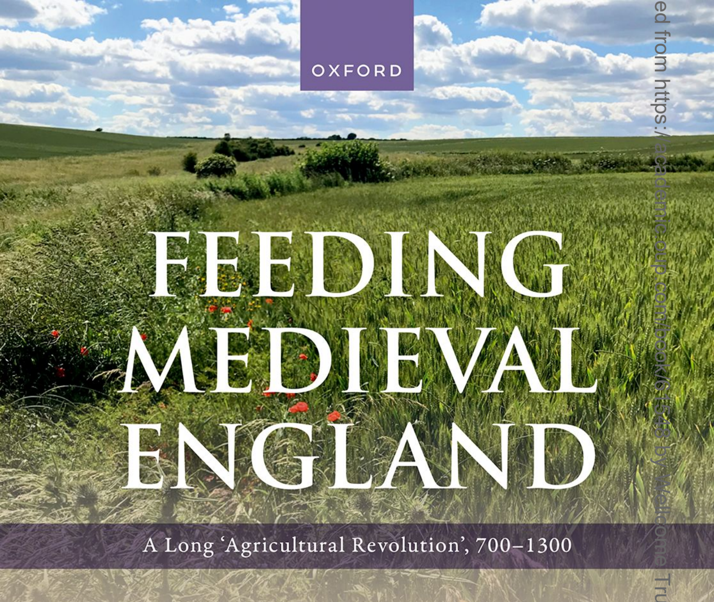

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FEEDING MEDIEVAL ENGLAND

A Long 'Agricultural Revolution', 700–1300

HELENA HAMEROW, MARK McKERRACHER,
AND THE FEEDSAX TEAM

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For Ros Faith and Debby Banham

PREFACE AND ACKNOWLEDGEMENTS

The debate surrounding what is often referred to as the medieval agricultural revolution has generated a voluminous literature, some of it dating back over a century. Yet despite considerable advances in our understanding of medieval farming, the debate has, in the absence of new evidence, largely stalled. Questions about the transformation of medieval farming and its impact on landscapes, communities, and economies remain important, however, not least at a time when farmers are striving to feed a growing population during a period of climatic warming and deteriorating soil health.

A five-year research project funded by the European Research Council under the Horizon 2020 scheme (Advanced Grant 741751; PI Hamerow) was established to generate new evidence that could be used to address these questions. The project, called 'Feeding Anglo-Saxon England: The Bioarchaeology of an Agricultural Revolution' (FeedSax), had its origins in research into the excavated remains of early medieval farmsteads around the North Sea Zone (Hamerow 2002, 2012). These could only be properly understood in the context of farmers' responses to changing pressures and opportunities, such as those presented by the first post-Roman markets and a growing demand for agricultural surpluses. The evidence from England suggested that the mid-seventh to mid-ninth centuries in particular saw marked changes in crop and animal husbandry regimes (Hamerow 2012, 144–62), an observation subsequently borne out by a more systematic investigation of the bioarchaeological evidence—especially archaeobotanical remains—undertaken by Mark McKerracher as part of his doctoral research (McKerracher 2014; 2016a). His findings confirmed the potential of such material to yield significant new evidence if subjected to science-based approaches. What began as 'FeedSax', with an emphasis on farming during the pre-Conquest period—inspired in part by the volume *Anglo-Saxon Farms and Farming*, to whose authors this volume is dedicated—grew into a project with a broader chronological range, as the potential for comparing evidence from pre- and post-Conquest contexts became apparent.

A project on this scale was only possible thanks to the long-term funding provided by the Horizon 2020 scheme. This enabled researchers with different specialisms and perspectives to work as a team over an extended period. We were determined to avoid working in silos, each producing a chapter on their own area of expertise. The decision to produce thematic chapters that draw on a range of sources and methods has, we hope, resulted in a volume that is more than the sum of its parts. This integrated approach also means that there are no 'lead' authors for individual chapters, most of which were written by several members of the team. This volume is complemented by a digital archive that can be freely accessed on the Archaeology Data Service (https://doi.org/10.5284/1057492; see below, p. xxiii for a guide to the archive). While this is designed to serve as supplementary material to this volume, the authors hope it will also be used by researchers as a resource in its own right, to support their work in the future.

A great many people have supported the project in various ways, and to them, we wish to express our thanks. Special mention and thanks go to Sam Neil, who worked as the project's archaeobotanical technician in 2018. In addition to those named below who generously provided access to data, we wish to thank the many colleagues who supported us with advice and feedback, and a willingness to answer questions on a huge range of topics. This includes Nicolas Schroeder and Alexis Wilkin who hosted a workshop in Brussels that enabled us to trial our approaches and ideas, and all the colleagues who attended project workshops in Oxford and Leicester. We were also fortunate to work in collaboration with Hannah Caroe and Tina Roushannafas as they completed their doctoral research at the University of Oxford, which made use of FeedSax material. Finally, we are grateful to John Blair and the anonymous reviewer for their comments on an early draft of this volume. Charlotte Loveridge, Rachel Atkins, and Cathryn Steele at OUP patiently supported us through the editorial and production process.

The generous assistance provided by the following individuals and organizations enabled us to assemble the large datasets that have been so central to the success of the project: the Laxton History Group, in particular Joy and Dik Allison, Mary and Robert Haigh, and Stuart Rose, who welcomed us to Laxton and facilitated our experimental work; David Wilson, former manager of Duchy Home Farm, Highgrove; John Hodgson, for his assistance with botanical surveys; and Claus Kropp, manager of the Lauresham Open-Air Laboratory at Lorsch. The following provided access to archives and data: Gabor Thomas (University of Reading); Lisa Moffett†, Gill Campbell, Anne de Vareilles, and Ruth Pelling (Historic England); Jacqui Mulville (Cardiff University); Ian Leins and Susan Harrison (English Heritage); David Ingham (Bedford Archaeology); Dale Serjeantson (zooarchaeological consultant); Sheila Hamilton-Dyer (zooarchaeological consultant); Craig Cessford (Cambridge Archaeological Unit); Andrew Mudd and Sarah Cobain (Cotswold Archaeology); Neil Faulkner†, Ellie Blakelock, and Gary Rossin (Sedgeford Historical and Archaeological Research Project); Graham Arnold, Alan Clapham, and Liz Pearson (Worcestershire Archaeology); Naomi Bergmans (Oxford Museum Service); Lisa Brown (Wiltshire Museum); Leigh Allen, Rob Brown, and Rebecca Nicolson (Oxford Archaeology); Wendy Carruthers (independent consultant); Rebecca Craven and Dawn Heywood (Lincolnshire Archives); Kath Hunter Dowse (archaeobotanical consultant); Rachel Fosberry and Elizabeth Popescu (Oxford Archaeology East); Denise Druce (Oxford Archaeology North); Emma West, Laura Bailey, Alex Smith, and Michael Wallace (Headland Archaeology); Susan Fox (Archaeological Collections, Roman Baths and Pump Room); Andy Chapman, Theodora Anastasiadou, and Lara Gonzalez-Carretero (Museum of London Archaeology); Mark Hinman, Tom Woolhouse, and Sian O'Neill (Pre-Construct Archaeology); Lorraine Mepham (Wessex Archaeology); Andrew Young (Avon Archaeology); Julie Rigden and Julie Kennard (Suffolk County Council Archaeological Service); Alison Nicholls and Joseph Perry (The Potteries Museum and Art Gallery, Stoke-on-Trent); Sara Wear (Heritage and Culture Warwickshire); Frank Green (New Forest National Park Authority); Peter Ditchfield (School of Archaeology, University of Oxford); Ben Donnelly-Symes and Justin Wiles (Cambridgeshire Archaeological Archives); Gill Woolrich (Southampton Museum); Thomas Cadbury (Royal Albert Memorial Museum); Ellen Simmons (Sheffield Environmental Archaeology Services); Brett Thorn (Buckinghamshire County Museum); and Will Partridge (Cornwall Council).

Pollen data were supplied by Michael Grant (University of Southampton/BPOL) and Petra Dark (University of Reading). Cores and samples for analysis, together with radiocarbon and OSL dates, were provided by Ben Pears and Tony Brown (University of Southampton), Amey PLC, and Headland Archaeology. Data were also extracted from the European Pollen Database (http://www.europeanpollendatabase.net/), and the work of the data contributors and the EPD community is gratefully acknowledged.

Finally, we are grateful to John Blair for sharing with us a list of some two hundred unpublished mid and late Saxon settlements recorded by the Archaeological Investigations Project (https://archaeologydataservice.ac.uk/archives/view/aip_he_2018/index.cfm) identified as part of his 'People & Places in the Anglo-Saxon Landscape' project.

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THE FEEDSAX DIGITAL ARCHIVE: A GUIDE

Mark McKerracher

SUMMARY

The FeedSax Digital Archive (https://doi.org/10.5284/1057492) comprises data, documents, images, and queries produced by the 'Feeding Anglo-Saxon England' (FeedSax) project between 2017 and 2022, at the Universities of Oxford and Leicester. These files can be accessed on the Archaeology Data Service and used to support future analyses and to serve as supplementary material to the present volume. The constituent files are divided into five sets, lettered A–E, as summarized below. In addition to this principal digital archive, the FeedSax Photographic Archive (https://doi.org/10.25446/oxford.20254137.v1) is hosted by the University of Oxford's Sustainable Digital Scholarship service. The photographic archive consists of 6,599 images and a metadata catalogue, which is equivalent to Digital Archive Document A23 in the present archive; the latter table provides DOI links to individual images. Each image is a microscope photograph of charred cereal grains selected for either destructive analysis by the FeedSax project (whether radiocarbon dating or stable isotope analysis) or geometric morphometric analysis by Tina Roushannafas as part of her doctoral research at the University of Oxford, in collaboration with FeedSax.

CITATION GUIDELINES

The FeedSax Digital Archive may be cited as follows:

Entire archive

McKerracher, M., Bogaard, A., Bronk Ramsey, C., Charles, M., Forster, E., Hamerow, H., Hodgson, J., Holmes, M., Neil, S., Roushannafas, T., Stroud, E. and Thomas, R. (2023). *Feeding Anglo-Saxon England: The FeedSax Digital Archive* [data-set]. York: Archaeology Data Service [distributor] https://doi.org/10.5284/1057492.

Individual documents

McKerracher, M. (2023). 'The FeedSax Digital Archive: A Description' (FeedSax Digital Archive Document A01) in McKerracher, M., Bogaard, A., Bronk Ramsey, C., Charles, M., Forster, E., Hamerow, H., Hodgson, J., Holmes, M., Neil, S., Roushannafas, T., Stroud, E. and Thomas, R. *Feeding Anglo-Saxon England: The*

FeedSax Digital Archive [data-set]. York: Archaeology Data Service [distributor] https://doi.org/10.5284/1057492.

SET A—'HAYSTACK'

Haystack is the SQL database that holds most of FeedSax's raw data, including secondary data compiled and transformed by the project, as well as primary data newly produced by FeedSax. Digital Archive Document A02 contains a long SQL script that will reconstruct the entire archived database in a MySQL/MariaDB environment. Supporting documentation is provided in the form of an Entity Relationship Diagram, setting out the structure of Haystack (Digital Archive Document A03), and a document outlining what the various tables and fields represent (Digital Archive Document A04). To improve the accessibility of the data for users without recourse to SQL, every table is also included here as a separate CSV file (Digital Archive Documents A05–A44). The documents in this set were produced by Mark McKerracher.

SET B—ARCHAEOBOTANY

Archaeobotanical data constitute a large proportion of Haystack: most are secondary data gleaned from both published reports and 'grey literature' or otherwise unpublished archive reports (see Digital Archive Documents A02–A04 to understand the structure and distribution of these data within Haystack). In addition to compiling such secondary data, FeedSax also produced new primary data from first-hand analysis of charred plant remains, represented in reports and data for assemblages from Coton Park (Digital Archive Documents B01–B02), Houghton (B03–B04), and Lyminge (B05–B06).

Certain standardized analyses, modelled on the methodology of McKerracher (2019), were applied to the complete national archaeobotanical dataset held within Haystack, both to produce a quantitative and descriptive characterization of medieval English archaeobotany and to prepare the datasets for more detailed statistical analyses as discussed in this volume. These standardized analyses and characterizations are presented in a national data report (Digital Archive Document B07), which is accompanied by a spreadsheet containing sample-by-sample attribute data, that is, calculated characteristics concerning the archaeobotanical composition of each sample (Digital Archive Document B08). Supporting metadata used in these and other archaeobotanical analyses are provided in Digital Archive Document B12.

Presence analyses were used to obtain a broad picture of the occurrence of different plant species across time and space: some example results are presented in Digital Archive Documents B42–B43, which should be interpreted with reference to the national report (B07). More complex multivariate statistical analyses were deployed by FeedSax to investigate crop husbandry practices through the lens of functional weed ecology. Data and graphs pertaining to these analyses are provided in Digital Archive Documents B10–B11 (for correspondence analyses) and B46–B49 (for discriminant analyses). In addition, a basic assessment of how many archaeobotanists produced the data compiled in Haystack is given in Digital Archive Document B45.

Where possible, the SQL queries that can be run against Haystack to replicate many of the standardized analyses used by FeedSax have also been included in the digital archive: see Documents B18–41 and B44 (to be interpreted with reference to the national report: B07).

Finally, FeedSax undertook botanical field surveys in two locations (Laxton, Notts, and Highgrove, Glos) to contribute to the analysis of soil disturbance (Bogaard *et al.* 2022). The original survey data are included here in Digital Archive Documents B14–B17, with corresponding taxonomic codes (based on *Flora Europaea* nomenclature) in B13.

The files in this set were produced by Mark McKerracher, except for the Laxton and Highgrove files (B13–B17), which are the work of John Hodgson, Amy Bogaard, Elizabeth Stroud, Alexander Weide, and Mark McKerracher, and B46–B49, which are the work of Amy Bogaard.

SET C—RADIOCARBON DATING

This set contains analytical reports from the FeedSax radiocarbon dating programme, with one report for each of the twenty-six sites for which the project dated charred grain or animal bone samples. Each report lists, calibrates, and interprets the radiocarbon dating results with reference to site-specific information; these results underpin the phasing used for these sites in Haystack (Digital Archive Documents A02 and A42). The radiocarbon table in Haystack also contains the results data, including dates obtained from cores, which do not have separate reports in this archive (Digital Archive Documents A02 and A38). Finally, Digital Archive Document C27 presents the FeedSax Universal Chronological Framework: a specially devised phasing structure for the fifth to fourteenth centuries, as outlined in Chapter 2 of this volume. These ‘FeedSax phases’ are referenced in Haystack’s Site Phase Table (Digital Archive Documents A02 and A42). Documents in this set were produced by Mark McKerracher.

SET D—STABLE ISOTOPE ANALYSIS

The principles, methods, and results of FeedSax's stable isotope analyses of charred cereal grains and animal bone collagen are set out at length in this volume and elsewhere (*e.g.* Stroud 2022). The 'raw' results—for both stable isotope analyses and, in some cases, FTIR analyses—are contained within Haystack (Digital Archive Documents A02, A20–A22, and A24–A27). Complementing these data, Digital Archive Document D01 presents a discrete study investigating variability in stable isotopic values from single grains of bread wheat, the results of which have informed FeedSax's wider methodology and interpretations. This document was produced by Elizabeth Stroud.

SET E—POLLEN ANALYSIS

The structure and schedule of the project meant that palynological data could not be incorporated into the Haystack database, but they are presented here—along with explanatory metadata and reference to further published details (*e.g.* Forster and Charles 2022)—in Digital Archive Document E01, accompanied by a map of sites in Document E02. These files were produced by Emily Forster.

REFERENCES

Bogaard, A., Hodgson, J., Kropp, C., McKerracher, M., and Stroud, E. (2022). 'Lessons from Laxton, Highgrove and Lorsch: building arable weed-based models for the investigation of early medieval agriculture in England', in M. McKerracher and H. Hamerow (eds) *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 25–39.

Forster, E. and Charles, M. (2022). 'Agricultural land use in Central, East and South-East England: Arable or pasture?', in M. McKerracher and H. Hamerow (eds) *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 61–86.

McKerracher, M. (2019). *Anglo-Saxon Crops and Weeds: A Case Study in Quantitative Archaeobotany*. Oxford: Archaeopress.

Stroud, E. (2022). 'Understanding early medieval crop and animal husbandry through isotopic analysis', in M. McKerracher and H. Hamerow (eds) *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 41–60.

ONE

An 'Agricultural Revolution' in the Making

> This he made to teach those who have lands and tenements and may not know how to keep all the points of husbandry, as the tillage of land and the keeping of cattle, from which great wealth may come . . .
>
> Walter of Henley, *Husbandry* (Lamond 1890)

INTRODUCTION

The link between cereal cultivation, wealth disparities, and the development of early states is widely seen as key to understanding the prehistoric origins of farming (Kohler *et al.* 2017; Scott 2017; Suzman 2017). Such a link also existed in medieval Europe, as the advent of new forms of cereal farming enabled landowners to amass wealth by expanding the amount of land under cultivation and, ultimately, exploiting the labour of others. By the time of the Norman Conquest, there were thousands of such landowners in England with their own estates, prospering from the rents extracted from those who worked the land (Fleming 2011). Cereals possess certain qualities that made them an easy target for medieval rent collectors: they are harvested at predictable times of year and are easily stored, transported, measured, and divided up. As Scott (2017, 129) has argued, this is why history is full of 'grain states' but not 'lentil states' or 'taro root' states. In many regions, medieval landowners could—at least until the subsistence crisis of the fourteenth century—enrich themselves more readily from land sown with cereals than anything else.

A unit of land sown with cereals also feeds many more mouths than the same unit used to graze livestock (Spedding *et al.* 1981, 355). The 'cerealization' of the countryside thus also sustained a period of steep demographic growth. The population of England at the time of the Domesday Book survey was likely to have been between *c.*1.7 and 2.5 million (Broadberry *et al.* 2010; Hinton 2013). This is only slightly less than the most recent estimates for the population of Roman Britain of between two and three million (Smith *et al.* 2016, 416; this is less than earlier estimates of up to four million, *e.g.* Millett 1990, table 8.5). It would have represented a substantial recovery from the post-Roman demographic collapse of the fifth to seventh centuries, which is widely assumed to have seen the population of Britain plummet, although by how much remains a matter for conjecture (Naismith 2025, 8).[1] By 1300, English farmers were feeding around five to six million mouths, and some regions were more densely populated than ever before.[2] Regardless of whether the minimalist or maximalist estimates of population size are accepted, this rate of growth is exceptional. It was mirrored in many other parts of Europe and was fuelled by an increase in agricultural outputs, which also supported the rapid expansion of towns and markets, especially post-1000.[3]

This increase in agricultural outputs was made possible in part by a fundamental reorganization of arable farming, which in some regions culminated in the spread of large, unenclosed 'open' fields with cultivation and grazing regimes that were, to varying degrees, communally managed. This reorganization changed not only the landscape but also the social geography and political economy of many parts of Europe. Cultivating such fields involved a degree of collective decision-making, for example, regarding a scheme of crop rotation such as planting winter wheat followed by spring barley. It could also involve the sharing or pooling of costly resources, namely the mouldboard plough and the team of oxen needed to pull it. In certain regions and environments, these shared arrangements, together with intermixed holdings, encouraged households to live in close proximity. The nucleated village was in part the by-product of this reconfiguration of farming practices (Astill 2009; Hooke 1998, 114–21; Hooke and Jones 2011; Renes 2010; Ten Harkel *et al.* 2017; Williamson 2013). Notwithstanding the observation that the nucleated village is an 'aberration' when viewed against the *longue durée* of human settlement in Europe—and the fact that many regions had few or no such villages—it has come to be seen as particularly expressive of medieval rural communities (Taylor 1983, 130–3).

The laying out of open fields in many parts of Europe along with associated developments in agrarian technologies has been described as a 'major upheaval', while the social, economic, and demographic consequences of this reorganization of farming were so profound as to be seen as 'nothing less than revolutionary' (Hall 2014, 212–13). They have been credited with sustaining the Carolingian state, driving population

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[1] Population estimates for these earlier centuries are notoriously variable. One recent calculation undertaken for the Netherlands—based on multiple archaeological proxies—estimates that the region saw an overall population decline of 70–80% during the fifth to ninth centuries (Grounewoudt and van Lanen 2018).

[2] Broadberry *et al.* (2010) opt for the somewhat lower figure, while the more 'orthodox' estimate of *c.* six million follows Postan (1966) and others.

[3] While many believe that changes in farming regimes and the arrangement of fields were largely driven by demographic growth (Blair 2018, 329–36; Lewis *et al.* 2001; Postan 1972; Thirsk 1964; though see Campbell 1981 for an alternative view), it is also acknowledged that population density did not in itself cause settlements to be reordered into nucleated villages and that some regions with dispersed settlements had population densities as great as those where nucleated villages came to dominate (Lewis *et al.* 2001, 192; *cf.* Rippon 2007, 106). It remains the case that 'it is often difficult or impossible to determine through historical research whether the demographic change was the cause or the effect of the changes in agricultural methods' (Boserup 1965, 17).

growth and shifting prosperity from southern to northern Europe (Duby 1954; White 1940, 152; 1962). Yet the transition from small-scale cultivation of individual, enclosed holdings using ards (also known as scratch ploughs) and spades on easily tilled but relatively poor soils, to the cultivation of extensive, unenclosed fields on heavier, more productive soils using the mouldboard plough remains poorly understood. Certainly, sophisticated ploughing technology as well as innovative management of arable were necessary to achieve substantially higher overall harvests.[4] The climatic changes associated with the 'Medieval Climate Anomaly' of *c.*1000–1300 must also have played a role in boosting harvests (Rohr *et al.* 2018; Xoplacki *et al.* 2011). As Bloch (1966, 35) noted many years ago, however, an agrarian regime 'is an intricate complex of techniques and social relations', and it remains far from clear what encouraged, or drove, farmers to innovate in this way. In particular, the degree to which such innovation was a response to 'top-down' pressures linked to growing seigneurial demands as opposed to 'bottom-up' peasant agency is far from clear, although both surely played a role.[5] While lords had 'the capital to invest and the resources to take risks'(Dyer 1997, 306), access to markets would have provided peasants with incentives to produce regular surpluses from an early date, as the large numbers and widespread circulation of silver coins in southern and eastern England during the eighth century suggest (Naylor 2016). Nor is there agreement over the causes of regional variability and the broad division between 'open' and 'hedged' landscapes still visible in Europe today (Rackham 1986, 5).[6] Regardless of the many uncertainties still surrounding the origins of open fields, their spread was unquestionably one of the transformative changes of the Middle Ages.

While the significance of this transformation is not in doubt, the timing and nature of the 'cerealization' of England—in particular the role played by open-field farming, and why it is found primarily in some regions and not others—have been hotly debated for over a century, ever since the publication of Seebohm's landmark work, *The English Village Community Examined in Its Relation to the Manorial and Tribal Systems and to the Common or Open Field System* (1883). This continuing controversy can largely be explained by the fact that researchers have had to rely almost entirely on indirect evidence, both written and archaeological, to infer when and how this unprecedented form of agriculture emerged. As Williamson (2018, 8) has observed, the debate has been 'fuelled to a large extent by an absence of hard evidence'. This volume presents the results of a research project whose central aim was to advance these debates by

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[4] Productivity per land unit (*i.e.* the ratio of output to input) as indicated by written sources was, however, low in this period; a yield of between three and five times the amount of seed sown appears to have been typical in the thirteenth century (Jordan 1996, 25).

[5] Hall (2014, 189; see also Harvey 1989) emphasizes evidence that 'points to lordly decision, agreed communally, that pasture should be converted to arable'. When it comes to the laying out of nucleated villages, however, Williamson (2013, 183) believes that 'the lordly planning of villages [is] largely mythical' and sees the apparently formal layout of open fields as resulting from a gradual expansion from an arable core.

[6] See Rippon (2008, 12–23) for a discussion of the possible causal factors underlying regional variation in the character of the British landscape.

generating new, direct evidence for medieval cultivation regimes.[7] This evidence derives primarily from the analysis of plant remains and animal bones recovered from excavated medieval settlements using a range of scientific techniques, some recently developed, for reconstructing ancient cultivation practices.

MEDIEVAL FARMING: RECENT DEBATES AND THE CURRENT IMPASSE

The complex and sometimes disputatious historiography surrounding the origins of open-field farming is the subject of several recent reviews and does not need to be rehearsed here (Hall 2014, 176–81; Rippon 2008; Williamson 2013, 8–19; 2018). To set the scene for the chapters that follow, however, it is helpful to consider current understandings of the origins and spread of open fields, together with recent challenges to long-held assumptions about the medieval 'agricultural revolution'.

The grand narrative regarding open fields was set out in the mid-twentieth century by historians who regarded the expansion of 'three-field' farming—the most highly regulated form of open-field farming—and the adoption of the mouldboard plough as technological improvements whose repercussions were comparable to those of the 'agricultural revolution' of the eighteenth century (Duby 1954; White 1940, 1962).[8] The mouldboard plough was seen as particularly important. Unlike the ard, which scratches a furrow into the surface of the field, the mouldboard plough inverts the soil, burying weeds and breaking up clods of earth, enabling farmers to cultivate larger areas and expand onto heavier, more fertile soils.

While such views have long been criticized as technological determinism (Hilton and Sawyer 1963), they remain influential. Three-field farming, for example, in which large swathes of arable could be given over to single cereal crops—effectively 'monocrops'—grown in systematic rotation, tends to be regarded as innovative and market-oriented. It is indicative of what Wickham (2005) has dubbed the 'feudal mode' of production, associated with the rise of lordship and a focus on surplus production. So-called subsistence farming based on mixed crops where two or more cereals were sown and harvested together in the same, small, continuously cultivated field, is in contrast generally associated with a more conservative, risk-averse 'peasant mode'

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[7] The project, 'Feeding Anglo-Saxon England. The Bioarchaeology of an "Agricultural Revolution"' (FeedSax, PI Hamerow), was supported by the European Union's Horizon 2020 Research and Innovation programme under grant agreement no. 741751.

[8] Duby (1954) saw these developments as reaching their peak in the tenth and eleventh centuries, while White (1940, 1962) dated the start of the 'revolution' to the eighth and ninth centuries.

of production, in which surpluses were rarely accumulated and wealth disparities were minimal (Wickham 2005, 535–47).

Debate persists over almost every aspect of the origins and spread of open fields in England: their date, their regional impact, and whether they were the cause or effect of demographic growth, urban development, and an increasing volume of trade. Despite this, certain key tenets of the traditional narrative remain broadly accepted. In particular, the link between regular open fields—particularly three-field farming—and the nucleated village is still widely regarded as fundamental. The latter is still often seen as effectively encased within its field system, 'into the nooks and corners of which it was . . . bound and fitted, and from which it was apparently inseparable' (Seebohm 1883, xiii).

This fundamental assumption has, however, recently been challenged. Oosthuizen (2010, 128) has drawn on archaeological evidence to argue that open fields and the nucleated village need not have had a shared origin. In particular, she notes that in some places, such as the Whittlewood area of the Midlands (Jones and Page 2006, 104; 236–42), open fields can be seen to predate nucleation. Furthermore, open-field systems could and did operate successfully in places where nucleated villages did not develop (Bloch 1966, 35; Taylor 1983, 131). The very existence of nucleation as a process whereby small, scattered settlements were abandoned as their inhabitants co-located to larger, planned villages, has been called into question by a recent study of the Midland landscape (Williamson *et al.* 2013). The authors of the study suggest that the evidence for such nucleation—mostly surface scatters of pottery—'may be illusory' and a result of the difficulty of dating such pottery combined with the shifting nature of settlements during the fifth to seventh centuries (ibid. 59). Blair (2018, 298) has recently argued that what he calls semi-nucleations—'clusters of farms that happen to be near each other for environmental reasons but are otherwise unconnected'—may have been associated with the intensive cultivation of infields, along with outfields consisting of 'very large commons and wastes'. Such outfields may over time have evolved into regular open fields, as the former—at first cropped only occasionally—came to be cultivated more regularly (Blair 2018, 294–301; 334–5).

A phased process by which the formal, planned villages of the post-Conquest period replaced looser, more irregular agglomerations of farms, now seems likely. Settlement archaeology broadly supports arguments for a relatively drawn-out process, at least in eastern and southern England, where growing numbers of mid Saxon settlements—dating approximately from the mid-seventh to mid-ninth centuries—associated with extensive complexes of enclosures and trackways, are being found (see Chapter 7). These represent a greater degree of planning and cooperation than is apparent in settlements of the fifth to mid-seventh centuries (Hamerow 2012). At the same time, we can now be confident that the 'classic' nucleated village of tofts and crofts, in which contiguous farmsteads front onto a densely built-up street or green, was a post-Conquest innovation (Creighton and Rippon 2017). While the striking geographical congruence of open fields and nucleated villages—most comprehensively set out by Roberts and Wrathmell (2002)—still requires explanation, the work of Williamson, Oosthuizen, and others demonstrates the need to date the origins of crop husbandry practices independently of the origins of the nucleated village (Oosthuizen 2013; Williamson *et al.* 2013).[9] The timing of the arable expansion suggested by this study and the implications for the founding of nucleated villages are considered in Chapter 7.

Three practices were key to the development of open-field farming as described in documents of the twelfth and thirteenth centuries. As Banham and Faith (2014) have pointed out, however, they need not have been introduced at the same time. These practices are (1) systematic crop rotation; (2) use of the mouldboard plough; and (3) low-input or 'extensive' cultivation, incorporating regular, short periods of fallow. Agricultural intensity can be defined in terms of the 'input', that is, manure and (human) labour, invested per land unit to boost productivity. Intensity thus 'represents a crucial axis for assessing the scale and productivity of past farming regimes, and their social and wider ecological implications' (Bogaard *et al.* 2016, 57). Although open-field farming is often referred to as representing an 'intensification' of cereal production, it was in fact less intensive per land unit than infield–outfield cultivation. As the area of arable expanded beyond the point where fertility could be maintained by manuring alone, regular, short fallow periods were introduced to 'rest' the soil while the droppings of livestock that grazed on the weeds and stubble in fallow fields helped restore fertility (Hall 2014, 189). Open-field farming can thus be characterized as a highly 'extensive', low-input cultivation system (see Chapter 3).

In the present study, this set of practices—systematic crop rotation, use of the mouldboard plough, and extensive, low-input cultivation—has been dubbed the 'mouldboard plough package' and used as a framing device. Together, these practices had a transformative impact on farming and rural society, but they need not have been inextricably linked. Crop rotation, for example, could have existed long before the mouldboard plough came into widespread use and could have been practised by individual or neighbouring farms before it was regulated communally. Adoption of the mouldboard plough did not necessarily involve a major reorganization of arable, and Banham and Faith (2014, 71–2) warn against assuming that, 'because the heavy plough existed in Anglo-Saxon England, there must have been . . . open fields'. We have tried to follow the advice of Joan Thirsk (1966, 11): '. . . it is tempting when the presence of one element of the common-field system is proved, to take the others for granted. This temptation must be resisted'.

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[9] As noted by Lewis *et al.* (2001, 193), the nucleated village was expressive of 'a particular idea of the shape that a village should take'. That this idea was not necessarily linked to a particular form of arable farming is illustrated by the fact that the 'street' village, with long, thin tenement plots fronting onto a street, was transplanted to the Middle East by the Crusaders in the twelfth century (Boas 2016, 62–8).

Exactly when the cultivation regimes associated with open-field farming first emerged and how quickly they spread remains unclear. Hall has argued that, at least in the Midlands, the spread of both open fields and nucleated villages began early, in the eighth or ninth century; proceeded rapidly; and was associated with the ploughing up of large tracts of ancient pasture. This model is based upon decades of archaeological fieldwork, mostly in Northamptonshire, combined with detailed study of early maps, the Domesday Book survey, late Saxon charters, and other documents (Hall 1982, 45–55; 2014, 175; *cf.* Audouy and Chapman 2009). Lewis *et al.* (2001, back cover) argue instead for the existence of a 'village moment' in Central England focused on the tenth and eleventh centuries, when the large-scale laying out of open fields and an accompanying reorganization of villages expressed a new economic system characterized by 'tofts, tithes, taxes and tenancies'.

In marked contrast to the idea of a pre-Conquest 'village moment', Banham and Faith (2014)—following historians such as Thirsk (1964)—argue that open fields played only a limited role in England prior to the Norman Conquest. They envisage a more gradual move away from infield–outfield systems operated individually by peasant farmers using traditional technologies. In such a system, small fields close to farmsteads ('inland') were intensively cultivated and manured using spades and ards, while the 'outland' was kept mostly under pasture. Instead of the direct replacement of such systems by open fields, they argue for a gradual trend towards more extensive methods of arable farming, which, in some regions, led eventually to the establishment of open fields. As part of this phased development, they emphasize the importance of 'convertible' husbandry, which involved the periodic cultivation of the outfield, the fertility of which was maintained not by manuring but by periods of fallow lasting several years. In some regions, convertible husbandry marked a step along the road to the 'dramatic reconfiguration of the landscape' represented by the laying out of open fields, while in others, for example in the South West, farmers successfully maintained such a system for centuries (Banham and Faith 2014, 284; Rippon 2007, 121).

Williamson (2003, 24; 2013) has stressed the primacy of soils and hydrology as determinants of field and village structures, stressing the need to understand 'the subtleties of the interaction between social and economic forms on the one hand, and aspects of soils, topography and climate on the other'. According to this view, common-field farming first developed in the eleventh and twelfth centuries on heavy clay soils that were prone to compaction if ploughed when too wet. This left only a brief 'window' for ploughing, with the result that peasant farmers—who shared the mouldboard ploughs and contributed plough beasts to the teams needed to pull them—had to coordinate their activities and therefore live in close proximity, encouraging the development of nucleated villages.

The persistence of such diverse and sometimes conflicting views is unsurprising given the difficulties involved in accurately tracing the spread of extensive cereal farming in time and space, as summarized by Banham and Faith (2014, 294–5):

> Often we have only very patchy evidence for what seems to be a new phenomenon and it is hard to tell whether that is because it was actually a rare phenomenon, or because there is a problem with the survival of evidence. Similarly, is what appears new really new, or is it just rising above the horizon of visibility for the first time? . . . In many cases, we can only say that what was the case at the beginning of our period had changed by the end.

Despite the lack of consensus, one thing is clear: the pattern of villages set amid expansive, unenclosed fields that eventually came to dominate around one third of the English landscape was entirely without precedent, a fact recently underscored by the 'English Landscapes and Identities' project, which traced the relationship between settlements and fields from the middle Bronze Age to the Norman Conquest (Gosden *et al.* 2021; Ten Harkel *et al.* 2017). These, and other recent contributions to the debate about open-field farming, highlight the continuing importance of understanding the dynamics of medieval farming and land use. Yet, after more than a century of research, reliance on traditional sources of evidence—Domesday Book, a handful of pre-Conquest charters and other documents, post-medieval maps, place names, and the pottery scatters left by manuring—has led to what can only be described as an impasse. Scientific methods developed to explore the prehistoric origins of farming offer a means of breaking this impasse by generating direct evidence for the conditions in which medieval crops were grown.

THE 'MOULDBOARD PLOUGH PACKAGE': NEW METHODS AND NEW EVIDENCE

In 2000, it was possible to write that 'evidence for the nature of agriculture in [late Saxon England] is slight' (Dark 2000, 157). Since then, the quantity and quality of the archaeological, bioarchaeological, and palaeoenvironmental evidence available for this period have increased dramatically, largely due to development-led excavation.[10] The present study is possible thanks not only to this expanding body of evidence but also to new analytical techniques originally used to investigate prehistoric cultivation regimes. It is now possible to apply scientific methods to a large dataset of medieval plant and animal remains and to consider the results alongside the remains of medieval farms themselves. Quantitative studies of medieval crop husbandry have made considerable progress in elucidating how proportions of wheat, barley, oats, etc. varied across different types of surface geology, revealing regional preferences and changing patterns of consumption (*e.g.* Rippon *et al.* 2014). Such quantitative approaches on their own, however, tell us relatively little about cultivation regimes and when or how these changed.

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[10] van der Veen *et al.* (2013) highlight the exceptional potential offered by the archaeobotanical remains from early medieval England in particular.

The large dataset of medieval plant and animal remains now available for England thus offers unprecedented opportunities for large-scale analysis, while experimental work to reconstruct farming practices offers new tools with which to interrogate it. These methods can elucidate the conditions in which crops were grown by analysing both cereal grains from archaeological contexts and the seeds of arable weeds harvested together with them, preserved through accidental charring, usually in the course of drying prior to storage. Archaeobotanical remains are analysed here using two different methods.[11] First, the principles of functional weed ecology are applied to a study of arable weed seeds from medieval contexts. Functional weed ecology recognizes that different weeds have different ecological preferences with regard to levels of fertility and disturbance; the kinds of weeds that grew alongside cereal crops therefore varied depending on the kind of plough used, the frequency of ploughing, the intensity of manuring and sowing times, that is, whether autumn and/or spring sowing were practised (see Chapter 2; Bogaard *et al.* 2001). This approach focuses not on specific weed species *per se*, but rather on functional traits such as leaf area, canopy height, and so on. Second, stable isotope analysis of charred cereal grains from medieval deposits was used to infer soil conditions and, from these, the presence or absence of systematic rotation (Chapters 2 and 4). Where crops were habitually grown in separate fields and thus in different soil conditions, differences would be apparent in the cereal grains at a molecular level (*i.e.* in nitrogen and carbon molecules).

Used together in this way, crop stable isotope analysis and functional weed ecology provide powerful tools for reconstructing the conditions in which medieval crops were grown (Chapters 3 and 4). More established approaches have also been deployed. A national database of archaeobotanical remains from (primarily) the seventh to thirteenth centuries, drawn from published and unpublished sources,[12] has been mined for quantitative and semi-quantitative (*i.e.* presence/absence) data to allow us to trace chronological and regional differences, for example in crop preferences. The general picture provided by the national database, available as part of an open-access digital archive (McKerracher *et al.* 2023; https://archaeologydataservice.ac.uk/archives/view/1003605/index.cfm), has been complemented by more in-depth examination of the plant remains from ten case study sites (see Chapter 2).

Due to its key role in increasing productivity, the introduction and spread of the mouldboard plough continue to dominate narratives of medieval farming (Henning

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[11] Bogaard *et al.* (2016) provides a worked example showing how plant stable isotope chemistry and functional weed ecology, used in the present study, can be used together to characterize a series of modern extensive and intensive traditional farming regimes.

[12] A dataset compiled as part of a pilot study was subsequently expanded and incorporated into the main project (McKerracher 2016b). The 'People and Places in the Anglo-Saxon Landscape' project identified a further 200 or so unpublished mid and late Saxon settlements recorded by the Archaeological Investigations Project (https://doi.org/10.5284/1050106), providing a wealth of new data. We are grateful to John Blair for making the results available to our project.

2009; Thomas *et al.* 2016). Because the plough had to be drawn by a team of oxen, its use has often been taken to imply the existence of open fields, as such teams were difficult to turn and therefore impractical in small, enclosed plots (Orwin and Orwin 1938; but see the caveat above by Banham and Faith 2014, 71–2). Understanding how and when the mouldboard plough came into widespread use also has important social implications, as peasant farmers needed to cooperate in order to acquire and operate this costly piece of equipment. While Domesday Book implies that the plough was practically ubiquitous in England by 1086, its widespread adoption may have begun significantly earlier. This process is difficult to trace archaeologically, however, because the remains of ploughs are seldom found in excavations, the iron presumably having been recycled in antiquity and the wood having decayed. To generate direct evidence for the spread of the mouldboard plough, cattle bones from excavated settlements were examined in order to trace the frequency and severity of pathological and sub-pathological changes associated with traction.[13] Cattle did not evolve to pull ploughs, and the strain resulting from doing so can manifest itself in adaptive and degenerative remodelling of the animals' skeletons (see Chapter 5). While few fragments of ploughs survive, cattle bones have been recovered in large numbers from a wide range of settlements, both rural and urban, providing a direct means of investigating the spread of this 'disruptive' technology. Smaller-scale work undertaken prior to the present study revealed that ninth- to eleventh-century settlements tend to produce more bones from older cattle and an increased number of castrates—more suited for heavy ploughing—than do earlier sites, hinting at an overall increase in the numbers of plough oxen in later Saxon England (Holmes 2014a, 67).[14] The work presented in Chapter 5, however, represents the first large-scale, systematic survey of the evidence for ploughing-related pathologies in medieval cattle, considered alongside livestock ratio and other data. Arable weed seeds were also analysed as a means of gauging levels of soil disturbance and hence the likelihood that a mouldboard plough had been used.

Pollen sequences provide the 'big picture' of land use by reflecting the wider floral ecosystem around individual settlements. Analysis of these sequences has enabled us to investigate the changing balance between arable, pasture, and woodland by region and over time (see Chapter 6). Despite the important role played by pollen analysis in our understanding of land use and farming in prehistoric Britain, it has until recently 'made little contribution to our understanding of the origins and development of the

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[13] A system for identifying cattle used for traction (Bartosiewicz *et al.* 1997) has recently been applied to sites from the Iron Age to Early Modern period, and refined through the analysis of pathology in semi-feral cattle (Thomas *et al.* 2021). The method has been shown to provide significant new information (*e.g.* Thomas 2008), but this is the first time that it has been applied systematically to medieval assemblages.

[14] The established method for identifying traction animals compares age-at-death and sex data with theoretical models of optimized production; an abundance of adult male cattle is typically interpreted as evidence of a cattle-rearing regime geared towards traction. Historical and ethnographic sources demonstrate, however, that such models are not universally applicable (*e.g.* Groot 2005).

medieval landscape’ (Rippon *et al.* 2006, 31). Research has been impeded by the fact that well-preserved pollen sequences—found mostly in boggy deposits—are notoriously difficult to obtain in the relatively dry lowland landscapes where the majority of excavated medieval settlements have been found. It has nevertheless been possible, by collating existing data as well as obtaining new samples, to conduct a large-scale analysis of the pollen record from across England in order to produce a national model of medieval land use. This analysis complements the archaeobotanical study of preserved cereal grains and weed seeds to reveal trends in land use, and the changing impact of cereal farming on different regions. It also complements the zooarchaeological evidence for the changing ratio of sheep to cattle by providing independent evidence for changes in the amount of land under cultivation.

Analysis of preserved grains and weed seeds has focused mainly on the seventh to thirteenth centuries due to the paucity of eligible archaeobotanical samples for the fifth and sixth centuries. The pollen evidence, however, makes it possible to situate this period within a much longer time frame, allowing us, for example, to examine the Roman to post-Roman transition. The relative proportions of pollen derived from woodland as opposed to arable or pasture in the late Roman and early medieval landscape have recently been considered in a major study (Rippon *et al.* 2015); the focus here, however, is primarily on anthropogenic indicators—plants other than cereals that thrive in farmed landscapes, that is, weeds—to establish the extent to which open landscapes were used for grazing or disturbed by the plough.

As set out in the following chapters, these approaches have been adapted and combined to allow for the integration of quantitative studies of preserved cereal grains, arable weeds, and pollen with stable isotope analysis of crop remains and zooarchaeological evidence, in recognition of the dynamic balance between cereal and livestock husbandry. This synthetic, interdisciplinary approach allows us to compare the results yielded by these differing sources and analytical methods and identify correspondences between changes in weed flora; isotopic signatures in grains, animal bone, and pollen data; and the archaeological remains of farms themselves. The organic nature of our primary source material has made it possible, furthermore, to trace change over time with greater chronological precision than previously possible, by using radiocarbon dating. The calibration of 189 radiocarbon dates as part of the FeedSax project forms the basis of the first absolute chronology for medieval settlement and land use in England (see Chapter 2).

REGIONAL AND CHRONOLOGICAL FRAMEWORKS

Medieval farming practices displayed marked regional differences, and even in the largely flat and fertile Midlands open-field farming did not develop everywhere (Hall 2014, 195). In recognition of this regional variability, evidence from across the whole of England was gathered from as many subregions as possible. In particular, we sought samples from each of three ecologically distinct zones that broadly correspond to the three main 'provinces' mapped by Roberts and Wrathmell (2002) in their seminal study of settlement form: the Central Zone, on whose heavy, rich soils one might expect to find the earliest evidence for open fields; the lighter, less fertile soils of the Southeastern Zone, where open fields were less common; and the wetter and hillier regions of the Northern and Western Zone, where infield–outfield agriculture and convertible husbandry are thought to have predominated until the Conquest and beyond. Identifying early medieval settlements in the Northern and Western Zone is difficult, however, and it was not possible to obtain as many archaeobotanical and zooarchaeological samples from this region as originally hoped. Excavated settlements from this region, furthermore, tend not to produce sufficiently abundant charred plant remains for the kind of scientific analyses described above (with a few notable exceptions such as Stafford, in the West Midlands). The explanation for this uneven distribution is unclear, but it may be that large, dense assemblages of charred cereals were more likely to form where large cereal surpluses were being produced, processed, and stored, and would be less likely to be found in regions with less emphasis on surplus production (see Chapters 2 and 7). This may explain why it was a relatively easy matter to identify suitable assemblages of charred grain from the Central Zone, but much harder to find such assemblages from the Northern and Western Zone. These three zones are, of course, very large and likely to have encompassed a variety of practices. For this reason, we adopted the smaller regional divisions used by Rippon *et al.* (2015), as detailed in Chapter 2.

The main time frame of the project, *c.*700–1300, is intended both to encompass the period traditionally associated with the medieval 'agricultural revolution', that is, the tenth to thirteenth centuries, and to provide a 'before and after' picture. Although this excludes the post-Roman centuries, the rich archaeobotanical assemblages needed for this kind of analysis are largely lacking for that early period. The pollen record, however (and to some extent the animal bone evidence), allows for a longer chronological span to be considered, incorporating the Roman as well as the post-Roman centuries (see Chapter 6).

SOME WORKING HYPOTHESES

In light of the varying and sometimes conflicting models that have been proposed for the development of medieval farming and land use, we made few assumptions about what we would find, beyond a general expectation that cultivation would become more extensive over time, above all in the Central Zone, the heartland of open-field farming (Banham and Faith 2014, 269). Several potential models did, however, present themselves. The first was that a significant increase in the markers of the 'mouldboard plough package'—systematic crop rotation, use of the mouldboard plough, and extensive, low-input regimes—would be associated with one particular period and be most pronounced in the Central Zone. Such an outcome would tend to support the hypothesis of a 'village moment', when changing socio-economic conditions developed in tandem with a new agronomic system.

Alternatively, markers for all three elements of 'the package' might increase gradually over time, suggesting a steady expansion: evolution rather than revolution. It has been suggested that convertible husbandry and similar systems were more widely practised than usually assumed, but that traces of such systems were obliterated by the laying out of open fields. Such a development is envisaged by Banham and Faith (2014, 284), who argue that there was a 'general direction of travel' for farmers throughout England during the mid and late Saxon periods: 'For some, the road ended in open-field farming, for others strip fields did the job and were preserved'. A pilot study to assess the quantity and distribution of archaeobotanical material from medieval England hinted at such a gradual process. The results reveal that samples that are unusually rich in charred plant remains—that is, containing 300 or more charred items—first appear in the seventh century and increase in frequency until the twelfth and thirteenth centuries (McKerracher 2016b, fig. 3).[15] While several explanations for this pattern are of course possible, one plausible interpretation is that the appearance of 'grain-rich' samples implies a change in behaviour from relatively piecemeal practices to more sustained, large-scale, and/or centralized processing and storage. In short, they may serve as a crude proxy for surplus cereal production on the grounds that 'increasing the volume and/or frequency of crop processing activities will increase the accidental charring of substantial batches of plant material' (McKerracher 2016b, 64). This hypothesis is strengthened by the observation that most of the grain-rich samples in the pilot study came from the Midlands, despite the fact that East Anglia produced the largest number of samples overall. These findings are broadly supported by an updated and more rigorous study of average density presented in this volume (see Chapter 7 and Appendix 2).

A third possibility is that crop rotation, use of the mouldboard plough, and 'extensification' each followed a distinct trajectory. Systematic crop rotation might, for example, have been practised long before the mouldboard plough was widely adopted, or vice versa. As already observed, these practices could, and in some contexts demonstrably did, exist independently.

ARCHAEOLOGY AND BIOARCHAEOLOGY

An important aspect of our approach has been to compare bioarchaeological evidence with the remains of excavated settlements. Significant changes in crop and animal

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[15] The pilot study considered 3,759 samples from 274 sites and identified 538 'grain-rich' samples (*cf.* Chapter 7). While the frequency of grain-rich samples clearly increased over time, this was not the case for samples overall; fewer samples were recorded for the eleventh to twelfth centuries than for the ninth to eleventh centuries (McKerracher 2016b, fig. 1).

husbandry practices would likely be reflected in the composition and layout of farms themselves and, potentially, in a changing settlement hierarchy. The settlement record, like the bioarchaeological one, is regionally variable, however, and comparing the two is not straightforward. Excavated settlements dating to the pre-Conquest period, for example, are heavily concentrated in central and eastern England. Examples from western England are few in number, and settlements in these regions are more difficult to recognize archaeologically, although progress in identifying such sites is being made (Blair 2018, maps 6–7; Hamerow 2012, fig. 1.1). Another potential bias is introduced by the fact that many of the settlements suitable for detailed study may reasonably be regarded as being of high status; surprisingly few sites can confidently be described as representing 'ordinary' communities (Hamerow 2012). When it comes to the evidence for medieval settlements, the material record, like the written sources, 'privileges the aristocratic or clerical gaze' (Wickham 2005, 544). The exponential increase in the number of medieval settlements excavated in the past thirty years combined with new strands of bioarchaeological evidence nevertheless allows the interrelationship of arable production, stock management, and settlement form to be explored in new ways.

STRUCTURE OF THE VOLUME

The key elements of our dataset are set out in Chapter 2, along with the methods used to analyse animal bones, plant remains, and pollen. The presentation of a uniform phasing scheme constructed for the project, based on a suite of new radiocarbon dates, is followed by discussions of the following: archaeobotanical analysis used to trace changes in soil fertility, ploughing regimes, and seasonal sowing; crop stable isotope analysis used to investigate crop rotation; zooarchaeological analysis used to trace the spread of the mouldboard plough; and pollen analysis used to reconstruct the type, scale, and intensity of land use. A number of papers published elsewhere and referenced in this volume present some of the methods used in an expanded form.

The volume is then structured thematically, according to the three elements of the 'mouldboard plough package'. Chapter 3 considers the 'extensification' of medieval cereal farming, first by analysing weed flora. This has allowed us to distinguish crops grown in low-input, 'extensive' conditions from those grown in more intensive conditions. These results are complemented by stable isotope analysis of cereal grains from ten case study sites to investigate the extent to which fertility was boosted by manuring. The archaeobotanical database is interrogated to establish what potential 'indicator species' and changes in the overall diversity of weed flora reveal about the chronological and regional development of arable expansion. Finally, changes in the ratio of sheep to cattle in animal bone assemblages are examined as a proxy for the expansion of arable farming.

Chapter 4 considers the evidence for systematic crop rotation, whereby farmers followed an agreed sequence of sowing and fallow. Not only did a regular short fallow period—normally one year out of every two or three—enable a higher proportion of arable land to be cultivated, but staggered sowing times (in autumn and spring) allowed the workload to be spread more evenly across the year and reduced the risk of crop failure. An analysis of arable weeds is used to look for evidence of seasonal sowing, while the stable isotope signatures of grains from the ten case study sites enable changes in the use of systematic rotation over time to be traced.

Over 80,000 plough teams are recorded in Domesday Book (Darby 1977, 336) reflecting the widespread adoption of the mouldboard plough. Chapter 5 explores the evidence for the spread of the plough, with a focus on establishing when and how it changed from being a high-status implement used at royal and monastic sites to an essential tool for farmers wishing to implement an extensive cultivation regime. A study of cattle bones—specifically, the proportions of older animals and males, and the occurrence of lower limb pathologies related to traction—is combined with an ecological study of arable weeds to gauge soil disturbance (which reflects the type and frequency of tillage) to reveal how the emphasis on traction increased over time.

Chapter 6 presents national and regional models of land use from the late Roman period to the later Middle Ages, based on pollen data collated from over fifty cores and supplemented by new analyses. Existing pollen studies have shown that much of England was already cleared of woodland by the late Roman period and that the post-Roman centuries saw relatively little woodland regeneration (Rippon *et al.* 2015). A new method deployed here allows for a more focused investigation within these open landscapes, to reveal the regionally specific expansion and contraction of arable relative to pasture and heath. This approach is used to trace regional changes in land use over time, with consideration of the types of land cover, emphasis of land use (*i.e.* arable, pasture, or mixed), and diversity of key crops and weeds. Crucially, this approach enables regional chronologies to be established, including for the north and west, where excavated settlements and archaeobotanical and faunal remains are relatively scarce. These regional chronologies reveal a marked and deep-rooted contrast between the North and West of England, and the South and East (*cf.* Gosden et al. 2021).

The different strands of evidence generated by the analyses presented in earlier chapters are brought together in Chapter 7 where they are considered in relation to the archaeological evidence for farmsteads and villages. The implications of this new evidence for our understanding of the medieval 'agricultural revolution' are then explored.

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TWO

Materials and Methods

INTRODUCTION

The quantity of archaeobotanical and zooarchaeological remains from medieval settlements in England has burgeoned over the past thirty years thanks to the expansion of development-led archaeology. This large dataset has enabled a range of analytical techniques to be deployed in conjunction and on a scale not previously possible, allowing developments in farming to be investigated at a national, regional, and local scale. Integrating such a wide range of approaches is itself novel, as is applying crop stable isotope analysis and functional weed ecology—previously used to investigate the prehistoric origins of farming (Bogaard *et al.* 2016)—to the medieval period. The overall aim of the methods used in this study is to compare the results of quantitative studies of preserved cereal grains, arable weeds, pollen, and animal bones with each other as well as with stable isotope analysis of crops (and, to a limited extent, fauna) to trace changes in farming practices and cultivation conditions regionally and over time. The integrated approach to land use, cereal cultivation, and livestock husbandry taken here is possible thanks to a national database of archaeobotanical, zooarchaeological, and pollen data from over seven hundred excavations, developed as part of this project. This database, called 'Haystack', provides the basis of the regional and national analyses undertaken by the project and has been deposited with the Archaeology Data Service (ADS) (McKerracher *et al.* 2023). In addition, ten case study sites were selected for more detailed investigation.

CASE STUDY SITES

Sites were selected for detailed analysis if they produced a sufficient quantity and range of bioarchaeological material to allow different strands of evidence to be compared—animal bones, plant remains (cereal taxa and arable weed flora), and pollen sequences—ideally across several centuries. It will be clear from Figure 2.1 that sites with archaeobotanical and zooarchaeological data are not evenly distributed across England. This geographical bias applies to the distribution of pre-Conquest settlements generally and is unlikely to be

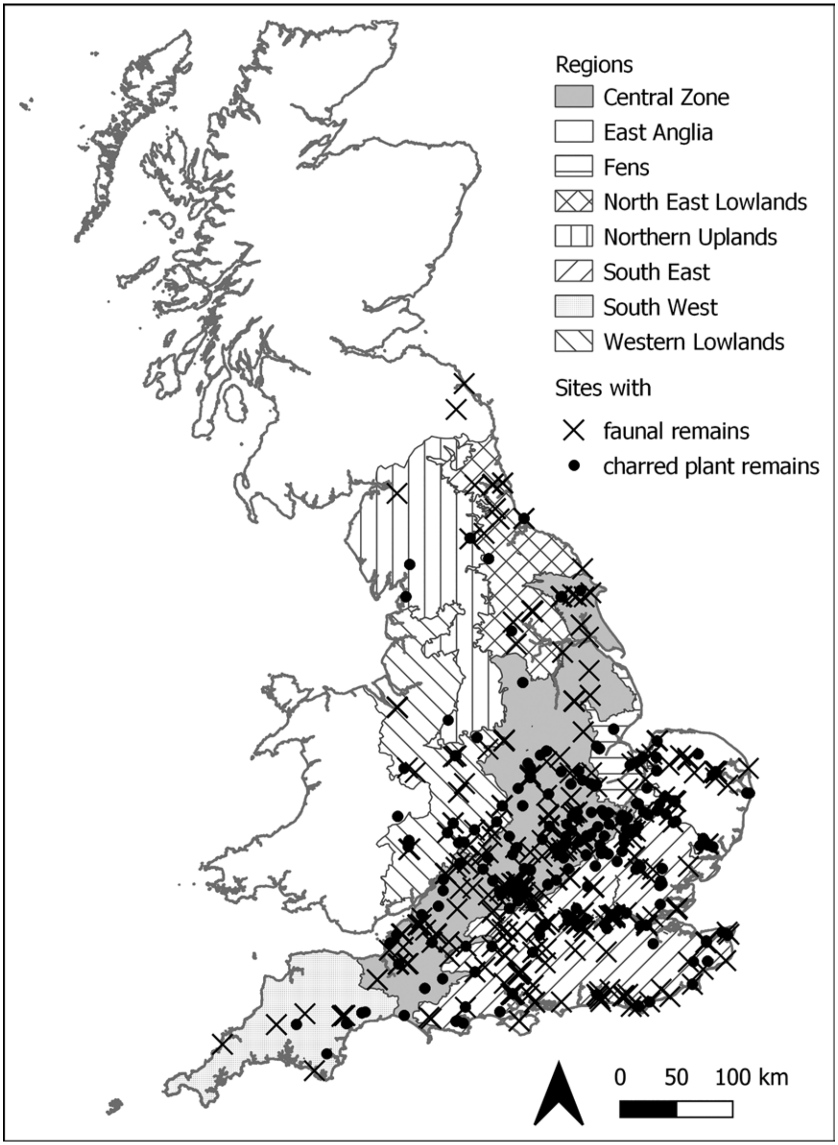

FIGURE 2.1. Distribution of sites with faunal and botanical remains in the FeedSax database. Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

primarily the result of modern affordances such as development, as discussed below (see also Blair 2018, 27 and fig. 4). The concentration of these settlements—and consequently of bioarchaeological remains—in central and eastern England appears instead to be largely the result of different 'building cultures', one of which is relatively easy to recognize, date, and recover archaeologically, while the other is virtually invisible (Blair 2018, 27 and fig. 4; Hamerow 2012, 90).

A further constraint on the approach taken here is the fact that soil conditions conducive to the preservation of one form of bioarchaeological material are often inimical to another, making it difficult to find sites where all materials are equally well preserved. The best pollen sequences, for example, are found primarily in the western uplands where the relatively acidic geology is not conducive to the preservation of bone; such sequences are largely conspicuous by their absence, however, in the main

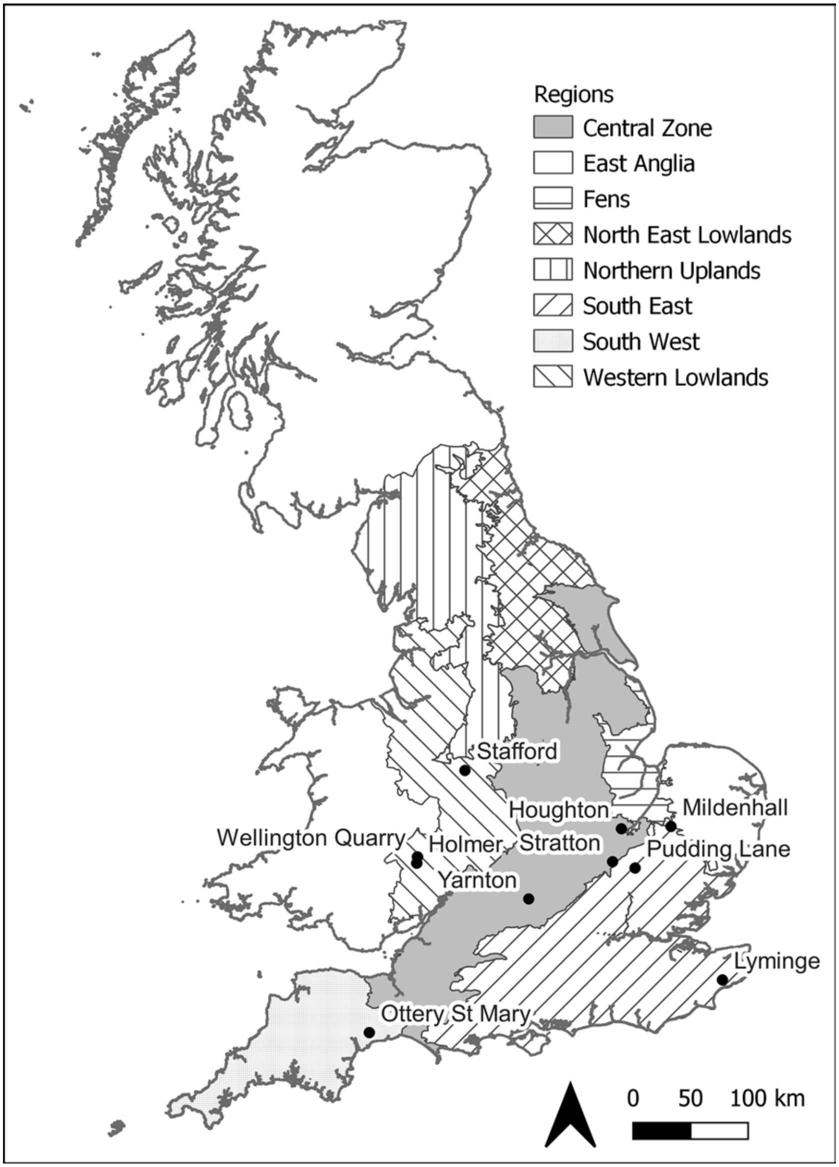

FIGURE 2.2. Distribution of case study sites. Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

Table 2.1. Case study sites and analyses carried out at each one.

Site—*region*	**Weed ecology**	**Stable isotopes**		**Animal palaeopathology**	**Radiocarbon dating**	**Pollen**
		Crops	**Animals**			
Yarnton—*Central Zone*	x	x			x	x
Stafford—*Western Lowlands*	x	x		x	x	x
Stratton—*Central Zone*	x	x	x	x	x	
Lyminge—*South East*	x	x	x	x	x	
Pudding Lane—*South East*	x	x			x	
Ottery St Mary—*South West*	x	x			x	
Houghton—*Central Zone*	x	x			x	
Mildenhall—*East Anglia*	x	x			x	
Holmer—*Western Lowlands*	x	x			x	
Wellington Quarry—*Western Lowlands*	x	x			x	

cereal-producing zones of central and eastern England. The large assemblages of animal bones needed to provide statistically robust results, furthermore, are more likely to be found at urban sites, whereas substantial deposits of charred cereals tend to be recovered from rural contexts. As a result, some regions contain no or only one case study site, a problem that particularly affects the South West, East Anglia, Fens, and the Northern regions.[1] Despite the constraints of differential preservation, ten case study sites were identified for detailed analysis (Figure 2.2; Table 2.1).

CHRONOLOGY: THE FEEDSAX PHASING

Our project required a secure chronological framework within which to determine the pace and timing of agricultural developments throughout the medieval period. The dating of excavated early medieval and medieval settlements has traditionally relied upon ceramic chronologies, but these are problematic for a number of reasons. First, ceramic-based dating of bioarchaeological material is obliged to assume that potsherds are genuinely stratigraphically associated with the floral or faunal remains in question, rather than being intrusive or residual. Second, ceramic chronologies generally lack precision and are seldom uniformly applicable across England. For the pre-Conquest period, some early coarse wares can be dated no more closely than 'early/mid Saxon' (*c*.450–850), while the more closely dated Ipswich Ware (*c*.725–850) has a regionally biased distribution (Blinkhorn 2012). Even where present, Ipswich Ware could indicate a date anywhere within

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[1] FeedSax uses the regional divisions developed by Rippon *et al.* (2015) for the 'Fields of Britannia' project, with data from less well-represented regions combined in some analyses (as detailed in text).

125 years, and many later medieval wares present a similar lack of both chronological precision and geographical uniformity (Spoerry 2016).

There is currently no systematic, national protocol for reviewing and updating early medieval and medieval ceramic chronologies in the light of new data, meaning that they tend to retain and reinforce conventional definitions, such as 'mid Saxon' (650–850), 'Saxo-Norman' (variously between the tenth and twelfth centuries), or 'high medieval' (variously between the eleventh and fourteenth centuries). Such conventional periodization—commonly deployed in excavation reports—is often loosely and implicitly structured around historical 'milestones' perceived as pivotal, at convenient two hundred-year intervals: the presumed arrival of Germanic speakers from mainland Europe (mid-fifth century), the first flourishing of monastic Christian culture (mid-seventh century), the first overwintering of Vikings in England (850), the Norman Conquest (1066), the Anarchy (mid-twelfth century), and the peak years of the Black Death (mid-fourteenth century). Dividing up archaeological sequences in this way inevitably risks making such milestone 'periods' appear more archaeologically meaningful than they really are, and can lead to circular arguments.

With pollen sequences too, where ceramic dating is not applicable, conventional periodization has often been used in earlier studies to correlate changes in vegetation with the historical milestones that they 'ought' to represent, such as an increase in tree cover with the departure of the Roman legions. Before the advent of scientific dating, and more specifically before age–depth models could benefit from Optically Stimulated Luminescence (OSL) and radiocarbon dates taken at multiple levels, a correlation-based approach was the only option for phasing pollen sequences (pioneered in particular by Oldfield 1963). While this is no longer common practice, it does mean that older data tend to have less secure chronologies (for a discussion of more modern approaches, see below: 'Pollen and land use').

Scientific methods have made an increasing—and increasingly precise—contribution to the dating of medieval evidence, especially since the advent of Accelerator Mass Spectrometry (AMS) radiocarbon dating through the 1980s and 1990s. Radiocarbon dating is invaluable for bioarchaeological and palaeoenvironmental studies such as this, as it enables the direct dating of organic remains. It is, however, an expensive and time-consuming procedure and therefore applicable only to a relatively small subsample of animal bones, plant remains, or peat strata from a given site. In addition, while improvements in AMS technology and enhancements to the calibration curves allow for ever greater precision and accuracy in radiocarbon dating, the date ranges obtained in earlier studies are often very broad, sometimes spanning more than two centuries (*e.g.* Young 2020, 237–8).

We mitigate the strictures of conventional periodization and the relative scarcity of high-precision radiocarbon dates through an extensive radiocarbon dating programme and the associated development of a new phasing framework.

The radiocarbon dating programme entailed the submission of bioarchaeological samples from selected sites to the Oxford Radiocarbon Accelerator Unit, as follows:

- 167 charred grain samples from twenty-five sites
- eight animal bone samples from two sites
- twenty peat, wood or sediment samples from six pollen cores

Radiocarbon determinations were returned with a high degree of precision (with standard uncertainties ranging from seventeen to twenty-nine years). The results were calibrated using the IntCal20 radiocarbon calibration curve and OxCal 4.4.2 (Bronk Ramsey 2009; Reimer *et al.* 2020) and recorded in the project database. Where appropriate stratigraphic information was available, the new radiocarbon results were combined with existing dating evidence (such as coins, radiocarbon dates, or dendrochronology) and subjected to chronometric modelling in OxCal 4.4.2 (Bronk Ramsey 2009). Reports on these analyses are available in the FeedSax digital archive (McKerracher *et al.* 2023).

While the number of new radiocarbon determinations thus obtained is very large, they are inevitably far too few to provide precise and reliable dates across the extensive national datasets of charred plant remains, animal bones, and pollen sequences. These datasets incorporate a range of different chronologies: some correspond to the conventional periods described above, while others are based upon site-specific evidence. A new uniform dating framework was therefore devised to accommodate and align, as far as possible, both the new radiocarbon dates and the phases that occur in existing excavation reports (Table 2.2).

The broad phases, labelled with letters A to H, approximate to the conventional or centurial divisions used in many excavation reports. Since our project is not directly concerned with changes that occurred before the fifth century or after the fourteenth, the scheme includes two ‘bookend’ phases: phase A0 applies to anything that predates *c.*420, and phase H refers to any time after 1400.

The boundary years associated with these phases should be considered flexible: they are ‘best fits’, not strict measurements. For instance, FeedSax phases A1–B2 (*c.*420–670) correspond roughly to what is conventionally referred to as the early Saxon period (*c.*450–650), phase C (*c.*670–880) corresponds to the mid Saxon period (650–850), and phases D1–E1 (*c.*880–1060) correspond to the late Saxon period (850–1066). In the absence of any further information, mid Saxon phases in excavation reports have therefore been aligned with phase C, but this adjustment does not mean that ‘mid Saxon’ material is being redated to a later time. Rather, it assigns such material a new calendrical definition, which could be empirically verified (and possibly refined) by radiocarbon dating. Similarly, FeedSax phase F (1220–1300) roughly corresponds with the thirteenth century, but in a fashion that better lends itself to alignment with the IntCal20 curve, which admits greater precision around 1220 than around 1200 (Figure 2.3).

Table 2.2. The FeedSax dating scheme.

Phase	Subphase	Approx. years AD
A0		Pre–420
A	A1	420–530
	A2	530–600
B	B1	600–630
	B2	630–670
C	C1	670–720
	C2	720–770
	C3	770–820
	C4	820–880
D	D1	880–920
	D2	920–950
	D3	950–980
	D4	980–1030
E	E1	1030–1060
	E2	1060–1080
	E3	1080–1120
	E4	1120–1160
	E5	1160–1220
F	F1	1220–1270
	F2	1270–1300
G	G1	1300–1360
	G2	1360–1400
H		1400+

The numbered subphases in the framework describe the maximum calibrated precision—give or take a few years—likely to be obtained from radiocarbon determinations with standard uncertainties of seventeen or more years, given the wiggles and plateaux revealed in the IntCal20 curve. For example, a radiocarbon determination (on charred grains from Stratton) of 1224 BP ± 18 years calibrates to cal. AD 772–881 (with 86.2% probability; Figure 2.4), corresponding to FeedSax phases C3–C4 (770–880). It is highly unlikely that any sample could ever be dated more closely than one of the FeedSax subphases; even a hypothetical determination of 1200 BP with extremely low standard uncertainty could not be calibrated to any date range tighter than cal. AD 820–880 (FeedSax C4; Figure 2.5).

The application of any kind of framework risks imposing an artificial chronological ‘shape’ onto archaeological and palaeoenvironmental sequences, but some kind of broad and uniform phasing system is necessary when dealing with large, diverse datasets, or else diachronic comparisons cannot easily be made. Our framework has been used in preference to those based solely upon conventional ceramic dates or historical

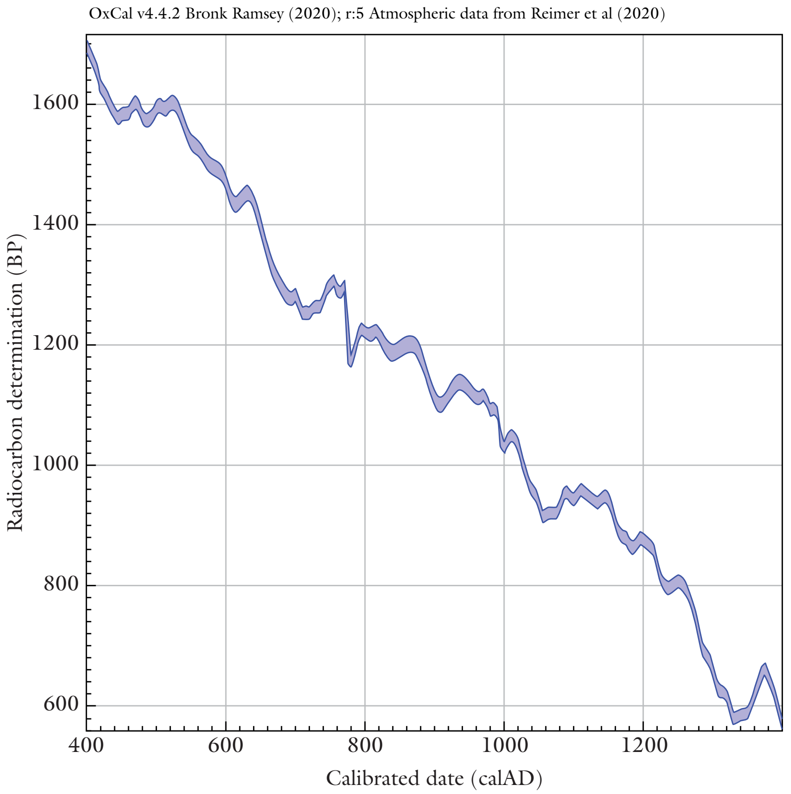

FIGURE 2.3. IntCal20 calibration curve for AD 400–1400 (Reimer *et al.* 2020).

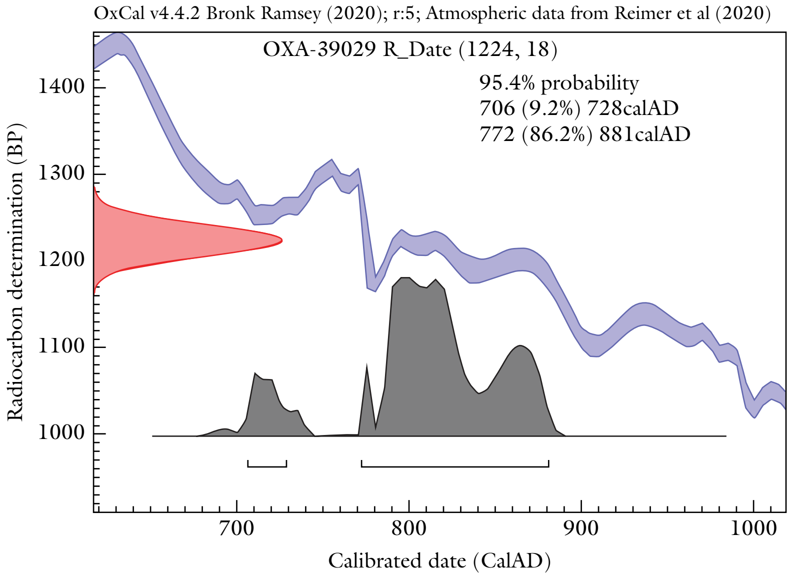

FIGURE 2.4. Example calibration of a radiocarbon date from the FeedSax project, using the IntCal20 calibration curve.

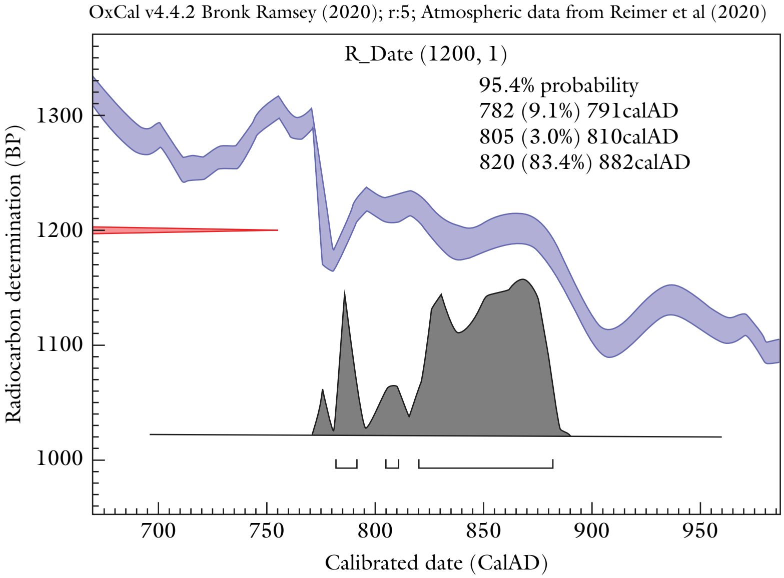

FIGURE 2.5. Calibration of a hypothetical ninth-century radiocarbon date using the IntCal20 calibration curve, demonstrating the maximum likely precision for such a sample.

'milestones', because it has an independent empirical basis (the IntCal20 radiocarbon calibration curve) and is equally applicable to zooarchaeological, archaeobotanical, and palynological data. While the application of the framework to the wider national datasets requires that we accept certain assumptions made in earlier excavation reports, it realigns these assumptions in such a way that they could, theoretically, be verified, falsified, or refined by future radiocarbon dating projects. Similarly, the zooarchaeological data derive from large, multi-feature assemblages phased by the excavators. These lack the more precise dates provided by single-context material used for the archaeobotanical analysis, and it was therefore not possible to analyse the faunal material according to the FeedSax phases, although results have subsequently been related to FeedSax phases where possible. Instead, aoristic analysis has been used to trace broad changes over time. This approach allows the probability of certain variables (*e.g.* species representation or sex data) to be identified from any fifty-year period based on the available data for that period (see Holmes *et al.* forthcoming for a full explanation of aoristic analysis as applied to zooarchaeological analysis).

ARCHAEOBOTANICAL ANALYSIS

Introduction

The charred remains of cereals and arable weeds, commonly recovered from excavated settlements, provide direct evidence of the crops that grew in early medieval and medieval England and of the husbandry regimes and environmental conditions under which they grew. While other crops, such as peas and beans, were grown in this era, cereals overwhelmingly dominate the archaeobotanical record. Not only did they constitute the greatest calorific portion of the medieval diet, but also the combustibility of cereals while being stored and milled, their proximity to fire during malting and drying, and the relative robustness of their grains, all render cereal harvests particularly apt to be routinely preserved by accidental charring (Banham and Faith 2014, 20–1). Charred botanical items—especially grains and seeds, but also sometimes pieces of chaff—have been preserved when, under low-oxygen conditions, they were incompletely burned (Charles *et al.* 2015). The resultant carbon 'fossils' are resistant to microbial decay. They are also very light, such that they can be floated out of excavated soil samples disaggregated in water.

Charred plant remains constitute the greatest part of the archaeobotanical record in England, as elsewhere (Hall and Huntley 2007, 9–10). Systematic environmental sampling at excavated sites, especially over the last three decades, has produced a vast archive of medieval charred plant data from across England, recorded in a diverse plethora of published and unpublished specialist reports (van der Veen *et al.* 2013). At the time of writing, there is no single, up-to-date, authoritative source collating all of these archaeobotanical data, nor are the data in original reports always presented in a standardized fashion with uniform nomenclature and recording protocols. It was therefore necessary to compile a new database of charred plant remains identified in medieval contexts from across England.

Archaeobotanical data collection

A pilot project undertaken in 2016 entailed a rapid manual survey of excavation reports, including:

(i) those published as monographs, or in national or regional journals and
(ii) those not formally published but available as digitized archive documents, so-called grey literature, from the ADS.[2]

Excavations predating 1970 were excluded from the survey, because they were deemed less likely to have deployed robust environmental sampling techniques. This rapid survey estimated that there would be up to four thousand samples from three hundred sites whose data we could utilize (McKerracher 2016b). During the main project, between 2018 and 2020, the archaeobotanical data identified in the pilot—supplemented by additional reports brought to our attention by excavators and fellow researchers—were collated and manually entered into a bespoke SQL (Structured Query Language) database.

[2] https://archaeologydataservice.ac.uk (accessed March 2022).

The resultant dataset, comprising 4,342 samples from 301 sites spanning the fifth to fourteenth centuries, is very extensive but cannot be considered comprehensive, as it was not practical to include data from every report. As already noted, there is a clear distributional bias in the dataset, focused around a roughly triangular area demarcated by the Thames to the south, East Anglia to the east, and a line running north-east from the Severn to the Wash (Figure 2.6). The scarcity of data from more northerly and westerly regions cannot be entirely due to geological factors, as is likely with the zooarchaeological data, since the preservation of charred plant remains is less affected by soil acidity than that of animal bones (Campbell *et al.* 2011, 5). A comparable

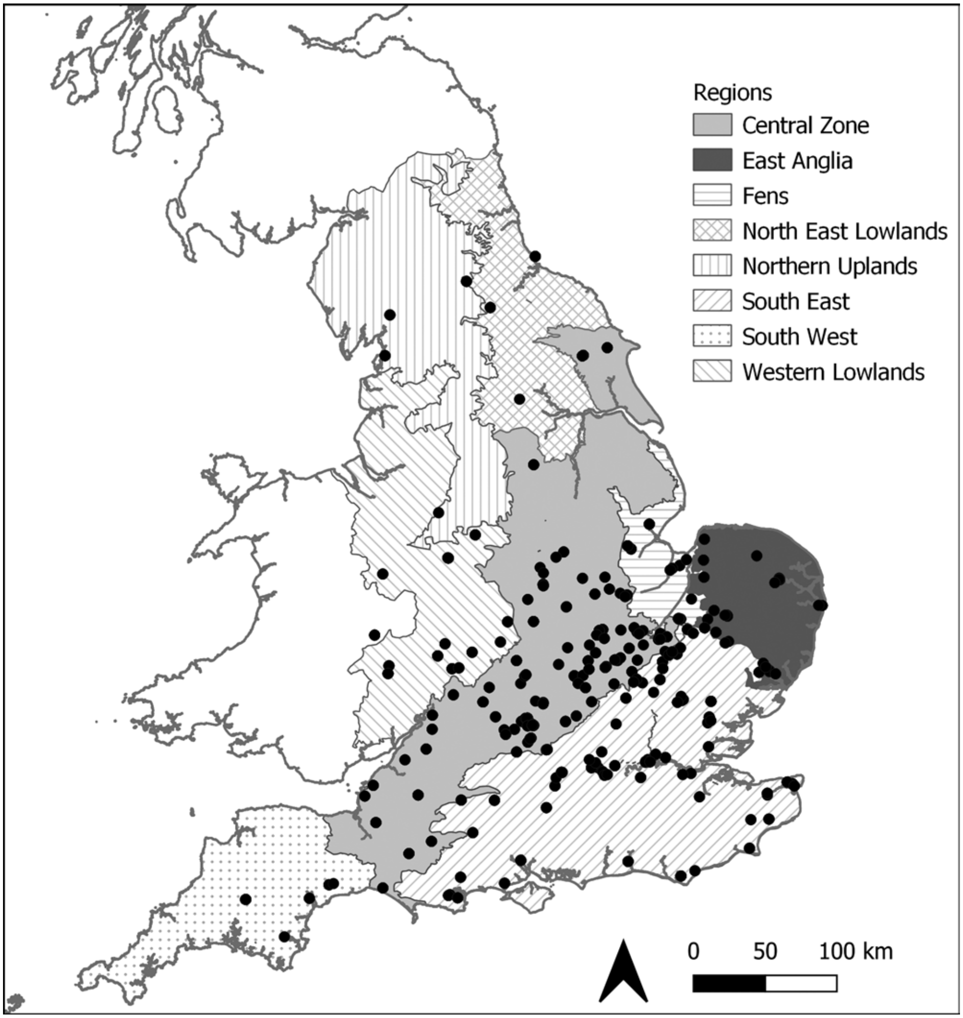

FIGURE 2.6. Distribution of sites in the FeedSax database with charred plant remains. Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

distributional bias identified by van der Veen *et al.* (2013, 177) was attributed to 'regional differences in modern settlement density and economic development and, consequently, in the number of archaeological interventions', but two genuine historical factors might also be at play here. First, the clustering of sites with charred plant remains approximately corresponds with the heartlands of medieval 'champion' farming, and it may be that the practices and productivity associated with this 'Midland system' and/or its precursors were particularly apt to create charred crop deposits (Roberts and Wrathmell 2000, 49–50; Williamson *et al.* 2013, 1–3). Second, as discussed above, Blair (2018, 24–35) has identified a very similar distribution of distinct 'Anglo-Saxon' archaeological evidence, best explained not as a function of skewed fieldwork but as the reflection of a more archaeologically visible culture restricted to a particular zone. A general dearth of identifiable and dateable early medieval archaeology beyond this zone would perforce mean a dearth of known early medieval charred plant remains.

Chronologically, the archaeobotanical dataset is somewhat more restricted than its zooarchaeological and palynological counterparts, focusing mostly on the period between the latter part of the seventh century and the end of the thirteenth century (FeedSax phases C–F), with a small number of earlier and later exceptions, mostly at case study sites. This restriction was imposed partly for practical reasons: data entry is time-consuming and it was necessary to set limits. In addition, previous research has identified that charred plant remains from the fifth to mid-seventh centuries (FeedSax phases A–B) are extremely scarce (McKerracher 2019, 52–7). Numbers of charred plant items in deposits from this period are generally so low that they end up being excluded from quantitative analyses and therefore do not easily justify the time and effort of data entry when more usable data are available from later centuries.

The preceding account concerns pre-existing data, produced by other archaeobotanists in earlier post-excavation projects. However, the database also includes new archaeobotanical data generated by FeedSax from analysis of assemblages from Lyminge (Kent), Houghton (Cambridgeshire), and Coton Park (Warwickshire). In addition, selection of radiocarbon dating samples from one site—West Cotton, Raunds (Northamptonshire)—revealed the presence of free-threshing wheat grains that, while identified in the archaeobotanical archive, are not listed in the published tables (Campbell and Robinson 2010, table 12.6).[3]

Using quantitative archaeobotanical data

A full description of the archaeobotanical dataset is provided, along with the database itself, in the FeedSax digital archive (McKerracher *et al.* 2023). In essence, attached

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[3] Namely, 303 grains in sample 45, and 207 grains in sample 114, all labelled as '*Triticum aest./comp.*'.

to each site in the dataset are a number of samples, and attached to each sample are a number of plant records: one for each kind of archaeobotanical item identified in that sample. Each plant record details the plant taxon identified, the part of the plant represented (*e.g.* seed), the quantity or estimated abundance of items, the mode of preservation (*e.g.* charred), and any qualifiers such as '*cf.*' or 'type'—which denote an archaeobotanical resemblance to a plant species, rather than a fully confident identification.

Archaeobotanists have developed many quantitative and semi-quantitative methods for the analysis of charred plant data, and the combined application of a suite of these methods enables us to trace patterns in surplus production, the relative importance of crops, and arable growing conditions across time and space. The informative value of quantitative and semi-quantitative methods rests upon how far the identified charred plant remains are considered to be representative of their native harvests, of which they must constitute only a tiny fraction. This study therefore imposes a set of quorums, defining, for instance, the minimum number of weed seeds that a sample must contain in order for it to be included in a weed ecological analysis. The parameters and values used in this study follow those set out by McKerracher (2019, 2).

Deposits of charred plant remains are most useful as proxies for agricultural activity when each represents a discrete episode of crop processing, that is, when it is realistic to presume that the crops and weeds represented were genuinely processed together as part of the same harvest, rather than co-occurring as waste mixed before or after deposition. Moreover, since different stages of crop processing (such as winnowing and fine sieving) remove different kinds of seeds, weed ecological analyses should ideally compare only samples that represent comparable stages in the crop processing sequence (see below). We have therefore applied two independent methods—utilizing the relative proportions of grain, chaff, and weed seeds, and the physical characteristics of the weed seeds, respectively—to interpret the samples in the dataset as artefacts of crop processing (methods invented by Jones 1987; 1990).

A certain pragmatism is also required in the data cleaning process. We cannot restrict our analyses to plant remains from storage contexts, such as burnt-down granaries, since these are exceptionally rare.[4] Processing deposits, such as from drying kilns, are rather more common, but the majority of charred plant remains come from pits and ditches, thus representing discarded waste. While smaller deposits in such features might be taken to represent the 'background noise' of cereal processing, richer, denser deposits are more likely to represent a single episode of processing and therefore less likely to include the spurious co-occurrence of taxa that had not grown together.

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[4] Among the few notable examples are the barns at Lydford and the probable storage rooms at Ottery St Mary, both in Devon (Green 1980; Mudd *et al.* 2018).

This preparatory work supported further analyses aimed at tracing patterns in surplus production, the relative importance of different cereals, crop rotation, soil fertility, and disturbance.

Tracing surplus production

Charred plant remains are routinely produced at settlements that handle cereal crops, and—in very general terms—the handling of more crops logically entails the accidental production of more charred plant remains (van der Veen and Jones 2006). Diachronic changes in the sheer mass of charred plant remains may therefore be used as a coarse proxy for changes in the scale of surplus production. How should this mass be measured? The number of charred deposits belonging to a particular phase at a particular site is not an adequate measure of crop processing activity, since it depends more directly upon variations in archaeological excavation and sampling strategies. Likewise, the numerical abundance of charred plant remains *within* individual deposits is not a reliable gauge of surplus production, since it may be possible to extract more charred items simply by sieving more soil. The average density of charred plant remains per litre of sampled soil is therefore a better measure, because it factors in variations in sample size; this value has therefore been calculated for each sample in the dataset whose original soil volume is known (see Appendix 2). Patterns in the occurrence of very dense charred deposits are unlikely to be an artefact of sampling biases: a sampling strategy, no matter how intensive, cannot manufacture dense concentrations that were not originally deposited in the medieval period (McKerracher 2022).

Relative importance of cereal taxa

Variations in the relative importance of the different cereals across time and space are fundamental to our understanding of medieval agriculture. These variations can be traced by three different methods, each relating to a different kind of 'importance' (McKerracher 2019, 64–83). First, prevalence denotes the breadth of a crop's distribution within a given region or period and is measured as the percentage of archaeological sites at which it has been identified. Second, frequency of use denotes how regularly a crop was grown, stored, and processed within a given region or period and is measured as the percentage of samples in which it has been identified. Third, relative productivity denotes the contribution of a crop to the total harvested goods of a site, region, or period and is calculated from the relative proportions of different cereal grains identified in individual samples—ideally only those samples that are deemed plausible to represent discrete episodes of crop processing (see above). It must be stressed that this can only be a relative measure: archaeobotanical grain counts give us no guide as to the absolute yields of different crops but may reveal whether, for instance, barley typically contributed more to the harvest than rye.

Weed ecology: Seasonal sowing and crop rotation

Cereal crops may be sown in the autumn or the spring, to different advantages: spring-sown crops are at less risk from adverse weather, but autumn-sown crops enjoy a longer growing period that can ultimately produce more biomass. There are both autumn- and spring-sown varieties of all four of the main cereals of medieval England: free-threshing wheat, barley, oat, and rye (Moffett 2006, 48). Hence, the seasonal cropping patterns generally associated with the developed 'Midland system' of open-field farming—with autumn-sown wheat and rye in rotation with spring-sown barley and oats—are not inherent to the crops themselves. To establish whether or not different cereals were systematically grown in different seasons, the *sine qua non* for 'Midland system' crop rotation, we must consider the arable weeds represented among those crops, since different weed species thrive under different crop husbandry regimes in different seasons.

An ecological study of field surveys in modern Germany successfully differentiated the weed flora of autumn- and spring-sown crops (Bogaard *et al.* 2001). The study found that the onset and duration of flowering in arable weeds together constitute a functional trait that successfully predicts crop germination time and can thus differentiate between the two sowing seasons. This differentiation was tested using a discriminant analysis based upon the presence or absence of particular species with particular flowering characteristics. In brief, weed species with an early or short flowering period enjoy a competitive advantage in autumn-sown fields, whereas those with a late or long flowering period have an advantage in spring-sown fields since they still have an opportunity to set seed after springtime ploughing (Bogaard *et al.* 2001).

On this basis, with reference to published floras, FeedSax has classified the arable weed species in the dataset as 'autumn-associated', 'spring-associated', or 'other' (including those with an intermediate or ambiguous flowering period). These classifications have been employed in correspondence analyses of crop and weed remains in Chapter 4. Correspondence analysis is an exploratory multivariate statistical technique that reveals associations between multiple variables: in this case, revealing which crop and weed taxa tend to occur together in archaeobotanical assemblages. The advantage of this approach, over the discriminant analysis that returns a binary 'autumn' or 'spring' classification for each sample, is that it allows us to explore relationships between seasonality and specific crop taxa, by including cereal remains in the analysis alongside arable weed seeds. Correspondence analysis was performed, and scatter plots were created, using Canoco 5.0 (ter Braak and Šmilauer 2012). Only samples with at least ten items (including both cereal and weed remains) were included in these analyses; weed taxa were only included if identified to species level, since more generic identifications are less ecologically meaningful.

Systematic and specific associations between particular crops and particular sowing seasons—as between wheat and autumn, for instance, or barley and spring—would be consistent with crop rotation, but not sufficient evidence to demonstrate the practice, since they might in theory represent autumn wheat and spring barley habitually grown in different fields. This equifinality problem can be addressed, to some extent, by crop stable isotope analysis, as discussed below. It should also be noted that a lack of systematic and specific associations between particular crops and particular seasons would not preclude the possibility of a two-course rotation system: if only one of two fields was cultivated in any given year, then we need not expect to find evidence of two sowing seasons.

Weed ecology: Fertility and disturbance

The ecology of an arable field is affected by not only the timing but also the intensity of its cultivation. Intensive cultivation entails high inputs of manure and human labour (*e.g.* weeding) on smaller plots of land, whereas extensive cultivation sacrifices labour and manure inputs for the sake of increasing the area of arable land. In this sense, medieval open-field farming can be seen as an extensive system. A functional ecological study of modern weed flora developed under traditional agricultural regimes has discovered how to differentiate between high- and low-input systems on the basis of weeds' functional traits (Bogaard *et al.* 2016). The study used discriminant analysis to develop a model for differentiating between fields in Asturias (Spain) subject to high inputs per unit area (intensive manuring and weeding) and those in Haute Provence (France) that received little or no manuring and weeding. Differentiation was achieved on the basis of five functional traits that predict the response of weed species to soil fertility and/or disturbance due to tillage and weeding: specific leaf area (leaf area/leaf dry weight), canopy height, canopy diameter, ratio of leaf area per node to fresh leaf thickness, and flowering duration.

A complementary perspective on soil disturbance and its ecological impact is provided by a functional ecological study of modern arable and hay meadow flora at Laxton, Nottinghamshire, where a limited but operational open-field system persists in the present day, and arable weed flora at Highgrove's Duchy Home Farm, Gloucestershire (see Bogaard *et al.* 2022). The Laxton–Highgrove study compared the flora of unploughed but periodically grazed and annually cut 'sykes' (areas of hay meadow within the field system that, unlike the fields, are not sprayed with herbicides) with those of arable land, surveyed in three environments: Highgrove's organic crop fields, Laxton's fallow fields (*i.e.* in the third, fallow year of the rotation scheme) that had not recently been sprayed, and in the unsprayed edges of cereal fields at Laxton. A discriminant analysis successfully separated the grassland flora of the 'sykes' from the weed flora of the arable fields, on the basis of two attributes relating to soil disturbance: flowering duration and (for perennials only) the ability to regenerate from vegetative fragments (Figure 2.7).

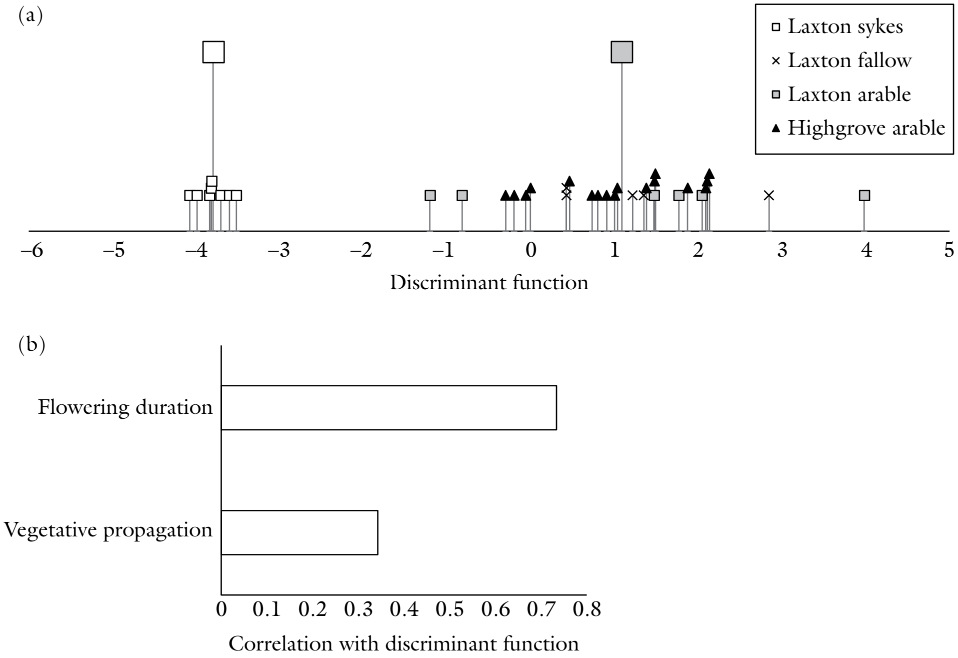

FIGURE 2.7. (a) The relationship of the Laxton sykes (open squares) and arable fields at Laxton and Highgrove (other symbols) to the discriminant function extracted to distinguish these two groups (larger symbols indicate group centroids); (b) correlations between the functional traits used as discriminating variables and the discriminant function.

The co-occurrence of both extensive and high-disturbance signatures from these complementary analyses would be consistent with heavy ploughing in open fields.

As with the correspondence analyses described above, only samples with at least ten weed seeds were included in these two discriminant analyses as unknown cases to be classified, and weed taxa were only included if identified to species level.

CROP STABLE ISOTOPE ANALYSIS

Introduction

The analysis of the stable isotopes of carbon and nitrogen has recently been applied to archaeological plant remains as a method to elucidate the growing conditions of crops (*e.g.* Fraser *et al.* 2011; Styring *et al.* 2016, 2017; Wallace *et al.* 2013, 2015). Stable isotope ratios provide information about plant water availability (carbon) and the level of soil ^{15}N enrichment (nitrogen). These methods were applied to the case study sites in order to understand the growing conditions of the crops, allowing inferences to be drawn regarding crop rotation and the potential expansion of cultivation onto different, for example, wetter, soils.[5]

The analysis of the isotopic ratio of ^{12}C to ^{13}C (δ^{13}C) can be used to understand water availability during a plant's growth, the slope of terrain on which the plant was grown, and the relative shadiness of the growing environment (Bogaard *et al.* 2016; Bonafini *et al.* 2013; Wallace *et al.* 2013). C_3 plants, which include wheat, barley, rye, and oat, preferentially use the lighter isotope (^{12}C) during photosynthesis. However, during times of water stress resulting from either high temperature or low water levels, a C_3 plant will use either of these isotopes. Consequently, C_3 plants grown under non-water-limiting conditions have more negative δ^{13}C values than those that were stressed by a lack of water. Different C_3 plant species have different δ^{13}C values when growing in non-water-limiting conditions due to physiological differences. This project focuses on four crop species: rye, free-threshing wheat, barley, and oat. Research indicates that there is a 1–2‰ δ^{13}C offset between free-threshing wheat and barley when grown in the same conditions (Anyia *et al.* 2007; Jiang *et al.* 2006; Voltas *et al.* 1999; Wallace *et al.* 2013). These four species have offsets: wheat and rye have similar δ^{13}C values, with rye slightly more positive, while oat is more negative than any of the other crops (Hamerow *et al.* 2020). This research was used as the baseline for understanding how wheat, barley, oat, and rye would look isotopically if they were grown in fields with the same water availability. The amount of precipitation and solar radiation expected for medieval England means that the plants are unlikely to have been limited by water availability. Consequently, carbon stable isotopes can be used to assess the compatibility of growing conditions between the crops.

The isotopic ratio of ^{14}N to ^{15}N (δ^{15}N) can be used to understand the enrichment of ^{15}N in the soil in which the plant was grown. A number of factors can enrich soil ^{15}N including microbial activity, seasonal wetting and drying of the soil, waterlogging, salinity and salt spray, aridity, and manuring (Engelaar *et al.* 2000; Fraser *et al.* 2011; Heaton 1987; Inglett *et al.* 2007; Styring *et al.* 2016; Yousfi *et al.* 2010). Determining which of these factors caused an elevation in soil ^{15}N is difficult and such elevation can be due to a combination of factors. The combination of stable isotopes and other methods for gauging soil fertility, such as weed ecology,

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[5] It is known that legumes such as vetches and beans were often planted as part of a rotation regime (Banham and Faith 2014; Stone 2005, 62–5). As legumes fix nitrogen from the air in their roots, the growing of legumes as a green manure would have added nitrogen to the soil. If the roots of these plants are left to rot in the soil, a small amount of 'new' nitrogen will be added to the soil nitrogen pool. This additional nitrogen would not, however, affect the stable isotope analysis, which only measures the *ratio* (rather than the amount) of light to heavy isotopes.

provides one way of disentangling the causes of elevated soil ^{15}N (*e.g.* Styring *et al.* 2017).

Aims and objectives

Stable isotope analysis of charred cereal grains was used to understand the cultivation conditions of four species (wheat, rye, oat, and barley) for case study sites distributed across different ecological zones. Crop δ^{15}N and δ^{13}C values have been used elsewhere to provide information regarding the overall soil conditions in which the crops were cultivated; we took the additional step of using crop isotopes to investigate the likelihood of systematic crop rotation. This is achieved through understanding whether the different species were cultivated in similar soil conditions and whether this changed over time. The hypothesis is that the archaeobotanical remains of crops grown in rotation in the same field(s) would have similar δ^{15}N values, while δ^{13}C values would reflect the known physiological offsets expected of the different species when grown under the same conditions. As δ^{13}C is indirectly linked to the amount of precipitation and sunshine per year, δ^{13}C values are likely to be variable. However, it is plausible that with a large set of samples, if the crops are grown in rotation over multiple years, the δ^{13}C values should reflect known physiological offsets of the different species. Consistent long-term variations in δ^{13}C values, distinct from those expected due to the physiological differences, would likely represent different growing locations. Soil ^{15}N enrichment may be more reliable in reflecting changes in crop cultivation locations, with significant differences between species over time indicating differences in location or husbandry methods.

Similar δ^{15}N and δ^{13}C values in multiple crop species do not necessarily represent crop rotation, however. Different fields could by chance have had the same soil ^{15}N enrichment and may have received the same amount of precipitation and sunshine; the different crops cultivated in them would therefore have similar values without having been grown in rotation. Furthermore, the cultivation of mixed crops, such as a maslin, would also result in the species having very similar isotope ratios. It is through the identification of similar crop isotope values over time, along with other evidence such as crop sowing times determined by examining associated weed flora (see above), that a case for crop rotation can be made. In short, while differing δ^{15}N and δ^{13}C values can be used to rule out crop rotation, similar values alone are not proof that rotation was practised.

Materials and methods: Archaeological cereal grains

It was originally planned to analyse bulk samples of around five grains per sample for all sites. This method was used for the sites of Stafford and Yarnton but was modified for subsequent sites as poor preservation of grains, new research indicating high charring temperatures, and the mixed nature of some deposits resulted in many sites having insufficient grains for bulk samples (Stroud *et al.* 2023). Consequently, the number of grains used per sample was changed, with the majority of samples consisting of a single grain. Whether a sample was analysed as a bulk or single grain sample depended on a number of factors including preservation, number of grains available, and type of context. Samples from primary deposits such as storage contexts or drying kilns were analysed as bulk samples, using five to ten grains per homogenized sample. The exceptions to this are the sites of Yarnton and Stafford (see above). Samples derived from secondary/tertiary deposits, contexts with limited information, or samples with fewer than five grains, were analysed as single grains. Bulk samples were analysed from three sites—Stafford, Yarnton, and Pudding Lane—with the remaining sites analysed as single grains, including a number of additional samples from Pudding Lane.

Given the destructive nature of isotopic analysis, the ventral side of each grain was photographed as a record of the material used. Further photographs were taken of each grain's internal morphology as a record of the charring temperature. A number of free-threshing wheat and rye grains were photographed for possible later morphometric analysis to investigate species or landrace. The resultant corpus of grain photographs is included in the FeedSax digital archive (McKerracher *et al.* 2023).

In order for grains to be selected for analysis, their external and internal morphology had to be consistent with grains experimentally charred at temperatures between 230 and 300°C (Stroud *et al.* 2023). Selected samples were cleaned of any adhering soil and modern material using a scalpel. Three to six samples per site were analysed by Fourier Transform Infrared Spectroscopy with Attenuated Total Reflectance (FTIR-ATR) using an Agilent Technologies Cary 640 FTIR instrument with a GladiATR accessory from PIKE Technologies, at the Research Laboratory for Archaeology and the History of Art (RLAHA), University of Oxford. These analyses were carried out to determine any contamination by carbonates, nitrates, or humic acids. The analyses followed the procedures set out in Vaiglova *et al.* (2014). The resultant spectra were compared against published spectra of charred seeds contaminated with nitrates, carbonates, and humic acids (Vaiglova *et al.* 2014). If samples showed evidence of contamination, all the samples from that particular site were pretreated. Carbonate contamination was detected at two of the sites isotopically analysed, Lyminge and Mildenhall. For those sites, the grains were placed in 0.5M HCL, which was heated to 70°C for 40 minutes or until any effervescence stopped. The acid was decanted, and the samples were washed in water until they reached a neutral pH. The samples were then frozen and freeze-dried.

The samples were weighed into tins and either analysed on the Sercon 20/22 continuous flow isotope ratio mass spectrometer coupled to an elemental analyser at

RLAHA for independent carbon and nitrogen determination or analysed for simultaneous carbon and nitrogen determination at Iso-Analytical Limited on a Europa Scientific 20-20 IRMS. Every tenth sample was duplicated to understand precision.

Four IAEA standards (N1, N2, CH6, and CH7) were included, along with EMA-P2 (δ^{13}C –28.19 ± 0.14‰, δ^{15}N –1.57 ± 0.19‰) and an in-house Alanine standard (δ^{13}C –26.91 ± 0.12‰, δ^{15}N –1.57 ± 0.2‰) for samples run at RLAHA. Samples run at Iso-Analytical also included their in-house standards of IA-R001 (–26.43 ± 0.043‰, δ^{15}N 2.55 ± 0.04‰), IA-R045 (δ^{15}N –4.71 ± 0.07‰), IA-R046 (δ^{15}N 22.04 ± 0.12‰), IA-R005 (δ^{13}C –26.03 ± 0.03‰), and IA-R006 (δ^{13}C –11.64 ± 0.04‰), as well as N1, N2, CH6, CH7, and EMA-P2. In total, four standards were used for calibrating samples analysed at Iso-Analytical (CH6, CH7, IA-R005, and IA-R006 calibrated to VPDB for carbon; and N1, N2, IA-R045, and IA-R046 calibrated to AIR for nitrogen), while P2 and IA-R001 were used as check standards. Samples analysed at RLAHA used a two-point calibration (CH6 and CH7 for carbon and N1 and N2 for nitrogen), with EMA-P2 and Alanine used as a check standard.[6]

Precision, accuracy, and overall analytical uncertainty were calculated following Szpak *et al.* (2017). Precision, relating to random errors, was gauged using the square root of the summed standard deviation of all repeated measurements within a relevant analytical session (Szpak *et al.* 2017). Accuracy, related to systematic measurement errors, was calculated as the square root of the sum of the root-mean-square of the difference between the measured means and the known values of the check standards in the relevant analytical runs and the known standard deviations of check standards (see Szpak *et al.* 2017 for detailed equations). Standard analytical uncertainty was calculated as the root-sum-square of precision and accuracy. Data points were removed if %N and δ^{15}N values both appeared extremely high (outlying samples).

Correction for the effect of charring followed the research conducted by Stroud *et al.* (2023) to determine the difference between charred and uncharred wheat, barley, rye, and oat (with grains charred at temperatures up to 300°C). All grains were corrected by 0.16‰ for δ^{13}C values and 0.33‰ for δ^{15}N values, with the uncorrected values available in the database along with site-by-site analytical details and raw data (McKerracher *et al.* 2023).

All statistical analysis and graphing were conducted using R (version 4.0.2) and RStudio (version 1.3.1073).

ZOOARCHAEOLOGICAL ANALYSIS

Introduction

Animal bones are common finds at many archaeological sites and often provide (along with pottery) the greatest quantity of excavated material. The development of zooar-

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[6] For full details on standards, see the FeedSax data archive (McKerracher *et al.* 2023).

chaeology as a discipline over the past fifty years means that established methods are available to aid in the analysis of animal remains. Detailed descriptions of many of these techniques are available elsewhere (*e.g.* Baker and Worley 2019; O'Connor 2003), although a summary of the key methods utilized is presented here.

Aims and objectives

The overall aim of the zooarchaeological analysis is to provide a comprehensive understanding of the use of draught cattle and the role of sheep in the expansion of arable farming in England between the fifth and fourteenth centuries. This was done using a threefold approach:

1. An examination of well-dated zooarchaeological assemblages from targeted sites, with a comprehensive strategy for recording pathologies of cattle feet and cattle and sheep mandibles.
2. An investigation of long-term trends using previously published data, with a synthetic quantification of species representation and mortality data from existing zooarchaeological reports.
3. Integration of the findings in relation to chronological, regional, and geological patterns to answer the following specific research questions:
    a. Is there sufficient evidence from the pathological/sub-pathological changes to cattle feet to infer the increased use of animals for draught and of the mouldboard plough?
    b. Is there any indication for a change in husbandry associated with the need to restrict access of livestock to certain types of land (*i.e.* limited access to pasture), and increased foddering?
    c. Is there a change in the relative proportions of cattle and sheep that could be related to an increasing emphasis on arable production and their uses primarily for meat or secondary products?

Materials and methods

The first part of the data-gathering exercise involved the analysis or reanalysis of animal remains from twenty targeted sites (Table 2.3; Figure 2.8). Some of these (*i.e.* Bow Street, Barking Abbey, Ketton, Lyminge, Wallingford, Sedgeford, Stoke Quay, and Stratton) were unpublished at the time of analysis, and the data were kindly made available by the excavators. The remaining, previously published sites were chosen for having large, well-preserved animal bone assemblages of known date. The sites included in the project are clustered in the east and south of the country (Figure 2.8), which is a result of the underlying geology, whereby the low soil pH in the north and west of England is not conducive to good preservation of animal remains (Baker and Worley 2019, 1). Indeed, the assemblage from Stafford (the only targeted site from

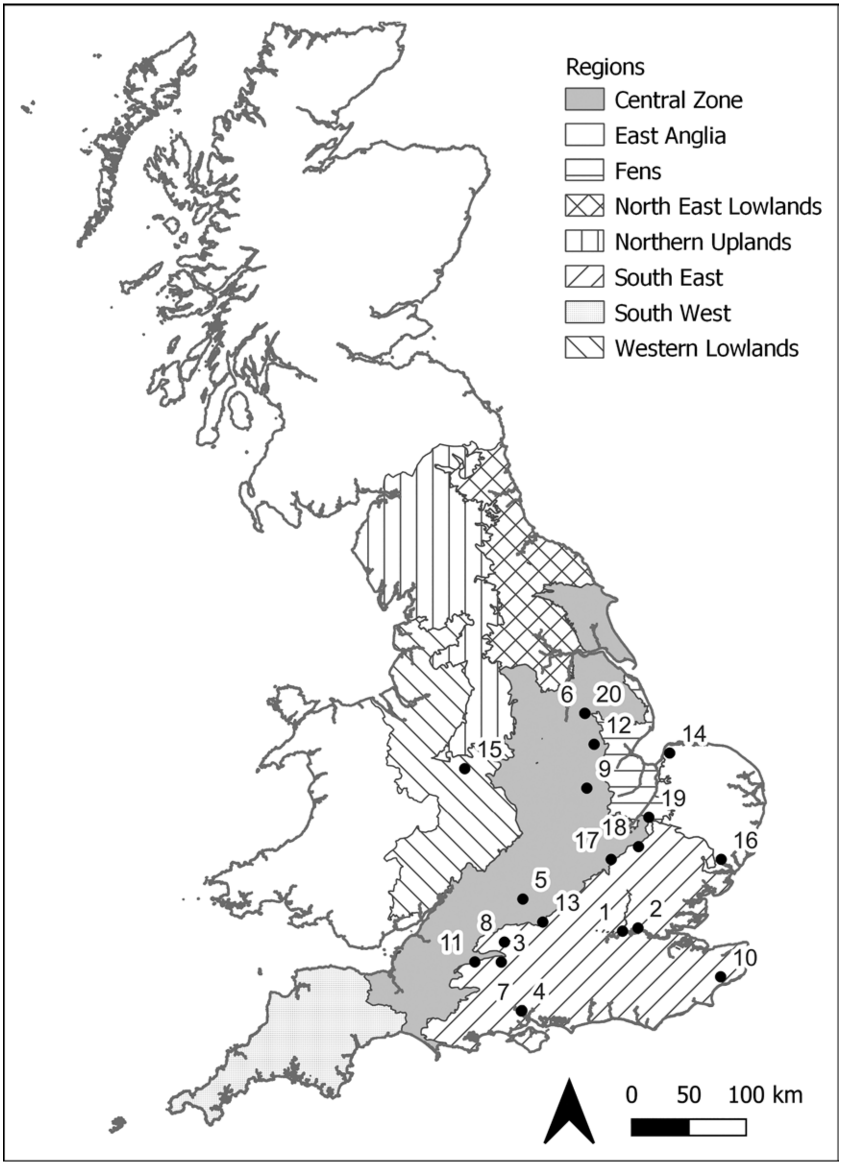

Figure 2.8. Distribution of zooarchaeological targeted sites (see Table 2.3 for key to site numbers). Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

western England) was very poorly preserved and of limited value for the identification of pathologies (Hamerow *et al.* 2020).

Bones were recorded from secure contexts dated between AD 400 and 1400, although occasionally phases that went up to 1500 were included (Table 2.4). Only specific anatomical elements were recorded: cattle mandibles, pelves, metapodia, and phalanges; sheep/goat mandibles and pelves. The following basic data were recorded for each anatomical element for cattle and sheep/goats:

TABLE 2.3. Metadata for targeted sites. Regions defined by Rippon *et al.* (2015), geology from Lowerre (2010). Map numbers relate to Figure 2.8. Elevation in metres above Ordnance Datum.

Site	Map no.	Dates	County	Region	Geology	Elevation	Reference
Bow Street, London	1	600–750	Middlesex	South East	Valley terrace	19	Holmes (2019)
Barking Abbey, London	2	500–1500	Middlesex	South East	Valley terrace	9	Holmes and Gordon (2020)
Cadley Road, Collingbourne Ducis	3	700–900	Wiltshire	South East	Chalk	130	Hamilton-Dyer (2001)
Cook Street, Southampton	4	650–875	Hampshire	South East	Valley terrace	2	Bourdillon (1993)
Eynsham Abbey	5	500–1330	Oxfordshire	Central Zone	Clay	74	Ayres *et al.* (2003)
Flaxengate, Lincoln	6	870–1400	Lincolnshire	Central Zone	Clay	42	O'Connor (1982)
French Quarter, Southampton	7	900–1350	Hampshire	South East	Valley terrace	2	Bates and Nicholson (2011)
High Street, Ramsbury	8	750–1300	Wiltshire	South East	Chalk	116	Coy (1980)
Ketton	9	850–1066	Rutland	Central Zone	Clay	51	Holmes (2018)
Lyminge	10	400–1300	Kent	South East	Chalk	101	Thomas (2013)
Market Lavington	11	400–1400	Wiltshire	Central Zone	Clay	88	Bourdillon (2006)
Quarrington	12	450–900	Lincolnshire	Central Zone	Valley terrace	25	Rackham (2003)
Reading Road, Wallingford	13	900–1300	Oxfordshire	Central Zone	Valley terrace	58	Holmes (2020)
Sedgeford	14	650–1025	Norfolk	East Anglia	Chalk	36	Faulkner *et al.* (2014)
Stafford	15	900–1300	Staffordshire	Western Lowlands	Valley terrace	77	Carver (2010)
Stoke Quay, Ipswich	16	700–1500	Suffolk	East Anglia	Valley terrace	25	Brown *et al.* (2020)
Stratton	17	600–1350	Bedfordshire	Central Zone	Valley terrace	41	Maltby (2022)
Trumpington Meadows	18	600–1066	Cambridgeshire	South East	Clay	30	Rajkovaca (2018)
West Fen Road, Ely	19	700–1400	Cambridgeshire	East Anglia	Clay	22	Higbee (2005)
West Parade, Lincoln	20	1050–1375	Lincolnshire	Central Zone	Clay	18	Scott (1999)

- Identification: taxon, element, condition (Behrensmeyer 1978), side, zone (Serjeantson 1996). The bones of sheep and goats are morphologically similar, but teeth, distal humeri, and proximal radii can be distinguished between the two taxa (Zeder and Lapham 2010; Zeder and Pilaar 2010), and goat bones were excluded.
- Age: long bone fusion (Silver 1969) and mandibular tooth wear (Grant 1982).
- Sex: pelvis morphology and metrics (Greenfield 2006; Popkin *et al.* 2012) and metapodial metrics (Albarella 1997a; Davis 1996; Davis *et al.* 2012).
- Size: measurements of cattle metapodials, first phalanges, and sheep and cattle teeth (von den Driesch 1976).

Only elements that met the following criteria were recorded:

- Mandibles with at least two teeth.
- Bones that were fused or fusing.
- Phalanges >95% complete, with the major diagnostic areas visible.
- Fragmentary metapodia were included, where the proximal and/or distal ends were complete enough to allow evaluation of all relevant potential pathological changes.

Data regarding specific pathologies were captured, including lesions on cattle metapodia and phalanges, and signs of calculus and periodontal disease on cattle and sheep mandibles. These are described in more detail below.

Changes to cattle feet

One of the most widely researched areas of animal palaeopathology concerns the skeletal changes brought about by the use of animals for labour. Over prolonged periods of time, repeated loading will produce inflammation of skeletal and associated soft tissues, resulting in new bone formation around articular margins (osteophytes), extension of the articular surface (broadening/lipping), breakdown of the joint cartilage resulting in bone-on-bone polishing eburnation, new bone formation at tendon/ligament attachment sites (enthesophytes), and other forms of bone remodelling (*e.g.* palmar depressions in metacarpals) (Baker and Brothwell 1980, 115; Bartosiewicz *et al.* 1997). Such effects are bilateral, increase with age, and manifest themselves most obviously in the distal limb elements (*i.e.* metapodials and phalanges) of the hind leg (Bartosiewicz and Gál 2013, 131; Holmes *et al.* 2021a; Thomas *et al.* 2021).

A pioneering study correlating such changes with the use of cattle for draught purposes was carried out by Bartosiewicz *et al.* (1997), which compared the feet of known working populations of cattle with those of animals bred purely for meat. Results showed that changes to the bones of the feet (metapodia and phalanges) were increasingly manifested in animals used for draught purposes but were affected by each animal's age, sex,

Table 2.4. Quantification of data recorded for each targeted site. Key: Ant = anterior; Post = posterior; Ph1 = first phalanx; Ph2 = second phalanx.

Site	Dates	Midpoint	Broad phase	Site type	Cattle								Sheep			
					Metacarpal	Metatarsal	Ant Ph1	Post Ph1	Ant Ph2	Post Ph2	Pelvis	Mandible	Pelvis	Humerus	Radius	Mandible
Barking Abbey	500–850	675	600–900	Religious	2	2	1				9	8	1	4	2	2
	850–1066	958	800–1100	Religious	1								1		1	
	1066–1200	1133	1000–1300	Religious	4	6	2				2	2	1	3	6	8
	1200–1500	1350	1200–1500	Religious	1	1				1	2	1		1	2	
Bow Street	600–750	675	600–900	Urban	16	21	10	1	3	2	18	18	8	17	32	22
Collingbourne	700–900	800	600–900	Rural	3	4	1	4	1		2	10	3	7	5	42
Cook Street	650–875	763	600–900	Urban	14	12	16	25	22	15	28	23	6	14	16	26
Eynsham	500–650	575	400–700	Rural	1	2	4	4	1	2	4	13	14	10	8	17
	650–850	750	600–900	Religious	32	18	28	25	18	11	24	18	46	64	47	109
	850–1066	958	800–1100	Religious	2	2	3	2			1	2	6	7	3	12
	1066–1300	1183	1000–1300	Religious	68	68	21	10	14	5	33	72	18	32	39	26
	1200–1330	1265	1200–1500	Religious	12	14	7	4	2	2	3	3	8	13	13	7
Flaxengate	870–1090	980	800–1100	Urban	40	32	20	35	16	34	56	27	41	47	51	55
	1060–1200	1130	1000–1300	Urban	50	55	29	26	30	22	52	39	52	69	49	127
	1200–1400	1300	1200–1500	Urban	11	12	9	14	13	13	8	10	22	20	19	33
French Quarter	900–1066	983	800–1100	Urban	26	29	10	19	4	6	21	31	7	4	18	40
	1066–1250	1158	1000–1300	Urban	23	31	11	22	7	7	16	43	14	19	19	63
	1250–1350	1300	1200–1500	Urban	31	24	17	18	3	8	19	32	8	20	20	45
Ketton	850–1066	958	800–1100	Rural	2	2	1	2	1	3					1	2
Lyminge	400–700	550	400–700	High status	17	12	13	15	17	10	11	27	4	8	6	38
	600–850	725	600–900	Religious	23	14	25	30	24	22	26	26	14	29	16	102
	1100–1300	1200	1000–1300	Rural	2	3	4	4		1	4	8	1	3	3	24

Continued

Table 2.4. *Continued*

Site	Dates	Midpoint	Broad phase	Site type	Cattle								Sheep			
					Metacarpal	Metatarsal	Ant Ph1	Post Ph1	Ant Ph2	Post Ph2	Pelvis	Mandible	Pelvis	Humerus	Radius	Mandible
Market Lavington	400–700	550	400–700	Rural	25	23	30	33	18	12	29	41	6	32	16	61
	700–900	800	600–900	Rural			1	1			1	1				4
	900–1175	1038	800–1100	Rural								1				4
	1100–1300	1200	1000–1300	Rural	1			2	1	1	1		1	3	1	
	1300–1400	1350	1200–1500	Urban	1				1							
Quarrington	450–650	550	400–700	Rural	5	13	5	5	3	9	9	18	2	4	4	16
	650–900	775	600–900	Rural	12	5	5	5	3	3	8	13	3	1	4	16
Ramsbury	750–850	800	600–900	High status	10	12	8	6	7	2	13	28	8	8	8	42
	800–1300	1050	800–1300	Rural											1	
Reading Rd, Wallingford	900–1075	988	800–1100	Urban	8	6	3	4	3		8	4	7	5	10	18
	1025–1175	1100	1000–1300	Urban	16	21	5	9	2	4	20	14	25	20	35	61
	1125–1300	1213	1000–1300	Urban	1						1		2	1		5
Sedgeford	650–875	688	600–900	Rural	8	6	7	6	4	6	8	14	7	11	9	33
	800–1025	913	800–1100	High status	19	11	11	19	15	10	13	18	22	28	17	60
Stafford	900–1100	1000	800–1100	Urban		2						1				
	1100–1300	1200	1000–1300	Urban	11	19	8	4	3	1	2	7		4	4	22
Stoke Quay	700–875	788	600–900	Urban	43	31	33	19	17	11	54	29	31	44	36	84
	825–1100	963	800–1100	Urban	9	18	9	8	7	3	18	16	3	15	16	24
	1050–1200	1125	1000–1300	Urban	18	21	16	18	5	8	19	15	10	21	22	25
	1150–1500	1325	1200–1500	Urban	9	12	3	7	5	1	19	12	6	13	15	19
Stratton	400–600	500	400–700	Rural	4	5	2	2	1	2	4	5	3	1	2	28
	600–850	725	600–900	Rural	16	10	6	6	2	2	13	20	4	8	4	54
	850–1150	1000	800–1100	Rural	15	13	7	8	2	4	15	26	3	8	5	68
	1150–1350	1250	1000–1300	Rural	14	13	1	3			13	21	2	8	4	26

Trumpington Meadows	600–700	650	600–900	Rural	5		5		1		7	11	4	9	5	79
	700–850	775	600–900	Rural	7	5		1	1		1	2	1	1	2	7
	850–1066	958	800–1100	Rural		4	1		1	1	1				1	3
West Fen Rd, Ely	700–875	788	600–900	Rural	3			1			1	3	1	1	2	4
	825–1150	988	800–1100	Rural	19	15	6	12	3	7	7	16	9	5	8	23
	1100–1200	1150	1000–1300	Rural	7	8	5	3	3	2	2	4	5	2	6	5
	1200–1400	1300	1200–1500	Rural	5	1	3			1	8	7	1			9
West Parade	1050–1300	1175	1000–1300	Urban	26	32	30	26	8	14	26	23	17	26	17	76
	1275–1375	1325	1200–1500	Urban	7	5	3	6	4	4	3	6	3	5	3	14
Total					705	675	445	474	296	272	663	789	461	675	633	1690

size, and breed. Later work has identified that some of these changes are age-dependent (Thomas *et al.* 2021), and data generated in this project have provided further insights into the influence of sex and body mass (Holmes *et al.* 2021a).

A recording protocol devised by Bartosiewicz *et al.* (1997), modified to remove age-dependent variables (Thomas *et al.* 2021) and the effects of fragmentation (Carlson Dietmeier 2018), was implemented (Table 2.5). This protocol allows the effects of pathological changes to the metapodia and phalanges to be scored and converted into a modified Pathological Index for each individual population or site (Bartosiewicz *et al.* 1997, 20).

Calculus and periodontal disease

Oral disease in domestic livestock has been well researched in archaeology (Baker and Brothwell 1980, 145–60; Bartosiewicz and Gál 2013, 171–82; Holmes *et al.* 2021c; Levitan 1985). Of relevance to this study is the occurrence of periodontal disease. This results from damage to the gingival tissues (gums) of the mouth caused by irritation by food during mastication, by impaction of food between the teeth and gum, and/or by a build-up of plaque (observed as calculus in archaeological material). Periodontal disease causes the gums to retreat and produces inflammation of the soft tissues. If the irritation continues, infection may enter the deeper tissues of the mouth causing resorption of the mandibular bone around the teeth (alveoli) and may lead to tooth loss.

Oral pathologies were recorded in cattle and sheep mandibles in three ways:

1. Calculus accumulation (Figure 2.9): calculus or plaque is easily observed on teeth as a black substance, sometimes with a metallic lustre (Levitan 1985). It is recorded on a scale of 0 (absent) to 3 (considerable).
2. Alveolar recession: infection of the mandible can be observed as resorption of the bone around the tooth. It is recorded following an existing scale of 0–5 detailed in Table 2.6 (Levitan 1985).
3. Periosteal new bone formation (Figure 2.10): new bone growth in response to inflammation of the periosteum (Waldron 2009) is a symptom of periodontal disease when observed on the mandibular bone. It was recorded as present (1) or absent (0).

Analysis

All statistical analyses were carried out using PAST (Hammer *et al.* 2001). Tooth wear was calculated following Jones (2006) for sheep and Jones and Sadler (2012) for cattle. Sex determinations were based on morphological traits of cattle and sheep pelves (Greenfield 2006; Popkin *et al.* 2012) and metrical distinction of cattle metacarpals (Davis *et al.* 2012). Metrical data were compared using the log scaling method (Davis 1996; Holmes 2014a; 2014b).

Table 2.5. Recording protocol for cattle feet (Bartosiewicz *et al.* 1997). Scoring range given in parentheses. Shaded cells = measurements used in the modified Pathological Index (Thomas *et al.* 2021).

Variable	Abbreviation	Description	Metacarpal	Metatarsal	1st phalanx	2nd phalanx
Proximal exostosis	PEX	New bone formation near the proximal articulation. This encompasses entheseal as well as osteophytic changes.	(1–4)	(1–4)	(1–4)	(1–4)
Proximal lipping	PLIP	Functional extension of the proximal articular surface due to new bone formation.	(1–3)	(1–3)	(1–4)	(1–4)
Distal exostosis	DEX	New bone formation near the distal articulation. This encompasses entheseal as well as osteophytic changes.	(1–4)	(1–4)	(1–4)	(1–4)
Broadening	BRD	Broadening of the distal (primarily medial) condyle of the metapodial, likely as an adaptation to loading.	(1–4)	(1–4)		
Depression	DEPR	Depressions on the palmar/plantar surface of the distal shaft of metapodials.	(1–3)	(1–3)		
Proximal eburnation	PEB	Eburnation on the proximal articular surface, pathognomonic of osteoarthritis.	(1–2)	(1–2)	(1–2)	(1–2)
Distal eburnation	DEB	Eburnation on the distal articular surface, pathognomonic of osteoarthritis.	(1–2)	(1–2)	(1–2)	(1–2)
Striation	STR	Transverse striations on the medio-proximal surface of metatarsals near the attachment site for the *musculus extensor digitorum brevis.*		(1–2)		
Striated facet	FAC	Striations on the triangular facet for the attachment of the *ligamentum accessorium.*	(1–2)			
Fusion of 2nd metacarpal	FUS	Ankylosis of the vestigial second metacarpal with the medial side of the third metacarpal.	(1–2)			

FIGURE 2.9. Recording system for dental calculus: (1) slight calculus visible usually on one side of the tooth; (2) moderate calculus build-up, usually on both sides of the tooth; (3) considerable calculus build-up that extends beyond the contour of the tooth.

FIGURE 2.10. Periosteal new bone formation.

TABLE 2.6. Recording protocol for alveolar recession (Levitan 1985).

Code	Definition
0	No recession
1	Recession of alveolar margin only
2	Alveolus widened out, pitted margins, more recession
3	Ante-mortem tooth loss and alveolus infilling
4	Infilling advance but not complete
5	New bone formation nearly complete

Synthesis of existing data

A considerable dataset of zooarchaeological reports currently exists for English sites, drawing on regional reviews and period-specific surveys (Albarella and Pirnie 2008; Holmes 2011, 2017; Sykes 2007). These data have been incorporated into the database and are available in the digital archive (McKerracher *et al.* 2023). Additional reports were included from more recent excavations and from sites in the north of England, which has not been subject to a published regional review. A total of 701 phased assemblages were recorded from 460 sites (Figure 2.11; Table 2.7). Data included the site name; phase and specific dates of occupation where available; number of fragments identified as cattle, sheep/goat, and pig; and ageing data.

To clarify the terminology: 'site' refers to an archaeological excavation, while 'assemblage' denotes the animal bones recovered from a particular phase or period at a site. Therefore, a multiphase site would have more than one assemblage, for example, one recovered from features dated to AD 400–600 and another from features dated

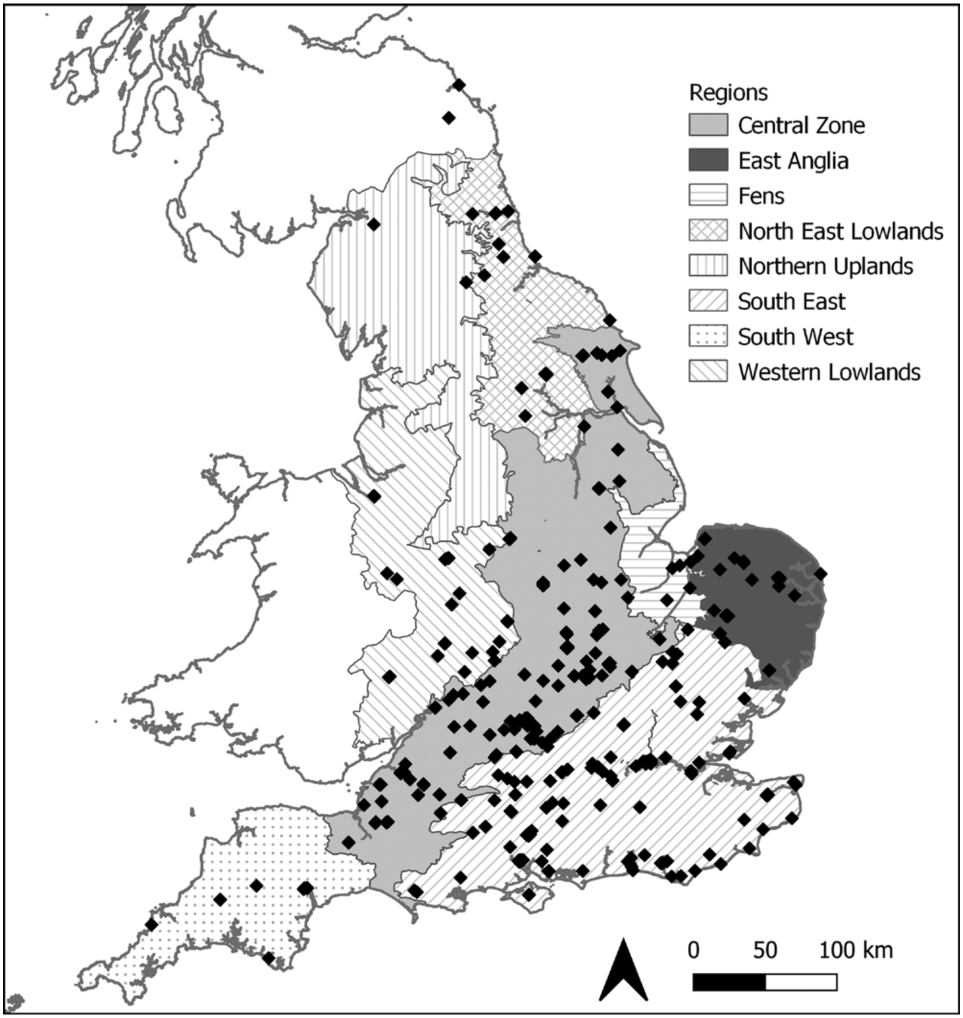

FIGURE 2.11. Distribution of all sites with faunal remains in the FeedSax database. Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

Table 2.7. Number of sites by phase and site type incorporated into the zooarchaeological analysis and recorded from published sources. Shaded columns = broad date ranges referred to in the text to allow inclusive analysis of diverse chronologies.

Site type	**400–700**	**400–900**	**600–900**	**600–1100**	**800–1100**	**800–1200**	**1000–1300**	**1000–1400**	**1200–1500**
Rural	56	7	35	1	12	9	22	19	18
Urban	5	2	27	1	64	29	113	60	73
Ecclesiastical			6	1	4	3	13	3	8
High status	3	1	14		9	5	37	16	25

to AD 600–800. The following criteria were applied to ensure the collection of reliable, meaningful data:

- Minimum number of one hundred fragments identified to cattle, sheep/goat, and pig.
- Location within England.
- Publication after 1960 (to ensure the likelihood of a minimum standard of retention and recording).
- Chronological span of a maximum of two broad periods—for example, assemblages of early Saxon (400–650, broadly phases A and B), mid Saxon (650–850, broadly phase C), or early-mid Saxon (400–850, broadly phases A1–C4) date would all be included, but an early to late Saxon assemblage (400–1066, phases A1–E1) would not, because of the poor chronological resolution offered by such a broad dating.

While the methods utilized in this study are well established, they are not without problems. Equifinality is a major challenge, with potential for several competing triggers for many of the pathologies being studied (most notably: age, size, sex, genetics, and environment). While the manifestations of lesions (joint inflammation, trauma, or periodontal disease) can be defined and recorded, there are multiple underlying aetiologies (Waldron 2009, 3). For example, joint lesions are often exacerbated by age or body mass—the longer an animal is alive, the more likely it is to be affected by joint degeneration, and the heavier or larger an animal, the more strain will be placed on the joint. It is only by using large-scale datasets, incorporating ageing and sexing data, that particular causes may be inferred (Baker and Brothwell 1980, 202; Bartosiewicz and Gál 2013, 154). During the course of this project, investigations were successfully carried out into the possible aetiologies of joint lesions and periodontal disease, to better understand their influence on interpretation of the dataset (Holmes *et al.* 2021a, 2021b, 2021d; forthcoming).

POLLEN AND LAND USE

Aims and objectives

The pollen analysis aimed to produce a detailed palaeoecological framework of landscape and vegetation change from *c.*AD 50 to 1500, in order to situate medieval land use within a longer time frame. The first objective was to establish the major types of vegetation (*e.g.* woodland, heath, and grassland) in different regions and how these changed through time in response to climatic shifts, farming, and other forms of land use. The second, more specific aim was to trace the changing nature and scale of cereal farming in England in the post-Roman and medieval period.

This entailed looking closely at pollen data to track the prevalence of crops and weeds associated with cultivation, determining the relative importance of arable and pastoral land use, and establishing the overall scale of land use.

Pollen data from a wide range of published and unpublished sources were digitized and collated. Existing pollen records covering some or all of the relevant time period were identified using databases compiled by Suggitt *et al.* (2015), the Fields of Britannia project (Rippon *et al.* 2015) and Michael Grant (BPOL), in addition to Petra Dark's pioneering work bringing together data for the first millennium AD (Dark 2000). Data were also extracted from the European Pollen Database.[7] New pollen samples were analysed from six locations: Abingdon Fish Ponds (Oxfordshire), Cranberry Bed and Green Sitches (South Yorkshire), Alport Castles (Derbyshire), Stafford West (Staffordshire), and two sites in Kempsey (Worcestershire).

Samples from Stafford West and Kempsey were provided by Headland Archaeology and members of the Flood and Flow project (University of Southampton), respectively. The cores from Abingdon and the Peak District were taken using a Russian chamber corer (Figure 2.12).

All cores and unprocessed samples were stored in cool, dark conditions and wrapped in plastic to retain moisture. Abingdon was chosen as a site because of its proximity to

FIGURE 2.12. Taking peat/sediment samples using a Russian corer at Daisy Banks Fen, Oxfordshire (Photo: E. Forster).

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[7] http://www.europeanpollendatabase.net (accessed April 2022).

early medieval settlements used in the present study, including the case study site of Yarnton, and because of the scarcity of dated, high-resolution pollen sequences from the Upper Thames region. Stafford and Kempsey were included owing to the presence of excavated early medieval and later settlements at or near these sites. Furthermore, Kempsey was an important addition as Romano-British/medieval pollen sequences from Worcestershire are scarce, while Stafford is a case study for archaeobotanical and isotopic analysis (Hamerow *et al.* 2020). The three remaining sites are in the Dark Peak (South Yorkshire/Derbyshire), an area of gritstone moorland and peat bogs with few documented medieval settlements, which might be expected to show very little farming activity, and certainly no cultivation, at this time. These sites were included because preliminary analysis at the University of Sheffield focusing on the medieval parts of the cores indicated that, despite the lack of evidence for contemporary settlement, there was farming activity in this area.

Materials and methods: Pollen extraction and identification

Pollen processing techniques vary and are not always described for published datasets. Some differences in the chemicals, timings, and other elements of the process may have (mostly minor) impacts on the composition of an assemblage. For instance, acetylation, which removes cellulose from samples, can destroy pollen and spores if it is carried out for more than a few minutes (Charman 1992) and would affect fragile pollen/spore types disproportionately, biasing the assemblage towards taxa with more robust pollen that survives the process (Figure 2.13). Micro-sieving to remove the <10 μm fraction, consisting predominantly of clay particles, may lead to the loss of very small pollen types (*e.g. Myosotis* sp., forget-me-nots). Other parts of the process are known to cause swelling or shrinking of pollen, which is problematic where measurements are required for identification (*e.g.* cereals). However, these issues can be avoided through careful processing, and/or recognized and accounted for by an

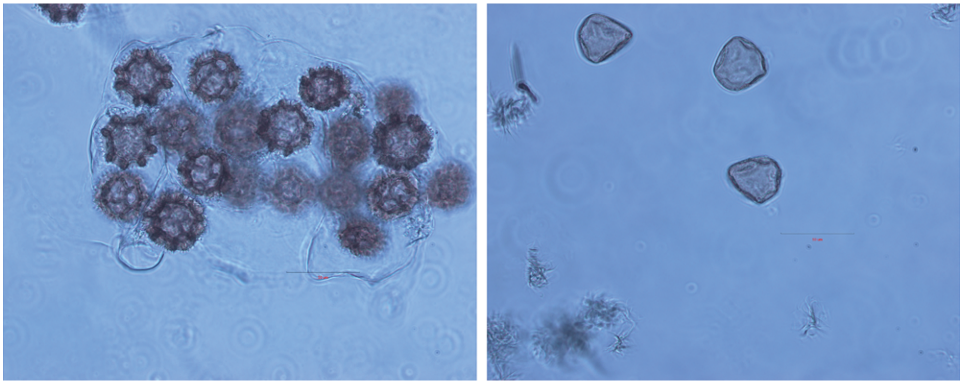


FIGURE 2.13. Examples of robust (Lactuceae, left) and delicate (Cyperaceae, right) pollen types.

experienced palynologist (*i.e.* through adjustment of measurements), so they are expected to have had little impact on the composition of published pollen data.

Analysed samples were subjected to standard procedures of potassium hydroxide digestion, macro-sieving at 180 µm, hydrofluoric acid treatment, acetylation, and mounting in silicone oil (Faegri and Iversen 1989; Moore *et al.* 1991). *Lycopodium* spore tablets were added to enable calculation of pollen concentrations, meaning the average number of pollen grains within a gram of sediment (Stockmarr 1971). Low concentrations might reflect poor preservation. A change in concentration might also indicate a shift in the rate of sediment accumulation or peat growth (*i.e.* faster accumulation would lead to a lower concentration, as there would be less time for pollen to settle on the surface before it was buried), which has implications for the chronology of the pollen core.

There is significant variability in the resolution and quality of published pollen data. Many pollen records span thousands of years with only a few samples covering the Romano-British/medieval period. The time span between samples therefore varies from a few decades to several centuries—in the latter case, it is more difficult to see trends over time and there may be substantial gaps (Figure 2.14). For our pollen cores, we aimed for a minimum of three samples per *c.*200 years, to gain a clear picture of change over time and to establish trends with more confidence. Some of the published records, particularly those from archaeological sites as opposed to 'off-site' semi-natural settings (peat bogs and lakes), have very short chronologies. These data cannot disclose change over time but do provide a valuable insight into land use close to settlements, even if it is only a snapshot of vegetation and farming during a brief period. Land use in these settings may be missed where only 'off-site' pollen records from distant peat bogs or lakes are used (*cf.* Rippon and Fyfe 2019, 141).

The amount of pollen counted per sample is also important. Preliminary 'assessment' counts of 100–150 are often carried out to establish broad patterns and to check pollen preservation. In samples/cores with poor preservation/very little pollen, and in commercial settings where finances are restrictive, full analysis may not be viable, in which case only assessment data will be produced. The majority of datasets included in the present study are based on full pollen counts (see below), but in some cases, this is uncertain as the counts achieved are not stated in all publications. At one or two sites, there were also poorly preserved samples within the sequence for which counts of 150 or less were achieved (*e.g.* Biddlesden; Branch *et al.* 2005)—these have been excluded from analysis. Standard, full pollen counts usually range from three hundred to five hundred land pollen grains (*i.e.* excluding aquatics). Within this range, the higher the count, the more likely it is that rarer types will be encountered. For most sites, this would include pollen of cereals, which, with the exception of rye (*Secale cereale* L.), are poorly dispersed (Edwards *et al.* 1986), and other crops such as hemp (*Cannabis sativa* L.) and flax (*Linum usitatissimum* L.). It is possible that counts of 150 or less, and possibly even those of three hundred or four hundred, may

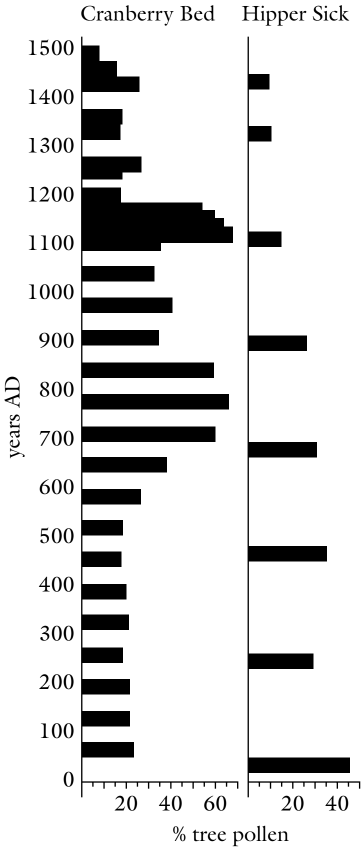


FIGURE 2.14. Percentages of tree pollen at two sites in the Peak District through time, showing differences in sampling resolution.

fail to find evidence for cultivation that would be seen with a count of five hundred. The majority of samples analysed for this project were counted to 450–500 land pollen grains on a Zeiss Axioskop microscope (×400 magnification). A small number of samples have counts of 300–450 where concentrations were too low to obtain a larger pollen count.

Identification of less common pollen types requires access to a key (*e.g.* Faegri and Iversen 1989; Moore *et al.* 1991) and a reference collection. Many plants produce pollen that cannot be distinguished from one or more other species using existing criteria and techniques and can only be identified to the level of genus, tribe, family, or 'type'. Type level identifications often encompass different species within a single genus/family, but some include taxa from different families (*e.g.* Bennett 1994), which may have quite different traits and habitats. Beyond this, levels of identification achieved depend on the palynologist's training and experience, the level of identification required for the study (especially for rarer types), and perhaps most importantly, the preservation status of the pollen. Pollen survives best in continuously waterlogged, anaerobic, and acidic environments; where preservation is poor, fragile types such as Liliaceae (lily family) may be lost, and other pollen/spores may be damaged in ways that make them unidentifiable, biasing the assemblage towards taxa with robust, easily recognizable pollen (*e.g.* Lactuceae—lettuce/dandelion tribe; Figure 2.13). This type of preservation bias is commonly seen in soil samples and assemblages from archaeological sites, although samples within otherwise well-preserved mire and alluvial sequences can be affected, for example, at Biddlesden (Branch *et al.* 2005) and Oxey Mead (Greig 2004). Recording the proportion of degraded and broken pollen and spores, both identified and unidentifiable, is a valuable tool for establishing preservation status and potential biases. These data were recorded for all new samples but were not always available for published datasets.

Identification of large grasses/cereals is notoriously difficult and requires measurement at high magnification (×1,000), after which pollen can be split into broad types (Andersen 1979; Tweddle *et al.* 2005). *Secale cereale* (rye) pollen is distinctive and can usually be identified by eye, though measurement is good practice. *Avena-Triticum* (oat/wheat) type and *Hordeum* (barley) type are more problematic; the former includes wild oat (*Avena fatua* L.) but is otherwise a reliable marker of cultivation, whereas *Hordeum* type includes domesticated and wild barleys, arable weeds such as *Elytrigia repens* (L.), Desv. ex Nevski (couch grass), and *Glyceria* R. Br. (sweet grass), a wetland/aquatic plant liable to grow in marshes, ditches, and other places commonly sampled for pollen (Andersen 1979). For our analyses, all Poaceae (grasses) with a diameter of 30 µm or more were measured at ×1,000 magnification with an eyepiece graticule and classified using Andersen's criteria. Some pollen was intermediate between types (*e.g. Hordeum/Avena-Triticum* type), and large Poaceae grains that did not meet the criteria for any of the three types were classed as 'Large wild grasses'. Most published records do not specify the criteria used for identification nor do they provide measurement data, classifying large grasses as 'Cereals', 'Cerealia', or 'Cereal-type', although *Secale cereale* is sometimes recorded separately. In these cases, it is not possible to establish the types of crops present or to rule out large wild grasses. *Cannabis/Humulus* L. identifications suffer a similar problem. *Humulus lupulus* L. (hops) pollen is smaller on average than *Cannabis sativa* L. (hemp) (Whittington and Gordon 1987), but there is overlap and—again—the identification criteria used are rarely stated. All *Cannabis/Humulus* pollen from our samples was found to fall within the expected measurements for *Cannabis sativa*.

Several nomenclatures for Northwest European pollen are in widespread use (*e.g.* Bennett 1994; Faegri and Iversen 1989; Moore *et al.* 1991). Most of the common trees and shrubs are identified to genus or species level and are broadly similar across nomenclatures, but classification of herbaceous taxa is far more variable. Species included within pollen types differ, together with the names chosen to represent those types. Taxonomic reclassification or renaming of families, genera, and species also leads to differences between older and newer studies. In order to compare data from different sites, a standard nomenclature was applied, following Bennett (1994) with a few exceptions (*e.g.* where the author's original pollen type did not fit neatly into a Bennett type).

Chronologies

Site chronologies vary greatly between studies in both their precision and reliability. In the best cases, there are multiple AMS (as used for Stafford West) or OSL (as used for Kempsey) dates for a single core, bracketing and falling within the Romano-British/medieval period. At the other extreme, some of the older, pre-AMS sequences have only one or two radiometric dates, and none between AD 50 and 1500—for example, Hipper Sick and Totley Moss (Hicks 1971). Radiometric dates are usually less precise than AMS dates since, in order to obtain sufficient carbon, the material sampled necessarily spans a greater depth in a standard 5–10-cm-diameter core. Other sequences suffer from dating reversals, contamination, and disturbance, all of which must be accounted for in analysis. Ideally, sites with problematic dates, those without at least two radiocarbon dates, and those without any in the Romano-British/medieval period, would be excluded from analysis entirely. However, owing to the scarcity of well-dated Romano-British and medieval sequences in several regions, some records that do not meet these criteria have been included, though they are treated with caution. Radiocarbon dates, including those from published work, were calibrated using the IntCal20 calibration curve (Reimer *et al.* 2020), and age-depth models were created in OxCal 4.4 (Bronk Ramsey 2008, 2009; Bronk Ramsey and Lee 2013).

Analysis and mapping

Cumulative percentage diagrams were produced for each site. Percentages were calculated relative to total land pollen (TLP) based on the following broad categories: trees, shrubs, heaths, and herbs and both with and without reeds, rushes, and sedges; these are likely to reflect the local environment at the sampling site but may also be found in hay meadows. Fluctuations in these predominantly wetland plants may also provide an insight into climatic conditions. Aquatics and spore-producing plants (ferns and mosses) were excluded from the TLP sum. Where necessary, pollen percentages were recalculated to exclude these categories from the TLP.

Establishing the overall land cover and changes related to major shifts in climatic conditions or land use, such as spread of heath or woodland clearance, is useful. However, at many of the lowland sites analysed, there was little change in these broad types between *c.*AD 50 and 1500. In some areas, much of the tree/shrub cover had been removed by the later Iron Age/Romano-British period, as previous analyses have shown (*e.g.* Fyfe *et al.* 2013; Rippon and Fyfe 2019; Rippon *et al.* 2015).

As understanding changes in the extent of arable and pasture was a key objective, a closer look at the herbaceous taxa, many of which are affected directly by cultivation and grazing, was necessary.

Arable/pastoral (AP) indices, which use ratios of herbs associated with these habitats, were first developed by Turner (1964) as a means of establishing the dominance of cultivation or grazing within a landscape. Variations on this index exist (*e.g.* Brown 1977; Donaldson and Turner 1977), but as none of these is perfect, Turner's original index was applied. Some pollen/plant types categorized as 'arable' and 'pastoral' are found in other habitats, particularly where soils are disturbed, and the difficulty of cereal identification is also problematic. Nonetheless, application to modern landscapes has found that the index works well as an indicator of land use (Pratt 1996).

The proportions of a broad range of types associated with arable and pastoral farming were also scrutinized to gain a clearer impression of changes in the scale and nature of cultivation/grazing over time. While the AP indices are undoubtedly valuable, a substantial increase in cultivation *and* grazing, wherein the ratio of arable to pastoral taxa remained constant, would not be reflected in the index. The arrival (or disappearance) of key indicators, including cereal types, potential non-cereal crops (*e.g.* hemp and flax), and *Centaurea cyanus* (cornflower, an arable weed), together with the overall diversity of AP types in the assemblage, was also recorded. Shifts in the type or diversity of relevant taxa present are likely to reflect changes in crops grown and/or methods of cultivation. For example, cornflower is a typical indicator of low-input cultivation (A. Bogaard pers. comm.).

ArcGIS Pro 2.6.2 (2020) was used to build a framework of topography, soils, underlying geology, hydrology, and rainfall patterns, all of which are important in determining the dominant natural vegetation types and may have influenced patterns of land use. Mapping was used to look at patterns at a range of scales, taking into account the expected catchment sizes for different pollen sites (*cf.* Bunting *et al.* 2004; Jacobson and Bradshaw 1981).

Feeding Medieval England: A Long 'Agricultural Revolution', 700–1300. Helena Hamerow, Mark McKerracher, Amy Bogaard, Mike Charles, Emily Forster, Matilda Holmes, Christopher Bronk Ramsey, Elizabeth Stroud, and Richard Thomas, Oxford University Press.

DOI: 10.1093/9780191988905.003.0002

THREE

The Intensity of Cultivation: Soil Fertility and the Expansion of Arable

> Manure your lands, and do not plough them too deeply, because manure wastes in descending.
>
> Walter of Henley, *Husbandry* (Lamond 1890)

INTRODUCTION: THE INTENSITY AXIS

The expansion of cereal farming in medieval England is often characterized as representing an intensification of agrarian production. This is generally taken to mean that farmers were producing larger surpluses and generally 'making the land work harder'. The term 'intensification' has also been used in the medieval context to refer to the cultivation of larger expanses of land and hence greater scales of production—that is, greater *land* intensity. Here, the term intensification is used instead to refer to greater labour investment per unit area of land in order to increase yields per unit (*cf.* Bogaard *et al.* 2019; Brookfield 1972)—that is, greater *labour* intensity. We distinguish intensification *sensu stricto* (labour intensity) from land intensity by using the concept of 'extensification' to refer to the latter (*cf.* van der Veen and O'Connor 1998). Extensification achieves greater yields by increasing the number of land units under cultivation while decreasing the amount of input (manure and human labour) per unit. A continuously cultivated infield would thus constitute a high-input, intensive system, whereas open-field farming, both 'regular' and 'irregular', is by definition low-input—an extensive system that made it possible to cultivate more land and increase overall grain yields without a *concomitant* increase in manure and (human) labour inputs. Evidence of such extensification would be found in declining inputs per unit and eventually declining soil fertility, as well as, potentially, in the expansion onto new soils. It should be observed that the term 'low-input' refers to the ecological conditions in the fields. Open-field farming was not 'low input' from the perspective of the people who work in the fields.

ARABLE EXPANSION: THE WRITTEN EVIDENCE

In a series of influential papers published in the 1960s and 1970s, the economic historian M. M. Postan argued that the demand for cereals to feed a rapidly growing medieval population required more land to be converted to arable (Postan 1966, 1972). One estimate based on written sources suggests that the six million or so acres under the plough in 1086 had increased to 10.5 million acres by *c.*1200 (Rippon *et al.* 2015, 324; Smith 2002, 187); it is indeed plausible that there was as much land under the plough in 1086 as in 1914 (Darby 1977, 131). Postan argued that the expansion of arable would have resulted in a concomitant reduction in the amount of pasture available for livestock, which in turn led to decreasing quantities of manure, making it increasingly difficult to maintain soil fertility. According to the Postan thesis, the growing ecological imbalance between arable and pastoral sectors, combined with a failure of farmers to innovate, resulted in declining soil fertility and yields per acre by the thirteenth century; by the fourteenth, this imbalance proved unsustainable, triggering a major subsistence crisis, with 'events eventually following a Malthusian course' (Campbell 1983, 26; see also Stone 2005, 39 and fig. 2.1).

Others, however, have pointed out that population growth, especially post-1000, created a large, cheap workforce that could be deployed to increase labour inputs and cultivate lands more (labour) intensively. In this way, hand-weeding, manuring, marling, and sowing legumes succeeded—at least in parts of eastern England—in maintaining or even increasing yields (Campbell 1983; Campbell and Overton 1991; Jones 2004, 183–4; Smith 2002, 187–88; Williamson 2022). Indeed, written sources of the twelfth and thirteenth centuries describe such practices, for example the collection of manure from cattle sheds and sheepcotes and the folding of sheep on fallow land, although it is difficult to establish from such sources how intensive (following the definition given above) such manuring actually was (Dyer 1995, 154; Faith 1997, 237). Archaeological evidence for this comes from 'manuring scatters'—surface scatters of medieval pottery sherds found in areas of former open fields that result from the practice of manuring arable with household waste. A recent analysis of such scatters supports the view that manuring with domestic waste increased post-1100, presumably in an attempt to boost the fertility of ever-expanding areas of arable, or perhaps of intensively cultivated 'inland' adjacent to settlements. It is possible, however, as the author of the study recognizes, that the increasing availability in this period of hard-fired, durable ceramics has skewed the picture (Jones 2004, 184; Blair 2018, 300; see also Parry 2006, 133; 276 for possible evidence for the manuring of infields in Northamptonshire).

More land was cultivated during these centuries, and farmers worked hard and deployed a range of innovations to maintain soil fertility. That is not in doubt. The question of whether these efforts were ultimately successful in maintaining fertility—on demesne and peasant land—can now be addressed directly, with new evidence. Several related aspects of 'intensity' are investigated here: soil fertility as reflected in weed ecology, which, in turn, reflects the intensity (and, by implication, scale) of arable production; the changing emphasis on arable versus pastoral farming using the ratio of sheep to cattle as a proxy; the incidence of periodontal disease in sheep and cattle as an indicator of foddering and/or fallow grazing; and the expansion of cereal farming onto heavier soils as reflected in weed ecology and crop stable isotope values.

ARABLE EXPANSION: THE ARCHAEOBOTANICAL EVIDENCE

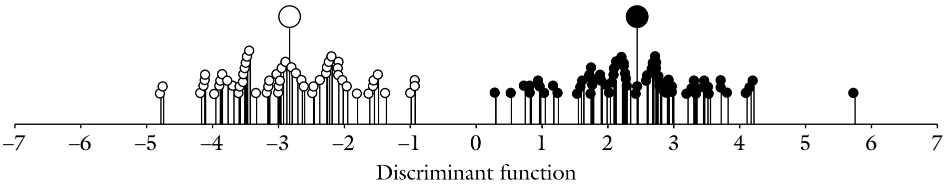
Weed ecology: A proxy for arable expansion

As introduced in Chapter 2, the project used a model for distinguishing relatively high- and low-input cereal farming systems based on functional ecological analysis of weed survey data from present-day 'traditional' cereal fields in Asturias and Haute Provence (Bogaard *et al.* 2016) (Figure 3.1a). The model consists of a linear discriminant analysis of the surveyed fields in which high- and low-input regimes are distinguished on the basis of five relevant functional ecological traits of constituent weed species in each field. Four of the five traits (specific leaf area (leaf area/leaf dry weight), canopy height and diameter, the ratio of leaf area per node to fresh leaf thickness) relate to soil fertility, while a fifth (flowering duration) reflects tolerance of soil disturbance, since the small-scale, intensively managed Asturian fields are both more fertile and disturbed than the expansive fields of Haute Provence (Bogaard *et al.* 2016). Archaeobotanical samples for this form of analysis came from published or (accessible) unpublished archaeobotanical datasets from early medieval sites in England falling within the period *c.*AD 500–1400. To be eligible, samples had to contain a minimum of ten potential weed seeds identified to species (excluding woody species/trees/shrubs and aquatic and likely foraged taxa).

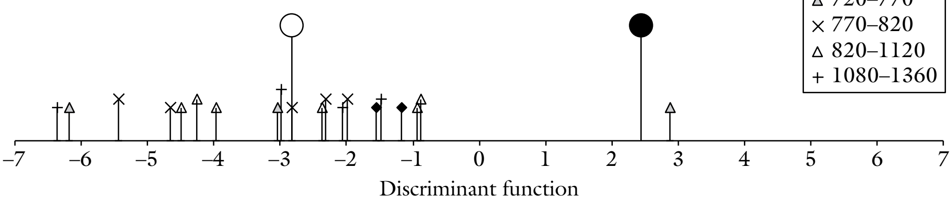
The eligible archaeobotanical samples were classified as unknown cases by the discriminant function extracted to distinguish the Asturian and Provençal fields, as set out in Chapter 2. A discriminant function score was calculated for each sample, positioning it along the discriminant function, which represents a (predominantly) fertility axis of intensity. Figures 3.1–3.3 show results from individual sites discussed here (results for all analysed sites are available in the digital archive: McKerracher *et al.* (2023), documents B46–B47), while Figure 3.4 summarizes the discriminant function scores of samples through time, by region (Central, Eastern, and Western Zones).

The site-specific and regional results all converge on the observation that most archaeobotanical samples reflect low-input growing conditions: that is, they mostly resemble the expansive, low-input fields of Haute Provence rather than the high-input, garden-like fields of Asturias. There is thus little evidence for small-scale, intensive

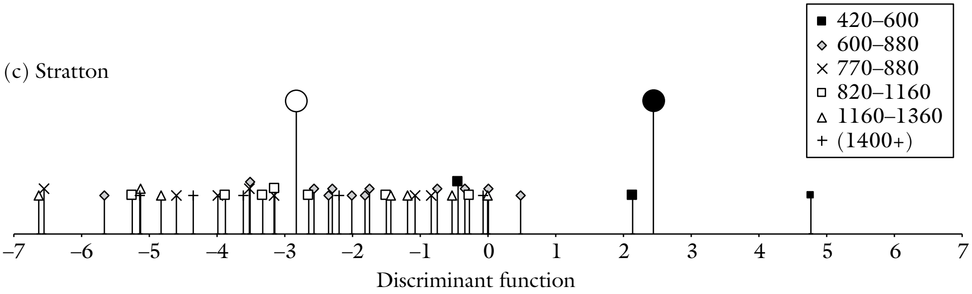
(a) model



(b) Higham Ferrers



(c) Stratton



(d) Lyminge

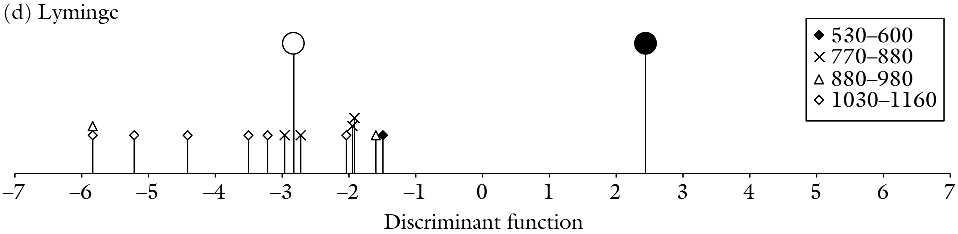


FIGURE 3.1. The top diagram shows the relationship of Haute Provence fields (open circles) and Asturias fields (filled circles) to the discriminant function extracted to distinguish these two groups (larger symbols indicate group centroids).

cultivation conditions.[1] It should be noted, however, that the weed ecological model sets the bar for 'intensity' quite high; a cultivation regime would have to be very intensive indeed to score above 0 on the discriminant function (Bogaard *et al.* 2016). It is perhaps

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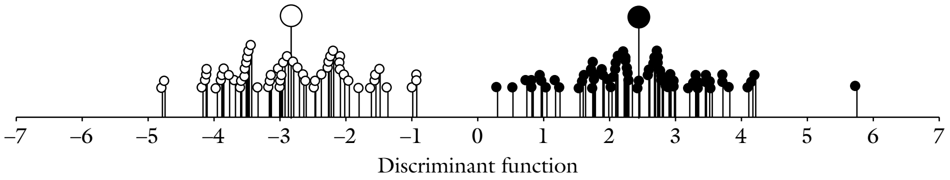
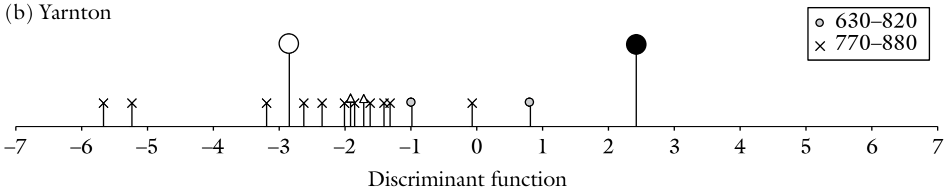
[1] The lack of wild herbivores from early medieval bone assemblages has constrained our ability to assess the impact of manuring directly from stable isotope analysis of cereal grains, although it has not prevented us from establishing whether some crops were enriched, *i.e.* preferentially manured, over others. Fertility has therefore been assessed entirely on the basis of the weed data.

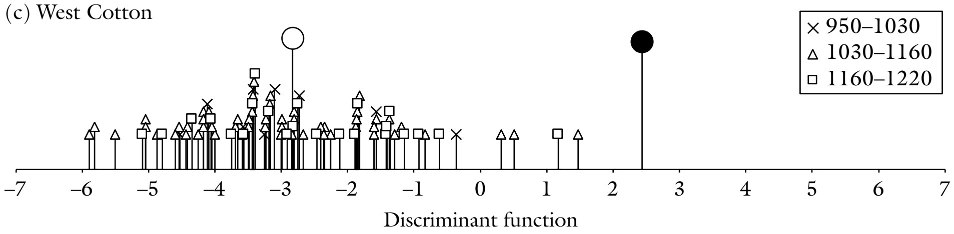
(a) model



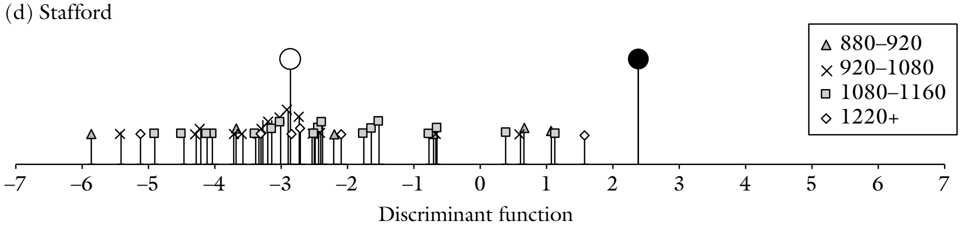
(b) Yarnton



(c) West Cotton



(d) Stafford



(e) Ely

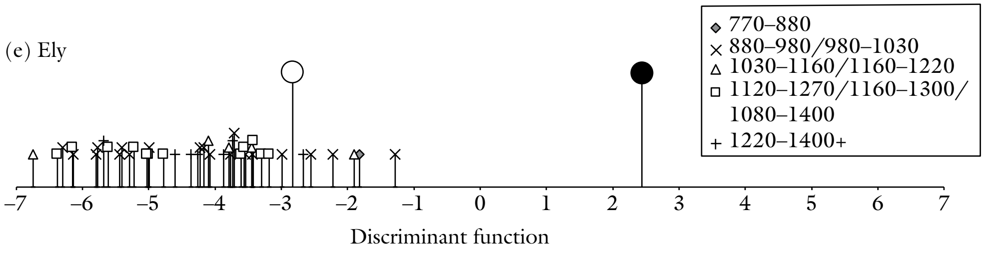
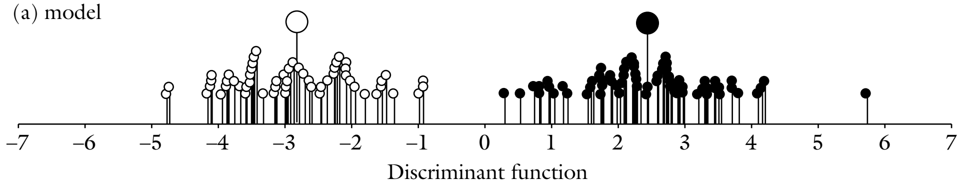
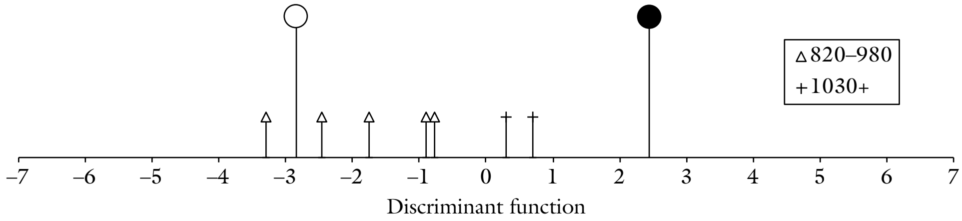


FIGURE 3.2. The relationship of archaeobotanical samples from Yarnton, West Cotton, Stafford, and Ely (b–e) to the discriminant function (a).

(a) model



(b) Wharram Percy



(c) Ottery St Mary

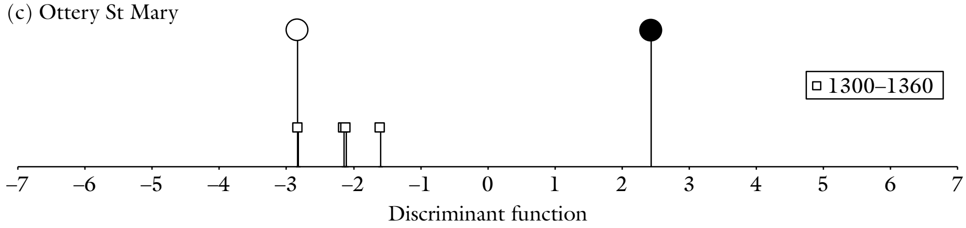


FIGURE 3.3. The relationship of archaeobotanical samples from Wharram Percy (b) and Ottery St Mary (c) to the discriminant function (a).

unsurprising then that so few medieval samples have been classified here as 'intensive'. Nevertheless, it can be seen that in all regions, throughout the period from *c.*700 to 1300, the majority of samples reflect a broad continuum of 'low input' soil conditions, albeit with a 'tail' of more intensive samples, ranging between 5% and 25% of the total.

Within this overall result, however, there are also discernible trends of declining discriminant scores and hence soil fertility through time, both within some individual sites and across certain regions. While only a small number ($N = 6$) of eligible samples date to FeedSax phases A and B (*i.e.* pre-700), it is notable that most of these produced higher, more 'intensive' scores than did later samples, suggesting a predominance of smaller-scale cultivation during the fifth to seventh centuries (see Figure 3.4a, for the Central Zone).[2] This is apparent, for example, at the settlements of Higham Ferrers (Northamptonshire) and Stratton (Bedfordshire) in the Central Zone and Lyminge in the Eastern Zone (Figure 3.1). Due to the limited number of early sam-

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[2] These also display significantly higher scores than do the mid-late Roman samples from the chalk downlands of Hampshire analysed by Lodwick (2023, Fig. 5d), suggesting a shift to smaller-scale, more intensive cultivation in the post-Roman centuries.

ples, it is not possible to establish whether these somewhat more intensive methods involved infield–outfield farming or something else. Nevertheless, the evidence adds weight to the argument for a shift to lower-input regimes during the eighth century. A general trend towards lower-input, more extensive regimes over time is, furthermore, apparent at Yarnton and West Cotton in the Central Zone, Stafford in the Western Zone, and Ely in the Eastern Zone (Figure 3.2). No obvious regional variability emerged from the analysis, although it is notable that samples from Wharram Percy (Figure 3.3a), the most northerly of the sites examined, and Ottery St Mary in the south-west (Figure 3.3b), while still reflecting broadly low-input cultivation regimes, are markedly less 'extensive' than most other sites in the study. Moreover, Ottery St Mary's tightly focused values reflect the fact that the samples derive from a single event, namely the destruction of a granary.

The summary scatter plot for the Central Zone (Figure 3.4a) shows a weak but significant trend of declining discriminant scores through time (mixed effects model with site as a random effect; conditional $R^2 = 0.16$, $p < 0.01$), as does the summary scatter plot for the Eastern Zone (Figure 3.4c) (conditional $R^2 = 0.15$, $p = 0.03$). The Western Zone does not show any trend through time, appearing resolutely low-input from the tenth century onwards, although this may be due to the fact that samples predating *c.*900 are lacking (Figure 3.4b).

Although the weed ecological data from the Central and Eastern Zones tell a story of gradually declining soil fertility, manorial accounts—as already noted—indicate that in some regions at least, gross yields did not decline and may in some cases even have increased in the thirteenth century. Campbell has argued, for example, that on demesnes in eastern Norfolk, declining fertility was mitigated through the use of green manures, marling, weeding, less frequent fallowing, and more frequent fallow ploughing, up to six times per cycle (Campbell 1983). The decline in soil fertility demonstrated by the weed ecology does not mean that measures designed to maintain fertility were not adopted; rather it shows that these efforts were in the face of a long-term trend that they were unable to reverse. Why were these measures ultimately inadequate? According to Postan, there was, by the thirteenth century, simply insufficient manure available relative to the amount of arable; the high value of manure and of the labour services involved in its collection, transport, and spreading tend to support the view that manure was a scarce resource (Banham and Faith 2014, 42–3; Jones 2009). Stone (2005, 66–9) has argued, however, that the decline in soil fertility apparent during the fourteenth century at the demesne farm at Wisbech Barton, Cambridgeshire, was not down to a lack of manure, some of which remained unused, and that the records reveal no clear link between stocking levels and yields: 'The cause of falling yields at Wisbech in the early fourteenth century is not to be found in soil exhaustion per se, but instead in the decisions and actions of the men who ran the farm' (Stone 2005, 72). There may have been other factors at play. Comet (1997, 26) notes that in eleventh-century France, fresh dung was spread directly onto the fields,

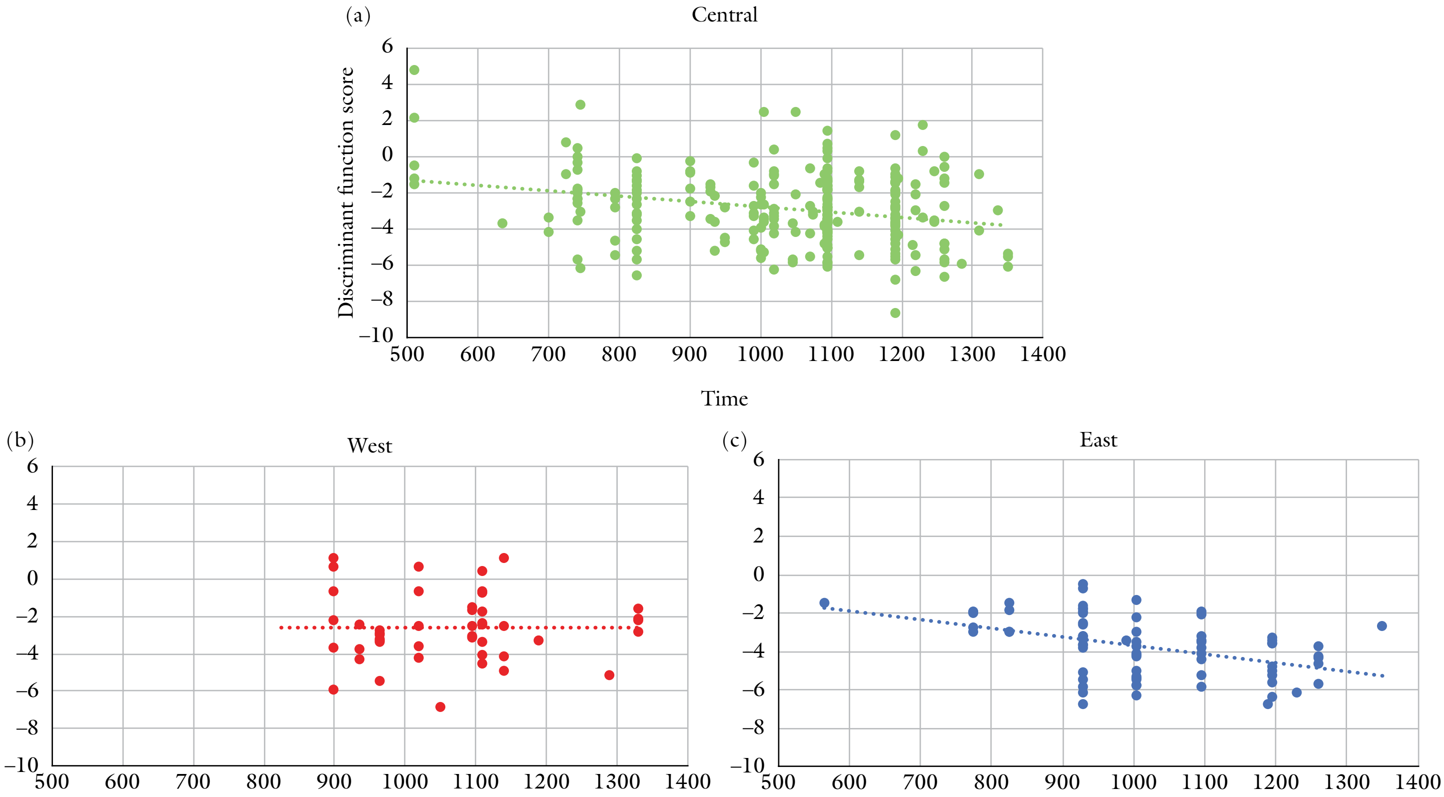


FIGURE 3.4. Scatter plots summarizing the discriminant function scores of archaeobotanical samples through time, by region: (a) central, (b) western, and (c) eastern. The *x*-axis shows the midpoint date of samples. Samples included contain at least three weed taxa identified to species and are assigned to a time span of less than 300 years.

a practice that could have resulted in a loss of nutrients from the soil (see discussion of the impact of manuring on isotope values, below). Intensive folding of sheep could have had a similar effect. Writing in the thirteenth century, Walter of Henley recommends instead mixing the manure with earth before spreading the mixture on to the fields (Lamond 1890, 21); this would have reduced leaching. Multiple ploughing of fallow could also have reduced the effectiveness of manuring by mobilizing and 'using up' organic matter; the passage quoted at the start of this chapter suggests that this was a problem of which farmers were aware. Fallow ploughing combined with growing use of the mouldboard plough increased net levels of soil disturbance (see Chapter 5). While experimental work has shown that fallow ploughing prevents the fallow reverting to a grassland and counters the compaction of the soil caused by grazing livestock (C. Kropp pers. comm. 2022), it could, paradoxically, have contributed to declining soil fertility even while, to some extent, preserving yields.

A case study undertaken in the Rhineland (Hamerow *et al.* 2021) provides a unique long-term perspective on arable weed ecology and crop growing conditions from the Neolithic to medieval periods, to which the English data can be compared (Figures 3.5–3.8). In the region west of Cologne, a trend towards extensification can be discerned by the later Bronze Age, continuing through the Iron Age, and reaching a peak in the supply systems that provisioned Roman military camps and associated

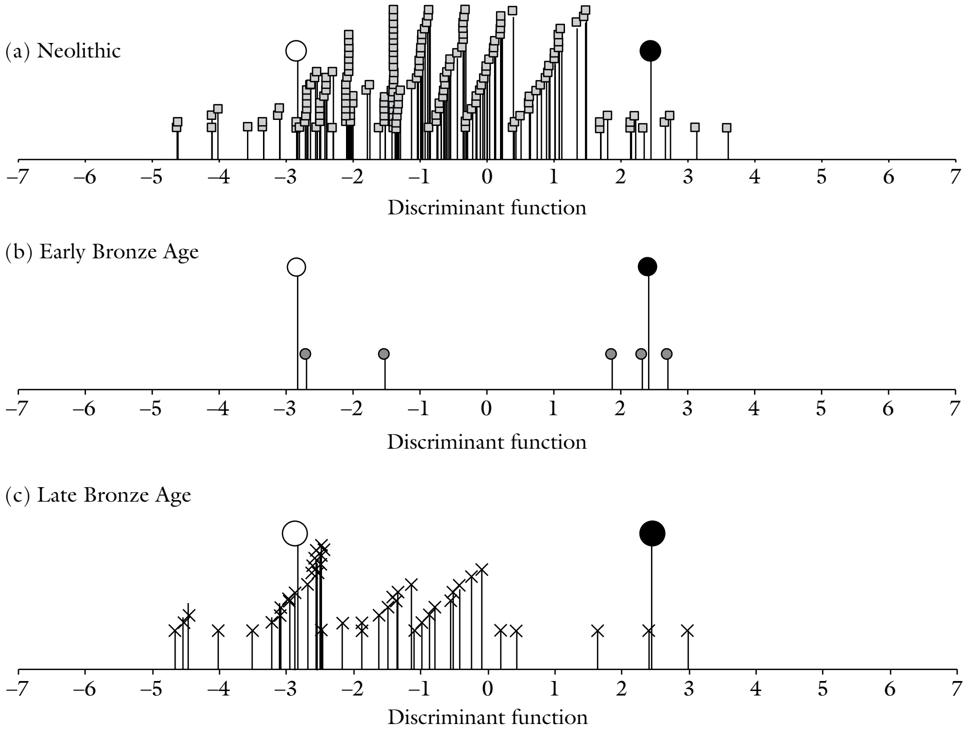


FIGURE 3.5. Discriminant scores of Neolithic and Bronze Age assemblages from the Rhineland.

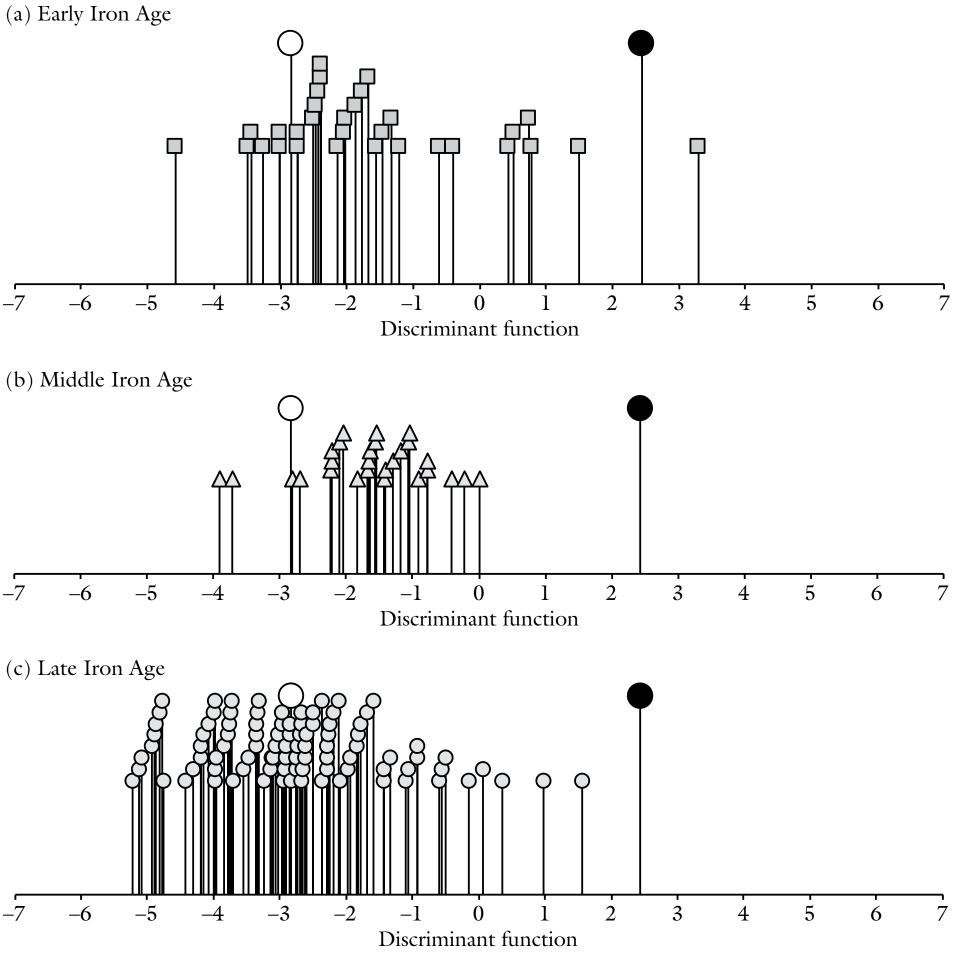


FIGURE 3.6. Discriminant scores of Iron Age assemblages from the Rhineland.

towns. Medieval archaeobotanical assemblages from the Rhineland reflect expansive, low-input production regimes that continued this long-term trend, while also reflecting a subtle shift towards lower fertility during the medieval period.

Weed ecological analyses of Iron Age and Roman archaeobotanical assemblages from Britain using the Asturias–Provence model (Bogaard *et al.* 2016) are sparse, but emerging results suggest that, here, too, medieval low-input farming was a continuation and reiteration of a longer-term agroecological trend. Recent work by Lodwick (2023) on Iron Age to Roman assemblages from Danebury, Hampshire shows that extensive, low-input farming was established in this landscape long before the medieval period, as in the Rhineland. As we shall see with the addition of further 'layers' of weed ecological and crop stable isotope data in subsequent chapters, what was distinctive about the medieval agroecology was its tendency towards higher soil disturbance levels (alongside declining fertility) through time—made possible by the mouldboard plough—combined with systematic crop rotation (Chapters 4 and 5).

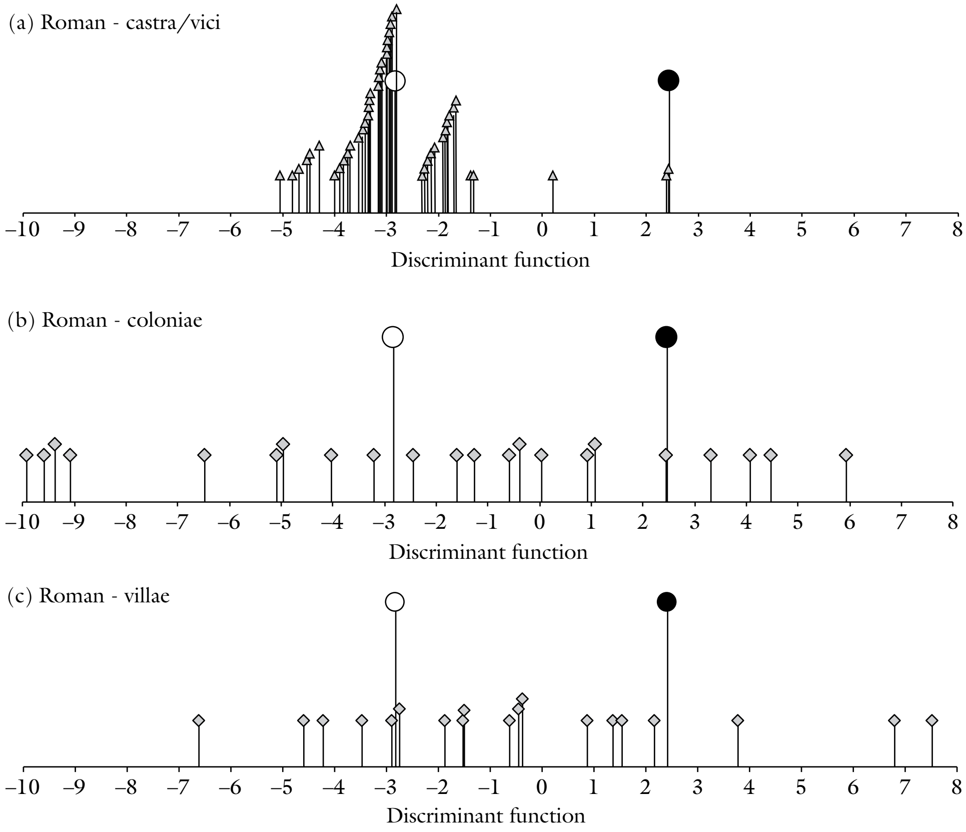
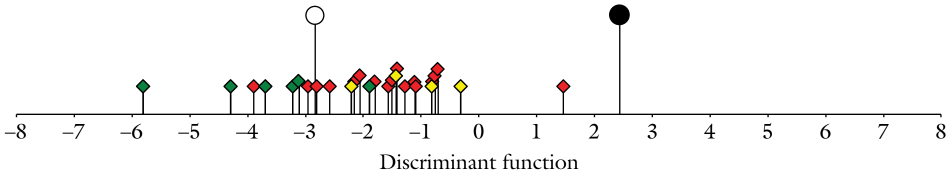


FIGURE 3.7. Discriminant scores of Roman weed assemblages from the Rhineland.

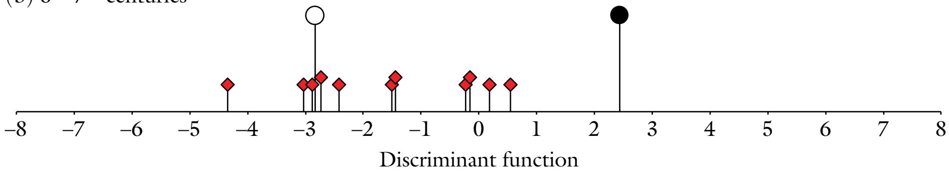
Weed diversity and arable expansion

The diversity of arable weeds represented in the archaeobotanical record can serve as a proxy for extensification for three reasons. First, a physical expansion of arable land may bring under cultivation a wider range of topographies and soil types—with a range of different land use histories—each favouring a different range of weed species. Second, a less intensive cultivation regime necessarily entails a less thorough approach to controlling weed populations, especially perhaps at field margins where tillage may have been less thorough and thus less effective at destroying weeds. Third, and specifically for the medieval period and when mouldboard ploughs were in use, the development of ridge-and-furrow landscapes created an inherently diverse terrain within arable fields, with alternating higher and lower levels of moisture, exposure, and disturbance. It is hypothesized here that weed diversity will increase particularly during the process of the expansion of arable land, as wild flowers' habitats were newly encroached upon. Subsequent years of crop husbandry may then have progressively 'weeded out' species that were more vulnerable to cultivation pressures: for instance, increasingly improved drainage consequent on ploughing may have increasingly disadvantaged species that thrive in damper soils.

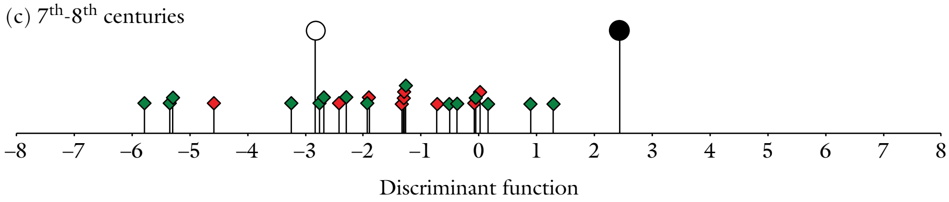
(a) 5th-6th centuries



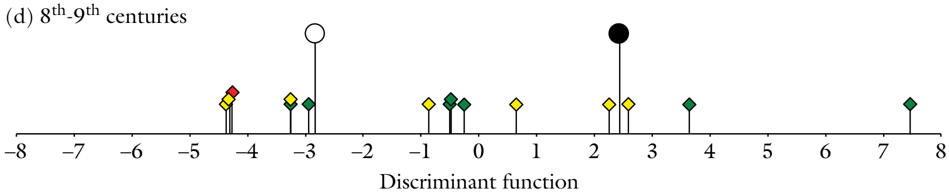
(b) 6th-7th centuries



(c) 7th-8th centuries



(d) 8th-9th centuries



(e) 10th century and later

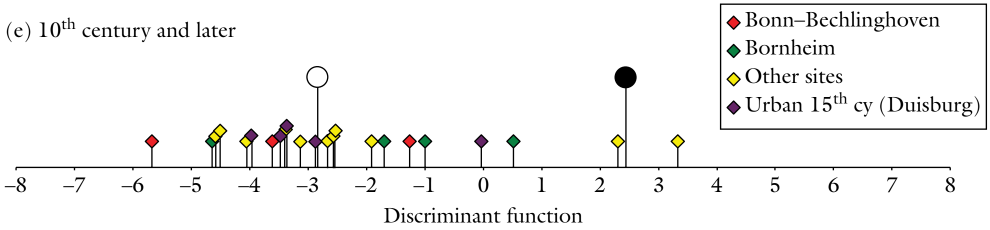


FIGURE 3.8. Discriminant scores of medieval weed assemblages from sites in the Rhineland.

From this generalized perspective, the ecological preferences or behaviours of *individual* weed species are not of central importance: the hypothesis is simply that the *number* of different weed species in the archaeobotanical record may reflect the degree of extensification (and especially arable expansion) in a given region and period. This approach must focus exclusively upon species-level identifications of weed seeds, since genus- and family-level identifications represent an unknowable number of different species, likely including those already identified to species level in the very same assemblages. To facilitate the investigation of geographical and chronological trends, these analyses are also restricted to the best-represented periods (phases C–F: *c.*AD 670–1300) and regions, thus excluding the two northern regions and the South West (see Chapter 2).

Data from all eight regions are included, however, in the counts of weed species graphed in Figure 3.9. This national picture shows an increase in weed diversity through phase C (670–880), a drop and slight recovery in phase D (880–1030), and

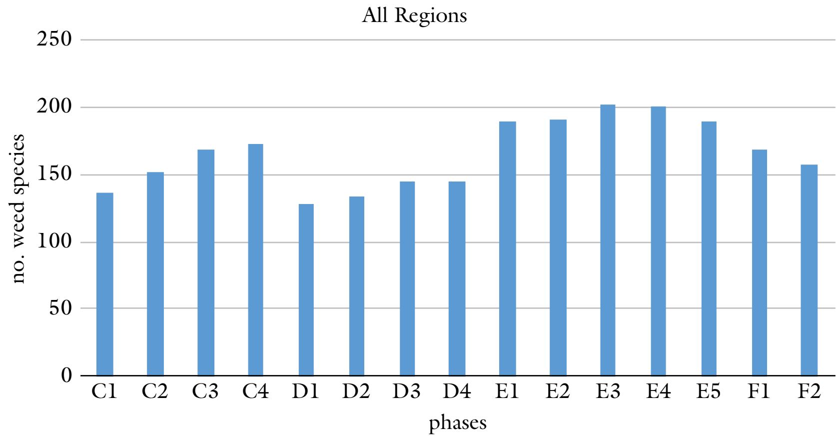


FIGURE 3.9. Numbers of weed species present in all regions, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

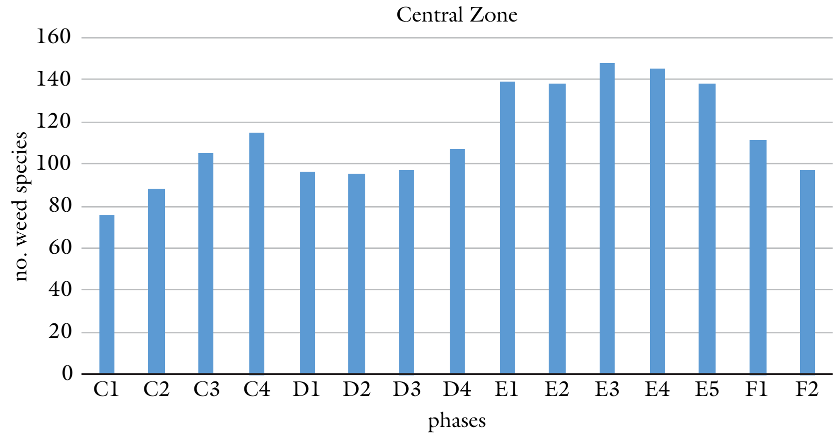


FIGURE 3.10. Numbers of weed species present in the Central Zone, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

then a further increase to a new peak in E1–E3 (1030–1120) before a steady fall through E4–F2 (1120–1300). This national pattern is broadly mirrored by the data from the Central Zone, perhaps unsurprisingly, as much of our evidence derives from this region (Figure 3.10): diversification through phase C, a reduction and small recovery in phase D, a new peak of diversity in E1–E3, then a steady reduction through E4–F2. Following the hypothesis set out above, it could thus be argued that in the Central Zone, phases C and D4–E3 witnessed arable expansion, while phases D1–D3 and E4–F2 were periods of consolidation, during which the cumulative effects of years of cultivation 'weeded out' those species of the diversified weed flora that were less tolerant of the environmental impacts of farming.

In the data for East Anglia, numbers of weed species are consistently lower than those recorded in the Central Zone throughout the whole period, perhaps reflecting a generally less varied arable landscape (Figure 3.11). The chronological trend in East Anglia superficially resembles that of the Central Zone, with diversification in phase C, contraction in D, diversification in E1–E3, and contraction in E4–F2. But the changes between phases are much smaller and, unlike in the Central Zone, there is no long-term, sustained diversification in the East Anglian weed flora. On the contrary, the overall trend is towards *lower* diversity.

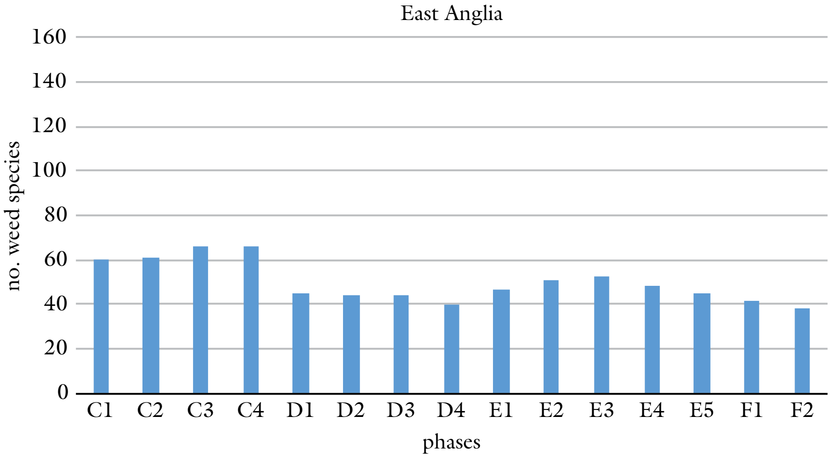


FIGURE 3.11. Numbers of weed species present in East Anglia, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

The numbers of weed species identified in the Fens are again much lower than those seen in the Central Zone—unsurprisingly, given that the Central Zone is a much larger region with more varied topography and geology—but broadly comparable to those recorded in East Anglia: between thirty and sixty species in most phases (Figure 3.12). However, the chronological trend in species diversity in the Fens

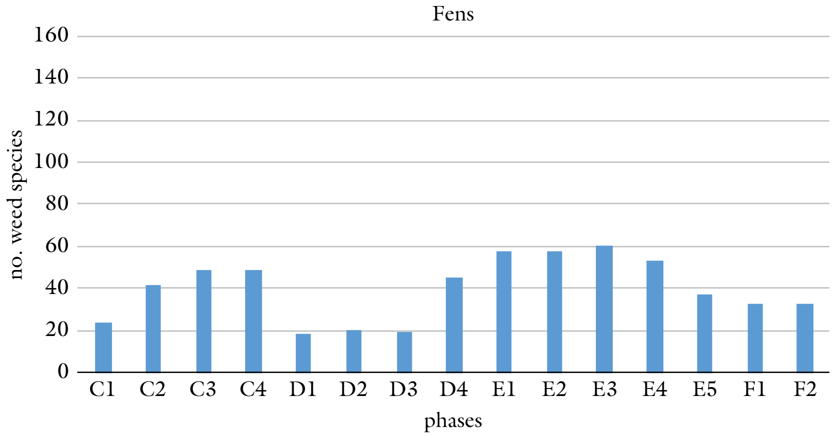


FIGURE 3.12. Numbers of weed species present in the Fens, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

FIGURE 3.13. Numbers of weed species present in the South East, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

resembles that of the Central Zone, rather than East Anglia: increasing during phase C (when arable farming is hypothesized to have begun in the Norfolk and Lincolnshire Fens; Murphy 2005), dipping in D1–D3, rising again through D4–E3, then falling through phases E4–F2.

The numbers of weed species identified in the South East are generally higher than those observed in East Anglia and the Fens, perhaps reflecting a greater variety of arable terrains, as in the Central Zone (Figure 3.13). The chronological trend, however, more closely resembles that seen in East Anglia, with the most sustained weed diversity in phase C, a fall in phase D, a partial recovery through phase E (peaking in E5, in this case: 1160–1220), and a slight dip in phase F. Hence, we may have here another instance of 'consolidation' in phase D, between relatively short episodes of expansion in phases C2 and (less markedly) E1 and E5. Overall, however, the range of environments under cultivation does not appear to have increased over time.

Finally, the data for the Western Lowlands exhibit a unique chronological trend, which contrasts with the national picture and the other regional patterns. The diversity of weed species increases steeply and continuously, with no sustained dips, between phases C1 and E4 (670–1160)—reaching a peak of 159 species, higher than any other phase in any other region—before a steep drop in E5 and no significant recovery in F1–F2 (Figure 3.14). According to the theoretical model followed here, the Western Lowlands therefore appear to have witnessed the most sustained processes of arable expansion in any of the regions studied, with no pronounced or sustained periods of consolidation until E5 (1160–1220), although this may reflect limited arable land use prior to the tenth/eleventh centuries relative to other regions, a hypothesis that finds support in the pollen data (see Chapter 6).

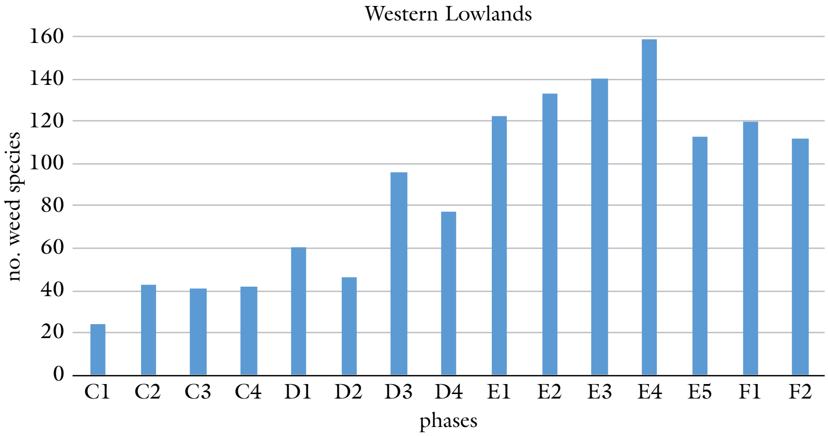


FIGURE 3.14. Numbers of weed species present in the Western Lowlands, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

Taking these results together, we might thus identify a period of arable expansion onto new terrains during phase C in most regions (670–880); a period of consolidation and/or contraction roughly corresponding to phase D (880–1030) in most regions except the Western Lowlands; renewed expansion during phases E1–E4 (1030–1160), to different degrees in different regions (only superficially in East Anglia); and then further consolidation and/or contraction through phases E5–F2 (1160–1300), to some extent in every region.

Expansion onto heavy soils?

An obvious elaboration of this simple species-counting approach is to consider which kinds of species were added to (or subtracted from) arable weed populations in particular phases, and whether these indicate the absorption of particular kinds of new terrain: specifically heavy clays, as might be expected to accompany the uptake of the mouldboard plough (see Chapter 5). An expansion or shift in settlement onto heavier soils from the mid-seventh century onwards has long been recognized, from both fieldwalking surveys (*e.g.* in the Sandlings of Suffolk: Newman 1992) and distributions of excavated settlements (Arnold and Wardle 1981; Hamerow 1991, 1992). This locational trend does not necessarily indicate, however, that there was a general expansion of arable farming onto heavy clay soils in this 'long eighth century'. Many excavated settlements dated variously between the fifth and ninth centuries in fact occupy riverine locations with both lighter gravel terraces and heavier clay vales within their hinterlands—and no automatic indication that the latter terrains were ploughed rather than grazed (McKerracher 2018, 35–38).

Weed ecology could in principle help to indicate where and when arable expanded specifically onto heavy clay soils. Unfortunately, it is difficult to pinpoint definitive 'indicator species' for heavy clays—since few if any weeds are exclusively characteristic of such soils—and a distinctive set of functional traits has not yet been characterized. Much weight is often placed upon stinking chamomile/mayweed (*Anthemis cotula* L.) as an indicator species, because of its close association with heavy clays noted in field observations (Kay 1971, 625). It is not unusual for the cultivation of heavy, damp, or clayey soils to be inferred solely from the presence of *Anthemis cotula* seeds in an archaeobotanical assemblage.[3] But the species is not exclusive to heavy clays: Kay (1971, 625) adds, for instance, that it is 'also locally common on the heavier chalk soils', and Stace (2010, 755; emphasis added) notes that it grows '*often* on heavier soils'. Above all, it remains unclear as to why, in biological terms, *Anthemis cotula* should be especially characteristic of heavy clay soils. The association is autecological (observation-based) rather than functional (trait-based), meaning that we do not yet fully understand *why* stinking chamomile favours heavy soils, and how this behaviour might be affected by different cultivation practices—if any—on such soils (Charles *et al.* 1997).

An updated review by Adhikari *et al.* (2020), intended as a successor to Kay's (1971) paper, investigates ecological reasons for the persistent invasiveness of this 'aggressively weedy' species in many countries around the world. Although it describes stinking chamomile's preference for 'slightly acidic, nitrogen-rich, heavy and clay-loam

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[3] Examples, often cautious, include Ballantyne (2005, 101; 2010, 171); Carruthers (2011, 41); Giorgi (2018, 27); Jones (2005, 199); McKerracher (2017, 131); Martin (2012, 166); Pelling (2013, 635); Straker (1995, 155). Not all reports specifically mention clays: some associate *A. cotula* with heavy calcareous/base-rich soils (*e.g.* Campbell and Robinson 2010, 435; Hunter and Nicholson 2014, 77).

soils' (Adhikari *et al.* 2020, 315),[4] the paper also notes that the species has achieved a global distribution in the modern era, having been reported from every continent (including Antarctica: Adhikari *et al.* 2020, 316). Such a distribution arguably depicts *Anthemis cotula* as an environmental opportunist more than a clay connoisseur. Moreover, it is stated that stinking chamomile is 'morphologically and reproductively plastic . . . enabling it to exploit a range of environments and overcome injury' (Adhikari *et al.* 2020, 317)—not an ideal qualification for an indicator species.

Other factors that potentially contribute to the invasive success of *Anthemis cotula* include the abundance of its seeds (5,000–27,000 per plant) and their long dormancy (viable for up to twenty-five years in the soil, pending environmental conditions conducive to germination: Adhikari *et al.* 2020, 315). It is this latter facet that Martin Jones (2009, 61) has drawn upon to associate *Anthemis cotula*—along with cornflower (*Centaurea cyanus* L.) and charlock (*Sinapis arvensis* L.)—with mouldboard ploughing; species with shorter and simpler seed dormancy are deemed more vulnerable to the deep burial and/or seasonal destruction consequent on deep ploughing. An association between *Anthemis cotula* and mouldboard ploughing would, arguably, necessarily accompany an association with heavy soils, which would have required mouldboard ploughing for extensive cultivation.

An additional observation pertaining to seed dormancy might also be relevant in this context. A five-year germination experiment, including simulated tillage three times per year, found that most *Anthemis cotula* seedlings appeared in the first and (especially) second years after sowing, with numbers declining thereafter (Roberts and Neilson 1981).[5] Hence, although seeds might remain viable for twenty-five years in the soil, Roberts and Neilson's study suggests that the majority of seedlings may appear within three years. It could be argued that this behaviour is highly compatible with a three-field system, in which every permutation of the arable regime (discounting climatic variables) is passed through every three years. This would allow *Anthemis cotula* seedlings to exploit the most suitable niche(s) within the whole three-year agricultural cycle, while leaving enough long-dormant seeds in the seedbank for the species quietly to endure a run of inclement years.

All of the factors discussed above—the observed predilection for heavy soils, the seed dormancy, the apparent emphasis upon germination within three years—could suggest that *Anthemis cotula* likely enjoyed a competitive advantage in three-field regimes utilizing mouldboard ploughs on heavy clay and clay–loam soils. But, given its phenotypic plasticity, there does not appear to be a strong case for treating stinking chamomile as a definitive indicator species for heavy clay cultivation. It is certainly risky to treat it as a *solitary* indicator species, since that approach is too readily skewed

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[4] *Cf.* Kay (1971, 625), noting a preference for heavy clay or clay-loam soils 'especially if they are *base*-rich' (my emphasis).

[5] The low seedling emergence in the year of sowing was attributed to the tough pericarp of the seeds, which required softening by soil microorganisms before germination (Roberts and Neilson 1981, 329).

by chance occurrences or contaminants that may be unrepresentative of a medieval settlement's original weed flora (Jones 1992, 136–37). It may still be informative, however, to trace the prevalence and frequency of this particular weed's occurrence across several sites, since chance occurrences and contaminants ought not to skew entire regional datasets as they might single-site interpretations.[6] The mere presence of *Anthemis cotula* seeds in a given region and period does not conclusively demonstrate the tillage of heavy terrains, but changes in frequency over time may be more significant.

On this basis, the possibility of 'heavy soil expansion' cannot be excluded at a national level: *Anthemis cotula* is the most prevalent weed species in the entire dataset, occurring at 66.6% of all sites, and the most frequent, occurring in 34.4% of all samples. Both prevalence and frequency increase between phases C1 and E1 (670–1060) and then change very little through phases E2–F2 (1060–1300) (Figures 3.15 and 3.16).

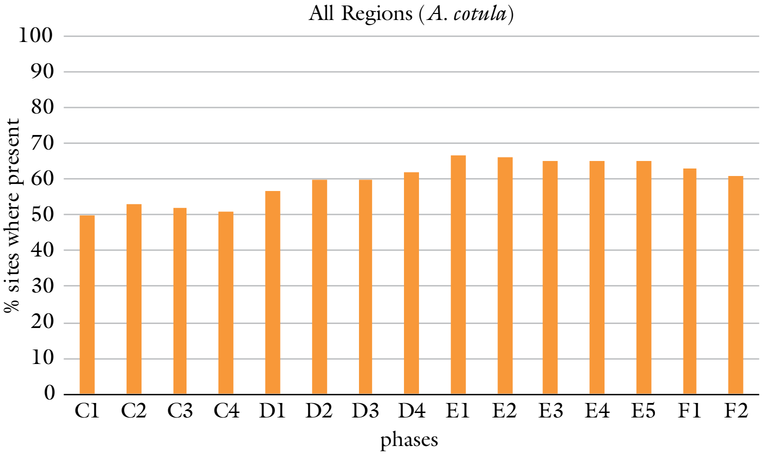

FIGURE 3.15. Prevalence of *A. cotula* seeds across all regions, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

The data for the Central Zone exhibit broadly similar but rather more stable patterns, with no pronounced or sustained change in prevalence (which remains relatively high and stable, around 70%) and a gentle overall rise in frequency between phases C and E before a small drop in phase F (Figures 3.17 and 3.18).

Prevalence and frequency are consistently much lower in East Anglia, which is perhaps unsurprising given that the region as a whole is less characterized by heavy clay

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[6] 'Prevalence' and 'frequency' here stand for the percentages of sites and samples, respectively, in which *Anthemis cotula* seeds have been identified: see the discussion of presence analyses in Chapter 2.

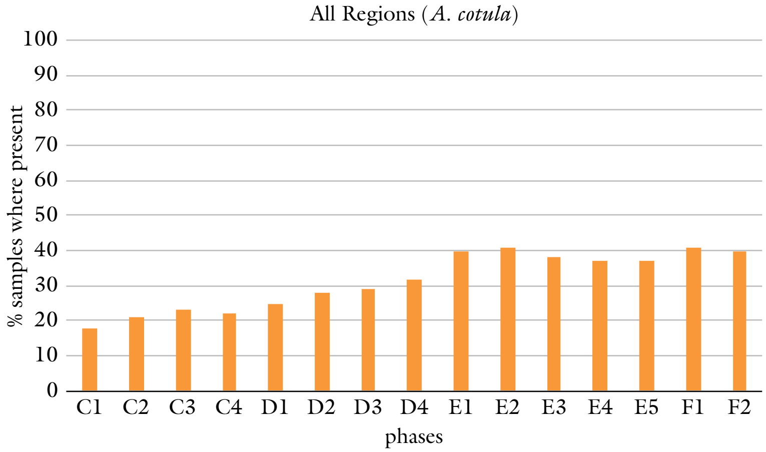

FIGURE 3.16. Frequency of *A. cotula* seeds across all regions, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

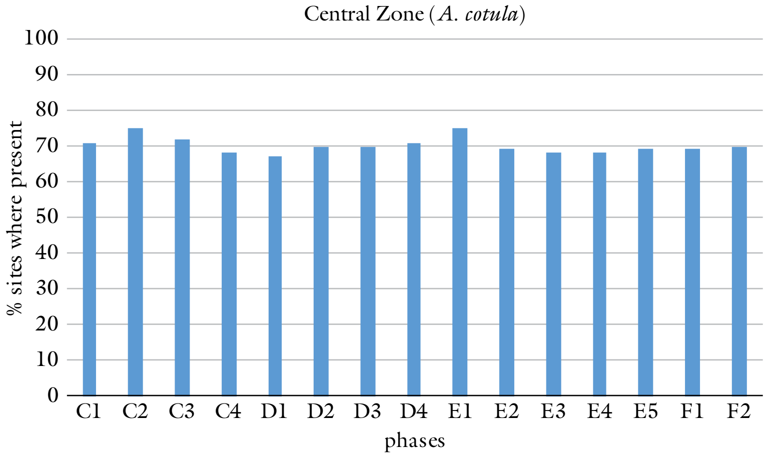

FIGURE 3.17. Prevalence of *A. cotula* seeds in the Central Zone, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

soils than the Central Zone. Although there are indeed substantial claylands in the central East Anglian Plain, these areas—and especially the poorly drained northern portion of the plain—are not well represented in the archaeobotanical dataset (Figure 2.1; Williamson 2003, 26–27; 94–101). The prevalence of *Anthemis cotula* in East Anglia rises to around 50% of sites throughout phases D2–E5 (950–1220), and overall frequency increases through phases D–E, before a modest decline by both measures in phase F (1220–1300) (Figures 3.19 and 3.20). The increased prevalence and

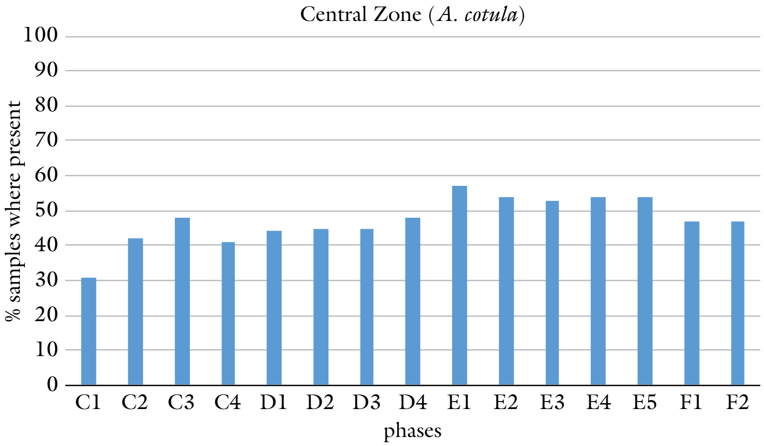

FIGURE 3.18. Frequency of *A. cotula* seeds in the Central Zone, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

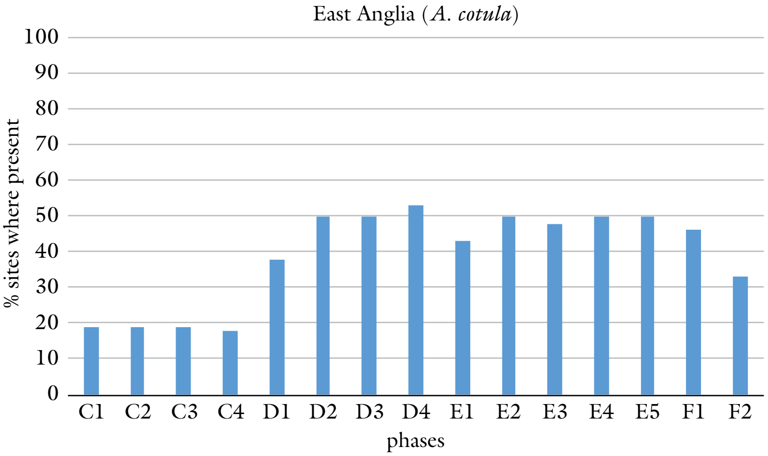

FIGURE 3.19. Prevalence of *A. cotula* seeds in East Anglia, by phase. Phase C1, 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

frequency of *Anthemis cotula* in phases D–E are particularly noticeable given the lack of any overall floral diversification in East Anglia (above, Figure 3.11). Thus, while there may have been little or no arable expansion onto new environments in phases D–E, there may yet have been an increase in the exploitation of already-cultivated heavy soils in this period.

Prevalence data for the Fens are restricted by the low numbers of sites (presence analyses in this study require at least ten sites or samples: see Chapter 2), but in phases C2–C4 at least, *Anthemis cotula* is clearly as widespread here as in the Central Zone,

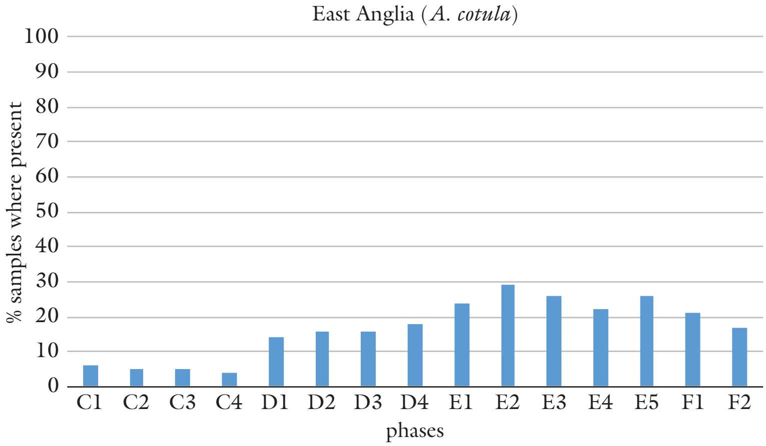

FIGURE 3.20. Frequency of *A. cotula* seeds in East Anglia, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

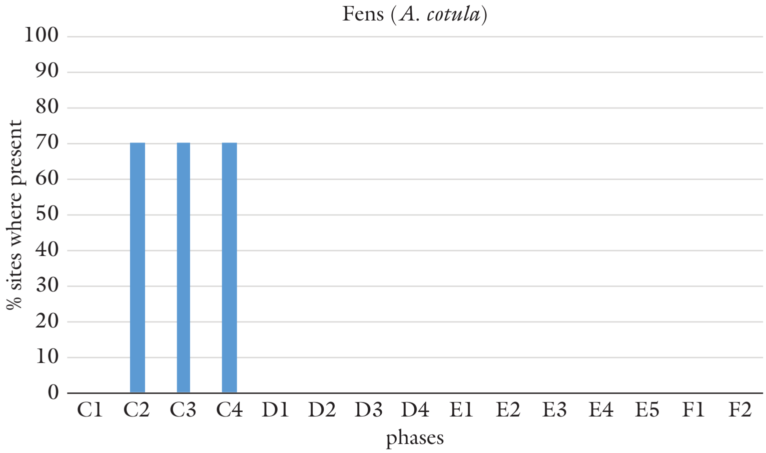

FIGURE 3.21. Prevalence of *A. cotula* seeds in the Fens, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

occurring at 70% of sites (Figure 3.21). Since both of these regions include expansive clayey terrains, this prevalence fits with the species' observed modern predilection for such soils. Despite this early prevalence, however, the frequency of *Anthemis cotula* seeds is low in phase C, but it rises markedly in phase D and again in E, with no decline in F (Figure 3.22). This step-change in phase D, in particular, would chime well with the findings of the Fenland Survey, which posited the erection of a sea wall around the tenth century, and consequent reclamation of land and expansion of agriculture, including on the heavy soils of the inland 'backfens' (Rippon 2002, 58; Silvester 1988, 156–64).

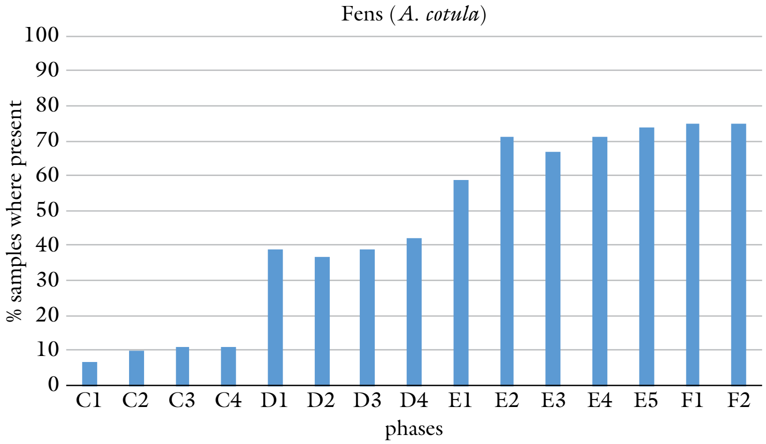

FIGURE 3.22. Frequency of *A. cotula* seeds in the Fens, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

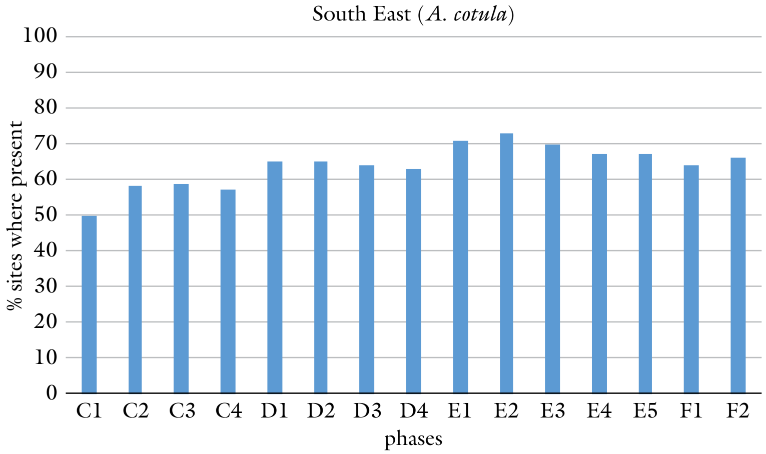

FIGURE 3.23. Prevalence of *A. cotula* seeds in the South East, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

Prevalence in the South East is relatively high, rising from 50% in phase C1, to 73% in E2—comparable to the Central Zone—before a slight overall decline between E3 and F2 (Figure 3.23). Despite this comparatively high prevalence, frequency is generally low, with levels more comparable to those seen in East Anglia, and seldom exceeding 30% until phase F (Figure 3.24). The implication is that, while *Anthemis cotula* clearly grew in many locations in the South East and East Anglia, it was never among the most frequently harvested cornfield weeds there.

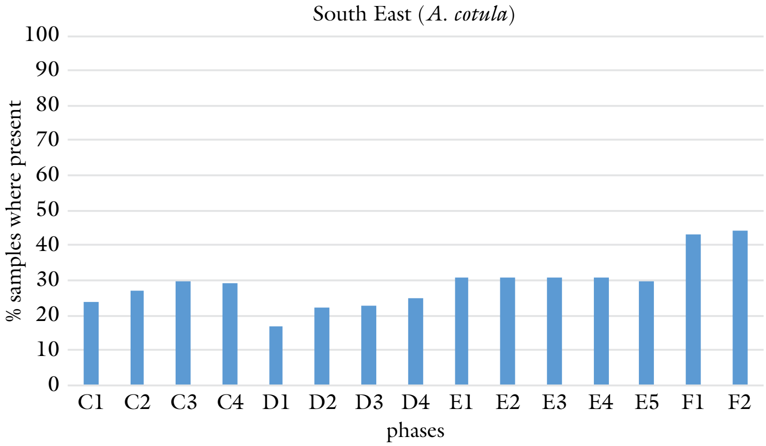

FIGURE 3.24. Frequency of *A. cotula* seeds in the South East, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

Finally, in the Western Lowlands, we have another truncated sequence for prevalence due to the low numbers of sites dated earlier than phase E3 (1080–1120). Where we have data, however, prevalence is high: exceeding 70% in phases E3–E5 before falling in phase F, but never below 50% (Figure 3.25). The frequency data reinforce this impression of a late decline in *Anthemis cotula*, but with an earlier peak in phases D3–E2 (950–1080) after a steady rise during C2–D2 (Figure 3.26). Hence, while there probably was an expansion onto heavy clay soils in the Western Lowlands sometime between the seventh and eleventh centuries, it apparently did not continue past the late eleventh century.

It is worth noting at this point that the changing frequencies of *Anthemis cotula* over time in different regions do not closely track the trajectories of overall weed diversity. In other words, when stinking chamomile increases or decreases its presence in a region/period, this is not simply because *all* weed species have a greater chance of occurring in that region/period. Thus, the fall in weed diversity seen during phase D in the Central Zone does not seem to affect the frequency of *Anthemis cotula* in that period, which does not dip (Figure 3.27). The same discrepancy is shown, even more strikingly, in the Fens (Figure 3.28). If, as hypothesized above, phase D witnessed a period of arable consolidation in those regions—with slowed expansion onto new terrains and an erosion of biodiversity—*Anthemis cotula* cannot have been among the species ‘weeded out’ by the cumulative impact of long-term cultivation. In these clayey regions at least, stinking chamomile clung tenaciously to its habitats despite (and perhaps even assisted by) the environmental

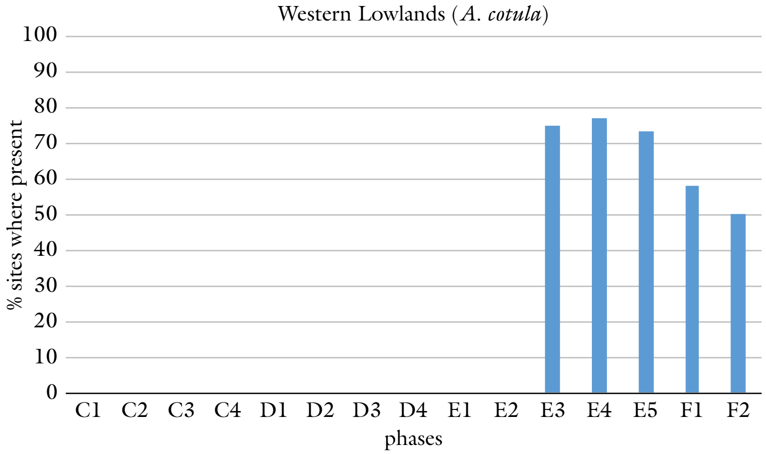

FIGURE 3.25. Prevalence of *A. cotula* seeds in the Western Lowlands, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

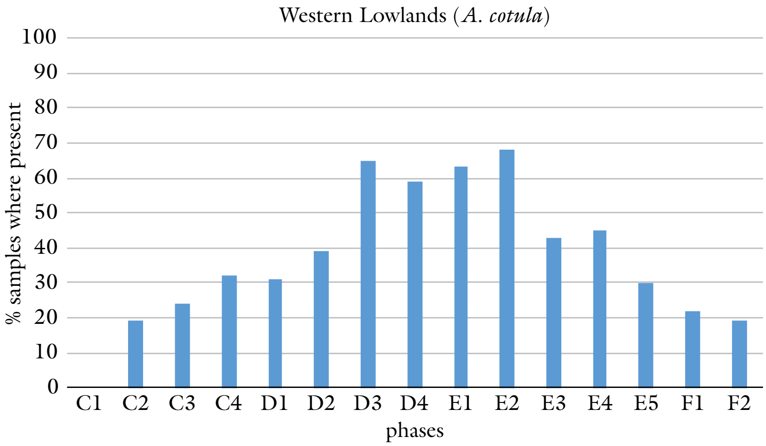

FIGURE 3.26. Frequency of *A. cotula* seeds in the Western Lowlands, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

impacts of crop husbandry. This tenacity is noted in Fitzherbert's (1523) *Boke of husbandrie*, where 'mathes' or 'dogfennell' (*A. cotula*) is described as 'the worst wede that is, except terre' (cited Jones 2009, 61).[7]

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[7] If 'terre' here corresponds with *Vicia* L./*Lathyrus* L. (vetches/tares), this archaeobotanical identification is indeed more common than *A. cotula* in the national dataset, occurring at 67.2% of sites and in 40% of samples.

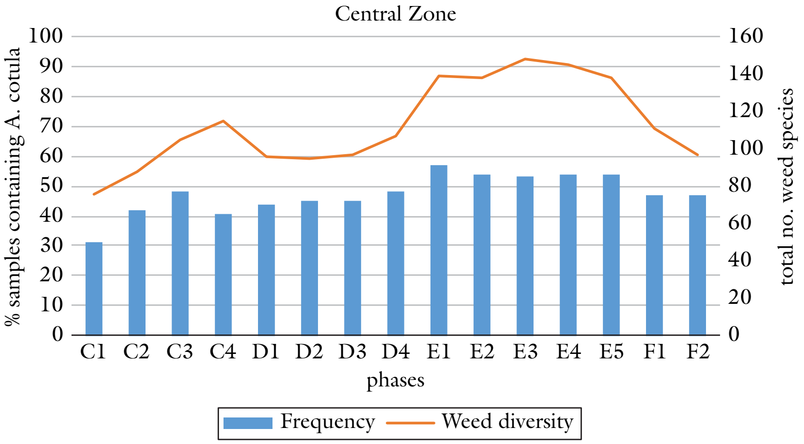

Figure 3.27. Frequency of *A. cotula* seeds in the Central Zone plotted against overall weed diversity, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

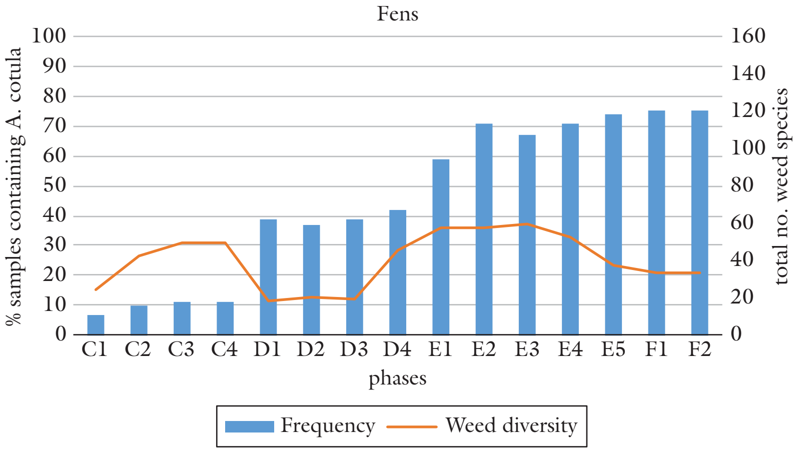

Figure 3.28. Frequency of *A. cotula* seeds in the Fens plotted against overall weed diversity, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

Conversely, in the Western Lowlands, the frequency of *Anthemis cotula* declines after E2, while weed diversity is still climbing to its peak (Figure 3.29). Therefore, if weed diversification indicates a continued expansion of arable onto new terrains, those newest fields did not encroach further upon stinking chamomile's domains. Perhaps those areas—heavy clays or otherwise—had already been exploited to their full potential by that time.

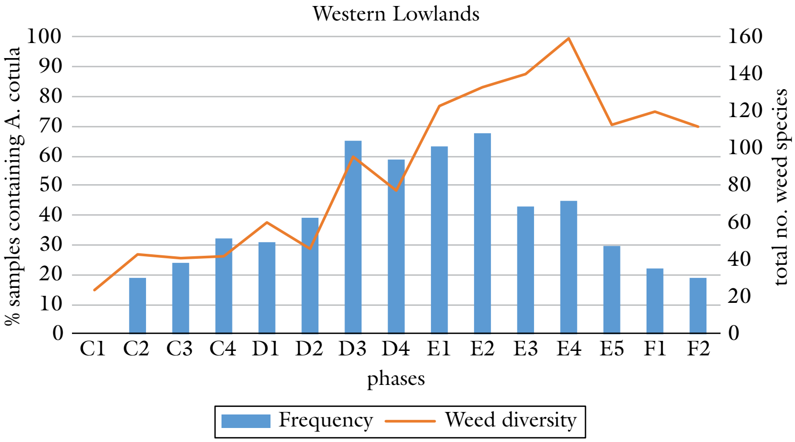

FIGURE 3.29. Frequency of *A. cotula* seeds in the Western Lowlands plotted against overall weed diversity, by phase. Phase C1 670–720; C2 720–770; C3 770–820; C4 820–880; D1 880–920; D2 920–950; D3 950–980; D4 980–1030; E1 1030–1060; E2 1060–1080; E3 1080–1120; E4 1120–1160; E5 1160–1220; F1 1120–1270; F2 1270–1300.

A possible narrative

We may now outline a narrative of arable expansion that is consistent with—though not conclusively demonstrated by—the results presented above (with strong caveats attached to inferences about heavy soils based on the prevalence and frequency of *Anthemis cotula*).

East Anglia seems to have witnessed either the least or the earliest arable expansion, with farmlands reaching their maximum extent or environmental variety as early as phase C (670–880), although, as noted above, the claylands of the central East Anglian Plain are poorly represented in the archaeobotanical dataset, giving us an incomplete picture. Within the subsequent overall stability, however, heavy soils may have been more frequently and systematically exploited over time. The South East similarly underwent little or no arable expansion after phase C, though there may have been a period of consolidation in phase D (880–1030) followed by renewed but very limited expansion in phase E (1030–1220). Within this pattern, heavy soils had a persistently limited role in the South East—unsurprisingly in a region more generally characterized by greensand, chalk downland, and forested sandstone ridges.

Arable expansion was much more pronounced in the Central Zone and Fens, and incorporated an increasing role for heavy soils (which are more common in these regions): proceeding mainly in phases C and E, interleaved with periods of consolidation (or potentially arable contraction) principally in phases D and F (1220–1300). However, the most dramatic sequence of arable expansion is seen in the Western Lowlands, continuing almost unabated throughout phases C–E, with no prolonged periods of consolidation or contraction until the late twelfth or thirteenth century.

Heavy soils may have played an increasingly important part in this expansion process, but only until phase E2 (1060–1080), when heavy-soil farmland perhaps reached its maximum extent and subsequent arable growth encroached upon different terrains instead.

ARABLE EXPANSION: THE ISOTOPIC EVIDENCE

As noted in Chapter 2, the $\delta^{15}N$ values of grain can tell us much about the soil conditions in which crops were grown, but careful consideration must be given to the different factors that can affect these values.[8] $\delta^{15}N$ values of cereal grains relate to the isotopic value of the nitrogen the plants utilized during growth. Multiple factors can influence the $\delta^{15}N$ value of plant-available nitrogen: microbial and fungal activity, seasonal wetting and drying, waterlogging, aridity, salinity/salt spray, manuring, fire, and nitrogen-fixing vegetation (Bogaard *et al.* 2007; Fraser *et al.* 2011; Grogan *et al.* 2000; Handley *et al.* 1999; Hartman and Danin 2010; Hobbie and Högberg 2012; Yousfi *et al.* 2010). Only once the potential factors influencing the $\delta^{15}N$ value of early medieval cereal grains have been disentangled, is it possible to use $\delta^{15}N$ values to shed light on agricultural expansion onto heavier soils. In general terms, however, such expansion would be expected to cause an enrichment in ^{15}N due to seasonal wetting/waterlogging and drying of such soils.

The $\delta^{15}N$ value obtained when cereal grains are analysed is the ratio of the two stable isotopes of nitrogen within the grain: ^{14}N and ^{15}N. As the $\delta^{15}N$ value is a ratio,[9] it does not provide any information about the *amount* of nitrogen in the soil. Soil with a small amount of plant-available nitrogen can still produce cereal grains with high $\delta^{15}N$ values; this would occur if the small amount of nitrogen was composed predominantly of the heavier isotope of nitrogen. Thus, it must be remembered that the $\delta^{15}N$ value provides no information about the amount of nitrogen available to the plant during growth; instead, it provides information about the relative proportion of the lighter to heavier isotopes of nitrogen available to the plants. To understand whether the plants had a high or low amount of nitrogen, referred to by some as soil fertility, we must use other proxies such as weed ecology.[10]

Nevertheless, while $\delta^{15}N$ values do not provide information about the amount of nitrogen available to a plant, they can be used to infer manuring levels of a plant.

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[8] $\delta^{13}C$ values are of limited use in temperate locations, due to the low occurrences of water-limited conditions; see Chapter 2 for details.

[9] Delta values provide the relative difference of an isotopic ratio between a sample and international standards—so in effect a ratio of a ratio.

[10] Some research has equated high $\delta^{15}N$ values with high fertility or soil health (see *e.g.* Dreslerová *et al.* 2021; Gron *et al.* 2021) but caution is advised in the absence of weed ecological data since high $\delta^{15}N$ values do not necessarily indicate high fertility.

To infer manuring (or other processes), modern studies are used to understand what $\delta^{15}N$ values occur under certain situations. Plants cultivated on manured soil have been found to have higher $\delta^{15}N$ values than plants from unmanured soil (Bogaard *et al.* 2013). As manure decomposes, the lighter isotope of nitrogen in the form of ammonia gas is released into the air, leaving the solid manure enriched in the heavier isotope (^{15}N). The $\delta^{15}N$ value of plants growing in such soil would be higher compared to unmanured plants. Other environmental processes, as explored further below, also alter the $\delta^{15}N$ ratio of soil nitrogen and therefore plants. Such processes also facilitate the removal of the lighter isotope, resulting in higher $\delta^{15}N$ values.

The $\delta^{15}N$ values of the case study sites' cereal grains are highly variable (Table 3.1), in part due to many of the samples being single grains; bulk sampling results in an averaging of the inherent variability of crop $\delta^{15}N$ values. Experimental work conducted as part of this project has shown that in a single field with low-level manuring, $\delta^{15}N$ values of single grains can vary by up to 3.6‰ (Std ± 0.9‰) (McKerracher *et al.* 2023, document D01). Bulk samples were analysed for Stafford, Yarnton, and some samples from Pudding Lane, potentially reducing their variability, while samples from all other sites consist of single grain samples (see Chapter 2 for details). In addition to this variability, the case study sites' $\delta^{15}N$ values are generally high, averaging around 6 or 7 ‰ (Table 3.1) in comparison to modern unmanured grains, which commonly have $\delta^{15}N$ values around 1–2‰ but vary depending on soil conditions, with manuring levels in particular elevating values (Bogaard *et al.* 2007; Fraser *et al.* 2011; Kanstrup *et al.* 2012; Styring *et al.* 2016). The highest modern experimental $\delta^{15}N$ values for manured cereals are >15‰ when grown in arid environments and, in one case, manured with sea bird guano (Styring *et al.* 2016; Szpak *et al.* 2012).

Several possible environmental factors that alter $\delta^{15}N$ values may be ruled out immediately due to the location of the case study sites.[11] Aridity, which elevates $\delta^{15}N$ values, can be discounted due to the temperate climate of England (Hartman and Danin 2010). Nitrogen-fixing vegetation can also be ruled out as the cause of elevated $\delta^{15}N$ values. While it is possible that leguminous crops (peas, broad beans, and vetches, etc.) were grown either as a cereal/pulse mixture or in rotation with medieval cereals, introducing nitrogen to the soil, such a process would result in a lowering of the $\delta^{15}N$ value, as leguminous nitrogen has a low $\delta^{15}N$ value (close to 0‰ if just using atmospheric N_2[12]) (Unkovich 2013). Salinity/salt spray, which can change plant $\delta^{15}N$ (Handley *et al.* 1997; Heaton 1987; Yousfi *et al.* 2010), can also be ruled out for all inland sites; only Lyminge and Ottery St Mary are sites where salinity/spray needs to be considered, being *c.*6.5 km and 8 km from the coast, respectively. However, these sites are not directly coastal; to be affected by oceanic derived nitrate in sea spray, which would elevate the $\delta^{15}N$ values of the crops, these would have had to have been

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[11] See Appendix 1 for soil maps for each of the case study sites.

[12] Atmospheric N_2 has a $\delta^{15}N$ value of 0‰, which is taken up by legumes.

grown at some distance from the site. Furthermore, samples from Lyminge and Ottery St Mary have very different δ^{15}N means, with the mean for Lyminge not particularly high (3.85‰), while Ottery St Mary (7.3‰) has the highest δ^{15}N values of the case study sites. This suggests that it is highly unlikely that the grains from Lyminge were affected by salt spray, although it is a possibility for Ottery St Mary.

Fire can raise the δ^{15}N value of soil nitrogen and therefore can elevate plant δ^{15}N values (Grogan *et al.* 2000). Of note is the practice of 'Devonshiring' or beat burning—part of the convertible husbandry tradition in Devon and Cornwall where weeds from neglected fields were burnt and the resulting ash spread on the ploughed field. The earliest records of beat burning date to the sixteenth century, but the practice is likely to have had medieval origins (Stanes 2009, 165). Isotopic research has found inconsistent patterns of plant δ^{15}N enrichment post burning, some studies finding plants with higher δ^{15}N values post fire, while other show no change or lower δ^{15}N values post fire (Beghin *et al.* 2011; Cook 2001; Grogan *et al.* 2000; Huber *et al.* 2013). Grogan *et al.* (2000) found up to a 6‰ difference in δ^{15}N values, but such an increase was found in non-arable systems with high biomass. One study of the potential arable consequences of burning on recently cleared forest fields found wheat grain had δ^{15}N values 3.8‰ higher in burnt fields compared to unburnt fields, but this study directly examines the impact of clearing forest with fire; hence, a large amount of biomass was burnt (Styring *et al.* 2017, 372).

Ottery St Mary is in Devon, and it is possible that crop δ^{15}N values may have been impacted by Devonshiring or a similar practice. As already noted, the δ^{15}N values from Ottery St Mary are significantly enriched (mean of 7.3‰), potentially due in part to the site's proximity to the coast. The site also produced some of the highest individual δ^{15}N values of any of the case study sites (>10‰). The very high δ^{15}N values at Ottery St Mary in fact suggest that fire was not the principal cause of this elevation, as fire would cause only a modest rise; if fire had any impact on δ^{15}N values at Ottery St Mary, it was in conjunction with another process that significantly enriched the landscape in ^{15}N. At the other sites, it is possible that burning prevented the microbial immobilization of nitrogen but the impact on δ^{15}N values is undetermined in a fully established temperate cropping system (Hoyle and Murphy 2006). Aridity, salinity, and fire can therefore be ruled out as significant factors that elevated the δ^{15}N values of the case study site's crops. While the possibility that fire elevated the δ^{15}N values at Ottery St Mary should not be completely dismissed, the enrichment of the crops at the site indicates that it was not the principal reason.

Modern studies indicate that the application of manure can enrich cereal grain ^{15}N compared to unmanured grains (Bogaard *et al.* 2013). The δ^{15}N values of the case study sites do show similar values to Iron Age, Roman, and medieval isotope values obtained from Northern European continental locations, many of which have been attributed to manuring (Bogaard *et al.* 2016; Heinrich 2012; Larsson *et al.* 2019; Lodwick *et al.* 2020; Makhad *et al.* 2022; Styring *et al.* 2017), with some of these studies supported with weed ecological data (*e.g.* Bogaard *et al.* 2016; Styring *et al.*

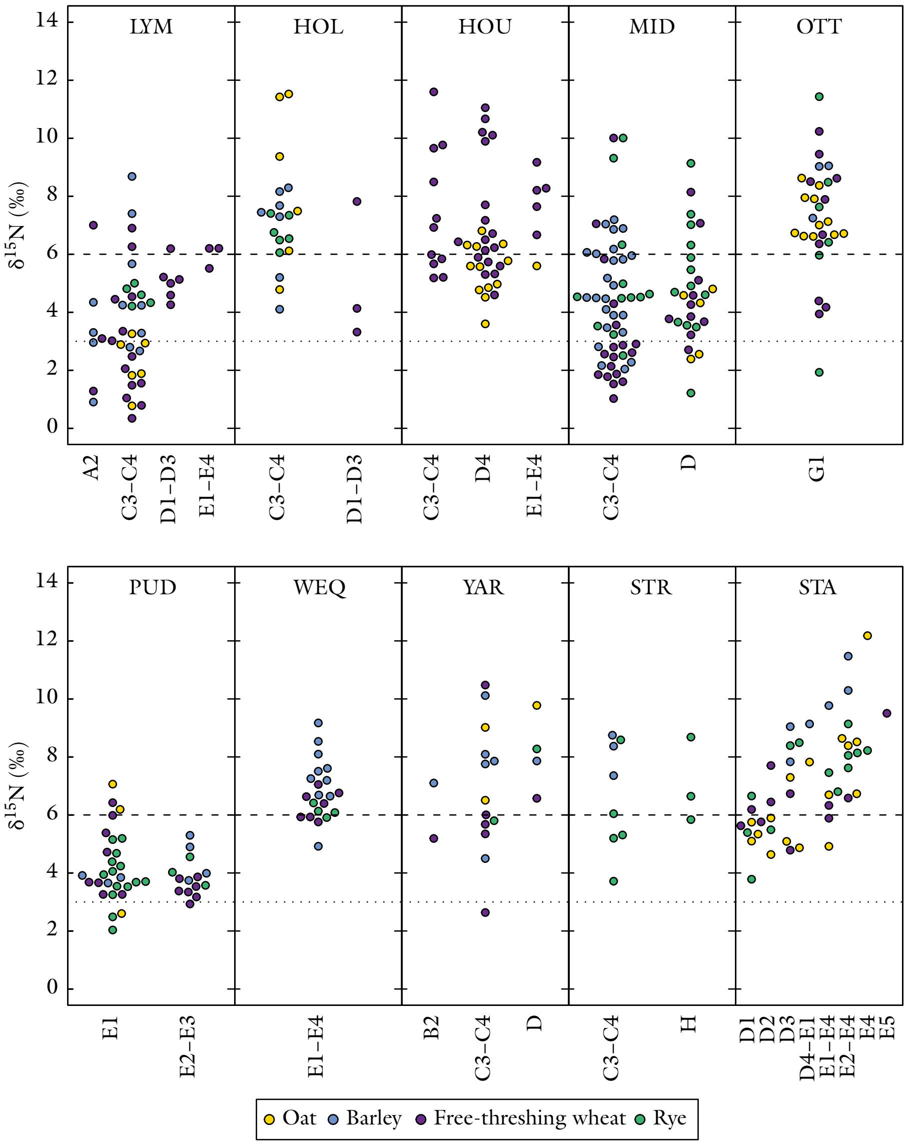

FIGURE 3.30. The δ^{15}N values of the cereal grains from the ten case study sites plotted by phase, shown against the modern manuring bands of Bogaard *et al.* (2013). The dashed line denotes the lower limit of high manuring, and the dotted line denotes the lower limit of moderate manuring. Note that the extremely high δ^{15}N values of rye from Ottery St Mary (>15‰) are not shown.

2017). The δ^{15}N values of seven of the ten case study sites, whether considered by phase or as site averages, are above 6‰—the value commonly used as the lower boundary of the high manuring band extrapolated from long-term experimental manuring using cattle manure in Germany, Denmark, and the UK (Bogaard *et al.* 2013). When the data from this project are compared, 53% of the samples plot within the ‘high manuring band’ (Figure 3.30). However, such bands do not take into account that the localized soil and environmental conditions in medieval England could have been very different from those used in the modern experiments; each site may have a different baseline, making it difficult to compare between sites.

In order to assess the relevance of modern manuring bands, many researchers have additionally used wild herbivore collagen values to extrapolate an unmanured vegetation's δ^{15}N value (*e.g.* Styring *et al.* 2017), allowing potential manuring to be understood in relation to natural ^{15}N enrichment; indeed, use of herbivore baselines was advocated by Bogaard *et al.* (2013). Unfortunately, there are no isotopic analyses of wild herbivore collagen from the case study sites. There are δ^{15}N values for fallow deer collagen from Roman sites in Kent that can be used to understand whether the δ^{15}N values of crops from Lyminge (also located in Kent) are significantly elevated, and therefore potentially manured (Madgwick *et al.* 2013). However, the temporal distance between the crops and the fauna (first to third century compared to eighth to tenth century) as well as the fact that the collagen data are from a different site (they are from the same region, but not the same location, ~30 km apart) means any results need to be interpreted with caution. Figure 3.31 shows the Lyminge crop isotope values graphed against the extrapolated wild/unmanured vegetation values from the Kent deer data—a band that takes into account the consumer-diet offset and the difference between δ^{15}N values of the leaves and stems, that is, what the herbivores would have been consuming, compared to the crop δ^{15}N values (Fraser *et al.* 2011; Steele and Daniel 1978). The majority of Lyminge's sample values fall within or below the shaded green range of extrapolated unmanured vegetation (Figure 3.31). Even the later phased free-threshing wheat values, which produced higher mean values than did the earlier phases, fall within the shaded band, albeit at the upper limit. This indicates that there is little difference between the δ^{15}N value of the crop com-

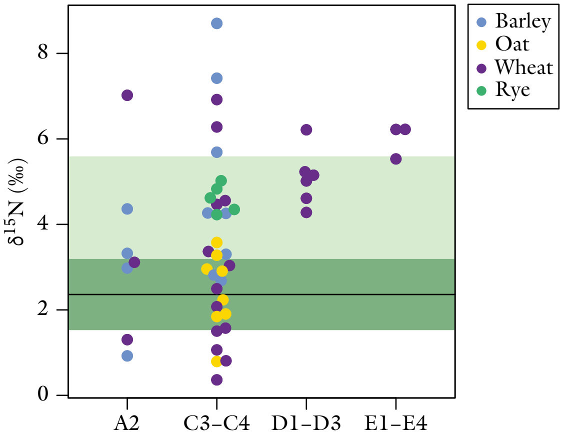

FIGURE 3.31. The δ^{15}N values of Lyminge cereal crops plotted with the wild/unmanaged vegetation band extrapolated from Roman deer data (Madgwick *et al.* 2013). Black line shows the average δ^{15}N value of the Roman deer data minus 4‰ for the trophic level offset. The dark green band shows one standard deviation around that average, while the light green band shows the grain to chaff offset.

pared to natural vegetation extrapolated from herbivore collagen, suggesting limited manuring. The trend of lower fertility seen within the weed ecology results also supports this (see above).

Conclusions regarding the manuring of the cereals at other case study sites are difficult to reach due to the lack of wild herbivore data. There are, however, two factors that suggest that *intensive* manuring is unlikely. The first is the weed ecology results (see above), which show a trend towards lower fertility conditions in fields over time. It is of course possible that manuring took place but had a limited effect on fertility, but this would suggest low-level manuring resulting in limited ^{15}N enrichment. As some sites produced some of the highest cereal grain δ^{15}N values so far obtained for Northern Europe, it seems unlikely that low-level manuring alone is the principal cause. Ottery St Mary produced some rye samples with δ^{15}N values greater than 20‰, and even with such high outlying values removed in data cleaning there are samples with δ^{15}N values greater than 10‰. Samples with values greater than 10‰ occur at other sites such as Stafford, Mildenhall, Houghton, Yarnton, and Holmer. The cultivation of cereals under different manuring levels has shown that a significant amount of manure (35 tons per hectare of cattle farmyard manure or slurry) is required to elevate cereal δ^{15}N values, with an average of 5.5‰ difference in δ^{15}N values of manured and unmanured grain (Fraser *et al.* 2011). The high amount of manure required to elevate cereal grain δ^{15}N values does raise an important question: would such an amount of manure have been available during the early medieval period, given the increasing proportion of sheep to cattle seen in the zooarchaeological data (see below and Figure 3.32)? Sheep could have produced manure for the fields: indeed, sheep manure is ideal for fertilizing crops as it provides a great source of nutrient and decomposes quickly. However, a very large number of sheep would be required to reach the 35 tons per hectare level.[13] Calculations based on modern sheep indicate ten sheep could produce ~6 tons per year[14], compared to ten cattle producing ~82 tons of manure per year[15] (Herbert *et al.* 2022).

It is possible that the manure used was a mixture from multiple species, something to note given that the modern model uses only cattle manure (farmyard manure and slurry). Manure from different species results in different levels of plant ^{15}N enrichment, with cattle and sheep manure resulting in lower δ^{15}N values than manure from other animals such as pigs or poultry or even human waste. Research shows that poultry and pig manuring results in a larger enrichment of plant tissues than does cattle manuring (see Szpak 2014 for a review), and while there is no research on the

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[13] The +35 tons/ha was based on modern experiments using farmyard manure (cattle). See Fraser *et al.* (2011) for details.

[14] Ten sheep weighing 160 kg each, barned for 195 days produce ~5.6 tons of manure per year. See Herbert *et al.* (2022) for equation.

[15] Ten cows at weighing 1,250 kg produce around 82 tons of manure per year (if barned for 195 days). See Herbert *et al.* (2022) for equation.

impact of manuring with human waste on the $\delta^{15}N$ value of plant tissue, theoretically it would result in an even higher enrichment than domestic herbivores[16], due to the higher trophic level of humans. It is highly likely that manure used on fields was a mixture taken from midden piles, and would have included human waste and manure from any animal available. The question is whether it would have resulted in such an enrichment in ^{15}N in the plants seen at some of the case study sites. The use of pig manure could elevate $\delta^{15}N$ values more than cattle manure, but this would have required the pigs to have been kept in such a way that their manure could be collected. Recent archaeological research as well as historical accounts suggest that pigs were highly herbivorous during the period, spending a large amount of time within woodlands, making collection of their dung difficult (Stroud 2022); another study, however, observed a significant decrease in $\delta^{15}N$ values in the fourteenth century, suggesting that pigs were more omnivorous in the earlier medieval period (Hamilton and Thomas 2013). Human waste certainly could have been included in the mixture used, but the amount of faeces produced by one person per year is minimal compared to the much larger herbivores (50–100 kg of faeces per year (Rose *et al.* 2015)). Thus, the consequence of a mixture of manure types is unlikely to have been the sole cause of the elevated $\delta^{15}N$ values observed.

The age of manure used also needs to be considered as fresh waste has a different $\delta^{15}N$ value to composted farmyard manure. The $\delta^{15}N$ value of manure increases over time, as time allows ammonia to escape with the lighter isotope. Composting also facilitates microbial activity, which can elevate the $\delta^{15}N$ value. Fresh waste—manure and urine—have a $\delta^{15}N$ value that relates to the diet of the animal of origin. Urine tends to be depleted in ^{15}N by ~2‰ compared to the diet of the animal, while manure tends to be enriched in ^{15}N by 2‰ (Steele and Daniel 1978). Urine contains a higher amount of nitrogen, and while depleted in ^{15}N when it leaves the body, soil that receives fresh urine is enriched in ^{15}N by around 1‰ due to the high level of volatilization that occurs (Frank *et al.* 2004). The medieval references to the practice of folding sheep on fields does raise the question whether such a practice would result in the high level of ^{15}N enrichment observed. While the decomposition of manure is slow, urine hydrolyses rapidly in the soil producing a product that once nitrified is vulnerable to leaching (Peoples *et al.* 1995). Thus, the impact of urine on elevating the $\delta^{15}N$ value of soil/plant could be limited.

In summary, the study sites have high $\delta^{15}N$ values, some of which fall within the high-level manuring bands of Bogaard *et al.* (2013). Unfortunately, the lack of wild herbivore bone collagen data means that the unmanured baseline value at each site is unknown. It is, nevertheless, unlikely that high-level manuring is the cause of the

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[16] Human waste may have a similar effect to that of pig manure on crop $\delta^{15}N$ values, as both may be omnivores. However, if humans consume a high proportion of meat, plants grown using their manure may be more enriched in ^{15}N than plants grown with pig manure.

elevated values, both because of the weed ecology and the fact that the very large numbers of livestock required are unlikely to have been available. Other possibilities exist, such as the use of different types of manure and the folding of sheep, but research indicates that these would not have elevated the δ^{15}N value to such a degree. Another process must be involved. The results therefore do not show that manuring did not occur but rather, when taken together with the low fertility signal found in the weeds, show that manuring did not increase the fertility of the soil to a significant extent.

If manuring was not the primary cause of the elevated δ^{15}N values at the case study sites, then other environmental factors need to be considered. The site of Stafford shows an increase in δ^{15}N values over time in direct contrast to the weed ecological evidence of low fertility (Hamerow *et al.* 2020). Manuring is unlikely to be the primary cause of the elevated δ^{15}N values over time, while other factors related to aridity and salinity can be ruled out. Given the location of Stafford, surrounded by a mixture of clay and alluvial soils, it was hypothesized that increasing δ^{15}N values seen at the site were the consequence of expansion onto heavier soils (Hamerow *et al.* 2020). Research shows that soils that are episodically waterlogged or experience seasonal wetting and drying cycles are enriched in ^{15}N, resulting in enriched plant values (*e.g.* Lim *et al.* 2015). Thus, changes in δ^{15}N values could, in part, reflect changes in the soil types cultivated, with an increased use of soil prone to waterlogging.

Lyminge, situated on the chalk downs in Kent has, as discussed above, limited enrichment above the calculated unmanured band and produced the lowest mean δ^{15}N values of the case study sites. This potentially reflects the type of soils surrounding the site—loams and silts—with only limited locations to the south and south-west of Lyminge having soils that are seasonally wet (Appendix 1). The limited availability of heavier (waterlogged) soil would mean that any expansion onto such soils would have had limited consequence on δ^{15}N values. Most of the ten case study sites—Ottery St Mary, Stafford, Yarnton, Holmer, Wellington Quarry, Houghton, and Stratton—have site δ^{15}N means greater than 6‰. Their local soil conditions are significantly different from Lyminge, however, and from other sites such as Pudding Lane and Mildenhall, which all have δ^{15}N means of less than 4.5‰. Ottery St Mary, Stafford, Yarnton, Holmer, and Wellington Quarry are all located near major rivers, and while Houghton and Stratton are not near rivers, they are located in areas of seasonally wet soils and clays (Table 3.1; Appendix 1). The elevated nature of the cereal δ^{15}N values is thus plausibly due to environmental conditions, the consequence of inundation and waterlogging on microbial activity within the soil.

Pudding Lane and Mildenhall are the two case study sites, other than Lyminge, which have site δ^{15}N means of less than 5‰ (4.1 ± 1‰ and 4.5 ± 2‰, respectively). Pudding Lane's samples fall predominantly within the 3–6‰ band, while Mildenhall is extremely variable with samples' δ^{15}N values ranging from ~1‰ to 10‰ (Figure 3.30). Mildenhall does have seasonally wet (sandy) soils although these occur in low

TABLE 3.1 The mean and standard deviation of the δ^{15}N values from the case study sites by phase, as well as a summary of soil types.

Site	δ^{15}N (‰)	δ^{15}N by phase (‰)		Soils
Lyminge	3.85 ± 1.95	A	3.3 ± 2	Loam, silts, loamy clay
		C	3.6 ± 2	Seasonally wet clay and loam
		D	5.1 ± 0.7	
		E	6 ± 0.4	
Yarnton	7.1 ± 2	B	6.1 ± 1.4	Loam
		C	6.9 ± 2.2	Seasonally wet clay, loam and silty clays
		D	8.1 ± 1.3	
Mildenhall	4.5 ± 2	C	4.4 ± 2.1	Sands, loam, peat
		D	4.7 ± 1.8	Seasonally wet deep sands
Stafford	7.2 ± 1.9	D	6.2 ± 1.4	Sands, loams
		D/E	8.5 ± 0.9	Seasonally wet loams and clays, clays with impeded drainage
		E	8.2 ± 1.8	
Houghton	6.9 ± 1.9	C	7.4 ± 2.2	Silts, clays
		D	6.6 ± 1.9	Seasonally wet loam and clays
		E	7.6 ± 1.3	
Stratton	6.8 ± 1.7	C	6.7 ± 1.9	Loam, clay, sandy and silty soils
		H	7.1 ± 1.5	Seasonally wet loams, peats and clays
Wellington Quarry	6.8 ± 1	E	6.8 ± 1	Loams and silts Seasonally wet silts
Holmer	7 ± 2.1	C	7.4 ± 1.9	
		D	5.1 ± 2.4	
Pudding Lane	4.1 ± 1.1	E	4.1 ± 1.1	Loams and clays
Ottery St Mary	7.3 ± 1.9 (all values: 9.1 ± 4.5)	G	7.3 ± 1.9	Loams, sands Seasonally wet loams, clays peats and silts

proportions compared to sandy and loamy soil. Pudding Lane is located on deep clay soils that extend to the south, while loam and silts extend to the north; however, there are no soils relating to seasonal wetting/drying or waterlogging. It is also possible that underlying geology plays a role, with Pudding Lane and Mildenhall situated on chalk bedrock—like Lyminge.

To summarize, the results of the isotopic analysis of cereal grains from the case study sites, when considered in conjunction with the weed ecology, suggest that the elevated δ^{15}N values are not a direct consequence of high-level manuring and that the major factors elevating δ^{15}N values are more likely due to environmental conditions, in particular seasonally wet soils. Stafford provides evidence of increasing cultivation of such soils over time as cultivation expanded onto wetter, seasonally waterlogged, heavier clays. At Lyminge, Pudding Lane, and Mildenhall, by contrast, relatively low cereal δ^{15}N values coincide with a preponderance of well-draining soils.

The isotopic data can also be used to study regional and temporal trends, overcoming some of the issues of limited samples or limited phases within sites. The δ^{15}N values—as shown above—are heavily site-dependent due to differing environmental conditions. To allow for comparisons between sites, or merging of data from multiple sites, the δ^{15}N values need to be normalized to mitigate the impact of those site-specific factors. To achieve this, the sites' phase means were subtracted from the individual values. The resulting normalized values are graphed by FeedSax phase in Chapter 4 (Figure 4.20). Variability in δ^{15}N values is greatest in phase C, followed by a trend of decreasing variability of the values over time in phases D to E. The high variability in the values in phase C suggests that the crops were cultivated under a wide range of conditions, possibly reflecting a wide range of soil types. Such a trend is also seen within the weed diversity data (above), which indicates high diversity in weed taxa during phase C. The weed data also show a further increase in diversity in phase E, notably in the Central Zone (*cf.* Figures 3.9–3.10), something not reflected in the normalized isotope data, which indicate that the δ^{15}N value variability is in fact at its lowest during phase E. We hypothesize that this is due not to a decrease in the range of different soils cultivated but rather to an increase in the practice of crop rotation, which averages the δ^{15}N value of crops across multiple growing conditions, reducing the variability (see Chapter 4).

ARABLE EXPANSION AND THE PASTORAL ECONOMY: THE ANIMAL BONE EVIDENCE

Although cattle were vital for traction, sheep are often regarded as synonymous with successful arable systems. Sheep fare better than cattle do on the marginal lands available for pasture when fertile lands close to farms are increasingly used for crops. They also provide a rich source of manure containing nutrients better suited to fertilizing plants than cattle, and can be moved away from the settlement to graze during the day (Campbell 2000, 154; Grant 1982, 156; McCormick 1991, 46). Prior to the twelfth century, when sheep became increasingly important for wool production (Rose 2017), they would have had a synergetic place within the arable system and this can be observed zooarchaeologically. For this reason, an increase in the proportion of sheep relative to cattle can suggest a growing emphasis on arable farming, while certain oral pathologies in both sheep and cattle may be useful to identify changes in diet linked to extensification and the consequent loss of fresh pasture (Holmes *et al.* 2021b).

The proportion of sheep to cattle: A proxy for arable expansion

Cattle dominate most post-Roman animal bone assemblages (Figure 3.32), reflecting their value as a portable store of wealth (Holmes *et al.* 2021a). A widespread, gradual increase in the proportion of sheep relative to cattle takes place from around AD 625.

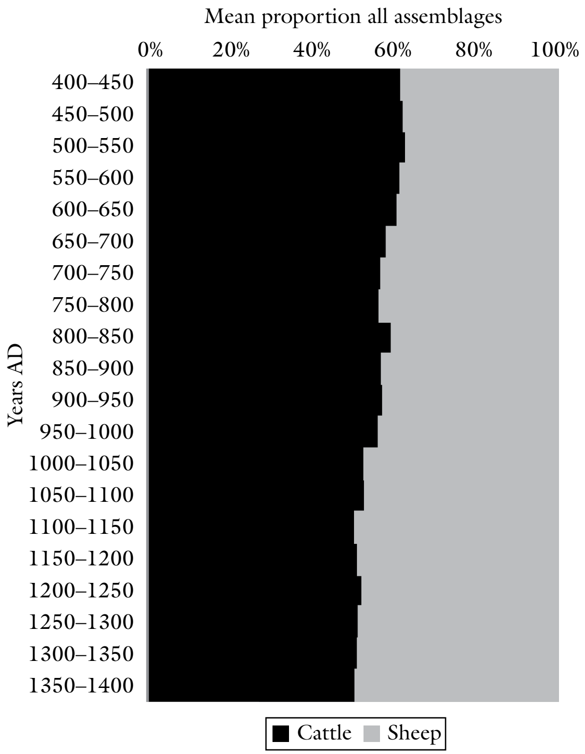

FIGURE 3.32. Relative proportion of cattle and sheep through time.

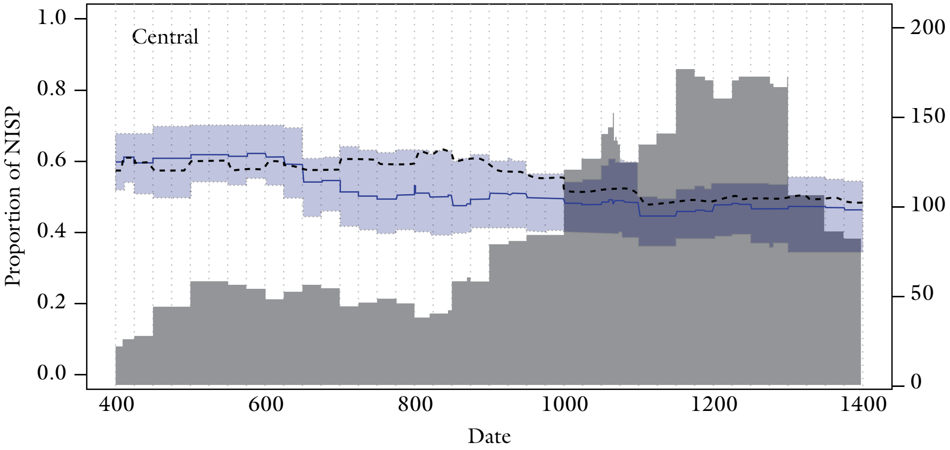

FIGURE 3.33. Continuous temporal mean of cattle and sheep/goats in the Central Zone (after Rippon *et al.* 2013). Grey shaded areas = sample size, dotted line = overall mean from all sites, solid line = regional mean, blue shaded areas = upper and lower quartiles (see Holmes *et al.* forthcoming).

This provides the first indication of changing agricultural production and potentially evidences an increasing emphasis on arable cultivation. This trend occurs in all regions, but by AD 700 sheep are particularly important in the Central Zone (Figure 3.33; Holmes *et al.* forthcoming). By the eleventh century, sheep and cattle are recorded in similar numbers (Grant 1988, 153; Holmes 2018, 70; Rippon *et al.* 2014, 223; Thomas 2007, 138), especially in the central and southern regions (Albarella 2019, 184; Holmes *et al.* forthcoming) (Figure 3.32), which compares well with contemporary evidence for the increasingly widespread and intensive use of cattle for draught (see Chapter 5) and the growing wool trade (Rose 2017; Ryder 1983, 447). The importance of wool in the economy combined with continuing arable expansion can be observed in the corresponding parity of sheep and cattle numbers from AD 1200 to 1250 in East Anglia, and AD 1300–1350 in the North.

Foddering of livestock: The evidence of oral pathologies

The more land that was set aside for crops inevitably meant that less was available for grazing, which would have restricted the number of animals that were kept close to the settlement. This could be offset in two main ways: by keeping animals off the land in either a stall or barn and feeding them cut hay and grain (fodder); or by grazing them on available land at the field margins, fallow fields, or pastures further away through daily or seasonal transhumance. Animals that were needed for farm work would necessarily be kept close to the settlement, and it is known that, by the tenth century, plough-beasts were kept inside for at least part of the day. The ploughman in *Aelfric's Colloquy* (late tenth century) describes one of his jobs as having to 'fill the oxen's bins with hay, and water them, and carry their muck outside' (Swanton 1993, 109). Reference is made to a 'stalled ox' from the late tenth century stock list of Yaxley, Huntingdonshire (Oliver 1999, 35), which describes old or surplus animals being fattened for meat (Trow-Smith 1957, 57). Animals kept in stalls require feeding, and one of the earliest English legal texts, *Ine's laws* (AD 688–694) sets the cost of hiring oxen as payment in fodder (Whitelock 1996, document 32.2.2). The cutting and feeding of hay to animals over winter is evident from at least the eighth century (Banham and Faith 2014, 124), and it may have been necessary to keep animals inside during a period of harsh weather, although archaeological evidence for animal housing is scarce (Banham and Faith 2014, 122; Hamerow 2012, 45). It is also worth reiterating that earlier changes in livestock husbandry can be observed in settlement organization, with the introduction of enclosures, droveways, and hay meadows from the later seventh and eighth centuries (Hamerow 2012, 178; see Chapter 7).

If, as postulated above, extensification of arable farming was associated with a loss of pasture, the need for increased yields also meant that farmers could no longer afford to leave large areas of land fallow for long periods as required in systems such as convertible husbandry and infield–outfield farming. Loss of pasture would thus have had implications for livestock diet, namely an increased reliance on foddering, fallow grazing, and/or grazing on marginal or 'waste' land. It is hypothesized that this could be reflected in an increase in certain oral pathologies in sheep and cattle due to consumption of poor, tough grasses on the field margins and the higher sugar content of hay and grain fed to stalled animals (Bartosiewicz 2008; Grant 1988; Haimovici and Haimovici 1971). The causal factors of such pathologies largely remain unexplored, though several modern studies have provided data to suggest that periodontal disease (observed as alveolar recession) is correlated with soil type and nutritional imbalance (Cutress and Ludwig 1969; Steele and Henderson 1977); acidic diets (incorporating silage); and the feeding of hard plant material such as hay (Ruiz de Arcaute *et al.* 2020).

The methods for recording calculus and alveolar recession (periodontal disease) are described in Chapter 2. Although the presence and severity of calculus and alveolar recession are strongly correlated with age (Holmes *et al.* 2021b), it is possible to generate an age-independent dataset. This was possible because the mean incidence of

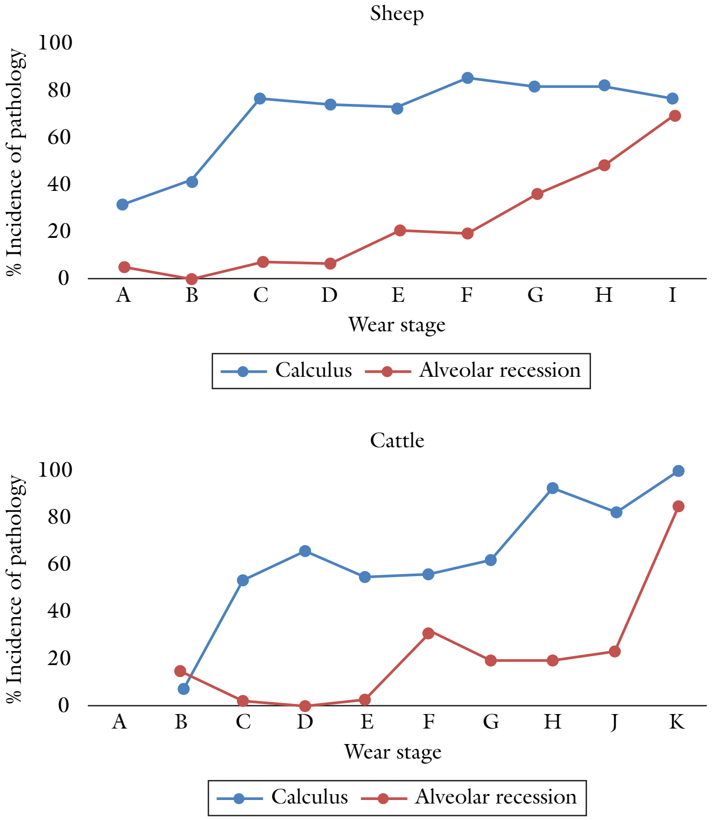

FIGURE 3.34. Effect of age on the incidence of calculus and alveolar recession in sheep and cattle mandibles. After Holmes *et al.* (2021b). See Table 3.2 for approximate ages at each wear stage.

Table 3.2. Mandibular wear stages commonly used to age cattle and sheep, with their corresponding approximate age ranges (months).

Stage	Cattle (Jones and Sadler 2012)	Sheep (Jones 2006)
A	0	<1
B	0–6	1–3
C	5–18	3–12
D	16–28	10–24
E	26–36	23–36
F	34–43	36–66
G	40–78	66–96
H	60–120	96–120
I/J	72–192	>120
K	168–240	–

calculus and alveolar recession was consistent between certain mandibular age stages: calculus—C and I in sheep and C and G in cattle; alveolar recession—stages E and F in sheep and F and J in cattle (Figure 3.34).

Data from each case study site are summarized in Table 3.3; the incidence of calculus and alveolar recession recorded for each site is provided in Figures 3.35 and 3.36 for sheep and Figures 3.37 and 3.38 for cattle. The incidence of both dental calculus and alveolar recession in sheep peaks in the period AD 800–1100, before falling in AD 1000–1300 and 1200–1500 (Table 3.4). Cattle exhibit a different pattern: the incidence of dental calculus increases between AD 400–700 and 600–900, with a large increase from AD 800 to 1100 that continues throughout the rest of the study period (Table 3.4). Alveolar recession shows little variation through time, decreasing slightly from a peak in AD 400–700. Although these results show a general pattern, there is no statistically significant difference between periods.

Differences in the findings between cattle and sheep is unsurprising, as it is likely that they were subject to different husbandry strategies and fed on different types of pasture and/or fodder. The ‘draught cattle’ signature identified in the dataset (see Chapter 5) implies a higher frequency of draught cattle from the ninth century, which coincides with an increase in calculus and alveolar recession in cattle (Table 3.4). It may be that the associated stalling of draught cattle, and subsequent change in diet to one limited in nutrients and based more on dried fodder that had a higher sugar content, led to increased oral pathologies.

A small increase in calculus is observed for sheep in the period between AD 800 and 1100 (Table 3.4), but there is little difference from preceding phases, suggesting continuity in sheep diet from the fifth century. The major change is observed from the eleventh century as a decrease in calculus and alveolar recession, which coincides with

Table 3.3. Number of incidences of calculus (sheep mandibles at wear stages C to I; cattle mandibles at wear stages C to G) and alveolar recession (sheep mandibles at wear stages E and F; cattle mandibles at wear stages F to J) recorded for each case study site and the total number of suitable mandibles (N mand).

Site	**Broad Phase**	**Sheep**				**Cattle**			
		Calc	**N mand**	**AR**	**N mand**	**Calc**	**N mand**	**AR**	**N mand**
Barking Abbey	600–900	2	4		1	2	2		
	1000–1300	4	7		2	1	1		1
Bow Street	600–900	16	22		6		7		4
Collingbourne	600–900	38	42	5	8	3	3		1
Cook Street	600–900	24	26		10	7	7		4
Eynsham	400–700	7	17	1	3		6		
	600–900	62	108	4	26	3	6	2	5
	800–1100	4	12		2				
	1000–1300	10	26		5	9	13	10	40
	1200–1500	4	7		5		1		2
Flaxengate	800–1100	49	53	3	12	6	7	1	10
	1000–1300	108	121	4	25	9	10	1	11
	1200–1500	27	32		5	2	3		3
French Quarter	800–1100	35	40	3	10	5	5	4	10
	1000–1300	57	62	2	19	8	11	2	10
	1200–1500	38	45	6	15	3	3	1	3
Lyminge	400–700	30	38		7	2	12	1	7
	600–900	73	101	4	9	2	8		4
	1000–1300	17	23		7	2	4		1
Market Lavington	400–700	53	59	3	7	13	16	3	6
	600–900	4	4		1				
	800–1100	4	4	2	2		1		1
Quarrington	400–700	16	16	1	5	9	9	1	2
	600–900	13	15	2	5	4	4	2	2
Ramsbury	600–900	36	41	6	8	2	3		4
Reading Rd, Wallingford	800–1100	18	18		6	2	2		

	1000–1300	56	60	1	12	7	7	4	7
	1000–1300	5	5		2	6	6	3	6
Sedgeford	600–900	28	33		5	6	6	2	2
	800–1100	48	60	4	14		1	1	1
Stafford	1000–1300		22		9				
Stoke Quay	600–900	73	83	2	14	5	9		2
	800–1100	20	24	1	4	5	7		1
Stoke Quay	1000–1300	25	25	3	8	2	3	1	4
	1200–1500	17	19		4	3	3	2	3
Stratton	400–700	24	27	1	7	3	3		
	600–900	49	53	1	10	3	5	1	3
	800–1100	57	68	1	8	7	11	3	7
	1000–1300	21	25		2	2	3	1	4
Trumpington Meadows	600–900	76	79	1	12	5	6	1	4
	600–900	4	5		1	2	2		1
	800–1100	3	3						
West Fen Rd, Ely	600–900	4	4		2				1
	800–1100	22	23		5	9	10		5
	1000–1300	5	5			2	2	1	2
	1200–1500	8	9		3	1	1		1
West Parade	1000–1300	57	75	2	20	4	4		6
	1200–1500	10	14	1	8	1	1		
Total		1361	1664	64	361	167	234	48	191

TABLE 3.4. Mean values by broad date range for incidence of calculus and alveolar recession. See Table 3.3 for details.

Sheep	**400–700**	**600–900**	**800–1100**	**1000–1300**	**1200–1500**
Calculus: incidence	80%	83%	86%	75%	79%
N assemblages	5	15	10	12	6
AR: Incidence	22%	18%	25%	7%	9%
N assemblages	5	15	9	11	6
Cattle	**400–700**	**600–900**	**800–1100**	**1000–1300**	**1200–1500**
Calculus: incidence	59%	65%	82%	78%	85%
N assemblages	5	12	8	11	13
AR: Incidence	33%	22%	28%	24%	25%
N assemblages	3	12	7	11	12
	400–700	**600–900**	**800–1100**	**1000–1300**	**1200–1500**
Draught cattle signature	40%	27%	63%	64%	60%
N assemblages	5	11	8	11	5

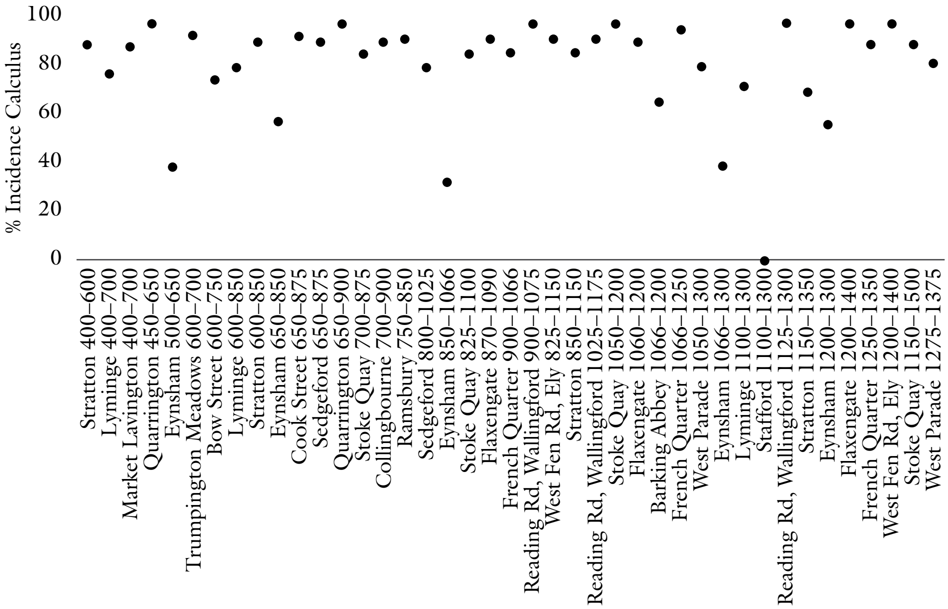

FIGURE 3.35. Sheep incidence of calculus (in animals between wear stages C and I) for each site by midpoint, for assemblages ≥5 mandibles. See Table 3.3 for sample sizes.

the period when draught cattle use was deemed to be widespread (see Chapter 5). This suggests that the changes to sheep husbandry brought about as more land was cultivated had no adverse effect; they were less likely to have been dominated by fallow grazing, which would be expected to produce more calculus and periodontal disease due to foddering and the consumption of hard stems. Conversely, increased mobility that may have been necessary to move sheep away from the arable for much

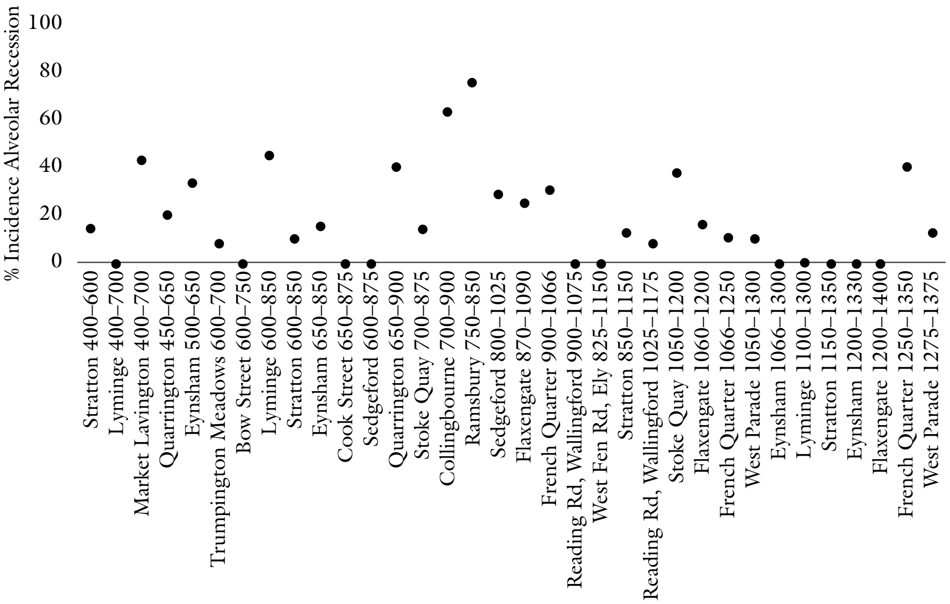

FIGURE 3.36. Sheep incidence of alveolar recession (in animals between wear stages E and F) for each site by midpoint, for assemblages ≥5 mandibles. See Table 3.3 for sample sizes.

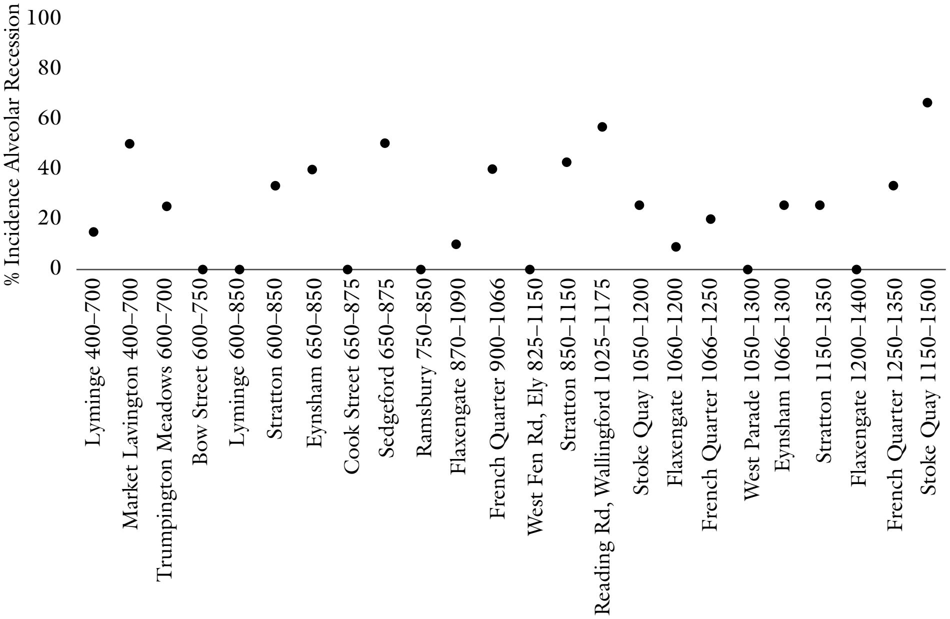

FIGURE 3.37. Cattle incidence of alveolar recession (in animals between wear stages F and J) for each site by midpoint, for assemblages ≥3 mandibles. See Table 3.3 for sample sizes.

of the year would potentially have brought sheep into contact with a greater range of nutrients and plant types from new and varied pastures that acted to reduce the incidence of these oral changes. Thus, the reduction in oral pathologies is consistent with the ingestion of a greater range of nutrients and less emphasis on hay, dried fodder, and poor grazing from fallow and field margins.

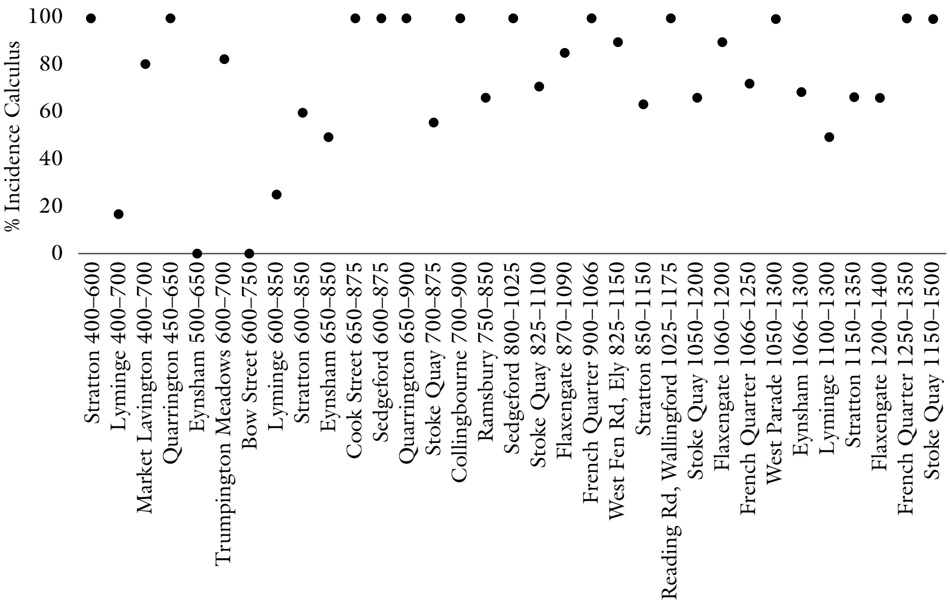

FIGURE 3.38. Cattle incidence of calculus (in animals between wear stages C and G) for each site by midpoint, for assemblages ≥3 mandibles. See Table 3.3 for sample sizes.

CONCLUSIONS

The evidence presented in this chapter does not reveal obvious 'step changes' in soil fertility over time, although a shift to more extensive crop husbandry practices around the eighth century (phases C1–C3) can be detected. Archaeobotanical samples from earlier phases, while few in number, indicate more intensive and, by implication, smaller-scale cultivation. Thereafter, the changing weed ecology reflects a shift to markedly low-input conditions and a subtle, long-term decline in soil fertility that can be traced through to the fourteenth century. This decline occurred despite a range of well-documented practices undertaken to maintain fertility, including manuring, marling, sheep folding, hand-weeding, and sowing legumes. This is probably due not only to a reduction in the quantity of manure available per land unit but also to an overall reduction in the amount of fallow and the introduction of multiple ploughing of fallow. This would, over time, have contributed to a net loss of soil fertility even while mobilizing organic matter in the soil and (temporarily) boosting yields.

A gradual expansion in the scale of arable farming is implied by changes in weed flora and the increasingly low-input conditions they reflect. This is seen most clearly in the Central Zone, the region for which we have the largest number of archaeobotanical samples across the longest chronological span. It is also indicated for all regions by the increasing sheep:cattle ratio. This points to a gradually increasing emphasis on arable from *c*.625 onwards, with a more marked increase from *c*.1000 (earlier in the Central Zone), the latter coinciding with the period when the evidence for draught cattle first becomes widespread (see Chapter 5). The evidence for weed diversity indicates that this increasing emphasis on arable farming included an expansion onto more diverse and heavier soils. This again can be seen most clearly in the Central Zone during the eighth and ninth centuries (phase C), alongside the transition to lower-input conditions. A second 'wave' of weed diversity *c*.1030–1220 (phase E) could reflect growing pressure on arable, leading to an expansion onto new, perhaps more marginal soils, and corresponds to a peak in the cattle bone evidence for dedicated draught animals (see Chapter 5). The gradually increasing evidence for dental calculus in cattle up to *c*.1100, a condition associated with stalling and foddering, also parallels the increased osteological evidence for draught cattle.

This chapter thus reveals a trend towards more extensive cereal farming between the eighth and thirteenth centuries, following what appears to have been a post-Roman reversion to somewhat smaller-scale cultivation (*cf.* Banham and Faith's period of 'abatement'; 2014, 141). It should not be assumed from this, however, that 'extensification' began in the medieval period. As noted above, our study tracing the changing intensity of cereal farming in the Rhineland reveals that 'extensification' was a process that began in later prehistory, proceeded gradually, and, despite pausing in the post-Roman centuries, never went into reverse. The low-input cultivation regimes seen in medieval England therefore represent the culmination of a long-term trend towards increasingly extensive cereal farming.

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FOUR

Crop Rotation and Seasonal Sowing

> If your lands are divided in three, one part for winter seed, the other part for spring seed, and the third part fallow, then is a ploughland nine score acres.
>
> Walter of Henley, *Husbandry* (Lamond 1890)

INTRODUCTION

Systematic crop rotation, requiring farmers to follow an agreed sequence of sowing and fallow, was a fundamental feature of regular open-field systems, although we cannot assume that rotation was entirely restricted to such systems. In a regular open-field system, crop rotation involved dividing a village's arable into two or three 'courses', often equating to two or three fields. In a two-field system, half the arable would lie fallow at any one time while the other half would produce the crop. In a three-field system, only one third of the arable was given over to fallow. One of the other 'courses' would consist of an autumn-sown crop (usually wheat, which benefits from a longer growing season) and the third a spring-sown crop (usually barley or oats, which are ready to harvest after a few months). A regular short fallow period—that is, one year out of every two or three—enabled more land to be brought under the plough while the fallow field provided valuable additional grazing as the expansion of arable reduced the amount of available pasture. Staggered sowing times also allowed the farmer's workload to be spread more evenly across the year and reduced the risk of crop failure. A field would be sown with winter corn by the end of October; following the harvest, it would be ploughed and sown with spring corn around March. After the second harvest, the field would be left fallow until the autumn of the following year when it would again be sown with winter corn (Orwin and Orwin 1938, 49–52). It was traditionally assumed that the three-field system became more prevalent as pressure on arable increased, but in fact, two-course rotation persisted throughout the medieval period (Banham and Faith 2014, 72; Thirsk 1966). It could even have been more profitable, as it enabled farmers to grow more of a single, high-value crop such as bread wheat, although this would also be more vulnerable to crop failure.

Common grazing of the fallow by livestock, primarily sheep, benefited both the animals, which 'topped up' on nutrients by grazing on stubble and weeds, and the soil, the fertility of which was boosted by their droppings.[1] Sheep thus provided an easy means of redepositing nitrogen from the pasture on which they grazed for much of the year, onto fallow fields. This practice had an important practical implication for a community: in an open-field system in which holdings took the form of unenclosed, intermingled strips, farmers would have to reach agreement regarding the sequence of rotation in order to prevent animals from straying onto the crops.

There is no consensus regarding when and how widely systematic rotation came to be adopted in England, either by individual farms or by whole communities (Banham and Faith 2014, 72–3; Thirsk 1964, 19). The earliest references to subdivided land date to the middle decades of the ninth century, and charters from Wiltshire and Berkshire dating to the second half of the tenth century appear to refer to intermingled strips, implying some degree of co-ordinated rotation so that all the strips in a field lay fallow at the same time (Blair 2018, 330–1; Hall 2014, 166–7; Zeller *et al.* 2020, 77).[2] This evidence relates only to a few specific places, however, and in any case need not imply that the entire arable belonging to a village was held in this way; it is equally possible that there was 'a multiplicity of small common fields, coexisting with land in severalty' (Faith 1997, 144). Two or more farmers could, furthermore, have cooperated without involving the entire community. The earliest detailed record of crop rotation in England is contained in manor-court records of the thirteenth century (Banham and Faith 2014, 72), although a lease of 1152 from Navestock manor in Essex strongly suggests the existence of three-field rotation, as it refers to part of the land being planted with winter corn and another with spring corn, as well as a grass or hay crop and 'rebinatas', or fallow (Thirsk 1964, 19).

The earliest written sources to record systematic crop rotation in England thus date to the twelfth and thirteenth centuries. Banham and Faith (2014, 72) caution that 'there is no evidence that open fields were common even in the eleventh century, and standard management regimes may have been a long way off'. But we should not assume that these earliest written sources tell us when systematic crop rotation first became widely practised; it is possible that the advent of manorial courts allowed practices that were already well established to enter the written record for the first time. It is notable that treatises such as Walter of Henley's 'Husbandry', written between 1276 and 1290 (Lamond 1890), do not instruct land managers in how to manage systematic rotations, as they do, for example, when describing optimal

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[1] See Stroud (2022) for an analysis of stable carbon and nitrogen isotopes in the bone collagen of medieval sheep and cattle as a means of inferring animal diet, including fallow grazing.

[2] For example, a charter of 956 records that an estate at Charlton, Berkshire, had 'no clear boundary, for ploughlands are parted by adjoining ploughlands' (Hall 2014, 167).

ploughing techniques (see Chapter 5), but simply make passing reference to rotation, implying that the practice would have been well known to the reader.

It is important to note that forms of rotation other than those used in two- and three-field systems were known in medieval England. Variable—that is, non-regulated, irregular—rotation on enclosed, individual holdings could have been practised at an early date, with systematic rotation representing a later 'micro innovation'. Even systematic rotation is likely in practice to have had a degree of flexibility (Banham and Faith 2014, 73). Convertible husbandry—where part of the outfield was cultivated for several years in succession and then fallowed for a similar number of years—and what Banham and Faith call wide 'strip fields' of a kind still visible in some regions, notably Cornwall, were alternative means of expanding cereal production (Banham and Faith 2014, 274–82). An alternative to rotation altogether would be a mixed crop, that is, sowing a mixture of two or three cereals together. This is a relatively common means by which farmers manage risk by growing 'a bit of everything' (van der Veen 1995). Indeed, mixed crops—mostly maslins (wheat/rye) and dredges (oat/barley)—could even be incorporated into rotations, as seen at Wisbech, Cambridgeshire, in the fourteenth and fifteenth centuries (Stone 2005).

Archaeobotany allows us to explore this topic further, beyond the limits of the written record, through the complementary approaches of functional weed ecology and crop stable isotope analysis. However, before deploying these methods to investigate when and how widely crop rotation was practised, we must recognize that not all aspects of rotation are susceptible to archaeobotanical investigation. In particular, legume crops are likely to be severely under-represented in the archaeobotanical record: unlike cereals, they are not routinely exposed to fire while being processed and are therefore much less likely to be preserved by charring (Campbell 2009, 246). For this reason, our dataset chiefly comprises cereal-dominated samples, with too few samples dominated by legumes (or jointly by cereals and legumes) to admit meaningful comparative analysis. Hence, if a rotation regime incorporated a spring legume crop as well as a winter cereal, the spring crop would be near-invisible in the archaeobotanical record.

As for the more abundant charred cereal deposits, their archaeobotanical and biomolecular composition may help us distinguish between crops grown in rotation, separately, or as mixed crops (such as maslins). The criteria for making these distinctions—as outlined in Table 4.1 and 'unpacked' in further detail in subsequent sections—are based upon four attributes of charred cereal assemblages: their cereal composition (mixed or pure); their carbon and nitrogen stable isotopic ratios (whether values for different crops are compatible or contrasting); sowing times (again, compatible or contrasting), as indicated by the accompanying arable weeds; and soil disturbance level (high or low), again indicated by the arable weeds. In brief, assemblages consistent with three-course rotation are distinguished from all other systems by a combination of mixed or pure cereal composition; crops with 'compatible' stable carbon and nitrogen isotope values but contrasting autumn and spring sowing times; and through their association with a weed flora reflecting high soil disturbance, as expected under mouldboard ploughing. Assemblages consistent with two-course rotation would similarly be associated with high soil disturbance levels but would likely feature a single crop. Preserved harvests of maslins would differ from those of three-course rotations by lacking contrasts in sowing times between crops, and by not necessarily being associated with the high disturbance levels generated by mouldboard ploughing. Finally, separately cultivated crops that were not rotated would be distinguished from three-course rotation by containing crops with 'incompatible' crop stable isotope values (indicating habitual cultivation in different fields), a lack of contrasting sowing times (indicating just a single sowing season), and variable disturbance levels.

Table 4.1. Criteria for assessing whether archaeobotanical samples represent different crops grown together, in rotation, or separately.

	3-course rotation	**2-course rotation**	**Maslin**	**Separate cultivation**
Cereal composition	Mixed or pure	Mixed or pure	Mixed[3]	Pure
Stable isotopes	Compatible	Compatible	Compatible	Incompatible
Crop sowing times	Contrasting	Compatible or contrasting	Compatible	Compatible or contrasting
Disturbance levels	High	High	Unclear	Unclear

CROP ROTATION, SEASONAL SOWING, AND ARCHAEOBOTANY

With these criteria in mind, we may now consider in more detail the four elements of three-course crop rotation that are, potentially, archaeobotanically detectable, while recognizing that irregular rotations were also practised but are difficult or impossible to discern from plant remains:

1. The regular cultivation of at least two different cereal crops, whether pure or mixed.
2. The regular practice of both autumn and spring sowing (a single sowing season would, by contrast, be compatible with two-course rotation, or no rotation).
3. The consistent sowing of particular crops in particular seasons.
4. The consistent sowing of different crops in the same fields (*e.g.* a single field bearing both barley and oat, whether in different years or together as a mixed crop), as opposed to different crops being customarily sown in different areas.

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[3] Mixing could be the result of post-depositional processes; a primary deposit is therefore necessary to establish a mixed crop with certainty.

Archaeobotany provides three proxies for these elements: (1) the relative proportions of cereal grains belonging to each crop type in archaeobotanical samples serve as a coarse proxy for the relative abundance of the crops processed at a given site, (2–3) the weed species preserved among those grains serve as a proxy for the sowing seasons utilized at that site, and (4) the biochemistry of those grains serves as a proxy for the environmental conditions in the fields within which they were grown.

While these data exist at the level of individual environmental samples, they are most informative when several samples from a site are analysed together, because we are seeking evidence for multi-year practices. By analysing more samples, we obtain data for more harvests and thereby build a more representative picture of customary, year-after-year practice. Certain caveats apply, however. First, no matter how many samples a site assemblage might contain, we will never attain a definitive, verifiably representative picture of farming in a given phase. While charred plant remains are routinely produced at cereal-handling settlements, we would need a site's grain stores to have fallen victim to annual post-harvest arson attacks for several centuries, with the charred wreckage systematically disposed of—and extensively excavated and sampled, after many undisturbed centuries—before we could claim to have a genuinely representative dataset.

Second, very few samples in the dataset derive from primary storage deposits, such as the burned-down granaries at Lydford and Ottery St Mary (both in Devon). Rather, the majority of samples derive from pits, ditches, or ovens/hearths—all features that are apt for cross-contamination of secondary or tertiary deposits. This fact, coupled with the broad phasing applied to most samples, means that there are almost no 'snapshots' of farming practice: individual samples instead contribute to a time-averaged picture of crop husbandry for a given phase spanning decades if not centuries. The upshot of these caveats is that we will only detect crop rotation if it was the dominant system of cereal husbandry feeding a site—thus contributing most to the charred plant record—during a given phase. Changes in practice *within* a phase would, archaeobotanically, be indistinguishable from various irregular practices happening at once: the end results would appear similarly jumbled.

The following analyses draw upon evidence from the case study sites supplemented by archaeobotanical data from selected additional sites in the national dataset, to extend the geographical scope of the sowing time investigation (Figure 4.1). It should be noted that the distribution of the assemblages remains biased towards the Central Zone, which unavoidably limits our ability to identify regional trends (see Chapter 2). Few sites, furthermore, produced adequate samples from enough different phases to identify exactly when systematic rotation was first introduced, if at all.

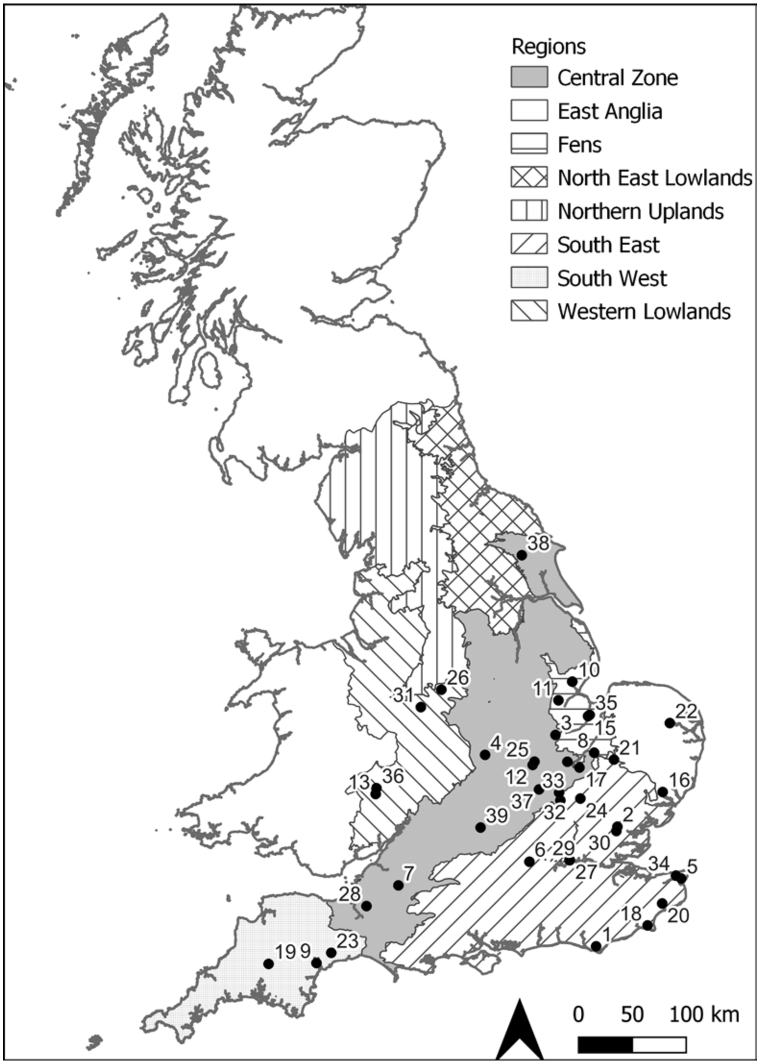

FIGURE 4.1. Map of sites included in the seasonal sowing analyses discussed below (see Figure 4.18 for key to sites). Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

INVESTIGATING SEASONAL SOWING THROUGH ARABLE WEEDS

For ease of reading, weed species in this discussion and the graphs that follow have been divided into three categories: 'autumn', 'spring', and 'other'. These categories, and indeed the whole functional weed ecology approach adopted here, were devised in a study of sowing times by Bogaard *et al.* (2001; see Chapter 2). The autumn weeds include only those species with early/short flowering periods; the spring weeds include late-flowering and long-flowering species; and the category of ‘other’ weeds includes all remaining weed species, that is, those with intermediate flowering periods or unclear seasonal associations. While spring-associated weeds could theoretically occur among an autumn-sown crop, the autumn-associated weeds ought nonetheless to have a competitive advantage in such circumstances. The converse is not true: autumn-associated weeds ought not to occur among spring-sown crops, as the spring ploughing would disturb their growth, leaving them unable to flower and set seed that year. It should be noted at the outset, however, that the original functional ecology study of sowing times (Bogaard *et al.* 2001) was based upon survey data from fields in Germany, not Britain. According to Silverside (1977, 8–9), Britain’s ‘milder oceanic winters’ render the ‘sharp distinction between winter and spring crops on the continent less evident in Britain’. As a result, it may be that we should not always expect such a clear polarity between the weed floras of autumn- and spring-sown crops.

The majority of medieval archaeobotanical assemblages, from sites across all parts of England, contain both autumn- and spring-associated weed species. It is therefore possible that sowing took place in both seasons, in all regions, through the entire medieval period. However, this does not mean that systematic seasonal sowing—let alone crop rotation—was practised always and everywhere. Correspondence analyses of crop and weed remains are needed to establish whether or not systematic seasonal sowing is represented archaeobotanically at these sites. Essentially, these correspondence analyses identify: (i) axes of association between plant taxa, based upon their representation in archaeobotanical samples, and (ii) axes of association between samples, based upon their archaeobotanical contents. In the resultant graphs for plant taxa, systematic seasonal sowing can reasonably be inferred if cereal taxa are differentiated along the same axis as autumn- and spring-associated weeds, and if potential biasing factors such as crop processing can be ruled out (see Chapter 2).

Samples were included in correspondence analyses only if they contained at least ten items (grains or seeds)—an arbitrary quorum but one that has been found to serve effectively in previous studies (McKerracher 2019, 102–24). Weed species were only included in correspondence analyses if they were identified to species level (for the purposes of assigning functional traits) and occurred in three or more samples; rarer species are less likely to be representative of the original arable flora and more likely to represent chance contaminants.

With these considerations in mind, we may now examine each of the four elements of crop rotation in turn.

Regular cultivation of at least two different crops (for three-course rotation)

Quantitative analysis of the entire national dataset shows that, overall, the cereal grains in approximately half of all samples are dominated (≥70%) by a single cereal: whether free-threshing wheat, barley, oat, or rye (McKerracher *et al.* 2023, Document B08). This pattern is significant because, although post-depositional mixing could artificially create a spurious maslin-like sample, there is no obvious way in which a genuine mixed crop might be artificially 'purified' in the archaeobotanical record. In such samples whose grain content is dominated by a single cereal, the remaining proportion (≤30%), consisting of one or more other cereals, could reflect post-depositional mixing, post-harvest contamination (during processing or storage), or contamination of the seed corn as a result of mixing in storage.[4] The percentage thresholds used here are arbitrary, but if provisionally accepted, they suggest that at least half of the national dataset represents 'pure' crops, whether in rotation cycles or not.

Where these relatively 'pure' samples are concentrated at particular sites, they can form assemblages so heavily dominated by a single cereal that it is not possible to assess seasonal sowing patterns; indeed, their very dominance tells against the operation of a three-course rotation system.

For instance, there are some sites in the south-west of the Central Zone whose assemblages primarily consist of wheat-dominated samples, such that we simply do not have adequate data for comparison with other crops. The assemblages from Eckweek (Avon)—spanning phases D1–E5 (*c.*880–1220)—and Shapwick (Somerset)—mainly spanning phases E1–G2 (*c.*1030–1400)—fall into this category. The weeds represented in these assemblages include both spring- and autumn-associated species. Since spring-associated weeds can occur in an autumn-sown crop, these data would be compatible with a crop husbandry regime dominated by a two-course rotation of winter wheat and fallow.[5] Alternatively, it remains possible that no rotation regime is represented by these data. In any case, there is no evidence to suggest that any kind of *three*-course rotation was practised.

Meanwhile, the majority of samples from sites in the silt fens of Norfolk and Lincolnshire—namely, Ingleborough, Walpole St Andrew, Gosberton, and Fishtoft (Figure 4.1)—are dominated by barley. This is an ecologically sensitive choice of crop, since barley is a particularly salt-tolerant cereal, and the silt fens were a saline environment subject to repeated marine flooding, especially before the construction of defensive banks from the late Saxon period onwards (Crowson *et al.* 2005, 4–11; Murphy 2010, 215). Among the weed flora in these assemblages, autumn-associated species are so scarce that the data-cleaning protocols for correspondence analysis remove all—or very nearly all—of them from the datasets. This pattern cannot be due to crop processing biases, since these assemblages are not wholly dominated by samples classed as fine-sieved by-products (which are biased towards spring-associated weeds: Bogaard *et al.* 2005). Arguably, the simplest explanation for this trend is that autumn

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[4] Ethnographic research suggests that such ostensible 'contamination' of the seed corn is to be expected and was probably tolerated by farmers (Jones and Halstead 1995).

[5] Other sites in this general area have similarly wheat-dominated assemblages, *e.g.* Puxton (Somerset), Wimborne Minster (Dorset), and Bridport (Dorset), so this could be a regional trend.

sowing was sometimes practised, but spring sowing (of barley, for the most part) was the norm and dominated arable farming in the silt fens throughout the period represented: mostly phase C (*c.*670–880). This would make ecological sense: the silt fens were prone to flooding, especially in winter, such that spring sowing may have brought consistently more reliable yields. Taken together, these data from the silt fens would be compatible with a crop husbandry regime dominated by a two-course rotation of spring barley and fallow. As with the wheat-dominated assemblages discussed above, there is nothing here to indicate a three-course rotation, and it also remains possible that no rotation system at all was practised, at least in the years for which we have data.

Regular practice of both autumn and spring sowing

Most of our assemblages contain both autumn- and spring-associated weed species, but that is not to say that both kinds of weed are always equally well represented. Indeed, there are some assemblages where one of the seasonal associations is almost entirely absent. For example, as discussed above, in the barley-dominated assemblages from the silt fens, autumn-associated weed species are exceedingly scarce, to the extent that crops seem to have been customarily sown in the spring, and only rarely in the autumn.

By contrast, evidence from the South West displays the opposite tendency, towards autumn sowing (sites located in Figure 4.1). Most of the samples from the South West, spanning the eleventh to fourteenth centuries, are dominated by oat and/or rye. Both autumn- and spring-associated weed species are represented at most sites in the region but, in general, those taxa associated with autumn sowing are much better represented—especially corn marigold (*Glebionis segetum* (L.) Fourr.).[6] At Lydford (Devon), where distinct, adjacent storage deposits of oat and rye were discovered, probably representing a single year's harvests in the early twelfth century, corn marigold and corncockle (*Agrostemma githago* L.) were both found as contaminants of the rye crop, indicating that rye, at least, was likely to have been autumn-sown that year (Green 1980; weed data are insufficient for correspondence analysis).

There is evidence from other sites to suggest that oat was also autumn-sown in this region: in the fourteenth-century assemblage at Ottery St Mary (Devon), both corn marigold and corncockle occur in samples dominated by oat grains, and the data-cleaning protocols result in there being no spring-associated weed species in the correspondence analysis for this site. Samples from Exwell Barton (Devon), dated to

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[6] Following Fitter and Peat (1994), this analysis assumes for corn marigold a flowering period of June to August, which—following Bogaard *et al.* (2001)—can be associated with autumn sowing. Although the 'Back from the Brink' conservation project defines corn marigold's flowering period as June to October (which would be consistent with both autumn and spring sowing, according to Bogaard *et al.* 2001), the same source claims that autumn seedlings are frost-hardy, which could confer some competitive advantage under an autumn-sowing regime (https://www.plantlife.org.uk/download_file/2695/860, accessed 10/11/2021).

phases E3–F2 (*c.*1080–1300), have a small weed flora similarly dominated by corn marigold and cereal components similarly dominated by oat and rye. Neither of these two assemblages consists entirely of fine-sieved products, so the lack of spring-associated weeds cannot be wholly due to crop processing biases at these sites.

Overall, there is no indication that different crops were systematically sown in different seasons in the South West, and it may well be that most crops were customarily sown in the autumn (despite an open-field system apparently operating at Ottery St Mary as late as the eighteenth century, according to Stanes 2009; *cf.* Hall 2014, 250). Although it receives high rainfall, the South West tends to have milder winters than other parts of England (Silverside 1977, 8–9; 18–19), a tendency that perhaps lessened the potential advantage offered by spring sowing in this region and so encouraged an emphasis on autumn sowing to reap the benefits of a longer growing season.

Conversely, there are several assemblages in the dataset in which spring-associated weeds tend to be in a clear majority, though not always to the same striking extent as in the silt fens, and without that region's corresponding emphasis upon a single cereal. After data cleaning in preparation for correspondence analysis, only one autumn-associated weed species[7] remained in each of the assemblages from Wharram Percy (North Yorkshire), Longstanton (Cambridgeshire), Boreham (Essex), Cottington Hill (Kent), Holmer and Wellington Quarry (Herefordshire), and the Royal Opera House site (London). These results—which collectively span the fifth to fourteenth centuries—are unexpected and warrant further consideration.

While exclusive (or near-exclusive) springtime sowing is ecologically consistent with barley cultivation in the seasonally flooded silt fens, there is no obvious reason for springtime sowing to be so heavily favoured at these other sites, which span a range of locations and terrains, none of which is at all comparable to the silt fens. Equally, none of these assemblages is overwhelmingly dominated by fine-sieved by-products, which carry an inherent bias towards spring-associated weeds, so the pattern is not explicable in terms of crop processing. Yet it is unlikely that, in these diverse locations, farmers would have habitually forsaken the advantages of a longer growing season and opted for a heavily spring-oriented crop husbandry regime without a compelling environmental imperative.

Another, perhaps more plausible, possibility is that a weed flora *non-exclusively* dominated by spring-associated species is in fact a realistic product of three-course rotation. Intuitively, it might seem that alternating autumn- and spring-sowing seasons should lead to a broadly balanced representation of both autumn- and spring-associated weeds. However, as outlined above, spring-associated weeds can occur among both spring-sown *and* autumn-sown crops, whereas autumn-associated

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[7] Usually either brome (*Bromus hordeaceus/secalinus* L.) or corncockle (*Agrostemma githago* L.): crop mimics whose seeds are difficult to remove from seed corn.

species should only infest autumn-sown crops (since they do not have time to regrow, flower, and set seed after the spring ploughing).

Thus, in a three-course rotation cycle (incorporating a spring/summer ploughing of the fallow), spring-associated weeds could grow in all three years (enjoying a competitive advantage in two of them), whereas autumn-associated weeds could thrive in just one year out of three. The net result after many repeated cycles could have been a weed flora dominated by spring-associated species, but still retaining some of the most effective autumn-associated crop mimics (like brome or corncockle). This 'autumn blurring' effect could be compounded by the lack of a sharp distinction—mentioned above—between the weed floras of winter and spring crops, a function of the 'oceanic' climate across much of Britain (as identified by Silverside 1977, 8–9). While there is an exception to this climatic tendency in the sandy Breckland of East Anglia—which has a more 'continental' climate with colder winters and lower rainfall—none of the spring-dominated assemblages listed above comes from that region (Figure 4.19; Silverside 1977, 18–19; Williamson 2013, 42–3).

The consistent sowing of particular crops in particular seasons

Correspondence analysis is an exploratory multivariate statistical technique that can discern axes of association between taxa according to their co-occurrence in samples (Chapter 2). In the resultant plots, the closer together species fall along a particular axis, the more closely their respective grains/seeds occur in the same samples in an assemblage. The origin (centre) of the graph represents typical composition in the assemblage; distance from the origin is thus a measure of deviation from the norm (Bogaard 2004, 92–4). In this instance, we are looking for associations between particular cereals and particular classes of weeds: that is, for cereal and weed taxa to separate along the same axis in a seasonal pattern.

An idealized example is shown in Figure 4.2. In this fictitious assemblage, the separation of taxa along the *x*-axis demonstrates that wheat and rye grains tend preferentially (not necessarily exclusively) to occur among seeds of autumn-associated weeds, whereas barley and oat grains tend preferentially to occur among seeds of spring-associated weeds. At this site, therefore, a classic 'champion' seasonal sowing pattern could reasonably be inferred: wheat and rye as autumn crops, barley and oats as spring crops. However, the distances between wheat and rye, and between barley and oat, tell against the presence of mixed (maslin or dredge) crops in this assemblage.

In practice, such clear patterns seldom emerge from real archaeobotanical data (though see Hamerow *et al.* 2021 for an example from the Rhineland). This is not just a question of taphonomy, representativeness, and the hypothesized 'autumn blurring' effect (outlined above). If systematic seasonal sowing was practised for only a part of the time span represented by an assemblage, its archaeobotanical signature is likely to be obscured by the less systematically distributed data from other phases. By

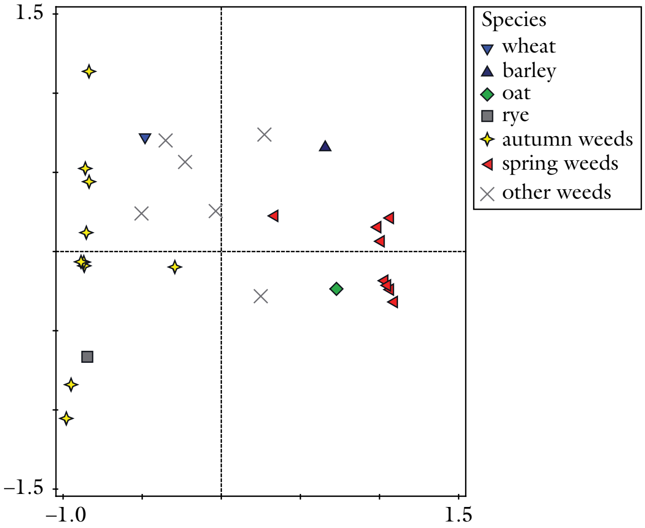

FIGURE 4.2. Idealized correspondence analysis results for plant taxa, representing seasonal sowing patterns in a classic 'champion' rotation, for illustrative purposes only.

contrast, if the emergent pattern *does* appear to be consistent with seasonal sowing, it is likely that this was practised in *every* phase represented in that analysis: such an archaeobotanical signature is inherently unlikely to emerge spuriously from a mixture of unsystematic regimes.

Theoretically, this chronological caveat could be overcome by analysing data for individual phases separately. In practice, however, individual phases often fail to produce enough data to support meaningful, representative correspondence analyses on their own. Moreover, some assemblages are relatively broadly phased: an assemblage assigned to phase D, for instance, could still represent multiple successive husbandry regimes within the period *c.*880–1030. It must be stressed, therefore, that results that are inconsistent with seasonal sowing cannot be taken as evidence that seasonal sowing was never practised at a given site. For this reason, it is important to bear in mind that 'positive' results (consistent with seasonal sowing) are inherently more meaningful than 'negative' results. Extended discussions of the results discussed below can be found in the FeedSax digital archive (McKerracher *et al.* 2023); only selected interpretations are presented here.

We have already excluded nine assemblages whose dominance by a single crop or by autumn-associated weed species renders them unsuitable for correspondence analysis, and also inherently implausible as products of three-course rotation regimes.[8] The remaining thirty assemblages fall into three groups: (1) seven with mainly

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[8] Namely, the assemblages from Eckweek, Shapwick, Fishtoft, Gosberton, Ingleborough, Walpole St Andrew, Exwell Barton, Lydford, and Ottery St Mary.

spring-associated weed species, as discussed above; (2) twelve with a mix of autumn- and spring-associated weeds and different cereals, but no clear separation of these groups (and/or between the cereals) in correspondence analyses; and (3) eleven with a mix of autumn- and spring-associated weeds that do separate along with cereal taxa in correspondence analyses.

In terms of the seven spring-dominated assemblages, in the most tenuous of our correspondence analyses, there are few associations between particular crops and autumn-associated weed species. One case is Wellington Quarry, where the sample richest in rye (53% of cereal grain) also has a weed seed component dominated by autumn-associated species: brome and corncockle (although the latter species is too rare overall for inclusion in the correspondence analysis, in that particular sample, its seeds in fact outnumber the rye grains). Hence, it may be that rye was preferentially autumn-sown at that site, at least in phases E1–E4 (*c.*1030–1160). The second case is Wharram Percy where, after data cleaning, the sole autumn-associated weed species is charlock (*Sinapis arvensis* L.), which occurs only in barley-dominated samples. So it may be that barley was preferentially autumn-sown at Wharram Percy, at least in phases C4–D3 (*c.*820–980). Otherwise, whether or not three-course rotation is in fact represented in these 'spring-dominated' assemblages, the consistent sowing of particular crops in particular seasons is impossible to detect.

We stand a better chance of detecting systematic seasonal sowing in the remaining twenty-three assemblages, which have more seasonally diverse weed floras. In twelve of these, however, neither axis of variation corresponds with the seasonal associations of the weeds. In the assemblage from Yarnton (Oxfordshire), for instance, there is little discernible separation either between cereals or between autumn- and spring-associated weed taxa (Figure 4.3). In the assemblage from Botolph Bridge

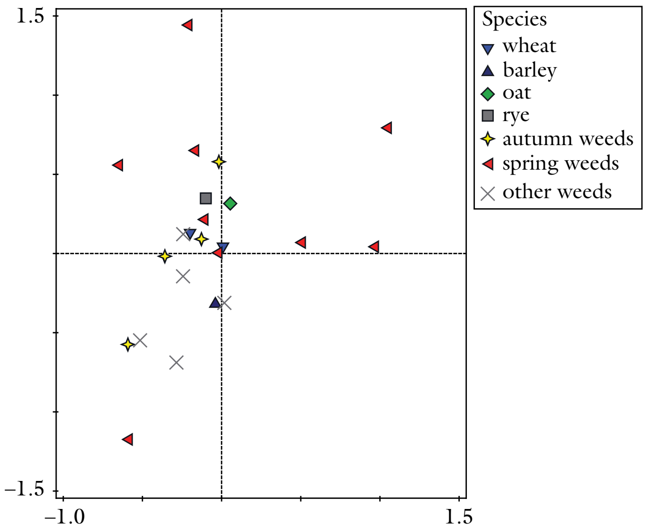

FIGURE 4.3. Correspondence analysis results for plant taxa from Yarnton.

(Peterborough), there is some separation along the *x*-axis between wheat and rye to the negative end, and barley and oat to the positive end, but this does not correspond with a seasonal trend among the weeds (Figure 4.4).

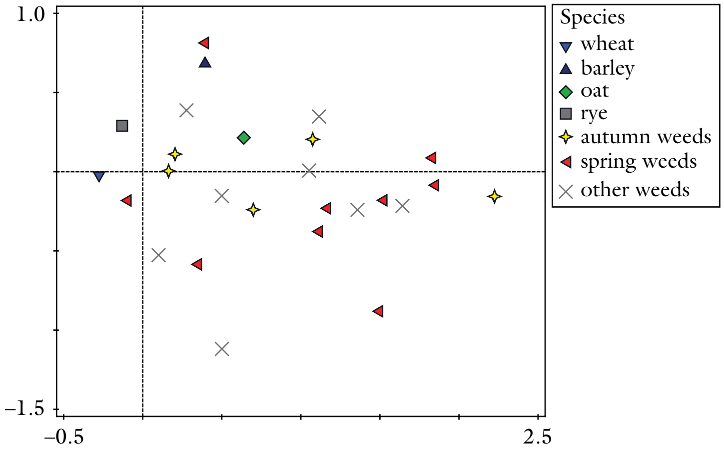

FIGURE 4.4. Correspondence analysis results for plant taxa from Botolph Bridge.

By contrast, the remaining eleven assemblages include a mix of autumn- and spring-associated weeds that do appear to separate along with cereal taxa in the correspondence analysis results. Some of these results are broadly consistent with the classic ‘champion’ pattern modelled above, with wheat and/or rye as autumn-sown crops, and barley and/or oats as spring-sown crops. These include the charred plant remains from Stafford, principally representing phases D1–E4 (*c.*AD 880–1160), as shown in Figure 4.5. The separation along the *x*-axis is not as clear-cut as in the idealized example but, as discussed above, such clarity cannot always realistically be expected. The seasonal association at Stafford is perhaps least compelling for oats, which falls around the point in the graph where autumn and spring weeds meet and overlap. It may be, therefore, that oats were sown in both seasons at different times, or in different places in the vicinity of Stafford. It should be remembered that Stafford was not a farm but a fortified *burh* and then a town in this period, and therefore likely to have been in receipt of cereals from different farms within its hinterland. It is also important to note here that, according to the stable isotope results, the analysed barley grains do not appear to have been grown in the same fields as the wheat and rye (see below; Hamerow *et al.* 2020). Hence, although the correspondence analysis strongly supports a distinction between spring barley and winter wheat/rye at the farms around Stafford, it does not provide conclusive evidence for a three-course rotation system at any individual farm.

The correspondence analysis for West Cotton, Raunds (Northamptonshire), includes far fewer weed species and the results are therefore less compelling, but they reveal a broadly similar tendency along the *x*-axis: wheat and rye more associated with autumn weeds, and oats and barley more associated with spring weeds (Figure 4.6).

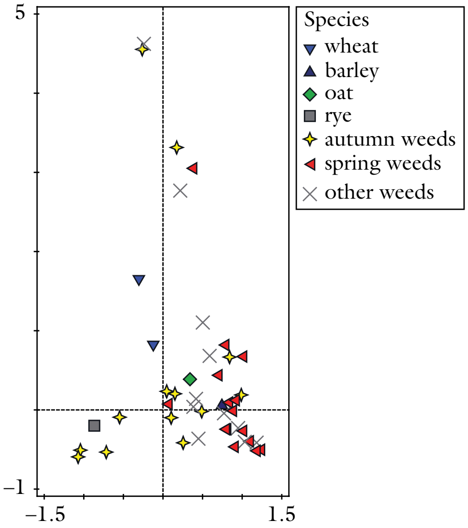

Figure 4.5. Correspondence analysis results for plant taxa from Stafford.

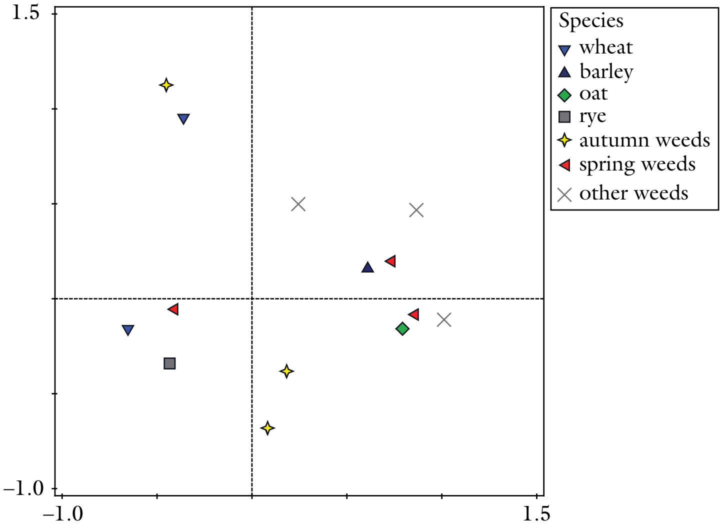

Figure 4.6. Correspondence analysis results for plant taxa from West Cotton, Raunds.

Systematic seasonal sowing—of the 'champion' kind—is therefore likely to have been practised, for at least part of time span represented by the West Cotton assemblage: principally phases D3–E5 (*c*.950–1220). During this period, settlement at West Cotton has been characterized as a late Saxon hall complex and subsequently a medieval manor (Chapman 2010).

Potentially the earliest indication of seasonal sowing is expressed by the data from West Fen Road, Ely (Cambridgeshire), which primarily span phases C2–E5 (*c*.720–1220).

Along the *y*-axis, there is a slight tendency for wheat, rye, and autumn-associated weeds to separate from barley, oats, and spring-associated weeds (Figure 4.7). As with West Cotton, the relatively restricted weed flora at Ely renders the results less compelling than those from Stafford. The seasonal separation in this graph is less marked in this analysis than in the preceding two. This could conceivably reflect a deviation from seasonal sowing at a particular time in the occupation sequence or at a particular place in Ely's hinterland.[9] Ely became an ecclesiastical centre in the late seventh century and may well have received food rents from a variety of farms on its estates, practising a variety of crop husbandry regimes (Mortimer *et al.* 2005).

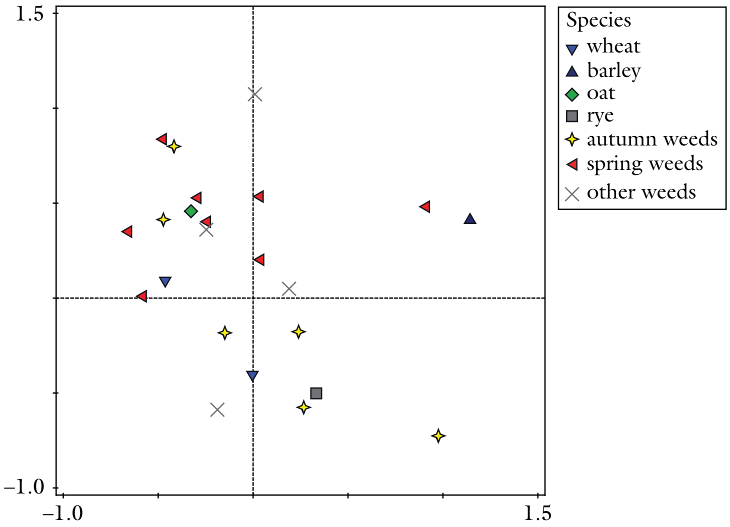

FIGURE 4.7. Correspondence analysis results for plant taxa from West Fen Road, Ely.

A similar interpretation could be offered for Bishopstone (East Sussex), a high-status courtyard complex whose occupation is dated to phases D1–D3 (*c.*880–980). Again, the analysis suffers from a paucity of weed taxa, with only a superficial separation between autumn- and spring-associated weeds (on the *x*-axis), but if the data show anything, they most plausibly show 'champion' seasonal sowing with autumn wheat and rye, and spring barley and oats (Figure 4.8).

The final assemblage that may support a similar interpretation is that from Higham Ferrers (Northamptonshire), with samples spanning phases A1–G1 (*c.*420–1360). For the eighth to ninth centuries, the site has been interpreted as a royal tribute collection centre (Hardy *et al.* 2007). If the whole assemblage is analysed together,

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[9] It should also be noted that one of the two autumn-associated weed species amid the spring-associated cluster is black mustard (*Brassica nigra* L.), which, although it can grow as a weed, might alternatively have been deliberately gathered or cultivated for culinary use, and so entered the archaeobotanical record that way.

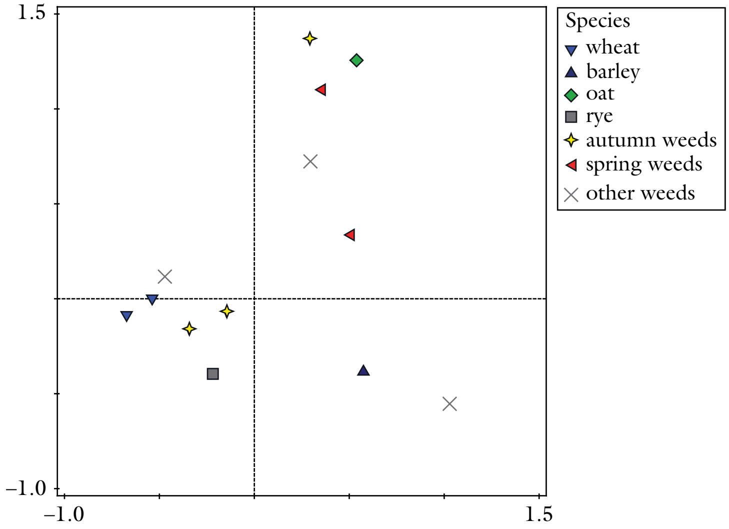


FIGURE 4.8. Correspondence analysis results for plant taxa from Bishopstone.

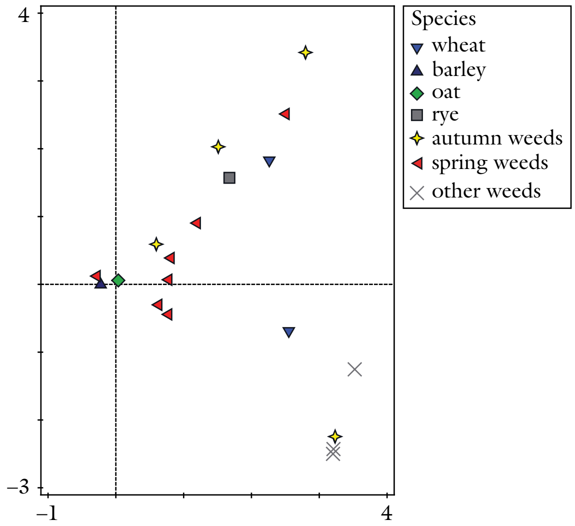


FIGURE 4.9. Correspondence analysis results for plant taxa from Higham Ferrers (all phases).

wheat and rye separate from barley and oats along the *x*-axis, but with no corresponding separation of seasonally associated weed species (Figure 4.9). However, if the analysis is restricted to samples dating from phases D1–G1 (*c*.880–1360, *i.e.* post-dating the 'tribute collection centre' phase), then the admittedly scant archaeobotanical data hint at an association between wheat, rye, and autumn-associated weeds on the one hand, and between spring-associated weeds, barley, and (less convincingly) oats on the other hand, along the *x*-axis (Figure 4.10).

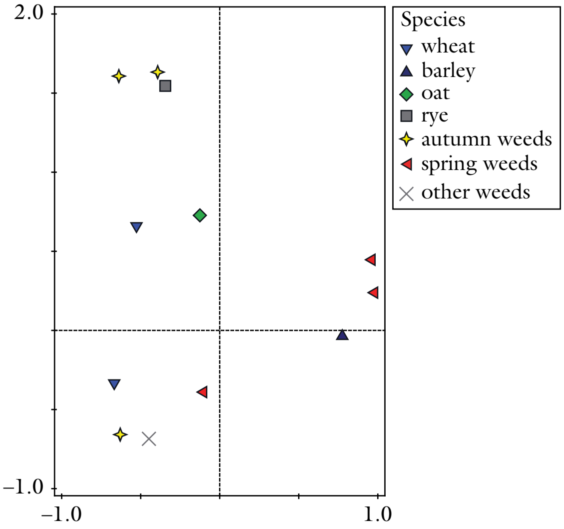


FIGURE 4.10. Correspondence analysis results for plant taxa from Higham Ferrers (phases D1–G1).

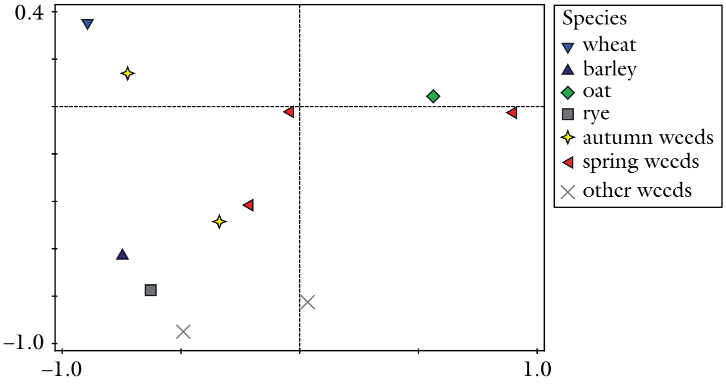


FIGURE 4.11. Correspondence analysis results for plant taxa from Springfield Lyons.

A variation on this theme is offered by the assemblage from Springfield Lyons (Essex), dated to phase D (*c*.880–1030). Here, the typically scant weed flora hints at the spring sowing of oats and the autumn sowing of wheat, barley, and rye (Figure 4.11). The settlement is described by Blair as a hall complex 'of a certain status' (2018, 370; see also Tyler and Major 2005).

Given all the considerations above, we can begin to identify a trend. The sites discussed so far occupy geographically and geologically different locations, but all can reasonably be described as high status: whether ecclesiastical (Ely), aristocratic (West Cotton, Bishopstone, perhaps Springfield Lyons), royal (Higham Ferrers), or political/economic (Stafford). A dearth of demonstrably 'ordinary' farming settlements in the archaeological record makes it difficult to draw any contrasts between high- and low-status sites. But we may at least make this point: that forms of systematic seasonal sowing compatible with three-course crop rotation seem to have supported centralized, high-status settlements—that is, those likely receiving cereals from outlying farms—from perhaps as early as the eighth century in the peat fens (Ely), around the junction of the Central Zone, Fens, and East Anglia, and from the late ninth or tenth century in the east midlands (Higham Ferrers, West Cotton), South East (Bishopstone, Springfield Lyons), and Western Lowlands (Stafford) (Figure 4.19).

Those six assemblages are the only examples found in this study to be compatible with 'classic' seasonal sowing patterns. Some other assemblages display potential signs of systematic seasonal sowing that do not appear to conform to any wider patterns. At Houghton (Cambridgeshire; phases C3–E4: *c.*770–1160), in the east midlands of the Central Zone, autumn- and spring-associated weeds separate relatively weakly along the *y*-axis, with spring-associated weeds tending to fall towards the higher end and autumn-associated weeds to the lower/negative end (Figure 4.12). Wheat, oat, and rye fall towards the most autumn-associated part, whereas barley and another wheat taxon fall towards the spring-associated part of the graph. The reason why there are two taxa representing wheat (in this and other assemblages) is that archaeobotanists often distinguish between positively identified free-threshing wheat grains and wheat grains of indeterminate type. The latter are most likely also to represent free-threshing wheats (given their occurrence in samples dominated by free-threshing cereals), but they are not sufficiently diagnostic for the archaeobotanist to count them as such. It remains possible, therefore, that in a given assemblage, 'free-threshing' and 'indeterminate' wheats represent different crops, possibly different species of free-threshing wheat. Hence, in this case, it is possible that different wheats were grown in different seasons.

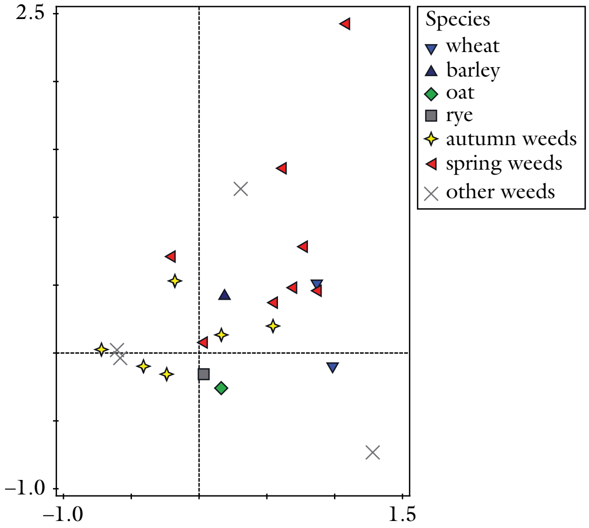


FIGURE 4.12. Correspondence analysis results for plant taxa from Houghton.

This analysis is based upon very few samples, however, which separate according to phase (Figure 4.13). Hence, it appears that the spring weeds are particularly associated with the samples from phases C3–C4 (*c*.770–880). It may be, therefore, that spring sowing (of barley and wheat) was more favoured in this earlier phase than in the subsequent phases D4–E4 (*c*.980–1160), and more than one variety of wheat may have been cultivated at this site. While it has not been possible to identify particular wheat species from the chaff in this assemblage, geometric morphometric analysis of selected charred grains suggests that rivet wheat (*Triticum turgidum* L.) may have been cultivated at Houghton, at least during the later phases (Roushannafas and McKerracher 2023).

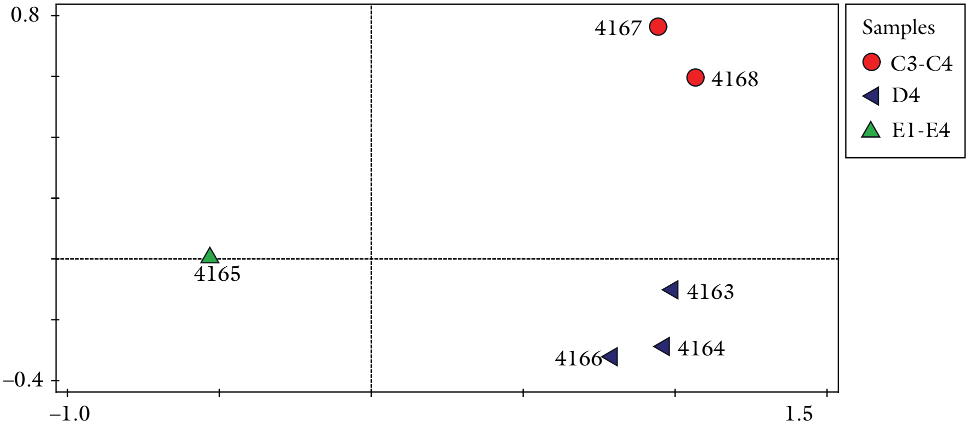


FIGURE 4.13. Correspondence analysis results for samples from Houghton, coded by phase.

Spring-sown wheat may be represented in another small assemblage of similar date (phases C3–C4, *c*.770–880): from the Shorts Gardens site within the emporium of Lundenwic, where wheat—which generally dominates the assemblage—is most associated with the weed species linked to spring sowing (see the relatively weak separation along the *x*-axis in Figure 4.14).

Some suggestion of the spring sowing of wheat can also be found at Mildenhall (Suffolk). The assemblage here mostly spans phases C3–E5 (*c*.770–1220), but seasonal sowing is most apparent if the analysis excludes the samples from phases C3–C4, leaving only samples dating from the late ninth to early thirteenth centuries: wheat then falls alongside two spring-associated weeds towards the positive end of the *x*-axis (Figure 4.15). Rachis (chaff) segments of both hexaploid (*Triticum aestivum* type) and tetraploid (*Triticum turgidum/durum* type) free-threshing wheats have been identified in earlier and later medieval samples at this site (Cobain 2019), so it may be that this variability contributed to the seasonal sowing pattern, albeit not straight away in the late eighth/ninth centuries. This is not to say that tetraploid wheat would necessarily have been the spring-sown crop. On the contrary, Moffett (2006, 48, Table 4.3) states that in Britain rivet wheat (*Triticum turgidum*) is a specifically autumn-sown crop.

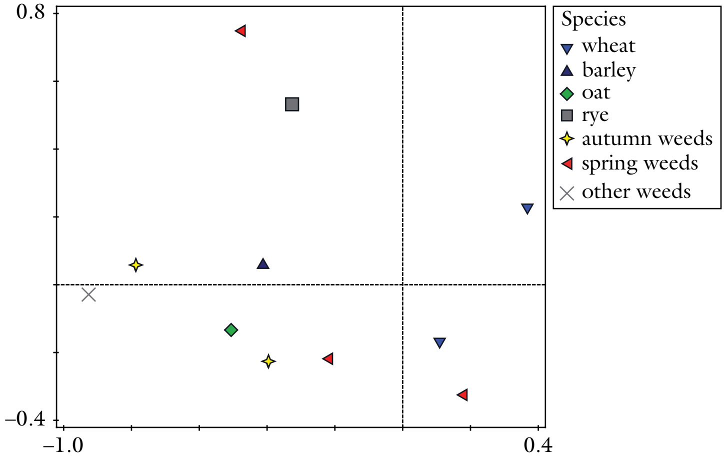


FIGURE 4.14. Correspondence analysis results for plant taxa from Shorts Gardens, London.

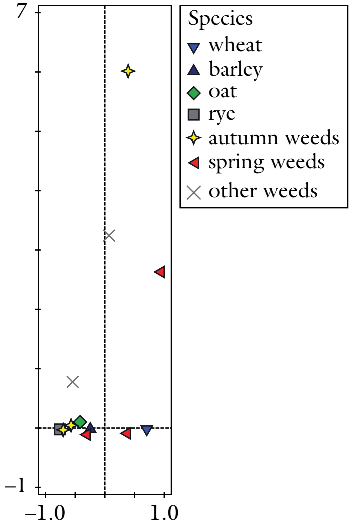


FIGURE 4.15. Correspondence analysis results for plant taxa from Mildenhall, phases D1–E5.

The crop assemblage from Pudding Lane, Barley (Hertfordshire; phases D3–E3: *c*.950–1120), is less diverse than that from Mildenhall: although all four cereals are present, wheat contributes more than 50% of the total cereal grain in nine of the eleven samples, while rye contributes more than 50% in the other two; barley and oats appear to be no more than minor crops (or merely contaminants) in these samples. The correspondence analysis suggests an association between rye and autumn sowing, while wheat could be associated with either season, or both (Figure 4.16). It may be, therefore, that systematic seasonal sowing here applied only to one crop (rye).

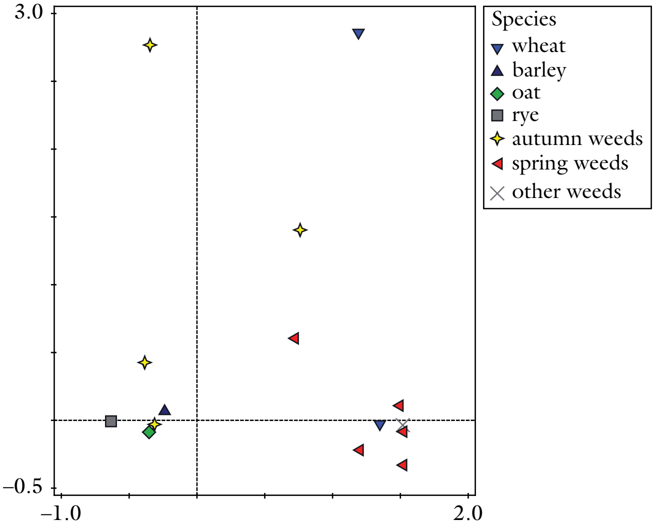


FIGURE 4.16. Correspondence analysis results for plant taxa from Pudding Lane.

Finally, the correspondence analysis of samples from Thanet Earth (Kent)—specifically, those dating from phases E1–G1 (*c*.1030–1360)—suggests that rye may have been spring-sown at that site, while the other cereals were autumn-sown: a very rare instance of apparently spring-sown rye (Figure 4.17). This is unexpected but not implausible: spring varieties of rye do exist, and some are still cultivated in the present day (Moffett 2006, 48, Table 4.3; J. Letts pers. comm.).

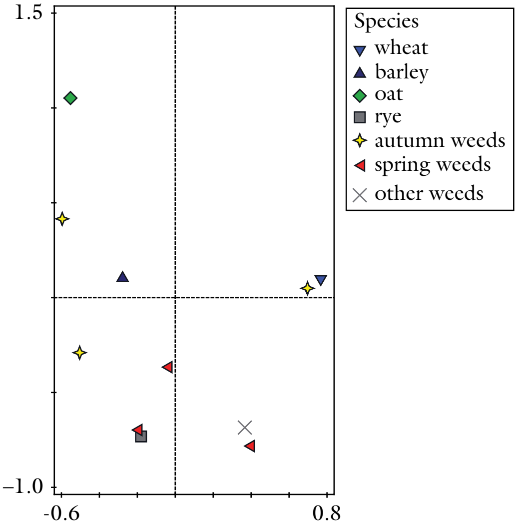
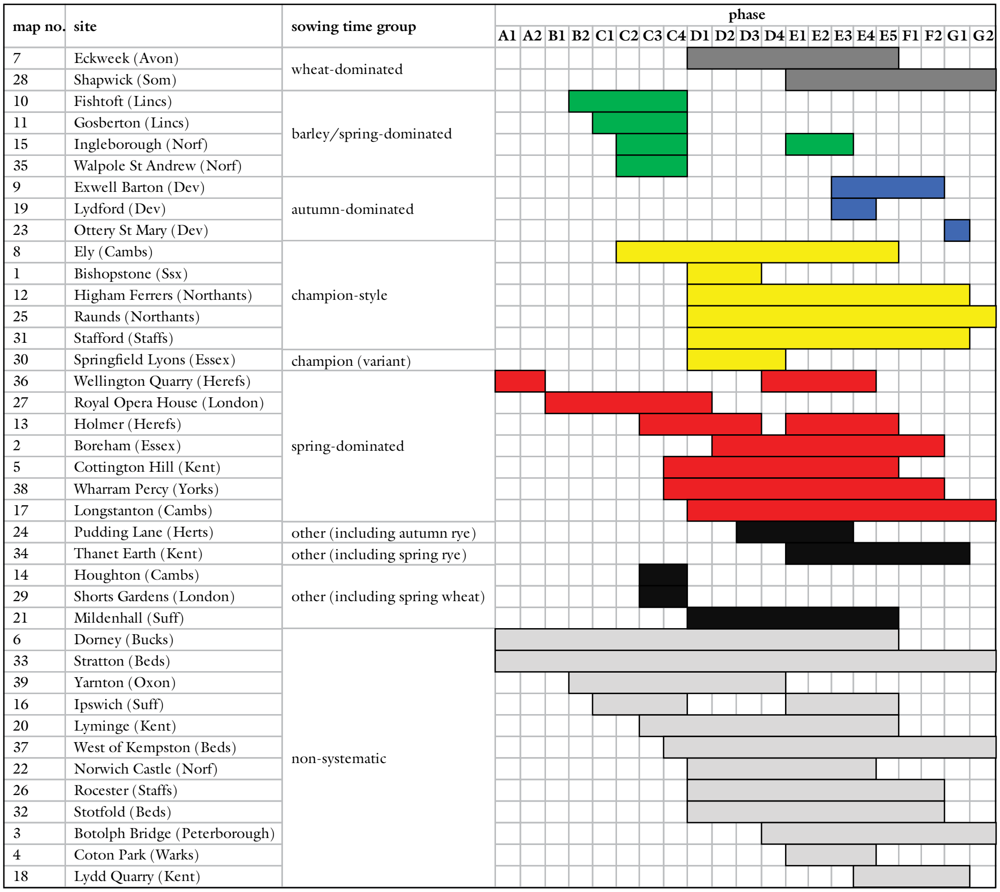


FIGURE 4.17. Correspondence analysis results for plant taxa from Thanet Earth, phases E1–G1.

The assemblages and their phases are summarized and mapped in Figures 4.18 and 4.19, categorized by the seasonal sowing pattern (or lack thereof) that they represent. Taken together, the results suggest that the classic 'champion' seasonal sowing pattern (autumn wheat/rye, spring barley/oats) may potentially be evident as early as the eighth century at Ely, near the conjunction of the Central Zone, East Anglia, and the peat fens and perhaps as early as the late ninth/early tenth century in the Western Lowlands, South East coast, and east midlands of the Central Zone—in particular association with centralized, high-status settlements. This is not, however, a universal pattern: many assemblages from across central and eastern England, spanning the fifth to fourteenth centuries and including high-status settlements such as Lyminge and Botolph Bridge, display no discernible patterns in seasonal sowing (though we cannot rule out that systematic seasonal sowing was practised at such sites, as discussed above).

Several assemblages dominated non-exclusively by spring-associated weeds could, arguably, represent an 'autumn blurring' effect resulting from alternating spring and



map no.	site	sowing time group	phase																				
			A1	A2	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	F1	F2	G1	G2
7	Eckweek (Avon)	wheat-dominated									■	■	■	■	■	■	■	■	■				
28	Shapwick (Som)														■	■	■	■	■	■	■	■	■
10	Fishtoft (Lincs)	barley/spring-dominated				■	■	■	■	■													
11	Gosberton (Lincs)						■	■	■	■													
15	Ingleborough (Norf)							■	■	■					■	■	■						
35	Walpole St Andrew (Norf)							■	■	■													
9	Exwell Barton (Dev)	autumn-dominated															■	■	■	■	■		
19	Lydford (Dev)																■	■					
23	Ottery St Mary (Dev)																					■	
8	Ely (Cambs)	champion-style						■	■	■	■	■	■	■	■	■	■	■	■				
1	Bishopstone (Ssx)										■	■	■										
12	Higham Ferrers (Northants)										■	■	■	■	■	■	■	■	■	■	■	■	
25	Raunds (Northants)										■	■	■	■	■	■	■	■	■	■	■	■	■
31	Stafford (Staffs)										■	■	■	■	■	■	■	■	■	■	■	■	
30	Springfield Lyons (Essex)	champion (variant)									■	■	■	■									
36	Wellington Quarry (Herefs)	spring-dominated	■	■										■	■	■	■	■					
27	Royal Opera House (London)				■	■	■	■	■	■	■												
13	Holmer (Herefs)								■	■	■	■	■		■	■	■	■	■				
2	Boreham (Essex)											■	■	■	■	■	■	■	■	■	■		
5	Cottington Hill (Kent)									■	■	■	■	■	■	■	■	■	■				
38	Wharram Percy (Yorks)									■	■	■	■	■	■	■	■	■	■	■	■		
17	Longstanton (Cambs)										■	■	■	■	■	■	■	■	■	■	■	■	■
24	Pudding Lane (Herts)	other (including autumn rye)											■	■	■	■	■						
34	Thanet Earth (Kent)	other (including spring rye)													■	■	■	■	■	■	■	■	
14	Houghton (Cambs)	other (including spring wheat)							■	■													
29	Shorts Gardens (London)								■	■													
21	Mildenhall (Suff)										■	■	■	■	■	■	■	■	■				
6	Dorney (Bucks)	non-systematic	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
33	Stratton (Beds)		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
39	Yarnton (Oxon)					■	■	■	■	■	■	■	■	■									
16	Ipswich (Suff)						■	■	■	■					■	■	■	■	■				
20	Lyminge (Kent)								■	■	■	■	■	■	■	■	■	■	■				
37	West of Kempston (Beds)									■	■	■	■	■	■	■	■	■	■	■	■	■	■
22	Norwich Castle (Norf)										■	■	■	■	■	■	■	■					
26	Rocester (Staffs)										■	■	■	■	■	■	■	■	■	■	■		
32	Stotfold (Beds)										■	■	■	■	■	■	■	■	■	■	■		
3	Botolph Bridge (Peterborough)													■	■	■	■	■	■	■	■	■	■
4	Coton Park (Warks)														■	■	■	■					
18	Lydd Quarry (Kent)																	■	■	■	■	■	

FIGURE 4.18. Chronological summary of seasonal sowing patterns derived from archaeobotanical data.

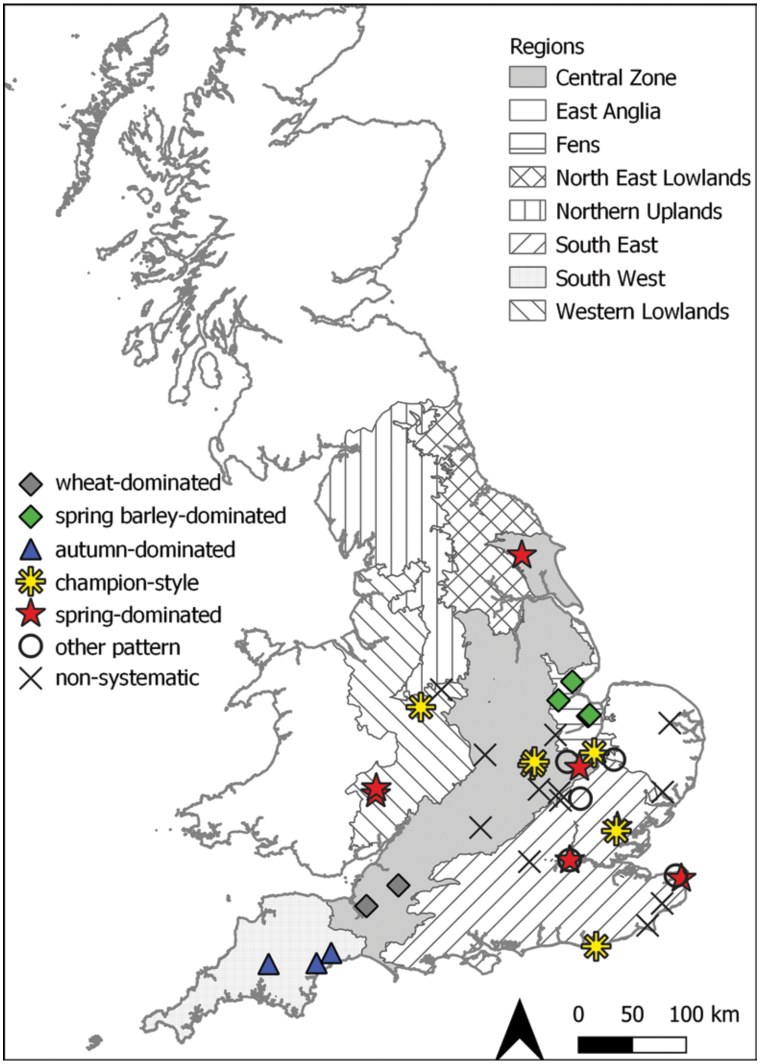


Figure 4.19. Map of sites discussed in this section, categorized by seasonal sowing patterns. *Cf.* Figures 4.1 and 4.18 for site identifications. Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

autumn sowing, as in a three-course rotation. The parent sites of these assemblages are geographically and geologically diverse, and there is no reason to believe that they were all of high status; collectively they span the fifth to fourteenth centuries, though the bulk of the evidence falls within phases D–E (*c.*880–1220). Besides a very small amount of fifth- to sixth-century data at Wellington Quarry, the earliest of these assemblages spans the seventh to ninth centuries and comes from the Royal Opera House site in London, representing part of the craft and trading settlement of Lundenwic. Taken together, both the 'champion-style' and 'spring-dominated' assemblages would be compatible with three-course rotations having been established by the late ninth/early tenth centuries, with a focus in the South East and the midlands of the Central Zone and Western Lowlands; the evidence from Ely and Lundenwic could conceivably represent a precocious or antecedent stage beginning in the seventh to eighth centuries, specifically associated with centralized settlements (*i.e.* those receiving cereals from outlying farms, rather than supplying all their own needs).

Other assemblages indicate a considerable variety of seasonal sowing patterns with no strict geographical or chronological patterning (though none is known to predate the late seventh century and there is some apparent bias towards the midlands and east coast). Some of these alternative patterns directly contradict the expectations of a 'champion' system. For instance, spring-sown wheat may have been included in some cropping regimes in the Central Zone from around the late eighth or ninth century, while rye may have been a spring crop at Thanet Earth between the eleventh and fourteenth centuries.

A special and ecologically sensible emphasis on spring-sown barley in the saline, seasonally flooded silt fens may have been established as early as the late seventh/early eighth century. Autumn sowing seems to have been preferred in the South West—a trend that seems to have been established by the early twelfth century (there are insufficient data for earlier periods)—perhaps in accord with the milder winter temperatures generally experienced in that region. In the adjacent, south-western part of the Central Zone, while there is no comparable emphasis upon autumn sowing, there is such a pronounced emphasis on wheat cultivation that there is no realistic possibility of identifying systematic seasonal sowing, let alone crop rotation, in the period represented (late ninth to fourteenth centuries).

Different crops in the same fields

It is not possible directly to assess this aspect of crop rotation using quantitative cereal and weed data alone. Rather, it requires consideration of grain biochemistry, as discussed below.

INVESTIGATING SYSTEMATIC CROP ROTATION USING STABLE ISOTOPE ANALYSIS

Understanding the nature of crop cultivation, and therefore crop rotation at individual sites, requires the examination of both crop stable isotope values and sowing times—the different attributes shown in Table 4.1. Stable isotopes of carbon and nitrogen provide information about the conditions in which the crops were grown; coupled with data on seasonal sowing, these provide insights into the likelihood that different cereal crops were grown in rotation (see Chapter 2 for detailed methodology).

Carbon isotopes provide information about the amount of sunshine and precipitation/soil moisture a plant receives during growth (water availability), but values vary with topography and annual rainfall (Bogaard *et al.* 2016; Wallace *et al.* 2013). That said, the use of carbon isotopes as a method for understanding water availability is less effective in temperate climates such as England, where plants generally have the necessary amount of water required for growth. While differences in δ^{13}C values are expected between some species due to physiological differences, marked differences between species in δ^{13}C values that reflect differences in growing conditions are not expected and a high amount of variability within species is possible. Therefore, direct comparison of the same species' carbon values over time is not useful for understanding changes in growing conditions. More useful is the comparison of different species' carbon values within an occupation phase, in order to assess whether or not the physiological offsets expected between the species are shown. For instance, when wheat and rye are similar and more positive than barley and oat (see Hamerow *et al.* 2020), these results would be consistent with rotation.

The ratio of the stable isotopes of nitrogen is more effective at identifying crops cultivated in similar soil conditions and so potentially in rotation. δ^{15}N values of the grains reflect the δ^{15}N value of the soil in which the plants were cultivated and the values differ depending on environmental conditions and different processes within the soil. Conditions such as seasonal wetting and drying, waterlogging, and aridity all affect the microbial activities within the soil, consequently changing the soil's isotopic ratio (Handley *et al.* 1999; Hartman and Danin 2010; Heaton 1986; Senbayram *et al.* 2008; Yousfi *et al.* 2010). The addition of manure also affects the δ^{15}N value by increasing it (Fraser *et al.* 2011). Comparing δ^{15}N values of the different crop remains from the same phase at a site can therefore be used to establish whether such crops were grown in soil with similar δ^{15}N values.

In summary, crops grown in rotation should display compatible stable isotope ratios, with offsets between species' δ^{13}C values consistent with their physiological offsets, but without significant differences between taxa in the case of δ^{15}N values. It is impossible to prove that rotation was practised, however, as it is theoretically possible that crops were grown in separate fields that happened to have similar conditions, or that multiple species were grown as a mixed crop in a single field. It is easier to demonstrate, using crop stable isotopes, that rotation was not practised. If δ^{15}N values for different cereals are significantly different, for example, it is highly unlikely that such crops were part of a systematic crop rotation. In a systematic three-course rotation system, it is expected that the different crops would be cultivated in the same soils: for example, the same field would bear winter wheat in year one and then spring barley in year two, such that barley and wheat would have similar δ^{15}N values. Being able to exclude rotation is significant, not least because an absence of systematic rotation indicates that the cereals in question were not grown in a regular open-field system.

It is also hypothesized that limited variability in δ^{15}N values is an additional indicator of systematic crop husbandry, that is, where most or all farmers in a community are using the same techniques. The variability of the individual isotope values provides information about how heterogeneous the growing conditions were, with lower variability among all species at a site hypothesized to indicate similar systematic cultivation. High variability in crop $\delta^{15}N$ values at a site may indicate the use of soils that vary considerably in $\delta^{15}N$ value—either a consequence of highly variable natural soil ^{15}N values within the arable fields or a consequence of different farmers using different methods within their fields. When variability in $\delta^{15}N$ values at a site is low, this suggests either that the soil surrounding the site was homogeneous with regard to ^{15}N enrichment or that farmers were cultivating the arable fields in very similar ways—for example, a communal form of crop husbandry where the different soil types were systematically shared among all farmers and the same levels of manuring occurred on all fields. While the use of crop $\delta^{15}N$ variability at a site must be tempered with other indicators such as $\delta^{15}N$ means, functional weed ecology, and an understanding of variability in soil types surrounding a site, tracking changes in variability over time at a regional level provides an opportunity to investigate whether or not there is a trend towards a more systematic form of crop husbandry in the early medieval period.

Results

The limited availability of suitable samples from case study sites—due to either the narrow range of crop species present in a given phase or poor preservation of a particular species over time—meant that it was often impossible to address change over time at individual sites. Nor was it possible at some sites to investigate comprehensively all crop species cultivated. At some sites, despite the presence of all crops (wheat, rye, barley, and oat), there were insufficient numbers of suitable grains of all species for isotope analysis because of preservation issues (*i.e.* high charring temperature or contamination; see Stroud *et al.* 2023). Inferences regarding the nature of crop rotation can therefore only be made for the species analysed, and it is possible that the excluded crops, had they been available for analysis, may have yielded different results. Some sites, such as Stratton, provided only limited information regarding crop rotation because the majority of grains were unsuitable for isotopic analysis. Others, such as Houghton, provided patterns suggestive of rotation but limited to just two crop species. Some sites such as Ottery St Mary have isotopic results for all four species, but only from one phase, so that tracing change over time is impossible.

Table 4.2 shows a summary of the isotopic results from the ten case study sites, indicating trends and differences between the sites and their phases. At some sites, there are differences between phases, while at others, change over time is limited. A number of the sites have isotopic results that are compatible with crop rotation, but in many of these cases, the compatibility only occurs in the later phases of the site, and/or with some but not all of the crop species. Some sites are also classed as *potentially* being consistent with rotation; these may have marked interspecies differences and unusually high values (*e.g.* Ottery St Mary and its extremely high rye $\delta^{15}N$ values), or extreme variability within a single species (*e.g.* Houghton and its bimodal wheat δ^{15}N values), but it is possible that such results are due to factors other than rotation. The bimodality at Houghton could be the result of importation of some wheat with a significantly different isotopic value, or the cultivation of two different forms of wheat, while the extremely high rye δ^{15}N values at Ottery St Mary could be the consequence of contamination. Other sites, such as Lyminge and Yarnton, are deemed inconsistent with rotation because of differences between species and markedly higher variability. A temporal trend is apparent, with earlier sites—or earlier phases of sites—producing limited evidence that is consistent with rotation, while later sites/phases tend to be more compatible. Table 4.2 also demonstrates three different ways of looking at the variability in δ^{15}N values: as indicated, high variability suggests that systematic rotation was not practised, while lower variability indicates that it may have been practised. There tends to be lower variability (red shading) over time (Table 4.2).

It is especially noticeable that the phases that demonstrate isotopic values compatible with rotation all occur from phase D onwards (*c.*880–1030).[10] Of the five sites with data from phases C3–C4, only two, Mildenhall and Holmer, show potential signs of crop rotation; in both cases, only two species have similar means. The only site not consistent with crop rotation in phase D is Houghton, which proved difficult to interpret due to its bimodal distribution of wheat δ^{15}N values and the comparison of only two species: wheat and oat. It is possible that some of the wheat was grown locally, in rotation with oat, while the wheat samples with the higher isotopic values were grown in a different location.

One of the variables shown in Table 4.2—the δ^{15}N offset—is calculated to normalize a site's δ^{15}N values against its δ^{15}N baseline. This allows the samples from all sites to be compared over time and enables overarching chronological trends to be investigated. It also means that values can be graphed irrespective of site. If a site is removed as a potential cause of variation in the data, it allows for between-site comparison and for changes at a larger time scale to be examined. This cannot be done on a site-by-site basis because of the patchiness of samples from different phases at individual sites. Figure 4.20 shows a clear trend towards lower variability over time between phases C–E, which have the highest numbers of samples. Examining the data by region is more difficult due to the uneven availability of the data; however, there are hints of regional trends. Sites in the South East, East Anglia, and the Central Zone exhibit a reduction in variability over time, from high variability in phase C to lower variability in phases D–E. In the South West and Western Lowlands, by contrast,

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[10] Isotopic analysis of rye, wheat, and barley grains from a malting complex dated to between the mid-eighth and early ninth centuries (FeedSax phases C2–C3) at Sedgeford, Norfolk, was undertaken as part of an independent doctoral research project by Hannah Caroe (University of Oxford), in collaboration with FeedSax. Caroe's results show that these cereals were all grown in similar soil conditions. This indicates that they were grown either in rotation or as a rye/wheat maslin (barley, constituting only 7% of the assemblage, is unlikely to have been deliberately grown as part of a mixed crop). Correspondence analysis hints at seasonal sowing, with rye and barley having a clear association with autumn-germinating weeds (Caroe 2022a, 2022b).

variability does not change over these three phases, suggesting a distinctive western crop husbandry trajectory.

Comparison of the seasonal sowing data shown in Figure 4.18 with the results of the isotopic analysis of cereal grains shown in Table 4.2 shows some complementary results (see Table 4.3). The few sites that produced material from earlier phases (notably Lyminge, Stratton, and Yarnton) show no evidence of systematic associations between sowing seasons and particular crop species. This is consistent with the stable isotope results, suggesting that there is no evidence of systematic crop rotation. The lack of evidence for seasonal sowing comes with some caveats, however, since taphonomic and other factors can distort or disguise evidence of systematic seasonal sowing. However, the combination of isotopic and weed data strengthens the case for a lack of systematic seasonal sowing or rotation in the earlier phases (*c.*420–880). By phase D (*c.*880–1030), however, a trend towards systematic crop rotation is indicated in both the isotopic and the seasonal sowing data. The clearest example of this comes from Stafford, where both the isotopic values and the archaeobotanical patterns are consistent with a classic 'champion-style' sowing regime (wheat and rye in autumn, barley and oat in spring) and systematic crop rotation (Hamerow *et al.* 2020).

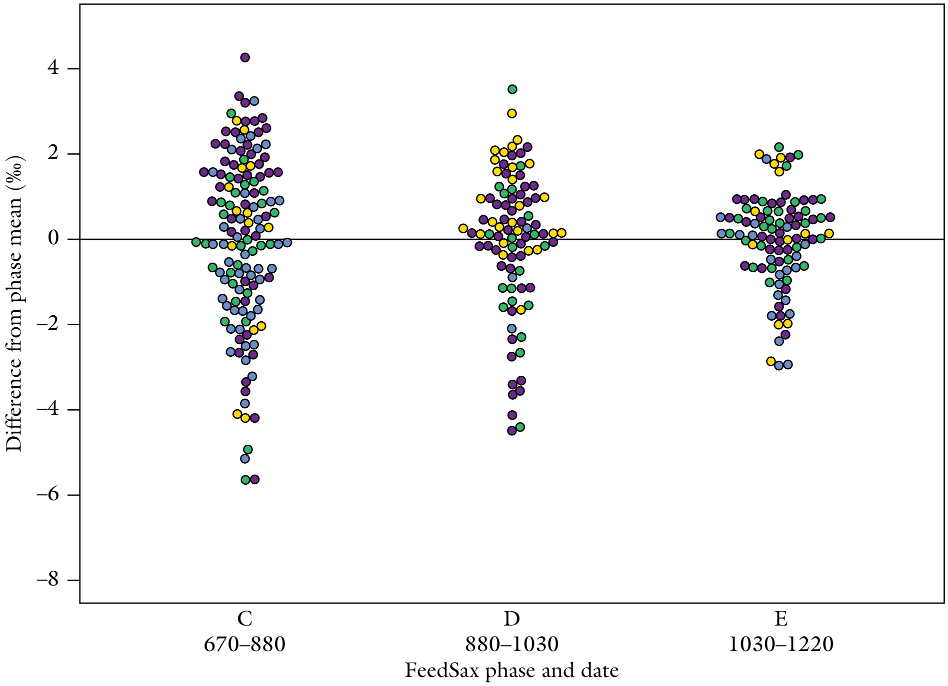

Figure 4.20. The difference from phase means of the δ¹5N values of species, from sites with material from phases C, D, and E. Yellow = oats, blue = barley, wheat = purple, green = rye.

Table 4.2. Summary of isotopic results from case study sites.

Site	Phase	Species	Overall rotation compatibility (similar means and low variability)	Compatible with rotation: are the means similar?		Overall variability (high, moderate, low)	δ ¹⁵N Standard deviation				δ ¹⁵N Offset				δ ¹⁵N Coefficient of variance (%)			
				$\delta^{15}N$	$\delta^{13}C$		Barley	Wheat	Oat	Rye	Barley	Wheat	Oat	Rye	Barley	Wheat	Oat	Rye
Lyminge	A2	Wheat/barley	No	N/a	Yes	High	1.4	2.9			0.4	0.5			44	89		
	C3–C4	All	No	Maybe	Yes	High	2.2	2.1	0.9	0.3	1.3	0.6	1.3	1	62	58	26	9
Stratton	C3–C4	Barley/rye	N/a	N/a	N/a	High	0.7			1.8	1.5			0.9	11			27
Yarnton	C3–C4	All (but only 1 rye)	No	No	Yes	High	2	2.8	1.8		0.76	0.9	0.86	1.1	29	41	26	
	D	All (1 of each)	N/a	N/a	N/a	N/a					0.3	1.5	1.6	0.2				
Mildenhall	C3–C4	Wheat/barley/rye	Potentially	Yes (not wheat)	Yes	Moderate/high	1.6	2.3		2.3	0.4	1.1		0.8	37	52		53
	D	Wheat/rye/oat	Yes	Yes	Yes	Moderate		1.7	1.2	2		0.1	1	0.5		36	25	43
Holmer and Wellington Quarry	C3–C4	Barley/oat/rye	Potentially	Yes (not oat)	Yes	Moderate	1.6		2.8	0.5	0.5		1.1	0.6	22		38	7
	E1–E4	Barley/rye/wheat	Yes	Yes (not barley)	Yes	Low	1.2	0.5		0.2	0.6	0.4		0.7	17	7		3
Houghton	D4	Wheat/oat	No	Maybe (wheat two populations)	Yes	Moderate		2.1	0.9			0.7	1.1			32	14	
	E1–E4	Wheat/oat	N/a	Only 1 oat	N/a	N/a		0.9	n/a			0.4	2			0.1	n/a	

Continued

TABLE 4.2. *Continued*

Site	**Phase**	**Species**	**Overall rotation compatibility (similar means and low variability)**	**Compatible with rotation: are the means similar?**		**Overall variability (high, moderate, low)**	**δ ^{15}N Standard deviation**				**δ ^{15}N Offset**				**δ ^{15}N Coefficient of variance (%)**			
				δ^{15}N	**δ^{13}C**		**Barley**	**Wheat**	**Oat**	**Rye**	**Barley**	**Wheat**	**Oat**	**Rye**	**Barley**	**Wheat**	**Oat**	**Rye**
Stafford	D	All	Yes	Yes	Yes	Low (high barley)	0.9	0.9	0.8	1.9	2.3	0.1	0.7	0.2	14	15	13	30
	E	All	Yes	Yes (not barley)	Maybe	Low (high barley)	1	1.6	2.1	0.7	2	1.1	0.2	0.3	13	20	26	9
Pudding Lane	E1	All	Potentially	Yes (not oat)	Yes	Low (high oat)	0.1	1.3	2.4	0.9	0.4	0.4	1.1	0.3	3	30	56	21
	E2–E3	Wheat, rye, barley	Yes	Yes	Maybe	Low	0.8	0.3		0.5	0.6	0.4		0.2	19	9		13
Ottery St Mary	G1	All	Potentially	Maybe (rye)	Yes	Low (high rye)	1	2.3	0.7	2.9	1.2	0.3	0.1	0.2	14	31	10	40

TABLE 4.3. Comparison of evidence for rotation (from stable isotope analysis) and seasonal sowing (from correspondence analysis of crop and weed remains) at the case study sites.

Site	Rotation	Sowing time
Lyminge	No	No systematic association—could be any cereal in any season
Stratton	Lack of data	No systematic association—could be any cereal in any season
Yarnton	No	No systematic association—could be any cereal in any season
Mildenhall	Yes	Spring wheat; autumn barley/oat/rye
Holmer	Potentially	Assemblage dominated by spring weeds
Wellington Quarry	Yes	Assemblage dominated by spring weeds
Houghton	Potentially	Spring wheat/barley; autumn oat/rye/wheat (possibly two different kinds of wheat)
Stafford	Yes	Champion-style (autumn wheat/rye; spring barley and possibly oat)
Pudding Lane	Yes	Autumn rye; wheat in spring and autumn
Ottery St Mary	Potentially	Potentially all autumn; oat possibly also in spring

Site-specific results

A few sites, notably Mildenhall, Wellington Quarry/Holmer, and Pudding Lane, produced samples from several phases, providing the opportunity to examine multiple species over two or more phases at an individual site, allowing temporal trends to be investigated. At Mildenhall, the samples from phases C3–C4 and D contain at least three different species. The δ^{13}C values in these phases show that wheat, rye, and barley (for phases C3–C4) and wheat, rye, and oat (for phase D) have similar levels of soil moisture, consistent with being cultivated within the local area and also consistent with the known physiological offsets for the species. This was found to be the case at the majority of the sites, including Wellington Quarry/Holmer; as mentioned above, the high rainfall experienced in temperate climates renders δ^{13}C values less useful as a tool for understanding differences in cultivation. There are exceptions to this pattern, however; sites such as Pudding Lane, Stafford, and Houghton have some species that do not fit the expected δ^{13}C offset. In the case of Pudding Lane's second phase of activity (spanning E2–E3), barley has a very similar δ^{13}C mean value to the wheat and rye, a similarity that would not be expected had these crops been cultivated under similar conditions. It is possible that there was a marked difference in precipitation between the cultivation years; barley may have been grown in significantly drier years, so incompatible δ^{13}C values are not by themselves sufficient reason to rule out crop rotation.

The δ^{15}N values allow differences in cultivation conditions to be more comprehensively understood, as differences in δ^{15}N values between species can be used to rule out the use of systematic crop rotation. At Mildenhall, the samples from phases C3–C4 show differences suggesting that not all crops were grown on similar soil conditions. Wheat has a significantly lower δ^{15}N mean value and higher variability when compared to rye and barley. Such results suggest that while rye and barley were grown in soils with similar ^{15}N enrichment, wheat was not and appears to have been grown in soil with lower ^{15}N enrichment. There are, of course, a myriad of other factors that could have caused this lower ^{15}N enrichment, including soils with less manuring or environmental conditions (such as waterlogging, or wetting and drying). Regardless of what caused the soil to be lower in ^{15}N, the key finding is that wheat was lower in ^{15}N than the other crops—which tells against systematic crop rotation, in which all crops were grown in the same soils.

The results from phases C3–C4 at Mildenhall thus suggest that crop rotation was not practised in this phase of the settlement (*c.*770–880). The results from phase D (*c.*880–1030) show that the crops were still grown in similar soil moisture levels, as the carbon results fit the known physiological differences. The δ^{15}N values from this phase, however, show differences compared with those from phases C3–C4. Wheat's δ^{15}N value in phase D is similar to those of rye and oat (no barley grains from this phase were suitable for isotopic analysis). These results therefore indicate a change in the cultivation conditions of wheat, moving from being cultivated in soil with a lower δ^{15}N ratio to soil with a similar isotopic ratio to the other crops. Such a change could indicate a shift towards a more systematic form of crop husbandry, specifically the introduction of crop rotation.

Variability is another factor that could be used to understand how homogeneous the cultivation conditions of crops were. As noted above, it is hypothesized that the higher the variability seen in δ^{15}N values, the more heterogeneous the cultivation conditions, with a wider range of soil types as well as of environmental and anthropogenic factors influencing δ^{15}N values. The lower the variability in δ^{15}N values within a species and the greater the similarity between the different species' ranges of variability, the more likely it is that there was a shared mode of crop husbandry, where the inputs are standardized for all species and between all farmers. Mildenhall provides the opportunity to look at variability and how it changes between the two phases. In phases C3–C4, wheat has a higher coefficient of variance compared to the other crops, while in phase D, the coefficients of variance of the three crops are lower and very similar (Table 4.2). The change in variance might be explained if wheat grew in a range of conditions in the early phase, but those conditions became more homogeneous in the later phase. When combined with the knowledge that wheat also had a different δ^{15}N mean value from the other crops in the earlier phase in comparison to the later phase, a plausible interpretation of the Mildenhall results is that the phase D results are more consistent with systematic crop rotation than those from phases C3–C4, with wheat having been treated differently in phases C3–C4, perhaps cultivated on more variable or a wider range of soils.

To consider the evidence for crop rotation at Mildenhall fully, the sowing times of the crops need to be compared to the isotopic results. This is because similar δ^{15}N values of crop species could result from different species having been grown together as a mixed crop in the same field, or grown in different fields with similar conditions, rather than being a sign of systematic rotation. As discussed above, Mildenhall's weed assemblage does not provide evidence of a consistent association between particular crops and specific sowing times (*e.g.* wheat/rye in autumn and oat/barley in spring). It does, however, suggest that during the later phases, wheat was sown in spring, and the other crops were sown in autumn: removal of samples dated to phases C3–C4 makes the spring association of wheat evident. This trend correlates with the Mildenhall isotopic results, which indicate a shift between the earlier and later phases, plausibly reflecting a switch to systematic seasonal sowing and crop rotation.

Mildenhall illustrates the complexities involved in understanding medieval cultivation regimes. While Stafford provides evidence of the classic rotation regime associated with the three-field system, other sites such as Mildenhall show more variability. Mildenhall's change in crop stable isotopes over time may point to the adoption of crop rotation in phase D (*c.*880–1030), while the seasonal sowing data indicate a possible association of crops with specific seasons in that period, albeit one that diverges from that traditionally associated with the three-field system. The crop rotation and seasonal sowing data highlight how crop cultivation regimes differ between sites, while still following some form of crop rotation and seasonal sowing from around the tenth century.

CONCLUSION

The majority of archaeobotanical samples analysed in this study come from settlements located in the Central Zone and consequently many are likely to derive from open-field systems (see Chapter 2). Whether individual samples represent peasant production or demesne farming or were grown on tenanted land is impossible to know. Our results do indicate, however, that in the Central Zone, South East, Western Lowlands, and East Anglia, systematic rotation was practised at a relatively wide range of sites by the tenth century. Only Stafford, however, provides unambiguous evidence of the 'classic' three-field regime, namely autumn-sown wheat and rye with spring-sown barley and (perhaps) oat. Systematic rotation appears to have been practised at Mildenhall by phase D, but with spring-sown wheat and autumn-sown rye, barley, and oat. Systematic rotation was also practised at Pudding Lane, Wellington Quarry, and potentially a few other sites, but these again did not follow the 'classic' regime. Conversely, systematic rotation does *not* appear to have been practised at either Lyminge during phases C3–E5 or Yarnton during phases B2–D4, despite the latter lying in an area of (undated and potentially much later) open fields (Hey 2004). Our analyses thus reveal a degree of variability and complexity that is not conveyed by the written sources.

While the presence of intermingled strips implies systematic crop rotation, the reverse is not true. A few late Saxon charters refer to subdivided or 'shared out' land

(Blair 2018, 330) and suggest that such land became increasingly common from the mid-tenth century onwards, at least in the southern and south-western midlands (no sources survive from this early period for the eastern zone; Blair 2018). Blair has argued that systematic, communally managed crop rotations would over time have 'transformed shares allocated by lot in occasionally cultivated outfields into permanent subdivided field systems' (2018, 333); Williamson too accepts the existence of intermingled holdings by the tenth century (2013, 177–82). The trend towards reduced isotopic variability from the late ninth and tenth centuries identified above is broadly consistent with this view.

A potential link between the results presented here and climate should be considered, while acknowledging that the kinds of data needed conclusively to establish or disprove such a link are lacking. Phase D coincides broadly with the onset of the Medieval Climate Anomaly (sometimes referred to as the Medieval Warm Period), although the exact timing of its onset and its impact on temperature and precipitation in Britain are matters of debate (Büntgen and Tegel 2011). The absence of autumn-dominated and champion-style assemblages prior to phase D (with the possible exception of Ely) is notable (Figure 4.18). Could this be connected to the onset of milder winters? The fact that spring-dominated assemblages are disproportionately well represented in phase C is largely because all assemblages from the fenlands—where a lack of autumn sowing is to be expected—happen to be of that date. Similarly, the dominance of autumn sowing in the milder conditions of the South West—for which only later assemblages are available—is unsurprising. While assemblages that produced no evidence for systematic seasonal sowing (*e.g.* of barley in spring) nevertheless show signs of autumn sowing (notably Dorney, Stratton, Yarnton, and Ipswich), only five out of the seventeen assemblages with early (pre-phase D) material did so. So, while autumn sowing was certainly practised prior to phase D, it appears to have become a more widespread and consistent part of crop husbandry regimes from the tenth century onwards and so—along with systematic rotation—could plausibly be linked to the onset of more favourable climatic conditions.

Feeding Medieval England: A Long 'Agricultural Revolution', 700–1300. Helena Hamerow, Mark McKerracher, Amy Bogaard, Mike Charles, Emily Forster, Matilda Holmes, Christopher Bronk Ramsey, Elizabeth Stroud, and Richard Thomas, Oxford University Press.

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FIVE

The Spread of the Mouldboard Plough: Draught Cattle and Disturbed Ground

> Some men will tell you that a plough cannot work eight score . . . acres yearly, but I will show you that it can.
>
> Walter of Henley, *Husbandry* (Lamond 1890)

INTRODUCTION

The mouldboard plough has traditionally been regarded as a radical innovation and the key element in a technological package that enabled northwest Europe to pursue a 'special path' towards increased productivity (Duby 1962; Mitterauer 2010; White 1962). Indeed, White (1962) argued that three-field farming was the direct result of the adoption of the mouldboard plough, although this view has long been criticized as technological determinism (Hilton and Sawyer 1963, 90).[1] Like so much of the narrative surrounding the medieval 'agricultural revolution', our understanding of the role played by the mouldboard plough relies heavily on limited and mostly indirect evidence. Nevertheless, few would disagree with the view that its widespread adoption—was critical to increasing agricultural outputs. As described in Chapter 1, the mouldboard plough allowed heavier, more fertile soils to be cultivated more readily and on a larger scale; it also increased the amount of land that could be ploughed in a day without a concomitant increase in human labour. In turning over the soil, it reduced the need for manual work such as breaking up clods of earth, in this way achieving both extensification—especially on heavier soils—and more effective tillage than an ard (Figure 5.1; Banham and Faith 2014, 58; Campbell 1983). The mouldboard plough can therefore with some reason be described as the combine harvester of its day: too expensive to be within reach of most peasant households, but essential if the benefits of large-scale, low-input cereal farming were

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[1] For a recent example of this view and an attempt to quantify the impact of the mouldboard plough on medieval agricultural productivity and urbanization in Denmark, see Barnebeck Anderen *et al.* (2016).

to be fully realized. It is nevertheless clear that the transition from ard to mouldboard plough in northwest Europe was a protracted process and that complex ards fitted with iron coulters and a wheeled fore-carriage remained in use in parts of Europe throughout the early Middle Ages, although on what scale remains unclear (Comet 1997; Fowler 1981, 269).[2]

FIGURE 5.1. Reconstructed early medieval ard at the open-air laboratory of Lauresham, at Lorsch, Germany (Photo: C. Kropp).

While it may indeed be 'a mistake to contrast the two instruments too radically', there is little doubt that on heavy, poorly drained soils the mouldboard plough had significant advantages over the ard (Comet 1997, 23–24). To what extent, however, is it correct to regard it as an early medieval innovation in Britain? To answer this question, it is necessary to consider what is known about the cultivation regimes used in Roman Britain. Although the heavy wheeled plough was used in parts of the Roman West and a recent survey has concluded that ploughs capable of turning over the soil existed in northeast Gaul (Henning 2009; Marbach 2001), finds of wooden shares along with preserved ard marks have led Lodwick and Brindle (2017, 42) to conclude that the ard

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[2] Evidence for cross-ploughing and thus (presumably) use of the ard has, for example, been dated to the twelfth century in Surrey (Fowler 2002, 204; Webster and Cherry 1972, 205).

was the main tillage implement of Roman Britain.[3] By the late Roman period, some ards were very substantial indeed and could be equipped with an iron share tip as well as an iron coulter: a blade mounted vertically in front of the share (Lodwick and Brindle 2017, 29). Indeed, a number of coulters from this period have been found in archaeological contexts in Britain, mostly associated with villa sites (ibid.).

Something similar to mouldboard plough certainly seems to have been in use elsewhere in Europe during the Roman period, both within the Empire and beyond it. In Denmark as in England, its introduction has traditionally been linked with the laying out of the first open fields. However, well-preserved traces of 'turned furrows' evidently produced by ploughs with mouldboards have been radiocarbon dated to between the first century BC and the later Roman Iron Age (Figure 5.2), casting serious doubt over the supposed link between the mouldboard plough and open field farming. Indeed, according to Larsen (2013, 199), this evidence means 'the idea of a technological revolution around AD 1000 acting as a catalyst for dynamic social changes is no longer tenable'. 'Turned furrows' have been found in regions stretching from Denmark—where they are concentrated in western Jutland—to northwest Germany, where they have been found associated with coastal settlement mounds such as Feddersen Wierde (Hamerow 2002, 143; Larsen 2013).

FIGURE 5.2. Section through 'turned furrows' in Denmark (Photo: Torben Egeberg, ARKVEST—Arkæologi Vestjylland).

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[3] Oosthuizen (2011, 385) nevertheless takes the view that the mouldboard plough was 'generally in use in the Roman centuries'.

It seems, therefore, that ploughs with mouldboards were in use in northwest Europe centuries before the laying out of the first open fields, although at what scale can only be guessed at. One possible explanation for the early use of the mouldboard in certain regions of northern Europe is the advent of autumn-sown rye grown on heavier clay soils that required the improved drainage provided by ridge-and-furrow ploughing (Larsen 2013).

In western and central Europe more generally, the heavy, wheeled plough (referred to as a '*carruca*' in documents from the 820s) was known from at least the second century, although its use expanded significantly in the eighth and ninth centuries. The Carolingian inventories known as polyptychs, however, demonstrate that not all farms had wheeled ploughs (Verhulst 2002, 67); whether all wheeled ploughs had mouldboards is unclear (C. Kropp pers. comm. 2020).

In England too, it has generally been assumed that the shift in emphasis from ard to plough occurred in the tenth and eleventh centuries, when both implements were first depicted in manuscript illustrations (Figure 5.3; Fowler 2002, 203–4). By the time of Domesday Book, such ploughs were very numerous in England, with the eighty thousand or so plough teams recorded (each notionally consisting of eight oxen) representing a substantial investment in livestock, iron, and specialist training (Darby 1977, 336).

FIGURE 5.3. Using a mouldboard plough (eleventh-century calendar illustration). British Library, Cotton Tiberius B, v, fol. 3r.

The assumption that the introduction of the mouldboard plough in England was closely linked to the advent of open-field farming needs to be critically re-examined in light of the discovery of a plough coulter at Lyminge in east Kent, where an early 'great hall complex' was succeeded by a royal monastery around the middle of the seventh century (Thomas *et al.* 2016). The coulter had been placed on the base of a building that can be firmly dated to the first half of the seventh century, probably as part of a closure ritual. The coulter shows signs of heavy use, and a small perforation close to its cutting edge indicates that it formed part of a 'swivel plough', a kind of mouldboard plough used in parts of the Frankish world (Thomas *et al.* 2016). Thanks to this remarkable find, it is now clear that the mouldboard plough was in use in England several centuries earlier than previously believed. Whether its use was restricted to royal sites that, like Lyminge, had close Frankish links, remains a moot point, although the discovery raises the possibility that royal and religious centres were 'early adopters' of this costly and sophisticated technology (Grigg 1982, 153).

Banham and Faith (2014, 721–2, 294) conclude that the mouldboard plough probably began 'to make an impact' in England in the eighth and ninth centuries. While the difficulties of turning a heavy plough pulled by a team of up to eight oxen meant that they could be used most efficiently in large, unenclosed fields, they caution against assuming that the presence of the mouldboard plough necessarily implies the presence of open fields. Similarly, use of such a plough need not imply the 'pooling' of oxen by farmers to provide the necessary traction. The laws of Ine of Wessex (688–726) indicate that by the late seventh century, farmers could hire each other's oxen and require 'the ceorl who has hired another's yoke [of oxen]' to pay in fodder (Whitelock 1955, EHD I, no. 32, §60).

The key question is therefore not 'when was the mouldboard plough first used in England?', but rather, when did it change from being a high-status implement used by royal or monastic establishments to an essential piece of equipment for farmers wishing to implement an extensive, 'low-input' cultivation regime of the kind described in Chapter 3? Indirect evidence for the spread of the mouldboard plough is provided by archaeology: changing settlement patterns in some regions indicate an expansion beyond the light, easily worked soils favoured during the fifth to seventh centuries (on river gravels, for example) onto heavier, more fertile, soils from the eighth century (Hamerow 1999). This may imply increasing use of the mouldboard plough, which would have made it more practical to cultivate such soils (Oosthuizen 2011, 385). Direct evidence of its use, however, is needed to establish whether use of the plough increased gradually over time or whether (and when) a more abrupt transition or 'tipping point' was involved. Such evidence has been generated by the present project in two complementary ways: first, by examining cattle bones to assess the changing emphasis on traction and use of draught cattle over time, and second, by establishing levels of soil disturbance in arable fields and hence the type and, potentially, frequency of tillage, through an ecological examination of arable weeds.

ZOOARCHAEOLOGICAL APPROACHES

The evidence provided by animal bones can be deployed in several ways to trace changes in the use of cattle for draught purposes. Indirect sources include an analysis of animal husbandry strategies derived from zooarchaeological data (*i.e.* demographic profiles).

Direct evidence comes from pathological and sub-pathological changes affecting the feet of cattle that are likely to indicate biomechanical stresses exacerbated by their use for draught purposes. Details of the methods used in this analysis are provided in Chapter 2. These approaches are based on two assumptions. First, increased use of cattle for traction (*e.g.* ploughing, harrowing, carting) generally results in a greater proportion of older males in the cattle population (although see below). Male cattle have little value beyond meat as they cannot be used for dairy, and even when solely used for breeding, far fewer bulls are required compared to cows (Slavin 2012, 1251 has suggested a theoretical ratio of fifty cows to one bull).

Second, more intensive use of draught cattle and/or a longer working life pulling heavy equipment such as a mouldboard plough and cultivation of heavier soils would result in a higher frequency and severity of lower limb bone remodelling compared to those observed in animals that pulled ards on lighter soil, or that were not used for traction.

CATTLE HUSBANDRY

Data captured by this project provide detailed zooarchaeological records on a scale and at a chronological resolution not previously attempted, and have contributed to a better general understanding of medieval animal husbandry (Holmes *et al.* forthcoming), the findings of which will be drawn on here. Earlier syntheses of zooarchaeological data have been crucial to the interpretation of animal husbandry in medieval England, although this has only ever been attempted on a regional level (Albarella 2019; Holmes 2018; Levitan 1987; Serjeantson 1996), with a relatively small dataset (Clutton-Brock 1976; Grant 1988; Noddle 1975), or for a specific period (Albarella 1997b, 1999; Crabtree 1989, 1996a, 1996b, 2012, 2014; Holmes 2013, 2016; O'Connor 2001, 2010; Sykes 2006, 2007, 2009; Thomas 2005a). Building on the results of these pioneering works, our data provide fresh insights into animal husbandry in England for the thousand years spanning AD 400–1400.

The demography (age and sex) of cattle herds can be used to infer the economic importance of secondary products (milk and traction) in comparison to meat and raw materials (skin, bone, horn, connective tissue). A greater proportion of older animals would be expected from a husbandry regime focused on secondary products, but deciphering the specific output is not so easy. Many medieval texts refer to the use of 'oxen', widely considered to be castrated males, for traction (Johannsen 2011, 14), but there is no reason why cows could not also have been used to pull carts or ploughs. For a peasant farmer, a cow may be a better option given the potential benefits of future calves and milk yields (Johannsen 2011). The keeping of cattle as a form of portable wealth may also affect herd demography (Holmes *et al.* 2021a). There is, therefore, potential for some ambiguity in the interpretation of cattle sex profiles, although a high proportion of older male cattle would certainly imply their use for traction.

In all phases, the data are largely consistent with a mixed husbandry regime (Table 5.1) in which some animals were culled to provide meat as they neared maturity, while some older animals were kept for secondary products. However, there are some periods when a greater emphasis on older animals can be observed. The fifth and sixth centuries are generally regarded as a time when relatively dispersed rural populations lived a self-sufficient lifestyle based on individual farms without formal markets (Crabtree 2018, 66). The majority of cattle were part of a mixed economy, with most kept for meat and some older animals for traction, breeding, and/or dairying on a small scale.

The development of international trade and non-agrarian populations living within semi-urban *wics* in the period *c.*650–850 implies increased agricultural surplus production, though the mechanics of this process are still debated (*e.g.* Crabtree 2018; Hamerow 2007; Holmes and Hamerow forthcoming; O'Connor 2010; Pestell 2011). Most rural communities continued to be self-sufficient, although some cattle were kept alive for longer, reflecting an increased need for surplus production of secondary products. An increase in the age at death of cattle from the tenth century reflects a growing emphasis on traction, as the production of grain was optimized to feed an

TABLE 5.1. Main focus of cattle production in England through time. Data from Holmes *et al.* (forthcoming).

Period	**FeedSax phase**	**Production**
400–450	A1	Mixed
450–500	A1	Mixed
500–550	A1	Mixed
550–600	A2	Mixed
600–650	B1–B2	Mixed
650–700	B2–C1	Mixed
700–750	C1–C2	Mixed
750–800	C2–C3	Mixed
800–850	C3–C4	Mixed
850–900	C4–D1	Mixed
900–950	D1–D2	Secondary
950–1000	D3–D4	Secondary
1000–1050	D4–E1	Secondary
1050–1100	E1–E3	Secondary
1100–1150	E3–E4	Diversification
1150–1200	E4–E5	Diversification
1200–1250	E5–F1	Diversification
1250–1300	F1–F2	Diversification
1300–1350	G1	Diversification
1350–1400	G1–G2	Diversification

expanding population (Albarella 2019, 213; Holmes 2018, 70; Sykes 2007, 37). From the twelfth century, an increase in the proportion of younger cattle is observed, linked to a greater demand for meat production, observed in a diversification between younger animals culled for meat and older animals used for secondary products, reflecting changing dietary demands and the introduction of horses for draught work (Holmes *et al.* forthcoming).

Female cattle predominate in all phases (Table 5.2), as would be expected, reflecting the cull of younger males for meat (Holmes *et al.* forthcoming). The use of metacarpals means that the sex data relate to older animals over twenty-four months of age (because it is not possible to sex unfused metapodia) and younger animals over seven months (when pelves fuse; Silver 1969). An increase in older males occurs from AD 800, implying a greater emphasis on draught work. The proportion of male cattle decreases between AD 800 and 1100, but recovers again from AD 1000 to 1300.

Table 5.2. Summary of cattle sex profiles. Data from Holmes *et al.* forthcoming.

Period	FeedSax phase	Sex
600–800	B1–C3	Mostly female, young males
800–1300	C3–F2	Mostly female, older males

To summarize, the national trend towards older male cattle from AD 800 and the corresponding importance of secondary products from AD 900 imply a growing emphasis on draught cattle. From AD 1100, the culling of much younger animals for meat is apparent alongside older cattle used for traction and/or dairy.

DRAUGHT CATTLE

Cattle in the wild are not subject to external loading or pulling forces. When they are subjected to such forces (*e.g.* through carting, carrying, ploughing, or harrowing) over a prolonged period of time, increased stress is placed on joints, which, when exceeding physiological limits, may precipitate adaptive changes to the soft and hard tissues. Pathological and sub-pathological changes associated with cattle used for draught purposes have previously been identified, and recording methods refined to take into account the age of animals and fragmentation of bones (Bartosiewicz *et al.* 1997; Carlson Dietmeier 2018; Thomas *et al.* 2021). A full description of the methods used in the present study is provided in Chapter 2, which details the process of converting severity scores of each recorded lesion into a *modified Pathological Index* (mPI) for each element that can then be compared reliably between assemblages. Research conducted as part of the FeedSax project has identified that the physiology, sex, and body mass of cattle also have an effect on the prevalence and severity of changes to the lower limb bones of cattle (Holmes *et al.* 2021b), which cannot be mitigated during analysis; steps can, however, be taken to gauge the impact of these variables. The physiological effects of stresses affecting the bones of the fore and hind limbs produce significantly different results. Approximately two thirds of the cattle's body weight is carried on the fore limbs, and the severity of lesions affecting the bones of the forelegs are subsequently greater than those affecting the hind limbs (Bartosiewicz *et al.* 1997, 95). By considering the bones of the fore and hind limbs separately, this differential effect can be mitigated. Furthermore, comparison of the mPI between the bones of the fore and hind limbs can provide a good indication of the extent of the stresses to which the hind limbs are subjected relative to the fore limbs, which will be greater in animals used for draught purposes (Holmes *et al.* 2021b).

Fifty-four assemblages from twenty targeted sites (Table 2.3, Figure 2.8) produced data on the pathological and sub-pathological changes in nearly 2,870 lower limb elements (Table 2.4). The mean posterior mPI results for each assemblage recorded from the targeted sites are presented in Figure 5.4, where higher values imply greater loading of cattle. The mean mPI of posterior elements from all assemblages is also provided to establish a comparison for high values. As described above, the physiology of cattle means that the mPI values are expected to be naturally greater for the anterior (fore limb) elements, yet additional loading produces a greater likelihood that changes will occur on the posterior (hind limb) elements, so assemblages with similar mPI values (less than 0.01 difference) for both the anterior and posterior limbs (Figure 5.5) are therefore likely to include draught cattle. It was also possible to plot individual mPI scores for the hind limb elements from each site (Figure 5.6), the presence of mPI scores above the mean suggesting the presence of individual draught animals.

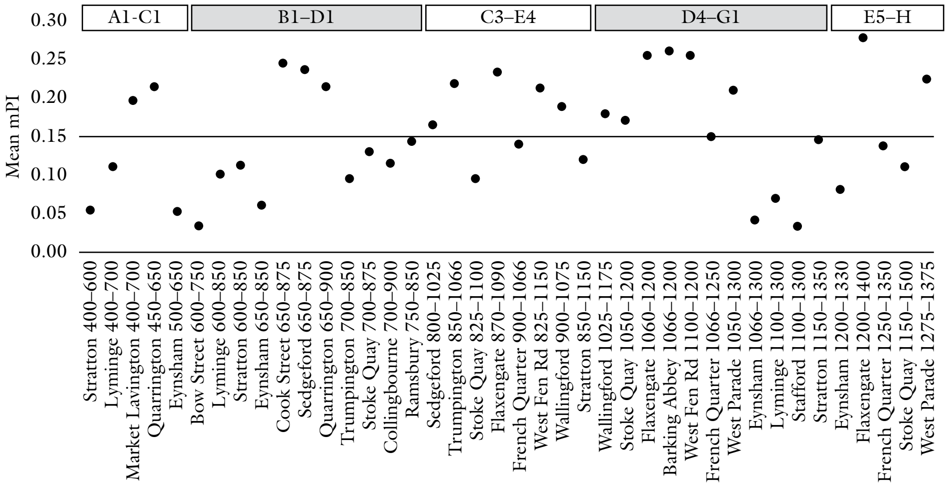

FIGURE 5.4. Mean modified Pathological Index (mPI) for posterior elements from all assemblages with ≥5 elements, in order of the midpoint of the date range of each assemblage. Line describes the mean mPI from all assemblages.

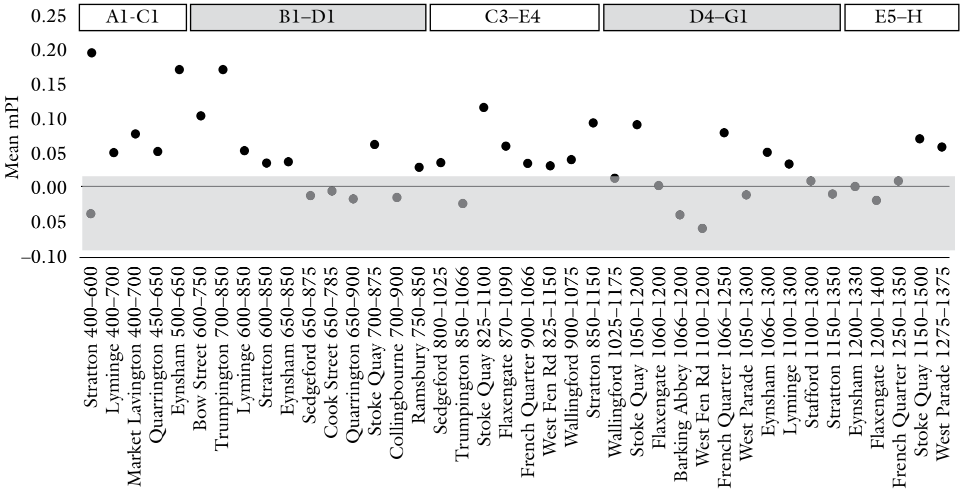

FIGURE 5.5. The difference in mean mPI values between anterior and posterior elements from all assemblages with ≥5 elements, in order of the midpoint of the date range of each assemblage. Shaded area depicts sites with scores that are considered sufficiently close to indicate the effect of hind limb loading.

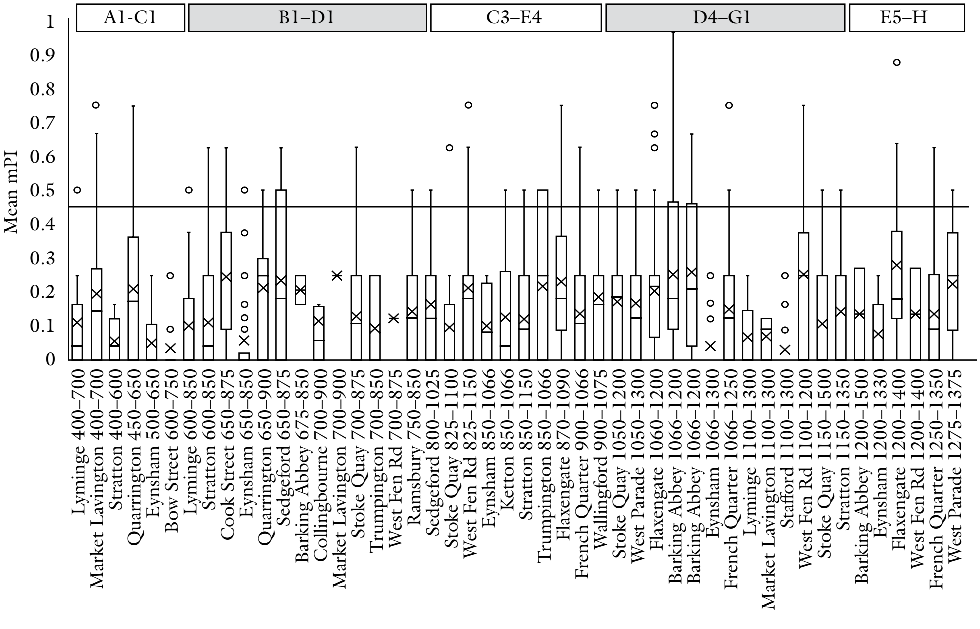

FIGURE 5.6. Modified Pathological Index (mPI) for posterior elements recorded from targeted sites. In order of the midpoint of the date range of each assemblage. Line represents the mean mPI of all draught oxen posterior elements.

These data allow the presence of potential draught cattle to be identified using three criteria. Assemblage-level data for mean mPI values and the difference between anterior and posterior values (Figures 5.4 and 5.5) can be combined with the absolute values from individual animals (Figure 5.6) to produce a 'draught cattle' signature for individual sites that meet at least two of these three criteria (Table 5.3, Figure 5.7).

TABLE 5.3. Number of criteria established for all assemblages with a large enough sample size to be considered for all three criteria. Those with a ‘draught cattle’ signature fulfil at least two criteria. Post = posterior; ant = anterior.

Site	Dates	FeedSax phase	N criteria	High post mPI	Similar ant-post mPI	Individual high mPI
Stratton	400–600	A1–A2	0	–	–	–
Lyminge	400–700	A1–C1	1	–	–	Y
Market Lavington	400–700	A1–C1	2	Y	–	Y
Quarrington	450–650	A1–B2	2	Y	–	Y
Eynsham	500–650	A1–B2	0	–	–	–
Bow Street	600–750	B1–C2	0	–	–	–
Lyminge	600–850	B1–C4	1	–	–	Y
Stratton	600–850	B1–C4	1	–	–	Y
Eynsham	650–850	B2–C4	1	–	–	Y
Cook Street	650–875	B2–C4	3	Y	Y	Y
Sedgeford	650–875	B2–C4	3	Y	Y	Y
Quarrington	650–900	B2–C4	3	Y	Y	Y
Trumpington	700–850	C1–C4	0	–	–	–
Stoke Quay	700–875	C1–C4	1	–	–	Y
Collingbourne	700–900	C1–D1	1	–	Y	–
Ramsbury	750–850	C2–C4	1	–	–	Y
Sedgeford	800–1025	C3–D4	2	Y	–	Y
Trumpington	850–1066	C4–E2	3	Y	Y	Y
Stoke Quay	825–1100	C4–E3	1	–	–	Y
Flaxengate	870–1090	C4–E3	2	Y	–	Y
French Quarter	900–1066	D1–E2	1	–	–	Y
Wallingford	900–1075	D1–E2	2	Y	–	Y
West Fen Rd, Ely	825–1150	C4–E4	2	Y	–	Y
Stratton	850–1150	C4–E4	1	–	–	Y
Wallingford	1025–1175	D4–E5	3	Y	Y	Y
Stoke Quay	1050–1200	E1–E5	2	Y	–	Y
Flaxengate	1060–1200	E2–E5	3	Y	Y	Y
Barking Abbey	1066–1200	E2–E5	3	Y	Y	Y
West Fen Rd, Ely	1100–1200	E3–E5	3	Y	Y	Y
French Quarter	1066–1250	E2–F1	1	–	–	Y
West Parade	1050–1300	E1–F2	3	Y	Y	Y
Eynsham	1066–1300	E2–F2	0	–	–	–
Lyminge	1100–1300	E3–F2	0	–	–	–
Stafford	1100–1300	E3–F2	1	–	Y	–
Stratton	1150–1350	E4–G1	2	–	Y	Y
Eynsham	1200–1330	E5–G1	1	–	Y	–
Flaxengate	1200–1400	E5–G2	3	Y	Y	Y
French Quarter	1250–1350	F1–G1	2	–	Y	Y
Stoke Quay	1150–1500	E4–H	1	–	–	Y
West Parade	1275–1375	F2–G2	2	Y	–	Y

The term 'draught cattle' is placed in inverted commas to emphasize the possibility that there are other potential factors affecting the findings such as cattle size and sex, although these factors are addressed wherever possible.

When the data are considered by individual assemblage only, as for the 'draught cattle' signature, sample sizes become too small to be reliable when comparing results over time. Therefore, individual posterior mPI values were combined for all elements to enable consideration of variables by broad phase. The data required a non-parametric test, so a Mann-Whitney U test was used on samples with at least ten mPI scores. Results were considered significant at $P \leq 0.05$.

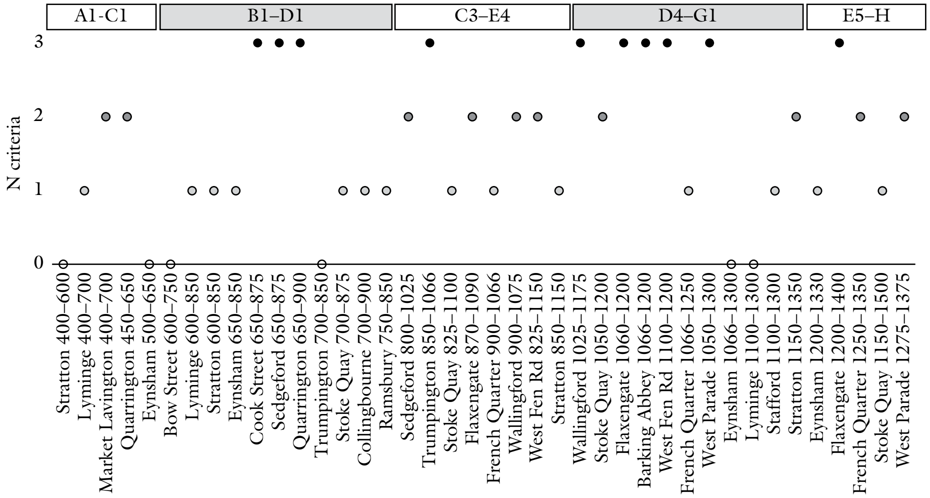

FIGURE 5.7. Number of criteria recorded for each assemblage eligible for all three criteria, in order of the midpoint of the date range of each assemblage. Assemblages with at least two criteria are considered to have a 'draught cattle' signature. See Table 5.3 for details.

Biological variables

A major consideration when interpreting the data is the effect of body mass, reflected by the size and sex of animals (male cattle generally being larger than females). Thus, larger and male animals (bulls and castrates) are more likely to exhibit greater severity of pathological and sub-pathological changes than are smaller and female cattle (Holmes *et al.* 2021b). To understand the likely impact of this factor, the ratio of male to female animals in each assemblage was calculated from metacarpal measurements (Davis *et al.* 2012), and measurements were taken on metapodials and phalanges (following standards defined by von den Driesch 1976).

Metrical data indicate that cattle became more robust (evidenced by an increase in depth measurements) in the period *c.*600–900 (Table 5.4), which is consistent with the increase in male cattle observed in the sex data (Table 5.2). A size diminution in all planes (length, breadth, and depth) follows in AD 800–1100, which likely reflects the increasing proportion of cows. The next significant change in the size of cattle occurs between AD 1000 and 1300 and AD 1200 and 1500, when cattle become less robust (based on depth measurements—there was no equivalent reduction in breadth measurements). This is contrary to the sexing data, where the proportion of males increases slightly, implying another contributing factor, such as the presence of a different morphotype.

TABLE 5.4. Significant differences in the size and shape of cattle bones through time. Based on results of a Mann-Whitney U test, using a minimum of ten samples. Only statistically significant changes between neighbouring chronologies are included.

	Length	**Breadth**	**Depth**		
Variable 1	600–900	600–900	400–700	600–900	1000–1300
Variable 2	800–1100	800–1100	600–900	800–1100	1200–1500
Sample size 1	97	258	41	142	151
Sample size 2	68	166	142	80	36
U statistic	2,070.5	18,698	2,177	4,588.5	2,077.5
Z statistic	4.08	2.21	2.46	2.38	2.20
Probability	<0.01	0.03	0.01	0.02	0.03
Mean 1	0.00	–0.01	–0.03	–0.01	–0.03
Mean 2	–0.02	–0.02	–0.01	–0.03	–0.04

Potential associations between sex and the occurrence of pathological and subpathological changes were investigated using a plot of the mean mPI of metacarpals that could be confidently sexed (Figure 5.8). Results indicate that cattle with the most severe deformations (mPI ≥ 0.40) were all male, and most of those (75–100% of metacarpals) in the extreme range (mPI = 0.30–0.40) were also male. It is not possible to be certain whether this was due to the larger size of males, or the selection of males for draught work. Given that the anterior mPI scores (in this case metacarpals) are expected to be higher due to the physiology of cattle, the mean mPI of posterior elements was also compared with the proportion of male cattle at fifty-year intervals (Figure 5.9). This produced a negative correlation ($r(38) = -0.62$, $P \leq 0.01$), again indicating that other factors affect the draught-related pathologies observed. When the dates were considered, there were clear chronological divisions, and this variable is considered next.

Change through time

Figure 5.7 shows the distribution of assemblages exhibiting a 'draught cattle' signature through time, and Table 5.3 summarizes the data by broad phase. Assemblages with a 'draught cattle' signature can be observed in all phases, becoming less common in the seventh century, and increasing from the ninth century (Table 5.5). This is supported by a statistically significant increase in posterior mPI values between these two phases (Table 5.6). However, when the nature of the 'draught cattle' signature is

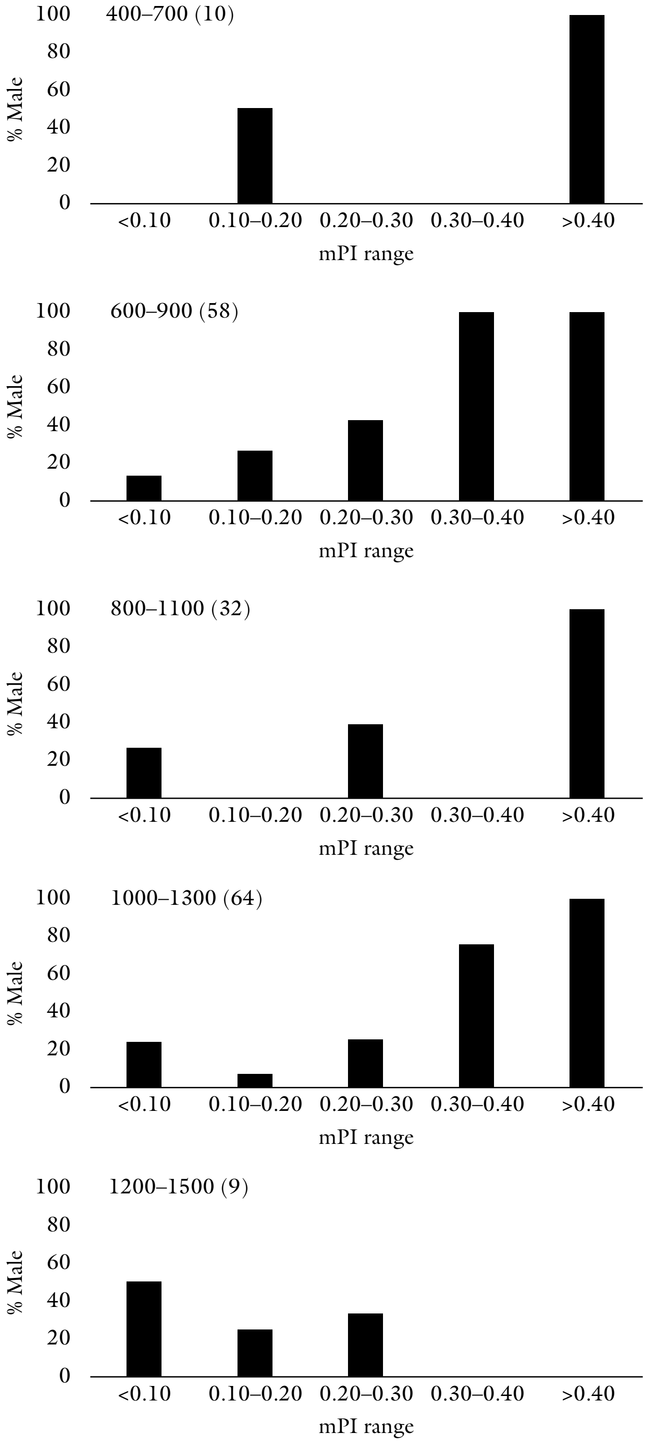

FIGURE 5.8. Comparison of mPI (modified Pathological Index) ranges of metacarpals of known sex. (n) = sample size.

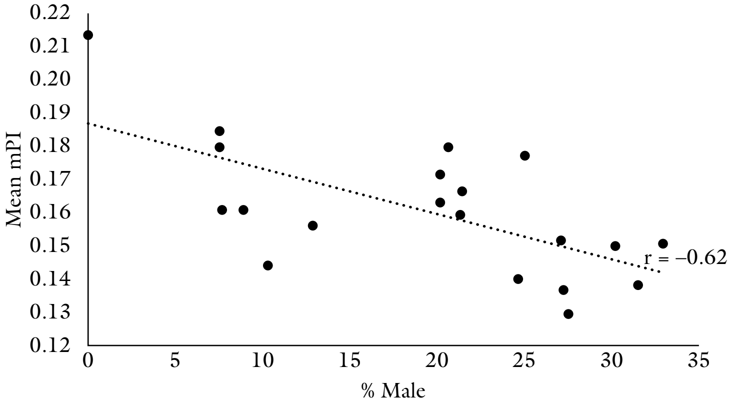

FIGURE 5.9. Correlation between posterior mPI and proportion of male animals. Data from Holmes *et al.* (forthcoming).

considered, there is some variability evident in the data (Figure 5.7). The 'draught cattle' signature in the post-Roman period (400–700) comes from Market Lavington and Quarrington, where animals with two of the three criteria are present. Of the eleven mid Saxon sites dating to 600–900, only three present a 'draught cattle' signature (Cook Street, Sedgeford, and Quarrington), yet these three signatures are very strong, including all three criteria. Such strong signatures are scarce in the tenth and eleventh centuries, the majority comprising just two criteria, although the proportion of sites at which they are observed increases considerably to five out of eight (Table 5.5), illustrating the significant change in mPI values between the two phases (Table 5.6).

The strongest 'draught cattle' signatures occur between AD 1000 and 1200, in all five assemblages (Table 5.5), all but one of which exhibits all three criteria. Assemblages with a chronology extending beyond 1200 exhibit more varied results, with the 'draught cattle' signature observed at only a third of sites. The difference in posterior mPI values between assemblages ending before 1200 (greater) and those with a longer chronology (lower) is statistically significant (Table 5.6). A reduction in the proportion of assemblages with a 'draught cattle' signature (three of five), and in the strength of that signature can also be observed in the period 1200–1500.

Site-specific variables

Table 5.5 presents the data for site-specific variables including soil type and height above Ordnance Datum (AOD). Urban/trading sites are excluded, as the animals brought to towns may have travelled some distance and been raised, worked, and fattened in different landscapes. There is no significant association between the proportion of 'draught cattle' signatures or mPI values observed in assemblages on heavy soils (clay and valley terraces) compared to those on lighter, chalk soils, although a

TABLE 5.5. Contingency tables for various factors with potential to affect the presence of a 'draught cattle' signature (DCS). See Tables 2.3 and 5.3 for details. * = site-specific variables not including data from urban sites.

Period	**N assemblages with DCS**	**Total N assemblages**	**%DCS**
400–700 (A1–C1)	2	5	40
600–900 (B1–D1)	3	11	27
800–1100 (C3–E3)	5	8	63
1000–1300 (D4–F2)	7	11	64
1000–1200 (D4–E5)	5	5	100
1000–>1200 (D4–H)	2	6	33
1200–1500 (E5–H)	3	5	60
Soil*	**N assemblages with DCS**	**Total N assemblages**	**%DCS**
Clay	5	10	50
Valley Terrace	3	6	50
Chalk	2	7	29
Height*	**N assemblages with DCS**	**Total N assemblages**	**%DCS**
Sea-level (<10 m)	1	1	100
Low (10–50 m)	8	12	67
Mid (50–100 m)	1	5	20
High (>100 m)	0	5	0
Site type	**N assemblages with DCS**	**Total N assemblages**	**%DCS**
Religious	1	5	20
High-status	1	3	33
Rural	8	15	53
Urban	10	17	59
Region	**N assemblages with DCS**	**Total N assemblages**	**%DCS**
Central Zone	11	18	61
East Anglia	5	8	63
South East	4	13	31
Western Lowlands	0	1	0

higher proportion of sites on heavier soils have a 'draught cattle' signature (50%) compared to those on chalk (29%) (Table 5.5). If the mean mPI values from all assemblages are considered (Figure 5.10), those from clay geologies are well above the average value between *c.*400 and 700, and again from *c.*800 to 1100. The data from *c.*600 to 900 are unusual, as the mean mPI values are greater on lighter soils, but this may be affected by the influence of site type: 87% of assemblages from this phase on clay were from religious sites (see below).

Height above sea level influences the presence/absence of a 'draught cattle' signature from assemblages, with a statistically significant association occurring between

Table 5.6. Significant results of Mann-Whitney U test carried out on posterior mPI values from all assemblages for various variables. * = not including urban data. Direction = change observed in posterior mPI values from variable 1 to variable 2.

	Phase		**Height***		**Site Type**					**Region (within phase)**		**Region (within region)**		
		1000–1300	**600–900**	**1000–1300**	**600–900**		**1000–1300**		**1200–1500**	**600–900**			**Central Zone**	
Variable 1	600–900	1000–1200	0–50 m	0–50 m	Elite	Elite	Elite	Elite	Elite	Central Zone	Central Zone	400–700	600–900	800–1100
Variable 2	800–1100	>1200	>50	>50	Rural	Urban	Rural	Urban	Urban	East Anglia	South East	600–900	800–1100	1000–1300
Sample size 1	365	215	159	45	152	152	107	107	25	91	91	48	91	159
Sample size 2	336	507	61	23	68	145	46	354	132	87	187	91	159	339
U statistic	52,474	44,737	3691.5	344	4041.5	8534.5	1624.5	10491	1152.5	2980.5	6935	1744.5	4641	23,658
Z statistic	3.46	3.94	3.02	2.38	2.85	3.62	3.97	7.32	2.46	3.10	2.72	2.18	4.93	2.28
Probability	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.03	<0.01	0.02
Mean mPI 1	0.13	0.22	0.17	0.20	0.09	0.09	0.06	0.06	0.08	0.10	0.10	0.14	0.10	0.20
Mean mPI 2	0.18	0.16	0.09	0.04	0.17	0.16	0.17	0.19	0.18	0.15	0.14	0.10	0.20	0.17

pathological index values and sites below and above 50 m (X^2(df = 3, N = 23) = 8.89, P = 0.03). It is notable that all five sites over 100 m (Table 5.5) are on chalk downlands. When all data were amalgamated and considered by phase, the mPI values were higher in lower altitude assemblages (Figure 5.11) and there were significant differences between the posterior mPI values recorded on sites below 50 m (greater) and those over 50 m (lower) in *c.*600–900 and 1000–1300 (Table 5.6).

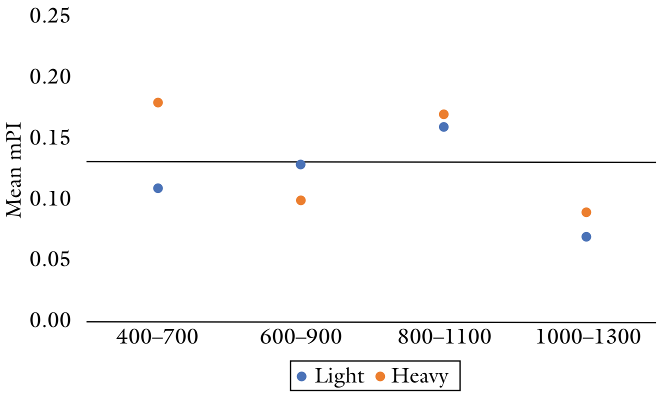

Figure 5.10. Mean posterior mPI scores by phase and geology for all data excluding urban sites. Line indicates the mean mPI from all assemblages excluding urban data.

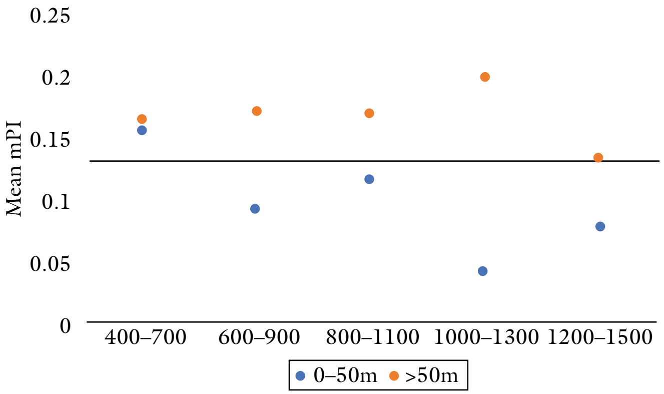

Figure 5.11. Mean posterior mPI scores by phase and height above Ordnance Datum for all data excluding urban sites. Line indicates the mean mPI from all assemblages excluding urban data.

Site type

'Draught cattle' signatures were less likely to be observed in religious and high-status secular assemblages than in rural and urban assemblages (Table 5.5). Religious and high-status secular sites were amalgamated into an 'elite' group to produce a larger and more comparable dataset when considering differences in mPI values between

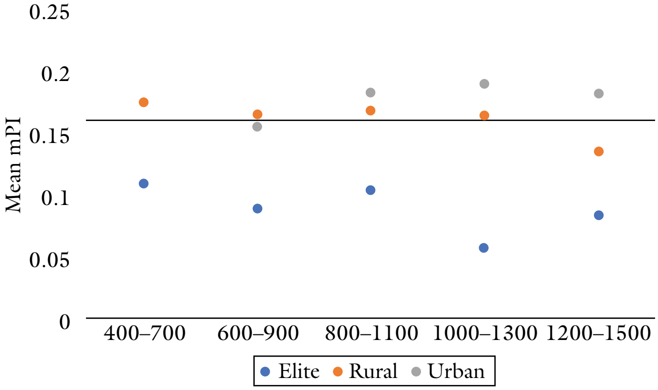

FIGURE 5.12. Mean posterior mPI scores by phase and site type for all data. Line indicates the mean mPI from all assemblages.

phases. The low mPI values at such sites are clearly shown in Figure 5.12, and significant differences exist between elite sites and rural and urban sites in all phases except *c.*400–700 and 800–1100 (Table 5.6).

Regional variation

Given the potential for redistribution of cattle or cattle carcasses between site types, all data were amalgamated for the purpose of investigating regional differences. A greater proportion of assemblages with 'draught cattle' signatures were observed in the Central Zone (61%) and East Anglia (63%) than in the South East (31%) and Western Lowlands (0%) (Table 5.5), although the last was only represented by a small sample from a single site and will not be considered further.

When considered by phase (Figure 5.13), the data were inconclusive: south-eastern sites produce consistent mPI values and those from East Anglian assemblages increase slightly from the seventh through to the late thirteenth centuries before decreasing again; the results for the Central Zone were more variable. This variability was exemplified by statistically significant changes in the mPI values derived from the Central Zone over time, showing a decrease between the fifth and seventh centuries, an increase from the seventh to ninth centuries, and another slight decrease between the eleventh and fourteenth centuries, although scores remain above the mean in this period (Table 5.6; Figure 5.13).

Discussion

The preceding interrogation of the zooarchaeological data has proven to be complex, yet ultimately successful in identifying periods of change in the use of cattle for traction. It is assumed that cultivation using cattle and ards took place throughout the

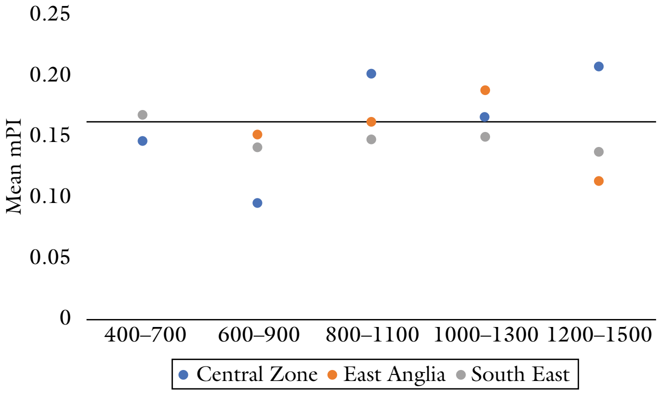

FIGURE 5.13. Mean posterior mPI scores by phase and region for all data. Line indicates the mean mPI from all assemblages.

time frame under consideration (see above; Banham and Faith 2014, 50). This assumption finds support in the calculation of mPI values on a modern, semi-feral herd of Chillingham cattle that were not subject to artificial loading. This is *c.*0.03 (Thomas *et al.* 2021, fig. 5), which is similar to an unworked group of young Romanian bulls raised for meat (*c.*0.03 and *c.*0.01, respectively; Bartosiewicz *et al.* 1997; Thomas *et al.* 2021). These values are lower than any of the mean mPI values observed in our data (Figure 5.4), corroborating the assumption that cattle were used for traction throughout the study period. The total mPI of the analysed sites does not come close to the mean pathological index of 0.33 calculated on Romanian draught oxen (Bartosiewicz *et al.* 1997), implying that at none of the targeted sites were cattle used exclusively for draught purposes over a long period of time.

The following discussion focuses on changes between the broad phases, allowing for within-phase differences. Data are summarized in Table 5.7, which incorporates the project phases (Table 2.2) as well as detailed changes observed at fifty-year resolutions adopted for the wider study of animal husbandry (see Chapter 2 and Holmes *et al.* forthcoming). For the purposes of this discussion, however, the use of broad phases is unavoidable as dating is limited by the reliance on assemblage-level data to calculate 'draught cattle' signatures.

AD 400–600 (FeedSax A)

While the post-Roman period in England is typified by small communities relying on mixed farming largely geared towards self-sufficiency, there is evidence that cattle were occasionally subjected to more demanding draught work at some sites. Recent work has indicated that while the economic and political systems of Roman Britain collapsed and the need for surplus arable production declined, there was some continuation of Roman field systems into the fifth and sixth centuries in a large part of lowland England (Banham and Faith 2014, 271; Rippon 2019a, 2019b). It is perhaps

TABLE 5.7. Summary of cattle data referred to in the discussion. Post = posterior; DCS = draught cattle signature; mPI= modified Pathological Index; region = regions defined by Rippon *et al.* (2015): CZ = Central Zone, EA = East Anglia (including Fens), SE = South East; height = metres above Ordnance Datum. * data from Holmes *et al.* (forthcoming).

Date	**FeedSax phase**	**Sex***	**Husbandry***	**Size**	**%DCS**	**Mean post mPI**	**Height**	**Site type**	**Region**
400–450	A1	Mostly female	Mixed		40	0.18		Lower at elite sites	
450–500	A1					0.18			
500–550	A1					0.16			
550–600	A2					0.16			
600–650	B1–B2		Mixed	More robust		0.14			
650–700	B2–C1				27	0.16	Greater mPI and DCS <50 m		CZ lower mPI than EA and SE
700–750	C1–C2					0.14			
750–800	C2–C3					0.13			
800–850	C3–C4	Mostly female + older males				0.14			
850–900	C4–D1			Smaller	63	0.16			CZ higher mPI than SE
900–950	D1–D2		Secondary			0.16			
950–1000	D3–D4					0.17			
1000–1050	D4–E1					0.18			
1050–1100	E1–E3				100	0.18	Greater mPI and DCS <50 m	Lower at elite sites	All similar
1100–1150	E3–E4		Diversification			0.14			
1150–1200	E4–E5					0.15			
1200–1250	E5–F1			Less robust	33	0.15			
1250–1300	F1–F2				60	0.15			CZ higher mPI than EA
1300–1350	G1					0.17			
1350–1400	G1–G2					0.21			

reasonable to suppose that some cultivation systems also continued in use, with largely the same rural populations continuing to farm, albeit at a reduced scale of production. The reduced demand for cereal surpluses once urban and military populations dwindled would have lessened the need for cattle to be used for draught. The 'draught cattle' signatures at Market Lavington (Wiltshire) and Quarrington (Lincolnshire) are therefore unexpected. Whereas at Quarrington evidence of Roman settlement lies west of the excavated area (Taylor 2003), at Market Lavington high-status Roman finds were recovered close to the site of the early medieval settlement (Williams and Newman 2006). Samples of cattle bone from the latter were therefore radiocarbon dated to verify that they were not residual Roman remains but genuinely belonged to the 'early Saxon' period—which proved to be the case.[4] It is therefore possible that at these sites, the use of cattle for draught continued in the Roman manner long after the need for regular surpluses had receded, which complements observations that urban provisioning in some areas appears to have remained unchanged into the sixth century, as at Wroxeter and York (O'Connor 2014). The mortality data at both Market Lavington and Quarrington are dominated by young cattle that died before their third year, with a few older and elderly cattle, which are candidates for draught animals. This is in contrast to Roman husbandry, which was based on older animals, reflecting the greater importance of secondary products in this period (Allen 2017). Thus, some modification to the animal economy had occurred in response to reduced consumer demand for cereals. As noted above, although ards are thought to have been the primary tool for tillage in Roman Britain, evidence of iron shares and coulters means that these could have been heavy enough to require considerable power to pull them, resulting in changes in the extremities of working animals. The first-century writer Columella, in *De Re Rustica*, refers to oxen and bullocks when describing best practice for ploughing (Thayer 2021, Book 2.2.22), and Maltby (2016) records the presence of adult males at several Roman rural sites, which is consistent with the males recorded with high mPI values in the post-Roman period (Figure 5.8).

The effects of size and sex, which are known to affect the presentation of pathological and sub-pathological changes in cattle feet (Holmes *et al.* 2021b), were considered in relation to post-Roman sites with the 'draught cattle' signature and those without. At Quarrington and Market Lavington, cattle were taller (based on a very small sample size), but breadth and depth measurements were smaller, which indicates that body mass was not a contributing factor to the mPI of these assemblages (Scott 1990). Similarly, the four complete metacarpals available from Market Lavington were from females (none was recovered at Quarrington), again indicating that an abundance of males was not the cause of the high 'draught cattle' signature.

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[4] Calibrated with IntCal20 (Reimer *et al.* 2020), the following dates were obtained: 536–604 (with 93.6% confidence), 534–603 (with 88.9% confidence), 535–604 (with 90.4% confidence), and 674–829 (with 94.0% confidence). Further details of radiocarbon dating are provided in the archive (McKerracher *et al.* 2023).

The absence of differences in the use of draught cattle between regions, site type, soil type, or site elevation in this period is consistent with the evidence for essentially self-sufficient agricultural systems. If farmers routinely used cattle for low-level carting, hauling, and pulling an ard before culling them at an early age for meat, the faunal assemblage would be unlikely to yield a 'draught cattle' signature.

AD 600–850 (FeedSax B–C)

Cattle continued to be used for a mixture of meat and secondary products, although the increase in males from *c.*800 is also consistent with a growing emphasis on draught usage. However, a 'draught cattle' signature is still observed only at relatively few sites (Cook Street, Southampton; Sedgeford, Norfolk; and Quarrington, Lincolnshire), though where present it is strong. The 'draught cattle' signature at Quarrington implies a continuation of farming methods from the previous phase, and at Cook Street may be related to the selective supply of older draught animals for meat at Hamwic (Bourdillon 1994). The association between draught cattle and the rural site of Sedgeford is less readily explained as this site is situated on light soils and there was no difference in the size of cattle compared to contemporary sites. However, Sedgeford was transformed in the ninth century from a seemingly ordinary rural farming community into a planned settlement with high-status elements, including a malting complex (Faulkner and Blakelock 2020). The need for large quantities of grain to supply the complex may thus explain the unusually high 'draught cattle' signature in this assemblage.

Variation can be observed on clay vales and alluvial valleys below 50 m AOD, where the 'draught cattle' signature is more common than on the higher chalk downlands, suggesting that agricultural strategies were increasingly adapting to local environments. This may relate to the availability of better-quality pasture and more abundant water sources needed for cattle in lowland areas, but may also indicate that such areas became focal points of agricultural production.

This is the first period that differences between site types are observed. The greater proportion of 'draught cattle' signatures recorded at urban sites potentially relates to the redistribution of ex-draught animals to towns and away from rural settlements The very low prevalence of 'draught cattle' signatures observed at high-status sites is unexpected as large estates would have required such animals, and oxen were included in lists of goods provided as tribute: for example, seven oxen from lands at Westbury and Henbury (Gloucestershire) to the Church of Worcester (793–796; Whitelock 1996, document 78.2.3). It is possible, however, that former working cattle were preferentially sent to towns for slaughter from outlying estates. Regional differences also begin to emerge in this period: the Central Zone has significantly lower mPI values than do the South East and East Anglia, implying the beginning of regionally defined exploitation of cattle in the south and east, perhaps relating to the increased production required to supply *wics* in these areas (Holmes 2013).

AD 850–1050 (FeedSax D)

The proportion of sites exhibiting a ‘draught cattle’ signature increases in this phase from 27% to 63%, and the mean posterior mPI values are consistently some of the highest observed. This coincides with a period of increased soil disturbance (see below), which may imply that the assemblages with ‘draught cattle’ signatures in part represent the increased stress caused by breaking new ground as well as pulling a mouldboard plough. The elevated ‘draught cattle’ signature and high posterior mPI values are in the Central Zone, suggesting a marked emphasis on cereal production in this region during this period.

The effects of site-specific variables on the ‘draught cattle’ signature are less marked in this period, with no statistically significant differences observed between different geologies, height AOD, or site type, although elite sites and those above 50 m continue to produce the lowest modified pathological index values.

AD 1050–1400 (FeedSax E–G)

A pronounced increase in both the frequency and strength of the ‘draught cattle’ signature is apparent in this period, which is characteristic of all assemblages dated to between AD 1025 and 1200 (phase E). This coincides with an increase in males from AD 1050. The ‘draught cattle’ signature occurs in all parts of the study area, further indicating a widespread increase in the use of cattle for draught purposes and, in all likelihood, of the mouldboard plough.

That said, assemblages extending into the mid-thirteenth to mid-fourteenth centuries are less likely to display a ‘draught cattle’ signature. This trend, combined with the decrease in mean posterior mPI scores and increase in beef cattle observed from AD 1100, suggests that the ‘draught cattle’ signature was ‘diluted’ by the presence of an increased surplus of animals whose sole purpose was for meat production. This is exemplified by the decrease in mean posterior mPI values in the Central Zone, which suggests that the move to beef production was concentrated in this region. This period also coincides with the growing use of horse power, particularly on lighter soils and in the east and south of England from the twelfth century following the introduction of the horse collar (Langdon 1986). This may be reflected in the lower posterior mPI values observed in East Anglia from AD 1250.

Another increase in ‘draught cattle’ signatures and posterior mPI values observed in fourteenth-century (phase G) assemblages is notable, indicating an increasing emphasis on the use of cattle for draught purposes. This is especially marked in the Central Zone, where values increase further, and again may be due to the preference for cattle over horses on the heavy soils of the midlands and the north. However, this coincides with the cattle pestilence of 1319–20 that killed as many as 62% of all cattle in England, and 55% of oxen (Slavin 2012). This would have severely reduced the available cattle population from which to draw working animals, and those left would have had to work harder and for longer, resulting in a greater prevalence of pathological and sub-pathological changes in cattle feet (Stone 2005, 150; Thomas 2008). The importance of draught oxen over beef cattle and breeding stock in subsequent years has been illustrated by Slavin (2012, fig. 1, 1251) in the prices paid and restocking levels. The role of redistribution is particularly notable in this period, as not only are draught cattle less commonly recorded on elite sites, but they are most likely to be recovered from urban assemblages, which implies the deliberate supply to medieval towns of ex-draught cattle from the hinterland.

SOIL DISTURBANCE AND TILLAGE: A FUNCTIONAL ECOLOGICAL STUDY OF WEED FLORA

The kinds of weeds that grew in medieval fields should express the net effect of both the type and frequency of ploughing. The key ecological parameter here is 'disturbance'—that is, in plant ecological terms, the destruction of plant biomass (Grime *et al.* 1988)—which in arable fields is determined first and foremost by the extent of mechanical perturbation through tillage. Here, we have focused on two functional ecological traits of arable weeds that reflect their ability to recover from disturbance and hence to thrive (or not) under heavily disturbed conditions: the duration of the flowering period, which reflects the span of the germination period and hence the ability of species to regerminate following disturbance, and (for perennial weeds only) the ability to regenerate from fragments of root/stolon/rhizome. In order to place archaeobotanical samples from early medieval fields on a spectrum of disturbance, we constructed a model that contrasts present-day high and low disturbance conditions in terms of these two traits. To do this, we conducted botanical surveys of the weed flora that develop in present-day arable fields subject to tractor ploughing—the modern equivalent of the mouldboard plough—at Highgrove's Duchy Home Farm, Gloucestershire and at the preserved open field landscape at Laxton, Nottinghamshire. We then compared these arable weed populations to the flora surveyed in ancient unploughed meadow verges or 'sykes' at Laxton (see Chapter 2; Bogaard *et al.* 2022; *cf.* Hamerow *et al.* 2020). We used the two functional traits of flowering period duration and vegetative propagation as discriminating variables in a discriminant analysis separating the arable fields from the 'sykes'. This successful separation offers a discriminant function to assess disturbance levels reflected in archaeobotanical assemblages.

We hypothesize that a field cultivated with a mouldboard plough following a standard two- or three-field rotation would exhibit more intensively disturbed conditions—that is, deeper and more frequent mechanical perturbation—than those found in ard-ploughed fields. Though ard ploughing can in practice be accompanied by manual tillage (hoeing) to break up clods of earth and hence raise disturbance levels (Halstead 2014, 11–66), this labour-intensive approach would become impractical in the context of expansive, extensive agriculture. In order to assess how disturbed early medieval fields tilled with the mouldboard plough would appear in weed ecological terms, we first applied the disturbance model based on Laxton and Highgrove (the 'Laxton–Highgrove model') to weed survey data gathered at the Lauresham experimental medieval farm, next to Lorsch Abbey in Germany, in 2019–20 (Bogaard *et al.* 2022; Kropp 2022). The results show that the Lauresham ridge-and-furrow fields align with the lower end of the modern tractor-ploughed field group, and provide a baseline for early medieval mouldboard ploughing (here termed the 'Lorsch baseline'). We would expect ard-cultivated fields to reflect lower levels of disturbance, for example, intermediate between the modern arable fields and the undisturbed 'sykes' along the discriminant function (see Chapter 2).

We hypothesize further that the more frequently the fallow was ploughed, the more 'disturbed' the weed signal should appear. In fourteenth-century Norfolk, for example, fallow could be ploughed up to six times (Campbell 1983, 29), as was the case in early twentieth-century Laxton (Haigh 2016, 16). The fallow year in the three-field system established at Lauresham is ploughed twice (Kropp 2022). In principle, we would expect even higher levels of disturbance in medieval fields with more frequent ploughing of the fallow and/or where two- versus three-field rotation was practised (Bogaard *et al.* 2022).

Several treatises on estate management survive from the thirteenth century that shed light on the ploughing regimes in fully developed two- and three-field systems, and even on the kinds of weeds that proved to be especially troublesome in these highly disturbed regimes. For example, Walter of Henley notes that the fallow field should be ploughed twice, once in April and again after midsummer, observing that if thistles are ploughed up before midsummer, 'for each one shall come up two or three' (Lamond 1890, 17; Oschinsky 1971, 164). Creeping thistle (*Cirsium arvense* (L.) Scop.) readily regenerates from rhizomes fragmented by deep ploughing, and the instruction to plough for a second time in the driest part of the summer suggests an attempt to minimize regeneration. It also echoes early twentieth-century practice at Laxton, where another perennial weed that readily regenerates from fragments, couch grass (*Elytrigia repens* (L.) Desv. Ex Nevski), was notorious for being 'propagated rather than killed by ploughing' (Allison *et al.* 2017, 109). The ability for certain perennial weeds to regenerate from fragments of root/rhizome/stolon is what we seek to capture by including that functional trait in our disturbance mode. Walter of Henley also notes that the first ploughing of the fallow should be with 'a deep, broad furrow to bring fertile soil to the surface without disturbing subsoil' (Oschinsky 1971, 164), while the second ploughing should 'not go too deep, but so that you can just destroy the thistles' (Lamond 1890, 13). The final ploughing, in preparation for sowing, should form narrow furrows 'that the seed may fall evenly' (Lamond 1890, 15). Ploughing the fallow also makes the soil more manageable when ploughing the following year, especially on clay soils (C. Kropp pers. comm.).

A final consideration is that, where the mouldboard was used to plough up former pasture/meadow, we would expect weeds reflective of these formerly low-disturbance conditions to persist for some time, perhaps up to a decade or more.

Though experimental evidence for this scenario is as yet lacking, experimental clearance and tillage of ancient woodland soil in the Hambach Forest, in the Rhineland west of Cologne, showed that woodland species persist for some years, despite increasingly intensive tillage (Bogaard 2002). It is possible, therefore, that low-disturbance weed signals from early medieval archaeobotanical samples reflect either ard ploughing and/or mouldboard ploughing of former pasture/meadow as arable expanded at the expense of grassland.

Results

The Laxton–Highgrove disturbance model outlined above was applied to sites with eligible samples in England (Figure 5.14).[5] The results for the Central Zone, by far the best represented region, are shown as a scatter plot of sample midpoint date by discriminant function score (Figure 5.15a). A positive but weak trend towards higher disturbance levels over time is apparent; this is statistically significant if all sites are considered together but is very narrowly below the conventional minimum of 95% significance (p = 0.06) if random effects of site are taken into account (Table 5.8). Either way, the implication is that disturbance levels of arable fields tended to increase, that is, improve, through time, though the trend is weak and there is a particular lack of eligible samples from the earliest and latest centuries under consideration. This increased disturbance is plausibly a function of both increasing use of the mouldboard plough and increasing frequency of tillage, that is, of fallow and/or two- versus three-field rotation.

The dotted line in Figure 5.15a shows the 'Lorsch baseline' identified in data from the ridge-and-furrow field at Lauresham; samples plotting above this line are consistent with mouldboard ploughing. The earliest samples that fall above this baseline date to the eighth century (*i.e.* phase C2–C4), although it must be recognized that only three samples predate 700. Thereafter, there is a consistent predominance of samples above the baseline. Figure 5.16 shows proportions of samples above and below the Lorsch baseline through time in the Central Zone. No statistically significant trend emerges from this admittedly somewhat crude analysis, but it is useful to note that around 20–40% of samples from the eighth century reflect disturbance levels *lower* than would be expected for mouldboard ploughing. This could reflect continued use of the ard and/or conditions in arable fields that had recently been converted from pasture.

The tendency towards increasing levels of disturbance through time in the Central Zone, albeit weak, is not matched in the Eastern and Western zones (Figure 5.15b–c; Table 5.8) In the case of the Western zone, this may in part be due to the lack of eligible samples earlier than the tenth century; a trend towards increasing disturbance through time is nevertheless apparent at some individual sites in this zone (notably

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[5] Site-by-site results are presented in the digital archive: McKerracher *et al.* (2023), documents B48–B49.

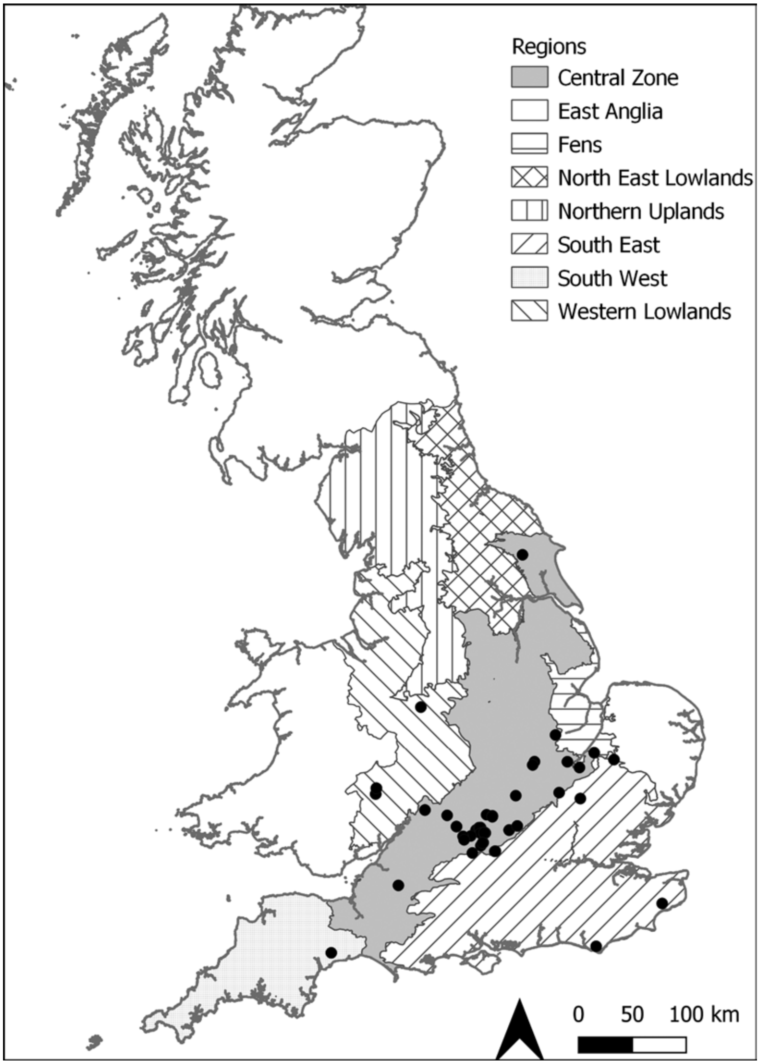


FIGURE 5.14. Map of sites included in the weed ecological analysis of soil disturbance. Samples were eligible for inclusion if they contained at least ten weed seeds identified to species level, representing at least three different taxa, and with a date range spanning no more than 300 years. Regional divisions from Rippon *et al.* (2015). Map created with QGIS (http://www.qgis.org, accessed 08/03/2022).

Stafford—see below). For the east, it is notable that the four eighth-century samples fall above the Lorsch baseline, supporting the case for some early use of the mouldboard plough (see above; Bogaard *et al.* 2022). In the Eastern zone, a tendency towards increasing disturbance through time can also be discerned at some individual sites, such as Mildenhall (see below).

Figures 5.17–5.24 show the results for a series of well-represented (*i.e.* with at least ten samples) and well-dated individual sites. Beginning with the Central Zone, one of the largest assemblages is that from West Cotton, Raunds (Northamptonshire; Figure 5.17), where the tenth- to thirteenth-century sequence illustrates a clear pre-

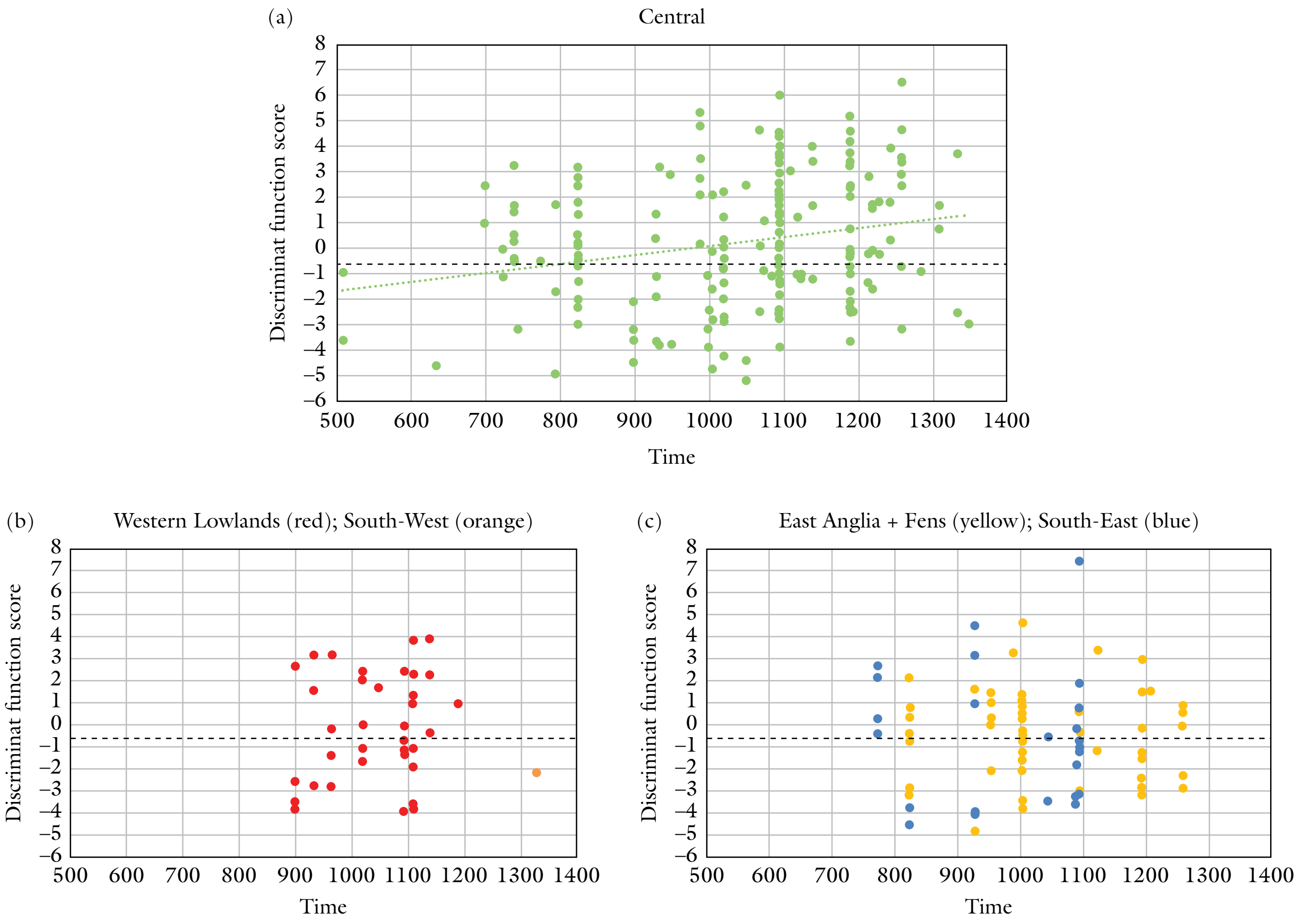


Figure 5.15. Linear regression analysis of weed flora from sites in (a) the Central Zone, (b) the South West and Western Lowlands, and (c) the South East, East Anglia, and the Fens, showing a weak positive trend towards higher disturbance over time in the Central Zone. The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

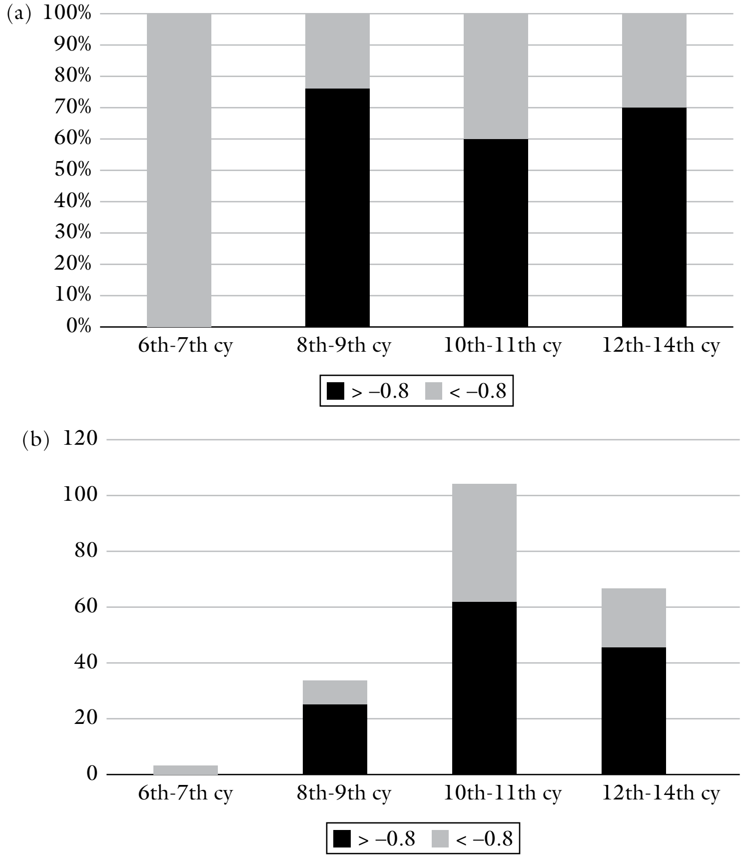
TABLE 5.8. Results of linear regression models of the discriminant analysis score and mid-point of the date range of samples from the Central, Eastern, and Western Zones as well as the results of mixed effects models that regard site as a random effect. ‘Eastern’ Zone includes East Anglia, the Fens, and South East. ‘Western’ Zone includes the South West and Western Lowlands.

Linear regression model

	Central Zone DA score			**Eastern Zone DA score**			**Western Zone DA score**		
Predictors	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	–3.36	–5.54 to –1.19	0.003	1.15	–2.95 to 5.26	0.577	–3.22	–11.77 to 5.33	0.45
Midpoint date	0.003	0.001–0.006	0.001	–0.002	–0.005 to 0.002	0.449	0.003	–0.005 to 0.01	0.492
Observations	207			70			39		
R^2/R^2 adjusted	0.051/0.046			0.008/–0.006			0.013/–0.014		

Mixed effects model

	Central Zone DA score			**Eastern Zone DA score**			**Western Zone DA score**		
Predictors	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***	**Estimates**	**CI**	***p***
(Intercept)	–2.3	–4.83 to 0.23	0.075	1.15	–2.96 to 5.26	0.577	–3.22	–11.82 to 5.38	0.451
Midpoint date	0.002	–0.0001 to 0.004	0.068	–0.002	–0.005 to 0.002	0.45	0.003	–0.005 to 0.01	0.493
Random Effects (site)									
σ^2	4.58			4.98			5.8		
τ_{00}	1.62_{Site}			0.00_{Site}			0.00_{Site}		
ICC	0.26			0			0		
N	27_{Site}			5_{Site}			6_{Site}		
Observations	207			70			39		
Marginal R^2/ Conditional R^2	0.019/0.276			0.008/0.008			0.013/0.013		



(c)

	6th-7th cy	8th-9th cy	10th-11th cy	12th-14th cy
> –0.8		26	62	46
< –0.8	3	8	42	20

FIGURE 5.16. Proportions of samples above and below the 'Lorsch baseline' through time in the Central Zone.

dominance of samples falling above the Lorsch baseline, many exceeding it by a significant margin, suggesting more frequent ploughing of fallow and/or two-field rotation. The earlier sequence at Higham Ferrers (Northamptonshire; Figure 5.18) includes some of the few pre-eighth-century samples from the entire Central Zone; it exhibits variable disturbance levels throughout, though none of the latest (eleventh- to fourteenth-century) samples falls far below the Lorsch baseline. At Stratton (Bedfordshire; Figure 5.19), the earliest samples, belonging to the seventh and/or eighth century, all fall above the baseline, and this remains the predominant trend in later phases. A similar situation is apparent at Yarnton (Oxfordshire; Figure 5.20), though here the two latest samples (phase D1–D3) exhibit a relatively low-disturbance signature—perhaps reflecting a breaking of new agricultural ground in this period, contemporary with the apparent shift in settlement focus (Hey 2004). Individual site sequences thus offer different 'windows' onto the general process and adaptation of mouldboard plough usage from the eighth century onwards in the Central Zone (Figure 5.15a).

Individual sites in other zones similarly reveal local variation. At Stafford, the only sizeable assemblage in the western zones, a trend of increasing disturbance through time is apparent, culminating in samples of the twelfth century and later that fall exclusively above the Lorsch baseline, signalling a pervasive use of the mouldboard plough by this time (Figure 5.21). In the eastern zones, the assemblage from Mildenhall (Suffolk) similarly illustrates a process of improving tillage through time, though here a predominance of high disturbance levels consistent with mouldboard ploughing can be seen from the eighth century onwards (Figure 5.22). Another sizeable East Anglian assemblage, from Ely (Cambridgeshire; the West Fen Road and Walsingham Way sites: Figure 5.23), tells a different local story, with a few eighth- to tenth-century samples reflecting low disturbance and a wide range of disturbance levels persisting through subsequent centuries. Finally, in the South East at Lyminge (Kent; Figure 5.24), high disturbance levels are apparent from the eighth century onwards and persist through later phases, though there is later variability (Bogaard *et al.* 2022).

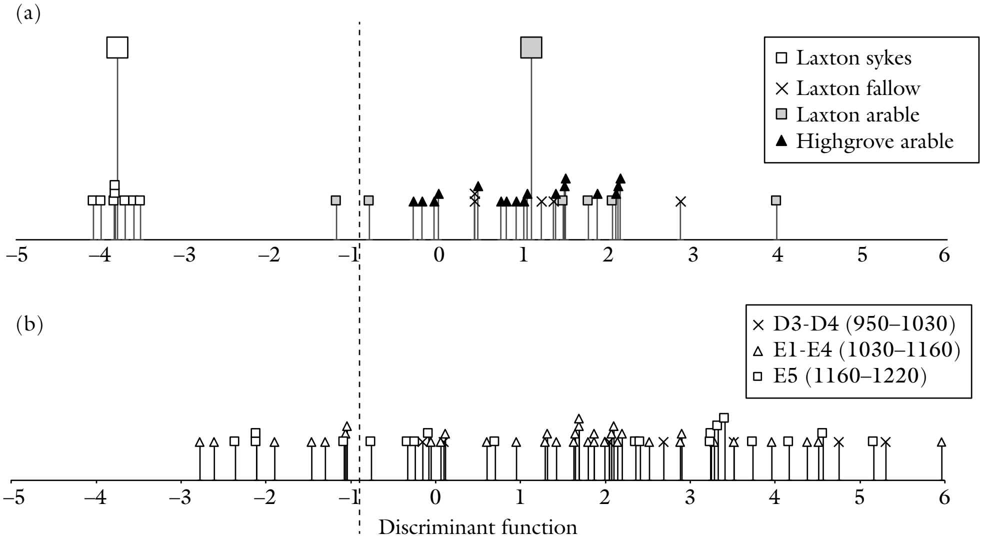


FIGURE 5.17. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from West Cotton to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

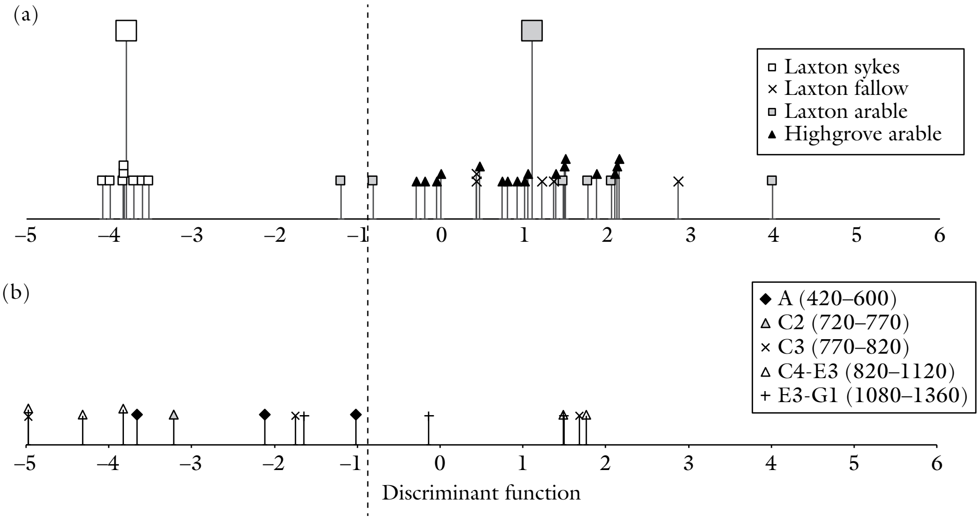


FIGURE 5.18. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from Higham Ferrers to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

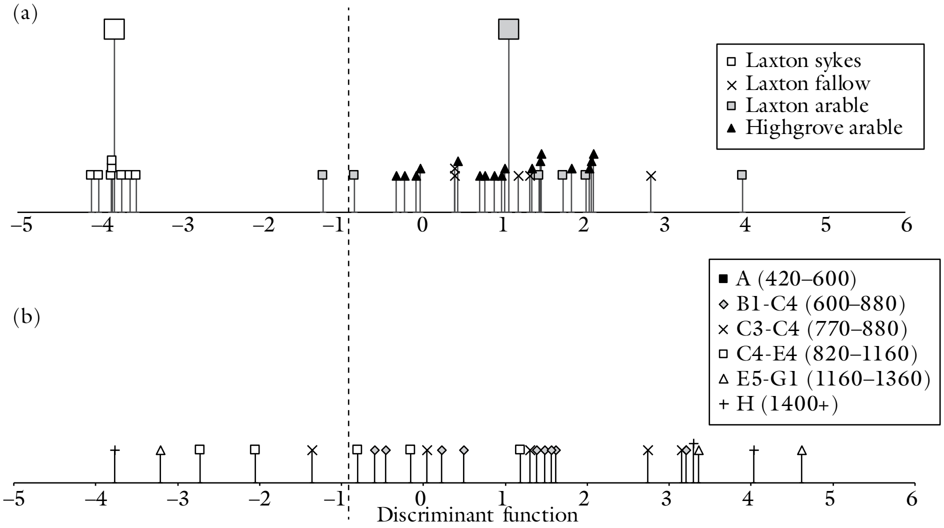


FIGURE 5.19. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from Stratton to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

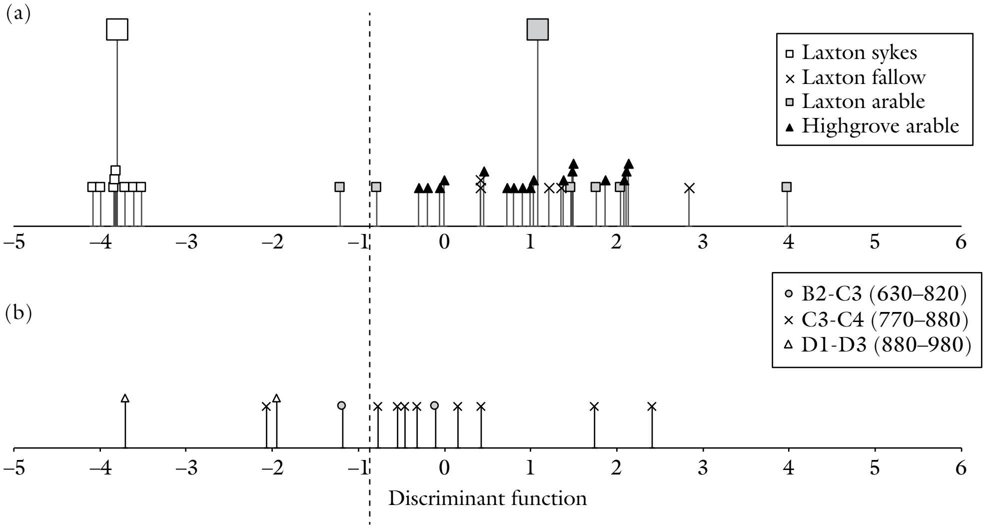


FIGURE 5.20. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from Yarnton to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

Application of the Laxton–Highgrove disturbance model to archaeobotanical assemblages from medieval England has revealed a general but weak tendency towards more disturbed conditions through time in the Central Zone, but not in the Western and Eastern zones, although this may be at least partly due to the lack of pre-eighth-century samples from the latter regions. Nevertheless, some individual site sequences in both the Western and Eastern zones reflect a tendency towards increasing disturbance through time, albeit on variable timescales. We interpret these trends towards higher disturbance levels as evidence of more pervasive use of the mouldboard plough, coupled with more frequent tillage.

The 'Lorsch baseline' of disturbance levels expected from mouldboard ploughing derived from the Lauresham experimental ridge-and-furrow fields provides a useful guide to assessing the introduction and adaptation of this costly technology. Disturbance levels consistent with mouldboard ploughing in England are dominant from the eighth century onwards. It may be no coincidence that a shift from lower to higher disturbance conditions is also observable in the Rhineland region west of Cologne in the seventh to eighth centuries (Hamerow *et al.* 2023). Despite the apparent practice of mouldboard ploughing in England from the eighth century onwards, however, a significant minority of archaeobotanical samples reflect lower disturbance levels through to the fourteenth century; these samples are likely to reflect continued use of the ard as well as the ongoing conversion of pasture to arable.

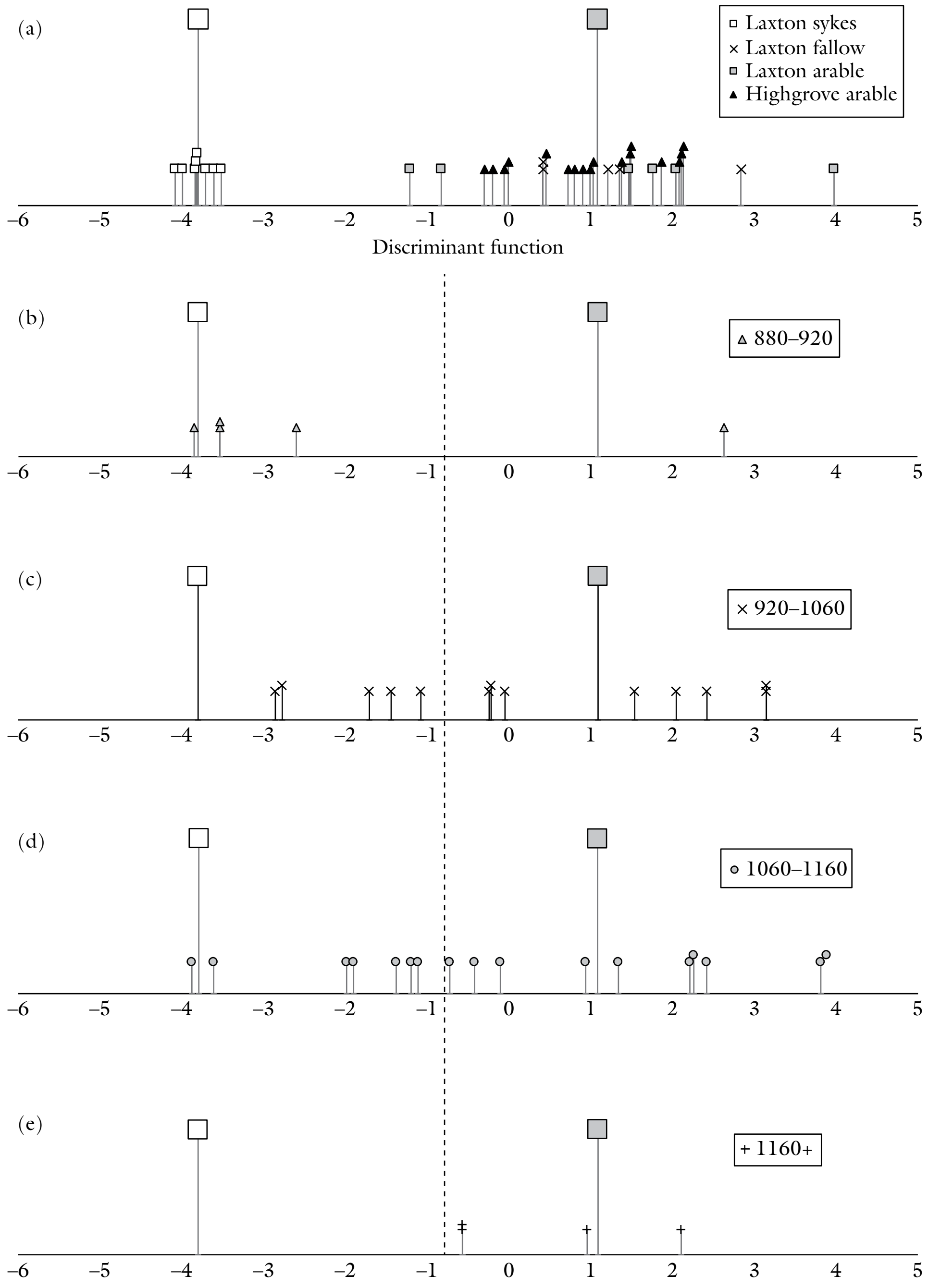


FIGURE 5.21. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b–e) the relationship of archaeobotanical samples from Stafford, divided by phase, to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

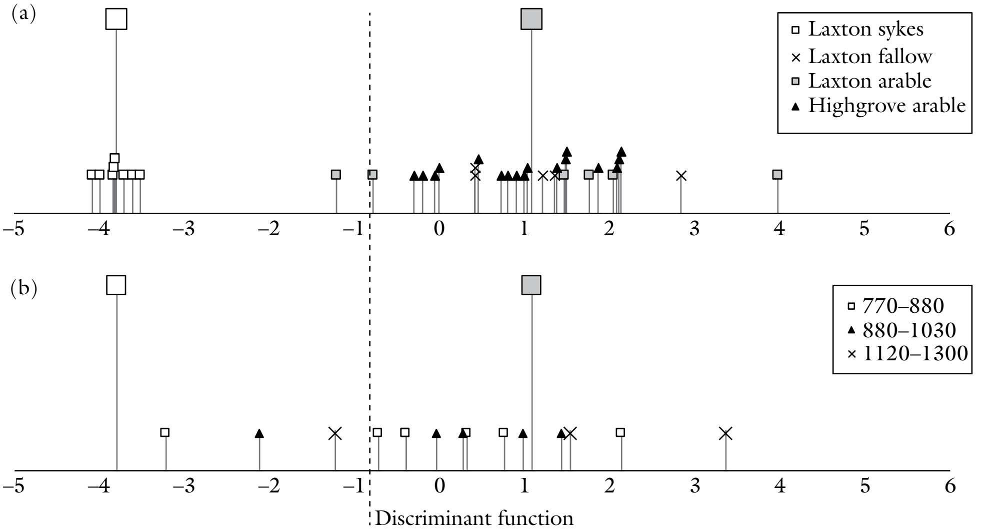


FIGURE 5.22. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from Mildenhall to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

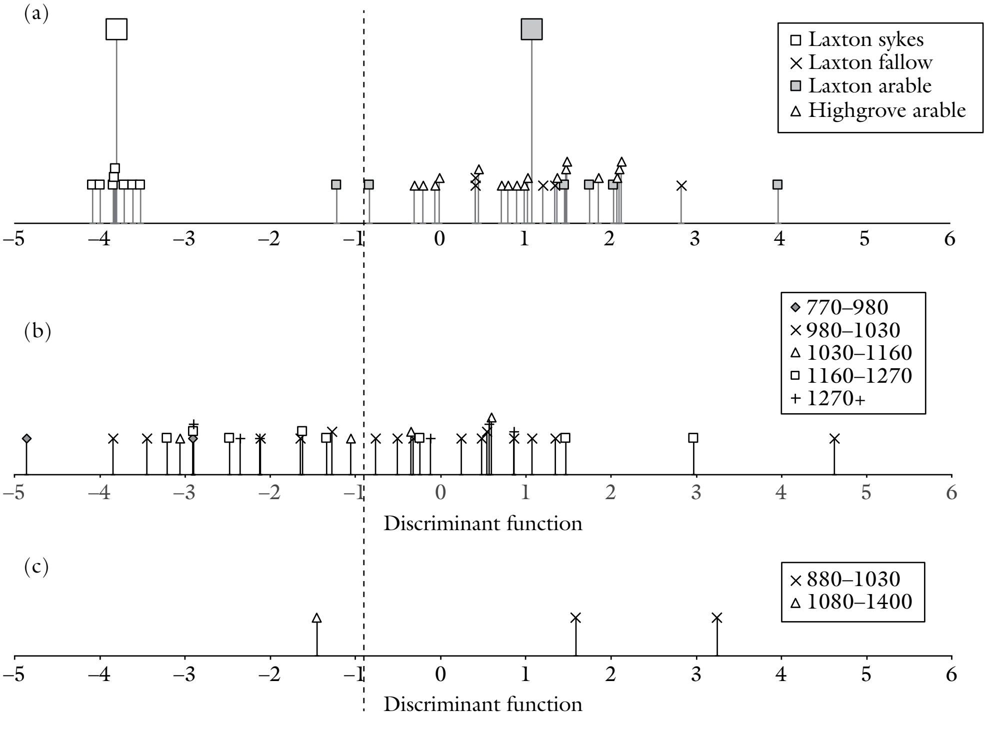


FIGURE 5.23. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; and the relationship of archaeobotanical samples from (b) West Fen Road and (c) Walsingham Way, Ely, to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

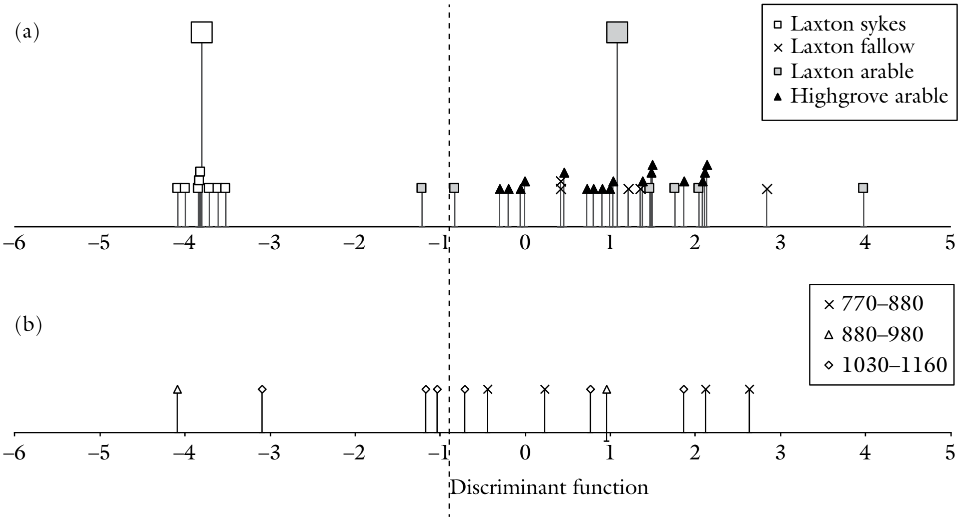


FIGURE 5.24. (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from Lyminge to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

CONCLUSION

The weed-based observations regarding changing levels of soil disturbance can now be compared to the zooarchaeological picture emerging for cattle use and traction. It is worth reiterating that the weed ecological evidence for disturbance levels indicates the *net effect* of the type and frequency of tillage, whereas the cattle foot bone evidence reflects how hard draught animals were working. These two aspects could reasonably be expected to align, at least broadly, but need not necessarily do so. For example, draught cattle could be worked very hard ploughing up pasture or scrubland during a period of arable expansion, potentially resulting in a higher rate of pathological and sub-pathological change; in weed ecological terms, however, a continuing 'pasture signal' would give the appearance of low-disturbance conditions. It is notable that in Figure 5.16a, the ratio of samples above the Lorsch baseline to those below the line reduces from around 70:30 during the eighth and ninth centuries, to 60:40 around AD 1000, precisely when one might expect use of the mouldboard plough, and therefore disturbance levels, to have increased. Expansion of arable onto previously unploughed ground may well explain this apparent discrepancy between the two forms of evidence. Similarly, high-disturbance conditions could in theory also be achieved by more frequent tillage using an ard, but this would be difficult to achieve at scale or on heavy clays and is therefore incompatible with the marked expansion of arable farming seen in this period (see Chapter 3).

The two lines of evidence—arable weed seeds and cattle bones—are nevertheless in broad agreement, despite the fact that the archaeobotanical and faunal assemblages are generally from different sites, and despite the apparent consumption of elderly ex-draught cattle by urban populations, a factor that further complicates the picture. The increase from *c*.800 onwards in male cattle and older animals and the occurrence of strong 'draught cattle' signatures in between a quarter and a third of the faunal assemblages examined, coincides with a predominance of archaeobotanical samples reflecting high disturbance levels consistent with use of the mouldboard plough. Higher mean posterior mPI values for cattle from the mid-ninth to mid-eleventh century, especially in the Central Zone, occur in parallel with a continued predominance of high disturbance levels in the archaeobotanical data and a drift towards even higher levels in the Central Zone. Further increases in the proportion of sites with a 'draught cattle' signature in the period *c*.1000–1200 parallel a continued subtle increase towards higher disturbance levels in the Central Zone generally and at some individual sites. The dearth of archaeobotanical samples predating the eighth century and post-dating the thirteenth prevents meaningful comparison with the zooarchaeological trends for these periods.

Neither the weed data nor the evidence from cattle bones points to a distinct 'tipping point' after which use of the mouldboard plough became widespread. The evidence is instead broadly consistent with a gradually increasing (and more systematic) use of the mouldboard plough over time. A 'step change' may, however, be apparent around 700, after which the majority of archaeobotanical samples point to high disturbance conditions, while the 'draught cattle' signature becomes common from the ninth century. These developments broadly coincide with an expansion of settlement onto heavier soils seen in parts of the country in the eighth and ninth centuries, which also suggests growing use of the mouldboard plough (see Chapter 3; Hamerow 1999; Oosthuizen 2011).

Feeding Medieval England*: A Long 'Agricultural Revolution', 700–1300*. Helena Hamerow, Mark McKerracher, Amy Bogaard, Mike Charles, Emily Forster, Matilda Holmes, Christopher Bronk Ramsey, Elizabeth Stroud, and Richard Thomas, Oxford University Press.
DOI: 10.1093/9780191988905.003.0005

SIX

Agricultural Land Use, *c.*AD 300–1500

> Survey your lands and tenements by true and sworn men . . . how many acres are in the demesne . . . and how many acres of pasture . . .
>
> Walter of Henley, *Husbandry* (Lamond 1890)

INTRODUCTION

This chapter brings together new and published pollen data from sites across England spanning the mid-first to late fifteenth centuries, to explore vegetation changes related to medieval agricultural land use and consider these within a longer time frame. A great advantage of the pollen record is that it is available for regions where other materials used in this study—animal bones, cereal grains, arable weed seeds—are scarce. This has allowed regional trends in land use to be investigated even in parts of England where medieval farms have left virtually no archaeological ‘footprint’ and excavated medieval settlements are a rarity, for example in the northwest.

The Roman period is widely understood to have witnessed a marked expansion of agricultural land use in England, particularly for cereal cultivation, owing to the requirements of the army, the growth of urban centres, and the need to produce a surplus for export (van der Veen and O’Connor 1998). In contrast, the end of Roman occupation, departure of the army and the associated collapse of formal markets, systematic taxation, and grain exports, as well as an overall decline in population are assumed to have led to a reduction in cultivation, with more ground lying fallow, used as pasture, or abandoned, resulting in an expansion of woodland/scrub. Farming in post-Roman Britain is thought to have been mixed, including both arable and pasture, and relatively small in scale until at least the seventh century (Banham and Faith 2014; Faith 2008).

For the sixth to seventh centuries, palaeoenvironmental records for parts of northwest Europe indicate cooler, wetter conditions sometimes referred to as the Late Antique Little Ice Age (LALIA) (Blackford and Chambers 1991; Büntgen *et al.* 2016; Charman 2010; Newfield 2018; Turney *et al.* 2005). It might be assumed that this would have further encouraged a contraction of arable farming and a consequent spread of heath, wetlands, and possibly woodland/scrub. Previous pollen studies, however, have found only limited evidence for change associated with the LALIA in lowland Britain (Forster and Charles 2022; Rippon *et al.* 2015). This period was followed by significant changes in the 'long eighth century', when infrastructure for crop processing, grain storage, and livestock management appeared in association with certain settlements, suggesting an increase in agricultural land use, at least in central and eastern parts of England (Hamerow 2012; McKerracher 2018). During the tenth to thirteenth centuries England's population increased significantly, coinciding with the widespread adoption of increasingly large-scale, 'extensive' arable production (see Chapter 3). This period also coincides roughly with the Medieval Climate Anomaly (MCA), a period of warming that may have encouraged expansion of cultivation into upland or northern areas previously considered 'marginal' and more suited to pasture than arable. In the fourteenth century the human population was ravaged first by a famine triggered by crop failures and livestock diseases and, later, by the Black Death. The dramatic fall in population is usually assumed to have caused a net reduction in both arable and pastoral farming and possibly expansion of woodland/scrub onto abandoned farmland.

This broad chronological narrative cannot, however, capture the complexity of developments in land use and vegetation across the whole country, with marked differences in geology, altitude, and rainfall likely to have affected land use patterns and—consequently—the pollen record. Regional and local differences in population density and access to resources and technology, including different crop types, ploughs, traction animals, and labour, are also likely to have contributed to differences in the scale and type of agricultural land use. In this chapter, pollen data are used to gain a better understanding of changes in arable and pastoral land use in different regions of England between the first and fifteenth centuries. Previous analyses of pollen data from the Roman and medieval periods have established that arboreal (tree and shrub) cover was already much depleted by this time, following substantial clearances of woodland/scrub in the Bronze and Iron Ages (*e.g.* Dark 2000; Rippon and Fyfe 2019; Rippon *et al.* 2015). Consequently, in most regions, vegetation cover in general terms does not appear to have changed dramatically during the first millennium AD. The Fields of Britannia project (Rippon *et al.* 2015) estimated approximate percentages of different land cover and land use types based on pollen percentages, identifying some regional differences in the extent of woodland cover, pasture, and arable over time but finding relatively little evidence for changes in land use between the Roman and early medieval periods. The project also demonstrated that in certain regions, many medieval field boundaries and the general 'grain' of the medieval landscape had their origins in the Roman period. The approach to identifying land use patterns taken here is quite different, using a combination of arable/pastoral indices (Turner 1964), a measure of the scale or intensity of agricultural land use (agricultural land use signal strength—ALUSS), the diversity of agricultural taxa

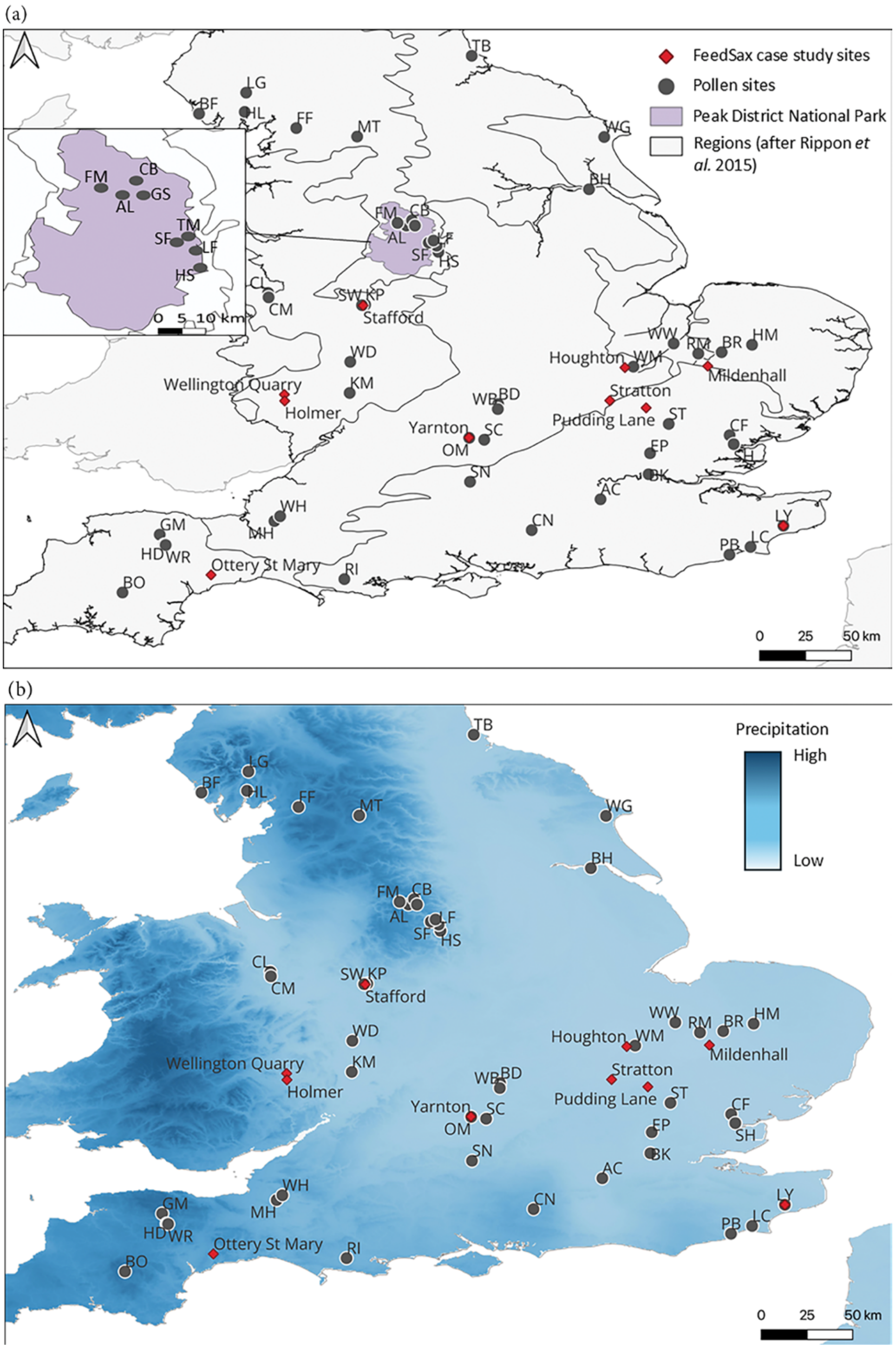


FIGURE 6.1. Locations of pollen sites included in this analysis together with FeedSax case study sites and: (a) study regions; (b) average January precipitation from 1960 to 1990 (data from Worldclim 1.4, Hijmans *et al.* 2005); (c) altitude data (data from ASTER GDEM V003, NASA/METI/AIST/Japan Spacesystems, and U.S./Japan ASTER Science Team 2019); and (d) bedrock geology (contains British Geological Survey materials © UKRI 2024).

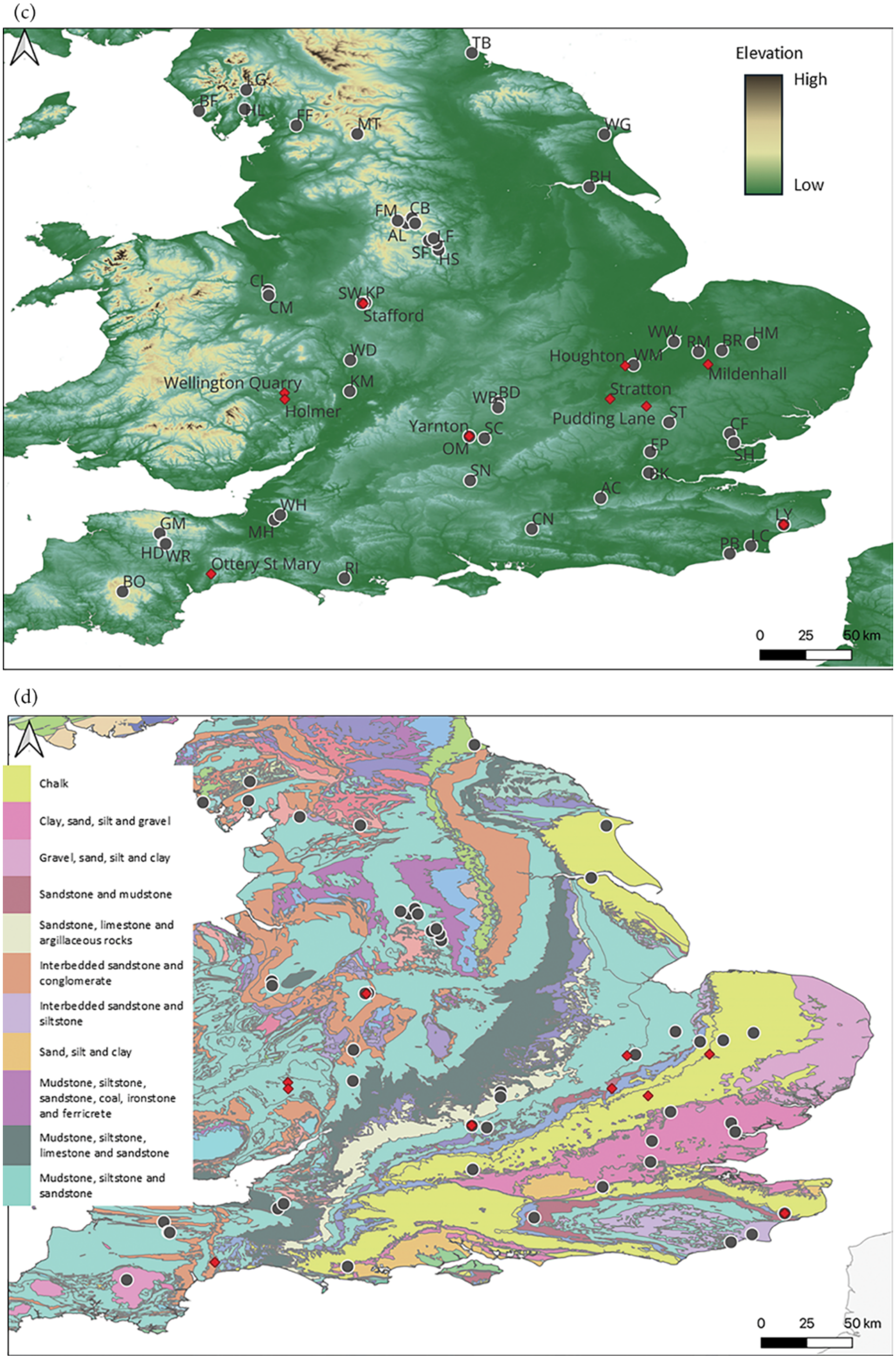


FIGURE 6.1. Continued.

present, and the distribution of pollen from key crops and weeds (see Chapter 2 for an explanation of these methods).

Differences in the distribution of different forms of evidence mean that, although data of one form or another are available for most of the country, the palynological, archaeobotanical, and zooarchaeological data are not always directly comparable at a regional level. As explained in Chapters 3 and 4, the majority of the archaeobotanical—and consequently plant isotopic—evidence for crop rotation and the extensification of arable farming comes from central England, as archaeological sites with large assemblages of charred plant remains for the period are concentrated in this region. Archaeobotanical data are available for most regions, but coverage in the north of the country is lacking and most of the case study sites lie within the Central Zone and Western Lowlands (Figure 6.1a). In contrast, well-dated, well-preserved pollen records are scarce in this area owing to a combination of geology (particularly where this creates good drainage, *e.g.* limestone or chalk), alkaline soils (in some areas), and relatively low rainfall (Figure 6.1b and d); pollen survives best in acidic, waterlogged/anaerobic conditions (Havinga 1984), so preservation in much of the Central Zone is poor. Ironically, the land use history of the area is also a major factor, in that centuries of ploughing and other agricultural activity have stripped away or disturbed sediments and soils, together with the pollen they contained. The UK Centre for Ecology and Hydrology's current land cover map shows much of central England as arable or improved grassland, which generally refers to pasture subjected to some form of management (*e.g.* weed control, planting of certain grassland species, drainage), in contrast to 'rough grazing' or unimproved pasture on heaths, salt marshes, and other rough ground (Marston *et al.* 2022). Pollen records in lowland regions are subject to further disturbance from urban development, which is more concentrated in low-lying areas and river valleys. Although some pollen data are available from the Central Zone, records are sparse considering the size of the region (Figure 6.1a) and coverage is markedly better elsewhere, with the largest concentrations of sites in the South East and Northern Uplands. Both regions include substantial national parks characterized by hilly or mountainous landscapes that are often subject to rough grazing rather than arable or urban development; rough grazing has a marked impact on the present-day vegetation and character of the landscape, but a relatively low impact on the underlying soils/sediments and consequently the pollen records within them. Heathland is also present in both regions, together with the South West. Wetland areas, and particularly peat bogs, often contain well-preserved pollen records.

Where possible, all pollen sites with dated records covering any part of the later Roman or medieval period were included in the analysis. For regions with large numbers of undigitized records (such as the Lake District/Cumbria (Northern Uplands) and the South West) and little or no archaeobotanical data, it was necessary to be more selective; the impact of this is most obvious for the South West, where data are limited to a small number of upland sites for which digital records were freely available in the European Pollen Database (*e.g.* Fyfe *et al.* 2003; EPD: http://www.europeanpollendatabase.net/). Owing to a paucity of well-dated records from the North East Lowlands, it was necessary to exclude this region from the analysis. In spite of the issues outlined above, there is at least one pollen site within a 20-km radius of six of the ten case study sites, and aside from Wellington Quarry and Holmer in the Western Lowlands, all have at least three pollen records within a 50-km radius (Figure 6.1a; Table 6.1).

Analysing proportions of major vegetation types from sites across England on a century-by-century basis through a set of complementary interpretative lenses, it has been possible to establish broad national trends in land use through the Roman and medieval periods. Although there is variability within and between regions, by considering the dataset we may divide the period from *c.*AD 43 to 1500 into four relatively distinct phases. It is also possible to identify broad regional differences in terms of both the distribution of woodland/scrub and the dominant forms of land use, most of which persist to the present day.

OVERALL VEGETATION PATTERNS

Figure 6.2 shows proportions of pollen from major vegetation groups for clusters of pollen sites in each region from the first to fifteenth centuries. The regions shown in Figures 6.1a and 6.2 follow those used by the Fields of Britannia project (Rippon *et al.* 2015); the types of landscapes and patterns of vegetation and land use tend to be broadly similar within them, although there is intraregional variability, hence the separate clusters (Figure 6.2; Table 6.1). Data are averaged across sites within each cluster and between centuries (*e.g.* second–third century, third–fourth century, etc.). This approach reduces the 'noise' created by intermittent records from individual sites, particularly those with unusually high or low arboreal or heathland cover, and has been applied to all datasets in this chapter.[1] Broadly, the pollen data indicate higher arboreal cover in the Northern Uplands and South East than in the Central Zone, East Anglia, and the South West, while the Western Lowlands have areas of both high (WL1—Shropshire) and low (WL2—Worcestershire and Staffordshire) arboreal cover. Heathland is concentrated in much the same areas as it is today, namely the Northern Uplands (*i.e.* the Peak District, Cumbria, and North Yorkshire) and the South West (Dartmoor, Exmoor), with smaller pockets in the Central Zone (*e.g.* the New Forest and the Somerset Levels), South East (*e.g.* Romney Marsh), and East Anglia (Breckland). There is relatively little change in the overall distribution of heathland throughout the period. The stark decline in heathland in the South East

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[1] Original data are available in the FeedSax Digital Archive (McKerracher *et al.* 2023, document E01), or on request from the authors.

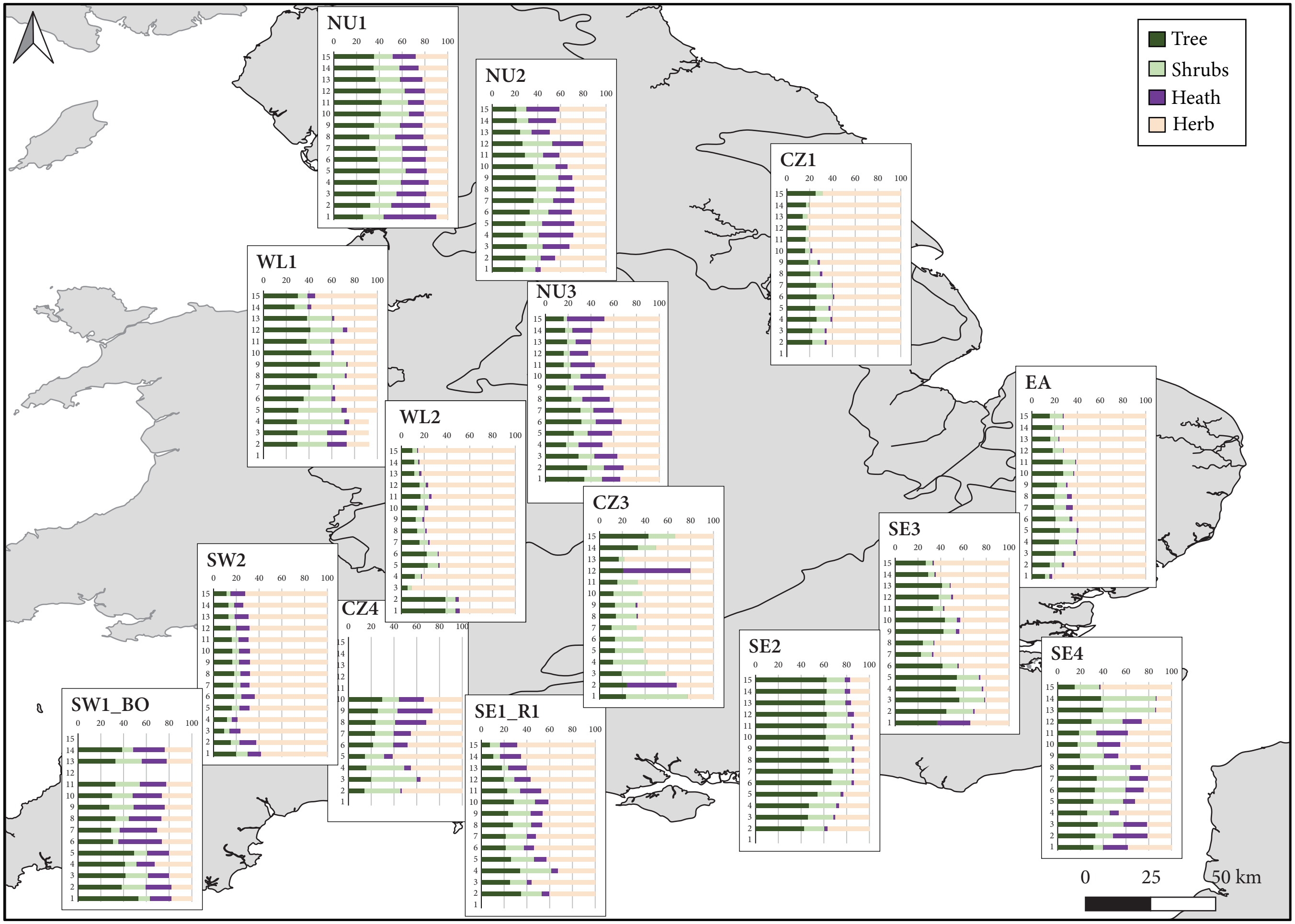

FIGURE 6.2. Major pollen types (trees, shrubs, heaths, and herbaceous taxa, *i.e.* 'herbs') in regional clusters, first to fifteenth centuries AD. See Table 6.1 for sites included in each cluster.

(SE4) by the twelfth–thirteenth centuries is due to the inundation of one site by rising seawater (Forster and Charles 2022; Waller *et al.* 1999), rather than a systemic reduction. Arboreal cover declines in most areas over time, as discussed below, but remains consistently higher in some regions and lower in others. The distribution of woodland, scrub, heathland and herbaceous taxa is positively correlated with altitude, higher rainfall, and—particularly in the case of heathland—acid geology/soil types (Figures 6.1b–d and 6.2).

ARABLE AND PASTORAL LAND USE: OVERALL PATTERNS

The pollen data show that regions with higher arboreal cover tend to have a greater focus on pastoral land use and—in most cases—lower levels of agricultural land use overall. This is particularly clear in the Northern Uplands and the South East. In contrast, in the more open landscapes of the Central Zone and East Anglia, arable farming is important from an early date and remains so throughout the medieval period. As explained in Chapter 2, direct comparisons of floral diversity between sites or even regions are problematic, as the size of pollen counts and levels of identification—determined by the type of analysis, the preservation condition of the pollen, and decisions made by the palynologist—have a significant impact on diversity scores at different sites. Nevertheless, changes within the regional or national averages are of interest, as an increase in arable weed diversity may reflect expansion onto previously uncultivated land (see Chapter 3). Most pastoral sites have lower diversity scores than those dominated by arable farming. This is largely because there is a wider variety of pollen types associated with cultivation than with grazing, but also because some pastoral taxa were excluded from the analysis (*e.g. Rumex* L. sp.—sorrel/dock) as the main focus here was on identifying expansion of arable rather than diversity of pastoral weeds. It is important to note that although there are different types of pastoral land use, these are not always easy to distinguish—or in some cases recognize—palynologically. Hodgson *et al.* (1999, 263) defined three major types of grassland: pasture, which is managed by grazing; hay meadow, managed by mowing; and unmanaged (or infrequently grazed/mown) derelict or semi-derelict grassland. Altitude and the availability of water and nutrients are also important, with upland grassland, heath, and most mires falling into an 'unproductive' category that could be classed as 'rough grazing'. The main pastoral indicators within the arable/pastoral indices used in this analysis are plantains (*Plantago* L. spp.), which are low-growing and resistant to trampling or grazing. These are more likely to be found in frequently grazed pasture (which may include rough grazing) than in meadows or derelict grassland, the presence of which is more difficult to establish palynologically. Although meadows are likely to have been widespread and could have been utilized for grazing or for harvesting fodder/hay, distinguishing between vegetation growing naturally in and around the wetland areas that are frequently sampled for pollen (*e.g.* lakes, floodplain sediments, bogs) and in a managed wet meadow is highly problematic based on pollen data alone and is not attempted here.

The broad patterns of vegetation and land use described above do not change significantly throughout the Roman and medieval periods: arboreal cover remains higher in the Northern Uplands, Western Lowlands, and South East where pastoral land use is also more prominent, while in the more open Central Zone, East Anglia, and South West, arable or mixed farming is more common. The scale/intensity of land use (ALUSS) is generally higher where arable dominates and lower in pastoral areas. By combining data for all sites in order to reveal broad chronological trends, it can be seen that even in the face of demographic catastrophes and favourable climatic developments, underlying regional land use trends persisted over the *longue durée*. Regional and national patterns of change are explored in the following sections.

PATTERNS OF VEGETATION AND LAND USE THROUGH TIME

Figure 6.3 shows national trends in arboreal cover, dominant land use type (API—arable/pastoral index), scale or intensity of land use (ALUSS), and diversity of crops and weeds (see Chapter 2). National averages are based on the combined regional averages, shown in Figure 6.4, with all regions having equal weight. This was considered more representative than giving all pollen sites equal weight in the national average, as the relatively wooded and pasture-dominated Northern Uplands and South East contain a larger number of pollen sites, skewing the distribution. Regional averages are not shown for periods for which fewer than three pollen records are available—unfortunately data are very sparse for the fourteenth and fifteenth centuries in the Central Zone and East Anglia, and from the first century in general, so these are not represented in the national averages. The WL1 cluster of sites in the Western Lowlands (Shropshire) have markedly higher arboreal pollen than do WL2 sites together with different land use histories, so these are plotted separately from the main arboreal and API curves for the region (Figure 6.4).

Mid-first to fourth centuries AD

With the exception of the Western Lowlands, most regions have good data coverage for this period, though as mentioned above, the first century is poorly represented (Figures 6.3 and 6.4). Previous analyses have shown that much of the English landscape was already relatively open with limited arboreal cover by the Roman period (*e.g.* Dark 2000; Forster and Charles 2022; Rippon *et al.* 2015). Combined data for all the sites (with the exception of the excluded onsite records—see Chapter 2) show that 62% of the forty-three sites with pollen data covering any part of the mid-first to the fourth century AD have an average of less than 50% arboreal pollen for that period (McKerracher *et al.* 2023, document E01). This suggests broadly open landscapes in much of the country, as trees and shrubs are generally overrepresented in pollen assemblages (see Chapter 2). Nationally, arboreal cover declines between the first and third/fourth centuries, suggesting clearance of some remaining woodland/scrub. However, only the Central Zone and the Northern Uplands see significant declines; average tree/shrub pollen actually increases in East Anglia and the South East at this time, while there is little change in the South West (Figures 6.3 and 6.4).

Over 50% of sites are dominated by pastoral land use in the Roman period, and APIs for most of the remaining sites suggest mixed farming (McKerracher *et al.* 2023, document E01). At a national level, agricultural land use (ALUSS) is low in the early Roman period, as is diversity of crops and weeds (Figure 6.3). There is an increased emphasis on arable farming throughout the Roman period, together with a sharp increase in overall land use (ALUSS) up to the second/third centuries and a gradual increase in crop/weed diversity. These changes suggest an expansion of farming in the Roman period and an increased focus on arable. The loss of tree/shrub cover in some regions may represent clearance for either cultivation or pasture, while the increase in

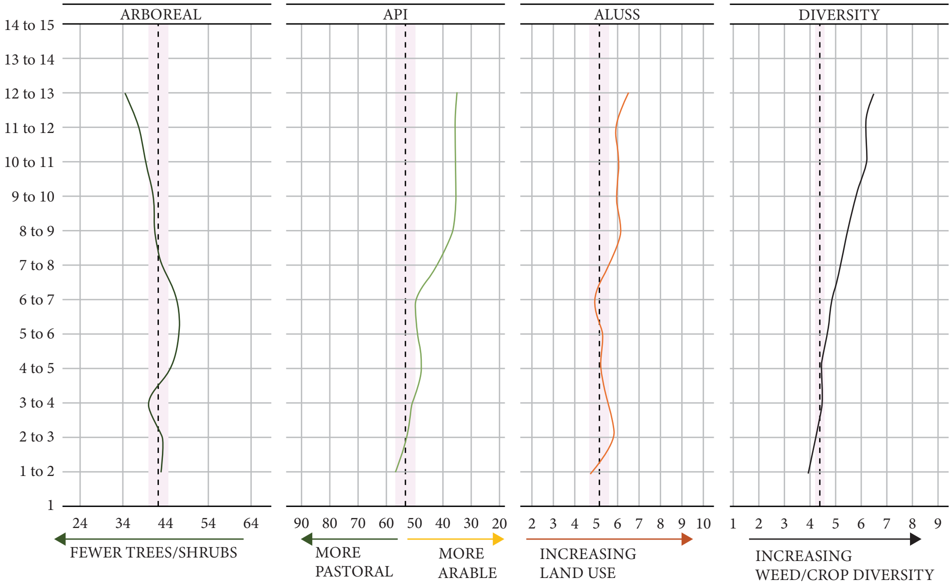

FIGURE 6.3. National averages for key pollen indicators (arboreal pollen percentage, API (arable/pastoral index), ALUSS (agricultural land use signal strength), and diversity of key crops and weeds) for the first to thirteenth centuries AD. The first, fourteenth, and fifteenth centuries are excluded from the national averages owing to a lack of data from several regions. The dotted vertical lines mark the Roman average, while the pink shaded areas show the Roman range for each indicator.

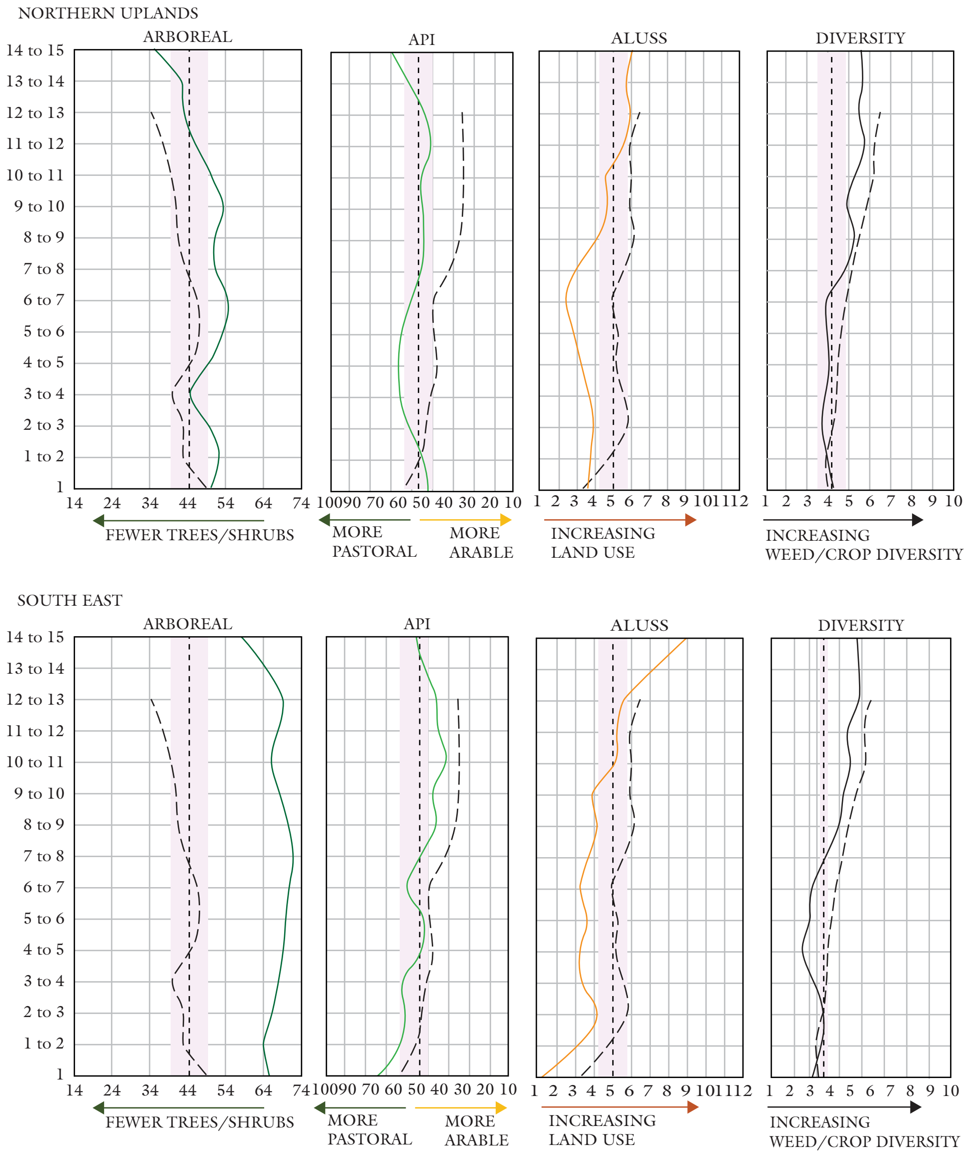

FIGURE 6.4. Regional averages for key pollen indicators (arboreal pollen percentage, API (arable/pastoral index), ALUSS (agricultural land use signal strength), and diversity of key crops and weeds) for the first to fifteenth centuries AD. The national averages (dashed lines) and national Roman average and range are shown as in Figure 6.3 (dotted vertical lines and pink shaded areas, respectively). Periods with fewer than three data points are excluded. For the Western Lowlands, the dotted green lines for arboreal percentages and API represent heavily wooded sites, while the solid lines represent more open sites.

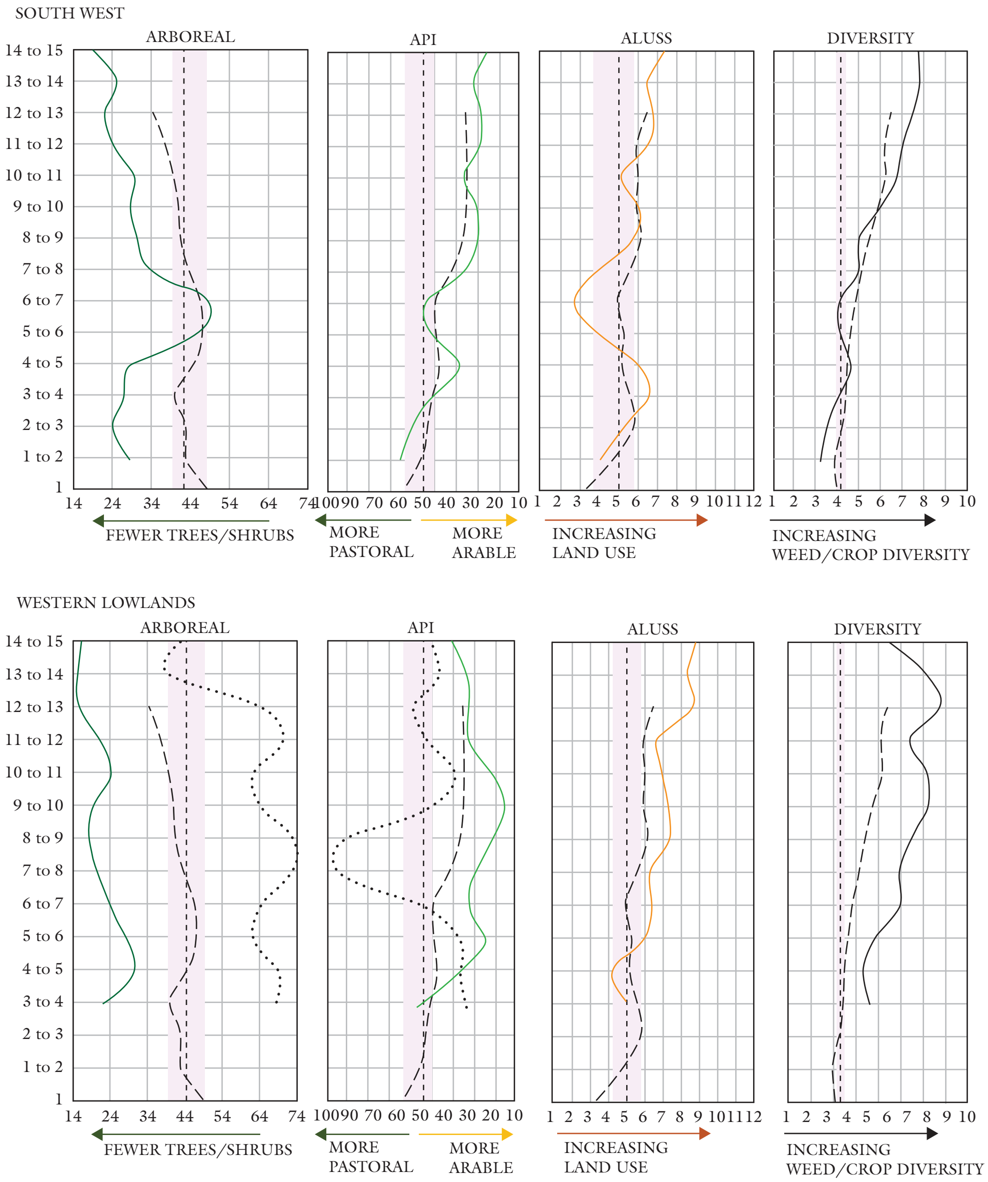

FIGURE 6.4. Continued.

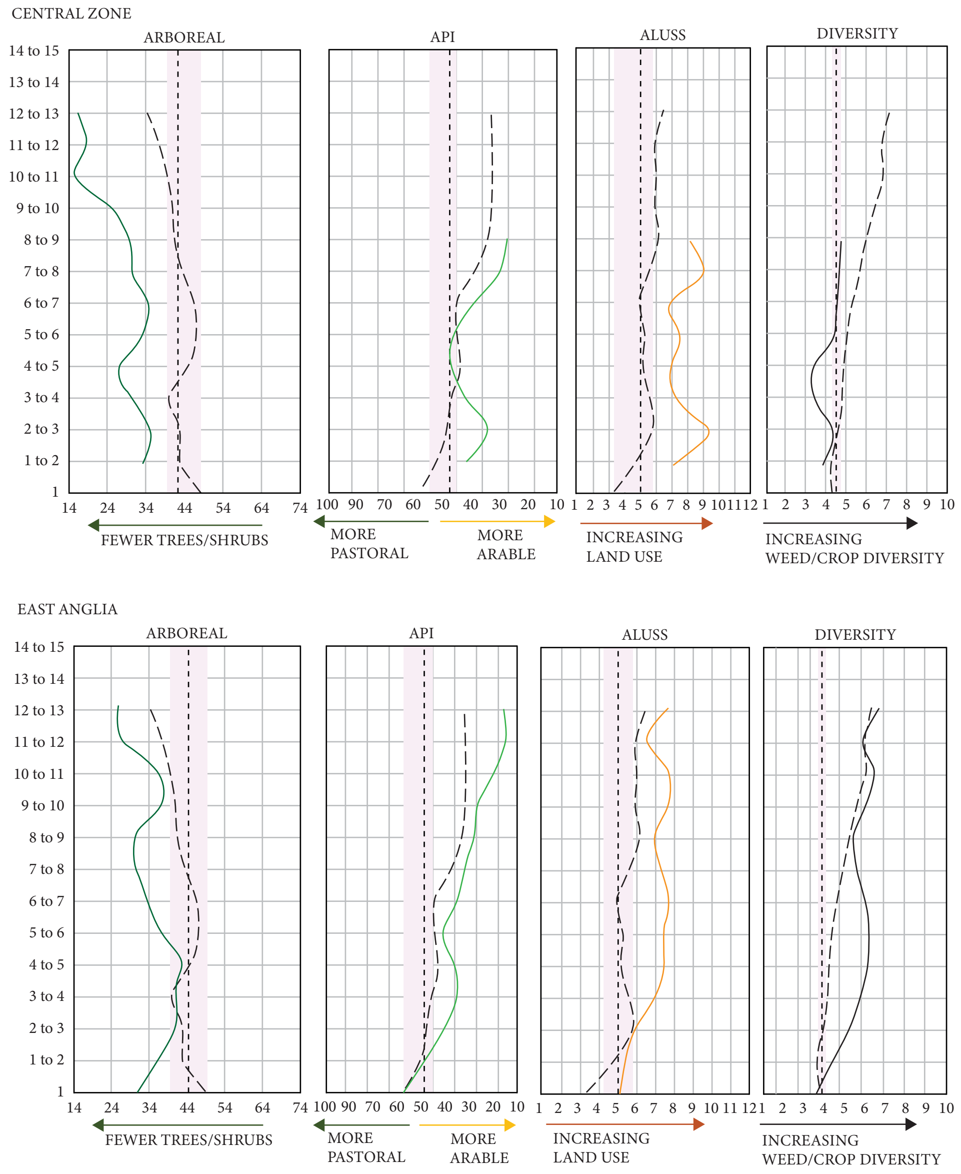

FIGURE 6.4. Continued.

diversity might represent expansion onto previously uncultivated ground, which may include former woodland/scrub, pasture, or rough ground. As explained in Chapter 3, a more diverse arable weed flora might be expected when previously uncultivated ground is converted to arable.

An interesting difference is seen in the Central Zone, East Anglia, and the South East when compared to the national averages for the period. These are generally considered to be regions where the impact of Roman occupation and withdrawal is expected to have been greater than elsewhere. In both the Central Zone and East Anglia, the regional APIs indicate an above-average focus on arable and the ALUSS shows higher overall land use. Although the South East is more pasture-focused throughout this period, in both this region and the Central Zone there is an increased emphasis on pasture in the third to fourth centuries, together with a drop in overall land use and diversity. These changes suggest a late Roman decline in arable and a reduction in land use overall. This is broadly consistent with the archaeological evidence, indicating that impacts on the landscape and land use were greater in the 'Romanized' South East and Central Zone (cf. Rippon *et al.* 2015).

The distribution of key crops and weeds expands gradually from the lowest point in the first century, with cereal types and hemp/hops becoming more widespread throughout the Roman period (Figure 6.5). Rye is unusual as it is more widely distributed in the first century and declines sharply by the second century. It is present sporadically in East Anglia, and at individual sites in the Western Lowlands, South West, and Northern Uplands throughout the Roman period. This distribution may reflect rye's ability to grow on poorer soils than other cereal crops, as acidic and sandy soils are common in these regions (*e.g.* heathland areas), but it is also possible that more detailed measurement of 'Cereal type' pollen in the Central Zone and South East would lead to identification of rye in those areas. The possibility of local rye cultivation has been suggested by Bush (1993, 61) for Willow Garth in the northeast of the Central Zone where 'Cereal type' and rye (*Secale cereale*) were not differentiated; the site is arable based on the API (McKerracher *et al.* 2023, document E01) and has an unusually strong land use signal strength throughout the Roman period and beyond.

Although there are few sites with data for the Roman period in the South West and Central Zone, the early absence of hemp/hop type (*Cannabis* L./*Humulus* L. or Cannabaceae) might suggest that these plants were less commonly cultivated here than elsewhere (Figure 6.5); hemp/hops is present in all other regions from the first to second centuries onwards, although the upland location of the pollen sites in the South West means their presence in lowland areas cannot be ruled out. Cornflower (*Centaurea cyanus* L.) appears—though only at Leash Fen in the Northern Uplands and Thorpe Bulmer in the North East Lowlands (not included in the broader analysis)—by the third century. These are sites with broadly pastoral/mixed land use, though the presence of cereals and a strong ALUSS suggests local cultivation in the Roman period (Bartley *et al.* 1976; Hicks 1971; McKerracher *et al.* 2023, document E01).

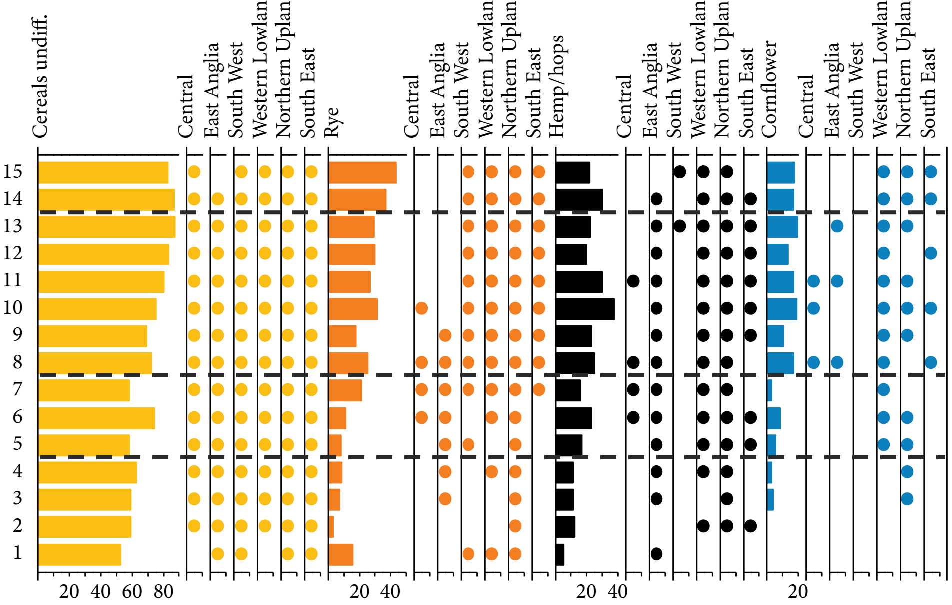

FIGURE 6.5. Distribution of key crops and weeds from the first to fifteenth centuries AD. For each taxon, the bar graph shows the overall percentage of sites with data for that period at which a taxon is found, while the dotted presence/absence graphs show whether a taxon is present in a given region.

Although there are sporadic finds in the Roman and earlier medieval periods, it is not until the eleventh to thirteenth centuries that it becomes a notable arable weed in charred crop deposits (data in McKerracher *et al.* 2023; Ruth Pelling pers. comm.), a pattern also seen in the Netherlands (Bakels 2012). As discussed below, however, the pollen record suggests an earlier spread.

In summary, at a national level, the Roman period sees a reduction in arboreal cover and an increase in farming, with an overall shift towards arable that is more pronounced in regions most affected by the Roman occupation, namely the South East, Central Zone, and East Anglia.

Fifth to seventh centuries AD

Previous work by the authors on the Central Zone, East Anglia, and the South East showed that increases in arboreal cover occur at a small number of sites in the post-Roman period, mostly in East Anglia (Forster and Charles 2022). The expanded dataset presented here, which includes three more regions and additional sites in the South East and Central Zone, shows that this phenomenon is in fact quite widespread. At a national level, arboreal pollen percentages increase by around 6% over 200–300 years, peaking in the sixth to seventh centuries. This seems likely to reflect a modest reduction in land use that allowed woodland/scrub to colonize abandoned crop fields or pasture. This pattern of arboreal expansion is repeated in most regions, though the timing and scale of change varies significantly—as mentioned previously, in some ‘Romanized’ areas the increase in arboreal taxa begins in the late Roman period. In East Anglia and the Western Lowlands, percentages of arboreal taxa increase until the fourth to fifth centuries, and then decline sharply. In contrast, in the Central Zone, the Roman decline in arboreal cover continues into the fourth to fifth centuries, after which there is a marked expansion, while in the South West a gradual increase from the third to fourth centuries is followed by a more substantial expansion between the fifth and seventh centuries. These differences appear to be related to land use, as discussed below.

During the post-Roman period, at a national level, there is little evidence for a dramatic shift in the emphasis of land use. As noted in previous analyses (*e.g.* Forster and Charles 2022; Rippon *et al.* 2015), the pollen data do not indicate large-scale abandonment of farmland in the post-Roman period. Surprisingly, given the expected disruption and decline in both population and crop exports in the early post-Roman period, the national trend towards an increasing emphasis on arable continues into the fifth century, followed by a slight shift towards pasture by the sixth to seventh centuries. Plant diversity continues to increase gradually, and key taxa become more widely distributed (Figure 6.5). The late Roman decline in ALUSS continues, however, suggesting a small reduction in the amount of farmland overall—and particularly of arable, given the shift towards pasture (Figure 6.4).

As in the Roman period, there are regional differences, most clearly in the Central Zone, East Anglia, and the Western Lowlands. In East Anglia and the Central Zone, the late Roman/early post-Roman shift towards pasture is reversed by the sixth to seventh centuries, with an increased emphasis on arable. While the extent/intensity of land use (ALUSS) fluctuates in the Central Zone, both here and in East Anglia it remains above the national average, actually increasing somewhat in East Anglia together with diversity. This agrees with the archaeobotanical data, which evidence increased arable weed diversity in these regions from the mid-late seventh to late-ninth centuries, suggesting an earlier expansion of arable here than in other regions (see Chapter 3). Palynologically, a similar pattern is seen in the Western Lowlands, although here the shift towards arable at the more open (WL2) sites begins even earlier, in the fifth century, while ALUSS and diversity increase from the fifth to sixth centuries. The dating of these changes, taken together with the declines in arboreal cover in both East Anglia and the Western Lowlands, suggests an overall increase in land use with a renewed emphasis on arable.

Some of the key taxa appear in regions where they are not recorded in the Roman period, notably cornflower in the Western Lowlands, potentially suggesting adoption of more ‘extensive’ cultivation techniques (see Chapter 3), and rye in the Central Zone and South East. There is no archaeobotanical evidence to indicate a significant increase in cultivation of rye before the later seventh century, yet the increased visibility of its pollen suggests a wider distribution within the landscape, as might be expected with an overall expansion of arable (or mixed) farming. Hop pollen is recorded in the fourth to fifth centuries at Codsend Moors in the South West (Francis and Slater 1992), a site excluded from this analysis, but it remains absent elsewhere in the region.

As noted by the authors in an earlier study (Forster and Charles 2022), the presumed cooler, wetter conditions of the Late Antique Little Ice Age (LALIA—mid-sixth to mid-seventh centuries) do not appear to have had a marked impact on the scale or type of agricultural land use in the Central Zone, the South East, or East Anglia. They suggested the LALIA may have had a greater impact on the north and west of England, where average rainfall is higher and there are large areas of upland (Figure 6.1b and c). The South West, and to a lesser extent the Northern Uplands, have increases in arboreal cover in this period together with declines in land use, but these shifts begin between the fourth and sixth centuries, seemingly too early to have been caused by the LALIA. There is also substantial variability between sites within these regions (McKerracher *et al.* 2023, document E01), suggesting that the changes are not related to climate. Furthermore, as mentioned above, the Western Lowlands—which also has higher than average rainfall for England—sees increases in overall land use and the arrival of new crops and weeds around this time. Changes in the percentage of heathland, which might be expected to expand in cooler/wetter conditions, follow no clear trend in most regions. There are increases at some sites in the sixth to seventh centuries, notably Brandon (East Anglia) and Meare Heath (Central Zone), but in the Northern Uplands and South West where heathland is most prevalent, there is no discernible expansion. Overall, the LALIA appears to have had no appreciable, consistent impact on vegetation cover or land use in England, a finding that aligns with other recent studies of environment and land use in Britain during this period (Rippon 2019b, 105–8; Rippon and Fyfe 2019, 138). The wetter, cooler conditions normally associated with the LALIA would, furthermore, have encouraged the continued cultivation of spelt rather than a shift to bread wheat, which is less tolerant of such conditions, yet a recent large-scale archaeobotanical study demonstrates a shift from glume wheats (spelt and emmer) to free-threshing bread wheat in England precisely during this period (van der Veen 2022, 323).

The small but widespread increases in arboreal cover, together with a decline in the scale/intensity of land use in some regions, could reflect some ‘abatement’ in cereal cultivation (Banham and Faith 2014) in the fifth to seventh centuries. However, the fact that it begins as early as the fourth century in some areas should be noted, and cautions against a simplistic correlation with the end of Roman occupation in the early fifth century. The timing and scale of arboreal expansions, shifts towards pasture, and declines in overall land use vary between and within regions, with the more ‘Romanized’ areas tending to see declines in the later Roman period followed by an earlier shift back towards arable than other regions. Significantly, as in previous analyses (Rippon 2019b, 102; Rippon and Fyfe 2019; Rippon *et al.* 2015, 57–85), no evidence was found for the large-scale abandonment of farmland in any region.

Eighth to thirteenth centuries AD

At a national level, this period is characterized by a continuing steady decline in arboreal cover, a higher level of agricultural land use and a marked shift towards arable-focused farming. Overall percentages of arboreal taxa decline between the seventh/eighth and twelfth/thirteenth centuries, suggesting ongoing, gradual clearance of trees and shrubs, including potentially hedgerows, as open fields were laid out. API shows a clear shift towards arable farming around the eighth century, which peaks in the ninth to tenth centuries. The scale or intensity of land use (ALUSS) also increases significantly in this early phase, and then more gradually until the twelfth to thirteenth centuries. Together, these changes indicate a substantial increase in agricultural land use beginning around the eighth century, with some clearance of remaining arboreal cover and a greatly increased emphasis on arable farming. The rise in percentages of pollen associated with agriculture (ALUSS), together with a steady increase in crop/weed diversity that continues until at least the tenth to eleventh centuries, suggests significant expansion of arable land. As explained in Chapter 3, ploughing of previously uncultivated/undisturbed soils is likely to have led to an increase in the diversity of weeds growing alongside the crops. Considering the increased emphasis on arable, the land converted to arable might have included former pasture in some areas. The expansion may have been facilitated by the use of mouldboard ploughs to till heavier clay soils (see Chapter 5).

The distribution of key taxa also increases steadily until the tenth to eleventh centuries, with cornflower, rye, and hemp/hops appearing in new areas. This is consistent with the overall expansion of arable and—in the case of cornflower—more widespread adoption of extensive cultivation practices and potentially the use of the mouldboard plough (see Chapter 3; Jones 2009, 61). Although the archaeobotanical evidence for cornflower indicates that it was not a particularly common arable weed until the eleventh to thirteenth centuries (see above), the pollen record reveals its earlier spread, with the most marked expansion taking place in the eighth to ninth centuries. In addition to being associated with more extensive cultivation techniques, it has been suggested that cornflower is favoured by winter sowing (Bakels 2012, 30; *cf.* Clapham *et al.* 1987), in which case its spread might be related to a particular crop being sown in winter rather than spring. This cannot be taken further using pollen data alone, but may warrant further investigation in future. After the tenth century, undifferentiated ‘Cereal type’ pollen, and to a lesser extent rye, continue to spread, while hemp/hops appears to contract somewhat and cornflower remains stable (Figure 6.5). Although diversity fluctuates slightly during this period, it remains markedly higher than the Roman average and range, and is significantly higher at the end of the period than at the beginning. Diversity seems to level off or even reduce slightly after the tenth to eleventh centuries. Interestingly, this trend is also seen in the archaeobotanical data from the early twelfth to early fourteenth centuries and is thought to reflect a period of consolidation as the early floral diversity of newly cleared arable was reduced to a more restricted range by decades of cultivation (see Chapter 3).

The broad trends towards reduced arboreal cover and an expansion of arable are widespread: almost all regions are more open—with a greater focus on arable farming, higher overall land use, and higher diversity—by the twelfth to thirteenth centuries than they were in the sixth to seventh centuries. Looking at the data more closely, we can discern interesting differences between regions. It should be noted that owing to the small number of Central Zone sites with pollen data covering the tenth to thirteenth centuries, together with the intermittent nature of the records, the three land use indicators (API, ALUSS, and diversity) are unreliable for this region after the eighth to ninth centuries. These data are therefore excluded from Figure 6.4 for the Central Zone and were not included in the national averages. Arboreal data (Figure 6.4) and distribution of key taxa (Figure 6.5) are not affected in the same way and continue to follow the broad national trends.

Although there are fluctuations in some areas, arboreal cover in all regions is lower in the twelfth to thirteenth centuries than in the seventh to eighth centuries. The smallest overall decline occurs in the South East, the region with the highest tree/shrub cover throughout the Roman and medieval periods, while the biggest fall in arboreal pollen is seen in the South West, with much of this occurring in the seventh to eighth centuries. In East Anglia, there is an increase in tree/shrub cover around the tenth to eleventh centuries, although this is followed by a renewed decline. As discussed in Forster and Charles (2022), this pattern of expansion is also seen at individual sites in the Central Zone and South East, and may reflect deliberate protection of oak woodland (Day 1991, 467).

All regions except the more open areas of the Western Lowlands (*i.e.* those with lower arboreal cover) are more arable-focused in the twelfth to thirteenth centuries than in the seventh to eighth centuries. As explained above, land use indicators are not available for the Central Zone after the eighth to ninth centuries owing to scarcity of data, but a wealth of archaeological and archaeobotanical evidence shows continuing expansion of arable in this region (see Chapter 3). As explained by Hamerow *et al.* (2020), the shift towards pasture and the decline in land use in some parts of the Western Lowlands may reflect changes specific to individual sites, which may not be reflected in a wider dataset (*i.e.* a possible change in land ownership at Crose Mere (Shropshire) and the expansion of the market town of Stafford, which may have pushed arable land further from the pollen sites). Almost all regions also see a significant increase in overall land use by the end of the period; the exception is East Anglia, where ALUSS is only negligibly higher following a decline in the eleventh to twelfth centuries, though it is worth noting that even during this decline, land use in the region remains higher than the national average.

Although not widespread, there are some indications that the warmer conditions of the Medieval Climate Anomaly (MCA) enabled a small expansion of arable in the Northern Uplands. Upland areas with higher-than-average rainfall might be considered 'marginal' or unsuitable for cultivation in general and are often dominated by rough grazing today. Land use in the Northern Uplands is dominated by pasture throughout the Roman and medieval periods although, following the national trend, there is a shift towards arable in the seventh to eighth centuries, together with increases in land use and diversity. However, a further shift towards arable occurs in the eleventh to twelfth centuries, coinciding with a peak in diversity and an increase in land use, which rises above the national Roman average for the first time. This pattern differs from other regions, in that the eleventh- to twelfth-century peak in the Northern Uplands is short-lived, being followed by a shift back towards pasture. The majority of sites in the region have cereals at this time, often together with hemp/hops, while far fewer sites have cornflower, perhaps suggesting less extensive cultivation regimes than seen elsewhere. It is possible that these changes were enabled by the warmer conditions of the MCA. While this is unlikely to have had much effect in lowland areas (Forster and Charles 2022; Rippon and Fyfe 2019), upland moorland regions might have become more hospitable to cultivation at this time, as seen in the establishment of year-round upland settlements in the South West (Costello 2021).

Fourteenth to fifteenth centuries

Pollen data for this period are relatively limited and sometimes lack direct dating evidence, so conclusions are necessarily tentative. As explained above, there are also too few data points (*i.e.* sites with pollen records covering the fourteenth to fifteenth centuries) for the Central Zone and East Anglia to calculate regional averages; national averages were also not calculated for this period owing to the lack of data from these regions. Nevertheless, where data are available, some notable trends emerge. Arboreal cover continues its decline, particularly in the more wooded parts of the Western Lowlands and in the South East. These two regions, together with the Northern Uplands, also see a shift towards pasture. In the South East, there is a significant increase in overall land use, while in other regions this remains broadly stable. Distribution of key taxa remains high, with a slight increase in the proportion of sites where rye is recorded.

In the Northern Uplands, the shift towards pasture is accompanied by an increase in heathland, which may have been used for rough grazing. The lack of further expansion and—in some areas at least—reduction in arable by the fifteenth century may reflect the impacts of the Black Death, livestock pestilences, and famines of the fourteenth century. There is well-documented evidence for the conversion of arable to pasture following the Black Death as the demand to feed an expanding population dissipated and the market for grain crashed; animal husbandry was a viable alternative since it was less labour intensive and more adaptable to uncertain markets (*e.g.* Campbell 1991, 153–9; Campbell and Overton 1993, 77–8; Dodds 2008; Dyer 1981; Thirsk 1997, 8). Although the Great Famine and Black Death are known to have had a catastrophic impact on the population, the pollen data indicate that woodland/scrub continued to decline, key crops and weeds remained widespread and, as it stands, the evidence does not suggest large-scale abandonment of farmland. However, the lack of any clear trends in land use reflecting the dramatic decline in population in the fourteenth century may well reflect the limitations of the data, and it is possible that increasing the number of well-dated sites and the resolution of the pollen data for this period in future will reveal more substantial impacts.

Feeding Medieval England: A Long 'Agricultural Revolution', 700–1300. Helena Hamerow, Mark McKerracher, Amy Bogaard, Mike Charles, Emily Forster, Matilda Holmes, Christopher Bronk Ramsey, Elizabeth Stroud, and Richard Thomas, Oxford University Press.
DOI: 10.1093/9780191988905.003.0006

Table 6.1. Pollen site codes, data, and regional clusters as shown in Figure 6.2. * Site excluded from national dataset owing to scarcity of data from region. ** Regional cluster excluded from Figure 6.2 as data are too scarce/intermittent or predominantly from onsite records.

Site code	Site name	Region	Cluster	County	Altitude/ m.a.s.l	Soil type/superficial geology (BGS)	Radiocarbon dates	Comments on chronology	Citations for original data
BH	Barrow Haven	Central	CZ1	Lincolnshire	–2	Seasonally wet deep clay	2	Extrapolated at constant rate for uppermost sample	Long *et al.* (1998)
BD	Biddlesden	Central	CZ2**	Northamptonshire	115	Seasonally wet deep clay	2	Extrapolated at constant rate for uppermost samples	Branch *et al.* (2005); Jones and Page (2006); Jones *et al.* (2006)
MH	Meare Heath	Central	CZ4	Somerset	10	Peat	4	Extrapolated up at constant rate	Beckett and Hibbert (1979)
OM	Oxey Mead (Yarnton)	Central	CZ3	Oxfordshire	60	Seasonally wet deep clay	2	1 date rejected. Extrapolated at constant rate to uppermost samples	Greig (2004)
SC	Sidlings Copse	Central	CZ3	Oxfordshire	100	Loam	4	1 date rejected. Extrapolated at constant rate to uppermost samples	Day (1991, 1993); EPD
WB	Westbury by Shenley	Central	CZ2**	Buckinghamshire	100	Shallow loam	2	Dendrochronological dates on context	Hale (1995)
WH	Whites Drove	Central	CZ4	Somerset	5	Peat	3	Extrapolated to surface	Housley *et al.* (2007)
WG	Willow Garth	Central	CZ1	East Riding of Yorkshire	18	Seasonally wet loam	5		Bush (1988)
BR	Brandon	East Anglia	EA	Suffolk	1	Peat	1	Upper date is based on associated pottery	Wiltshire (1990)
HM	Hockham Mere	East Anglia	EA	Norfolk	33	Peat	6	Well dated	Bennett (1983); EPD
RM	Redmere	East Anglia	EA	Norfolk	0	Peat	4	Extrapolated to surface—radiocarbon dates all predate the FeedSax period	Waller (1994); EPD

WW	Welney Washes	East Anglia	EA	Norfolk	2	Seasonally wet deep silty	8	Well dated—extrapolated at constant rate for uppermost samples	Waller (1994); EPD
WM	Willingham Mere	East Anglia	EA	Cambridgeshire	2	Deep clay	2	Extrapolated to surface—radiocarbon dates all predate the FeedSax period	Waller (1994); EPD
TB	Thorpe Bulmer*	Northeast Lowlands	–	County Durham	80	Seasonally wet deep loam to clay	3	Extrapolated to surface	Bartley *et al.* (1976)
AL	Alport	Northern Uplands	NU2	Derbyshire	390	Peat to loam	2	Dates almost bracket the period—extrapolated to surface	FeedSax (unpublished)
BF	Barfield Tarn	Northern Uplands	NU1	Cumbria	10	Seasonally wet deep red loam	2	Upper date is based on SCP curve	Forster (2010) (unpublished)
CB	Cranberry Bed	Northern Uplands	NU2	South Yorkshire	290	Peat to loam	2	Extrapolated to surface	FeedSax; Hamerow *et al.* (2020)
FF	Fairsnape Fell	Northern Uplands	NU1	Lancashire	510	Seasonally wet deep loam	7	Two core/monolith sections dated separately and correlated based on pollen	Mackay and Tallis (1994)
FM	Featherbed Moss	Northern Uplands	NU2	Derbyshire	500	Blanket peat	7	Extrapolated at constant rate for uppermost samples	Tallis and Switsur (1973)
GS	Green Sitches	Northern Uplands	NU2	Derbyshire	435	Blanket peat	3	Dates bracket the period	FeedSax (unpublished)
HS	Hipper Sick	Northern Uplands	NU3	Derbyshire	335	Seasonally wet deep peat to loam	1	Extrapolated to surface—NB date is Neolithic	Hicks (1971); EPD
HL	Hulleter Moss	Northern Uplands	NU1	Cumbria	7	Peat	8	One reversed date excluded; extrapolated at a constant rate	Coombes *et al.* (2009)

Continued

Table 6.1. *Continued*

Site code	Site name	Region	Cluster	County	Altitude/ m.a.s.l	Soil type/superficial geology (BGS)	Radiocarbon dates	Comments on chronology	Citations for original data
LF	Leash Fen	Northern Uplands	NU3	Derbyshire	290	Blanket peat	3	Extrapolated to surface	Hicks (1971); EPD
LG	Loughrigg Tarn	Northern Uplands	NU1	Cumbria	99	Stony loam	5	Upper date is based on SCP curve	Forster (2010) (unpublished)
MT	Malham Tarn	Northern Uplands	NU1	North Yorkshire	370	Silty	4	Extrapolated at constant rate to surface	Brown, A.D. (2006), EPD
SF	Stoke Flat	Northern Uplands	NU3	Derbyshire	330	Seasonally wet deep peat to loam	1	Extrapolated at constant rate to surface	Long *et al.* (1998)
TM	Totley Moss	Northern Uplands	NU3	Derbyshire	358	Loam	1	Extrapolated at constant rate to surface–NB date is Neolithic	Hicks (1971); EPD
AC	Ashtead Common	South East	SE2	Surrey	30	Seasonally wet deep clay	5		Waller (2010)
BK	Beckton	South East	SE3	London	4	Seasonally wet deep clay	6	1 date rejected—extrapolated to surface—radiocarbon dates all predate the FeedSax period	Batchelor (2009); EPD
CF	Colemans Farm	South East	SE3	Essex	20	Deep loam	3	Possible truncation/ break in accumulation between dates is problematic; tentative chronology	Murphy *et al.* (2002)
CN	Conford	South East	SE2	Hampshire	70	Sandy	2	Extrapolated to pine rise for uppermost samples	Groves *et al.* (2012)
LC	Little Cheyne Court	South East	SE4	Kent	–1	Seasonally wet deep clay	4	Well dated—extrapolated at constant rate for uppermost samples	Waller *et al.* (1999)

EP	Lodge Road, Epping	South East	SE3	Essex	117	Seasonally wet deep clay	3	1 date rejected; well dated	Grant and Dark (2006)
LY	Lyminge	South East	SE4	Kent	100	Silty	4	Dates are for contexts—pollen sample dates estimated according to context	Maslin (2017)
PB	Pannel Bridge	South East	SE4	East Sussex	4	Seasonally wet deep clay	8	Extrapolated to surface—radiocarbon dates all predate the FeedSax period	Waller (1993)
RI	Rimsmoor	South East	SE1**	Dorset	55	Deep sandy	2	Extrapolated up at constant rate. NB—dated material covers larger depths than usual so error ranges within the age-depth model are more substantial than usual	Waton (1983)
SH	Slough House Farm	South East	SE3	Essex	10	Seasonally wet deep loam	1	Dendrochronological date on context	Wiltshire (1992); Murphy and Wiltshire (1993)
SN	Snelsmore	South East	SE2	Berkshire	135	Loam	2	Extrapolated up at constant rate. NB—dated material covers larger depths than usual so error ranges within the age-depth model are more substantial than usual	Waton (1983)
ST	Stansted	South East	SE3	Essex	70	Seasonally wet deep clay	2	Extrapolated to surface for approximate accumulation rate—very short sequence	Murphy (1988); Wiltshire (1991)

Continued

Table 6.1. *Continued*

Site code	Site name	Region	Cluster	County	Altitude/ m.a.s.l	Soil type/superficial geology (BGS)	Radiocarbon dates	Comments on chronology	Citations for original data
BO	Broad Down	South West	SW1	Devon	505	Blanket peat	9	Very well dated—extrapolated to surface	Fyfe and Woodbridge (2012); EPD
GM	Gourte Mires	South West	SW2	Exmoor, Devon	291	Peat to loam	4	Extrapolated to surface	Fyfe *et al.* (2003); EPD
HD	Hares Down	South West	SW2	Devon	242	Seasonally wet deep peat to loam	2	Extrapolated to surface	Fyfe *et al.* (2004); EPD
WR	Windmill Rough	South West	SW2	Devon	259	Seasonally wet deep peat to loam	3		Fyfe *et al.* (2004); EPD
CL	Clarepool	Western Lowlands	WL1	Shropshire	94	Stony loam	2	Extrapolated to surface	Kneen and Lageard (2015)
CM	Crose Mere	Western Lowlands	WL1	Shropshire	100	Peat	3	Extrapolated to surface	Beales (1980)
KM	Kempsey	Western Lowlands	WL2	Worcestershire	14	Deep loam	?	Sample dates provided based on OSL (Flood and Flow project)	‘Flood and Flow’ project (Pears *et al.* 2023); FeedSax
KP	Kings pool	Western Lowlands	WL2	Staffordshire	70	Deep red loam to clay	1	Extrapolated at a constant rate based on surface date	Bartley and Morgan (1990); EPD
SW	Stafford West	Western Lowlands	WL2	Staffordshire	77	Seasonally wet deep clay	5	Extrapolated up at a constant rate to surface	FeedSax; Hamerow *et al.* (2020)
WD	Wilden Marsh	Western Lowlands	WL2	Worcestershire	40	Seasonally wet deep sandy	2	Extrapolated up at a constant rate to surface	Brown, A.G. (1988)

SEVEN

A Long ‘Agricultural Revolution’

THE SPREAD OF THE MOULDBOARD PLOUGH PACKAGE

Extensification: The beginning of a ‘long revolution’

Following a period of ‘abatement’ in arable farming, extensive, low-input cultivation was the first element of the mouldboard plough package to become widespread (see Chapters 3, 5, and 6; Banham and Faith 2014). The return to somewhat smaller-scale, more intensive farming practices in the fifth and sixth centuries presumably reflects the absence of a formal market for grain and of systematic surplus extraction as well as, presumably, a reduction in population size. Weed and pollen evidence points to a shift towards lower-input, presumably larger-scale cultivation during FeedSax phase C (*c.*670–880), broadly corresponding to the ‘long eighth century’. This shift is likely to mark the resumption of a long-term trend that began in later prehistory towards increasingly extensive cultivation practices (Hamerow *et al.* 2021). The potential drivers of this long-term trend are considered below but may include a tendency for farmers, where possible, to improve their food security by cultivating, slightly more land than necessary in order to mitigate the risk of a poor harvest. In most years, this would amount to what Halstead (2009) has called a ‘normal surplus’.

One might nevertheless question why an extensive regime that involved decreased inputs per land unit continued to be pursued during the eleventh to thirteenth centuries, a time of population growth and cheaper labour costs, when good-quality arable land was in increasingly short supply (Williamson 2022, 215). The reduction in soil fertility over time reflected in the weed flora of the Central and Eastern Zones (Figure 3.4) suggests that the large quantities of manure per unit of arable needed to boost soil fertility significantly were unavailable, yet the net requirement for human labour inputs need not have decreased. The need to maintain yields in the face of declining fertility may, indeed, have resulted in more effort being devoted to weeding, harrowing, marling, and other labour-intensive activities carried out over ever-larger areas (Faith 1997, 237; Jones 2004; Smith 2002, 187; Stone 2005, 51–72). Extensification appears, furthermore, to have begun well before the period of peak population growth. While the precise drivers of extensification remain unclear, it seems to have involved a degree of 'path dependence'; as the Rhineland study suggests, once farmers started down the path of extensification, they were unlikely to turn back (Hamerow *et al.* 2021).

To judge from manorial and other records, crop yields were low relative to seed corn sown, generally between 3:1 and 5:1 in the thirteenth century, and did not increase significantly until the eighteenth century (Campbell and Overton 1993, table 5; Jordan 1996, 25). As seen in Chapter 3, the weed ecology in all regions for which data are available is generally consistent with low-input, low-fertility conditions and so low yields are unsurprising. For the Central Zone, the weed data indicate a subtle but significant decline in soil fertility beginning around the eighth century, although there is nothing to indicate that a 'cliff edge' was reached in the thirteenth or fourteenth century.

The prevalence of bulk cereal processing over time can be traced by examining the chronological distribution of 'rich' archaeobotanical samples, that is, those containing at least thirty items per litre of soil, including grains, chaff, and weed seeds (Figure 7.1). This indicates that bulk cereal processing was widespread throughout phases C to E, with moderately rich samples present at more than 80% of sites and very rich samples at more than 60% of sites in each phase. In contrast, the chronological distribution of the samples themselves—an indication of how characteristic bulk cereal processing was in each phase—reveals that phase E (*c.*1030–1220) has the highest proportions of rich samples, while phase D (*c.*880–1030) has the lowest (Figure 7.2).[1] Overall, these findings are consistent with: (a) the successful maintenance of crop yields into phase E, despite the long-term decline in soil fertility, and (b) a more varied pattern of growth in phase D, less characterized by bulk processing but perhaps reflecting a 'bedding in' period during which new techniques gained traction, followed by a period of more firmly established productivity in phase E. The fact that such dense deposits are strongly correlated with kilns, ovens, and hearths, all of which are most common in phase E and have a direct association with bulk cereal processing, serves to reinforce the impression that large harvests and centralized processing had become especially characteristic of the cereal economy of the mid-eleventh to thirteenth centuries (see Appendix 2).

Written sources for some regions, including parts of Norfolk and Cambridgeshire, indicate that overall yields on demesne lands were maintained or even increased in the thirteenth century and into the fourteenth by adopting measures such as planting

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[1] To avoid distortion, these figures exclude two 'hotspots'—*i.e.* marked concentrations of dense samples dated to phase E—at West Cotton (Central Zone; sixty-four samples in total) and Ipswich (East Anglia; thirty-four samples in total).

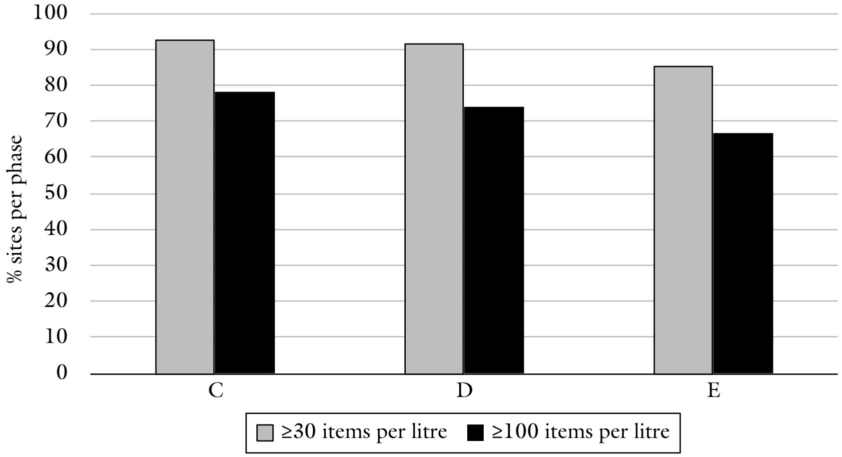

FIGURE 7.1. The chronological distribution of sites producing rich archaeobotanical samples.

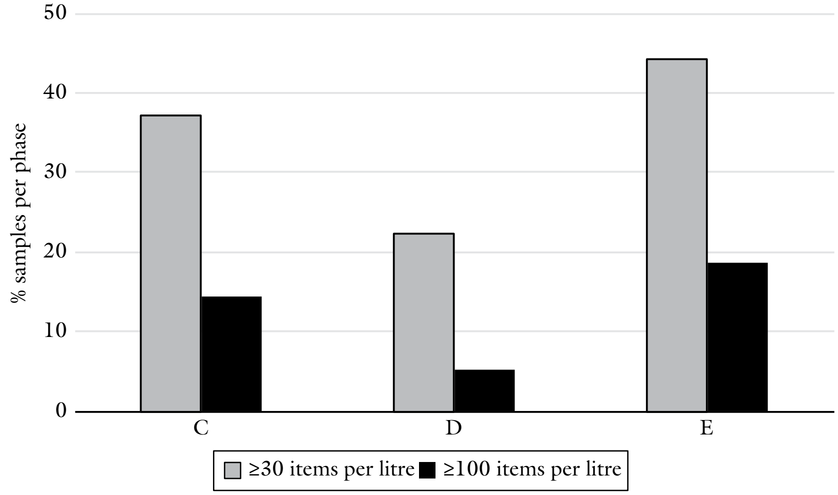

FIGURE 7.2. The chronological distribution of rich archaeobotanical samples, excluding ninety-eight samples from 'hotspots' at Ipswich and West Cotton (see Appendix 2).

legumes, reducing or eliminating fallow, hand weeding, fallow ploughing, and folding sheep (Campbell 1983; Stone 2005, 51–72). As the weed ecology demonstrates, however, these measures may have slowed the subtle downward trend in soil fertility seen in the Central and Eastern Zones but were insufficient to reverse it. The multiple ploughing of fallow would actually have contributed to the net loss of soil fertility by accelerating the breakdown of organic matter and release of nutrients, even while bringing nutrients to the surface and temporarily boosting yields (Montgomery and Biklé 2021). The weed data thus appear to support the view that many farmers would have been unable to escape a 'vicious circle of declining soil fertility and falling yields' (Campbell 1983, 35).

As Williamson (2022, 219–22) has pointed out, labour inputs such as ploughing and spreading of manure would have become increasingly inefficient in open-field systems as fields expanded and those working in them had to move between ever more widely scattered strips. Where there was declining soil fertility, greater overall labour inputs would have been required in order to maintain yields although, as already noted, a growing population made labour relatively cheap in the twelfth and thirteenth centuries (ibid.). A tipping point of inefficiency at which extensification strategies became unsustainable may nevertheless have been reached before the fourteenth century, but above all in the aftermath of the Black Death, when labour was again scarce and expensive. These developments may ultimately have heralded the end of extensification.

The spread of the mouldboard plough

Analysis of arable weed flora from the Central Zone indicates that levels of soil disturbance began to increase around the time that more extensive cultivation regimes were adopted, namely during FeedSax phases C1–C3 (Chapter 5, Figure 5.15). This is also when settlement, which had retreated in the post-Roman period to light, easily tilled soils, for example on river terraces, began to return to heavier soils that would have been difficult or impossible to work with an ard (Hamerow 1992, 1999). While this timing might suggest that extensification and use of the mouldboard plough were linked, the relatively limited evidence for traction-related pathologies on cattle bones prior to the ninth century suggests that, in its earliest stages, extensification was largely achieved by means of ard cultivation, or at least without the use of dedicated plough oxen. The proportion of sites with a 'draught cattle signature' increases gradually over time, peaking between *c.*1000 and 1200 (broadly corresponding to FeedSax phase E), while the persistence of some 'low disturbance' weeds across all sites may reflect continuing use of the ard as well as the ploughing up of pasture (*cf.* Banham and Faith 2014).

The adoption of the mouldboard plough made it possible for the first time to achieve a high level of soil disturbance—comparable to that achieved by modern ploughing—on a large scale. Nevertheless, the results of the present study indicate that widespread adoption of the mouldboard plough was slow in coming and the factors that determined if a particular household or community decided to adopt this technology would have been grounded in local conditions. Despite this apparently gradual uptake, it should be remembered that from the perspective of individual households and communities, the acquisition of a mouldboard plough represented not incremental change, but a major investment in future productivity. It also meant a shift from farming regimes geared towards self-sufficiency, low risk, and food security to ones increasingly directed towards producing substantial, regular surpluses.

Systematic crop rotation

It has recently been argued that the origins of medieval crop rotation lie in a 'bottom up' innovation designed to accommodate the particular demands of bread wheat, which rapidly replaced spelt as the wheat of choice in England during the fifth to seventh centuries (van der Veen 2022). Bread wheat—which, as the key constituent of white, leavened bread, had a high social and market value[2]—is easily out-competed by weeds and prefers relatively nutrient-rich soil conditions. The evidence presented in Chapter 4, however, suggests that *systematic* crop rotation was not introduced into England until the late eighth to ninth centuries (phases C3–C4)—well after the shift to bread wheat, although before the earliest written sources recording the practice—becoming relatively widespread during the late ninth to mid-eleventh centuries (phase D).

The national database confirms the importance of bread wheat in England—especially in the Central Zone, South East, and Western Lowlands—as well as a corresponding tendency towards increasing crop diversity, with oat and rye being grown more frequently in those regions over time (Appendix 4). Broader crop repertoires are more resilient in the face of environmental change, and a growing emphasis on bread wheat, indeed monocrops of any kind, would have increased risks for farmers; crop rotation would have helped mitigate those risks. Although modern varieties of bread wheat require intensive weeding and high fertility, and therefore may 'not [thrive] in extensive cultivation practices' (van der Veen 2022, 324), some traditional landraces of bread wheat do grow successfully under an extensive regime (see Bogaard *et al.* 2016 for an example from Haute Provence). The weeds from wheat-dominated samples analysed here indicate that medieval wheat grew in the same low-fertility conditions as other crops and must therefore have evolved to grow successfully in such conditions.

The spread of systematic rotation and use of the mouldboard plough thus followed similar chronological trajectories, perhaps because both practices required, or were at least facilitated by, a degree of cooperation between farmers. These practices were, however, by no means invariably linked at the level of individual sites. At Mildenhall, 'high disturbance' samples consistent with the use of a mouldboard plough were already predominant in phases C3 and C4 (*c.*770–880), while the earliest isotopic evidence for systematic rotation dates to phase D (*c.*880–1030; Figure 5.24). At the royal monastery of Lyminge, a predominance of 'high disturbance' samples from phases C3/C4 together with the discovery of a seventh-century coulter from mouldboard plough suggests that this community was an early adopter of the plough (see Chapter 5). No evidence was found, however, for systematic rotation in

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[2] An annual render payable to the clergy of Worcester Cathedral recorded in a document of 847 specifies 600 loaves of white bread (Finberg 1972, 103).

this early phase. At Yarnton too, systematic crop rotation was ruled out for phases C3 and C4, despite samples from this phase displaying a 'high disturbance' signature (Chapter 4 and Figure 5.20).

THE PACE OF CHANGE

The 'long eighth century' (FeedSax phase C: c.670–880)

The evidence presented in the preceding chapters is suggestive of piecemeal development, with little to suggest a co-ordinated 'great replanning' of farming systems in the Central Zone or indeed elsewhere (Brown and Foard 1998). Periods of more rapid, wide-ranging change can nevertheless be discerned, as becomes apparent when the evidence from excavated settlements is considered alongside the bioarchaeological data. The period that stands out most clearly is FeedSax phase C, broadly corresponding to the later seventh to later ninth centuries. This saw a shift to lower-input, larger-scale cultivation regimes as indicated by the arable weed data and by the widespread appearance in the pollen record of cornflower, a weed associated with low-input conditions (see Chapter 6). The pollen record also indicates a markedly increased emphasis on arable land use alongside an increase in the scale of agricultural land use generally. Archaeobotanical evidence for weed diversity from most regions also points to arable expansion onto new terrains—and presumably heavier soils—during the same period (see Chapter 3). Increases in crop/weed diversity and an expansion in the distribution of crop (*i.e.* rye) and cornflower pollen also point to an expansion of arable cultivation, as these pollen types appear in more locations over time (Figure 6.5). The increase in levels of soil disturbance seen at some sites, again notably in the Central Zone, suggests that the mouldboard plough came into use during this period, although analysis of cattle bones suggests that it did not become widespread for some time. At no point during the period under study, however, does the pollen record suggest a 'spectacular clearing episode' of the kind sometimes posited, largely based on written sources (Williams 2000, 36; 2003). Although all regions saw some decline in tree and shrub pollen over time, no evidence was found for significant levels of deforestation (see Chapter 6). Indeed, not until the twelfth century did tree cover overall drop significantly below Roman levels.

The layout of farms and villages also changed markedly during phase C, notably in eastern and southern England, where the archaeological 'footprint' of settlements is clearest. The first complexes of ditched-and-banked enclosures since the Roman period appear, representing a variety of livestock enclosures. These are often associated with drove ways as well as timber structures (Blair 2018, 151–3; Hamerow, 67–119; McKerracher 2018, figs. 26–34). Their appearance suggests that livestock were being managed in new ways that required their movement to be carefully controlled, presumably because they were being kept closer to buildings and fields, at least at certain times of year. They may also reflect a need to sort and manage sheep, for example to collect ewes for milking and rams for castration. Enclosures would also have made it easier to collect manure.

Such settlement complexes—or 'semi-nucleations' (Blair 2018)—were irregular and bore little resemblance to the planned, compact 'nucleated' villages of tofts and crofts that emerged around the middle of the eleventh century (Creighton and Rippon 2017). Even so, some incorporated demarcated, regular plots, indicating a growing interest in clearly delineated holdings. At Quarrington in Lincolnshire, for example, three rectilinear east–west ditches were established, probably in the later seventh or eighth century, defining plots each around 23 m wide. The settlement appears to have gone out of use by the ninth century, although the remains of ridge and furrow indicate that later ploughing followed the same orientation as the earlier enclosures. While there is nothing to indicate that these early plots were actively maintained, it is evident that the 'general structure of the landscape' was established during the mid-seventh to mid-ninth centuries (Taylor 2003).

An interest in establishing and maintaining regular plots is also reflected in the layouts of Cottenham and West Fen Road, Ely, settlements in Cambridgeshire where the size of enclosures established during the seventh or eighth century remained remarkably consistent over time, suggesting a measure of control. The excavator of West Fen Road has suggested that 'the longevity of most of the enclosures suggests that individual farmsteads lay within them, possibly with the property passing from one generation to the next' (Mortimer *et al.* 2005, 129). It has also been argued that many settlements established in the seventh and eighth centuries (though not in the ninth) were laid out using a grid system based on a unit of measurement known as the 'short perch' (Blair *et al.* 2020). This new interest in regularity and defined holdings emerged at a time when 'stable control of property was being established in parallel with institutional structures for Christianity [and] methods of estate management were being developed; these developments were surely linked (Dyer 2020, 59). The construction of such complexes of ditched enclosures, which could be both extensive and long-lived, would have required co-ordination between households and ongoing cooperation in order to maintain and modify them. Keeping livestock closer to settlements would also have led to 'a closer integration of the livestock, now nearer to hand, with the arable' (Banham and Faith 2014, 274).

Written sources suggest that a form of infield–outfield cultivation preceded open fields and may have been associated with the semi-nucleations, with terms like *feldlandes* and *feldan dal* seemingly referring to 'arable shares ploughed up from open pasture' (Blair 2018, 334). Blair (2018, 294–301) has argued that the occasional cropping of areas within the outfield evolved over time into more regular, large-scale cultivation, eventually leading to the development of open fields. The weed data from infield–outfield systems of the kind Blair describes might be expected to separate out into two distinct groups reflecting the two different soil conditions involved: a high-fertility 'infield' group and a low-fertility 'outfield' group. None of the sites examined, including 'semi-nucleations' such as West Fen Road, Ely (Figure 3.2), produced such a pattern, however. Instead, the great majority of samples plot at the low-fertility, 'extensive' end of the axis, albeit with a 'tail' of samples reflecting somewhat higher fertility conditions. This does not, however, rule out the presence of infield–outfield systems; indeed, it would be difficult to distinguish the weed ecology of outfields from that found in open fields. Regional and other biases in our sample may also be partly responsible. It is likely, for example, that open field regimes involving the bulk processing and storage of harvests were inherently more likely to produce the dense archaeobotanical deposits required for analysis than the smaller-scale, more intensive practices that preceded and may have continued alongside such regimes.

Banham and Faith (2014, 68) note that the reorganization of landholding needed to lay out open fields would have been easier in regions where farms already lay close together. In the same way, the cooperation needed to lay out extensive ditched enclosures and drove ways would have laid the groundwork for households to cooperate in other ways. Unfortunately, late Saxon written sources such as the *Rectitudines singularum personarum* and *Gerefa* (Douglas and Greenaway 1996, *EHD* II, at 813–14) deal exclusively with 'vertical' relationships between landlords and those who worked the fields and tell us little about how farmers interacted with each other and went about their daily tasks (Banham and Faith 2014). Cooperating in the construction of a complex of paddocks and drove ways need not, of course, have translated into shared teams of oxen or agreed systems of crop rotation. It appears, however, that a significant step in this direction was taken during phase C.

During the same period, the settlements characteristic of the fifth to seventh centuries, with roughly equally sized residences and a farming strategy geared towards minimizing risk rather than maximizing output, began to be replaced by a more clearly differentiated settlement hierarchy (Hamerow 2012). This included settlements with the first centralized crop processing and storage facilities since the Roman period, including corn-drying kilns, malting ovens, barns, and watermills (Hamerow 2012, 151–5; McKerracher 2018). Such 'capital projects', built with the wealth generated by the cereal surpluses they were designed to process and store, had an obvious practical purpose but also represented an investment in future productivity. They were also—as in the Roman world—a form of display and a means of demonstrating ownership of a productive estate (Purcell 1995).

The innovations introduced during phase C, when considered together with the appearance of centralized grain storage and processing facilities and the first dense deposits of charred grain—all evidence for larger harvests, processed in bulk—point towards a new interest in surplus production, albeit at a relatively small proportion of sites. The potential drivers behind extensification, use of the mouldboard plough, and systematic rotation are considered below. One possible factor, however, is an emerging market for grain, above all, for wheat. Such a market was well-established by the eleventh century to judge from a reference in the Anglo-Saxon Chronicle to a famine in 1044, when the price of corn was ‘so dear as no man remembered before’ and a ‘sester of wheat went up to 60 pence and even further’ (ASC E, Laud Chronicle, Garmonsway ed./transl. 1972). It may, however, have emerged significantly earlier, in the age of the trading ports known as *emporia*, which peaked in the first half of the eighth century. The last decades of the seventh century and first decades of the eighth also saw the emergence and circulation on a large scale of the first silver—that is, comparatively low-value—coins since the Roman period, the first mass-produced pottery, and the appearance of production sites for commodities such as iron, salt, and malt, all of which point to thriving mercantile activity (Blair 2018, 253–6; Clarke 2023; Faulkner and Blakelock 2020; Hardy *et al.* 2007; Naismith 2025; Newton and Summers 2023). A market for grain was well-established in the Frankish world in the eighth century, as recorded at the Council of Frankfurt in 794, when one penny bought twelve loaves of wheat bread, fifteen loaves of rye, twenty of barley, and twenty-five of oat (Loyn and Percival 1975); such a market may have emerged in England around the same time.

Farmers and lords (FeedSax phase D: c.880–1030)

Cattle bones and arable weeds suggest that the use of the mouldboard plough first became relatively widespread during phase D, broadly spanning the late ninth to mid-eleventh centuries, implying that heavier soils were increasingly being cultivated. Systematic rotation was also more widely practised than in phase C, as seen in the crop stable isotope data (Figure 4.20). The pollen record indicates that the emphasis on arable land use reached a peak around the eighth and ninth centuries, which was maintained during the tenth and eleventh (Figure 6.3). Regional patterning in crop preferences emerged more clearly in phase D, with oat and rye, for example, becoming particularly prominent in the Western Lowlands and barley in the Fens (Figures 7.3–7.5; see Appendix 4 for a full discussion of regional patterning in crop preferences). This suggests that cropping choices were being increasingly calibrated to local conditions in order to optimize productivity. While these regional trends become more pronounced in phase D, it should be observed that some may have originated as early as the seventh century (McKerracher 2019).

Phase D also saw the Central Zone emerge as a clear ‘hot spot’ for wheat cultivation (Appendix 4, Figure A4.9) as well as the introduction into England of rivet wheat (*Triticum turgidum*; Roushannafas and McKerracher 2023). The long growing season required by rivet wheat means that it would most likely have been an autumn-sown crop, allowing a different crop to be sown in the spring. Its introduction into a rotation would thus have had the advantage of spreading the workload of the harvest over a

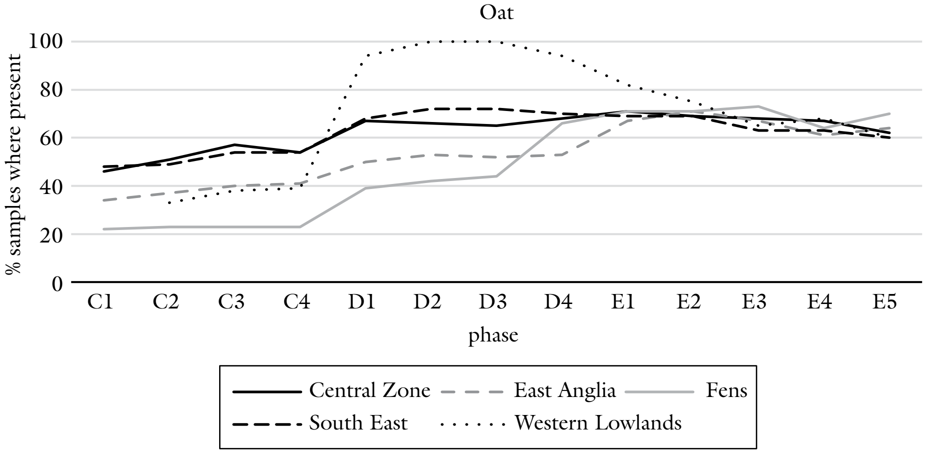

FIGURE 7.3. Frequency of oat over time, for regions with sufficient data (see Appendix 4).

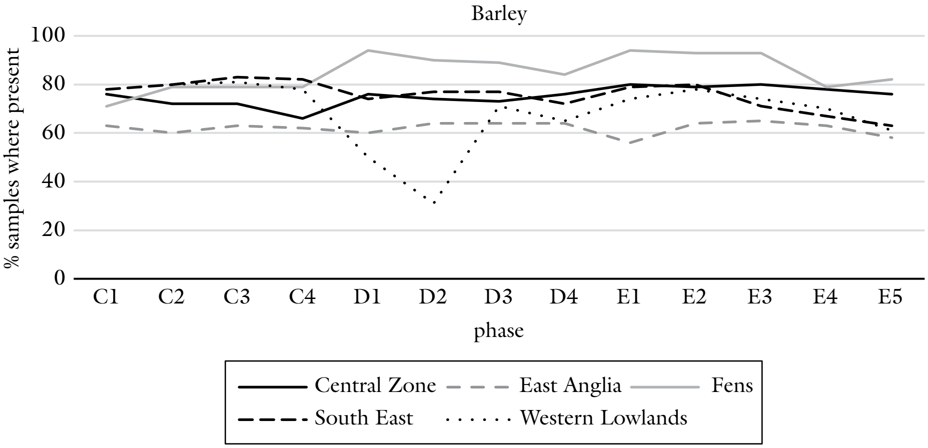

FIGURE 7.4. Frequency of barley over time, for regions with sufficient data (see Appendix 4).

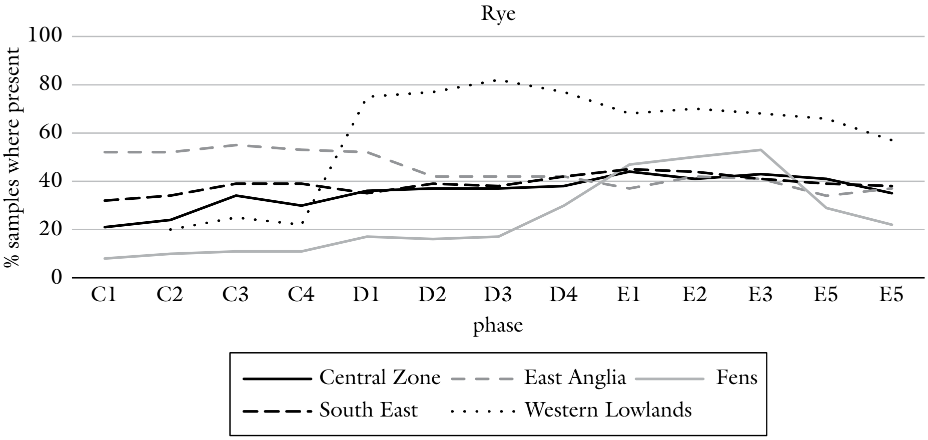

FIGURE 7.5. Frequency of rye over time, for regions with sufficient data (see Appendix 4).

longer period and reducing the risk of crop failure. It is also somewhat more resistant than bread wheat to both disease and birds, which perhaps made it attractive as an 'insurance' crop—a buffer against the failure of bread wheat harvests (Moffett 2006, 48, Table 4.3).

The appearance of the first 'proto-manorial' complexes also dates to this period. These are characterized by distinctive forms of aristocratic architecture—'angle-sided' and aisled halls—and belong to what Blair (2018, 311–17) has described as a mid-tenth-century 'watershed' characterized by an expansion of markets and towns. This period also witnessed an increasingly asymmetric wealth distribution, as Wickham calls the 'feudal mode' began to replace peasant-dominated modes of production, although small producers remained important throughout this period (Naismith 2025, 44; Wickham 2005, 349–50). In addition to halls, 'proto-manorial' complexes included special-purpose structures such as kitchens, latrines, towers, and private churches, as seen at Raunds (Northants), Goltho (Lincs), Faccombe Netherton, Portchester (Hants), and Bishopstone (Audouy and Chapman 2009; Beresford 1987; Cunliffe 1975; Fairbrother 1990; Hamerow 2022, 19; Thomas 2010). Such complexes have been characterized as 'thegnly' and associated with the development of local lordship. Some, however, could equally have been the residences of 'upwardly mobile' *ceorlas*, free peasants who had acquired enough land to prosper from markets in wool and cereals, and fund ostentatious lifestyles (Blair 2015, 192; Fleming 2011; Reynolds 1999, 124–35). Their appearance is likely to relate to the breaking up of sprawling landholdings managed by means of relatively light-touch demands on peasants for renders in kind ('extensive lordship') into smaller estates, intensively exploited by local landowners who demanded more onerous rents and services (Faith 1997, 56–88; Williamson 2013, 25–6). Enough of these 'proto-manorial' complexes have been excavated to suggest a concentration in the Central Zone. The 'semi-nucleations' established in phase C also continued into this period, although the timber structures associated with them became more ephemeral and amorphous (Blair 2015, 283–5). Outside of the Central Zone, evidence for ordinary farms of this period is remarkably scarce, perhaps signalling a shift to less archaeologically visible architectural forms (Blair 2018, 328). Thus, the cereal surpluses stored and processed at Stafford between the ninth and eleventh centuries provide some of the best archaeobotanical evidence available for this period, but where and how the farmers who produced these surpluses lived remains largely a mystery (Hamerow *et al.* 2020).

The bioarchaeological evidence thus indicates that the overall scale of cereal farming increased in phase D, alongside a growing emphasis on surplus production. It is far from clear, however, where surplus grain was stored, as storage features are rarely identified in excavated settlements. Indeed, direct evidence for grain storage is virtually non-existent in England during the fifth to seventh centuries, appearing in the eighth, but remaining scarce until the eleventh and twelfth centuries (Gardiner 2013; McKerracher 2018, 70–80). A market for large ceramic vessels did emerge, however, during the late ninth and tenth centuries. Some of these vessels could have been manufactured and marketed to meet a new need to store grain (and perhaps other foodstuffs) that was fully processed and ready for consumption. Thetford-type and Stamford Ware jars provide the earliest evidence for these large vessels, which were capable of holding up to 17 litres and are best interpreted as stationary storage vessels, given their thin walls and considerable weight when full (Giertz 2000; M. Mellor pers. com. 2024). Some were clearly imitations of Carolingian products (*e.g.* 'Reliefband' amphorae) and may initially have been manufactured by Frankish potters 'transplanted' to England by Viking raiders (Giertz 1996, 2000). Such large, ostentatiously decorated vessels may in this way represent a materialization of surplus production (Figure 7.6).

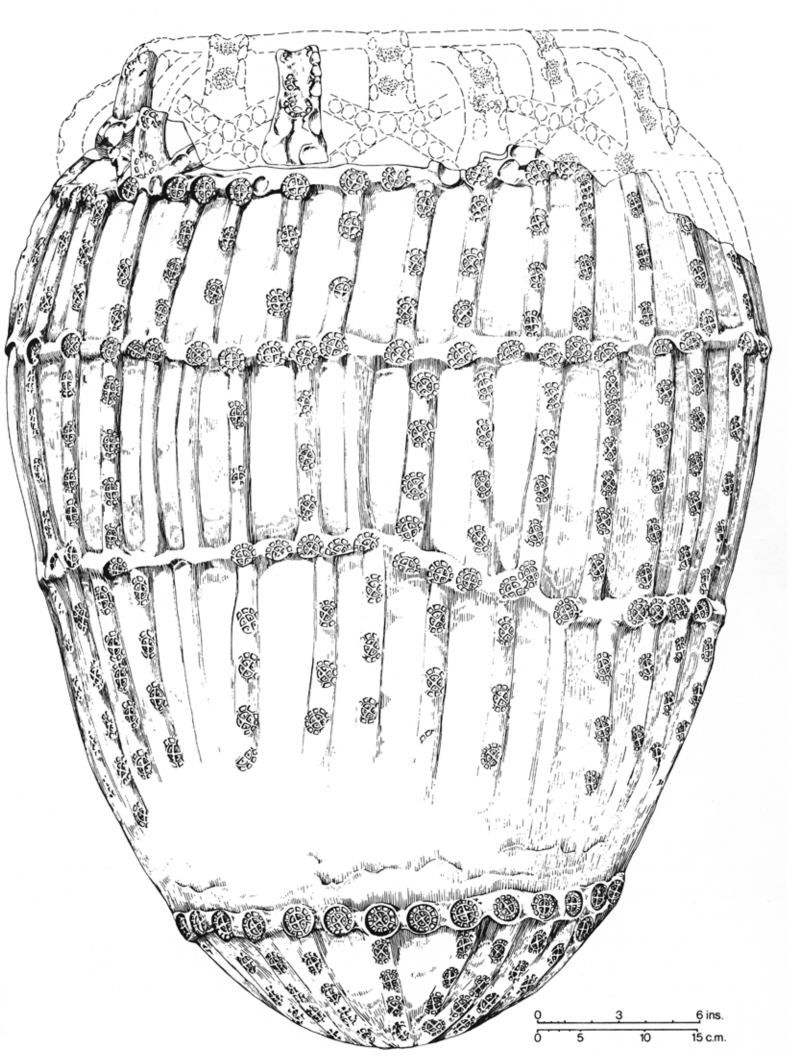

FIGURE 7.6. Thetford-type Ware storage vessel (after Wilson 1976, fig. 7.16).

The mouldboard plough package and the nucleated village (FeedSax phase E: c.1030–1220)

The most striking innovation in settlement form seen in the whole of our period is the nucleated village, whose impact on the landscape, particularly of the Central Zone, has been described as 'weightier and more permanent than any since the Roman occupation' (Blair 2018, 414). By the time such villages first appeared around the middle of the eleventh century, the different elements of the mouldboard plough package were well-established, although it was not until phase E that systematic rotation and use of the mouldboard plough became truly widespread, the former potentially being linked to the development of regular open-field systems (*cf.* Williamson *et al.* 2013). As already observed, the archaeobotanical record suggests that bulk cereal processing also became both regular and widespread in phase E, particularly in the Central Zone (see above, Figures 7.1 and 7.2). It seems likely that the innovations associated with the mouldboard plough package had by now become sufficiently widespread in some regions—above all the Central and Eastern Zones—to reach a critical mass, so that 'further diffusion [became] self-sustaining' (Rogers 2003, 343). After this point, communities that failed to adopt the mouldboard plough package may have found themselves at an economic, and potentially social, disadvantage. Evidence for true innovation in farming during phase E is, however, limited; instead, what we see appears to mark an escalation of earlier trends. Nevertheless, the marked increase in phase E of very rich archaeobotanical deposits (Figure 7.2) is likely to reflect a significant scaling-up of cereal production as the elements of the mouldboard plough package became inter-operational and the expansion of markets and urban populations provided further incentives to optimize outputs.

A number of explanations have been advanced for the formation of nucleated villages, variously emphasizing economic, administrative, social, and environmental factors (summarized by Jones and Page 2006, 80–3; see also Rippon 2008, 1–22). While it seems unlikely that the establishment of nucleated villages was directly linked to the spread of the 'package' given the piecemeal progress of the latter, Blair (2018, 410) sees it as 'closely connected . . . with the slow but steady advance of open-field agriculture', with the 'immediate pressures' of the period from *c.*1050 to 1150 providing a catalyst (*cf.* Williamson 2022, 219). The growing evidence that nucleated 'toft and croft' villages were sometimes inserted into pre-existing open-field systems (Blair 2018, 329–36; 408–15; Creighton and Rippon 2017; Jones and Page 2006) indicates that the establishment of the village could have represented a secondary stage following on from the development of a field system over a much longer period, as argued by Faith (1997, 235).[3] Whether nucleated villages in some sense 'evolved'

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[3] Evidence from Belgium indicates that there, too, row villages were 'planted' within open-field systems by the Count of Flanders (Verbrugghe and de Clercq 2022).

from the less regular semi-nucleations remains unclear. The archaeological evidence for the traditional model that sees the abandonment of small, scattered hamlets and their replacement by larger, planned villages as part of a process directed 'from above' is relatively scant. It has recently been challenged by a 'growth and fusion' model, which sees villages developing more organically, as house plots were added within a pre-existing framework provided by underlying open-field strips (Williamson 2018, 12–15; Williamson *et al.* 2013). The evidence generated by the present study cannot shed new light on the question of planning *per se*, or when the intermingled strips characteristic of the fully developed, regular open-field systems first appeared. It does, however, support the view that nucleation was more closely linked to new, more systematic methods of surplus extraction than to a certain type of cultivation regime.

THE SPREAD OF THE MOULDBOARD PLOUGH PACKAGE: BOTTOM-UP OR TOP-DOWN

As one historian has observed concerning the written sources for medieval England, 'we are never going to have much more than scraps of information about peasant farming' (Stone 2005, 262). Yet most cereals were grown on peasant land. One advantage of the bioarchaeological evidence used in this study, therefore, is that most of it is likely to derive from peasant holdings. Written sources, in contrast, mostly document what happened on demesne land which was presumably better resourced, although analysis of peasant productivity in the late Middle Ages suggests that this need not have translated into higher yields (Naismith 2025, n. 58; Stone 2005, 262–72). Archaeology therefore has an important contribution to make to the long-standing debate regarding whether the changes seen in farming during this period were co-ordinated by local lords—proprietors of the 'proto manors' described above—or whether 'bottom-up' peasant initiative was equally or more important (Dyer 1985; Williamson 2013, 124).

The archaeobotanical evidence indicates that the shift to extensive, low-input cultivation regimes, along with the shift to bread wheat, took place too early and was too widespread to be anything other than a reflection of 'bottom-up' processes and decisions taken by peasant farmers (*cf.* McKerracher 2020). It also suggests that the mouldboard plough and systematic rotation were, like watermills and malting ovens, innovations introduced by, and initially restricted to, a small number of royal and monastic 'hubs' which also served as a locus for commercial exchanges (Naismith 2025). In agriculture, as in so many things, monasteries appear to have served as agents of change from the middle decades of the seventh century (Blair 2018, 176). The wider reach of these new technologies during phase D may mark a transition to the 'seigneurial' farming regimes reflected in contemporary documents, for example, in the list of services owed by peasants to lords contained in the late tenth- or early eleventh-century document known as the *Rectitudines Singularum Personarum* (Douglas and Greenaway 1996, *EHD*, 813–14). It is, however, also likely to reflect prosperous peasants who held their own land—*ceorlas*—availing themselves of these new, more productive methods. Indeed, it may have been the possibility of ‘upward mobility’, reflected in another early eleventh-century document, *Geþyncðo*, sometimes known as the ‘promotion law’ (Runciman 1984, 104; Whitelock 1955, *EHD* I, no. 52 at 432), that encouraged more enterprising farmers to adopt the mouldboard plough package as a route to prosperity and thegnly status. One way in which a *ceorl* could attain such status was by undertaking costly building projects such as the construction of a ‘*burhgeat*’—an elaborate gateway into a fortified homestead—presumably paid for, at least in part, by the sale of agricultural surpluses.

It is intriguing to note that both the ‘draught cattle’ signature, indicative of the regular use of the mouldboard plough and dedicated plough teams, and grain-rich samples, indicative of bulk cereal processing, follow similar chronological trajectories: in both cases, phase C is characterized by a small number of ‘pioneer’ sites of high status with strong bioarchaeological signatures for both practices, which may have been ways of signalling technological sophistication and links to the Carolingian world. Phase D sees a wider distribution of these practices, but a weaker bioarchaeological signal. Phase E is characterized by both widespread distribution and strong bioarchaeological signals. A possible model to explain this pattern is that in phase C, a small number of communities associated with high-status centres regularly used a mouldboard plough pulled by dedicated draught animals and processed and stored harvests in bulk, whereas in phase D, a wider range of communities used the plough and processed cereals in bulk, but in a less regular manner. In phase E, the use of the mouldboard plough and the centralized bulk processing of cereals became both regular and widespread.

The late ninth and tenth centuries appear in this way to have seen the beginning of community-to-community transmission of the mouldboard plough package. The evidence suggests that some households continued to do things differently, however. The persistence of ‘low disturbance’ weeds at many sites suggests continuing use of the ard by some farmers even where ‘high disturbance’ weeds indicate that the mouldboard plough was predominant. Similarly, even as the increasing uniformity of stable isotope values over time indicates that systematic crop rotation was increasingly common, a diversity of practice is apparent at the level of the individual site.

REGIONAL PATTERNS: HOW DISTINCTIVE WAS THE CENTRAL ZONE?

The prominence of the Central Zone as a source of charred plant remains and animal bones is in part explained by its sheer size relative to other regions and the fact that it contains a correspondingly large number of extensively excavated settlements (Figure 7.7; Chapter 2; Blair 2018, fig. 4).

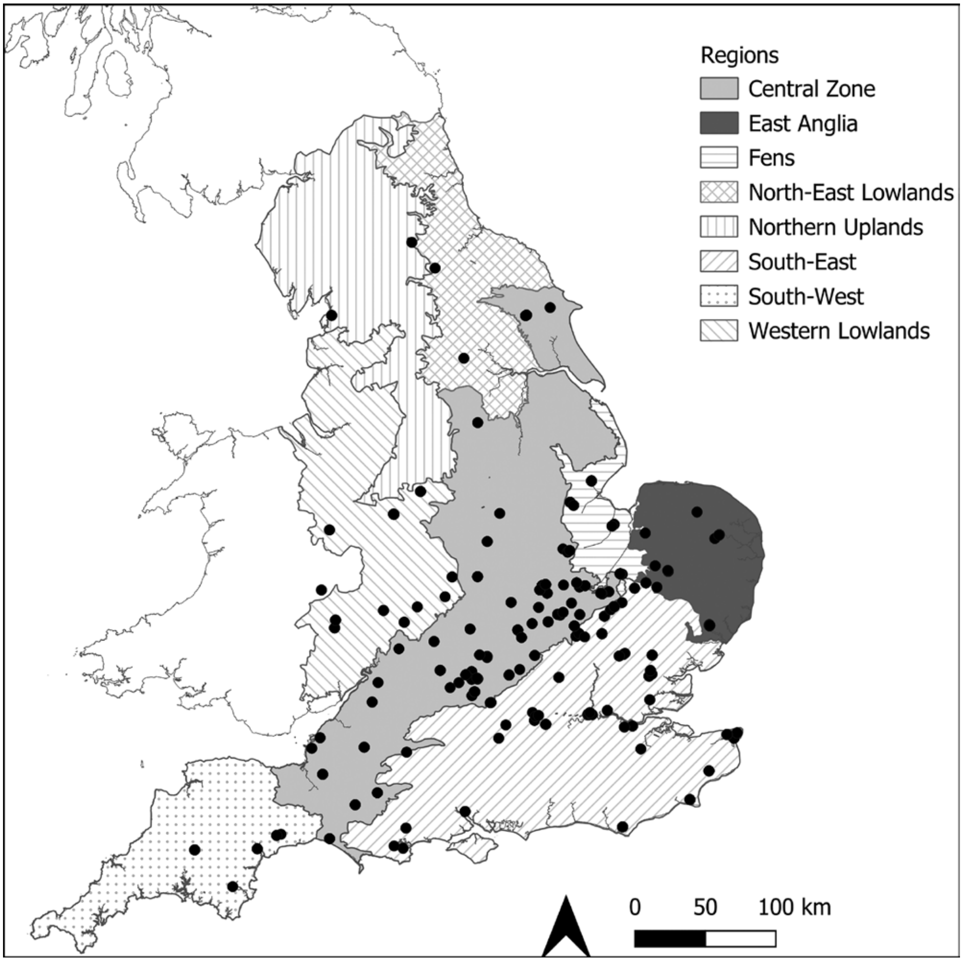

FIGURE 7.7. Distribution of sites producing samples with ≥30 free-threshing cereal grains identified to genus/species level (see Appendix 3).

There may, however, be other factors at play. Arable farming in the Midlands region of England, a core part of the Central Zone, has long been argued to have emerged as distinctively arable from as early as the eighth century (Hall 2014, 195; Roberts and Wrathmell 2002). A counter-argument, however, is that the region referred to by Roberts and Wrathmell (2002) as the 'Central Province' only emerged as distinctive in terms of settlement form and cultivation regime between the mid-tenth and twelfth centuries, with the development of the 'Midland System' of open-field farming, in which individual holdings took the form of intermingled strips (Blair 2018, 412–15; Williamson 2013). The analyses of animal bones, plant remains, and pollen presented in the preceding chapters provide a novel means of investigating this question and the supposed distinctiveness of the Central Zone as an 'early adopter' of the mouldboard plough package.

In Chapter 3, the relative proportion of sheep to cattle bones was used as a proxy for the degree to which farming was focused on arable production. This showed that approximate parity between the two species was reached earlier in the Central Zone (*c*.700–750) than in other regions for which data are available, although East Anglia was not far behind (Figure 3.33). The pollen record for the Central Zone is relatively sparse and should be treated with caution, but it too suggests a strong arable emphasis at an early date, from the sixth/seventh century, although again, arguably no earlier than in East Anglia (Figure 6.4). While arboreal pollen declines in all regions over time, it decreases sharply at some sites in the Central Zone during the tenth and eleventh centuries, suggesting an expansion of arable at the expense of trees and shrubs and potentially the removal of hedges, although more pollen records would be needed to confirm this as a regional pattern (Figure 6.4).

Another distinctive feature of the Central Zone is the importance of wheat, which features more prominently in cropping patterns there than in any other region. While regional preferences can be discerned for other crops, the link between wheat and the Central Zone stands out (Appendix 4, Figure A4.9). Indeed, samples from the region contain such a high percentage of wheat grains that the Central Zone might reasonably be called the 'wheat belt'. This predominance of wheat is apparent by phase D at the latest and becomes particularly marked during phase E. While the 'wheat belt' largely corresponds to areas of heavy soils, wheat is also practically ubiquitous in samples from other regions, notably the South East and East Anglia. Nevertheless, the cultivation of wheat appears to have been most significant in the Central Zone.

Very rich archaeobotanical samples are also disproportionally well-represented in the Central Zone, particularly in phase E, suggesting that the bulk processing and storage of grain were more regular occurrences in this region than elsewhere (Table 7.1 and Figure 7.8). It should be noted, however, that such deposits appear to be under-represented in East Anglia relative to their representation in the total dataset; given the region's strong arable focus, this requires explanation. The set of samples available contains little from sites on the fertile soils of central East Anglia and may therefore not be representative of the region as a whole.[4] Conversely, dense samples appear to be somewhat over-represented for the more wooded, pastorally focused South East (Table 7.1), perhaps because of a cluster of sites near the border with the Central Zone and the impact of a few 'hot spots' such as the high-status sites of Lyminge and Bishopstone. It therefore appears likely that practices associated with the bulk processing and hence charring of crops were carried out with the greatest regularity in the Central Zone and, unsurprisingly, were least likely to occur in the seasonally waterlogged Fens (Table 7.1 and Figure 7.8).[5]

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[4] The rich archaeobotanical assemblage from the malting complex at Sedgeford in North Norfolk could not be included as it had not been fully recorded at the time the FeedSax project was underway (Caroe 2022a, 2022b; Faulkner 2022).

[5] The Western Lowlands have been excluded from these calculations because the region is represented by only twenty-five samples; given how much smaller this sample set is compared to other regions, it was deemed inappropriate for interregional comparison.

TABLE 7.1. Distribution of rich samples by region and average density threshold, excluding 98 samples from 'hotspots' at Ipswich and West Cotton.

Region	# Samples	% Samples	
		≥30 Items per litre	≥100 Items per litre
Central Zone	138	47.1	18.1
East Anglia	94	21.3	8.5
Fens	74	25.7	5.4
South East	171	35.1	15.2
Total	*502*		

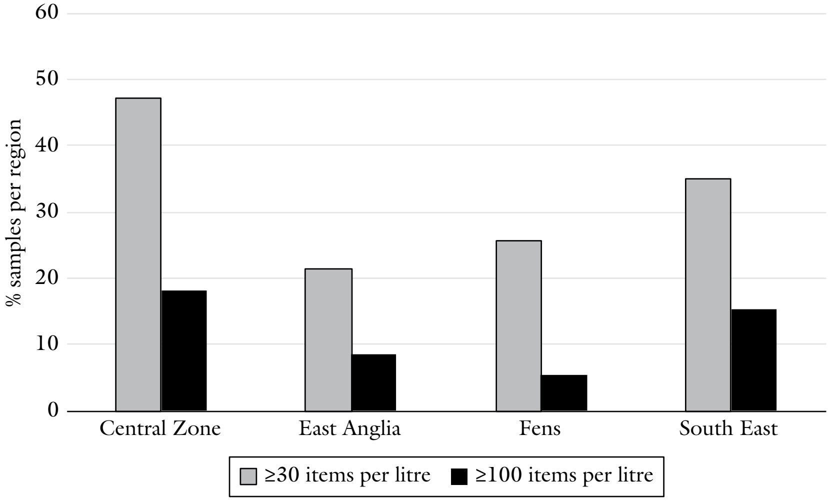

FIGURE 7.8. Distribution of rich samples by region and average density threshold, excluding ninety-eight samples from 'hotspots' at Ipswich and West Cotton.

DRIVERS OF CHANGE

Monocausal explanations are insufficient to account for England's emergence from its period of post-Roman 'abatement' in cereal farming are clearly inadequate. Technological innovation, traditionally seen as the catalyst for the 'agricultural revolution', was nevertheless undeniably important. The evidence set out in the preceding chapters demonstrates, however, that the separate elements of the mouldboard plough package were present in England long before they became widespread and were first documented. Systematic crop rotation and the mouldboard plough were not widely taken up for several centuries after they were first introduced. The gains in overall yields recorded for the twelfth and thirteenth centuries were not, furthermore, primarily achieved by boosting fertility through intensive manuring. Rather, they reflect a major expansion of arable made possible by increasingly extensive cultivation regimes in which low input was coupled with high disturbance. The changes in agricultural practice seen in this period thus took diverse forms, with diverse causes and outcomes.

Significant demographic shifts should also be considered as potential drivers of change, and it has recently been argued that the plague that affected England between 664 and 687 played a role in ending the period of 'abatement' (Naismith 2025). According to Naismith, a reduced workforce coupled with a greater availability of arable land would have encouraged survivors towards more land-extensive cultivation regimes. The ready availability of farmland may also have encouraged the production of larger, more regular agricultural surpluses that could be sold at the marketplace. The sheer number and spread of early silver pennies (Naismith 2025, Map 1) indicate that prosperous peasants as well as elites participated in these transactions, even if the infrastructure associated with surplus production—watermills, malting ovens, barns, etc.—tends to be associated with high-status sites.

Conversely, population *growth* is widely regarded as a key driver of change with regard to field systems and settlement patterns during the tenth to twelfth centuries. While acknowledging the difficulties of demonstrating such growth, Blair observes that 'it is hard to make sense of the period without hypothesizing a rising demographic trajectory, gaining momentum during *c*.900–1050 and continuing through *c*.1050–1200' (Blair 2018, 316). Such evidence as there is for population growth comes largely from written sources, although to this can now be added a meta-analysis of radiocarbon dates from England, used as a proxy for demographic growth and decline (Bevan *et al.* 2017). The results of this analysis suggest a gradual increase in overall population from the fifth century onwards, followed by an 'abrupt decline' around the fourteenth century. The study also indicates, surprisingly, that a peak was reached around the eighth century and that a drop-off began soon after 1000, although these results lack the resolution needed to pinpoint these chronological shifts more precisely and should be treated with caution (Bevan *et al.* 2017, fig. 2). While the evidence generated by our study can shed little new light on demographic trends *per se*, the early appearance but slow take-up of systematic crop rotation and the mouldboard plough suggest that, while the rate of population growth was not uniform across the whole period, more rapid growth from around the year 1000 was a critical factor in encouraging these no-longer-new technologies to be widely taken up. An intensification of sea-fishing (known as 'the fish event horizon') and chicken rearing took place around the same time and could also have been linked to this growth (Barrett *et al.* 2004; Loog *et al.* 2017). Estimated variations in population densities based on Domesday Book (Green and Cresswell 2021, 39) broadly correlate with the regional patterns seen in the pollen record, with the arable/pastoral index for East Anglia and the Central Zone, both regions with high population densities in 1086, indicating a particularly strong arable emphasis (see Figure 6.4).

Local lordship is another factor that would have encouraged the spread of the mouldboard plough package and an increasing emphasis on surplus production, although some have argued that its impact on fields and farming systems prior to the Norman Conquest was relatively limited (Faith 2008; Williamson 2018, 2022). Williamson (2018) argues, furthermore, that it is unnecessary to invoke lordly intervention to explain the appearance of open fields and nucleated villages. It is nevertheless reasonable to suppose that, in certain regions, the adoption of the mouldboard plough and systematic rotation would have been promoted by landowners seeking to maximize marketable surpluses. Our evidence from phases D and E is consistent with a scenario in which local lordship encouraged changes in farming practices from the tenth century onwards. There is, however, no reason to think that the bioarchaeological materials analysed came primarily from the lands of such lords, and so this cannot be the whole answer. Halstead (2009, 70) has argued that even without elite demand and systematic surplus extraction, subsistence farmers will seek to produce a modest surplus as 'a normal response to the risk of scarcity' and naturally 'tend to cultivate an area large enough to ensure the food supply in a season of poor yields'. He refers to this as a 'normal surplus'. While local lordship presumably provided a stimulus for the increased emphasis on surplus production seen in phase D, it was not the primary driver of agricultural change; there must have been surpluses in the first place for elites to appropriate and mobilize. Technological capacity, perhaps combined with favourable environmental conditions, was the prerequisite to increasing the scale and regularity of surplus cereal production.

Such favourable conditions arrived with a period of warmer, drier conditions in northern Europe known as the 'medieval climate anomaly' (MCA) and presumably played a role in increasing overall cereal outputs between *c.*1000 and 1300 (Büntgen and Tegel 2011; Dyer 2002; Rohr *et al.* 2018; Xoplacki *et al.* 2011). The precise impact on England of the MCA in terms of temperature and precipitation remains poorly understood, however, and the apparently limited impact of the Late Antique Little Ice Age on land use in lowland Britain (see Chapter 6) should caution us against making assumptions about the role of climate change in this period. Nevertheless, it seems likely that the improved conditions made it easier for farmers to produce larger surpluses with greater regularity, making cereals a more reliable route to prosperity, particularly in regions that had previously been less well suited for cereal cultivation. The pollen record for the Northern Uplands, for example, suggests a marked increase in the scale and intensity of agricultural land use (ALUSS) from around the year 1000, perhaps as a result of more favourable climatic conditions, although a similar trend could not be recognized for other regions (see Figure 6.4). The pollen record does not, furthermore, provide evidence of a more widespread expansion onto 'marginal' lands during this period, whether due to climatic improvements or for other reasons. Another possible response to the warmer conditions was the cultivation of new cereal varieties; the introduction of rivet wheat into England around the onset of the MCA may well be an example of this (see above). Similarly, as noted in Chapter 4, the practice of autumn sowing appears to have become more widespread from the tenth century onwards and so—along with systematic rotation—could plausibly be linked to the onset of more favourable climatic conditions.

The relationship between the spread of the 'mouldboard plough package' and the revival of regional and long-distance trade must also be considered. The shift to more extensive cultivation regimes and the introduction of systematic rotation as well as the mouldboard plough date broadly to the period when England's first international trading ports, known as emporia, were established, with London, Ipswich, and Hamwic (Saxon Southampton) being the largest and most intensively studied examples. Two competing models have been proposed to explain the relationship between a reorganization of farming and the appearance of the emporia. Blinkhorn (2012, 91) has suggested that the changes in farming indicated by the appearance of livestock enclosures and a shift to heavier soils were driven by the need to support 'a system for the large-scale production of material for trade, particularly food'. An alternative, 'farming first' argument sees rural production as ultimately driving the economic transformations of this period (Moreland 2000, 97): 'We can show that the emergence of the emporia was intimately connected with intensified production in the English countryside. More precise dating…might allow us to go further and argue that the emporia were in fact a product of this transformation in production'. The more precise dating evidence presented here appears to bear out this contention. It points to significant changes in farming strategies beginning in the seventh century and continuing through the ninth: widespread changes in soil fertility together with the more frequent appearance of cornflower in the pollen record suggest bottom-up change, while archaeological evidence, in particular the construction of agricultural infrastructure such as watermills, corn drying kilns, and barns, points to agricultural innovations emanating from high-status centres at around the same time. Evidence of extensification is, however, not restricted to the hinterlands of the emporia or to those parts of the country where people regularly used coinage and were able to purchase mass-produced commodities such as Ipswich Ware. The fact that the mouldboard plough and systematic crop rotation first became widespread during the tenth and eleventh centuries, becoming nearly ubiquitous in some regions from the mid-eleventh, suggests that the incentives to produce marketable surpluses and the need to feed a growing population were key factors in the production of larger harvests.

CONCLUSION: A LONG 'AGRICULTURAL REVOLUTION'

The concept of a medieval 'agricultural revolution' driven by technological innovation was challenged soon after it was first proposed (Hilton and Sawyer 1963; see Chapter 1). Even the early modern 'agricultural revolution' now appears less revolutionary than it once did and some of the improvements traditionally associated with that period are now known to have had medieval origins (Becket 1990; Thomas 2005b; Thomas *et al.* 2013). The extent to which the evidence presented in this volume supports the notion of a medieval 'agricultural revolution' depends, of course, on how such a revolution is defined. This study has found little evidence of a 'great leap forward' impelled by technological innovation. Nevertheless, several centuries of incremental changes and improvements, occasionally punctuated by more abrupt shifts, had a cumulative impact that might reasonably be described as revolutionary. The results presented in the preceding chapters reveal how separate innovations in the farming system came together over the course of several centuries to 'co-occur as a complex' (van der Veen 2010, 1; *cf.* Banham and Faith 2014, 295; Dyer 1997). These improvements, which first appeared during the 'long eighth century', converged around the end of the first millennium to have a transformative impact, not only on agricultural production but also on the material worlds of farmers and consumers. In some places, new cultivation regimes, along with new pressures and incentives to produce substantial, regular surpluses, reshaped daily life. The results also show that even after new technologies were available, most farmers, whether by choice or through lack of opportunity, did not initially adopt them. The availability of such technologies was not in itself enough to change behaviour. Other factors such as the cost and availability of labour and land, environmental factors, community structures, market conditions, and perhaps local tradition must have been paramount.

Although the developments referred to here as the 'mouldboard plough package' spread in a piecemeal fashion, it is important to remember that decisions taken by households or communities to adopt them may nevertheless have represented radical new departures to those concerned. Introducing a new crop or rotation would represent a simple innovation that could be easily taken up, trialled, and rejected if unsuccessful.[6] However, once farmers had invested in a mouldboard plough, torn up the hedges surrounding their fields, and amalgamated their arable, there was no easy way back; these were decisions that, for the households involved, were largely irreversible in a way that the introduction of a new crop or of seasonal sowing was not.

Our use of a range of proxies to investigate medieval farming was only possible thanks to the vast amount of archaeological and bioarchaeological materials unearthed by development-led excavations in recent decades and to the development of science-based techniques with which to interrogate them. Of course, such material by itself cannot tell us whether the fields that produced the crops and livestock whose remains we analysed were enclosed or open, farmed in strips, or associated with a particular form of landholding. Its geographical distribution is also uneven and some periods are less well-represented than others. An even larger, better-preserved, more evenly

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[6] See Stone (2005) for examples of adaptable decision-making by farmers in the fourteenth century, especially in relation to cropping and manuring strategies.

distributed dataset would of course yield a more complete and more detailed picture of farming and land use. Even such a dataset, however, would lack the fine-grained resolution provided by the written sources for individual manors, which disclose farm-by-farm and year-by-year variability (*e.g.* Stone 2005; Titow 1972). Nevertheless, the sheer abundance of the archaeological data now available has enabled broad chronological and regional trends in farming to be discerned for the first time, demonstrating the power of the approach taken here to generate new evidence, new answers, and new questions.

Feeding Medieval England: A Long 'Agricultural Revolution', 700–1300. Helena Hamerow, Mark McKerracher, Amy Bogaard, Mike Charles, Emily Forster, Matilda Holmes, Christopher Bronk Ramsey, Elizabeth Stroud, and Richard Thomas, Oxford University Press.
DOI: 10.1093/9780191988905.003.0007

APPENDIX 1

Soil Maps for Case Study Sites

Maps showing major soil types in the vicinity of case study sites for which crop stable isotope data are available. Mapping derived from soils data, Cranfield University (NSRI) and for the Controller of HMSO (2012); Land Information System (2013). Scale: 1:60,000.

🟨	Shallow clay
🟨	Clayey
🟧	Deep clay
🟫	Shallow silty
🟫	Silty
🟫	Deep silty
🟫	Deep red loam to clay
🟫	Deep loam to clay
🟧	Shallow loam
🟫	Loam
🟫	Deep loam
🟥	Deep red loam
🟫	Stony loam
🟨	Stony sandy
⬜	Dune sand
⬜	Sandy
⬜	Deep sandy
⬜	Non soil

🟫	Seasonally wet deep peat to loam
🟪	Seasonally wet deep red clay
🟦	Seasonally wet deep clay
🟦	Seasonally wet silty to clayey
🟩	Seasonally wet deep silty to clay
🟦	Seasonally wet deep red silty
🟦	Seasonally wet deep silty
🟪	Seasonally wet loam to clayey
🟪	Seasonally wet deep loam to clay
🟪	Seasonally wet loam
🟦	Seasonally wet deep loam
🟥	Seasonally wet deep red loam
🟪	Seasonally wet deep red loam to clay
🟪	Seasonally wet deep sand
🟪	Seasonally wet deep sand
⬛	Peat
⬜	Water

FIGURE A1.1. Key to soil maps.

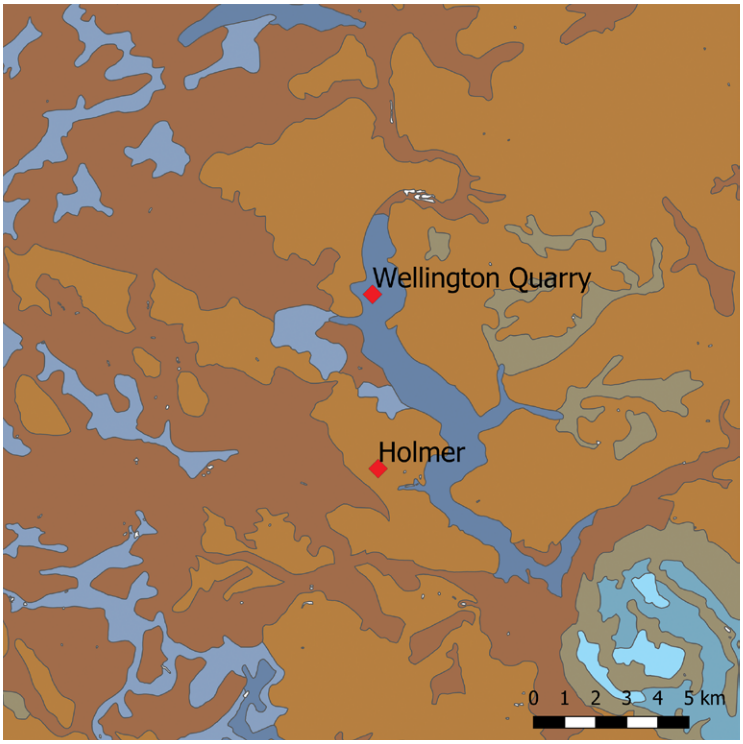

FIGURE A1.2. Soil map for Holmer and Wellington Quarry, Herefordshire.

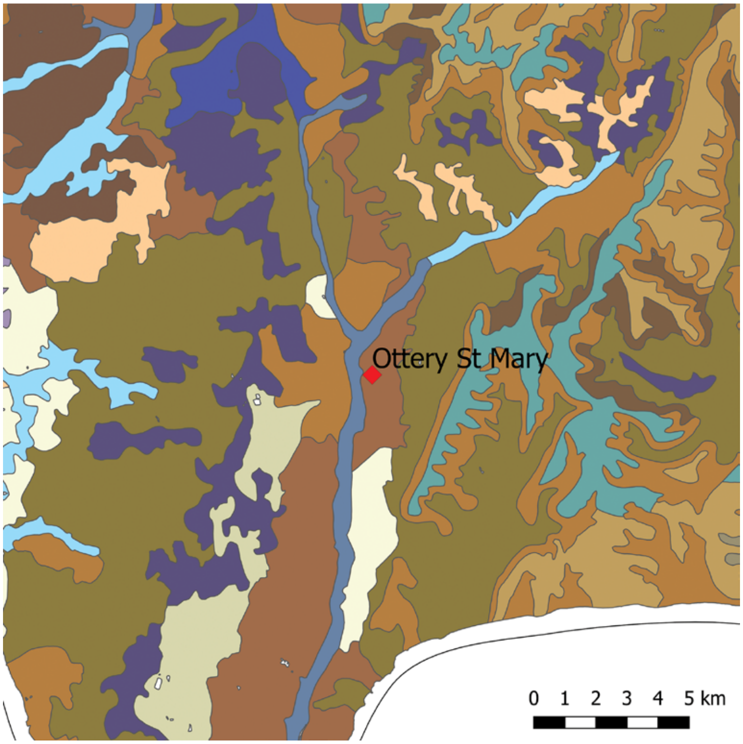

FIGURE A1.3. Soil map for Ottery St Mary, Devon.

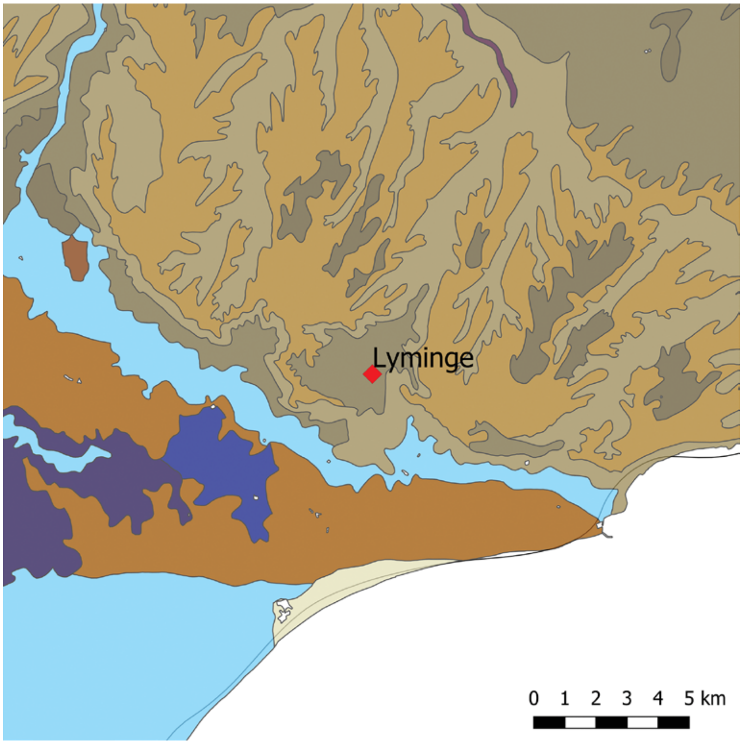

Figure A1.4. Soil map for Lyminge, Kent.

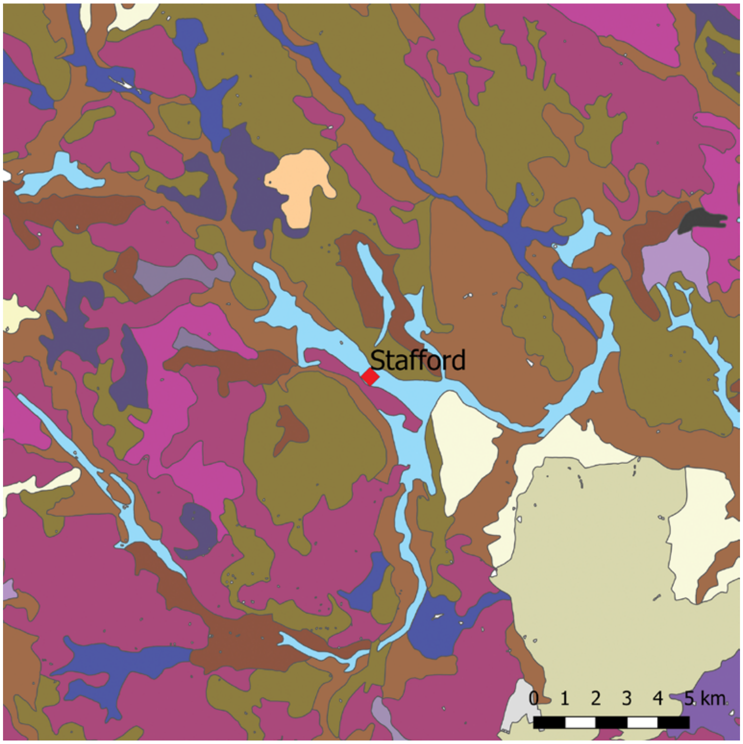

Figure A1.5. Soil map for Stafford, Staffordshire.

FIGURE A1.6. Soil map for Houghton, Cambridgeshire.

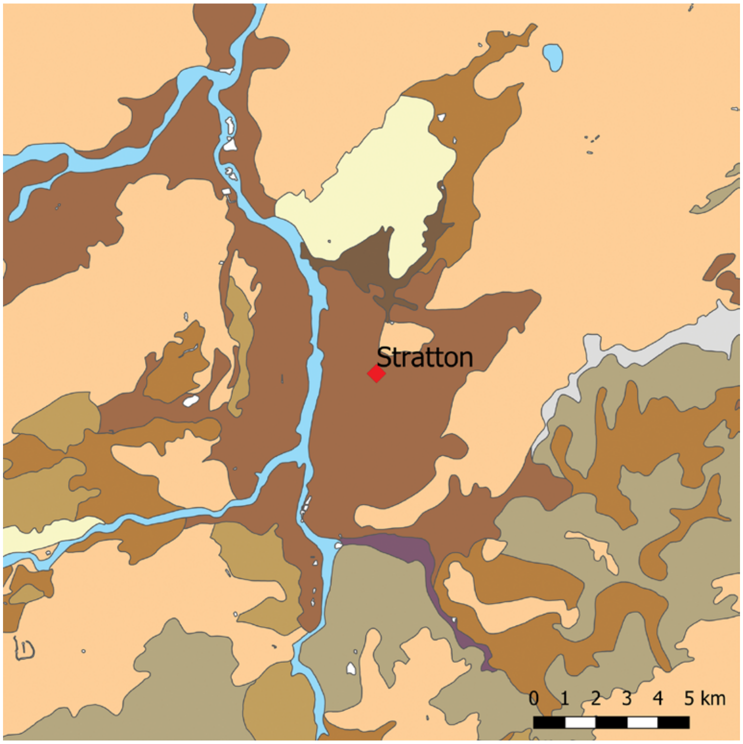

FIGURE A1.7. Soil map for Stratton, Bedfordshire.

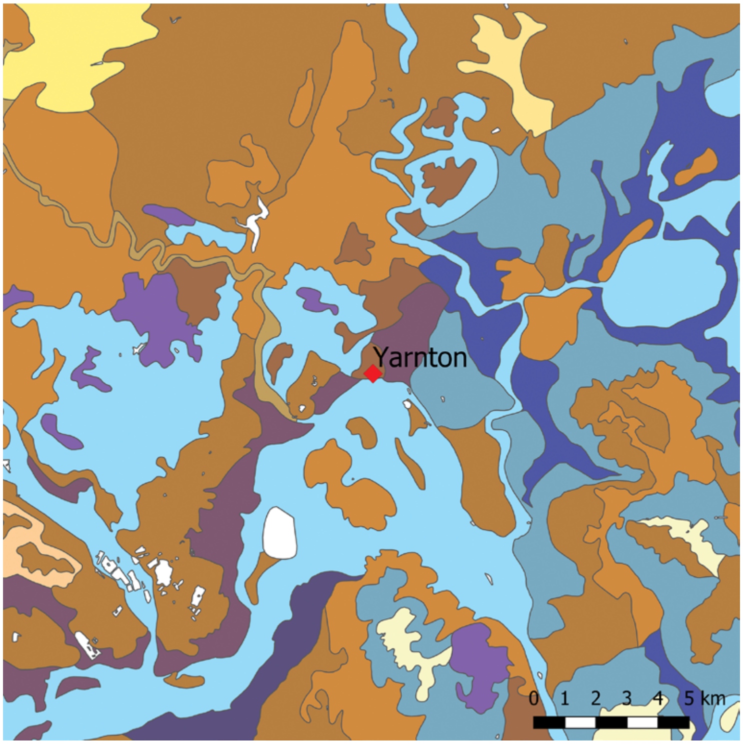

FIGURE A1.8. Soil map for Yarnton, Oxfordshire.

APPENDIX 2

Average Density of Charred Plant Remains: Tracing Surplus Production

It was proposed in Chapter 2 that the average density of charred plant remains—that is, the number of charred items per litre of soil processed—in individual archaeobotanical samples may serve as a coarse proxy for the scale of surplus cereal processing and/or production. Average density has therefore been calculated, to the nearest integer, for all FTC samples (as defined in Appendix 3) for which soil volume data were available: a total of six hundred samples across the core regions and phases, with average densities ranging from one to 16,384 items per litre. Any thresholds for identifying 'dense' samples must perforce be arbitrary, but experimental values of thirty and one hundred have proved to be sufficiently rigorous to exclude the 'background noise' of relatively sparse samples which any cereal-handling settlement is likely to produce, regardless of scales of surplus. Hence, most of the six hundred samples have an average density lower than thirty; only 254 samples (42.3%) have thirty or more items per litre, and only 112 (18.7%) have one hundred or more items per litre.

It could be contended that average density of charred plant remains in a sample is likely to be biased by the volume of that sample. For instance, a supposedly dense deposit might appear sparse if 'diluted' in a greater volume of sampled soil, while a relatively small number of items in a very small sample could appear spuriously dense, for example, ten items in a 0.1 litre sample would have an average density of one hundred, despite (potentially) constituting a negligibly tiny deposit. We can test this hypothesis by plotting average density against sample volume for the entire set of six hundred samples (Figure A2.1). This graph supports the general hypothesis: samples with the very highest densities (>2,000 items per litre) clearly tend to have very low volumes, whereas samples with the very highest volumes (>50 litres) tend to be of very low average density. In practice, however, relatively few samples fall into these more extreme categories; the majority (five hundred, or 83.3%) have volumes no greater than 50 litres and average densities no greater than two hundred and fifty. Plotting the data for these five hundred samples alone reveals a much less clear-cut pattern (Figure A2.2). There is still a tendency for average density to decrease as soil volume increases, but it is much less pronounced; it is certainly not the case that removing the lowest-volume samples would thus remove the relatively dense samples. In addition, the majority of these five hundred samples (461, or 92.2%) have a volume of at least 10 litres, which can hardly be considered small in absolute terms and is evidently sufficient to identify densities greater than fifty (equating to at least five hundred items).

If we therefore assume that the relatively dense samples represent a genuinely meaningful subset, we can assess their distributions across time and space. First, we may assess whether these 'rich' samples (*i.e.* those of relatively high density) are especially concentrated in any particular region and/or phase. Examining chronological trends first, Table A2.1 compares the percentages of rich samples in the sample sets for the core phases. These results show that, with

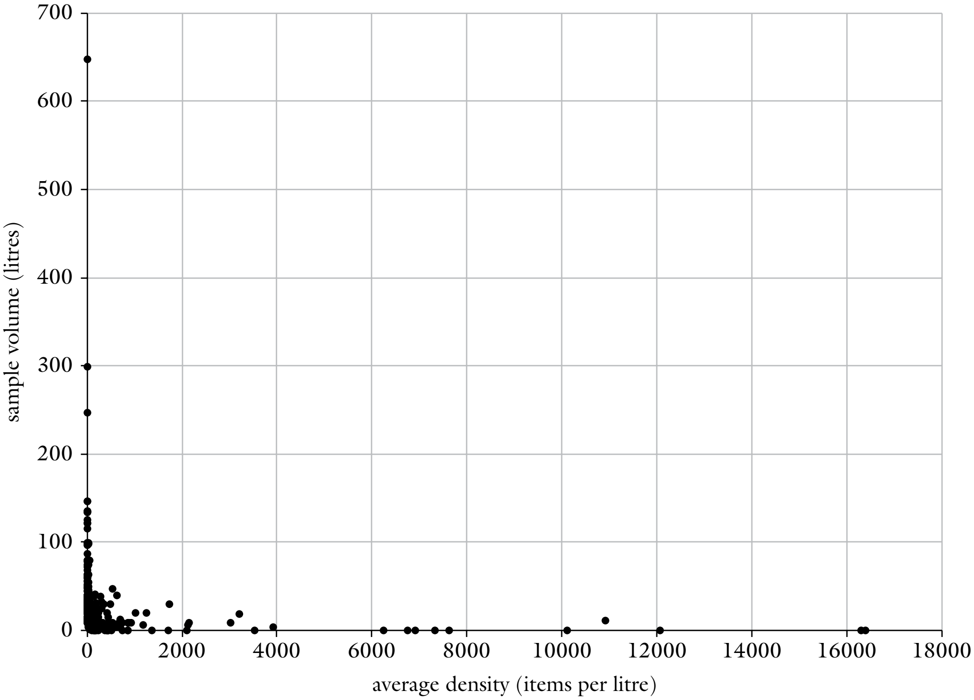

FIGURE A2.1. Scatter graph of average density against sample volume, for all six hundred samples in this analysis.

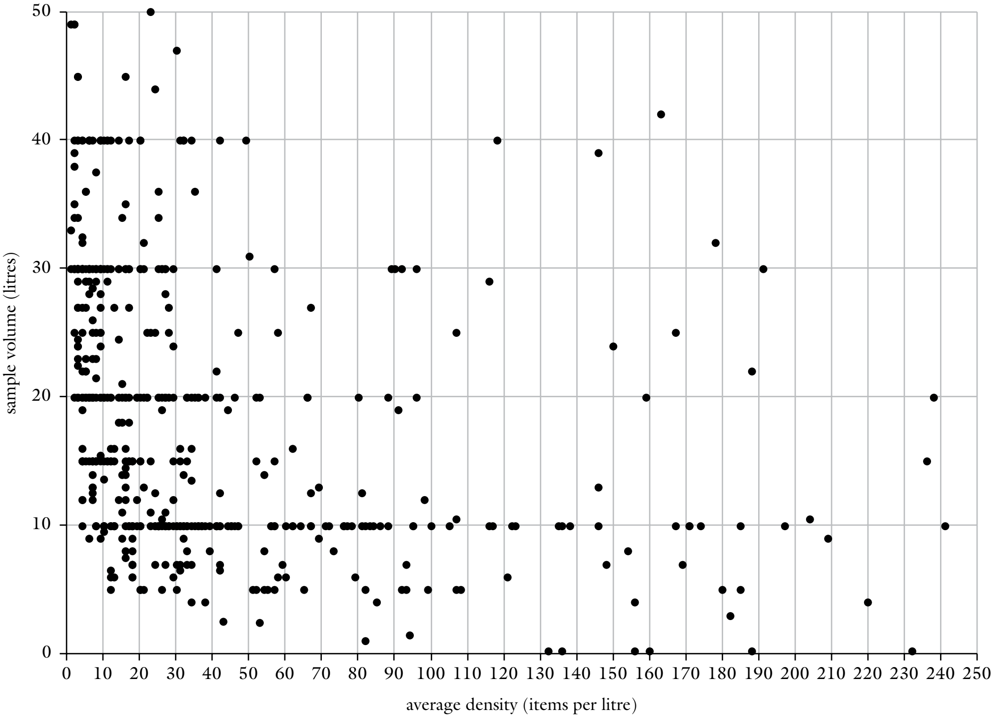

FIGURE A2.2. Scatter graph of average density against sample volume, for five hundred samples with average density of ≤250 and soil volume of ≤50 litres.

TABLE A2.1. Distribution of samples by phase and average density threshold.

Phase	**# Samples**	**% Samples**	
		≥30 Items per litre	**≥100 Items per litre**
C	167	37.1	14.4
D	152	22.4	5.3
E	281	56.2	28.5
Total	*600*		

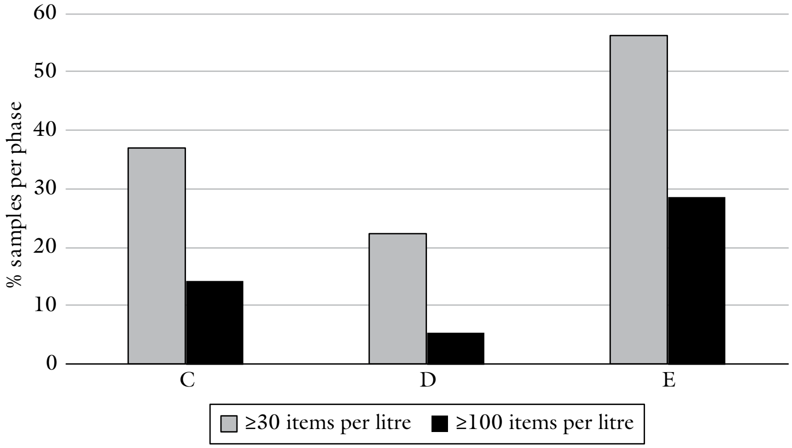

FIGURE A2.3. Distribution of samples by phase and average density threshold.

both density thresholds, rich samples are most characteristic of phase E (*c*.1030–1220), and least characteristic of phase D (*c*.880–1030) (Figure A2.3).

It should be noted that these figures may be somewhat distorted by the presence of two 'hotspots'—that is, marked concentrations of rich samples dated to phase E—at West Cotton (Central Zone; sixty-four samples in total) and Ipswich (East Anglia; thirty-four samples in total). If we exclude these ninety-eight samples from the calculations, however, then the same basic trends emerge: denser samples are best represented in phase E, and least well represented in phase D (Table A2.2; Figure A2.4).

TABLE A2.2. Distribution of samples by phase and average density threshold, excluding ninety-eight samples from 'hotspots' at Ipswich and West Cotton.

Phase	**# Samples**	**% Samples**	
		≥30 Items per litre	**≥100 Items per litre**
C	167	37.1	14.4
D	152	22.4	5.3
E	183	44.3	18.6
Total	*502*		

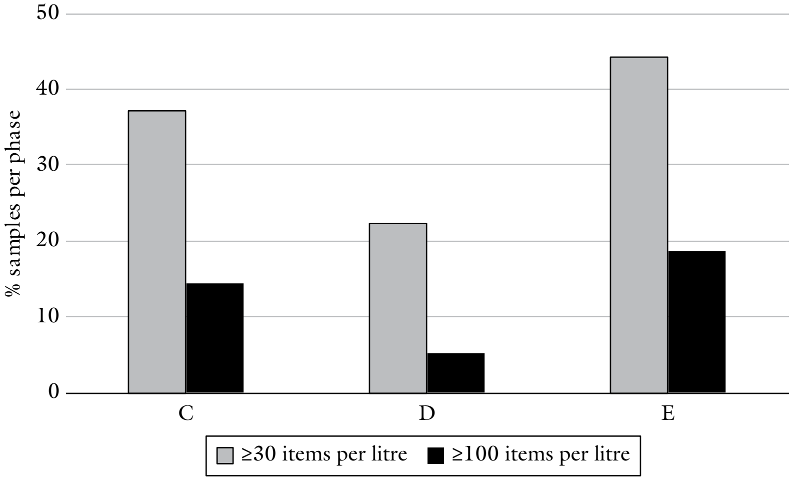

FIGURE A2.4. Distribution of samples by phase and average density threshold, excluding ninety-eight samples from 'hotspots' at Ipswich and West Cotton.

Turning now to regional comparisons using the same data—and excluding those same ninety-eight 'hotspot' samples from West Cotton and Ipswich—we find that rich samples are markedly well represented in the Central Zone, followed by the South East, and least well represented in East Anglia and the Fens (Table A2.3; Figure A2.5).[1]

TABLE A2.3. Distribution of samples by region and average density threshold, excluding ninety-eight samples from 'hotspots' at Ipswich and West Cotton.

Region	**# Samples**	**% Samples**	
		≥30 Items per litre	**≥100 Items per litre**
Central Zone	138	47.1	18.1
East Anglia	94	21.3	8.5
Fens	74	25.7	5.4
South East	171	35.1	15.2
Total	*502*		

It therefore appears that certain practices in the Central Zone (and perhaps the South East), and during phase E—whether in production, processing, distribution, and/or consumption—were particularly conducive to the creation of dense charred crop deposits; and the opposite might be said of the Fens and East Anglia, and phase D more generally.

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[1] The Western Lowlands have been excluded from these calculations, because the region is represented by only twenty-five samples; given how much smaller this sample set is, compared to the other regions, it was deemed inappropriate for the interregional comparison.

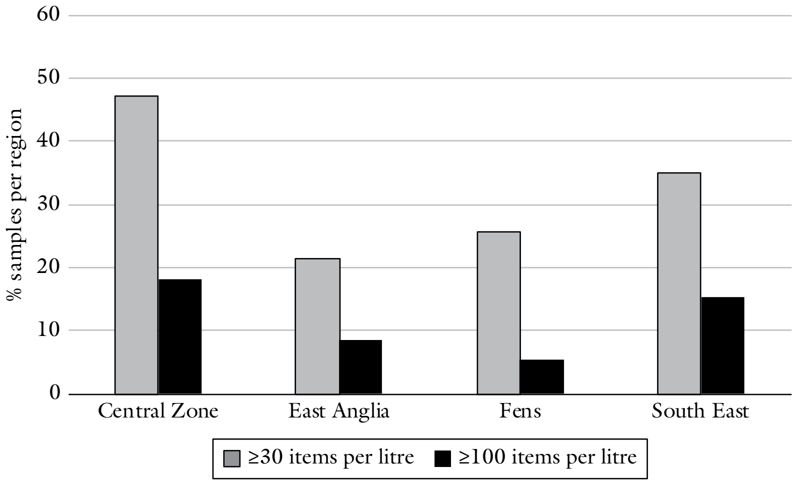

FIGURE A2.5. Distribution of samples by region and average density threshold, excluding ninety-eight samples from 'hotspots' at Ipswich and West Cotton (rich samples only).

How then might we interpret these relatively dense deposits, in terms of the medieval cereal economy? The varying patterns in sample density cannot be attributed simply to changes in settlement type, for example, greater concentrations of charred cereal remains at urban 'consumer' sites, since dense samples occur frequently at both rural (*e.g.* Eckweek, Higham Ferrers, West Cotton) and urban sites (*e.g.* Ipswich, Oxford, Stafford). It appears that 'central' places may be particularly well represented among these sites: not only towns, but also ecclesiastical sites such as Lyminge and Ely, and secular high-status centres of various kinds, including West Cotton, Higham Ferrers, Wharram Percy, and Norwich Castle. Such a bias is not exclusive—settlements such as Yarnton and Stratton cannot necessarily be deemed high-status—but seems inherently plausible, given that such sites are (by definition) locations where goods are likely to be assembled, stored, and processed in bulk. But this factor cannot explain the geographical and chronological tendencies, because 'centralizing' settlements occur in all three phases.

There is a stronger correlation, however, with a particular kind of context: deposits associated with ovens, kilns, or hearths appear more likely to be relatively dense. Table A2.4 shows the average density data broken down by standardized feature type categories, focusing on the most common categories, namely pits, ditches, and ovens/hearths.[2] Some caution is due here, given that we have a far smaller sample set for ovens/hearths, but the emergent trend is very pronounced: rich samples are far better represented among ovens/hearths than among pits or ditches (Figure A2.6). Indeed, such a tendency might well be expected of contexts closely and specifically associated with crop processing, such as grain-drying kilns.

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[2] We have excluded feature types that have too few samples to constitute a representative set (such as posthole and SFB, with eleven and six samples, respectively) and types such as 'miscellaneous structural feature' that are too vague or heterogeneous to be of use here.

TABLE A2.4. Distribution of samples by standardized feature type and average density threshold.

Feature type	# Samples	% Samples	
		≥30 Items per litre	≥100 Items per litre
Pit	224	37.5	13.4
Ditch	114	47.4	14.9
Oven/hearth	45	62.2	40.0
Total	*383*		

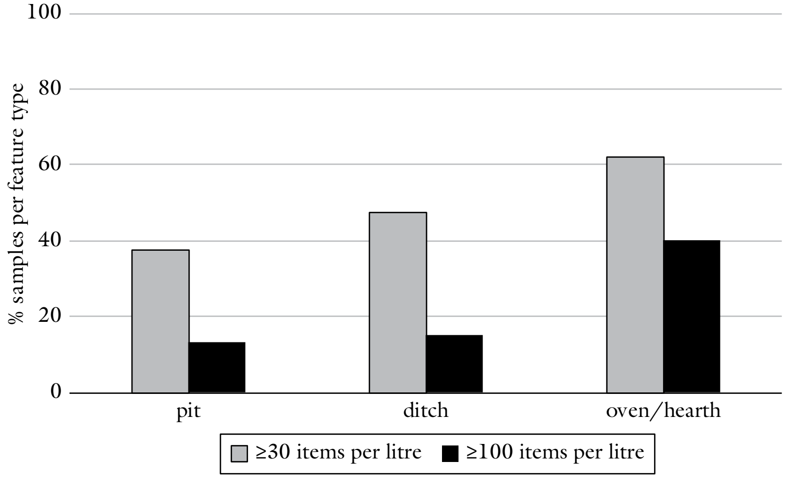

FIGURE A2.6. Distribution of samples by standardized feature type and average density threshold (rich samples only).

This contextual bias may in part explain the regional and chronological trends presented above. The overall sample numbers for ovens/hearths are not especially large, but their distribution is instructive: of the twenty-eight samples from ovens/hearths with average densities ≥30 items per litre, eighteen (64.3%) come from sites in the Central Zone, and twenty-two (78.6%) are dated to phase E. The latter are dominated by samples from West Cotton in the Central Zone (thirteen samples) and Pudding Lane, which falls within the South East but close to the boundary with the Central Zone (six samples). The dominance of the West Cotton assemblage here is particularly significant, since it indicates that oven/hearth contexts are not the only factor influencing the overall chronological and geographical patterns, since we have already established that those trends persist even if West Cotton's phase E samples are excluded (see above).

Nonetheless, the strong representation of ovens/hearths among the denser samples can be cited in support of a more general inference: that sample density is directly related to the scale (and/or centrality) of cereal processing. On this basis, returning to the data presented above, one could argue that the scale of cereal processing fell in phase D (*c*.880–1030) but grew sharply in phase E (*c*.1030–1220) and that it was notably high in the Central Zone but comparatively low in East Anglia and the Fens. Some of these inferences are not necessarily surprising. Much of the Central Zone is characterized by fertile clays, whereas the seasonally waterlogged Fens present a more challenging arable environment; and the post-Conquest period represented by phase E is already known to have witnessed demographic and urban growth, which themselves imply the greater production and processing of greater cereal surpluses (see Chapter 1). But what should we make of the apparent decrease in average density in phase D? This 'late Saxon' period is marked by trends, such as the growth of early towns and the proliferation of watermills, which are hardly consonant with a *reduction* in cereal surpluses.

A different light is shed on the question if we consider the proportions of *sites* with samples passing each density threshold, phase by phase (Table A2.5; Figure A2.7). These results show a very different pattern: the majority of sites in every phase produce some rich samples, and such sites are *least* well represented in phase E (though the differences are not great). Hence, the chronological fluctuations in the percentages of rich samples discussed above (Tables A2.1 and A2.2) do not signify that the 'surplus processing' activities—however they are defined—became less *widespread* in phase D then much more widespread in phase E. These fluctuations may instead represent the *pervasiveness* of those practices, that is, the proportion of cereal processing activities that were undertaken in a piecemeal or centralized manner. The operative word here is 'proportion': the apparent decline in rich samples in phase D need not be absolute and therefore need not indicate a literal reduction in surplus processing. Rather, it could represent a rise in piecemeal processing. In other words, if phase D witnessed an expansion of cereal farming, this expansion may to a considerable extent have been channelled through piecemeal rather than centralized crop processing activities.

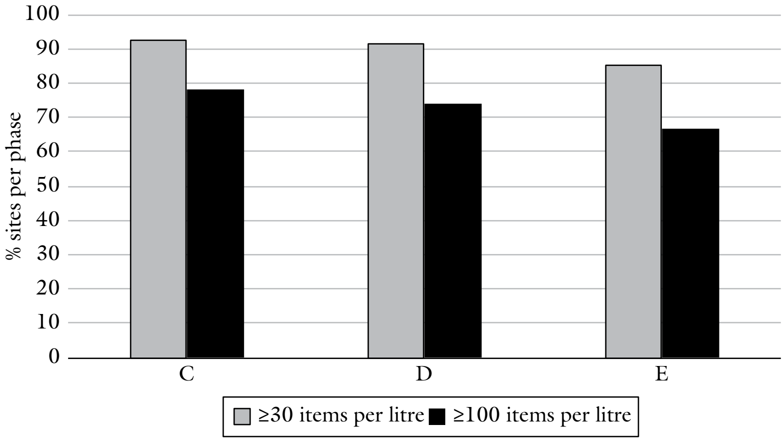

FIGURE A2.7. Distribution of sites by phase and average density threshold of samples.

Table A2.5. Distribution of sites by phase and average density threshold of samples.

Phase	# Sites	% Sites with samples	
		≥30 Items per litre	≥100 Items per litre
C	41	92.7	78.0
D	23	91.3	73.9
E	48	85.4	66.7

A broad-brush narrative might be inferred thus: bulk processing appears as a new and widespread phenomenon in phase C (*c*.660–880). In phase D (*c*.880–1030), these practices remain widespread but piecemeal activity increasingly characterizes the cereal economy. Finally, in phase E (*c*.1030–1220) bulk processing practices become slightly less widespread—that is, somewhat more concentrated at certain sites—but definitively more characteristic of the cereal economy in general, especially in the Central Zone but less so in East Anglia and the Fens.

APPENDIX 3

The Composition of the Archaeobotanical Dataset

An extended quantitative account of the national archaeobotanical dataset and its overall 'shape' and composition is provided in Digital Archive Document B07 along with detailed methodological considerations. Some of the key findings are highlighted here; please consult the digital archive for fuller details.

Charred plant remains occur in 4,182 samples at 301 sites, spanning FeedSax phases A–G (*c.*420–1400) and representing all eight regions of England. The distributions of these sites and samples are, however, very uneven across time and space. There is a chronological bias towards phases C–F (*c.*670–1300), due to a deliberate emphasis on this period during data collection (see Chapter 2). Within this span, however, there is a marked increase in both sites and samples around phase E (*c.*1030–1220) (Figures A3.1 and A3.2).

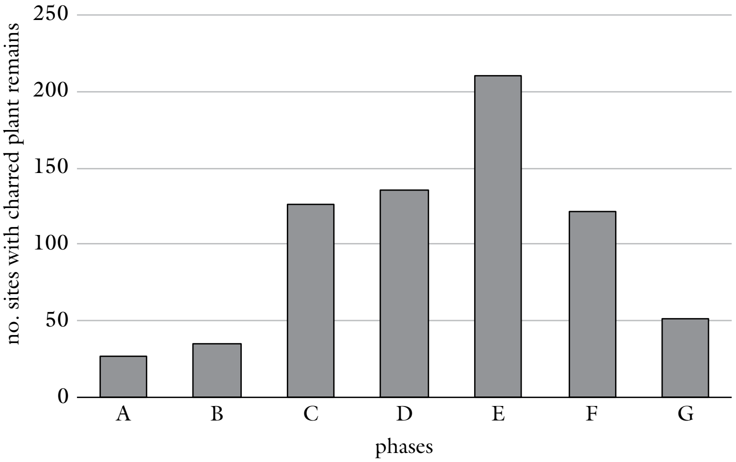

FIGURE A3.1. Chronological distribution of sites with charred plant remains.

Geographically, there is a clear regional bias towards the Central Zone and South East, and to a lesser extent towards East Anglia, the Fens, and Western Lowlands. Data for the South West and especially the northern regions are negligible by comparison. As discussed in Chapter 2, these geographical biases may be due to diverse factors, including the skewed foci of modern development-led fieldwork, archaeological visibility within a distinct Anglo-Saxon 'culture zone', and perhaps the variable impact of different medieval agricultural regimes upon the archaeobotanical record (Figures A3.3 and A3.4; cf. Chapter 2, Figure 2.1).

As a result of these imbalances in the distribution of our data, it is not possible to draw equally detailed and representative inferences about all regions and periods. Analyses and emerging narratives will therefore focus upon the period *c.*670–1300 (*i.e.* phases C–F), and five regions: the Central Zone, East Anglia, Fens, South East, and Western Lowlands.

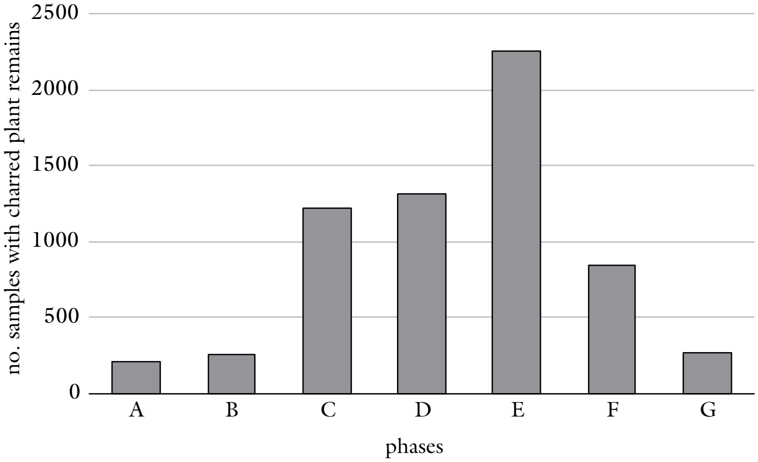

FIGURE A3.2. Chronological distribution of samples with charred plant remains.

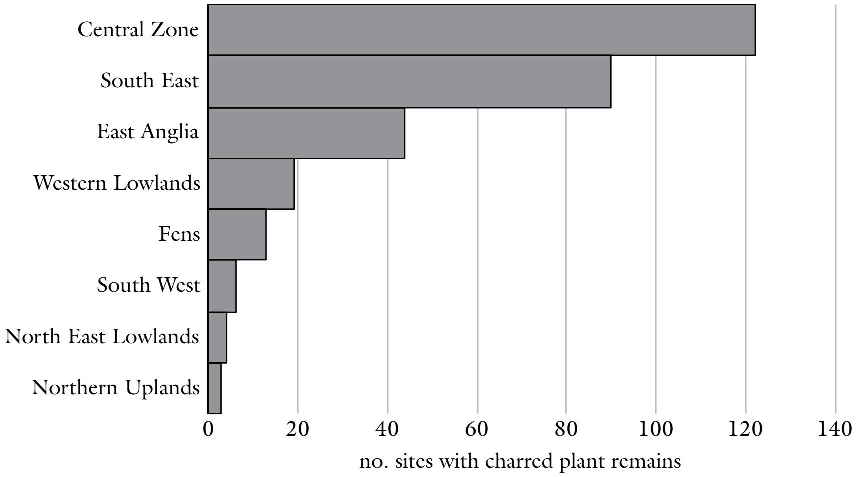

FIGURE A3.3. Regional distribution of sites with charred plant remains.

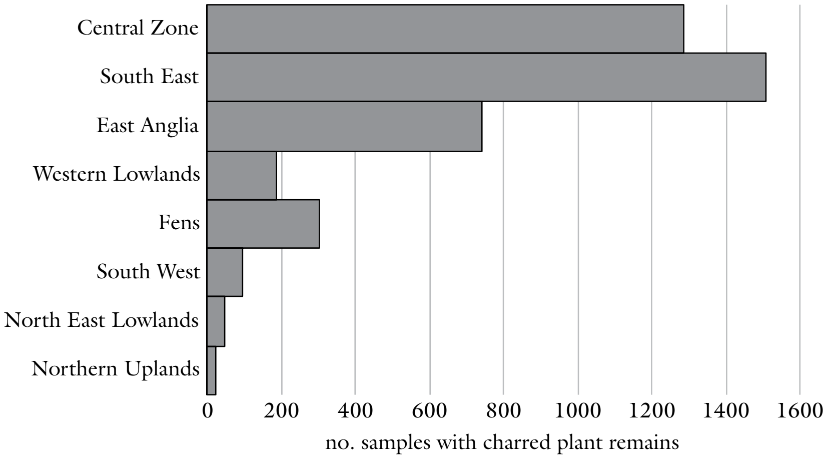

FIGURE A3.4. Regional distribution of samples with charred plant remains.

REFINING THE DATASET

Crop dominance

The distributional trends outlined earlier pertain to samples with *any* recorded charred plant remains in the dataset, irrespective of how well-quantified those data may be, or how directly relevant they are to the study of crop husbandry. All of this comprehensive dataset is potentially useful in presence analysis, a semi-quantitative approach to assessing overall patterns of occurrence for a given plant taxon (see Chapter 2). The quantitative analyses required by this project, however, demand a particular subset of the data, comprising archaeobotanical samples with quantified records (meeting a set quorum of items), and of broadly comparable composition—that is, dominated by the charred remains of free-threshing cereals and/or arable weeds.[1]

To begin with, we can restrict the set to those 2,289 samples with quantitative data dominated specifically by charred—as opposed to waterlogged or mineralized—plant remains. We can narrow this set down further, to the 1,984 samples (86.7%) whose crop component is dominated by cereals. By contrast, two samples had crop components dominated by pulses, and a further two were dominated by flax, which confirms the general expectation that charring as a mode of preservation is biased towards cereal crops (McKerracher 2019).[2] Of this cereal-dominated subset, 1,454 samples (73.3%) were dominated by free-threshing cereals—including rye, oats, hulled barley, and free-threshing wheat—while only eleven were dominated by hulled wheats (emmer and/or spelt). This pattern confirms the general expectation that medieval English farming focused primarily upon free-threshing cereal types (Moffett 2011).[3]

Unless otherwise stated, the quantitative analyses presented elsewhere in this book focus exclusively upon these 1,454 free-threshing cereal-dominated samples (hereafter 'FTC

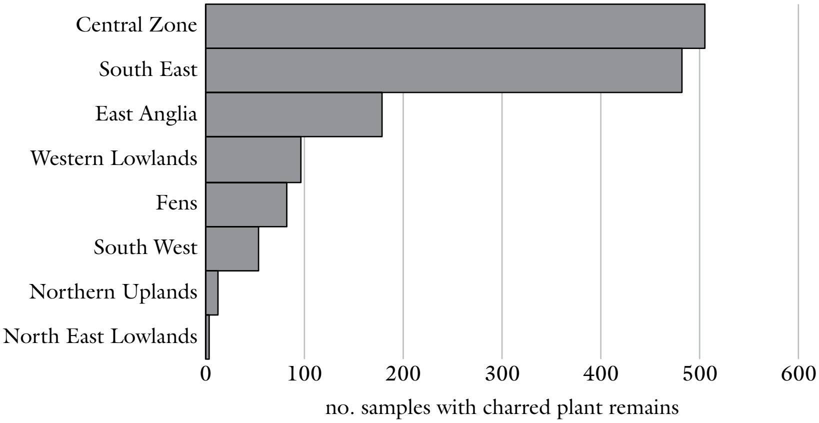

FIGURE A3.5. Regional distribution of FTC samples with ≥30 free-threshing cereal grains identified to genus/species level.

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[1] The methods employed in the following passages, including criteria for concepts such as 'dominance', are set out in Digital Archive Document B07.

[2] The remainder had either no single dominant crop type, or insufficient remains to admit analysis.

[3] The remainder had either no single dominant cereal type, or insufficient remains to admit analysis.

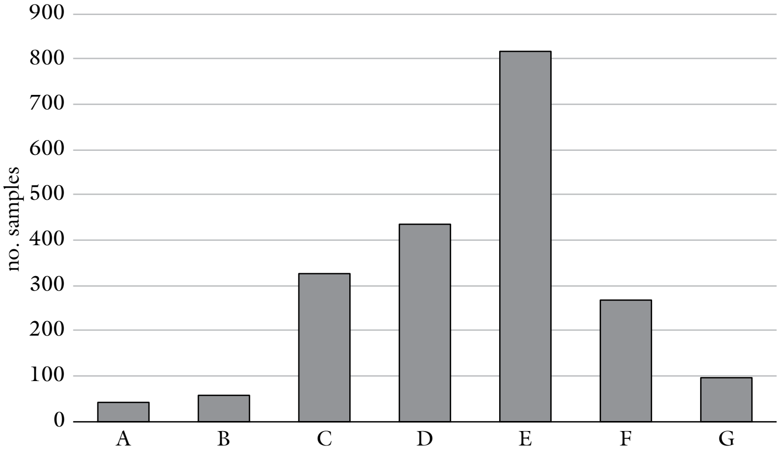

FIGURE A3.6. Chronological distribution of FTC samples with ≥30 free-threshing cereal grains identified to genus/species level.

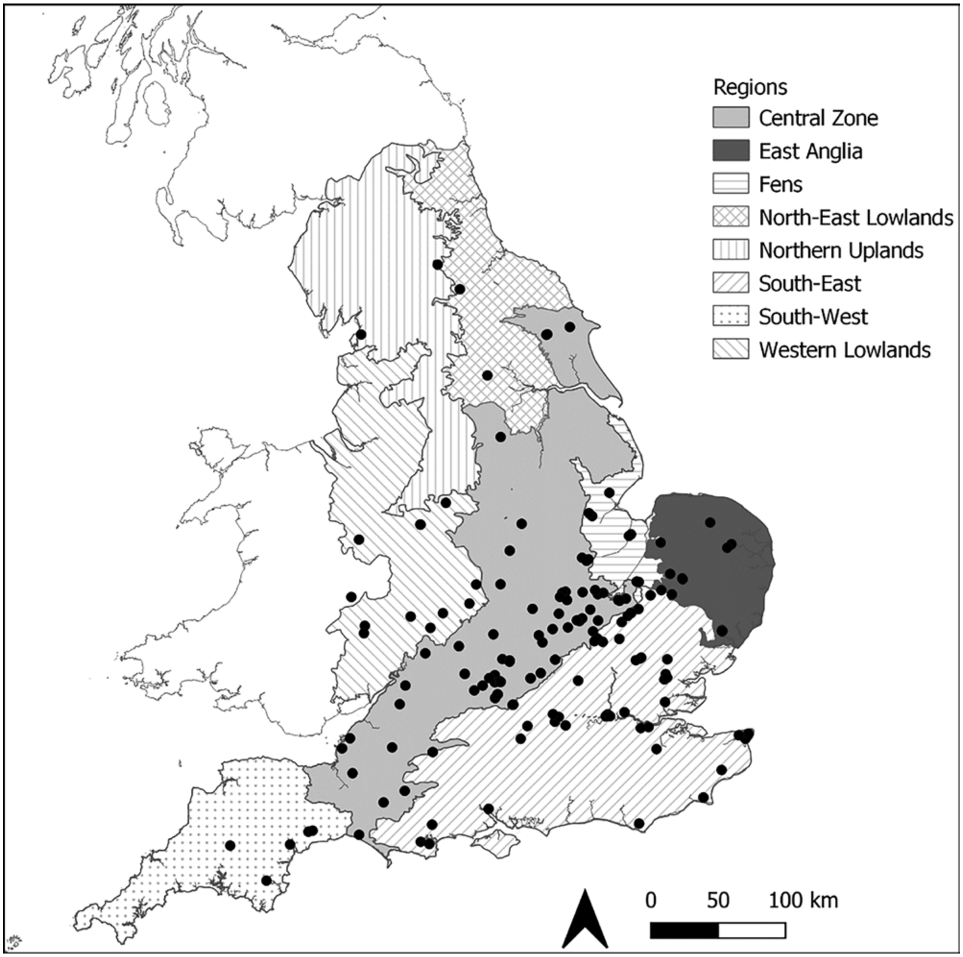

FIGURE A3.7. Distribution of sites with FTC samples with ≥30 free-threshing cereal grains identified to genus/species level.

samples', in this appendix). Where relative proportions of cereal grains are calculated per sample, these calculations draw only upon samples with at least thirty free-threshing cereal grains identified to genus or species level. There are 1,414 such samples across 191 sites, and they are heavily skewed towards the Central Zone and South East, and towards phases C–E (above all, phase E: 1030–1220), thus starkly repeating and refining the overall distributional biases in the archaeobotanical dataset as outlined above (Figures A3.5–A3.7). In the discussions that follow, therefore, the 'core regions' are the Central Zone, South East, East Anglia, Fens, and Western Lowlands; the 'core phases' are C (670–880), D (880–1030), and E (1030–1220).

Crop processing

Chapter 2 mentioned two complementary methods devised by Glynis Jones (1987, 1990) for classifying archaeobotanical samples in terms of which crop processing stages they are most likely to represent. This is relevant here because there are times when, for analytical purposes, we should compare 'like with like'. The crop processing sequence introduces biases in the representation of certain crops and weeds; hence, differences in the botanical composition of samples might be taken to reflect differences in crop husbandry, when in fact they represent differential taphonomic biases.

The combined application of these methods to the 1,454 FTC samples (as per McKerracher 2019, 37–52) has revealed that, for those 828 samples eligible for the full combined analysis, almost half (47.8%) are most likely to represent grain-rich 'products'—whether just coarse-sieved (USG), or fine-sieved as well, that is, fully processed (FSP) (Table A3.1).[4]

TABLE A3.1. Crop processing classification of FTC samples.

Crop processing classification (with shorthand code)	**# Samples**	**% Samples**
By-product of winnowing and coarse sieving (CWBP)	13	1.6
By-product of fine sieving (FSBP)	52	6.3
Product of coarse sieving (USG)	173	20.9
Product of fine sieving (FSP)	223	26.9
No clear classification	367	44.3
Total	**828**	**100.0**

It is worth noting, too, that a further 341 samples are fine-sieved products (FSP) according to the ratio-based method but have too few classifiable weed seeds (<10) to be eligible for the discriminant analysis method; yet this very dearth of weed seeds could be cited in support of the FSP interpretation. Hence, there is an additional set of samples that can be grouped with the other grain-rich product samples, if a broader-based sample set is required to maximize available data for comparison.

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[4] Ineligible samples either had insufficient remains to admit analysis or returned classifications with relatively low probability (<0.8): see Digital Archive Document B07.

APPENDIX 4

Regional and Chronological Cropping Patterns

Previous analyses have suggested that, between the seventh and mid-ninth centuries, cereal cropping choices became increasingly tailored to local environmental conditions—with a focus, for example, on salt-tolerant barley in the saline silt fens, and on rye in the sandy Breckland—as a means of securing greater and/or more reliable surpluses (McKerracher 2018, 102–6). The latter study had, however, a relatively restricted geographical and chronological focus: East Anglia and the Upper Thames valley, between the fifth and mid-ninth centuries. We may now extend the scope of the question. Did this environmentally sensitive approach to cropping persist in other regions and phases of medieval England, and thus contribute to both extensification and productivity more generally?

The Fields of Britannia project (Rippon *et al.* 2014) has argued that surface geology did, indeed, influence regional emphases on different cereals as well as livestock species, at least within their chosen transect of England running south-west–north-east between Cornwall and Norfolk. From as early as the fifth to seventh centuries, they find wheat to be predominant on clayey terrains, rye on heathland, and barley on valley terraces. Similar tendencies—especially the aforementioned emphasis on barley in the Fenland marshes—are seen to persist between the eighth and mid-ninth centuries. Data for the period between the mid-ninth and mid-eleventh centuries, which present a growing emphasis on wheat, also reveal the predominance of barley on chalklands, and a distinctively oat-based husbandry in Devon and Cornwall, a pattern that is apparent from the fifth century onwards and continues into the mid-eleventh to mid-fourteenth centuries. By this time, in the high or late medieval period, wheat's wider dominance and rye's overall decline have become even clearer, but there are still certain correlations between crop choice and surface geology, apparent in both archaeobotanical and documentary sources: with rye still favoured on heathland, for example, and wheat on heavy clays (Rippon *et al.* 2014, 231–6).

Before considering the comparative results produced by FeedSax, it is important to highlight certain methodological differences between FeedSax and Fields of Britannia. First, FeedSax has attempted to study the whole of England rather than a selected transect—although, in practice, some of the northern and north-western regions excluded by Rippon *et al.* have proved to be too poor in archaeobotanical evidence to admit quantitative analysis here, too (*cf.* Chapter 2). Second, Rippon *et al.* classify most sites specifically according to geology, for example, Jurassic Clay or Chalk, whereas FeedSax uses broader regional groupings—such as the Central Zone and East Anglia, as devised elsewhere by the Fields of Britannia project (Rippon *et al.* 2015)—which do not have such an exclusive geological character. This divergence does not make the two sets of results incomparable, but it does mean that they will offer different perspectives on regional patterning. Third, Rippon *et al.* focus primarily on rural settlements, whereas the FeedSax dataset embraces all settlement types, including urban and high-status sites. While such 'central places' may well have received cereals from a variety of different geologies, most are arguably likely to have been fed from hinterlands within their respective regions (see *e.g.* McKerracher 2019, 119, on the variegated hinterland of Anglo-Saxon Ipswich). The archaeobotanical data from such sites can thus, we argue, legitimately contribute to comparative analysis at a regional level.

The two studies also use archaeobotanical data in significantly different ways. Rippon *et al.* calculate the percentages of wheat, barley, oats, and rye from the *summed* totals of grains, from all samples at all sites in each geological group: they produce aggregated averages and 'average of averages' values. By contrast, as detailed in Chapter 2, FeedSax deploys presence analyses (at both site and sample levels) and also calculates relative proportions of cereal grains at a sample-by-sample level. The FeedSax approach thus supports a more fine-grained interpretation, avoiding the potentially obscuring effects of regional-level aggregation of quantitative data. The FeedSax dataset is also somewhat larger than that analysed by Rippon *et al.*, and benefits from data newly available in the intervening years, although it also undoubtedly draws upon many of the same site assemblages.

In light of all these considerations, the FeedSax analyses are intended to provide fresh and complementary insights by using similar data in different ways.

PATTERNS IN THE FEEDSAX DATASET

Prevalence

Following McKerracher (2019), this study examines three different dimensions of crops' respective 'importance' across different regions and phases: prevalence, frequency, and relative productivity. Prevalence is gauged as a form of presence analysis: the percentage of sites, for a given region and period, at which a crop taxon is present (see Digital Archive Document B07 for a fuller explanation of the approach taken). This serves as a proxy for how widespread a crop was in that place and time: at what proportion of farming settlements was it part of the local crop repertoire? It thus offers a perspective on crop diversification, too. Unfortunately, prevalence could be examined for only three regions—the Central Zone, East Anglia, and the South East—the others having insufficient data to support a significant chronological sequence of site-based presence analyses.

The results for free-threshing wheat show that this crop was practically ubiquitous in the Central Zone and South East, with little or no significant change over time, except perhaps for a small, gentle rise in the Central Zone (Figure A4.1). It was also very widespread in East Anglia, with some small fluctuations but little overall change over time. In general terms, therefore, it can be said that free-threshing wheat was a component of the crop repertoire nearly everywhere in these regions throughout phases C–E (*c*.670–1220).

The results for barley are remarkably similar: it is practically ubiquitous, occurring at more than 80% of sites in each of the three regions, in all phases (Figure A4.2). Within this general near-ubiquity, there is little overall change through time in the Central Zone and South East, but a modest increase in prevalence in East Anglia occurs in phase D and is largely sustained through phase E. Thus, barley was a component of the crop repertoire nearly everywhere in these regions throughout *c*.670–1220, and above all in East Anglia during *c*.880–1030.

The data for oat present a more varied picture, although it may be said that it was clearly a widespread crop in all regions and all phases, if not always ubiquitous (Figure A4.3). It is consistently very widespread (70–80%) in East Anglia, though less so than wheat or barley. It displays a similar prevalence in the South East in phase C and then falls in phase D before rising through phases E1–E4 to nearly 90% (around as ubiquitous as barley). In the Central Zone, oat's prevalence rises to around 90% as early as D1, and stays high thereafter—again, around as high as barley in this region, and almost as high as wheat: all three are practically ubiquitous in the Central Zone for most of the period.

Rye's prevalence is the most varied and complex of all (Figure A4.4). It tends to be the least widespread of the cereals, never really approaching ubiquity except for during phase D in East Anglia when it occurs at 90–94% of sites. Otherwise, it displays a gentle rise in prevalence in the Central Zone through phases C1–D1 (670–920), from 50% to about 60%, and remains around this level thereafter. In the South East, it becomes rapidly less widespread through phases C4–D4, from 74% to 50%, then spreads again even more rapidly through E1–E3, back to 77%.

A general summary of prevalence might therefore run as follows. Wheat and barley were practically ubiquitous: a component of the crop repertoire in nearly all places throughout the period, with extremely slight biases towards barley in East Anglia and towards wheat in the South East. Barley and wheat enjoyed roughly equal ubiquity in the Central Zone, which witnessed some diversification over time, with oats and (to a lesser extent) rye being added to the crop repertoire of more sites by the late ninth century, such that oats became almost as widespread as barley and wheat. In the South East, by contrast, oats and rye were apparently

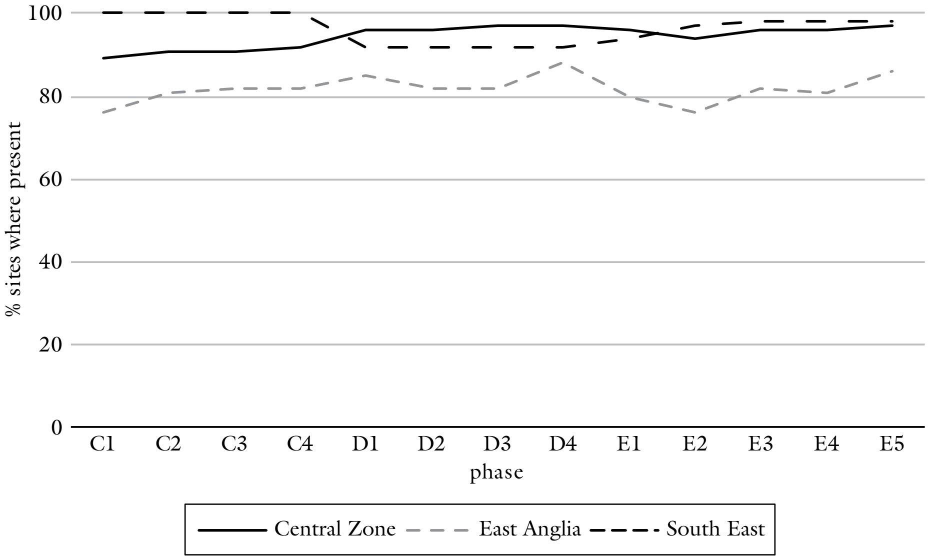

FIGURE A4.1. Prevalence of free-threshing wheat over time, for regions with sufficient data.

dropped from the repertoire of several sites through phase D, though they spread again in phase E. In East Anglia, oats and rye remained fairly widespread throughout the period but neither were really ubiquitous except for during phase D, which saw a peak in the prevalence of rye. Phase D (880–1030) thus emerges as a period of greater crop diversity in the Central Zone and East Anglia—continuing the diversifying trend already observed by McKerracher (2018) in the seventh and eighth centuries—but the opposite is true of the South East. Phase E (1030–1220) then appears as a time of consolidated diversity in all regions.

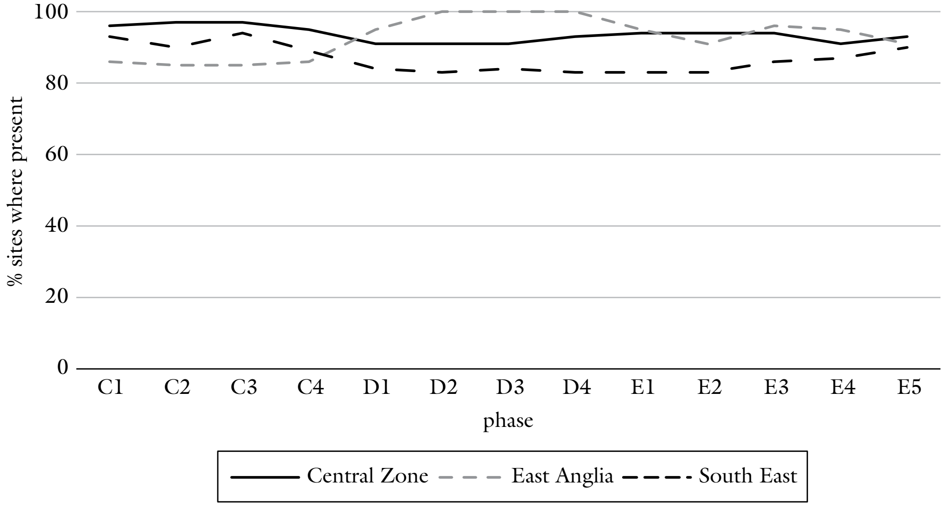

Figure A4.2. Prevalence of barley over time, for regions with sufficient data.

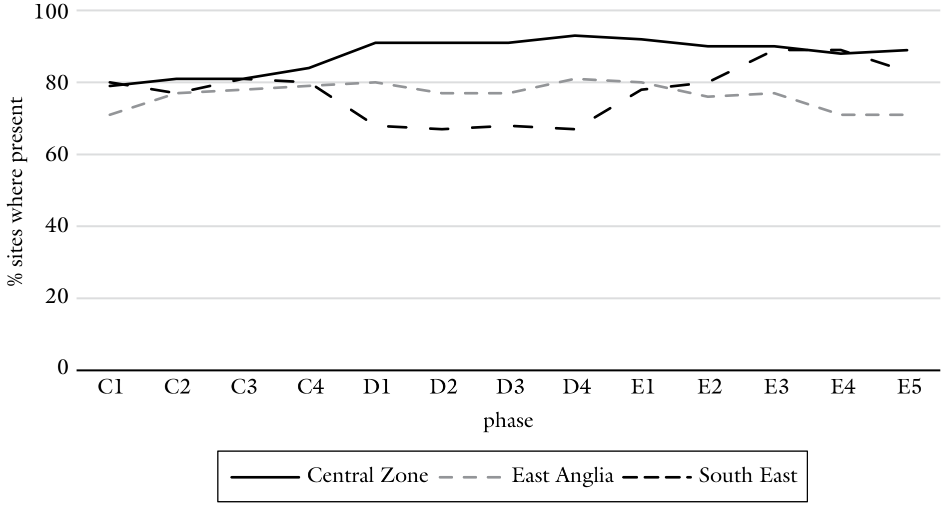

Figure A4.3. Prevalence of oat over time, for regions with sufficient data.

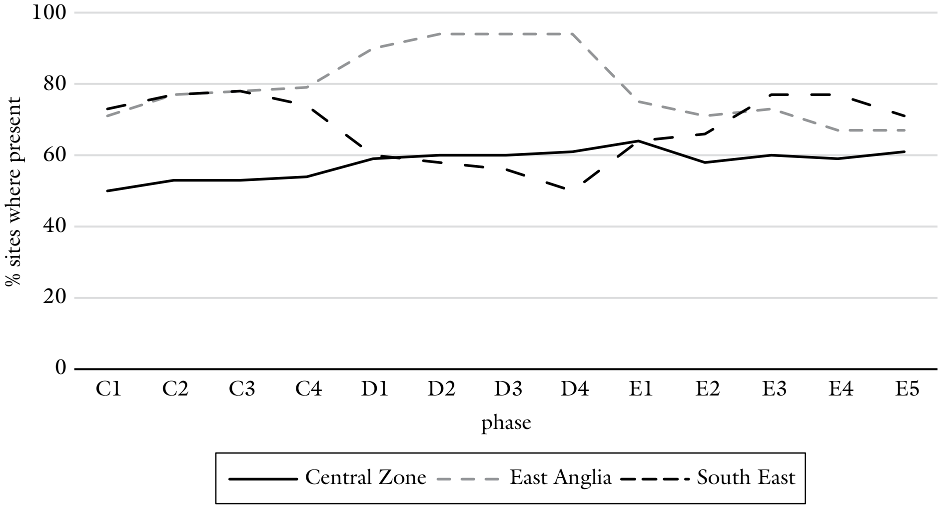

FIGURE A4.4. Prevalence of rye over time, for regions with sufficient data.

Frequency

While prevalence reflects how widespread each crop was as a component of local crop repertoires, frequency is a proxy for how often each crop was grown in each region and period, that is, whether it was a regular or only occasional part of the harvest. Frequency results, representing the percentage of archaeobotanical samples in which a crop taxon occurs for each region/phase, are available for more regions, including the Fens and Western Lowlands as well as the Central Zone, East Anglia, and South East.[1] They also, as a rule, produce more variable and complex pictures than do the prevalence data.

Hence, it appears that wheat was practically always grown in the Western Lowlands throughout the period, and increasingly so in the Central Zone and South East from D1 onwards (Figure A4.5). By contrast, it was far from being a constant harvest staple in the Fens and East Anglia, despite its high prevalence in the latter region (see above). While it still occurred in around 60% of harvests in East Anglia during phases C–D, it occurred slightly less frequently in phase E. In the Fens, it grew in a minority of harvests during phase C, but then abruptly in a majority from D1 onwards, though with a sharp temporary dip in phase E1. This stark difference between phase C and phases D–E makes more sense when we note that the different periods are biased towards different parts of the Fens: the later data are dominated by assemblages from Ely—situated among the peaty Black Fens, near to loamy and clayey soils suitable for wheat—while the dataset for phase C is dominated by samples from sites such as Gosberton in the silt fens; these latter samples are heavily dominated by barley, an appropriately salt-tolerant crop in this saline, seasonally flooded environment (Murphy 2010; and see further below).

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[1] Although the Western Lowlands lack sufficient data for phase C1.

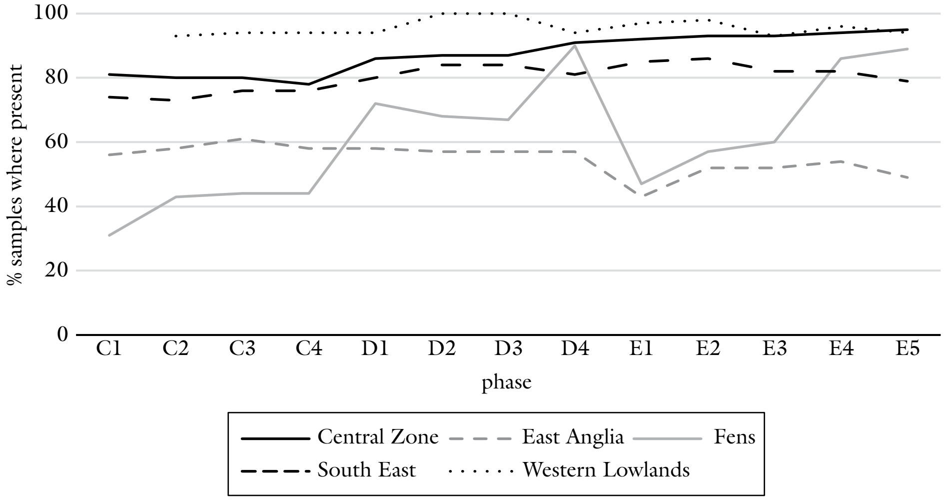

FIGURE A4.5. Frequency of free-threshing wheat over time, for regions with sufficient data.

Accordingly, the frequency data for barley are consistently high in the Fens and, intriguingly, become even higher still in phases D–E, despite the shift in data distribution towards the peat fens in this period (Figure A4.6). Barley thus seems to have been very much a staple crop of the whole Fenland region, throughout all these phases. In East Anglia, the results for barley are strikingly similar to those for wheat: barley occurs in around 60% of samples throughout phases C–E. It was more common still in the Central Zone and South East, with a modest rise in the former region and a slight decline in the latter. In the Western Lowlands, the pattern is similar to that in the South East, except for an abrupt dip in phases D1–D2—reaching a low of 31%—before an even steeper recovery to 71% in D3.

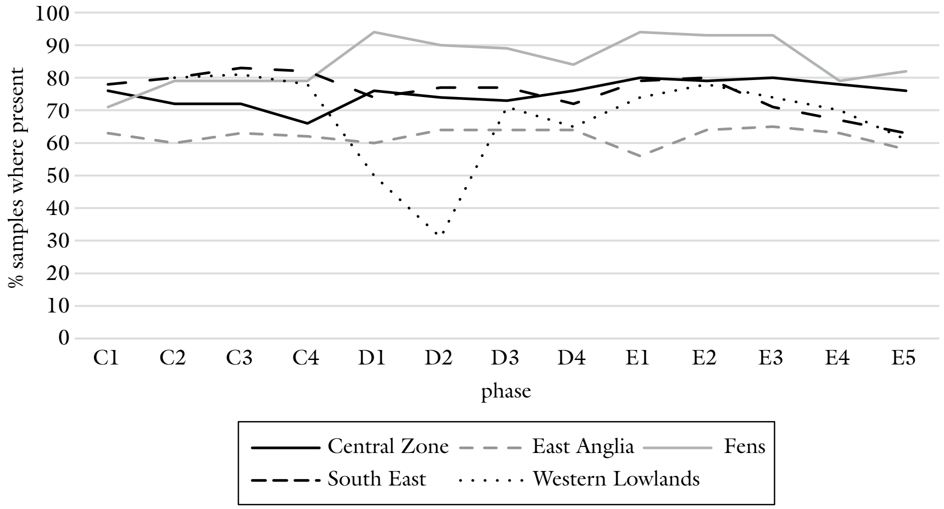

FIGURE A4.6. Frequency of barley over time, for regions with sufficient data.

Turning to oats, there is a striking, universal trend towards increased frequency over time, with values for all regions converging on the range 60–70% by phase E5, from a starting range of 22–48% (Figure A4.7). Within this overall increase, the most marked jump is in the Western Lowlands in D1, with frequency then peaking at 100% in phases D2–D3 (*i.e.* in the period *c.*920–980, oats occurs in every sample), before a gradual fall to converge with the general range of 63–73% by phase E3. The Western Lowlands data exhibit a similar pattern for rye, with a sharp jump in phase D1–D3, albeit to a lower peak of 82% (Figure A4.8). Thus, the period *c.*880–980 seems to have been a time of marked crop variety in the Western Lowlands, with oats and rye suddenly grown far more often than not, along with wheat—but less so barley, for unclear reasons.

East Anglia is unusual in displaying a gentle overall decline in the frequency of rye, from a peak of 52–55% in phase C (the highest of all regions) to 37–42% in phase E, more in line with the values for the Central Zone and South East. The most unusual pattern is for the Fens: here, rye begins and ends the sequence with the lowest frequency of all regions, but in between, it shows a fairly steep continuous increase through to phase E3, before a rapid fall. This steady rise of rye, but not the fall, echoes the contemporaneous increased frequency of oats in the Fens (Figure A4.7).

To summarize, it may be said that wheat and barley tended to be the most frequently grown crops overall, in most regions, but with oats and (to a lesser extent) rye increasingly common over the course of the period. In addition to this gradually increasing frequency for most crops over phases C–E, there is a marked (but temporary) peak in the frequency of oats and rye in the Western Lowlands during phase D. This means that, for this period, most samples contain wheat, oats, and rye, with barley a much less frequent component.

The exception to the wider trend towards higher frequencies for most crops across the whole period is East Anglia. While oats were grown here increasingly often over time, rye and wheat were sown less often as time went on, while barley's frequency remained fairly constant. These trends together would be consistent with a pattern of intraregional diversification, with a greater variety of crop combinations across East Anglia, and therefore a less cohesive trajectory for the region as a whole.

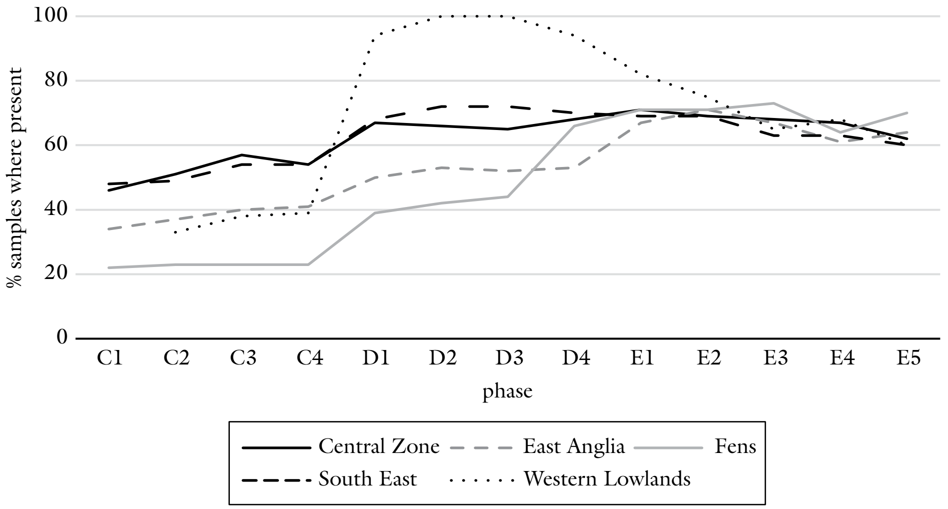

FIGURE A4.7. Frequency of oat over time, for regions with sufficient data.

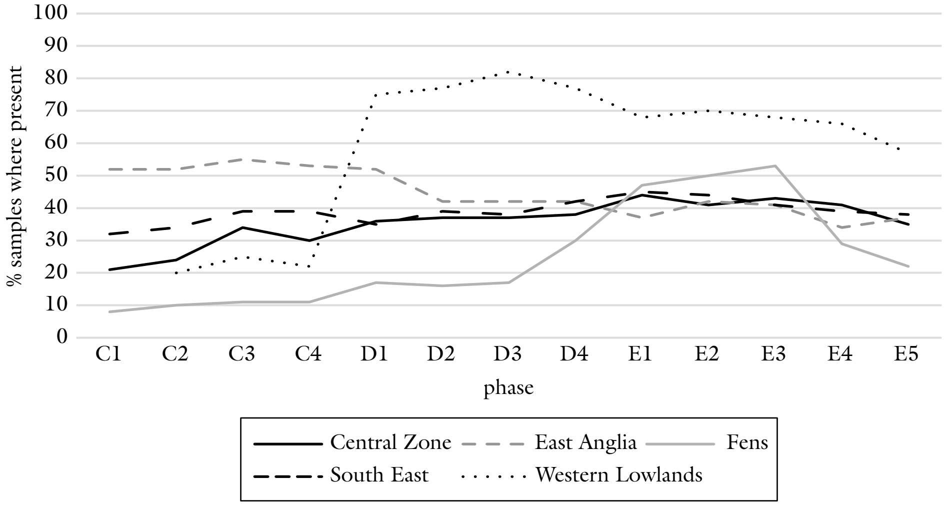

Figure A4.8. Frequency of rye over time, for regions with sufficient data.

Relative productivity

One of the most striking patterns emerging from the relative productivity data, as illustrated in interpolated heatmaps, is the appearance of a 'wheat belt' more or less corresponding with the Central Zone, or at least its southerly portion (Figure A4.9). The maps show that wheat contributes a notably high percentage of grains to samples in this area (as indicated by darker shading), fairly consistently throughout phases C–E but especially in phase E. The pattern within the Central Zone extends only about as far north as Peterborough, but data become scarcer north of this point, so it cannot be ruled out that the wheat belt would extend further north if more evidence emerged to fill out the 'datascape'. This impression of a regional preference for wheat is certainly consistent with the presence analyses discussed above, which show wheat to be practically ubiquitous at sites in the Central Zone throughout the sequence and to maintain a high (and steadily increasing) frequency among samples. Wheat's apparent predominance throughout the seventh to thirteenth centuries in this area arguably goes against a purely economic interpretation: wheat cultivation cannot simply have been relying on, or responding to, the growth of towns and markets in the later part of the period but was rather continuing a custom established at least as early as the seventh century.

Moreover, this 'wheat belt' is not strictly contained within the Central Zone. Ely, which has a wheat-rich assemblage, lies very close to the boundary line between the Fens and the Central Zone, and there are a few other wheat 'hotspots' that fall outside of the Central Zone *sensu stricto*, but which are not very far removed: Holmer and Wellington Quarry in the Western Lowlands; and Barley, Stotfold, and Stratfield Mortimer in the South East. Each of these sites has loamy and clayey soils in its near hinterland, and it may therefore be tempting to posit an environmentally grounded interpretation: that is, free-threshing wheat thrives on rich heavy soils, and therefore it was favoured in a widely clayey region.

But such a simple environmental model does not necessarily suffice. The Central Zone does not present a homogeneous environment, clayey or otherwise. While there is a broad correspondence between this Central Zone and a swathe of Jurassic bedrock from Dorset to Yorkshire, outcrops include not only the mudstones of the Oxford Clays, for instance, but also limestone hills. Conversely, there are of course clay soils in England outside of the Central Zone, and although some of these may tend to be less fertile—such as those on the London Clay and Weald Clay, in the South East—others are potentially more favourable, such as on the East Anglian boulder clays (Williamson 2003, 94–101). Indeed, as we have seen, free-threshing wheat is practically ubiquitous not just in the Central Zone but also in the South East (and to a lesser extent East Anglia) throughout phases C–E, and frequency tends also to be relatively high in most regions (above 50% for most regions and phases: Figure A4.5).

So free-threshing wheat was not a uniquely widespread crop in the 'wheat belt', nor was it grown uniquely often there. Rather, it was in some sense markedly more *productive*—the farmers there were growing wheat more successfully than in other parts of England. It can therefore also be said that wheat grains contribute disproportionately to the archaeobotanical record, especially for phase E, in an area which also tends disproportionately to produce dense concentrations of charred crop remains, again especially in phase E (*c.*1030–1220). As we have already seen, there is also some correlation between these denser deposits and hearths or kilns, an association that is perhaps indicative of bulk processing practices becoming more widespread—especially in the Central Zone—at this time (see Appendix 2). Thus, the 'wheat belt' may correspond to a 'bulk processing belt'—although, it should be said, there is no straightforward correlation between high average density and a high percentage of wheat grains among the individual samples.

What, then, does the 'wheat belt' actually signify? The fact that farmers were growing wheat most successfully here implies that they were able to make best use of the heavy, clayey terrains most conducive to wheat cultivation: not because such terrains were unavailable elsewhere, but because they were being used particularly effectively here. Perhaps the simplest explanation for this effectiveness is heavy ploughing, that is, a special precocity and thoroughness in the uptake of the mouldboard plough in this belt.[2] Such an interpretation accords with the zooarchaeological and weed ecological evidence discussed in Chapter 5, which similarly reveals the Central Zone as a particular locus for mouldboard ploughing, especially by phase E. It is also consistent with this area's broad (but not exact) correspondence with the 'Central Province' heartlands of open-field farming and village nucleation, considering Williamson's arguments that heavier, clayey terrains in these parts of the country naturally compelled the development of cooperative modes of agriculture and settlement (Roberts and Wrathmell 2000; Williamson 2003).

It should be noted that this interpretation presupposes the cultural and economic desirability of free-threshing wheat: the notion that, given the opportunity, early medieval English farmers had strong reasons to enhance wheat production. Indeed, there is good documentary evidence for the cultural and economic value of wheat in early medieval England (as assembled by Banham 2010). But the archaeobotanical data imply that this value, this desirability, was not exclusive. For, to reiterate, barley and oats—and sometimes also rye—were widely and frequently

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[2] This perspective closely mirrors the model for Anglo-Saxon wheat cultivation posited by Banham (2010).

grown across several regions (see above). Moreover, the relative productivity heatmaps suggest that the 'wheat belt' consolidated over time but did not spread—which might have indicated a growing demand for wheat (Figure A4.9). Rather, the other three crops were clearly also in wide demand throughout the period. Although there are no such broad and striking regional trends in the relative productivity of the other crops, nothing resembling the wheat belt, there are nonetheless some more contained indications of regional or environmental specialization.

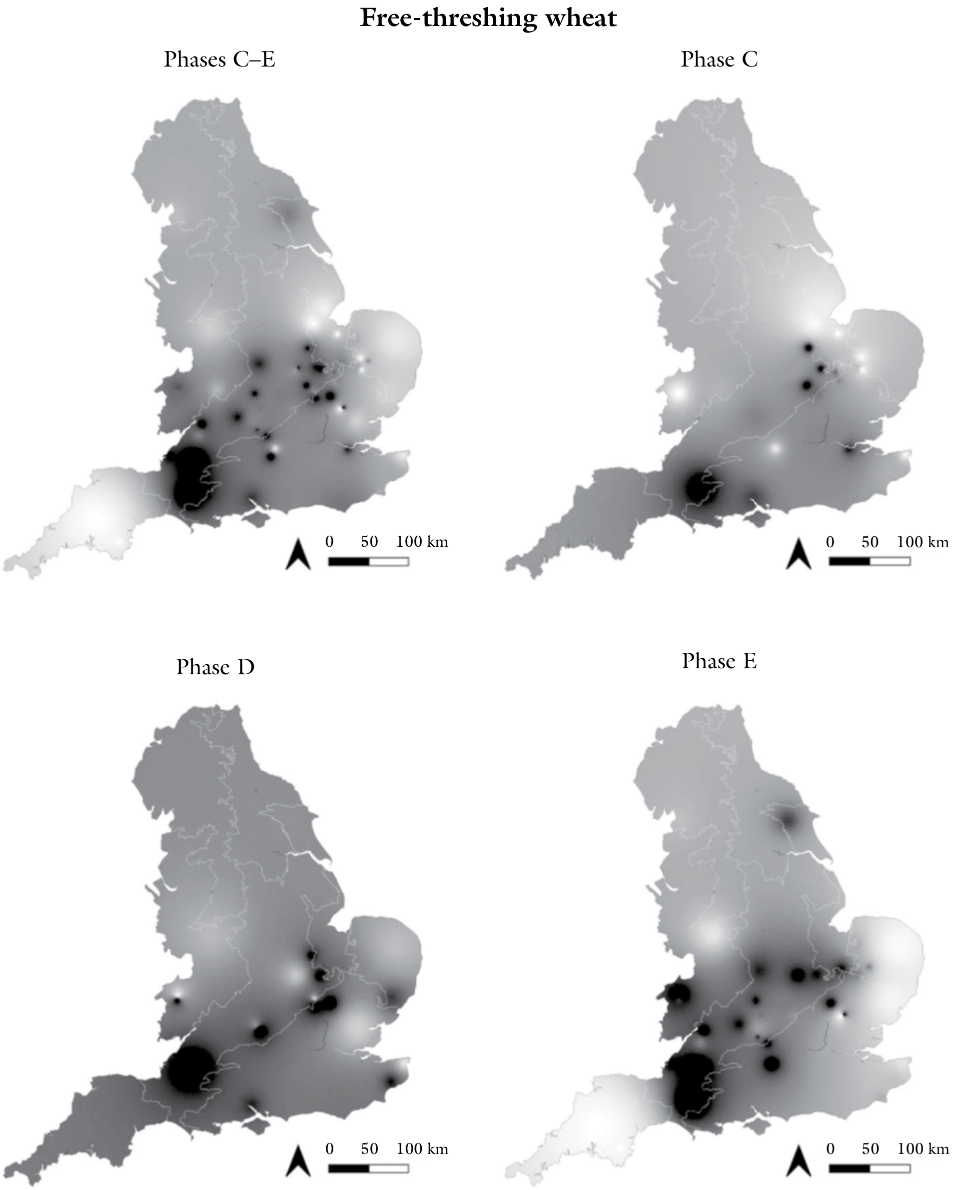

FIGURE A4.9. Relative productivity heat maps for free-threshing wheat.

So, for instance, the Fens—specifically, the silt fens—display the biggest 'hotspot' for barley in the relative productivity heatmaps (Figure A4.10), illustrating once again the correlation between this saline environment and salt-tolerant crop (as observed by Murphy 2010, and noted above in the frequency data: Figure A4.6). As with the frequency results for the Fens, the fact that this barley hotspot appears only in the map for phase C is plausibly due to the absence of any data for the silt fens in phases D–E, rather than representing an end to local barley cultivation. Two other, rather smaller barley hotspots seem to persist through phases C–E, occupying environments very different from the silt fens: the free-draining soils of Thanet in north-east Kent (South East region), and Holmer and Wellington Quarry in the Western Lowlands—the same area we have seen above as a wheat hotspot, so clearly not a place that specialized exclusively in either barley or wheat cultivation but rather perhaps had multiple discrete specialisms in separate parts of the landscape.

So, with the possible exception of Thanet, any starkly defined preference for barley cultivation on light soils—such as on chalk downlands—appears conspicuous by its absence. This does not mean that barley-rich samples are absent from such environments. There are some barley-rich samples from Bishopstone on the chalk South Downs, for instance, and from Ipswich near the sandy Suffolk coast. But in neither case do they constitute an overriding local or regional pattern; rather, other samples from the same sites are dominated by other crops (such as wheat, at Bishopstone). This fact perhaps explains why, despite barley's generally high prevalence and frequency, its relative productivity heatmaps appear largely pale, especially in phases D–E. Barley was in almost every settlement's crop repertoire and was very frequently grown throughout the period—in other words, it was a widespread staple—but it was almost never the most *productive* crop. The chief exception to this generalization is of course the silt fens, where the environment was perhaps too salty to support a decent yield from any other crop (see also Chapter 4).

Turning now to oats: the heatmaps are broadly consistent with a general increase in oat cultivation over time, with the overall shading tending to darken through phases C–E, especially in the South West and East Anglia (plus Essex, in the South East region)—rather like a negative of the picture for free-threshing wheat (Figure A4.11, *cf.* Figure A4.9). There are no appreciable hotspots in phase C, but for phase D the main locus is Springfield Lyons (Essex, South East), which has six samples with 90–100% oat grains.[3] In phase E, there are darker patches around Stansted (Essex, west of Springfield Lyons) and Ipswich (the Suffolk port town, where twelve samples have 99–100% oat grains).[4] Some oat-rich samples at Norwich Castle in phases D and E leave something of a smudge in central Norfolk too.

It is fair to note that, as a rule, such sites need not be representative of wider trends in cropping preferences. For instance, Murphy suggests that the oat-rich samples at Springfield Lyons and Ipswich could derive specifically from burnt fodder stores, thus biasing the assemblage towards a crop (*i.e.* oats) which may have been harvested specifically for feeding animals. In support of this idea, he cites a horseshoe and spur that were found in the same cellar fill as the charred oat deposits at Foundation Street in Ipswich (Murphy 2005, 159–60). The implication is that these data thus reflect a particular local usage of oats, rather than a more general special role for oats in the cereal economy. But the FeedSax dataset now shows that relatively oat-rich

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[3] Springfield Lyons may have been experimenting with seasonal sowing: see Chapter 4.

[4] All from a single excavation site at Foundation Street.

Barley

Phases C–E

Phase C

Phase D

Phase E

FIGURE A4.10. Relative productivity heat maps for barley.

samples may be characteristic of a wider region, embracing East Anglia and Essex, and not simply at these ‘central places’ such as towns and castles. There is no obvious indication that the settlement at Stansted, for instance, was of high or central status; nor that all the contexts with oat-rich deposits have clear equine associations.

The clearest regional trend in the oat data, however, is in the South West, and echoes the observations of Rippon *et al.* (2014, 231–6): agriculture in this region focused heavily on oats, and also rye, with wheat or barley generally much less in evidence. The FeedSax data for this region are heavily biased towards the Lydford granaries assemblages (phase E), but Rippon *et al.* trace this emphasis on oats back as far as the fifth century; there are also oat-rich samples at Ottery St Mary as late as phase G1 (*c.*1300–1360). Oat cultivation thus appears to be a mainstay of a long regional tradition.

Is there anything here to suggest a strong environmental factor influencing the productivity of oats in the landscape? Climate is certainly not a common factor. East Anglia and the South West experience 'Continental' and 'Atlantic' climates, respectively: the former drier but with harsher winters, the latter wetter but with milder winters (*e.g.* Silverside 1977, 8–9; 18–19). In terms of terrain and geology, each area has significant intraregional variety: including limestone, chalk, sands, and moorland in the South West; and wetlands, heathlands, clay vales, chalk, and the distinctive sandy Breckland in East Anglia. We should also remember that—heatmaps notwithstanding—the prevalence and frequency results for oats in East Anglia are relatively but not extraordinarily high for any phase; oats are consistently more widespread in the Central Zone than in East Anglia, for instance (Figure A4.3).[5] Following the reasoning above for wheat, therefore, we might instead say that East Anglian and South Western farmers made—relatively, and increasingly through phases D–E—more productive use of their oat-lands. Moffett (2006, 48, table 4.3) writes that oats not only tolerate poorer soils than do other cereals but also 'yield less than other cereals grown in good conditions'. The implication of productive oat cultivation may therefore be that, whereas Central Zone farmers optimized and extended their use of rich heavy clays, East Anglian and South Western farmers optimized their use of poorer soils for arable farming through careful selection and pairing of crops and lands.

Such an interpretation is further supported by the data for rye. As we have already seen, it seldom approaches ubiquity, except for in East Anglia during phase D, although this peak is set against a gentle fall in frequency in this region across the period (Figures A4.4 and A4.8). Conversely, rye becomes less widespread in the South East during phase D, despite a gentle overall rise in frequency across the period. But the most pronounced hotspot in the rye heatmaps centres on the sandy Brecklands, mainly in phase C (Figure A4.12), when that particular spot is especially well represented in the dataset. As noted in earlier studies, the cultivation of relatively drought-tolerant, deep-rooted rye seems a sensible way to make most productive arable use of this notably dry district (*e.g.* McKerracher 2018, 102–6). Another apparently productive zone of rye cultivation appears in the South West—specifically, a local pattern characteristic of the Lydford granary assemblage (phases E3–E4) rather than the South West as a whole. Since rye performs relatively well on acid soils (*e.g.* Briggle 1959, 3), it is significant that Lydford's immediate hinterland includes much in the way of free-draining acid soils.[6]

Two other darker patches on these maps, for phases D and E, are accounted for by individual sites: Howgill Brook (Northern Uplands), which again is situated among acid soils, and Stafford (Western Lowlands)—but the latter should not, in this instance, be seen as a measure of local rye productivity in the Western Lowlands. Despite having some rye-rich samples, Stafford is in fact notable for having a very crop-diverse assemblage. All four main cereals are

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[5] No prevalence and frequency data are available for the South West, because of the relative scarcity of data for this region.

[6] https://www.landis.org.uk/soilscapes/index.cfm (accessed September 2023).

Oats

Phases C–E

Phase C

Phase D

Phase E

FIGURE A4.11. Relative productivity heat maps for oat.

well represented at Stafford, along with some rarities: bristle oat, two-row barley, and a tetraploid wheat (Moffett 1987). We should also recall the marked peak in the frequency of oats and rye in the Western Lowlands around phase D (Figures A4.7 and A4.8)—another symptom, perhaps, of a flair for experimentation and ultimately perhaps crop rotation in this region (*cf.* Hamerow *et al.* 2020; and Chapter 4 on rotation).

In conclusion, two overarching ideas have emerged from this discussion. First, the three proxies for the importance of crops are rarely in simple alignment, and no single proxy can accurately reflect the fuller, more complex picture. One could not, for instance, predict the 'wheat belt' from the prevalence and frequency data. Conversely, the frequency data for wheat could be taken to imply a heartland of wheat growing in the Western Lowlands, whereas in fact crop diversity is a marked characteristic of the largest assemblage in that region (*i.e.* Stafford). Second, the three proxies together paint a general picture of a relatively stable crop spectrum in many places, with some increased intraregional variety across phases D–E, and a widespread but not universal tendency to optimize arable productivity through both technological innovation (*i.e.* mouldboard ploughing) and/or ecologically sensitive cropping choices. While many of these

FIGURE A4.12. Relative productivity heat maps for rye.

tendencies seem to become more pronounced over time, however, they are continuing trends that were apparently set in train as early as the seventh century, and which therefore do not seem to have been simply dependent on the growth of urban markets, or socio-cultural impacts such as Viking incursions and the establishment of the Danelaw. The 'wheat belt', in particular, bears no obvious relation to a single, geographical explanatory variable, and barley's general resilience as a widespread staple appears to have resisted all the vicissitudes of the early medieval period.

BIBLIOGRAPHY

Adhikari, S., Burke, I.C., and Eigenbrode, S.D. (2020). 'Mayweed chamomile (*Anthemis cotula* L.) biology and management—a review of an emerging global invader'. *Weed Research* 60: 313–22. https://doi.org/10.1111/wre.12426

Albarella, U. (1997a). 'Shape variation of cattle metapodials: age, sex or breed? Some examples from medieval and postmedieval sites'. *Anthropozoologica* 25–6: 37–47.

Albarella, U. (1997b). 'Size, power, wool and veal: zooarchaeological evidence for late medieval innovations', in G. De Boe and F. Verhaeghe (eds), *Environment and Subsistence in Medieval Europe*. Brugge: Institute for the Archaeological Heritage of Flanders 9, 19–31.

Albarella, U. (1999). '"The mystery of husbandry": medieval animals and the problem of integrating historical and archaeological evidence'. *Antiquity* 73: 867–75.

Albarella, U. (2019). *A Review of Animal Bone Evidence from Central England*. Portsmouth: Historic England.

Albarella, U. and Pirnie, T. (2008). *A Review of Animal Bone Evidence from Central England Evidence [dataset]*. York: Archaeology Data Service. https://doi.org/10.5284/1000317

Allen, M. (2017). 'Pastoral farming', in M. Allen, L. Lodwick, T. Brindle, M. Fulford, and A. Smith (eds), *New Visions of the Countryside of Roman Britain Volume 2: The Rural Economy of Roman Britain*. London: Britannia Monograph 30, 85–141.

Allison, J., Cottee, J., Godson, J. and Haigh, M. (2017). *The Variety of Village Life. A Snapshot in Time: Laxton in Peace and War, 1900–1920.* Laxton: Laxton History Group.

Andersen, S.T. (1979). 'Identification of wild grass and cereal pollen'. *Danmarks Geologiske Undersøgelse, Årbog* 1978 66–92.

Anyia, A.O., Slaski, J.J., Nyachiro, J.M., Archambault, D.J., and Juskiw, P. (2007). 'Relationship of carbon isotope discrimination to water use efficiency and productivity of barley under field and greenhouse conditions'. *Journal of Agronomy and Crop Science* 193 (5): 313–23.

Arnold, C.J. and Wardle, P. (1981). 'Early medieval settlement patterns in England'. *Medieval Archaeology* 25: 145–9.

Astill, G. (2009). 'Anglo-Saxon attitudes. How should post-AD 700 burials be interpreted?', in D. Sayer and H. Williams (eds), *Mortuary Practices and Social Identities in the Middle Ages*. Exeter: Liverpool University Press, 222–35.

Audouy, M. and Chapman, A. (2009). *Raunds. The Origin and Growth of a Midland Village, AD 450–1500: Excavations in North Raunds, Northamptonshire 1977–87.* Oxford: Oxbow Books.

Ayres, K., Ingrem, C., Light, J., Locker, A., Mulville, J., and Serjeantson, D. (2003). 'Mammal, bird and fish remains and oysters', in A. Hardy, A. Dodd, and G. Keevill (eds), *Aelfric's Abbey: Excavations at Eynsham Abbey, Oxfordshire 1989–1992.* Oxford: Oxford Archaeology, 341–432.

Bakels, C. (2012). 'The early history of Cornflower (*Centaurea cyanus* L.) in the Netherlands', *Acta Palaeobotanica* 52 (1): 25–31.

Baker, J. and Brothwell, D. (1980). *Animal Diseases in Archaeology*. London: Academic Press.

Baker, P. and Worley, F. (2019). *Animal Bones and Archaeology: Guidelines for Best Practice*. Portsmouth: English Heritage.

Ballantyne, R. (2005). 'Plants and seeds', in R. Mortimer, R. Regan, and S. Lucy (eds), *The Saxon and Medieval Settlement at West Fen Road, Ely: The Ashwell Site*. Cambridge: Cambridge Archaeological Unit, 100–12.

Ballantyne, R. (2010). 'Charred and mineralised biota', in G. Thomas (ed.), *The Later Anglo-Saxon Settlement at Bishopstone: A Downland Manor in the Making, CBA Research Report 163*. York: Council for British Archaeology, 164–76.

Banham, D. (2010). '"In the Sweat of thy Brow Shalt thou eat Bread": cereals and cereal production in the Anglo-Saxon landscape', in N.J. Higham and M.J. Ryan (eds), *The Landscape Archaeology of Anglo-Saxon England*. Woodbridge: Boydell Press, 175–92.

Banham, D. and Faith, R. (2014). *Anglo-Saxon Farms and Farming*. Oxford: Oxford University Press.

Barnebeck Anderen, T., Sandholt Jensen, P., and Volmar Skovsgaard, C. (2016). 'The heavy plow and the agricultural revolution in Medieval Europe'. *Journal of Development Economics* 118: 133–49.

Barrett, J., Locker, A., and Roberts, C. (2004). 'The origins of intensive marine fishing in medieval Europe: the English evidence'. *Proceedings of the Royal Society* 271: 2417–21.

Bartley, D.D. and Morgan, A.V. (1990). 'The palynological record of the King's Pool, Stafford, England', *New Phytologist* 116: 177–94.

Bartley, D.D., Chambers, C. and Hart-Jones, B. (1976). 'The vegetational history of parts of south and east Durham', *New Phytologist* 77: 437–68.

Bartosiewicz, L. (2008). 'Environmental stress in early domestic sheep', in Z. Miklíková and R. Thomas (eds), *Current Research in Animal Palaeopathology: Proceedings of the Second ICAZ Animal Palaeopathology Working Group Conference*. Oxford: British Archaeological Reports, British Series S1844: 3–13.

Bartosiewicz, L. and Gál, E. (2013). *Shuffling Nags, Lame Ducks: The Archaeology of Animal Disease*. Oxford: Oxbow.

Bartosiewicz, L., Van Neer, W., and Lentacker, A. (1997). *Draught Cattle: Their Osteological Identification and History*. Belgium: Musee Royal de L'Afrique Centrale Tervuren, Belgique.

Batchelor, C.R. (2009). *Middle Holocene Environmental Changes and the History of Yew (Taxus baccata L.) Woodland in the Lower Thames Valley*. Unpublished PhD thesis, Royal Holloway, University of London.

Bates, A. and Nicholson, R. (2011). 'The animal and fish bones', in R. Brown and A. Hardy (eds), *Trade and Prosperity, War and Poverty: An Archaeological and Historical Investigation into Southampton's French Quarter. Oxford Archaeology Monograph 15*. Oxford: Oxford Archaeology, 233–40.

Beales, P.W. (1980). 'The Late Devensian and Flandrian vegetational history of Crose Mere, Shropshire', *New Phytologist* 85: 133–61.

Becket, J.V. (1990). *The Agricultural Revolution*. Oxford: Basil Blackwell.

Beckett, S. and Hibbert, F. (1979). 'Vegetational change and the influence of prehistoric man in the Somerset Levels', *New Phytologist* 83: 577–600.

Beghin, R., Cherubini, P., Battipaglia, G., Siegwolf, R., Saurer, M., and Bovio, G. (2011). 'Tree-ring growth and stable isotopes (^{13}C and ^{15}N) detect effects of wildfires on tree physiological processes in *Pinus sylvestris* L.'. *Trees* 25: 627–36. https://doi.org/10.1007/s00468-011-0539-9

Behrensmeyer, A.K. (1978). 'Taphonomic and ecologic information from bone weathering'. *Paleobiology* 4 (2): 150–62.

Bennett, K.D. (1983). 'Devensian late-glacial and Flandrian vegetational history at Hockham Mere, Norfolk, England. I. Pollen percentages and concentrations', *New Phytologist* 95 (3): 457–87.

Bennett, K.D. (1994). *Annotated Catalogue of Pollen and Pteridophyte Spore Types of the British Isles.* Cambridge: Department of Plant Sciences, University of Cambridge.

Beresford, G. (1987). *Goltho: The Development of an Early Medieval Manor, c. 850–1150.* London: Historic Buildings and Monuments Commission.

Bevan, A., Colledge, S., Fuller, D., Fyfe, R, Shennan, S., and Stevens, C. (2017). 'Holocene fluctuations in human population demonstrate repeated links to food production and climate'. *PNAS* 114 (49): E10524–31.

Blackford, J.J. and Chambers, F.M. (1991). 'Proxy records of climate from blanket mires: Evidence for a Dark Age (1400 BP) climatic deterioration in the British Isles', *The Holocene* 1: 63–7.

Blair, W.J. (2015). 'The making of the English house: domestic planning, 900–1150'. *Anglo-Saxon Studies in Archaeology and History* 19: 184–206.

Blair, W.J. (2018). *Building Anglo-Saxon England.* Princeton: Princeton University Press.

Blair, W.J., Rippon, S., and Smart, C. (2020). *Planning in the Early Medieval Landscape.* Liverpool: Liverpool University Press.

Blinkhorn, P. (2012). *The Ipswich Ware Project: Ceramics, Trade and Society in Middle Saxon England.* London: Medieval Pottery Research Group.

Bloch, M. (1966). *French Rural History. An Essay on Its Basic Characteristics.* Trans. J. Sondheimer. London: Routledge and Kegan Paul.

Boas, A. (2016). *Crusader Archaeology, The Material Culture of the Latin East*, 2nd ed. London: Routledge.

Bogaard, A. (2002). 'Questioning the relevance of shifting cultivation to Neolithic farming in the loess belt of Europe: evidence from the Hambach Forest experiment', *Vegetation History and Archaeobotany* 11: 155–68.

Bogaard, A. (2004). *Neolithic Farming in Central Europe.* London: Routledge.

Bogaard, A., Fochesato, M., and Bowles, S. (2019). 'The farming-inequality nexus: new insights from ancient Western Eurasia'. *Antiquity* 93: 1129–43.

Bogaard, A., Fraser, R., Heaton, T.H.E., Wallace, M., Vaiglova, P., Charles, M., Jones, G., Evershed, R.P., Styring, A.K., Andersen, N.H., Arbogast, R.-M., Bartosiewicz, L., Gardeisen, A., Kanstrup, M., Maier, U., Marinova, E., Ninov, L., Schäfer, M., and Stephan, E. (2013). 'Crop manuring and intensive land management by Europe's first farmers'. *Proceedings of the National Academy of Sciences* 110: 12589–94.

Bogaard, A., Heaton, T.H., Poulton, P., and Merbach, I. (2007). 'The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices'. *Journal of Archaeological Science* 34 (3): 335–43.

Bogaard, A., Hodgson, J., Kropp, C., McKerracher, M., and Stroud, E. (2022). 'Lessons from Laxton, Highgrove and Lorsch: building arable weed-based models for the investigation of early medieval agriculture in England', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow.* Liverpool: Liverpool University Press, 25–39.

Bogaard, A., Hodgson, J., Nitsch, E., Jones, G., Styring, A., Diffey, C., Pouncett, J., Herbig, C., Charles, M., Ertuğ, F., Tugay, O. Filipovic, D., and Fraser, R. (2016). 'Combining functional weed ecology and crop stable isotope ratios to identify cultivation intensity: a comparison of cereal production regimes in Haute Provence, France and Asturias, Spain'. *Vegetation History and Archaeobotany* 25: 57–73. https://doi.org/10.1007/s00334-015-0524-0

Bogaard, A., Jones, G., Charles, M., and Hodgson, J.G. (2001). 'On the archaeobotanical inference of crop sowing time using the FIBS method'. *Journal of Archaeological Science* 28: 1171–83.

Bogaard, A., Jones, G. and Charles, M. (2005). 'The impact of crop processing on the reconstruction of crop sowing time and cultivation intensity from archaeobotanical weed evidence', *Vegetation History and Archaeobotany* 14: 505–9.

Bonafini, M., Pellegrini, M., Ditchfield, P., and Pollard, A.M. (2013). 'Investigation of the "canopy effect" in the isotope ecology of temperate woodlands. *Journal of Archaeological Science* 40 (11): 3926–35.

Boserup, E. (1965). *The Conditions of Agricultural Growth*. London: Allen and Unwin.

Bourdillon, J. (1993). 'Animal bones', in M. Garner 'Middle Saxon evidence at Cook Street, Southampton (SOU 254)'. *Proceedings of the Hampshire Field Club and Archaeological Society* 49, 116–20.

Bourdillon, J. (1994). 'The animal provisioning of Saxon Southampton', in J. Rackham (ed.), *Environment and Economy in Anglo-Saxon England*. York: Council for British Archaeology, 120–5.

Bourdillon, J. (2006). 'Animal bones', in P. Williams and R. Newman (eds), *Market Lavington, Wiltshire: An Anglo-Saxon Cemetery and Settlement*. Salisbury: Wessex Archaeology, 150–69.

Branch, N.P., Burn, M., Green, C.P., Silva, B., Swindle, G.E., and Turton, E. (2005). *Whittlewood Project: Preliminary Results of the Environmental Archaeological Investigations*. York: Archaeological Data Service.

Briggle, L.W. (1959). *Growing Rye*. Washington D.C.: U.S. Department of Agriculture.

Broadberry, S., Campbell, B., and van Leeuwen, B. (2010). *English Medieval Population: Reconciling Time Series and Cross-Sectional Evidence*. https://warwick.ac.uk/fac/soc/economics/seminars/seminars/conferences/venice3/programme/english_medieval_population.pdf

Bronk Ramsey, C. (2008). 'Deposition models for chronological records'. *Quaternary Science Reviews* 27: 42–60.

Bronk Ramsey, C. (2009). 'Bayesian analysis of radiocarbon dates'. *Radiocarbon* 51: 337–60.

Bronk Ramsey, C. and Lee, S. (2013). 'Recent and planned developments of the program OxCal'. *Radiocarbon* 55: 720–30.

Brookfield, H.C. (1972). 'Intensification and disintensification in Pacific agriculture: a theoretical approach'. *Pacific Viewpoint* 13: 211–38.

Brown, A.D. (2006). *Late-Holocene palaeoclimates: cross-validation of multiple proxies from lake and bog archives in Northern England*. Unpublished PhD thesis, University of Southampton.

Brown, A.G. (1988). 'The palaeoecology of Alnus (alder) and the Postglacial history of floodplain vegetation. Pollen percentages and influx data from the West Midlands, United Kingdom', *New Phytologist* 110: 425–36.

Brown, A.P. (1977). 'Late-Devensian and Flandrian vegetational history of Bodmin Moor, Cornwall'. *Philosophical Transactions of the Royal Society of London B* 276: 251–320.

Brown T. and Foard, G. (1998). 'The Saxon landscape: a regional perspective', in P. Everson and T. Williamson (eds), *The Archaeology of Landscape*. Manchester: Manchester University Press, 67–94.

Brown, R., Teague, S., Loe, L., Sudds, B., and Popescu, E. (2020). *Excavations at Stoke Quay, Ipswich: Southern Gipeswic and the Parish of St Augustine*. Norwich: East Anglian Archaeology.

Büntgen, U. and Tegel, W. (2011). 'European tree-ring data and the Medieval Climate Anomaly'. *PAGES News* 19 (1): 14–15.

Büntgen, U., Myglan, Vladimir S., Ljungqvist, Fredrik Charpentier, McCormick, Michael, Di Cosmo, Nicola, Sigl, Michael, Jungclaus, Johann, Wagner, Sebastian, Krusic, Paul J., Esper, Jan, Kaplan, Jed O., de Vaan, Michiel A.C., Luterbacher, Jürg, Wacker, Lukas, Tegel, Willy, and Kirdyanov, Alexander V. (2016). 'Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660'. *Nature Geoscience* 9: 231–6.

Bunting, J., Gaillard, M.J., Sugita, S., Middleton, R., and Broström, A. (2004). 'Vegetation structure and pollen source area'. *The Holocene* 14: 651–60.

Bush, M.B. (1988). 'Early Mesolithic disturbance: a force on the landscape', *Journal of Archaeological Science* 15: 453–62.

Bush, M.B. (1993). 'An 11 400 year palaeoecological history of a British chalk grassland', *Journal of Vegetation Science* 4: 47–66.

Campbell, B. (1981). 'Commonfield origins. The regional dimension', in T. Rowley (ed.), *The Origins of Open Field Agriculture*. London: Routledge, 112–29.

Campbell, B. (1983). 'Agricultural progress in Medieval England: some evidence from Eastern Norfolk'. *The Economic History Review* 36 (1): 26–46.

Campbell, B. (1991). 'Land, labour, livestock, and productivity trends in English seigniorial agriculture 1208–1450', in B. Campbell and M. Overton (eds), *Land, Labour and Livestock: Historical Studies in European Agricultural Productivity*. Manchester: Manchester University Press, 144–82.

Campbell, B. and Overton, M. (1991). *Land, Labour and Livestock. Historical Studies in European Agricultural Productivity*. Manchester: Manchester University Press.

Campbell, B.M. (2000). *English Seigniorial Agriculture 1250–1450*. Cambridge: Cambridge University Press.

Campbell, B.M.S. and Overton, M. (1993). 'A new perspective on Medieval and Early Modern agriculture: six centuries of Norfolk farming c.1250–c.1850'. *Past and Present* 141: 38–105.

Campbell, G. (2009). 'Plant and invertebrate remains', in M. Audouy and A. Chapman (eds), *Raunds. The origin and growth of a midland village AD 450–1500. Excavations in north Raunds, Northamptonshire 1977–87*. Oxford: Oxbow Books, 222–47.

Campbell, G. and Robinson, M. (2010). 'The environmental evidence', in A. Chapman (ed.), *West Cotton, Raunds: A Study of Medieval Settlement Dynamics AD 450–1450. Excavation of a Deserted Medieval Hamlet in Northamptonshire, 1985–89*. Oxford: Oxbow Books, 427–515.

Campbell, G., Moffett, L., and Straker, V. (2011). *Environmental Archaeology. A Guide to the Theory and Practice of Methods, from Sampling and Recovery to Post-excavation*. 2nd ed. Swindon: English Heritage.

Carlson Dietmeier, J.K. (2018). 'The oxen of Oxon Hill Manor: pathological analyses and cattle husbandry in eighteenth-century Maryland'. *International Journal of Osteoarchaeology* 28 (4): 419–27.

Caroe, H. (2022a). *"For a quart of ale is a dish for a king!" Malting, Brewing and Beer in the Mid Anglo-Saxon Period*. DPhil thesis, University of Oxford.

Caroe, H. (2022b). 'Malting brewing and beer in Anglo-Saxon England. Mid Saxon Sedgeford. A case study', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 179–98.

Carruthers, W. (2011). 'The charred and mineralised plant remains', in A. Thompson, P. Chapman, and A. Chapman (eds), *Anglo-Saxon and Medieval Settlement at the Former Post Office Training Establishment, Wolverton Mill, Milton Keynes, Buckinghamshire. Excavations 2004*. Northampton: Northamptonshire Archaeology Report 11/50, 37–45.

Carver, M.O.H. (2010). *Stafford Field Reports 1975–1990: FR9*. York: Archaeology Data Service (distributor). https://doi.org/10.5284/1000117

Chapman, A. (2010). *West Cotton, Raunds: A Study of Medieval Settlement Dynamics AD 450–1450. Excavation of a Deserted Medieval Hamlet in Northamptonshire, 1985–89*. Oxford: Oxbow Books.

Charles, M., Forster, E., Wallace, M., and Jones, G. (2015). '"Nor ever lightning char thy grain": establishing archaeologically relevant charring conditions and their effect on glume wheat grain morphology'. *STAR: Science & Technology of Archaeological Research* 1 (1): 1–6.

Charles, M., Jones, G., and Hodgson, J.G. (1997). 'FIBS in archaeobotany: functional interpretation of weed floras in relation to husbandry practices'. *Journal of Archaeological Science* 24 (12): 1151–61.

Charman D. (1992). 'The effects of acetylation on fossil Pinus pollen and Sphagnum spores discovered during routine pollen analysis'. *Review of Palaeobotany and Palynology* 72: 159–64.

Charman, D.J. (2010). 'Centennial climate variability in the British Isles during the Mid–Late Holocene', *Quaternary Science Reviews* 29: 1539–54.

Clapham, A.R., Tutin, T.G. and Moore, D.M. (1987). *Flora of the British Isles*. 3rd edition. Cambridge: Cambridge University Press.

Clarke, G. (2023). *Salt-Winning on the Lyn: Anglo-Saxon and Medieval Industry at Gaywood's North Marsh, King's Lynn, East Anglian Archaeology* 180.

Clutton-Brock, J. (1976). 'The animal resource', in D. Wilson (ed.), *The Archaeology of Anglo-Saxon England*. London: Methuen, 373–92.

Cobain, S. (2019). 'Plant macrofossils and charcoal', in T. Havard, M. Alexander and R. Holt (eds), *Iron Age Fortification Beside the River Lark: Excavations at Mildenhall, Suffolk. East Anglian Archaeology Report* 169. Cirencester: Cotswold Archaeology, 130–40.

Comet, G. (1997). 'Technology and agricultural expansion in the Middle Ages. The example of France, North of the Loire', in G. Astill and J. Langdon (eds), *Medieval Farming and Technology. The Impact of Agricultural Change in Northwest Europe*. Leiden: Brill, 16–39.

Cook, G.D. (2001). 'Effects of frequent fires and grazing on stable nitrogen isotope ratios of vegetation in northern Australia'. *Austral Ecology* 26: 630–6. https://doi.org/10.1046/j.1442-9993.2001.01150.x

Coombes, P.M.V., Chiverrell, R.C. and Barber, K.E. (2009). 'A high-resolution pollen and geochemical analysis of late Holocene human impact and vegetation history in southern Cumbria, England', *Journal of Quaternary Science* 24: 224–36.

Costello, E. (2021). 'The Colonisation of Uplands in Medieval Britain and Ireland: Climate, Agriculture and Environmental Adaptation', *Medieval Archaeology* 65 (1): 151–79. https://doi.org/10.1080/00766097.2020.1826123

Coy, J. (1980). 'The animal bones', in J. Haslam (ed.), 'A Middle Saxon Iron Smelting Site at Ramsbury, Wiltshire'. *Medieval Archaeology* XXIV, 41–53.

Crabtree, P. (1989). 'Sheep, horses, swine, and kine: a zooarchaeological perspective on the Anglo-Saxon settlement of England'. *Journal of Field Archaeology* 16: 205–13.

Crabtree, P. (1996a). 'Production and consumption in an early complex society: animal use in middle Saxon East Anglia'. *World Archaeology* 28 (1): 58–75.

Crabtree, P. (1996b). 'The wool trade and the rise of urbanism in middle Saxon England', in B. Wailes (ed.), *Craft Specialization and Social Evolution: In Memory of V. Gordon Childe*. Pennsylvania: University of Pennsylvania Museum of Archaeology and Anthropology, 99–105.

Crabtree, P. (2012). *Middle Saxon Animal Husbandry in East Anglia*. Bury St Edmunds: East Anglian Archaeology, 143.

Crabtree, P. (2014). 'Animal husbandry and farming in East Anglia from the 5th to the 10th centuries CE'. *Quaternary International* 346: 102–8.

Crabtree, P. (2018). *Early Medieval Britain: The Rebirth of Towns in the Post-Roman West*. Cambridge: Cambridge University Press.

Creighton, O. and Rippon, S. (2017). 'Conquest, colonisation, and the countryside', in D. Hadley and C. Dyer (eds), *The Archaeology of the Eleventh Century*. London: Society for Medieval Archaeology, 57–87.

Crowson, A., Lane, T., Penn, K., and Trimble, D. (2005). *Anglo-Saxon Settlement on the Siltland of Eastern England*. Sleaford: Lincolnshire Archaeology and Heritage Reports, 7.

Cunliffe, B. (1975). *Excavations at Portchester Castle. Volume II: Saxon*. London: Society of Antiquaries.

Cutress, T. and Ludwig, T. (1969). 'Periodontal disease in sheep 1. Review of the literature'. *Journal of Periodontology-Periodontics* 40 (9): 529–34.

Darby, H.C. (1977). *Domesday England*. Cambridge: Cambridge University Press.

Dark, P. (2000). *The Environment of Britain in the First Millennium AD*. London: Duckworth.

Davis, S. (1996). 'Measurements of a group of adult female Shetland sheep skeletons from a single flock: a baseline for zooarchaeologists'. *Journal of Archaeological Science* 23: 593–612.

Davis, S.J., Svensson, E.M., Albarella, U., Detry, C., Gotherstrom, A., Pires, A.E., and Ginja, C. (2012). 'Molecular and osteometric sexing of cattle metacarpals: a case study from 15th century AD Beja, Portugal'. *Journal of Archaeological Science* 39: 1445–54.

Day, S.P. (1991). 'Post-glacial vegetational history of the Oxford region', *New Phytologist* 119: 445–70.

Day, S.P. (1993). 'Woodland origins and "ancient woodland indicators": a case study from Sidlings Copse, Oxfordshire, UK', *The Holocene* 3 (1): 45–53.

Dodds, B. (2008). 'Output and productivity: common themes and regional variations', in B. Dodds and R. Britnell (eds), *Agriculture and Rural Society after the Black Death: Common Themes and Regional Variations*. Hatfield: University of Hertfordshire Press, 73–88.

Donaldson, A.M. and Turner, J. (1977). 'A Holocene pollen diagram from Hallowell Moss, near Durham City, UK'. *Journal of Biogeography* 4: 25–33.

Douglas, D.C. and Greenaway, G. (1996). *English Historical Documents II, 1042–1189*. London: Routledge.

Dreslerová, D., Hajnalová, M., Trubač, J., Chuman, T., Kočár, P., Kunzová, E., and Šefrna, L. (2021). 'Maintaining soil productivity as the key factor in European prehistoric and Medieval farming'. *Journal of Archaeological Science: Reports* 35: 102633.

Duby, G. (1954). 'La révolution agricole médiévale'. *Revue de Géographie de Lyon* 29: 361–6.

Duby, G. (1962). *L'économie rurale et la vie des campagnes dans l'Occident médiéval*. Paris: Aubier.

Dyer, C. (1985). 'Power and conflict in the Medieval English village', in D. Hooke (ed.), *Medieval Villages*. Oxford: Oxford University Committee for Archaeology, 27–32.

Dyer, C. (1995). 'Sheepcotes: evidence for Medieval sheep farming'. *Medieval Archaeology* 39: 136–64.

Dyer, C. (1997). 'Medieval farming and technology: conclusion', in G. Astill and J. Langdon (eds), *Medieval Farming and Technology. The Impact of Agricultural Change in Northwest Europe*. Leiden: Brill, 293–313.

Dyer, C. (2002). *Making a Living in the Middle Ages*. Yale: Yale University Press.

Dyer, C. (2020). 'The historical background of the pre-Conquest site', in D. Hinton and D. Peacock (eds), *Impinging on the Past. A Rescue Excavation at Fladbury, Worcestershire, 1967. With an Account of the Historical Background by C. Dyer*. St Andrews: The Highfield Press, 54–9.

Dyer, C.C. (1981). *Warwickshire Farming 1349–c.1520: Preparations for Agricultural Revolution*. Dugdale Society Occasional Papers No. 27, Oxford.

Edwards, K.J., McIntosh, C.J., and Robinson, D.E. (1986). 'Optimising the detection of cereal-type pollen grains in pre-elm decline deposits'. *Circaea* 4: 11–13.

Engelaar, W., Matsumaru, T., and Yoneyama, T. (2000). 'Combined effects of soil waterlogging and compaction on rice (*Oryza sativa* L.) growth, soil aeration, soil N transformations and 15N discrimination'. *Biology and Fertility of Soils* 32: 484–93.

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

Fairbrother, J. (1990). *Faccombe Netherton: Excavations of a Saxon and Medieval Manorial Complex*, 2 vols. London: The British Museum.

Faith, R. (1997). *The English Peasantry and the Growth of Lordship*. London: Leicester University Press.

Faith, R. (2008). 'Forms of dominance and the early medieval landscape', *Medieval Settlement Research* 23: 9–13.

Faulkner, N. (2022). 'An agro-social revolution in a Mid Saxon village: making sense of the Sedgeford excavations', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 161–78.

Faulkner, N. and Blakelock, E. (2020). 'The excavation of a mid Anglo-Saxon malthouse at Sedgeford, Norfolk: an interim report'. *Anglo-Saxon Studies in Archaeology and History* 22: 68–95.

Faulkner, N., Rossin, G., and Robinson, K. (2014). *Digging Sedgeford: A People's Archaeology*. Lowestoft: Poppyland Publishing.

Finberg, H.P.R. (1972). ‘Anglo-Saxon England to 1042’, in Finberg, H.P.R. (ed.) *The Agrarian History of England and Wales I.2 - A.D. 43-1042*. Cambridge: Cambridge University Press, 383–525.

Fitter, A. and Peat, H.J. (1994). ‘The ecological flora database’, *Journal of Ecology* 82: 415–25.

Fitzherbert, A. (1523). *Boke of Husbandry*. London: Pynson.

Fleming, R. (2011). ‘Land use and people’, in J. Crick and E. van Houts (eds), *A Social History of England 900–1200*. Cambridge: Cambridge University Press, 15–37.

Forster, E. (2010). *Palaeoecology of human impact in Northwest England during the early medieval period: investigating ‘cultural decline’ in the Dark Ages*. Unpublished doctoral thesis, University of Southampton.

Forster, E. and Charles, M. (2022). ‘Agricultural land use in central, east and south-east England: arable or pasture?’, in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval ‘Agricultural Revolution’: Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 61–85.

Fowler, P. (1981). ‘Farming in the Anglo-Saxon landscape’. *Anglo-Saxon England* 9: 263–80.

Fowler, P. (2002). *Farming in the First Millennium AD*. Cambridge: Cambridge University Press.

Francis, P.D. and Slater, D.S. (1992). ‘A record of vegetation and land use change from upland peat deposits on Exmoor. Part 3: Codsend Moor’, *Proceedings of the Somerset Archaeology and Natural History Society* 136: 9–28.

Frank, D.A., Evans, R.D., and Tracy, B.F. (2004). ‘The role of ammonia volatilization in controlling the natural 15N abundance of a grazed grassland’. *Biogeochemistry* 68 (2): 169–78.

Fraser, R., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B.T., Halstead, P., Merbach, I., Poulton, P.R., Sparkes, D., and Styring, A. (2011). ‘Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices’. *Journal of Archaeological Science* 38: 2790–804.

Fyfe, R., Twiddle, C., Sugita, S., *et al.* (2013). ‘The Holocene vegetation cover of Britain and Ireland: overcoming problems of scale and discerning patterns of openness’. *Quaternary Science Reviews* 73: 132–48.

Fyfe, R. and Woodbridge, J. (2012). ‘Differences in time and space in vegetation patterning: analysis of pollen data from Dartmoor, UK’, *Landscape Ecology* 27: 745–60.

Fyfe, R.M., Brown, A.G., and Rippon, S.J. (2003). ‘Mid- to late-Holocene vegetation history of Greater Exmoor, UK: estimating the spatial extent of human-induced vegetation change’, *Vegetation History and Archaeobotany* 12: 215–32. https://doi.org/10.1007/s00334-003-0018-3

Fyfe, R.M., Brown, A.G. and Rippon, S.J. (2003). ‘Mid- to late-Holocene vegetation history of Greater Exmoor, UK: estimating the spatial extent of human-induced vegetation change’, *Vegetation History and Archaeobotany* 12 (4): 215–32.

Fyfe, R.M., Brown, A.G., and Rippon, S.J. (2004). ‘Characterising the late prehistoric, “Romano-British” and medieval landscape, and dating the emergence of a regionally distinct agricultural system in South West Britain’. *Journal of Archaeological Science* 31: 1699–714.

Gardiner, M. (2013). ‘Stacks, barns and granaries in early and high Medieval England’, in A. Vigil-Escalera Guirado, G. Bianchi, and J.-A. Quiros (eds), *Horrea, Barns and Silos. Storage and Incomes in Early Medieval Europe*. Bilbao: Universidad del País Vasco, 23–38.

Giertz, W. (1996). 'Middle Meuse valley ceramics of Huy-type: a preliminary analysis'. *Medieval Ceramics* 20: 33–64.

Giertz, W. (2000). 'Reliefbandamphoren aus St Quirin im Kontext karolingischer Keramik', in M. Tauch (ed.), *Quirinus von Neuss. Beitrage zur Heiligen-, Stifts- und Münstergeschichte*. Cologne: Wienand, 222–71.

Giorgi, J. (2018). 'Charred plant remains', in G. Arnold, T. Rogers, and R. Bradley (eds), *Archaeological Investigations at Land to the North of Roman Road and West of the A49, Holmer West, Hereford, Herefordshire*, unpublished report by Worcestershire Archaeology, 26–9.

Gosden, C., Green, C., Cooper, A., Creswell, M., Donnelly, V., Fanconi, T., Glyde, R., Kamash, Z., Mallet, S., Morley, L., Stansbie, D., and Ten Harkel, L. (2021). *English Landscape and Identities. Investigating Landscape Change from 1500 BC to AD 1086*. Oxford: Oxford University Press.

Grant, A. (1982). 'The use of toothwear as a guide to the age of domestic ungulates', in B. Wilson, C. Grigson, and S. Payne (eds), *Ageing and Sexing Animal Bones from Archaeological Sites*. Oxford: British Archaeological Reports, 91–108.

Grant, A. (1988). 'Animal resources', in G. Astill and A. Grant (eds), *The Countryside of Medieval England*. Oxford: Blackwell, 149–87.

Grant, M.J. and Dark, P. (2006). *Re-evaluating the concept of woodland continuity and change in Epping Forest: new dating evidence from Lodge Road*. Unpublished Report for the Corporation of London.

Green, F.J. (1980). *Lydford, Devon: Grain Deposits from the 12th Century Granary*. Ancient Monuments Laboratory Reports (Old Series) 3108.

Green, C. and Cresswell, M. (2021). *The Shaping of the English Landscape. An Atlas of Archaeology from the Bronze Age to Domesday Book*. Oxford: Archaeopress.

Greenfield, H. (2006). 'Sexing fragmentary ungulate acetabulae', in D. Ruscillo (ed.), *Recent Advances in Ageing and Sexing Animal Bones*. Oxford: Oxbow, 68–86.

Greig, J. (2004). 'Wider landscape: pollen from the Yarnton floodplain', in G. Hey (ed.), *Yarnton: Saxon and Medieval Settlement and Landscape*. Oxford: Oxford Archaeology, 369–79.

Grigg, D. (1982). *The Dynamics of Agricultural Change: The Historical Experience*. London: Hutchinson.

Grime, J.P., Hodgson, J.G. and Hunt, R. (1988). *Comparative Plant Ecology: A Functional Approach to Common British Species*. London: Unwin Hyman.

Grogan, P., Burns, T.D., and Chapin, F.S. 3rd. (2000). 'Fire effects on ecosystem nitrogen cycling in a Californian bishop pine forest'. *Oecologia* 122: 537–44. https://doi.org/10.1007/s004420050977

Gron, K.J., Larsson, M., Gröcke, D.R., Andersen, N.H., Andreasen, M.H., Bech, J.H., Henriksen, P.S., Hilton, R.G., Jessen, M.D., Møller, N.A., and Nielsen, F.O. (2021). 'Archaeological cereals as an isotope record of long-term soil health and anthropogenic amendment in southern Scandinavia'. *Quaternary Science Reviews* 253: 106762.

Groot, M. (2005). 'Palaeopathological evidence for draught cattle on a Roman site in the Netherlands', in J. Davies, M. Fabiš, I. Mainland, M. Richards, and R. Thomas (eds), *Diet and Health in Past Animal Populations: Current Research and Future Directions*. Oxford: Oxbow, 52–7.

Groenewoudt, B.J. and van Lanen, R.J. (2018). 'Diverging decline. Reconstructing and validating (post) Roan population trends (AD 0-1000) in the Rhine-Meuse Delta'. *European Journal of Post-Classical Archaeologies* 8: 189–218.

Groves, J.A., Waller, M.P., Grant, M.J. and Schofield, J.E. (2012). 'Long-term development of a cultural landscape: the origins and dynamics of lowland heathland in southern England', *Vegetation History and Archaeobotany* 21: 453–70.

Haigh, M. (2016). *Open Field Farming in Laxton. A Snapshot in Time: Laxton in Peace and War, 1900–1920.* Laxton: Nottingham Local History Association.

Haimovici, A. and Haimovici, S. (1971). 'Sur la presence de parodontopathies marginales sur des restes subfossiles de mammifères de stations pre- et protohistoriques du territoire de la Roumanie'. *Bulletin de l'Groupe International des Rècherches Stomatologiques* 14: 259–71.

Hale, D.N. (1995). 'Pollen analysis of Saxon sump deposits at Westbury', in R. Ivens and P.S. Busby (eds), *Tattenhoe and Westbury: Two Deserted Medieval Settlements in Milton Keynes.* Aylesbury: Buckinghamshire Archaeological Society, 413–15.

Hall, A. and Huntley, J.P. (2007). *A Review of the Evidence for Macrofossil Plant Remains from Archaeological Deposits in Northern England.* English Heritage Research Department Report Series 87/2007.

Hall, D. (1982). *Medieval Fields.* Aylesbury: Shire Books.

Hall, D. (2014). *The Open Fields of England.* Oxford: Oxford University Press.

Halstead, P. (2009). 'The economy has a normal surplus: economic stability and social change among early farming communities of Thessaly, Greece', in P. Halstead and J. O'Shea (eds), *Bad Year Economics. Cultural Responses to Risk and Uncertainty.* Cambridge: Cambridge University Press, 68–80.

Halstead, P. (2014). *Two Oxen Ahead: Pre-Mechanised Farming in the Mediterranean.* Oxford: Wiley-Blackwell.

Hamerow, H. (1991). 'Settlement mobility and the "middle Saxon shift": rural settlements and settlement patterns in Anglo-Saxon England'. *Anglo-Saxon England* 20: 1–18.

Hamerow, H. (1992). 'Settlement on the gravels in the Anglo-Saxon period', in M. Fulford and E. Nichols (eds), *Developing Landscapes of Lowland Britain. The Archaeology of the British Gravels: A Review.* London: Society of Antiquaries of London, 39–46.

Hamerow, H. (1999). 'Settlement patterns', in M. Lapidge, J. Blair, S. Keynes, and D. Scragg (eds), *The Blackwell Encyclopaedia of Anglo-Saxon England.* Oxford: Blackwell, 416–18.

Hamerow, H. (2002). *Early Medieval Settlements: The Archaeology of Rural Communities in North-West Europe 400–900.* Oxford: Oxford University Press.

Hamerow, H. (2007). 'Agrarian production and the emporia of mid Saxon England, ca.AD 650-850', in J. Henning (ed.) *Post-Roman Towns, Trade and Settlement in Europe and Byzantium. Vol. 1. The Heirs of the Roman West.* Berlin: Walter de Gruyter, 219–32.

Hamerow, H. (2012). *Rural Settlements and Society in Anglo-Saxon England.* Oxford: Oxford University Press.

Hamerow, H. (2022). 'The 'FeedSax' project: rural settlements and farming in early medieval England', in McKerracher, M. and Hamerow, H. (eds) *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow.* Liverpool: Liverpool University Press, 3–24.

Hamerow, H., Bogaard, A., Charles, M., Forster, E., Holmes, M., McKerracher, M., Neil, S., Bronk Ramsey, C., Stroud, E., and Thomas, R. (2020). ‘An integrated bioarchaeological approach to the medieval “agricultural revolution”: a case study from Stafford, England, c. AD 800–1200’. *European Journal of Archaeology* 23 (4): 585–609.

Hamerow, H., Zerl, T., Stroud, E., and Bogaard, A. (2021). ‘The cerealisation of the Rhineland: extensification, crop rotation and the medieval ‘agricultural revolution’ in the *longue durée*’. *Germania* 99: 157–83.

Hamerow, H. with Kropp, C., Zerl, T., and Bogaard, A. (2023). ‘Roman to medieval cereal farming in the Rhineland: weeds, tillage, and the spread of the mouldboard plough’. *Landscape History* 44 (2): 5–13. https://doi.org/10.1080/01433768.2023.2284544

Hamilton, J. and Thomas, R. (2013). ‘Pannage, pulses and pigs: isotopic and zooarchaeological evidence for changing pig management practices in later medieval England’. *Medieval Archaeology* 56 (1): 234–59.

Hamilton-Dyer, S. (2001). ‘Animal Bone’, in J. Pine, *The Excavation of a Saxon Settlement at Cadley Road, Collingbourne Ducis, Wiltshire.* Wiltshire Archaeological and Natural History Magazine 94: 102–9.

Hammer, Ø., Harper, D., and Ryan, P. (2001). ‘PAST: paleontological statistics software package for education and data analysis’. *Palaeontologia Electronica* 4 (1): 9.

Handley, L.L., Austin, A.T., Robinson, D., Scrimgeour, C.M., Raven, J.A., Heaton, T.H.E., Schimdt, S., and Stewart, G.R. (1999). ‘The 15n natural abundance (δ^{15}N) of ecosystem samples reflects measures of water availability’. *Australian Journal of Plant Physiology* 26: 185–99.

Handley, L.L., Robinson, D., Forster, B.P., Ellis, R.P., Scimgour, C.M., Gordern, D.C., Nevo, E., and Raven, J.A. (1997). ‘Shoot δ^{15}N corelates with genotype and salt stress in barley’. *Planta* 201: 100–2.

Hardy, A., Charles, B., and Williams, R. (2007). *Death & Taxes. The Archaeology of a Middle Saxon Estate Centre at Higham Ferrers, Northamptonshire.* Oxford: Oxford Archaeology.

Hartman, G. and Danin, A. (2010). ‘Isotopic values of plants in relation to water availability in the Eastern Mediterranean region’. *Oecologia* 162 (4): 837–52.

Harvey, P.D.A. (1989). ‘Initiative and authority in settlement change’, in M. Aston, D. Austin, and C. Dyer (eds), *Rural Settlements of Medieval England.* Oxford: Blackwell, 31–43.

Havinga, A.J. (1984). ‘A 20-year experimental investigation into the differential corrosion susceptibility of pollen and spores in various soil types’, *Pollen et spores* 26: 541–58.

Heaton, T. (1986). ‘Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: a review’, *Chemical Geology* 59: 87–102.

Heaton, T. (1987). ‘The 15/14N ratios of plants in South Africa and Nambia: relationship to climate and coastal/saline environments’. *Oecologia* 74: 236–46.

Heinrich, F. (2012). *Nitrogen and Carbon Stable Isotope Analysis and Manuring: Agricultural Practices in the Upper Thames Valley during the Iron Age and Roman Period: The Case of Gravelly Guy.* Thesis submitted for MSc in Archaeological Science, University of Oxford.

Henning, J. (2009). ‘Revolution or relapse? Technology, agriculture and early medieval archaeology in Germanic Central Europe’, in G. Ausenda, P. Delogue, and C. Wickham (eds), *The Langobards before the Frankish Conquest.* Woodbridge: Boydell Press, 149–73.

Herbert, S., Hashemi, M., Chickering-Sears, C., Weis, S., Miller, K., Carlevale, J., Campbell-Nelson, K., and Zenk, Z. (2022). *Manure Inventory*. University of Massachusetts Amherst Extension Crop, Dairy, Livestock and Equine Program Factsheet (accessed July 2022). https://ag.umass.edu/crops-dairy-livestock-equine/fact-sheets/manure-inventory

Hey, G. (2004). *Yarnton. Saxon and Medieval Settlement and Landscape*. Oxford: Oxford Archaeology.

Hicks, S. (1971). 'Pollen-analytical evidence for the effect of prehistoric agriculture on the vegetation of North Derbyshire'. *New Phytologist* 70: 647–67.

Higbee, L. (2005). 'Large vertebrates', in R. Mortimer, R. Regan, and S. Lucy (eds), *The Saxon and Medieval Settlement at West Fen Road, Ely: The Ashwell Site*. East Anglian Archaeology Report 110, 89–96.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., and Jarvis, A. (2005). 'Very high resolution interpolated climate surfaces for global land areas'. *International Journal of Climatology* 25: 1965–78.

Hilton, R. and Sawyer, P. (1963). 'Technical determinism: the stirrup and the plough'. *Past & Present* 24: 90–100.

Hinton, D. (2013). 'Demography: from Domesday and beyond'. *Journal of Medieval History* 39 (2): 146–78.

Hobbie, E.A. and Högberg, P. (2012). 'Nitrogen isotopes link mycorrhizal fungi and plants to nitrogen dynamics'. *New Phytology* 196: 367–82. https://doi.org/10.1111/j.1469-8137.2012.04300.x

Hodgson, J.G., Halstead, P., Wilson, P.J., and Davis, S. (1999). 'Functional interpretation of archaeobotanical data: making hay in the archaeological record', *Vegetation History and Archaeobotany* 8: 261–71.

Holmes, M. (2011). *Food, Status and Complexity in Saxon and Scandinavian England: An Archaeozoological Approach*. Unpublished PhD thesis, University of Leicester.

Holmes, M. (2013). 'Entrepreneurs and traditional farmers: the effects of an emerging market in middle Saxon England', in M. Groot, D. Lentjes, and J. Zeiler (eds), *Barely Surviving or More than Enough? The Environmental Archaeology of Subsistence, Specialisation and Surplus Food Production*. Leiden: Sidestone Press, 247–78.

Holmes, M. (2014a). *Animals in Saxon and Scandinavian England: Backbones of Economy and Society*. Leiden: Sidestone Press.

Holmes, M. (2014b). 'Does size matter? Changes in the size and shape of animals throughout the English Saxon period (AD 450–1066)'. *Journal of Archaeological Science* 43: 77–90.

Holmes, M. (2016). '"We'll have what they're having", cultural identity through diet in the English Saxon period'. *Environmental Archaeology* 21 (1): 59–78.

Holmes, M. (2017). *A Review of Animal Bone Evidence from the Saxon to Post Medieval Periods in Southern Britain* [dataset]. York: Archaeology Data Service. https://doi.org/10.5284/1047191

Holmes, M. (2018). *Southern England: A Review of Animal Remains from Saxon, Medieval and Post Medieval Archaeological Sites*. Portsmouth: Historic England.

Holmes, M. (2019). *Bow Street Magistrates Court, 28 Bow Street, City of Westminster, WC2E 7AW (BWM15): Animal Bone Assessment*. Compass Archaeology Unpublished Report 2019.

Holmes, M. (2020). *Former Police Station, Reading Road, Wallingford, Oxfordshire (WAPO 18): The Animal Bones.* Oxford Archeology Unpublished Report 7198.

Holmes, M. and Gordon, R. (2020). *Abbey Retail Park (South), Abbey Road, Barking, London (ARE15): The Animal Bones.* Thames Valley Archaeology Unpublished Report.

Holmes, M. and Hamerow, H. (forthcoming). 'The animal economy: a zooarchaeological perspective on agriculture and trade in Anglo-Saxon England AD 600–900', in R. Hoggett and N. Faulkner (eds), *The Anglo-Saxon Agricultural Revolution in Norfolk: Proceedings of a Conference to Mark the 25th Anniversary of the Sedgeford Historical and Archaeological Research Project.*

Holmes, M., Hamerow, H., Orton, D., and Thomas, R. (forthcoming). 'Milk, wool and grain: the animal economy of medieval England (AD 400 to 1400)'.

Holmes, M., Hamerow, H., and Thomas, R. (2021a). 'Close companions? A zooarchaeological study of the human–cattle relationship in Medieval England'. *Animals* 11 (4): 1–18.

Holmes, M., Thomas, R., and Hamerow, H. (2021b). 'Identifying draught cattle in the past: lessons from large-scale analysis of archaeological datasets'. *International Journal of Paleopathology* 33: 258–69.

Holmes, M., Thomas, R., and Hamerow, H. (2021c). 'Periodontal disease in sheep and cattle: understanding dental health in past animal populations'. *International Journal of Paleopathology* 33: 43–54.

Holmes, M., Thomas, R., and Hamerow, H. (2021d). 'Lesions in sheep elbows: insights from a large-scale study'. *International Journal of Paleopathology* 34: 50–62.

Hooke, D. (1998). *The Landscape of Anglo-Saxon England.* Leicester: Leicester University Press.

Hooke, D. and Jones, R. (2011). 'Methodological approaches', in N. Christie and P. Stamper (eds), *Medieval Rural Settlement, Britain and Ireland, AD 800–1600: Settlements, Landscapes and Regions.* Oxford: Windgather Press, 31–42.

Housley, R.A., Straker, V., Chambers, F.M. and Lageard, J.G.A. (2007). 'An ecological context for the post-Roman archaeology of the Somerset Moors (South West England, UK)', *Journal of Wetland Archaeology* 7: 1–22.

Hoyle, F.C. and Murphy, D.V. (2006). 'Seasonal changes in microbial function and diversity associated with stubble retention *versus* burning'. *Australian Journal of Soil Research* 44: 4007–423.

Huber, E., Bell, T., and Adams, M. (2013). 'Combustion influences on natural abundance nitrogen isotope ratio in soil and plants following a wildfire in a sub-alpine ecosystem'. *Oecologia* 173: 1063–74. https://doi.org/10.1007/s00442-013-2665-0

Hunter, K. and Nicholson, R. (2014). 'Waterlogged plant remains', in A. Dodd, J. Goodwin, S. Griffiths, A. Norton, C. Poole, and S. Teague (eds), *Excavations at Tipping Street, Stafford, 2009–10 (Stafford Archaeological and History Society Transactions Volume XLVII)*, 75–7.

Inglett, P., Reddy, K., Newman, S., and Lorenzen, B. (2007). 'Increased soil stable nitrogen isotopic ratio following phosphorus enrichment: historical patterns and tests of two hypotheses in a phosphorus-limited wetland'. *Oecologia* 153: 99–109.

Jacobson, G.L.J. and Bradshaw, R.H.W. (1981). 'The selection of sites for palaeovegetational studies'. *Quaternary Research* 16: 80–96.

Jiang, Q., Roche, D., and Hole, D.J. (2006). 'Carbon isotope discrimination of two-rowed and six-rowed barley genotypes under irrigated and non-irrigated field conditions'. *Canadian Journal of Plant Science* 86: 433–41.

Johannsen, N. (2011). 'Past and present strategies for draught exploitation of cattle', in U. Albarella and A. Trentacoste (eds), *Ethnozooarchaeology*. Oxford: Oxbow, 13–19.

Jones, G. (1987). 'A statistical approach to the identification of crop processing'. *Journal of Archaeological Science* 14 (3): 311–23.

Jones, G. (1990). 'The application of present-day cereal processing studies to charred archaeobotanical remains'. *Circaea* 6 (2): 91–6.

Jones, G. (1992). 'Weed phytosociology and crop husbandry: identifying a contrast between ancient and modern practice', *Review of Palaeobotany and Palynology* 73: 133–43.

Jones, G. and Halstead, P. (1995). 'Maslins, mixtures and monocrops: on the interpretation of archaeobotanical crop samples of heterogeneous composition', *Journal of Archaeological Science* 22: 103–14.

Jones, G.G. (2006). 'Tooth eruption and wear observed in live sheep from Butser Hill, the Cotswold Farm Park and five farms in the Pentland Hills, UK', in D. Ruscillo (ed.), *Recent Advances in Ageing and Sexing Animal Bones*. Oxford: Oxbow, 155–78.

Jones, G.G. and Sadler, P. (2012). 'Age at death in cattle: methods, older cattle and known-age reference material'. *Environmental Archaeology* 17: 11–28.

Jones, J. (2005). 'Plant macrofossil remains from site 71', in C. Treen and M. Atkin (eds), *Wharram. A Study of Settlement on the Yorkshire Wolds, X: Water Resources and Their Management*. York: University of York, 191–200.

Jones, M. (2009). 'Dormancy and the plough: weed seed biology as an indicator of agrarian change in the first millennium AD', in E. Weiss (ed.), *From Forager to Farmers. Papers in Honor of Gordon C. Hillman*. Oxford: Oxbow Books, 58–63.

Jones, R. (2004). 'Signatures in the soil: the use of pottery in manure scatters in the identification of medieval arable farming regimes'. *The Archaeological Journal* 161: 159–88.

Jones, R. and Page, M. (2006). *Medieval Villages in an English Landscape: Beginning and Ends*. Macclesfield: Windgather Press.

Jones, R., Dyer, C. and Page, M. (2006). 'Changing settlements and landscapes: medieval Whittlewood, its predecessors and successors', *Internet Archaeology* 19. https://intarch.ac.uk/journal/issue19/5/index.html

Jordan, W. Chester (1996). *The Great Famine. Northern Europe in the Early Fourteenth Century*. Princeton: Princeton University Press.

Kanstrup, M., Thomsen, I.K., Mikkelsen, P.H., and Christensen, B.T. (2012). 'Impact of charring on cereal grain characteristics: linking prehistoric manuring practice to δ15N signatures in archaeobotanical material'. *Journal of Archaeological Science* 39 (7): 2533–40.

Kay, Q.O.N. (1971). 'Anthemis Cotula L'. *Journal of Ecology* 59 (2): 623–36.

Kneen, S. and Lageard, J.G.A. (2015). *COMM2: Vegetation history from Colemere and Clarepool Moss, Shropshire*. Manchester: Manchester Metropolitan University.

Kohler, T., Smith, M.E., Bogaard, A., *et al.* (2017). 'Greater post-Neolithic wealth disparities in Eurasia than in North America and Mesoamerica'. *Nature* 551: 619–22.

Kropp, C. (2022). 'Cattle and tillage in early medieval Europe: first results from the Lauresham Laboratory for Experimental Archaeology, Germany', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 111–24.

Lamond, E. (ed and tr.) (1890). *Walter of Henley's Husbandry*. London and New York: Longmans, Green, and Co.

Land Information System. (2013). *National Soil Map*. Cranfield: Cranfield University.

Langdon, J. (1986). *Horses, Oxen and Technological Innovation: The Use of Draught Animals in English Farming from 1066 to 1500.* Cambridge: Cambridge University Press.

Larsen, L. Agersnap (2013). 'The mouldboard plough in the Danish area 200–1500 AD', in J. Klapste (ed.), *Agrarian Technology in the Medieval Landscape, Ruralia X.* Turnhout: Brepols, 225–36.

Larsson, M., Bergman, J., and Lagerås, P. (2019). 'Manuring practices in the first millennium AD in southern Sweden inferred from isotopic analysis of crop remains'. *PLoS One* 14 (4): e0215578.

Levitan, B. (1985). 'A methodology for recording the pathology and other anomalies of ungulate mandibles from archaeological sites', in N. Fieller, D. Gilbertson, and N. Ralph (eds), *Palaeobiological Investigations.* Oxford: British Archaeological Reports, 41–54.

Levitan, B. (1987). 'Medieval animal husbandry in south west England: a selective review and suggested approach', in N. Balaam, B. Levitan, and V. Straker (eds), *Studies in Palaeoeconomy and Environment in South West England.* Oxford: British Archaeological Reports, 51–80.

Lewis, C., Mitchell-Fox, P., and Dyer, C. (2001). *Village, Hamlet and Field.* Macclesfield: Windgather Press.

Lim, S.S., Kwak, J.H., Lee, K.S., Chang, S.X., Yoon, K.S., Kim, H.Y., and Choi, W.J. (2015). 'Soil and plant nitrogen pools in paddy and upland ecosystems have contrasting δ15N'. *Biology and Fertility of Soils* 51 (2): 231–9.

Lodwick, L. (2023). 'Cultivating villa economies: archaeobotanical and isotopic evidence for Iron Age to Roman agricultural practices on the chalk Downlands of southern Britain'. *European Journal of Archaeology*26 (4): 445–66 .

Lodwick, L. and Brindle, T. (2017). 'Arable farming, plant foods, and resources', in M. Allen *et al.* (eds), *The Rural Economy of Roman Britain.* London: Society for the Promotion of Roman Studies, 11–84.

Lodwick, L., Campbell, G., Crosby, V., and Müldner, G. (2020). 'Isotopic evidence for changes in cereal production strategies in Iron Age and Roman Britain'. *Environmental Archaeology* 26 (1): 13–28.

Long, D.J., Chambers, F.M. and Barnatt, J. (1998). 'The palaeoenvironment and the vegetation history of a Later Prehistoric Field System at Stoke Flat on the Gritstone Uplands of the Peak District', *Journal of Archaeological Science* 25, 505–19.

Loog, L., Thomas, M., Barnett, R., Allen, R., Sykes, N., Paxinos, P., Lebrasseur, O., Dobney, K., Peters, J., Manica, A., Larsen, G., and Erikkson, A. (2017). 'Inferring allele frequency trajectories from ancient DNA indicates that selection on a chicken gene coincided with changes in medieval husbandry practices'. *Molecular Biology and Evolution* 34 (8): 1981–90.

Lowerre, A. (2010). 'The atlas of rural settlement in England GIS'. *Landscapes* 2, 21–44.

Loyn, H.R. and Percival, J. (1975). *The Reign of Charlemagne. Documents on Carolingian Government and Administration.* London: Edward Arnold.

Mackay, A.W. and Tallis, J.H. (1994). 'The recent vegetational history of the Forest of Bowland, Lancashire, UK', *The New Phytologist* 128 (3): 571–84.

Madgwick, R., Sykes, N., Miller, H., Symmons, R., Morris, J., and Lamb, A. (2013). 'Fallow deer (*Dama dama dama*) management in Roman South-East Britain'. *Archaeological and Anthropological Sciences* 5: 111–22.

Makhad, S.B., Pradat, B., Aguilera, M., Malrain, F., Fiorillo, D., Balasse, M., and Matterne, V. (2022). 'Crop manuring on the Beauce plateau (France) during the second iron age'. *Journal of Archaeological Science: Reports* 43: 103463.

Maltby, M. (2016). 'The exploitation of animals in Roman Britain', in M. Millett, L. Revell, and A. Moore (eds), *The Oxford Handbook of Roman Britain*. Oxford: Oxford University Press, 791–807.

Maltby, M. (2022). 'Faunal remains', in D. Shotliffe and D. Ingham (eds), *Stratton, Biggleswade: 1,300 Years of Village Life in Eastern Bedfordshire from the 5th Century AD*. Oxford: Archaeopress, 180–206.

Marbach, A. (2001). *Recherches sur les instruments aratoires et le travail du sol en Gaule Belgique. Catalogue des pièces métalliques d'instruments aratoires de la Gaule*. PhD thesis, Archéologie et Prehistoire, Université Paul Verlaine.

Marston, C., Rowland, C.S., O'Neil, A.W. and Morton, R.D. (2022). *Land Cover Map 2021 (1km summary rasters, GB and N. Ireland)*. NERC EDS Environmental Information Data Centre (online resource). https://doi.org/10.5285/a3ff9411-3a7a-47e1-9b3e79f21648237d

Martin, G. (2012). 'Botanical remains', in T. Wilson, D. Cater, C. Clay, and R. Moore (eds), *Bacton to King's Lynn Gas Pipeline Volume 1: Prehistoric, Roman and Medieval Archaeology*. East Anglian Archaeology Report No. 145. Lincoln: Network Archaeology, 166.

Maslin, S.P. (2017). 'Anglo-Saxon economy and ecology by a downland stream: a waterlogged sequence from the Anglo-Saxon royal settlement at Lyminge, Kent', *Environmental Archaeology* 23 (2): 1–15.

McCormick, F. (1991). 'The effect of the Anglo-Norman settlement on Ireland's wild and domesticated fauna'. *MASCA* Supplement to Vol. 8: 41–52.

McKerracher, M. (2014). *Agricultural Development in Mid Saxon England*. Unpublished DPhil. thesis, University of Oxford.

McKerracher, M. (2016a). 'Bread and surpluses: the Anglo-Saxon "bread wheat thesis" reconsidered'. *Environmental Archaeology* 21: 88–102.

McKerracher, M. (2016b). 'Playing with fire? Charred grain as a proxy for cereal surpluses in early medieval England'. *Medieval Settlement Research* 31: 63–6.

McKerracher, M. (2017). 'Seeds and status: the archaeobotany of monastic Lyminge', in G. Thomas and A. Knox (eds), *Early Medieval Monasticism in the North Sea Zone (Anglo-Saxon Studies in Archaeology and History 20)*. Oxford: School of Archaeology, University of Oxford, 127–34.

McKerracher, M. (2018). *Farming Transformed in Anglo-Saxon England*. Oxford: Windgather Press.

McKerracher, M. (2019). *Anglo-Saxon Crops and Weeds: A Case Study in Quantitative Archaeobotany*. Oxford: Archaeopress.

McKerracher, M. (2020). 'Standing on the shoulders of peasants: agency and risk in Anglo-Saxon farming', in J.A. Quirós Castillo (ed.) *Archaeology and History of Peasantries 1. From the Late Prehistory to the Middle Ages*. Documentos de Arqueología Medieval 14. Vitoria-Gasteiz: Universidad del País Vasco, 113–23.

McKerracher, M. (2022). 'Prospect and protect: syntironomy and cereals in early medieval England', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 125–44.

McKerracher, M., Charles, M., Bronk Ramsey, C., Hodgson, J., Hamerow, H., Zerl, T., Stroud, E., Neil, S., Bogaard, A., Thomas, R., Holmes, M., and Forster, E. (2023). *Feeding Anglo-Saxon England (FeedSax): The Bioarchaeology of an Agricultural Revolution* [dataset]. York: Archaeology Data Service. https://doi.org/10.5284/1057492. https://archaeologydataservice.ac.uk/archives/view/1003605/

Millett, M. (1990). *Romanization of Britain: an Essay in Archaeological Interpretion.* Cambridge: Cambridge University Press.

Mitterauer, M. (2010). *Why Europe? The Medieval Origins of Its Special Path.* Chicago: University of Chicago Press.

Moffett, L. (1987). *The Macro-Botanical Evidence from Late Saxon and Early Medieval Stafford.* Ancient Monuments Laboratory Report 169/87.

Moffett, L. (2006). 'The archaeology of medieval plant foods', in C.M. Woolgar, D. Serjeantson, and T. Waldron (eds), *Food in Medieval England.* Oxford: Oxford University Press, 41–55.

Moffett, L. (2011). 'Food Plants on Archaeological Sites: the nature of the archaeobotanical record', in H. Hamerow, D.A. Hinton and S. Crawford (eds), *The Oxford Handbook of Anglo-Saxon Archaeology.* Oxford: Oxford University Press, 346–60.

Montgomery, D.R., and Biklé, A. (2021). 'Soil health and nutrient density: beyond organic vs. conventional farming', *Frontiers in Sustainable Food Systems* 5: 699147.

Moore, P.D., Webb, J.A., and Collinson, M.E. (1991). *Pollen Analysis.* Oxford: Blackwell Scientific Publications.

Moreland, J. (2000). 'The significance of production in eighth-century England', in Hansen, I.L. and Wickham, C. (eds) *The Long Eighth Century.* Leiden: Brill, 69–104.

Mortimer, R., Regan, R., and Lucy, S. (2005). *The Saxon and Medieval Settlement at West Fen Road, Ely: The Ashwell Site, East Anglian Archaeology.* Cambridge: Cambridge Archaeological Unit, 110.

Mudd, A., Cobain, S., and Haines, C. (2018). 'A medieval building and its contents at island farm, Ottery St Mary, East Devon: excavations in 2014'. *Internet Archaeology* 47. https://doi.org/10.11141/ia.47.4

Murphy, P. (1988). *The Stansted Airport Project, Essex, Part 3. The British Rail sections (BRS). AML Report 166/88.* London: Historic Monuments and Buildings Commission for England.

Murphy, P. (2005). 'Environment and economy: a summary', in A. Crowson (ed.), *Anglo-Saxon Settlement on the Siltland of Eastern England.* Sleaford: Heritage Trust of Lincolnshire, 260–2.

Murphy, P. (2010). 'The landscape and economy of the Anglo-Saxon Coast: new archaeological evidence', in N.J. Higham and M. Ryan (eds), *Landscape Archaeology of Anglo-Saxon England.* Woodbridge: Boydell Press, 211–21.

Murphy, P.L., Robinson, M. and Tinsley, H. (2002). 'Environmental evidence', *Essex Archaeology and History* 33: 31–46.

Murphy, P. and Wiltshire, P.E.J. (1993). *An analysis of microfossils and macrofossils from waterlogged deposits at Slough House and Chigborough Farms, near Heybridge, Essex.* London: English Heritage.

Naismith, R. (2025). 'Economic Change, Silver, and the Plague of 664–687 in England', *Past and Present* (gtae048 – advance online publication). https://doi.org/10.1093/pastj/gtae048

Naylor, J. (2016). 'Emporia and their Hinterlands in the 7th to 9th centuries AD. Some comments and observations from England', in I. Leroy and L. Verslap (eds), *Les cultures des littoraux au haut moyen age, Revue du Nord* Vol. 24. Lille: Bibliothèque Georges Lefebvre, 59–67.

Newfield, T. (2018). 'The climate downturn of 536–550', in S. White *et al.* (eds), *The Palgrave Handbook of Climate History.* London: Palgrave Macmillan, 447–93.

Newman, J. (1992). 'The late Roman and Anglo-Saxon settlement pattern in the Sandlings of Suffolk', in M. Carver (ed.) *The Age of Sutton Hoo: The Seventh Century in North-Western Europe*. Woodbridge: Boydell Press, 25–38.

Newton, A.S. and Summers, J.R. (2023). 'An Anglo-Saxon iron-working site in north Norfolk'. *Anglo-Saxon Studies in Archaeology and History* 23: 150–66.

Noddle, B. (1975). 'A comparison of the animal bones from 8 medieval sites in Southern Britain', in A. Clason (ed.), *Archaeozoological Studies*. Amsterdam: North Holland Publishing Company, 248–60.

Oliver, L. (1999). 'Cyninges fedesl: the king's feeding in AEthelberht, ch.12'. *Anglo-Saxon England* 27: 31.

O'Connor, T. (1982). *Animal Bones from Flaxengate, Lincoln c.870-1500*. The Archaeology of Lincoln XVIII(1) (Lincoln 1982).

O'Connor, T. (2001). 'On the interpretation of animal bone assemblages from wics', in D. Hill and R. Cowie (eds), *Wics: The Early Medieval Trading Centres of Northern Europe*. Sheffield: Sheffield Academic Press, 54–60.

O'Connor, T. (2003). *The Analysis of Urban Animal Bone Assemblages: A Handbook for Archaeologists*. York: Council for British Archaeology.

O'Connor, T. (2010). 'Livestock and deadstock in early medieval Europe from the North Sea to the Baltic'. *Environmental Archaeology* 15 (1): 1–15.

O'Connor, T. (2014). 'Livestock and animal husbandry in early medieval England'. *Quaternary International* 346: 109–18.

Oldfield, F. (1963). 'Pollen-analysis and man's role in the ecological history of the South-East Lake District'. *Geografisker Annaler* 45 (1): 23–40.

Oosthuizen, S. (2010). 'Medieval field systems and settlement nucleation: common or separate origins?', in N. Higham and M.J. Ryan (eds), *Landscape Archaeology of Anglo-Saxon England*. Woodbridge: Boydell Press, 107–31.

Oosthuizen, S. (2011). 'Anglo-Saxon fields', in H. Hamerow, D. Hinton, and S. Crawford (eds), *The Oxford Handbook of Anglo-Saxon Archaeology*. Oxford: Oxford University Press, 377–404.

Oosthuizen, S. (2013). 'Debate: the Emperor's old clothes and the origins of medieval nucleated settlements and their open fields'. *Medieval Settlement Research* 28: 96–8.

Orwin, C.S. and Orwin, C.S.L. (1938). *The Open Fields*. Oxford: Clarendon Press.

Oschinsky, D. (1971). *Walter of Henley and Other Treatises on Estate Management and Accounting*. Oxford: Clarendon Press.

Parry, S. (2006). *Raunds Area Survey*. Oxford: Oxbow Books.

Pears, B., Brown, A.G., Toms, P.S., Wood, J., Pennington, B.T. and Jones, R. (2023). 'Rapid laminated clastic alluviation associated with increased Little Ice Age flooding co-driven by climate variability and historic land-use in the middle Severn catchment, UK', *The Holocene* 33 (12): 1474–88.

Pelling, R. (2013). 'The plant remains', in B.M. Ford and D. Poore (eds), *Under the Oracle: Excavations at the Oracle Shopping Centre Site 1996–8: The Medieval and Post-Medieval Urban Development of the Kennet Floodplain in Reading*. Oxford: Oxford Archaeology, 624–35.

Peoples, M.B., Bergersen, F.J., Brockwell, J., Fillery, I.R.P., and Herridge, D.F. (1995). 'Management of nitrogen for sustainable agricultural systems,' in *Nuclear Methods in Soil–Plant Aspects of Sustainable Agricultural Systems*. Vienna: Internation Atomic Energy Agency, 17–35.

Pestell, T. (2011). ‘Markets, emporia, wics, and “productive” sites: pre-Viking trade centres in Anglo-Saxon England’, in H. Hamerow, D. Hinton, and S. Crawford (eds), *The Oxford Handbook of Anglo-Saxon Archaeology*. Oxford: Oxford University Press, 556–79.

Popkin, P., Baker, P., Worley, F., Payne, S., and Hammon, A. (2012). ‘The sheep project (1): determining skeletal growth, timing of epiphyseal fusion and morphomentric variation in unimproved Shetland sheep of known age, sex, castration status and nutrition’. *Journal of Archaeological Science* 39: 1775–92.

Postan, M. (1966). ‘Medieval Agrarian Society in its prime: England’, in M. Postan (ed.), *The Cambridge Economic History of Europe, Vol. I: The Agrarian Life of the Middle Ages*. 2nd ed. Cambridge: Cambridge University Press, 549–632.

Postan, M. (1972). *The Medieval Economy and Society*. London: Weidenfeld and Nicolson.

Pratt, K. (1996). *Development of Methods for Investigating Settlement and Land-Use Using Pollen Data: A Case Study from North-east England circa 8000 cal. BC—cal. AD 500.* Unpublished PhD thesis, Durham University.

Purcell, N. (1995). ‘The Roman villa and the landscape of production’, in T. Cornell and K. Lomas (eds), *Urban Society in Roman Italy*. London, UCL Press, 157–79.

Rackham, J. (2003). ‘Animal bones’, in G. Taylor, An Early to Middle Saxon Settlement at Quarrington, Lincolnshire. *Antiquaries Journal* 83: 231–80.

Rackham, O. (1986). *The History of the Countryside*. London: Dent.

Rajkovaca, V. (2018). ‘Animal bones’, in C. Evans, S. Lucy, and R. Patten (eds), *Riversides: Neolithic Barrows, a Beaker Grave, Iron Age and Anglo-Saxon burials and Settlement at Trumpington, Cambridge*. Cambridge: McDonald Institute for Archaeological Research, 243–52.

Renes, H. (2010). ‘Grainlands. The landscape of open fields in a European perspective’. *Landscape History* 31 (2): 37–70.

Reimer, P.J., Austin, W., Bard, E., *et al.* (2020). ‘The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP)’. *Radiocarbon* 62: 725–57.

Reynolds, A. (1999). *Later Anglo-Saxon England. Life & Landscape*. Stroud: Tempus.

Rippon, S. (2002). ‘Infield and outfield: the early stages of marshland colonisation and the evolution of medieval field systems’, in T. Lane and J. Coles (eds), *Through Wet and Dry; Essays in Honour of David Hall*. Sleaford and Exeter: Lincolnshire Archaeology and Heritage Report Series No. 5 and WARP Occasional Paper 17, 54–70.

Rippon, S. (2007). ‘Emerging regional variation in historic landscape character: the possible significance of the “Long Eighth Century”’, in M. Gardiner and S. Rippon (eds), *Medieval Landscapes*. Macclesfield: Windgather Press, 105–21.

Rippon, S. (2008). *Beyond the Medieval Village*. Oxford: Oxford University Press.

Rippon, S. (2019a). ‘Continuity and change: the field systems and patterns of land-use in early medieval England’. *Studia Historica. Historia Medieval* 37 (1): 7–27.

Rippon, S. (2019b). ‘Changing landscapes? Land, people and environment in England, AD 350–600’, in P. Diarte-Blasco and N. Christie (eds), *Interpreting Transformation of People and Landscapes in Late Antiquity and the Early Middle Ages*. Oxford: Oxbow Books, 95–112.

Rippon, S. and Fyfe, R. (2019). ‘Variation in the continuity of land-use patterns through the first millennium AD in lowland Britain’, in A. Izdebski and M. Mulryan (eds), *Environment and Society in the Long Late Antiquity*. Leiden: Brill, 135–54.

Rippon, S., Fyfe, R., and Brown, A. (2006). ‘Beyond villages and open fields: the origins and development of a historic landscape characterized by dispersed settlement in SW England’. *Medieval Archaeology* 50: 31–70.

Rippon, S., Smart, C., and Pears, B. (2015). *The Fields of Britannia. Continuity and Change in the Late Roman and Early Medieval Landscape*. Oxford: Oxford University Press.

Rippon, S., Wainwright, A., and Smart, C. (2014). ‘Farming regions in Medieval England: the archaeobotanical and zooarchaeological evidence’. *Medieval Archaeology* 58 (1): 195–255.

Roberts, B. and Wrathmell, S. (2000). *An Atlas of Rural Settlement in England*. London: English Heritage.

Roberts, B. and Wrathmell, S. (2002). *Region and Place: A Study of English Rural Settlement*. London: English Heritage.

Roberts, H.A. and Neilson, J.E. (1981). ‘Seed survival and periodicity of seedling emergence in twelve weedy species of compositae’. *Annals of Applied Biology* 97: 325–34.

Rogers, E.M. (2003). *Diffusion of Innovations*. New York: Free Press.

Rohr, C., Camenisch, R., and Pribyl, K. (2018). ‘European Middle Ages’, in S. White *et al.* (eds), *The Palgrave Handbook of Climate History*. London: Palgrave Macmillan, 247–63.

Rose, C., Parker, A., Jefferson, B., and Cartmell, E. (2015). ‘The characterization of feces and urine: a review of the literature to inform advanced treatment technology’. *Critical Reviews in Environmental Science and Technology* 45 (17): 1827–79.

Rose, S. (2017). *The Wealth of England: The Medieval Wool Trade and Its Political Importance 1100–1600*. Oxford: Oxbow Books.

Roushannafas, H. and McKerracher, M. (2023). ‘Diversity of early medieval free-threshing wheat cultivars supported by geometric morphometric analysis of grains’. *Environmental Archaeology* 2023. https://doi.org/10.1080/14614103.2023.2223406

Ruiz de Arcaute, M., Lacasta, D., González, J.M., Ferrer, L.M., Ortega, M., Ruiz, H., Ventura, J.A., and Ramos, J.J. (2020). ‘Management of risk factors associated with chronic oral lesions in sheep’. *Animals* 10 (9): 1–11.

Runciman, W.G. (1984). ‘Accelerating social mobility: the case of Anglo-Saxon England’. *Past & Present* 104 (1): 3–30.

Ryder, M. (1983). *Sheep and Man*. London: Duckworth.

Scott, J.C. (2017). *Against the Grain. A Deep History of the Earliest States*. New Haven & London: Yale University Press.

Scott, K. (1990). ‘Postcranial dimensions of ungulates as predictors of body mass’, in J. Damuth, B. MacFadden, and D. John (eds), *Body Size in Mammalian Paleobiology: Estimation and Biological Implications*. Cambridge: Cambridge University Press, 301–35.

Scott, S. (1999). ‘Animal bones from West Parade 1971-2’, in M. Jones (ed.), *The Archaeology of Lincoln Vol VII-2: The Defences of the Lower City, Excavations at the Park and West Parade 1070-2 and a Discussion of Other Sites Excavated up to 1994*. York: Council for British Archaeology, 236–47.

Senbayram, M., Dixon, L., Goulding, K.W.T. and Bol, R. (2008). ‘Long-term influence of manure and mineral nitrogen applications on plant and soil d15N and d13C values from the Broadbalk Wheat Experiment’, *Rapid Communications in Mass Spectrometry* 22: 1735–40.

Seebohm, F. (1883, publ. 1905). *The English Village Community Examined in Its Relation to the Manorial and Tribal Systems and to the Common or Open Field System*. London: Longmans, Green & Co.

Serjeantson, D. (1996). 'Animal remains in Hampshire: beyond environment and subsistence', in D. Hinton and M. Hughes (eds), *Archaeology in Hampshire: A Framework for the Future*. Winchester: Hampshire County Council, 71–80.

Silver, I.A. (1969). 'The ageing of domestic animals', in D.R. Brothwell and E.S. Higgs (eds), *Science and Archaeology*. London: Thames and Hudson, 283–302.

Silverside, A.J. (1977). *A Phytosociological Survey of British Arable-Weed and Related Communities*. Unpublished PhD thesis, Durham University.Silvester, R.J. (1988). *The Fenland Project Number 3: Marshland and the Nar Valley, Norfolk*. East Anglian Archaeology Report No. 45. Dereham: Norfolk Archaeological Unit.

Slavin, P. (2012). 'The Great Bovine Pestilence and its economic and environmental consequences in England and Wales, 1318–501'. *The Economic History Review* 65 (4): 1239–66.

Smith, A., Allen, M., Brindle, T., and Fulford, M. (2016). *New Visions of the Countryside of Roman Britain, Volume 1: The Rural Settlements of Roman Britain*. London: Society for the Promotion of Roman Studies.

Smith, R. (2002). 'Plagues and peoples. The long demographic cycle, 1250–1670', in P. Slack and R. Ward (eds), *The Peopling of Britain. The Shaping of a Human Landscape*. Oxford: Oxford University Press, 177–210.

Spedding, C.R.W., Walsingham, J.M., and Hoxey, A.M. (1981). *Biological Efficiency in Agriculture*. London and New York: Academic Press.

Spoerry, P. (2016). *The Production and Distribution of Medieval Pottery in Cambridgeshire*. Bar Hill: Oxford Archaeology East.

Stace, C.A. (2010). *New Flora of the British Isles*. 3rd ed. Cambridge: Cambridge University Press.

Stanes, R.G. (2009). 'The husbandry of Devon and Cornwall'. *Report and Transactions of the Devonshire Association for the Advancement of Science* 141: 153–80.

Steele, K.W. and Daniel, R.M. (1978). 'Fractionation of nitrogen isotopes by animals: a further complication to the use of variations in the natural abundance of 15N for tracer studies'. *The Journal of Agricultural Science* 90 (1): 7–9.

Steele, K.W. and Henderson, H. (1977). 'Occurrence of periodontal disease in sheep in the Mangonui, Whangaroa, Hokianga, and Bay of Islands counties'. *New Zealand Journal of Agricultural Research* 20 (3): 301–8.

Stockmarr, J. (1971). 'Tablets with spores used in absolute pollen analysis'. *Pollen and Spores* 13: 615–21.

Stone, D. (2005). *Decision-Making in Medieval Agriculture*. Oxford: Oxford University Press.

Straker, V. (1995). ' "Plant macrofossils", in Ratcliffe, J. 'Duckpool, Morwenstow: A Romano-British and early medieval industrial site and harbour'. *Cornish Archaeology* 34: 155–8.

Stroud, E. (2022). 'Understanding early medieval crop and animal husbandry through isotopic analysis', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution': Crop, Stock and Furrow*. Liverpool: Liverpool University Press, 41–60.

Stroud, E., Bogaard, A., Charles, M., and Hamerow, H. (2023). 'Turning up the heat. Assessing the impact of charring regime on the morphology and stable carbon and nitrogen isotopic values of cereal grains'. *Journal of Archaeological Science* 153: 1–10.

Styring, A., Ater, M., Hmimsa, Y., Fraser, R., Miller, H., Neef, R., Pearson, J., and Bogaard, A. (2016). 'Disentangling the effect of farming practice from aridity on crop stable isotope values: a present-day model from Morocco and its application to early farming sites in the eastern Mediterranean'. *The Anthropocene Review* 3 (1): 2–22.

Styring, A.K., Rösch, M., Stephan, E., Stika, H.-P., Fischer, E., Sillmann, M., and Bogaard, A. (2017). 'Centralisation and long-term change in farming regimes: comparing agricultural practices in neolithic and iron age South-West Germany'. *Proceedings of the Prehistoric Society* 83: 357–81.

Suggitt, A., Jones, R., Caseldine, C., Huntley, B., Stewart, J., Brooks, S., Brown, E., Fletcher, D., Gillingham, P., Larwood, J., Macgregor, N., Silva, B., Thomas, Z., Wilson, R., and Maclean, I. (2015). 'A meta-database of holocene sediment cores for England'. *Vegetation History and Archaeobotany* 24: 743–7.

Suzman, J. (2017). *Affluence without Abundance. The Disappearing World of the Bushmen.* London: Bloomsbury Press.

Swanton, M. (1993). *Anglo-Saxon Prose.* London: J.M. Dent.

Sykes, N. (2006). 'From cu and sceap to beffe and motton: the management, distribution and consumption of cattle and sheep in Medieval England', in C. Woolgar, D. Serjeantson, and T. Waldron (eds), *Food in Medieval England: Diet and Nutrition.* Oxford: Oxford University Press, 56–71.

Sykes, N. (2007). *The Norman Conquest: A Zooarchaeological Perspective.* Oxford: British Archaeological Reports.

Sykes, N. (2009). 'Animals, the bones of medieval society', in R. Gilchrist and A. Reynolds (eds), *Reflections: 50 Years of Medieval Archaeology 1957–2007.* London: Society for Medieval Archaeology, 347–61.

Szpak, P. (2014). 'Complexities of nitrogen isotope biogeochemistry in plant-soil systems: implications for the study of ancient agricultural and animal management practices', *Frontiers in Plant Science* 5: 288.

Szpak, P., Metcalfe, J., and Macdonald, R.A. (2017). 'Best practices for calibrating and reporting stable isotopes measurements in archaeology'. *Journal of Archaeological Science: Reports* 13, 609–16.

Szpak, P., Millaire, J-F., White, C.D., and Longstaffe, F.J. (2012). 'Influence of seabird guano and camelid dung fertilization on the nitrogen isotopic composition of field-grown maize (Zea mays)'. *Journal of Archaeological Science* 39 (12): 3721–40. https://doi.org/10.1016/j.jas.2012.06.035

Tallis, J.H. and Switsur, V.R. (1973). 'Studies on Southern Pennine peats: VI A radiocarbon-dated pollen diagram from Featherbed Moss, Derbyshire', *Journal of Ecology* 61 (3): 743–51.

Taylor, C. (1983). *Village and Farmstead: A History of Rural Settlement in England.* London: George Philip.

Taylor, G. (2003). 'An early to middle Saxon settlement at Quarrington, Lincolnshire'. *Antiquaries Journal* 83: 231–80.

Ten Harkel, L., Franconi, T., and Gosden, C. (2017). 'Fields, ritual and religion: holistic approaches to the rural landscape in long-term perspective (c. 1500 BC – AD 1086)'. *Oxford Journal of Archaeology* 36 (4): 413–37.

ter Braak, C.J.F. and Šmilauer, P. (2012). *Canoco Reference Manual and User's Guide: Software for Ordination (Version 5.0).* Ithaca: Microcomputer Power.

Thayer, B. trans. (2021). *De Re Rustica of Columella.* https://penelope.uchicago.edu/Thayer/E/Roman/Texts/Columella/de_Re_Rustica/2*.html (accessed 10/08/2021)

Thirsk, J. (1964). 'The common fields'. *Past & Present* 29: 3–25.

Thirsk, J. (1966). 'The origins of the common fields', *Past & Present* 33: 142–7.

Thirsk, J. (1997). *Alternative Agriculture: A History: From the Black Death to the Present Day.* Oxford: Oxford University Press.

Thomas, G. (2010). *The later Anglo-Saxon settlement at Bishopstone: a downland manor in the making.* York: Council for British Archaeology.

Thomas, G. (2013). 'Life before the Minster: the social dynamics of monastic foundation at Anglo-Saxon Lyminge, Kent'. *Antiquaries Journal* 93: 109–45.

Thomas, G., McDonnell, G., Merkel, J., and Marshall, P. (2016). 'Technology, ritual and Anglo-Saxon agriculture: the biography of a plough coulter from Lyminge, Kent'. *Antiquity* 90: 742–58.

Thomas, R. (2005a). *Animals, Economy and Status: Integrating Zooarchaeological and Historical Data in the Study of Dudley Castle, West Midlands (c.1100–1750).* Oxford: British Archaeological Reports.

Thomas, R. (2005b). 'Zooarchaeology, improvement and the British Agricultural revolution'. *International Journal of Historical Archaeology* 9 (2): 71–88.

Thomas, R. (2007). 'Food and maintenance of social boundaries in medieval England', in K. Twiss (ed.), *The Archaeology of Food and Identity.* Illinois: Southern Illinois University, 130–51.

Thomas, R. (2008). 'Diachronic trends in lower limb pathologies in later medieval and post-medieval cattle from Britain', in G. Grupe, G. McGlynn, and J. Peters (eds), *Limping Together Through the Ages: Joint Afflictions and Bone Infections, Documenta Archaeobiologiae 6.* Rahden: Marie Leidorf, 187–201.

Thomas, R., Bellis, L., Gordon, R., Holmes, M., Johannsen, N., Mahoney, M., and Smith, D. (2021). 'Refining the methods for identifying draught cattle in the archaeological record: lessons from the semi-feral herd at Chillingham Park'. *International Journal of Paleopathology* 33: 84–93.

Thomas, R., Holmes, M., and Morris, J. (2013). '"So bigge as bigge may be": tracking size and shape change in domestic livestock in London (AD 1220–1900)'. *Journal of Archaeological Science* 40: 3309–25.

Titow, J. (1972). *Winchester Yields: A Study in Medieval Agricultural Productivity.* Cambridge: Cambridge University Press.

Trow-Smith, R. (1957). *A History of British Livestock Husbandry to 1700.* London: Routledge and Kegan Paul.

Turner, J. (1964). 'The anthropogenic factor in vegetational history. I. Tregaron and Whixall Mosses'. *New Phytologist* 63: 73–90.

Turney, C., Baillie, M., Clemens, S., Brown, D., Palmer, J., Pilcher, J., Reimer, P. and Leuschner, H.H. (2005). 'Testing solar forcing of pervasive Holocene climate cycles', *Journal of Quaternary Science* 20 (6): 511–18.

Tweddle, J.C., Edwards, K.J., and Fieller, N.R.J. (2005). 'Multivariate statistical and other approaches for the separation of cereal from wild Poaceae pollen using a large Holocene dataset'. *Vegetation History and Archaeobotany* 14: 15–30.

Tyler, S. and Major, H. (2005). *The Early Anglo-Saxon Cemetery and Later Saxon Settlement at Springfield Lyons, Essex. East Anglian Archaeology* 111. Chelmsford: Essex County Council.

Unkovich, M. (2013). 'Isotope discrimination provides new insight into biological nitrogen fixation'. *New Phytologist* 198 (3): 643–6.

Vaiglova, P., Snoeck, C., Nitsch, E., Bogaard, A., and Lee-Thorp, J. (2014). 'Impact of contamination and pre-treatment on stable carbon and nitrogen isotopic composition of charred plant remains'. *Rapid Communications in Mass Spectrometry* 28: 2497–510.

van der Veen, M. (1995). ‘The identification of maslin crops’, in K.H. Kroll and P. Pasternak (eds), *Res Archaeobotanicae, International Workgroup for Palaeoethnobotany, Kiel 1992*. Kiel: University of Kiel, 335–43.

van der Veen, M. (2010). ‘Agricultural innovation: invention and adoption or change and adaptation?’. *World Archaeology* 42 (1): 1–12.

van der Veen, M. (2022). ‘All change on the land? Wheat and the Roman to Early Medieval transition in England’. *Medieval Archaeology* 66 (2): 304–42.

van der Veen, M. and Jones, G. (2006). ‘A re-analysis of agricultural production and consumption: implications for understanding the British Iron Age’. *Vegetation History and Archaeobotany* 15: 217–28.

van der Veen, M. and O’Connor, T.P. (1998). ‘The expansion of agricultural production in later Iron Age and Roman Britain’, in J. Bayley (ed.), *Science in Archaeology: An Agenda for the Future*. London: English Heritage, 127–43.

van der Veen, M., Hill, A., and Livarda, A. (2013). ‘The archaeobotany of Medieval Britain: identifying research priorities for the 21st century’. *Medieval Archaeology* 57: 151–82.

Verbrugghe, G. and de Clerq, W. (2022). ‘Little Flanders beyond Wales. The historical context of Flemish settlement landscapes in South Pembrokeshire’, in S.C. Thomson (ed.), *Strangers at the Gate! Multidisciplinary Explorations of Communities, Borders and Othering in Medieval Western Europe*. Leiden: Brill, 98–112.

Verhulst, A. (2002). *The Carolingian Economy*. Cambridge: Cambridge University Press.

Voltas, J., Romagosa, I., Lafarga, A., Armesto, A.P., Sombrero, A., and Araus, J.L. (1999). ‘Genotype by environment interaction for grain yield and carbon isotope discrimination of barley in Mediterranean Spain’. *Australian Journal of Agricultural Research* 50 (7): 1263–71.

von den Driesch, A. (1976). *A Guide to the Measurement of Animal Bones from Archaeological Sites*. Cambridge, Massachusetts: Harvard University Press.

Waldron, T. (2009). *Palaeopathology*. Cambridge: Cambridge University Press.

Wallace, M., Jones, G., Charles, M., Fraser, R., Halstead, P., Heaton, T.H.E., and Bogaard, A. (2013). ‘Stable carbon isotope analysis as a direct means of inferring crop water status and water management practices’. *World Archaeology* 45 (3): 388–409.

Wallace, M.P., Jones, G., Charles, M., Fraser, R., Heaton, T.H.E., and Bogaard, A. (2015). ‘Stable carbon isotope evidence for Neolithic and Bronze Age crop water management in the Eastern Mediterranean and Southwest Asia. *PLOS ONE* 10 (6): e0127085. https://doi.org/10.1371/journal.pone.0127085

Waller, M.P. (1993). ‘Flandrian vegetational history of South-Eastern England. Pollen data from Pannel Bridge, East Sussex’, *New Phytologist* 124 (2): 345–69.

Waller, M.P. (1994). *The Fenland Project Number 9: Flandrian environmental change in Fenland*. Cambridge: Cambridgeshire County Council.

Waller, M. (2010). ‘Ashtead Common, the evolution of a cultural landscape: a spatially precise vegetation record for the last 2000 years from southeast England’, *The Holocene* 20 (5): 733–46.

Waller, M.P., Long, A.J., Long, D. and Innes, J.B. (1999). ‘Patterns and processes in the development of Coastal Mire vegetation: multi-site investigations from Walland Marsh, Southeast England’, *Quaternary Science Reviews* 18: 1419–44.

Waton, P.V. (1983). *A palynological study of the impact of man on the landscape of central southern England, with special reference to the chalklands*. Unpublished PhD thesis, University of Southampton.

Webster, L.E. and Cherry, J. (1972). 'Medieval Britain in 1971', *Medieval Archaeology* 16 (1): 147–212.

White, L. (1940). 'Technology and invention in the Middle Ages'. *Speculum* 15 (2): 141–59.

White, L. (1962). *Medieval Technology and Social Change*. Oxford: Oxford University Press.

Whitelock, D. (1955). *English Historical Documents I, c.500–1042*. London: Eyre & Spottiswoode.

Whittington, G. and Gordon, A.D. (1987). 'The differentiation of pollen of the pollen of *Cannabis sativa* L. from that of *Humulus lupulus* L.'. *Pollen and Spores* 29: 111–20.

Wickham, C. (2005). *Framing the Early Middle Ages. Europe and the Mediterranean 400–800*. Oxford: Oxford University Press.

Williams, M. (2000). 'Dark ages and dark areas. Global deforestation in the deep past'. *Journal of Historical Geography* 26 (1): 28–46.

Williams, M. (2003). *Deforesting the Earth: From Prehistory to Global Crisis*. Chicago: University of Chicago Press.

Williams, P. and Newman, R. (2006). *Market Lavington, Wiltshire, An Anglo-Saxon Cemetery and Settlement. Excavations at Grove Farm, 1986-90*. Salisbury: Wessex Archaeology.

Williamson, T. (2003). *Shaping Medieval Landscapes*. Macclesfield: Windgather Press.

Williamson, T. (2013). *Environment, Society and Landscape in Early Medieval England: Time and Topography*. Woodbridge: Boydell Press.

Williamson, T. (2018). 'Open fields in England: an overview', in C. Dyer, E. Thoen, and T. Williamson (eds), *Peasants and Their Fields. The Rationale of Open-Field Agriculture, c 700–1800*. Turnhout: Brepols, 5–28.

Williamson, T. (2022). 'Agriculture, lords and landscape in Medieval England', in M. McKerracher and H. Hamerow (eds), *New Perspectives on the Medieval 'Agricultural Revolution: Crop, Stock and Furrow'*. Liverpool: Liverpool University Press, 211–34.

Williamson, T., Liddiard, R., and Partida, T. (2013). *Champion: The Making and Unmaking of the English Midland Landscape*. Liverpool: Liverpool University Press.

Wiltshire, P.E.J. (1990). *A palynological analysis of sediments from Staunch Meadow, Brandon, Suffolk*. London: English Heritage.

Wiltshire, P.E.J. (1991). *Palynological analysis of British Rail sections at Stansted Airport, Essex*. London: English Heritage.

Wiltshire, P.E.J. (1992). *Palynological analysis of sediments from a series of waterlogged features at Slough House Farm, Near Heybridge, Essex*. London: English Heritage.

Xoplacki, E., Fleitmann, D., Diaz, H., von Gunten, L., and Kiefer, T. (eds) (2011). *Medieval Climate Anomaly*, PAGES news 19.1.

Young, A. (2020). *Eckweek, Peasedown St John, Somerset. Survey and Excavations at a Shrunken Medieval Hamlet 1988–90*. Abingdon: Routledge.

Yousfi, S., Serret, M.D., Voltas, J., and Araus, J. (2010). 'Effect of salinity and water stress during the reproductive stage on growth, ion concentration, Δ13C and δ15N of durum wheat and related amphiploids'. *Journal of Experimental Botany* 61: 3529–42.

Zeder, M. and Lapham, H. (2010). 'Assessing the reliability of criteria used to identify post-cranial bones in sheep, Ovis, and goats, Capra'. *Journal of Archaeological Science* 37: 2887–905.

Zeder, M.A. and Pilaar, S. (2010). 'Assessing the reliability of criteria used to identify mandibles and mandibular teeth in sheep, Ovis and goats, Capra'. *Journal of Archaeological Science* 37: 225–42.

Zeller, B., West, C., Tinti, F., Stoffella, M., Schroeder, N., van Rhijn, C., Patzold, S., Kohl, T., Davies, W., and Czock, M. (2020). *Neighbours and Strangers: Local Societies in Early Medieval Europe*. Manchester: Manchester University Press.

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