Lapsana communis* has also been interpreted as evidence for slash-and-burn fields in woodland (see p. 27). 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: 185–6) and could in any case be shaded by the crop itself rather than by trees or hedges (Willmans 1988).

The existence of hedges at a number of LBK sites, however, 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: 192–6, 1992; Castelleti and Stäuble 1997). In contrast to these results, potential hedge or 'border vegetation' species 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 (1971) argues against cereal–pulse rotation, however, on the basis of the repeated occurrence of a narrow range of weed species in LBK-Rössen crop assemblages in the lower Rhine basin, inferring 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). The 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 (Gill and Vear 1980: 177, 182), while cereals can be grown on a small or garden scale (Charles *et al.* 2002).

Other forms of non-intensive hand cultivation in the later Neolithic

Various authors describing crop cultivation in the Alpine Foreland 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 (pp. 29–30), 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 the Lake Zurich sites is 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 cultivation with grazed short-fallow breaks (*Feld-Graswirtschaft*) is suggested (Schibler and Jacomet 1999), but with hand cultivation, smaller cultivation plots and a more 'open' crop stand than in later periods (see p. 33).

A somewhat different interpretation is presented by Maier (1999, 2001: 78–109) for the weed assemblages associated with charred crop stores at Hornstaad-Hörnle IA, an early lakeshore settlement (3915 BC) on Lake Constance, destroyed by fire after *c.* ten 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 the interpretation by Rösch (1990b, 1996, 2000a) of pollen and microscopic charcoal evidence from Lake Constance, Maier detects no evidence for shifting cultivation.

Modest area yield estimates of *c.* 600 or 650 kg/ha have been used to model the economies of the Lake Zurich sites (Jacomet *et al.* 1989: 90–1; Gross *et al.* 1990) and Hornstaad-Hörnle IA (Billamboz *et al.* 1992; Dieckmann *et al.* 1997; Maier 1999) (Table 2.1), underlining the relatively low intensity of husbandry. Gross *et al.* (1990) conclude, based on an area yield figure of 650 kg/ha, that the later 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 *c.* 520 kg/ha would be available for consumption) also contributes to the inference that cereal cultivation provided no more than 50 per cent of the human diet (Table 2.1).

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.

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, 1989a, 2000). Intensive garden cultivation is characterized 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, 1989a, 2000; G. Jones 1992; G. Jones *et al.* 1999). Use of the term ‘garden’ in conjunction with staple crops such as cereals may be jarring for readers accustomed to Western gardens of flowers, vegetables and fruit (Leach 1997), but the term is intended to convey the intensity of this form of husbandry, with almost individual attention to crop plants and consequently a limited scale of production.

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: 219–21, 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 2.1; see also p. 29), 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 1982: 262, 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-west Spain, indicates that spelt yields of 1700–1900 kg/ha (down to 800 kg/ha in bad years) are regularly achieved using intensive husbandry methods such as manuring and hand-weeding (Charles *et al.* 2002) (Table 2.1). 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 hoed three times during the growing season but no manure was applied (Reynolds 1992) (Table 2.1). 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 2.1), sometimes resulting in the conclusion that ard cultivation was necessary or that households were surviving 'on the breadline'. 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 2.2. As area yields approach the levels reported for the Asturias spelt (*c.* 1500+ kg/ha), the area cultivated falls to 1 ha per household or less (Table 2.2). 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 (80 per cent+) of the diet, allowing *c.* 2500 kcal per person per day given that 1 kg wheat provides *c.* 3000 kcal (Gregg 1988: table 1, 73). Other authors arguing for less intensive forms of hand cultivation and lower area yields (see p. 41) have arrived at low area estimates (e.g. 1 ha per household or less) by assuming that cereals provided no more than 50 per cent of the diet, estimated to amount to as little as 100 kg per person per year (Gross *et al.* 1990; Billamboz *et al.* 1992) (Table 2.1). It should be stressed that the figures in Table 2.2 are of heuristic value only; yields will have varied from year to year, and overproduction under normal weather conditions was probably necessary in order to ensure coverage for bad years (Forbes 1982: 360–75; Halstead 1989b).

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 produced 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 stabilized at *c.* 1200 kg/ha (Rothamsted Experimental Station 1991); average yields of unmanured barley and wheat in the Woburn experiment (1877–1927)

Table 2.2 Estimates of the cultivated area for a household of five (requiring 1,500 kg cereals per annum*), assuming negligible deduction for seed corn

Area yield (kg/ha)	*Cultivated area (ha)*
400	3.75
500	3.00
600	2.50
700	2.14
800	1.88
900	1.67
1000	1.50
1100	1.36
1200	1.25
1300	1.15
1400	1.07
1500	1.00
1600	0.94
1700	0.88
1800	0.83

Note: *The requirement of 300 kg per person per year is based on the assumption that cereals provide the bulk (*c.* 80 per cent or more) of the diet, allowing 2500 kcal per person per day given that 1 kg of cereals provides *c.* 3000 kcal (Gregg 1988: table 1, 73).

are of a similar order (Russell and Voelcker 1936) (Table 2.1). Of course, the Rothamsted and Woburn results are influenced by modern conditions, including improved cereal varieties and widespread use of herbicides. The higher 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 2.1).

Though average yields for unmanured cereals in modern experiments appear reasonably high, experimental evidence also shows that yields on unmanured plots tend to decline in the medium term before stabilizing and that manuring can maintain higher yields over many years (Russell and Voelcker 1936: 236, 239; Rowley-Conwy 1981) (Table 2.1). 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 1982: 360, 2000a). Thus, even if the average yields of unmanured Neolithic fields matched the *c.* 1000 kg/ha reported from modern experiments, the poor yields would be substantially less (e.g. 500 kg/ha or less – Table 2.1). If households depended on quite high area yields – a likely possibility given the limited area a household could hand cultivate and harvest (see p. 30) – manuring would be one way of ensuring that relatively poor yields remained adequate.

Heavy manuring of cereal plots may encourage cereal plants to 'lodge' (i.e. fall over and lie flat), but ethnographic evidence suggests that allowing sheep or goats to graze unripe crops counteracts this effect and encourages 'tillering' (i.e. the production of multiple shoots in the same plant) (Tusser 1984: 105; Forbes 1995, 1998; Burns 2003; P. Halstead, field notes from Asturias and Greece). A number of factors other than manuring also affect lodging (weed infestation, weather, straw-length of cereal variety). Farmers in Asturias growing spelt (a particularly tall cereal crop) using intensive methods 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).

Intensive garden cultivation in the early–middle Neolithic

As noted above, early–middle Neolithic weed assemblages tend to contain a mixture of character species of the Chenopodietea (root/row-crop weeds and ruderals) and Secalinetea (winter cereal weeds). Willerding (1980, 1981, 1983a, 1985, 1986: 335, 1988b) has argued that the association between Chenopodietea and cereals, which he considers to have been autumn-sown, indicates an open crop stand enabling root/row-crop weeds to germinate in the spring and compete with established plants. This explanation has found wide acceptance among archaeobotanists (Gluza 1983; Jacomet *et al*. 1989: 144, 155; Wasylikowa 1989; Stika 1991; Brombacher and Jacomet 1997). Late ripening of einkorn and emmer has also been cited as a possible cause (Gluza 1983; Wasylikowa 1989). Alternatively, archaeobotanists have interpreted 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 2000a; 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 (1989a) has suggested that the occurrence of Chenopodietea character species in LBK crop samples could indicate labour-intensive practices such as 'manuring or middening 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 1989a; 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). Furthermore, an ongoing study of the effect of late harvesting of einkorn on weed floras in southern France shows that late harvesting does not encourage floras rich in Chenopodietea character species (M. Charles and G. Jones pers. comm.). Field observations 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 in Borja, Spain, where Chenopodietea species tend to occur in irrigated fields with a dense crop stand rather than in more open, unirrigated fields (M. Charles and G. Jones pers comm.). 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 explanation for the presence of Chenopodietea in archaeobotanical weed assemblages is contamination by ruderal vegetation (G. Jones 1992). This is a distinct possibility for some early–middle Neolithic weed assemblages dominated entirely by Fat Hen (*Chenopodium album* L.), 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 (Knörzer 1967, 1988, 1997; Bakels 1979, 1983/4, 1991b; Stokes and Rowley-Conwy 2002) (see also Chapter 4).

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). Mikkelsen and Langohr (1998) have detected soil micromorphological evidence for livestock trampling (implying grazing and manuring) in a buried cultivation horizon near the LBK site of Aubechies, Belgium. Based on a study of LBK buried soils in Luxembourg and Lorraine, Fechner *et al.* (1997) have argued that high-yielding, long-term cereal cultivation could only be carried out with regular applications of manure. LBK manuring may have caused the high phosphate levels detected at two sites in their study, 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 (Halstead 1987; Forbes 1982: 237, 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) summarized eighteenth- and nineteenth-century sources on manuring in western Europe and suggested 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 (*c.* 1 ha). While manure was probably in chronic shortage in the early–middle Neolithic, as in more recent times (Barker 1985: 52–4; Alcock *et al.* 1994), it appears plausible that a household keeping a few cattle each for meat and perhaps milk (see Chapter 1), 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 manure as well as 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 1989a). 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, 1989b). 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 1997b). There is little firm evidence for draught animals in the early–middle Neolithic: 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* (see p. 30).

Clear evidence for specialized dairying is also lacking, though there are possible indications of milk use from the LBK onwards (see Chapter 1).

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); 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: 192–6, 1992; Castelletti and Stäuble 1997) may hint at the existence of hedge-enclosures (see also p. 39) 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.

Intensive garden cultivation in the 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 (1997b) has recently argued that manuring with animal dung should be considered part of the 'secondary products revolution' of the later Neolithic (see also Chapter 1), when the first direct evidence of stalling and manured fields appears. It is likely, Bakels (1997b: 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 Weier (Pfyn culture). A layer of organic material washed into the lake adjacent to the settlement contained 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 (Overgaard Nielsen 1989; Robinson and Rasmussen 1989). One of several structures identified as byres contained layers of dung between three successive wooden floors (Overgaard Nielsen *et al.* 2000). The dung includes probable fodder remains (Rasmussen 1989; Robinson and Rasmussen 1989) and an insect fauna associated with dung and decaying matter (Overgaard Nielsen *et al.* 2000). Evidence for animal stalling has been identified at only one other site in the later 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 widespread leaf and/or branch foddering (Rasmussen 1989, 1990; Lüning 2000: 147). 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 1989a; Gross *et al.* 1990; Hüster-Plogmann and Schibler 1997). 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.

It should be emphasized that the 'sudden appearance' of evidence for stalling and for an abundance of dung and fodder in settlements coincides with the emergence of lakeshore settlements of the Alpine Foreland, where organic remains are preserved by waterlogging. In non-waterlogged conditions, plant and insect remains associated with animal manure would not generally be preserved, and the dung itself may be 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.

Summary

- Archaeologists have applied the shifting cultivation model to all phases of the Neolithic, based on a variety of assumptions and indirect evidence. Due to uncertainty over the sort of weed flora associated with this form of cultivation, archaeobotanical data have as yet been of little use in this context.
- According to some archaeologists, early–middle Neolithic farming was based on extensive cultivation with the ox-drawn ard; others have suggested that this was a 'revolutionary' introduction in the later Neolithic. Archaeobotanical evidence has not played a decisive role in either case. Ethnographic evidence suggests that the use of unspecialized

traction animals does not greatly increase the area a farming family can cultivate.

- Floodplain cultivation is a widely accepted model of early–middle Neolithic crop husbandry, based mainly on settlement pattern data. Archaeobotanical data cited in support of a spring sowing regime, which is a requirement of floodplain farming, could be interpreted in other ways.
- Intensive garden cultivation could account for the mixture of root/row-crop and winter cereal weeds typical of Neolithic archaeobotanical assemblages. The common assumption that intensive crop husbandry practices such as manuring did not feature in the early–middle Neolithic is open to question.
- Clearly, the potential of archaeobotanical evidence to distinguish between rival models of crop husbandry has yet to be fully exploited.

3

THE KEY VARIABLES OF PERMANENCE, INTENSITY AND SEASONALITY AND THEIR WIDER IMPLICATIONS

Introduction

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 discussed in the previous chapter, 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 central aim of this book is to see what light the archaeobotanical dataset available from the study area can shed on the relative validity of these models.

Table 3.1 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

Table 3.1 The relationship of the four major crop husbandry models to the three variables of permanence, intensity and seasonality

Models	*Permanence*		
Shifting cultivation	Transient plots	*Intensity*	
Extensive ard cultivation	Fixed plots	Extensive	*Seasonality*
Floodplain cultivation		Intensive	Spring sowing
Intensive garden cultivation			Autumn or spring sowing

distinguish between floodplain and intensive garden cultivation where the latter involves autumn sowing. The broad social and economic implications of the three key variables are considered below.

Permanence (shifting versus fixed-plot cultivation)

A broad implication of shifting cultivation for early farmers in central Europe is that it would allow a higher degree of mobility than fixed-plot cultivation. Whittle (1996a: 160–2, 176–7, 363–4, 1996b, 1997) has suggested that LBK longhouses acted as 'tethers' in a mobile way of life associated with extensive 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: 143–8, 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 large timber longhouses . . . occupations fluctuated in size and duration; rather few were in continuous use.
>
> (Whittle 1996a: 363–4)

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: 91–2).

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 an exaggeration (Zvelebil 2000b; cf. Gronenborn 1999: 137). Zvelebil (2000b) 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 timescale 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 2000b). 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 not be a viable option. Moreover, autumn sowing of crops (i.e. seasonality of cultivation – see p. 58) would only add to the scheduling conflicts noted by Zvelebil and Rowley-Conwy (1986; cf. Jacomet *et al.* 1989: Fig. 74, 223–5).

Like shifting cultivation, high levels of hunting in Neolithic contexts have sometimes been linked to direct continuity with the Mesolithic (Benecke 1994a: 85), though the assumed relationship between hunting and indigenous ancestry has been criticized (Uerpmann 1977; Gronenborn 1999: 164). Until recently, hunting was considered an activity of negligible importance in the LBK (Müller 1964), but there is growing evidence that levels of hunting varied (Döhle 1993, 1994; Lüning 2000: 113–16; 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 (see p. 51) – 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. Here also, there is controversy over the permanence of agricultural plots (see Chapter 2). High levels of wild fauna at some lakeshore sites – particularly early sites (*c.* 4400–3900 BC) as well as later Pfyn-period occupations (*c.* 3700–3600 BC) – have been related to their 'Mesolithic' heritage and used as an indirect argument for mobility (Whittle 1996a: 216–22). High levels of hunting in these periods, however, coincide with climatic evidence for short cold phases and perhaps also with failing crop production (Schibler *et al.* 1997a, 1997b; Hüster-Plogmann *et al.* 1999; Lüning 2000: 128–30). A further perspective is suggested by Halstead's (1999) interpretation of changes in hunting levels in Neolithic Greece by reference to greater obligations to share wild versus domesticated foods.

Clearly, the link between shifting cultivation and 'indigenous' farming – like that between hunting and Mesolithic ancestry – is tenuous at best; in fact, the shifting cultivation model was originally linked to Neolithic colonisation (see Chapter 2). Equally, the assumption that other forms of crop husbandry reflect the cultivation practices of 'immigrant' farmers is questionable (see p. 58).

The permanence of cultivation plots may have implications for tenurial claims on land and on social ranking (Boserup 1965: 79–81; Goody 1976: 20–2; Wilk and Netting 1984; Barrett 1994: 143–5). Halstead (1989b) has noted that sustained imbalances in production are unlikely to develop under a shifting cultivation regime: land tends to be owned communally because a given plot may only be cultivated once every *c.* 15–20 years, making individual use rights and 'ownership' of specific plots meaningless (Netting 1971; Grigg 1974: 58, 74; Brown 1978: 70, 109–11, 113–43; 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 formalized, inherited social rank) for the LBK and, indeed, much of the Neolithic (e.g. Bogucki 1988: 122–8, 1999: 209; Coudart 1998: 104, 110–11). A lack of social ranking, however, could also be consistent with fixed-plot farming. Halstead (1989b) has argued that lasting 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 central Europe (Bogucki 1988: 92; Gregg 1988: 5; Halstead 1989a). Recent claims for pre-LBK cultivation in central Europe based on early occurrences of cereal pollen (Haas 1996; Erny-Rodmann *et al.* 1997; Price *et al.* 2001) could 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 south-east Europe suggests that early Neolithic crop production in the study area was especially prone to risk (Halstead 1989a).

Halstead (1989a) has pointed to other indications of high risk in the LBK. First, dispersed settlement and unpainted pottery in the LBK contrasts with agglomerated 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, 1989a, 1989b; O'Shea 1981; Halstead and O'Shea 1982), 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 (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 central Europe may be suggested by broadening crop spectra from the middle Neolithic onwards (Bakels 1991a, 1997a), by a tendency towards increasing regionalization of material culture through the Neolithic (Lüning 1988, 1997, 2000: 16–20; Hodder 1990: 135–6; 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: 122–9) and by the reduced circulation of *Spondylus* shell ornaments in the later Neolithic (Bogucki 1988: 198). 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.

If fixed-plot cultivation were generally practised 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 in the middle–later Neolithic. Coudart (1998: 114) has argued that the emergence of leaders ('Big Men') is more plausible in the middle Neolithic than the early Neolithic: increasing regionalization 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 south-east Poland. Bogucki (1999: 208–30) 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 formalized political authority.

Intensity (intensive cultivation versus extensive ard 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 that large-scale surplus production also requires the availability of landless or dependent workers at harvest time (see also Chapter 2). The need for harvesting labour, high-maintenance (specialized) 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 ard cultivation with oxen, as argued by Lüning (1979/80, 1980, 2000: 160–1, 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; Bogucki 1993, 1999: 227–30) for the later Neolithic, 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 1989b), but social stratification is not a prerequisite.

Some authors have inferred considerable social inequality among households in the early–middle Neolithic, thus increasing the plausibility of extensive ard cultivation. Lüning (1988, 1997, 2000: 202) has argued that the so-called *Großbau* type of longhouse – that is, with three sections (tripartite), including a 'south-east' (or front) section thought to contain crop storage facilities on an upper floor – may have had control 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; Gronenborn 1999). Roof space would provide warm, dry conditions for cereal storage (Rowley-Conwy 2000b). 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 more cereal chaff (glume wheat glume bases) and weed seeds occur 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 density of glume wheat glume bases and weed seeds is higher in pits associated with the tripartite type. 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 processed per longhouse type. The association between material resembling 'processing waste' (glume wheat chaff, weed seeds) and tripartite longhouses is interpreted as evidence 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. A greater frequency of decorated pottery sherds and finished flint tools in pits associated with tripartite 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. Gronenborn 1999). Animal bone data from Cuiry-lès-Chaudardes in the Aisne valley 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).

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 organization in the later LBK and middle Neolithic involved inherited status and some form of domination or exploitation by elite households. In a similar vein, Modderman (1988) suggests that the end of the *Bandkeramik* tradition, associated with evidence of violent conflict, was brought about by revolt against a socio-economic system in which the distribution of food was controlled by a minority.

Other authors (Bogucki 1988: 122–8, Coudart 1998: 104, 110–11) have challenged the interpretation of variability in longhouse size or type as evidence of social ranking. Coudart (1998: 104, 110–11) 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 emphasizes 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 any case, the archaeobotanical evidence for a contrast between tripartite longhouses and other structures is unconvincing in its calculation (e.g. based on the amalgamation of plant remains from different deposits or contexts). Even if it is assumed that glume wheat chaff and weed seeds are particularly associated with tripartite longhouses, this could reflect greater household size.

According to Bogucki (1988: 122–8), 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 mobilize labour beyond their immediate household, widespread risk and uncertainty would have been much more prominent in the early–middle Neolithic and would 'cut short any sort of aggrandizing behaviour involving labour control' (cf. Halstead 1989a, 1989b). Second, settlement fissioning would further dampen intra- and inter-community tendencies towards social hierarchy (cf. Gilman 1981). Third, like Halstead (1989a), Bogucki interprets long-distance exchange (e.g. *Spondylus* shell ornaments) as evidence of the support networks needed for farming in a temperate European environment. 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 early–middle 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.

Turning to the social context of extensive ard cultivation in the later Neolithic, 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. By contrast, other authors supporting extensive ard cultivation from the TRB period onwards have admitted that the evidence for social stratification is limited. Sherratt (1991, 1997) has 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: 227–30) argues that animal traction in the latter half of the fourth millennium BC was 'revolutionary' but notes that the expected effect – hereditary elites – was delayed (Bogucki 1999: 230). These admissions of 'delay' from authors advocating the 'revolutionary' impact of ard cultivation suggest that the social significance of Neolithic ard cultivation may have been limited (see also Chapter 2).

Seasonality (floodplain cultivation versus intensive garden cultivation)

A particular implication of the floodplain model, according to Bogucki (1996, 1999: 181), refers to the debate over Neolithic colonization 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 colonization' (Bogucki 1996: 253). A link between floodplain cultivation and colonization 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 that floodplain cultivation could be implemented with little labour input (see Chapter 2), 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 (see p. 52), 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 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 (see Chapter 2). 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 the use of pigs to clear fallow. This need for integration would limit potential for economies with 'separate' arable 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 (see p. 52) and so discourage the balanced pursuit of gathering and hunting alongside cultivation.

Summary

- The four major crop husbandry models proposed for the study area can be distinguished by the variables of permanence, intensity and seasonality.
- The permanence of cultivation plots has implications for the mobility of Neolithic communities, tenurial claims on land and the potential for social inequality.
- The intensity of cultivation has implications for surplus production and social stratification, and hence for the interpretation of variability in burial and the form and size of houses and settlements.
- The seasonality of cultivation has implications for time and labour investment in farming, integration of crop and livestock husbandry and scheduling of agricultural tasks.

4

ARCHAEOBOTANICAL, ECOLOGICAL AND STATISTICAL METHODOLOGY[1]

Selection of the archaeobotanical dataset

In order to assess which form(s) of crop husbandry were practised in the study area on the basis of Neolithic arable weed data it is necessary to select suitable archaeobotanical samples. In particular, it is important that each selected archaeobotanical sample originates from a single archaeological deposit, is sufficiently rich in crop and weed remains for statistical analysis and derives from a single crop type and crop processing stage. Samples meeting all of these criteria provide the best evidence of the original weed floras growing on cultivated plots and hence of crop growing conditions. The 'pool' of archaeobotanical reports available for the selection of Neolithic samples from the study area consisted of those published by 1999 as well as several unpublished datasets made available to the author. A summary of the rationale behind each selection criterion, and the way in which they were implemented, is presented below.

Charred versus waterlogged preservation

While the plant remains recovered from Neolithic sites in the loess belt of central Europe are almost always preserved by charring, the lakeshore sites of the Alpine Foreland have produced a large dataset of waterlogged plant remains (Jacomet and Kreuz 1999: 293–300). The interpretation of waterlogged remains 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 (Jacomet *et al*. 1989: 132–4; Maier 1991, 2001: 78–108; Brombacher 1997; Brombacher and Jacomet 1997). For this reason, therefore, only charred plant remains were considered for analysis, including those from waterlogged sites and in samples of otherwise waterlogged plant material.

Stratigraphic origin

A basic concern of the archaeobotanical analysis discussed in this book is to interpret the co-occurrence of arable 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: 77–9); 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 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 weed seeds because they have been fully processed and cleaned. Furthermore, crop stores sometimes contain other edible 'contaminants' (e.g. apple seeds, hazelnuts, concentrations of wild Cruciferae seeds) that were not harvested with the crops themselves (Jacomet *et al*. 1989: 132; Schlichtherle 1981; Maier 2001: 37–50, 123–6). On the other hand, the residues or by-products from crop cleaning are often rich in weed seeds and so may also provide useful information on past weed floras (Hillman 1981, 1984a, 1984b; G. Jones 1984). By-product material, however, is usually found in 'open' contexts (i.e. midden-type 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. Samples from both 'open' and 'closed' contexts, therefore, were considered for selection.

For each archaeobotanical report, the stratigraphic origin of every archaeobotanical sample was assessed. If a sample appeared to derive from more than one feature (usually pits), it was excluded from consideration. Similarly, if a sample clearly combined distinct deposits within the same pit or feature, it was excluded. In some cases, a number of samples 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.). Where possible, the author of the relevant archaeobotanical report was contacted to check the homogeneity of the pit fill. If the contents of a number of samples from the same pit or feature were reported separately, similarity between adjacent samples was assessed in order to decide whether or not they should be amalgamated. The goal was to avoid the two extremes of amalgamating separate deposits (potentially derived from different sources) or of allowing over-representation of a single deposit. 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.

While most decisions about amalgamation involved relatively discrete features such as pits, several sites in the Alpine Foreland contained layers of burned material covering part or all of the settlement. These layers represented the destruction of settlements by fire and tended to preserve large quantities of crop remains. At one such site, Hornstaad-Hörnle IA, Maier (2001: 37–50) has defined clusters of samples representing separate stores of crops (free-threshing wheat, barley and einkorn/emmer) associated with particular houses. These sample clusters, therefore, were treated as large samples from distinct contexts.

Weed content

In order to isolate weed-rich samples, only those samples containing at least 30 charred seeds of weed taxa identified more or less to species (including 'cf.' identifications), or to two or three species within a genus, were considered for selection. 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 (genus- or family-level) were disregarded in the assessment of weed-richness.

Certain taxa with edible fruits were also excluded from consideration as potential arable weeds. These include fruit-bearing trees and shrubs (*Cornus sanguinea* L., *Corylus avellana* L., *Malus sylvestris* Miller, *Prunus padus* L., *Prunus spinosa* L., *Pyrus communis* L., *Rosa* spp., *Rubus* spp., *Sambucus nigra* L., *Sambucus racemosa* L.), plus a few edible herbaceous species (*Anethum graveolens* L., *Apium graveolens* L., *Fragaria* spp., *Petrosilenum crispum* (Miller) A.W. Hill) that include possible cultivars (Küster 1985; Brombacher 1997; Brombacher and Jacomet 1997; Maier 2001: 76–7). Opium poppy (*Papaver somniferum* L.) was also excluded since there is good evidence that it was cultivated in at least the later Neolithic (Brombacher and Jacomet 1997; see also Knörzer 1998 for a high number 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* (L.) Gaertner, *Sorbus aria* (L.) Crantz, *Viscum album* L.). Of course, there are other edible species such as Fat Hen (*Chenopodium album* L.) and Black Bindweed (*Fallopia convolvulus* (L.) A. Löve) that occur mainly or exclusively in ruderal or arable habitats (Jacomet *et al.* 1989: table 80), but excluding all edible taxa *a priori* was considered undesirable due to the potential loss of ecological information (see also p. 66).

Available archaeobotanical data from the study area 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. Weed seed identifications, therefore, needed to be standardized to enable meaningful comparison of samples identified by different archaeobotanists over a long period (cf. Colledge 2001: 183). This standardization was carried out based on the level of identification generally appropriate for the relevant taxa in their usual charred state. The standardized identifications of weed taxa (see Table 4.4) 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.

Crop content

In addition to the requirement for at least 30 potential arable weed seeds, archaeobotanical samples also needed to contain at least 50 crop items to be considered for selection. The crop content of archaeobotanical samples was used to classify them according to predominant crop type and subsequently to evaluate the crop processing stage(s) they represented (see pp. 64–5). Before classifying samples based on their crop content, however, the crop composition of samples needed to be standardized and simplified. Simplified crop categories are listed in Table 4.1. The basic rationale for this simplification 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

Table 4.1 Simplification of crop identification categories

Category	*Contents*
Glume wheat grains	Grains of glume wheat species (einkorn, emmer, spelt)
Glume wheat glume bases	Glume bases of glume wheat species (einkorn, emmer, spelt)
Free-threshing cereal grains	Grains of free-threshing cereal species (naked, hulled or indeterminate barley, durum wheat, bread wheat)
Free-threshing cereal rachis	Rachis internodes of free-threshing cereal species (naked, hulled or indeterminate barley, durum wheat, bread wheat)
Indeterminate cereal grains	Grains of indeterminate cereal and/or wheat
Millet grains	Seeds of cultivated millet species (broomcorn and foxtail millet)
Pulses	Seeds of cultivated pulse species (pea, lentil)
Flax	Seeds of cultivated and/or indeterminate flax
Opium poppy	Seeds of opium poppy

identification of crop processing stage. Crop species of the same type – that is, crops processed in a similar way (e.g. the glume wheats einkorn, emmer and spelt; the free-threshing cereals bread wheat, macaroni wheat and barley) – may be grown together as a mixed or 'maslin' crop (cf. G. Jones and Halstead 1995). It has often been argued, for example, that emmer and einkorn were grown together as a 'maslin' in the LBK and subsequent Neolithic periods in central Europe (Willerding 1980, 1983b; Bakels 1991b; Knörzer 1997, 1998). In addition, like the weed seed identifications (see p. 63), crop identification methods vary among archaeobotanists. As well as crop identification, quantification methods for crop seeds and chaff were also standardized so that counts of crop parts from different sites would be comparable.

Samples were classified based on their simplified crop composition. Only those samples dominated by a single crop type (at least 90 per cent of the total crop material) – or with at least 70 per cent of one *cereal* type, the remainder of the crop material consisting mostly of indeterminate cereal material – were considered in relation to further selection criteria.

Taphonomic factors affecting sample composition

Once weed and crop content had been simplified and standardized, the next step was to consider some of the taphonomic processes that may affect crop and weed composition. One of the most important factors is crop processing. 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, 1984b, 1985; G. Jones 1983, 1984, 1987, 1992; Peña Chocarro 1996). Of particular interest here is the effect of crop processing on weed composition. 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. 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. The impact of crop processing, therefore, needs to be assessed *before* interpreting the weed composition of archaeobotanical samples as evidence of crop husbandry (G. Jones 1981, 1983, 1984, 1987, 1992).

Two methods were used to identify the processing stage(s) represented by archaeobotanical samples: (1) classification of samples based on their crop content (that is, both the crop types and the plant parts – grains, chaff elements – 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 (grains and chaff elements – rachis internodes of free-threshing cereals, glume bases of glume wheats) in whole plants of each cereal species in order to identify crop processing stage; the mixing of processing stages can 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 (G. Jones 1990). The second method, based on physical weed seed types, relies on the observation that weed seeds with particular physical properties are removed at different stages in the crop processing sequence, such that the weed type composition of a sample may correspond to a single processing stage or to a mixture of stages (G. Jones 1983, 1984, 1987). 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).

The effect of other taphonomic factors on archaeobotanical sample composition was also considered. Harvesting methods (e.g. ear- versus sickle-harvesting), for example, may have varied during the Neolithic in the study area. Variation in harvesting methods would affect the composition of archaeobotanical weed assemblages: much more weed material tends to be collected by sickle- than by ear-harvesting, for example (Hillman 1981; Reynolds 1985, 1993). Different harvesting methods may also affect the range of weed species typically harvested: there is experimental evidence to suggest that ear-harvesting tends to select the seeds of climbing weeds (e.g. Black Bindweed, *Fallopia convolvulus* (L.) A. Löve, and Cleavers, *Galium aparine* L.) (Reynolds 1985, 1993). Differences in weed composition among archaeobotanical samples from different harvesting regimes, therefore, may obscure similarities or differences in crop husbandry. Unlike crop processing, however, there is no theoretical reason why harvesting method should introduce an *ecological* bias in the composition of the weed flora collected.

Comparison between modern data on the amounts of weed material sickle-harvested with cereals and archaeobotanical data from the study area indicate that archaeobotanical samples meeting the selection criteria outlined above could all potentially derive from sickle-harvesting, though this includes clear archaeobotanical instances of sickle-harvesting high on the straw (Maier 2001: 98–100). Furthermore, very few of the archaeobotanical cereal samples are dominated by the seeds of climbing weeds, as expected in ear-harvested cereals. Variation in harvesting height rather than harvesting method, therefore, appears to be the major taphonomic variable relating to harvesting. The maximum plant heights of weed species can be used to monitor the possible effects of variable harvesting height on weed composition (see Chapter 6).

A further taphonomic factor considered in some detail is the possibility that some or all of the archaeobotanical material derives from animal dung burned as fuel. Ethnohistorical evidence shows that, even in regions where wood fuel is readily available, dung may be a fuel of choice rather than of necessity (Anderson and Ertug-Yaras 1998; Charles 1998). Application of the criteria proposed by Charles (1998) for recognizing dung-derived material, however, failed to produce any firm positive evidence for this source. Moreover, the contents of waterlogged animal dung from lakeshore settlements in the Alpine Foreland (Robinson and Rasmussen 1989; Rasmussen 1993; Akeret and Jacomet 1997; Haas *et al.* 1998; Karg 1998; Akeret *et al.* 1999) suggests that animals were fed a variety of fodder types (twig/branch foddering, cereal material, browsing of blackberry bushes, herb/grass foddering, etc.) that, if charred, could not easily be mistaken for unmixed crop processing products or by-products.

A final taphonomic consideration is that certain species growing as arable weeds may also have been collected separately as food, fodder or for some other purpose. A clear case of this has been detected at Hornstaad-Hörnle IA (Schlichtherle 1981; Maier 2001: 37–50, 123–6), where charred clusters of Cruciferae seeds (Turnip, *Brassica rapa* L., and Flixweed, *Descurainia sophia* (L.) Webb ex Prantl) in some of the charred cereal stores appear to reflect the separate collection of these species; in other crop stores at this site, these species occur at much lower levels and appear to have been harvested with crops as arable weeds. Those cereal stores at Hornstaad-Hörnle IA that included 'collections' of Cruciferae seeds (Maier 2001: Figures 29, 35) were excluded from the archaeobotanical analysis.

The most widespread evidence in the study area for separate collection of a potential arable weed species relates to Fat Hen (*Chenopodium album* L.). Historical and ethnographic sources attest to the use of the seeds and (young) leaves of *C. album* as food, and archaeobotanists have long recognized 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 study area and period under consideration, two sorts of charred evidence for the collection of *C. album* have been emphasized in the archaeobotanical literature: (1) the occurrence of samples entirely dominated by *C. album* seeds, containing little cereal material and few seeds of other wild taxa (Knörzer 1967, 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 (Knörzer 1967, 1973; cf. Bakels 1991b). Knörzer (1967, 1973) has argued that unripe seeds point to the collection of immature plants for their leaves, the seeds being discarded as waste. The presence of unripe seeds, however, is a dubious indicator of separate collection 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 per cent *C. album* seeds (of all identifiable charred items combined), several examples are included among those archaeobotanical samples meeting the selection criteria described above. Though *C. album* may represent a weed harvested with crop material in many of the selected archaeobotanical 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 (see Chapters 5 and 6).

The archaeobotanical dataset selected

Application of the various criteria described above, including comparison of results from the two methods of identifying crop processing stage, identified a total of 126 archaeobotanical samples from the study area as containing unmixed crop and weed material from a single crop type and processing stage. These samples represent a fraction of the thousands of archaeobotanical samples available from the study area, but offer the best evidence for crop growing conditions. The selected dataset, summarized by crop type and processing stage in Table 4.2, forms the basis of analyses discussed in subsequent chapters.

By far the most common type of sample among those selected is dominated by glume wheat material. The glume wheats in these samples were identified as various combinations of einkorn, emmer and einkorn/emmer. The samples from the LBK site of Vaihingen, analysed by the author (unpublished data), also regularly include a third glume wheat type resembling modern *Triticum timopheevi* Zhuk and recently described by G. Jones *et al.* (2000b).

Table 4.2 The archaeobotanical dataset selected, summarized by crop type and crop processing classification

	No. samples
Glume wheat samples:	
Glume base samples (fine sieve by-products)	110
'Spikelet' samples (both fine sieved and unsieved)	8
Grain samples (fine sieve products)	6
Free-threshing cereal samples:	
Unthreshed sample	1
Grain sample (fine sieve product)	1

The major stages in free-threshing cereal and 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 (one or more grains enclosed by glumes) and does not release grains from chaff (Hillman 1981, 1984a, 1984b). 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 account of glume wheat processing, Hillman 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 offers a plausible explanation for the prevalence of glume wheat glume bases on Neolithic sites in the study area (Gregg 1989; Meurers-Balke and Lüning 1992).

Most of the selected glume wheat samples are dominated by chaff (glume bases) and were classified by crop processing analysis as by-products of fine sieving (110 out of 126, 87 per cent). Other glume wheat sample types consist of grain samples classified as fine sieve products and possible ‘spikelet’ samples (grain stored in spikelet form). The status of the ‘spikelet’ samples is somewhat uncertain – they may represent mixtures of product and by-product material rather than spikelets. Assuming that they are genuine, the ‘spikelet’ samples include some that appear to have been fine sieved (that is, they are like fine sieve products in terms of the physical weed seed types they contain) and others that appear unsieved (that is, they contain a mixture of weed seed types associated with fine sieve products and by-products).

In addition to the 124 glume wheat samples, two free-threshing cereal samples were selected (Table 4.2). One of these is dominated by free-threshing wheat grain and was classified as a fine sieve product. The second ‘sample’ is an individual cereal store from Hornstaad-Hörnle IA consisting of mostly unthreshed free-threshing wheat (Maier 2001: 40, Figure 28).

Figure 4.1 shows the location of the 29 sites with selected archaeobotanical samples suitable for statistical and ecological analysis. Table 4.3 lists all 126 samples suitable for further analysis, together with period, context and bibliographic information.

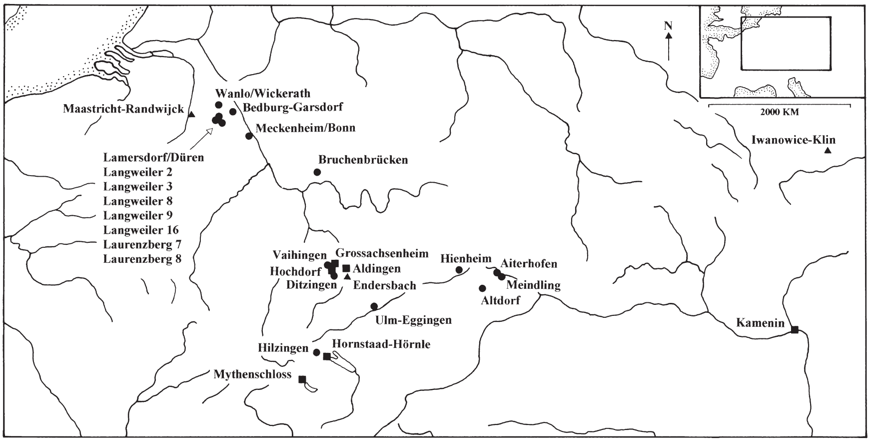

Figure 4.1 Map showing the location of archaeological sites from which the selected archaeobotanical samples derive; circles = early Neolithic (LBK), triangles = middle Neolithic (e.g. Rössen, Lengyel), squares = later Neolithic

Collection of weed ecological data for the selected archaeobotanical dataset

A new ecological approach to the interpretation of archaeobotanical weed data, the FIBS method (see Introduction), was applied to the selected archaeobotanical dataset. This approach requires the measurement of 'functional attributes' – morphological or behavioural characteristics that are functionally related to species' autecology (see pp. 76–87). The measurement of morphological functional attributes requires the collection of mature, robust specimens found growing in arable fields, field margins, ruderal habitats, etc. (Charles *et al.* 1997, 2002, 2003; Bogaard *et al.* 1999, 2001; G. Jones *et al.* 2000a).

Once the archaeobotanical dataset had been selected, therefore, the next step was to target the most frequently occurring weed taxa in these samples for the collection of specimens 'in the field' and the measurement of morphological functional attributes. Standardized identification categories for the weed taxa in the selected archaeobotanical samples are listed in Table 4.4, together with the number of samples in which each taxon occurs. Weed taxa occurring in at least three of the selected archaeobotanical samples from the study area (i.e. at least 2 per cent of samples) were targeted, and functional attribute measurements were obtained for all 35 of these species. Since some standardized identification categories for weed taxa consist of up to three species (e.g. *Bromus arvensis* L./*hordeaceus* L./*secalinus* L.) or multiple subspecies (e.g. *Phleum pratense* L., which includes subsp. *bertolonii* and subsp. *pratense*), the number of individual species/subspecies requiring functional attribute measurements exceeded the number of archaeobotanical weed taxa

Table 4.3 Period, context and bibliographic information for the selected archaeobotanical samples; EN = early Neolithic, MN = middle Neolithic, L = later Neolithic

Site	*Period*	*Context description*	*Reference*
Aiterhofen	EN (LBK)	Level B20, pit 84	Bakels 1983/4
Aldingen	LN (Schwieberdingen)	Pit 131	Piening 1986a, 1992
Altdorf	EN (LBK)	Level 152/5, pit 1	Bakels 1983/4
Bedburg-Garsdorf	EN (LBK)	Pit 28	Knörzer 1974
Bedburg-Garsdorf	EN (LBK)	Pit 41	Knörzer 1974
Bedburg-Garsdorf	EN (LBK)	Pit 44	Knörzer 1974
Bruchenbrücken	EN (LBK)	Pit 283	Kreuz 1990
Bruchenbrücken	EN (LBK)	Pit 29	Kreuz 1990
Ditzingen	EN (LBK)	Pit 257	Piening 1998
Ditzingen	EN (LBK)	Pit 520	Piening 1998
Ditzingen	EN (LBK) (/MN (Rössen))	Pit 946	Piening 1998
Endersbach	MN (Großgartach)	Pit	Piening 1982
Grossachsenheim	LN (Schussenried)	Pit 427, layer 3	Piening 1986b
Hienheim	EN (LBK)	Pit 1211, layer 2	Bakels 1978, 1986
Hilzingen	EN (earlier LBK)	Pit 348e	Stika 1991
Hilzingen	EN (earlier LBK)	Pit 348f	Stika 1991
Hilzingen	EN (late LBK)	Pit 394	Stika 1991
Hilzingen	EN (middle LBK)	Pit 537	Stika 1991
Hochdorf	LN (Schussenried)	Pit 186, layer 1K	Küster 1985
Hochdorf	LN (Schussenried)	Pit 315, layer 2	Küster 1985
Hochdorf	LN (Schussenried)	Pit 326	Küster 1985
Hochdorf	LN (Schussenried)	Pit 330, layer 1	Küster 1985
Hochdorf	LN (Schussenried)	Pit 403, layer 5	Küster 1985
Hochdorf	LN (Schussenried)	Pit ('drying oven'), layer 3	Küster 1985
Hochdorf	LN (Schussenried)	Pit ('drying oven'), layers 4 and 4a	Küster 1985
Hochdorf	LN (Schussenried)	Pit 460, layer A1	Küster 1985
Hochdorf	LN (Schussenried)	Pit 485, layer 4	Küster 1985
Hochdorf	LN (Schussenried)	Pit 486, layer A	Küster 1985

Hochdorf	LN (Schussenried)	Pit 592, layer 3	Küster 1985
Hornstaad-Hörnle IA	LN (Hornstaad)	Burned crop store (House 13)	Maier 2001
Iwanowice-Klin	MN (Lengyel)	Pit 231	Litynska 1990
Kamenin	LN (Baden)	Object 80	Nevizansky 1980; Hajnalová 1989
Lamersdorf/Düren	EN (LBK)	Pit A	Knörzer 1967, 1968, 1971
Langweiler 2	EN (LBK)	Pit 306	Knörzer 1973
Langweiler 3	EN (LBK)	Dark layer in pit	Knörzer 1972
Langweiler 8	EN (LBK)	Pit 1033/position 7, charred layers	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 1482/position 11, charred layer	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 2126/position 9, charred layer	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 2146/positions 4 and 11	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 2148/position 19, charred layer	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 2799/position 15, charred layer	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 2799/position 15 (2), charred layer	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 3881, dark layer in pit	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 3911/position 14, charred layer	Knörzer 1988
Langweiler 8	EN (LBK)	Pit 52/position 5, charred layer	Knörzer 1988
Langweiler 9	EN (LBK)	Pit 1061/position 17 (layer III)	Knörzer 1977
Langweiler 9	EN (LBK)	Pit 1061/position 19 (layer IV)	Knörzer 1977
Langweiler 16	EN (LBK)	Pit 3/position 52	Knörzer 1997
Laurenzberg 7	EN (LBK)	Pit 200/position 6	Knörzer 1997
Laurenzberg 7	EN (LBK)	Pit 200/position 5	Knörzer 1997
Laurenzberg 7	EN (LBK)	Pit 200/position 7	Knörzer 1997
Laurenzberg 7	EN (LBK)	Pit 372	Knörzer 1997
Laurenzberg 7	EN (LBK)	Pit 430/position 4	Knörzer 1997
Laurenzberg 7	EN (LBK)	Pit 713/position 6	Knörzer 1997
Laurenzberg 8	EN (LBK)	Pit 13/position 6	Knörzer 1997
Maastricht-Randwijck	MN (Rössen)	Pit 13, samples 62–3 amalgamated	Bakels 1991a; Bakels *et al*. 1993
Meckenheim/Bonn	EN (LBK)	Pit 24	Knörzer 1967, 1968, 1971
Meckenheim/Bonn	EN (LBK)	Pit 72	Knörzer 1967, 1968, 1971
Meindling	EN (LBK)	Pit 100–1	Bakels 1992b

Table 4.3 continued

Site	*Period*	*Context description*	*Reference*
Meindling	EN (late LBK)	Pit 115–3	Bakels 1992b
Meindling	EN (LBK)	Pit 98	Bakels 1992b
Mythenschloss	LN (Corded Ware)	Structure G	Jacomet *et al*. 1989, unpublished data; Brombacher and Jacomet 1997
Ulm-Eggingen	EN (LBK)	Long pit (sample 122/29a)	Gregg 1989
Ulm-Eggingen	EN (LBK)	Long pit (sample 123/1c)	Gregg 1989
Ulm-Eggingen	EN (earlier LBK)	Pit (sample 153/1)	Gregg 1989
Ulm-Eggingen	EN (LBK)	Pit (sample 24/16)	Gregg 1989
Ulm-Eggingen	EN (middle LBK)	Long pit of structure 18 (sample 26/23)	Gregg 1989
Ulm-Eggingen	EN (late LBK)	Long pit of structure 20 (sample 34/1)	Gregg 1989
Vaihingen	EN (LBK)	Pit (level 1/surface 180060/feature 10/samples 97–98 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1/surface 180070/feature 11/samples 117–121 amalgamated)	Bogaard unpublished data
Vaihingen	EN (late LBK)	Pit (level 1–2/surface 135060/feature 9/sample 224)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 135040/feature 14/samples 228–229 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 225050/feature 15/samples 364–366 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 225070/feature 1/sample 396)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 255120/feature 6/samples 467–470 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 255050/feature 13/samples 616–619 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 255060/feature 1/samples 630–635 amalgamated)	Bogaard unpublished data

Vaihingen	EN (LBK)	Pit (level 1–2/surface 255040/feature 18/samples 640–641 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier? LBK)	Pit (level 1–2/surface 255050/feature 1/samples 645–646 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier? LBK)	Pit (level 1–2/surface 255050/feature 1/samples 695–698 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier? LBK)	Pit (level 1–2/surface 285100/feature 7/samples 720–721 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 285070/feature 6/sample 857)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 285060/feature 3/samples 893–897A amalgamated)	Bogaard unpublished data
Vaihingen	EN (middle LBK)	Pit (level 1–2/surface 285050/feature 1/samples 925–927 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 195050/feature 5/samples 1034–1037 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 195070/feature 22/samples 1050–1052 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 195040/feature 1/samples 1100–1104 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 195040/feature 1/samples 1105–1109 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 195040/feature 1/samples 1110–1112 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 195040/feature 2/samples 1113–1116 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 240080/feature 2/samples 1202–1204 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 240050/feature 2/samples 1258–1260 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 4–5/surface 195080–90/feature 27/sample 1294)	Bogaard unpublished data

Table 4.3 continued

Site	*Period*	*Context description*	*Reference*
Vaihingen	EN (late LBK)	Pit (level 1–2/surface 105040/feature 2/sample 1301)	Bogaard unpublished data
Vaihingen	EN (late LBK)	Pit (level 1–2/surface 105040/feature 2/samples 1322–1324 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 5/surface 195080–90/feature 6/samples 1325–1327 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 270040/feature 2/sample 1344)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 270040/feature 2/sample 1349)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 2–3/surface 270040/feature 13/samples 1451–1454 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 2–3/surface 270050/feature 15/samples 1455–1460 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 2–3/surface 270050/feature 16/samples 1469–1470 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 300040/feature 2/samples 1488–1491 amalgamated)	Bogaard unpublished data
Vaihingen	EN (middle LBK)	Pit (level 1–2/surface 210070/feature 16/samples 1599–1600 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 210040/feature 12/samples 1741–1742 amalgamated)	Bogaard unpublished data
Vaihingen	EN (middle LBK)	Pit (level 1–2/surface 315040/feature 1/samples 1919–1923 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier? LBK)	Pit (level 1–2/surface 345040/feature 1/sample 2068)	Bogaard unpublished data
Vaihingen	EN (earlier? LBK)	Pit (level 1–2/surface 345040/feature 1/samples 2080–2082 amalgamated)	Bogaard unpublished data
Vaihingen	EN (middle LBK)	Pit (level 1–2/surface 315960/feature 12/samples 2444–2445 amalgamated)	Bogaard unpublished data

Vaihingen	EN (LBK)	Pit (level 1–2/surface 315980/feature 13/samples 2528–2533 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 300960/feature 12/samples 2542–2545 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 315000/feature 25/samples 2569–2571 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 6–7/surface 345900/feature 33/samples 2688–2690 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 300970/feature 16/sample 2709)	Bogaard unpublished data
Vaihingen	EN (LBK) (/MN)	Pit (level 1–2/surface 360940/feature 3/samples 2760–2764 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 285980/feature 5/sample 2867)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 285970/feature 9/samples 2868–2871 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 270990/feature 1/samples 2923–2924 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 255980–270980/feature 1/sample 2929)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 225960/feature 1/sample 2973)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 225980/feature 20/sample 2976)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 225980/feature 20/samples 2979–2982 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 225980/feature 4/samples 2987–2989 amalgamated)	Bogaard unpublished data
Vaihingen	EN (LBK)	Pit (level 1–2/surface 225000/feature 9/samples 2994–2999 amalgamated)	Bogaard unpublished data
Vaihingen	EN (earlier LBK)	Pit (level 1–2/surface 225000/feature 4/sample 3009)	Bogaard unpublished data
Wanlo/Wickerath	EN (LBK)	Pit 188	Knörzer 1980
Wanlo/Wickerath	EN (LBK)	Pit 202, layer 3	Knörzer 1980

targeted. Behavioural functional attributes that consist of data from Floras (e.g. the onset and length of the flowering – see pp. 83–4) were gathered for all weed taxa in the selected archaeobotanical samples (Table 4.4).

FIBS has previously been applied to modern surveys of weed floras developed under traditional husbandry regimes (Charles *et al.* 1997, 2002, 2003; Bogaard *et al.* 1999, 2001; G. Jones *et al.* 2000a). In the course of this previous work, 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 major categories of functional attributes used in this study and their relationships to habitat conditions are summarized in Table 4.5 and described in more detail on pp. 76–87.

As noted earlier, the measurement of morphological functional attributes involves locating robust, well-established specimens of plants (i.e. those flowering or setting seed) growing 'in the field'. 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. The study area falls within the Atlantic-continental zone of Europe (cf. Oberdorfer 1994: Figure 2). A further aspect of measurement strategy, therefore, was to obtain at least two collections of each species within Atlantic-continental Europe.

Measurement procedures for functional attributes

The ecological rationale and measurement procedures for the functional attributes in Table 4.5 are presented in summarized form below. These methodological descriptions follow previous publications on FIBS study of modern crop husbandry regimes (see references for each attribute, below), though the measurement procedures for some attributes have been somewhat revised.

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.* 2000a; see also Charles *et al.* 1997, 2003; Bogaard *et al.* 1999, 2001)

Weeds with potentially large canopy dimensions (canopy height and/or diameter) are characteristic of productive sites with infrequent disturbance. Those with consistently smaller canopy dimensions are indicative of one of two scenarios: unproductive conditions with infrequent disturbance or productive conditions with frequent disturbance.

Table 4.4 The standardized potential arable weed taxa and their frequency in selected samples (botanical nomenclature follows Tutin *et al.* 1964–1993)

Standardized weed taxa	*No. samples*
Agrimonia eupatoria L.	1
Agrostemma githago L.	1
Agrostis canina L.	1
Arenaria serpyllifolia L.	2
Astragalus glycyphyllos L.	1
Atriplex patula L./*prostrata* (Boucher) ex DC.	2
Brassica rapa L.	1
Bromus arvensis L./*hordeaceus* L./*secalinus* L.	84
Bromus erectus Hudson	1
Bromus sterilis L./*tectorum* L.	33
Camelina sativa (L.) Crantz	1
Carex muricata L.	1
Carex spicata Hudson	1
Chenopodium album group	122
Chenopodium ficifolium Sm.	4
Chenopodium glaucum L.	1
Chenopodium hybridum L.	1
Chenopodium polyspermum L.	16
Circaea lutetiana L.	1
Conium maculatum L.	1
Daucus carota L.	1
Descurainia sophia (L.) Webb ex Prantl	3
Digitaria ischaemum (Schreber) Muhl.	1
Echinochloa crus-galli (L.) Beauv.	39
Fallopia convolvulus (L.) A. Löve	120
Festuca rubra L.	2
Galeopsis angustifolia Ehrh. ex Hoffm./*ladanum* L./*segetum* Necker	3
Galeopsis bifida Boenn./*speciosa* Miller/*tetrahit* L.	1
Galium aparine L.	18
Galium mollugo group/*verum* group	3
Galium palustre *L.*	1
Galium spurium L.	59
Hyoscyamus niger L.	3
Hypericum perforatum L.	1
Knautia arvensis (L.) Coulter	2
Lamium amplexicaule L.	1
Lapsana communis L.	55
Leontodon autumnalis L.	2
Leucanthemum vulgare Lam.	1
Lolium perenne L.	1
Luzula campestris (L.) DC./*multiflora* (Retz.) Lej.	2
Malva sylvestris L.	2
Chamomilla recutita (L.) Rauschert	1
Moehringia trinervia (L.) Clairv.	1
Myosotis arvensis (L.) Hill	1
Myosoton aquaticum (L.) Moench	1
Nepeta cataria L.	2

Table 4.4 continued

Standardized weed taxa	*No. samples*
Origanum vulgare L.	1
Papaver rhoeas L.	3
Pastinaca sativa L.	1
Phleum pratense L.	60
Pimpinella saxifraga L.	1
Plantago lanceolata L.	2
Plantago major L.	3
Poa annua L.	6
Poa compressa L./*nemoralis* L./*palustris* L.	1
Poa pratensis group/*trivialis* L.	6
Polygonum amphibium L.	2
Polygonum aviculare group	9
Polygonum lapathifolium L.	17
Polygonum minus Hudson	2
Polygonum persicaria L.	20
Potentilla argentea L.	1
Ranunculus repens L.	3
Rumex acetosa L./*thyrsiflorus* Fingerh.	5
Rumex acetosella L.	11
Rumex conglomeratus Murray/*sanguineus* L.	5
Rumex crispus L./*obtusifolius* L.	2
Sambucus ebulus L.	3
Saponaria officinalis L.	1
Setaria pumila (Poiret) Schultes	8
Setaria verticillata (L.) Beauv./*viridis* (L.) Beauv.	30
Sherardia arvensis L.	1
Silene dioica (L.) Clairv.	2
Silene latifolia Poiret	2
Silene nutans L.	1
Silene vulgaris (Moench) Garcke	8
Sisymbrium officinale (L.) Scop.	1
Solanum nigrum L.	64
Sonchus asper (L.) Hill	5
Stachys sylvatica L.	1
Stellaria media (L.) Vill.	1
Trifolium arvense L.	2
Trifolium dubium Sibth.	1
Trifolium pratense L.	2
Trifolium repens L.	3
Urtica dioica L.	2
Valerianella dentata (L.) Pollich	19
Valerianella rimosa Bast.	2
Verbascum nigrum L.	2
Verbena officinalis L.	1
Veronica arvensis L.	2
Veronica hederifolia L.	1
Vicia hirsuta DC.	18
Vicia tetrasperma (L.) Schreber	1

Table 4.5 The major categories of functional attributes used and their ecological significance

Functional attribute	*Ecological attribute*	*Relationship to habitat conditions*	*References*
(a) Attributes relating to the duration and quality of the growth period			
Maximum canopy height and diameter	Maximum plant size, the product of growth rate and period of growth	Positively correlated with potential productivity and negatively with disturbance of habitat	Grime 1979
Maximum leaf weight and area per node	Maximum nodal unit of foliar growth	Positively correlated with potential productivity of habitat	Grime 1979; Givnish 1987; Bogaard *et al.* 1998
Leaf area per node/leaf thickness	Plant growth rate	Positively correlated with potential productivity of habitat	Jackson 1967; Dale 1982; Givnish 1987; G. Jones *et al.* 2000a
Mean specific leaf area (leaf area/dry leaf weight)	Plant growth rate	Positively correlated with potential productivity of habitat	Reich *et al.* 1992; Reich 1993; van Arendonk and Poorter 1994
Mean leaf dry matter content (dry leaf weight/fresh leaf weight)	Dry matter investment in leaves and (inversely) plant growth rate	Negatively correlated with potential productivity of habitat	Garnier and Laurent 1994; Ryser 1996
(b) Attributes relating to seasonality and/or the ability to regenerate rapidly following disturbance			
Life history of annuals (summer or winter annual)	Season of growth	Winter annuals associated with autumn sowing and summer annuals with spring sowing	Ellenberg 1950
Germination time	Beginning of life cycle	Autumn-germination associated with autumn sowing and spring-germination with spring sowing	Ellenberg 1950

Table 4.5 continued

Functional attribute	*Ecological attribute*	*Relationship to habitat conditions*	*References*
Estimated epidermal cell endopolyploidy	Indication of cool-season growth	Positively correlated with autumn sowing	Grime *et al*. 1988; Melaragno *et al*. 1993
Onset of the flowering period	Timing of life cycle	Late onset of flowering associated with spring sowing	Grime *et al*. 1988; Sans and Masalles 1995
Length of flowering period	Duration of life cycle and therefore potential to regenerate from seed	Positively associated with spring sowing and disturbance	Grime *et al*. 1988; Sans and Masalles 1995
Vegetative spread (horizontal or vertical root system)	Ability of perennials to regenerate vegetatively from root fragments	Horizontal root system positively associated with disturbance	Håkansson 1982; Mortimer 1990
(c) Attributes relating to water use			
Mean stomatal size	Capacity to restrict transpirational water loss	Positively correlated with moist, productive conditions and negatively with droughted conditions	Salisbury 1927; Carpenter and Smith 1975; Donselman and Flint 1982
Mean stomatal density	Capacity to restrict transpirational water loss	Negatively correlated with moist, productive conditions (given the negative relationship between size and density) and positively with droughted conditions	(As above)
Epidermal cell size	Capacity to minimise loss of turgor	Negatively correlated with droughted conditions	Cutler *et al.* 1977

Sources: Charles *et al*. (1997, 2003), Bogaard *et al*. (1999, 2001), G. Jones *et al*. (2000a).

For each species, canopy dimensions were measured at one to five locations (see Bogaard *et al*. 1998 for semi-basal species). The most plausible published Flora height (J. Hodgson pers. comm.) was used to calculate maximum canopy height as follows:

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

and this was used if it exceeded the maximum canopy height measured in the field. Canopy height for climbing species was calculated as the height of the stem at an angle of 45 degrees. Maximum stem length measured in the field was compared with maximum stem length from Tutin *et al.* (1964–1993) and the larger used to calculate maximum canopy height for climbing species. Mean canopy dimension (the mean of maximum canopy height and maximum canopy diameter) was also calculated for each species since height and diameter can act as alternative means of achieving high biomass.

Leaf size attributes (G. Jones *et al*. 2000a; see also Bogaard *et al*. 1999, 2001; Charles *et al*. 2003)

Weed species with large amounts of leaf per node (measured as maximum leaf weight per node and maximum leaf area per node) are associated with productive conditions. By contrast, species with small amounts of leaf per node are associated with less productive conditions. In addition, the ratio of leaf area per node to leaf thickness can 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. The area of five leaves was measured per collection (using the Aequitas Image Analysis program – Dynamic Data Links 1993–1996) and the maximum individual leaf area for each species was multiplied by the usual number of leaves per node. Maximum leaf weight per node was calculated by dividing maximum leaf area per node by mean specific leaf area (see p. 82). The intervenal leaf thickness of five fresh leaves from each collection was measured using a dial thickness gauge. The ratio of maximum leaf area per node to mean leaf thickness was calculated for each species.

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

An index combining canopy size (canopy height and diameter) and leaf size (leaf weight per node) indicates habitat productivity and predicts the type of ruderal strategy *sensu* Grime (1979). The 'competitive ruderal' strategy (CR) class comprises large species of productive, relatively undisturbed habitats. The 'ruderal' strategy class *sensu lato* is a composite group of medium-sized species consisting of both ruderals (R) in the strict sense of Grime (1979), occurring in highly fertile/highly disturbed conditions, and weeds of sites with intermediate fertility and less disturbance (R/CSR). 'Stress-tolerant ruderals' (SR), small species of unproductive habitats, represent the third strategy.

Maximum canopy height, maximum canopy diameter and maximum leaf weight per node values (see p. 81) were scored on a 1 to 5 scale for each species (see Bogaard *et al.* 1998 for categories) and the three attribute scores added together to give index values ranging from 3 to 15. Index values can be used to predict Grime's (1979) 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 the dimensions of individual ramets have already been successfully used (Hodgson *et al.* 1999) in calculating strategy *sensu* Grime (1979).

Leaf 'density' attributes (G. Jones *et al.* 2000a; see also Charles *et al.* 1997, 2003; Bogaard *et al.* 1999, 2001)

A high specific leaf area (SLA, leaf area/dry leaf weight) generally indicates a fast growth rate and hence a productive habitat, while a low specific leaf area reflects less fertile situations with slower growth. Leaf dry matter content (DMC, dry leaf weight/fresh leaf weight) also measures growth rate.

About 1g fresh weight of leaves was gathered from each collection and weighed in a fully turgid state. The areas of five leaves from each collection were measured using the Aequitas Image Analysis program (Dynamic Data Links 1993–1996). Both samples were dried at 80°C and weighed. SLA is expressed as leaf area (mm^2) per unit of dry weight (mg) and DMC as a percentage (dry weight × 100/fresh weight). For both attributes, the mean 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.

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 in the autumn (winter annuals, in life history terms) are reduced in spring-sown crops by ploughing in the spring, after which they are unable to establish themselves. Conversely, annuals germinating in the spring or early summer (summer annuals) are disadvantaged in autumn-sown crops due to shade cast by the developed crop-weed canopy. Modern weed survey data indicate that species germinating in both autumn and spring (winter/summer annuals) tend to be associated with autumn-sown crops, presumably because they tend to germinate mainly in this period (Bogaard *et al.* 2001). These associations between germination time and sowing time should also apply to perennials that regenerate regularly from seed.

Germination times were abstracted from the *Ciba-Geigy Weed Tables* (Häfliger and Brun-Hool, 1968–1977) 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.* 2000a)

Opportunistic annuals (and perennials regenerating from seed) that can germinate over a wide range of temperatures and that mature rapidly (e.g. Chickweed, *Stellaria media* (L.) Vill.) tend to have a long flowering period. 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. Species with a late onset of flowering (July or later) are at a competitive disadvantage in autumn-sown crops and so should also be associated with spring rather than autumn sowing. By contrast, weed species with an early (January–March) or intermediate (April–June) onset of flowering and a short flowering period (1–3 months) tend to germinate before spring ploughing and should be particularly associated with autumn-sown crops.

Rothmaler (1995) provided data on the onset and length of the flowering period. Table 4.6 shows the flowering onset/length classes.

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

It is expected that winter annuals, particularly those that complete their life cycle early, will exhibit endopolyploidy (multiplication of the chromosome number) and a wide range of epidermal cell sizes, while the cell size of

Table 4.6 Flowering onset/length classes

Flowering onset/ length classes	*Flowering onset*	*Flowering duration*	*Associated sowing regime*
Short-flowering, early – intermediate onset	January–June	1–3 months	Autumn
Late-flowering	July	1–5 months	Spring
Long-flowering	January–June	>5 months	Spring
Medium flowering duration, intermediate onset	April–June	4–5 months	Autumn or spring

Source: Bogaard *et al*. (2001).

summer annuals will tend to be more uniform. Endopolyploidy in winter annuals may enable them to grow opportunistically during warm periods. Epidermal cells adjacent to stomatal guard cells tend to remain diploid, whereas polyploid cells are located further away from stomata.

The area of one cell next 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 mean area of both cell types was calculated per species. Epidermal cell endopolyploidy was calculated for each species as follows:

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

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

Successful perennials weeds often possess a network of horizontal rhizomes or stolons that, when cut into fragments, regenerate rapidly, promoting vegetative spread. Perennial species lacking these horizontal systems of rhizomes/stolons also lack this capacity for vegetative spread. On the other hand, some perennials with rhizomes/stolons are associated with relatively undisturbed habitats and do not regenerate freely from fragments (e.g. Stinging Nettle, *Urtica dioica* L., and Common Reed, *Phragmites australis* (Cav.) Trin. ex Steudel).

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.

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: 52–4). 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: 67–8). 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*. 2000a; see also Charles *et al*. 1997, 2003; Bogaard *et al*. 1999)

It appears that plants from dry habitats tend to have smaller, more numerous stomata, in contrast to plants with fewer, larger stomata from wetter habitats.

Following the method of Beerling and Chaloner (1992), acetate impressions were taken from the upper and lower surfaces of each of three replicate leaves per species collection. Stomatal density (expressed as no. per mm^2) was measured at two points on each upper and lower leaf surface impression. For each of three upper leaf surface impressions, the lengths (μm) of three stomata (closed, where possible) were measured using the Aequitas Image Analysis program (Dynamic Data Links 1993–1996). Mean stomatal density and length were calculated per species.

Epidermal cell size (G. Jones *et al*. 2000a; see also Charles *et al*. 1997, 2003)

At times of water shortage, cell turgor is better maintained in small cells than in larger ones. Small cell size, therefore, may be advantageous in droughted conditions.

Using the Aequitas Image Analysis program (Dynamic Data Links 1993–1996), the area (μm^2) of one epidermal cell as far away from stomata as possible was measured for each of three replicate acetate impressions of the upper leaf surface of each collection. Mean cell size was calculated 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.* 2000a; see also Bogaard *et al.* 1999; Charles *et al.* 2003)

Cell wall undulation is thought to reflect habitat moisture: undulating cell walls provide leaves with greater tensile strength under conditions of high turgor.

Using the Aequitas Image Analysis program (Dynamic Data Links 1993–1996), cell wall undulation was estimated by measuring the perimeter and maximum diameter (µm) of one cell as far from stomata as possible on 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.* 2000a; see also Charles *et al.* 1997, 2003; Bogaard *et al.* 1999)

Weed species associated with droughted conditions may have deep roots in order to access subsoil water. Root diameter at 10 cm (positively correlated with rooting depth) is used to estimate rooting depth.

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

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.* 2000a; see also Bogaard *et al.* 2001)

Weed species with an equal distribution of stomata on both leaf surfaces (amphistomaty) are associated with unshaded habitats (where carbon dioxide limits photosynthesis), whereas species of shaded habitats (where light limits photosynthesis) tend to have thin leaves with stomata more restricted to one surface.

Stomatal density was measured at two 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 maximum percentage of total stomata occurring on one leaf surface (upper or lower). Species with 45 to 55 per cent of stomata on both surfaces were classified as amphistomatous and species with >55 per cent of stomata on one surface as non-amphistomatous.

Attribute relating to habitat stability

Presence of a persistent seed bank (G. Jones *et al.* 2000a; see also Charles *et al.* 1997, 2003; Bogaard *et al.* 1999)

Most arable weed species can form a persistent seed bank in the soil, but seed persistence is particularly important in habitats with unstable conditions from year to year (e.g. due to variable levels of disturbance or productivity) because it allows species to survive unfavourable years.

Seed persistence was predicted using the method of Bekker *et al.* (1998), in which seed size and shape are combined in the formula, log (seed weight × √seed shape). This index is negatively correlated with seed persistence. For each species, seed shape is assessed as the mean variance of seed dimensions (length, breadth and thickness) for five dispersules. Index values were categorized into five equal size classes. Species with hard seed coats (e.g. in the families Convolvulaceae, Geraniaceae, Leguminosae and Malvaceae) were placed in the lowest (most persistent) class.

Modern weed studies as analogues for models of past crop husbandry

Modern weed survey studies that encompass a range of crop growing conditions are required for comparison with the selected archaeobotanical samples in order to assess the relevance of the four crop husbandry models discussed in Chapters 2–3. 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) (see Introduction). 'Traditional' crop husbandry regimes practised today certainly do not encompass all combinations of husbandry practices of relevance to the past, but the small range of regimes dealt with below relate to the three variables of critical importance to ongoing debate over the nature of cultivation in the study area during the Neolithic: the permanence, intensity and seasonality of cultivation (see Chapter 3).

It should be emphasized that the FIBS method allows ancient and modern weed assemblages to be compared not on the basis of species but of their functional attributes (see Introduction). This opens the way for comparisons between different biogeographical regions, time periods, etc.

Permanence: the Hambach Forest experiment

While shifting cultivation is unknown as a traditional husbandry regime in the study area today, a number of agricultural experiments motivated by archaeological research questions have included short-term cultivation of newly cleared woodland soil: 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: 27–8, 36–8). In addition, new experiments were begun near Stuttgart in 1994 (Rösch 1996, 1998a, 2000a; Rösch *et al.* 2002). Of the experiments that have been completed, the Hambach Forest experiment is particularly useful for the interpretation of Neolithic weed assemblages in the loess belt: the plots were laid out on freshly cleared loess that had supported mixed oak woodland since medieval times. Critically, the weed floras that developed on experimental plots were surveyed just before harvest time over a series of cultivation seasons. Experimental conditions obviously differed in some ways from those of the Neolithic (Meurers-Balke and Lüning 1990), but nevertheless the weed surveys provide comparative data of clear relevance to the interpretation of archaeobotanical weed assemblages from the study area.

Analysis of the Hambach weed survey data (Bogaard 2002a, 2002b) demonstrates that the weed floras of cultivation plots managed as in a shifting cultivation regime (i.e. freshly cleared plots with little or no tillage or hand-weeding) can be distinguished from long-lived permanent plots by the high proportion of perennial (versus annual) weeds, especially woodland perennials. In subsequent cultivation seasons on these plots, more severe tillage methods and also hand-weeding tended to be applied, with the result that woodland perennial weeds decreased in favour of perennials from disturbed habitats. Throughout the six-year period covered by the weed surveys, however, perennial weed species were dominant (57–100 per cent of weed species present); annuals did manage to colonize plots from the first cultivation season onwards, but perennials always outnumbered annuals. By contrast, cultivation of permanent plots over many years is associated with weed floras dominated by annual weeds (Ellenberg 1996: 871–905).

The outline of a 'shifting cultivation weed flora' indicated by the Hambach Forest experiment – a high proportion of perennial weeds, including woodland perennials – agrees with general observations from other experiments on the weed floras in newly cleared and burned fields (Engelmark 1995; Rösch 2000a; Rösch *et al.* 2002). In fact, weed seeds harvested along with cereals grown during the first cultivation season following clearance and burning in the ongoing Forchtenberg experiment near Stuttgart (Rösch *et al.* 2002: table 4) reflect a dominance of perennials, including woodland perennials.

In order to determine whether or not the selected archaeobotanical samples could derive from shifting cultivation, proportions of perennial(/biennial) versus annual weeds (based on both seed counts and species presence) were calculated for each sample using life history data from Rothmaler (1995), and the occurrence of woodland species was monitored using the phytosociological classification of species in Ellenberg *et al.* (1992).

Intensity: a study of contrasting cultivation scales in Evvia, Greece

A weed survey study of traditional winter-sown 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.* (2000a) applied the FIBS method (see pp. 69–87) to the weed data from this study and found that functional attributes relating to the response of the weed species to fertility and disturbance (SLA, canopy height and diameter, leaf area per node:leaf thickness, length of the flowering period and stomatal distribution) could be used to distinguish intensively and extensively cultivated plots.

Seasonality: a sowing time study in Germany

Hüppe and Hofmeister (1990) have synthesized available phytosociological data (*c*. 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 and found that functional attributes relating to the seasonality of the weed species (in particular, the onset and length of the flowering period) could be used to distinguish the two sowing regimes.

A 'test case': intensively cultivated winter-sown spelt in Asturias, Spain

A weed survey study of 65 plots of intensively cultivated winter-sown spelt wheat in Asturias, north-west Spain was conducted by Charles *et al.* (2002). Spelt plots in this study received high inputs of manure and disturbance (hoeing/harrowing after sowing, hand-weeding, etc.) (Charles *et al.* 2002).

The Asturias study did not encompass a continuum of cultivation intensity like the Evvia study but offered valuable comparative data on the weed floras of intensively cultivated cereals rather than pulses. Furthermore, the study provided an opportunity to consider whether or not functional attribute data could distinguish between spring-sown crops on the one hand and intensively cultivated winter-sown crops on the other: 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) (G. Jones 1992; G. Jones *et al.* 1999). 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.* 2000a; Bogaard *et al.* 2001).

The FIBS method was applied to the Asturias dataset in order to allow comparison with the Evvia and Germany datasets on the basis of weed functional attributes (Charles *et al.* 2002). Comparison of the Asturias and Evvia data relating to cultivation intensity (using discriminant analysis – see below) demonstrated that, as expected, the cereal plots in Asturias resembled the Evvia pulse 'gardens' (rather than the 'fields') in terms of their functional attributes relating to fertility and disturbance (Charles *et al.* 2002). Comparison of the Asturias and German data relating to sowing time (using discriminant analysis) showed that, again as expected, the winter-sown spelt plots in Asturias mostly resembled autumn-sown crops in the Germany study rather than spring-sown crops on the basis of functional attributes relating to seasonality (Charles *et al.* 2002).

To summarize, the 'test case' in Asturias demonstrated the overall success of the FIBS method for identifying the sowing regime and intensity of spelt cultivation (Charles *et al.* 2002). It appears that the suite of functional attributes identified to distinguish intensive and extensive pulse cultivation in the Evvia study can be applied to a different crop type (spelt wheat) and another geographical area with contrasting climate. Moreover, it 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.

Methods of multivariate statistical analysis

Discriminant analysis

Discriminant analysis offers one way of comparing archaeobotanical 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: discriminant functions extracted to distinguish modern crop processing groups on the basis of their weed type composition can be used to classify archaeobotanical samples according to the modern groups.

Discriminant analysis is 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 function derived from all members of the groups except the one being classified.

Two of the modern weed studies (Germany, Evvia – see p. 89) include functional attribute data for contrasting husbandry practices (autumn versus spring sowing and intensive versus extensive cultivation of pulses, respectively) and have previously been subjected to discriminant analyses of these predefined husbandry groups using mean functional attribute scores per studied weed association (Germany) or cultivated plot (Evvia) as the discriminating variables (G. Jones *et al.* 2000a; Bogaard *et al.* 2001; see also Charles *et al.* 2002). Discriminant analyses from these two studies have also been used to classify the spelt plots in the Asturias study (see p. 90) (Charles *et al.* 2002) and were similarly used to classify the selected archaeobotanical samples.

Mean attribute scores per studied association or cultivated plot were calculated using semi-quantitative (presence/absence) data, as in Charles *et al.* (2002). The formula used for the calculation of mean attribute scores per studied association or cultivated plot (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, using semi-quantitative data, k = '1' for species present in a studied association or cultivated plot and '0' for absent species, a = attribute value for the species, and n = number of species present per studied association or cultivated plot. Mean attribute scores for archaeobotanical samples were calculated in the same way.

Simplification of both modern and archaeobotanical weed data to the level of species' presence/absence – as in the semi-quantitative method already outlined – greatly enhances their comparability. If quantitative data are used, discriminant functions extracted for distinguishing the modern studies on the basis of quadrat counts (Evvia) or cover/abundance scores (Germany) are not directly applicable to archaeobotanical data based on weed seed counts. In the semi-quantitative approach, the calculation of functional attribute scores for modern 'units of analysis' (cultivated plots or studied 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. 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 data 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. Moreover, it has been demonstrated that the contrasting husbandry regimes in Evvia and Germany can be discriminated successfully on the basis of semi-quantitative weed data (Charles *et al.* 2002).

For the classification of archaeobotanical samples using the discriminant function extracted to distinguish autumn and spring sowing regimes (Germany), all weed taxa (Table 4.4) were included, since the discriminant function is 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 full collection of functional attribute measurements were included, since the discriminant function is based on a range of functional attributes.

A further methodological point relates to the functional attribute measurements used in discriminant analyses comparing the archaeobotanical samples with the modern studies. In order to compare 'like with like', the range and ecological significance of functional attributes should be similar in the geographical regions concerned, and, in particular, species common to both archaeobotanical and modern datasets should be represented by the same functional attribute values. Given that there is little evidence of geographical bias in most functional attributes between the Mediterranean and Atlantic-continental zones of Europe, it is justified 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 data from Evvia with the archaeobotanical samples were based on the full set of available measurements from across Europe, such that species common to more than one dataset were represented by the same functional attribute values.[2]

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: 183–91; Buurman 1999; Charles and Bogaard 2001). The following description of the method is summarized from a number of sources (Gauch 1982; ter Braak 1987, 1987–1992; Jongman *et al.* 1987; Lange 1990; G. Jones 1991) 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 by observing how far these variables predict the arrangement of species and/or samples in the scatter plot (see also p. 94).

There are various guidelines for assessing the arrangement of species and samples in the scatter plot (Lange 1990: 43–4). First, the origin (0,0 co-ordinate) 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.[3] 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 species points is not a measure of their association – this can only be interpreted on the basis of their divergence from the origin.

CA was used to explore variation in weed composition among archaeobotanical samples. The analysis was carried out on seed counts (per sample) of standardized weed taxa only (see Table 4.4); crop taxa and other 'non-weed' taxa were excluded. CANOCO for Windows (ter Braak and Smilauer 1997–1999) was used to carry out the correspondence analysis and CANODRAW (Smilauer 1992) to plot the results. Axis 1 was plotted horizontally and axis 2 vertically in the correspondence analysis plots. A problem with CA is that it emphasizes rare species and samples (often containing a small number of items) dominated by rare species (Gauch 1982: 213–14; Jongman *et al.* 1987: 109–11; G. Jones 1991). These species and samples may be pulled out as outliers from the remaining samples and species, which are clumped together. To minimize such outliers (which are usually due to chance occurrences), the rarest taxa (i.e. those occurring in very few archaeobotanical samples) were left out of the analysis (for details of taxa included, see Chapter 6) (cf. Gauch 1982: 213–14; Lange 1990: 73–6; G. Jones 1984, 1991). Partly in anticipation of this problem, weed taxa occurring with reasonable frequency in selected archaeobotanical samples were targeted for the collection of functional attribute measurements (see p. 69).

By coding data points in correspondence analysis plots of samples using symbols for extrinsic variables, a range of sample variables (e.g. archaeological site, geographical region) were examined as possible factors underlying variation in weed composition. In order to identify any ecological aspects of variation in weed composition, weed taxa included in the correspondence analysis were classified according to their functional attribute values or other ecological characteristics.

There are several ways of illustrating variation in functional attribute values (or other ecological characteristics) 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.* 2000a), 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.

For 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 characteristics) 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 in 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 the sample plot are represented by symbols whose size varies according to the number of seeds of a dominant species, in order to explore the impact of this species on the analysis.

Summary

- A total of 126 archaeobotanical samples from 29 sites meet the criteria defined to identify those samples containing adequate numbers of charred crop and weed remains and deriving from a single archaeological deposit, crop type and crop processing stage.
- The selected dataset, consisting mainly of (fine sieve) by-products from the processing of emmer and einkorn wheat, represents a small fraction of the samples available but offers the best evidence for crop growing conditions in the study area.
- Functional attribute measurements for the archaeobotanical weed assemblage targeted those species occurring with reasonable frequency in the selected samples. Morphological functional attributes were measured using well-established specimens of plants growing 'in the field', while behavioural attributes were assessed using published sources of data such as Floras.
- Several modern weed survey studies are suitable for comparison with the archaeobotanical data on the basis of weed ecology in order to assess the validity of previously proposed crop husbandry models for the study area.
- The multivariate technique discriminant analysis, using semi-quantitative (presence/absence) data, is appropriate for comparisons between modern and archaeobotanical weed data, while correspondence analysis offers a way of exploring variation in weed species composition among archaeobotanical samples.

5

TESTING THE FOUR MAJOR CROP HUSBANDRY MODELS

Introduction

The aim of this chapter is to compare the weed composition of the selected archaeobotanical samples with modern weed data from a range of crop husbandry regimes (shifting cultivation, autumn versus spring sowing and intensive versus extensive cultivation) in order to assess the relevance of the four major crop husbandry models discussed in Chapters 2–3. Using the FIBS method, arable weed assemblages can be compared on the basis of their *functional attributes* rather than on the basis of *species*, thus allowing comparisons between different sets of species from contrasting biogeographical regions and time periods. These comparisons are meaningful because of the functional nature of the attributes concerned: that is, the attributes explain why species occur under certain habitat conditions and not others. Thus, the functional attributes (and other weed ecological characteristics) useful in distinguishing the present-day husbandry regimes (see Chapter 4) 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. 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.

Comparison of the archaeobotanical data with modern weed data from shifting cultivation (the Hambach Forest experiment)[1]

Analysis of the Hambach data showed that weed floras in experimental plots managed as in a shifting cultivation regime – that is, recently cleared of woodland and sown with little to no tillage and no hand-weeding during the growing season – were dominated by perennial weeds, especially perennials of woodland (see Chapter 4). By contrast, the weed floras of long-lived permanent cultivation plots are dominated by annual weed species (Ellenberg 1996: 871–905). In order to assess whether or not the selected archaeobotanical samples could derive from shifting cultivation, proportions of perennial(/biennial) versus annual weeds were calculated for each sample and the occurrence of woodland species was monitored (see Chapter 4).

Results

Figure 5.1 summarizes the proportions of perennials in the archaeobotanical samples based on seed counts (Figures 5.1a–b). These proportions are shown with and without Fat Hen (*Chenopodium album* L.), an annual species that may not always be present as an arable weed harvested with cereals (see Chapter 4). 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 per cent including *C. album*, 8 per cent excluding *C. album*) contain at least 50 per cent perennial taxa. Figure 5.1 also shows the proportions of perennials, based on taxon counts, present in samples containing at least ten taxa in total (Figures 5.1c–d). Whether calculated with or without *C. album*, none of these samples contains 50 per cent or more perennial taxa. In contrast to the proportions of perennials based on taxon counts in the Hambach experimental plots (57–100 per cent of weed species present), therefore, the archaeobotanical samples are much richer in annual taxa.

There may be a tendency for perennial weeds to be under-represented in archaeobotanical weed assemblages, particularly in the first cultivation season after clearance, since seed set may be delayed in some species. Even if a

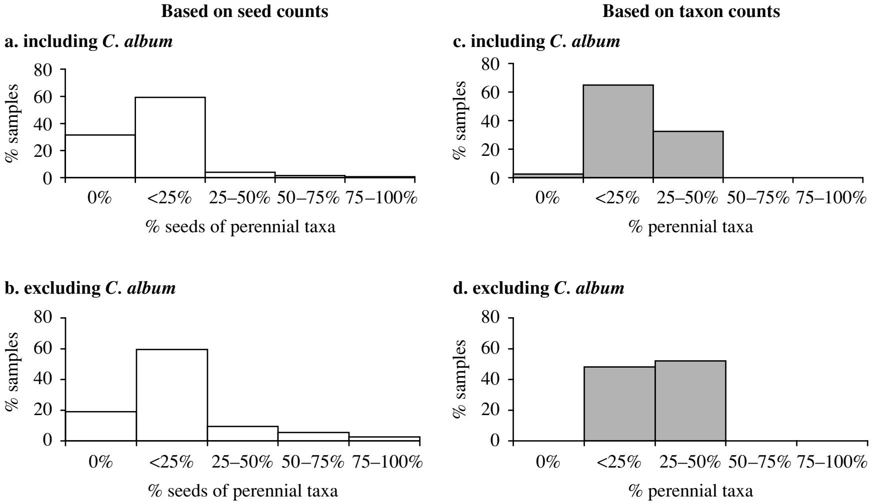

Figure 5.1 Histograms showing proportions of perennials in the archaeobotanical samples: (a) all samples (n=126); (b) samples (n=71) including at least 30 weed seeds after the removal of *Chenopodium album*; (c) all samples (n=37) with at least ten weed taxa; (d) samples (n=25) with at least 30 weed seeds and ten weed taxa after the removal of *C. album*

Table 5.1 Woodland taxa in the archaeobotanical samples

Site *Context* *Period*	*Bedburg-Garsdorf* *Pit 28* *Early Neolithic (LBK)*	*Hornstaad-Hörnle IA* *House 13 crop store* *Later Neolithic (Hornstaad)*
Woodland perennials:		
Circaea lutetiana L.		Present
Stachys sylvatica L.	Present	
Woodland annual:		
Moehringia trinervia (L.) Clairv.		Present

minority of perennial taxa in a sample were accepted as consistent with shifting cultivation, however, woodland perennials are very rare in the archaeobotanical samples. A total of two woodland perennial species occur in only two samples (*c.* 2 per cent of samples) (Table 5.1). Slow perennial seed set is unlikely to explain the rarity of woodland perennials *per se* since there should be no specific bias against seed set in woodland perennials as opposed to perennials from other habitats. Unlike the Hambach plots, neither of the two samples in Table 5.1 contains 50 per cent or more perennials (whether based on seed or taxon counts).

Woodland annuals are of more ambiguous status in relation to shifting cultivation since only one annual of this type occurred in the Hambach experiment, though it was associated with plots managed as in a shifting cultivation regime (Bogaard 2002a). Woodland annuals are also rare in the archaeobotanical samples: one woodland annual species (Three-nerved Sandwort, *Moehringia trinervia* (L.) Clairv.) occurs in one sample also containing one woodland perennial species (Table 5.1). Though woodland annual species in general are few, 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.

Discussion

The dominance of annuals and rarity of woodland taxa among the archaeobotanical samples strongly suggests that they do not derive from newly cleared fields managed as in a shifting cultivation regime. 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) represents a charred cereal (free-threshing wheat) store at the lakeshore site of Hornstaad-Hörnle IA (established 3915 BC), the earliest settlement known on Lake Constance (Dieckmann *et al.* 1997). Crop husbandry at Hornstaad-Hörnle has been the subject of controversy: Maier (1999, 2001: 78–109) has interpreted the charred weed assemblage as evidence of fixed-plot cultivation, while Rösch (1990b, 1996, 2000a) has inferred shifting cultivation primarily on the basis of pollen and microscopic charcoal evidence from the region (see Chapter 2). The occurrence of woodland species in a cereal store from Hornstaad-Hörnle may reflect the relatively short occupation of the settlement (*c.* ten years) preceding the fire that preserved the crop stores rather than shifting cultivation *per se*. Another possibility, suggested by Maier (1999, 2001: 85), is that woodland or woodland-edge species occur occasionally as weeds in the stored cereals at Hornstaad-Hörnle because some cultivation plots were situated along the edge of woodland.

In Chapter 1 reference was made to an ongoing debate over the extent to which the 'natural' vegetation of central Europe is closed woodland (albeit in a mosaic of regeneration states at any one time) (Zoller and Haas 1995) or a more open form of woodland ('woodland pasture') created by the influence of large native herbivores (Vera 2000). Even if the woodland pasture model is accepted for the study area, the dominance of annuals in the archaeobotanical samples suggests that they do not derive from 'low intensity' cultivation of plots newly cleared of established perennial vegetation (including perennial grassland and shrub vegetation as well as woodland patches) and managed with little or no tillage and hand-weeding.

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

Shifting cultivation is an 'extreme' form of husbandry that can be distinguished from fixed-plot cultivation in a straightforward manner by considering the relative proportions of perennial versus annual weeds and by monitoring the occurrence of woodland species as weeds. Distinguishing between the weed floras of different sowing regimes, or different cultivation intensity levels, is rather more difficult and a different method – discriminant analysis – was used to compare relevant modern weed studies with the archaeobotanical samples.

As discussed in Chapter 4, discriminant functions extracted to distinguish modern cultivation plots/weed associations from contrasting husbandry regimes (i.e. autumn versus spring sowing in Germany; intensive versus extensive cultivation in Evvia) 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, would not be 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 (as presence/absence data), however, their comparability is greatly enhanced. Application of the semi-quantitative discriminant analyses to a modern test case, the spelt plots in Asturias, have demonstrated their overall success as methods for identifying sowing regime and cultivation intensity (Charles *et al.* 2002). The aim of this section is to apply the semi-quantitative discriminant analyses to the archaeobotanical samples as a means of identifying the sowing regime and cultivation intensity of the cereal plots from which they derive.

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

Results

The discriminant function extracted from semi-quantitative data to distinguish autumn and spring sowing regimes in Germany was 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 modern test case (Charles *et al.* 2002). The discriminating variables from which the discriminant function was derived for Germany relate to the most important seasonality attribute identified by Bogaard *et al.* (2001) as indicative of sowing time: the onset and length of the flowering period. Three nominal variables corresponding to the three indicative categories for this attribute (see Table 4.6) were used: early-intermediate/short flowering, late flowering and long flowering (see Chapter 4 for functional attribute descriptions). As shown by Charles *et al.* (2002), the discriminant function extracted by the analysis correctly reclassified 89 per cent of the modern weed associations (33 out of 37); Figure 5.2 shows the correlation of each variable with the discriminant function.

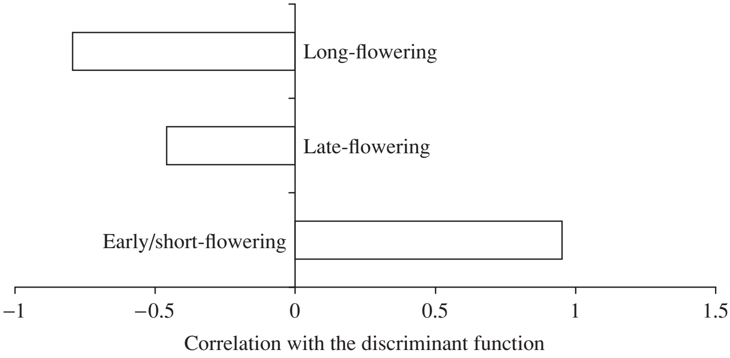

Figure 5.2 Results of the discriminant analysis separating autumn- and spring-sown weed associations in Germany based on semi-quantitative data: plot of correlations between the functional attributes and the discriminant function

Table 5.2 The classification of archaeobotanical samples (n=126) by the discriminant function extracted to distinguish weed associations from autumn- and spring-sown crops (Germany), showing samples classified with high probability (≥0.90) and low probability (<0.90)

Archaeobotanical samples		*Autumn-sown*		*Spring-sown*	
Cereal type	*Processing stage*	*With high probability*	*With low probability*	*With high probability*	*With low probability*
Free-threshing	Unthreshed	1			
Glume wheat	Unsieved 'spikelets'	5			
Glume wheat	Fine sieve by-products	81	4	18	7
Glume wheat	Fine sieve products	6			
Glume wheat	Sieved 'spikelets'	2	1		
Free-threshing	Fine sieve product		1		

Table 5.2 summarizes the classification of archaeobotanical samples by the discriminant function. Eighty per cent of the samples are classified as autumn-sown and 94 per cent of these 'autumn' samples are classified with high probability. The discriminant scores for each sample are plotted in Figure 5.3c; discriminant scores for weed associations in the Germany study (Figure 5.3a) and for spelt plots in Asturias (Figure 5.3b) are also plotted. Clearly, the discriminant scores for the archaeobotanical samples show the most variation.

G. Jones (1992) has shown that crop processing may introduce biases in the ecology of weed species characteristic of different processing stages. In particular, 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. Furthermore, consideration of the processing behaviour (i.e. the physical seed types) of the weed species in the sowing time study in Germany (Bogaard 2002b) indicates that weed species with 'small free heavy' seeds (G. Jones 1984), associated with by-products, tend to be late- or long-flowering and so to indicate spring sowing, while weed species with 'big free heavy' seeds (G. Jones 1984), associated with products, tend to be early-intermediate/short-flowering and so to indicate autumn sowing.

In Figure 5.4, the discriminant scores of archaeobotanical samples from different processing stages are plotted separately. The single unthreshed free-threshing cereal sample and the unsieved glume wheat 'spikelet' samples are all classified as autumn-sown (Table 5.2; Figure 5.4a). Unthreshed cereals would be completely unprocessed, and unsieved spikelets would have undergone fewer processing stages than fine sieve by-products or products; both, therefore, are closer to the original cereal harvest than samples from other processing stages. Though the status of 'spikelet' samples is somewhat

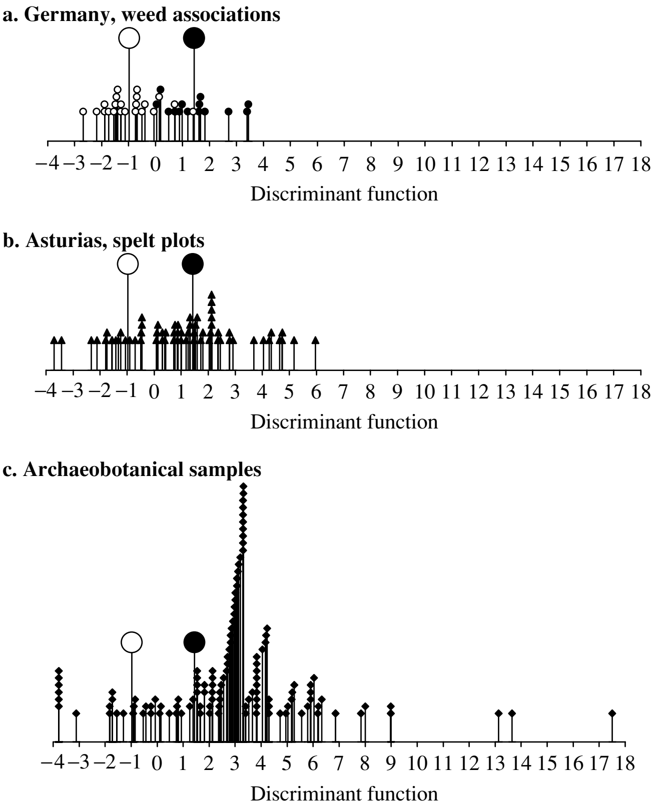

Figure 5.3 The relationship of (a) autumn-sown (•) and spring-sown (◦) weed associations from Germany, (b) Asturias plots (▴) and (c) archaeobotanical samples (◆) to the discriminant function extracted to distinguish autumn- and spring-sown weed associations from Germany based on semi-quantitative data (in all plots, larger circles indicate the position of centroids for Germany groups)

uncertain (i.e. they may represent mixtures of product and by-product material rather than genuine spikelets – see Chapter 4), it is worth emphasizing that those samples that appear to be least affected by processing were classified as autumn-sown.

The glume wheat fine sieve by-products (Figure 5.4b) cover nearly the full range of discriminant scores for the archaeobotanical samples (Figure 5.3c) 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). Most of the fine

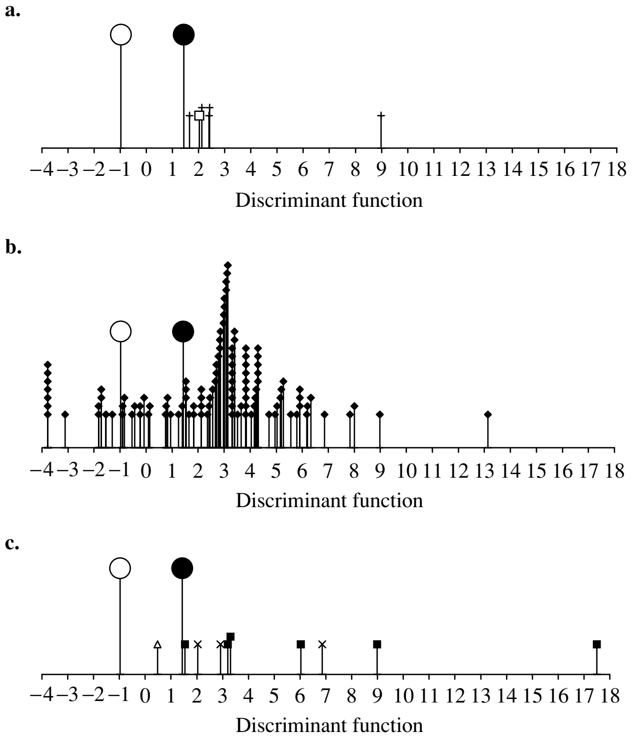

Figure 5.4 The relationship of archaeobotanical samples from different processing stages to the discriminant function based on semi-quantitative data: (a) unthreshed free-threshing cereal (□) and unsieved glume wheat 'spikelet' (+) samples; (b) fine sieve by-products, glume wheat (◆); (c) sieved glume wheat 'spikelet' (×) and fine sieve product samples (■ glume wheat, ▵ free-threshing cereal). Large circles indicate the position of centroids for Germany groups

sieve by-products (78 per cent), 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; Figure 5.4c), 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.

Table 5.3 The classification of archaeobotanical samples, with *Chenopodium album* removed (n=71*), by the discriminant function extracted to distinguish weed associations from autumn- and spring-sown crops (Germany), showing samples classified with high probability (≥0.90) and low probability (<0.90)

Archaeobotanical samples		*Autumn-sown*		*Spring-sown*	
Cereal type	*Processing stage*	*With high probability*	*With low probability*	*With high probability*	*With low probability*
Free-threshing	Unthreshed	1			
Glume wheat	Unsieved 'spikelets'	4			
Glume wheat	Fine sieve by-products	49		6	2
Glume wheat	Fine sieve products	5			
Glume wheat	Sieved 'spikelets'	3			
Free-threshing	Fine sieve product	1			

Note: *The samples containing at least 30 seeds of weed taxa after the removal of *C. album*.

Results without Chenopodium album

The discriminant function based on semi-quantitative data was also used to classify archaeobotanical samples with *Chenopodium album* removed. This was done in order to see how the samples are classified when this species is excluded, given that it may be present in some samples as a collected food plant rather than an arable weed (see Chapter 4). Its removal reduces the number of archaeobotanical samples (containing at least 30 weed seeds) from 126 to 71. Not surprisingly, given that it flowers late, an even greater proportion of samples are classified as autumn-sown in the semi-quantitative analysis (Table 5.3). Overall, however, the results of the analyses with and without *C. album* are very similar: the vast majority of samples (80–89 per cent) are classified as deriving from autumn-sown crops. Since *C. album* does not have a great effect on this overall outcome, the analysis including this species (and all samples) will be the focus of subsequent discussion.

Discussion

The classification of the archaeobotanical samples by the discriminant function based on semi-quantitative data (Table 5.2; Figures 5.3, 5.4) strongly suggests that most (if not all) samples derive from autumn-sown cereals. The strongest evidence for this is the classification of most fine sieve by-products as autumn-sown, despite a potential bias in the opposite direction introduced by crop processing. This result is further underlined by the classification of the unthreshed cereal sample (and unsieved glume wheat '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 weed 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.

Differences in precise sowing time between the Asturias study (winter sowing) and Germany study (autumn sowing) may account for the greater spread of discriminant scores among Asturias plots (Figure 5.3). The even greater spread of discriminant scores among archaeobotanical samples (Figure 5.3c) 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) (Figure 5.4b), however, may suggest that factors other than processing are at work. Perhaps cereal sowing in the archaeological study area extended from the autumn through to the winter months; this tendency would have the effect of spreading labour requirements over a longer period. Another possibility is that high cultivation intensity (see below) resulted in a blurring of the autumn sowing 'signature' in some archaeobotanical samples.

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

Results

The discriminant function extracted from semi-quantitative data to distinguish intensive and extensive pulse cultivation in Evvia was 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 modern test case (Charles *et al.* 2002).[2] The discriminating variables from which the discriminant function was derived for Evvia are the six fertility and disturbance attributes identified by G. Jones *et al.* (2000a) as the most useful for distinguishing intensive and extensive cultivation: SLA, canopy height and diameter, leaf area per node:leaf thickness, length of the flowering period and stomatal distribution (amphistomaty) (see Chapter 4 for functional attribute descriptions). The discriminant function extracted by the analysis correctly reclassified 89.5 per cent of the modern weed associations (34 out of 38); Figure 5.5 shows the correlation of each variable with the discriminant function.

Table 5.4 summarizes the classification of archaeobotanical samples by the discriminant function. Ninety-eight per cent of samples are classified as gardens and 98 per cent of these 'garden' samples are classified with high probability. The discriminant scores for each sample are plotted in Figure 5.6c; discriminant scores for cultivation plots in the Evvia study (Figure 5.6a) and for spelt plots in Asturias (Figure 5.6b) 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.

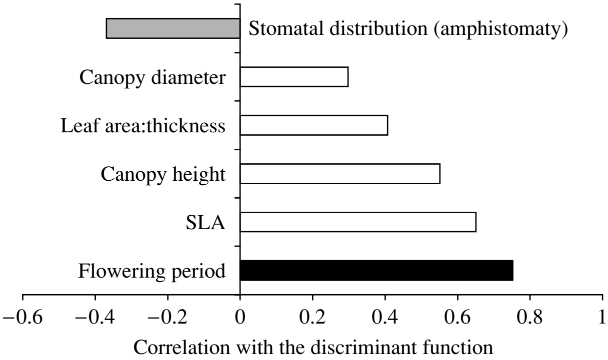

Figure 5.5 Results of the discriminant analysis separating Evvia pulse gardens and fields based on semi-quantitative data: plot of correlations between the functional attributes and the discriminant function, where open bars = attributes relating to the duration and quality of the growth period, black bar = attribute relating to the capacity to regenerate under conditions of high disturbance and grey bar = attribute relating to shade tolerance

Table 5.4 The classification of archaeobotanical samples (n=126) by the discriminant function extracted to distinguish pulse fields and gardens (Evvia), showing samples classified with high probability (≥0.90) and low probability (<0.90)

Archaeobotanical samples		*Field*		*Garden*	
Cereal type	*Processing stage*	*With high probability*	*With low probability*	*With high probability*	*With low probability*
Free-threshing	Unthreshed samples			1	
Glume wheat	Unsieved 'spikelets'			4	1
Glume wheat	Fine sieve by-products		2	108	
Glume wheat	Fine sieve products			4	2
Glume wheat	Sieved 'spikelets'			3	
Free-threshing	Fine sieve product			1	

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 (root/row-crop weeds and ruderals) to Secalinetea (winter cereal weeds) decreases through the processing sequence. In terms of 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 husbandry regime. Consideration of the processing behaviour (i.e. physical seed types) of weed species in the modern studies in conjunction with

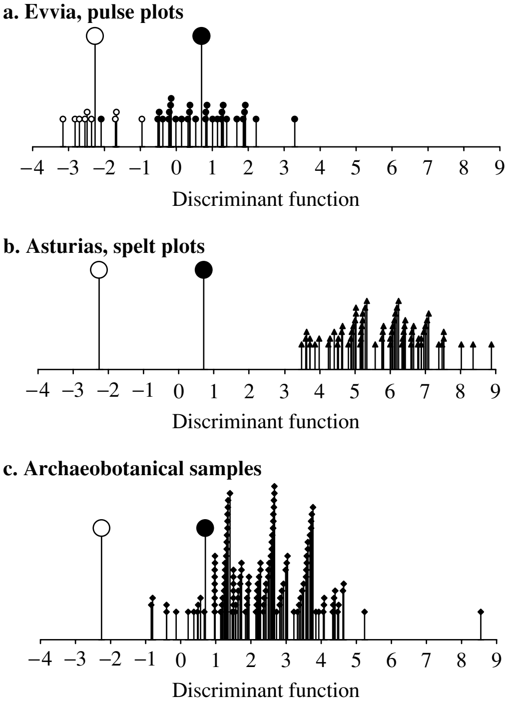

Figure 5.6 The relationship of (a) Evvia pulse gardens (•) and fields (∘), (b) Asturias plots (▴) and (c) archaeobotanical samples (◆) to the discriminant function extracted to distinguish Evvia gardens and fields based on semi-quantitative data (in all plots, larger circles indicate the position of centroids for Evvia groups)

their values for the functional attributes relating to cultivation intensity, however, suggests that crop processing does not introduce a serious bias in the weed composition of fine sieve by-products and products (Bogaard 2002b).

Nevertheless, in order to explore the possible impact of crop processing on the inference of cultivation intensity, in Figure 5.7 the discriminant scores of archaeobotanical samples from different processing stages are plotted separately. The unthreshed free-threshing cereal sample, which should be unaffected by processing, is classified as deriving from garden-type cultivation, as are the unsieved glume wheat 'spikelet' samples (Table 5.4; Figure 5.7a). All but two (98 per cent) of the glume wheat fine sieve by-products are classified as gardens (Table 5.4; Figure 5.7b). The ten product samples (fine sieve products and sieved glume wheat 'spikelet' samples) are classified as gardens (Table 5.4; Figure 5.7c). Despite the possible bias towards indicators of extensive cultivation in the weed composition of product samples, therefore, all are classified as gardens. This result, together with the classification

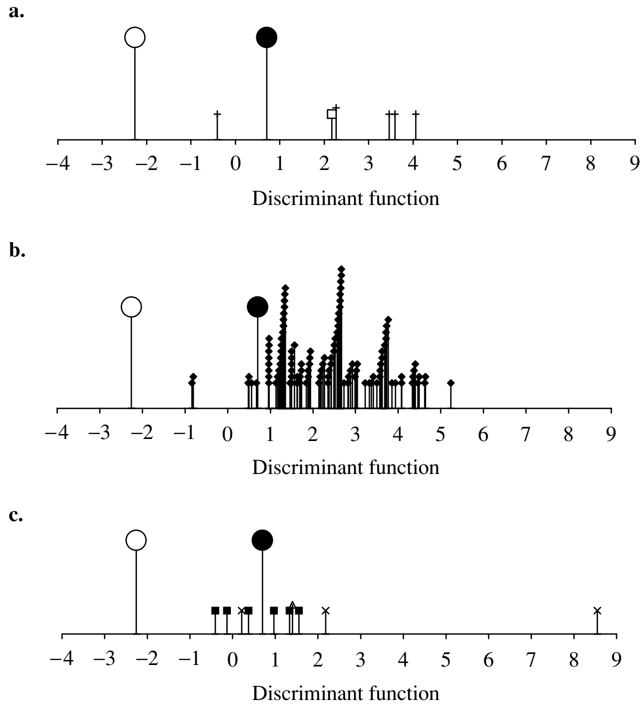

Figure 5.7 The relationship of archaeobotanical samples from different processing stages to the discriminant function based on semi-quantitative data: (a) unthreshed free-threshing cereal (□) and unsieved glume wheat 'spikelet' (+) samples; (b) fine sieve by-products, glume wheat (◆); (c) sieved glume wheat 'spikelet' (×) and fine sieve product samples (■ glume wheat, ▵ free-threshing cereal). Large circles indicate the position of centroids for Evvia groups

of relatively 'unprocessed' cereal samples (i.e. the unthreshed cereal sample 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.

Results without Chenopodium album

The discriminant function based on semi-quantitative data was also used to classify archaeobotanical samples with *Chenopodium album* removed. As in the classification of samples according to sowing regimes (p. 104), 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 (see Chapter 4). The results of analyses with and without *C. album* are very

Table 5.5 The classification of archaeobotanical samples, with *Chenopodium album* removed (n=71*), by the discriminant function extracted to distinguish pulse fields and gardens (Evvia), showing samples classified with high probability (≥0.90) and low probability (<0.90)

Archaeobotanical samples		*Field*		*Garden*	
Cereal type	*Processing stage*	*With high probability*	*With low probability*	*With high probability*	*With low probability*
Free-threshing	Unthreshed samples			1	
Glume wheat	Unsieved 'spikelets'			4	
Glume wheat	Fine sieve by-products		1	56	
Glume wheat	Fine sieve products		1	3	1
Glume wheat	Sieved 'spikelets'			2	1
Free-threshing	Fine sieve product			1	

Note: *The samples containing at least 30 seeds of weed taxa after the removal of *C. album*.

similar: the vast majority of samples (97–98 per cent) 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) – demonstrates that the samples contain other taxa indicative of intensive cultivation. Since *C. album* does not have a great effect on the overall outcome, the analysis including this species (and all samples) will be the focus of subsequent discussion.

Discussion

The classification of the archaeobotanical samples by the discriminant function based on semi-quantitative data (Table 5.4; Figures 5.6, 5.7) strongly suggests that most of the samples derive from intensive cultivation regimes. The best evidence for this is the classification of relatively 'unprocessed' cereal samples (i.e. the unthreshed cereal sample and possibly also the unsieved 'spikelet' samples) as gardens, as well as the classification of all product samples as gardens despite an ecological bias in the opposite direction that crop processing may tend to introduce. The classification of most samples as gardens, therefore, appears genuinely to reflect intensive cultivation; extensive cultivation in a minority of cases, however, cannot be ruled out.

In the comparison of the archaeobotanical samples with weed associations of autumn- and spring-sown crops in Germany (p. 105), it was noted that crop processing 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.

The discriminant scores for the Asturias plots tend to be more extreme than those for the Evvia gardens (Figure 5.6). 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 not surprising, therefore, that the Asturias plots, though most similar to the Evvia gardens, tend to be more extreme in their discriminant scores.

The fact that the Asturias scores also tend to be more extreme than the scores for the archaeobotanical samples (Figure 5.6) suggests that the latter derive from conditions that were less productive and/or less severely disturbed than the Asturias spelt plots. More generally, such contrasts reflect the fact that the modern weed survey studies (Germany, Evvia, Asturias) are themselves unique cases to some extent. The Evvia gardens and fields, for example, represent specific points along a broad potential continuum of cultivation intensity. Indeed, differences in discriminant scores between the modern weed studies and ‘unknown cases’ (e.g. the archaeobotanical samples) may provide a useful starting point in the reconstruction of past husbandry regimes having no exact analogue among the modern weed studies available.

The combined results for sowing time and cultivation intensity

The classifications of archaeobotanical samples according to sowing regime and cultivation intensity are cross-tabulated in Table 5.6. The clear majority of samples (78.5 per cent) are classified as deriving from autumn-sown ‘gardens’; the next largest group (20 per cent) consists of samples classified as deriving from spring-sown ‘gardens’; 1.5 per cent of samples are classified

Table 5.6 Cross-tabulation of the classification of archaeobotanical samples by the semi-quantitative discriminant analyses; high probability = ≥0.90, low probability = <0.90

		Autumn-sown		*Spring-sown*	
		High probability	*Low probability*	*High probability*	*Low probability*
Field	High probability				
	Low probability	2			
Garden	High probability	91	5	18	7
	Low probability	3			

as deriving from autumn-sown 'fields'; no samples are classified as spring-sown 'fields'.

As discussed in connection with the classification of Asturias plots (see Chapter 4), 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 (Charles *et al*. 2002). The classification of 79 per cent 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 crop processing stages. While the 'autumn garden' samples derive from all processing groups, 'spring garden' samples derive exclusively from fine sieve by-products. This pattern suggests that crop processing accentuates the dual role of flowering period already noted. Thus, the association of long flowering with intensive cultivation, combined with the tendency of weed species with 'small free heavy' seeds – associated

Table 5.7 Combined classification of archaeobotanical samples by processing group

Cereal type	*Processing stage*	*Autumn field*	*Autumn garden*	*Spring field*	*Spring garden*
Free-threshing	Unthreshed		1		
Glume wheat	Unsieved 'spikelets'		5		
Glume wheat	Fine sieve by-products	2	83		25
Glume wheat	Fine sieve products		6		
Glume wheat	Sieved 'spikelets'		3		
Free-threshing	Fine sieve product		1		

with fine sieve by-products (G. Jones 1984) – to be long- or late-flowering (Bogaard 2002b), may have contributed to the classification of some fine sieve by-products as 'spring gardens'.

These possible relationships cast doubt on the legitimacy of the 'spring garden' classifications, which could be due entirely to crop processing combined with the dual role of flowering period. Crop processing is unlikely to contribute to the two 'autumn field' classifications (fine sieve by-product samples – Table 5.7), though the dual role of flowering period may be a contributing factor. 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.

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

It remains to consider how the combined sowing time/cultivation intensity classification of archaeobotanical samples relates to the archaeological site, geographical region and chronological period from which samples derive. Tables 5.8 and 5.9 show the relationships between combined sowing regime/cultivation intensity classification and these other variables. Table 5.8 shows that 'spring garden' and 'autumn field' samples do not characterize any particular site with multiple samples, with the exception of LBK Hilzingen, where all four samples were classified as 'spring garden'. Samples from the three well-represented sites (with at least ten samples each – LBK Langweiler 8, later Neolithic Hochdorf and LBK Vaihingen) are all mostly (≥75 per cent) classified as 'autumn garden'. These three sites occur in two of the three well-represented regions (with at least ten 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 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 ten samples each) – the early and later Neolithic. All of the 'spring garden' samples date to the early Neolithic (LBK); most of these samples (72 per cent) are from Vaihingen and Hilzingen, with one to 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.

To summarize 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. The most secure

Table 5.8 The relationship of husbandry regime to archaeological site and geographical region

Sites	*Autumn field*	*Autumn garden*	*Spring garden*	*Total*
Aiterhofen			1	1
Altdorf		1		1
Hienheim/Donau		1		1
Meindling		2	1	3
Lower Bavaria		*4*	*2*	*6*
Bruchenbrücken (*Mainz*)		2		2
Aldingen		1		1
Ditzingen		2	1	3
Endersbach		1		1
Hochdorf		11		11
Grossachsenheim	1			1
Vaihingen		42	14	56
Neckar valley	*1*	*57*	*15*	*73*
Mythenschloss (*Switzerland – Zurich)*		1		1
Iwanowice-Klin (*Poland – Krakow*)		1		1
Bedburg-Gamersdorf		3		3
Lamersdorf/Düren		1		1
Langweiler 2			1	1
Langweiler 3		1		1
Langweiler 8		9	1	10
Langweiler 9		2		2
Langweiler 16		1		1
Laurenzberg 7	1	5		6
Laurenzberg 8		1		1
Maastricht-Randwijck		1		1
Meckenheim/Bonn		2		2
Wanlo/Wickerath		2		2
Lower Rhine–Meuse basin	*1*	*28*	*2*	*31*
Kamenin (*Slovakia – Nové Zámky*)		1		1
Hilzingen			4	4
Hornstaad-Hörnle IA		1		1
Ulm-Eggingen		4	2	6
Southern Baden-Württemberg		*5*	*6*	*11*
Total				*126*

Table 5.9 The relationship of husbandry regime to chronological period

Period	*Autumn field*	*Autumn garden*	*Spring garden*	*Total*
Early Neolithic	1	81	25	107
Middle Neolithic		3		3
Later Neolithic	1	15		16

conclusion, however, is that well-represented sites, regions and periods (with at least ten samples per group) are dominated by 'autumn garden' samples.

While the results presented in this chapter imply overall homogeneity, there remains considerable potential for variation in husbandry practices – for example, in the severity of soil disturbance or level of soil productivity. The reconstruction of crop husbandry regimes can be pursued further by exploring variation among archaeobotanical samples in their weed composition and by considering individual functional attributes, and hence potentially specific husbandry practices or aspects of husbandry (Chapter 6).

Summary

- The comparisons of archaeobotanical and modern weed data presented in this chapter suggest the following: the Neolithic archaeobotanical samples generally reflect long-established cereal plots that were autumn-sown and cultivated using intensive methods, resulting in relatively high levels of soil disturbance and productivity.
- Consideration of taphonomic factors (crop processing and possible contamination by separately collected Fat Hen, *Chenopodium album* L.) indicates that the inference of intensively cultivated, autumn-sown cereal plots is not an artefact of taphonomy.
- On the other hand, the classification of a minority of archaeobotanical samples as deriving from spring-sown, intensively cultivated plots may be due to a seasonality bias introduced by crop processing, combined with the tendency of intensive cultivation to promote weeds indicative of spring sowing.

6

IDENTIFICATION OF SEPARATE ECOLOGICAL GRADIENTS AND SPECIFIC CROP HUSBANDRY PRACTICES

Introduction

While Chapter 5 was concerned with comparing the archaeobotanical samples to entire modern husbandry regimes, this chapter will explore specific aspects of crop husbandry (e.g. manuring, tillage and weeding, 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) (G. Jones *et al*. 1999, 2000a). Most 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 Neolithic 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 (see Chapter 5). This chapter, therefore, will also explore variation in all 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 (see Chapter 5) – will also be considered.

Exploring variation in weed composition in relation to archaeological site, region and period

Before considering individual functional attributes in relation to weed composition it is necessary to explore variation in composition among archaeobotanical samples and to identify any floristic trends that are plausibly due to differences in crop husbandry. The statistical method used to explore variation is correspondence analysis (see Chapter 4). By considering variation among archaeobotanical samples containing crop material of the same type and from the same crop processing stage, variation in crop husbandry can potentially be isolated from other possible causes of variation, especially crop processing, which exerts a major influence on both crop and weed composition (see Chapter 4).

The largest group of archaeobotanical samples selected for ecological and statistical analysis consists of glume wheat samples dominated by glume bases and classified as fine sieve by-products (see Chapter 4, Table 4.2). These samples comprise a large group appropriate for correspondence analysis to identify crop husbandry practices.

Fat Hen (*Chenopodium album* L.) appears to represent both an arable weed harvested with crops and a separated collected resource in the study area (see Chapter 4). Thus, its status as an arable weed harvested with crop material,

Table 6.1 Codes for weed taxa in the correspondence analysis

Codes	*Weed taxa*
BROMAHS	*Bromus arvensis/hordeaceus/secalinus*
BRSTETEC	*Bromus sterilis/tectorum*
CHENFIC	*Chenopodium ficifolium*
CHENPOL	*Chenopodium polyspermum*
ECHICRU	*Echinochloa crus-galli*
FALLCON	*Fallopia convolvulus*
GALESLA	*Galeopsis angustifolia/ladanum/segetum*
GALIAPA	*Galium aparine*
GALISPU	*Galium spurium*
HYOSNIG	*Hyoscyamus niger*
LAPSCOM	*Lapsana communis*
PHLEPRA	*Phleum pratense*
PLANMAJ	*Plantago major*
POAANN	*Poa annua*
POAPRTR	*Poa pratensis* group/*trivialis*
POLYAVI	*Polygonum aviculare* group
POLYLAP	*Polygonum lapathifolium*
POLYPER	*Polygonum persicaria*
RUMEACL	*Rumex acetosella*
RUMESACO	*Rumex conglomeratus/sanguineus*
RUMETHAC	*Rumex acetosa/thyrsiflorus*
SETAPUM	*Setaria pumila*
SETAVIVE	*Setaria verticillata/viridis*
SILEVUL	*Silene vulgaris*
SOLANIG	*Solanum nigrum*
SONCASP	*Sonchus asper*
TRIFREP	*Trifolium repens*
VALEDEN	*Valerianella dentata*
VICIHIR	*Vicia hirsuta*

particularly in samples dominated by it, is in some doubt. In order to explore variation in weed composition independently of the influence of *C. album*, the correspondence analysis of fine sieve by-products was carried out with this species removed.

A correspondence analysis, therefore, was carried out on the glume wheat fine sieve by-product samples and all weed taxa except *Chenopodium album* (29 taxa) occurring in at least three samples; all samples containing at least 25 seeds of these taxa were included (67 samples)[1] (Figures 6.1–6.5). One particular species, Timothy Grass (*Phleum pratense* L., phlepar in Figure 6.1 – see Table 6.1 for species codes), is associated with samples at the positive (right) end of axis 1 and negative (bottom) end of axis 2; the dominance of *Phleum* in these samples is shown in Figure 6.2. In addition, high proportions of another species, Narrow-fruited Cornsalad (*Valerianella dentata* (L.) Pollich, valeden in Figure 6.1 – see Table 6.1), occur in some samples at the positive end of axis 1. The location of samples in other areas of the correspondence analysis plot is largely determined by a range of different taxa.

In order to assess the influence of external variables such as archaeological site, region and chronological period on weed composition, these variables were used to code sample points in the correspondence analysis plot (see Chapter 4). In Figure 6.3, with samples coded by archaeological site, there is a clear separation of two particular sites along axis 1: Hochdorf samples are

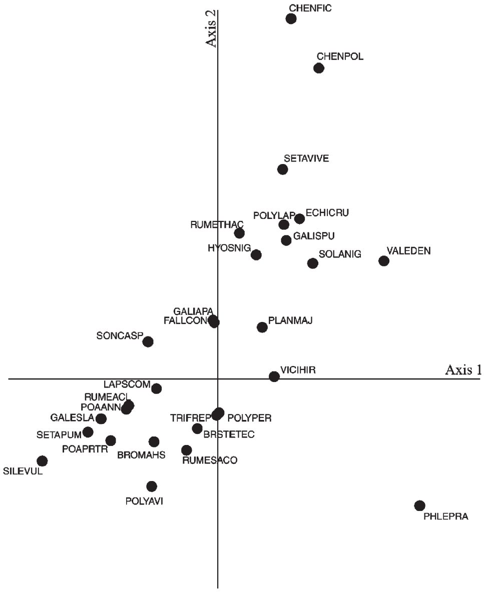

Figure 6.1 Correspondence analysis plot of weed species in the glume wheat fine sieve by-product samples (see Table 6.1 for species codes)

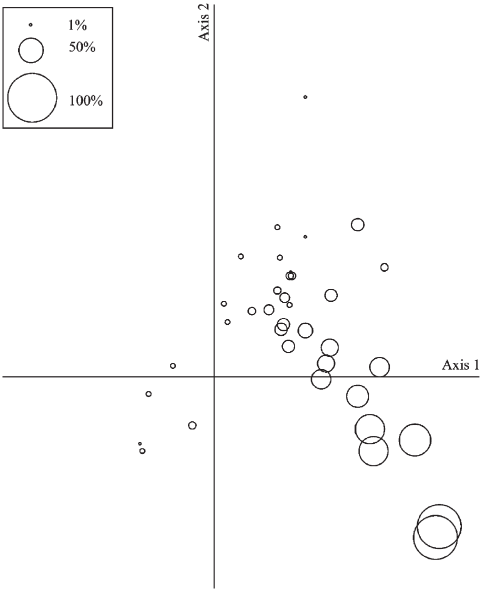

Figure 6.2 Correspondence analysis plot of glume wheat fine sieve by-product samples showing the contribution of *Phleum pratense* L. (per cent weed seeds)

located towards the negative (left) end and Vaihingen samples towards the positive (right) end. Interestingly, Hochdorf and Vaihingen are located close together in the same region (the Neckar valley) but differ in date (later Neolithic/Schussenried culture and early Neolithic/LBK, respectively). Along axis 2, two particular sites (Hilzingen, Ulm-Eggingen) are located towards the positive (top) end (Figure 6.3).

Figure 6.4, with samples coded by region, reveals a degree of regional clustering. Samples from sites in the lower Rhine–Meuse basin are located towards the negative ends of both axes (bottom left). Samples from sites in southern Baden-Württemberg and lower Bavaria are relatively neutral on axis 1 but are located (to different degrees) towards the positive (top) end of axis 2.

Figure 6.5, with samples coded by chronological period, shows some weak separation between later Neolithic samples, towards the negative ends of both axes (bottom left), and early Neolithic (LBK) samples elsewhere. There is considerable overlap between the two groups, however, and this weak contrast is largely caused by the (much clearer) separation of LBK Vaihingen and later Neolithic Hochdorf (see Figure 6.3).

Clustering of samples from the same archaeological site could be influenced by site-specific taphonomic factors such as preservation and recovery. The clustering of samples by region as well as by site, however, indicates that

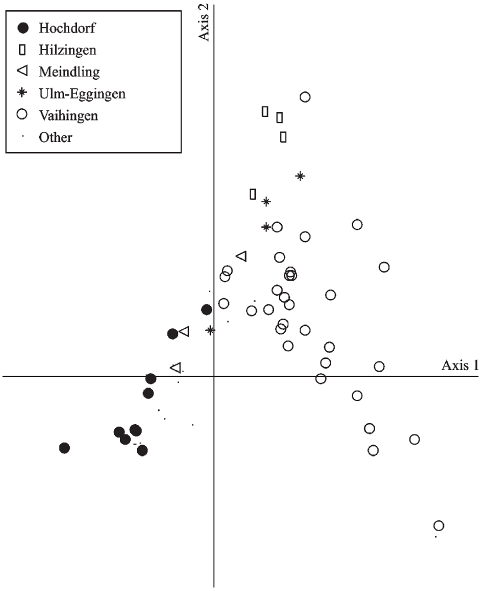

Figure 6.3 Correspondence analysis plot of glume wheat fine sieve by-product samples showing the archaeological sites from which samples derive

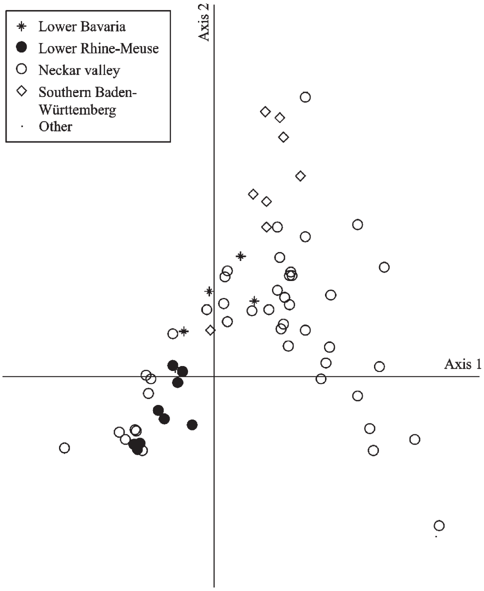

Figure 6.4 Correspondence analysis plot of glume wheat fine sieve by-product samples showing the geographical regions from which samples derive

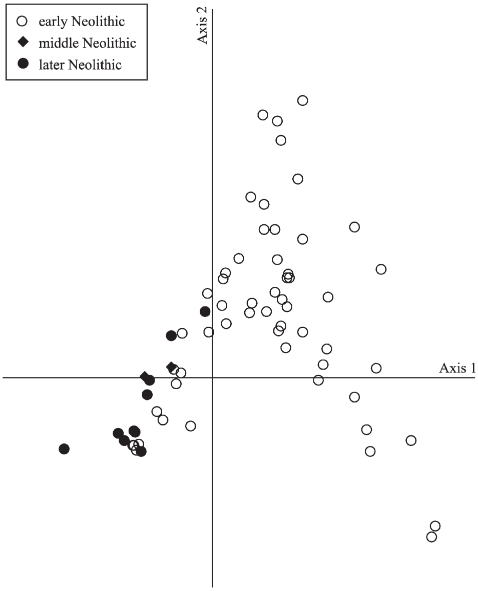

Figure 6.5 Correspondence analysis plot of glume wheat fine sieve by-product samples showing the period from which samples derive

other factors such as crop husbandry are at work. Furthermore, site-specific or regional trends in harvesting height and general soil type can be excluded as the cause of clustering. No patterning is evident when sample points in the correspondence analysis are coded according to the lowest maximum plant height per sample as an estimate of harvesting height (plot not shown). General soil type is also not a major factor since only one site included in the correspondence analysis (Hilzingen) is not located on loess. 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 *c.* 10 km apart but date to the early Neolithic/LBK and later Neolithic/Schussenried culture, respectively.

Exploring ecological trends in weed composition

Weed taxa included in the correspondence analysis were classified according to their individual functional attribute values (e.g. canopy height, length of the flowering period, etc.), and these classifications were used to interpret the correspondence analysis plot. Since a small number of taxa (e.g. *Phleum pratense*) tend to dominate the glume wheat samples, pie-charts of seed counts were used for assessing the importance of individual functional attributes (see Chapter 4). If there is a trend in the values of functional attributes (from low to high or vice versa) along the axes in the correspondence analysis plot, ecological causes of variation in weed composition can be inferred. These ecological trends, in turn, can be related to differences in crop growing conditions and hence in husbandry practices.

Attributes relating to seasonality

Attributes relating to seasonality (life history, germination time, flowering onset/length, estimated cell endopolyploidy) were considered first since sowing regime may affect the interpretation of functional attributes relating to disturbance and the duration and quality of the growth period (Bogaard *et al*. 2001).

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 (see Chapter 4).

Samples at the positive (right) end of axis 1 are dominated by perennial taxa (especially *Phleum pratense*) (Figure 6.6). This trend is not relevant to

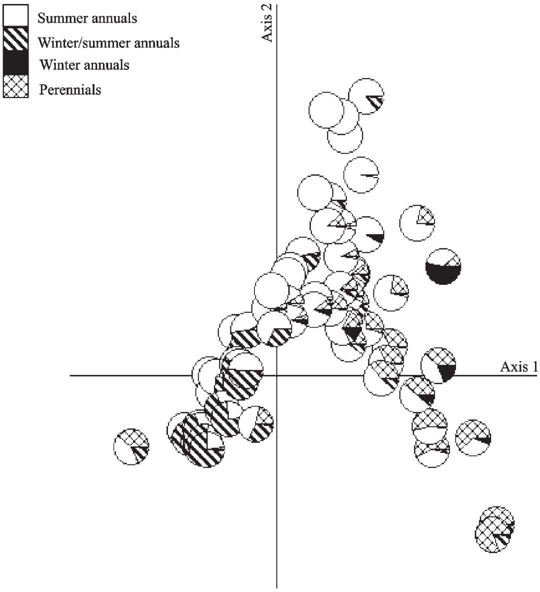

Figure 6.6 Correspondence analysis plot of glume wheat fine sieve by-product samples showing life history sowing regime and will be discussed in connection with soil disturbance (see pp. 125–9). Samples towards the negative (left) end of axis 1 are (with some exceptions) dominated by winter/summer annuals. Summer annuals predominate in samples towards the positive (top) end of axis 2 and winter annuals are prominent 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.

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 (see Chapter 4).

Samples at the positive (right) end of axis 1 are dominated by autumn-germinating taxa (especially *Phleum pratense*) while those towards the negative (left) end are (with some exceptions) dominated by autumn/spring-germinating taxa (Figure 6.7). This pattern is probably not caused by

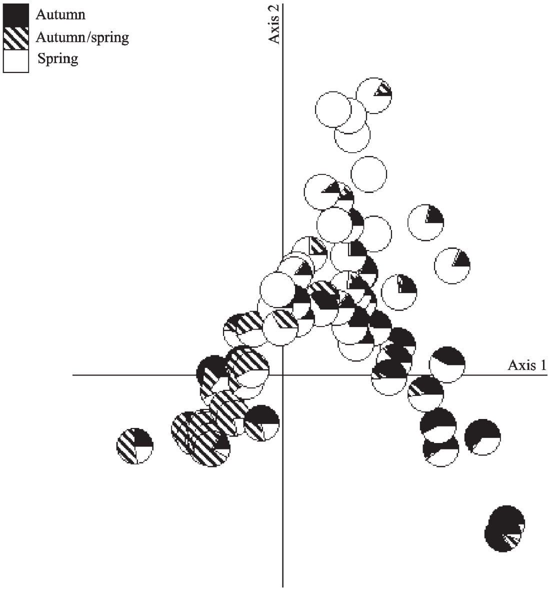

Figure 6.7 Correspondence analysis plot of glume wheat fine sieve by-product samples showing germination time

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.

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 (see Chapter 4). Flowering onset/length was the best attribute for distinguishing autumn- and spring-sown crops in the correspondence analysis of weed associations in Germany (Bogaard *et al.* 2001) and was used in the discriminant analysis of sowing regimes in Germany (see Chapters 4 and 5).

There is no trend along axis 1: early–intermediate/short-flowering taxa predominate at both ends (Figure 6.8). 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.

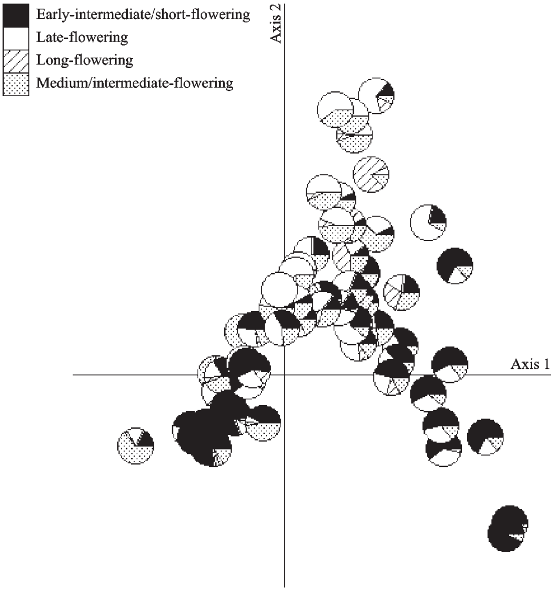

Figure 6.8 Correspondence analysis plot of glume wheat fine sieve by-product samples showing flowering onset/length

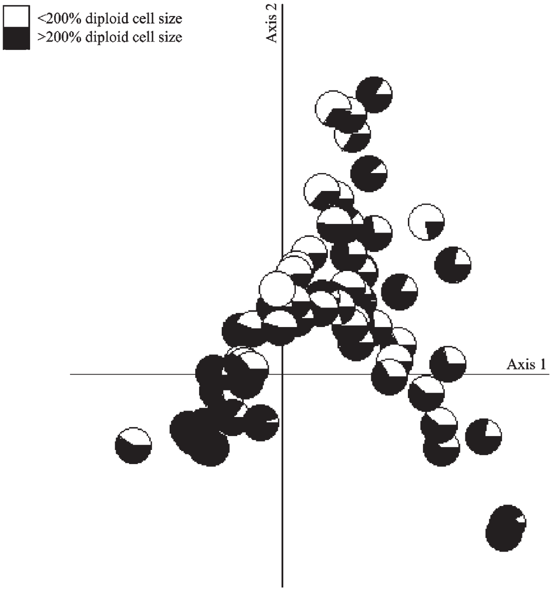

Figure 6.9 Correspondence analysis plot of glume wheat fine sieve by-product samples showing estimated epidermal cell endopolyploidy

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 (see Chapter 4).

There is no trend along axis 1: taxa with high endopolyploidy predominate at both ends (Figure 6.9). 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.

Summary of seasonality attributes

Differences in sowing regime do not explain the major axis of variation in 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 (Figure 6.3) – 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 such as Hilzingen in southern Baden-Württemberg – see Figure 6.3) 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 Figure 6.3) are rich in autumn sowing indicators. The samples that emerge as possibly spring-sown in the correspondence analysis were also classified as spring-sown by the discriminant analysis (e.g. samples from Hilzingen – Table 5.8).

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 (see p. 123) but is considered here in more detail and in isolation from time of flowering onset.

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 (see Chapter 4).

There is no trend along axis 1: short-flowering taxa predominate at both ends (Figure 6.10). 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.

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 (see Chapter 4). 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).

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, due especially to Clustered or Wood Dock, *Rumex conglomeratus* Murray/*sanguineus* L., and Bladder Campion, *Silene vulgaris* (Moench) Garcke) (Figure 6.11a). The few perennials with vegetative spread also occur at low

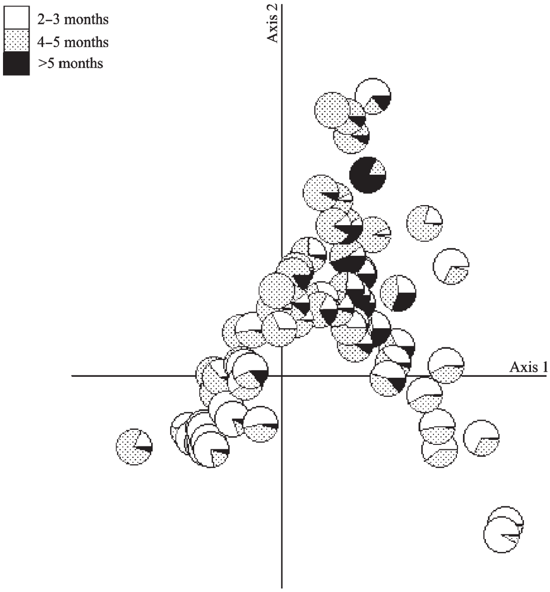

Figure 6.10 Correspondence analysis plot of glume wheat fine sieve by-product samples showing length of the flowering period

levels in samples towards the negative end of both axes (bottom left) (Figure 6.11b). 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.

Combining flowering period and vegetative spread

Length of the flowering period was combined with vegetative spread and annual/perennial life history in order to summarize disturbance-related trends among the samples. 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 characterized by perennials with and without vegetative spread as well as by short-flowering annuals (associated with moderate levels of disturbance) (Figure 6.12a–b).

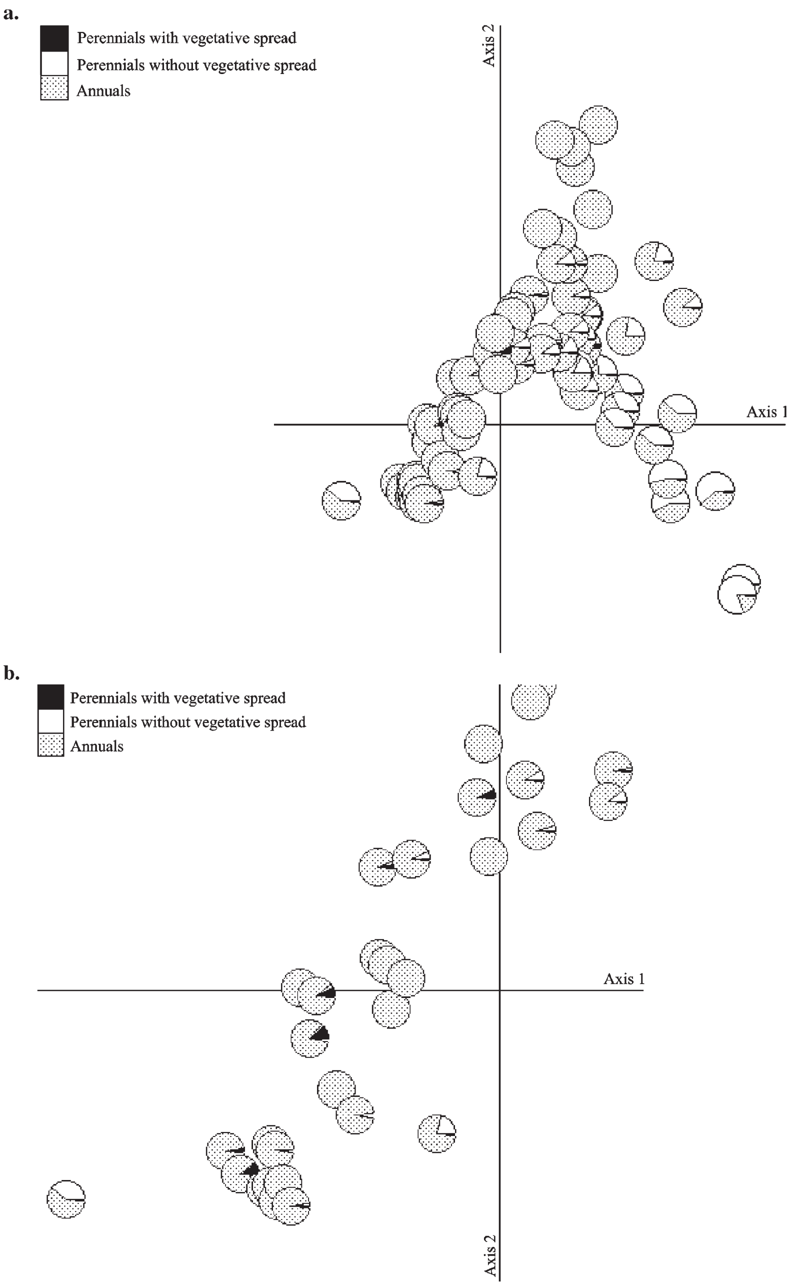

Figure 6.11 Correspondence analysis plot of (a) glume wheat fine sieve by-product samples and (b) an expanded section around origin showing vegetative spread

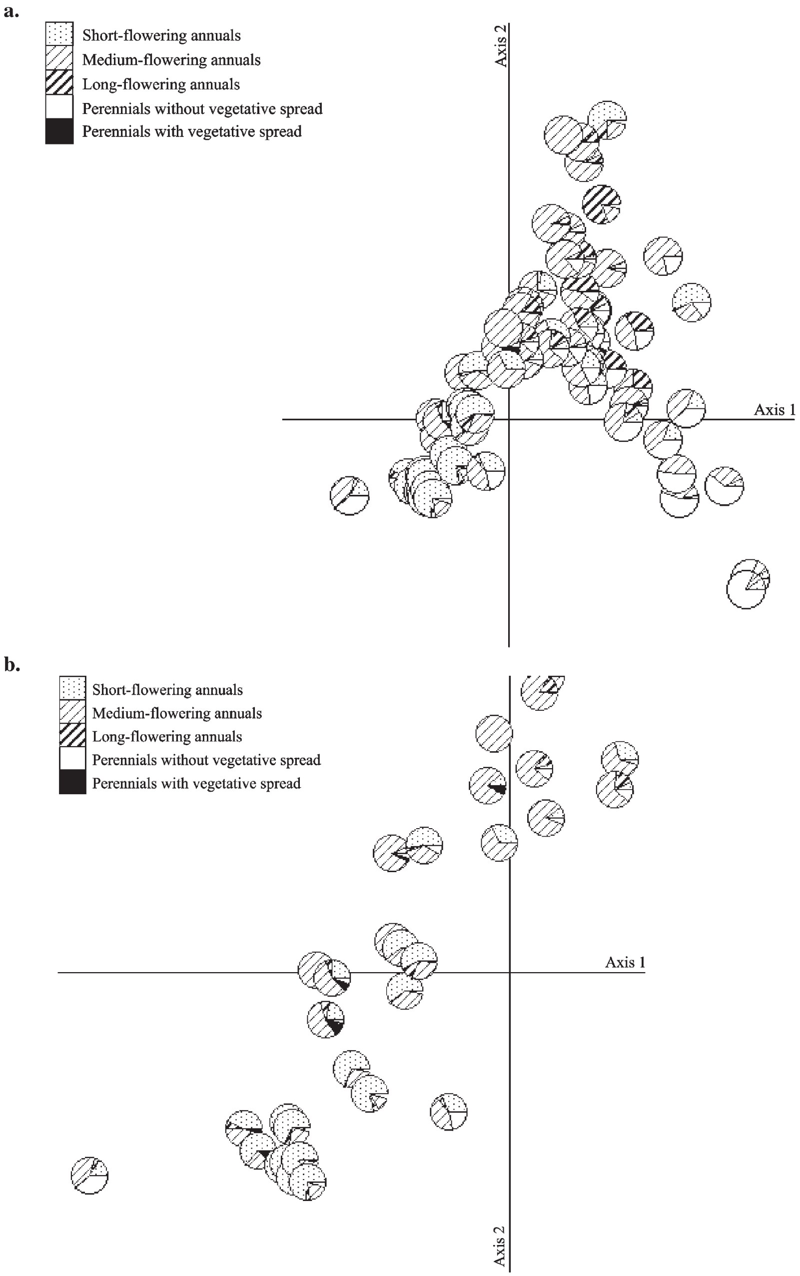

Figure 6.12 Correspondence analysis plot of (a) glume wheat fine sieve by-product samples and (b) an expanded section around origin showing vegetative spread (perennials) and length of the flowering period (annuals)

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 midway along the axis.

Summary of disturbance attributes

It appears that the major site-related contrast along axis 1 (Figure 6.3) 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 – Figure 6.4) 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 – Figure 6.4 and later Neolithic Hochdorf plus some LBK Vaihingen samples – Figure 6.3).

While trends in seasonality attributes along axis 2 may be explained by a sowing time contrast along this axis (see pp. 124–5), 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 (Figures 6.6, 6.11) 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 primarily reflects a trend in disturbance level.

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' (see Chapter 4). One attribute, the weed size index, combines plant size and leaf size attributes.

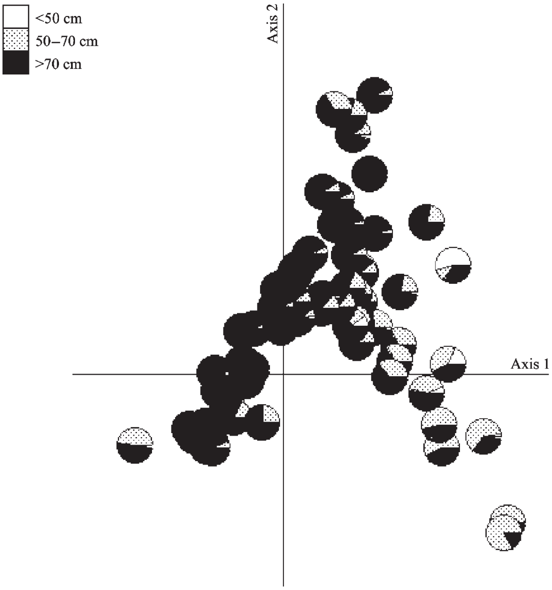

Figure 6.13 Correspondence analysis plot of glume wheat fine sieve by-product samples showing mean canopy dimension

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 (see Chapter 4).

With canopy height and diameter combined in mean canopy dimension, a trend from high (>70 cm) to medium (50–70 cm) and low (<50 cm) is apparent from the negative (left) to positive (right) end of axis 1 (Figure 6.13). This could suggest a gradient of increasing fertility from right to left along axis 1, but the influence of disturbance on canopy size must also be considered. 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.

Weed size index

It is expected that weed species with high index values (14–15) will be associated with productive, relatively undisturbed habitats, species with medium index values (8–13) with either highly fertile/highly disturbed conditions or relatively undisturbed conditions of medium fertility, and species with low

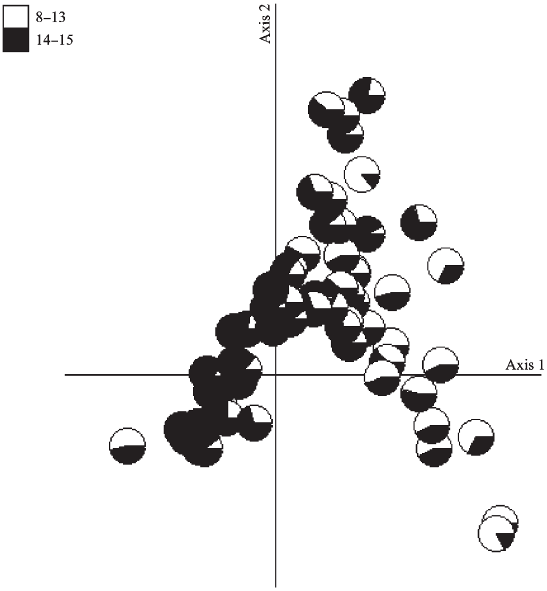

Figure 6.14 Correspondence analysis plot of glume wheat fine sieve by-product samples showing the weed size index

index values (<8) with undisturbed conditions of low fertility (see Chapter 4). There were, in fact, no taxa with values of <8 in the archaeobotanical samples, which itself suggests either disturbed or fertile conditions (or both).

A clear trend from high (14–15) to medium index values (8–13) is evident along axis 1 from the negative (left) to positive (right) end (Figure 6.14). This pattern may suggest that there is a gradient of increasing fertility from right to left along axis 1, though, as noted for canopy size, disturbance may also play a role. Thus, the medium-sized taxa at the positive (top) end of axis 2 may reflect high fertility combined with high disturbance.

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 (see Chapter 4).

Taxa with small leaf area per node (<1500 mm^2, especially *Phleum pratense* and *Valerianella dentata*) predominate in samples located at the positive (right) end of axis 1 (Figure 6.15). Taxa with medium leaf area per node (1500–5000 mm^2) 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

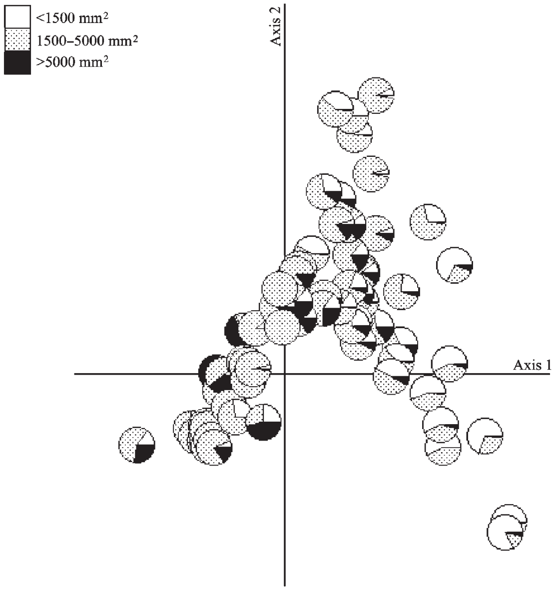

Figure 6.15 Correspondence analysis plot of glume wheat fine sieve by-product samples showing leaf area per node

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.

Similarly, in the plot showing leaf area per node:thickness (Figure 6.16), taxa with low values (<10,000 mm, especially *Phleum pratense* and *Valerianella dentata*) predominate in samples located at the positive (right) end of axis 1 and those with high values (>10,000 mm) at the negative (left) end. This suggests that there is a gradient of increasing fertility from right to left along axis 1.

There is no clear patterning in relation to the third functional attribute in this category, leaf weight per node (plot not shown).

Leaf 'density' (specific leaf area)[2]

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 (see Chapter 4).

Taxa with low SLA (<20 mm^2/mg, especially *Phleum pratense*) predominate in samples at the positive end (right) of axis 1 and those with high SLA (>20 mm^2/mg) at the negative (left) end (Figure 6.17). This suggests that there is a gradient of increasing fertility from right to left along axis 1.

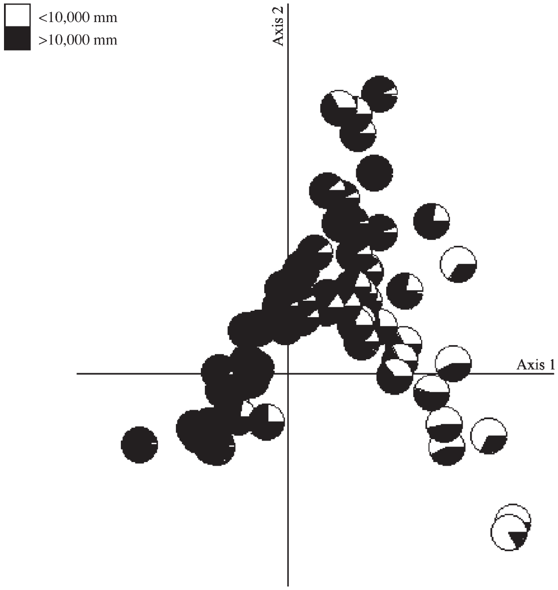

Figure 6.16 Correspondence analysis plot of glume wheat fine sieve by-product samples showing leaf area per node:thickness

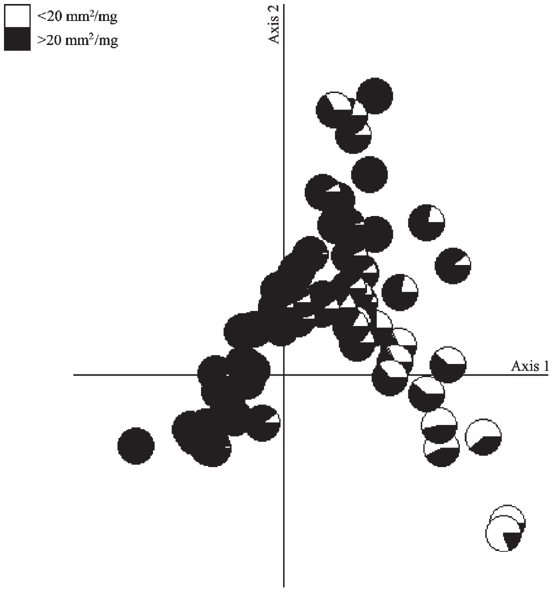

Figure 6.17 Correspondence analysis plot of glume wheat fine sieve by-product samples showing specific leaf area

Summary of fertility attributes

Functional 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) (Bogaard *et al.* 2001). 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 (see Chapter 4). Leaf size and 'density' attributes, however, should be relatively unaffected by disturbance level.

The patterning of fertility attributes along axis 1 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 relatively undisturbed conditions and are securely identified as autumn-sown. The apparent fertility differences, therefore, appear 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 interpretation could also explain the predominance of taxa with medium canopy dimension and weed size index in these samples: species of medium size are expected to characterize 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 primarily a fertility axis, therefore, 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 (Figures 6.3, 6.4). Samples from early–middle Neolithic sites in the lower Rhine–Meuse basin and from later Neolithic Hochdorf (bottom left) appear to derive from the most fertile conditions, with moderate disturbance (Figures 6.3, 6.4).

Attributes relating to water use[3]

As noted in Chapter 4, rainfall in the study area is variable but on the whole fully adequate for cereal production, and so it is unlikely that watering/irrigation 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.

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 (see Chapter 4).

Taxa with large stomata (length of guard cells >38 μm) predominate at the negative end of both axes (bottom left) but taxa with medium (32–38 μm) and small (<32 μm) 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 (Figure 6.18). This may suggest that samples tend to derive from increasingly moist habitats from right to left along axis 1.

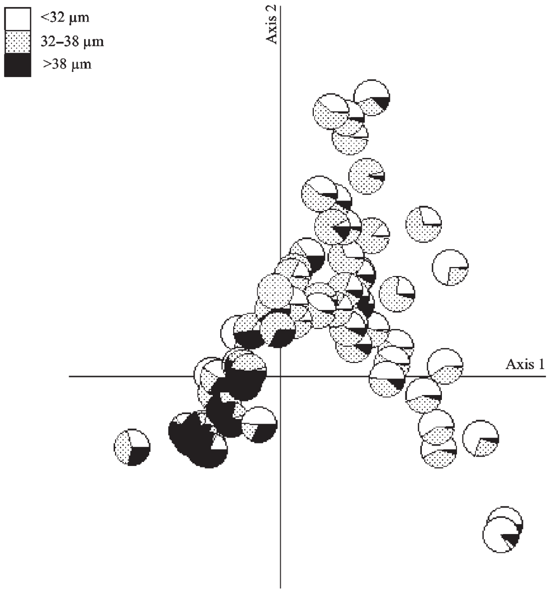

Figure 6.18 Correspondence analysis plot of glume wheat fine sieve by-product samples showing guard cell length (a measure of stomatal size)

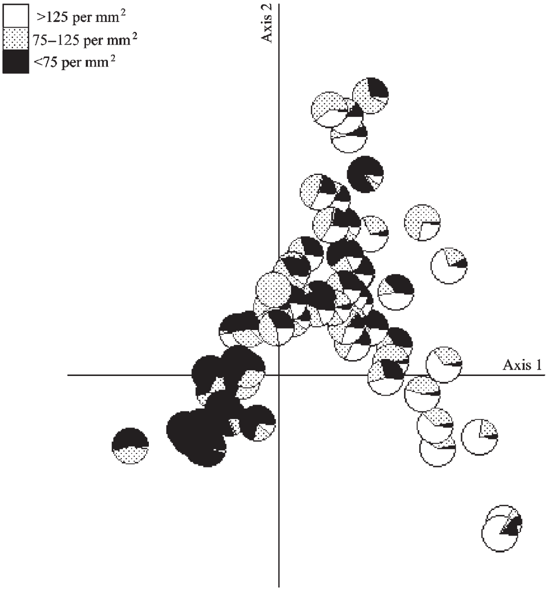

Figure 6.19 Correspondence analysis plot of glume wheat fine sieve by-product samples showing stomatal density

Taxa with high stomatal density (>125 per mm^2) predominate in samples at the positive end of axis 1 and the negative end of axis 2 (bottom right) (Figure 6.19). Taxa with low stomatal density (<75 per mm^2) 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.

Summary of water use 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. 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.

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 per cent on one leaf surface), will be associated with unshaded conditions, whereas species with stomata mostly restricted to one or other leaf surface (95–100 per cent on one surface) will be associated with shaded conditions (see Chapter 4).

No clear trends are evident when the correspondence analysis is coded using this attribute (plot not shown).

Attribute relating to habitat stability (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 (see Chapter 4).

Taxa with the greatest seed persistence (longevity index < −1.0 and/or hard seed coats) are most abundant in samples towards the positive (right) end of axis 1 and taxa with the least seed persistence (longevity index > −0.5) at the negative (left) end, suggesting a trend of increasingly stable conditions from right to left along axis 1 (Figure 6.20).

As noted in Chapter 4, 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

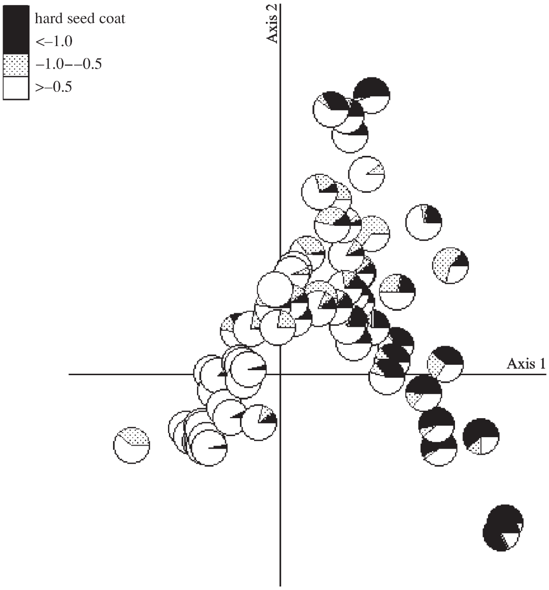

Figure 6.20 Correspondence analysis plot of glume wheat fine sieve by-product samples showing the seed longevity index (inversely related to seed persistence)

in terms of water availability, soil fertility or some other ecological factor affecting survival. The trend of decreasing seed persistence from right to left along axis 1 coincides with increasing productivity (fertility and water availability) and suggests that the most productive conditions (represented by samples in the bottom left area of the plot) were also the most stable.

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). The occurrence of 'non-arable' taxa in the archaeobotanical samples may indicate a wider range of growing conditions (e.g. less fertile and/or disturbed) than strictly 'arable' taxa.

Character species of two grassland classes, Molinio-Arrhenatheretea (*Phleum pratense*) and Sedo-Scleranthetea (*Valerianella dentata*), predominate in samples towards the positive (right) end of axis 1 (Figure 6.21). Character species of the Secalinetea and Chenopodietea are most abundant towards the positive (top) end of axis 2. Character species of ruderal communities (Artemisietea,

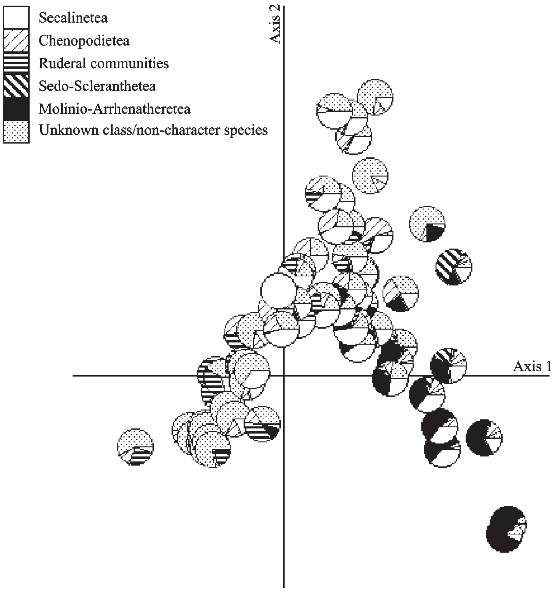

Figure 6.21 Correspondence analysis plot of glume wheat fine sieve by-product samples phytosociological class

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. These patterns are interpreted below in connection with a general synthesis of ecological trends in the correspondence analysis.

Synthesis of ecological trends and their relationship to crop husbandry practices

It has been demonstrated that various ecological trends occur among glume wheat fine sieve by-products. These trends are represented schematically in Figure 6.22: 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.

In terms of broad habitat classifications (Figure 6.21), 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. Taxa characteristic of '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 (Figure 6.21). Finally, taxa characteristic of 'medium productivity and high disturbance' are associated with arable (highly disturbed) habitats (Figure 6.21).

The ecological trends summarized in Figure 6.22 may explain the patterning in terms of archaeological site, region and chronological period noted earlier (Figures 6.3–6.5). The major site contrast along axis 1 (Figure 6.3), between Vaihingen (right) and Hochdorf (bottom left), clearly relates to differences

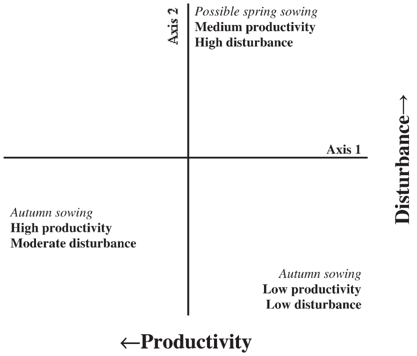

Figure 6.22 Schematic representation of major ecological trends in the correspondence analysis of glume wheat fine sieve by-product samples

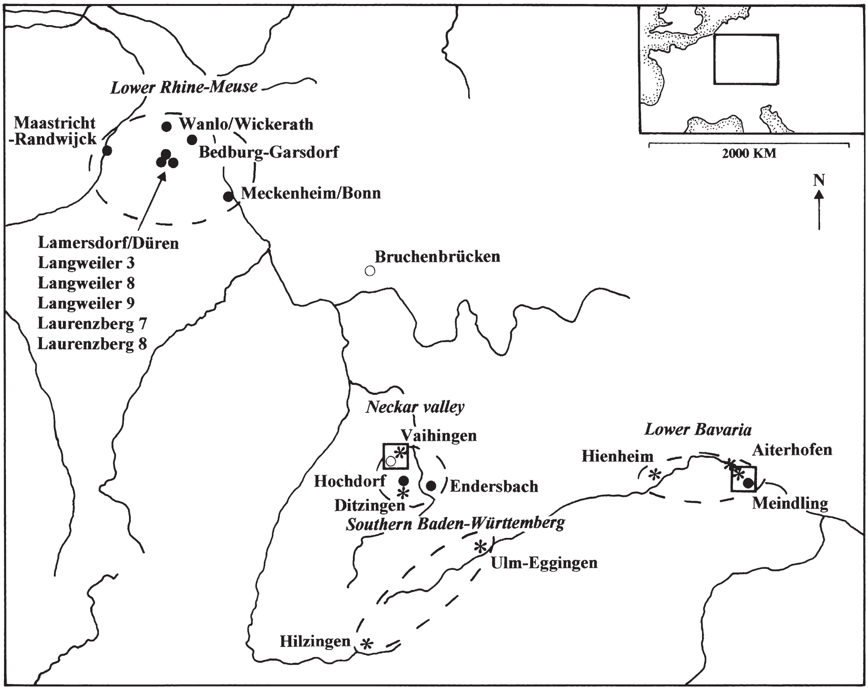

Figure 6.23 Map showing sites with samples included in the correspondence analysis and their crop growing conditions; white circles = low productivity/low disturbance, black circles = very high productivity/moderate disturbance, asterisks = high productivity/high disturbance. Squares enclose sites with two symbols each, indicating a range of growing conditions (Vaihingen in the Neckar valley, Meindling in lower Bavaria)

in productivity. Samples from the lower Rhine–Meuse basin are located along with those from Hochdorf in the bottom left area of the plot (Figures 6.3, 6.4), indicating very productive, moderately disturbed conditions. Samples from southern Baden-Württemberg (Hilzingen, Ulm-Eggingen) reflect higher levels of disturbance (Figures 6.3, 6.4). 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 (Figures 6.3, 6.4).

Figure 6.23 shows the distribution of sites and their crop growing conditions within the study area. The Neckar valley (including both LBK Vaihingen and later Neolithic Hochdorf) appears to be the most variable region in terms of growing conditions. Southern Baden-Württemberg and lower Bavaria tend towards the category of 'medium productivity/high disturbance', while the lower Rhine–Meuse sites all fall within the 'high productivity/moderate

Table 6.2 The relationship of chronological period to growing conditions (productivity and disturbance)

Period	*Low productivity low disturbance*	*Medium productivity high disturbance*	*High productivity moderate disturbance*	*Total*
Early Neolithic	x	x	x	55
Middle Neolithic			x	2
Later Neolithic			x	10

disturbance' group. Most of these sites are LBK in date, and the regional patterning of growing conditions suggests the existence of regional crop husbandry traditions (see pp. 147–51).

In terms of chronological patterning, 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 (Figure 6.5). Though the clustering of post-LBK samples may reflect general 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 and regions (Figures 6.3, 6.4) in terms of specific husbandry practices. As shown in Chapter 5, the glume wheat samples generally derive from fixed cultivation plots that were intensively cultivated and autumn-sown. The implication is that ecological trends in the correspondence analysis should be interpreted within this overall context. For example, samples indicating 'low productivity/low disturbance' (Figure 6.22) are only 'low' in comparison to the other samples in the analysis. In terms of the comparison with the Evvia pulse gardens, 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.

In addition to the relative nature of differences in crop husbandry practices revealed through the correspondence analysis, problems of equifinality – multiple possible causes for a given outcome – arise in the reconstruction of specific husbandry practices since different husbandry measures or aspects of the crop growing environment may have similar ecological effects. It is difficult, for example, to demonstrate using functional attributes that manuring was practised as a means of regulating productivity, and therefore that differential levels or frequency of manuring caused differences in levels of productivity. An alternative explanation is that 'natural' soil organic content of cultivation plots varied between sites, resulting in different productivity levels.

Nevertheless, there is strong circumstantial evidence from the study area, discussed in Chapter 2, in favour of manuring as a significant variable affecting productivity. First, domestic cattle and pigs remain distinctly smaller than their wild counterparts throughout the Neolithic (Benecke 1994a: 48–55; Döhle 1997; Lüning 2000: 105), suggesting small-scale livestock keeping focussed on the settlement and its immediate hinterland, including arable plots. While there is no direct evidence for stalling in the early–middle Neolithic, pens or hedged enclosures (Kreuz 1988b, 1990: 192–6, 1992; Castelletti and Stäuble 1997) could have been used to collect dung, and livestock may also have been folded on stubble or fallow in enclosed cultivation plots. Second, historical and ethnographic data (e.g. Slicher van Bath 1963: 260; Alcock *et al.* 1994; P. Halstead, field notes from Asturias, Spain) indicate that a household keeping a few cattle for meat and perhaps milk, as well as a few sheep/goat and pigs, could, by strategic folding of animals on stubble and spreading of collected manure, effectively replenish nutrients in intensively cultivated plots. Third, farming families practising hand cultivation and without access to additional seasonal labour at harvest time would be dependent on reasonably high area yields from the relatively small area they could cultivate and harvest (Halstead 1995); manuring would help to ensure that even relatively poor harvests remained adequate. It seems reasonable to infer, therefore, that manuring constitutes a major variable determining differential productivity levels.

Problems of equifinality also concern the variable levels of soil disturbance indicated by the archaeobotanical samples. First, two major crop husbandry practices – tillage at the start of the growing season and weeding during the growing season – may be involved, and there is no clear way of delineating these two practices using the functional attributes relating to disturbance level. Both tillage and weeding are likely components of an intensive husbandry regime, but very thorough tillage may make subsequent weeding unnecessary (G. Jones *et al.* 1999). A second problem concerns the methods used for tillage: hand tillage using a hoe of wood or antler could have a similar effect to careful ard ploughing on a small-scale followed by hoeing. Moreover, the relative nature of the differences detected using correspondence analysis makes it impossible to ‘assign’ the variable soil disturbance levels shown in Table 6.2 to particular methods of tillage.

Table 6.3 summarizes differences in specific husbandry practices among the archaeobotanical samples. Manuring is assumed to be the primary variable affecting productivity levels, and tillage and weeding are assumed to co-vary. A range of factors could contribute to the relatively low levels of tillage/weeding and manuring associated with growing conditions of low productivity and disturbance (Table 6.3). 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. Forbes 1982: 243–8, 2000a, 2000b; Halstead 1987).

Table 6.3 Interpretation of observed ecological trends in terms of crop husbandry practices (EN = early Neolithic, MN = middle Neolithic, LN = later Neolithic)

Growing conditions	*Archaeological sites*	*Tillage and weeding*	*Manuring*
Low productivity and disturbance	Bruchenbrücken, Vaihingen (both LBK)	Low intensity	Low intensity
Medium productivity and high disturbance	Aiterhofen, Ditzingen, Hienheim, Hilzingen, Meindling, Ulm-Eggingen, Vaihingen (all LBK)	High intensity	Medium intensity
High productivity and moderate disturbance	Endersback (MN), Hochdorf (LN), Meindling (LBK), lower Rhine–Meuse sites (LBK-MN)	Medium intensity	High intensity

A further possibility, suggested by the 'grassland' classification of prominent taxa in this area of the plot (Figure 6.21), is that these growing conditions were created by some form of rotation between arable and short-term grass fallow, perhaps on the order of one to two years' duration (cf. Karg 1995). Short fallow, even if untilled (weedy fallow), can promote weed control by encouraging non-arable vegetation that is more easily eradicated by subsequent cultivation (cf. Ellenberg 1996: 901–2); 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, weedy fallow would tend to allow the continued growth of weeds with low seed persistence (J. Hodgson pers. comm.), whereas the 'grassland' samples under discussion are associated with high seed persistence (Figure 6.20). Third, short-term 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). Fourth, 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. Self-heal, *Prunella vulgaris* L., Creeping Cinquefoil, *Potentilla reptans* L., and White Clover, *Trifolium repens* L.). 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, Timothy Grass (*Phleum pratense* L.) – 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 *P. 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-term grass fallow is indicated by the 'low productivity/low disturbance' samples.

A case for grazed short-term fallow could perhaps be made for samples indicating high productivity and moderate disturbance (Table 6.3). Some of these samples contained low-growing perennials with horizontal root systems such as White Clover (*Trifolium repens* L.). This category also reflects a greater emphasis on manuring than the previous group, along with more thorough tillage and weeding (Table 6.3). 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.

The medium productivity and high disturbance group suggests relatively intensive cultivation, including high levels of soil disturbance as well as some manuring (Table 6.3). This would presumably involve thorough tillage and some weeding during crop growth. Productivity would be maintained by direct applications of stall manure/household refuse and/or by manure from grazing livestock.

Interpretation of variability in crop husbandry practices

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 (Sahlins 1972: 101–48; Halstead 1989a, 1989b). 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. Variation in husbandry practices has been demonstrated both within and between sites. The best example of intra-site variation is Vaihingen, while regional differences within the LBK may contribute to inter-site trends. Finally, there is a clear contrast between LBK Vaihingen and later Neolithic Hochdorf.

Intra-site variability and settlement layout

While most of the sites in this study are associated with one particular set of growing conditions, samples from Vaihingen show considerable variation, from the low productivity/low disturbance 'extreme' in the correspondence analysis plot (bottom right) towards medium productivity/high disturbance (the positive end of axis 2) (Figure 6.22, Table 6.3). A 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 (cf. Forbes 1982, 2000a, 2000b; Halstead 1987). But such unavoidable variability should affect all sites, and so other factors may also be relevant. First, Vaihingen is by far the best-represented site in terms of numbers of samples, and so 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, suggesting that husbandry practices at Vaihingen were genuinely more variable. Second, large-scale excavation at Vaihingen 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 (see Chapter 1). A ditch and 'palisade' enclosed the settlement at Vaihingen for a brief period in the earlier LBK (Flomborn phase); the ditch was subsequently filled in and used for burial (Krause 2000). The enclosure is associated with high nucleation by LBK standards: it is estimated that *c*. 30–50 contemporary longhouses occurred within the enclosed area and its immediate vicinity (a total area of *c*. 5 ha) during the Flomborn phase (Strien in press).

This relatively high degree of nucleation at Vaihingen may correspond with a tendency for intensive husbandry practices to decrease with distance from home: in more nucleated settlements, farmers would tend to cultivate plots at varying distances from home, resulting in more variable cultivation intensity (cf. Halstead 1987; Chapman 1990; Alcock *et al*. 1994; G. Jones *et al*. 1999; Kotsakis 1999; Forbes 2000a, 2000b). P. Halstead (field notes) reports, for example, that direct manuring of fields (by spreading of carted stall manure) around the modern village of Assiros in Greek Macedonia was restricted to a *c*. 500 m radius of the settlement; beyond this point, manuring was carried out indirectly, by allowing sheep to graze on stubble/fallow. A complication here is that the settlement layout at Vaihingen – especially its overall size – appears to have changed over time (Krause 2000; Strien 2000a, in press). 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 (H.-C. Strien pers. comm.).

The relative uniformity of husbandry practices among sites in the lower Rhine–Meuse basin coincides with a dispersed settlement pattern (*Streusiedlungen*) and crop 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 up to 11 contemporary longhouses spread over 7 ha (Lüning 1988, 1997), 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, encouraging more consistent and intensive husbandry.

The contrast in ecological variability between Vaihingen and the lower Rhine–Meuse basin (with samples mainly from the Aldenhoven Plateau), therefore, may relate to relatively nucleated versus dispersed settlement, 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. The layout of other LBK sites with multiple samples in the correspondence analysis is not known in detail (Kind 1989; Dieckmann and Fritsch 1990; Modderman 1992). Variability in cultivation intensity at Vaihingen might allow increased scope for inequalities to develop between households if plots at varying distance from 'home' were not distributed equally. Precisely in order to reduce such potential for inequalities, ethnographic evidence suggests that there may be a tendency for household landholdings around nucleated settlements to be fragmented and scattered across the landscape, at varying distances from home (Forbes 1982: 353, 2000a).

Settlement layout, however, does not appear to explain the similarity between samples from Hochdorf and those from LBK sites in the lower

Rhine–Meuse basin. Though the density and extent of the settlement at Hochdorf in unclear, close spacing of houses at other later Neolithic sites (Keefer 1993: 128) suggests that the layout may have been much more nucleated than that of the lower Rhine–Meuse sites. It is known that the houses at later Neolithic Hochdorf were small, post-built structures typical of this period, and the total size of the settlement can be estimated as *c.* 20–30 contemporary houses based on better-preserved later Neolithic settlements in southern Germany (e.g. Aichbühl, Ehrenstein) (Keefer 1988: 42–3, 1993: 135, 143). Perhaps small household size at Hochdorf, together with moderate village size, reduced the impact of greater nucleation on cultivation intensity, such that the radius of the cultivated zone surrounding the settlement did not exceed the distance over which manure could be spread, for example (see also p. 152).

Regional differences within the LBK

Regional differences in ceramic decoration emerged during the LBK period and became increasingly accentuated in its later phases (Lüning 1988; Modderman 1988; Kneipp 1995). Regional differences in 'economy' may also have existed during the LBK. Sielmann (1971, 1972) made an early attempt to distinguish regional economic strategies by defining 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 relating them to stylistic differences in ceramic decoration. More recently, there have been attempts to identify regional differences in crop spectra (Willerding 1980, 1983b; Willms 1991; Küster 1995b: 81–6; Heim and Jadin 1998; Lüning 2000: 60), weed assemblages (Bakels 1992a; Küster 1995b: 86–7) and faunal spectra (Döhle 1993, 1994; Arbogast and Jeunesse 1996; Tresset and Vigne 2001).

Functional ecological differences in weed taxa appear to reflect regional differences during the LBK: samples from multiple LBK sites within the lower Rhine–Meuse basin, lower Bavaria and southern Baden-Württemberg share weeds with similar functional attributes. On the other hand, the Neckar valley group is dominated by the contrast in weed functional attributes between LBK Vaihingen and later Neolithic Hochdorf and, to a lesser extent, diversity within Vaihingen itself (ranging from 'low productivity/low disturbance' to 'medium productivity/high disturbance'). The only other LBK site in the Neckar valley included in the correspondence analysis is Ditzingen, represented by a single sample in the 'medium productivity/high disturbance' group (Table 6.3).

Küster (1992, 1995b: 86–7) has suggested that regional differences in the species composition of weed assemblages reflect a lack of seed corn circulation between regions. Such 'economic independence', however, cannot explain regional differences in weed functional attributes. If crop husbandry practices were uniform between regions, lack of seed corn circulation would not create regional weed floras distinctive in their functional attributes. Regional differences in weed ecology imply *both* differences in husbandry practices and a lack of seed corn circulation.

Table 6.4 lists a number of variables that might be expected to co-vary with regional differences in LBK crop husbandry practices. Each of these variables is considered below. It should be noted that general soil type (loess versus non-loess) has been excluded as a cause of differences in weed composition since only one site (Hilzingen) does not occur on loess (see also p. 120).

Crop spectra

In general, a similar range of crops (emmer, einkorn, pea, lentil, flax, opium poppy) is attested in each of the regions in Table 6.4, though their relative importance may have varied (Lüning 2000: 60). Mixtures of emmer and einkorn – the glume wheats on which the ecological analysis was based – are by far the most abundantly and consistently found crops in every region (Jacomet and Kreuz 1999: 295). Of the various differences in crop spectra that have been proposed over the whole zone of LBK settlement, free-threshing wheat occurs only sporadically and at low levels in some regions, usually as grain rather than the more distinctive chaff (Maier 1996), and its apparent absence from lower Bavaria may be meaningless. Otherwise, the absence of barley (hulled or naked) in lower Bavaria, and its virtual absence in the lower Rhine–Meuse basin, offers the only obvious contrast between the regions in Table 6.4. Barley tends to occur at low levels even in the regions where it is attested and its chronological and geographical significance is uncertain (Jacomet and Kreuz 1999: 295).

Barley is considered by some archaeobotanists to be more tolerant of poor growing conditions than emmer or einkorn (e.g. Heim and Jadin 1998; Rösch 2000b), though it is questionable whether barley is truly more stress-tolerant than einkorn (cf. Percival 1974: 171). The absence of barley from lower Bavaria, and its virtual absence from the lower Rhine–Meuse basin (where is attested only by a few specimens from the LBK well at Erkelenz/Kückhoven – Knörzer 1998), may relate to the relatively high productivity of growing conditions demonstrated for glume wheats in these regions. Clearly, however, more data on the weed taxa associated with barley itself would be needed in order to determine the conditions under which it grew.

Faunal spectra

Animal husbandry may affect both productivity (e.g. through manuring) in cultivation plots and soil disturbance levels (e.g. weedy fallow for grazing reduces soil disturbance, whereas hand-weeding for fodder increases soil disturbance). Animal bone assemblages from LBK sites in the Neckar valley,

Table 6.4 Variability between those regions included in the correspondence analysis during the LBK

	Lower Rhine–Meuse	*Neckar valley*	*Southern Baden-Württemberg*	*Lower Bavaria*	*References*
Crop growing conditions	High productivity and moderate disturbance	Low productivity and disturbance to medium productivity and high disturbance	Medium productivity and high disturbance	Medium productivity and high disturbance to high productivity and moderate disturbance	
Crop spectra	Barley virtually absent	Barley present	Barley present	Barley absent	Küster 1995b: 83; Knörzer 1998; Lüning 2000: 60
Faunal spectra	(High cattle?)	High pig and wild	High pig and wild	High pig and wild	Döhle 1993; Tresset and Vigne 2001
Regional ceramic group	Rhine–Meuse group	Württemberg group	Württemberg group (/upper Rhine group)	Bavaria–Danube group	Lüning 1988; Strien 2000a, 2000b, pers. comm.

southern Baden-Württemberg and lower Bavaria are generally characterized 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. Cattle are bulk manure providers (Rowley-Conwy 1981) but unlike pigs would not directly promote thorough soil disturbance. By contrast, growing conditions at sites in southern Baden-Württemberg (Hilzingen, Ulm-Eggingen), lower Bavaria (Aiterhofen, Hienheim, Meindling), and to some extent the Neckar valley (Ditzingen, some samples from Vaihingen), tend towards medium productivity and high disturbance – conditions that could be promoted through pig husbandry. The lack of adequate bone evidence from the lower Rhine–Meuse basin, however, means that this hypothesis must remain speculative.

Material culture

Regional coherence in ceramic decorative style offers a direct reflection of social links and interaction. Groupings based on LBK ceramic decoration have been defined on a broad regional scale (Lüning 1988; Strien 2000b). 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 partially correspond to stylistically distinct ceramic groups: the lower Rhine–Meuse sites form part of the Rhine–Meuse ceramic group and the lower Bavaria sites corresponds to the Bavaria–Danube group (Table 6.4). The Neckar valley and Ulm-Eggingen both fall within the Württemberg group, while Hilzingen forms part of a localized Hegau group with strong affinities to the Württemberg group until the late LBK (when it more closely resembles the upper Rhine group) (Table 6.4) (Lüning 1988; Strien 2000a, 2000b, pers comm).

Summary

Regional differences in crop husbandry practices in the LBK may articulate with differences in faunal spectra, though this interpretation is limited by the poor preservation of animal bone assemblages in the lower Rhine–Meuse basin. Regional patterning in crop husbandry practices broadly coincides with regional coherence in ceramic decoration.

It is likely that both crop and animal husbandry contributed to and were affected by social cohesion on a regional scale, as reflected in shared ceramic styles. In terms of animal husbandry, small-scale intensive herding on a household basis would rely on exchanges of livestock between households and settlements in order to ensure demographic viability (cf. Halstead 1992b). In terms of cultivation, close similarity in crop husbandry practices and weed floras among sites in the same region is consistent with the circulation of seed corn, perhaps based on obligations to share surplus crops with kin whose crops had failed, as well as shared aims and expectations regarding crop production and a close synchronization of activity cycles. An underlying cause of regional similarity in crop husbandry practices may have been intermarriage between settlements, promoting the spread of similar crop husbandry practices (see Chapter 7). The diversity of crop husbandry practices at Vaihingen, on the other hand, may reflect its unusually nucleated character (see p. 146).

LBK Vaihingen versus later Neolithic Hochdorf

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

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, a broader cereal spectrum is evident (Küster 1985; Rösch 2000b; Bogaard unpublished data). Einkorn and emmer (occurring as mixtures) are the only well-attested cereal crops at Vaihingen. By contrast, naked barley is well attested at Hochdorf, in addition to einkorn/emmer mixtures, and free-threshing wheat also occurs at low levels. There is, however, no obvious link between an apparently broader cereal spectrum and greater productivity of crop growing conditions for einkorn/emmer at Hochdorf.

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 (Arbogast 2000) and Hochdorf (Makovicz-Poliszot 1988) exhibit this tendency. Detailed 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 per cent at Vaihingen and 7 per cent at Hochdorf, based on total numbers of identified specimens). Obvious differences between the two sites in animal husbandry, therefore, are lacking.

Household and settlement size

The one- to two-roomed houses known from Schussenried sites are smaller than LBK longhouses (Keefer 1993: 128–45). The Hochdorf houses are on average *c.* 5.5 long and 3.5 m wide (Keefer 1988: 44), whereas the Vaihingen longhouses tend to be 7 m wide and at least 20 m long (Krause 2000). The difference in house size may indicate that residential units were smaller in the later period. A further difference may be the overall size of the two settlements – as noted above, as many as 50 contemporary longhouses existed at Vaihingen (Flomborn phase), whereas Hochdorf perhaps consisted of *c.* 20–30 houses by analogy with other, better preserved later Neolithic settlements in the region. It is plausible, therefore, that the approximate radius of the cultivated zone surrounding the settlement at Hochdorf was significantly smaller than that at Vaihingen and that the ‘fall off’ in cultivation intensity with distance from home was much reduced.

Summary

Given the proximity of the two sites it is unlikely that the apparent crop husbandry differences between LBK Vaihingen and later Neolithic Hochdorf reflect environmental contrasts; crop and faunal spectra also do not appear to be directly relevant here. Instead, differences in crop husbandry may coincide with social contrasts, specifically household and settlement size.

Summary

- Variation in weed species composition among the archaeobotanical samples is consistent with variability in crop husbandry practices between sites and also, during the early Neolithic, between regions.

- Consideration of the functional attribute values for the archaeobotanical weed species has identified two major ecological axes of variability among the samples: a trend in soil productivity and a trend in soil disturbance.
- Differences in soil productivity probably relate to differences in the intensity and regularity of manuring, whereas different soil disturbance levels reflect variation in the effectiveness of tillage and weeding.
- Variability in crop husbandry practices at Vaihingen may reflect its unusually nucleated character, with a 'fall off' in cultivation intensity (e.g. manuring levels) with distance from home. By contrast, the loose groupings of longhouses known from the Aldenhoven Plateau (lower Rhine–Meuse basin) are associated with more consistent growing conditions of high productivity.
- Regional differences in weed floras and crop husbandry practices during the early Neolithic broadly coincide with regional ceramic groups, perhaps reflecting the intensity of intermarriage and also seed corn circulation within regions.

7

CONCLUSIONS

Neolithic farming in central Europe

The results of the archaeobotanical analysis (Chapters 5 and 6) can now be used to assess the crop husbandry models previously proposed for the study area (Chapters 2 and 3). This chapter will also explore the broader implications of crop and animal husbandry practices for understanding the agricultural transition in central Europe.

The archaeobotanical samples suitable for statistical and ecological analysis were all cereal samples, mostly glume wheat samples containing einkorn and emmer (see Chapter 4). The results of the archaeobotanical analysis, therefore, relate above all to the husbandry of these cereals; no samples of other crops (e.g. pea, lentil, flax) were suitable for analysis. While the focus on cereals may affect the range of crop husbandry practices reconstructed, the probable importance of cereals in crop production (Willerding 1980; Gregg 1988: 73; Halstead 1989a; Gross *et al.* 1990), together with the likelihood of rotation between crops (Bogucki 1988: 82; Stika 1996; Willerding 1983b, 1988b; Jacomet *et al.* 1989: 166–7), suggests that the conclusions drawn for cereal husbandry reflect the nature of crop husbandry in general.

Reconsideration of the four major crop husbandry models

Shifting cultivation

It is now possible to reject shifting cultivation as a model for Neolithic crop husbandry in central Europe based on ecological comparison of the weed floras surveyed in the Hambach Forest experiment with the archaeobotanical weed data (see Chapter 5). The strength of this argument is that it constitutes positive evidence against Neolithic shifting cultivation in central Europe. Previous arguments against shifting cultivation have tended to emphasize that it would be ecologically unnecessary (Modderman 1971; Lüning 1980; Rowley-Conwy 1981; Barker 1985: 141–3). Thus, for example:

> It has often been suggested that the *Linearbandkeramik* sites were occupied as part of a system of shifting cultivation. On the basis of

> the site territories and an estimate of their exploitation potential, it appears that shifting cultivation would not have been necessary and would probably have been wasteful of resources.
>
> (Jarman and Bay-Petersen 1976: 180–1)

This argument is based on the assumption of human economic rationality – that the full potential of 'site territories' was exploited and that these resources were used efficiently. Moreover, such arguments do not directly address the case recently made for shifting cultivation by archaeologists seeking continuity in mobile lifestyle between the Mesolithic and Neolithic (Barrett 1994: 143–8, 1999; Whittle 1996a: 160–2, 176–7, 363–4, 1996b, 1997; Thomas 1999: 23–32). For these writers, mobility is embedded in the social fabric of Neolithic communities, an account of the economy in which the 'ecological necessity' and 'wastefulness' of shifting cultivation is arguably irrelevant (cf. Polanyi 1957). Testing this scenario requires arguments that do not make assumptions about human behaviour. The middle range theory used to interpret the archaeobotanical weed data from the study area as evidence for crop husbandry meets this criterion – the assumptions associated with this interpretation concern plant rather than human behaviour (see Introduction). The resulting interpretation points unambiguously to the cultivation of long-established fixed plots.

Fixed-plot cultivation implies that at least part of the community was more or less sedentary, tending cultivation plots and stores of grain at the 'home base' (G. Jones 2000). The rejection of shifting cultivation, however, does not necessarily weaken the case for widespread indigenous adoption of agriculture in the Neolithic (as opposed to its introduction by migrating farmers). As discussed in Chapter 3, the assumption of a mobile, shifting cultivation regime as a necessary corollary of indigenous farming is itself problematic: the mobility of late Mesolithic hunter-gatherers may be exaggerated (Zvelebil 2000b), the seasonal movements of mobile hunter-gatherers and the interannual shifts of swidden cultivators take place on different timescales (G. Jones 2000) and the notion of a transitional forager-farmer economy does not take sufficient account of scheduling conflicts (Zvelebil and Rowley-Conwy 1986; Rowley-Conwy 2000b). The corresponding expectation of an 'intrusive' form of crop husbandry facilitating colonization (i.e. floodplain cultivation) is also questionable (see p. 159).

Rejection of shifting cultivation also does not necessarily imply a rejection of the egalitarian social structure associated with it (see Chapter 3): fixed-plot cultivation – particularly when it involves widespread uncertainty – can be consistent with a lack of social ranking (Halstead 1989b). Fixed-plot cultivation, however, does harbour the potential to promote inequality between households once widespread risks have diminished: with the development of crop strains adapted to local conditions, for example, lasting inequalities between households might develop as some farming families tended to succeed and others to fail (Halstead 1989b) (see also p. 157).

Gilman (1981) identified the replacement of Neolithic shifting cultivation by extensive ard ploughing of fixed plots as the trigger for the emergence of social stratification in Bronze Age Europe. 'Capital-intensive' farming – investment through land clearance, specialized plough animals and equipment – effectively created a captive audience for aspiring leaders as communities became increasingly unwilling to abandon intensively managed land. The rejection of the shifting cultivation model for the Neolithic period, however, removes the novelty of fixed-plot cultivation in the Bronze Age. What emerges from the results of the archaeobotanical analysis is that high labour investment in fixed plots was characteristic of Neolithic farming in central Europe from the outset.

Most archaeobotanical samples included in the ecological analyses date to the early Neolithic (LBK), but the rejection of shifting cultivation notably includes the crop store from Hornstaad-Hörnle IA on Lake Constance (Table 4.3), dating to the earliest Neolithic phase of lakeshore settlement in the region (Dieckmann *et al.* 1997). As discussed in Chapter 2, pollen and microscopic charcoal sequences from the Lake Constance area have been interpreted as evidence of shifting cultivation, involving cyclical changes in woodland composition and burning (Rösch 1990b, 1996, 2000a). The Hornstaad-Hörnle cereal store included in the archaeobotanical analysis contains two woodland taxa but is dominated by annual weeds and so does not conform to the profile for shifting cultivation defined on the basis of the Hambach weed survey data (see Chapter 5). The archaeobotanical analysis suggests, therefore, that the phenomena registered by the pollen and microscopic charcoal data do not reflect the management of arable land and may instead indicate the management of separate woodland areas, a possibility suggested by Brombacher and Jacomet (1997: 270). This case illustrates the potential of crop husbandry reconstruction based on the most direct evidence available (archaeobotanical data on ancient weed floras) to refine the interpretation of more open-ended forms of off-site palaeoecological data such as regional pollen spectra (cf. Bogaard *et al.* 2000). In fact, the short span of the settlement (*c.* ten years) prior to its destruction by fire may explain the unusual occurrence of woodland species as weeds (see Chapter 5).

Extensive ard cultivation

Extensive ard cultivation of cereals is unlikely given the overwhelming classification of archaeobotanical samples as deriving from intensive cultivation (see Chapter 5). This does not exclude the possibility of ard cultivation *per se*, but rather 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 Chapter 2, that large-scale extensive cultivation with specialized plough oxen is unlikely to have developed in the study area during the Neolithic. Given that the bulk of samples included in ecological analyses date to the early Neolithic (LBK), these results are particularly relevant to Lüning's (1979/80, 1980, 2000: 160–1, 163, 181) model of extensive ard cultivation from the LBK onwards (see Chapter 2).

As discussed in Chapter 3, extensive ard cultivation presupposes social stratification in its reliance on high maintenance plough oxen and landless or dependent labourers (Halstead 1995). Extensive ard cultivation in the LBK, therefore, would support the case for inherited social status that has been made on the basis of variability in features such as longhouse size/form and grave goods (Modderman 1988; van de Velde 1990; Jeunesse 1996). In terms of crop production and consumption, it has been suggested that large tripartite longhouses represent the dwellings of higher status households associated with crop storage and the redistribution of crops to lower status households lacking crop stores (Lüning 1988, 1997, 2000: 202; Modderman 1988; Coudart 1998: 72, 76, 104; Gronenborn 1999).

While the rejection of extensive ard cultivation for the LBK does not remove the possibility that inequalities developed between households, it excludes social stratification as a *precondition* of cultivation. In the absence of social stratification as a necessary prerequisite, it is reasonable to interpret LBK households as largely independent economic units tied into local and regional social networks. As noted in Chapter 3, the quantitative archaeobotanical data that have been used to support the case for exclusive crop storage in large tripartite longhouses (Boelicke 1982; Knörzer 1988) is unconvincing. Exceptionally good preservation at Hornstaad-Hörnle IA has provided some of the best evidence in Neolithic Europe for household-level crop production, as well as other forms of procurement and consumption (Dieckmann 1991; Dieckmann *et al*. 1997).

The relevance of the extensive ard cultivation model to the later Neolithic has been less thoroughly assessed as there were only 16 later Neolithic archaeobotanical samples suitable for inclusion in ecological analyses (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). Furthermore, later Neolithic samples classified as deriving from intensive cultivation include a Baden culture sample (from Kamenin, southern Slovakia – Table 4.3) and a Corded Ware culture sample (from Mythenschloss, Lake Zurich – Table 4.3). The Baden and Corded Ware cultures have been particularly associated with a revolution in the exploitation of secondary products from animal domesticates (Sherratt 1981, 1997), including animal traction to pull the ard (see Chapters 1 and 2). A larger archaeobotanical dataset is clearly needed in order to address Sherratt's wide-ranging theory of unilinear agricultural development, but the results presented here appear to support an alternative model, outlined by Rowley-Conwy (2000a), in which historical contingency and local environmental conditions shape the crop and animal husbandry practices of farming communities rather than successive waves of innovation from the Near East.

Floodplain cultivation

Horticultural plots in river floodplains – as widely assumed for the early–middle Neolithic in particular – would require a spring sowing regime in order to avoid destruction of crops by earlier flooding (see Chapter 2). In fact, the vast majority of samples have been identified as autumn-sown (Table 5.6), a result that excludes the possibility of cultivation within the flooding zone of watercourses.

The minority of samples that appear to derive from spring-sown crops may be the result of taphonomic processes and/or high cultivation intensity. Given the tendency of crop processing to exaggerate the abundance of spring sowing indicators in fine sieve by-products (see Chapter 5), it is significant that all of the samples classified as 'spring-sown' derive from this processing stage (Table 5.7). Intensive soil disturbance would also encourage high levels of spring sowing indicators in the weed flora generally (see Chapter 6). It is quite possible, therefore, that samples classified as 'spring-sown' do not reflect a potential degree of floodplain cultivation but rather a combination of taphonomic processes (crop processing, possibly also contamination by separately collected Fat Hen, *Chenopodium album* L. – see Chapter 4) and/or high levels of soil disturbance due to thorough tillage and weeding.

Furthermore, the minority of (LBK) samples identified as spring-sown derive from sites where the potential for floodplain cultivation appears to be limited: Vaihingen, Ditzingen, Ulm-Eggingen, Aiterhofen, Meindling, Langweiler 2 and Langweiler 8 (Table 5.8) are all located near streams with narrow floodplains (Lüning 1982a, 1988, 2000: 184; Kind 1989: 19, 23; Stehli 1989; Bakels 1992a; Piening 1998; Krause 2000). The situation of Hilzingen – the only site with multiple samples associated exclusively with spring sowing (Table 5.8) – is more ambiguous due to erosion, colluviation and drainage around the site since the Neolithic (Dieckmann and Fritsch 1990).

Given that floodplain cultivation was not widely practised in the LBK, there are other considerations that may have influenced the location of early–middle Neolithic settlements. It seems plausible that river/stream valleys provided an important form of seasonal pasturage for livestock in an otherwise wooded environment (Bakels 1978: 139; Wasylikowa 1989; cf. Zoller and Haas 1995; Brombacher and Jacomet 1997). The proximity of early–middle Neolithic settlements to river/stream valleys, therefore, may relate primarily to animal rather than to crop husbandry.

As discussed in Chapter 3, floodplain cultivation has been associated with the theory that the spread of LBK culture across Europe took place through colonization (Sherratt 1980; Bogucki 1996). The presumed link between floodplain cultivation and 'immigrant' farmers, however, is open to question: if floodplain cultivation could be implemented with little labour input, it could perhaps be adopted more readily by indigenous hunter-gatherers than other forms of cultivation, and scheduling conflicts arising in the autumn between hunting/foraging and cereal cultivation would be reduced by sowing crops in spring, as required in a floodplain cultivation regime. The rejection of floodplain cultivation, therefore, should not be used to suggest that early Neolithic farmers were necessarily of indigenous origin.

Intensive garden cultivation

The intensive garden cultivation model proposed by Halstead (1989a) 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) suggests that cereals tended to be cultivated intensively with high inputs of 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 (see p. 158).

As discussed in Chapter 2, 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, grazing of cereals to prevent lodging and promote tillering). It is unlikely, therefore, that a separate pastoral component of the economy developed during the period analyzed (cf. Halstead 1987, 1989a, 2000). Intensive garden cultivation also suggests high area yields and hence smaller cultivation areas per household than commonly assumed. Given yields of *c.* 1500 kg/ha (cf. intensive spelt cultivation in Asturias – Table 2.1), for example, a household of five individuals (each requiring *c.* 300 kg/year, assuming that cereals provided the bulk of the diet) would need to cultivate as little as *c.* 1 ha (Table 2.2). Such a cultivation area falls well within the labour capacity of ethnographic farming families (Halstead 1995). 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 Zimmerman 1988; Kalis and Meurers-Balke 1997, 1998), 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 general reassessment of perspectives on the agricultural transition (see below).

Implications for the agricultural transition in the loess belt

A fundamental question surrounding the 'spread' of the LBK is whether it represents the movement of communities from south-east Europe, the adoption of new practices by local hunter-gatherers or some combination of colonization and indigenous acculturation. While both shifting and floodplain cultivation have been rejected as models of Neolithic crop husbandry, the assumed link between these crop husbandry regimes and indigenous versus immigrant identity has also been called into question. Though crop husbandry practices do not directly reveal the origin of Europe's first farmers, the nature of the farming regime does have important implications for the daily routines, longer-term outlook and ideology of LBK farmers. The nature of LBK farming, therefore, is of central importance to accounts of the transition to agriculture and its consequences in the loess belt, as well as in other parts of Europe where farming was eventually adopted under LBK influence, including the Alpine Foreland.

The archaeobotanical analysis presented here indicates that crop husbandry in the LBK period[1] was based on intensive garden cultivation of fixed plots that were sown in the autumn (see Chapter 5). Within this general regime there was some variation in practices relating to soil productivity (manuring) and disturbance (tillage and weeding). This variation can be understood as reflecting a degree of flexibility in farming practice based on available time and labour etc., but variation also emerges more specifically in connection with relatively high nucleation of longhouses at Vaihingen and with regional traditions in crop husbandry practices (see Chapter 6).

Like crop husbandry, livestock keeping in the LBK period appears to have been relatively small scale and intensive. Domestic populations of cattle and pigs remain distinctly smaller than their wild counterparts throughout this period, suggesting the predominance of small herds confined to the vicinity of the 'home base' (Benecke 1994a: 48–55; Döhle 1997; Lüning 2000: 105; cf. Halstead 1996). Available mortality data for cattle and sheep/goat assemblages do not appear to indicate specialized management aimed at milk or wool production – strategies that would enhance the plausibility of extensive herding (Halstead 1996); rather, a generalized meat-oriented strategy is considered likely (Arbogast 1994: 91; Benecke 1994a: 95, 1994b: 122–3). Again, as for crop husbandry, there is some evidence of regional variability (e.g. in proportions of domesticates) within this overall intensive regime (Benecke 1994a: 84–5; Arbogast and Jeunesse 1996; Tresset and Vigne 2001). Possible links between regional crop and animal husbandry traditions were discussed in Chapter 6.

This overall picture of LBK farming has five major implications for the Mesolithic–Neolithic transition in the loess belt, discussed below.

Farming practices and the spread of the LBK

Since Childe (1929: 45–6) first proposed his influential hypothesis of immigrant farmers practising slash-and-burn cultivation, the Mesolithic–Neolithic transition in central Europe has generally been understood as a development facilitated, if not actually caused, by a crop husbandry regime 'pre-adapted' to rapid spread. Thus, floodplain cultivation appeared to offer an obvious way forward for migrant farmers from south-east Europe, enabling them to pursue the same low-input cultivation strategies from Anatolia through to central Europe (Sherratt 1980). Meanwhile, shifting cultivation evolved from a model explaining the spread of immigrant farmers (as in Childe's formulation) into a model for indigenous acculturation and the maintenance of a mobile lifestyle (Whittle 1996a: 160–2, 176–7, 363–4, 1996b, 1997; cf. Barrett 1994: 143–8, 1999; Thomas 1999: 23–32).

The picture of LBK crop husbandry that emerges from the archaeobotanical weed evidence, however, does not resemble a regime that would inevitably spread across Europe, whether by migration, indigenous adoption or some combination of the two. Several lines of evidence support this contention. 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 and 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 timescale. The long-term benefits of manuring on soil productivity, along with the short-term damage it can cause by encouraging the crop to lodge (see Chapter 2), underline its role as an essentially *long-term investment* in a fixed plot of land. Second, it appears unlikely, in light of the predominance of intensive garden cultivation in the LBK, that the spread of farming was a product of the targeted search for fertile patches of loess or alluvial soil for cultivation: manuring/middening and careful tillage can create an artificial garden soil in intensively cultivated garden plots (G. Jones *et al.* 1999), removing the need to rely on the inherent properties of the 'natural' soil. A third point relates to the value of intensively cultivated plots, once established, 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 laboriously 'from scratch'.

The small-scale and intensive nature of LBK animal husbandry also does not lend itself to the rapid spread of farming. Extensive herding would in some ways help to explain the spread of migrating people, and it has also been seen as conducive to indigenous assimilation and the maintenance of a mobile way of life (Whittle 1996a: 162, 1997). Intensive animal husbandry, on the other hand, implies close integration with arable production and a lack of mobility.

In sum, close attention to the 'economic' evidence for the LBK appears to remove any ecological imperative underlying the spread of farming. There is no reason to believe that the spread of the LBK settlement was in any way prefigured in the farming regime itself. Rather, the spread of farming took place *despite* the intensive nature of crop and animal husbandry.

LBK farming and its uptake by Mesolithic hunter-gatherers

A further development of the arguments made above with regard to the spread of farming pertains to the indigenous acculturation scenario (e.g. Dennell 1983: 176; Modderman 1988; Whittle 1996a: 363–4, 1996b, 1997). The intensive farming regime reconstructed for the LBK implies that indigenous hunter-gatherers who adopted farming changed their economic practices radically. Two lines of evidence point in this direction. First, widespread autumn sowing of cereals would exacerbate the 'scheduling crisis' in autumn for communities attempting to pursue intensive foraging and hunting alongside agriculture in temperate Europe (Zvelebil and Rowley-Conwy 1986; Rowley-Conwy 2000b) (see also Chapter 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: Figure 74, 223–5). 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: Figure 74, 223–5) or hunted fauna (Suter and Schibler 1996: Figure 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. The implication is that the indigenous adoption of agriculture would have entailed a rapid commitment to a new farming way of life.

Second, intensive crop and animal husbandry have been linked in a number of ways to risk-buffering in the context of small-scale household production (Halstead 1987, 1989a, 1989b). Crop 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 (see Chapter 2) and to produce a surplus in good years to supplement poor returns in bad years. Small-scale herding of domestic animals would reinforce intensive cultivation by providing manure for arable plots. It seems reasonable to suppose that risk minimization would only become a paramount concern if the survival of the household and wider community depended on the success of farming. Thus, while 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 extensive 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 and animal husbandry were closely integrated and together provided the bulk of the human diet.

Within an indigenous acculturation perspective, therefore, the intensive nature of LBK farming suggests that agricultural practices were rapidly adopted and tended to displace hunting and gathering. While this conclusion might seem to support the view that the LBK involved significant migration rather than indigenous acculturation, a scenario of rapid adoption in some ways resembles other, more widely accepted cases of indigenous adoption. In northern Europe, Price (2000) has recently likened the rapid spread of TRB (*Trichterbecherkultur* or Funnel-necked Beaker culture) pottery and domesticates across northern Europe and southern Scandinavia to the 'explosive' spread of LBK culture across the loess belt. Zvelebil and Rowley-Conwy (1984, 1986) have argued that the actual replacement of a hunting and gathering economy by a farming economy in northern Europe was rapid, though it followed a millennium of forager–farmer interaction across the frontier zone. Perhaps a period of forager–farmer interaction that began across the claimed agricultural frontier in the Great Hungarian Plain (Zvelebil 2000b: Figure 7.1) prepared the way for a rapid adoption of agriculture as part of the spread of LBK culture.

The implications of cereal sowing time for LBK farming in temperate Europe

It has sometimes been claimed that spring sowing was a critical innovation that allowed farming practices to spread beyond the 'climatic bottleneck' of the Carpathian basin, which marks the approximate boundary between Mediterranean and temperate Europe (Butzer 1972: 580; Barker 1985: 146; Bogucki 1996). By sowing crops in the spring, it is argued, damage to crops by the harsh winters of temperate Europe could be avoided, facilitating the spread of crop cultivation. This theory was originally advanced without any direct archaeobotanical support (Butzer 1972: 580), and since then archaeobotanists have in some cases inferred spring sowing of cereals in the early Neolithic (Groenman-van Waateringe 1979; Gluza 1983; Bakels and Rouselle 1985; Rösch 2000a), in other cases autumn sowing (Knörzer 1967, 1971, 1988, 1991; Willerding, 1980, 1983a, 1985, 1988a) (see also Chapter 2). Rather than reflecting 'genuine' variability in cereal sowing times these differences may be due to a combination of the effects of intensive cultivation (promoting the growth of Chenopodietea, which are sometimes used as indicators of spring sowing – G. Jones e*t al.* 1999) and contrasting methodologies for inferring sowing time.

The archaeobotanical analysis presented here provides strong evidence for continuity in the autumn(–winter) sowing of the cereals emmer and einkorn beyond the 'climatic bottleneck' of the Carpathian basin. There is some evidence to suggest that the effects of the climatic transition were reduced by a warmer climate during the Atlantic period in central Europe than at present (Starkel 1995). Nevertheless, the practice of autumn sowing in the LBK suggests that the adjustment of crop cultivation to more temperate conditions was more complex than previously thought. In ecological terms, the success of farming in temperate Europe may have been based on the gradual development of crop strains adapted to local conditions and not on obvious adjustments in crop husbandry. Autumn sowing of cereals may have been considered advantageous for farmers in two ways: first, autumn sowing involves a longer growing period and hence higher yields than spring sowing; second, autumn sowing of cereals may have enabled farmers to divide the labour of soil preparation and sowing over two seasons if other crops (pulses, flax, poppy) were spring-sown (Gregg 1988: 76–8, 132; Jacomet *et al.* 1989: 142; Kreuz 1990: 173; Brombacher and Jacomet 1997: 264).

In contrast to crop sowing time, major adjustments were clearly made to animal husbandry practices as farming spread across south-east and central Europe (Halstead 1989a; Benecke 1994a: 82–4). While sheep/goat predominated in Neolithic Greece and the Balkans, cattle were dominant in the LBK, a change that may reflect a greater emphasis on animal husbandry in the loess belt, given that cattle are better adapted to browsing and grazing in a wooded landscape (Halstead 1989a). While LBK herding remained essentially small-scale and intensive, this change in animal husbandry can be interpreted as a reflection of the risks associated with the cultivation of 'foreign' crop strains in temperate Europe, resulting in a more even economic balance between crop and animal husbandry than in Neolithic Greece, for example, where animal husbandry appears to have played a relatively minor role (Halstead 1981a, 1989a).

Intensive garden cultivation and LBK ideology

Recent writing on the Neolithic in Europe has suggested that there was a novel ideological separation between nature and culture, in contrast to a Mesolithic world-view emphasizing continuity between the human sphere and the natural world (e.g. Hodder 1990: 53; Bradley 1998: 20–35). Much of the commentary on Neolithic ideology has focused on its ritual expression through burials and monuments in northern and north-west Europe. The wealth of economic evidence for routine activity in LBK settlements of the loess belt, however, is critical for understanding concepts introduced by the first farmers in central Europe. The habitual actions associated with intensive garden cultivation can be viewed as a way in which ideology developed and was perpetuated in everyday life (cf. Bourdieu 1977, 1990). These actions included daily tending of plots (e.g. protection, small-scale weeding) as well as more seasonal activities such as manuring, tillage, sowing, intensive weeding and harvesting. Over the longer term, for example, these habitual activities might give rise to concepts of 'ownership' over the land cultivated as well as the crops themselves, claims that could be extended from one generation to the next.

In contrast to floodplain and shifting cultivation, it is striking that intensive garden cultivation involves the creation of entirely 'artificial' growing conditions, including the development of a rich garden soil. The high-maintenance 'artifice' of an intensive garden regime may have provided a central example of the transforming power of culture over nature or, looked at another way of working in partnership with nature, of 'feeding' the land in order to make plants grow (Ingold 1996). The spread of this form of crop husbandry would not be limited by the distribution of the loess itself, since it would not be dependent on the inherent fertility of loess-based soil. Intensive garden cultivation in the LBK, therefore, suggests that the agricultural frontier zones in the North European Plain and Alpine Foreland primarily represent ideological barriers between LBK farmers and hunter-gatherer groups rather than ecological barriers based on differences in soil type (cf. Bradley 1998: 11). The intensive nature of crop growing itself may have posed an important barrier to its acceptance by hunter-gatherers because it required a radically different level of management and intervention in the plant life cycle. Evidence for Mesolithic plant use in northern Europe suggests that perennial plant species played a major role – for example, calorific sources such as hazelnut, as well as roots and tubers of woodland perennial species such as wild garlic (e.g. Kubiak-Martens 2002). The management and protection of these perennial plants of relatively undisturbed habitats would bear little resemblance to the intensive management of an LBK cereal-growing regime (cf. Rowley-Conwy 1986).

A further obstacle to hunter-gatherer acceptance may have been the type of land tenure associated with LBK cultivation. Intensive garden cultivation entails long-term investment in stationary plots of land, suggesting that farming households might claim use rights and 'ownership' of the plots they maintained (Netting 1971). The implication is that intensive garden cultivation involved not only direct 'ownership' of domesticated plants (cf. Bradley 1998: 33–5) but also of the land on which they were grown. Such claims over land may have been as alien to Mesolithic hunter-gatherers as the contrived growing conditions and high maintenance of LBK plant husbandry.

The importance of cultivation plots in the development of LBK communities emerges from a contrast between their potential long-term use and indications (from ^{14}C dating of site occupations combined with phasing) that longhouses were used for relatively short periods of time (*c.* 20–30 years) before being 'replaced' by new structures (Stehli 1994: 122–35, 182; Pavlů

2000: 268). One possibility is that the longhouses were abandoned following the death of an occupant (Bradley 1998: 44, 2001). The archaeobotanical evidence suggests that there was continuity in the use of cultivation plots associated with specific households despite shifts in the actual longhouse structure occupied. While it is conceivable that a weed flora typical of intensive cultivation could develop in *c.* 25 years, such that cultivation plots 'drifted' along with the longhouses, one would expect in this case to find archaeobotanical weed evidence for the periodic establishment of new plots. The implication is that long-established cultivated plots served as potent symbolic and economic links between longhouse generations. Like the monumentality of the longhouse itself (Hodder 1990; Sherratt 1995), cultivation areas reflected the importance of the household as the fundamental social and economic unit (cf. Sahlins 1972: 95–7).

The way in which intensive garden cultivation contributed to the creation and maintenance of 'household space' may help to explain the apparent tendency of longhouses to be replaced within specific areas of the settlement (Lüning 1988, 1997; Stehli 1994: 86–108; Pavlů 2000: 274). The tendency towards proximal replacement of longhouses seems to reflect a basic principle of long-term use-rights to specific parts of the settled area. Spatial constraints on the drift of longhouses over time may also reflect the location of cultivation plots nearby, given that cultivation intensity tends to be inversely correlated with distance between plots and the home base (G. Jones *et al.* 1999). Pavlů (2000: 274) suggests that the borrow pits dug next to longhouses were quickly filled in and levelled because cultivation actually took place directly among the houses; a related possibility is that old house sites themselves were cultivated (cf. Netting 1971). In many cases (most strikingly at Vaihingen – Krause 2000; Strien 2000a, in press), however, the residential area would be too restricted to accommodate sufficient cultivation (perhaps *c.* 1 ha or more) for each farming family. The division of space between households, therefore, may have extended to determine the configuration of plots in the wider landscape beyond the immediate residential area.

Ethnographic evidence points to the central role of women in plant foraging and in horticulture, while men are often associated with hunting, woodland clearance and extensive plough agriculture (Boserup 1965; Goody 1976; Brown 1978: 78–85; Watson and Kennedy 1991; Ingold 1996). The close relationship between women and horticulture reflects their central role in childcare at the home base (Hastorf 1998). In the LBK, the association between women and cultivation is reinforced by the likelihood that intensively managed plots were located near the home (cf. G. Jones *et al.* 1999). While hunting levels may have been relatively low in many LBK communities, it seems plausible that men also undertook forest clearance and managed livestock, especially where this involved movement well beyond the home base – including exchanges of animals between households and communities (cf. Halstead 1992b).

As noted in Chapter 1, the small size of LBK communities suggests that most were not demographically viable, with the implication that there must have been considerable intermarriage between communities. Recent strontium isotope work on human remains from LBK cemeteries in the Rhine valley appears to provide evidence for female migration and patrilocality (Price *et al*. 2001; Bentley *et al*. 2002, 2003). One possibility is that non-local females came from forager communities in the surrounding uplands. If this is the case, a critical form of acculturation for these women may have been to learn the techniques of intensive garden cultivation and assume responsibility for household plots. On the other hand, if women were exchanged among LBK communities, they may have been particularly valued as experienced cultivators as well as child bearers (cf. Cullen 1985). Whether incoming women were from foraging or other farming communities, it seems plausible that the routines of crop husbandry constituted a prime mechanism for their assimilation into new households.

Farming practices and the end of the Bandkeramik *tradition*

The disappearance of the *Bandkeramik* tradition of longhouses and distinctive incised pottery in central Europe around 4400 BC, and its replacement by different regional patterns of settlement and material culture variously related to the TRB phenomenon, has sometimes been linked to problems arising from farming. Gregg (1989: 398) interpreted overall uniformity in the weed assemblages at Ulm-Eggingen as evidence of a 'relatively inflexible planting strategy' that was disadvantageous in the long term, preventing farmers from adapting to changing climatic conditions. Another theory, proposed by Rösch (2000a), is that soils deteriorated during the early–middle Neolithic due to the cultivation of fixed plots without manuring or fallow.

Neither of these explanations for the disappearance of the *Bandkeramik* tradition is supported by the interpretation of early–middle Neolithic crop husbandry practices presented here. First, intensive garden cultivation of autumn-sown cereals appears to have been the predominant form of crop husbandry throughout the Neolithic (Table 5.9). This result implies both that manuring/middening was practised, making deterioration in soil quality unlikely, and that the general character of crop husbandry did not change radically in the later Neolithic in response to problems in the earlier Neolithic. Second, an exploration of trends in weed composition among glume wheat samples (see Chapter 6) indicates that crop husbandry practices did vary within the LBK as well as between the LBK (at Vaihingen) and the later Neolithic (at Hochdorf) in the Neckar valley. Thus, it appears that, though there was a remarkable conservatism throughout the Neolithic in the practice of intensive garden cultivation, there was flexibility and variation within this overall framework.

An alternative explanation points to mounting social tension. Modderman (1988: 130) suggested that the end of the *Bandkeramik* tradition was brought about by 'revolt against a social system based on an economy in which a few people controlled the distribution of food'. This explanation assumes that variation in longhouse size and form reflects social stratification and that farming households were not largely independent economic units. There is however no compelling evidence that crops were redistributed by the occupants of large, tripartite houses (see also Chapter 3).

During the early and middle Neolithic there is increasing regionalization of material culture and a broadening of the crop spectrum (see Chapter 3). These developments may reflect increasing stability in crop production: the scope of support networks could become more localized as general threats to crop production diminished. A heightened emphasis on local sharing and support may have caused social disruption as obligations to share based on kinship were renegotiated. Perhaps this is the context in which the widespread material culture of the *Bandkeramik* disappeared.

The agricultural transition in the Alpine Foreland

The agricultural transition in the Alpine Foreland is often regarded as one of indigenous adoption (Barker 1985: 124; Sherratt 1990, 1995; Bogucki 1996) based, for example, on Mesolithic–Neolithic continuity in settlement around the former lake of the Wauwilermoos in western Switzerland (Wyss 1979). Though shifting cultivation has recently been associated with Neolithic settlement in the Alpine Foreland (see Chapter 2), the archaeobotanical weed evidence from two Neolithic lakeshore sites analysed here (Hornstaad-Hörnle IA on Lake Constance, Mythenschloss on Lake Zurich – see Table 5.8) points to continuity in the intensive cultivation of fixed plots from the loess belt to the Alpine Foreland. These general conclusions agree with more wide-ranging archaeobotanical studies of the Hornstaad-Hörnle crop stores (Maier 1999, 2001) and the Lake Zurich sites (Jacomet *et al*. 1989; Brombacher and Jacomet 1997), which also suggest fixed plots rather than shifting cultivation (see Chapter 2).

Reference has been made to the potential importance of ideological rather than edaphic barriers for the adoption of intensive cultivation beyond the loess belt. In fact, within the LBK period intensive garden cultivation was already practised south of the loess, at the site of Hilzingen near the western end of Lake Constance (Figure 4.1). Given that the intensive garden cultivation regime characterized both the LBK and the Neolithic of the Alpine Foreland, the apparent frontier of agricultural settlement around the southern edge of the loess belt is probably to be explained as hunter-gatherer resistance to a fundamentally different way of life. The eventual adoption of intensive cultivation in the Alpine Foreland was not just about 'subsistence change';

as argued above, the practice of intensive cultivation itself was a central expression of Neolithic ideology.

Neolithic communities to the north and west of the loess belt may also have practised intensive garden cultivation. The nature and role of Neolithic crop cultivation in this area is controversial; one view is that the actual 'substitution' of foraging by farming was rapid (Zvelebil and Rowley-Conwy 1984, 1986), but recently there has been emphasis on the potential transience of Neolithic settlement and cultivation in northern Europe and Britain (Bradley 1998: 10, 161; Thomas 1999: 23–32). Most radically, the proliferation of mortuary monuments in north and north-west Europe has been interpreted as ritualized references to earlier longhouses and communities of the loess belt in the virtual absence of crop cultivation as a day-to-day reality (Bradley 1998: 49, 161–3). This minimal view of crop cultivation is based on negative evidence – a lack of settlement remains, and hence a lack of archaeobotanical evidence for crops and their weeds. Rowley-Conwy (2000b) has recently emphasized the danger of this reasoning for the British Neolithic, where concentrations of charred cereals on some sites attest to the potential importance of cultivation (see also G. Jones 2000; Monk 2000).

The origins of intensive garden cultivation

In addition to continuity of intensive crop husbandry through the Neolithic period in the loess belt and Alpine Foreland, available evidence from the southern Balkans and Greece appears to reflect small-scale and intensive cultivation (Halstead 1981a, 1989a, 1989b). While such widespread similarity in the nature of early crop husbandry may appear surprising given the variable ecology of the regions where early farming was established, the 'buffered' and 'artificial' character of intensively cultivated plots (e.g. lack of reliance on 'natural' soil conditions) may help to explain the conservatism of early crop cultivation across Europe.

Did the intensive cultivation of crops emerge only in Neolithic Europe? This form of crop husbandry requires sedentism (by at least part of the community) and cooperative work and consumption within households as well as integration between crop and animal husbandry such that, for example, manure is available to maintain high fertility levels in cultivation plots. The earliest period in which these factors appear to coincide is the Pre-Pottery Neolithic B (PPNB, *c.* 8800–6850 BC) in the Near East. While a significant degree of sedentism stretches back to the later Epipalaeolithic in the Near East, the emergence of formalized household dwellings and household storage (Flannery 1972; Wright 2000), as well as herding of domesticated sheep/goat, pig and cattle (Peters *et al.* 1999), is associated with the PPNB. In the preceding Pre-Pottery Neolithic A (*c.* 9400–8800 BC), there is evidence of domesticated crops but no clear morphological evidence of animal domestication aside from domesticated dog (Peters *et al.* 1999; Colledge 2001: 8–9, 150); small circular PPNA dwellings, descended from those of the late Epipalaeolithic Natufian tradition, appear to reflect a fluid boundary between common and household space (Wright 2000).

Modern agricultural experiments in south-west Asia and the eastern Mediterranean attest to the benefits of manuring for crop yields, provided adequate moisture is available (Halstead 1987; Cooper 1991). Direct evidence for intensive garden cultivation in the form of archaeobotanical assemblages of arable weeds accompanying crop remains at Neolithic sites in the Near East is difficult to identify because potential weed seeds could in many cases be derived from plants grazed by animals and preserved through the burning of animal dung as fuel (Miller 1996; Charles 1998). Nevertheless, a statistical and ecological study of potential arable weed assemblages in the Levant by Colledge (1998, 2001: 187–9) reveals possible indications of a shift towards more intensive tillage in the PPNB, in keeping with the emergence of full-blown intensive cultivation. During the PPNB there was an expansion of arable farming and livestock herding both within the Fertile Crescent and, on its periphery, into Cyprus (Vigne *et al.* 1999; Cauvin 2000: 75–104; Peltenberg *et al.* 2001). It could be argued that the subsequent expansion of farming into Europe was contingent upon the emergence of intensive mixed farming, a form of agriculture 'insulated' to an extent from environmental variation by intensive labour inputs. Of course this 'insulation' does not explain *why* farming did spread, but the creation of 'artificial' growing conditions would enhance the feasibility of farming across a range of environments. Future work on Neolithic crop husbandry in the Near East and Europe could profitably explore the extent of continuity in early cultivation regimes, but further investigation is also required into the role of early agriculture in the historical trajectories created by households and communities on a site-specific and regional scale.

NOTES

4 ARCHAEOBOTANICAL, ECOLOGICAL AND STATISTICAL METHODOLOGY

1 Full details of the methodology summarized in this chapter are given in Bogaard (2002b).

2 Attributes relating to the timing and duration of flowering (see p. 83) are an exception, however, since flowering times do show considerable variation from one region to another. In fact, the Germany study and the archaeobotanical study area share a similar climate and so flowering times were taken from the same regional Flora (Rothmaler 1995). For the Evvia study, flowering data were taken from sources more appropriate to this climatic region (Strid and Tan 1997; Strid pers. comm. – see G. Jones *et al.* 2000a) and so, for example, the same species occurring in the Evvia study, on the one hand, and the archaeobotanical samples, on the other, could be represented by somewhat different flowering times.

3 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.

5 TESTING THE FOUR MAJOR CROP HUSBANDRY MODELS

1 A version of this work has recently been published (Bogaard 2002a) in application to a broader archaeobotanical dataset: all published weed-rich samples from the loess belt, plus the site of Vaihingen (Bogaard unpublished data).

2 The discriminant analysis based on semi-quantitative data differs slightly from that presented by Charles *et al.* (2002): the functional attribute data (for SLA, canopy height and diameter, leaf area per node:leaf thickness and stomatal distribution) here incorporate all available data for the Evvia species from across Europe in order to facilitate comparison with the archaeobotanical weed data, which are similarly represented by available data from across Europe (see Chapter 4).

6 IDENTIFICATION OF SEPARATE ECOLOGICAL GRADIENTS AND SPECIFIC CROP HUSBANDRY PRACTICES

1 One sample (pit 283 at Bruchenbrücken – see Table 4.3) was removed as an outlier.

2 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 (see Chapter 4) and so needs to be considered separately for each group.

Though the majority of weed taxa in the correspondence analyses of glume wheat samples are dicotyledonous, the seeds of monocotyledonous taxa (e.g. *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.

3 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 (see Chapter 4). Though the majority of weed taxa 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.

7 CONCLUSIONS

1 Many of the LBK samples suitable for inclusion in the ecological analyses (Table 4.3) are not dated to a particular LBK phase, but it should be noted that none have been definitely assigned to the earliest (*älteste*) LBK.

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