Interdisciplinary Contributions to Archaeology

Evangelia Pişkin · Arkadiusz Marciniak
Marta Bartkowiak *Editors*

Environmental Archaeology

Current Theoretical and Methodological Approaches

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Preface

In September 2014 at the 20th European Association of Archaeologists Annual Meeting held in Istanbul, Turkey, we organised a session entitled "Environmental Archaeology and Archaeology: Divided we Stand (still?)". The inspiration for this stemmed from our concern and interest in a variety of issues. One of the most important was the actual position of what is termed "environmental archaeology" within the field of what one may call "mainstream archaeology". This issue was tackled before, and perhaps the book with most prominent expression is the one edited by Umberto Albarella back in 2001, entitled *Environmental Archaeology: Meaning and Purpose*. There, the definition of the discipline and indeed the very usefulness/uselessness of the term itself were intensively questioned by several researchers. The issue of what environmental archaeology is has also been discussed briefly or extensively in various other works and in almost every "handbook" published on the matter. This seems to have been a long and hard debate without consensus being reached yet.

Next to this was the consideration and concern with new developments in the field including a proliferation of new techniques, methods and approaches that have introduced a range of possibilities next to traditional subjects, which surely is a certain achievement; nevertheless their technical concepts are sometimes difficult to comprehend, evaluate and make useful. A further inquiry was the integration of various lines of evidence to produce a stronger basis for archaeological interpretation.

Environmental archaeology today encompasses an ever-widening suite of subdisciplines. "Environmental archaeologists" of whatever field of specialisation are routinely called upon to collaborate in archaeological projects under the fashionable "interdisciplinary approach" umbrella. Despite its long history, exceptional projects and numerous such studies addressing wider issues of archaeological research, the discipline often remains to be seen as an auxiliary undertaking aimed at supporting "mainstream" archaeology. It is also not unusual that different specialists work alongside with each other but the results they produce have hardly any reference to other specialised analysis, despite the fact that they address similar issues. Nevertheless, the need to collaborate and communicate is apparent today more than ever.

Here, we wanted to refresh the discussion and touch on what the current state of the affair is after many years of environmental archaeology theory and practice. This book contains a selection of papers, some of them presented at that meeting, some other written for this volume, discussing the position of the discipline and its practitioners from various standpoints as well as some case studies targeting to showcase that environmental archaeology is nothing else but archaeology.

Ankara, Turkey Evangelia Pişkin

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Marta Bartkowiak received her MA at Adam Mickiewicz University in Poznań, and she is currently completing her PhD dissertation regarding the problem of introduction and intensification of production and consumption of milk and dairy products among the Neolithic communities of NW Anatolia and Central Serbia. Her research interests encompass archaeology of food, biomolecular archaeology as well as application of up-to-date methods from field of chemistry and biology on the ground of archaeology. She is also interested in sociocultural transformations of communities from Neolithic Anatolia, the Near East and the Balkan Peninsula. Moreover she participated in many international projects such as *Catalhoyuk Research Project*, *Seshat: Global History Databank*, *NeoMilk – The Milking Revolution in Temperate Neolithic Europe and The Times of Their Lives: Towards Precise Narratives of Change for the European Neolithic Through Formal*

Chronological Modelling. She was a PhD fellowship holder of LeCHE Project (*Lactase Persistence in the early Cultural History of Europe)* funded by the 7th EU framework Marie Curie Initial Training Networks (FP7-ITN-215362-2).

Environmental Archaeology: What Is in a Name?

Evangelia Pişkin and Marta Bartkowiak

1 By Whose Direction Found'st Thou out this Place?

Environmental archaeology as a distinct discipline begun at least 50 years ago, but if seen as an interest with the past environment, its roots go back in the XVIII and XIX centuries. The crucial information needed for building analytical and theoretical apparatuses for "natural sciences" had studies concerning the formation processes and stratigraphy undertaken by geologists, geographers and palaeontologists (such as Nicolas Steno, 1638–1686; Charles Lyell, *Principles of Geology*, 1850; Richard Owen, *Palaeontology or a Systematic Summary of Extinct Animals and Their Geological Relations*, 1850). These also contributed to the development of field techniques, sampling strategies and documentation (Evans 2003). During this period, there also began a shift from treating artefacts as "pieces of art" or "insular finds" to studying them in their "natural" context and detailing the information of their provenance (in particular as a help to establish chronology).

However, the most significant imprint on environment archaeology had the Darwinian theory of evolution. This inspiring idea of the transformation of all species through natural selection, adaptation to changing natural conditions and existence of strict relations between all living creatures had far going consequences (Darwin 1859; Wallace 1858) for both natural and social sciences. Transformations that often went hand in hand and at the same time influencing the way life and society was perceived to work, proceed and change. Creatures and societies evolved

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under the rule of "survival of the fittest" coined by Herbert Spencer (Spencer 1864). First of all, it implicated that all living beings come under the same one universal rule, and so are humans. This belief stimulated further investigation regarding the origin of the *Homo* species and resulted in studies such as those undertaken by Leakey's in Africa (1931 and next), Raymond Dart (on "Taung Child" – and the Australopithecus – 1924) or Marie Eugène François Thomas Dubois (on "Java man", 1891) to mention just few (Aiello 2006; Haviland et al. 2013).

Moreover, the assumption of species modification through time generated the questions of the environmental settings in which such modifications occur and thus have become a great motive for research on palaeoenvironment. These issues were raised, for example, in Ferdinand Keller's investigations concerning macrofossils of plant (1878) and palynological studies undertaken by Johannes Iversen (1941) or Ernst Jakob Lennart von Post (quantitative analysis of pollen, creation of modern pollen diagram, 1916) (Evans and O'Connor 1999, 1–9).

Additionally, the biological model of progression was also adopted in the grounds of anthropology and archaeology and improved by scholars such as Augustus Pitt-Rivers (1827–1900), Lewis H. Morgan (*Ancient Society*, 1877) and Edward B. Tylor (*Primitive Culture* and *Anthropology*, 1871), who deeply believed in the progressive nature of human culture and, as Morgan himself suggested, that the humankind went through some particular stages on "the ladder of development" from the lowest to the highest step (called by him as "savagery" through "barbarism" to reach a "civilization" step at the end) (Morgan 1877).

At the same time, studies regarding the interaction of past environment and human cultures were initiated, two well-known examples of which are the multidisciplinary project concerning the origin of agriculture headed by Robert John Braidwood (Jarmo, and later, Amuq Plain, and in SE Anatolia) and Jens Jacob Asmussen Worsaae in Scandinavian bogs in Europe (Braidwood 1960; Worsaae 1847).

Undoubtedly, the beginning of environmental archaeology might be characterized as a time of uninterrupted enrichment of science, interlacing of different disciplines and building the basis of modern methodology. Notwithstanding, environmental archaeology was still a rather weakly related group of various methods or analytical techniques than a separated discipline with finely defined scientific goals, approaches and paradigms, elaborated coherent methodology and clearly specified identity (Evans 2003; Dincauze 2000, 3–4).

The first half of the twentieth century brought vivacity in both perception of environment and diversification of approaches to the environmental archaeology. For a long time, the environment has been perceived as a passive background, setting of human activities, where "things happen". The researchers focused mainly on the reconstruction of past environmental conditions, or they examined the process of animal and plant evolution (or domestication of some species). These research perspectives have been modified, particularly, thanks to scholars such as Grahame Clark (1952, *Prehistoric Europe: the Economic Basis*) or Julian Steward (1955, *Theory of Culture Change: The Methodology of Multilinear Evolution*), who postulated studies on the interconnections between the habitat and past society. The conception of cultural evolution coined by Steward (Steward 1955) highlighted the role of geographical or natural setting in the process of changing societies and the ability of communities to adapt to various environments.

The role of environment in the process of altering the human societies was showcased by novel studies undertaken by Grahame Clark in Star Carr (in 1949) which proved the whole potential of interdisciplinary studies and engagement of many specialists in order to understand the economic efficiency of particular habitats and explore the ways of how the environment was used (especially in case of raw material acquisition) by humans (Clark 1954, 1972).

Despite of these few pioneering works, this period was rather a time of consolidation of this discipline and amplification of its methods. The development of new methods such as radiocarbon analysis (Libby 1952) and isotopic analysis (Emiliani 1954) and their application to archaeology made possible the precise dating of archaeological deposits and study on past climate (through examination of oxygen isotopes found at deep sea cores). These advancements demonstrated the significant role of ecofactual evidence, which earlier were often marginalized (see also Renfrew 1973).

The turning point in the formation of environmental archaeology as a discipline on its own right is associated with the movement of "New Archaeology" and later "New Geography" (Hagget and Charley 1969). Both argued for the strongest need of keeping scientific rigours in archaeological investigations and emphasized the role of environment, which affected and moderated human behaviours. The processualism understood the culture as "extrasomatic means of adaptation" sensitive to changes evoked in ecosystem and always striving to achieve homeostasis (Binford 1962, 1968). In other words, the transformation of the environmental component (such as climate) was expected to generate a modification in the cultural system. This means that through careful examination of the environmental settings and the archaeological site, it will be possible to explain the process of cultural system transformation through time. This approach metamorphosed archaeological goals and the way of perception of the habitat that is the archaeological site's surroundings. All data concerning the ecosystem were grouped together and perceived in a synthetic way. In consequence all areas of research within environmental archaeology became very important and integrated with the archaeological problem at hand. The "borrowing" strategy of simply obtaining the results of specialist analysis started to fade. Instead of using the descriptive matter of presenting the gathered information, the scholars used the data to create storage and manage the elaborated databases in order to testify or verify the scientific hypothesis, often adapting up-to-date methods and statistical models (e.g. Renfrew 1973; Clarke 1977; Watson et al. 1971).

These studies addressed chiefly questions regarding economy and subsistence strategy and acquisition of natural resources. This period was also associated with the birth of settlement archaeology and spatial analysis in archaeology (e.g. *Spatial Archaeology* by David Clarke 1977). The most influential works belong undoubtedly to Eric Higgs and Claudio Vita-Finzi. They proposed a new model called "Site Catchment Analysis" (SCA) to study the matter of exploitation of the land around any given site and establish the limit/border of accessibility of particular important resources including features such as type of soil, land form and type of vegetation (Vita-Finzi and Higgs 1970). They assumed that the environment was used by past populations in the most optimal way in order to obtain necessary resources whilst at the same time minimizing the loose of energy needed to acquire them (Vita-Finzi and Higgs 1970). The other commonly applied method originated from the field of geography was "Thiessen polygons", which aims to define the territory exploited by any site and describe the settlement network (Kipfer 2000, 563; Hammond 1972; Hodder 1972; Renfrew 1973).

Another set of seminal studies at that time was concerned with site formation and depositional/post-depositional processes which influenced significantly the preservation of archaeological material, including ecofacts, and their context of recovery (Schiffer 1972; Limbrey 1975). In these inquiries palaeozoology and zooarchaeology have played important role with the development of the field of taphonomy (Efremov 1940; Lyman 1994; Behrensmeyer and Hill 1980). Simultaneously, paleoenvironmental studies were flourishing in terms of new methods such as micromorphology and sediments analysis (Butzer 1971, 1982) and new techniques for archaeological data collection such as sieving and flotation (Jarman and Higgs 1972; Kaplan and Maina 1977).

All these entangled "environment archaeology" stronger with "mainstream archaeology" (and archaeological departments as well) and had a significant effect on the perception of it, forming its "professional" identity and establishing its position within archaeology circles (Albarella 2001).

At the same time period, "environmental archaeologists" established their own associations such as "Association for Environmental Archaeology (EAA)" in 1978 dedicated to "the study of human interaction with the environment in the past through archaeology and related disciplines" and popularize the results. The "International Council for Archaeozoology (ICAZ)" is another one such association promoting zooarchaeological studies. Simultaneously, international peer-reviewed journals with single focus on science and environment were published such as *Journal of Archaeological Science* (since 1974), *Circaea* (between 1983 and 1996, change in 1997 into *Environmental Archaeology: The Journal of Human Palaeoecology*) and *Geoarchaeology, Vegetation History and Archaeobotany*, to mention a few.

Whilst environmental archaeology seemed to be a most promising inquiry right at the heart of archaeological research, doubts arose for the usefulness of *any* "science in archaeology". The main subject of critique was directed towards the processualist's belief in the objectivity of archaeological sciences and the possibility of revealing the "truth" of past processes by applying of scientific methods. On the contrary, the new movement, post-processualism, addressed the issue of subjectivity in the archaeological investigation and pointed out the relativeness of archaeological records (e.g. Hodder 1986). The post-processual approach has not been a coherent movement, and many theoretical theses have been crystalized through time within it, but they shared a basic body of ideas. It highlighted the dominant role of the archaeologists in the interpretation of the data whose viewpoints were determined by many conscious or unconscious factors (Hodder 1986; Shanks and Tilley 1992; Tilley 1997). It disputed the idea of rational exploitation of environment by humans and emphasized the contribution of cultural and social agents in the way of its usage. The environment has been seen not as something universal, staying in opposition to human culture, but as a part of a social word with which it became contextualized and might have been perceived and experienced in various ways. In other words, the environment is not the environment: It is an artefact "created" by human actions/perceptions, entangled in social processes and should be analysed as a part of the later (Albarella 2001). Thus, the interpretative post-processual archaeology does not reject the need of collecting and managing the archaeological/environmental data, but, for a part of it, it postulates to diversification of research perspectives (resurfacing themes from the progenitor of it, the historical archaeology) and closer integration of theory with the material records (Albarella 2001).

Under this influence, research intensively focused on social structure and ideology questions. For instance, the study of past diet has not been any longer just a simple matter of subsistence strategy, but it became a media for building social and cultural meanings, negotiating social status or expressing the gender role (Tringham 1991; Wylie 1992; Gibbs 1987). The elements of the environment have now obtained agency (Evans 2003; Ingold 1996; Poole 2015). Many of these are not totally novel topics but rather a move for emphasis to be put on these aspects of the data. Most importantly perhaps the ground was created for the construction of new theoretical frameworks, and new labels for those were proposed such as social zooarchaeology (Marciniak 2005; Overton and Hamilakis 2013; Russel 2012; Sykes 2014; Vandergugten 2015) and social palaeoethnobotany (Bruno and Sayre 2017; Palmer and van der Veen 2002; Madella 2014; Morehart and Morell-Hart 2015). Long-lasting and more important consequence of this line of thought is the abandonment/critical application of descriptive and rational models of human behaviour that was the flagship of processualism and the (partly) replacement of them by flexible and multilayered interpretations, cut to case.

A large number of publications pay tribute to the immense growth and diversifications of approaches that environmental archaeology experienced and developed in the last 30 years or more, to a large extent under the influence of the changing face of mainstream archaeology. These surely demonstrate the deep involvement of environmental archaeology with mainstream archaeology. It is also an outcome of the fact that the demographics and attitudes of its practitioners have changed. Whilst at first scientist of various disciplines were called upon when needed to provide consultancy for archaeologists resulting to the notorious "laundry lists" of species present, now archaeology graduates are trained on the fields of environmental archaeology, and researchers coming into it with a science background delve deeply in the methods and theory of archaeology. Thus today "environmental archaeologists" have developed a vast array of detailed studies touching directly to questions right in the heart of any conceivable archaeological inquire.

Today, the simple lists of species is a thing of the long past. We are also past the *first* attempts of environmental archaeology to define its goals and develop its methods and techniques (mostly within processualism). In the past has been left the post-processual critique too. We are now in a stage where, whilst still armed with the old "processualist" models but well versed in their drawbacks, we have developed and are developing a plethora of new approaches and attitudes (towards data as well as ourselves) and have prepared/are preparing an ever-growing arsenal. Truly, there is a proliferation of even more new techniques, some with their roots back to the past and firmly set with even more science ever. Amongst these perhaps the most fashionable are genetics, isotopes, geometric morphometrics and the GIS revolution for every conceivable use.

Involved in all contemporary archaeology concerns, environmental archaeology has closely followed or pioneered on various directions of theoretical and practical concerns of archaeological practice. Not satisfied with the results of studying just a site, we are now looking at the "big picture" at a regional or almost continental studies, and "big questions" are sought to be answered by "big data" (Colledge 2016; Colledge et al. 2013). What we do with our data and the metadata pool of information is another important move and has led to advocating the "open access need" (Kansa et al. 2007; Kansa and Kansa 2013; Kansa et al. 2014; Conolly et al. 2011; Orton et al. 2016; Prinzl et al. 2014). Looking at any problem from multiple viewpoints is strongly desirable, and integration of various environmental data sets and/or with other archaeological data is in the fore front (Etten and Hijmans 2010; Van Derwarker and Peres 2010).

All these put on the archaeological inquiry side of the discipline; there also seems to be an increasing soul searching in environmental archaeology circles considering the usefulness of it for both the society and the scientific community. Many voices have risen up the issue of why and for whom we carry out our research and how the discipline could contribute meaningfully to important problems of this epoch we live, the "Anthropocene" (Braje 2015; Murphy and Fuller 2017; Riede et al. 2016). Just the very name of it, "Anthropocene", makes it clear how useful will be to retrieve and make use of knowledge of past human decisions that shaped the planet. Conservation biology, sustainability, vulnerability and resilience, landscape ecology and conservation and climatic change are dominant fields to which many environmental archaeologists believe there is a call for them (Lyman 2006; Lyman and Cannon 2004). At the same time, problems such as coping with natural disasters including learning from past experience what to expect and how to respond to it together with how to prepare the public for such possibilities are issues on which many of us think they can bring an important input to benefit public, scientists and policymakers by providing the depth of time experience that contemporary observation lacks. Relatively recently this "move" was expressed in a collection of articles in the edited volume with the most eloquent title "The Future from the Past" (Lauwerier and Plug 2003). These trends have often urged or became examples for a collaboration and – once more – integrated approach across various archaeological subdisciplines as well as other than archaeological disciplines (Erickson and Candler 1989; Hartman 2017). As new as this approach looks, it is indeed not that young if one remembers the Negev desert experiment (Evenari et al. 1961).

2 What's Montague?

Contemporary narratives concerning the environmental archaeology often oscillate between very popular recent terms such as archaeological science, archaeometry, bioarchaeology, biomolecular archaeology or geoarchaeology. Both terms – archaeometry and bioarchaeology – have a long tradition. Whilst the first one was coined in the 1950s by Christopher Hawkes to name a new journal dedicated to presenting the results of scientific method's application on the ground of archaeology and associated with newly founded Research laboratory for Archaeology and the History of Art, the bioarchaeology was introduced by Grahame Clark during his study on Starr Carr and highlighted the cooperation between various discipline of science and archaeology (Hawkes 1968; Clark 1972). Contemporary, environmental archaeology is perceived as a part of archaeological science (or scientific archaeology) together with dating methods and artefacts studies, e.g. by Tite (Tite 1991, 140, 147), Denham (2012, 305–6), Chambers (2013, 342) and many others (Pollard & Heron 2008, 2; Wilkinson and Stevens 2003, 16–17). It is also often subdivided into two parts – bioarchaeology and geoarchaeology (e.g. Chambers 2013, 342) – or more, e.g. four (earth science, bioarchaeology, zooarchaeology and archaeobotany) (Reitz et al. 2008, 5). Moreover, it is also understood in a broader way – as including "archaeological use of ancient biomarkers […]; chemical and mineral analysis of artefacts and the wide range of dating applications in archaeology" (Chambers 2013, 342). From this point of view, the environment seems to be rather a general thematic label bonding together these studies rather than an independent discipline (see also Albarella 2001; Chambers 2013; Wilkinson and Stevens 2003).

Surprisingly, the environmental archaeology is still seen by many mostly through prism of used methods without taking into account its theoretical background. It is perceived as highly specialized, expert discipline using very sophisticated and up-to-date methods (e.g. Brown and Brown 2011). What seems to be a hazard is its instrumental treatment again. Incorporation of environmental studies into field of archaeological science (see also more general discussion about archaeology and science, e.g. Johnson 2010, 34–47) and labelled as highly specialized domain, again, makes it very distant from the "mainstream" archaeology. Albarella called this process exceptionally accurate as "alienation" (2001, 7).

Is this statement still valid? In fact, we think there are various degrees and types of "alienation":

1. Geographical alienation: Even though environmental archaeology has grown up to a very complex and mature research area, this condition is not uniform across the globe. It is rather prevalent at the academic circles of a handful of leading countries. The rest of the world has to cope with a less than satisfactory situation. For the very fact, many countries have a handful of practitioners or even not that much. Whilst in countries with long tradition in the discipline researchers have the luxury of musing over all details of applications and interpretations, we have an extreme poverty plaguing colleagues and projects in areas where only the

minimum requirements of the profession are met, if at all. “Mainstream archaeology” colleagues in such locations are far from considering environmental archaeology an essential part of their project planning and executing (Chase et al. 2004; Fairbairn 2005).

2. Period alienation: There is an alienation as we move from the older time periods to the younger. Archaeologist studying the very distant past are much better versed on the information environmental archaeology can provide and more inclined to work with environmental archaeologists than their colleagues studying more recent eras. Often in the countries where the discipline is well rooted the “period” studied has relatively little effect but it gets really serious in regions where environmental archaeology is already lagging behind. Both, the geographic and period cases demonstrate sufficiently that alienation with mainstream archaeology still stands.
3. At a time when integration of various lines of evidence for better archaeological interpretations is recognized as most important, there is alienation amongst environmental archaeologists.
   (a) What we would call “a second science revolution” in archaeology has given the opportunity to environmental archaeology to grow to a huge tree with so many branches that makes communication and comprehension of results difficult amongst environmental archaeologists themselves. Even in cases where the materials under study are the same there is such a big range of methods and techniques to deal with the data that it seems we have departed on a path separating us further to “sub-specialist schools”, each engaged in heated discussions on very specific topics hardly been able to follow up another “school” of another closely related over-specialization.
   (b) The biggest division within environmental archaeology is perhaps to be found amongst those of us who deal with “geoarchaeology” and “bioarchaeology”. Even though all parts of the environment are surely interconnected, the researchers on these fields seem very far from being able to exchange information, follow up the results or sometimes understand each other. Not because it is not necessary – quite the opposite – but simply because it is difficult. This volume is an example of this situation.
4. There is a research driven versus all – other –type of work alienation. As “research driven” we define here projects started with specific research questions – usually planned by Universities. The second type of work is not designed beforehand but responds to “developer” needs and it is by large salvage work. In several countries, this is carried out by commercial archaeology, in others by museums or other state bodies. There is no doubt that the policymakers of the second type of projects have quite different views on the importance of environmental archaeology compared to the designers of research-driven projects.
5. We are still in alienation with the society despite the cry for an ethical responsibility not to stay indifferent and a-political.

3 It Is nor Hand nor Foot, nor Arm nor Face

Having denied to discuss the "name" at the beginning of our paper we come now to contradict ourselves tellıng that this worth some consideration.

For one thing why are we called environmental archaeologists and not simply archaeologists? We feel that this actually has its roots to the very distant past of archaeology whose ghost is still to be seen on the names of many archaeology departments around the word: "Department of Archaeology and History of Art". This is what archaeology was at its birth, and this is what environmental archaeologists are not: Simply, we do not study art(efacts)! Therefore a name should be found to describe these new categories of research materials (ecofacts) and studies (environmental archaeology) within archaeology. Is there a reason to keep carrying on this name?

Having a name might be as much a plague as a blessing. For one thing, it gives an identity and a banner under which one can promote its own case. In the practical side of archaeological methods, perhaps one of the biggest achievements of the label "environmental archaeology" within archaeology is that overall the "discipline" is acknowledged as important, "ecofacts" are considered materials worth of studying and excavators more often than not take care to collect at least some "environmental archaeology samples" even when a specialist is not part of their team instead of dumping them on the spoil heap. On the other hand, a "name" requires to state what it is and what it is not. The preceding parts of this article showed how difficult is to define "what is it" comprehensively enough to cover the ever-renewed and very wide aims of it. Defining what is not is another thorny subject and one of the negative outcomes is the perceived (but false) division of archaeology to environmental archaeology and "mainstream" archaeology.

There is no doubt that environmental archaeology is archaeology, for it is called exactly that. But the remaining qualifying word "environmental" is less clear. Attempts to conceptualize the word "environmental" have sometimes put the emphasis on reconstructing the environment, sometimes the economic exploitation of it and other times the social aspects of past cultures. All of them included and excluded parts of what we do. This is actually an expected struggle for a field that has been grown enormously. Minimalistic approaches have been proposed such as adopting a very simple definition that "environmental archaeology is the study of ecofacts". One may say though that ecofacts are artefacts, considering that ecofacts found at an archaeological site are (mostly) collected intentionally by people to be used (even if totally unmodified). Another such definition is that "environmental archaeology studies the interaction of humans with nature". This is a very attractive option because its simplicity allows it to be much wide and accommodating without putting any restriction on direction or form of research. Nevertheles such a loose description is in danger of becoming elusive and confusing? Because what is any human action which does not involve interaction with nature?

Environmental Archaeology has been also described as "human ecology" (Butzer 1971), "economic prehistory" (O'Connor 2001) or "Quaternary paleoecology" (Coles 1995; Delcourt and Delcourt 1999). These reflected a variety of research perspectives, traditions, experiences and approaches of practitioners of environmental archaeology. Thus, it appears almost impossible to group them all together and create one, commonly accepted definition. Is it really necessary? Is environmental archaeology a matter of definition as Terry O'Connor wrote (O'Connor 1998)? The discipline, serving a multitude of inquiries and being served by an ever-growing body of techniques, whatever definition given, there will always be an appropriate argument to debunk it. This can surely be an endless, maybe fruitless, discussion which we may choose to give up taking heart on that nobody knows why a rose is called a rose but everybody knows what a rose is: for we know its components and its usefulness.

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Environmental Archaeology: The End of the Road?

Umberto Albarella

In December 1998, I organised a session as part of the Theoretical Archaeological Group (TAG) conference held in Birmingham, England. It was entitled 'Environmental archaeology: Meaning and Purpose'. Having spent most of my career up to that point as a practitioner of what I had become used to regard as a branch of archaeology, I was feeling increasingly constrained by it. I felt an urgent need to stimulate a debate on the issue – what is environmental archaeology, and is it really of any use? The session generated interest beyond my imagination! Throughout the day the room was packed with people, many forced to sit on the floor, and others were not even able to enter the room. Several excellent papers were presented, and the discussion was lively and, at times, even rather fierce. The proceedings of the session were eventually published (Albarella 2001), though the book was unfortunately put on the market by the publisher Kluwer at an extravagantly high price, which limited its distribution. Nonetheless, it does seem to have left a mark, however small, and the interest in the topic seems to have been rekindled in recent years. Ben Gearey, Suzi Richer, Seren Griffiths and Michelle Farrell organised a session at TAG (Bradford) in 2015 to celebrate the 15th year of publication of the book. The session, entitled ' "Humming with cross fire and short on cover…" Revisiting and reflecting on Environmental Archaeology: Meaning and Purpose', featured a few of the original contributors but also many new researchers. Then there is this book, edited by Evangelia Pişkin, Arek Marciniak and Marta Bartkowiak, which has a different ethos, but also revisits some of that debate.

Predictably, the parameters of the discussion have changed in the last 15 years, though not as much as one might have expected. New elements have emerged, some of the old problems appear to have been partly resolved, but quite a few sticking points of the past have proven to be resilient. Pişkin and Bartkowiak provide a valuable

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summing up of the development of environmental archaeology set within the history of archaeological thought. That history gives us the insights we need to understand the challenges that an interpretation of environmental archaeology has today.

One area where there has been definite progress concerns the greater integration of different areas of archaeology leading to a more comprehensive understanding of past human societies. Biological and geological studies today tend to contribute more to core archaeological questions than was the case in the late 1990s. Although problems of communication within archaeology still certainly exist, it is now more likely to see conference sessions, books and even journals, jointly tackling social and ecological issues. Even greater advances have occurred in the world of education and training, and, consequently, many younger researchers have moved well beyond some of the unhelpful categorisations that characterised past approaches. The quest for integration, promoted for many years by several visionary researchers (e.g. Butzer 1982; Luff and Rowley-Conwy 1994; O'Connor 1998), has produced results.

Such advances must, however, be interpreted within the context of developments in archaeological theory and the variable fortunes of various schools of thought. Like fashion clothing, intellectual trends tend to develop like self-enhancing energy systems, until they reach a point of absurdity, which is when their decline becomes inevitable. This is what happened to post-processual archaeology which, initially developed from a very reasonable suggestion not to interpret human societies in a mechanistic way, ended up becoming a caricature of itself in the 1990s and, as a consequence, lost influence. Post-processualists tried to recycle themselves as 'cultural archaeologists' (e.g. Hodder 2000), thus presenting a new challenge for archaeological integration. If there was an archaeology that dealt with 'culture', was there another archaeology that operated in a different sphere? And what was it? Perhaps the 'environment'? Had a new niche for environmental archaeology been created? Fortunately, few fell into this trap, and in fact 'cultural archaeology' never really took off. The times had fortunately changed, and the discipline as a whole had matured.

Yet, as soon as some of us felt that the 'struggle' had nearly been won and that the artificial separation between culture and environment could finally be regarded as a thing of the past, some of the so-called environmental archaeologists have started defining themselves as 'social archaeologists' of various kinds (e.g. social archaeobotanists, zooarchaeologists, geoarchaeologists, etc.; see references in Pişkin and Bartkowiak). The implication of such choice is that mainstream 'environmental archaeologists' do not deal with 'societies' and 'social issues'. This is incongruous and an inadvertent attempt to throw us back to the day when the nature-culture dichotomy raged.

To understand the organisation of human societies is one of the aims of archaeological investigations of any kind, and it relies upon any type of evidence. It represents an important thematic investigation, no differently from environment, landscape, settlement, religion, trade and mobility – all key subjects in archaeology. There is therefore nothing wrong for archaeobotanists or zooarchaeologists to declare a special interest and/or focus in the understanding of social structure as part of their investigations. This is different, however, from proposing the existence of a subdiscipline appositely dealing with social issues. This would, by default, imply that other archaeologists, or environmental archaeologists, do not have equal rights to investigate societal organisation. The attitude is potentially discriminatory and takes me back to the core point of my 2001 contribution – namely, that the main issue of the fragmentation of archaeological subdisciplines has to do far more with academic status than with a genuine intellectual debate.

As Thomas (2001) pointed out, there is a logic to the existence of archaeology branches such as archaeobotany, zooarchaeology and geoarchaeology, as these are defined on the basis of the materials they study (plants, animals and soils). The ability to analyse such remains requires specific training, and therefore it makes sense that specialists in such areas are created. This is not the case with broader concepts such as society and environment, which represent thematic investigations that should be the subject of study of *all* archaeologists. Although it is perfectly understandable for a pottery specialist not to have the expertise to identify plant remains and for a zooarchaeologist not to be familiar with stone tool typologies, all these researchers cannot possibly afford to ignore key issues in archaeology such as economy, environment, society and religion. We must all engage with these subjects, which is why there should be no room in modern archaeology for environmental, social, let alone cultural, archaeologists.

Environmental archaeology not only does not have its own study material, but it cannot also be classified on the basis of its methods and theories. None of those can be restricted to just one area of archaeology, and, in fact, they often need to look well beyond archaeology to embrace more general approaches to scientific investigations. To regard environmental archaeology as the branch of archaeology that investigates the relationship between people and nature – a possibility that Pişkin and Bartkowiak are prepared to discuss – would mean to accept that human societies operate outside, rather than as part of, the natural world. Archaeology studies the material remains of our past, and everything that past humans have made and managed comes from nature – the animals they kept and hunted; the plants they grew and foraged; the stones used to make walls, houses, objects and statues; the clay turned into ceramic, floors and buildings; and the metals extracted to make weapons, decorative objects and other tools. The relationship between humans and the rest of the natural world is not one aspect of archaeology but rather the essence of it. To confine it to a branch of archaeology means to accept the position of humans outside the realm of nature, its superiority over other beings, and agree that our role is to make nature operate to our service, rather than adapt to planet-wide ecological forces.

I have seen no evidence in the last 15 years that could persuade me to change the view I held in the late 1990s. The main purpose of my book was to deconstruct the concept of environmental archaeology and to investigate ways in which different areas of archaeology could operate together more harmoniously. I do appreciate the effort to revitalise environmental archaeology in a new light, but I believe that the issue we have been grappling with in the last couple of decades has not been confined to mere semantics, but has a lot to do with the essence of archaeological interpretation. I have admired the seductive parallel between the 'rose' and 'environmental archaeology' mentioned at the end of Pişkin and Bartkowiak's paper, but I must admit that I find it unconvincing. Unlike the rose, who we all know what it is, despite ignorance about the origins of the name, in the case of environmental archaeology, we know perfectly well what the origins of the term are, but, despite much debate, we are still unsure about what it is and whether it really represents anything worth of note.

'Environmental archaeology' is the product of a misunderstanding of what archaeology means, as well as the position of humans in the world of nature. It is time for it to become confined to the history of research. It has fulfilled an important role, but also generated confusion, and it no longer represents a valid or useful interpretive tool. It is time to move on and aspire to an archaeology diversified in its skills and approaches, but fully integrated in its questions and aims.

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Changing Perspectives: Exploring Ways and Means of Collaborating in Environmental Archaeology

G. V. Campbell, C. Barnett, W. Carruthers, L. Pearson, R. Pelling, and D. N. Smith

1 Introduction

One of the questions that this book seeks to address is the extent to which environmental archaeology is still regarded as an add-on to archaeological excavation projects. In particular it explores how integration, in terms of using environmental archaeological evidence to address important questions about the past at the site and landscape level, and the sharing of results and interpretations of different types of evidence within multidisciplinary teams, leads to better outcomes.

Environmental archaeology has been an established part of archaeological practice from the early 1970s (Evans and O'Connor 1999, 5). Within the UK, the introduction of Planning Policy Guidance Note 16: Archaeology and Planning (PPG16) in 1990 resulted in a huge growth in developer-funded archaeology and the number of archaeological excavations undertaken (Darvill and Russell 2002; Fulford and Holbrook 2011). At the same time the number of environmental archaeologists has grown and the range of materials studied as well as the techniques and methods used to study these materials has greatly increased. However, the

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environmental archaeology sector is still tiny in comparison to the archaeological sector as a whole (Aitchison and Rocks-Macqueen 2013). In addition, the workforce is varied, with environmental archaeologists working as sole-traders, for commercial archaeology companies, for universities and for national heritage organisations. As such their working conditions differ considerably, as do the drivers for work undertaken, which often forms a small part of much larger projects. This can present challenges in terms of integrating the results generated from research undertaken by environmental archaeologists with those produced by other specialists, for example artefact specialists. These challenges are nothing new (see Luff and Rowley-Conwvy 1994), but the growth in the amount of data available and the birth of the digital age means that we need to ensure that we are not just continuing to collect data for the sake of it but rather directing our efforts and resources to answer key research questions. These challenges, in terms of integration and a rapidly changing working environment, are not unique to the UK; we therefore hope our observations will provide a useful perspective for archaeological practice in other countries.

This chapter focuses on the experiences of environmental archaeologists working on multidisciplinary projects in different parts of the historic environment sector in the UK: national heritage organisations, academia, commercial archaeological units, archaeological units sponsored by local government and freelance specialists. Rather than entailing a general survey of environmental archaeologists and their experiences, it uses as a starting point the results of the Mind the Gap project conducted by Bell et al. (2014) which reported on some of the challenges involved in managing large projects (Bell et al 2014), and some of the issues raised on the archaeobotany email discussion list (https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=ARCHAEOBOTANY) regarding a mismatch between research syntheses based in universities on the one hand and those creating the data as part of developer-funded archaeological projects on the other.

We considered our own experiences of working within multidisciplinary projects, and how the way we work and what is expected of us as individuals working in and with a range of different organisations varied both in terms of priorities and drivers for our work. These are presented as personal views rather than those of the organisations within which we work. They are illustrative rather than exhaustive but we hope to bring out some common themes that need to be considered when collaborating on multidisciplinary projects if we are to achieve fully integrated interpretations and realise the full potential of the research undertaken. These general issues and themes are discussed in the final section of the chapter which makes suggestions regarding the measures that lead to successful collaborative projects.

Discussion on the archaeobotany email list focused on the dichotomy between commercial archaeology carried out as part of the planning process and environmental archaeology research undertaken as part of research funded by the UK research councils and others. The results of commercially funded environmental archaeology are a huge resource which is mined by research projects but sometimes undervalued or not thought sufficiently rigorous. Part of the problem here may be that the data procured as part of developer-funded projects is not collected with a given research project or question in mind but rather to offset harm[1] to heritage assets.[2]

Other issues include access to grey literature and poor signposting of archives, both digital and material. Furthermore, there is rarely funding for specialists working on developer-funded projects to carry out research that places the assemblages or sites they investigate in their wider context. Added to this publication may only cover the major or the most significant results as determined by the client or project manager, taking into account costs, word limits and audience. This can mean that important results, especially negative ones, are not adequately disseminated. Thus trends and patterns which are apparent to practitioners working in particular regions, and/or on specific materials, are not borne out by the published data. There is therefore a pressing need for us to share our datasets (see Arbuckle et al. (2014) for a recent example within zooarchaeology) and increase the dialogue between the academic and commercial sectors.

The Mind the Gap project (Bell et al. 2014), funded by the Arts and Humanities Research Council as part of the Science and Heritage Programme, sought to capture the experiences and attitudes of participants in research projects. The survey conducted as part of the project asked researchers and users of research about one collaborative project they had been involved in over the last 5 years. The survey was designed to assess whether those questioned had achieved their personal goals as well as their level of satisfaction with the project outcomes and the project impact. Those taking part in the survey were also asked about what helped or hindered their project split into two themes:

- Background – specialism, experience, place of work and role
- Project – size and complexity

There were just over 200 responses to the questionnaire. A wide range of projects were included, but projects that comprised only academic researchers were excluded. The study showed that the users of research have practice-focused goals, whereas for researchers in academic institution publication, career development and intellectual goals are more important. Hybrid researchers, those that both do and use research, and the category into which most environmental archaeologists fit, have a mixture of both practice-focused and intellectual goals.

The project findings of most import to environmental archaeologists and archaeological practice were that large projects present challenges in terms of the research dynamic[3] and that multidisciplinary projects lead to better outcomes. However, and

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[1] Harm as used in this context is ‘Change for the worse, here primarily referring to the effect of inappropriate interventions on the heritage values of a place’ (English Heritage 2008, 71).

[2] A heritage asset is ‘a building, monument, site, place, area or landscape identified as having a degree of significance meriting consideration in planning decisions, because of its heritage interest’ (National Planning Policy Framework, Department for Communities and Local Government 2012, Annex 2: Glossary).

[3] A healthy research dynamic is crucial for collaborative research. It comprises a number of elements, namely, trust, shared goals, communication, openness and relationships (Bell et al. 2014).

importantly, more than six subject specialisms make project management very difficult and can affect success, whilst collaboration takes time and needs to be resourced properly (Bell et al. 2014, 4).

Archaeological projects are complex projects by their very nature. In other words, we do difficult projects all the time and often very well. However, However, we need to recognise that complex projects are hard to manage and that better ways and means of working together are required at a time when the way that research is conducted is rapidly evolving and facing increasing fiscal downward pressure, concerns that apply not only to UK archaeology but also in other areas of the world (Kansa 2012).

Collaborating on projects should be an enriching experience. How can we make it one and what makes a good project? In order to start exploring these issues, we decided to get together and compare our own experiences, focusing on the concept of communities of practice.[4] We wanted to understand how our priorities and approaches differed depending both on our place of work and also on our roles and responsibilities. From this, we hoped to better understand each other's needs and aspirations and how to develop better projects and ways of working.

2 Our Communities of Practice

Gill Campbell and Ruth Pelling work for the Historic England (formerly English Heritage). Figure 1 is a representation of their communities of practice.

Their role in Historic England centres on heritage protection and providing advice on making and managing changes to historic places. They help to provide the evidence base for establishing the significance or value of archaeological sites and work to ensure best practice in environmental archaeology through training, teaching, as well as the promotion and maintenance of high professional standards.

Issues that can affect collaboration on projects include a focus on heritage protection and the assessment of significance which tends to place more emphasis on archaeological structures rather than the ecofact and artefact assemblages they contain. The nature of the research they carry out, as would be expected for a national heritage body, centres on a national rather than an international scale. At the same time, work on projects is squeezed by the time required to provide advice, input into strategy and policy development and management tasks, whilst public engagement and outreach activities are directed towards history rather than science.

On the other hand, there is less emphasis on a 3- or 4-year project cycle than is the case within the university sector giving a certain amount of freedom to conduct research which requires medium-term investment over 5–10 years. Also, within Ruth and Gill's department, continuing professional development (CPD) is well-supported, and partnership working is encouraged. Specialists can manage their

[4] The pursuit of an enterprise or series of enterprises (practice) and the attendant social relations (community) (Wenger 1998, 45).

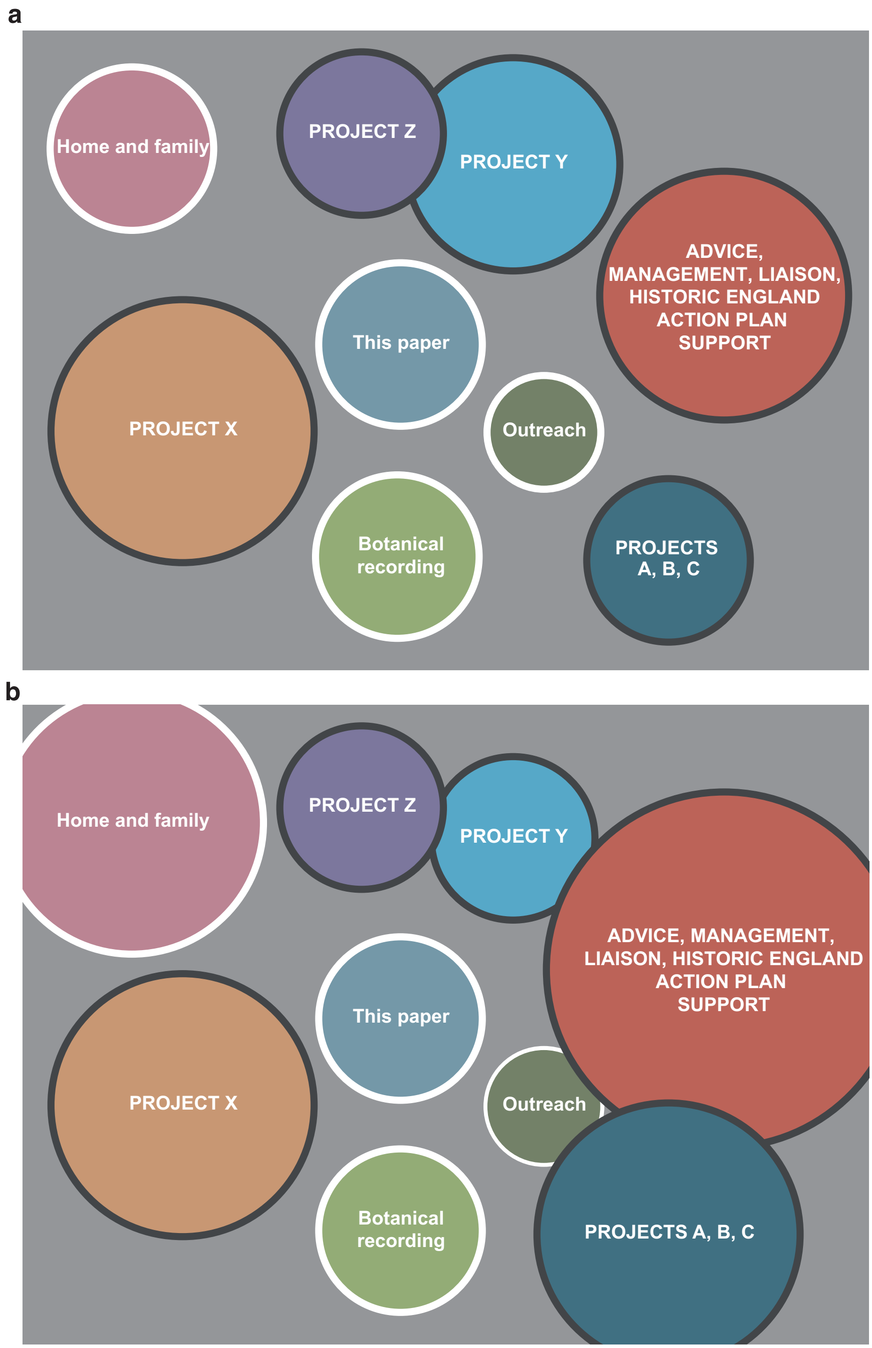

Fig. 1 Map of communities of practice for archaeobotanists/environmental archaeologists working in a state-funded heritage organisation (Gill Campbell, Ruth Pelling); (**a**) planned, (**b**) in practice. The use of uppercase indicates core business activity

own projects, including projects involving fieldwork, with this becoming a more common occurrence in the last few years.

Dr. David Smith is an archaeoentomologist and a senior lecturer in the Department of Classics, Ancient History and Archaeology at Birmingham University. At the time when this paper was written he was seconded 2 days a week as welfare tutor at the Birmingham International Academy. A representation of his communities of practice is shown in Fig. 2. David has recently returned to his substantive post but many of the issues raised here still apply.

Aspects that affect his ability to collaborate on projects include the university's core commitment to teaching excellence and the requirement that all research activity must be aimed at achieving 3*/4* Research Excellence Framework (REF) return. However, the ranking of different types of publications varies depending on the department where the specialist works. David works in the School of History and Cultures which values single authored books alongside research journal publications. If he was based in a scientific department single authored or lead authored journal articles would be key performance indicators. Unfortunately many of the primary publications that result from the type of collaborations discussed here do not fall into this category of publication. Grant capture from major funders, such as the UK research councils, is also now expected as routine, and to be successful, an emphasis on answering research questions of international importance is required. Many of the small scale commercial projects discussed in this paper do not have this level of international reach. In addition, for David, at the time of writing this paper 40% of his time (2 days a week) was taken up with his role as welfare tutor.The university also expects full economic costing (FEC) rates to be paid for staff involved in research. These rates are often more than some funders, and small medium enterprises (SMEs) are willing to pay.

However, on the positive side, David's university encourages involvement with the wider community and knowledge transfer. David's department also appreciates the income generated from small collaborative projects, where he undertakes work on insect remains, and considers this to be research funding. These types of projects, either singularly or collectively, can also lead to be turned into REF publications. David's university recognises this. Such research can also provide, or lead to, research projects for undergraduate, masters and PhD students.

At the same time, David has addressed high FEC rates by developing novel working techniques leading to cheaper bids and helping with his workload. This activity is included in David's Work Allocation Model (WAM) and therefore planned.

Liz Pearson is a senior environmental archaeologist at the Worcestershire Archaeology, a council-sponsored commercial archaeology unit (part of Worcestershire Archive and Archaeology Service). A representation of her communities of practice is given in Fig. 3.

Central to her work is the need for earning targets to be maintained in order for the unit to remain viable and in business. The majority of her work is in commercial contract archaeology, but other types of project are possible, if funded. Collaborative projects which are relevant to people living in the area are more likely to be supported

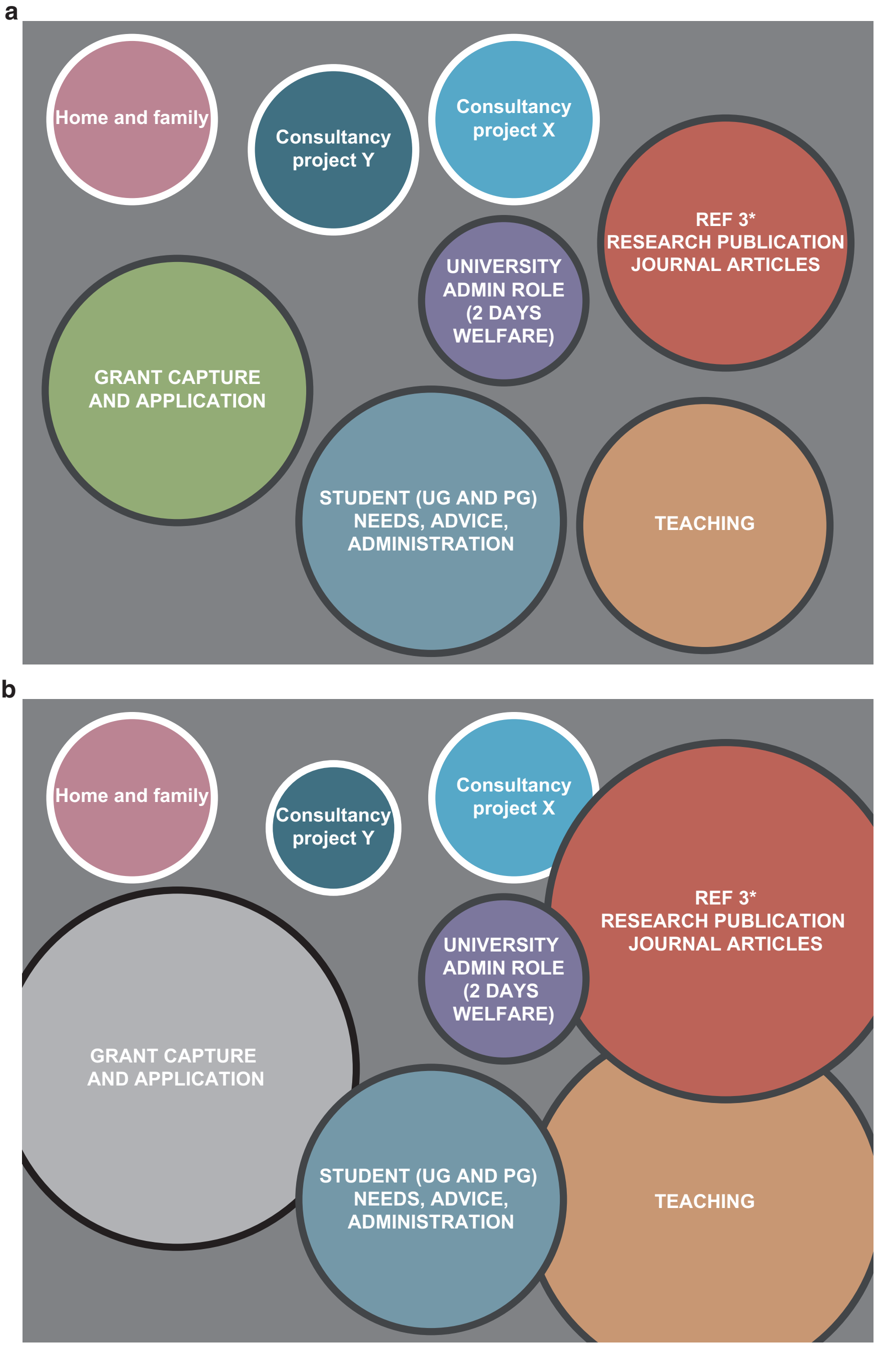

Fig. 2 Map of communities of practice for an archaeoentomologist/environmental archaeologist working within a university (David Smith); (**a**) planned, (**b**) in practice. The use of uppercase indicates core business activity

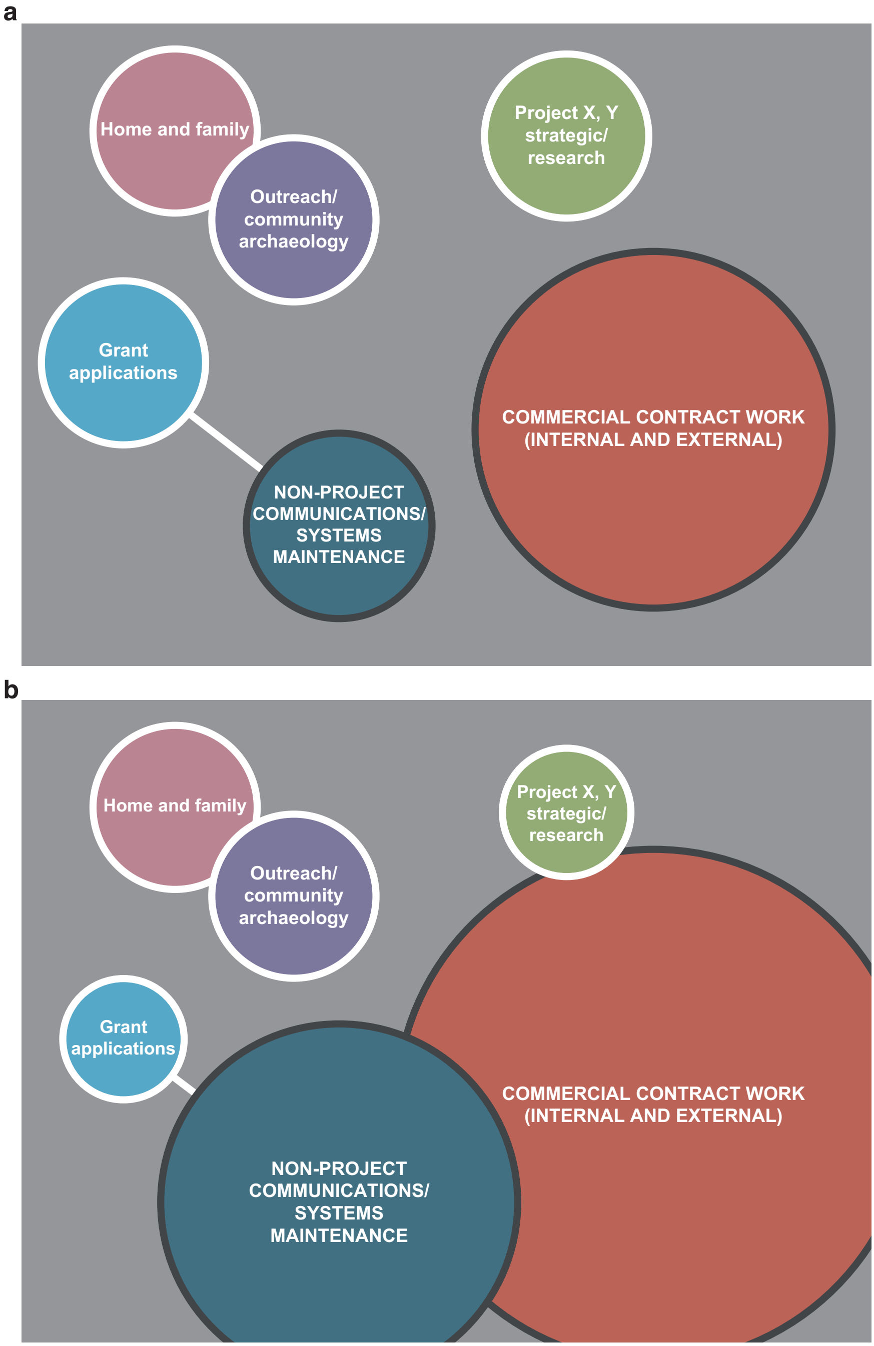

Fig. 3 Map of communities of practice for an archaeobotanist/environmental archaeologist working in a commercial archaeology company sponsored by a local council (Liz Pearson); (**a**) planned, (**b**) in practice. The use of uppercase indicates core business activity

than those on a national or international scale. However, the time Liz has available for developing ideas, applying for grants and contributing towards discussion on professional issues are increasingly squeezed both as a result of the current market and because the Worcestershire City Council, as a result of government policies, is withdrawing resources generally.

On the other hand, the council supports involvement with the wider professional community, and particularly with the general public, despite funding constraints, whilst the close connection between the field archaeology unit (Worcestershire Archaeology), curators, the Historic Environment Record (HER) and museums fosters exchange of knowledge and understanding which can result in strategic or HER enhancement projects and other positive outcomes.

Catherine Barnett, at the time when our discussions took place, was a principal archaeological scientist at the Wessex Archaeology, a commercial archaeology unit with charitable trust status. A representation of her communities of practice is given in Fig. 4.

The company's existence depends on its ability to bring projects in on budget. A tension therefore exists between the bottom line and research. There is a perception that specialist's work loses money, though this is not the case. The major challenge for Catherine was the availability of suitable specialist staff, coupled with a need for a tight turnaround. Managing grants and projects is complex, especially where subcontractor(s) are involved and takes up a great deal of time including dealing with bureaucracy and laws on subcontracting such as the need to pay value-added tax. Little or sporadic direct contact between environmental specialists (as opposed to general managers) with clients and funders can also result in environmental archaeology being sold short and important aspects of sites and assemblages being neglected or not brought to publication.

However, collaborative research can be used to demonstrate the company's pedigree. A supportive manager at the Wessex Archaeology recognised the value her research brought to the company. Her depth of specialist knowledge meant she was able to identify important and significant results and had the freedom to manage her own time effectively; in her particular case, Catherine also had direct contact with clients and funding bodies and was able to raise their enthusiasm and gain support for environmental archaeology investigations, although this is not usually the norm.

Wendy Carruthers is a freelance archaeobotanist of international standing. She works on research projects and on commercial archaeology projects. A representation of her communities of practice is given in Fig. 5.

The main issue affecting her working life is the difficulty in earning a living wage, especially taking into consideration the lack of holiday pay and that there is no sick pay, without taking out costly insurance. Funding to attend conferences and training courses also needs to be covered from her earnings. In addition, the time that Wendy can devote to developing ideas and writing research papers is limited given that these activities are not funded.

Costing projects can also be problematic. Wendy can be presented with an inadequate fixed budget or budget that cannot be extended even when it is clear that

Fig. 4 Map of communities of practice for an archaeobotanist/environmental archaeologist working in a local commercial archaeology company unit with charitable trust status (Cathy Barnett); (**a**) planned, (**b**) in practice. The use of uppercase indicates core business activity

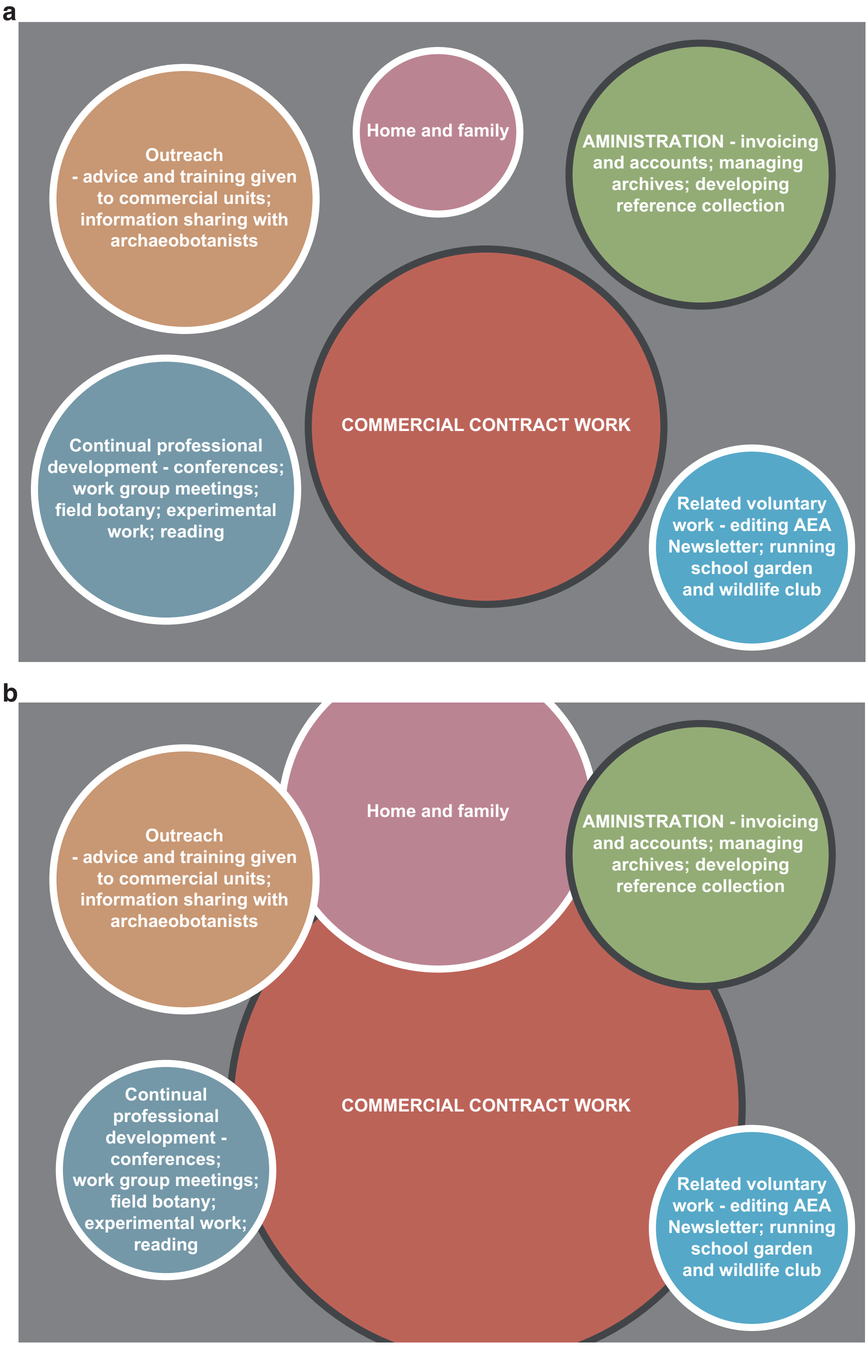

Fig. 5 Map of communities of practice for a freelance archaeobotanist (Wendy Carruthers); (**a**) planned, (**b**) in practice. The use of uppercase indicates core business activity

additional work is required if the research potential of the material is to be realised. It can also be years between the completion of an assessment[5] and the point at which funds are released for analysis presenting problems in terms of timetabling work. Short notice is often given of projects requiring completion, and the storage space required for material awaiting analysis or deposition into an archive can be difficult to find and fund.

Also, and importantly, because Wendy is based at home, people ask her to help in a crisis. This means the community of family and friends, a factor that can take be an overriding in all our lives at times (see also Fig. 1b), can exert more influence than on those who are not home-based.

There are however benefits to working as a freelancer. Wendy is able to choose the hours she works to fit around the family and other interests. She has no boss, does not have to travel to work, attend administrative meetings and/or deal with office politics. She has acquired a great deal of experience over the years through working on large numbers of projects covering all periods and all types of preservation. This often includes gaining knowledge of particular geographic areas which means her knowledge is valued by her clients and peers. She also has the freedom to develop her own methods and approaches unconstrained by organisational procedures.

3 General Issues

A number of general issues emerged from this comparison of our experiences and the discussions that took place as part of this process.

It is clear that goals vary greatly within environmental archaeology, between environmental archaeologists and field archaeologists as well as between researchers. Where and how we work influences these goals. Notably, institutions vary in their *locus operandi*. Universities want to attract research funding from the UK and European research councils, and this means seeking to answer questions that are of international importance. National heritage bodies concentrate on national importance, whereas for a county council sponsored unit research needs to be directed towards what matters to people living and working in their area. These different drivers are not necessarily incompatible but need to be taken into account when developing collaborative projects.

The uptake of new scientific and analytical techniques and theoretical frameworks for interpreting data within commercial archaeology is slow because within projects time to consider new approaches is limited. There is a tendency to replicate what has been done before at other sites rather than develop new approaches. This can result in lost opportunities, especially when new and unexpected discoveries are made.

[5] The assessment of an assemblage involves determining its potential to answer the research aims of a project and also its value beyond this. It is a specific project stage in archaeological projects (Chartered Institute for Archaeologists 2014).

There is also an inclination to treat all aspects of the archaeological resource in the same way (a default mode) rather than seek to answer specific questions about the past and design projects that aim to answer these questions.

While public engagement is encouraged, it tends to be poorly resourced and rely on the willingness of individuals to do this outside and beyond their normal working hours. Flexible and part-time working are becoming increasingly common, and whilst this is a positive development in many ways, workloads need to adjust accordingly. Too often we are trying to stretch our resources beyond their capacity as funding becomes ever tighter. Related to this, there are not many opportunities for environmental archaeologists at an early stage in their career, though the situation does seem to be gradually improving.

The way in which we work is also changing, reflecting the pace of technological change seen in the first decade of the twenty-first century. This last point is illustrated by reference to the European Commission consultation on Science 2.0 or Open Science (European Commission 2014; see also Kansa 2012). We are moving into a world where open access publication and open data are becoming the norm. In addition, we both create and have access to increasingly large datasets, whilst the number of actors in science and addressees of science continues to grow.

The way in which archaeology is recorded in the field and laboratory is also changing. Systems based on geographical information systems (GIS) are becoming commonplace, and databases which allow the project team access to each other's results are being more widely used. This means learning new skills but also presents challenges as we can become overwhelmed with information and the size of our email inboxes. In addition, in reality, not all the project team will have access to the full range of information about a project because they either don't use the same recording system or software. So one of the tasks that is required within projects is one of ensuring that all the project experts have access to the information they need. However, only giving project experts or specialists the information they need to carry out given tasks or analyses does not allow for unexpected insights and interpretations to emerge and can lead to loss of engagement in project aims and outcomes.

Use of digital recording systems and the datasets produced also means we need to consider carefully how to make our data accessible and that the publication of data and data as a product in its own right is sufficiently valued. Coupled with this is the need to be vigilant about data standards and metadata.

There also are many more ways that we can tell each other and the world about our work: tweets, blogs and vlogs. For example, it is possible to send a digital photograph from site straight to the specialist and ask advice and conduct virtual site visits. This can, and is, opening up new audiences to the world of environmental archaeology. However, it also requires learning new skills and having access to up-to-date technology. In conjunction with these developments, incentives and resources for these types of dissemination need to be considered and thought of as a research output.

4 Recommendations and Conclusion

So in conclusion and coming out of our discussions, what are the solutions to some of the issues we face and what measures need to be put in place to make a project successful, foster healthy research dynamics and encourage collaboration?

4.1 Recommendations

Echoing the findings of the Mind the Gap project (Bell et al. 2014, 4), we need to understand each other's goals and the strengths and weaknesses of our different communities of practice. This will aid us in developing shared goals and approaches that will benefit both researchers and environmental archaeological practice. Coupled with this, there seems to be considerable merit in developing lists of burning questions at regional, national and international scales along the lines of those produced for palaeoecology (Seddon et al. 2014). These summaries would be more readily accessible than research frameworks for those working at the coalface of developer-funded archaeology, who may have limited time to devote to reading beyond their immediate area of interest.

Better, rather than more communication is needed within project teams making full use of the new media at their disposal. Dividing complex projects into work packages, with ambassadors for each work package, will help to bring environmental archaeology to the attention to developers and other funding bodies. Linked to this, we need to prioritise public engagement to win more support and funding. The audience is out there, but we need to engage with them directly wherever possible and be given the time and resources to do this effectively. Fundamental to this is improving access to the results of our work for everyone, including our peers.

We also need to provide more CPD opportunities, including formal and informal training, work placements and cross training, another of the key recommendations that came out of the Mind the Gap project (Bell et al. 2014, 9). Feedback on the reports we produce and regular peer review of our work would help to raise standards and increase competence. Avenues for support (financial or other) for publication of important results which cannot or will not be published through developer funding should be considered.

4.2 What Makes a Good Project?

If results produced by different specialists are going to be considered and fully integrated, all members of the project team need to feel that their contribution is valued and that their opinion will be heard and feel comfortable with expressing their views to the team. Knowing what individual team members hope to get out of their involvement and helping each other to achieve these goals is important, especially for larger projects. Regular updates including access to each other's results can help increase engagement and satisfaction. For large projects, there is no substitute for team meetings at key project stages. These help for a variety of reasons. Firstly, cross-referencing between specialists (environmental and finds) highlights whether results from one specialist might have a bearing on the interpretation that another specialist makes and could potentially even suggest a change of approach or methods. Results from one area of a site or from a particular context or a particular assemblage can take on more significance (or vice versa). Secondly, project team meetings help keep the finish line from drifting too much because of the need for most involved to get to a certain point in the project for the meeting to make sense. Lastly, meetings can also foster the research dynamic and encourage mutual engagement across different disciplines and institutions.

Having clearly defined roles and responsibilities assists considerably when dealing with issues that arise during project implementation and with resolving conflicts. We should also consider balancing personalities and skills within project team if at all possible (see Bell et al. 2014, 5, 7) and play to our strengths. Having a flexible approach, whereby new questions that come out of the investigation can be addressed and less fruitful avenues abandoned or cut back, is also extremely useful. However, this means placing equal value on all aspects of the archaeological resource. Finally, when it comes to dissemination, publication and sharing of results, full presentation and acknowledgement of key specialist input and data is needed; the trend to integrated reports and relegation of specialist reports to archive detracts from and can mask important results. Although this is becoming less of an issue as publication of citable datasets online becomes the norm.

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Environmental Archaeology in Southern Scandinavia

Kurt J. Gron and Peter Rowley-Conwy

1 Introduction

In this contribution we examine environmental archaeology in southern Scandinavia, the part of Europe in which it was first developed. Our perspective will be that ever since the dawn of prehistoric archaeology, environmental archaeology has been central to it – not an ancillary 'scientific' subdiscipline. Some of the most prominent theoretical positions held by 'conventional' archaeologists over the past century have in fact been based on the findings of environmental archaeology. Furthermore, findings and theories promulgated by practitioners in southern Scandinavia have been extrapolated to other areas of Europe and the wider world.

This runs counter to the perspective taken in many histories of archaeology; but such histories are usually written by 'conventional', not environmental, archaeologists. We will however demonstrate that most information on 'what life was like' in the past comes from environmental work. The major conflicting views on such issues as whether agriculture appeared due to indigenous adoption or immigration derive largely from the findings of environmental archaeology. Those who argue that theoretical posturing sets the archaeological agenda need to accept that environmental archaeology just as often sets the theoretical agenda.

We define 'environmental archaeology' broadly. It comprises not just the classic palaeoeconomic studies of animal bones (zooarchaeology) and plant remains (archaeobotany). Vegetation history and palynology have been of central importance since the earliest days of the discipline, and geoarchaeology has also had a major impact. Recent decades have seen the appearance of three major new methodologies: the study of DNA, both ancient and modern; of isotopic analysis of organic materials, including human and animal bones; and of lipid residues in

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ceramics. Since these all provide information regarding human modification of the landscape, subsistence practices, and economic changes, we class them all as environmental archaeology.

We will start with environmental archaeology's origins as a discipline in a southern Scandinavian perspective. We will then narrow our focus to encompass its methods as applied to the question of agricultural origins in the region at ca. 4000 B.C. The methodological approaches described, of course, have been applied to numerous and disparate archaeological questions, but the 'why', 'how', and 'who' questions regarding farming's start have proven the basis for arguably the most coherent, persistent, and long-term debate for which there is still no consensus opinion. As such, the discourse and applied environmental archaeological methods have been intricately linked from the start.

We stress that what follows is a personal viewpoint. We are prehistoric archaeologists, and we recognise that we emphasise work in the earlier chronological periods while glossing over much that has been done on the archaeology of the more recent periods. This is not because we consider the later periods unimportant, but it simply reflects the twin constraints of space and lack of expertise. Others are more competent than we are to remedy this deficiency.

2 The Early Development of Environmental Archaeology: 1842–1970

2.1 1842–1851: The Creation of Environmental Archaeology

Environmental archaeology began in the early 1840s. Some related work had begun earlier – the Swedish zoologist Sven Nilsson, based in Lund, identified a pig canine tooth from a passage grave excavated in 1819 (Nilsson 1822), and some years later he argued that people in the Stone Age defined by C.J. Thomsen (1836) were hunter-gatherers (Nilsson 1835). But the first hands-on environmental archaeologist was J.S.S. Steenstrup (1813–1897).

Japetus Steenstrup was a natural historian with broad interests. His first venture was into the stratigraphy of peat bogs. During his formative years, the dominant figure in Danish geology was Georg Forchhammer, a catastrophist of the old school who believed that the earth had gone through repeated convulsions in the relatively recent past. What we now recognise as glacial moraine underlay the Danish peat bogs, and Forchhammer believed it had originated in a catastrophic flood emanating from Sweden that had swept over Denmark (Forchhammer 1835). Another huge flood wave engulfed Denmark in later times, felling numerous trees, some of which survived in peat bogs with their trunks all aligned in the direction of the wave (Forchhammer 1844).

Steenstrup's achievement was to use detailed observations to demonstrate that Forchhammer was wrong. In so doing, he laid the foundations for all subsequent

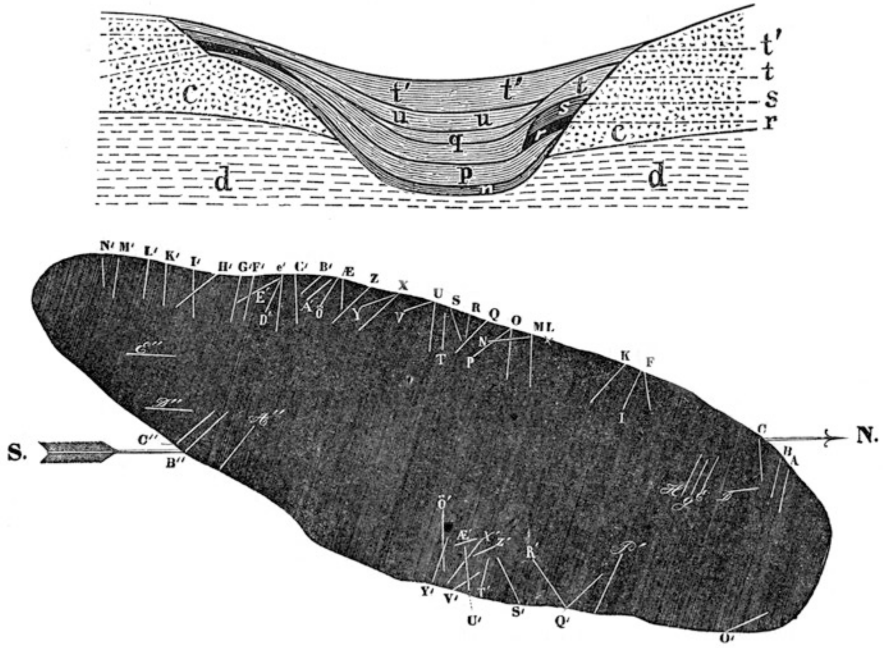


Fig. 1 Top: Steenstrup's section through Lillemose bog, showing the forest layers (From Steenstrup 1842: Fig. VII). c: gravel with boulders; d: gravel layer, the base of the bog; r, s, t: edge deposits formed by trees falling into the bog; r: layer of pine fragments; s: layer of oak fragments; t: layer of alder fragments; n: the aspen layer; p: the pine layer; q: the oak layer; u: layer of *Hypnum proliferum*; t': the alder layer. Bottom: Steenstrup's plan of the fallen pine trees in Sneglekjær bog, showing their alignment towards the centre. This small bog measured only some 140 m along its longest axis (From Steenstrup 1842: Fig. VIII)

palynological studies. The Royal Danish Academy of Sciences and Letters had offered a prize for the best essay on why there were remains of pine trees (not native to Denmark) in Danish peat bogs, then being dug out for fuel. Steenstrup examined the Vidnesdam and Lillemose bogs north of Copenhagen, and his prize-winning essay was published in 1842 (Steenstrup 1842). He observed two vital things. First, the pine trees occurred in a discrete layer quite low down in the bogs. Below the pine layer was a layer of aspen. Above the pines was a layer of oak, above them again a layer of alder (Fig. 1 top). Beech trees dominated the nineteenth-century Denmark, but were rarely found in peat bogs. Steenstrup had identified what we now recognise as the postglacial forest succession – although it was not yet understood that glaciers had once covered Denmark. Second, the trees preserved in peat bogs did *not*, as Forchhammer had claimed, all point in the same direction: their crowns pointed towards the centre of the bogs, demonstrating that they had fallen naturally, presumably at different times (Fig. 1 bottom). The process was therefore gradual, not catastrophic, involving the same processes that are at work today. This is the essence of geological uniformitarianism.

Steenstrup estimated that each of his five forest stages – aspen, pine, oak, alder, beech – spanned at least one or two millennia, thus giving a time depth of up to 10,000 years. This was remarkable, because in Vidnesdam bog he found a human-made artefact in the oak layer (Steenstrup 1842, Fig. 3). Soon after, he found evidence that pine trees in the layer below had been deliberately felled and burnt by people (Steenstrup 1848a [1851, 25]). This pushed the human presence in Denmark back to perhaps 8000 years, far longer than the Biblically derived chronology could admit. This was the first 'long' chronology proposed for humankind based on any reliable scientific evidence.

Shell middens were recognised as human settlements in 1850, as the result of work by the 'Lejre Committee', or (retrospectively) the 'First Kitchen Midden Commission', formed in 1848. This comprised Steenstrup, Forchhammer, and the youthful archaeologist J.J.A. Worsaae. Twentieth-century histories of what happened usually present Worsaae as the leading light; Steenstrup (if mentioned at all) is described as the specialist zoologist who assisted Worsaae (e.g. Gräslund 1987, 34–5; Klindt-Jensen 1975, 71–2; Schnapp 1996, 302–3). This however tells us more about the structure of later twentieth-century archaeological projects than about what the Lejre Committee did. It was undoubtedly Worsaae who first came fully to the conclusion that the middens were waste discarded after consumption by people – kitchen middens or *køkkenmøddinger* (Petersen 1938) – but most of the supporting evidence and the subsequent ideas came from Steenstrup.

In 1848, shell heaps on land were expected to be natural banks, now above sea level because the land had risen. The great Linnæus himself had in 1746 examined the huge shell banks at Uddevalla on the west coast of Sweden, which accumulated without any human involvement (Linnæus 1747 [1928, 218–223]). Steenstrup had however found Stone Age flint blades in a shell midden as early as 1837, which placed the middens (like the oak and pine layers in the peat bogs) within the period of human occupation of Denmark (Steenstrup 1848b). In early 1851 Steenstrup presented the joint results of the 1850 fieldwork to the Academy (Worsaae could not do this because he was not yet a member). Worsaae had worked at Mejlgaard, Steenstrup at Havelse and Bilidt; their results were identical, Worsaae's idea causing everything to fall into place. Bivalves such as oysters lay with their halves separated, but their edges were not worn, so they had not been washed up onto dry land by huge storms. Furthermore, they lay intermingled with ash, charcoal, fishbones, heated stones, etc. There were numerous stone tools and animal bones. Steenstrup noted that the bones were sharp-edged, not rolled; they were smashed for their marrow; some had been burnt, but *after* they had been broken; and many antlers showed signs of cutting. The animals were deer and wild boar, with no domesticates; some bones were dog-gnawed, so dogs were the only domestic animal (Steenstrup 1851).

Steenstrup even sketched out the methods he would use to examine settlement seasonality (Steenstrup 1851). In 1869 he gave a lecture demonstrating that the shell middens were occupied all year. Red and roe deer antlers were in all stages of growth, and some were shed; bird bones of both winter and summer migrants were found; but most tellingly he had procured a collection of modern pig mandibles of precisely known ages, slaughtered at monthly intervals up to 14 months of age:

> If we now compare these with the jaws of the wild boar that the ancient inhabitants consumed, we find that at one and the same place wild boar piglets were eaten aged 1 month, 2 months, 3 months etc all through the year; thus the people also stayed in one and the same place all through the year. (Steenstrup 1870, 15, translated by PR-C)

Steenstrup's work dealt with human behaviour which he had elucidated, in a landscape which he had reconstructed. This identifies him as the first practicing environmental archaeologist in Europe.

2.2 1900–1916: Placing People in Time and the Landscape

These years saw the earliest Danish settlement evidence pushed back into Steenstrup's pine period and also saw some shell middens brought into the later era of farming. Both these developments were as the result of classic environmental archaeological studies.

The Second Kitchen Midden Commission was established in 1893, under the leadership of Sophus Müller. It excavated eight shell middens, the results being published in 1900 (Madsen et al. 1900). The largest excavations were at Ertebølle, which has become the eponymous type-site of the Late Mesolithic period. The work of the Commission was characterised by careful excavation: finds were recorded by square metre and 20 cm excavation spit, and ceramic conjoins between squares were plotted to show the surface of the midden at particular points in time (Müller, in Madsen et al. 1900, 72–75). The conclusions of Worsaae and Steenstrup were confirmed and extended: the middens were dwelling places occupied throughout the year, based on the seasonality determinations of the zooarchaeologist Herluf Winge.

Perhaps the most notable achievement was the Commission's demonstration that only five of their middens were Mesolithic – the other three were Neolithic (though they did not use those terms but rather 'Older Stone Age' and 'Younger Stone Age'). A few polished stone axes and decorated ceramics turned up on the surface of the Mesolithic middens, but were found throughout the Neolithic ones. Very few of these were illustrated; however, the publication laid greater stress on the animals and plants. In the Neolithic middens, Winge identified mainly domestic cattle, pigs, and sheep, contrasting with the deer and wild boar in the Mesolithic ones. He distinguished between wild boar and domestic pig on size: lower third molar displayed hardly any metrical overlap (Fig. 2 top). Neolithic people also cultivated cereals. At all three Neolithic middens, Georg Sarauw identified impressions of wheat and barley in the ceramics, and the Leire Aa midden yielded a sample of 48 charred grains of barley, probably six-row (mentioned by Neergaard, in Madsen et al. 1900, 144, 157, 171). This realisation that some shell middens were of Neolithic date was to have far-reaching ramifications through the twentieth century.

The middens produced other charcoal as well. The project's botanist, Emil Rostrup, identified many to species. He identified 295 fragments from Ertebølle, of which 218 were oak; no pine was found (Rostrup, in Madsen et al. 1900, 90) (Fig. 2 bottom). This established a chronological link between the shell middens, which

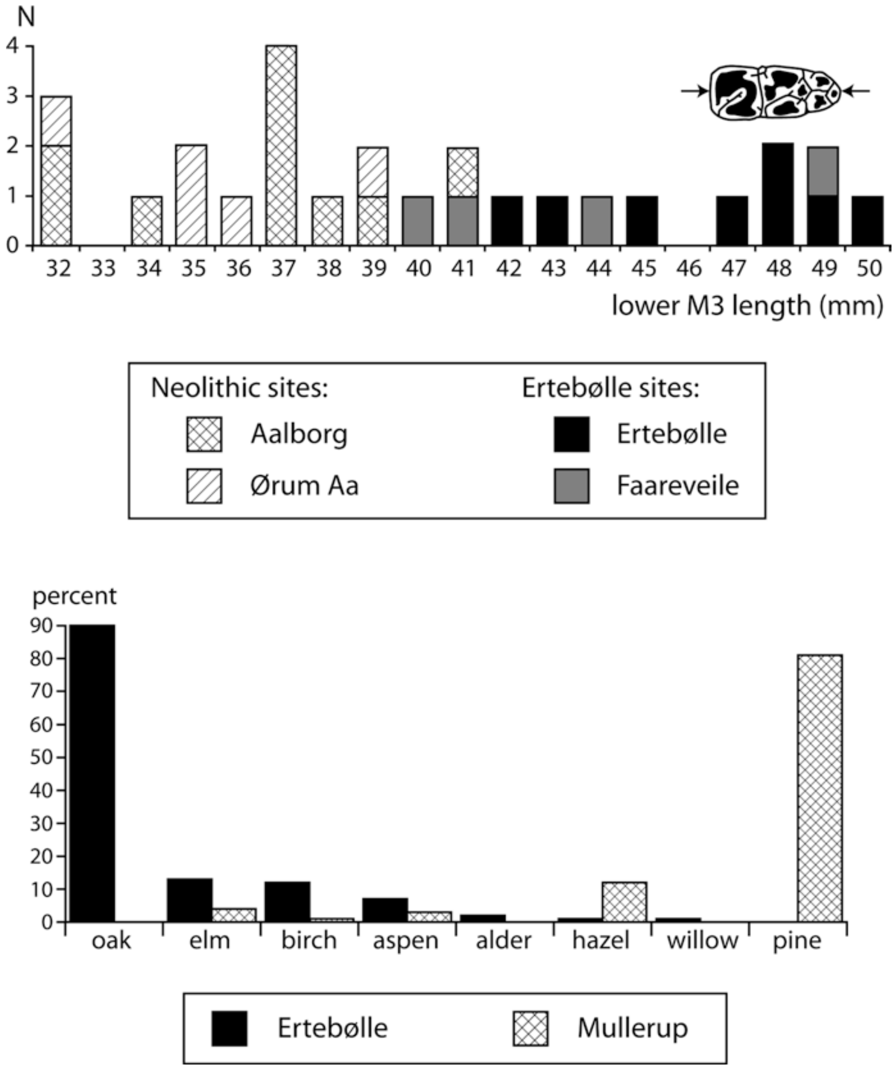


Fig. 2 Top: measurements of *Sus* lower M3, showing the size difference between wild boar and domestic pigs from the Mesolithic and Neolithic shell middens excavated by the Second Kitchen Midden Commission (from Winge, in Madsen et al. 1900, 87, 122, 145 and 160). Bottom: frequencies of identified charcoal at Late Mesolithic Ertebølle (from Rostrup, in Madsen et al. 1900, 90) and Early Mesolithic Mullerup (from Rostrup, in Sarauw 1903, 188). Rostrup's Ertebølle figures are the percentage of the 560 square metres excavated in which the species was found; the Mullerup figures are the percentages of the 1033 identified fragments of charcoal

were on the raised beaches of the maximum postglacial marine transgression, called (then and now) the Littorina Sea, and Steenstrup's oak forest period.

When the Second Kitchen Midden Commission's volume went to press, the Mesolithic shell middens were the oldest sites known in Denmark. In 1900 however Georg Sarauw excavated Mullerup in the Maglemose bog ('Maglemose' means simply 'large bog' in Danish). Mullerup produced three classic environmental archaeological studies, concerning, respectively, its date, its geomorphology, and its landscape context.

The dating of the site proved that Steenstrup had been right in 1848 when he claimed that some pine trees had been felled by humans. Sarauw (1903) rapidly concluded that Mullerup was older than Ertebølle. The absence of pottery suggested a very early date (ceramics were common in the Ertebølle middens). 1033 fragments of waterlogged wood and bark were collected during the excavation, and Rostrup identified them: 835 were pine, 120 were hazel, and 45 were elm; not one was of oak (Rostrup, in Sarauw 1903, 188) – completely different from the proportions at Ertebølle (Fig. 2 bottom). Recent work in Sweden had demonstrated that the first hazel and elm appeared late in the pine period, so Sarauw concluded that Mullerup dated to late in the pine period (op. cit., 289). A freshwater lake, the 'Ancylus Lake' (Munthe 1892), had preceded the Littorina Sea, and most trees dredged up from the submerged Ancylus forests were indeed pine. This agreed with the animal bones: Herluf Winge identified black woodpecker (*Dryocopus martius*), a species characteristic of pine woodland (Winge, in Sarauw 1903, 195). Among the mammals, elk and aurochs were common, and these had previously been found at other Ancylus period sites. Sarauw believed that the elk was extinct in Denmark by the end of the pine period (op. cit., 291); it is now known to have survived on the Jutland peninsula, but he was correct that it had disappeared from Zealand (Aaris-Sørensen 1980). Mullerup thus dated to the pine period, corresponding to the Ancylus Lake.

Mullerup's local geomorphology was unravelled by a multidisciplinary team. Organic items were spectacularly well preserved in the waterlogged peat. All the specialists concurred that the peat had formed in an ancient lake. Above the basal moraine was a layer of blue clay, identified by the geologist Nikolai Hartz as probably late glacial (Hartz, in Sarauw 1903, 158). Above this came a layer of mud, identified by the limnologist Carl Wesenberg-Lund as forming in shallow lake water (Wesenberg-Lund, in Sarauw 1903, 159–160). The upper part of this mud contained numerous snail shells, which Valdemar Nordmann identified as inhabiting lake water a metre or two deep (Nordmann, in Sarauw 1903, 160). Above the mud came the peat. Sarauw concluded that the lower part of the peat, which contained the artefacts, formed in open water because it contained open-water plants like waterlilies. Above this were the matted roots of the common reed (*Phragmites communis*), which grows in marshy lake edges. And above this the peat was full of the roots of sedges. This sequence clearly showed that the ancient 'Lake Maglemose' was filling with dead vegetation, turning from open lake to bog (Sarauw 1903,162).

Mullerup's landscape context was however a problem for Sarauw: how could a settlement be in peat laid down in open water? The peat did not dry out even seasonally, because the waterlilies required continuous submergence. He considered various options (op. cit.: 175–85). The first was that he had found a lake dwelling like those in Switzerland, believed to be villages built on piles over open water (Keller 1854). Such a village required some 50,000 wooden piles to support it; but no such piles were present in the Maglemose, and there were no post holes in the lake bed. The next possibility was an artificial island or crannog, like those in Scotland (Munro 1882) and Ireland (Wood-Martin 1886), but once again the mass of stone and timber that would have been piled on the lakebed should have survived. Finally, Sarauw speculated that people had camped on the ice during winter, so the cultural debris sank to the lake bed when the ice melted in spring – but this did not work either because Winge's zoological study showed that Mullerup was occupied in *summer*. Some species were summer visitors – in particular red kite (*Milvus milvus*) and crane (*Grus grus*). There were also bones of ducklings so young that they were summer fledglings. Sarauw knew that these bones might occur naturally in the lake sediments and not be an indicator of settlement seasonality, but since one of the duckling bones bore cut marks made with a stone tool, this could be ruled out (op. cit.: 177, n. 1). Sarauw was forced into the conclusion that people lived on a floating raft and dropped artefacts into the water. He admitted that there was no evidence for such a raft, but he was unable to explain the site in any other way (op. cit.: 177–8).

Sarauw's problem was soon solved, through the earliest scientific reconstruction of a non-coastal prehistoric hunter-gatherer landscape. This was the work of one of the most significant figures in the history of Danish environmental archaeology: the palynologist and botanist Knud Jessen.

In 1903 Carl Neergaard excavated another settlement at Mullerup, just over 100 metres from the one Sarauw had excavated. The geologist Lauge Koch undertook a major landscape study in 1915, with assistance from Knud Jessen (Koch 1916). Koch excavated a trench next to Neergaard's and took cores along two transects across the bog (Fig. 3). The sites were not in open water, but on the flanks of two barely discernable small islets or holms, now known as 'Sarauw's holm' and 'Neergaard's holm', respectively. These were low rises in a morainic ridge projecting out into the contemporary lake. Jessen cut a trench to the west from Koch's excavation, and this was crucial in placing the site into its landscape context. On the top of Neergaard's holm, the peat layer dwindled to just a couple of centimetres in thickness, and the archaeological finds were more tightly packed (Fig. 3 middle). A couple of preserved tree stumps were found there, indicating tree growth on the top of the holm; stone tools occurred among their roots (Koch 1916, 7–8). Jessen's trench traced the peat layer out into the former lake. On top of the holm, it was forest peat, indicating rather soggy dry land. This metamorphosed into sedge and reed peat, which would have grown on the waterlogged lake shore, and then into lake peat, indicating open water (Koch 1916; Jessen 1935a, b, 5–13). Jessen placed the contemporary lake shore at about the 4 m contour, allowing the landforms to be plotted accurately (Fig. 3 top). This demonstrated that parts of both sites had lain on moderately dry land. Jessen also recovered artefacts from the lake (Fig. 3 bottom). Jessen and Koch concluded that people had actually lived on the tops of the holms, where their excavation had found traces of hearths. The material in the deeper peat was rubbish dumped off the edge of the settlement, into the lake (Koch 1916, 11). Sarauw's floating raft was no longer required; the holms were the actual living sites.

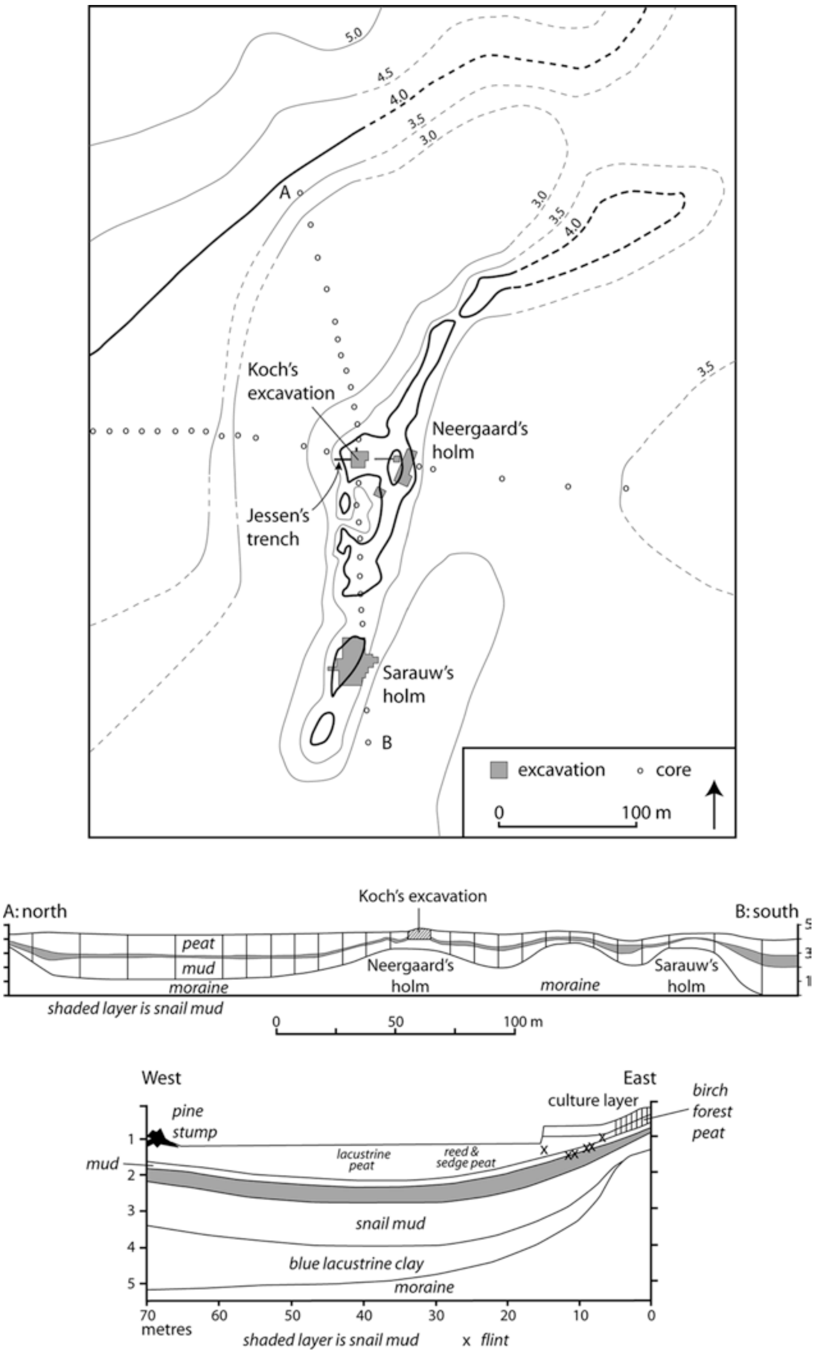


Fig. 3 Top: contour map of the Mullerup region of the Maglemose bog, showing the excavations, coring locations, and the contour lines above present sea level that this established. The emphasised 4 m contour was identified by Jessen as the lake shore at the time of occupation (Redrawn and modified from Koch 1916: Fig. 1). Middle: profile established by the core line A–B, showing the two holms or islets in the prehistoric lake (Redrawn and modified from Koch 1916: Fig. 2). Bottom: profile from Jessen's trench, measured by him in 1915 but not published until later (Redrawn and modified from Jessen 1935a: Fig. 1)

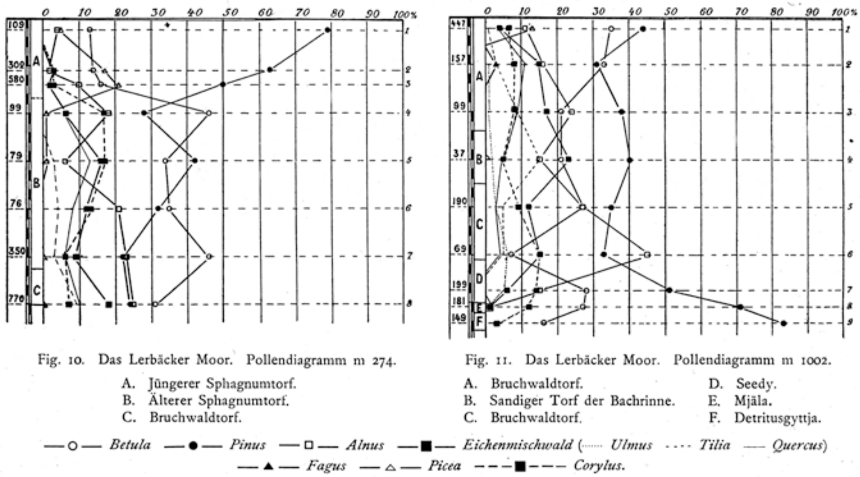
This work by Jessen and Koch marked a spectacular departure in environmental archaeology. For the first time, a settlement site in the interior was placed in its landscape context. Jessen's lake-edge model saw considerable refinement in the 1920s (see Rowley-Conwy 2010) but has stood the test of time and still forms the basis for our understanding of the landscape context of such sites.

2.3 1916–1937: Developing the Environmental Chronology

Work continued on Steenstrup's forest epochs. The Norwegian Axel Blytt had proposed that the four main phases represented alternating periods of dry and wet climate: the Boreal, a dry phase, corresponding to Steenstrup's pine period; the Atlantic, a moist phase with oak and other deciduous trees; the Sub-Boreal, drier and warmer, seeing a forest recession; and the Sub-Atlantic, humid and cool (Blytt 1876). Initially greeted with scepticism, this scheme was taken up by the Swede Rutger Sernander, who demonstrated its correctness in a series of peat bogs in Sweden, Denmark, and Northern Germany (Sernander 1908, 1909). This came to be known as the 'Blytt-Sernander' scheme (see Iversen 1973, 13–14). This zonation worked well where the stratigraphy was clear; a case in Sweden where it was *not* clear led the Swede Lennart von Post to develop pollen analysis.

Von Post (1916) faced a problem in Lerbäck bog. In its NE part, he identified all four Blytt-Sernander phases using conventional macroscopic remains. But the SW part of the bog comprised *Sphagnum* peat, which could not be assigned to phase. Von Post used pollen analysis to date this part of the bog, stating that he developed the technique himself for this precise purpose (von Post 1916, 262). Figure 4 (top) shows (right) von Post's pollen diagram confirming his attribution of the NW sequence in the Blytt-Sernander scheme and (left) his diagram (his Fig. 9) in the *Sphagnum* peat area. He argued that the major rise in pine at the top of the left diagram was not visible in the right diagram. Sample 1 in the right diagram corresponded to between samples 3 and 4 in the left diagram. The bottom of the left diagram corresponded to samples 2 and 3 in the right diagram. This neat technique allowed von Post to date the formation of the two parts of Lerbäck bog and show that they did not overlap much in time.

Pollen analysis was rapidly adopted in Denmark. Knud Jessen (1920) used it to confirm his layer attributions in Sækkedam bog. He subsequently developed the full numerical scheme that remains in place today, in which the late glacial phases I, II, and III refer to the Early Dryas, the Allerød, and the Younger Dryas, respectively, followed in the postglacial by IV (the Pre-Boreal), V and VI (the Boreal, with pine trees), VII (the Atlantic, with mixed oak forest), VIII (the Sub-Boreal, with a recession in mixed oak forest), and IX (the Sub-Atlantic, seeing an increase in beech and sometimes pine) (Jessen 1935b). Jessen's first diagram using these phases came from Brøndum bog and spanned the entire lateglacial and postglacial (Fig. 4 bottom). He used the precision of his scheme to date archaeological items found in



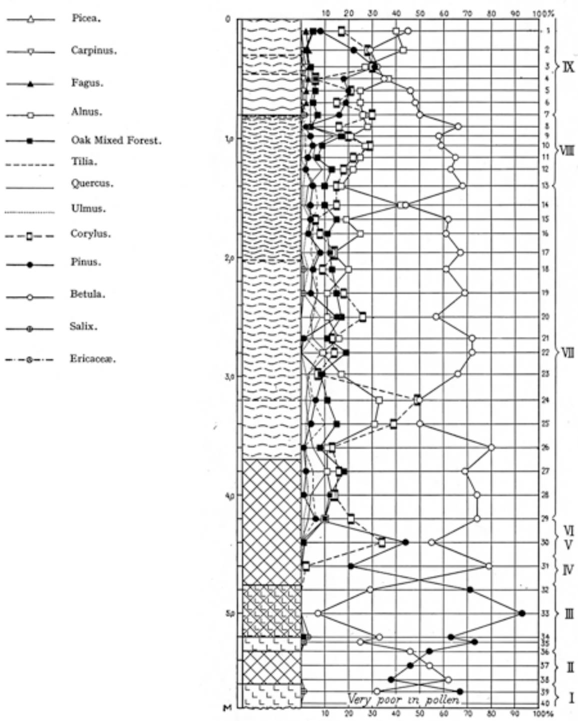


Fig. 4 Top: the first pollen diagrams ever published, from Lerbäck bog in Sweden (Reproduced from von Post 1916, Figs. 10 and 11). The numbers down the left side of each give the number of pollen grains counted. See text for discussion. Bottom: the first pollen diagram to be numerically zoned in the method now used, from Brøndum bog in Denmark (Reproduced from Jessen 1935b, Fig. 3, by kind permission of *Acta Archaeologica*)

bogs, showing, for example, that the Bronze Age fell into upper zone VIII (Jessen op. cit.).

The Littorina marine transgression, to which the shell middens were linked (see above), was also being subdivided. Otto Rydbeck (1928) argued that the Järavallen raised beach in western Sweden showed that the Littorina Sea had two maxima, the second dating to the Neolithic. This was developed in Denmark by Johannes Iversen (1937), whose work at Søborg revealed no fewer than four successive transgression maxima, all falling towards the end of Jessen's zone VII, the Atlantic period (it should be noted that in 1937 the Atlantic to Sub-Boreal transition was placed at the start of the major recession in the mixed oak forest curve (Jessen 1935b, 188); only in 1941 was it moved to its current position at the elm decline, as discussed below).

This new precision in the pollen and marine transgression chronologies immediately had theoretical consequences that Northwest European archaeologists live with to this day.

2.4 1937–1947: Environmental Chronology and the Forager-Farmer Overlap

These developments in the marine and pollen chronologies led to a flurry of archaeological dating activity, which apparently demonstrated that some Ertebølle sites were contemporary with the Neolithic. This led to immigration becoming the accepted understanding for the appearance of farming (the situation by 1942 is shown in Fig. 5 left).

The Finnish archaeologist Carl Axel Nordman was the first to argue that the Ertebølle was a *periferikultur*, contemporary with Neolithic farmers in central Europe. Cultural impulses such as ceramics spread from the farmers to the foragers (Nordman 1927, 31–2). Rydbeck's (1928) study of sea levels at Järavallen (see above) led him to conclude that the two cultures existed contemporaneously even within southern Scandinavia. He pointed out that many Danish Ertebølle shell middens had produced a few Neolithic artefacts. This suggested that the Ertebølle continued parallel with the Neolithic Passage Grave Period, although people kept to their coastal foraging lifestyle (Rydbeck 1928, 67–73).

Jørgen Troels-Smith published three papers in 1937 alone, all dating Ertebølle sites: Alstrup III was on a beach he equated with Jessen's fourth marine transgression (1937a); Brabrand, a major settlement, he pollen-dated to zone VIII (1937b); and Amager III and IV were on beaches he dated to Jessen's fourth transgression (1937c). In the same year, Jessen placed the Klintesø shell midden (published by the Second Kitchen Midden Commission in 1900) early in zone VIII using marine transgressions (Jessen 1937). The forager-farmer overlap was also confirmed by artefactual means. C.J. Becker found some Neolithic items in the Ertebølle site at Ordrup Næs. He dated this site to the latest part of the Ertebølle, contemporary with the Passage Grave Period, and regarded the Neolithic items as imports acquired from the farmers (Becker 1939). Therkel Mathiassen argued that a similar admixture in Mesolithic Strandegaard showed that this site was contemporary with the

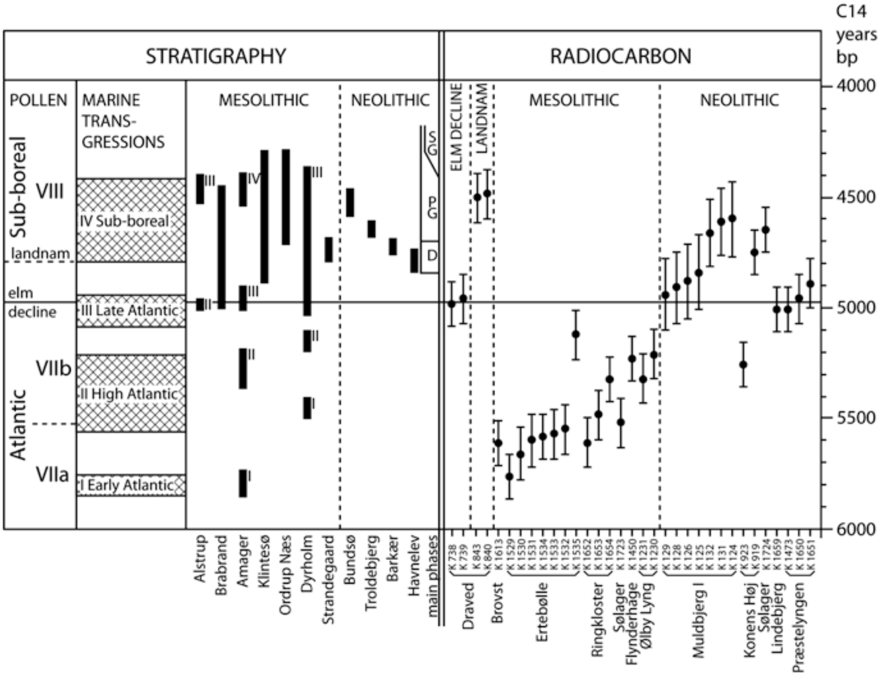


Fig. 5 Chronological relationships between Mesolithic and Neolithic as understood by environmental archaeology in 1942 (left, partly based on Troels-Smith 1942, Fig. 5) and by radiocarbon dating in 1970 (right). Pollen zones follow Jessen (1935b), except that the zone VII–VIII boundary is placed at the elm decline, not at the 'landnam' decline in deciduous forest (following Iversen 1941, 21–2). The marine transgressions are those distinguished at Søborg (Iversen 1937), named as proposed by Troels-Smith (1942, 168). Neolithic phases indicated by D (Dolmen Period), PG (Passage Grave Period), and SG (Single Grave or Corded Ware) – the last two partially overlapping in time. Radiocarbon dates selected from Tauber (1956, 1960, 1966, 1968, 1970). Note that the radiocarbon scale applies only to the right side of the figure; the only chronological marker common to both parts is the elm decline. The pollen and transgressions columns on the left cover substantially more time than the radiocarbon scale on the right (see relative positions of the landnam)

nearby Neolithic site of Havnelev (Mathiassen 1940). The Third Kitchen Midden Commission was set up to examine this and excavated the Ertebølle site of Dyrholm; layer III of this site was also dated to zone VIII (Troels-Smith 1942).

All these Ertebølle sites were thus contemporary with the Neolithic. At that time the Dolmen Period was believed to be the first Neolithic phase in Denmark, the Passage Grave Period coming next. Jessen (1938) pollen-dated the Neolithic site of Troldebjerg, artefactually belonging to the early Passage Grave Period, to zone VIII, noting that Bundsø was a little younger. Havnelev belonged to the Dolmen Period (Mathiassen 1940), which Iversen (1941) demonstrated was also in zone VIII. Mathiassen (1940, 38) noted that Neolithic Barkær was also Dolmen Period, but a little younger than Havnelev.

These dated sites are all plotted in Fig. 5 (left). The importance of this chronological overlap can hardly be overstated, because it led to general agreement that the Neolithic farmers were immigrants (e.g. Mathiassen 1940, 35–36; Iversen 1941, 43; Becker 1939, 272–280; Troels-Smith 1942, 175) – it could hardly be otherwise, with foragers continuing to live largely on coastal resources just a few kilometres away from people with a full farming economy. Environmental archaeology thus provided the archaeological/anthropological explanation for the appearance of farming in southern Scandinavia.

The cultural and economic gulf between immigrant farmers and indigenous foragers was underlined by Iversen's epoch-making realisation that farming practice was visible in the pollen diagrams. Gudmund Hatt (1937, 134) had suggested that the earliest farmers would employ swidden cultivation. This involved forest clearance, burning the felled vegetation, a brief episode of cultivation, soil exhaustion due to lack of manuring, and settlement movements followed by another clearance. These extensive clearances were what Iversen detected in his pollen diagrams (Iversen 1941). Forest stage VIII in the Blytt-Sernander scheme, the Sub-Boreal, had long been seen as a period of forest recession due to drought. Iversen argued that people, not drought, were the cause. He termed the clearances the 'landnam' phase, an archaic Scandinavian term meaning 'land occupation', which has now entered the international vocabulary. Since the date of a landnam episode might vary from place to place, Iversen argued that the boundary between VII and VIII should be moved to the elm decline, a natural climatic event (op. cit., 21–22).

Figure 6 shows selected taxa from Iversen's classic diagram from Korup (from Iversen 1941, Fig. 3). The elm decline starts at analysis 3, marking Iversen's new transition between zones VII and VIII. The arrival of farmers, marked by 'Neol.', is at analysis 6. There was thus a chronological gap between the zone boundary and the start of farming. Iversen distinguished between regional and local farming impacts. By analysis 7, oak forest was declining, indicating clearance some way away from the pollen site. This was accompanied by the first trace of *Plantago lanceolata*, "the 'trail' of the Neolithic farmer in the pollen diagram" (Iversen 1941, 27). At analysis 11 oak forest fell abruptly, accompanied by a sharp rise in herbs and cereals; this was the local landnam phase of clearance and burning. The Korup pollen site is right next to the settlement of Barkær, which Mathiassen (1940) dated artefactually to the Dolmen Period (see above). Analysis 11 was evidently the precise time that Barkær was established and people cleared the forest. Analysis 12 saw the abandonment of the clearing, marked by the increase in recolonising birch, followed by hazel.

This environmental tour de force had a huge impact on archaeological interpretation. In 1947 C.J. Becker subdivided the Early Neolithic into three phases, A, B, and C. The archaeological record revealed little about phase A, but the environmental work described above nevertheless allowed Becker to come to a clear conclusion:

> From an ordinary ethnological viewpoint the problem can be put rather more clearly than the archaeological material by itself would allow…. Although the purely archaeological material may not show signs of such a clear break at the very first appearance of Neolithic culture that one could conclude from this that there was a new immigration, a straightforward invasion of considerable size, one need not hesitate in drawing the line sharply.

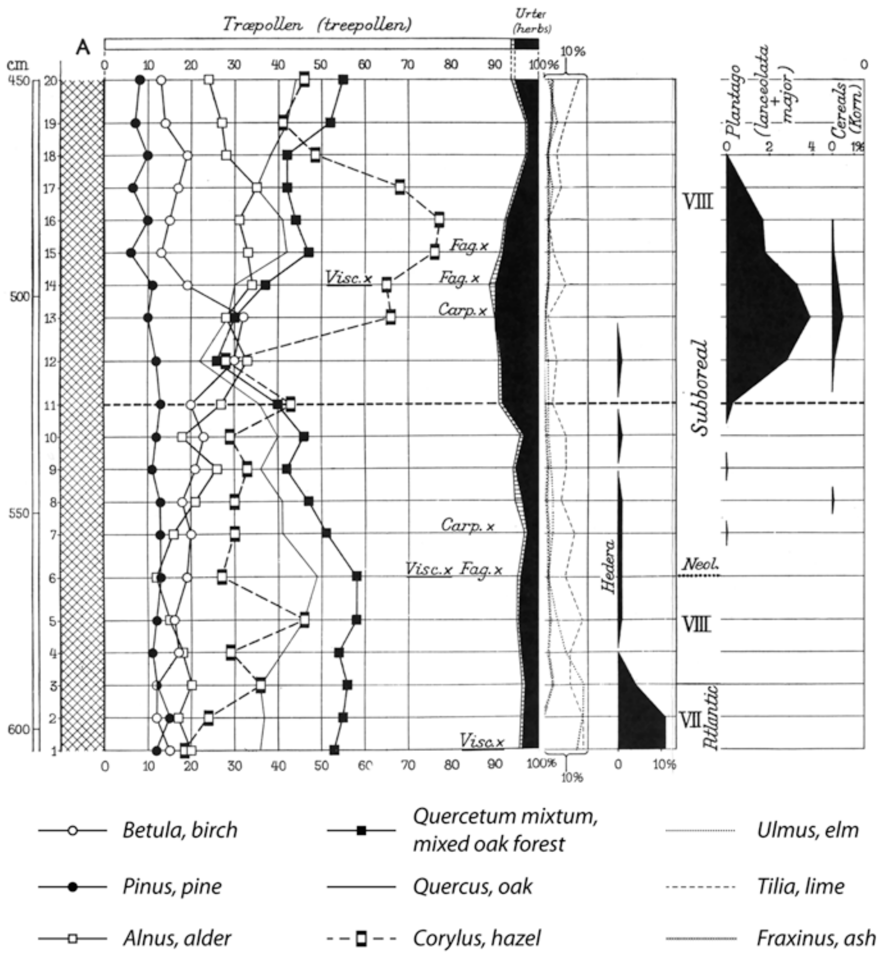


Fig. 6 Selected taxa from the pollen diagram from Korup (From Iversen 1941, Tavle IV). The boundary between pollen zones VII and VIII, marked by the start of the elm decline, is at the level of analysis 3. See text for further discussion. (Reproduced by kind permission of GEUS, the Geological Survey of Denmark and Greenland)

> Although the Neolithic A-group proposed here is so far as badly known as any Danish Stone Age group, its position at the start of the farming cultures by itself makes it certain that we are dealing with a complete cultural entity, and not with a number of new ceramic forms and other individual cultural traits which, spread through cultural transmission, came to characterise a particular phase of the old foraging culture…. (Becker 1947, 286, translated by PR-C)

This clear statement shows how environmental dating and understanding dominated archaeological interpretations. In the next few years, this was developed in an unexpected way.

2.5 1947–1966: Nuances of Overlap, the Debate Between Becker and Troels-Smith

World War II saw a resurgence of peat digging for fuel in Danish bogs, leading to many new finds. Many deliberate depositions of Early Neolithic beakers were uncovered, and these were the ones that Becker (1947) divided into his phases A, B, and C. Becker's interests were mainly typological, and his finds were not pollen-dated, but he did suggest that his earliest phase, with A-beakers and pointed-butted axes, was earlier than the Dolmen Period with its B- and C-beakers and thin-butted axes (Becker 1947, 121).

Troels-Smith meanwhile had been working on numerous sites in the great bog of Aamosen. In 1953 he published a highly influential paper coming to very different conclusions from Becker. In Aamosen too, many Early Neolithic beakers had turned up, and Troels-Smith dated some by pollen analysis. He concurred with Becker's A-B-C sequence and also that the A-beakers preceded Iversen's landnam phase. There were however two crucial differences: first, Troels-Smith argued that the elm decline was *not* a natural phenomenon as Iversen had supposed, but resulted from the pollarding of elm trees so that their leaves could be fed to stalled cattle and, second, that this was done by people of the Ertebølle culture, who were also the makers of the A-beakers. Only after this phase did the makers of the B-beakers immigrate and cause the landnam clearances.

It was the site of Muldbjerg I that convinced Troels-Smith that the A-beakers were an integral part of the Ertebølle culture. This site had a largely Ertebølle artefactual assemblage except that most of the ceramics were A-beakers. Most of the animals were wild, but there were a few domestic cattle. Troels-Smith later (1960a) developed this scenario, arguing that the absence of undergrowth pollen meant that the uncleared oak forest was a hostile place containing few ungulates and fewer people: the pre-Ertebølle population of Denmark was limited to the coasts and numbered as few as 30 people (Troels-Smith 1960a, 102). Cattle could not feed themselves in this forest but had to be permanently stalled – hence the feeding with elm leaves. Muldbjerg I was a summer hunting camp; the cattle and cereal plots were elsewhere, probably at coastal sites (Troels-Smith 1960b). Four cattle teeth from Dyrholm I were smaller than aurochs, closer to later domestic animals in size, and might have been domestic (Degerbøl 1963, Figs. 14 and 15). A Neolithic building at Weier in Switzerland yielded a deposit of preserved cowdung containing many twig and leaf fragments, offering support to the leaf foddering hypothesis (Troels-Smith 1955).

Troels-Smith's classic pollen diagram is reproduced in simplified and annotated form in Fig. 7. The chronological markers on the right are as originally published in Danish (Troels-Smith 1953, Fig. 2; also 1960a, Fig. 2) and later in English translation (Troels-Smith 1960b, Fig. 8). The italic descriptions on the left are additions. Elm is in the left column, the elm decline occurring at the first horizontal line. Iversen's landnam starts at the dated appearance of the B-beakers, followed by the successive regeneration of birch, hazel, and oak forest. The upper peak of plantain and grasses marks the establishment of permanent fields and grazings.

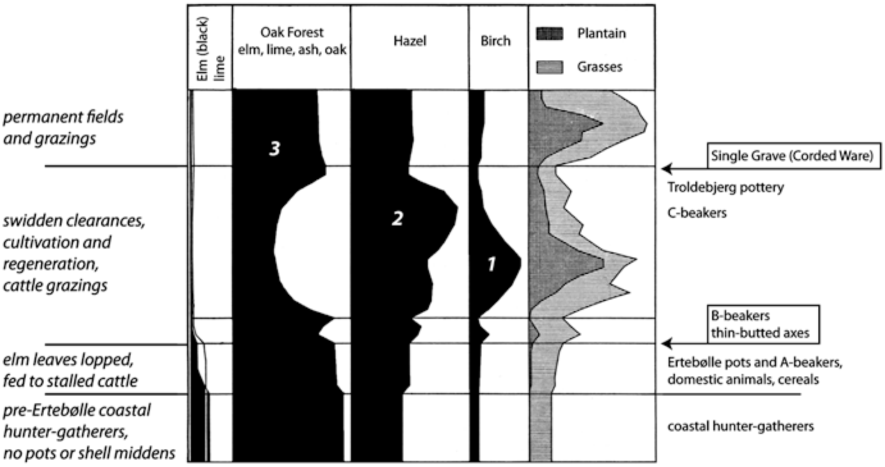


Fig. 7 Selected taxa from Troels-Smith's diagram from Aamosen (From Troels-Smith 1953, Fig. 2, by kind permission of Det Kongelige Nordiske Oldskriftselskab). Annotations on right translated from the Danish (cf Troels-Smith 1960b, Fig. 8); italicised explanations on left and numbered stages on pollen curves are added

This diagram was massively influential; but in retrospect we can see major problems with it. It is in fact not one diagram in itself, but is 'the simplified sum of a large number of pollen diagrams, which are in turn based on a very large number of statistically certain individual analyses. In all this diagram is based on the counting of over one million pollen grains' (Troels-Smith 1953, 11–13, translated by PR-C). The upper section was added from a diagram from Dyrholm in Jutland (op. cit., 13). Troels-Smith stated that the landnam phase reflected not one clearing, but many separate ones that could not be separated out (op. cit., 13). But if this were the case, the successive birch – hazel – oak forest regeneration (marked 1, 2 and 3 in Fig. 7) should be more long drawn out and contemporaneous as different clearings went through their regeneration stages at different times. The Aamosen pollen diagram is evidently a highly idealised 'mind's eye' rendering by Troels-Smith, in which there is a conflict between the local and the regional scales.

Troels-Smith's time scale was also problematic. For the Ertebølle and the A-beakers to be part of one and the same culture, the entire Ertebølle, complete with all the shell middens and pointed-base ceramics, had to be placed at or after the elm decline, and that is where Troels-Smith placed it (Troels-Smith 1953, 41–43; 1960a, 103–105; 1960b). This explicitly referred to the classical Ertebølle culture at sites such as Dyrholm II (Troels-Smith 1953, 60, n 37). As late as 1966, he was stating that 'Dyrholm II is pollen-analytically dated to the time about the elm fall' (Troels-Smith 1966, 516). This is however in clear contradiction with his original publication of Dyrholm: phase III at that site started *before* the elm decline, and phase II was earlier still (see Fig. 5, in which the position of the Dyrholm is taken from Troels-Smith 1942, Fig. 5). There is in fact a clear 30 cm gap in the Dyrholm dia-

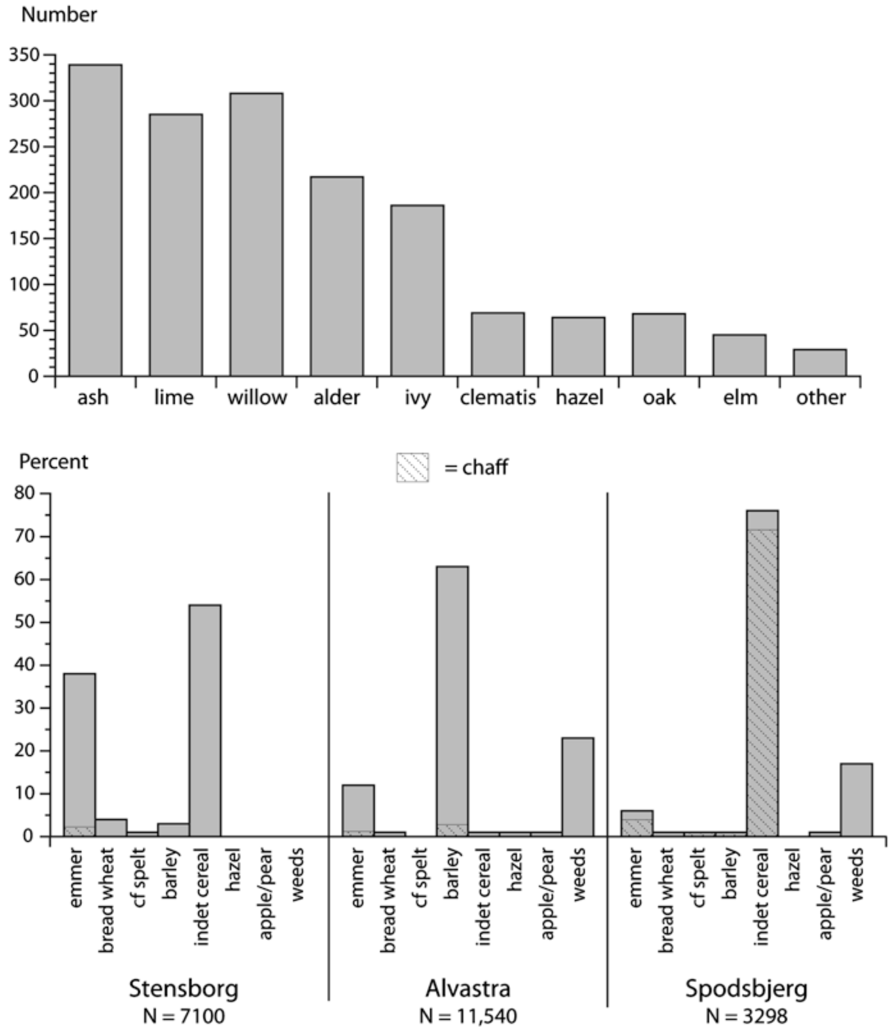


Fig. 8 Top: number of identified twig and leaf fragments in the Neolithic cow dung from Weier, Switzerland. (Data from Rasmussen 1989, Table 2). Bottom: macrobotanical assemblages from Stensborg (Early Neolithic), Alvastra, and Spodsbjerg (Middle Neolithic). (From Larsson and Broström 2011, Table 1; Göransson 1995, Tables 3, 4, and 5; and Robinson 1998, Table 1, respectively)

gram between the end of Dyrholm II and the elm decline (Troels-Smith 1942, 191 and Tavle V).

Becker was not slow to point out the chronological issues. He published some pits from Store Valby, which contained pure A-beakers with no hint of Ertebølle; A-beakers were thus not part of the Ertebølle. The classic Ertebølle, he argued, was a pure forager culture that predated the elm decline (Becker 1954, 157); later Ertebølle sites continued alongside the immigrant farmers and acquired A-beakers and other cultural elements from them (op. cit., 160). All the cereal impressions at Muldbjerg I were on A-beakers, not Ertebølle pots, so even the post-elm decline Ertebølle was a pure foraging culture (op. cit., 166). Becker's relative dating of Ertebølle sites was backed up by a clear typological change in axe typology, from core to flake axes (Becker 1939, 236–237). But Troels-Smith did not accept this and continued to argue that the classic Ertebølle of the Dyrholm II stage dated to the elm decline (1966, 516). He did however point out that several Ertebølle sites purportedly overlapping the Neolithic were not well dated: this went for most of those plotted in Fig. 5 (Troels-Smith 1966, 520–521).

The key point in the 1950s and earlier 1960s was that both Becker and Troels-Smith were arguing for a chronological overlap between farmers and foragers, which thus implied that the farmers had to be immigrants (even though in the Troels-Smith scenario the Ertebølle/A-group had acquired a little farming before the immigration). This neatly backed up the prevailing theoretical ideas in European archaeology, which saw Neolithic farmers as incomers stemming ultimately from the Near East. Major changes were however afoot: radiocarbon dating was about to render these views obsolete.

2.6 1966–1972: Radiocarbon and the Demise of the Forager-Farmer Overlap

The Copenhagen radiocarbon laboratory was one of the first to be set up in Europe, its first dates being run in 1952 (Anderson et al. 1953). One of the first sites dated was Muldbjerg I (Tauber 1956), which after correction produced an average based on nine samples of 4770 ± 80 bp (Tauber 1960). For a few years Muldbjerg I floated in time, but from 1966 the Ertebølle and the Early Neolithic rapidly fell into place.

Figure 5 (right) shows the important early determinations. The elm decline and the landnam were early targets at the well-stratified Draved bog (Tauber 1966). Muldbjerg I fell, as expected, between the two. So, soon, did a variety of other Early Neolithic sites. The Ertebølle, however, did *not* overlap with the Neolithic: a series of dates from the preserved section from Ertebølle, and a variety of other sites being excavated at the time, all fell before about 5200 bp. One of the Ertebølle dates looked anomalously late, one of the pair from Neolithic Konens Høj anomalously early; without these, the two periods fell neatly end-to-end.

Tauber presented this in the mainstream archaeological journal *Antiquity* in 1972 (Tauber 1972). The end-to-end pattern raised the remarkable possibility that no Neolithic immigration was required at all; the foraging Mesolithic could evolve indigenously into the farming Neolithic. The impact of this was profound. It came in the same year as Colin Renfrew's *Before Civilization*, which used radiocarbon dating to demonstrate, for example, that the British Early Bronze Age was far too early to have resulted from traders coming from the early civilisations in the Eastern Mediterranean. Indigenous development was the only possible cause (Renfrew 1972). By demolishing the forager-farmer overlap, Tauber's results opened up the possibility that even agriculture could have a largely indigenous origin – just as theoretical perspectives were ready to receive this idea. In Britain, Higgs and Jarman (1969) argued that there was no hard division between ‘wild’ and ‘domestic’ animals. Wild cattle and pig were indigenous to NW Europe and could have been locally domesticated in the later Mesolithic (e.g. Smith 1970), a suggestion that meshed with Degerbøl’s (1963) identification of some cattle at Dyrholm I as possibly domestic (see above). Indigenism remained the generally accepted explanation for the origins of agriculture in the region for some decades (e.g. Dennell 1983; Barker 1985; Zvelebil 1995; Price 1996).

3 Development and Diversification Since 1970

3.1 Regional Studies

In the last 30 years, the initiation and execution of large interdisciplinary regional studies have yielded a wealth of new information regarding the Neolithisation process. This is because even the most spectacular sites cannot be placed in a landscape, and therefore a system, without a broader perspective, chronological, disciplinary, geographic, and otherwise. These studies have involved a wide range of methodologies and have generated a wealth of results that far outstrip the pioneering studies described above. In particular, investigations in advance of large infrastructure projects have provided a wealth of information mostly owing to the simple reason that otherwise extensive and well-funded exposure and investigation would not have occurred at these localities. Furthermore, such large-scale projects often result in a compendium of results or monograph, tying together broad datasets as a coherent story. Since the 1990s, the finds and results from these projects have been no less than astonishing and have radically expanded upon the available data regarding agricultural origins.

One of the earliest examples involved the building of the fixed link bridge between Zealand and Fyn in Denmark, across the Great Belt or Storebælt (Pedersen et al. 1997). In preparation of construction, several coastal areas were excavated, including the island Sprogø, located almost directly between the two larger Danish islands, near coastal waters and coastal areas on either side, and through the depths of the Storebælt. Underwater preservation, coupled with a comprehensive picture of sea-level change, dendrochronological dating of submerged trees, and variation through time allowed a reconstruction of the coastal settlement system on either side of the transition to agriculture in the region in context with the local environments (Pedersen et al. 1997). Importantly, the discovery of preserved stationary fish weirs from the Neolithic offered a complimentary perspective on the role of aquatic resources in the Neolithic (Pedersen 1997), and the Early Neolithic occupations on Sprogø reinforced the limited impact on the local environment and continuing role of hunting in the Early Neolithic (Nielsen 1997).

In the early 2000s, an infrastructure development project aimed at improving the rail link between Scania and eastern Denmark uncovered a series of Early Neolithic sites near what is today Malmö (see Rudebeck 2010). One of these, Almhov, yielded a series of pits dating to the earliest ENI and the largest recovered faunal assemblage to date from the incipient Neolithic (Rudebeck 2010). Stemming from these larger sample sizes, it has become possible to directly address previously restricted population-based questions such as for what purposes were cattle being raised and were they moved across the landscape in the earliest Neolithic (Gron et al. 2015, 2016).

Another example, while not strictly an application of environmental archaeology, was Magnus Andersson's work on the Early and Middle Neolithic landscape in western Scania (Andersson 2004). Drawing its source material from excavations in advance of the building of a new rail line along the west coast of the region, new perspectives upon the distribution of settlement and change through the earliest Neolithic became possible.

More is to be expected. Current excavations in advance of the building of a fixed link between the southern Danish island Lolland and the northern German coastal island Fehmarn (the Fehmarn Belt Project) have revealed outstanding conditions of preservation and some truly remarkable finds. These include hafted flint axes, transverse points still in their shafts, and in situ organic remains (Mortensen et al. 2015). Only time will tell regarding the impact of this ongoing project, but it is fair to say that our understanding of Neolithisation can only be increased by evidence from this hitherto under-investigated region as already substantial evidence of Neolithic stationary fishing weirs has emerged.

It is not only infrastructure projects offering regional perspectives of course. The Ystad project in Scania was undertaken from ca. 1982–1990 and aimed to integrate landscape and societal change from the Mesolithic to historical times in a specific area of southern Scania (Berglund 1991). This ambitious project tied together researchers from paleoecology, plant ecology, archaeology, and human geography in order to tell a coherent story of the human impact and environmental interaction in the *longue durée*.

Research on Bornholm regarding landscape, environmental impact, and changing subsistence strategies has been ongoing on an island-wide scale for a number of years now. The scientific results are forthcoming (Nielsen and Nielsen 2017) and will offer a complimentary view on the Neolithisation process in mainland areas of southern Scandinavia from a local and landscape-wide scale.

Lastly, but certainly not least, shell midden excavations in eastern Jutland, Denmark, have been ongoing for many years under the direction of Søren H. Andersen (see Andersen 1991, 1993a, 2004, 2007, 2008a; and many more). By focusing on the stratified shell middens and scientific analyses of their Mesolithic and Neolithic occupations, these investigations have resulted in an unparalleled view of change and continuity across the transition to agriculture. Most strikingly, they have illustrated that at places like Bjørnsholm (Andersen 1993a; Bratlund 1993), Visborg (Enghoff 2011), Havnø (Andersen 2008b), and Norsminde (Andersen 1991), the earliest centuries of the Neolithic were characterised by remarkable continuity with the Mesolithic.

In aggregate these regional studies have offered a new, landscape-wide view of processes leading to and after the transition to agriculture. More than anything, they have served to A) greatly expand the available dataset useful for addressing the relationship between humans and their environments, B) introduce an understanding of the variability in the Neolithisation process across the landscape, and C) have underscored the complexity of the transition.

3.2 Archaeological Chemistry

Starting in 1981 with perhaps *the* seminal paper in the archaeological sciences regarding agricultural origins in southern Scandinavia, Henrik Tauber presented data demonstrating a profound shift in diets between Danish Mesolithic and Neolithic populations: marine foods were predominant in the Ertebølle, terrestrial foods in the Neolithic (Tauber 1981). Since, a number of isotopic studies detailing human (including using proxies) have largely reinforced this view (Fischer et al. 2007; Richards et al. 2003) but are not without conflicting perspectives (Lidén et al. 2004; Milner et al. 2004). The meaning of this massive shift in human diets is unfortunately less than clear. The reason for this is that the chronological timing of the dietary shift and the relationship of human diets to available subsistence resources do not necessarily neatly correspond to the start of the Neolithic. This primarily owes to the need for a marine reservoir correction on radiocarbon dates on individuals with marine-dominated diets directly at the transition. Within this uncertainty it does appear that at or about the introduction of farming, there are some individuals eating marine foods and some individuals eating terrestrial foods on the landscape at the same time (see Fischer et al. 2007). Furthermore, there is evidence for a continuation of the exploitation of marine resources in the form of continuing occupation at the shell middens (Andersen 2008a) as well as stationary fish traps (Mortensen et al. 2015; Pedersen 1997). In aggregate, this means that some ambiguity remains with regard to how to interpret the dietary isotopes in context.

While some analyses of animals have been presented as baselines relating to human dietary studies (Fischer et al. 2007), in the context of new methodological applications (Craig et al. 2006), to isotopically characterise certain taxa (Robson et al. 2016), or as secondary to traditional zooarchaeological analyses (Richter and Noe-Nygaard 2003; Ritchie et al. 2013; Magnussen 2007; Hede 2005), several studies have focused specifically on fauna with regard to understanding the Mesolithic-Neolithic transition. Broadly, this work has aimed to reconstruct past feeding environments and any potential change in animal populations, habitats, and diets between the Mesolithic and Neolithic, as well as to investigate animal husbandry strategies in the earliest years of the Neolithic.

Early work included carbon isotope analyses of various classes of fauna from the Store Åmose bog system on Zealand (Noe-Nygaard 1995), which demonstrated the utility of such applications in documenting environmental change and differences in the landscape. Later work was built on this application (Noe-Nygaard et al. 2005), comparing domestic and wild cattle values with deer baselines and documenting a closure of the forest through the Atlantic and Sub-Boreal and arguing that cattle were being kept in open environments. Building on this, we have recently published a broader, landscape-wide view of variation in deer diets in order to place cattle in the landscape (Gron and Rowley-Conwy 2017). Perhaps not surprisingly, with a broader perspective on geographic variation and the addition of nitrogen isotope analyses, we were able to determine that cattle were being raised in small areas cleared by humans in the earliest Neolithic.

The application of other isotopic techniques has been much less common. Strontium isotope work has been hampered by two main factors: (1) the geology across southern Scandinavia is largely homogenous, resulting in limited potential for answering many research questions, and (2) the general lack of baseline values. The former cannot be avoided as it is simply the geological reality, but fortuitously, in a series of recent studies, the latter has largely been rectified (Frei and Frei 2011; Frei and Price 2012; Price et al. 2012a, b, 2017). As such, it has become possible to start addressing basic but simple questions regarding the earliest Neolithic, about which little is known regarding the actual practice of farming. One example is our recent paper (Gron et al. 2016) which demonstrates the movement of cattle by boat across the Øresund in the earliest Neolithic using strontium isotope proveniencing.

Very little other isotope work has been completed specifically addressing questions pertaining to the transition. Initial analyses of oxygen isotopes, for example, on materials from somewhat later in the Neolithic (Sjögren and Price 2013) demonstrated that seasonal variation in $\delta^{18}O$ is recorded in hypsodont Scandinavian cattle teeth. However, the only application directly relevant to the understanding of agricultural origins to date is our study of birth seasonality of cattle in the earliest Neolithic from the aforementioned site Almhov, in Scania (Gron et al. 2015). In that study, we demonstrated multiple birth seasons for the cattle in the sample, which we interpreted as evidence of dairying in the earliest Neolithic. Other applications are rarer still. Only recently has the manuring of crops during the Early Neolithic been demonstrated through elevated charred cereal $\delta^{15}N$ values (Gron et al. 2017). Similarly, sulphur isotopes have only really been applied once to Scandinavian materials about the transition, and then as a proof of concept (Craig et al. 2006), the conclusion of which stated limited potential awaiting future research.

Another approach has been to analyse ceramics directly to determine the composition of food crusts and therefore what was being prepared in the pots. A number of studies have taken this approach, looking at both the stable isotopic composition of bulk food crusts and more detailed analysis of lipids within those crusts (see Heron et al. 2013; Craig et al. 2007, 2011; Isaksson and Hallgren 2012). The earliest applications capitalised upon excellent underwater organic preservation (Andersen and Malmros 1984), while in the recent years more detailed and specific approaches have become more common, attempting to parse specific components of what was being cooked (Craig et al. 2007, 2011; Heron and Craig 2015; Isaksson and Hallgren 2012). Other approaches have looked at what was being used as fuel in the so-called blubber lamps (Heron et al. 2013).

3.3 Ancient DNA

In the last few decades, a series of genetic studies have started to address the question of agricultural origins in northern Europe. On a basic level, three lines of inquiry have been explored, including asking who were the people involved in the transition and were they related, what were their characteristics, and lastly what can genetic analyses of non-human species tell us. For the most part, the focus has been on other Neolithisation events and not strictly on Scandinavia (Bramanti et al. 2009; Haak et al. 2010; Soares et al. 2010).

Only a few studies have addressed Scandinavian material directly. Skoglund et al. (2012) found a marked genetic discontinuity between TRB farmers and hunter-gatherers. However, this study did little to address the start of farming in the region because of the simple fact that the hunter-gatherer individuals were from the Pitted Ware Culture (PWC), Neolithic hunter-gatherers much later than the last Mesolithic foragers. Another study, based on a broader sample both culturally and chronologically, including modern samples postulated a replacement of Mesolithic Danes by incoming Neolithic groups (Melchior et al. 2010). Further genetic work has also addressed the relationship between members of the PWC and contemporary farmers (Malmström et al. 2009), but again the crucial question regarding relationships between the last foragers and the first farmers remains unaddressed (Malmström et al. 2015). However, when local Mesolithic hunter-gatherers are taken in comparison with TRB individuals, at least in some capacity, it becomes clear that hunter-gatherers intermixed with the first farmers (Skoglund et al. 2014). As such, any simple conclusions regarding agricultural origins can no longer be drawn.

Perhaps of more import for understanding the transition is investigating the presence of lactase persistence in Late Mesolithic and Early Neolithic populations. In at least one study (Malmström et al. 2010), the percentage in a Neolithic population of Pitted Ware Culture (PWC) hunter-gatherers who could digest lactose was vanishingly small compared to modern proportions of the Scandinavian population. While seemingly this demonstrates that perhaps the Neolithic population of Scandinavia was largely unable to digest milk, as always there are limitations when it comes to understanding agricultural origins. For example, if processed correctly, milk products can be consumed by those without lactase persistence, and therefore the presence or absence of lactase persistence does not say much about how or if dairy was consumed.

The genetics of the domesticated species themselves have lent a complimentary view of the transition. One approach to the question looked at the adaptive processes of crop plants themselves to different climates as possible players in the timing and spread of agriculture to Scandinavia and elsewhere (Jones et al. 2012). The genetics provided a plausible explanation for the delay in the spread of agriculture to the region, although again causality is hard to demonstrate. A different approach aimed to rectify some conflicting information regarding unexpectedly small *Bos* sp. specimens from the latest Mesolithic site Rosenhof, Germany (Scheu et al. 2008). In this case, the genetic data showed that in fact there was no evidence for local or early domestication at the site and that the earliest domesticates were associated with the widespread adoption at or around 4000 cal BC (Scheu et al. 2008). Perhaps the most contentious claim proposed is that Ertebølle hunter-gatherers possessed domestic pigs (Krause-Kyora et al. 2013) based on mtDNA in pig remains from Ertebølle sites. Quickly rebutted (Rowley-Conwy and Zeder 2014) on the basis of basic zooarchaeology as well as domestic and wild pig behavioural ecology, this study probably best represents the limitations of genetic analyses.

3.4 Archaeobotany

A steady, if not geographically inconsistent, series of palynological studies has been completed in the last decades relating to the latest Mesolithic and earliest Neolithic (Andersen 1992, 1993b; Berglund 1985, 1991; Göransson 1988; Lagerås 2008; Rasmussen 2005; Regnell and Sjögren 2006; Regnell et al. 1995; Schrøder et al. 2004; Skog and Regnéll 1995). In general, these studies have, through a series of palynological sequences from across the region, demonstrated a series of disparate vegetation changes from the late Atlantic into the Sub-Boreal, an increase in secondary successive species and evidence of disturbance (Andersen 1998; Berglund 1969; Lagerås 2008), and the presence of heat-deformed pollen interpreted as being the result of burning for slash-and-burn agriculture (Andersen 1992). In some cases, no discernable anthropogenic effects on the environment are seen in the ENI at all (Regnell and Sjögren 2006).

Various lines of environmental archaeology have focused on the elm decline, with the result that this vegetational change is now regarded as probably not due to human activity after all. The earliest farmers would not have been very numerous. Later calculations suggested that to reduce elm by the amount they did, they would have been pollarding impossibly large numbers of elm trees (Rackham 1980, 266) and feeding impossibly large numbers of cattle (Rowley-Conwy 1982). The twigs and leaves in the cow dung from Weier, argued by Troels-Smith (1955) to be support for the leaf foddering hypothesis, were identified by Peter Rasmussen, who showed that they came from a wide variety of species (Fig. 8 top); only 3% of them were in fact elm (Rasmussen 1989, Table 2). It has become increasingly clear that the elm decline occurred all over Europe and beyond and at the same time regardless of the local cultural and economic situation. The possibility that the elm decline was caused by disease was reinforced by a new epidemic decimating Europe's elm trees in the 1980s (Perry and Moore 1987), and the *Scolytus* beetle, the vector in the 1980s outbreak, was identified in deposits dated to the elm decline (Girling and Greig 1985).

Palynology in general is beset with several fundamental limitations, including the need for the use of proxy species, difficulties and variability regarding the size of catchments for pollen cores, and the interplay with local processes of which some have nothing to do with human activities (Berglund 1985). With regard to the transition to agriculture, there are two key issues: first, the pollen of domestic cereals simply does not travel very far (Berglund 1985); and second, there are major problems in distinguishing cereal pollen from that of some native wild grasses (Behre 2007; Lahtinen and Rowley-Conwy 2013). Basic palynological analyses by themselves are therefore much better at demonstrating large-scale human impacts on existing environments (e.g. deforestation, increases of species that thrive in open areas, or demonstrating heating) than at detecting the earliest traces of agriculture in a region. It is in the context of these limitations therefore that the palynological record at present is interpreted to show little noticeable human impact on the floral composition of southern Scandinavia in the first centuries of the Neolithic, with widespread clearance only visible by the ENII, or around half a millennium after the introduction of domesticated plants and animals (Gron and Rowley-Conwy 2017).

Plant macrofossils offer complimentary and more concrete evidence of the presence of agriculture on a landscape. However, in order to be preserved (and therefore identified), a very certain series of conditions must be met, including that the grains must have been burned, they must be specifically sought using soil flotation, and lastly they must be identifiable (see Sørensen 2014). Flotation has been patchily employed in Southern Scandinavia and rarely on a large scale, which necessarily limits the conclusions. Conversely, cereal impressions in ceramics may also be used to document the presence of domestic cereals (Sørensen and Karg 2014). It is generally agreed upon that several forms of wheat and barley are present as domestic grains in the earliest part of the Neolithic in southern Scandinavia (Sørensen and Karg 2014) although the rarity of samples from the Early Neolithic has hindered our understanding of agriculture in this crucial period. The Middle Neolithic is better understood. Figure 8 (bottom) presents the major assemblages from Alvastra and Spodsbjerg (Göransson 1995; Robinson 1998). One major Early Neolithic sample comes from Stensborg (also in Fig. 8), and directly dated cereal grains from the unpublished assemblage from Almhov also date to the Early Neolithic (Nilsson and Rudebeck 2010). Plant frequencies in archaeobotanical assemblages cannot be simply be read at face value in the way that animal bones can: animal bone assemblages accumulate over a period of time and are probably representative of the economy as a whole, while an archaeobotanical assemblage may be charred as a single event and thus represents only one particular activity at one precise moment in time (Rowley-Conwy and Legge 2015, 431). Such chance factors probably account for the variability between sites in Fig. 8.

Within the limits of our ability to date cereal finds, the transition to agriculture looks increasingly like an abrupt switch to a cereal-based economy. There is no good evidence for the cultivation of cereals in the Late Mesolithic (Sørensen 2014, I, 60). Two claimed direct dates are in fact on items of uncertain provenience and/or identification, while a third stems from a misprint in a table (Nilsson and Rudebeck 2010, 117). For the Early Neolithic, the evidence from Stensborg in Fig. 8 is at least as compelling as that from the Middle Neolithic sites and pushes evidence for the major importance of cereal agriculture back to near the start of the Neolithic.

Recently, however, archaeobotanical research has expanded into the identification of microfossil crust inclusions for the identification plant species using starches (Saul et al. 2012) and phytoliths (Saul et al. 2013). The results of these studies have indicated that food was being spiced in some cases using species of little nutritional value and that a complete replacement of wild resources by domesticated species does not seem to be in evidence in the earliest Neolithic.

3.5 Zooarchaeology

Many zooarchaeological methods were developed early on, for example, the distinction between wild and domestic pigs (see above and Fig. 2). This continued through the mid-twentieth century: Magnus Degerbøl routinely separated small domestic pigs from large wild boar, for example, at Neolithic Bundsø and Mesolithic Dyrholm II (Degerbøl 1939, 1942 – see Rowley-Conwy et al. 2012, Fig. 3). The separation between wild and domestic cattle is more complex because cattle are sexually dimorphic. As noted above, Degerbøl (1963) identified a few Late Mesolithic cattle from Dyrholm II as domestic. He soon amended this: as more of the smaller female aurochs became available, the aurochs size range broadened to overlap more with male domestic cattle. The Dyrholm II specimens fell in this overlap zone and could therefore no longer be definitely classified as domestic (Degerbøl and Fredskild 1970). A few specimens at Late Mesolithic Rosenhof were also identified as domestic (Nobis 1975), but they too fall in the metrically intermediate zone (Rowley-Conwy 2013). These are the specimens subsequently identified as aurochs through aDNA (Scheu et al. 2008, discussed above). The most recent synthesis suggests that there were no domestic cattle in the Late Mesolithic (Sørensen 2014, I, 86–89). Domestic pigs were claimed from the same site on the basis of aDNA, but these remain problematic (see above).

Current dating methods allow us only to say that the first domestic animals appeared somewhere close to the Mesolithic/Neolithic boundary. Smakkerup Huse provides a clear illustration of the problems (Price and Gebauer 2005). The animal bone assemblage is classically Mesolithic comprising wild animals, birds, and fish, with a few domestic dogs – except that four domestic cattle bones were also recovered (Hede 2005). The site is on the island of Zealand, where Mesolithic hunters had exterminated the local aurochs two millennia before the arrival of farming (Aaris-Sørensen 1999), so misidentified aurochs can be ruled out. Figure 9 shows the calibrated dates. Most dates fall before 4000 cal BC, but the two dated cow bones fall after this. They could thus be intrusive Neolithic cattle. They were found together with other faunal items, however, and there were no Neolithic cultural items, so it is possible that they might fall into terminal Mesolithic times (Price and Gebauer 2005, 124). This example shows how vital it is that problematic specimens be directly dated.

Some Early Neolithic sites however are largely dominated by wild animals – while others have mostly domestic ones. Figure 10 shows a selection. Muldbjerg I is dominated by red deer and Anneberg by seal, while domestic animals dominate at Almhov and Skumparberget. The difference is underlined by the fact that there are very few fish at Almhov and Skumparberget, while there are some 3000 at Muldbjerg and no fewer than c. 75,000 at Anneberg. Thus in both the northern and southern

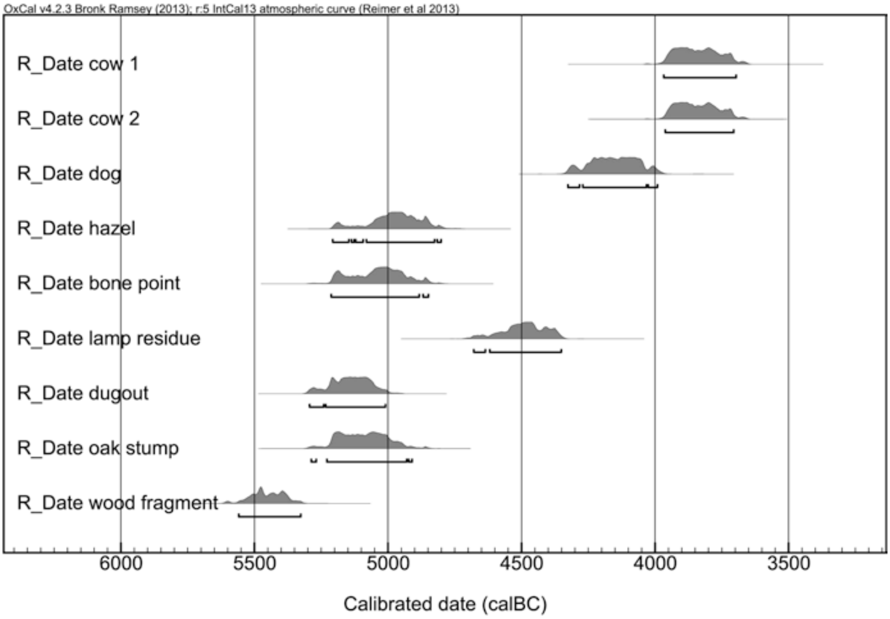


Fig. 9 Recalibrated radiocarbon dates from Smakkerup Huse. Determinations from Price and Gebauer (2005), Table 8.1, recalibrated using OxCal 4.1 with the IntCal 09 curve (Bronk Ramsey 2009)

TRB, some sites are dominated by domesticates, while others continue a largely 'Mesolithic' way of life. Thus the Mesolithic-Neolithic transition is not clear-cut – not because there are domestic animals in the Mesolithic, but because some Early Neolithic sites continue to be dominated by wild mammals.

In terms of recovery, zooarchaeology has advanced markedly. It was the first sector of archaeology in which it was realised that it is essential to sieve all deposits if smaller items and taxa are not to be differentially missed (Payne 1972). The impact of sieving is shown in Fig. 10 (bottom). There was a major increase in Late Mesolithic mammal and bird assemblage size following the introduction of the technique in the late 1960s. This is even more true of assemblage size of fish bones, which require even finer sieve mesh to recovery the numerous small fish bones (Gron and Robson 2016, Fig. 1). Fine sieving has led to a much better understanding of the importance of fish in the Ertebølle, particularly through the work of Inge Bødker Enghoff (e.g. Enghoff 1983, 1994, 2011). Only through this work has it become possible to reconcile the zooarchaeological record with the marine diet documented by stable isotope analysis (see above); without the small fish, terrestrial mammals dominate the picture.

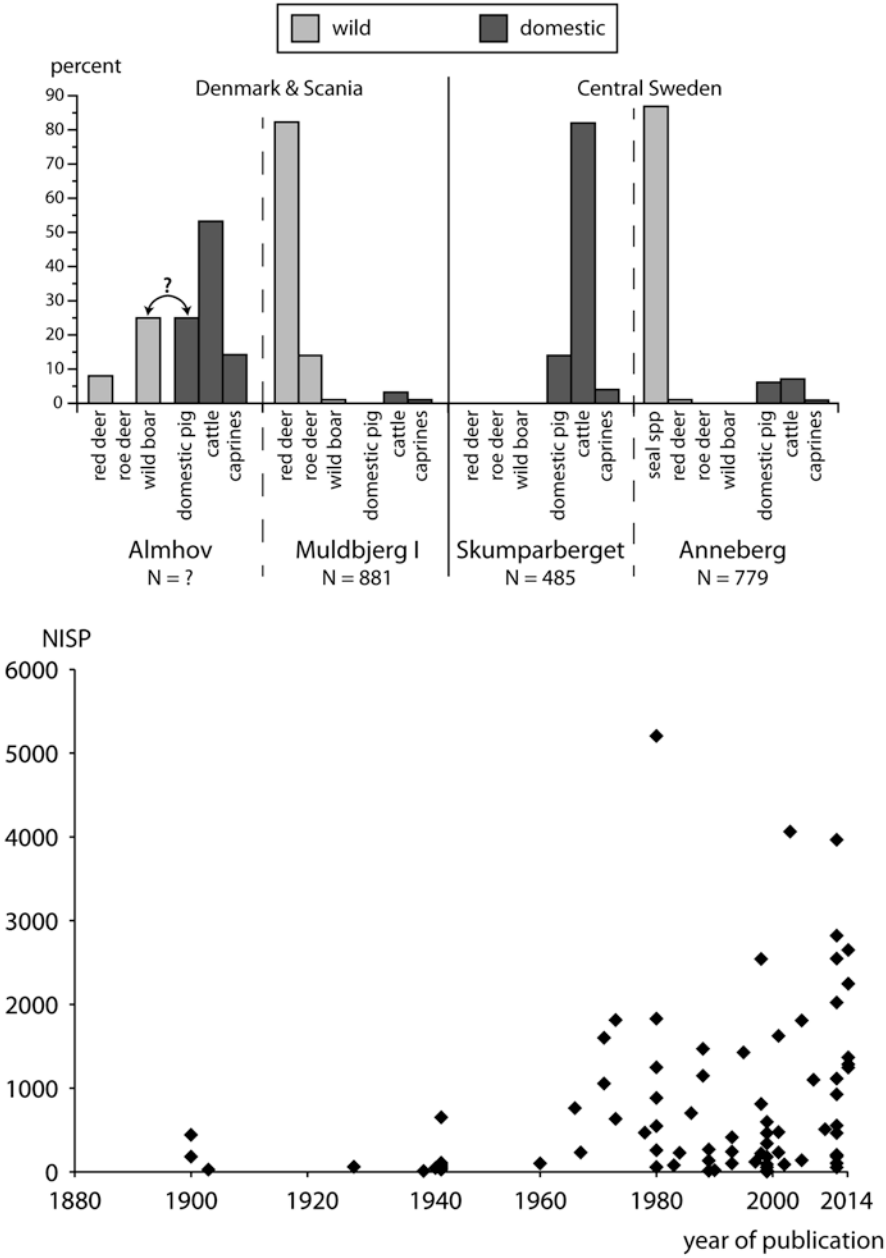


Fig. 10 Top: some Early Neolithic faunas. Muldbjerg I from Noe-Nygaard (1995), Table 6; Almhov figures estimated from Nilsson and Rudebeck (2010), Fig. 7 (wild and domestic pigs are not separated, so the percentage is shown in both columns); Skumparberget from Bäckström (1996), Table 15; Anneberg from Segerberg (1999), Table 100. Bottom: size of Late Mesolithic faunas correlated with date of publication. (Modified from Gron and Robson 2016, Fig. 1)

3.6 Ecosystem Modelling

In the late 1970s and 1980s, a series of papers addressed EBK economy and settlement system from the standpoint of what was essentially a human behavioural ecology (HBE) approach. These papers aimed to establish a basis for understanding the observed site distribution within EBK settlement systems through calculating various aspects of local productivity. One of the present authors applied such an approach in a series of papers (Rowley-Conwy 1983, 1984) which endeavoured to explain the context of the complex foraging adaptations observed in EBK society, as well as calculate the effect of changes in resource availability on societies resulting in the transition to agriculture. This approach then assigned a most likely scenario for the transition to agriculture resulting from the reduction in a single cornerstone resource – the oyster – owing to changes in ocean salinity (Rowley-Conwy 1984). This approach can be criticised because it applied only to those areas of Denmark where oysters were available and could not directly account for the transition in the rest of southern Scandinavia or indeed Britain and Ireland, which all saw the appearance of agriculture at the same time (Schulting 2010).

Another approach was to take a regional view of resource availability to establish the types and degrees of change that would be required in order to upset the EBK subsistence system and presumably usher in agriculture (Paludan-Müller 1978). While useful for understanding the environmental and economic underpinnings of EBK subsistence, the above studies largely assigned human actors a passive role in culture change, as well as implicitly considering agricultural origins in the region the result of local individuals changing their subsistence strategy.

3.7 Ongoing Fundamental Research

Despite new methodological applications outlined above, it is easy to forget the value and necessity of fundamental and traditional methods. Since the year 2000, for example, essential zooarchaeological analyses have been performed from the vital early farming sites Almhov (Magnell 2015), Saxtorp (Nilsson and Nilsson 2003), and Hunneberget (Magnell 2007) giving for the first time a more complete view of resource exploitation during the early years of the Neolithic. Additionally, a series of similar analyses of Ertebølle localities (Enghoff 2011; Hede 2005; Magnussen 2007; Richter and Noe-Nygaard 2003; Ritchie et al. 2013) have greatly expanded our understanding of regionality and variability across southern Scandinavia.

The study of molluscs also has also continued, with new developments expanding our toolbox for understanding environmental change and resource exploitation. For example, thin sectioning of molluscs has shown a reliable tool for understanding seasonality of exploitation at the shell middens (Milner 2002), and ongoing work incorporating salinity proxies from oysters and other proxies has allowed a reconsideration of the causes of the oyster decline concomitant with the start of farming (Lewis et al. 2016).

The instigation of underwater excavations have expanded the possibility for the recovery or preserved organic remains. The impact has been multifold, not least of which is the filling in of the giant black box southwest of the zero line of isostatic rebound (Christensen 1995; Mertz 1924) which was hitherto represented by very, very few Stone Age sites. Underwater excavations at Tybrind Vig (Andersen 1985; Andersen 2013), in the Storebælt (Pedersen et al. 1997), Ronæs Skov (Andersen 2009), and elsewhere (see Lübke et al. 2011) have immeasurably increased the available sample of preserved organic remains available for study while simultaneously allowing a view of regions from which very little is known.

4 Looking Forward

We are fast approaching the bicentennial of environmental archaeology as applied to southern Scandinavia and in particular to the question of agricultural origins in the region. Despite this duration of strong scholarship, a consensus opinion regarding the ultimate (or even proximate) causes of the shift from foraging to farming at around 4000 B.C. remains elusive. Dominant points of view have come and gone, but the data remain, resulting in a situation where we have perhaps the best documented transition to agriculture in the world, but one we still do not really understand.

As we stated at the beginning of this chapter, it is our impression that more often than not, it is methodological innovation which leads the theory building instead of vice versa. There are exceptions, of course, but the dominant paradigmatic shifts have followed in the wake of the major methodological developments (C14 dating, stable isotopic geochemistry, aDNA, or further back zooarchaeology and palynology) or simply large projects which have yielded new data in previously under-investigated geographic locations. Nonetheless, old ideas have cycled back and are sure to go out of vogue with time. This underscores the larger and simplest of problems that our samples are, in general, far too small. We do not have enough Early Neolithic sites, large enough faunal assemblages, enough burials from the latest Mesolithic and earliest Neolithic, etc. to which we can apply our substantial environmental archaeological analytical toolkit.

It should go without saying that any one method, extant or future, will not 'solve' the question of agricultural origins in southern Scandinavia. If anything, the suite of methods has revealed significant, and probably substantial, variation within the Neolithisation process across the landscape. The true story is probably a combination of reasons, and our best attempts at accessing its underpinnings are probably through a combination of methods. If the long history of environmental archaeology in the region has taught us one lesson, it is that there is no substitute for fundamentals and that an integrated approach to research led by environmental archaeologists comfortable with interdisciplinary engagement is the only safe way forward.

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A Man and a Plant: Archaeobotany

Maria Lityńska-Zając

1 Introduction

A man is surrounded by plants, no matter in which part of the globe and under which changeable climatic conditions he lives. Basically, plants are not encountered individually; instead they form communities of different types, some of which are primeval and natural, while others are of anthropogenic nature, i.e. transformed by a man. Plants play an enormous ecological role as providers of oxygen and primary producers of organic matter. Their economic significance cannot be overestimated either.

"Plants have been used by humans for various purposes. Multiple applications of plants are possible thanks to their specific properties. Some species, such as grasses commonly encountered in our surroundings, produce caryopses that contain a considerable amount of starch, as well as carbohydrates, proteins and fats, due to which they are cultivated as cereal crops all over the world, and constitute the major source of food for humans. An enormous alimentation role is played by other crop species, such as peas, beans, lentils or faba beans that contain a significant amount of proteins, fat, starch, fibre and mineral salts. There are commonly known numerous species of fruit and vegetable crops, mainly rich in vitamins and mineral salts. Other plants containing chemically active substances, such as alkaloids, tannins, glycosides, glucosinolates, mucilage, organic acids or vitamins, are used in cooking as spices (black pepper, mustard), production of medicines (fennel, camomile) and cosmetics as beauty and therapeutic products (nettle). There are also plants that can serve for production of textiles (flax, hemp, cotton) or natural dyes (elder and oak bark). Finally, people use woody plants for making furniture and small everyday objects" (Lityńska-Zając and Nalepka 2008).

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In a word, “plants are essential to human existence” (Hastorf 1999, 56).

The history of plants is within the scope of interests of palaeobotany, a part of which is archaeobotany. Distinctiveness of this scientific discipline results from the nature of sources it examines. Assemblages subject to archaeobotanical studies emerged as a direct outcome of human activity and are preserved in archaeological layers or features created partially or mostly by men, whereas Quaternary palaeobotany investigates associations that formed naturally, at most more or less influenced by humans and preserved in geological deposits shaped by natural processes (i.a. lacustrine sediments and peat soils). The general difference between these two scientific disciplines mentioned above is based on the type of remains they study, which with regard to archaeobotany are not entirely fossilised (Fuller 2002, 248; Lityńska-Zając and Wasylikowa 2005, 24).

2 Archaeobotany: Definition and Brief History

According to the Polish handbook, “archaeobotany aims to recognise the mutual relationship between a man and a plant in the past, based on an analysis of all plant remains that could be recovered from archaeological sites. The scope of archaeobotany encloses, on one hand investigations of various applications of plants in human activities, changes in flora and vegetation caused by this activity, and evolution of cultivated species, on the other hand a recognition of the impact of natural environment and available plant resources on the development of human civilisations” (Lityńska-Zając and Wasylikowa 2005, 23).

In the existing literature, very similar definitions of the discipline in question can be found (e.g. Greig 1989; Jacomet and Kreuz 1999; Fuller 2002, 247; Denham et al. 2009; Mariotti Lippi 2012; Pearsall 2015). In some related publications, the term palaeoethnobotany is used, derived mostly from American tradition (Hastorf 1999, 55). There are authors who consider these two terms to be synonymous; others give them different meanings (Lityńska-Zając and Wasylikowa 2005, 23). In the latter case, palaeoethnobotany is defined as a scientific discipline dealing with plants that were utilised by men for various purposes (Dimbleby 1967; Popper and Hastorf 1988, 2; Hastorf 1999, 56; Fuller 2002, 248; Pearsall 2015, 1–2). The terms archaeobotany and palaeoethnobotany were introduced by a Danish scholar, H. Helbæk (Helbæk 1959).

The first interests in fossil materials and the beginnings of widely understood palaeontology as an individual discipline of science reach back to the first half of the nineteenth century (Raup and Stanley 1984). Archaeobotany is also a discipline of relatively young tradition, the beginning of which is dated to 1865 when a dissertation by a Swiss botanist O. Heer was published, dedicated to plants from Swiss pile dwellings of the Neolithic and the Bronze Age (Heer 1865). The greatest achievements in archaeobotanical studies have been presented in numerous handbooks (e.g. Renfrew 1973; Greig 1989; Jacomet and Kreuz 1999; Lityńska-Zając and Wasylikowa 2005; Pearsall 2015); therefore, they will not be quoted here. Amongst the latest accomplishments, one should name a collection of articles referring to the history of development and expansion of agriculture and cultivation of plants in many regions of the Old World (Colledge and Conolly 2007) and an overview based on detailed case studies, giving the grounds for new research concepts (Conolly et al. 2008). Recently, the significance of studies on stable isotopes has grown, which are successfully used for reconstruction of paleo diet and allowed the investigators to prove that fertilisation of farmlands is a practice employed by humans since the beginning of the Neolithic period (Bogaard et al. 2013, 2016; Styring et al. 2014a, 2014b).

Archaeobotanical studies in Poland (in Polish tradition often referred to as Quaternary palaeobotany) were initialised by investigations carried out by A. Kozłowska (1921), although they were preceded by occasional identifications of diaspores obtained from Peruvian mummies (Lityńska-Zając and Wasylikowa 2005, 32). The interwar period delivered a relatively small number of elaborated sites (Jaroń 1936, 1938, 1939). However, there were botanists who undertook many interesting studies useful in identifying the remains. Matlakówna (1925) subjected grains of modern cereal plants to burning process in order to recognise deformations that must have affected the forms of plant remains obtained from archaeological sites. Swederski (1925) performed microscopic observations of the structure of "siliceous skeletons" (phytoliths) within fruits of various plants (acc. to Lityńska-Zając and Wasylikowa 2005, 31–34).

The period following the Second World War stimulated a significant flourishing of archaeobotanical studies, which have induced, especially recently, a growing interest of scholars and have been gaining more and more significant position as a part of regular archaeological research. This resulted in an emergence of many detailed papers referring to finds obtained from particular archaeological sites. Investigations conducted in that time delivered a great number of detailed studies referring to finds encountered at particular archaeological sites, including an elaboration of abundant materials coming from medieval cities, such as Gdańsk (Lechnicki et al. 1961; Badura 2011), Poznań (Moldenhawer 1939; Klichowska 1969; Koszałka 2008), Przemyśl (Wieserowa 1967), Wrocław (Klichowska 1961), Kraków (Wasylikowa 1978; Wieserowa 1979; Mueller-Bieniek 2012a), Wolin (Latałowa 1999a, 1999b), Elbląg (Latałowa et al. 1998) and Kołobrzeg (Latałowa and Badura 1996; Badura 1998, 1999), as well as development of methods employed for their examination (Wasylikowa et al. 2009; Zemanek and Wasylikowa 1996). Noteworthy were also case studies dedicated to individual sites, yet referring to exceptional finds (Table 1).

Recognition of cultivated plant species encountered at various archaeological sites has led to numerous attempts at reconstruction of the crop structure within the present territories of Poland (Klichowska 1972a, 1976, 1984; Wasylikowa 1984; Wasylikowa et al. 1991). The most recent overviews are rather of regional nature (Mueller-Bieniek 2002, 2007; Lityńska-Zając 1997a, 2007) or refer to a single chronological unit, namely, the Roman Period (Lityńska-Zając 1997b). Research topics associated with the reconstruction of crop structure were widely addressed in the European related literature (e.g. Hajnalová 1993; Maier 1999; Bogaard 2004;

Table 1 Selected examples of exceptionally interesting archaeobotanical finds from Poland.

Site	Chronology	Plant remains	Description	Related literature
Gwoździec, com. Zakliczyn, site 2	Neolithic (Linear Pottery culture)	*Malus sylvestris*	Pit	Bieniek and Lityńska-Zając (2001)
Szarbia, com. Koniusza, site 14	Bronze Age (Mierzanowice culture)	*Lithospermum officinale*	Grave, plaster (cataplasm) made of tar with the fruit	Baczyńska, Lityńska-Zając (2005a); Lityńska-Zając (2005b)
Lutomiersk–Koziówki, near Łódź	Late Bronze Age (Lusatian culture)	*Xanthium strumarium*	Pit	Mueller-Bieniek et al. (2015)
Wreśnica, com. Sławno, site 7	Tenth century	*Linum usitatissimum*	Bunch of compressed stems of flax with weeds	Latałowa (1998); Latałowa and Rączkowski (1999)
Kraków	Medieval period	*Daucus carota*	Cultural layer	Mueller-Bieniek (2010)

Kreuz et al. 2005; Hajnalovà 2007, 2012; Kreuz 2007; Conolly et al. 2008; Dreslerová and Kočár 2013; Stika and Heiss 2013).

Moreover, studies carried out by palaeobotanists addressed numerous detailed issues. A significance of weeds in archaeological finds was discussed for the first time by W. Giżbert (1971). K. Wasylikowa (1983) presented theoretical possibilities of economic and ecological interpretations based on examinations of remains of wild herbaceous plants encountered in vegetal deposits or scattered within archaeological layers and features. The latter author (Wasylikowa 1978, 1981) was the first botanist who introduced a phytosociological and autecological method into Polish science based on ecological indicator values developed by Ellenberg (1950, 1974) and then by Zarzycki (Zarzycki et al. 2002), used for interpretations of subfossil material. Those methods were employed in many other papers dedicated to, e.g. materials of the Lengyel culture from site 62 in Mogiła (Gluza 1983/1984) or the Roman Period in Otałążka (Madeyska 1984) and Wąsosz Górny (Bieniek 1999a). Investigations carried out at numerous European sites were also based on this methodology (e.g. Körber-Grohne 1967; van Zeist 1974, 1996/1997; Knörzer 1975; Behre 1976, 1993). However, it should be stressed that engaging the above-mentioned phytosociological method in examinations of subfossil materials has been subject to criticism on many occasions (e.g. van der Veen 1992; Cappers 1994). Analyses of wild plants gathered during archaeological excavations allowed the researchers to reveal the origins and trace transformations of synanthropic flora and vegetation in prehistoric and early historical times (Lityńska-Zając 2005). Other studies focused on comparison of transformations recorded in the current synanthropic flora in a given region with archaeological data, for instance, in medieval Kraków (Trzcińska-Tacik and Wieserowa 1976; Trzcińska-Tacik and Wasylikowa 1982) and the Roman site in Jakuszowice, com. Kazimierza Wielka (Trzcińska-Tacik and Lityńska-Zając 1999).

Simultaneously with the studies on fruits and seeds, remains of wood (xylology) and charcoal (anthracology) found within archaeological materials were subject to examinations (e.g. Smart and Hoffman 1988; Kadrow and Lityńska-Zając 1994).

In the second half of the twentieth century, archaeobotanical interests expanded, including studies on tubers and other plant tissues encountered at archaeological sites (Hillman et al. 1989; Hather 1991, 1993, 2000; Kubiak-Martens 2005, 300–320), as well as phytoliths (Piperno 1988, 2006; Polcyn et al. 2005, 372–385). Moreover, a pollen analysis was introduced (e.g. Makohonienko 1998; Makohonienko et al. 1998a) to investigate "cultural layers on settlements and fillings of archaeological features [*on-site analysis*], and obtain information that has not been recorded in natural biogenic deposits [*off-site analysis*]" (Wasylikowa et al. 2005, 37; comp. also Wasylikowa 2005, 347; Rösch et al. 2014).

Nowadays, environmental and archaeological investigations often take a form of close interdisciplinary cooperation, starting from the moment of assuming a certain research strategy suitable for a given site and ending with a collective, archaeological and environmental interpretation of sources, which is becoming a more and more popular practice (e.g. Wacnik et al. 2014; Kittel et al. 2014; Mueller-Bieniek et al. 2015, 2016). There is another example provided by the material from Stradów that served for reconstruction of the picture of an early medieval settlement complex based on archaeological, biological (botanical and zoological) and written sources (Lityńska-Zając et al. 2010). Thanks to employing written sources and archaeobotanical data obtained in Gdańsk and dated to the fourteenth to fifteenth century, a more comprehensive list of species utilised by human communities of those times was elaborated (Badura et al. 2015). Similar analyses covering both of the above-mentioned types of sources were performed for Krakow in the Renaissance period (sixteenth to early seventeenth centuries) (Wasylikowa and Zemanek 1995; Zemanek and Wasylikowa 1996; Zemanek 2012).

3 Plant Remains

The source materials collected for archaeobotanical studies are plant remains referred to as subfossil plant remains. By tradition, they are divided into two groups, macro- and microremains. The former group encloses i.a. fruits, seeds and vegetative parts of plants, including wood and charcoal. The latter embraces, e.g. sporomorphs (pollen grains of flowering plants and spores of cryptogams), diatoms, phytoliths and starch grains (e.g. Jacomet and Kreuz 1999; Lityńska-Zając and Wasylikowa 2005; Pearsall 2015).

The quantity and quality of plant materials that can be recovered from an individual archaeological site are a resultant of a number of depositional and post-depositional factors affecting plants and their conservation, determining whether they are preserved until present or not. In a word, only a small part of truly abundant ancient flora and vegetation has been preserved in archaeological features and cultural layers till nowadays. This is due to many factors, amongst which, in very simple terms, the most important are the following:

1. Natural properties resulting from the anatomy of entire or parts of plant organs, supporting their preservation within a given sediment
2. A manner in which the plant naturally existed in the environment
3. Selective activity of men due to particular roles played by given plants in human economy
4. A number of the so-called post-depositional processes activated after the plant had been covered with a sediment (Lityńska-Zając and Wasylikowa 2005; Wasylikowa et al. 2009; Pearsall 2015, 35)

Macroscopic plant remains can be encountered in different forms, such as charred, uncharred (waterlogged), mineralised, frozen or dried specimens. Under climatic conditions of Central Europe, charred and uncharred remains are most frequently recovered. A state of preservation of plant "deposits" depends on numerous factors, including conditions of conservation occurring at particular archaeological sites. Studies on conservation processes (fossilisation) of organic matter (plants) that become active at the moment of covering the material with sediments are within the scope of interests of taphonomy (e.g. Lityńska-Zając and Wasylikowa 2005, 37–46, and literature quoted there; Antolin and Buxó 2011). Terms referring to taphonomy were introduced into archaeobotany by U. Willerding (1979, 1990/1991). When making an attempt to interpret plant material, one must realise that taphonomic processes were responsible for depositing and preserving a given plant material within a particular archaeological site, feature or cultural layer. For instance, charred specimens could have gotten into the sediment from fireplaces and wind-spread conflagration or as a result of burning down of an archaeological feature in situ, e.g. storage pits containing crop reserves (Lityńska-Zając 1994). An occurrence of charred grains of cereals and fruits, or seeds of other cultivated species or weeds e.g. recovered nearby fireplaces might have been due to preparation of food from crops that incidentally contained undesirable plants (e.g. Wasylikowa 1997; Wilkinson and Stevens 2008). Uncharred remains (waterlogged) may be either of autochthonous, as "remnants of plants having grown in the certain time and space" (Mueller-Bieniek 2012a, 31), or allochthonous origin, as "plants having been intentionally or accidentally brought to a given region" (Mueller-Bieniek 2012a, 31). Such remains can be recovered from cultural layers of medieval cities (e.g. Latałowa et al. 2003; Badura 2011; Mueller-Bieniek 2012a) or archaeological sites situated in wetlands, such as peat bogs or lacustrine deposits (Jaroń 1938; Kalis et al. 2015). Uncharred plant material can also be found in deep features reaching down to the groundwaters, such as wells (Greig 1988; Tyniec et al. 2015) or latrines (Greig 1994; Tomczyńska and Wasylikowa 1999). Determining the age of uncharred remains obtained from sites situated in the so-called drylands occurring, e.g. on loess soils, thus in regions being constantly above the groundwater table, is always controversial, and in most cases, such remains are considered to be contaminations of younger or even modern chronology (Lityńska-Zając and Wasylikowa 2005, 41–42). Noteworthy is also the fact that the composition of recovered plant remains is affected by the manner of exploring archaeological features, taking samples and preparing collected materials for laboratory examinations.

The type of an archaeological site, feature or cultural layer determines the possibility of recovering plant remains that may be deposited within it (Lityńska-Zając and Wasylikowa 2005, 47). For instance, storage pits usually contain remains of cultivated plants, possibly accompanied with field weeds, though their number is frequently scarce, which supports a utilitarian function of these features. Although collective finds of remains of cereals or other crop species are also encountered, they are rather sporadic (e.g. Gluza 1983/1984; Kohler-Schneider 2001; Palmer 2004; Lityńska-Zając 2005; Sady 2015; Mueller-Bieniek et al. 2016). When charcoals are found in features at dwelling sites, particularly in hearths or fireplaces, they provide the investigators with information about the type of wood used as fuel (e.g. Chabal et al. 1999; Asouti and Austin 2005; Moskal-del Hoyo 2013). Charcoals also occur at cremation cemeteries, in urns, recesses or grave pits, being remnants of funeral pyres (e.g. Deforce and Haneka 2012; Stępnik 2001; Moskal-del Hoyo 2012; Lityńska-Zając 2015). Grave pits may contain remains of plants that had been placed there as grave goods (e.g. Klichowska 1972b; Latałowa 1994; Moskal-del Hoyo and Badal 2009). Certain plant remains are sometimes found in amazing contexts. Finds of cereals in burial-related features are most likely due to their ritual function, not corresponding with their economic role (Viklund 1998, 175). Perhaps a similar significance is that of finds of tubers of *Arrhenatherum elatius* subsp. *bulbosum* (Mueller-Bieniek 2012b). In some cases, it can be assumed that fruits and seeds or charcoals got into sediments altogether with the dirt swept from the closest surroundings to cover grave pits (Lityńska-Zając et al. 2014).

Apart from plant remains, numerous sites delivered interesting finds in a form of impressions or tiny fragments of charred or dried tissues, mainly caryopses and parts of cereal husks, preserved within burnt clay and on pottery surface (e.g. Jacomet and Kreuz 1999 and literature quoted there; Burchard and Lityńska-Zając 2002; Lityńska-Zając 2002; Lityńska-Zając and Wasylikowa 2005). These are usually traces of by-products produced in the course of cleaning grains, which were intentionally added to clay mass as the so-called temper (e.g. Lityńska-Zając and Wasylikowa 2005; Fuller 2013). Recently conducted studies (micromorphological and anatomical analyses) indicated an intentional application of thoroughly selected, fine-grained, plant additive in production of pottery (Moskal-del Hoyo et al. 2017).

Archaeobotanical examinations, regardless of the type of plant remains (fruit, seeds, wood fragments, phytoliths or sporomorphs), cover three major stages of field and laboratory research, which are as follows: (1) recovering samples from archaeological sites, (2) extracting plant remains from the samples and sorting the material obtained and (3) identifying plant material. Different plant materials require suitable procedures to be employed in the field and during laboratory examinations (e.g. Lityńska-Zając and Wasylikowa 2005, 182–193; Pearsall 2015, 35), developed by those “subdisciplines” separately, according to their specific research goals. The entire above-mentioned process should be preceded by assuming an appropriate strategy of sampling, matching the characteristics of a given archaeological site (Kadrow 2005).

Identifying macroscopic and microscopic plant remains is based on a confrontation of fossil materials with comparative collections of modern specimens, supported by the respective literature (Hillman 1984; Miksicek 1987; Jacomet and Kreuz 1999; Lityńska-Zając and Wasylikowa 2005; Nesbitt 2006). From the European viewpoint, there are very useful tools to perform such analyses, e.g. plant identification keys and atlases designated for identification of fruits and seeds (Kulpa 1974; Körber-Grohne 1991; Jacomet 2006; Cappers et al. 2006; Cappers et al. 2009; Neef et al. 2011) and vegetative parts of plants, including wood and charcoals (Esau 1973; Schweingruber 1978, 1982, 1990; Hejnowicz 2002; Grosser 2003), tubers and other storage organs (Hather 1993, 2000), pollen grains (Fægri and Iversen 1978; Fægri et al. 1989; Dybova-Jachowicz and Sadowska 2003; Wasylikowa 2005) and finally phytoliths (Piperno 1988, 2006; Twiss 1992; Meunier and Colin 2001).

A separate branch of studies helpful in identification of fossil materials are examinations of morphology of fruits and seeds. As mentioned above, fossil material is usually identified with the use of existing plant identification keys based on morphological properties of modern diaspores. For obvious reasons, most of these keys neglect changes caused by fossilisation. Therefore, many publications referring to plant remains contain morphological descriptions regarding those deformations (e.g. Wasylikowa 1978, millet grasses; Wieserowa 1979, genus *Galeopsis*; Bieniek 1999b, *Stipa*; Latałowa 1998, *Spergula*). A monograph describing morphological properties and measurements of charred caryopses of brome *Bromus* was written by I. Gluza (1977), while the variability in achenes of the genus *Ranunculus* was presented by Trząski (1994). In order to conform current material to fossil remains, modern diaspores were subject to artificial fossilisation: maceration (e.g. seeds of *Juncus*, Körber-Grohne 1964; caryopses of grasses Poaceae, Körber-Grohne 1991) or burning (Hopf 1975; Hillman et al. 1983; Wilson 1984; Kislev and Rosenzweig 1991). Other examples were described in handbooks of archaeobotany (Hather 1993; Lityńska-Zając and Wasylikowa 2005, 204–212).

A crucial matter for reasoning in archaeobotanical studies is a correct identification and description of plant remains. As a result of identifying all types of plant remains preserved at archaeological sites, a list of taxa can be obtained. This term was used purposefully since plant material is identified to various taxonomic levels (the level of species, genus, family or morphological type. The latter category was distinguished, e.g. at the site in Nabta Playa, in Egypt; see Wasylikowa 1997). The level of possible identification of plant remains is mostly due to a morphological or anatomical diversity of specimens under analysis and their more or less legible distinctive traits, the state of their preservation and possibilities provided by laboratory examinations engaged by a given discipline (Lityńska-Zając and Nalepka 2008, 2012). Employing new techniques and instruments (scanning electron microscope) has considerably expanded those possibilities (Conolly 1976; Karcz 2008). However, one should keep in mind that the list of taxa determined for a certain archaeological site will never correspond with all the plants that grew in surroundings of human settlements and were utilised by men. Nevertheless, this list delivers a lot of useful information enabling an interpretation of the sources with regard to reconstruction of the ancient environment (palaeoenvironment), exploitation of natural plant resources and development of agriculture. The most favourable approach, in respect of further interpretations, is to identify plant remains to the level of species (Lityńska-Zając and Wasylikowa 2005; Lityńska-Zając and Nalepka 2012) because higher taxonomic units (e.g. genus) usually enclose species existing in varied environments.

Apart from the quality composition, a properly performed archaeobotanical analysis should also provide quantitative data. One of these parameters is the abundance, i.e. an absolute number of specimens belonging to a given taxon identified within a sample. This data allows the investigator to assess, within certain limits, the role of particular plants. Another parameter quoted in presentations of plant remains is the frequency or ubiquity, referring to the number of samples containing remains of a particular taxon, determined for the entire site (Lityńska-Zając and Wasylikowa 2005, 201). With regard to the quantitative type of analyses, it is essential to realise that there is no simple, direct relation between the quantitative share of a given taxon within the entire archaeobotanical material and the role it played in both ancient vegetation and human economy in the past. This relation is disturbed by natural factors on one hand and on the other hand by anthropogenic factors resulting from purposeful or unintentional activities of men. Nevertheless, the quantitative share of particular taxa within different samples obtained from one or a few other sites may contain important information about their emergence and significance in the past, providing that it was properly interpreted. Therefore, it can be assumed, with certain limitations, that plant remains abundantly and frequently represented in archaeological materials are those having commonly occurred in ancient flora. Moreover, the species that are often encountered at sites within one chronological horizon indicate that they were utilised by communities of a given cultural unit. However, this has not been proved for all case studies (comp. discussion Mueller-Bieniek 2012a).

4 Interpretation of Plant Remains

Assemblages of archaeobotanical data obtained in the course of excavations provide the grounds for interpretation of sources. This interpretation may enclose individual archaeological sites or a complex of sites ascribed to a particular cultural unit or sites situated within a given geographical region. Well-dated materials allow the investigators to trace changes in a taxonomic composition of vegetation throughout the time. Reconstruction of elements of human economy or the ancient environment of man's life is based on many theoretical assumptions that were briefly discussed below in the context of particular issues addressed in this chapter (Lityńska-Zając and Wasylikowa 2005).

As mentioned above, one of the major factors responsible for the fact that a given plant got into archaeological layers was the economic activity of men. For obvious reasons, this activity was strictly determined by the natural environment. Men could only use what was available in their surroundings. Having introduced the agriculture over a given area, humans became the major factor in shaping the environment, to a smaller of greater extent.

The major research trends in archaeobotany are developing in two separate directions. Some of them address strictly biological issues. For instance, a comparative analysis of DNA and proteins provided scholars with reliable explanations to major affinities between taxa of various ranks and revealed the mechanisms of their evolution that lead to an emergence of new taxa, e.g. crop plant species (Zohary et al. 2012). An archaeological context of fruits and seeds deposited at excavated sites delivers information referring to dispersion of crop plants within both their origin centres and beyond. Moreover, it evidences an acquaintance of agriculture in a given time and space, which is strictly determined by the cultural development of human communities.

Other research tasks of archaeobotany are associated with reconstruction of particular elements of natural environment, as well as development and directions of evolution of synanthropic flora (e.g. Willerding 1986; Lityńska-Zając 2005). Due to their specific cultural nature, an assemblage of plant remains recovered from an archaeological site enables an identification of alternative paths of how agriculture emerged and expanded and reconstruction of certain aspects of human economy in the past, including plant cultivation. This issue is also closely connected with reconstruction of many conditions and techniques applied in ancient agriculture.

Archaeobotany can also provide basic information about an occurrence of wild species used by people for consumption, or playing certain roles in their economy, healing treatments, magic and religious practices, and art. Moreover, this discipline may be helpful in reconstruction of the impact of humans on the natural environment.

The major problem, in the light of the above-mentioned matters, is the state of the art of archaeobotanical studies, which is due to cognitive values of unit data. There are finds that enable very precise and detailed interpretation of sources preserved in a given archaeological context. Others are extremely difficult to be assessed explicitly. Nevertheless, systematic gathering of data may lead to a better recognition of subfossil floras. An important research postulate, raised by many scholars in the related literature, is an encouragement to take a large number of samples, even if they are very small, from features of varied nature, providing the investigators with more representative research material. This will make the assessment of the archaeological context more accurate and ensure the most comprehensive spectrum of plant remains as possible (Jones 1991; Lityńska-Zając and Wasylikowa 2005).

5 Cultivated Plants

Qualitative and quantitative data of cultivated plant remains preserved at archaeological sites provided the grounds for developing models of structure of ancient crops (Lityńska-Zając and Wasylikowa 2005, 489–491). According to theoretical

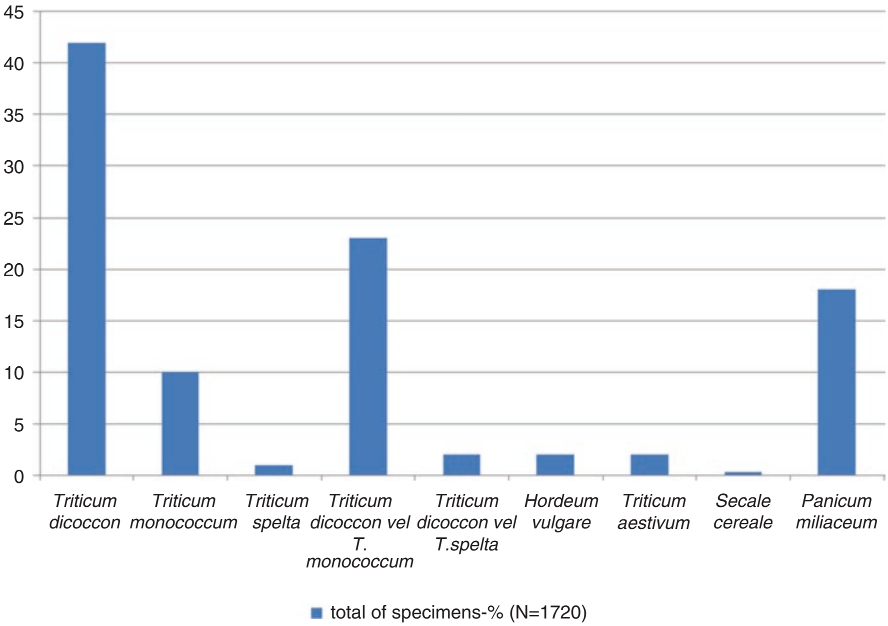

Fig. 1 The percentage of the total of cereal remains from the sites of the Linear Pottery culture (SE Poland)

assumptions, they revealed simple relations between the shares of particular species within a given assemblage. For addressing the issues raised in this paper, the author compiled data obtained from 23 archaeological sites of the Linear Pottery culture located in south-western Poland (Lityńska-Zając et al. 2017). With regard to the region in question, recovered plant remains enclosed charred caryopses and fragments of cereal husks and impressions in burnt clay of several cereal species, such as *Triticum dicoccon*, *T. monococcum*, *T. spelta*, *T. aestivum*, *Hordeum vulgare*, *Panicum miliaceum* and *Secale cereale.*

Based on the fossil material, it is possible to obtain relatively reliable information about plant species that were cultivated in the past, and the occurrence of their remains proves a local cultivation of certain plants by communities having lived in the settlement (region or culture) under investigation. Far more difficult is to recreate quantitative relations between particular plants and determine their share within the ancient crops. Therefore, for interpretation of the above-mentioned data, two comparative methods were engaged: (1) the share of particular species per total number of plant remains classified into the respective category of sources (Fig. 1) and (2) the frequency of occurrence of particular plant species at given archaeological sites (Fig. 2). On this basis, a prevalence of remains of dehusked wheat was recorded, represented mostly by emmer and less numerous einkorn. The former species is also the most frequently encountered at the sites under scrutiny. Both wheats were surely the most common crop species of those times in various regions

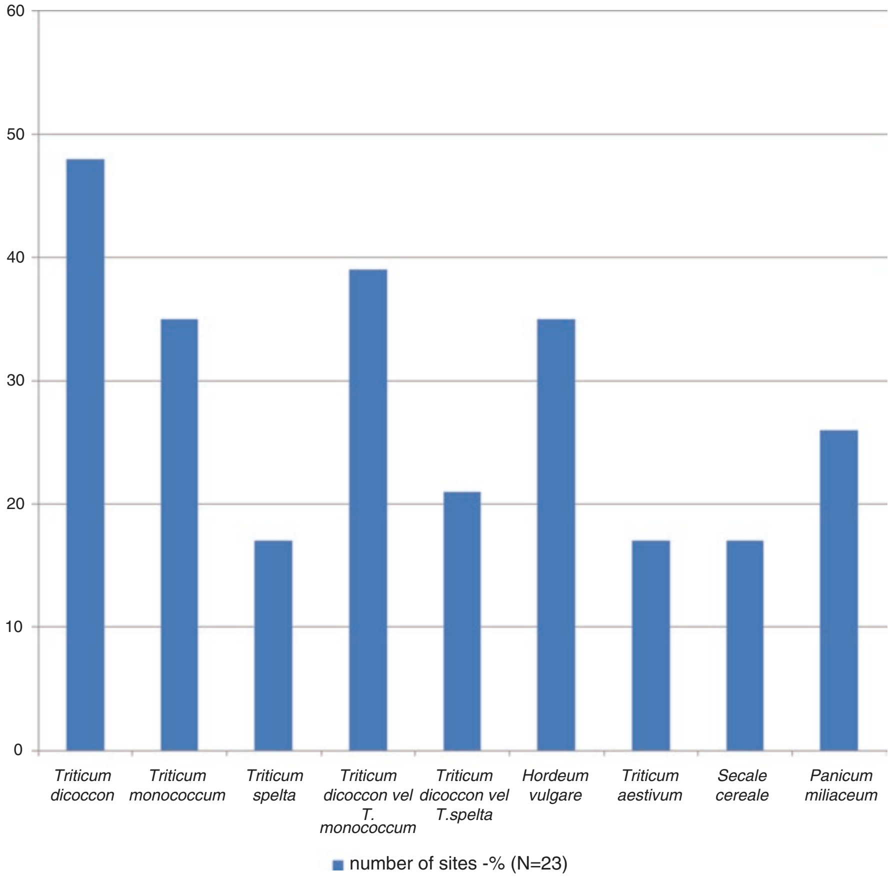

Fig. 2 The frequency of cereals in the Linear Pottery culture sites. The percentage of the total number of sites with macroscopic plant remains ($N = 23$)

of Poland (Bieniek 2007; Lityńska-Zając 2007) and neighbouring countries as well (e.g. Hajnalovà 2007; Dreslerová and Kočár 2013). Slightly different observations were made while investigating the Early Neolithic sites in Bulgaria and to the north of the Alps (Kreuz et al. 2005; Kreuz 2007), where a predominance of einkorn over emmer was recorded, which was explained by different climatic conditions. Spelt *T. spelta* occurred at four sites and was poorly represented. Relatively frequently encountered plant species (eight sites), though represented by a small number of remains, was *Hordeum vulgare*. Its representation in assemblages of macroscopic remains dated to the Early Neolithic recovered in other regions of Europe is also rather poor (e.g. Conolly et al. 2008; Zohary et al. 2012). The role of this species within a structure of crops cultivated by communities of the Linear Pottery culture is not entirely explicit. It might have been cultivated on a small scale and was of little, if any, economic significance of that time. It could have co-occurred with wheat on crop fields, being just a weed (e.g. Bogaard 2004, 14; Kreuz et al. 2005). With regard to the number of identified plant remains, a considerable position was taken by *Panicum miliaceum.* Remains of millet were recorded at European archaeological sites relatively early, though the latest research indicated that it was no sooner than in the fourth or third millennium cal. B.C., when this species expanded in crop fields (Moreno-Larrazabal et al. 2015 and literature quoted there). Remains of *Secale cereale* were encountered at four archaeological sites in a form of few charred caryopses and an impression of a spike with solid rachis internodes (Giżbert 1961). Archaeobotanical sources documented the late introduction of rye into cultivation (Wasylikowa 1983; Behre 1992; Lityńska-Zając and Wasylikowa 2005, 99), which is also confirmed by palynological sources (Okuniewska-Nowaczyk et al. 2004, 349).

Amongst other cultivated plants found in cultural layers ascribed to the Linear Pottery culture in south-western Poland, seeds of *Linum usitatissimum* and *Pisum sativum* were recorded. Determining an economic significance of crop plants, in particular papilionaceous plants, is definitely more difficult due to the fact that they are poorly represented in fossil materials (Lityńska-Zając 2013). Therefore, it is uncertain whether their small share results from their truly marginal role within the structure of crops of that time or there are different reasons connected to an exceptional fragility of charred seeds of papilionaceous plants, being susceptible to fragmentation (Tanno and Willcox 2006). However, one should keep in mind that at many archaeological sites, including those in Poland, there were recorded numerous remains of *Pisum sativum* (e.g. within a feature of the Trzciniec culture in Słonowice, Calderoni et al. 1998–2000) and *Lens culinaris* (e.g. in features of the Lusatian culture in Sobiejuchy, Palmer 2004). These species arrived in Europe altogether with primeval variants of wheat and barley (Zohary et al. 2012). They occurred rather sporadically and in small numbers at the Neolithic sites in Poland (Lityńska-Zając 2013) and north-western Europe (McClatchie et al. 2014). Probably, they became more common in crop structure of the Late Bronze Age, simultaneously with the spread of millet cultivation (Kohler-Schneider 2001).

Stating that inhabitants of the Linear Pottery settlements were farmers is a kind of truism. Based on the material gathered, we can conclude that the major components of their plant-based diet were agricultural products, mainly cereals (Nowak 2009, 62 and literature quoted there). Unfortunately, we cannot explicitly estimate what was the share or other cultivated plants in this diet, including papilionaceous plants.

6 Wild Plants

One of the major issues referring to studies on elements of everyday life of prehistoric human communities is determining the strategies employed by those communities to satisfy their basic needs connected with acquiring food (e.g. Helbæk 1960; van der Veen 2007; Behre 2008; López-Dóriga 2011). Gathering various parts of plants collected from natural and anthropogenic habitats, supported by hunting and fishing, was a major food supply for humans in the Palaeolithic and Mesolithic, which was proved by finds obtained from sites dated to those periods. Based on archaeobotanical studies, it was established that gathering could have been continued also in the following periods, after the introduction of agriculture in a given region (Pirożnikow and Szymański 2005), and most probably was of selective nature manifested by choosing only certain species (Dembińska 1976). Famine periods stimulated a rapid increase in demand for gathered food. "Gathering in the time of famine strives to exploit the maximum of opportunities offered by the environment; everything is collected then, everything what can be eaten, using the knowledge gathered by former generations, which is always alive due to high frequency of occurrence of famine periods" (Twarowska 1983, 231; Lityńska-Zając 2012). The volume of gathered products reached the levels of crop yields (Helbæk 1960), and food made from them played an essential role in men's diet (Ayerdi et al. 2016). A part of those plants could have been gathered easily, in the closest surroundings of men's dwelling sites due to highly effective production of seeds of particular species (Behre 2008), which consequently were able to provide large volume of crops. Gathering plants was seasonal and dependent upon the rhythms of nature.

Determining the type of a diet of prehistoric communities based on plant remains in a form of fruits, seeds and vegetative parts of plants that have been preserved at archaeological sites is a complex and difficult issue. In fossil materials obtained from sites of various cultures or located in certain geographical regions, remains of spontaneous herbaceous plants or relics of fruits of trees and shrubs usually did not occur collectively, in large numbers that would directly indicate their intentional utilisation. Taking into account various limitations (Lityńska-Zając 2008) hindering the assessment of fossil materials, it was assumed that its major criterion is the manner of utilisation of plants as described in ethnological sources, i.e. "a criterion of potential usefulness" (e.g. Zegarski 1985; Tylkowa 1989), and the knowledge of chemical, physical and biological properties of particular species (Kuźniewski and Augustyn-Puziewicz 1986; Ożarowski and Jaroniewski 1989). This hypothesis is based on an assumption that these properties have been known to humans for ages. However, it must be stressed that amongst plants growing in men's surroundings, and commonly occurring in flora, most of them have an economic application, and many of them can be used for consumption (comp., e.g. Maurizio 1926; Twarowska 1983; Łuczaj 2004).

When making an attempt to reconstruct plant-based diet of prehistoric societies, one cannot neglect the fact of possible utilisation of vegetative parts of plants, which due to their perishable nature are very rarely encountered at archaeological sites (Skrzyński 2012, msc.). Furthermore, there are very rare finds of underground organs of plants, such as roots, rhizomes or bulbs, and inflorescences, which have also been used by men (Kubiak-Martens 2005; Szymański 2008; Colledge and Conolly 2014). This is particularly readable at sites located in drylands, where charred remains of herbaceous plants have usually preserved in a form of diaspores. A more complete picture of humans' diet can be obtained from investigating sites situated in moisture areas, where "green" parts of plants may be encountered (e.g.

Kubiak-Martens 2005; Wilkinson and Stevens 2008). Nevertheless, a prevalence of plant remains at archaeological sites supports an assumption that they constituted an important element of everyday food. This is supported by analyses of the teeth and hair of the Iceman discovered in 1991 in the Alps (Oeggl 2000; Heiss and Oeggl 2009) or examinations of the stomach content of human corpse excavated from turf sediments in northern Europe (Harild et al. 2007) and finally investigations of latrines and coproliths (Reinhard and Bryant 1992; Tomczyńska and Wasylikowa 1999; Badura 2003; Shillito et al. 2011).

Based on botanical research conducted at prehistoric and medieval archaeological sites in Poland, 968 taxa of various ranks have been distinguished until present. Amongst them there are many species of wild plants of significant utility qualities (e.g. Maurizio 1926; Twarowska 1983; Łuczaj 2004, 2013). Due to obvious reasons, only a small part of them is presented below.

An important alimentation role was played by plants producing soft fruits ready to eat just after picking, such as raspberries and blackberries of the genus *Rubus* and various species of blueberries *Vaccinium*. They contain a lot of vitamins and microelements, including magnesium, calcium and ferrum. Those fruits cannot be stored for a long time without heat treatment. Remains of these plant species were recorded at many archaeological sites in the territory of Poland.

There is another group of plants that can be consumed directly after picking or stored for a long time. This group encloses, e.g. hazelnut *Corylus avellana*. An abundant find of hazelnut shells, containing 11,045 specimens identified in 61 samples, was recovered at site 7 in Krzyż Wielkopolski and dated to the Mesolithic period (Kabaciński and Lityńska-Zając in print). The remains of hazelnuts discovered at this site represented two different states of preservation, i.e. charred and uncharred specimens. This manner of conservation may indicate varied forms of their utilisation and consumption, as fresh and dried or roasted fruits. The process of drying and roasting aimed to increase the durability of nuts that could be stored for a longer period of time. A side effect of this process was changing the flavour of nuts and making it spicier. Diaspores of this species were also encountered at archaeological sites dated to younger chronological periods. Seeds of hazel have a high calorific value and contain fats, proteins, sugars and vegetable oil rich in unsaturated fats (Byszewski 1972, 337; Podbielkowski 1985, 192–193; Tomanek 1987, 256), as well as many microelements, such as calcium, magnesium, ferrum, phosphorus, potassium and B-group vitamins. Hazelnuts are tasty and can be eaten directly after picking. They can also be stored but only in a dried form (Maurizio 1926, 67; Łuczaj 2004, 118). Common hazel is one of the species, the fruits of which could have played the major alimentation role in human's diet in the Mesolithic period (Kertész 2002). They could be eaten fresh and did not require any special treatments and processing before consumption (Kubiak-Martens 2002).

Another species, the remains of which are discovered at archaeological sites in Poland, is wild apple *Malus sylvestris*, though its finds are not very frequent and abundant. The oldest remains of this species, seeds and fragments of fruits, were recorded at a site of the Linear Pottery culture in Gwoździec, com. Zakliczyn (Bieniek and Lityńska-Zając 2001 and literature quoted there). Others come from the Mesolithic site in Dąbki in Pomerania (Kubiak-Martens 1998). There is no doubt that fruits of common pear *Pyrus communis* and plum *Prunus* were also gathered. Apples, pears and plums contain a lot of vitamin C and other groups of vitamins, microelements and fibre. They could be eaten fresh or stored in a dried form. Possibly other plants, such as fruits of hawthorn *Crataegus*, dogwood *Cornus* and oak nuts (acorns) *Quercus*, were also gathered. In prehistoric archaeobotanical materials, finds of fruits of the latter are not frequently encountered, and their assemblages, if found, usually do not contain many specimens.

Vegetative parts of herbaceous plants, such as sorrel, goosefoot and nettle, were also gathered and used for making salads and pottages. For instance, young individuals of *Chenopodium album* could be eaten fresh or cooked (Łuczaj 2004, 101). White goosefoot was also used to feed domesticated animals (Szot-Radziszewska 2007). Its seeds could have been utilised to produce flour and groats and as an additive to flour for baking bread. However, it must be stressed that an excessive content of white goosefoot seeds in bread may cause various pathological symptoms experienced by individuals who ate these products (Bagiński and Mowszowicz 1963, 39). In the opinion of some scholars, in particular regions of the globe species in the family of Chenopodiaceae were used for consumption as early as in the last glacial period (McConnell 1998). White goosefoot, being a species of crop fields and ruderal habitats, grew nearby human dwelling sites and produced ca. 100,000 seeds per 1 individual (Tymrakiewicz 1962, 31–32; Behre 2008), which made it a highly available food source in the surroundings of ancient settlements. Remains of white goosefoot have been commonly encountered in archaeological materials of various chronologies collected in the territory of Poland (Lityńska-Zając 2005, 87).

7 Farming

Since the beginning of the Neolithic period, humans have been engaged in cultivation of plants. It is possible to determine the nature of crops based on, amongst others, weeds co-occurring within a single feature with grains of cereals (Lityńska-Zając 2005). An alternative interpretation of the characteristics of cultivations is based on edaphic requirements and biological properties of cultivated species (Lityńska-Zając and Wasylikowa 2005).

The oldest variants of hulled wheat, such as emmer and einkorn, were most likely sown together as a mix, which is supported by the fact that they often occur within one archaeological feature identified as a storage pit. This is very legible in materials of the Funnel Beaker culture (Kruk et al. 2016), though in Ćmielów (Podkowińska 1961) pure deposits of *Triticum dicoccon* were encountered as well. There is no doubt that a certain part of crop species was cultivated in monocultures. This mainly concerns millet *Panicum miliaceum* requiring special agricultural treatments based on maintaining appropriate interrows and a manner of harvesting crops suitable for this particular species (Strzelczyk 2003; Lityńska-Zając 2005). Another species that could have been cultivated in monoculture was *Hordeum vulgare*.

However, at site G in Słonowice, within a feature of the Trzciniec culture, caryopses of barley co-occurred with seeds of common pea (Calderoni et al. 1998–2000; Lityńska-Zając 2005, 155–157). The fact that remains of these two species lay within a single pit may indicate either an intentional sowing of mixed seeds of barley and pea or a secondary mixing of the material primarily stored in two separate, probably wooden containers. The latter may be supported by fragments of wood preserved in the pit in question. This interpretation of the material seems to be the most probable; however, one cannot reject a hypothesis that this particular species composition proves crop rotation, i.e. a practice of growing a series of different types of crops in the same area in sequenced seasons. It can be assumed that mixed seeds of barley and pea were sown together in the same area. Perhaps common pea was grown in vegetable gardens as well (Kruk 1980; Kruk and Milisauskas 1999; Bogaard 2004; Nowak 2009; Kruk et al. 2016).

Remains of wild herbaceous plants co-occurring with remains of cereals within a single storage pit can provide the grounds for economic interpretations leading to a reconstruction of major agricultural activities. This chapter presents the data published in a monograph entitled *Weeds* (*Chwasty*) (Lityńska-Zając 2005). One of the elements of such analysis is an assessment of the degree of weed infestation of growing crops. This can be described through the ratio of a total number of weed diaspores to the number of cereal caryopses. The following stage of the analysis may cover an assessment of habitats where crop fields were established, which is based on habitat requirements referring to a particular crop plant and co-occurring species of weeds. In order to draw such characteristics, the so-called ecological indicator values were used (Zarzycki et al. 2002) for three parameters that describe the following properties of soil: W, moisture; Tr, trophism; and R, soil acidity. Then the type of crop should be determined, which means answering the question whether the cereals were sown in autumn (winter crops) or in spring (spring crops). To solve this issue, properties of both the cereals and the accompanying weeds should be taken into account; the latter can be divided, depending on their life cycles, into short-lived and perennial weeds, while the former enclose spring plants, overwintering plants, winter plants and biennials. Having performed the analysis of composition of weed species, an attempt to determine the manner of crop harvesting can be made. Such considerations are based on the knowledge of the height of weeds which constitute four layers within a single crop field.

The analysis presented here was based on observations of the contemporary relationships between the weeds having grown within the crops and the nature of these crops. When performing such an analysis, one should keep in mind that the significance of weeds can sometimes be ambiguous for several reasons. Some of them result from the properties of plants that can have a wide range of ecological tolerance and, in certain cases, cannot be considered precise markers of given economic treatments. This method can be engaged in analysing plant materials found within a single archaeological feature, where except for remains of a crop plant, diaspores of field weeds were also encountered. However, it must be assumed that the co-occurring specimens had grown together on a single field. With regard to the present conditions, employing the method of bioindication can be successful and

Table 2 Weeds in the sample of rye from the Early Medieval feature (no. 18/87) at Parchatka, site 12 (After Lityńska-Zając 2005).

Species name	Number of remains	Ecological indicators						Height	Life forms	Flowering time
		W min	W max	Tr min	Tr max	R min	R max			
Agrostemma githago	11	3	3	3	4	4	5	90	RO/J	VI–VII
Artemisia cf. *vulgaris*	43	3	3	4	4	4	5	50–150	W	VII–IX
Echinochloa crus-galli	16	3	4	4	5	3	4	30–70	RJ	VII
Fallopia convolvulus	3	3	3	3	4	3	4	100	RJ	VII–IX
Lychnis flos-cuculi	6	4	4	4	4	4	5	35–80	W	VII–IX
Melandrium album	12	3	3	4	4	4	4	30–100	R/D/W	V–IX
Plantago lanceolata	1	2	4	3	4	4	4	5–60	W	V–IX
Polygonum persicaria	3	3	3	4	3	4	4	100	RJ	VII–X
Rumex crispus	10	3	4	4	4	4	4	40–100	W	VI–VIII
Setaria pumila	73	2	3	3	3	3	4	10–40	RJ	VII–IX
Spergula arvensis	3	3	3	2	3	2	3	10–60 (100)	RJ	VII–IX
Urtica dioica	2	3	4	4	5	4	4	100	W	VI–X
Mean index value		2.9	3.4	3.5	3.9	3.6	4.2			

Explanations: ecological indicators, W soil moisture value, Tr trophism value, R soil acidity value, ecological numbers according to Zarzycki et al. (2002); life forms, R annuals, J summer annuals, O winter annuals, D biannuals, W perennials; height in cm; height; life forms; flowering time after Tymrakiewicz (1962) and Szafer et al. (1986).

provide reliable results providing that a minimum number of ten species was proved to coexist on a single filed (Borowiec 1972).

The above-mentioned issues were presented based on materials dated to the Early Middle Ages, recovered from site 12 in Parchatka (eastern Poland), from the feature 18/87, where more than 2400 specimens caryopses and 81 fragments of spike rachis internodes of *Secale cereale* were found. Within these features, fruits and seeds of apple *Malus sylvestris* were also recorded. This feature served as a pit for storing food reserves. Most likely a part where the crops were kept was separated from the other part where gathered plants were stored. These could have been organic containers or a kind of a wooden structure, the traces of which have been preserved in a form of charcoals.

In the storage pit in question, remains of crop plants were accompanied with 12 species of weeds (Table 2). The degree of weed infestation of grains amounted to 0.175. A mean moisture value ranged between 2.9 and 3.4. A distribution of this parameter indicates that these species grew in similar habitats and could have grown on fresh soils, though some of them had a wider range of moisture tolerance (W 3–4). Others could develop only on moist (*Lychnis flos-cuculi*) or dryer soils (*Setaria pumila* and *Plantago lanceolata*). A mean value of trophism index ranged from 3.5 to 3.92. Most of the species revealed similar requirements with regard to this parameter, and they could grow on various soils, from mesotrophic to eutrophic. A species growing on oligotrophic soils was represented by *Spergula arvensis*, while *Echinochloa crus-galli* and *Urtica dioica* developed on extremely fertile soils. A mean value of soil pH index ranged between 3.6 and 4.2. The range of variability in this parameter indicated that the species under analysis were not adapted to uniform soil conditions. One of them preferred acid to moderate acid soils (R 2–3). Three of them could grow on neutral to alkaline substratum (R 4–5). For others the most favourable soil conditions were neutral or moderate acid. Nevertheless, crop fields where the weeds in question grew could have been established on fresh soils, from moderately poor to fertile and neutral.

Within the biological spectrum of the crop under scrutiny, the group of weeds was dominated by annuals, spring plants and perennials. The latter can develop in spring crops. They can also grow on crop fields established on previously untilled lands. The composition of weed species indicated a spring cultivation of rye. Nowadays, this cereal is mainly cultivated as winter crop. On crop fields, there are also encountered spring cultivars, old and younger ones, presently cultivated mainly as forecrop or feed for domesticated animals. However, it cannot be excluded that sowing of rye in the Early Middle Ages was performed in autumn. If that was the case, a large number of spring weed species within winter rye should be explained with a low crop density, creating favourable growth conditions for weeds, the germination period of which was in springtime (Wasylikowa 1983).

A significant part of weed species reaches the height of crops. There are also a few smaller plants, the maximum height of which amounts to 40–60 cm. This indicates that cereal spikes were removed with considerably long fragments of stems. Rye is a fast-ripening crop species. Under current climatic conditions, its harvest takes place in July. The blooming period of species found in the sample in question indicates that this was a very probable time of harvest of this particular crop.

8 Wood Utilisation

Remains of wood recovered from archaeological sites are mainly represented by fragments of firewood used in households and collected in surrounding forests in a form of brushwood. Such wood was highly available to human communities, and did not require a long-distance transportation. Anthracological examinations revealed that the charcoal produced from firewood was characterised by a high biodiversity, thanks to which the preserved wood remains can deliver information about the local ancient stands (Badal 1992; Asouti and Austin 2005; Moskal-del Hoyo 2013). For reconstruction of ancient forest stands, the most suitable is charcoal obtained from hearths. However, it should be stressed that characteristics of ancient forest plant communities based only on identification of wood remains are highly limited due to the fact that most of the charred wood fragments can be determined to the level of genus exclusively (see below). Wood, which is obvious, was also used for various constructions and buildings and production of furniture required in households.

9 Palaeoenvironmental Reconstructions

When describing a palaeophytocenosis, the principle of actualism is employed. A reconstruction of ancient vegetation can be based on phytosociological grounds. In such a case for every species recovered from archaeological layers, a current affiliation to a syntaxon is given, thanks to which it is possible to describe various types of plant communities that could have grown in the surroundings of ancient human settlements (Lityńska-Zając 2005). Phytosociology is based on the fact that in nature plants grow in aggregates, constituting a certain spatial entity, and referred to as a community, i.e. phytocenosis. These communities are characterised by a defined floristic composition and can be recognised based on a specific combination of species and the so-called characteristic and differential species. Plant communities of one type are named plant associations. Ecological conditions, under which the association is able to develop, are determined by ecological requirements of species that constitute this association and a competition between those species. Every species has a wider ecological amplitude than the association as a whole, and growing in the association, it exploits only a limited range of its developmental opportunities. Due to this, a strictly defined plant association is a sensitive marker of environmental conditions, under which it exists. Associations of similar floristic composition are combined into higher syntaxonomic units, which are indicators of habitat conditions. These properties of syntaxa make them helpful in synecological phytoindication, which means concluding about habitat conditions and the intensity and manner of human impact on vegetation (Medwecka-Kornaś et al. 1972; Matuszkiewicz 2001).

Employing the phytosociological method in archaeobotany is based on an assumption that the list of species found at a particular archaeological site provides the grounds for recognition of ancient plant communities. The nature of factual materials imposes considerable limitations on palaeophytosociology, which are mainly due to two facts. Firstly, we can never be sure whether the species discovered together constituted one, particular phytocenosis in the past. Secondly, presently encountered plant complexes have their history, and we do not know when they took a modern form; thus classifying species within a palaeofloristic list according to their current syntaxonomic typology may lead to false reconstruction of ancient syntaxa. Therefore, when employing the phytosociological method in palaeoecological reconstructions, one should always keep in mind that the conclusions drawn are only research hypotheses that cannot be considered strong evidence used for reconstruction of the past.

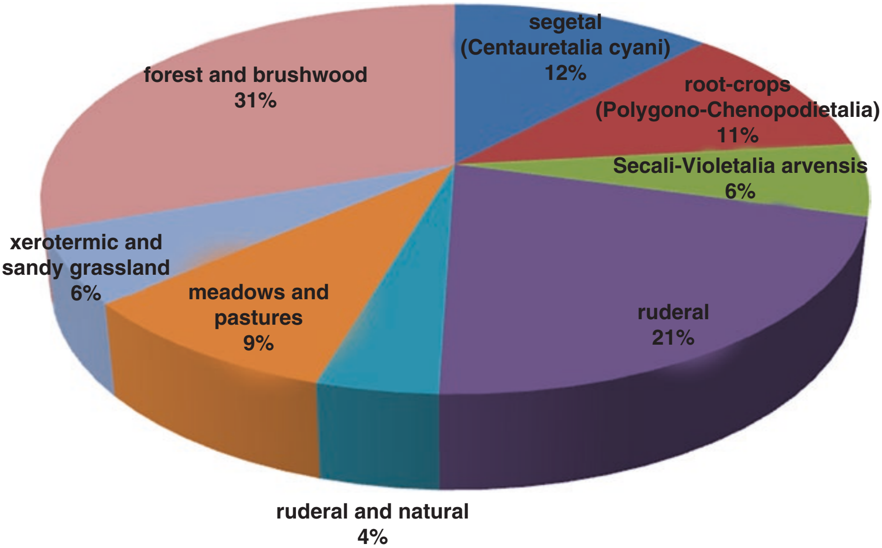

Fig. 3 Frequency (in %) of plants from anthropogenic and natural habitats on site 2 at Kraków-Pychowice (After Lityńska-Zając 2001)

An example of plant material elaborated in the above-mentioned manner is a case study of site 2 in Kraków-Pychowice dated to the Roman Period (Lityńska-Zając 2001), where six species of cereals and two species of other crop plants were identified. Based on diaspores of wild herbaceous plants, 43 taxa were determined to the level of species. Trees and shrubs were represented by five species and nine genera. With regard to 66 species, their current taxonomic affiliation was determined. Distribution of the number of characteristic species of particular syntaxa indicated that the most numerous were plants growing in various forest and shrub communities (Fig. 3). In present-day habitats of oak-hornbeam forests, communities with oak, lime, maple, beech and hazel could have grown. In varied types of riparian forests, such tree species as alder, ash and maple occurred, while herbaceous plants were represented by *Stellaria nemorum* and *Urtica dioica*; the latter might have also grown in ruderal places. The second most frequent group of plants was field weeds, represented by species typical of cereal crops, such as *Centauretalia cyani* (e.g. *Agrostemma githago*, *Centaurea cyanus*, *Bromus secalinus* and *Papaver rhoeas*). An occurrence of this group of weeds is explained by a presence of cereal remains recorded at the site in question. The material under analysis also contained remains of weeds typical of root crops (*Polygono-Chenopodietalia*, e.g. *Echinochloa crus-galli*, *Setaria pumila* and *Polygonum persicaria*) and those encountered in both types of crops mentioned above (*Secali-Violetalia arvensis*, e.g. *Fallopia convolvulus* and *Thlaspi arvense*). The species that are presently typical of root crops could have grown with spring cereals and millet crops and in vegetable gardens. They might have also co-occurred with other cereals providing that the crop density was low. These weeds could have grown with pea crops that had to be sown in two rows in order to maintain appropriate interrows. The site in question delivered an abundant collection of ruderal plants, growing on soils rich in nitrogen, phosphates and potassium chloride, in the closest surroundings of human dwelling sites. Finally, species typical of non-forest communities, namely, meadow, pasture and grassland plants, are represented in relatively large numbers.

As evidenced by the above-mentioned example, remains of wood can be used, within certain limitations, to reconstruct plant communities, thus habitats they had lived in. However, in such a case, employing palynology would be much more beneficent. Palynology is a useful tool in reconstructions of vegetation cover having existed in ancient landscapes. It is commonly employed in archaeology to assess the vegetation at regional level. Pollen diagrams can also serve for identifying traces of cattle grazing, crop cultivation or burning of plants, which allows us to understand ancient practices associated with land preparation for farming (e.g. Behre 1981; Makohonienko et al. 1998b; Latałowa 2003).

10 Summary

The above-quoted examples of case studies and archaeobotanical interpretations do not close the list of all possible applications of this discipline. As mentioned above, the author aimed to present results of studies conducted at sites mainly located in the present territories of Poland.

The analysis of plant remains delivered a great number of significant information referring to plant management by prehistoric human communities. The author indicated that wild species identified in assemblages of macroscopic remains are derived mostly from communities that developed within the dwelling and economic zones of human activity. Archaeobotanical studies are highly interesting from the viewpoint of botany and agricultural sciences. They are mainly employed for resolving certain issues related to the history of cultivated and synanthropic plants. Plant remains that were properly and accurately dated are indisputable records documenting the time and place of the occurrence of particular species. With regard to cultivated species, they provide the grounds for establishing the earliest locations of their occurrence and tracing the paths of their expansion.

A significance of archaeobotany for archaeology results from the fact that it delivers materials allowing the investigators to answer certain questions referring to plant management in the past centuries. Of major significance is the possibility to reconstruct plant food consumed by humans and domesticated animals, coming from both gathering and farming. Gathering of wild plants was the only way of obtaining them within the scope of subsistence economy of the Palaeolithic and Mesolithic periods. Employing reconstructions of palaeophytocenoses makes it possible to “place” archaeological sites in their environmental context and reveal conditions, under which the ancient human communities came to live.

Based on the experience gained so far, one can also state that in order to obtain a more complex picture of plant significance in the existence of prehistoric human societies cooperation between scholars specialised in various disciplines is extremely important, enabling an exchange of information, designing of complementary studies and thorough verification of the results obtained. This wide-scope interpretative approach has been marked in the related studies of the recent years.

When making attempts to reconstruct human economy and the nature of environment, a certain dose of scepticism is recommended, keeping in mind that one of the characteristic traits of fossil materials is their incompleteness.

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Bridging Archaeology and Genetics

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1 Introduction

The discovery of DNA over 50 years ago led to a revolution in the medical and biological fields. Following the advent of polymerase chain reaction (PCR) a couple of decades later (Mullis and Faloona 1987), DNA became just as valuable a tool in archaeology. Armed with mitochondrial DNA fragments, archaeologists and geneticists explored human origins (Ingman et al. 2000; Lazaridis et al. 2014), identified domestication centres (Bruford et al. 2003) and investigated evolutionary relationships between species (Pitra et al. 2004; Sanchez-Puerta and Abbona 2014). The technological development of massive parallel sequencing also known as next-generation sequencing (NGS) in the last decade has facilitated the acquisition of ancient and modern nuclear DNA data. Whole nuclear and mitochondrial genomes have largely contributed to our understanding of ancient populations on a much larger scale as well as our identification of phenotypically important nuclear loci.

With sequencing techniques evolving rapidly and becoming more powerful in generating large amount of molecular data, the need for an open, clear and comprehensible dialogue between archaeologists and geneticists is crucial. The power of sequencing techniques in generating high-resolution data can lead to apparently conclusive results, leading geneticists to omit the importance of the archaeological context. Similarly, the field is still marred by misconceptions

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regarding the potential of genetics applied to archaeology, and archaeologists need to be aware of what can be realistically achieved by genetics.

In the following paper, we first provide a brief introduction to the history of the field of archaeogenetics. We then address some of the discipline's major misconceptions which remain widely spread among academic and nonacademic audiences. We define these assumptions by highlighting issues within our current knowledge based on technical possibilities and use successful case studies to demonstrate the current potential of genetics applied to archaeology. We then highlight the practical considerations required for archaeogenetic research. Finally, we explore ways to improve dialogue between archaeologists and geneticists to allow for better future collaborations between both disciplines.

2 Genetic Research Within Archaeology: A Brief History of Ancient DNA

First discovered in the 1860s by Friedrich Miescher, deoxyribose nucleic acid (DNA) was not properly understood until nearly a century later when Alfred Hershey and Martha Chase found it carried hereditary genetic information essential to the development, structure and function of an organism (Bromham 2008). Its chemical and physical structures were revealed in 1953 by James Watson and Francis Crick, showing the DNA molecule comprises two chains forming a double helix held together by nucleotides. These nucleotides consist of a base, a sugar (deoxyribose) and a phosphate linked together to form the basic structural unit of DNA (Bromham 2008; Watson and Crick 1953).

These revolutionary discoveries became the backbone of medical and biological research, and in the 1980s, the full potential of DNA began to be explored as questions on the longevity of the molecule and its survival rate in extinct creatures drew interest. Dried muscle tissue from the salt-preserved skin of a 140-year-old quagga (*Equus quagga*) was the first successful DNA extraction from ancient tissues (Higuchi et al. 1984). The sequencing of the extracted DNA via bacterial cloning proved to be of sufficient quality and size to explore the phylogenetic relationships of this species, which was identified as an extinct zebra. This cutting-edge study prompted researchers to begin the application of genetics to archaeological questions. The following year, Pääbo replicated Higuchi's methods and successfully recovered ancient human DNA from an Egyptian mummy radiocarbon dated to 2430 +/−120 years BP (Paabo 1985).

The development of the polymerase chain reaction (PCR) (Mullis and Faloona 1987) led to an exponential increase of early molecular work. The revolutionary aspect of this technique resides in its ability to successfully amplify extremely low quantities of DNA (theoretically down to a single molecule) such as the quantity usually present in ancient materials. The first use of the PCR method for archaeological purposes was conducted on extracted DNA from a 7000-year-old brain (Paabo et al. 1988). Several spectacular claims quickly followed, each constantly pushing back the age of the extracted sample: in 1990, Golenberg et al. successfully recovered DNA from a 17–20-million-year-old fossil leaf sample from the genus *Magnolia* (Golenberg et al. 1990); in 1992, DeSalle's team amplified fragments of mitochondrial and nuclear DNA from a fossil termite *Mastotermes electrodominicus* preserved in a 25–30-million-year-old Oligo-Miocene amber (DeSalle et al. 1992). Two years later, Woodward et al. extracted small fragments of DNA from 80-million-year-old bone samples recovered from a Cretaceous period coal bed in Utah (Woodward et al. 1994), while Cano et al. (1993) recovered DNA from a 120–135-million-year-old weevil. These last two studies marked what could be regarded as the 'height' of these early genetic studies. It seemed time had no real impact on the degradation of DNA.

By the end of the millennium however, critical reviews began to question the validity and authenticity of these results. Scepticism on the newly reviewed survival rate of DNA and the fact that the reported work could not be replicated led many to suggest the results were caused by contamination (Gibbons 1994; Handt et al. 1994; Morell 1993; Paabo and Wilson 1991; Richards et al. 1995). Indeed, even a minute quantity of modern DNA could outcompete the low number of ancient DNA sequences during amplification. Consequently, measures were proposed to ensure the authenticity of the results, and Cooper and Poinar's (2000) and Hofreiters' et al. (2001) checklists became standard procedures in ancient DNA laboratories. With the implementation of rigorous contamination and authenticity controls as well as methodological improvements (Ho and Gilbert 2010), ancient DNA (aDNA) research regained its credibility. Researchers have been able to reconstruct the mammoth's mitochondrial genome from a *Mammuthus primigenius* sample dating to 13,400–11,900 years BP (Krause et al. 2006) and draft the Neanderthal nuclear genome demonstrating a history of hybridisation with humans (Green et al. 2010). Today, the introduction of next-generation sequencing has enabled a higher resolution of the generated data (both in terms of ancient genomes recovered and the completeness of these genomes), expanding the potential of molecular biology in addressing archaeological questions. With such success, it is easy to forget or overlook limitations, yet it is imperative that these are acknowledged.

3 The 'Magic Wand Approach': Misconceptions and Current Potential of Ancient DNA Studies

In 1990, Michael Crichton's novel 'Jurassic Park' popularised claims that DNA could be recovered from million-year-old fauna and flora preserved in amber (Crichton 1990), much like DeSalle's work in 1992. Although academics are aware such accomplishments are not feasible, other preconceived ideas on the potential of aDNA in archaeology persist. The breadth of successful and high-impact applications combined with these misconceptions has resulted in researchers across the field hoping to apply genetics to any issues they wish to resolve. This is unsurprising: with the field of aDNA being relatively young, misconceptions of the discipline are easily widespread. Theoretically, given DNA is the ‘blueprint’ of an organism, any questions on physical traits as well as ancestry should be inscribed in the molecule and easily recoverable. Practically however, this ‘magic wand approach’ omits numerous issues notably regarding the quality of the sample and our current understanding of the genome. It is thus important that we distance ourselves from the misconception that DNA holds all the answers and that we recognise the limitations of aDNA studies the same as any disciplines within archaeological science.

Below, we explore common misconceptions on the application of genetics to main archaeological research themes, highlighting associated issues and presenting successful case studies to illustrate the current potential of archaeogenetics.

3.1 Linking Genotypes to Phenotypes

Of major interest within the fields of both archaeology and evolutionary biology is the phenotypic reconstruction of extinct and archaeological specimens. Theoretically, the DNA should contain all the information required. The difficulty lies in the gaps of our knowledge regarding the genes and loci underlying specific phenotypic traits. While we know the function of certain genes and have successfully applied our findings on archaeological specimens, such as the FOXP2 gene partially responsible for language in Neanderthals (Krause et al. 2007) or the EPAS1 gene linked to altitude adaptation in Denisovans (Huerta-Sanchez et al. 2014), the function of most genes remains unknown. Hopes of a holistic understanding of the phenotype from a sample are thus impossible due to our current inability to link genes to their specific phenotypic variants.

Furthermore, phenotypic traits typically have multiple genes responsible for their expression. Human height, one of the most heritable human phenotypes, provides an excellent case study to illustrate this point. Human stature correlates with limb bone length across all ages, allowing osteologists to reconstruct an individual’s height based on the measurement of their intact long bones and inputting them into formulae. Unfortunately, these formulae are imperfect and present margin errors ranging from 2.99 to 5.05 cm (White and Folkens 2005). However, when it comes to genetics, estimating human stature is currently just as problematic. Genome-wide association studies on thousands of people have identified 54 loci associated with human height variation. However, this 54-loci genomic profile was found to only account for 4–6% of the height variance (Aulchenko et al. 2009). To detect further height genes, bigger meta-analyses of genome-wide association study would have to be undertaken, requiring a much larger sample size. Consequently, due to costs and resources, identifying the gene(s) linked to human height is unlikely in the foreseeable future. Finally, let us not forget that stature is the result of both genetic predisposition and childhood periods of environmental and social stresses, and as such, the sole use of genetics will only provide a partial picture.

In some cases however, research areas of interest can be partially explored by multiple phenotypic traits linked to an individual coding gene or a series of well-known coding genes. For instance, it is possible to genetically investigate animal coat colouration. In 2011, Pruvost investigated the depiction of horses on Palaeolithic cave walls to understand whether the coat colours represented creative artistic expressions or an accurate representation of the variation found in predomestic horses. Through the genotyping of nine coat colour loci in 31 predomestic horses from Europe, Siberia and the Iberian Peninsula, they found all horse colour phenotypes including the leopard complex spotting were present in prehistoric horse populations, highlighting the cave paintings' accurate and realistic depictions of contemporary animals (Pruvost et al. 2011). In the case of animal coat colouration, over 300 genes have been found directly or indirectly associated with pigmentation alone (Montoliu et al. 2010), but the identification of these 9 loci as playing key roles allowed for such a research to be possible. Other examples of successful phenotypic trait reconstruction via ancient genetics include the widespread yellow leg trait in chickens (Eriksson et al. 2008).

3.2 Phylogeny, Phylogeography and Evolutionary History

Originally, phylogenies were based on morphological and behavioural features. However, with the appearance of molecular data where DNA sequences provide a unifying framework, organisms became all comparable, from the level of the individual to that of the kingdom. The nature of DNA makes molecular data ideal for statistical analysis: haplotypes (DNA sequences each defined by a combination of variable sites) are seen as evolutionary units, thus allowing the investigation of ancestral relationships and the evolutionary ancestry of species. Phylogeography is similar in principal to phylogenetics, but geographic location is a key component: phylogeography combines phylogenetically related sequence variants with their ancient and modern geographical distributions (Bradley 2006). This can therefore be used to trace a population's origin and migration.

For instance, by sequencing the mtDNA control region from 122 modern and 22 ancient chickens from Polynesia and Island Southeast Asia, Thomson et al. identified the 'ancient Polynesian genetic signature' believed to be the authentic founding mitochondrial DNA chicken lineage dispersed across the Pacific. The presence of this genetic signature in modern chicken populations from several Pacific island suggests this original lineage still survives and similar haplotypes found in the Philippines point towards a possible origin for this Pacific dispersal (Thomson et al. 2014).

Phylogeny and phylogeography thus provide powerful tools in addressing archaeological questions. However, they also include limitations such as the lack of available data for numerous species. Generally, this is caused by the difficulty of getting access to the required samples (i.e. due to museum restrictions), bad preservation meaning no remains are left to be stored or researched, or the fact that the species itself was never previously researched. Such a case can be seen for the Java deer (*Rusa timorensis*). Indeed, much of our knowledge on the phylogenetic relationships between deer species comes from phenotypic features. In 2004, the complete mitochondrial cytochrome *b* gene of 32 extant Old World deer taxa, the extinct Schomburgk's deer and representatives of all living cervid subfamilies was sequenced. The phylogenetic tree grouped the sambar deer *Rusa unicolor*, the Java deer and the hog deer *Axis porcinus* together based on 99–100% statistical support (Pitra et al. 2004). Unfortunately, this is the extent of our current knowledge on *Rusa timorensis* as no other genetic studies have been conducted on the species itself. This is problematic when archaeological specimens are found, such as those recovered from the Dutch colonial Fort Frederik Hendrik on Mauritius. The lack of a proper reference database (only two sequences had been published at the time of study) meant it was impossible to know if the recovered bones were indeed from Java deer or whether they belonged to another species or sub-species (Lebrasseur 2010). A good reference database is therefore important for comparison of DNA sequences within and between species. In case of extinct species though, such a dataset may be impossible to compile.

In addition, not all phylogenies obtained are correct. It is not uncommon to find two research groups publishing contradictory molecular phylogenies for the same species (Bromham 2008). Phylogenies can also be contradictory or wrong because limited sampling cannot represent variation and certain genomic regions (such as cyt b) may be under selective pressures and won't necessarily be representative of the species as a whole. It is thus important to combine these results with other evolutionary hypothesis based on biogeography, morphology and the fossil record.

Despite these limitations, the use of phylogenetics and phylogeography has been successfully applied to the question of domestication as early as the late 1980s (Avise et al. 1987). Loftus et al. used mtDNA fragments to investigate whether or not *Bos indicus* and *Bos taurus* derived from the same domestication episode around 8,000–10,000 years BP (Loftus et al. 1994), while Yang et al. used phylogenetic analysis on a range of modern and ancient Chinese buffalo to show that the ancient samples were not the direct ancestors of modern domesticates. This indicates that water buffalo were not first domesticated in China (Yang et al. 2008). Another example is Vila et al.'s 1997 mitochondrial genetic analysis on dog domestication. Vila was among the first to hypothesise that dogs descended from the grey wolf (*Canis lupus*) (Vila et al. 1997). This early study had quite an impact on highlighting the potential of genetic studies in providing details on domestication where conventional zooarchaeological techniques failed (Larson 2011).

Another advantage is that molecular data recovered from ancient and modern specimens holds a record of evolutionary history. This is very valuable when dealing with organisms that leave no fossil record. This is shown, for instance, in the study on *Mycobacterium tuberculosis*, the causative agent of human tuberculosis, and its introduction into the New World. Scientists were unable to reconcile the pathogen's phylogeography with the bioarchaeological data. While the latter presented osteological evidence for tuberculosis in pre-Columbian societies (Roberts and Buikstra 2003), the genetics argued that all modern American strains are closely related to those of European origin supporting the hypothesis that tuberculosis was first introduced in the New World by Europeans (Hershberg et al. 2008). The answer to these contradictions came with the recovery of three 1000-year-old mycobacterial genomes from Peruvian skeletons. The identification of the pathogen confirmed the bioarchaeological data, while the sequencing of the ancient strains showed they shared a common ancestor with those restricted to seals and sea lions. The authors concluded that a zoonotic transfer of the bacterium must have occurred during pre-Columbian times, probably through infected marine mammal exploitation by coastal peoples of South America (Bos et al. 2014).

3.3 Are Modern Populations Representative of Ancient Populations? The Cases of the Serial Founder Effect Model, Admixture and Population Replacement

Whether it be in human history or domestication research, studies often interpret mtDNA results based on demographic stasis illustrated through 'serial founder effect' models. In short, these models assume that following their initial expansion from a point of origin, populations remained in the geographical locations they first colonised, exchanging migrants with close neighbours at a very low rate. If indeed correct, then identifying the geographical origin of a particular domesticate would simply involve finding the geographical region with the highest genetic diversity (Pickrell and Reich 2014).

The model however implicitly assumes that populations today are direct representatives of past populations who used to live in that same locality. Crucial to the interpretation of the data is the fact that these models do not allow for admixture that we know occurred through population replacements and long-range migration. Genetic research on domesticates have already begun to show the dangers of using modern populations to infer the past (Flink et al. 2014), while Pickrell and Reich demonstrated that a declining heterozygosity in populations located further and further away from their presumed point of origin (as defined by the serial founder effect models) is consistent with multiple scenarios (Pickrell and Reich 2014). Furthermore, the domestication of certain plants is not as straightforward as a single domestication event. In the case of the banana, the origin of its cultivated form arose from multiple intra- and interspecific hybridisation events (Li et al. 2013).

Until recently, the majority of domestication studies were conducted on modern datasets. Indeed, limitations on the number of well-preserved archaeological samples impaired the size of high-resolution ancient DNA dataset, leading to modern data being the preferred choice. However, modern populations often little reflect the past and numerous events of migration, admixture and population replacement may have occurred. Perhaps the best case study to illustrate this point is that of dogs.

The domestication of the dog has puzzled archaeologists and geneticists for decades. While the archaeological record suggests a European domestication centre

(Larson et al. 2012), mitochondrial DNA based on modern populations speculates a single domestication event within East Asia due to its larger genetic diversity (Pang et al. 2009; Savolainen et al. 2002). Other types of genetic data including a genome-wide SNP survey and Y-chromosome markers either support this theory (Brown et al. 2011) or refute it (Boyko et al. 2009; Sacks et al. 2013). Consequently, although it is generally agreed among both archaeologists and geneticists that there only was a single domestication event, no consensus on the geographic and temporal origins of dog domestication has yet been reached. By comparing modern mtDNA sequences and full genomes with modern SNP data, ancient European mtDNA sequences and the full genome sequencing of a late Neolithic dog (4800 years BP) excavated in Ireland, Frantz et al. showed dog domestication history and dispersal were more complex than originally thought. The study found that the divergence time between the East Asian and the Western Eurasian dog core groups occurred after the appearance of the first domestic dogs in either of these regions. This consequently implies that indigenous dog populations were already present in both Europe and East Asia prior to this divergence. One hypothesis is the migration of Eastern European dogs into Europe between 6,400 and 14,000 years BP by human movement. These would have then partially replaced the indigenous Palaeolithic European dog populations. Furthermore, haplotype comparison between ancient and modern data revealed that the majority of ancient European dogs belonged to haplogroup C or D, while most modern European dogs fell within haplogroups A and B. This highlights a clear turnover in the mitochondrial ancestry of European dogs which fits with the introduction of East Asian dogs (Frantz et al. 2016). Although the authors state that ancient Eurasian dogs and wolves are needed to confirm a dual domestication, this study highlights events that cannot be inferred from modern data alone. Other studies which have highlighted similar issues include Leonard et al. (Leonard 2008; Leonard et al. 2000).

4 Practical Considerations for Undertaking Archaeogenetic Research

4.1 Samples

One of the practical factors to be considered prior to utilising a genetic approach includes the material itself, its degree of preservation and the availability of reference data. Most genetic research is informative as it compares changes in the genome either over time or space, but multiple viable samples from the same species are usually vital for good comparison. Once multiple samples with suitable levels of preservation have been identified, appropriate reference sequences need to be located. As most extractions of archaeological material will also include contaminant sequences, the sequences obtained will need to be matched (or aligned) to a modern sequence of the species under investigation.

4.1.1 The Abundance of the Archaeological Record

While ancient DNA is essential to providing a direct window into the past, it relies primarily on the findings of ancient remains as well as the attributed dates. Some geographical regions have been more focused upon than others in terms of archaeological investigations, which already biases the recovery of faunal remains. A similar case can be made for hominids. Furthermore, while museums usually have excellent records of their collections, some remains lack the contextual information that makes genetic analysis informative for broader archaeological interpretation. Site information can be lost either from the illegal trade of artefacts or due to the poor records from early excavations when the field of archaeology was more the pastime of the elite than a robust scientific discipline.

4.1.2 The Need for Reference Sequences

Humans and most domestic animals have many published sequences available to researchers. However, if the work is focused on a niche organism, previously published sequences are not guaranteed. Furthermore, the reference sequence must contain the same region of the genome as the one under study. These are usually mitochondrial or ribosomal, but ultimately the targeted region will depend on the archaeological question at hand. Depending on the statistical analysis, you may even need multiple copies of the genome of interest so that past variation can be understood in comparison to modern genetic variation. Reference sequences can be found in public database such as NCBI (http://www.ncbi.nlm.nih.gov/genbank/) or EBI (http://www.ebi.ac.uk). Without the factors outlined above, genetic research cannot be carried out successfully.

4.2 Choosing Genetic Markers

Until the development of NGS, mtDNA was the most extensively used genetic marker in archaeogenetic studies. However, with the development of more powerful sequencing techniques, Single Nucleotide Polymorphism or SNPs are becoming increasingly popular. Below we explain the nature of each of these genetic markers including their advantages which are important to consider when designing a research project.

4.2.1 Mitochondrial DNA (mtDNA)

While the majority of our DNA is found within chromosomes in the nucleus of cells, a small portion is found within organelles in the cells' cytoplasm called mitochondria. These are important organelles for the smooth functioning of cells as they represent the latter's principal source of energy. Mitochondrial DNA is a small molecule with a circular structure found in multiple copies within mitochondria. It is involved in respiration and codes for proteins and RNAs essential for the function of the mitochondrion (Savolainen 1999). Even though it is of a relatively small size compared to the nuclear genome (an average of 16,000 base pairs for the mitochondrial genome versus billions of base pairs for the nuclear genome), the mitochondrial genome and the control region in particular have often been used by population geneticists and molecular systematicists for phylogenetic and phylogeographic studies (Galtier et al. 2009; Larson 2011).

Mitochondrial DNA is relatively easy to amplify due to its abundant number of copies present within each cell; for every one copy of the nuclear genome, there are thousands of copies of the mitochondrial genome. Indeed, each cell encompasses between 1,000 and 10,000 mitochondria depending on the type of cell, and 2 to 10 mtDNA molecules can be found within each mitochondrion. The number of mtDNA molecules in a cell therefore ranges between 2,000 and 100,000 (Savolainen 1999). This is an appealing prospect when dealing with very small amounts of DNA or ancient samples. For instance, mtDNA has proved useful in forensic analyses where a single dog hair from a crime scene was successfully analysed (Angleby and Savolainen 2005; Savolainen 1999). More recently, a study amplified the full mitochondrial genome of several archaeological canids, some dating as far back as 36,000 years BP (Thalmann et al. 2013).

Mitochondrial DNA also possesses a maternal mode of inheritance. It is passed down from mother to offspring through the cytoplasm of the oocyte (egg). The head of the sperm which fuses with the oocyte to deliver nuclear DNA from the paternal side does not possess any mitochondria. Therefore, the father does not contribute towards the embryo's mitochondrial DNA. There has been some speculations over this fact, but so far, no examples within the vertebrate pedigree have revealed paternal inheritance (Ritvo 1986; Savolainen 1999). Finally, mitochondrial DNA does not recombine, and all changes occurring within a mitochondrial DNA genome sequence are thus the results of mutations (Larson 2011). This reduces the number of scenarios to consider in interpreting the results.

A majority of the mitochondrial DNA codes for proteins and RNAs. These are crucial to the functioning of the mitochondrion. Among its 16,000 base pairs, however, is a major non-coding region called the Control Region (CR) or Displacement loop (D-loop) located between the genes coding for tRNA-proline and tRNA-phenylalanine. This region varies in length depending on the organism. For instance, the control region in humans consists of 1,122 base pairs (Anderson et al. 1981), while those, for example, of the chicken and the dog consist of 1,227 base pairs and 1,270 base pairs, respectively (Desjardins and Morais 1990; Kim et al. 1998). Due to this region not coding for any proteins and not being part of the transcription/translation process, mutations occurring within the control region do not affect the functioning of the organism. Consequently, these mutations are not quickly selected out but rather accumulate quickly over time. This accentuated evolution rate allows for large sequence divergence between species as well as between individuals. This provides the perfect tool for geneticists as it allows for the differentiation of individuals within the same species and allows us to understand the demographic history of a species based on sequences (Larson 2011).

4.2.2 Single Nucleotide Polymorphism (SNP)

Single nucleotide polymorphism or 'SNP' refers to sites in the genome where the nucleotide sequence differs between individuals of a population. The term is coined based on the fact that these usually comprise one-base mutation and are carried by a portion of society. Technically, a particular variant must have been identified in at least 5% of the individuals of a given population to be considered a polymorphism, but in actual practice, any locus that differs among all individuals is seen as such (Bromham 2008).

Only a few SNPs will play a causal role in differences between organisms; as such, SNP analysis focuses on pinpointing the regions of the genome containing alleles associated with the trait of interest. In general, a particular SNP located near the targeted gene will tend to be inherited along with that gene. Consequently, if a causal difference is present in the gene (leading to a specific allele), it should be connected to an identifiable gene nearby. This being said, a 'perfect' link between SNP and trait does not generally exist (Bromham 2008). In the case of the yellow colour of the legs of chickens, researchers identified the gene underlying the yellow skin by combining linkage analysis and identical-by-descent (IBD) mapping across breeds with the yellow skin phenotype. They found a SNP located at nucleotide position 5,237,523 bp at the distal end of chromosome 24 and its obvious candidate gene BCDO2 known to encode an enzyme whose role is to cleave colourful carotenoids into colourless apocarotenoids (Eriksson et al. 2008). A few years later, Gridland Flink sequenced this SNP in 25 ancient European chickens and found that 20 were homozygous for the white skin allele, demonstrating the 'yellow leg' trait was not a domestication gene as originally thought but one which had undergone strong selection pressure in the last few hundred years (Flink et al. 2014). SNPs are therefore useful to identify specific trait and are particularly valuable when it comes to investigating genetic diseases.

4.2.3 Multi-target Loci

Different parts of the genome can be indicative of different processes, and therefore using only one target for interpreting archaeological questions can be misleading. Multiple targets can mitigate and highlight biases of only one region. This point underlies the dramatic findings that humans and Neanderthals had never hybridised (Krings et al. 1997). In 2010 however, this well-established fact became disputed when Neanderthal nuclear DNA was sequenced, and it was found that humans and Neanderthals shared 1–4% of their genome (Green et al. 2010).

4.3 A Question of Methodology

4.3.1 The Advent of Next-Generation Sequencing

Limitations to Sanger sequencing led to the development of massively parallel/next-generation sequencing (NGS). While there are multiple platforms for undertaking NGS, they all rely upon template preparation, sequencing and imaging, genome alignment and assembly methods (Metzker 2010). These platforms include Pacific Biosciences' RS, Roche's GS FLX Titanium/GS Junior, Ion Torrent's SOLiD/PGM and Illumina's HiSeq/MiSeq. The majority of companies do a tabletop device, while larger, more powerful versions produce more accurate greater sequence yields per run and so ultimately are cheaper per run. The latter two companies dominate the market as they have the greatest accuracy. Despite the slower running time, the Illumina platforms are most commonly used for aDNA studies as it has been found to consistently have lower error rates, higher conversion efficiencies, higher read numbers for homopolymer stretches and lower sequencing cost per Gb in comparison to its competitors, even if the initial cost of the instrument is higher (Hofreiter et al. 2015; Quail et al. 2012). Sanger sequencing is more accurate and can sequence longer reads, but NGS is a platform for providing billions of short reads inexpensively with lower time and labour costs. This means that NGS is better suited for researchers targeting poorly preserved samples, wishing to target multiple genome regions or wishing to analyse large number of samples.

4.3.2 Is DNA Always the Most Appropriate Tool? Exploring Alternatives

There are cases where genetics is a viable technique for addressing a specific archaeological question, but this does not necessarily mean it always is the most efficient. For instance, it is of common knowledge that a high proportion of faunal remains recovered from archaeological excavations are highly fragmented and morphologically unidentifiable. When such specimens are deemed of important value (i.e. confirming the first introduction of a species in a non-native environment), archaeologists will often resort immediately to genetics. However, using aDNA to map faunal assemblage data from a single site is rarely undertaken given the time and cost each bone fragment requires for its sequencing.

In 2013, Murray et al. designed a cost-effective method to taxonomically identify bulk-bone powder samples through high-throughput sequencing. They sampled 50–150 morphologically unidentifiable bone fragments for each of the 15 stratigraphic layers of the archaeological sites of Devil's Lair and Tunnel Cave in Australia. Using two HTS platforms, they successfully extracted aDNA from all 15 bulk-bone powder samples, including one from a layer dated to between 44,260 and 46,890 years BP (uncalibrated), making it the oldest aDNA recovered to date in Australia. Numerous bird, reptile and mammal species were identified (Murray et al. 2013). This ground-breaking technique is rapid, effective and indeed cost-efficient and will no doubt become a valuable tool for the identification of fragmented bones in the foreseeable future.

However, if a smaller project wishes to identify a handful of bones for which funding is limited, alternatives to genetics exist and need consideration as they may overall be cheaper and better suited to the research project. For instance, the recently developed technique of Zooarchaeology by Mass Spectrometry or ZooMS is a cheaper method for the rapid identification of bone fragments. In 2010, the cost for a sample analysis was of 5€ (Buckley et al. 2010). Using peptide fragment of bone collagen, the principle relies on protein barcoding: mass spectra is used to reflect the protein sequence of a sample which can then be linked to a specific protein or protein fragment. Although the method presents limitations similar to DNA such as the need for a good reference database and a good collagen content, it has successfully been used to identify mammals (Buckley et al. 2009, 2010) and fish (Richter et al. 2011). Consequently, the choice of technique between aDNA or ZooMS is really dependent on the research question, the number of samples to be analysed and the allocated budget. A good example is the recently published study by Brown et al. where they used ZooMS on over 2,000 fragmented bones in order to identify whether any possessed a human signal (Brown et al. 2016). Had they chosen Murray's technique, they would have identified the presence of a Neanderthal signal but would have been enable to identify the bone from which the signal came from. Consequently, not only is it a question of costs but also of the identification of valuable specimens.

Genetic techniques can be used to confirm former species identification conducted by alternative methods, but whether or not such an approach should be undertaken is to be questioned. In-depth palynological work was carried out by van Geel et al. where they recovered a detailed description of the contents of a mammoth's stomach. With further aDNA analysis, they discovered one new species and two species originally classified at the genus level (van Geel et al. 2011). As these new findings did not affect the conclusions found in this paper, one has to question whether the application of an expensive technique was really suitable. The best examples of the application of genetics to the archaeological record are when the appropriate samples and reference sequences are available, in addition to careful consideration as to why aDNA is the best approach to address the research question. This is something both archaeologists and geneticists should consider before embarking into this disciplinary field.

4.4 The Plagues of Ancient DNA

4.4.1 DNA Post-mortem Decay

Well-recognised in the archaeological field is the issue of post-mortem DNA decay. At the death of an organism, its DNA degrades through the action of endogenous nucleases (Hofreiter et al. 2001). Should conditions be favourable such as rapid dessication, low temperatures or high salt concentrations, the nucleases will either be destroyed or become inactive. This does not mean the DNA will be preserved indefinitely: slower processes such as oxidation and background radiation will continue the degradation process. In addition, destabilisation and breaks in the molecule may follow as a result of deamination, depurination and other hydrolytic processes (Hofreiter et al. 2001). This post-mortem decay alters the DNA strands, affecting the survival rate of DNA and resulting in a bias in the application of aDNA techniques to the archaeological record. The genetic record of ancient samples is much denser around temperate regions, while good DNA-yielding samples in regions with hot and humid climates such as Asia are limited as the success rate of extraction is lower. This has the knock on effect of researchers undertaking only limited research in certain regions in order to maximise the chance of producing data.

4.4.2 DNA Contamination

Reports of contamination have plagued DNA research for decades. For instance, a few studies have claimed a Polynesian introduction of the chicken in South America prior to the arrival of the Europeans based on genetic analysis conducted on an ancient chicken bone from the El Arenal-1 site in Chile (Storey et al. 2007). It was recently shown that the observed conclusions most likely resulted from contamination (Thomson et al. 2014). Cooper and Poinar (2000) have specified several measures of precaution that need to be carefully followed for the amplification of authentic DNA. Although some of their authenticity criteria may only apply to specific types of analyses, appropriate laboratory facilities and work area, blank controls, independent replication and cloning amplification products remain essential and should not be discarded. Contamination is of greater issue for samples with high levels of post-mortem decay as the ratio of endogenous to modern DNA becomes smaller. This results in a greater chance of the ancient DNA being buried in the excess PCR product from the modern contaminant, and therefore no useful data can be recovered.

5 Towards the Future: Improving Collaborations

5.1 Limiting Destructive Sampling

The destructive nature of sampling naturally leads to some researchers and collection curators being reluctant in offering valuable specimens for genetic analyses. A degree of sensitivity is therefore required for successful collaborations between the owner(s) of a collection and the geneticists. This is of particular importance if the sample in question is rare or valuable (which unfortunately makes it inherently of greater interest to researchers). All archaeological material is precious, but the information they have within their DNA is also valuable as it can shed light on some major archaeological questions and debates, allowing for breakthroughs in our knowledge of the past. Consequently, compromises can be made to satisfy both parties, and here dialogue is crucial.

Firstly, good records of the specimen prior to them being sampled are essential for the 'preservation' of the find and also for museum references. Ideally, these records should include accurate measurements of the bones, high-quality photos and if possible 3D modelling. Such records would also provide opportunities for the samples to be integrated within different types of analyses for future research. For instance, 3D modelling could be used for geometric morphometrics.

When selecting a sample for aDNA analyses, there should be careful consideration as to which area of the bone is to be targeted. Diaphyses are essential for bone identification and complete long bones tend to be valued for their metrics. As such, non-diagnostic bones should be targeted. If impossible, a sample taken from the shaft of a long bone leaving the diaphyses and the greatest length intact is a good option. When dealing with museum specimens in particular, several alternatives can be considered, such as the root of a tooth for medium to large mammals or crusties (dried tissue present inside the skull). In both these cases, the damage is unnoticed and leaves the possibility for full museum display.

In cases where these options are not available, several factors need to be kept in mind upon sampling. Figure 1 shows an image of various types of sampling. The small hole highlighted produced about 80 mg of powder and was used for both DNA and percent nitrogen analysis (a prescreening technique for radiocarbon dating). This sampling technique is not visible from the front of the cranium and is barely noticeable from the back. This is the best approach for satisfying both researchers and curators. While the L-shaped sample next to the hole was originally used for histological analysis, there are case examples when this type of sampling strategy is used unnecessarily for aDNA. This strategy ruins the integrity of the sample for other researchers and reduces the curatorial value of the object. Reluctant curators are usually protective of their collection due to this type of destructive sampling. A considerate researcher will therefore attempt to minimise the damage to the structural and visual integrity of the specimen, in addition to avoiding bioinformatically informative regions. Careful sampling is the best way forward as it results in minimal damage to important collections. In turn, curators/archaeologists will become confident in the sampling skills of their collaborators and should therefore be more willing to provide specimens for geneticists.

5.2 Understanding Terminology and Methodology

Terminology is an issue in all cross-discipline research. Every discipline uses their own specific terms clearly understood within their field but ambiguous to those outside of it. This makes it difficult for an accurate dialogue to take place between

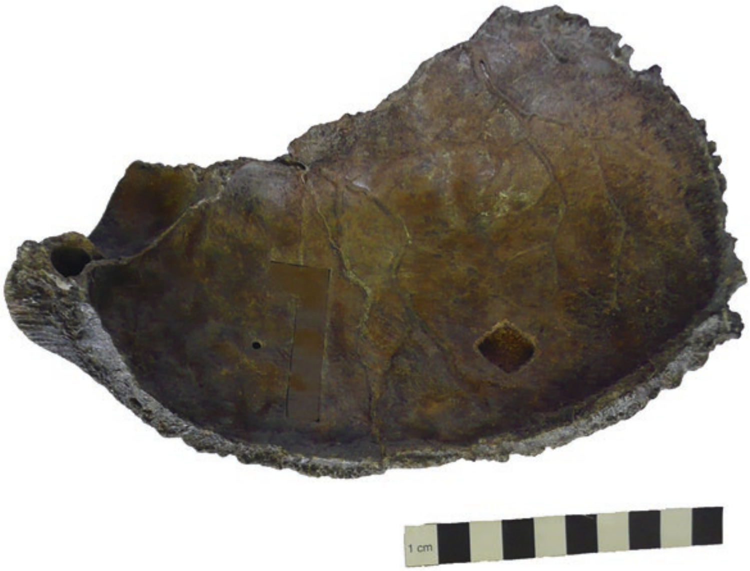

Fig. 1 Šal'a II – Neanderthal left parietal bone (discovered in 1993 at Šal'a-Veča, Slovakia) and half frontal bone (discovered in 1995 ca 800 m downstream of the first one). The L-shape represents 1.5 g sampled for histological and aDNA analysis. The tiny hole represents 80 mg sampled for aDNA analysis using key-hole drilling technique so as to keep surface damage minimal (With many thanks to Rachel J. A. Hopkins. Picture by Rachel J.A. Hopkins)

collaborating disciplines unless both parties are familiar with one another's 'language'. Indeed, while specific terminology is vital for succinctly describing a piece of research, the disadvantage lies in that the resulting paper becomes less accessible to others who may be interested in the results. This can lead to misinterpretation of the data and the proliferation of inaccurate data in the archaeological record.

Regarding modelling, this is an integral part of the genetic analysis as it provides the framework by which the extracted sequences are interpreted. However, unless the archaeologist has taken evolutionary anthropology, biology or bioinformatics, the workings of the various models can be complicated to understand. Well-established models and implied assumptions are rarely explicitly stated in papers; therefore these are lost to readers from outside the field. A thorough understanding of the assumptions gives others the ability to judge the strength of the conclusions drawn from the results and contribute further evidence that supports or disproves those conclusions.

On the other hand of the scale resides the archaeological context, well known to the field of archaeologist/site excavator, whereas the geneticist on the team may not possess the same depth of knowledge about the civilisation they are studying. Pervading assumptions of behaviour may be presumed in their work, or they may not attempt to incorporate their findings with the full breadth of archaeological data (which may be cause by a lack of awareness). If looking through the literature, one will find several papers attempting to answer archaeological-related questions published by researchers of which none are archaeologists or possess an archaeological background. This situation in which experts of one of the important field of research are not even consulted is rather alarming and results in publications lacking emphasis on historical perspective within the research, rendering the paper of limited historical significance. When archaeologists are involved in the team (as they should be for better credibility to the research), it is up to the archaeologists to attempt to implement these genetic findings into a holistic framework including aspects that may never be considered otherwise (for instance, typology, agency of artefacts, phenomenology, processual and post-processual theory, etc.).

In addition to being aware of how cross-discipline misjudgements may influence research, the biases within a field may have a negative impact on the success of collaborations between archaeologists and geneticists. The field of genetics is rapidly developing, and as such, some high-profile papers are predominantly implementing novel techniques rather than addressing a question of historical interest. Archaeologists need to be aware that the latest techniques in aDNA are not necessarily appropriate for the research question they wish to address, not taking into account that these new techniques are usually more expensive. For instance, investigating coat colour or the sex of an animal is accomplishable through pyrosequencing, a technique much quicker and cheaper than NGS. However, should the research question include investigating the genetic diversity of the animal on top of other phenotypic traits, the full mitochondrial sequencing coupled with a capture approach is better suited. Similarly, geneticists need be aware that some aspects of the archaeological record remain highly debated especially in regions with a fragmented record. Different approaches to the archaeological record can lead to individuals holding a strong opinion on the topic in question, leading to a possible inadvertent bias in their interpretation of the genetic data provided.

6 Concluding Remarks

The field of archaeogenetics is in constant expansion due to the continuous developments in sequencing techniques. PCR and in the last decade NGS have allowed for complete nuclear and mitochondrial genomes to be sequenced, giving us access to large amounts of data. This has unlocked a deeper understanding of the past including past populations and their origins, the evolution of diseases and their spread through time and the evolution of phenotypic traits through their loci. As we enter the fourth decade of ancient DNA, sequencing methods will continue to grow more powerful in the amount and quality of data they can attain. Third-generation sequencing (TGS) (Oxford Nanopore Technology), a nanopore sequencing technology, is currently being developed and is said to be the next breakthrough in genetic research.

Whether or not TGS becomes widely used among archaeogeneticists is yet to be seen, but one fact remains: the current potential of genetics applied to archaeological questions requires a clear and comprehensive dialogue between archaeologists and geneticists to allow successful collaborations between both disciplines. Research questions heavily define the genetic markers and methodology to be used, while a good interpretation of the results will only be possible if the geneticist understands the archaeological context and if the archaeologist understands the analyses conducted. Adequate sampling strategies, practical prerequisites such as appropriate reference material, good laboratory guidelines to avoid contamination and an understanding of the terminology and limitations of aDNA are key to smoother collaborations in the future.

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Wood Charcoal Analysis in Archaeology

Ceren Kabukcu

1 Introduction

In the great majority of archaeological sites plant macro-remains are preserved by carbonisation. Wood charcoal is amongst the most abundant and ubiquitous of these remains, providing ample opportunities for the investigation of past woodland vegetation dynamics and human impacts on the landscape. The aim of this chapter is to briefly outline the historical development of wood charcoal analysis (anthracology) as applied in archaeological research and present and discuss more recent methodological developments in this field. The primary concern here is to evaluate how anthracology as a field of inquiry has changed in recent years to address research questions relating to palaeoecology, woodland growth conditions in the past and woodland management practices.

2 From Its Beginnings to 'Anthracology as Palaeoecology'

Charcoal analysis (anthracology) involves the identification and examination of carbonised wood remains relying on the observation of the three-dimensional anatomical structure of wood. The earliest known identifications of wood macrofossils were carried out in the nineteenth century by Unger (1849) and later by Heer and Passerini (in Pigorini 1865) (see also commentaries by Castelletti 1990; Paysen 2012). In the following decades through to the early twentieth century, macrobotanical identifications, including carpological and anthracological remains, became more widespread

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(Maby 1932). In the first half of the twentieth century, methods of wood and charcoal identification were becoming more efficient. Initially, specimens were impregnated with resin, and thin sections were obtained from resin blocks for examination using transmitted light microscopy. However, some researchers (e.g. Maby 1932; Grimes and Hyde 1935) had started using less time-consuming techniques, whereby charcoal fragments were not resin-treated; instead they were hand-sectioned to obtain a fresh, clean break and examined with a hand lens or under a low power, binocular microscope, which also reduced the cost of analysis and enabled the identification of several fragments with ease. By the second half of the twentieth century, this technique had become a standard, and (with the adoption of darkfield, reflected light microscopy) much higher numbers of wood charcoals from a range of sites and contexts could be analysed as a result (cf. Couvert 1968; Western 1969, 1971; Leney and Casteel 1975; Vernet et al. 1979). In addition, the increasing number of archaeobotanical reference collections around this time, such as the Cecilia A. Western Wood Reference collection established in the late 1960s with a specific focus on the identification of archaeological wood charcoal macro-remains, significantly facilitated future anthracological research (Asouti 2017, Charcoal Analysis Web).

Alongside these methodological developments and the first publication of comprehensive wood anatomy atlases in Europe (e.g. Greguss 1955, 1959), interest in vegetation history and pollen analysis also increased, fuelled in part by an increasing awareness of human impacts on the environment (Godwin 1956; Smith 1970). One of the earliest studies to explore the potential of wood charcoal assemblages for inferring prehistoric vegetation dynamics was the publication of the wood charcoal assemblage from Maiden Castle (Dorset) in Britain (Salisbury and Jane 1940). Salisbury and Jane (1940) combined species identifications with the examination of growth ring morphology (i.e. average growth ring width and estimated log dimensions) and argued that the proportions of species observed in the assemblage, mostly deriving from fuel wood, reflected to some degree prehistoric woodland composition around the settlement. Their particular emphasis was on the issue of fuel wood availability and selection. Based on the evidence for the presence of a majority of branch wood and twigs in the charcoal assemblage, they argued that fuel wood was collected in the environs of the settlement and that it was 'non-selective' (i.e. collected without regard to the burning properties of the different species of wood). Their interpretations were heavily criticised by Godwin and Tansley (1941) who stressed the importance of cultural parameters determining the selection of wood for fuel and argued that anthracological assemblages, as a result of selection bias, could not reflect prehistoric vegetation accurately. Thus, one of the enduring debates in anthracology started and continues to this day: how representative are the remains of fuel wood debris with regard to past vegetation cover? In addition, Godwin and Tansley touched upon three important concepts in the interpretation of charred fuel wood macro-remains: collection (selective vs. non-selective), the impact of taphonomic processes and their quantification potential.

One of the most influential concepts addressing the issue of quantification of wood charcoal macro-remains was the 'law' (process) of fragmentation proposed by Chabal (1988, 1992), based on the statistical analysis of archaeological assemblages. The author observed that charcoal fragments from archaeological sites, independent of their wood anatomical and/or chemical characteristics (i.e. independent of species), tend to fragment in a way that produces a high number of smaller fragments and a low number of large fragments, resulting in a log-normal size and weight class distribution. Chabal argued these observations on fuel waste taphonomy reflect the random nature of impacts on charcoal fragmentation resulting from the combined effects of mass loss during burning, fuel waste discard in midden-like areas, post-depositional weathering and burial of the charcoal fragments. In the archaeological case studies, Chabal established that the random nature of taphonomic impacts renders anthracological samples suitable for subsampling utilising a rarefaction (or taxon diversity saturation) curve and, furthermore, can be evaluated for their representativeness in terms of taxon composition by a close examination of taxon abundance values in stratigraphic sequences. Methodologically, these findings formed the backbone of present-day anthracological analysis concerned with reconstructing fuel use practices, which rely on wood charcoal fragment counts obtained from deposits containing long-term accumulations of fuel waste (e.g. middens; see also the terms *synthetic* cf. Théry-Parisot et al. 2010a; *charbon de bois dispersés* cf. Chabal et al. 1999).

These developments in wood charcoal quantification were closely matched with a more palaeoecological research trajectory in anthracology, stemming from the influence of the principle of least effort (PLE) in the interpretation of wood fuel use. PLE, proposed by Zipf (1949) argued that all human behaviour is explained by the general rule that the least amount of effort is spent to obtain maximum returns. It has greatly influenced anthracological interpretation with its central assumption that fuel wood collection would take place close to the settlement and that all available woody species would be universally collected in direct proportion to their availability in the past vegetation (cf. Prior and Price-Williams 1985; Tusenius 1989; Chabal 1992; Shackleton and Prins 1992). More specifically, Shackleton and Prins (1992) proposed that in high-density woodland environments, fuel economies tend to be selective towards preferred wood fuel species and are characterised by the routine collection of readily available dry deadwood in close proximity to habitation sites. By contrast, under conditions of wood scarcity, fuel economies would be non-selective, targeting all available species. Based on this theoretical foundation, PLE-inspired interpretations of anthracological datasets have proposed that archaeological wood charcoal taxon frequencies may represent an accurate reflection of local woodland composition and its changes through time. They can thus be used as a source of evidence for palaeoenvironmental reconstruction in a manner similar, if not identical, to that of pollen analyses (Chabal et al. 1999).

While there has been debate concerning whether or not fuel wood collection is determined by cultural selection (i.e. culture-specific definitions of ‘good fuel’) or functional motives (i.e. maximising calorific and energy returns), this has not resulted in systematic theoretical approaches in this field, with some exceptions (e.g. Asouti and Austin 2005; Dufraisse 2008, 2012; Picornell et al. 2011). Proponents of culturally determined fuel selection (e.g. Heizer 1963; Godwin and Tansley 1941; Smart and Hoffman 1988) have argued that wood collection reflects the preferences of prehistoric communities that depend on sociocultural value systems, as opposed to purely functional, optimal behaviour patterns. Thus, it has been argued that archaeological fuel wood remains cannot provide a sound inference on the local (or regional) availability and distribution of woody plants. A further expression of this argument is that data based on quantified charcoal datasets cannot accurately reflect the entire spectrum of wood fuel use (e.g. Willcox 1974, 2002; Zalucha 1982; Smart and Hoffman 1988; Brady 1989; Piqué 1999). Therefore, any reconstructions of species availability and/or use would be at best partial. More recent anthracological investigations, aided by ethnographic and ethnoarchaeological investigations of fuel use and selection, have stepped away from such a polarised view of the palaeoecological significance of anthracological research.

Ethnoarchaeological work on fuel use by Picornell et al. (2011) in the Fang villages of Equatorial Guinea demonstrates the importance of economic and cultural parameters in determining fuel collection areas and the selection of fuel species. The authors report that fuel wood collection takes place not only within the immediate vicinity of the settlement but rather in areas that are 'socialised' spaces. These areas (*tsií*, orchards; *ekot*/*mbut*, fallow land) are spaces in which the spirits of the animals, the plants and the ancestors do not roam. By contrast the rainforest (*afán*) is never used for fuel wood collection as it is considered to be the home of the spirits. The authors argue that even though a concept of 'good fuel' exists (woods that are dense, burn slowly and produce little smoke) this does not translate in habitual preference for, and use of, such taxa. The 'good fuel' property is invoked only when extraordinary circumstances (short-term fuel shortages or requirements for special events) necessitate additional labour for wood procurement. Instead, the byproducts of agricultural activities (woodland clearance for the establishment of new tree groves) are regularly used as a source of domestic fuel wood. Several wood species are never collected (even from cleared fields) because they are deemed to be 'bad fuels' due to cultural restrictions. This case study and several other ethnographic accounts demonstrate that while fuel needs and patterns of use develop in response to everyday subsistence activities, at the same time, they are also the results of locally determined strategies of fuel use and cultural perceptions.

Functional or cultural perceptions of the qualities of individual species may sometimes outweigh practical necessities. For instance, the Erenk of Siberia reportedly avoid using birch wood as fuel, as they believe it to be harmful to humans; instead they use larch in various states (green, dead, rotting) for most fuel needs (Henry 2011). Therefore, selective pressures may not always be exerted equally on the most abundant species in the landscape. In some cases, cultural distinctions of fuel preference may act as markers or ethnic, communal or socio-economic boundaries, regardless of species availability. Along these lines, the Erenk (Siberia), for example, choose the location of their settlements partly based on the availability of standing dead larch trees in the vicinity. To view such cultural norms of habitation and resource use in a purely functional way (i.e. settlement location chosen based on the availability of particular wood species in the natural vegetation) would be misleading and simplistic. If this was the case, and energy returns rather than cultural factors were the driving factor behind fuel use and settlement location, the same group of people would not have a problem burning shrub species and birch wood.

In sum, fuel selection (or more correctly procurement) cannot be considered as predominantly functional, cultural or technologically and environmentally optimal. From an anthropological perspective, all such considerations (and perhaps several more not necessarily amenable to direct empirical investigation) contribute to the decision-making strategies of individuals and social groups about how, when, where and which fuels to use for a wide range of purposes. In the end, what we find in the archaeological record are the material residues of fuel procurement and consumption representing the end product of complex *chaînes opératoires* of fuel use (Dufraisse et al. 2007; Dufraisse 2012). As a result, anthracological assemblages, along with the residues of other fuel types, reflect not only the vegetation accessible to (and used by) the communities in any given settlement but also the ways in which such resources were perceived, adapted to local conditions and technologies and finally incorporated into daily life (and by extension, subsistence economies).

3 Recent Methodological Developments

The focus of more recent anthracological work has been on refining our understanding of wood charcoal taphonomy, particularly in relation to residues derived from fuel waste. Several experimental and ethnoarchaeological investigations (Sect. 3.1) have addressed depositional and post-depositional processes impacting charcoal fragmentation in relation to species, the nature of post-depositional disturbances and the estimation of log diameter. In addition to taphonomic concerns, considerable effort has been expended on understanding wood condition (i.e. green wood vs. deadwood) and the diameter of the logs used in fires (Sect. 3.3). These developments are largely inspired by ethnographic evidence highlighting the importance of dry deadwood availability and log size in fuelwood collection (Sect. 3.2). Additionally, the detection methods for the identification of woodland management practices in archaeological wood charcoals have become increasingly important (Sect. 3.4).

3.1 Wood Charcoal Taphonomy

The processes impacting the preservation of wood charcoal remains deriving from fuel waste debris relate to practices of primary deposition (e.g. hearth type), redeposition (discard) and post-depositional weathering (e.g. soil moisture, surface exposure and freeze-thaw cycles) and trampling by people and animals. More recent advances in the study of wood charcoal taphonomy come from numerous experiments by Théry-Parisot et al. (2010b), Lancelotti et al. (2010), Chrzazvez (2013) and Chrzazvez et al. (2014). These were conducted for testing Chabal's hypotheses regarding the observed patterning in charcoal fragmentation, particularly in relation to fragmentation during burning and weathering following the discard of fuelwood waste. Théry-Parisot et al. (2010b) conducted fire experiments using a single species in each fire experiment to test whether species-specific wood anatomical features have any significant impact on the rate of charcoal fragmentation and/or the number of fragments produced. The carbonised wood fragments were collected at the end of each experiment, sieved into different size fractions (>4 mm, 4–2 mm, <2 mm) and counted to assess the fragmentation indices for each species. The purpose was to evaluate whether fragment counts reflect the original quantities of wood placed in the fire and the effects of taxon-specific properties on rates of fragmentation (e.g. wood density, chemical composition, anatomy, etc.). The authors found no significant correlation between species-specific variables and the fragmentation rates of wood charcoal. When the entire experimental assemblage was quantified based on fragment counts (295,688 fragments of >2 mm charcoal, produced from 110 controlled fire experiments), the results confirmed the original relative proportions of species used as fuel for 6 out of the 11 species selected for these experiments (Théry-Parisot et al. 2010b: 86 & Figs. 4–6 therein).

Chrzazvez (2013) conducted a different series of repeated experiments testing the post-depositional fragmentation of wood charcoals. She used equal numbers of wood charcoal fragments from each taxon, with the aim of evaluating the rates of fragmentation of different species under surface weathering conditions, freeze-thaw cycles, mechanical pressure and wet-dry cycles. She reported that of all the species tested, oak and beech charcoal produced the highest number of fragments, especially in <2 mm fractions (Chrzazvez 2013: 293–298 & Figs. 152–155). As a result of trampling, surface weathering, freeze-thaw cycles and mechanical pressure, a majority of >2 mm fragments broke down into smaller size classes for all the species included in the experiments. In most archaeological wood charcoal assemblages, <2 mm fragments rarely preserve enough anatomical features to permit botanical identification. Conditions of repeated wet-dry cycles resulted in a very high proportion of <1 mm charcoal fragments. Chrzazvez concluded that overall mechanical pressure produces the highest fragmentation rate; all experiments resulted in higher fragmentation rates amongst size fractions <2 mm (Chrzazvez 2013: 306–312).

Théry-Parisot et al. (2010b) and Chrzazvez (2013; see also Chrzazvez et al. 2014) found that >4 mm size fractions were more representative with regard to the relative proportions of the wood originally burnt as fuel and the quantities of wood charcoal fragments subjected to post-depositional fragmentation, respectively. However, occasional differences were also evidenced: Of all the taxa included in the experiments conducted by Chrzazvez (poplar, hazel, pine, ash, oak, beech, maple, birch, juniper, hornbeam), oak charcoals produced the highest number of >4 mm fragments, while poplar produced the least. Yet both sets of experiments demonstrated that the taxa most intensively used as fuel still emerged as the most abundant ones in the resulting wood charcoal assemblages. Thus, as originally suggested by Chabal et al. (1999), focusing on the analysis of fragments >2 mm and especially >4 mm provides the most reliable reconstruction of the relative proportions of the woody taxa used as fuel. Regardless of any discrepancies that may be observed in the carbonisation stage, depositional and post-depositional processes appear to impose a random and even filter on charcoal fragmentation for all the tested species.

The detailed ethnoarchaeological investigations at the village of Sarakini (Thrace, Greece) by Ntinou (2002) demonstrated that the wood charcoal fragments contained in fire features (hearths, ovens) contained either the remains of the most recent burning event and/or a very small amount of residual fuel waste accumulated over longer periods. Ntinou also observed that more expedient fire features (e.g. open fires next to seasonal work sites or those on the edges of agricultural fields) contained fuel waste debris reflecting the vegetation in the immediate vicinity of the hearth. As these tend to be features with minimal pyro-technological requirements and less labour investment, the fuel used in them is likely to reflect a resource maximisation scenario (Ntinou 2002: 115–120). On the other hand, more permanent and complex fire features, such as outdoor ovens and domestic hearths, contained a mix of preferred fuel sources and easy to collect ones. Ntinou reports that these features are cleaned on a regular basis and their debris deposited in designated midden areas. The author's analysis of midden charcoals demonstrated that they represented a composite picture of fuel use in contemporary fire features. These observations provide further support to the preferential selection by analysts of specific context types containing charcoal scatters accumulated over long periods of time (e.g. midden and midden-like deposits) as the most suitable proxies for reconstructing long-term trends in fuel collection and consumption.

Until recently, charred plant remains were thought to be composed of mostly inert carbon, which would render them durable to further decomposition. Instead, more recent research demonstrated that the major components of woody tissues (cellulose, hemicellulose and lignin) are converted into benzenoids, known to be unstable in alkaline conditions (Cohen-Ofri et al. 2006; Braadbaart and Poole 2008; Braadbaart et al. 2009; Huisman et al. 2012). Burnt plant remains are therefore subject to further decomposition after carbonisation, quite independently of other depositional and post-depositional variables. Such alkaline conditions could be prevalent in archaeological contexts if burnt plant debris was discarded together with the accompanying ash from fires (ash is predominantly alkaline, containing a significant amount of calcium and potassium oxides). Similarly, Rebollo et al. (2008) demonstrated through experiments under controlled pH conditions that soil alkalinity results in the degradation and fragmentation of wood charcoals, while acidic soils might also result in the accumulation of mineral deposits on charcoal particles. Further evidence for decomposition and degradation of carbonised remains is provided by Scott (2010) and Ascough et al. (2011) who report that, as a result of oxidising conditions, the graphitic components of wood charcoal degrade with time into materials chemically and macroscopically similar to humic acids.

3.2 Fuel Selection and Use

As already discussed, ethnographic work has highlighted the significance of dry-deadwood availability and size of logs as important criteria in fuelwood collection. Thus, recent anthracological work has sought to incorporate studies of patterns of

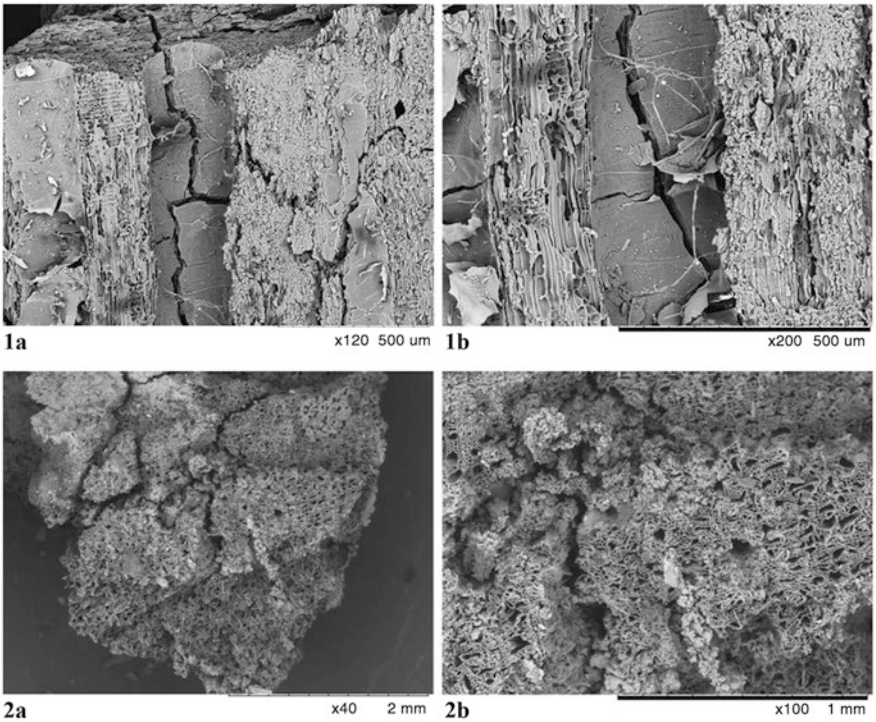

Fig. 1 Fungal decay preserved in archaeological wood charcoal specimens. 1a, 1b: *Quercus* (Çatalhöyük), fungal mycelia preserved in vessel walls. 2a, 2b: Salicaceae (Boncuklu), collapsed vessels, fibres and parenchyma tissue, most likely as a result of fungal decay

wood decay and reconstructions/estimations of log diameter into anthracological analyses which had previously relied solely on botanical identification. Experimental charring of fungi-affected wood by Moskal-del Hoyo et al. (2010) and Théry-Parisot (2001) has provided new evidence on the preservation of remnants of fungal hyphae and spores in wood charcoal (see also Fig. 1). The alterations observed in wood anatomy as a result of fungal attacks, as well as the mycelium and deposits of crystal oxalate salts in vessel elements, can be readily observed in wood charcoals. Previously, microscopic observations of fungal hyphae were interpreted as post-depositional attack on the charcoal (Heiss and Oeggl 2008), whereas only imprints of fungal mycelia on vessel walls were considered to be reliable indicators of fungal infestation prior to charring. However, experimental work by Moskal-del Hoyo et al. (2010) demonstrated that fungal hyphae can also be preserved in charcoal, and the use of this criterion alongside other anatomical effects of fungal rot (e.g. collapsed vessel walls, crystal oxalates) may confirm the use of deadwood as fuel. The same authors suggest that preserved hyphae attached to cell walls can be safely interpreted as evidence of fungal attack prior to charring (Moskal-del Hoyo et al. 2010: 211).

More recent work on the identification of different states of decay in conifer wood by Henry and Théry-Parisot (2014) confirms that the various stages of fungal decay and rotting can be detected through the detailed study of the wood anatomical features of charcoal specimens. These authors report that the degree of cell deformation and the frequency with which such features occur in a charcoal fragment could be indicative of the degree of fungal and/or microbial decay of the wood before charring. In the most severe cases, the dominant presence of fungal hyphae is accompanied by severe cellular deformation (collapsed and/or thin cell walls dominating the transverse section, alongside the occurrence of gaps and cavities in wood grain). Such features could be interpreted as indicators of whether deadwood was collected in earlier stages of decay or in the rotting stage. More experimental work is necessary for establishing reliable signatures of fungal decay stages in hardwoods that are more common in temperate and semiarid regions.

Estimates of minimum log diameter of fuel wood harvested have been applied in anthracology in a variety of ways since the 1970s (Willerding 1971) and were later developed further by other researchers (Hillebrecht 1982; Marguerie 1992; Marguerie and Hunot 2007; Ludemann and Nelle 2002; Dufraisse 2002, 2006; García Martínez and Dufraisse 2012; Paradis et al. 2013). As mentioned earlier, the size of wood can be as important as species availability in what concerns fuel selection. Therefore, considerable emphasis has been placed on improving wood calibre estimation methodologies over the last two decades. There are two main approaches currently employed in anthracology: (1) qualitative estimation of growth ring curvature and (2) quantitative calculation based on growth ring curvature and the angle between rays.

The qualitative ring curvature estimation criteria developed by Marguerie (1992) and Marguerie and Hunot (2007) classify growth rings into three groups (Fig. 2): curvature degree (CD) 1, weakly curved rings; CD 2, moderately curved rings; and CD 3, strongly curved rings. The definition of curvature classes is based on the observation that small branches and twigs have strongly curved growth rings while moderately large trunks are classified as CD 2 and large trunks as CD 1.

Quantitative methods of calibre estimation made using a transparency printed with growth ring perimeters of different diameter classes provide a visual estimate of growth ring morphology (cf. Willerding 1971; Lundström-Baudais 1986; Ludemann and Nelle 2002; Dufraisse 2002, 2006). Another variant is the use of the 'circle tool' in microscope imaging software to provide a good fit of a circle or arc on the largest visible growth ring of a specimen (Ludemann 2006; see also Fig. 2). Both methods have shortcomings when it comes to measurements on specimens with growth anomalies (e.g. wavy growth rings resulting from climatic or mechanical stress).

Trigonometric methods of quantitative diameter estimation use the angle of the rays together with the outermost growth ring boundary (Fig. 2, Paradis et al. 2010, 2013). These authors conducted repeated measurements on collected wood of known diameter (both freshly cut and carbonised) to test the reliability of various techniques of wood calibre estimations, comparing trigonometric estimation methods with the circle tool (Paradis et al. 2013). They report that measurements made using the circle tool produce a much larger error margin (nearly 1/3 of the measurements resulted in >60% error) because they seek to calculate the perimeter of the original

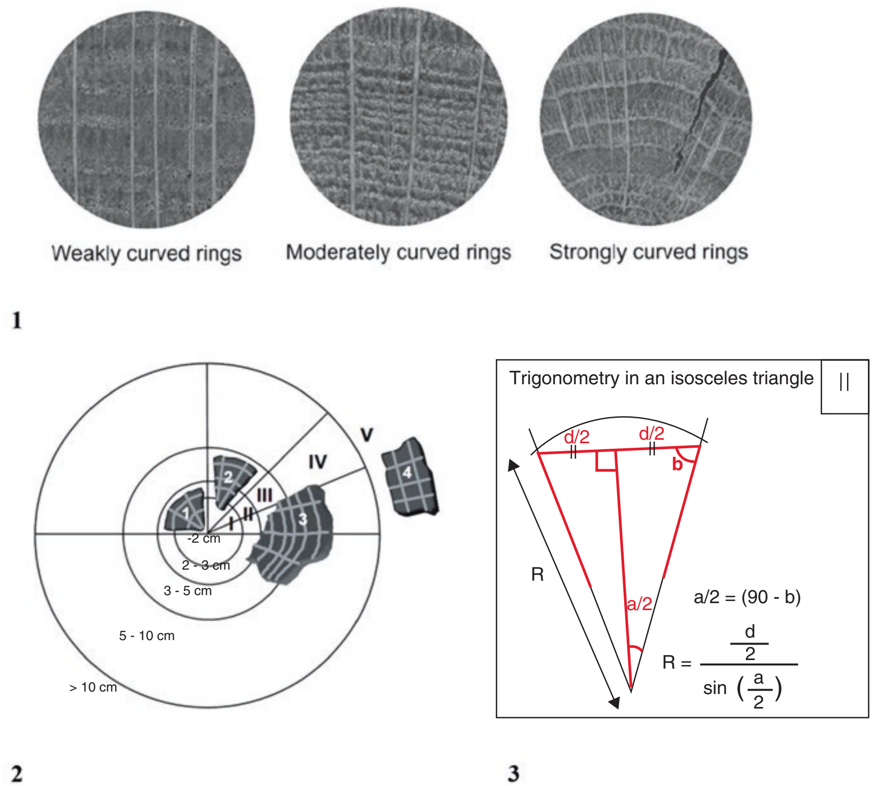

Fig. 2 Diameter estimation methods. 1. Test card for qualitative evaluation of tree-ring curvature degree (After Marguerie and Hunot 2007). 2. Circle tool used for the estimation of wood diameter size classes represented in an anthracological assemblage (After Ludemann 2006). 3. Method of calculation of estimated radius of curvature (R) using the trigonometric method; minimum estimated diameter = 2 × R (After Kabukcu 2017)

log rather than its diameter. By contrast, techniques which rely on geometric and/or trigonometric measurements using the angle of the rays and the distance between two rays to calculate the radius of curvature produce a much smaller margin of error. This is because several anchor points are used thus accounting for variability in curvature. It is also noted, however, that it is often difficult to make accurate diameter measurements of twigs (≤1 cm in diameter) due to the acute angle of the rays close to the pith (Paradis et al. 2013).

On a theoretical basis, Dufraisse (2008: 203) has proposed that fuel waste debris comprises wood charcoal fragments that are representative of the calibre of the logs originally put into fires. In the same paper, Dufraisse also argues that the majority of the preserved charcoal fragments likely derive from the largest diameter portions of the logs originally put into fire. For example, the burning of a log of 15 cm diameter will produce wood charcoal fragments most of which when measured with the trigonometric tool will generate diameter estimates approximating 10–15 cm. Recent burning experiments by Théry-Parisot et al. (2016) conducted on wood of known diameter have provided new insights into the preservation of diameter size classes. Following repeated burning experiments with uniform diameter logs and whole branches/trunks, these authors found significant differences in charcoal diameter classes compared to the proportions of wood diameter classes originally put into fire. While burning experiments have been limited with regard to the different possible combinations of log sizes (i.e. mixtures of larger and smaller logs, log-splitting, etc.), this particular study suggests that when a log is placed into the fire, the outer portions of the log (i.e. those in immediate contact with the fire) are more likely to burn completely and/or preserve as small charcoal fragments. In the case of large diameter logs of uniform diameter (e.g. 15–20 cm), the results of diameter estimation indicate a greater number of fragments in the 5–10 cm and 10–15 cm diameter classes. In the case of fires using predominantly 7–10 cm diameter logs, diameter estimations indicate a far greater number of fragments falling in the 0–5 cm diameter class. When a whole trunk, with all branches and twigs, is burnt, the resulting wood charcoal diameter classes are similarly dominated by small diameters (Théry-Parisot et al. 2016: 492–493). These findings, if tested further with additional fuel use scenarios and under diverse burning environments (e.g. ovens, hearths, outdoor fire features), hold distinct potential for improving current understandings of log diameter representation in archaeological wood charcoal assemblages.

3.3 *Woodland Growth Conditions: Ecophysiological Attributes on Charcoal Wood Anatomy*

One of the greatest concerns with diameter estimations applied to archaeological wood charcoal remains is to ascertain whether smaller-diameter specimens derive from the inner portions (e.g. the heartwood) of large trunks or from twigs/branches. This necessitates identifying the occurrence of heartwood and sapwood in charcoal fragments. For conifers such determinations may prove difficult, as the main difference between the sapwood and heartwood relates to colour, which is unobservable in carbonised wood remains. On the other hand, in hardwood species that form tyloses (e.g. oak), these are usually absent from the sapwood. Tyloses are overgrown parenchyma cells which spread through pitting on vessels filling out the vessel cavity (Fig. 3). In the heartwood, groups of tyloses often become lignified and block vessel cavities completely thus increasing the resistivity of wood to the spread of fungal hyphae (Wilson and White 1986: 207–211; Taylor et al. 2002). Thus, recording the presence of tyloses provides a useful means of assessing which part of the stem charcoals are likely to have derived from (Dufraisse et al. 2017). However, when trees are felled during their active growth season, tyloses may develop in the sapwood as well. Tyloses may also form when wood is cut during dormancy and

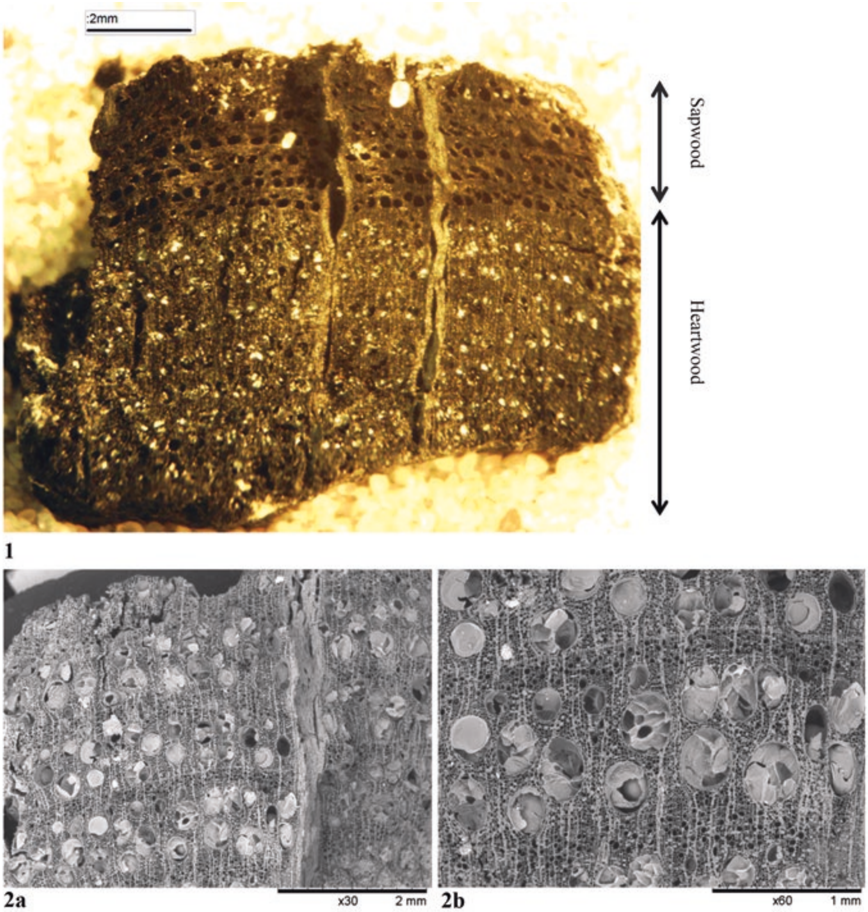

Fig. 3 1. *Quercus* (Çatalhöyük), transition zone from heartwood (with tyloses) to sapwood (without tyloses) (Stereo-zoom microscope digital image). 2a, 2b: *Quercus* (Çatalhöyük), tyloses in earlywood vessels

then stored for a period of time or as a result of other kinds of physical injury (trauma) (Murmanis 1975; Schweingruber 2007).

Several wood anatomical features can provide evidence of woodland growth conditions, environmental stress, damage to the bark and cambium by exogenous factors or anthropogenic impacts (Kabukcu 2017, see Fig. 4). Open wounds (e.g. from bark stripping) cause increased cell formation and cell wall thickening, as well as a change in fibre direction, all resulting in scar tissue formation. Callus formation can be caused by numerous factors including bark and cambium scarring caused by lightning, fire, bark stripping, frost and hail damage, the shedding of twigs and/or needles, etc. (Schweingruber 2007: 188). Traumatic resin canals in conifers and traumatic gum ducts in hardwoods can also form in response to factors such as

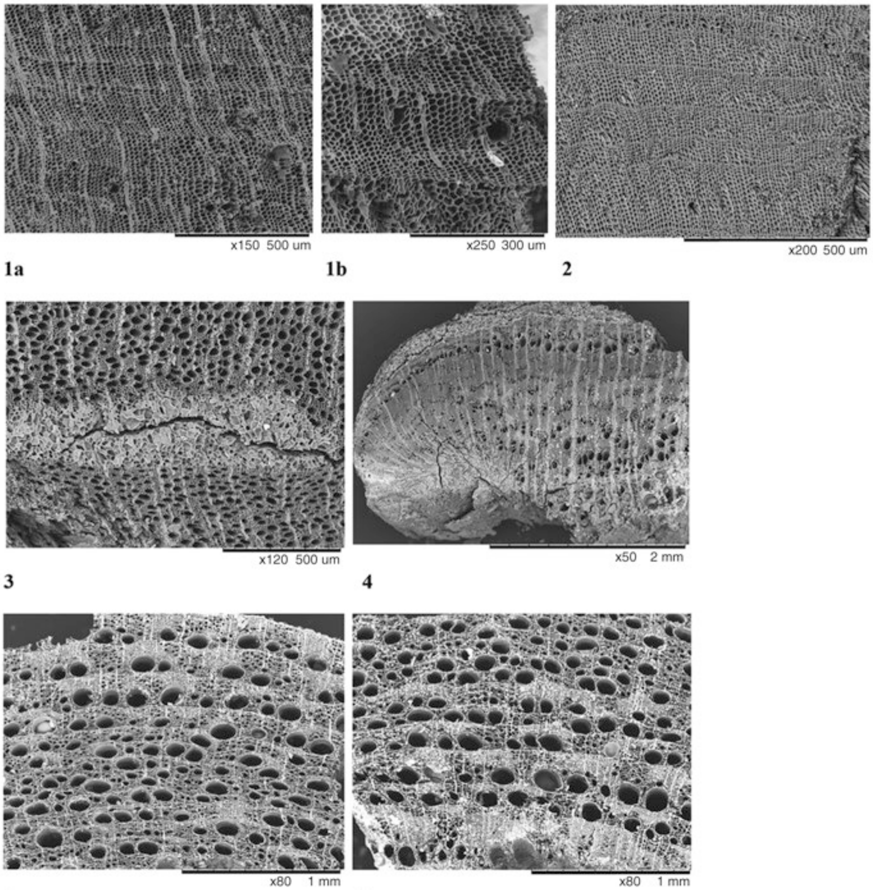

Fig. 4 Qualitative wood anatomical features associated with tree ecophysiology, examples from anthracological remains. 1a, 1b: *Juniperus* (Çatalhöyük), deformed tracheids, narrow and discontinuous rings. 2: *Juniperus* (Pınarbaşı Epipaleolithic), narrow and discontinuous growth rings, deformed tracheids (right). 3: Maloideae (Çatalhöyük), callus tissue. 4: Ulmaceae (Çatalhöyük), scar tissue (wound or damage occurred shortly after initial earlywood formation, radial overgrowth continued during the latewood and earlywood of the following year). 5a, 5b: *Quercus* (Çatalhöyük), round wood fragment with narrow and discontinuous rings

spring frost and other extreme weather conditions and defoliation (Schweingruber 2007: 85, 182, 187). Conditions of severe ecological stress (drought, widespread defoliation) may also lead to the formation of very narrow (<0.2 mm) and/or false growth rings (Schweingruber 2007: 98–99). Increased competition in the understorey (for light and/or nutrients and water) and browsing pressures can result in the formation of series of narrow and/or discontinuous growth rings, resulting from reduced growth rates.

3.4 Woodland Management

Woodland management entails the creation and maintenance of anthropogenic woodland habitats, whereby the density of woodlands stands, their species composition and cycles of regeneration are controlled, to a great extent, by people. These practices can range from more established silviculture systems (e.g. coppicing and pollarding) to the protection of woodland stands and clearance of invasive herbaceous plants and shrubs (Asouti and Kabukcu 2014). In most cases, woodland management relies on the capacity of trees to regenerate from dormant buds on the trunk/stump or from root suckers. In anthracology, particularly in relation to people-environment interactions and palaeoecology, the reconstruction of ancient woodland management, especially the identification of the prehistoric use of coppicing/pollarding practices, has become an important research area. Several recent archaeological applications, including dendrochronology (e.g. Billamboz 2008; Bleicher 2014) and dendroanthracology (e.g. Ludemann and Nelle 2002; Nelle 2002; Dufraisse 2006; Deforce and Haneca 2015), have addressed the question of past woodland management activities through observations on archaeological wood (including carbonised and waterlogged remains). In anthracology woodland management is studied through the application of log/wood diameter estimations (discussed earlier) alongside observations on average growth ring width (e.g. Ludemann and Nelle 2002; Nelle 2002; Dufraisse 2006, 2008; Wright 2017). Such methods may indicate, for example, the predominant presence of more uniform (and small) diameter classes in anthracological assemblages and/or growth improvement patterns, both of which may reflect past woodland management practices. Approaches relying on diameter classes can be problematic due to the differential rates of diameter preservation in archaeological wood charcoal specimens (see discussion earlier; also Théry-Parisot et al. 2016). Additionally, practices such as coppicing, pollarding or bark shredding do not always produce wood logs of uniform diameter. In fact, if coppicing is carried out for the purpose of fuel wood production, then stems of variable sizes will be harvested comprising a mixture of trunk wood, branches and twigs. On the other hand, if management is predominantly aimed at leafy fodder production or building poles, then more uniform diameter classes would have been selected.

Furthermore, it is often difficult to differentiate between the impacts on wood anatomy of management strategies (such as coppicing, pollarding, lopping, etc.) and other environmental factors. Several ecological and anthropogenic factors impact on the growth conditions of managed or unmanaged stands. This situation is further accentuated by the vast amount of intraspecific variability observed in the wood anatomical characteristics of seedlings, long and short shoots and stems. Various studies of managed woodlands (e.g. Rozas 2003, 2004; Corcuera et al. 2006; Copini et al. 2010; Altman et al. 2013; Deforce and Haneca 2015) have demonstrated that management strategies impact wood anatomy either by enhancing or hindering radial growth (hence growth ring width). Generally, shoots growing from cut-down coppice stools have larger vessel diameter and wider growth rings compared to seedlings (see Fig. 5). After a cycle of thinning, involving either the cutting of a patch of coppice stools or the thinning of standards, the remaining trees experience a period of improved growth conditions characterised by an abrupt increase in ring width (referred to as growth release period) (Fig. 5; also Schweingruber et al. 1990; Corcuera et al. 2006; Altman et al. 2013; Schweingruber 2007). Growth release is sustained for 5–10 years, with ring width substantially higher than average growth years. In the years leading up to a cycle of cutting, most sprouts and stems on coppice stools display reduced growth rates, due to competition for light and nutrients caused by increased canopy density (referred to as growth suppression period) (see Fig. 5; also Schweingruber et al. 1990; Rozas 2004; Bleicher 2014). On the other hand, pollarding, pruning and browsing result in a sudden reduction in growth rate, due to trauma and subsequent radial overgrowth (Fig. 5; also Thiébault 2006; Schweingruber 2007: 139).

In rare instances where large numbers of small-diameter wood with pith and bark preserved have been recovered at archaeological sites, these applications can be refined to follow a more dendrochronological methodology (i.e. involving continuous ring-width measurements and comparisons across populations in the same phase; see Deforce and Haneca 2015). In such cases, growth dynamics observed in individual specimens can shed light on management practices with greater accuracy. Recent applications of such methods, by Kabukcu (2017) on the anthracological assemblage from the prehistoric site of Çatalhöyük in central Turkey, highlight the potential of combining diameter estimation methods with continuous growth ring-width measurements and recording of indicators of ecological stress, for characterising woodland management and other environmental impacts on tree growth conditions. In deciduous oak charcoals, diameter classes and curvature degree estimates, proportion of tyloses (indicating presence/absence of heartwood) and continuous ring-width measurements were used to evaluate in detail temporal changes in woodland growth dynamics. Specimens with pith and bark preserved were rare. For this reason, the analysis focused on evaluating average radial growth and rates of change in radial growth observed for each specimen (i.e. the difference between the widest and the narrowest ring width per specimen). Based on these observations, it was argued that deciduous oak charcoals at Çatalhöyük originated mostly from a mixture of coppice shoots, branches and twigs, alongside fragments derived from mature trunk wood.

With the exception of annual growth ring-width measurements, applications of quantitative wood anatomy on archaeological wood charcoal remains have been limited to date. Studies of wood anatomical variation in wild, feral and domesticated olive populations (cf. Terral 2002; Terral and Durand 2006; Terral and Arnold-Simard 1996; Terral and Mengüal 1999) have indicated that variations in vessel density, vessel diameter, total vessel area and growth ring width might signal the effects of different climatic conditions or the impacts of management practices. For instance, lower vessel density has been reported for wild olives growing in conditions of higher moisture availability resulting from irrigation and competing vegetation clearance (Terral and Arnold-Simard 1996).

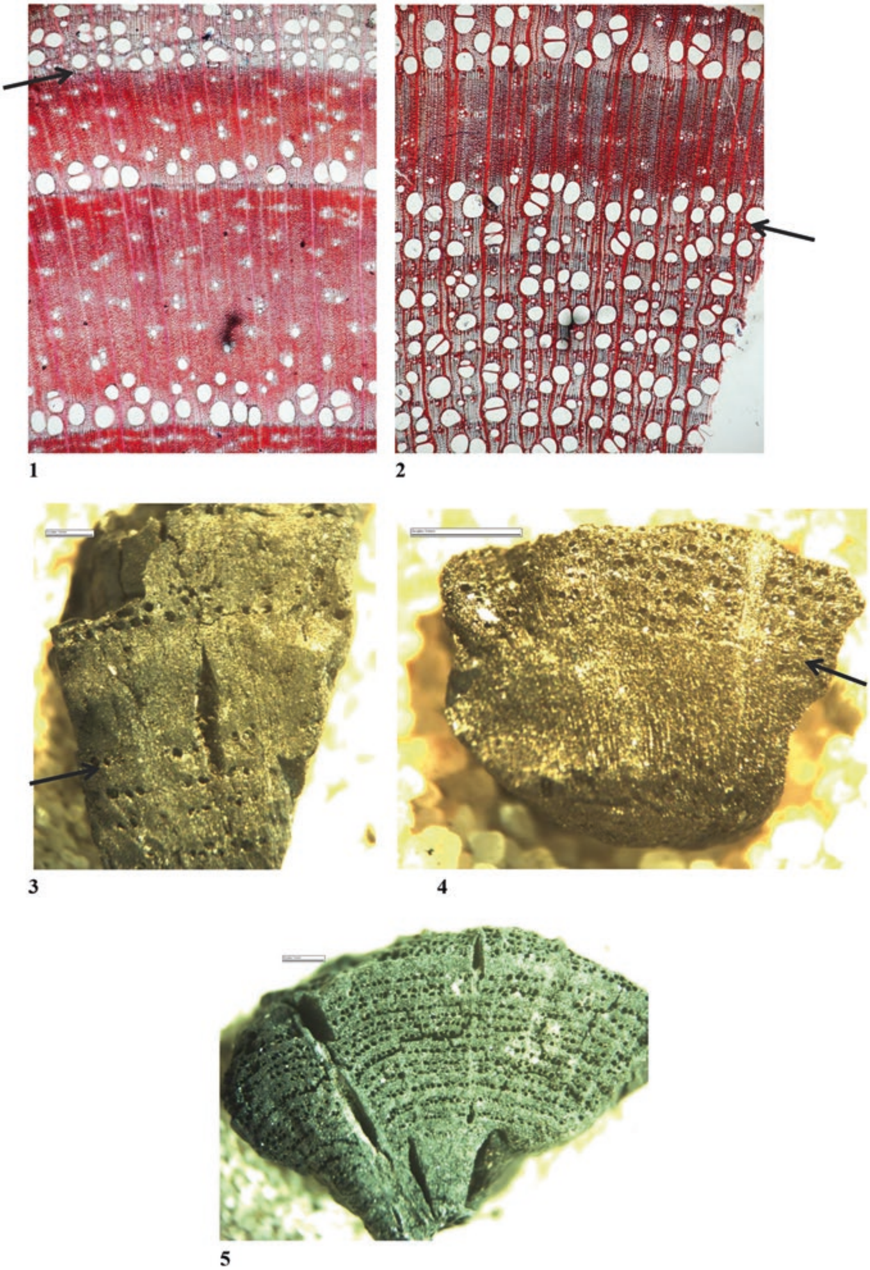

Fig. 5 Growth variability under woodland management. 1. *Fraxinus excelsior*, crown lopping (e.g. pollarding), results in successive growth reduction indicated by arrow. 2. *Fraxinus excelsior*, coppiced stem; arrow indicates growth release period. 3. *Quercus* (Çatalhöyük), arrow indicates growth release. 4. *Quercus* (Çatalhöyük), arrow indicates growth suppression. 5. *Quercus* (Çatalhöyük), suppressed/dwarfed sapling or shoot with brief periods of growth improvement (1–2: images by author, reference material kept by the WSL, F.H. Schweingruber; 3–5: images by author)

4 Conclusions

The aim of this chapter was to summarise the main methodological and interpretative developments in the field of charcoal analysis (anthracology), defined as the study of wood fuel remains derived from archaeological sites. Following the development of charcoal analysis predominantly as a method for reconstructing past woodland composition and its changes through time, more recent applications emphasised the complexities of palaeoecological and cultural signals preserved in archaeological fuelwood remains. It is now well established that anthracological remains (when analysed following strict protocols regarding sample choice and subsampling laboratory procedures) can provide a representative picture of the relative proportions of fuelwood species used by past societies. Anthracological assemblages represent the material residues of people-woodland interactions. Carbonised wood fuel remains embody the signatures of the growth conditions and life histories of the individual trees and shrubs collected as fuel and of the woodland ecologies they have derived from. Thus, not only species composition but also the form, ecological function and environmental setting of past woodland vegetation, and the ways in which these were impacted by management activities, should also be studied. Anthracology provides a unique set of analytical tools with which to disentangle the varied phases of the complex feedback cycles between vegetation, climatic conditions and past woodland management and landscape use practices. For these reasons, archaeological wood fuel remains represent a category of archaeobotanical data that are exceptionally well suited for reconstructing the evolution and long-term histories of anthropogenic landscapes.

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Palaeoethnobotanical Contributions to Human-Environment Interaction

Gary W. Crawford

1 Introduction

I could easily have become a botanist or ecologist when I was a student, but my interests also included human behaviour and our ancient past. Palaeoethnobotany provided the context for me to explore issues that connected people to plants through time. The best definition of palaeoethnobotany as I practice it is "the analysis and interpretation of the direct interrelationships between humans and plants for whatever purpose as manifested in the archaeological record" (Ford 1979). Lately the definitions of palaeoethnobotany and archaeobotany have become blurred. Originally, archaeobotany focussed on the plant remains and the nuances of their identification and assessing traits that distinguish domestication; however, the definition of palaeoethnobotany at least clarifies my background and training. Within environmental archaeology, a subdiscipline that focusses on the interaction of people and the environment, one purpose of palaeoethnobotany is to understand how plant remains can inform this interaction. Palaeoethnobotany addresses many other issues that include social and culinary practices, food preparation and cooking, diet, subsistence practices, agricultural origins, plant domestication, and crop dispersal (Hastorf 1999; Sayre and Bruno 2017; VanDerwarker et al. 2015). These issues are not mutually exclusive and require articulation with environmental issues; however, my chapter does not offer an overview of these topics. Technical aspects such as recovery, preservation, or identification of plant remains have been reviewed elsewhere within the last few years (e.g. VanDerwarker et al. 2015; Marston et al. (or "d'Alpoim Guedes and Warinner") 2014) so are not covered here. Ceren Kabukcu reviews wood charcoal analysis in another chapter in this volume. I focus on the particulars of my experience in East Asia and Eastern North America with issues in

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palaeoethnobotany as they pertain to human-environment interaction. I emphasize how plants can inform reciprocal interaction between people and the environment and provide some historical background and assess current theoretical perspectives that are mainly, but not exclusively, situated in human ecology. Nearly 20 years ago, I assessed progress in the Northeast region of North America and came to the conclusion that the potential for palaeoethnobotanical research envisioned in the 1960s and early 1970s was finally being realized and that the discipline had finally come of age (Crawford 1999). The same can be said for much of the world today.

2 History and Progress

Palaeoethnobotany is primarily an anthropological field of enquiry that examines the interplay of people and the environment informed by human culture, although a significant component of archaeological plant research focusses on plant remains morphology, domestication, plant distribution, and other specific plant-related issues. My anthropological influences are numerous, but among them the most influential was Richard Yarnell who supervised my doctoral research. He taught both in the anthropology department and in the ecology curriculum at the University of North Carolina. Before I studied with Yarnell, my undergraduate preparation included the fundamentals of anthropology, archaeology, botany, and ecology. However, Yarnell exposed me to novel ways of integrating the complexities of each of these areas, being explicit about reciprocity in human ecology. Vegetation bears the signature of human influence and people in turn developed stable relationships with their anthropogenic landscape, at least periodically and that palaeoethnobotany can inform these issues (Yarnell 1963, 1965, 1982). Their integration did not lie strictly in environmental archaeology; it needed to be in the more inclusive world of human ecology or ecological anthropology. My influences are not only Yarnell but include Geoffrey Dimbleby (1978), Jane Renfrew (1973), Karl Butzer (1975, 1982), Edgar Anderson (1971), Andrew Vayda (1969; Vayda and Mccay 1975), and his students, Fredrik Barth (1956) and Roy Rappaport (1971), to name a few. Eugene Odum's (1963, 1969, 1975, 1983) ecological succession has also informed my archaeological research.

Palynology was prominent in what was probably the first major treatise on people and their relationship to the environment in the Old World (Dimbleby 1978). Jane Renfrew (1973) published the first major English-language synthesis of archaeobotany. The volume provided a synopsis of what we knew about European and Southwest Asian plant remains particularly as they pertained to early agriculture rather than to environmental issues. The palaeoethnobotanical approach that has its beginnings in North America contrasts with that of Dimbleby and Renfrew. New World palaeoethnobotany developed parallel to New World archaeology whose roots were deeply integrated with the ethnographies of indigenous New World peoples (Ford 1979; Willey and Sabloff 1993). Palaeoethnobotany thus developed with strong relationships to anthropological inquiry and the relationships that indigenous people had and have with their environment. Melvin Gilmore, and Volney Jones and his students, who in the early days included Richard Yarnell, were instrumental in developing the foundations of North American palaeoethnobotany. In fact, Volney Jones was an ethnobotanist before he started identifying archaeological plant remains early in career at the University of Michigan (Ford 1978). Richard Yarnell's monograph, *Aboriginal Relationships Between Culture and Plant Life in the Upper Great Lakes Region* (1964), compiled archaeological plant remains data available at the time in the first synthesis of palaeoethnobotany in an explicit interactionist perspective. Two issues Yarnell encouraged us to investigate were manifestly ecological: anthropogenesis and the use of disclimax/early succession vegetation. Following through on these issues where I work in northeastern North America has been hit and miss (Crawford 1999) although elsewhere in North America some attention to these issues has been productive (e.g. Minnis 1978; Hammett 1992, 1997).

Accomplishments related to land use and landscape reconstruction and change are assessed in a comprehensive review of research in palaeoethnobotany (Hastorf 1999) and updated 17 years later (VanDerwarker et al. 2015). The environmental examples in these reviews involve people impacting their environment but not vice versa. The reviews also acknowledge that environment-focused research generally emphasizes plant communities and understanding particular habitats and co-occurrences of plants represented in the archaeological record. Assessing the influence of climate change on agriculture is still a significant research area.

One way to examine trends in palaeoethnobotanical research is to examine specific compilations such as the journal *Vegetation History and Archaeobotany*, the voice of the International Work Group for *Palaeoethnobotany* (emphasis mine) whose focus is not entirely representative of the field, being Quaternary plant ecology, palaeoclimate, and ancient agriculture with an emphasis on the Old World. A review of 94 articles published in *Vegetation History and Archaeobotany* from 2015 through 2017 shows that palynology still dominates (48% of the papers) followed by archaeological seed analyses (33%) (Fig. 1). One paper among the 94 investigates a New World region. The other papers focus on Eurasia and Africa. Most of the palynology and wood charcoal papers are related to environmental reconstruction, but some are addressing anthropogenic forest composition and management (e.g. Dotte-Sarout 2016; López-Sáez et al. 2016). None of the seed-focused papers address human-environment *interaction* as the main point of inquiry, although a few explore anthropogenesis. Exploited habitats are often addressed (e.g. Ramsay and Holum 2015), while another paper examines anthropogenesis as a factor in the abundance of *Canarium schweinfurthii* (Oas et al. 2015). Popular topics among the non-palynology papers are subsistence, plant use, domestication, and type of cultivation practiced. In fact, no explicit archaeological-theoretical perspectives are articulated. Research is materialist or processual, data-driven, and often inductive. Methods are favoured over theoretical perspectives (e.g. Wright 2010) except for issues such as agricultural origins and intensification.

Several edited volumes add to this discussion (Marston et al. (or "d'Alpoim Guedes and Warinner") 2014; Madella et al. 2014). Four chapters of 14 in Madella

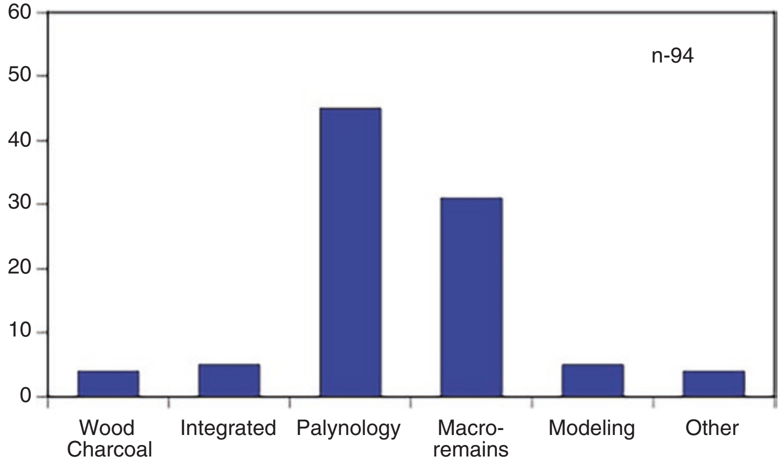

Fig. 1 Percentage of articles in six categories published in *Vegetation History and Archaeobotany* (2015–2017)

et al. (2014) are case studies in "archaeobotany and vegetation history". Two of these chapters are concerned explicitly with ecology: Miller's chapter (2014) explores the interaction of people, plants, and climate, while Riehl (2014) explores whether archaeological plant remains have ecological meaning beyond being weeds. Marston et al. (or "d'Alpoim Guedes and Warinner") (2014) include three chapters that emphasize plants in environmental archaeology (Smith 2014; Gremillion 2014; Messner and Stinchcomb 2014). Recurring themes in both volumes are methodology and subsistence.

Theory in palaeoethnobotany and archaeobotany involves a wide range of issues and topics, but ecology-related theoretical perspectives are not necessarily a dominant focus when we consider journals and edited books over the last 3–5 years. Human ecology is providing the richest body of theory relevant to insights on human-environment interaction derived from ancient plant studies (e.g. Smith 2014; Gremillion 2014; Crawford 2014; Zeder 2016). Current foci are human behavioural ecology (HBE), anthropogenesis, historical ecology, and niche construction theory. Nagaoka and Wolverton (2016) go even further, suggesting that any archaeological research involving human-environment interactions in the past can find an intellectual home in the broad discipline of ethnobiology.

3 Human Ecology

Establishing the ecological context is essential whether we are investigating plant domestication, agricultural origins and intensification, resilience of particular human adaptations in the past, or other related issues. Palaeoethnobotany does not have its own unifying theory (Ford 1979); however, the principles of human ecology and ecological models and methods provide relevant contexts within which the interrelationships between humans and plants in the past may be framed. Determinism is the bane of causality in archaeological explanations (e.g. Hodder and Hutson 2003). Palaeoethnobotany is not immune to deterministic explanations either. Diffusion, climate change, and/or demography may, of course, be part of the equation, but we should not force-fit data to such influences. Doing so is agenda driven, not hypothesis testing. Argumentation becomes circular, and alternative models are usually ignored because these factors are assumed to be the only possible explanations. In many cases, climate change is not the underlying cause of environment change; anthropogenic impacts such as soil salinification resulting from irrigation are usually more significant (e.g. Jacobsen and Adams 1958; Redman 1999). Another view holds that climate change and its environmental impact may have had a significant impact on human lifeways (Messner and Stinchcomb 2014). Human ecology broadens the discourse to conceptualize human culture in part as a result of interaction with physical and biological variables and involves diverse research at different scales (Lopes and Begossi 2009).

Andrew Vayda's vision of human ecology came to focus on contextualizing issues through an open and flexible research agenda (McCay 2008). Vayda proposed that it was best to start with a problematic situation and then examine who does what and to what effect. The data are contextualized through time in order to understand the consequences of human actions. The methodology is problem driven with a clear reference to historical analysis and proximate causation. In other words, the specifics are important. Palaeoethnobotanical data are quite specific and without doubt lend themselves to historical analysis. Dimbleby (1978) was well aware that plants form a significant background for human life and recognized the role human populations played in vegetation history. The role anthropogenic fire played in rolling back succession and creating specific vegetation particularly interested him; however, unlike my own research that focusses on charred seeds and fruit, pollen provided the data for his analysis. Dimbleby clearly understood that anthropogenic influences were discernable even before modern humans evolved.

Disclimax/early succession vegetation feeds into our human ecological approach because it engages the concepts of ecological succession, disequilibrium, and biodiversity. Climax or late succession forests, for example, are old seres that have maximized standing biomass (Odum 1969). Young seres are characterized by short-lived organisms and high net reproduction rates while communities reassemble (Odum 1969; Letcher et al. 2015). This translates to high rates of seed, fruit, and herbaceous plant production. Any form of disturbance leading to disequilibrium transforms vegetation to an early successional stage. Fauna also mirror the changes in vegetation so an understanding of ecological succession permits the prediction of animal demography and biodiversity. Plant assemblages from archaeological sites thus provide insight into actions taken by people to impact biodiversity and ecosystem resilience and production. Agriculture, for example, is a form of ecosystem in which people have created particular forms of plant biodiversity and productivity that require significant human intervention through the life span of the organisms that are involved (Rindos 1984). Community structure is, therefore, not simply determined by climate and soil. Disturbance plays an important role in plant community structure. In fact most ecosystems are in some state of recovery from their last disturbance (Reice 1994). Archaeological plant remains provide an important window into the equilibrium state of local ecosystems.

Ecological resilience refers to the degree of disturbance that an ecosystem can withstand without changing its structure and maintenance processes (Gunderson 2000). An ecosystem may have several equilibrium states, usually resulting from human-induced state changes. People can change nutrient levels, species composition, soil composition, and so on relatively quickly. Whether different equilibrium states exist in the absence of human activities is open to question (Gunderson 2000), but in archaeological research, humans are part of the equation, so our issues involve human presence. Activities such as agriculture and urban development can have long-term impacts on the ability of ecosystems to return to their previous state. Transplanting, cutting, and anthropogenic fire may affect the resilience of ecosystems over shorter timescales. Resilience theory in archaeology acknowledges that relationships between people and the environment may be stable or changing and that the time depth offered by archaeology can document a diverse range of interactions (Redman 2005). A key point in archaeological resilience theory is derived from ecological resilience: many equilibria and cultural systems are possible (Redman 2005; Redman and Kinzing 2003). Archaeological plant remains can contribute to the ecosystem resilience discourse because of their potential to provide deep historical depth.

Three theoretical approaches to plant-human interaction offer productive avenues of enquiry in addition to resilience theory: niche construction, diet breadth/optimal foraging, and historical ecology. A few palaeoethnobotanists have begun to embrace the niche concept. The first use of the concept in anthropology appears to have been in 1956. Barth (1956), using a case study from Swat, Pakistan, defined a niche as the place of a group in its total environment, its relationship to resources and competitors. Separate ethnic groups, although living in the same region, occupied separate niches. In other words, a niche is defined with respect to an occupant. This relativist niche contrasts with the concept of habitat that is defined by a set of environmental conditions but not by how the organism is feeding, competing, or otherwise behaving. Without the organism, the relative niche effectively does not exist. Of course, habitat and niche overlap but they are not identical. Early ecological succession, for example, may be characterized as an important "regeneration niche" (Letcher et al. 2015). Niche construction refers to organisms actively modifying, creating, and interacting with their habitat and with other organisms. In the plant kingdom, for example, some plants such as barley and black walnut have allelopathic effects, that is, they chemically inhibit competition from other plants or resist pathogens (Heisey 1997; Liu and Lovett 1993). Niche construction or ecological engineering (Odling-Smee et al. 2003) is a broader concept than anthropogenesis although the plant signals in the archaeological record are the same. Palaeoethnobotanists are able to discern ecological engineering by considering how ethnohistorically or ethnographically documented activities such as purposeful expansion of habitats, changing soil conditions by churning mud, transplantation, arboreal resource management through selective culling, burning, and sowing wild seed to increase or insure the abundance of specific early succession plant taxa (Smith 2014).

Human behavioural ecology (HBE) is a neo-Darwinist perspective that applies evolutionary ecology to human behaviour (Winterhalder and Smith 2000). It applies mathematical modelling to explain an adaptive problem (Winterhalder and Smith 2000). The most common application is to decisions about resources in the context of diet breadth and risk. Assumptions in HBE include optimization, a cost-benefit measure, and behavioural options (Gremillion 2014; Winterhalder and Smith 2000). Under changing circumstances, according to HBE, people will choose resources in order to optimize yield. Resources evidenced at sites are, therefore, a result of yield optimization decisions. HBE is not a common theoretical perspective in palaeoethnobotany but has made contributions to agricultural origins and understanding cases of changed resource diversity (Gremillion 2014). Understanding which variables contribute to optimization is crucial given that many variables may be unanticipated; ethnographic research indicates that optimality may not be what it is conventionally assumed to be (Gillreath-Brown and Bocinsky 2017). For example, socializing opportunities created while preparing difficult-to-process grain such as emmer wheat, and the taste and texture of emmer wheat are valued over other, less energy optimal wheats (D'Andrea and Haile 2002).

Finally, historical ecology is a form of human ecology that focusses on landscape rather than ecosystems (Balée 2006). It has close epistemological links to niche construction in that anthropogenic landscape transformation and disequilibrium are central to historical ecology. Much of palaeoethnobotany as it pertains to landscape and anthropogenesis is situated in historical ecology. Modelling in archaeobotanical research, for example, is mainly landscape and agriculture oriented (Gillreath-Brown and Bocinsky 2017). In the following examples, I explore how plant remains may contribute to the discussion of human-environment interaction, particularly from the perspectives of historical ecology and niche construction.

4 Japan: Jomon and Satsumon Cultures

The Jomon cultures of Japan represent a diverse set of adaptations that resemble agriculture but defy characterization as farmers (Crawford 2008). The Jomon Period offers an excellent opportunity to explore resilience, historical trajectories, and anthropogenesis/niche construction because of its significant longevity that covers not only the Pleistocene-Holocene boundary but climate and sea level changes throughout much of the Holocene. Jomon material culture and settlement patterns superficially resemble those of agricultural societies, yet intensive production and consumption of grain did not support Jomon cultures. The Jomon developmental trajectory began in the Late Pleistocene much like the predecessors of the Chinese Neolithic did; however, Early Holocene Jomon populations established a different relationship with

Japanese archipelago ecosystems than did the Chinese Neolithic cultures (Crawford 2011a). A valuable historical ecology-focused discussion currently revolves around the extent to which demographic and socioeconomic changes occurred and how resource diversity contributed to resilience and change during the Jomon in northeastern Japan (Habu 2015). Plant remains are direct evidence of resource extraction and use, so provide another dataset with which to test hypotheses of resource diversity and the effects that Jomon people had on these resources. Some scholars characterize the Jomon populations as specifically nonagricultural hunter-gatherers who lived relatively passively in the relatively rich ecosystems of the Japanese islands (e.g. Kobayashi et al. 2004; Imamura 1996) that provided marine and other aquatic resources such as salmon and shellfish as well as deer, chestnut, walnut, acorn, and horse chestnut/buckeye. This interpretation overlooks critical aspects of Jomon-environment relationships. For example, palaeoethnobotanical research indicates that the immediate Jomon environments were not quite "natural" Crawford (2008).

Beginning in the late 1970s, we began a long-term study of plant remains from Jomon sites in northeastern Japan. The charred plant remains recovered by flotation represent a far greater diversity of utilized plants and a more complex ecological setting than the standard model does. I estimate that close to 200 taxa are represented in the plant remains from northeastern Jomon sites (Crawford 1983). A quantitative and contextual analyses of these plant taxa indicate that fewer than 20 of these are common to most Jomon sites and they are found in contexts indicating that the plants were abundantly growing in and around Jomon occupations and recovered in contexts suggesting their utilization (Crawford 1983, 1997). Most of the plants are herbaceous annuals: grasses, several species of *Polygonum* (knotweed) and *Rumex* (sheep sorrel), and *Chenopodium*, possibly *C. ficifolium*. Although we recovered at least 18 types of grasses, only 2 or 3 are common: barnyard grass (*Echinochloa crus-galli*), *Digitaria*, and a type of Triticeae, likely either *Elymus* or *Agropyron*. The latter taxon was found only in one context, at the Yagi site on an activity surface in what would have been a bowl-shaped depression on top of the fill of a collapsed pit house. Barnyard grass has been recovered from nearly every northeastern Japan Jomon site from which we have collected flotation samples. Caryopses of this grass are normally recovered from hearths, floors, pits, and post holes, at least in the Kameda Peninsula. The grain size distribution from the Middle Jomon Usujiri B site is bimodal suggesting that Jomon people were selecting for larger seeded grains. A specimen recovered from the interior surface of the base of a pot is morphologically identical to the domesticated form of broomcorn millet, Japanese millet (*Echinochloa utilis*) (Crawford 2011a).

The knotweed family (Polygonaceae) is represented by at two or three genera: *Polygonum*, *Rumex*, and probably *Persicaria* (smartweed). The most common is Japanese knotweed (*Polygonum cuspidatum*), a perennial plant that has spread throughout much of the northern hemisphere and is a noxious weed. This relationship with people appears to have begun during the Jomon. *Rumex* is found at Early and Middle Jomon sites but is more common or in higher densities in the Middle Jomon. All are early succession taxa, that is, they flourish in disturbed, sunlit habitats. Shrub and tree fruit are also well represented at Jomon sites too. These are primarily *Actinidia*, bramble (*Rubus*), elderberry (*Sambucus*), and *Aralia*. The latter genus has both herbaceous and arboreal taxa in Hokkaido, and both may be represented. These all produce abundantly in well-lit habitats such as clearings and woodland edges. These perennials are late early succession taxa. Two mid-succession taxa relatively common at Jomon sites are sumac and lacquer tree (Noshiro and Sasaki 2014; Crawford 2011a). Their seeds are distributed quite differently from most other taxa. Lacquer production and use began quite early during the Jomon Period in Hokkaido. Both sumac and lacquer tree prefer prolonged, disrupted habitats. Sumac grows in clones, while the lacquer tree, in order to produce enough lacquer for production purposes, needs to be grown in orchards. Other tree fruits evidenced at sites in Hokkaido are Amur corktree (*Phellodendron amurense*), walnut (*Juglans ailantifolia*), and chestnut (*Castanea crenata*). Abundant remains of chestnut don't occur until later periods in Hokkaido, as evidenced at the Late Jomon Seizan site (e.g. Crawford 1983, 1997). Some Jomon contexts in Hokkaido have high densities of nut remains, while many do not. Elsewhere in Japan, aDNA, pollen, and macro-remains indicate that nut management was important in some areas (Noshiro and Sasaki 2014; Sasaki and Noshiro 2004; Sato et al. 2003). Arboreal resource management is an important issue and has been a focus of attention not only in Japan but in the New World (for a summary, see VanDerwarker et al. 2015) and, to some extent, Europe. Understanding the ecology of nut and other arboreal resource productivity is crucial to modelling arboreal resource management and domestication.

Plant remains from Jomon sites are consistent with the interpretation that a diverse mosaic of anthropogenic habitats of varying maturity were in the vicinity of Jomon habitations (Fig. 2). By expanding the area of these mosaics, while maintaining their diversity, anthropogenic resource richness was maintained, and productivity was intensified. The normal ecosystem resilience was impacted by human activities that established a variety of anthropogenic plant communities. Some of these communities would have been inadvertent, while others were purposefully maintained. Barnyard grass and lacquer tree were likely cultivated. Japanese millet and barnyard grass seeds are distinguishable today, and the bimodal distribution of the Middle Jomon barnyard grass seeds from Hokkaido suggest that barnyard grass was responding to its interaction with humans by producing larger seeds. However, because seed size is likely a late trait to evolve during the domestication process, selection for other traits such as the reduction of inflorescence brittleness may have been developing and developing earlier, but because we don't recover rachis segments of barnyard grass, we have no way of knowing. Nevertheless, plant remains from northeastern Jomon sites indicate that the Jomon people were living in a human-modified ecosystem. The local vegetation was significantly anthropogenic, meaning that plant diversity (and terrestrial animal diversity) was relatively high. In central Honshu, soybean (*Glycine max* subsp. *soja*/*G. max* subsp. *max*) and adzuki (*Vigna angularis*) morphologies are consistent with their domestication by 4000 B.P. Comparable examples have not been found outside Japan, so it appears that these plants were domesticated in Japan (Lee and Crawford 2011). Domestication of plants during the Jomon period occurred in anthropogenic contexts and in a

Fig. 2 Environs of the Middle Jomon Usujiri B site in 1977. Many plants growing in the patchy range of early successional vegetation around the site today are found among the charred plant remains recovered from the site

human-mediated vegetation equilibrium that was productive and diverse. This, in turn, facilitated an array of near-complex, Neolithic-like Jomon populations.

The ultimate demise of the Jomon in northeastern Japan was not the result of an ecological failure; instead, it was a complex process that involved interaction with the rapidly developing Japanese society to the southwest (Crawford and Takamiya 1990). The resilient Jomon systems in southwestern Japan were impacted by a significant event: a wave of migrants bringing a Chinese/Korean form of agriculture that included rice, barley, wheat, and millets dramatically altered the lives and landscape of the Jomon. By the end of this new Yayoi period, most of Honshu, Kyushu, and Shikoku became the home of burgeoning farming cultures. Hokkaido Jomon cultures transformed too, but they maintained a distinctive identity that was a continuation of the Jomon, the Epi-Jomon culture. This speaks to their general resilience. After several centuries of relative stability, the Epi-Jomon declined and ceased to exist (Takase 2014). How this happened is unclear. Nevertheless, by the sixth century A.D., this culture no longer existed. If the preceding 10 millennia of Jomon occupation of Hokkaido were involved with the creation and maintenance of anthropogenic habitats, then we might expect to see a return to non-human-mediated ecological resilience. North America, for example, was not a pristine wilderness before European contact (Denevan 1992; Hammett 1992, 1997). Habitual use of certain habitats, burning, and farming had transformed parts of the North America landscape. After European contact populations declined by as much as 90% or more, and the subsequent lack of indigenous ecological maintenance activities resulted in the return of mature ecosystems. A similar process may have happened in Hokkaido.

Epi-Jomon We have intensively flotation-sampled several Epi-Jomon sites (Crawford 1987; D'Andrea 1995). Qualitatively, the plant remains are similar to those of the preceding Jomon plant assemblages. Quantitatively, however, distinctions are clear. The large K-135 site in Sapporo has numerous pits, outdoor hearths, and no evidence of dwellings. The site is stratified, and several occupations are separated by alluvium. Walnut, chestnut, and acorn are relatively common but occur in dense concentrations in some localities but are in low densities in other localities. Many contexts have no nut remains at all. Other perennials include a variety of tree and shrub fruit as well as Japanese knotweeds. One context has a particularly high density of Japanese knotweed indicating that it was of some significance to the inhabitants of the site. Herbaceous plants are not particularly common. However, they are not absent either. The habitats people were exploiting appear to have been ecologically more mature with some representation of early successional plants. No evidence of increased landscape clearing or ecological disruption, trends that we would expect if the Epi-Jomon population was locally increasing at a year-round or near year-round village, has been found. Although the K135 site has a grain of barley (*Hordeum vulgare*) among its plant remains, none of the evidence points to the residents cultivating plants. Barley is probably a component of the well-documented networking between the Tohoku Yayoi and the Epi-Jomon. Plant resources appear to been more targeted than in preceding periods too. In other words, anthropogenesis during the late Epi-Jomon period appears to have been inadvertent or simply a result of periodic human influences and periodic flooding that had a role in plant succession. What caused this human ecological and demographic shift is not known; however, the types and quantities of plant remains are consistent with smaller populations who were no longer impacting the landscape as their ancestors did.

Satsumon Finally, sociopolitical circumstances led to a new form of human-environment interaction. Epi-Jomon populations were replaced by a new culture with a mixed economy of farming, hunting, fishing, and gathering and who were ultimately the ancestors of the Ainu. This new culture is known as the Satsumon. Its origins and development are closely linked to the relationships people in Tohoku had with southwestern Japan. As centralized political authority and related socioeconomic institutions developed in the southwestern region, Tohoku cultures developed too but maintained their independence and local identities. One significant development was the establishment of rice, millet, barley, and other crop cultivations in Tohoku. Sometime in the seventh or eighth century A.D., the earliest Satsumon peoples became established in southwestern Hokkaido bringing agriculture with them. They also hunted, fished, and collected plants. This mixed economy established a new human ecology in Hokkaido. Landscape clearance was undertaken not only to create hamlets and villages but to create fields. So far, no evidence of rice paddies has been found in Hokkaido; dry field creation and maintenance were the main concerns. On average about 40% of the plant remains from Satsumon and Tohoku Yayoi sites are rice and other crops. In Hokkaido, the proportion of crops at Satsumon sites is similar although we have found outliers with both low percentages (5%) and high percentages (90%) of crop representation. Few nut remains are found at the sites indicating that woodlands were returning to mature states in which nut trees were not particularly common. Instead, people were investing their ecological management efforts in more specific habitat creation. Many of the grass taxa identified at Jomon sites are found at Satsumon sites, but the grasses are far more diverse and include a wider range of Paniceae tribe grasses, predominantly green foxtail grass (*Setaria viridis* subsp. *viridis*). Contrasting with the earlier Jomon sites, Japanese knotweed is no longer a significant component of the plant assemblages; rather *Polygonum densiflorum* or *Polygonum lapathifolium* is common. This is consistent with the annual cultivation cycle typical of field maintenance. Japanese knotweed was probably still a significant component of the vegetation along forest edges and trails, but because alternative resources were available, people seem not to have included it in their plant-collecting activities. Furthermore, the qualitative and quantitative similarities shared by the Early through Late Jomon and Satsumon assemblages indicate that annual disturbances maintained similar habitats (Crawford 1997). That is, Satsumon and Jomon sites were occupied for lengthy, continuous periods, and plant cultivation was likely practiced by both cultures, although they were not the same type of cultivation. The density of annual plants, particularly weeds, at Satsumon sites is significantly higher than at Jomon sites consistent with the view that Jomon people practiced a smaller scale of cultivation than the Satsumon people.

5 Ontario, Canada: Archaic and Late Woodland

Preceding the establishment of intensive domesticated plant production in Ontario, for example, was a several millennia-long Archaic Period culture. This culture is characterized by the absence of pottery, an emphasis on hunting, fishing, and gathering and a range of landscape investment from seasonal use of particular territories to relatively long-term use of a local area. The McIntyre site on Rice Lake fits the second land use pattern. McIntyre was occupied periodically for several thousand years (Johnston 1984). Contrary to the pervasive perspective of passive human involvement in the local ecosystems, the McIntyre plant remains have signatures of anthropogenesis and a specific cultural niche. Charred butternut shells (*Juglans cinerea*) are in such quantities that they must have been an important resource (Yarnell 1984). Butternut, however, is rare in local forests and, like all nut trees, does not produce much mast in a mature woodland (mature sere). Yarnell (1984) argues for butternut tree management and if this is the case, the Late Archaic McIntyre population had made a significant, long-term investment in a particular form of plant ecology. Other perennial, arboreal taxa requiring open, sunlit areas include hawthorn (*Crataegus* sp.), bramble, sumac (*Rhus typhina*), and grape (*Vitis* sp.). All do well in openings and in edge habitats, particularly in areas that people cleared. In fact, these taxa are common in later agricultural contexts in Ontario. Herbaceous plants are dominated by two taxa: *Chenopodium hybridum* and cleavers (*Galium* sp.). *Chenopodium hybridum* grows well in semi-shaded areas, as do cleavers. Both were found in high densities indicating that they were important to the McIntyre site residents. There is no evidence that any of these plants were cultivated; all the plants recovered from the site except butternut were probably invasive to the habitats people had inadvertently created, and people took advantage of them and may have encouraged them to grow. People were likely aware of the plants in addition to butternut that were responding to their regular use of this location. McIntyre is situated on the shores of Rice Lake so initially fishing may have attracted people to this locale, but the addition of anthropogenic habitats that provided attractive resources ensured that people would return for several millennia. This is consistent with Yarnell's observation that mobile indigenous bands seasonally returned to camps because of the anthropogenic vegetation that was useful to them (Yarnell 1964).

People were living in substantial year-round villages and grew maize, sunflower, squash, and tobacco in Ontario by 1100–1200 A.D. (Late Woodland II period). Common bean was added to the repertoire of crops in the next century (Hart et al. 2002). The diversity of plants recovered from these late Woodland Period sites is significantly greater than in previous periods although the plants represented at Late Archaic sites are still part of the later assemblages (Crawford 2014). Plants had some of the same opportunities in the environment near and inside late Woodland communities that they had in earlier periods. That is, arboreal perennials such as trees, shrubs, and vines from edge and sun-exposed habitats were still important components of the vegetation. Nut trees are not represented to any great extent although this seems to depend on the particular site. Annual, herbaceous plants are recovered in much higher densities after 1200 A.D., and many of these plants were probably field weeds. Examples include American nightshade (*Solanum americanum*), ground cherry (*Physalis* sp.), knotweeds, goosefoot, portulaca (*Portulaca oleracea*), and certain grasses. Strawberry (*Fragaria virginiana*), a fruit almost absent from earlier periods, is recovered in high densities from many contexts so its abundance correlates with agriculture because it thrives in early succession contexts (open and plenty of sunlight). The goosefoot is a different species than the one at McIntyre, that is, not the shade-tolerant species. Although the goosefoots are notoriously difficult to identify to species, the Late Woodland species appears to be a weedy variety of *C. berlandieri*, a species that does well in disturbed, sunny habitats. Most of the grasses are members of the Triticeae and Paniceae.

Berries from shrubs such as bramble (blackberry or raspberry) and blueberry are usually found in high densities at Late Woodland Ontario sites too (Monckton 1992; Ounjian 1998; Crawford and Smith 2003). Bramble seed density is several orders of magnitude higher than at any Jomon or East Asian Neolithic site that I have studied. Not only are their preferred habitats common (well-lit habitats, early- to mid-succession seres), but, given the ubiquity and density of the seeds from these plants, their habitats were extensive and likely maintained by people. Bramble, because it can form dense hedgerows, may have functioned as a barrier. Blueberry production responds well to burning, so Late Woodland peoples probably included fire in their landscape management repertoire. We can't rule out American nightshade, ground cherry, goosefoot, or strawberry cultivation either. A parallel case is made for the Neolithic of the northeastern Iberian Peninsula where the systematic use of tree, shrub, and herbaceous plant fruit is documented and likely interrelated in some way with farming practices (Antolín and Jacomet 2014).

The plant assemblages from Ontario Late Woodland sites reflect an extensive and variable anthropogenic vegetation mosaic that offered a diverse array of plant resources. The relationship between plants and their communities and people during the Late Woodland was more complex than in preceding periods. The extensive clearance that would have been required for the construction and maintenance of Late Woodland villages and their associated fields had far-reaching ecological impacts (Fig. 3). The edge habitats, clearings, and extensive trail systems that joined communities also had an impact on plant communities. These anthropogenic ecosystems were created and maintained for up to two decades, and then villages moved. But that would not have been the end of it. Abandoned village/town locales would have taken decades to reforest and would have continued to be important plant collecting areas. We should not assume that the plants represented in the samples from a particular site represent plants collected only from the immediate vicinity. By the late sixteenth and early seventeenth centuries when Europeans made first contact with indigenous peoples, they described a landscape not that different from

Fig. 3 Reconstruction of the Crawford Lake site near Campbellsville, Ontario. Small-diameter trees were extensively used in order to construct the large, multifamily longhouses. Communities were normally several hectares in area and significantly altered local vegetation

the landscape they were familiar with in France (in the Ontario case). They observed a landscape of fields, orchards, and pastures. The archaeological record is consistent with these observations (Crawford 2014).

A challenge for palaeoethnobotanical research in Ontario is to sort out when and under what circumstances this landscape transformation began. The best evidence resulted from our Princess Point (Late Woodland I Period) project that we developed in the early 1990s (Smith and Crawford 1997). The first indications of a changed relationship between people and the landscape in Ontario became evident when we compared Princess Point settlement locations with the locations of the preceding Middle Woodland sites. Middle Woodland sites are distributed across the landscape, while Princess Point sites are, with a few exceptions, close to major rivers and lakeshores. This contrast is remarkable and required explanation. The recovery of plant remains from selected Princess Point sites combined with geomorphological research provided the answer. Charred maize fragments are present in our sample of Princess Point sites. The majority of Princess Point sites are situated on floodplains or, more accurately, river bars (Walker et al. 1997; Crawford et al. 1998). These river bars never continuously added alluvium through annual flooding. Flooding appears to have been episodic, that is, sometimes alluvium was deposited suddenly, and at other times alluvium accretion was slow in any at all. Princess Point sites along the Grand River are all associated with a palaeosol (Crawford et al. 1998, 2006). The development of this palaeosol correlates with a period of river bar stability, that is, little evidence of regular flooding is apparent during the occupation. If the water was high during the particular spring runoff, water was diverted by channels leaving the occupations that were close to the river relatively dry. These locations appear to have provided the best locations for early maize production, but the location was not simply a stable location with rich soils. It was also an anthropogenic setting. The maize is associated with plant remains more commonly found at the later agricultural sites. Seeds of grasses, chenopod, American nightshade, ground cherry, and purslane, for example, are found in many flotation samples and develop high densities by the end of the Princess Point period (Saunders 2002; Crawford et al. 2006). Bramble, the significant biennial shrub that is represented in such high densities at late Woodland II occupations, is present but in low densities at the river bar sites, but at the later, more substantial sites, bramble density becomes quite high suggesting that the Late Woodland II pattern of bramble use had emerged. The Princess Point period was both a period of agricultural development and a time when the anthropogenic environment so valued by later agricultural peoples was emerging.

6 Lower Yangtze Valley, China, and the Problem of Rice Domestication

The environmental circumstances of plant domestication are crucial to understanding this evolutionary process. Domestication selects for traits that increase the fitness of certain organisms such as rice (*Oryza sativa*) in a human-mediated environmental context. Understanding rice domestication is a challenge because we need to understand the circumstances in which wild rice developed a connection with people. Rice can be harvested in the wild, but its seed production is relatively low compared to modern domesticated rice, and combined with asynchronous ripening, rice would not have been a significant resource until these traits changed (for a comprehensive discussion, see Crawford 2011b). Modern domesticated rice may hybridize among different varieties and also hybridizes with its wild ancestor, and this creates a weed that is not particularly desirable. Isolating new phenotypes in human created habitats would help maintain the new phenotypes and potentially accelerate their evolution. The earliest paddy fields date to between 7000 and 4000 BP (Zheng et al. 2009) and are associated with communities that were built on or very close to wetlands, so only limited isolation of the crop was achieved by this time. Given the circumstances, deterministic explanations relying on single causes such as population growth or climate change forcing people to domesticate organisms (lower-ranked resources according to the diet breadth model) because of resource imbalances have their difficulties because they tend to rely on correlations and the correlations are imprecise (e.g. Maher et al. 2011). Niche construction theory is opening other avenues of inquiry because it incorporates human-environment interaction and acknowledges an active human role in the environment. Niche construction theory can contribute to understanding how domestication takes place (Smith 2012). Human enhancement of certain taxa in these contexts would elevate their rank in an optimization model (Smith 2012). Smith incorporates climate change, resource catchment, traditional ecological knowledge, and the observation that domestication generally takes place in resource-rich areas such as river floodplain corridors and lake and marsh/estuary margins. The lower Yangzi Valley is just such a location.

The lower reaches of the Yangzi River lie within a few metres of sea level, and sites dating from about 8000 years ago have all been impacted by either flooding or sea level changes (e.g. Jiang et al. 2004; Shu et al. 2010; Zong et al. 2007) (Fig. 4). From oldest to youngest, the Kuahuqiao, Hemudu, Liangzhu, Guangfulin, and Maqiao cultures all have sites that are waterlogged or have components that are waterlogged. As a result, the most diverse plant remains assemblages in China are from these cultures (e.g. Jiang et al. 2004; Fuller et al. 2011; Pan 2017). Niche construction likely played a significant role in the early development of agriculture in the region (Pan 2017; Pan et al. 2017). Kuahuqiao and Xiasun are two Kuahuqiao culture sites (8000–7000 BP) situated on the perimeter of a wetland between two hilly ridges in the Yangzi delta. The location provided access to aquatic plant resources, a variety of habitats for animal resources that included migratory waterfowl and wading birds all of which are evidenced among the archaeological remains. The area is so rich given, for example, that in the spring and fall some estimates place over a million birds feeding in the Yangzi delta during their migration (Pan 2017). Aquatic resources are diverse in the region, so, unsurprisingly, several aquatic plants such as rice, foxnut (*Euryale ferox*), and water caltrop (*Trapa natans*) became economically important here. Furthermore, about three dozen plant families are represented among the remains from all period, and all plant parts are

Fig. 4 The Yuyao River near the Hemudu Site has a rich aquatic environment and floodplain near sea level

represented, including tubers and stems (Pan 2017; Fuller et al. 2011; Jiang 2013; Jiang et al. 2004; Zhejiang Provincial Museum 1978; Pan et al. 2017). Other plants commonly evidenced in these cultures include arboreal plants such as hog plum, plum, peach, apricot, and acorn. Acorn abundance is exceptional. Specially designed pits were constructed as early as 7500–7000 BP to store these nuts. A half-dozen pits at Kuahuqiao contained large numbers of acorns, while more than a dozen pits each filled with a roughly estimated 20,000 acorns have been discovered at the Tianluoshan site. Kuahuqiao evidences a diverse resource base from aquatic habitats, edge communities along wetland borders, and upland ecotones (Pan et al. 2017; Pan 2017).

Aquatic and terrestrial flora and fauna provisioned Kuahuqiao and Xiasun for about 1000 years, so Pan (2017) poses the question: how was the productivity of these resources maintained when wetland ecological succession would have led to aquatic biomass accumulation and ultimately the reduction of productive capacity of the ecosystem? Sustainable harvesting and hunting methods appear to have been essential for the maintenance of both Kuahuqiao culture villages (Pan et al. 2017). Abundant charcoal fragments in pollen cores are evidence for regular burning of the marshes around the site, and charcoal density is ten times higher during the occupation than prior to it (Innes et al. 2009; Shu et al. 2010; Zong et al. 2007). The charcoal fragments have not been identified; however, their source was likely from both the marshes and uplands. Oaks tend to be fire tolerant, so oak savannas develop when anthropogenic fires are set and where oaks are an important component of the vegetation. Peach, apricot, and plum are also fire tolerant. Many of these resources, then, were likely abundant, and their productivity maintained because of anthropogenic activities (Pan et al. 2017). Peach cultivation and domestication has its beginnings at Kuahuqiao too (Zheng et al. 2014). Water caltrop and foxnut were likely harvested by boat as they are today although wading to harvest them may also have been practiced. Both methods would cause some disturbance and introduce nutrients, thus increasing production somewhat. This harvesting method permitted continued dispersal of seed and maintenance of these plant populations (Pan 2017). Overharvesting would likely reduce the size of seeds and fruits, and, so far, this is not evidenced (Pan et al. 2017). Ultimately, some of these resources (e.g. pig, rice, peach) responded by developing phenotypes that benefited both people and the organisms themselves. At Kuahuqiao, terrestrial resources were more commonly exploited in the middle and later periods suggesting that the aquatic habitats were deteriorating, probably due to salinification associated with the sea level rise that forced abandonment of this lowland. On the whole, the major influence on local vegetation appears to have been anthropogenic rather than climate.

We knew little about what preceded the Kuahuqiao and subsequent cultures that were already cultivating rice to varying degrees until the discovery of the Shangshan culture about 10 years ago. Shangshan culture sites are situated in interior river basins at elevations ranging from about 40 to 100 m above sea level (Fig. 5). Shangshan, the type site for the culture, occupies a large portion of a terrace and has numerous pits and basins that may be houses (Jiang et al. 2016). In fact, all Shangshan culture sites are situated on terraces rather than on the floodplain, unlike the lowland sites such as Kuahuqiao and Tianluoshan. Two sites, Huxi and Qiaotou, have roughly 2-m-deep ditches associated with them. The reason for the ditches is not clear although ditches are common during the Neolithic of North and South China. They probably serve several purposes such as bringing water close to the community, establishing community boundaries, and refusing disposal. Phytoliths, seeds, and rice spikelet bases collected from the Huxi site ditch provide some insight into the ditch ecology through its lifespan (Zheng et al. 2016). The rice at Huxi is an early domesticated type and appears to have been growing close to, or in the ditch. As the ditch is filled with sediment, organic debris and human refuse also accumulated. Fewer rice glume phytoliths relative to rice leaf phytoliths were deposited than in the deeper deposits. Rice grains and rice spikelet bases have been recovered from the ditch sediments too. *Miscanthus* and *Phragmites*, common weeds in and near rice fields, are also represented in the phytoliths. *Phragmites* phytoliths are recovered in higher density in the later stages of the ditch when it was shallower. These ditches may play a role in bringing rice into direct contact with settlements or may have been purposefully constructed to do so along with its other purposes. The research also points to the usefulness of several lines of evidence, in this case phytoliths combined with larger plant remains such as rice spikelets. In an unrelated study in the Yiluo River valley, grass phytoliths were statistically assessed, and contextualized with reference to charred plant remains from the same sites, to deter-

Fig. 5 View from the Shangshan culture, Hehuashan site terrace overlooking the ancient floodplain of the Qujiang River. The site is situated in an upland, intermountain river basin

mine the extent to which wet versus dry systems existed (Weisskopf 2016). Likely, the rice was not grown in extensively irrigated fields like it was to the south.

7 Modelling

Quantitative reconstruction of vegetation may still be accomplished best by palynological research (Gaillard et al. 2008) but normally involves several lines of evidence. Reconstruction need not be limited to woodlands or woodland clearance but can also be applied to intensity and sustainability of agriculture, for example. A few examples of modelling techniques include agent-based and mechanistic crop growth models, the Landscape Reconstruction Algorithm (LRA), and POLLSCAPE (Baum et al. 2016; Gaillard et al. 2008; Mehl and Hjelle 2015). Modelling may also include experimental studies such as one that examined weed ecology and how it varies in different fertility and disturbance regimes (Bogaard et al. 2016). Among other problems being examined are whether field systems were permanent or shifting, whether burning was necessary to maintain fields, and the extent to which climate change and anthropogenic impacts trigger long-term vegetation changes, the role of irrigation, and the intensity and sustainability of agriculture (Saqalli et al. 2014; Pędziszewska and Latałowa 2015; Baum et al. 2016). Another approach proposes casting a wider net to build models using, for example, charred plant remains, climate and population movement data, and social constructs to model movement of agriculture to the Tibetan Plateau (d'Alpoim Guedes 2016). Modelling is the main approach of HBE, particularly the circumstances behind resource choices. A novel assessment of how to test risk (chance of loss) models using plant and animal remains explores diversification and intensification and how to measure them. Marston (2011) examines ratios of taxa, diversity indices, and weed patterns to assess diversification, while markers of irrigation and grazing versus foddering can help the role of intensification. Understanding risk is also crucial to resilience theory. GIS is also being employed but places less emphasis on plant remains and more emphasis on landscape "measurement" to detect spatial patterning in order to predict where, for example, maize may have been grown when agricultural was first developing in Mexico (Hanselka and King 2017). Another study involved experimental gardening in collaboration with the Hopi and emphasizes that both the environmental and cultural context are crucial (Sundjordet 2017). Ecological models, whether they be based on niche construction, optimal foraging, or a synthesis of the two, require considering a broad range of factors.

8 Summary

Archaeological plant remains including macro-remains, phytoliths, and pollen and non-pollen palynomorphs (NPP) are offering substantial insights into human-environment relationships. Palynology is still providing the predominant database for palaeoenvironmental reconstruction, while other archaeological plant remains tend to focus on identifying habitats that were being exploited. Much of the latest palaeoethnobotanical research that is the focus of this chapter is data-driven, empirical research with no explicit theoretical perspective. Popular topics include discerning the type of agriculture in a region, the impact of agriculture on landscapes, and the extent of clearing around archaeological sites. Agricultural origins are also an important focus. Much of the latest data on agricultural origins are being recovered in East Asia where basic research on the topic was lacking until about 15–20 years ago. Research is moving away from descriptive results and deterministic explanations to more nuanced understandings of human-environment interactions. Productive lines of inquiry are being pursued by situating palaeoethnobotany in the broader discourse of human ecology and ethnobiology. This means explicitly engaging with culture as well as the environment. Ethnographic research addressing archaeological issues related to human-plant interaction is providing important insight, particularly regarding modelling and identifying the unanticipated. Foci trending in theoretical discussions are human behavioural ecology (HBE) that emphasizes optimal foraging or diet breadth, historical ecology, resilience, anthropogenesis, and niche construction. Niche construction is broadening the discussion of anthropogenesis and the diet breadth model to a more nuanced conceptualization of human-environment interaction that includes considering intentional ecological engineering such as landscape management.

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Ethnoarchaeology as a Means of Improving Integration: An Ethnozooarchaeological Study from Cyprus and Its Contribution to the Integration of Zooarchaeology with Archaeobotany and Other Lines of Archaeological Evidence

Angelos Hadjikoumis

1 Introduction

This study is based on the notion that analogical reasoning (Vaihinger 1924) plays an essential role in the interpretation of archaeological data. Ethnography and ethnoarchaeology are among the most common sources of analogues employed in archaeological interpretation. There are, however, important differences between them. Ethnography is conducted without archaeological interpretation specifically in mind, while ethnoarchaeology is conducted to address specific archaeological issues. Approaches on the use of these sources vary widely in the degree of acceptance of relevance between ethnoarchaeologically observed practices and the archaeologically recovered material remains of past human activity (e.g. Ascher 1961; Binford 1967; Gould and Watson 1982; Hodder 1982; Wiley 1985). Archaeological interpretation has not been immune to problems of misuse of ethnoarchaeological data (see overview in Halstead 2014: 329–354). This study is permeated by a positive stance towards the use of ethnoarchaeological data as a heuristic tool that expands the range and improves the resolution of archaeological interpretations (cf. David 1992: 352). Its main focus, however, is how ethnoarchaeology can play a central role in the integration of different lines of archaeological evidence. It demonstrates how a primarily ethnozooarchaeological study, on traditional sheep and goat husbandry in Cyprus (e.g. Hadjikoumis 2017), has provided opportunities for the integration of zooarchaeology with other lines of evidence (e.g. plant and landscape use, human osteology, etc.). The advantage of ethnoarchaeology stems from the fact that it allows the study of multiple lines of evidence in 'alive' contexts,

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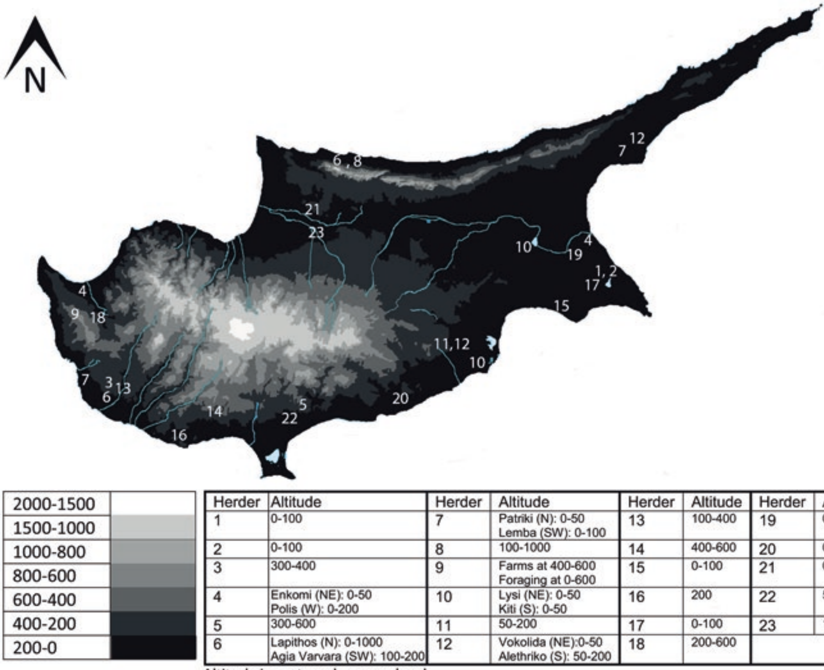
as opposed to the fragmentary nature of archaeological materials studied in isolation to one another. The remains of animals and plants, for example, are studied, identified and quantified by different specialists, often at different times and frequently without forming part of a systematic attempt to integrate the findings.

In the archaeological literature, there are many examples of studies that have achieved a high level of integration of two or more lines of evidence with beneficial effects on our knowledge of the past (e.g. Albarella and Trentacoste 2011; Halstead 1987, 2012; Halstead and Isaakidou 2011; Schulting 2014; Vaiglova et al. 2014). The interpretative framework employed in most of these studies has mainly involved data from experimental archaeology, ethnoarchaeology or their combination. To some degree, integration is difficult due to a, frequently occurring, lack of resolution of equal degree between different lines of archaeological evidence. Moreover, the lack of geographically and environmentally specific models that could greatly enhance interpretations is currently a limiting factor in achieving better integration between different lines of evidence, especially those involving plants, animals and the landscape in general. There is, however, ample scope for improvement of the tools and framework employed to interpret the large volume of high-quality data generated by the study of human, animal and plant remains. The main aim of this study is to provide a selection of examples that highlight the potential of ethnoarchaeology as a useful tool for integration in archaeology, as well as a heuristic tool in archaeological interpretations.

2 Methods

The ethnoarchaeological data collected were aimed at addressing zooarchaeological questions on sheep and goat husbandry in the mid-late twentieth-century Cyprus and are mainly presented elsewhere (e.g. Hadjikoumis 2017; Hadjikoumis et al. submitted). Data were collected in Cyprus by the author from April to September 2013 through structured interviews with 23 herders of sheep, goats or both. The interviews were semi-structured and a strict format was avoided. This format was preferred to encourage interviewees avoid providing idealised answers prompted by a false impression that they are expected to ‘perform’ well. In the interviews, specific zooarchaeological themes were raised by the author, but conversation was allowed to develop freely. Some of the themes addressed were environmental context (e.g. vegetation and terrain), physical characteristics of animals (e.g. breeds), age and sex composition of herds, practical aspects of husbandry, mobility, animal diet and consumption of meat and other products. These themes were originally targeted due to their relevance to zooarchaeological issues, but in this study the focus is shifted to the ‘collateral’ benefits in terms of integration between zooarchaeology and other lines of evidence. General information on the herders and their level of experience, as well as their management strategies, the environment and composition and demography of their herds are presented in a separate study (Hadjikoumis 2017: Tables 1–4).



Herder	Altitude	Herder	Altitude	Herder	Altitude	Herder	Altitude
1	0-100	7	Patriki (N): 0-50 Lemba (SW): 0-100	13	100-400	19	0-100
2	0-100	8	100-1000	14	400-600	20	0-300
3	300-400	9	Farms at 400-600 Foraging at 0-600	15	0-100	21	0-300
4	Enkomi (NE): 0-50 Polis (W): 0-200	10	Lysi (NE): 0-50 Kiti (S): 0-50	16	200	22	50-250
5	300-600	11	50-200	17	0-100	23	100-200
6	Lapithos (N): 0-1000 Agia Varvara (SW): 100-200	12	Vokolida (NE):0-50 Alethriko (S): 50-200	18	200-600		

Altitude in metres above sea level

Fig. 1 Map of Cyprus showing the location and altitude of the areas in which interviewed herders managed sheep/goat (Source: Hadjikoumis 2017: Fig. 15.1, p.127). Each number corresponds to an interviewee. Double occurrence of a number indicates the displacement of a herder in 1974

Data collection covered most of Cyprus except altitudes above 800 m in the Troodos Mountains in the centre of the island (Fig. 1). The reasons for this geographic pattern are legal and environmental. In the case of goat herds, their absence from high altitudes is a recent event caused by a 1913 British colonial law excluding them from extensive upland areas in order to protect the forests (e.g. Orr 1918: 141). Only tethered goats were allowed in those areas (Christodoulou 1959: 191, map 5), but this type of management was not targeted in this study. The absence of sheep from upland areas, however, was attributed by most interviewees to its poor performance in steep mountains covered by shrubs and trees (Christodoulou 1959: 189, map 3). Sheep husbandry in Cyprus during the last century was paired with cereal cultivation and carob or olive plantations in the lowland belt surrounding the mountains and the central plain (e.g. Bevan 1919: 2).

Some of the interviewed herders supplied information about their activities in two areas due to their dislocation after the 1974 Turkish invasion. Independent of the herder's location, priority was given to their activities prior to the 1970s and before traditional animal husbandry practices were abandoned in subsequent decades. All interviewees, except one, were men as free-range herding of sheep and goat was usually a man's profession in Cyprus. Women usually tended stalled or tethered animals, a practice not covered by the study. Most of the herders had more than 30 years of experience in sheep/goat herding.

3 Results

3.1 Overview of System

Some analyses of the data collected in this ethnozooarchaeozoological study have already been published (Hadjikoumis 2017), and some are in the process of being published (Hadjikoumis et al. submitted), although only from a purely zooarchaeological perspective. Here the focus is shifted towards the interactions between sheep/goat husbandry and other categories of information such as plants, use of landscape and even human skeletal remains. Due to the focus of the study on sheep and goat husbandry, the most extensive information provided involves plant species included in the diet of these two animal species. Before presenting the plants mentioned by the herders, it is useful to briefly describe the overall agricultural and pastoral system in which both plants and animals were integral parts of.

The degree of availability of wild or cultivated plants to sheep and goat herds varied in traditional agriculture in the early and mid-twentieth-century Cyprus, with the main factor being the extent to which land was suitable for cultivation. Priority was usually given to cultivations as the majority of people living outside the urban centres in the early–mid-twentieth-century Cyprus were farmers (Christodoulou 1959: 108). Most herders were themselves also farmers to some degree, and most farmers also kept a few animals. Traditionally, people defined themselves as being ‘farmers’ or ‘herders’ based on which activities were perceived as dominant in their everyday routines and annual cycle. Concerning the interviewed sheep and goat herders, most of their agricultural activities were geared towards improving the productivity of their herds through the provision of more and higher-quality feed. Moreover, the herders commented on the general pattern of mobility and use of the landscape in order to increase the productivity of their pastoral and agricultural activities and avoid conflict with farmers. As it is clear from the map in Fig. 1, the landscape around most rural communities in Cyprus consisted of a combination of lowlands with relatively shallow soils, usually near rural settlements, and hilly/mountainous areas at variable distances. Descriptions of the seasonal pattern of mobility between these zones reveal a high degree of adaptation to this landscape, local vegetation and the seasonality of agricultural activities, as well as other community-specific economic activities. More specifically, the majority of herders have described the mobility and diet of their herds on a seasonal basis, consisting of two main periods, November–May and June–October.

The reliance on wild plants, traditionally, was at its heaviest from November, when annual plants germinate at the start of the rainy season, until May when these resources become gradually exhausted and their nutritional value reduced. This period coincides with the growth phase of cereals, legumes, trees and other crops. The exhaustion of communal pastures and fallow land occurs at around the same time as cereal harvest and processing. The cereal harvest, and that of other crops, signalled a relaxation of restrictions in the mobility of sheep and goat herds within this landscape, as well as the availability of new opportunities (see below). Approximately from October to June, sheep and goat herds were restricted to scrublands and hilly, rocky and fallow land areas. In areas where the landscape was predominantly hilly and unsuitable for cultivations, herds, especially of goats, continued to forage year-round.

Most herders mentioned that, traditionally, the most difficult months in terms of securing their herd's diet were March–April and October. March to April was a period of high demand in nutritious food for lactating females and their growing lambs/kids, but such food was difficult to come about because most cultivations were in their growing or ripening phase, while wild vegetation was gradually being exhausted. This was not such a pressing problem in areas with more land available to animals. In more intensively cultivated areas (especially the lowlands of southeast and central Cyprus), herders usually addressed this problem by cultivating their own or rented fields of cereals and legumes. During the difficult months before the main bulk of cereals and legumes (destined for human consumption) were harvested, the herders drove their sheep and goat into their half-ripened cereal and legume fields (more frequently the latter) to feed. After the cereal and legume harvest (focused around June), the pressure for tight control of herds was relaxed. Moreover, some herders locally had access to other kinds of agricultural refuse such as the leafy parts of potatoes, carrots and other crops (see details below). For reasons of compatibility between agriculture and pastoralism, there was a strong tendency towards predominantly sheep herds in primarily agricultural areas (e.g. central plain and surrounding areas) and goats in more hilly areas where land plots were smaller and discontinuous with large tracts of land unsuitable for growing cereals and legumes on a large scale (e.g. south and west). The absence of actively growing crops from June to September allowed the herders to fuse their herds (usually between two relatives or in-laws), as a single herder could control a larger number of animals. Managing larger herds was easier without many restrictions in their mobility, and labour requirements were also sharply reduced as the milking season ended in late spring/early summer in preparation for the next mating season. Herd sizes usually increased from 60–100 to 150–200, with few exceptions of larger herds. It has also been mentioned by many herders that 'at the time of our grandparents' (i.e. late nineteenth to early twentieth century), the scale of sheep/goat husbandry was even smaller with herds rarely exceeding 40–60 animals per family. Herder 18, for example, mentioned that when he was young (i.e. 1960s and 1970s), the largest goat herd in his village consisted of 50 goats and that his father raised 10 children mainly by managing a herd of 20 goats. The scale of traditional husbandry, however, is not the focus of this paper, and this issue has only been superficially touched here to highlight that the scale of husbandry has an effect on, as well as influenced by, many other parameters such as the economic basis (more pastoral or agricultural), the seasonality of agricultural and pastoral tasks (milking, harvest, cereal processing, breeding, slaughtering, etc.) and other activities in the yearly agricultural cycle.

September and October were also difficult months in the diet of free-range sheep/goat herds because stubble and fallen seeds from harvested cereal fields, as well as wild plants, were gradually being depleted from grazing and also lost nutritional value through desiccation. Furthermore, by September–October, many farmers were burning any remaining stubble in their fields as part of preparations for sowing. Besides an island-wide anticipation of the first rains (usually in October, although frequently failing in the recent past), which would signal the imminent availability of a new cycle of vegetation, solutions to the September–October shortages varied. Most herders stored hay or grain (usually from cereals and legumes they cultivated or bought from/exchanged with farmers) to use in such periods of shortage. Furthermore, wherever available, herders took advantage of other opportunities such as fallen carobs (harvested in late summer/early autumn), pruned tree branches and other types of agricultural refuse.

Long-distance mobility in traditional sheep/goat herding practices in Cyprus was rare, mainly due to economic and legal reasons. The lowland areas of Cyprus, at least for the last 150 years, were predominantly covered by privately owned cultivations, with areas of low agricultural potential (usually communal or government land) being reserved for sheep/goat grazing. This arrangement acted against long-distance mobility as it would have been difficult for herders to drive large herds through the landscape without causing considerable damage. Relations between herders and farmers within communities and between adjacent communities were generally amicable and mutually beneficial, but long-distance mobility would have rendered serious disputes more probable due to lack of familiarity and absence of the constantly negotiated economic arrangements that existed between herders and farmers of the same area. Moreover, as it has already been mentioned, goat herds were excluded by law from forested areas (almost exclusively above 400 m asl) since the early twentieth century, while the traditional (fat-tailed) variety of sheep in Cyprus was deemed by herders as unsuitable to thrive on the steep stony mountain slopes and thorny vegetation. Rather ironically, such areas today are those where the feral ancestor of domestic sheep, the Cypriot mouflon, thrives.

3.2 Plants in Sheep/Goat Diet

The plants exploited by traditional herders in the twentieth-century Cyprus in order to feed their sheep and goat (or mixed) herds can be divided into wild plants growing naturally (i.e. not cultivated) and plants cultivated by the herders or other farmers. Concerning the wild vegetation in the areas covered by the study (Fig. 1), the herders did not elaborate on specific plant species. Most of them mentioned that their animals grazed ‘whatever grows naturally in the area’. The interpretative potential of such generic information is restricted, as it can only be used to strengthen the rather self-evident assumption that animal herders tend to feed their animals relatively near their place of residence. Nevertheless, this generic answer can be developed into more useful information if combined with vegetation and land use maps of the areas where the interviewed herders exercised their profession (e.g. Christodoulou 1959; Hand et al. 2011). Several herders, however, mentioned several examples of wild plants that their animals particularly like to feed on. The identifications of plant species mentioned below can be considered as reliable based on the author's familiarity with the specific linguistic tradition and environmental setting, although there is always some degree of uncertainty especially in cases of closely related species.

Herder 1 mentioned that sheep would not feed on Mediterranean saltbush (*Atriplex halimus*) unless they were particularly hungry, as it has happened during the severe drought of 1941. Sheep herds from his village consumed hedges of saltbush that were planted by farmers of a neighbouring community around their fields. Herders 2 and 12 mentioned a generic term (*αρκοτριφυλλούιν*) translatable as 'wild clover/trefoil' referring to a plant particularly preferred by their sheep. They referred to one or more species of the genus *Trifolium*, such as the ubiquitous *Trifolium campestre* and *T. stellatum*, or other species that grow widely in Cyprus (e.g. *T. tomentosum*, *T. pilulare*, *T. clypeatum*). Sheep in particular preferred eating this plant which, according to herder 2, contributed to higher and better milk yields. Herder 12 mentioned that it was at its best for animal consumption in March. Crown daisy (*Glebionis coronaria*) was also consumed by the sheep and goat of herder 2, among a multitude of other wild annual plants. Herder 7 mentioned the mallow (*Malva sylvestris*), crown daisy (*Glebionis coronaria*) and plants of the mustard family (e.g. *Sinapis arvensis* and *Sinapis alba*) as examples of wild plants preferred by his herd of sheep. Beyond these annual plants, herder 7 mentioned that sheep and goat herds in the area also consumed the branches and fruits of wild (or abandoned cultivations of) olive (*Olea europaea*), carob (*Ceratonia siliqua*) and the fruits of the jujube shrub (*Ziziphus lotus*), all of which were also consumed by people either directly or indirectly (e.g. oil production from olive and jujube and syrup from carob). Moreover, he commented that in his community they collectively decided which plots of land would be cultivated each year and which would be left uncultivated and available to sheep/goat grazing. This was done so that each land parcel would revert from one status to the other approximately every 1 or 2 years. Herder 7 also remembered that prior to mechanisation, there was more competition for access to harvested cereal fields due to the use of such fields and the agricultural waste they produced by oxen, donkeys and other animals. Similar arrangements were common in most agricultural communities in Cyprus, and many other herders commented on them.

Herder 8 mentioned that his free-range goats particularly liked the leaves and fruits of the Mediterranean hawthorn (*Crataegus azarolus*). Beyond this, he generally commented that woolly sheep do not thrive on steep slopes with thorny vegetation and that goats are the better choice in such environments. Herder 9 mentioned that, besides annual plants, his goats regularly browsed on branches of shrubs and trees such as olive, carob and species of *Pistacia* (e.g. *Pistacia terebinthus* and *P. lentiscus*) that were either wild or in abandoned fields. Herder 12 has observed his sheep eating over a period of 30 years and noticed that ‘as in humans, different sheep have different preferences. One animal might like more a certain plant and another animal might like another plant’. The same herder and also herder 14 mentioned that in the last 30–40 years, with the abandonment of agriculture and the countryside in general, more carob and olive trees are not tended or harvested. Such trees are nowadays viewed as ‘wild’ vegetation, and their fallen fruits and branches are available to herds of sheep and goats. Herder 13 mentioned that most of his goats avoid consuming pine (*Pinus brutia*) branches, but occasionally few do consume it. None of the sheep herders have mentioned pine consumption, and there is no reference for such an occurrence. Herder 15 mentioned that tree branches are suitable only for feeding goats and that, as a sheep herder, he has never offered them to his animals. As other herders, herder 16 has repeated the preference of goats in eating shrubs (e.g. of the genus *Pistacia*), as well as young trees and branches within reach on larger trees (mostly ‘wild’ olive and carob trees). He also expressed the opinion that the most crucial factor for animal husbandry in Cyprus is rainfall. Without sufficient rainfall that promotes lush growth of plants, animal numbers and the herder’s income are reduced. The availability and affordability of imported animal feed are relatively recent phenomena. Herder 19 added more species consumed by his free-range herd of goats such as plants of the genus *Asphodelus* ubiquitous in Cyprus (e.g. *Asphodelus fistulosus* and *A. ramosus*). The only female herder (21) mentioned that her goat herd, among other wild plants, fed on *Ziziphus lotus* and *Cistus salviifolius* and/or *C. parvifolius*.

Some herders also provided information on plants that may cause some degree of poisoning to sheep and goat. Herders 4 and 13 mentioned that if animals consumed the oleander (*Nerium oleander*), they would die, but this was never a serious concern as sheep and goats avoid the plant. The only real danger would be if oleander was accidentally included in chopped hay, which is a fairly modern development and used more as cattle or horse feed rather than sheep/goat feed. Moreover, herder 5 mentioned that in his 48-year experience, only once his sheep ‘fell down and started trembling’, which he attributed to the fact that they were grazing in a field dense with the common poppy (*Papaver rhoeas*). Herder 17 mentioned an occasion when after an entire day in the farm, and hence on an empty stomach, the next morning his ewes consumed annual mercury (*Mercurialis annua*) just outside the farm and eight of them died. He has attributed their death to the consumption of this plant on an empty stomach because another group of ewes that grazed outdoors the previous day, and hence their stomach was not empty, were not affected after ingesting the same plant. Conflicting information was mentioned concerning the sea squill (*Drimia aphylla*), as herder 8 mentioned that his goats ate it but other herders mentioned that it caused diarrhoea to their goats.

The most extensive information supplied from the herders concerning their animal’s diet concerned cultivated plants. Unlike the rather circumstantial information they supplied on wild plants, most herders gave information both on the species of cultivated plants that their animals consumed and the rationale behind such decisions. Table 1 presents the plants mentioned by the herders, as well as information on their use and seasonality.

Table 1 Cultivated plant species, their role in sheep/goat diet and seasonality in their use in the twentieth-century traditional agricultural systems in Cyprus

Plant species	Production and use	Seasonality of use in sheep/goat diet
Wheat (*Triticum* sp.)	*Grain*: Produced primarily for human consumption *Straw/fallen grain*: Extensively exploited to feed sheep/goat herds Both grain and straw stored for use during low availability of natural food and to feed breeding/lactating animals	*Grain*: Year-round but cheaper in periods/years of high availability *Straw/fallen grain*: Main season June–august, after harvest *Stored dry grain/straw*: Year-round if available/afforded, September–October (little naturally available food) and October–March (to boost breeding and milk production)
Barley (*Hordeum* sp.)	*Grain*: In most years, produced more as animal food, by herders and farmers *Straw/fallen grain*: Same as with wheat Both grain and straw stored for use during low availability of natural food and to feed breeding/lactating animals	Same as above
Maize (*Zea mays*)	*Grain*: Produced for human and sheep/goat consumption *Rest of plant*: Used only to feed sheep/goat	Both grain and rest of plant available after harvest (summer/early autumn), unless grown by herders for direct grazing in the field by sheep/goat (late spring/summer)
Sudan grass (*Sorghum sudanense*)	Entire plant grown to be consumed directly by animals	Year-round
Lentil (*Lens culinaris*)	Pods and rest of plant cultivated to be grazed directly by sheep/goat or harvested and stored as hay. Same use for rest of plant after harvest of pods for human consumption	*Direct grazing*: Late spring due to dropping availability of natural food and tight mobility restrictions due to ripening cereals and legumes *Freshly harvested*: Early summer *Stored dry hay*: Consumed year-round if available/afforded but march–may, September–October (little naturally available food) and October–March (boost for breeding and milk production)
Broad bean (*Vicia faba*)	Same as above	Same as above
Common vetch (*Vicia sativa*)	Pods and rest of plant cultivated to be grazed directly by sheep/goat or harvested and stored as hay	Same as above
Bitter vetch (*Vicia ervilia*)	Same as above	Same as above

(continued)

Table 1 (continued)

Plant species	Production and use	Seasonality of use in sheep/goat diet
Grass pea (*Lathyrus sativus*)	Same as above	Same as above
Soya bean (*Glycine max*)	Same as above	Same as above
Trefoil (*Trifolium* sp.)	Same as above (no pods)	Same as above (no pods)
Carob (*Ceratonia siliqua*)	Leaves/branches: Direct consumption from trees or after pruning Fruit: Mainly for human consumption but fallen and unharvested fruits exploited by sheep/goat herders	Leaves/branches: Year-round Fruit: Mainly late summer/autumn, after harvest
Olive (*Olea europaea*)	Same as above	Leaves/branches: Year-round Fruit: Autumn and winter, fallen fruit before and after harvest
Citrus trees	Fallen fruits: Occasionally exploited to feed sheep herds	Late spring and summer, after harvest
Other Melon, watermelon, potato, taro, carrot, sesame, cotton, peanut, pruned vine branches, etc.	'Leftover' produce and leafy parts after harvest	Year-round, depending on availability locally

3.3 Other Exploitation of Wild Plants and Animals by Sheep/ Goat Herders

Herder 2 has also contributed information concerning the use of local plants in the construction of structures necessary for the management and well-being of his herd. More specifically, he referred to the jujube shrub (*Ziziphus lotus*) as prime material, due to its thorns and dense woody branches, to construct corrals for sheep and goats. He also added that such corrals were traditionally constructed just by placing cut jujube branches either directly on the ground or on dry stone bases consisting of one or two rows, in both cases to erect a fence. Herder 23 provided similar information concerning his area. Another plant species that played a similar role and was mentioned by several herders is the boxthorn (*Lycium schweinfurthii*). Herder 7 mentioned that shepherds also manufactured brooms from thorny burnet (*Sarcopoterium spinosum*), used to swipe outdoor spaces such as yards and animal corrals. On the same matter, herders 10 and 23 mentioned that he manufactured such brooms to swipe the manure from the corral where he kept his sheep and sell it to farmers or exchange it with access to their fields and other commodities (e.g. wheat/barley straw and grain).

Most herders have also mentioned that they hunted or captured (with their dogs or traps) wild animals of small size. Familiarity with local landscapes and fauna enabled many traditional sheep/goat herders to supplement their family's diet mainly with hares but also several bird species (mainly partridge but also smaller species). Beyond wild animals, many also collected mushrooms, wild plants and fruits for eating (asparagus, caper, eryngo, wild artichoke, common mallow, bladder campion, wild rocket, purslane, azarole fruit, jujube fruit, etc.), as well as condiments (black mustard, rosemary, oregano, thyme, etc.).

3.4 Use of Landscape

Besides the adaptation of sheep and goat management to differences in vegetation and landscape locally, the herders highlighted the economic and cultural importance of other elements in the landscape that are integral parts of herd management. Such elements include wells, springs, rivers, pools of fresh water and safe access points to the sea. Despite the fact that Cyprus is nowadays considered as a predominantly semiarid region (UNESCO 1979), none of the herders have mentioned any difficulty in finding water for their animals. Most attributed this to the large number of wells dotted throughout the Cypriot countryside, especially the lowlands of central and eastern Cyprus. The central and north mountain ranges and foothill areas, especially the western areas of Cyprus, receive more rain, and hence herders come across more rivers, springs and water pools. Most herders, however, stressed that extracting water from wells for their animals was a particularly arduous task, involving the use of buckets made of goat or sheep leather to pull water up the well to fill stone or wooden troughs for the animals to drink from.

Another activity related to water was the washing of animals, particularly sheep during the summer months, after shearing. This practice is common to all sheep-breeding cultures, although the exact rationale and practicalities involved differ (Frizell 2004). In areas that were far from the sea, this was done in water pools within riverbeds or small artificial water reservoirs, but in the majority of cases in Cyprus, it was done in the sea. The rationale of most herders was health and overall well-being of their animals as they claimed that washing helps remove parasites and contributes to the disinfection and healing of wounds. Nowadays this practice is forbidden by law (e.g. generally forbidding the access of animals to the sea), but even in the past, the location was selected carefully and was not changed over generations. The long use of the same spots for washing sheep (or other animals) is also reflected in the many relevant toponyms in Cyprus (e.g. *λούμαν* which translates as 'bath' or 'wash'). Such locations were usually selected with safety and ease of access in mind. Locations with strong currents were avoided, and, usually, rocky 'platforms' or low cliffs were selected, from which animals could be pushed into the sea, rather than having to be convinced to walk into it on a sandy or gravely beach. In some cases, these locations were used for so long that herders gradually improved them by adding steps, in addition to the levelling effect of animal trampling over decades and centuries.

The importance of these locations, however, goes beyond the need to provide fresh water for sheep/goat herds or washing them. Many of the interviewed herders have mentioned that in many such locations, they met with other herders from their community and neighbouring communities. In these places, besides socialising, herders were striking deals involving the exchange of animals or animal products, selling/buying land (also with farmers), as well as other transactions. The location of drinking water and access to suitable animal washing spots and the use of such places over generations made them into points of exchange of information, products and animals between communities.

3.5 Human Skeletal Remains

The effect of pastoral activities on the human skeleton is an area that attracted little research attention. An ethnoarchaeological study such as the one presented here could not have significantly improved the dearth of information on the subject. Nevertheless, even if in an unforeseen way, it contributed to this area through the case of one herder and a reference by another. Herder 1, who was 84 at the time of the interview and worked as a sheep herder from the age of 12 to 74, presented a permanent dislocation of the distal phalanges on his thumb and index fingers. Both the distal phalanges were permanently reconfigured in a sideways direction (instead of the expected ‘straight’ direction along each finger’s axis) due to sustained pressure over long periods of time of opposition of the thumb and index. He confirmed that this was caused by decades of milking large numbers of sheep. Unfortunately, due to the death of the herder a few months after the interview, the exact configuration of his distal phalanges was not investigated further through radiography. Herder 17 has also mentioned the case of a herder from a neighbouring village, who was so severely injured by a charging ram during mating season that he became permanently unable to walk. His injuries were inflicted mainly on the pelvis and hip.

4 Discussion

Most zooarchaeologists, archaeobotanists or archaeologists of any specialisation have limited experience of the rhythms of the agricultural year and how variable it can be from place to place and from year to year. We also usually lack an intimate knowledge of the plant and animal species involved, the landscape, as well as the variability in strategies to manage them. This distance between the researcher interpreting archaeological and environmental data and the experiences of farmers and pastoralists is nowadays inevitable. This, however, does not constitute a problem in itself as there are more, and to some extent better, ways of developing good knowledge of the components of agricultural systems and the interactions between humans, plants and animals in a given landscape. Ethnoarchaeology is currently the most comprehensive tool available to address this problem. In the 1980s several authors urged for research attention to the quickly vanishing traditional systems of plant and animal management in SE Europe (e.g. Nandris 1985). In the last 30 years, several ethnoarchaeological studies on traditional plant and animal management were carried out in SE Europe (e.g. Chang and Toutellotte 1993; Jones 1992, 1996; Halstead 1990, 1998; Halstead and Isaakidou 2011). An important reason why archaeologists have been increasingly in a position to characterise the remains of different farming and pastoral activities in the archaeological record is the analogical reasoning developed based on such ethnoarchaeological studies. Moreover, these studies have improved the quality of archaeological interpretations and promoted the integration between different lines of relevant evidence.

Ethnoarchaeological studies of traditional plant and animal management in the eastern Mediterranean and Middle East have been less common and usually conducted with a purely ethnographic perspective or a focus on high-altitude (e.g. Deniz and Payne 1979; Digard 1981), inland (Elliott et al. 2015) or desert areas (e.g. Cappers 2002). This study, as well as others stemming from the same fieldwork conducted in Cyprus (Hadjikoumis 2017; Hadjikoumis et al. submitted), adds to the limited available knowledge on traditional agricultural systems in insular and coastal environments of the eastern Mediterranean. The specific study admittedly focused on traditional sheep and goat management. Nevertheless, the nature of ethnoarchaeology is such that even when it focuses on specific questions, the data to address them are usually collected in live contexts (or within living memory), in which all its elements are still organically connected. The results presented above constitute examples of 'collateral benefits' produced by ethnoarchaeological research that can promote integration within environmental archaeology. These results are further discussed below in the light of their interconnectedness and potential to improve archaeological interpretation, especially in the fields of zooarchaeology and archaeobotany.

Most of the information provided by the herders involved the use of plants in the diet of sheep and goat herds. The information cannot be considered as a faithful record of vegetation in a given area, neither a full record of sheep/goat diet. It has to be recognised that each herder mentioned only a few examples of plants in a rather haphazard way. Nevertheless, the plant species mentioned in the results, both wild and domestic (Table 1), can be useful to archaeobotanists, mainly in two ways. The first, more technical, involves the recovery and identification of any remains of the plant species mentioned in sheep/goat coprolites or areas of settlements where animal herds were stabled. Moreover, some of the wild plants preferred by sheep and goat are also consumed by humans (e.g. mallow, mustard, azarole fruit) or otherwise utilised (e.g. use of jujube shrub in fencing or its fruit for food/oil extraction), thus increasing the chance of their remains being recovered at archaeological sites. The probability of preservation of parts of such plants is relatively low, at least in the climatic conditions prevalent in Cyprus, but should be pursued as it has been shown that the potential is higher than previously assumed. Beyond the routine recovery and identification of several species of cereals and legumes at even the earliest of the Pre-Pottery Neolithic sites in Cyprus, some of the wild plants mentioned by the herders (e.g. plants of the genera *Sinapis*, *Malva* and *Pistacia*) have also been identified (e.g. at Ais Yiorkis, see Lucas et al. 2012: 121, Table 1).

The second way in which these ethnoarchaeological observations can be useful to archaeobotanists and zooarchaeologists is the knowledge around the, usually multiple, uses of each of these plants as well as the seasonality in their exploitation for different purposes (e.g. animal vs human consumption, possibility of storage of hay made from such plants in the past). For example, it may prove to be a fertile line of investigation to explore whether the seasonality of precipitation and in turn the growth peak of annual vegetation, closely connected to both cereal/legume cultivations and sheep/goat management, fluctuated in different periods and how agricultural systems adapted to such changes.

Concerning cultivated plants specifically, the number of species cultivated for animal consumption in recent and current traditional practices in Cyprus has increased considerably with the addition of species from other continents (e.g. maize, soya bean, Sudan grass, etc.) and new varieties. Nevertheless, sheep and goat diet (more sheep than goat) was based, until recently, on agricultural 'waste' from a suite of cereals and legumes (Table 1), similar to that present at several Pre-Pottery Neolithic sites in Cyprus (Colledge 2003; Lucas et al. 2012; Miller 1984; Murray 2003; Vigne et al. 2012; Willcox 2000). With the improvement of current archaeobotanical tools and the development of new ones, it would be interesting to pursue the identification of different uses of cultivated plants in the past such as those observed in recent traditional practices in Cyprus (i.e. cultivation of cereals or legumes for sheep/goat herds or use of agricultural waste from plants cultivated mainly for human consumption). The identification of such practices can help archaeobotanists and zooarchaeologists improve the degree of integration between agriculture and sheep/goat management in the more distant past. In addition to cereals and legumes, the use of either fruits or branches of fruit trees in sheep/goat diet as it was mentioned by the herders (Table 1) can also be archaeologically explored (e.g. identification of semi-digested fruit seeds).

Beyond the consumption of wild and cultivated plants, sheep and goat herders made good use of the crop rotation system (usually 1–2 years) at each community. This involved access to plants thriving in fallow fields. The identification of such plant communities and the association of their remains with sheep/goat diet (e.g. through the study of coprolites, spherulites, isotopes, pollen, etc.) would contribute towards interpretations integrating the management of sheep/goat herds and the agricultural landscape. Moreover, as it is already well known (Balasse and Ambrose 2005), sheep and goat have different dietary preferences and are also managed differently in traditional herding. In the twentieth century in Cyprus, the vast majority of herds consisted either exclusively of goats or (almost) exclusively of sheep. There were many cases where herders added 'a few' goats into sheep herds 'to push sheep to forage for longer and at a greater range', but a balanced mixture of sheep and goat numbers was extremely rare, exactly due to the many differences in behaviour, diet and other requirements. The identification of such differences in the archaeological record of Cyprus or similar environmental settings would shed much-needed light upon differences in the use of the landscape by sheep and goat herders, through comparisons with ethnoarchaeological observations such as those reported here.

The results presented in this study have also highlighted several other uses of plants by sheep/goat herders. Beyond the good knowledge of edible plants the herders collected as additions to their diet, several plant species were used for purposes other than to feed their animals or themselves. Several shrub species have been mentioned (e.g. jujube and boxthorn), placed on a low wall or directly on the ground for the construction of corrals to keep sheep and goat herds or sections of them (e.g. lactating females and lambs/kids). Such structures, although ephemeral, could leave archaeologically recognisable remains in the form of low dry stone walls near habitation areas. Moreover, the remains of the fruit of the jujube shrub could potentially be preserved (through carbonisation or, unlikely concerning Cyprus, waterlogging) and recovered from similar structures or other archaeological contexts. The issue of equifinality would have to be addressed, as most plants usually have multiple uses (e.g. the jujube shrub is exploited as human food, animal food, construction material and most probably fuel). Beyond the use of plants in structures related to sheep/goat management, additional uses of plants mentioned by the herders have the potential to be identified in the archaeological record, mostly through a rigorous recovery of archaeobotanical remains and their analysis. For example, the use of thorny burnet to manufacture brooms for outdoor earthen surfaces such as the yards of houses and animal enclosures is difficult to establish in the distant past. It is worth, nevertheless, to keep in mind such uses in cases where remains of this plant are recovered in archaeobotanical samples.

Other examples of potentially recognisable structures or modifications of natural rocky outcrops in the archaeological record are those described by the herders as spots where they drove sheep herds into the sea. The selection of such locations was careful to facilitate access and ensure the safety of the animals. The long, multigenerational use of these spots rendered them more artificial than natural with the levelling of the rock from animal trampling and the addition of steps carved by the herders. In addition to their purely practical purpose, such locations also served the herders as hubs to exchange information and strike deals. Even if such structures were identified archaeologically, their use as described by the herders cannot be assumed. Ethnoarchaeological analogues, however, can inform and enrich the interpretative potential of ancient structures reminiscent of corrals and spots for washing animals. Other types of structures used by the herders in the semiarid environment of the twentieth century were wells and troughs (stone or wooden) used over most of central and eastern Cyprus. Despite the aridity, according to the herders, such networks of wells ensured that their animals were never deprived of water. With this analogue in mind, the identification of networks of wells in ancient landscapes would enhance the integration between animal management and landscape use.

Most herders mentioned that they occasionally hunted or captured wild animals whilst out with their herds. This observation might be relevant to the interpretation of predominantly domestic faunal assemblages with small percentages of wild fauna in them. For example, in many Neolithic assemblages in southeast Europe, small percentages of wild animals might represent such occasional hunting activities by herders or farmers.

Although not strictly of environmental nature, the evidence produced by this ethnoarchaeological study on the effects of intensive milking of sheep/goat by herders can also inform the interpretation of ancient human remains. The single example of dislocation of distal phalanges due to intensive milking of sheep over decades, as well as from the early age of twelve, does not amount to substantial evidence. It opens up, however, the possibility of identification of similar pathologies in the archaeological record, which could serve as a proxy of intensive milking in the past.

In conclusion, the observations on traditional sheep/goat husbandry in the mid- and late twentieth-century Cyprus and their discussion demonstrate, through practical examples, ethnoarchaeology's potential to enrich archaeology's interpretative framework as well as contribute towards further integration between different lines of evidence (animal, plant, human, architectural remains, landscape, etc.). The use of ethnoarchaeology and ethnography as sources of analogies for the more distant past does not constitute a novel approach. This study, however, is a contribution to an existing corpus of relevant studies. A novel aspect of this study lies in that it provides information, relevant primarily to zooarchaeologists and archaeobotanists, from a geographical area where it was previously unavailable. This information is also relevant to similar insular or coastal environments in the eastern Mediterranean. The results of the study also illustrate how inextricably woven agriculture and sheep/goat, as well as other livestock, management is and how aspects of it can be identified in the archaeological record. It also provides information on overall use of the landscape, structural remains and even pathologies on herders due to intensive milking. Despite the fact that the results presented are essentially the 'collateral benefits' of an ethnozooarchaeological study (Hadjikoumis 2017), it demonstrates that ethnoarchaeology can become an even more useful tool in the integration between many archaeological subdisciplines, especially when used in geographically relevant contexts.

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Exploring the Wetland: Integrating the Fish and Plant Remains into a Case Study from Tianluoshan, a Middle Neolithic Site in China

Ying Zhang

1 Introduction

The site of Tianluoshan was discovered and excavated initially in 2004, and several field seasons have taken place ever since. The material culture and chronology indicate that Tianluoshan belongs to the famous Hemudu culture, which is described as a representative of Middle Neolithic culture in the lower Yangtze River region by both Chinese and Western textbooks (Bellwood 2005; Chang 1986; Higham 2005; Liu and Chen 2012; Zhang and Wei 2004). Animal and plant remains are found well preserved due to the waterlogged environment, providing excellent materials for studying subsistence economy, agriculture development, and palaeoenvironment of the Hemudu culture.

Fish, among the wild animals, has been an important and reliable protein resource in the Yangtze River region. In terms of lower Yangtze River valley, water bodies of various kinds can be found: river, brook, lake, pond, wetland, paddy field, etc. There is no doubt fish and other aquatic resources (animals and plants) were playing a very important part in the subsistence, and they still are. Fish remains are commonly present in the archaeological animal assemblages along the Yangtze River, particularly when sieving is systematically applied. At Zhongba Site, for example, a salt production site of the Final Neolithic and Bronze Age in the upper Yangtze River valley, fish remains comprise a considerable majority of the animal assemblage (Flad 2004, 2005; Flad and Yuan 2006). It is proposed that fishing and hunting were the primary modes of meat acquisition in the Yangtze River valley in the Neolithic (Yuan et al. 2008).

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This study attempts to place the food resources back into the ecosystem and to discuss the exploitation of the environment and the interrelationship between humans, environment, and food resources in a broader background.

2 Background Review to the Study Area

The site of Tianluoshan (30°01’N, 121°22′E) is located in a small valley at the southeast edge of the lower Yangtze River region, to the south bank of the Hangzhou Bay (Fig. 1). It is one of the most low-lying areas in the lower Yangtze, only 2–3 m above sea level. Geological investigation indicates that the physiographic settings in this area have remained the same since the Jurassic and Cretaceous periods (Zhejiang Provincial Bureau of Geology and Mine 1989). The main stream on the plain, Yao River, passes through the valley. A group of Neolithic sites have been found along the Yao River, among which Hemudu and Tianluoshan are the most famous and well-preserved ones.

Located in the subtropical zone, the lower Yangtze River experiences a subtropical monsoon-dominating climate, characterized by a mild and humid climate (mean temperature 16.2 °C), high precipitation (about 1300–1400 mm per year), and plenty of sunshine (2061 h annually), making it an ideal place for vegetation growth, animal habitats, and human occupation. The weather shifts significantly between seasons: winter is cold and dry, summer is hot and humid but with little precipitation, and spring and autumn are warm and rainy (Chen 1985, P93–121).

Palaeoenvironmental research reveals that the climate and environment have changed several times throughout the Holocene. The Early and Middle Holocene were warmer and wetter in eastern China. The mean temperature during this climatic optimum could be 2–4 °C warmer than that of today, and southern vegetation zones had shifted northwards (Liu et al. 2007a; Qin et al. 2010; Tao et al. 2006; Yu et al. 1998, 2000; Zhang 2006; Zuo et al. 2016). The climate tended to be temperate and mildly dry from 4000 BC. Palaeoenvironmental studies also detect several

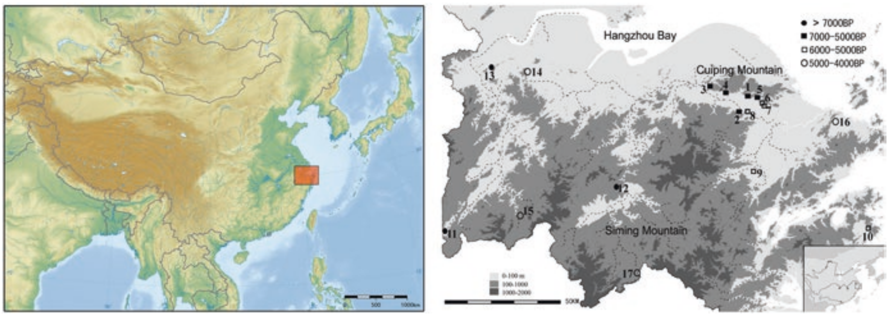

Fig. 1 Location and landforms of the research area and the distribution of Tianluoshan (Qin et al. 2010)

sea-level fluctuations during the Holocene which influenced human diet and caused response (Mo et al. 2011; Zheng et al. 2012).

The Neolithic cultures in the lower Yangtze Region can be divided into three phases by the evolution of society (Liu and Chen 2012). In the early Neolithic phase (7000–5000 BC), sedentism and agriculture arose, and the 'Neolithization' began; in the Middle Neolithic phase (5000–3000 BC), social inequality emerged; the Late Neolithic phase (3000 BC–2000 BC) is symbolized by the rise and fall of early complex societies. In this system, a Pleistocene-Holocene transition era (22000–7000 BC) is named before the early Neolithic phase based on foraging and collecting subsistence economy. As a result, Shangshan, which is usually considered as the earliest Neolithic site in the lower Yangtze (Jiang 2013; Zhejiang Province Institute of Archaeology and Cultural Heritage and Pujiang Museum 2007), is included in this phase.

The Middle Neolithic cultures in the lower Yangtze are represented by the Hemudu culture in the Ningshao Plain and the Majiabang culture and subsequently the Songze culture in the Lake Taihu region (Table 1). It is the key period and key region for rice agriculture, indicated by the large quantities of rice remains which are generally found at sites of this time period, the increasing ratio of rice spikelet bases with morphological features of domestication, and rice fields. The Hemudu culture is named after the type site Hemudu, which was discovered and excavated in the 1970s. Extremely rich materials are preserved due to the waterlogged environment. Wooden pile-structured dwellings, in which mortise-tenon techniques are employed to connect timbers, are found to be approximately 23 m long 7 m wide. Pottery is mainly black and grey, tempered with fibre and/or sand; some of them are decorated with plant and animal motifs. Among all the bone tools from Hemudu, the most eye-catching is the bone spade (or 'Si' in Chinese) which is mainly made from the scapula of water buffalos or sambar. The discovery of abundant animal bones and rice remains, including husks, chaffs, leaves, and rice grains, led to a long-termed discussion on the development of agriculture in the Yangtze River region.

Table 1 The Neolithic chronology of the lower Yangtze River region, summarized from Liu and Chen (2012)

Chronology	Phase	Archaeological culture	Sites
22,000–7,000 BC	Pleistocene-Holocene Transition	Shangshan culture (9,000–7,000 BC)	Shangshan
7,000–5,000 BC	Early Neolithic	Kuahuqiao culture (6,000–5,000 BC)	Xiaohuangshan (7,000–6,000 BC) Kuahuqiao
5,000–3,000 BC	Middle Neolithic	Hemudu culture (5,500–3,300 BC) Majiabang culture (5,000–4,000 BC) Songze culture (4,000–3,300 BC)	Hemudu Tianluoshan Majiabang Xiaodouli
3,000–2,000 BC	Late Neolithic	Liangzhu culture (3,300–2,000 BC)	Fanshan, Yaoshan, etc.

The rice remains were first identified as domesticated rice of *Oryza sativa* subsp. *indica* (You 1976), and the discussions afterwards focus on distinguishing the exact variety of rice (Tang et al. 1999; Zhou 2003). Domesticated dog, pig, and water buffalo are also identified from the faunal assemblage (Wei et al. 1989). With the environmental, archaeobotanical, and zooarchaeological research, Hemudu has been described as a farming society with 'intensive rice agriculture' and written in Chinese and western textbooks (Bellwood 2005; Chang 1986; Higham 2005; Lu 1999). However, a reassessment of the existing comparative data about a decade ago suggests that these claims appeared overstated (Fuller et al. 2007, 2008; Qin et al. 2006). The research on newly excavated materials confirms a heavy reliance on the wild resources, including acorns, aquatic nuts, deer, and fish, even though rice was cultivated (Fuller et al. 2009, 2011; Zhang 2015; Zhang et al. 2011). Molecular biological analysis suggests that the widespread *Bubalus mephistopheles* was an indigenous wild species to prehistoric China (Liu et al. 2006; Yang et al. 2008). The procedure of pig domestication is slightly vague. Although pigs are believed to be domesticated in the Middle Neolithic Yangtze (Yuan and Flad 2002; Yuan et al. 2008), the morphological features, cull patterns, and stable isotope data suggest that they are more like wild boars (Zhang 2015; also see Fuller et al. 2011; Liu and Chen 2012; Yuan et al. 2008).

3 Materials and Methods

Tianluoshan is a representative site of the Hemudu culture. It was first excavated in 2004, and several seasons of excavation have been undertaken until now. Estimated through drilling investigation, the whole Tianluoshan site covers about 30,000 m^2 (Sun 2011). Radiocarbon dates indicate that the site was occupied approximately from 5000 to 4000 Cal BC, belonging to the Hemudu culture (Sun 2011; Wu et al. 2011). Both radiocarbon dates and the study of artefacts suggest that the cultural layers (layers 3–8) can be divided into three phases: the earliest phase 1 is from layer 8 to 7, phase 2 is from layer 6 to 5, and phase 3 includes layers 4 and 3 (Fig. 2). The fish remains for this study are from the stratigraphic layers. They are generally well-preserved due to the waterlogged environment; however, those from the upper layers are weathered possibly because of the fluctuation of underground water level. Apart from them, eight 10 metres by 5 metres trenches (K1 to K8,), surrounding the major excavation area, were excavated to build the foundation of a conservation shelter for the site. Several storage pits of acorns and a pit (labelled as 'H1') filled only with fish bones were found in K7. Those fish remains were studied by Nakajima et al. (2010a, b, 2011) and thus shall not be included in this study.

The fish remains were retrieved from wet sieving through two sized meshes: 4.5 and 2.8 mm. However, most of the head bones and girdle bones are very fragmented to be recognized by the collectors who unfortunately are not familiar with the anatomy of fish, leading to a result that the study materials mainly consist of vertebrae,

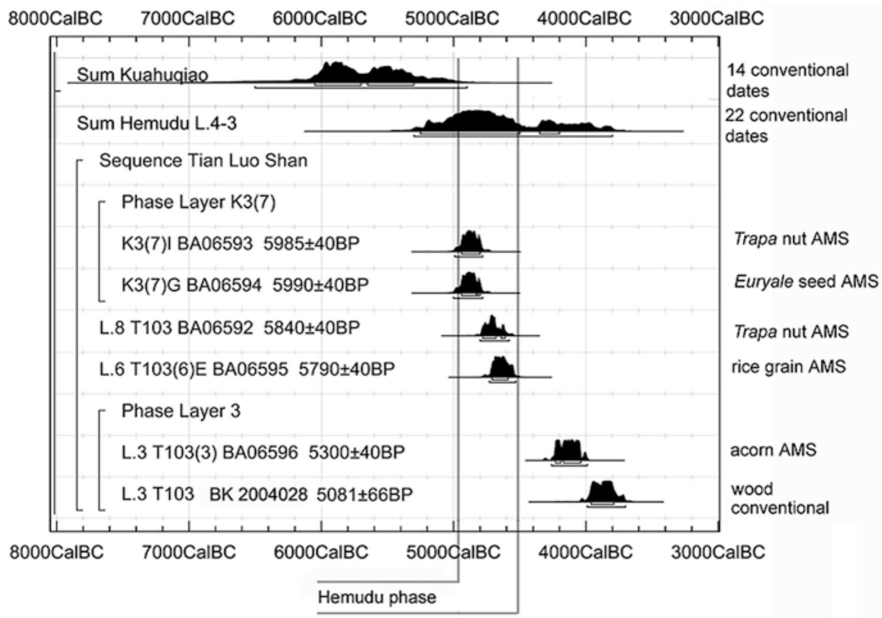

Fig. 2 The radiocarbon dates of Tianluoshan (Wu et al. 2011). The earliest radiocarbon date of Tianluoshan comes from the K3(7) samples (layer 7 in trench DK3), about 4900 Cal BC, followed by layers 8 and 6 in the main excavation area, about 4800–4700 Cal BC. Layer 3 is dated to approximately 4200–4000 Cal BC

basioccipitals, pharyngeal bones, and teeth. Otoliths are not preserved probably due to the acid environment.

Subsamples were taken as the basic units for sorting, recording, identification, and quantification during analysis because of the large quantity of bones from each context. Zooarchaeological procedures were used during this analysis as set forth by Wheeler and Jones (1989) and described by Casteel (1976). The fish remains from each subsample were initially sorted into broad taxonomic categories and identified to genus and species when possible. Any evidence of butchering, weathering, or thermal alteration was recorded. Measurements were taken where appropriate, mainly for the purpose of fish size reconstruction.

3.1 Fish Length Reconstruction

Unlike mammals, fish grow constantly through their lives. As calcium gradually deposits on the outer side of bone structures, older fish tend to have bigger bones and larger size. By reconstructing the original size/length of fish, we may learn about the fishing techniques and strategies. There are several methods to estimate the length of fish. For example, Casteel (1976) summarized and compared five major methods that have been employed in zooarchaeological research. Fishery biologists also study the methods for size reconstruction, to identify and estimate the size of prey fish from fish's stomach content and then to investigate the diet of fishes and the ecosystem (Campbell 1968; Fickling and Lee 1981; Mann and Beaumont 1980; Radke et al. 2000).

After examining the commonly used methods, the single regression method is considered to be simple and accurate enough to meet the research object of this study. Nakajima et al. data (2010b, 2011, 2012) are employed to reconstruct the length of common carp and crucian carp. However, snakehead (*Channa argus*), the most predominant fish from Tianluoshan, has been barely recorded and studied. There is scarce data on the growth rate and seasonal growth of annulus in literature. Therefore, a reference collection of modern wild snakehead is acquired for body length reconstruction and seasonality assessment in this research. Since aquaculture has been well developed in China in order to meet the large demand of fish consumption, and the fish species present at Tianluoshan have become cultured fish now, it is not easy to capture wild fish for reference collection without help.

Reference specimens were collected from Hubei Province with the help of Dr. Zhang E from the Institute of Hydrobiology (IHB), Chinese Academy of Science, following the sampling strategy in Van Neer and colleagues' study (Van Neer et al. 1999, 2004). From December 2012 to July 2013, monthly samples of 22 snakehead specimens were obtained and processed by the IHB. Measurements of the fish and basioccipitals are taken for the reconstruction of regression curve, and the annuli distribution of each individual is recorded for the estimation of fishing seasons.

The single regression method was used to reconstruct the original body length of snakehead from the size of the basioccipital. The correlation between body length and the width of basioccipital was derived from metric data of modern snakeheads, shown in Fig. 3. A single regression equation is derived accordingly:

$$\mathrm{BL} = 42.76W_{\mathrm{basio}} + 39.94$$

3.2 Seasonality Assessment

There are several ways to analyze the seasonality of fishing. The most commonly used method is to read the growth rings on hard tissues. Fish grows following a certain pattern of continuity and periodicity. As fish grows larger, calcium gradually deposits at the margin of hard tissues so that they expand outwards, leaving traces, usually in the form of concentric circles, known as the growth rings or circuli, on them. Among all the hard tissue parts, scales, otoliths, fin spines, opercula, and vertebrae are frequently used for investigating age and growth of fish in fishery and zooarchaeological studies. The growth rate of hard tissues is highly influenced by water temperature and day-length; therefore, in temperate and frigid zones where water temperature and day-length change annually, the growth rings are regularly

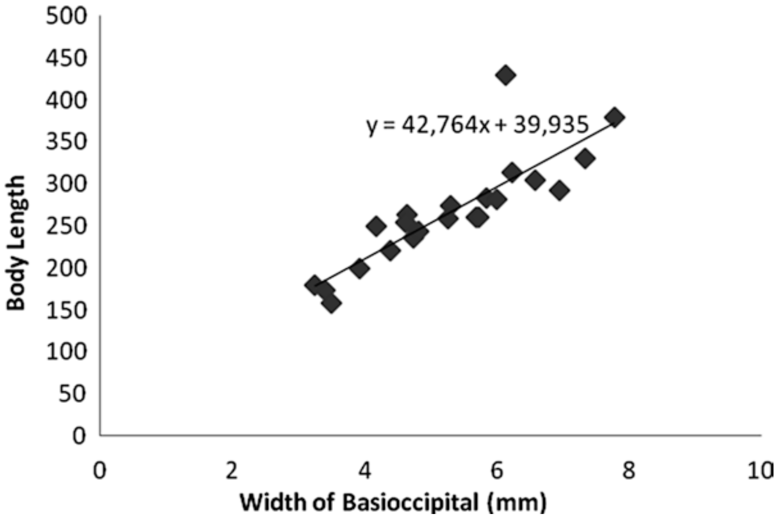

Fig. 3 Regression analysis between body length (standard length) and the width of snakehead basioccipital, based on the measurements of modern specimens

distributed as fast-slow growing circles accordingly (Moyle and Cech 2004; Wurtsbaugh and Cech 1983), providing a good possibility to make a subjective assessment of age and death season.

Zooarchaeologists also use the continuous increase of body length (Nakajima 2002, 2006; Nakajima et al. 2010a, b) to estimate the fishing season. Due to the seasonal breeding and the constant growth rate within a species, a fish can only grow to a certain size at a certain age and vice versa.

Plus, fish performs seasonal behaviours, including migration, spawning, and torpor (hibernation), which are triggered by the change of environmental factors (Gabriel et al. 2005; Krause 1956; Matsui 1996; Moss et al. 1990; Stewart 1977). The migrating fish, such as Pacific salmon, were only available to our ancestors in the spawning migration season. Even fish which make local spawning migrations are more vulnerable during their spawning when they school in shallow waters.

In this study, different assessment methods are applied according to fish species and the quality of the study material. The cull season for snakehead is estimated from the distribution of growth rings, by examining the outermost annulus on the articulation surface of the basioccipital. After observing the modern snakehead specimens, we have found that the new annulus normally appears in spring, from February to May, mostly in February. It keeps growing in summer, forming the fast-growing annulus which can be observed slightly lower than the winter annulus. The winter annulus is relatively narrower, dense, and slightly higher than the summer annulus. Each basioccipital with a clear-cut outermost circle is observed under a stereomicroscope, compared with modern specimen, assessed, and recorded. The seasonality of common carp and crucian carp is assessed following Nakajima and colleagues' research, by reconstructing the body length and comparing with the known growth curve. The life history and seasonal behaviours of fish are considered during analysis.

4 Results

4.1 Range and Relative Proportions of Taxa

A total number of 230,000 fish bones from 40 contexts are examined for this study. Seventy-four subsamples, each containing 300–400 specimens, are taken for statistical analysis. Six species of common fish have been identified from the assemblage, including common carp (*Cyprinus* sp. Linnaeus), crucian carp (*Carassius carassius* (Linnaeus)), top-mouth culter (*Culter* sp. Basilewsky), catfish (*Silurus* sp. Linnaeus), snakehead (*Channa argus* (Cantor)), and Japanese sea bass (*Lateolabrax* sp. Cuvier) (Table 2). Fish are mainly identified to the genus level; snakehead and crucian carp can be identified to the species level with the aid of zoogeographical analysis. The common carp is identified as *Cyprinus carpio* by the pharyngeal bone (Nakajima et al. 2011). Statistically, these six species take up nearly 90% of the total number, and snakehead among all the fish shows clear predominance in each phase, from 45% to 70% (Table 2). Crucian carp takes the second place (13–34%), followed by common carp and catfish with a consistent proportion around 5%. The amount of the culter fish and Japanese sea bass is relatively minor, normally less than 1%.

Table 2 Relative taxonomic abundance of fish at Tianluoshan by NISP and NISP %.

		Phase 1		Phase 2		Phase 3	
Taxon	Family	NISP	%	NISP	%	NISP	%
Common carp *Cyprinus* sp. Linnaeus	Cyprinidae	2807	4%	5676	5%	716	6%
Crucian carp *Carassius carassius* (Linnaeus)	Cyprinidae	9070	13%	38,097	34%	1891	15%
Top-mouth culter *Culter* sp. Basilewsky	Cyprinidae	361	0.5%	330	0.3%	37	0.3%
Catfish *Silurus* sp. Linnaeus	Siluridae	2945	4%	5027	4%	747	6%
Northern snakehead *Channa argus* (cantor)	Channidae	48,581	70%	50,338	45%	6477	53%
Sea bass *Lateolabrax* sp.	Serranidae	308	0.4%	643	0.6%	289	2%
Unidentified		1090	7.1%	2303	11.2%	670	18.4%

4.2 Body Length Reconstruction

The body length distribution of common carp from each layer is shown as a single peak spanning a wide range approximately from 180 to 580 mm. According to literatures, fish of this length are from 1 to 5 years old (Hubei Provincial Institute of Hydrobiology 1976). Similar distribution pattern occurs to crucian carp (Fig. 4). The range and peaked point resemble that of H1 (Nakajima et al. 2010a, Fig. 6), but the slope is rather gradual. From the perspective of taphonomy, the content of a pit is usually accumulated in a short time and may receive better preservation. In the case of H1, the fish remains represent a few catches within a short time, probably during the breeding season of crucian carp. Conversely, the fish remains from the stratigraphic layers represent a long-term accumulation and tend to be affected by taphonomic issues such as weathering and trampling.

Shown by the wide span of the distribution, snakeheads of different size, approximately from 140 to 900 mm, used to be captured by the Tianluoshan people. Fish between 200 and 400 mm were captured more often, possibly indicating a selection by fish size (Fig. 5). Snakehead grows fast. Records show that it can reach 19 cm only 1 year after hatching and increase 10 cm per year thereafter (Hubei Provincial Institute of Hydrobiology 1976, P212). The recorded maximum length is 1 m (Novikov et al. 2002). Although snakeheads over 600 mm are rare at Tianluoshan, to catch individuals of such large size may require certain skills.

4.3 Seasonality

The length distributions of common carp and crucian carp from layers are consistent (Fig. 4), indicating all-year-round fishing. By studying the reconstructed body length and growth rate of carp, Nakajima and colleagues (2010a, b, 2011) propose that both common carp and crucian carp from H1 were captured in spring and early summer, possibly during breeding season when fish schooled in shallow water.

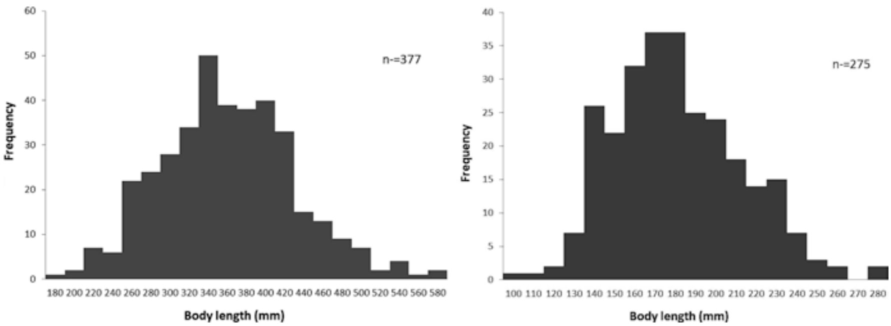

Fig. 4 Body length distribution of common carp (left) and crucian carp (right) from Tianluoshan, without separating phases

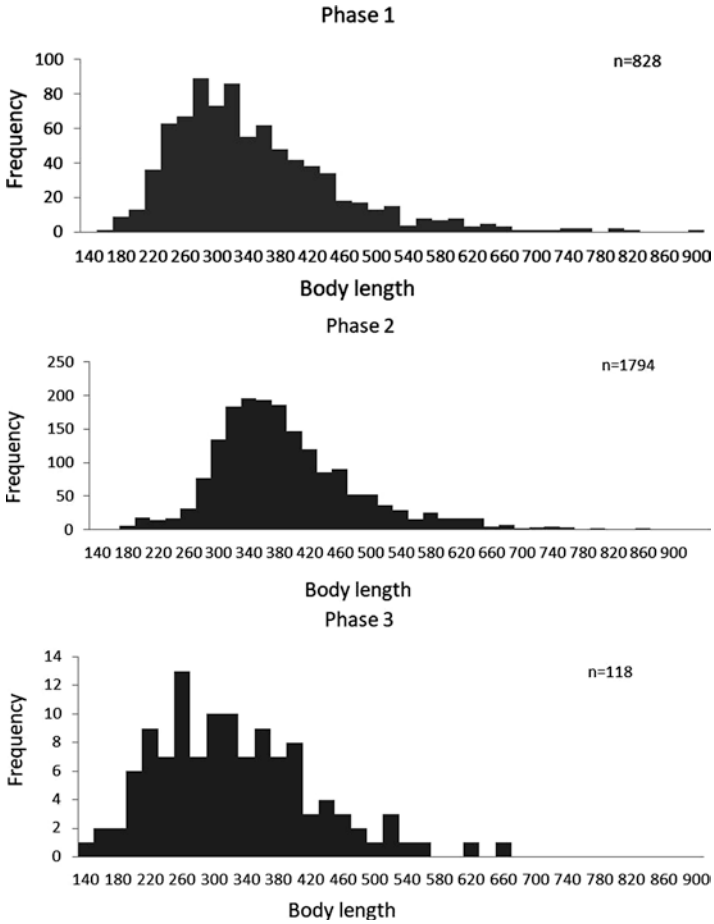

Fig. 5 The body length distribution of snakehead in three phases

The distribution pattern, especially the sudden rise of the distribution curve, shows similarity with that of Nakajima and colleagues' result, possibly indicating that carp fishing became intense in spring and early summer.

The distributions in Fig. 6 show that snakehead fishing is performed throughout the year but more intensively in spring, generally from February to April. Interestingly, the fishing season does not overlap with the spawning season of *Channa argus*, which is usually from late May to July in the Yangtze River region. Fish usually display special behaviours during spawning, including migration, courtship, schooling, and sometimes parenting for a few species. When spawning season comes, snakeheads migrate to shallow and vegetated areas and build a nest by clearing plants in a cylindrical zone. The nest can be recognized from the floating plants. The parents guard their eggs and larvae for about 20 days and are very protective and aggressive during these days. The nesting and parenting behaviours make them exposed and vulnerable to fishermen. Ethnographic records show that

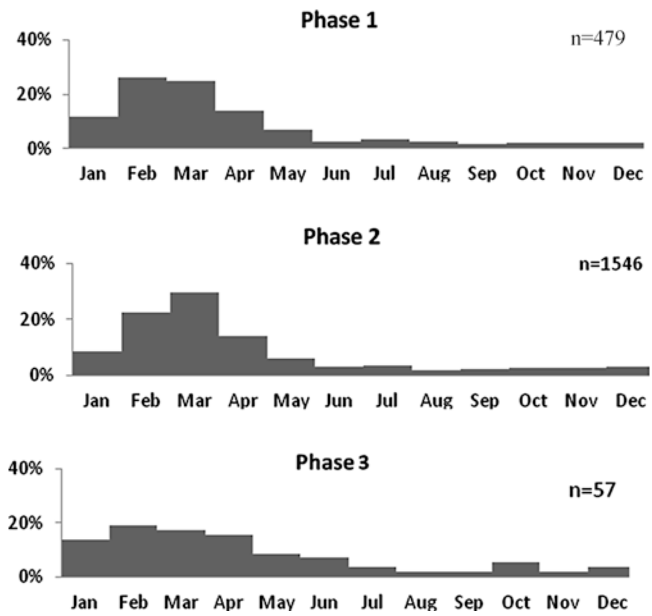

Fig. 6 Seasonality distribution of snakehead, estimated from basioccipitals

villagers in the upper Yangtze River region (Sichuan Province) catch snakeheads by simply irritating them with live bait (e.g. frogs) and then collecting them with scoop baskets (Lan 1958). However, snakeheads also display distinctive behaviour out of the spawning season. When dry season comes, they can either migrate to deep water or bury themselves in mud, reducing metabolism and oxygen demand until the warm monsoon season comes. Plus, snakehead displays a behaviour called 'sun-bathing' by the fishermen. In summer and autumn, snakeheads like to float and stay on the water surface on sunny days, possibly because of the low oxygen level when the temperature rises. Catching the 'sunbathing' snakeheads is another common strategy.

Due to the complicated behaviours of snakehead, the fishing season does not have to tally with the spawning season. Fishing season, as well as fishing methods, can be decided according to the environment, change of seasons, and probably other subsistence activities. In this case, fishing is not simply an activity; it is an element in the entire subsistence economy.

5 Archaeobotanical and Environmental Research

Before the discovery of Tianluoshan, the understanding of the Hemudu culture was primarily based on the remains from the Hemudu site. According to the preliminary report (Zhejiang Natural Science Museum 1978) and the final report (Zhejiang

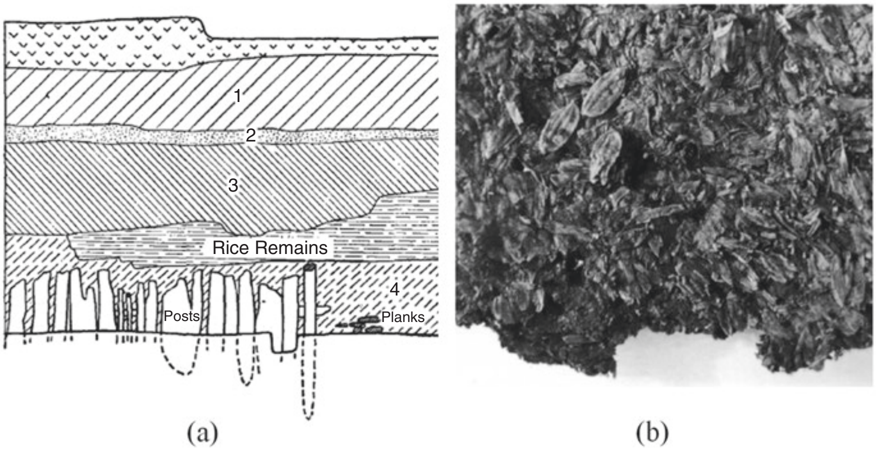

Fig. 7 Stratigraphic profile of Hemudu (**a**) and detailed view on the rice remains. (**b**) 1–4 in graph (**a**) are the four strata of the cultural deposits. The thick layer containing rich rice remains lies between layers 3 and 4. Timber posts are shown planted under layer 4

Provincial Institute of Cultural Relics and Archaeology 2003), animal and plant remains accumulated densely in the Hemudu culture deposits, especially in the early Hemudu culture layer (layer 4). Rice, among all the remains, has been discussed very intensively. Most of the rice remains are straw, leaves, and husks; rice grains are found occasionally (Fig. 7). It was estimated that the thick layers of rice remains might be the debris of 120 tons rice (Yan 1982), although these did not represent a single depositional event judging by the stratigraphic photographs. Dog, pig, and water buffalo among all the species are identified as domesticated animals. Accordingly, Hemudu is presented as an example of early intensive rice agriculture in many texts (e.g. Bellwood 2007; Chang 1986; Higham 1995).

Soon after the excavation, the rice remains were identified as domesticated rice of the *Hsien* variety, i.e. *Oryza sativa* subsp. *indica* (You 1976). Discussions over the following 20 years have focused on identifying the variety of rice and whether they were of the *indica* variety or the *japonica* variety, using different measurements. Hemudu and the lower Yangtze River have been considered as the centre for rice agriculture in the world (Bellwood 2005). The discussions of Hemudu rice have also deeply influenced the research of Neolithic agriculture in China. As Hemudu was considered as a developed agricultural society, archaeologists began to pursue the origins of rice domestication from Early and Middle Neolithic sites. A common opinion is that rice domestication started about ten millennia ago, based on various rice finds such as the rice husks found in pottery debris from Shangshan, represented by Liu and colleagues' studies (Jiang and Liu 2006; Liu et al. 2007b). Meanwhile, Fuller, et al. suggest that the domestication of rice was still in progress during the Middle Neolithic Age (Fuller et al. 2007, 2009).

Apart from the rice remains, a variety of fruits and seeds of wild plants are also found at Hemudu, including acorns (*Quercus* sp.), water chestnuts (*Trapa* sp.),

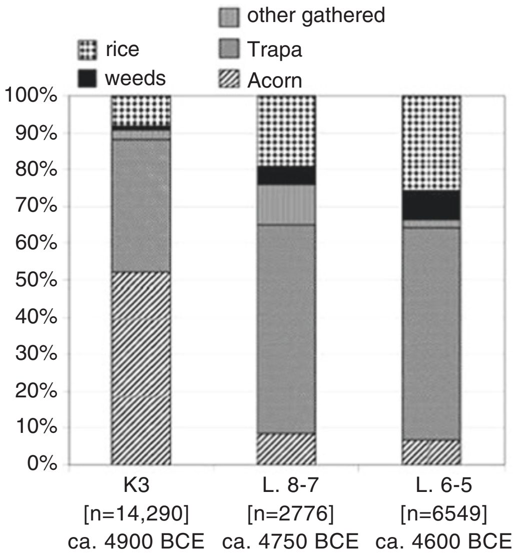

Fig. 8 Proportion of plant remains from sieved samples from the three periods at Tianluoshan (Fuller et al. 2009, Fig. 2)

foxnuts (*Euryale ferox*), peaches (*Amygdalus persica*), and jujube (*Choerospondias axillaris*); many of them are found in storage pits (Qin et al. 2006; Zhejiang Provincial Institute of Cultural Relics and Archaeology 2003, P216–218). Restricted by retrieval methods, smaller seeds and fruits were not collected. The information on plant remains was supplemented by the many more complete samples from Tianluoshan. More than 50 species have been identified from the floral assemblage. There are four predominant plant food resources: acorns (including deciduous *Lithocarpus* and evergreen *Cyclobalanopsis* types), water chestnuts, aquatic foxnuts, and rice. Acorns and wild aquatic plants have been stable food resources for a long time, at Tianluoshan, while rice appeared to be a supplementary resource. However, the proportion of rice increases from 8% to 24% and that of acorns declines remarkably (Fig. 8). The findings of acorn storage pits may indicate that acorns were used as backup food and then gradually abandoned. On the spikelet bases, the proportion of domesticated type increases (Fig. 9), indicating that rice domestication was in progress (Fuller et al. 2009). The finding of ancient field areas where rice grew and farming tools were found (Fig. 10) also supports the conclusion that rice was an important food with targeted production practices.

In palaeoenvironment studies, vegetation and climate are normally reconstructed through micro plant remains such as pollens, phytoliths, and diatoms. Regional pollen diagrams show a large amount of wetland grass (*Typha* and *Cyperaceae*) pollen and declines in oak (*Quercus*, *Lithocarpus/Castanopsis*, *Cyclobalanopsis*) and/or chestnut (*Castanea*) pollen between 6000 and 4500 BC (Kanehara and Zheng 2011; Tao et al. 2006), indicating large areas of wetland and probably a decrease of nut-bearing trees.

Qin et al. (2010) notice that the plant types from archaeological sites usually differ from the functional plants (PFTs) in biome reconstruction. Therefore, they map

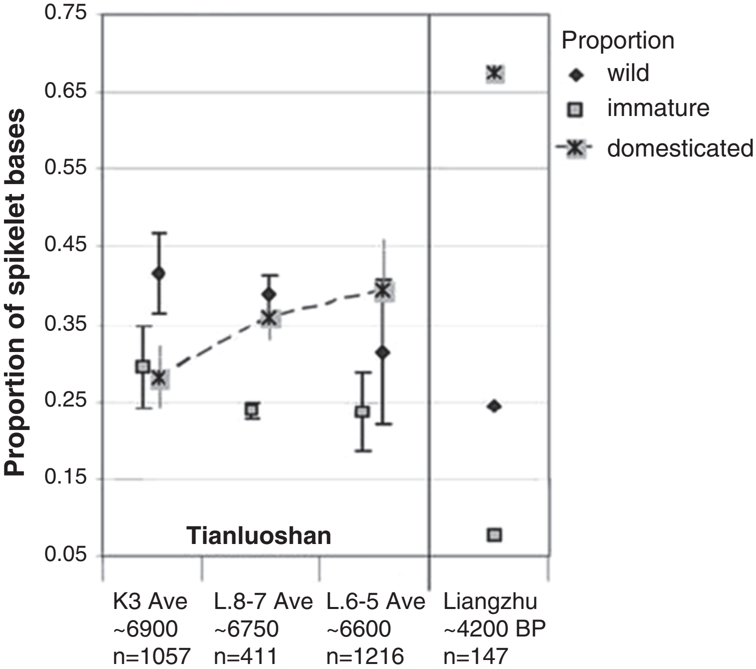

Fig. 9 Proportions of wild, immature, and domesticated rice spikelet bases from three sequential periods at Tianluoshan (Fuller et al. 2009, Fig. 4)

the distribution of Neolithic vegetation using macro plant remains such as seeds and fruits and hence discuss the exploitation of different catchments around the site. The advantage of this mapping is that it can illustrate the distribution in a small-scale area in detail.

In the plains area, there were plants adaptive to humid and aquatic environments, including *Salix*, *Trapa* (water chestnut), *Euryale* (foxnut), *Nymphoides*, *Oryza* (rice), *Typha*, etc. In the subtropical evergreen and broad-leaved forest (Fig. 11, mixed forest A) at the foot of hills, there were *Albizia*, *Broussonetia*, *Ficus*, *Armeniaca*, and *Vitis*; *Camellia* and *Zelkova* could be found in valley foothills. At the elevations between 100 m and 800 m, there was also mixed forest of evergreen and broad-leaved trees (Fig. 11, mixed forest B) but dominated with different trees, including *Lithocarpus*, *Cyclobalanopsis*, *Diospyros*, *Choerospondias*, *Acitinidia*. The highest area of Siming Mountain in the south would have had a distribution of broad-leaved forest mixed with conifers, composed with some trees in mixed forest B (see Fig. 11) and an increasing proportion of *Cinnamomum*. There are also *Amygdalus* (wild peaches), *Morus* (mulberries), and *Liquidambar* (sweet gum), which could have been used for building timbers in the past.

Environmental research on the sea level change indicates that there have been several fluctuations throughout the Holocene. It rose rapidly in the early Holocene

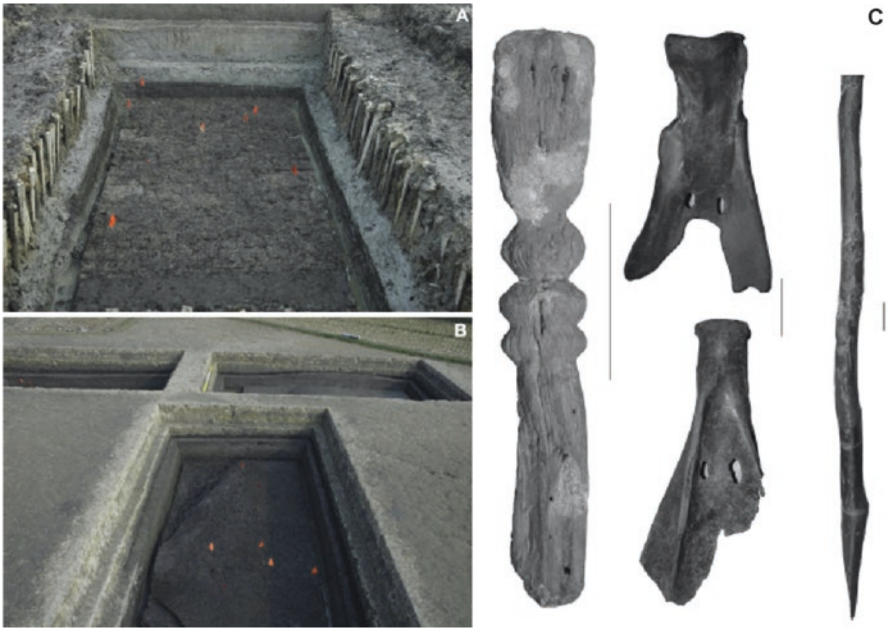

Fig. 10 Two layers of rice-growing fields at Tianluoshan and the relevant farming tools. A is the early rice field dated to 4650–4490 BC, lying 2.8 m deep under the surface. Wooden pegs are used for preventing collapse of the walls during excavations. B is the later field dated to 3340–3090 BC. Red flags mark the locations where pottery sherds are found. C shows the farming tools found at Tianluoshan; from left to right, they are wooden knife, bone spades, and wooden dibble. Spades are found within the settlement and the other two in the paddy field. Scale is 5 cm. Pictures are quoted from Zheng et al. (2009)

and kept at high levels until about 5000 years BC. Part of the coastal plain area was under water during those three millennia. Since around 5000 years BC, the sea level was relatively lower, and a series of low-lying plains was formed (Tao et al. 2006; Zhang et al. 2004). Wang et al. (2006) argue that the sea level started to rise again at about 4000 years BC and stayed at a high level until 1500–1000 BC. Palaeosalinity analysis of diatoms, plant seeds, and sediment samples reveals sea-level transgressions and regressions before, during, and after the occupation of Tianluoshan site (Li et al. 2009, 2010; Mo et al. 2011; Zheng et al. 2012). According to Zheng et al. (2012), there are at least two huge transgressions, which are from 6400 to 6300 BP and from 4600 to 2100 BP, in the Ningshao Plain, since the regression between 7500 and 7000 BP. It is also suggested that the invasion of the sea water could have negative influence to the subsistence and thus the development of the Hemudu culture (Mo et al. 2011). The sea level has been close to the present-day level over the last 3000 years.

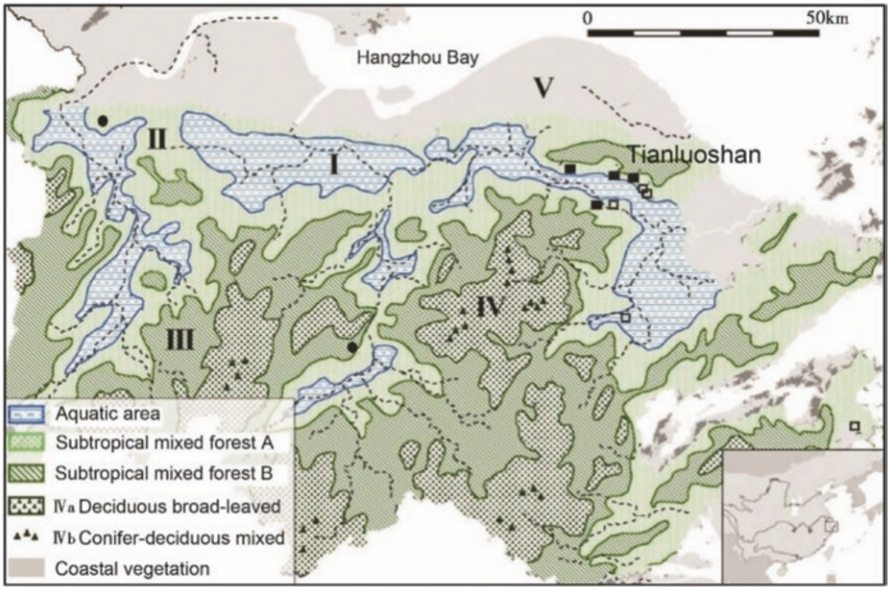

Fig. 11 The vegetation reconstruction of Hemudu culture period in the south of Hangzhou Bay area, including Ningbo-Shaoxing Plain (Qin et al. 2010)

6 Discussion

6.1 Fishing and the Environment

Biological research is fundamental for zooarchaeological topics such as palaeoenvironmental conditions, subsistence, and domestication (Reitz and Wing 2008, P28–29). Knowing fish ecology and behaviours benefits the discussion on fish remains (Wheeler and Jones 1989), especially for integration research, to understand the interrelationship between fish and the environment and to understand why and how people chose to catch these fish.

The most significant characteristic of the Tianluoshan fish assemblage is the absolute predominance of snakehead. As a predatory fish in the ecosystem, the proportion of snakehead in a natural water body is usually quite low. Take the Taihu Lake for example: the total proportion of snakehead and several other fish species take up merely 12.5% of the total population in 2000 (Chen and Wu 2008). In order to solve this puzzle, the life history of snakehead and five other fish are carefully looked through, to find out commons or difference, which may indicate the environment they were caught from.

Channa argus inhabits the tranquil water bodies with muddy bottoms and plenty of aquatic vegetation, such as ponds, reservoirs, and even rice paddies. Snakehead has the ability to breathe directly from air, making them tolerant to brutal conditions like hypoxic waters and dry seasons, which most fish cannot survive. As a top predator in the food chain, snakeheads feed on various organisms, including zooplankton, phytoplankton, insects, small crustaceans, fish, and frogs (Courtenay and Williams 2004; Editorial Committee of Fauna of Zhejiang 1991; Hubei Provincial Institute of Hydrobiology 1976). The habitat environment and behaviours of common carp and crucian carp are very alike. They prefer backwaters with rich vegetation but are tolerant of a wide variety of conditions in natural and artificial reservoirs, even with low oxygen concentrations, high pH levels, high temperature, organic pollutants, etc. (Hubei Provincial Institute of Hydrobiology 1976, P128–129; Kottelat and Freyhof 2007, P145; Yang 1987, P49). The spawning season of carp in this region is generally from April to June; for crucian carp, it is from March or April until early July. Catfish also has a high tolerance for water conditions. They prey on smaller fish, invertebrates, and insects. Culter fish, also known as top-mouth culter fish, is a carnivorous cyprinid in the temperate zone of Europe and Asia. They usually inhabit rivers and floodplain lakes with aquatic macrophytes, living and feeding near the bottom as well as in mid-water and near the surface. Sea bass is an inshore species found in coastal water, estuaries, and fresh waters at the west of the Pacific Ocean. The adults are catadromous, returning to sea to spawn in deeper rocky reefs or inshore areas, and juveniles ascend rivers to brackish or fresh water. Sea basses are commonly found in the estuary of Yangtze River and tributaries, sometimes downstream rivers.

By reviewing the habitat and behaviours of the fish, it is getting clear that most of the fish (except for sea bass) share the same habitat, indicating that they are possibly caught from the same environment. More importantly, they are tolerant to various environment even brutal conditions like low oxygen and high temperature. Plus, the species diversity is quite low, although the number of edible fish species in the lower Yangtze Region is quite large (Editorial Committee of Fauna of Zhejiang 1991; Ni and Zhu 2005). It is summarized that at least 54 species are potential food fish in the study area (Zhang 2015). Here we may ask: which is the cause of low diversity in the fish remains, selective fishing or environmental factors?

Environmental research reveals that Tianluoshan was located near a considerably large area of wetlands, which was an important food resources catchment, and also the probable catchment for fishing (Fuller et al. 2011; Kanehara and Zheng 2011; Zheng et al. 2011). From the perspective of ecology, wetlands can be defined as an ecosystem that arises when inundation by water produces soils dominated by anaerobic processes and forces the biota, particularly rooted plants, to exhibit adaptation to tolerate flooding (Keddy 2000). Wetlands share common features with both aquatic and terrestrial systems. Nevertheless, there are two features that together make wetlands unique: anaerobic soils and water and the distinguishing macrophytes (van der Valk 2006, P3). Anaerobic soils and water is the basic characteristic of wetlands and should be responsible for the corresponding adaption of wetland plants and animals.

The distribution of fish is controlled by factors including oxygen levels, water depth, water chemistry, and water temperatures (Mathews 1998). Generally, fish species are not unique to wetlands and are also found in adjacent lakes and streams. However, due to the anaerobic water and the periodic dry season (with no or very shallow standing water), fish may be absent from some kinds of wetlands. If not, their number and diversity are expected to be much lower compared to fish in other aquatic ecosystems, e.g. riverine and oceanic fish. However for most fish, the anaerobic water is not endurable. Fish which succeed to survive have developed certain ways to overcome the issue. Some have developed special organs to breathe directly from the air, such as catfish, lungfish, and snakehead. They also spawn buoyant eggs which can float on water surface to obtain enough oxygen. Parenting is also very useful to increase the rate of larvae's survivorship. These fish may migrate or hibernate to overcome the dry seasons. A few cyprinids also show great endurance to the wetland environment, especially common carp and crucian carp. They prefer tranquil waters and manage to survive the anoxic conditions in several ways (van der Valk 2006, P78). Wetland is the shelter, feed place, and spawning field for them.

The wetland ecology explains the existence of the fish species at Tianluoshan and the simplicity of the fish assemblage composition: the Tianluoshan people may not have much fish species to choose due to the simple ecosystem of the wetland. Snakehead, among all the fishes from Tianluoshan, is probably the most adaptive to wetland. Although there is no record of the exact proportions of each fish species in the wetland fish populations, it can be inferred that the proportion of snakehead and other air-breathing fish, which are carnivorous, is higher than that in other wide and deep water bodies such as rivers and lakes, where the fish diversity is much higher, just like the Taihu Lake.

6.2 *Investigating the Fishing Methods: Ethnographic and Zooarchaeological Analysis*

Fishing hooks, net sinkers, harpoons, and stone walls are probably the commonest fishing tools that have been discovered from archaeological sites, yet they may only represent a small proportion of all fish-capturing methods that were used at the site, for that many of them do not leave archaeological evidences. Ethnographic records are important resources for archaeological research when direct evidence of fishing techniques is absent, and also the reference data to reveal how the uncovered fishing artefacts worked. Archaeologists have been receiving help from ethnographic records for decades. Louis Binford benefited from Nicholas Gubser's (1965) and John Campbell's (1968) ethnographic work among the Nunamiut, and his work (Binford 1978, 2014) further contributes to the interpretation of archaeological faunal record.

Interestingly, no fishing tools like harpoons or net sinkers have been reported from Tianluoshan (Sun 2011). At the site of Hemudu, which has larger amount of fish remains, direct evidence of the fishing gear is also very rare: two stone net sinkers and two harpoons made of bone (Fig. 12) (Zhejiang Province Institute of Archaeology and Cultural Heritage 2003), indicate that the fishing gear must have been far more abundant than those that have been preserved. There could be two

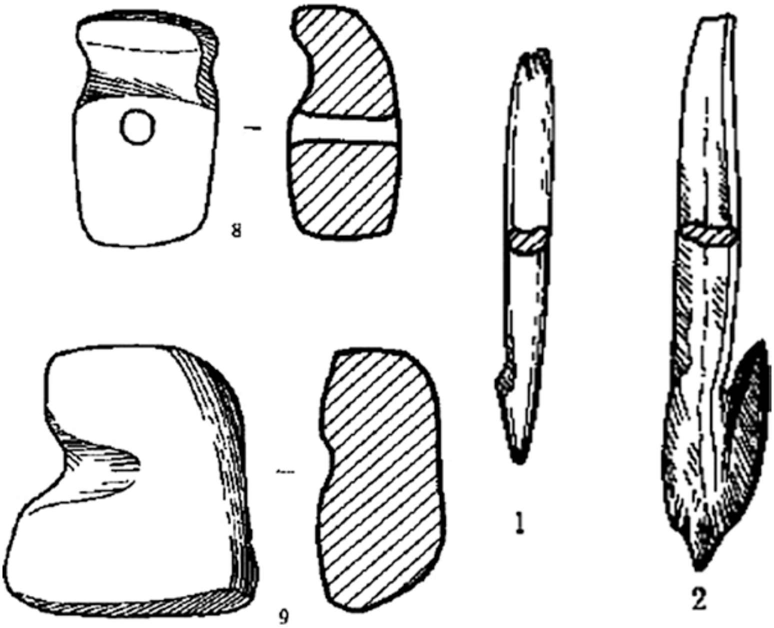

Fig. 12 The excavated fishing tools from Hemudu: net sinkers (left) and harpoons (right) (Zhejiang Provincial Institute of Cultural Relics and Archaeology 2003).

explanations for this scarcity of fishing tools: on one hand, most of the fishing gear was made of organic substance such as wood, bamboo, rope, etc., which could be hardly preserved; on the other hand, people might use nonconventional fishing gears which had not been correctly identified by archaeologists.

Fishing in wetlands is severely restricted by the environment. In deep and vast water bodies, netting and hooking can be the most applicable methods, but not in shallow waters. The low water level makes it difficult to cast or set nets, and the rich vegetation causes obstacles for both netting and hooking. Instead, ethnographic evidence show that some fishing equipment is especially applicable for wetland fishing, such as scoop baskets, traps, and a variety of 'falling gear' (Fig. 13), which are nets or pots particularly designed to clamp down on top of the fish and close in on them (Gabriel et al. 2005). The environmental limitations of wetlands have eliminated many common fishing methods and narrowed the possible choices to a few methods. Nevertheless, the wetland fishing gears share a common feature: they rarely leave any archaeological evidence. It is difficult to investigate the fishing techniques and skills at Tianluoshan directly from artefacts.

Each fishing gear and method usually applies to certain targets which are classified by various criteria, such as behaviour (e.g. nocturnal and migrating fish), habitat (e.g. deep/shallow water fish), or simply size, causing selectivity (Colley 1987; Lagler 1978; Millar 1995; Rollefsen 1953). Therefore, it is possible to discuss the fishing strategies by analyzing the species composition of fish remains, mortality

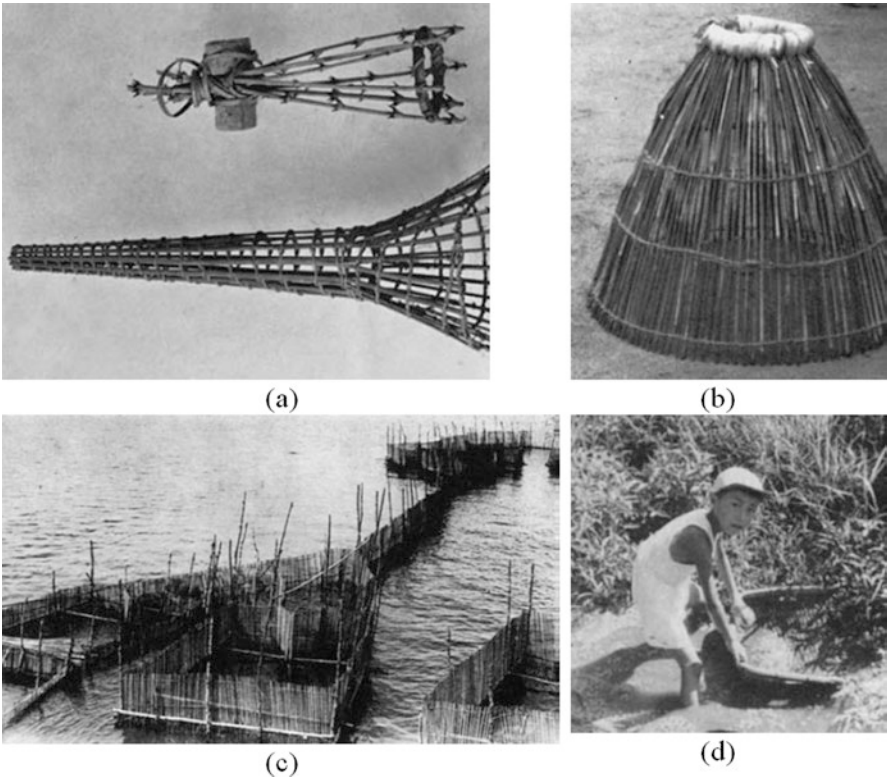

Fig. 13 Fishing gears which are applicable for wetland: (**a**) thorn-lined traps of Oceania; (**b**) cover pots used in Kerala, Southern India; (**c**) fences arranged as traps off the Ivory Coast (Photographed by Gabriel et al. 2005); (**d**) winnowing basket used as scooping basket in Japan, indicating that a tool can be multifunctional (Gabriel et al. 2005)

profiles, and the size of fish. A simple example is that catastrophic mortality profile possibly implies fish poisoning. In Balme's (1983) study on the fish remains from four sites along the Darling River in western New South Wales, she was able to distinguish gill net and drum trap fishing by their distributional patterns of fish length (Fig. 14b).

Figures 4 and 5 show a selection of fish by body size. Interestingly, although the sizes of the three predominant fish vary greatly from each other, the size reconstruction indicates that the selection by size is quite similar, concentrating on the individuals between 140 mm and approximately 450 mm. Hence, for crucian carp, which is much smaller than the other two species, the size of fish selected tends to be 140 mm and above. This result indicates that fish selection could possibly be caused by fishing methods. It also infers that those three species were possibly captured using the same fishing methods, rather than being targeted by individual species.

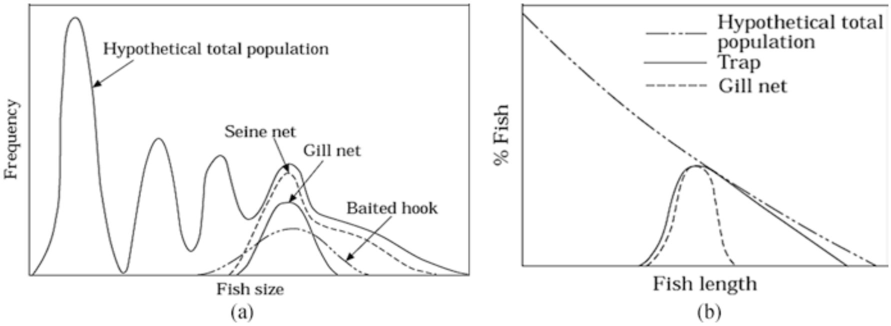

Fig. 14 Fishing gear selectivity model (**a**) for gill net, hook, line, and seine net (Hamley 1975) and (**b**) for drum trap and gill net (Balme 1983)

Yet, it is quite difficult to decide the exact fishing methods merely from fish size reconstruction. They can be narrowed down to a group of methods which have a selection of fish size, such as trapping, scooping, and covering with falling gear. One or several of them could have been practised at Tianluoshan.

In conclusion, interpreting fishing strategy at archaeological sites requires a sophisticated knowledge of fish behaviour and habitat, according to which the specific fishing gears were chosen and the fishing strategy was applied. When there is not enough direct evidence of fishing gears, the deduction of fishing methods can be made according to the analysis of fish remains, sometimes with the assistance of ethnographic records.

6.3 Scheduling the Exploitation of Aquatic Resources

Scheduling the exploitation of various resources is an important part of the subsistence economy. Some resources are only available at fixed time in a year, like fruits, nuts, and migratory fish, while the others are available throughout the year, but their distribution, the costs and risks of acquiring them, and the quality of their nutrients and by-products may vary between seasons. By scheduling the resource exploitation, we can find out how people cope with fluctuating abundances of edible resources and solve conflicts when several resources are available at the same time.

In addition, the seasonal cycles in resources have significant impacts on the sites and societies. On one hand, they influence where sites are located, when they are occupied, how many people live there, and the activities that occur at them (Reitz and Wing 2008, P261). On the other hand, they influence the coordination of labour among men and women of different age groups within the society (Gragson 1993; McGovern 1994).

The edible resources from Tianluoshan can be roughly categorized into two groups: seasonal and nonseasonal. Fruits and nuts are highly seasonal resources which can be only collected in fixed seasons of the year. Plus, the fruiting season is usually rather short, so it requires great labour to collect the fruits and nuts before they get rotten or eaten by animals. For instance, the harvest season of acorns from Tianluoshan is suggested to be from August to November due to lack of species-level identification; this is also the period when the majority of Lithocarpus and Cyclobalanopsis in South/Southeast China fruit (Fuller et al. 2011). In reality, the peak season for acorn collecting is perhaps 1–3 weeks only, as acorns just begin to fall off trees once they come into maturity (Hillman 2000). There was possibly conflict in the time and labour that were spent on acorn gathering and rice cultivation, and the conflict would eventually become more serious as rice agriculture developed. In the meantime, hunting and fishing only occasionally occurred in autumn. This was probably arranged on purpose to avoid the extremely busy season.

In general, it shows a well-planned scheduling for exploiting different resources in a year. The events are dispersed throughout the year, barely overlapping. Fishing was practised throughout the year according to the seasonality reconstruction but was more intense in certain months. For snakeheads, the intensified fishing mostly occurred in spring; but as time goes by, the fishing season extended. The concentrated fishing seasons for the cyprinids occurred slightly later, normally from late spring to summer. By integrating with the seasonality of aquatic plants, the exploitation of the aqua resources is regularly scheduled at different seasons of the year (Fig. 15).

The schedule of exploiting the common aquatic resources indicates that the wetlands were constantly used for subsistence. As the harvest of aquatic plants is highly restricted by seasonality, fish may well have been the routinely procured resource for consumption. The seasonality analysis of sika deer and wild boar remains shows that hunting is relatively intense during winter, avoiding conflict with fishing and collecting.

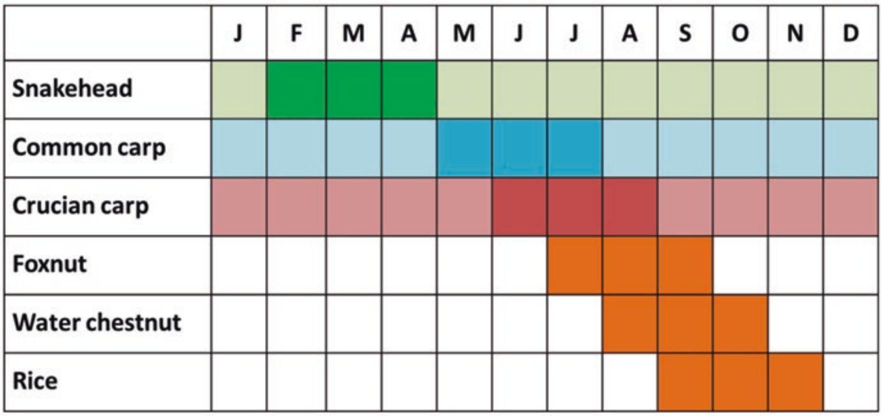

Fig. 15 Seasonality of fishing at Tianluoshan, comparing with fruiting period of selected aqua plant taxa based on *Flora of China* and *Flora Hubeiensis* (Fuller et al. 2011). Coloured blocks represent the months when the resource is exploited, and dark-coloured blocks show the time when exploitation is intensified

7 Conclusion

The presence of substantial quantities of fish remains confirms that fishing was an important component in the subsistence economy at Tianluoshan. The analysis indicates snakehead, crucian carp, and common carp can be regarded as co-staples. The limited range of fish species suggests that the inhabitants of Tianluoshan were specialized fishers rather than broad-spectrum foragers. The presence of wetland, riverine, estuarine, and marine fish indicates varied environment for fish exploitation; however, detailed analysis of the three predominant fish suggests that fishing mostly occurred in a rather concentrated area, i.e. the wetlands.

Integrated with the archaeobotanical results, the importance of wetlands in the Tianluoshan subsistence is highlighted. Archaeobotanical research indicates that aquatic plants from the wetlands, including wild water chestnuts, foxnuts, and cultivated rice, were the major plant food resources at Tianluoshan throughout the Hemudu period. In addition, although not included in this research, a large number of soft-shelled tortoise and waterfowl which inhabit the wetland has been uncovered from Tianluoshan. These findings indicate that wetland might be the core region for subsistence at Tianluoshan.

Ecology is about the natural environment and the interrelationships between organisms and their surroundings. It includes information about an animal's living, such as where it lives; what it eats; what, where, and how it pursues food; the breeding season; living style (group or isolated); etc. Such knowledge is fundamental for any hunting and fishing activities; hence it is accumulated and passed down by the hunters and fishermen from generation to generation. It is also fundamental for zooarchaeological studies investigating past subsistence economies. A stable subsistence system is founded on firmer ground, based on biological and ecological knowledge, allowing for repeated and reliable success in securing targeted species (Reitz and Wing 2008, P88).

Fishing is a complicated subsistence activity which involves various tools, techniques, and strategies. Strategically, there is no clear boundary between fishing and hunting. Many methods are known in both fishing and hunting, such as spearing, harpooning, shooting, and trapping (Gabriel et al. 2005, P2). The comprehensive analysis of the fish remains, artefacts, and environment suggests that a variety of size-selective fishing methods adaptive to the wetland environment were probably applied at Tianluoshan. The specific techniques might include trapping, scooping, and using falling gear. Most of the fishing tools involved were possibly made of plant materials.

This analysis may push us to reconsider the function of some structures in the settlement. At the low-lying area of the site, a feature made of a group of stakes is interpreted as a fence and log-bridge structure separating the settlement and the outside (Sun 2011). However, it is proposed here that the structure of this feature might have been a fishing barrier, like the one used by Native Americans and in Fig. 13c. Hopefully more evidence will be uncovered in the future to understand the function of this kind of features.

It requires a broad knowledge about animal habitats, behaviours, life history, the environment, and the ecosystem to establish an efficient and sustainable schedule for hunting, fishing, and gathering events. The intensified exploitation of varied resources was arranged at different times of the year to avoid conflicts in labour and time. However, the exploitation season of certain resources seemed to be related judging from the ecological and cultural background. Rice cultivation might have influenced the scheduling of other resources. As rice farming became more and more important in the cultures thereafter, the scheduling strategy might have changed accordingly.

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All or Nothing: Spatial Analysis and Interpretation of Archaeological Record Based on the Integration of Artifactual, Ecofactual, and Contextual Data at the Medieval Site of Komana

Mustafa Nuri Tatbul

1 Introduction

This paper is derived from one of two pilot studies implemented in order to integrate multiple ecofactual and artifactual data types and to deal with highly disturbed archaeological record (For the application and results of the first pilot study see Tatbul 2013). It aims at defying function of a complex and densely built area from the twelfth- to thirteenth-century Danishmend/Seljuk phase at Hamamtepe. This area has multiple rooms, and almost each of them has oven installations. Often, several ovens are found within each room. Despite the fact that the ovens seem to have been used for cooking, their high number may indicate that they also supported industrial activities. Another difficulty in specifying the function of these rooms was the small number of in situ artifacts and the very poor preservation of floor deposits for which very little and fragmentary evidence remained. The study presented in this article involves a spatial investigation of one of the rooms aimed at understanding the character of the archaeological record, especially the room fill as a potential indication of the room function in terms of different activities carried out inside (For the detailed spatial analysis of the archaeological data of Danishmend/Seljuk occupation phase at Komana, see Tatbul 2017).

In particular the objectives of this study are threefold: (1) to understand the nature of the archaeological record in terms of *primary* and *secondary refuse* depositions (see Schiffer 1996; 1972) and understand a complex of post-abandonment processes, (2) to integrate different categories of artifacts and ecofacts and reconstruct the character of activities card out in these contexts, and (3) to define strong contextual ties between space, features, and artifacts/ecofacts as the elements of this spatial unity.

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2 Historical and Archaeological Context of Komana/ Hamamtepe

Komana/Hamamtepe archaeological site is located in the Gümenek village, ca. 10 km northeast of the Tokat province of Turkey. It has been uninterruptedly occupied for about 2000 years from the Hellenistic to Ottoman periods. The modern-day village is expanded over the remains of the ancient settlement (Fig. 1).

As a result of the excavations carried out since 2009, a large number of ceramics and architectural remains from the Hellenistic and Roman periods have been revealed (Erciyas and Tatbul 2017; Erciyas and Tatbul 2016; Erciyas and Tatbul 2015; Erciyas 2014; Erciyas et al. 2011). The earliest evidence of architecture comes from the early Byzantine period and is represented by mortared wall foundations (for detailed information on the phases and layers, see Erciyas et al. 2015). It was followed by a cemetery phase accompanied by two adjacent middle Byzantine chapels dated back to the tenth to eleventh centuries and later by Danishmend/ Seljuk occupation of twelfth to thirteenth centuries, where the archaeological record reflects a prosperous period at the site, as indicated by dense industrial and domestic production, consumption, and discard behaviors. The twelfth to thirteenth centuries occupation at the site is represented with rooms that were constructed with dry walls. Numerous ovens and pits were recovered within these spaces. These features have rich contents of refuse disposals such as artifacts, animal bones and plant

Fig. 1 Aerial view of Komana/Hamamtepe archaeological site (Source: KARP archive)

remains. Density of utility features and archaeological materials suggests a very busy daily life at the site. The site is encircled with a fortification wall, which was first used in the earlier Byzantine times and then restored and used during the twelfth to thirteenth centuries by the Danishmends/Seljuks.

The latest occupational level comprises the sixteenth- to seventeenth-century Ottoman dwelling units and probably stables, where larger spaces with fewer utility features (ovens and pits) have been observed. The only material evidence from the Ottoman phase comprises a very small number of pottery, coins, and terra-cotta tobacco pipes.

The site is significant for its elevated position in the middle of a valley, its location in the Yeşilırmak (Iris River) basin and trade as well as transportation route, fertile agricultural and pasture lands, and a variety of natural resources.

3 The Nature of Archaeological Record

3.1 Formation and Depositional Processes

The excavations at Hamamtepe revealed a significant degree of depositional and postdepositional processes. A number of the tenth- to eleventh-century graves got truncated by the construction of the twelfth- to thirteenth-century Danishmend/Seljuk structures. Similarly, the construction of the sixteenth- to seventeenth-century Ottoman floors and wall foundations considerably truncated the twelfth- to thirteenth-century occupational levels by destroying different features and disturbing spatial arrangements of different types of artifacts.

Hence, while studying the twelfth- to thirteenth-century deposits, it is required to understand the character of formation processes and their impact upon archaeological deposits. In terms of interpreting the archaeological record while conducting spatial analysis at intrasite level, Schiffer's definitions of behavioral patterns, whether *primary* or *secondary refuse* originated from intrasite activities, are required for comprehensive understanding of the nature of archaeological record.

Accordingly, the archaeological materials originating from the twelfth- to thirteenth-century room have been systematically investigated in order to define *primary* and *secondary* refuse patterns taking place at Hamamtepe. Following Schiffer (1996: 1972), I defined primary refuse as originating from domestic activities within the room limits whenever these are associated with in-built feature. At the same time, I attempted to test whether any of the highly disturbed and fragmented materials from the room fill can be used to discern human behavior. In contrast to the room fill, plant data from oven and pit deposits are considered as direct evidence of human activities.

3.2 Integration, Evaluation, and Interpretation of Different Strands of Evidence

Integration of plant remains and animal bone data remains one of the major tenets of environmental archaeology since the late 1980s (Marston et al. 2014). This goes in tandem with studies of formation and depositional processes of botanical assemblages (Marston et al. 2014). A thorough understanding and definition of preservation conditions and formation of macrobotanical assemblages from archaeological contexts is based upon routine procedures (Gallagher 2014).

In many archaeological studies, however, different categories of data such as pottery, metals, or glass still remain to be studied separately. However, in some other instances, plant remains and animal bones are studied separately, but their interpretation is coordinated and integrated (Van Derwarker 2010, 65). A quantitative integration of both types of data is rather uncommon. Van Derwarker (2010) proposes five simple measures of data integration: ubiquity, diversity, ratios, correlation, and spatial analysis (Van Derwarker 2010). Integration of flora and fauna is particularly crucial as both types of data are of significant value for studies of agropastoral economic production, exchange, and consumption. Moreover, they are the strongest indication of primary domestic activity in the form of consumption refuse and storage (See Twiss et al. 2009: a spatial analysis case study of a Neolithic house at Çatalhöyük, where the team identified household organization in food storing activities through organic data types).

Not only integration of plant remains and animal bones but also artifactual data are important for studying the past processes. Different categories of artifacts can be used for studying different forms of production, storage, and consumption. These can also be used for recognizing activity areas and function of different in-built features, such as fire installations and pits.

An efficient integration of these three types of data is only possible by careful examination of contexts in which they occur (See Putzeys 2007: for his spatial and contextual analysis of entire archaeological data recovered in specific areas at the Roman site of Sagalassos. His comprehensive analysis integrates all data in hand). Smith (2013) proposed a procedure for identifying a cesspit in archaeological record integrating contextual stratigraphic formation and faunal, floral, and cultural data. By studying the twelfth- to thirteenth-century medieval cesspit at Komana, we distinguished a combination of rich mineralized macrobotanical remains mostly grapes and fig seeds; animal bones of nonfood species such as rodents, cat, and insects; well-preserved artifacts; and pit fill of greenish sandy soil with a suitable structure for water retention in the bottom (Fig. 2).

While studying household activities at Fortuna Domus (Cartagena, Spain), Bermejo and Quevedo (2014) have undertaken a comparative spatial analysis between two occupation phases integrating all artifact groups and macrofaunal remains aimed at recognizing production, redistribution, and consumption patterns. This approach made it possible to distinguish social and economic patterns of household activities in successive occupational phases, even though the quality and

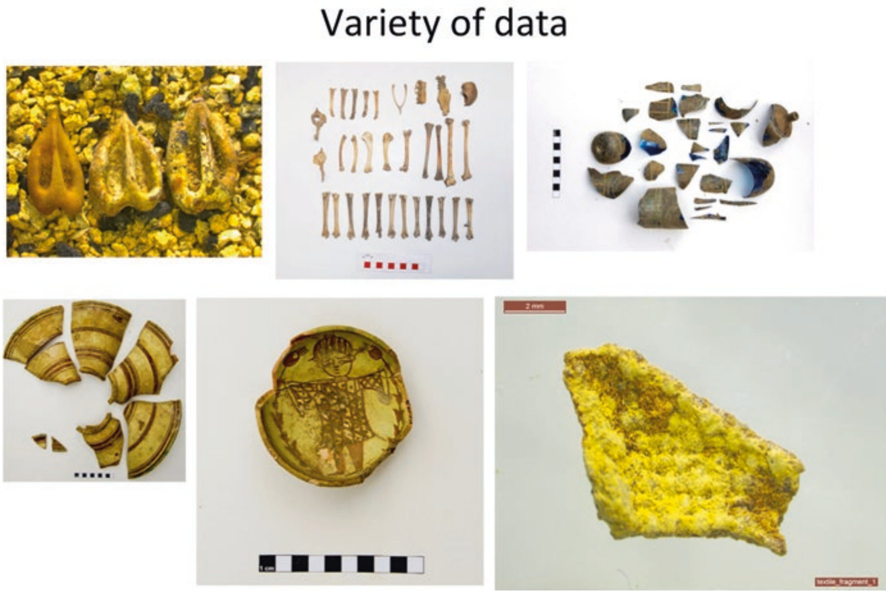


Fig. 2 Composition of materials recovered from the twelfth- to thirteenth-century Medieval cesspit at Komana (Source: KARP Archive) from left to right, at top row mineralized grape seeds, bird bones, blue perfume bottle, refitable fine ceramics, and a cloth fragment

quantity of available data was not always satisfactory. The analysis led to interesting results, e.g., recognition of different consumption patterns in two Roman phases, one dominated by a mixed seafood and ovicaprid diet while the other focused exclusively upon consumption of maritime resources.

Hardin (2004), in his study of activities related to food preparation and serving at domestic setting at the Iron Age Tel Halif, integrated architectural elements, various artifact types, microartifacts, and economic macrofauna and flora originating from a burned and well-preserved sealed context that was formed when a building collapsed due to a destructive event. He was able to differentiate artifactual, macrobotanical, and macrofaunal contents of five rooms to suggest activity types for each room such as food preparation, food storing, or weaving activities.

4 Methods and Materials

In this paper, a combined spatial, contextual, and statistical analysis has been adopted to study the case from the Komana site. However, due to a small number of available samples, neither ubiquity nor diversity measures have been studied.

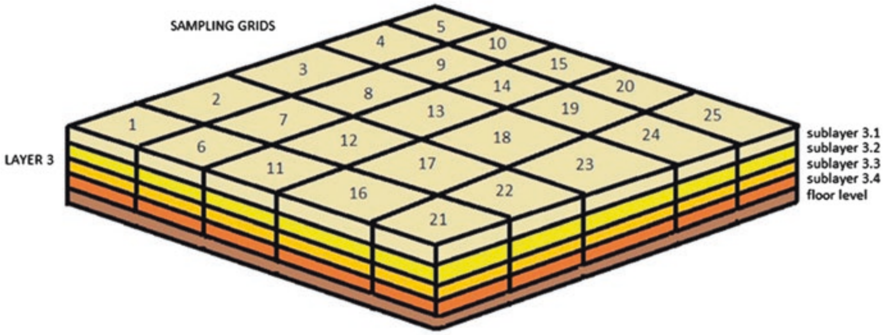


Fig. 3 An example of gridding applied in a 5 × 5 m trench

Fig. 4 Trench sampled in the case study (Source: KARP Archive)

4.1 Data Collection

In order to understand the formation of room fill right above the twelfth- to thirteenth-century floor and recognition of spatial patterning of different types of data pertaining to human behavior, the excavations were carried out in nine grids, each 1 m × 1 m, located in selected parts (Figs. 3, 4, and 5). The materials were collected in vertical and horizontal artificial delimited units in order to systematically record dispersal of different types of data, such as ceramics, metals, glass, small

Fig. 5 Grid sampling (Source: KARP Archive)

finds, animal bones, and plant remains. They were then identified and quantified and their distribution carefully recorded. After the establishment of the grids, remaining parts of the room that were out of the grids were also collected. In order to see any possible pattern of all the materials recovered within the room fill, these were later combined with the grid materials and evaluated together (as total materials of the room).

4.2 Soil Sampling

Soil samples were taken from layers and oven; a small container on a platform; an ashy pit, most likely related to ovens; as well as patches of open burnt layer.

4.3 Data

4.3.1 Ceramic Data

Ceramics recovered from the room were highly fragmented. They represented three major types: fine ware, cooking ware, and storage ware. The frequency of each type was calculated. Despite a significant postdepositional disturbance, their presence, along with ovens and faunal and botanical materials, was believed to indicate food-related practices.

4.3.2 Metal Data

Amorphous metal fragments and slags were found in room fill. They are indicative of metal production activity. The most common were nails, mainly associated with elements of wooden construction, both decorative and constructional.

4.3.3 Glass Data

Relatively common bracelets imply presence of fine glassware use, while frits and are indicative of glass production.

4.3.4 Botanical Data

Archaeobotanical data were recovered from the soil samples originating from four different contexts: container on a platform, the oven base, an ashy pit, and burnt layer patches. Cereals, legumes, and fruits were recovered but for the sake of simplicity were analyzed together. However, grapes were treated separately due to a special role it played.

4.3.5 Faunal Data

Animal bones were identified at species and anatomical element level. Highly fragmented and unidentifiable to species bones were also recorded at size categories as ox size, sheep size, pig size, and small mammal sized taxa. A distribution of bones within the room was analyzed in order to discern a mode of refuse disposal as well as subsistence-related practices.

4.3.6 Heavy Residue Data

HR of the soil samples was analyzed in order to see whether there was industrial acitivity within the sampled space. Fragments of production wasters such as glass, metal and ceramic slags were sought for.

5 Interpretation of Integrated Datasets

Out of three major types of ceramics, the most common was fine ware followed by cooking ware and storage ware (Fig. 6). The frequency of these types of ceramics was then calculated in subsequent layers above the floor.

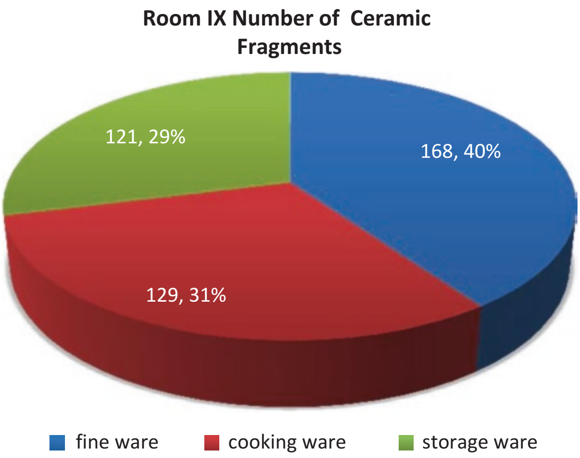
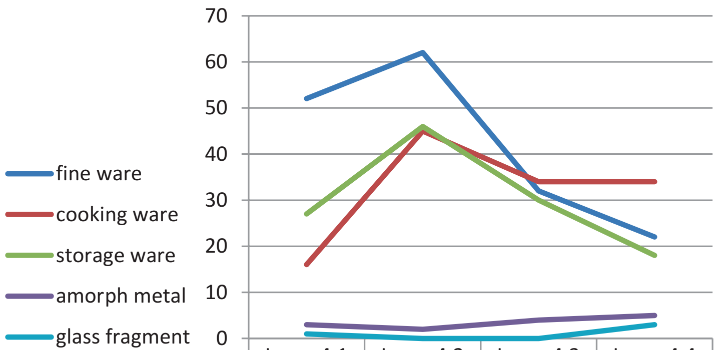


Fig. 6 Proportion of ceramic types in the fill of room IX



	Layer 4.1	Layer 4.2	Layer 4.3	Layer 4.4
fine ware	52	62	32	22
cooking ware	16	45	34	34
storage ware	27	46	30	18
amorph metal	3	2	4	5
glass fragment	1	0	0	3

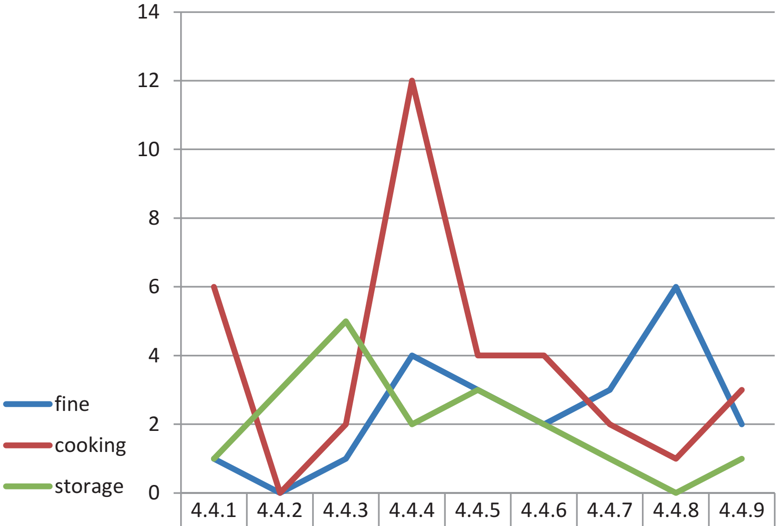
Fig. 7 Frequency of different categories of material in subsequent sublayers of room IX

Out of the four analyzed sublayers, Layer 4.2 contained the highest number of ceramics. In the absence of in situ ceramic vessels from the room floor, all three distinguished types are represented in a similar number. Pottery is accompanied by a few fragments of glass and metals (Fig. 7).

The horizontal distribution of ceramic fragments was only shown for the last sublayer (Layer 4.4), which was immediately over the occupation floor. Grid number 4 and 5 had the most concentration of ceramics (Fig. 8).

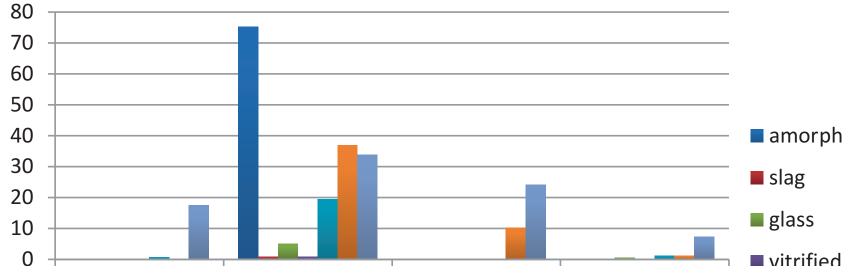
When the functional ceramic groups among the grids were analyzed, grid 4 showed significant concentration of cooking ware fragments, grid 8 fine ware, and grid 3 storage ware (Fig. 9).

Fig. 8 Layer 4.4 distribution of total ceramics among nine grids. The darker the coloring, the higher the number of ceramics



	4.4.1	4.4.2	4.4.3	4.4.4	4.4.5	4.4.6	4.4.7	4.4.8	4.4.9
fine	1	0	1	4	3	2	3	6	2
cooking	6	0	2	12	4	4	2	1	3
storage	1	3	5	2	3	2	1	0	1

Fig. 9 Horizontal distribution of ceramic groups among the grids of sublayer 4.4



	oven F38	pit Fx5	container F39	fill
amorph	0	75.27	0	0.08
slag	0	0.76	0	0
glass	0	5.04	0	0.44
vitrified	0	0.84	0	0.15
fine	0.6	19.51	0	1.16
cooking	0	36.85	10.26	1.22
storage	17.46	33.88	24.07	7.38

Fig. 10 Quantified HR samples (grams)

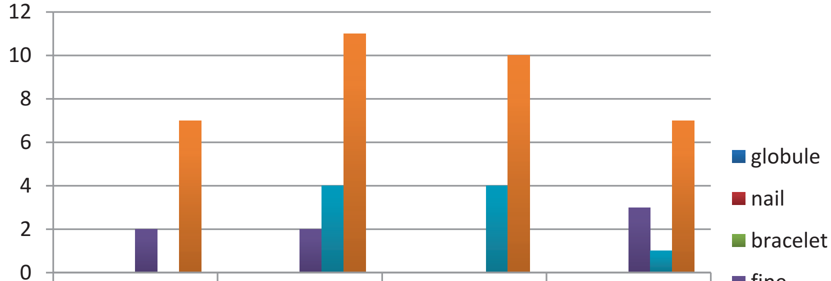
A lack of slag and other waste-related materials related to the production of ceramics, metal, or glass implies a domestic character of the room, most likely related to food preparation. This is irrespective of a discovery of a piece of metal slag (260 gr) from the pit. It was most likely intrusive and may have originated from the adjacent area used for metal production.

HR sample from the oven F.38 does not contain any metal, glass, and slag fragments except for a few small pieces of fine and storage wares, most likely from the room fill. This indicates that the oven was used for nonindustrial purposes (Figs. 10 and 11).

HR sample from a soft pit (Fx5) contained a very low number of metal, glass, slag, and ceramic fragments which were insufficient to imply any special refuse or industrial activities. These results rather imply food-related activities in room IX.

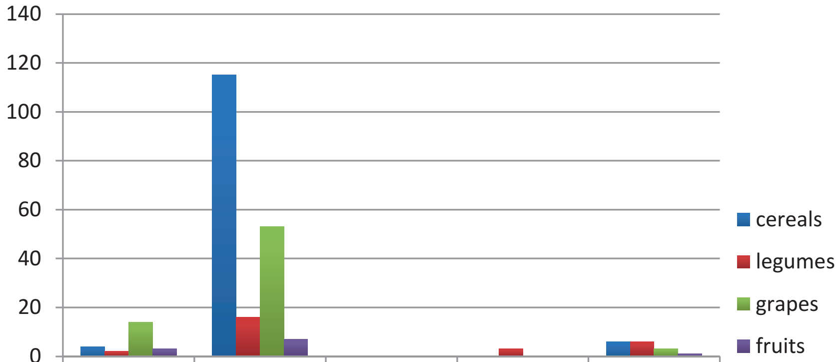
Archaeobotanical data recovered from the oven and pit was the most direct evidence of food preparation activities (for the preliminary archaeobotanical report on the excavations see Pişkin and Tatbul 2015). This is further corroborated by presence of a considerable number of cooking pots from the room fill as well as an oven rake-out.

Soil samples from oven (F38) revealed presence of charred economic plant remains such as cereals (4), legumes (2), grapes (14), and fruits (3). A large number of organic material including 115 cereals, 16 legumes, 53 grapes, and 7 charred fruit remains were found on another pit (Fx5) (Fig. 12). Both oven and pit clearly contained refuse materials, in particular charred plant remains, most likely related to food preparation.



	oven F38	pit Fx5	container F39	fill
globule	0	0	0	0
nail	0	0	0	0
bracelet	0	0	0	0
fine	2	2	0	3
cooking	0	4	4	1
storage	7	11	10	7

Fig. 11 Quantified HR samples (No. of specimens)



	oven F38	pit Fx5	cooking pot	container F39	fill
cereals	4	115	0	0	6
legumes	2	16	0	3	6
grapes	14	53	0	0	3
fruits	3	7	0	0	1

Fig. 12 Plant remains in different contexts

Fig. 13 Animal species composition in room IX

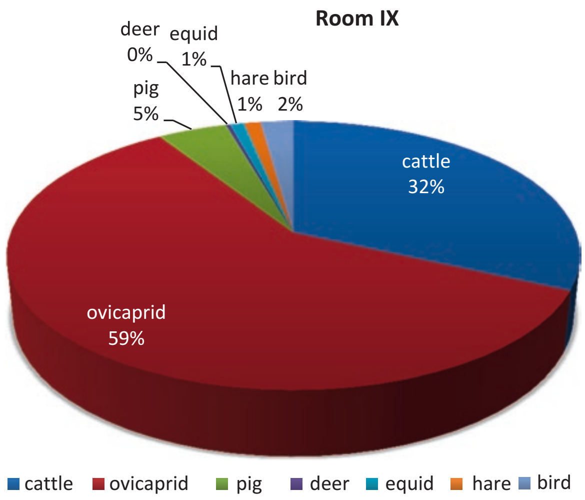
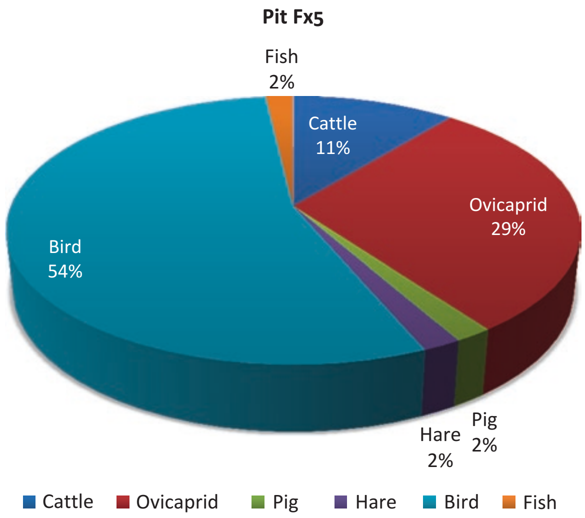
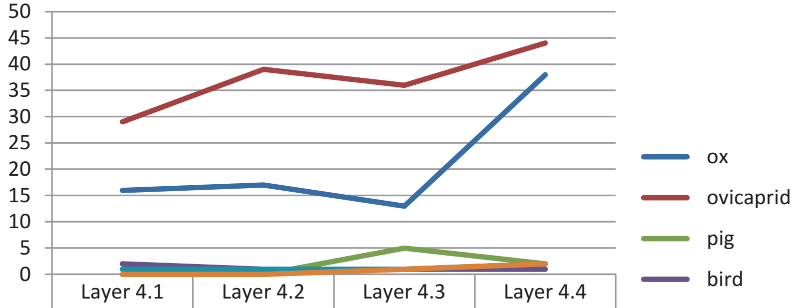


Fig. 14 Animal species composition in Pit Fx5



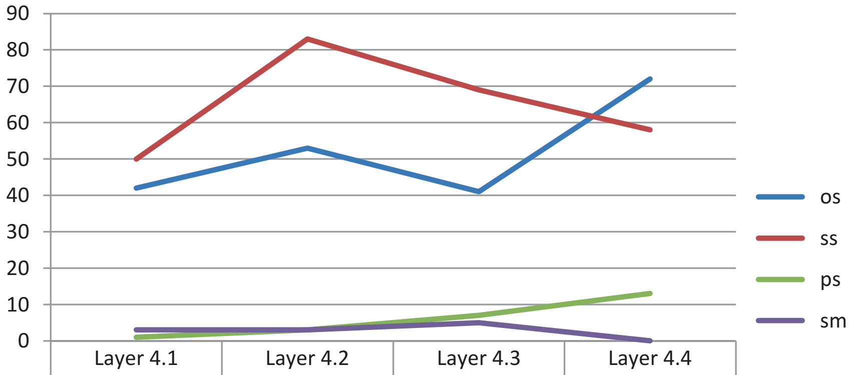
Zooarchaeological data indicate the exploitation of ovicaprid, cattle, pig, as well as birds, hare, and fish. The assemblage is dominated by sheep/goats (59%) and cattle (32%) (Fig. 13). Interestingly, bird bones are by far the most common species in pit (54%) followed by ovicaprids (29%) and cattle (11%) (Fig. 14). Through HR analysis, it was possible to record fish (2%).

NISP showed that ovicaprid bones are the most abundant species in all sublayers, outnumbering cattle, the second most common species (Fig. 15). Pig, bird, hare, and equid bones are much less common. The same pattern is observed for the unidentified fragments at animal size level. While sheep-size bone fragments dominate in



	Layer 4.1	Layer 4.2	Layer 4.3	Layer 4.4
ox	16	17	13	38
ovicaprid	29	39	36	44
pig	1	0	5	2
bird	2	1	1	1
hare	1	1	1	2
equid	0	0	1	2

Fig. 15 Animal species composition in subsequent sublayers



	Layer 4.1	Layer 4.2	Layer 4.3	Layer 4.4
os	42	53	41	72
ss	50	83	69	58
ps	1	3	7	13
sm	3	3	5	0

Fig. 16 Unidentifiable animal bone fragments in size categories (ox size, sheep size, pig size, and small mammal size)

three uppermost sublayers, cattle-size bones dominate in Layer 4.4 (Fig. 16). Pig-size and small mammal bones are much less common.

In sublayer 4.4, animal bones are mainly concentrated in grids 4 and 5 (Fig. 17). This corresponds with the concentration of ceramics in these contexts. However, the reason for overrepresentation of both categories of data in both grids is unclear.

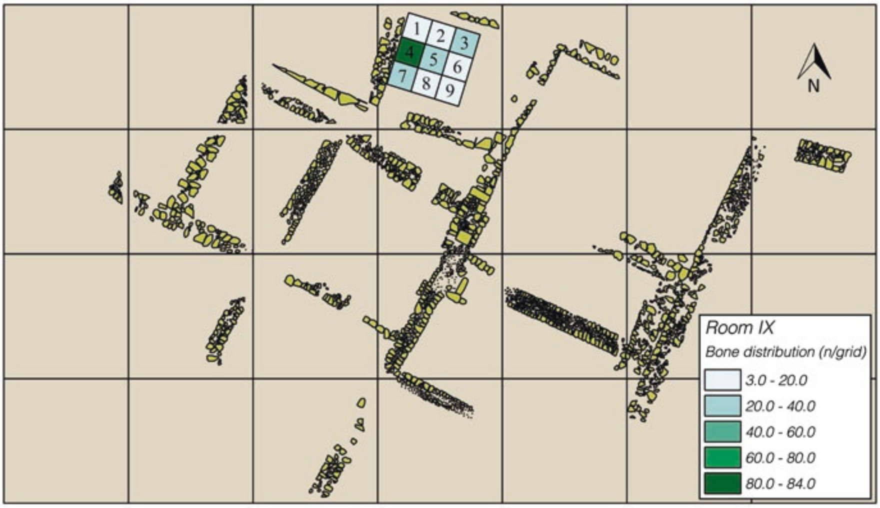


Fig. 17 NISP of animal species in grids of Layer 4.4

The faunal assemblage from the room IX fill (59% ovicaprid and 32% cattle) (Fig. 13) was quite similar to a species composition at the twelfth- to thirteenth-century Komana with dominance of ovicaprids (66.3%) and cattle (30.6%) (Pişkin 2015, 117–8). However, the assemblage recovered from a pit context (Fx5), most likely a primary refuse, is characterized by entirely different species composition dominated by bird bones (54%), followed by sheep/goats (29%), cattle (11%), pig (2%), and hare (2%) (Fig. 14).

These assemblages imply a significant difference between room fill and pit contexts. This difference is most likely attributed to distinct behavioral pattern indicating special refuse disposal practices related to consumption of birds.

6 Conclusions

At glance, it is clear that all major pottery types, animal and plant species are present in the assemblages.

A detailed contextual sampling strategy employed at the site made it possible to discern spatial distribution of different categories of data. Accordingly, clusters of ceramics and bones have been recorded in two grids, but they do not remain associated with in-built structures such as oven and pit. This does not come as a surprise considering a high level of fragmentation of different categories of materials implying a significant impact of postdepositional processes. The character of paleoenvironmental data is also very informative. For instance, animal species composition was clearly different in room fill and pit. While the former is similar to species composition for the entire settlement, the corresponding species proportions in pit are completely different.

These differences are most likely attributed to the origin of these two assemblages. Both the oven and pit are closed contexts more likely representing the remains of the "last use" of these features and therefore the "last use" of the room while materials from the room fill may have been accumulated over a significant period of time. These observations prompt us conclude that the room fill appears to be unsuitable for recognizing its spatial organization and that the fill itself can be highly differentiated.

Integration of archaeobotanical, zooarchaeological, and artifactual data, along with their clearly contextual analysis, offers a heuristically valuable solution for discerning and understating activity patterns in different dwelling structures. The analyzed materials from both in-built structures and the fill of room IX at Komana clearly indicate food-related activities. While the importance of artifacts from this standpoint is problematic, ecofacts provided more reliable and direct evidence.

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