Edited by:

MARTA DAL CORSO, WIEBKE KIRLEIS, JUTTA KNEISEL, NICOLE TAYLOR, MAGDALENA WIECKOWSKA-LÜTH, MARCO ZANON

HOW'S LIFE?

Living Conditions in the 2nd and 1st Millennia BCE

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Sidestone Press

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Preface of the series editors

With this book series, the Collaborative Research Centre 'Scales of Transformation: Human-Environmental Interaction in Prehistoric and Archaic Societies' (CRC 1266) at Kiel University enables the bundled presentation of current research outcomes of the multiple aspects of socio-environmental transformations in ancient societies by offering this new publication platform. As editors, we are pleased to be able to publish monographs with detailed basic data and comprehensive interpretations from different case studies and landscapes as well as the extensive output from numerous scientific meetings and international workshops.

The book series is dedicated to the fundamental research questions of the CRC 1266 dealing with transformations on different temporal, spatial and social scales, here defined as processes leading to a substantial and enduring reorganization of socio-environmental interaction patterns. What are the substantial transformations that describe human development from 15,000 years ago to the beginning of the Common Era? How did the interaction between natural environment and human populations change over time? What role did humans play as cognitive actors trying to deal with changing social and environmental conditions? Which factors triggered the transformations that led to substantial societal and economic inequality?

The understanding of human practices within the often intertwined social and environmental contexts is one of the most fundamental aspects of archaeological research. Moreover, in current debates, the dynamics and feedback involved in human-environmental relationships have become a major issue looking at the sometimes devastating consequences of human interference with nature. Archaeology, with its long-term perspective on human societies and landscapes, is in the unique position to trace and link comparable phenomena in the past, to study the human involvement with the natural environment, to investigate the impact of humans on nature, and the consequences of environmental change on human societies. Modern interlinked interdisciplinary research allows for reaching beyond simplistic monocausal lines of explanation and overcoming evolutionary perspectives. Looking at the period from 15,000 to 1 BCE, the CRC 1266 takes a diachronic view in order to investigate transformations involved in the development of late Pleistocene hunter-gatherers, horticulturalists, early agriculturalists, early metallurgists as well as early state societies, thus covering a wide array of societal formations and environmental conditions.

The volume *How's life? Living conditions in Europe during the 2nd and 1st millennia BCE* brings human beings and their daily routines into focus for a time period that is characterised by superordinate transformations driven by innovations in metal working, increasing social complexity, and early globalisation. The edited volume furthermore disputes the modern pictorial representation of Metal Age living conditions and intends to supplement the current state of the art on the ‘big’ questions of Metal Age transformations by providing a perspective on everyday life. It aims at providing a ‘feeling’ for life in the past and encourages the pursuit of a holistic understanding of ancient lifetimes. The book is the outcome of the session ‘Socio-Environmental Dynamics over the Last 12,000 Years: The Development of Landscapes IV’ organized by the group of editors Marta Dal Corso, Wiebke Kirleis, Jutta Kneisel, Nicole Taylor, Magdalena Wieckowska-Lüth, and Marco Zanon at the International Open Workshop of the Graduate School ‘Human Development in Landscapes’ and the CRC1266 ‘Scales of Transformation’. We are very thankful to all of the editors for their engagement during the workshop and the preparation of this volume, but in particular to Marta Dal Corso for taking on the in depth editing of this book. Many thanks go also to Katharina Fuchs and Hermann Gorbahn, who controlled the editing flow, and Carsten Reckweg, especially for preparing the figures for publishing. We further wish to thank Karsten Wentink, Corné van Woerdekom and Eric van den Bandt from Sidestone Press for their excellent responsive support in realizing this volume process.

Wiebke Kirleis and Johannes Müller

Contents

Editors' preface

The focus of archaeological research on the European Bronze Age has mainly been placed on those aspects which are novel in respect to previous periods; such as mobility, including long-distance transport and cultural exchanges, and metalwork, related for instance to warfare and social status. Most recently, the ever-increasing and broadening aDNA dataset has added to theories about the genetic ancestors of geographically-distant groups of Bronze Age populations and tried to further define the movements of people. These exciting highlights reveal the breaking innovations of the period, but often they concern only a small portion of population, rare archaeological artifacts, and specialized activities, while little attention is given to common, routine activities and general living conditions. However, the frequent (almost standard) multi-disciplinarity in archaeological research has brought our understanding of pre- and protohistoric human communities and their local environments to a much more precise level than few decades ago. What do we know then about the everyday life of Bronze Age people? And how do we graphically depict and divulge our knowledge?

These questions form the background of the present book, which stems from the session "How's life? Living conditions in Europe in the 2nd and 1st millennia BC", organised by the editors for the International Open Workshop "The creation of Landscapes V" that took place at Kiel University (Kiel, Germany) in March 2017. The session had three invited speakers and overall 17 oral contributions, nine of which became the articles in this volume of proceedings. Within the book section "Life in action: Metal production, health conditions and dietary choices", Johanna Brinkmann considers the economic aspects of metal production, including the energy expenditure needed in labour and fuel procurement, which gives attention to individual efforts. Gundula Lidke and colleagues present the anthropological analyses conducted on human bodies found at the battlefield in the Tollense Valley (Germany). Healed and lethal traumas, as well as chronic illnesses, are depicted, reflecting the health conditions of the participants in this conflict before and during the event. Finally, Sofia Filatova and colleagues present the study of botanical macro-remains in Hungary, where they investigate the role of pulses; economically-relevant plants whose edibility is linked to precise preparations techniques and which are otherwise poisonous. The book section "The place of living: Routine activities, the management of waste and of natural resources" deals with the crops and wild plants found on sites in northern Germany in the contributions by Almuth Alsleben for the site of Rothenkirchen, where routine cereal processing is described, and by Dragana Filipovic *et alii* about the exceptionally rich pit deposit of Wismar-Wendorf. In the subsequent contribution, Aslı Oflaz and colleagues present an overview of olive trees in the Eastern Mediterranean: through different kinds of *Olea* remains the authors explore the origins of this symbol of the Mediterranean landscape and diet. Finally, Magdalena Wieckowska-Lüth and Immo Heske present the microfossil record of pollen and non-pollen palynomorphs from the Hünenburg hillfort (Germany), showing the potential of the method for the reconstruction of local environmental conditions. The last book book section "Living in the past: The (graphic) representation of past living conditions" focuses on the character of illustrations concerning Bronze Age societies. Yvonne Van Amerongen depicts the interior of a Bronze Age Dutch house, combining elements known from excavations in order to bring the building "to life". Jutta Kneisel takes the example of the site of Bruszczewo (Poland), where partially waterlogged conditions allowed a good preservation of organic and inorganic items, for the creation of realistic illustrations and the discussion of previous overly idyllic scenes.

As editors, we are extremely thankful to all the contributors to the volume, as well as to the session, for the productive scientific discussion that hopefully will shed some new light on the everyday life of Bronze Age people. Thank-you also to the CRC 1266 "Scales of Transformations in Prehistoric and Archaic Societies" for accepting our proceedings in this series and for the support given by the CRC1266 Office. Thank-you also to Samson Goetze for the book cover.

Marta Dal Corso, Wiebke Kirleis, Jutta Kneisel, Nicole Taylor,
Magdalena Wieckowska-Lüth, Marco Zanon

Copper output, demand for wood and energy expenditure – Evaluating economic aspects of Bronze Age metallurgy

Johanna Brinkmann[1]

Abstract

Numerous methods are applied in the analysis of copper and bronze artefacts, from typological studies to chemical analysis. A rarely applied method is the calculation of the energy expenditure. This calculation gives a comparative value for every copper or bronze artefact, which reflects the energy expenditure required for the production of an artefact. The method allows us to compare the expenditure used for the production of metal artefacts in different periods of the Bronze Age. In addition, a calculation of the required wood resources illustrates the human impact on the environment. Thus, information about the manufacturing process together with information about the energy expenditure can provide an insight into economic decisions, practices of daily life and ultimately the living conditions in the Bronze Age. The results of the energy expenditure calculations and the estimations concerning the copper output and the demand for wood correspond to the archaeological record, which shows an increasing amount of evidence for metallurgical activities with the beginning of the Middle Bronze Age. The archaeological evidence is also an indication for the manufacturing process becoming more effective during that time. At the same time, the copper output and thus the number of produced artefacts increased, together with the demand for wood and the energy expenditure invested in metallurgy.

Keywords: Bronze Age, Central Europe, energy expenditure, demand for wood, copper output

Introduction

Information about the manufacturing process of copper and bronze artefacts together with the calculation of the energy expenditure can provide an insight into economic decisions, practices of daily life and ultimately the living conditions in the Bronze Age.

Are there any differences between the manufacturing processes and the energy expenditure used in the Early Bronze Age compared to the ones used in the Middle and Late Bronze Age? Are the differences in the production process reflected in the

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calculation of the energy expenditure? How many artefacts were manufactured from the estimated amount of copper mined at different sites (*e.g.* the Mitterberg)? And how much wood resources are required for metallurgy? The calculation of the energy expenditure allows quantification and gives us an idea about the percentage of daily or annual labor required for example to manufacture individual burial equipment or a hoard inventory. This way our understanding of the bronze production processes is extended, including technical aspects such as manufacturing processes as well as economic aspects such as resource management.[3]

State of the art

Energy expenditure

Numerous methods are used in the analysis of copper and bronze artefacts, from typological studies to chemical analyses. A rarely applied method is the calculation of the energy expenditure (*e.g.* Müller 1990a; Dieck 2014). This calculation provides a comparative value for every copper or bronze artefact, which reflects the energy expenditure used for the production of an artefact (Brinkmann in prep.).

Below a calculation of the energy expenditure required for the complete production process of copper and bronze artefacts is presented. This process includes numerous production steps like the prospection of resources, the preparation for mining, mining activities, ore beneficiation, smelting, alloying, casting, post-processing and the transport. The following calculations include only those parts of the production sequence for which direct archaeological evidence can be provided, namely mining activities, ore beneficiation, smelting, alloying, casting and post-processing. In the analysis of the technical production steps, which precedes the calculation of the energy expenditure, it is necessary to consider the operational sequence, the so-called *chaîne opératoires*. The concept of the *chaîne opératoire* was coined by André Leroi-Gourhan in 1964 (Leroi-Gourhan 1964, 164; Roux 2017, 1) and describes the empirical analysis of

> '*step-by-step physical actions and material procedures by which ancient technicians procured, prepared, modified,* […] *their material culture.*' (Dobres 2000, 167).

Leroi-Gourhan's theory is rooted in French cultural ethnography which promoted the cultural dimension of material culture (Roux 2017, 1) and in which technical acts were also social acts (Darvill 2008, 84).

The terms labour and value must be critically considered. When calculating labour, it needs to be reflected in two ways, which type of value will be determined (in the sense of the determined value in person hours as well as in the sense of the potential economic value). The description of the value of objects from prehistory is highly problematic, as modern ways of thinking and economic concepts are easily often unintentionally transferred to pre-industrial times. A detailed discussion of this problem would go beyond the scope of this article. However, in general, it can be said that the value-added process can be divided into three different approaches, depending on whether the value is considered as a result of exchange processes, production processes or consumption processes (Bernbeck 2009, 30-31, with a detailed version and literature). In the first volume of Capital: Critique of Political Economy K. Marx defined the exchange value of objects in capitalist systems as the amount

3 The article is based on my Master thesis which was submitted to Kiel University in 2016 and will be published in the series Archäologische Berichte of the Deutsche Gesellschaft für Ur- und Frühgeschichte (DGUF). I am especially indebted to the CRC 1266 for providing financial support for the preparation of this paper.

of labour necessary to produce a marketable commodity compared to the labour necessary to produce other things[4] (Bernbeck 2009, 45). This means that in capitalism labour constitutes a value of goods. But what is the situation like in non-capitalist systems or non-industrial societies? After discussing different anthropological approaches, R. Bernbeck, who deals with the topics production and value with regard to archaeological investigations at great length, concludes that the question whether labour in non-capitalist societies can be considered as a useful analysis unit remains to be solved. Although this assertion is rather unsatisfactory, it is a fact that

> '*labour* […] *in non-capitalist societies cannot be detached from their ideological and political interlocking*' (Bernbeck 2009, 47-49, translated).

In this connection, it is important to consider that labour in non-capitalist societies does not constitute an abstract commodity. Therefore, it must be emphasized that in the following article the term labour is not used in the sense of the Marxist concept of labour. It is bound to modern forms of society and can not necessarily be transferred to the Bronze Age (Bernbeck 2009, 48; Dieck 2014, 258).

Hence, within a non-industrial society the meaning of labour differs from today's understanding of labour. Consequently, the question arises in how far the labour or expenditure of time invested to carry out a certain activity play a role in prehistory. The expenditure of time used for metallurgical activities was probably integrated into different daily rituals and other activities (Müller 1990b, 216). However, C. Eibner (1979, 160) is of the opinion that the profitability of the individual metal processing steps already played a great role during prehistory. Furthermore, W. Fasnacht states that

> '*when for example in countless grinded pin tips, knife edges and razor blades only the strictly necessary part with regard to function seems to have been soft-annealed, homogenized and cold forged, this obviously means that time, energy and labor had already been optimized before the age of production*' (Fasnacht 1994, 239, translated).

Determining the value of an object and the labour used to produce it in the sense of the expenditure of time used for its production carries the risk of transferring modern ideas of labour in a market economy sense to prehistory. Dealing with the

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4 „Ursprünglich erschien uns die Ware als ein Zwieschlächtiges, Gebrauchswert und Tauschwert. Später zeigte sich, daß auch die Arbeit, soweit sie im Wert ausgedrückt ist, nicht mehr dieselben Merkmale besitzt, die ihr als Erzeugerin von Gebrauchswerten zukommen. Diese zwieschlächtige Natur der in der Ware enthaltenen Arbeit ist zuerst von mir kritisch nachgewiesen worden. Da dieser Punkt der Spingpunkt ist, um den sich das Verständnis der politischen Ökonomie dreht, soll er hier näher beleuchtet werden. […] Rock und Leinwand sind aber nicht nur Werte überhaupt, sondern Werte von bestimmter Größe, und nach unsrer Unterstellung ist der Rock doppelt soviel wert als 10 Ellen Leinwand. Woher diese Verschiedenheit ihre Wertgrößen? Daher, daß die Leinwand nur halb soviel Arbeit enthält als der Rock, so daß zur Produktion des letzteren die Arbeitskraft während doppelt soviel Zeit verausgabt werden muß als zur Produktion der erstern.“ (Marx 1981, 23, 27).

"At first sight a commodity presented itself to us as a complex of two things – use-value and exchange value. Later on, we saw also that labour, too, possesses the same two-fold nature; for, so far as it finds expression in value, it does not possess the same characteristics that belong to it as a creator of use-values. I was the first to point out and to examine critically this two-fold nature of the labour contained in commodities. As this point is the pivot on which a clear comprehension of political economy turns, we must go more into detail. […] Coats and linen, however, are not merely values, but values of definite magnitude, and according to our assumption, the coat is worth twice as much as the ten yards of linen. Whence this difference in their values? It is owing to the fact that the linen contains only half as much labour as the coat, and consequently, that in the production of the latter, labour-power must have been expended during twice the time necessary for the production of the former." (original translation from: Marx and Engels 1990, 34-35, 38).

question of the production costs during the Early Bronze Age, St. Shennan (1999, 352-353) takes the view that striving after the least effort is not only a result of capitalism but a profoundly human characteristic. That way, he opposes the common doctrine existing in British research which rejects any investigation of the effort or performance:

> '*The mind-set which currently dominates British archaeology is one which rejects any analysis of other cultures, past or present, in terms of the costs and benefits associated with particular practices, as the imposition of a modern capitalist value system.*' (Shennan 1999, 352)

This view is based on a distinction into us (modern capitalist society) and them (non-industrial society) and is intensified by strong post-colonial feelings of guilt: *"We trade commodities, They give gifts"* (Shennan 1999, 352 with capitalization). The underlying idea is that every cultural group has a unique world view which is incomprehensible for other groups. Based on two ethnographic examples Shennan proves that in pre-industrial societies as well the expenditure of time used for the production of commodities plays a role. Based on his examples he transfers D. Ricardo's Theory of Comparative Costs (1817, 146-185) to Bronze Age Europe. According to this theory, it is more efficient to produce commodity X by yourself, if it is cheaper to produce commodity Y and exchange it for commodity X (Shennan 1999, 352-355). Although the transfer of such a model to non-industrial societies should be considered in a rather critical way, the archaeological example presented above shows that to a certain extent an optimization of energy and labour can be expected. However, it must be kept in mind that in pre-historic and pre-industrial societies different concepts of value and labour existed. A transfer of the principle of least effort to prehistory in the sense of a deeply human characteristic like Shennan suggeststhus has to be considered very critically, as it shows an unreflecting capitalist way of thinking.

In German research the question of labour invested to carry out certain activities and production steps has often been discussed on a small scale, *e.g.* based on studies on different craft activities (see *e.g.* Holdermann and Trommer 2010; Hanning 2012; Stöllner *et al.* 2012). Considerations of the expenditure of time are almost exclusively linked to experimental archaeological investigations. The only systematic study in which the amount of labour is used as an accounting unit comes from T. Kerig (2016 unpublished). Kerig's focus, however, lies on other periods and kinds of source materials and fully excludes the field of early metallurgy (Kerig 2013, 139). This article is based on the assumption that the expenditure of time used for the production of commodities – in this case of bronze artefacts – allows conclusions on the effort that prehistoric societies invested for metallurgic activities. The labour reflects the so-called natural price within classical economics, which results from the sum of the expenses used for production and distribution (Kerig 2016, without page number). This assumption will serve as a basis for further interpretations. The question whether the expenditure of time used to carry out an activity already played a role in prehistory and whether the value of objects (regardless of its nature) is also expressed in the labour invested for their production cannot be answered by using archaeological methods. The results of the labour calculations open up the opportunity to compare the expenditure of time for different metallurgical activities (*e.g.* ore dressing and smelting) and thus, to contribute to a better understanding of the bronze production steps. At the same time, the expenditure of time used for the production of different copper and bronze objects can be calculated and compared with each other. In this sense the following article aims at contributing to the establishment of energy expenditure calculations as a useful analysis unit for the investigation of prehistoric bronze objects and the societies producing them.

Archaeological evidence for Bronze Age metallurgy

Looking at the archaeological evidence for copper and bronze metallurgy in Central European Bronze Age, some differences between the Early Bronze Age (2200-1600 BCE) in contrast to the Middle Bronze Age (1600-1300 BCE) and Late Bronze Age (1300-800 BCE) can be observed. In the working area (Fig. 1), in Central and Southern Germany as well as in the adjacent Austrian, Swiss and Italian Alps, archaeological evidence for primary and secondary metallurgy exists (this includes, among other things, mining sites, beneficiation and smelting sites as well as settlements with evidence for metallurgical activities: see below).

Bronze Age copper mining and ore smelting is indicated by numerous artefacts and features in the Northern Greywacke zone in the Austrian Alps (*e.g.* Mitterberg district) (Krause 2003, 36) as well as in North Tyrol (Kelchalm, Schwaz/Brixlegg) and in Upper Styria (Eisenerzer Alpen), Lower Austria, Grisons and South Tyrol (Modl 2004, 115). In prehistoric times the copper ore was exploited, following lode deposits into the mountain, extracting fahlore and chalcopyrite as well as malachite and azurite from secondary deposits (Ottaway 1994, 18). In comparison, there is no evidence for prehistoric tin extraction in Central Europe. Cornwall and Devon in England, Brittany and the Massif Central in France as well as the Bohemian and Slovakian Ore Mountains and Galicia in Spain are considered as sources for Bronze Age tin. Tin ores were most probably extracted from alluvial and eluvial secondary deposits in the form of cassiterite (Hauptmann and Weisgerber 1985, 18-19; Ottaway 1994, 18-19; Krause 2003, 42; Haustein and Pernicka 2008, 387-388, 395, 397; O'Brien 2015, 154, 185).

In the working area numerous copper and bronze artefacts from hoards (see *e.g.* Stein 1976) and graves (see *e.g.* Primas 2008) as well as from primary and secondary

Figure 1. Selected copper mining sites in Europe with depicted working area (source: author).

production sites are known. Therefore, in this area it is possible to trace the production process from the ore to the finished artefact.

The copper mining sites in the working area are characterized by the findings of stone hammers (*Rillenschlägel*), traces of fire setting, deep mining and surface shaft mining (*Pingenbau*) (O'Brien 2015, 31; Kienlin 2013, 423-424). The earliest evidence for copper mining in the working area comes from the Brander lode in the southern Mitterberg district in Austria and dates back to 1900-1700 BCE (Stöllner *et al.* 2011a, 124). More direct evidence derives from the Middle and Late Bronze Age (*e.g.* traces of mining activity from the Mitterberg district and from Schwaz/Brixlegg: Stöllner *et al.* 2011a; Goldenberg *et al.* 2011a). All evidence for ore beneficiation in the working area comes from Middle and Late Bronze Age sites (*e.g.* Troiboden: Stöllner *et al.* 2011b; Mauk F: Goldenberg *et al.* 2011a, 69-72). These sites are characterized by waste heaps and stone tools, which indicate a meticulous ore beneficiation, because they contain nearly no ore (Rieser and Schrattenthaler 2002, 34, 89). The beneficiation includes the sorting, grinding and washing of the ores (O'Brien 2015, 221-222).

Smelting sites in the working area derive mainly from the Middle and Late Bronze Age (see Stöllner 2015 for details). Only in Trentino, South Tyrol, copper smelting from the third millennium BCE is evidenced by the presence of slags, charcoal, pits, rectangular fireplaces and tuyères (Silvestri *et al.* 2015, 202-203). In the Late Bronze Age, the alpine smelting facilities have a standardized ground plan with two working platforms containing a roasting bed and two furnaces (Modl 2004, 116-117; see *e.g.* site Mauk A: Goldenberg *et al.* 2011a, 72-76; Goldenberg 2015, 157). Which forms of process control were used in the Bronze Age is still open to debate. In short, there are three different smelting techniques whose application is discussed for the Bronze Age: the so called co-smelting (an oxidizing smelting process conducted in the crucible, see Rostoker *et al.* 1989, 72), an oxidising smelting process in a hearth pit (as indicated by the pit features from South Tyrol mentioned above) and a reducing smelting process in a furnace (as indicated by the alpine smelting features mentioned above). In the oxidizing process the smelting can be conducted in two to three passes. Afterwards the generated copper matte needs to be roasted and smelted again forming black copper (unrefined copper) (Herdits 1993, 32; Goldenberg *et al*. 2011b, 88). Oxidizing smelting techniques are evidenced by numerous findings (mainly small quantities of slags) from Early Bronze Age alpine settlements, for which the use of co-smelting is assumed (*e.g.* Buchberg: Martinek 1995, 576-579; Martinek and Sydow 2004, 204, 209-211; Höppner *et al.* 2005, 300-301; Klinglberg: Shennan 1995, 261-262). The pit features from South Tyrol and the amount of circulating copper suggests that the production of copper was conducted in hearth pits in large quantities during the Early Bronze Age – presumably using oxidizing smelting techniques.

A transition in the metallurgical process is visible in the period at the end of the Early and the beginning of the Middle Bronze Age with the occurrence of smelting facilities in the eastern Alps *e.g.* in the Mitterberg district (see above). The slags from these sites indicate that the smelting was conducted under reducing conditions (Herdits 1996, 21-22). The reducing process is a minimum two-staged process which includes a prior roasting of the ores. It is called ore roasting reduction (*Röstreduktionsprozess*) (Hauptmann and Weisgerber 1985, 27-28) or "old German process" ("*alter deutscher Prozess*"). This process encompasses a lengthy roasting process in a roasting bed under oxidizing conditions to lower the iron and sulphur content of the ore. Afterwards the ore is smelted in a furnace several times producing first matte and then black copper (Eibner 1982, 404-406; Rostoker *et al.* 1989, 72; Herdits 1993, 33; Ottaway 1994, 101-102). It becomes apparent, that at the end of the Early and the beginning of the Middle Bronze Age the oxidizing smelting process is replaced by a smelting technique that runs under reducing conditions. This reducing process allows the production of larger amounts of metal, but presupposes a more complex furnace construction, which is indicated by furnace features from the Eastern Alps (Modl 2004, 115; Herdits and Löcker 2004, 177; Stöllner 2015, 100). For the casting of copper or bronze artefacts hearth pits were used. From the working area only three sites with sparse features are evident (Säckingen, Baden-Württemberg: Gersbach 1969, 65, 71-72; Taltitz, Saxony: Simon 1992, 54-56; Parchim, Mecklenburg-West Pomerania: Becker 1989, 129-132; In other parts of Europe the evidence for casting processes is sparse as well). Further archaeological findings which indicate casting activities are tools like casting moulds, tuyères and crucibles and slags as well as lumps of copper or bronze (Ganslmeier 2011, 120, Abb. 2). After the casting the artefacts need to be reworked. This post-processing includes the removal of the waster and the casting burr, the grinding of the surface, repeated cold hammering and annealing, polishing and possible decoration (Iaia 2015, 83). The post-casting processes are evidenced by metallurgical tools and metallographic analyses (Ottaway 1994, 124) as well as by production waste like fragments of burr, swarf or scrap metal (Ganslmeier 2011, 120, Abb. 2). From about 1300 BCE onwards mainly bronze tools are used in the post-processing, while in the Early Bronze Age and before stone tools were used (see Holdermann and Trommer 2010, 797; Freudenberg 2009; Iaia 2015, 83-84, 91). Main changes in the metallurgical process can also be observed in the alloying process. During the Copper and Early Bronze Age copper and arsenic-copper was used, from the end of the Early and the beginning of the Middle Bronze Age onwards tin-bronze becomes more and more accepted (Kienlin 2010, 823-824, 831-834).

Methods

The term *energy expenditure* characterizes the expenditure used for an activity, for example the building of a house. It is measured in *person-hours*. One person-hour corresponds to the work one person can provide in one hour. The evaluation of the energy expenditure thereby allows us to compare the expenditure used for the production of metal artefacts in different periods of the Bronze Age. In addition, a calculation of the required wood resources (charcoal findings from different sites indicate that wood and not charcoal was used in the smelting process, *e.g.* see Klemm 2015, 197-199; Tecchiati 2015, 83-86; Hanning 2012, 82-83) illustrates the human impact on the environment (*e.g.* see Dörfler 1995 for the wood consumption in Roman Iron Age iron smelting in Schleswig-Holstein). In bronze metallurgy, wood is required for every manufacturing step, especially for mining, smelting, melting and post-processing (Fig. 3). How do you calculate the energy expenditure for a 4000-year-old process for which no written records exist? All used information about the energy expenditure for the different manufacturing steps were collected from about 80 scientific publications of archaeological experiments[5] and compiled in a catalogue (see Brinkmann in prep.) for further processing. To provide a solid basis for the evaluation of published scientific experiments the archaeological evidence for Bronze Age metallurgy in the working area was studied extensively. The combination of the reconstructed production steps from the archaeological record with the time data and the weights of the resources from the published experiments allow a calculation of the energy expenditure in person-hours (Fig. 2).

In this connection, publications regarding the production steps mining, ore beneficiation, smelting, casting and post-processing could be included as well as the asso-

5 Data were taken from *e.g.* Stöllner *et al.* 2012, 72; Lewis 1990, 56, Tab. 1; Popov *et al.* 2014, 38-39 (mining activities); Herdits 1993, 35-38; Doonan 1994, 86-87 (ore beneficiation); Modl 2004, 120-124; Goldenberg *et al.* 2011b, 89; Hanning 2012, 79-82; Lorscheider *et al.* 2003, 305, Tab. 1 (smelting); Holdermann/Trommer 2010, 802; Siedlaczek 2011, 114; Werner/Barth 1991, 299-303; Binggeli *et al.* 1996, 6-7 (casting); Faoláin/Northover 1998, 78-79; Holdermann/Trommer 2011, 126, Abb. 7; Iaia 2015, 87 (post-processing) (this is an extract, all references in Brinkmann in prep.).

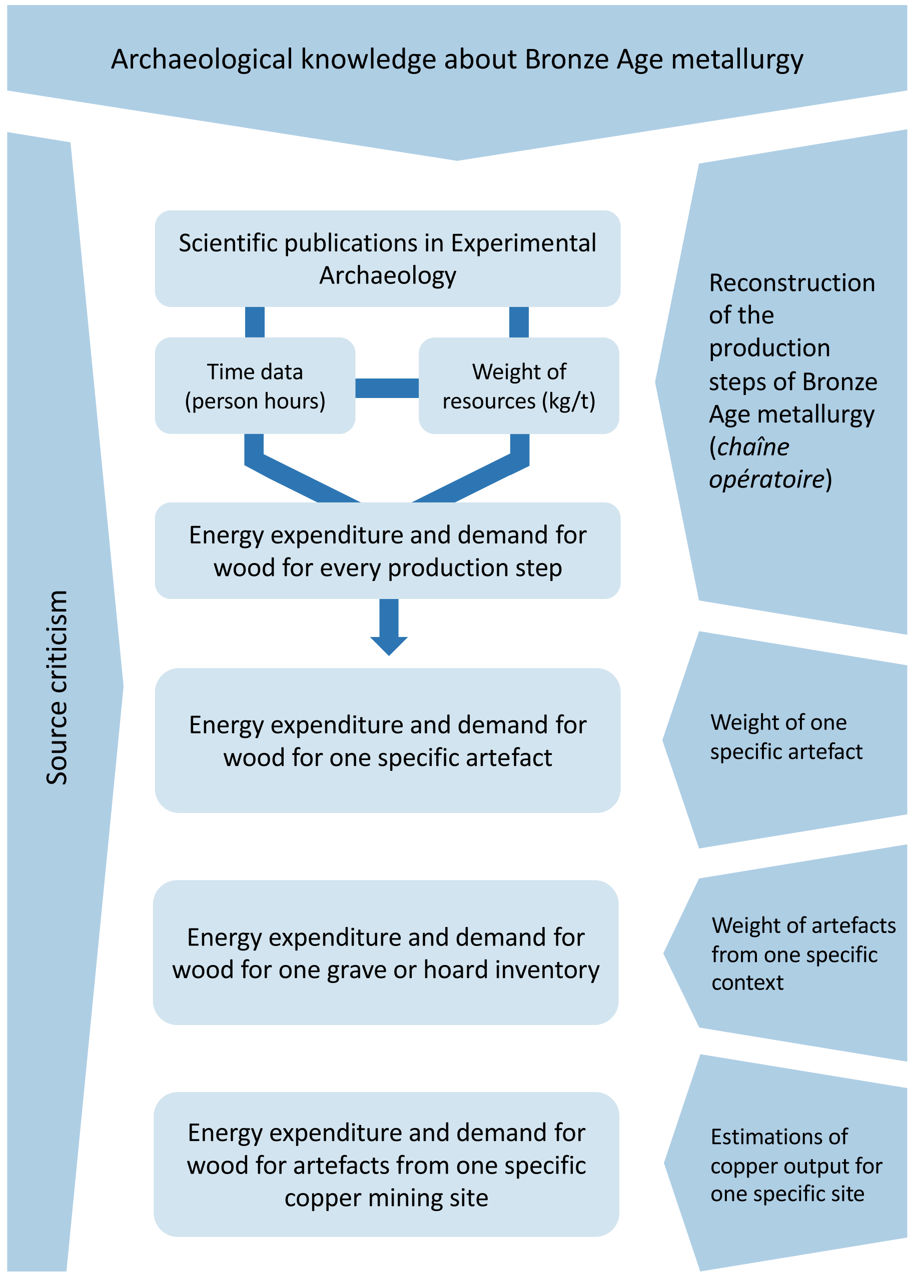


Figure 2. Methodological structure of the approach used in this paper (source: author).

ciated tool manufacturing. These production steps represent the whole production sequence of bronze metallurgy and are documented by the archaeological record in the working area. For the calculation of the energy expenditure only those experiments were included which meet scientific quality standards and were conducted by technically skilled experts using only materials available in prehistory.

When working with data from experimental archaeology, a critical assessment of the sources is required. It is important to bear in mind that experiments do not provide evidence, but hypotheses and potential interpretations, and that there is always more than one possible approach. The aim of many archaeological experiments is

> '*to replicate past phenomena* […] *in order to generate and test hypotheses to provide or enhance analogies for archaeological interpretation*' (Mathieu 2002, 1).

Thus, these experiments can provide important hints regarding the implementation of production processes in metallurgy and the invested energy expenditure. But they are of course influenced by modern values, norms and models (Vorlauf 1991, 88).

In the catalogue the collected time data for the different activities were put into relation with the weight of the required resources in kg (*e.g.* X kg wood is required to smelt Y kg copper ore) to create comparability for data from different experiments, determining the ore-wood-ratio for every production step. In doing so, the average amount of invested time and wood was calculated for each of the above named production steps. The generated data (mainly the ore-wood-ratio in the different production steps) was later implemented into a Microsoft excel sheet to simplify the calculations and to enable the testing of the method by means of examples from the Early Bronze Age in contrast to the Middle and Late Bronze Age. In this manner the energy expenditure for any copper or bronze object can be calculated providing that its weight is documented. The calculations refer to the weight of the artefacts as an indicator for the required amount of raw material. It was chosen to work with average weights for artefact categories (see results). This has the advantage, that calculations can be conducted with estimated weights. Since there is no archaeological evidence for the metallurgical treatment of tin ores available, the energy expenditure for the production of tin is assumed to be one-tenth of the expenditure used in the production of copper, as tin bronzes are assumed to contain ten percent tin (Brinkmann in prep.).

The demand for wood to be used for the different production steps was calculated from the ore-wood-ratio given in the catalogue (Brinkmann in prep). Unfortunately, a lot of important information concerning the used wood was not available in the used publications (this is a general problem when dealing with data from experimental archaeology). In most publications it had not been specified which wood species and types of wood (*e.g.* twigs, branches, pieces of the trunk) were used in the experiments (data was taken from about 80 different publications). Consequently, it was not possible to derive the qualities and species of the used wood from the literature. Of course, one has to be aware that different wood species have different qualities and burning temperatures and that the woodland composition surrounding the sites varies, depending on environmental conditions and wood usage patterns (see *e.g.* Jansen and Nelle 2014 and Jansen and Nelle 2011 for the impact of human activity on the landscape). Although these constraints limit the conclusions that can be drawn from the calculation of the demand for wood, it was chosen to calculate the demand for wood as an interesting addition to the calculation of the energy expenditure. In all calculations it was assumed that wood and not wood charcoal was used in the manufacturing process (see above). The amount of wood is specified in kg or in t (which was unit that was used in most of the consulted literature). Furthermore, this enables a direct comparability with the amounts of ore or copper used in the calculation of energy expenditure. In the few cases in which wood charcoal was used in the experiments presented in the consulted literature, for the calculation the weight of wood charcoal was adapted to one of wood with a ratio of 5:1 (according to Hanning 2012, 81: experimental smelting in Late Bronze Age alpine furnaces). Through the connection of the energy expenditure calculations with the calculations of the demand for wood using the ore-wood-ratio, it is possible to calculate not only the energy expenditure but also the demand for wood needed in the production of any copper or bronze object with documented weight, using the above mentioned Microsoft excel sheet (Brinkmann in prep.).

In connection with the calculation of energy expenditure and the related demand for wood it is interesting to have a look at the estimated copper output for different sites of the working area and adjacent European regions (most estimations come from adjacent European regions, because for the working area there is only data from the Mitterberg region available, see Fig. 1. In the literature the estimations concerning the total copper output from different mining sites vary greatly (Tab. 1, column 2). Estimations from the literature concerning six sites are compiled in Tab. 1 (column 1). Given the published approximate period of use (column 4) and the estimated copper output, it is possible to calculate the average amount of copper mined per year (column 5). It has to be emphasized that this average amount per year has limited validity, since the estimation of the exact period of use for mining sites is very difficult.

Assuming that one copper artefact weights 200 g on average, the number of artefacts produced from the annual amount of copper can be determined (column 6). Using the above mentioned ore-wood-ratio, the number and weight of these hypothetical artefacts, the demand for wood for the manufacturing of these artefacts can be calculated. The wood required for the annual production of the artefacts from the estimated output is given in t to allow for comparability with the estimated amount of copper and in ha to estimate the potential human impact on the landscape (column 7 and 8; wood in hectares meaning how many hectares of forest are needed for the production of the artefacts).

The calculation of the specified hectares is based on the assumption that one hectare of forest contains 260 cubic meters of wood (O'Brien 2015, 275). With 550 kg of coniferous wood per cubic meter, this results in 143,000 kg or 143 t of wood per hectare (Pichler *et al.* 2012, 88-89; Oeggl and Schwarz 2015, 257).

Results

Energy expenditure and demand for wood

The results of the energy expenditure calculations are presented below using the production of 100 adzes in the Early Bronze Age in contrast to the Middle and Late Bronze Age as an example. With the adzes an artefact category was chosen that was

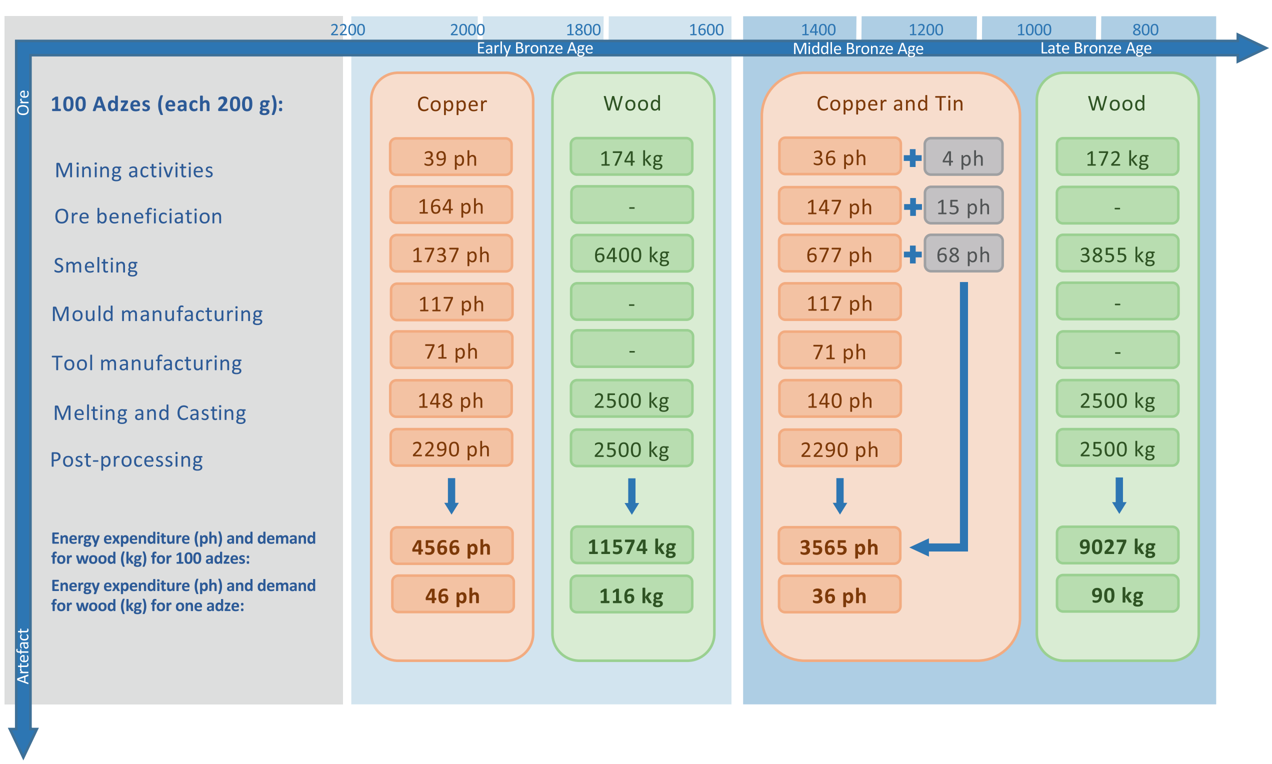


Figure 3. Energy expenditure (in person hours: ph) and demand for wood (in kg) required in the production of 100 adzes in the Early Bronze Age as well as in the Middle and Late Bronze Age, including all manufacturing steps (in cases in which the demand for wood is not specified, no information was available) (source: author).

available throughout the whole Bronze Age and of which different types existed. The adze types differ in weight (*e.g.* socketed adzes are on average lighter than flanged adzes or palstaves), however, most of them have a weight around 200 g (weights after Anemüller 1999, 77-137), therefore 200 g was chosen as an average weight for the artefact category adze.

The energy expenditure calculations show that the different production processes of the Early Bronze Age in contrast to the Middle and Late Bronze Age result in a different energy expenditure for metallurgical activities in the mentioned periods. This is mainly due to the use of different smelting processes. The results of the energy expenditure calculations are presented below, using the production of 100 copper and tin bronze adzes as an example (Fig. 3).

Looking at the results (Brinkmann in prep.), it becomes clear that the production of 100 copper adzes (200 g copper each) using Early Bronze Age production techniques needs an energy expenditure of 4,566 person-hours on average, which makes 46 person-hours for one copper adze. The production of 100 tin bronze adzes (180 g copper and 20 g tin each) using Middle and Late Bronze Age technology in turn needs an energy expenditure of 3,565 person-hours on average, which makes 36 person hours for one tin-bronze adze. Comparing the results, it can be noted that in the Early Bronze Age the energy expenditure required for the production of one adze exceeds the expenditure for one Middle or Late Bronze Age adze by ten person-hours. This can mainly be ascribed to the less effective oxidizing smelting process used in the Early Bronze Age. Looking at the different manufacturing steps, it can be stated that the post-processing requires the highest energy expenditure followed by the smelting process, even though the expenditure for the latter one decreases, employing Middle and Late Bronze Age techniques. It should be noted that recycling was not included in the present example, as the use of scrap metal might lower the required energy expenditure.

For the production of copper and bronze wood is required as fuel (see above), mainly for the mining activities (setting fire), the smelting process,casting and post-processing. The energy expenditure calculations make it possible to calculate the demand for wood from the ore-wood-ratio taken from the experimental data. These calculations show that the production of one copper adze in the Early Bronze Age requires 116 kg of wood, while 100 adzes require 11,574 kg of wood. In comparison, in the Middle or Late Bronze Age the production of one tin bronze adze requires 90 kg of wood, while 100 adzes require 9027 kg of wood (Fig. 3). This is an indication that the later process is more effective in terms of resource consumption, mainly due to the reducing smelting process, which has a lower demand for wood. Considering the demand for wood for the different production steps, it can be shown that the smelting process requires by far the highest amount of wood, followed by casting and post-processing.

These results indicate that the Early Bronze Age process is more suitable for the production of small charges, while the Middle and Late Bronze Age production process is more effective, when it comes to larger production charges, and therefore is suitable for the production of large amounts of bronze objects. In case only one adze is to be produced, the Early Bronze Age process is more effective, because the Middle and Late Bronze Age production technique requires the construction of a relatively complex smelting facility. Using the Early Bronze Age production technique for the production of larger charges however, as exemplified by the 100 adzes, requires more energy expenditure than applying the Middle and Late Bronze Age production process. In this regard, the results match the archaeological evidence, showing a development in the metallurgical treatment of ores at the end of the Early Bronze Age. The building of standardized smelting facilities at the beginning of the Middle Bronze Age reveals an increase in mining activities and bronze production in contrast to the Early Bronze Age (Modl 2004, 125). Hence, with the end of the

Early Bronze Age (ca. 1600 BCE) a smelting process was developed that was more effective particularly because of the increased amount of metal produced. Despite this more effective production process it can be assumed that an increase of bronze production in the Middle and Late Bronze Age is accompanied by an increase in the demand for wood resources.

Amount of copper and demand for wood

Since no evidence for tin extraction is available in the working area (see state of the art), the following remarks focus on the Bronze Age copper output. Many scholars have discussed the amount of copper ores mined in the Bronze Age (for references see Tab. 1). This has led to different estimations and evaluations (*e.g.* Stöllner 2015, 102; Pittioni 1951, 32). By comparing these published estimations, we get an impression of the dimension of Bronze Age copper mining. For better comparability, the annual average amount of copper for each site was calculated using the estimated total copper output and period of use (Tab. 1). To get a better impression of the dimension, the number of artefacts produced from the annual average amount of copper is indicated. In addition, the resultant demand for wood used in the production of these artifacts is shown. Like in the metallurgical treatment of the ores, there is a discrepancy with regards to the copper output of the Copper and Early Bronze Age and the one of the Middle and Late Bronze Age. From the beginning of the Middle Bronze Age onwards the mining activities and the copper output increased significantly. This is reflected in the increased amount of produced artefacts and the demand for wood. From the working area in Central Europe no archaeological evidence is available for Copper or Early Bronze Age mining activities. Therefore, there are no estimations for Early Bronze Age mining from this area that can be included. For this reason, estimations concerning Copper and Early Bronze Age mines from other parts of Europe are included (see Fig. 4): the mining sites of Ai Bunar, Bulgaria (Copper Age), Saint-Véran, France (Early Bronze Age), and Mount Gabriel, Ireland (Early and Middle Bronze Age). In addition, with the estimation from Cypriot mines (from the Bronze Age to the

Table 1. Mining areas with available estimations concerning the copper output (columns 1-4 from literature in column 9, columns 5-8 by author).

Site/Mining area	Estimated total copper output (from literature)	Date	Period of use	Amount of copper mined per year	Number of artefacts (200 g) from amount of copper per year	Required wood per year (t)	Required wood per year (ha)	References
Ai Bunar (Bulgaria)	750 t	4800-4300 BCE	500 years	1,5 t	7,500	870 t	6 ha	Ottaway 1994, 57, O'Brien 2015, 51
Saint-Véran (France)	1,400 t	2400-2000 BCE	400 years	3,5 t	17,500	2,025 t	14 ha	Bourgarit *et al.* 2008, 1-4
Mount Gabriel (Ireland)	15,25 t	1700-1400 BCE	300 years	0,05 t	250	30 t	0,2 ha	O'Brien 2015, 130-135
Mitterberg main lode (Austria)	10,000 t	1600-900 BCE	700 years	14 t	70,000	6,980 t	50 ha	Eibner 2005, 38.
Mitterberg total (Austria)	20,000 t	1900-900 BCE	1,000 years	20 t	100,000	9,975 t	70 ha	Stöllner 2015, 101-102; Stöllner *et al.* 2011*a*, 114
Mitterberg total, Tirol, Salzburg region (Austria)	50,000 t	1900-900 BCE	1,000 years	50 t	250,000	24,935 t	175 ha	Stöllner 2015, 102; Pittioni 1951, 32
Troodos Mountains (Cyprus)	200,000 t	2500 BCE-AD 500	3,000 years	67 t	335,000	33,410 t	234 ha	O'Brien 2015, 61
Uluburun wreck (Turkey)	10 t	14th century BCE	single event	10 t	50,000	4,990 t	35 ha	Newton *et al.* 2005, 115-116

Roman Period) and the example of the Uluburun shipwreck (Late Bronze Age) two analogies are presented, which facilitate the understanding of the dimensions of Bronze Age mining in the working area.

Looking at Figure 5, it can be seen that the included Copper and Early Bronze Age mines show a relatively low annual copper output with 1.5 t for Ai Bunar and 3.5 t for Saint-Véran. While the Early to Middle Bronze Age mine of Mount Gabriel yields only 50 kg. In comparison, the estimated Middle and Late Bronze Age annual output exceeds the previous one by far with 14 t for the Mitterberg main lode, 20 t for the whole Mitterberg area and 50 t for the Mitterberg area, Tyrol and the Salzburg

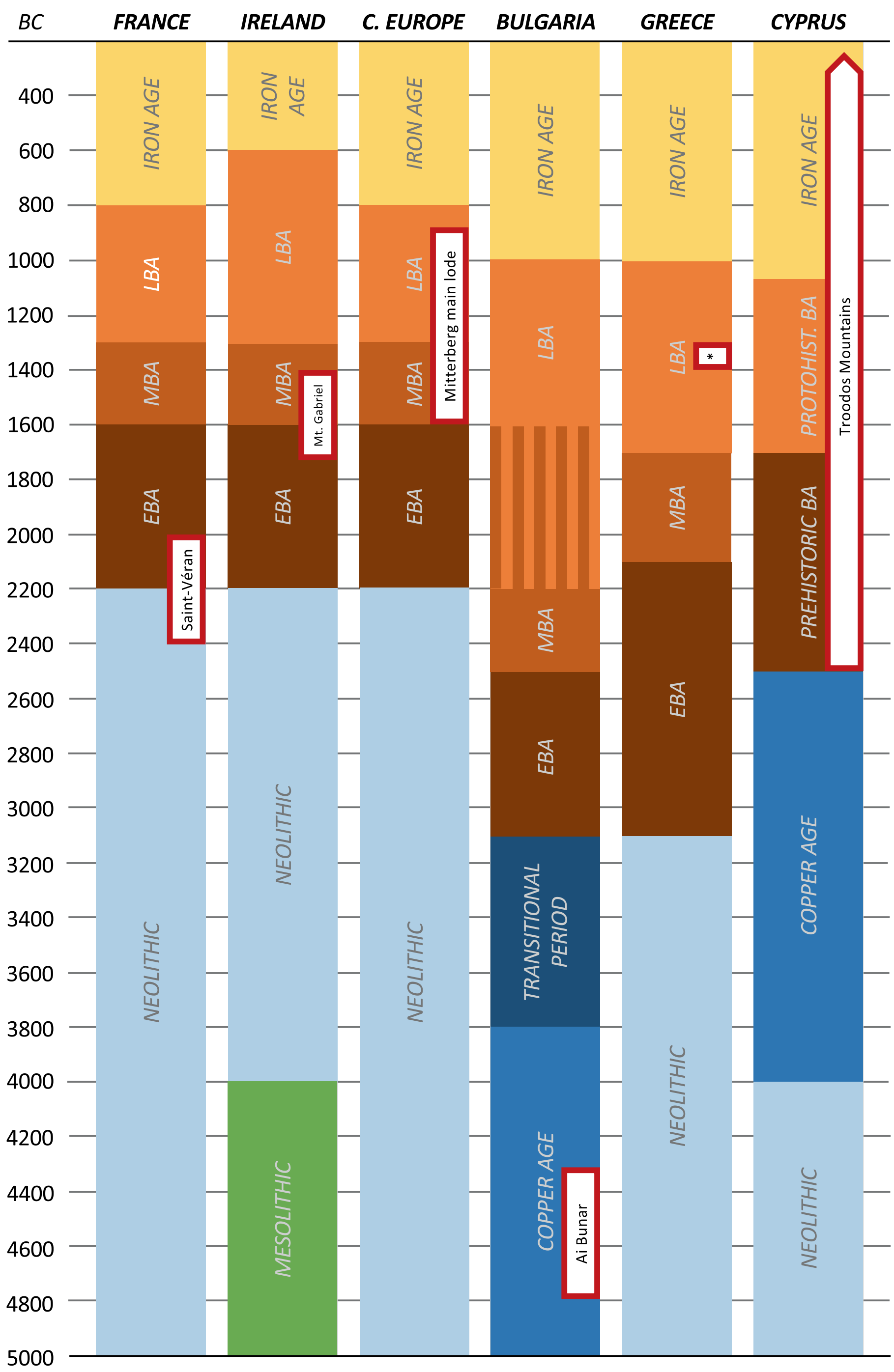


Figure 4. Chronological chart for the working area (Central Europe) and all regions mentioned in the Text (France, Ireland, Bulgaria, Greece and Cyprus). The dating of the mining sites and the Uluburun wreck are indicated by the red boxes. The placement of shipwreck of Uluburun in the Greek chronological system is based on different finds from the wreck (see Pulak 2005, 80, although other systems could be applied: see Yalçın et al. 2005, 682-685). EBA: Early Bronze Age, MBA: Middle Bronze Age, LBA: Late Bronze Age, BA: Bronze Age (source: author, after Schnurbein 2009, 238-239; Knapp 2013, 27, Tab. 2; Boyadziev 1995, 179, Tab. 4).

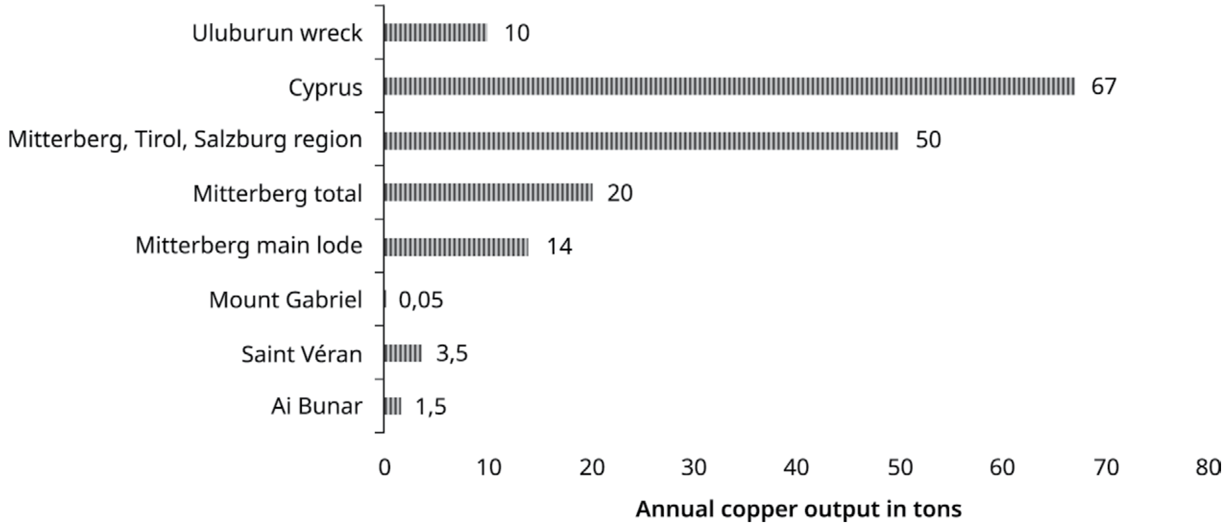
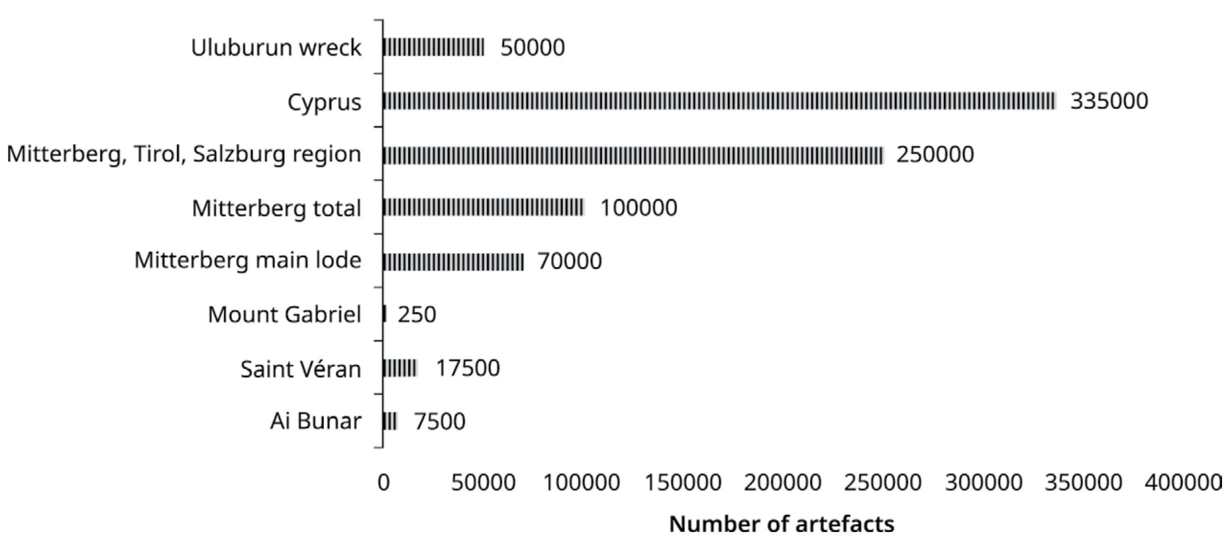


Figure 5. The annual amount of copper in tons mined in different areas, calculated from the estimated total amount of mined copper and the period of use in Tab. 1 (source: author).

region. The prehistoric mining areas of Cyprus provide a good comparison with an average annual output of 67 t of copper, exceeding even the large amounts of mined copper from the Mitterberg region in Austria. The famous Bronze Age ship wreck of Uluburun, which sank at the end of the 14th century BCE in front of the Turkish coast carried about 10 t of copper in its cargo, more copper than the diagrammed Copper and Early Bronze Age mines produced annually on average.

To get an impression of the amounts of metal, which were possibly produced from the annual average copper output, the number of artefacts is specified below. Assuming that one European copper or bronze artefact has an average weight of 200 g, the annual average output results in the following annual number of artefacts for the Early Bronze Age (Fig. 6): 7,500 artefacts from 1.5 t of copper from Ai Bunar and 17,500 artefacts from 3.5 t of copper for Saint-Véran. The Early and Middle Bronze Age mine of Mount Gabriel yields only 250 artefacts from 50 kg of copper. Corresponding with the higher annual average copper output in the Middle and Late Bronze Age, the number of annually produced artefacts in this period is much higher: 70,000 artefacts from 14 t of copper for the Mitterberg main lode, 100,000 artefacts from 20 t of copper for the whole Mitterberg area and 250,000 artefacts from the Mitterberg area, Tirol and the Salzburg region. In comparison, with the average annual output of 67 t of copper from the Cypriot mines 335,000 artefacts

Figure 6. The annual number of artefacts produced from the estimated annual amount of copper in different mining areas, presuming a weight of 200 g for each artefact; for references see Tab. 1 (source: author).



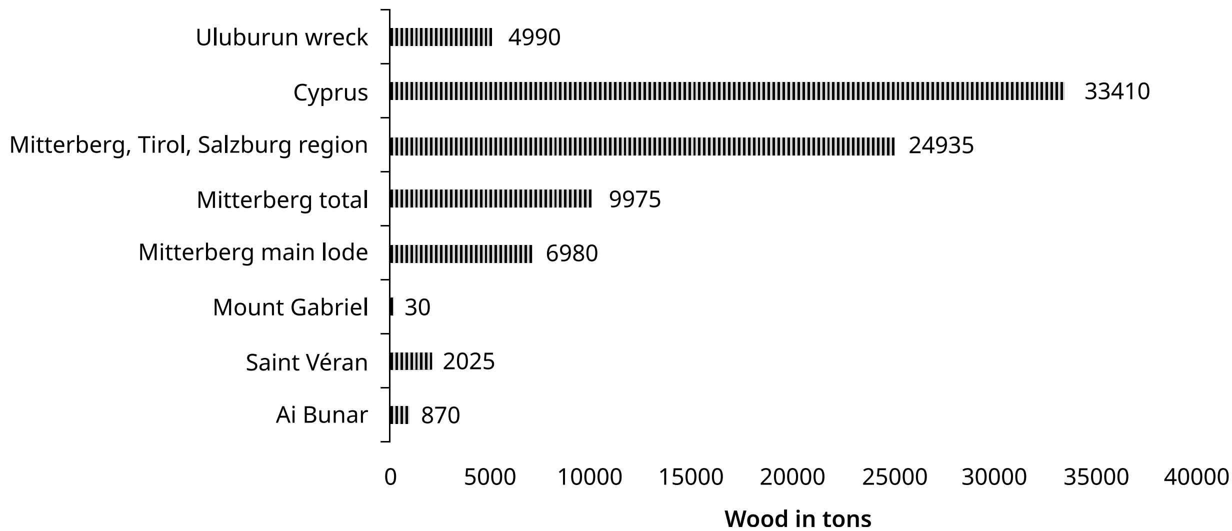


Figure 7. Required wood resources in tons for the annual production of the artefacts in Fig. 6; for references see Tab.1 (source: author).

can be produced per year. From the 10 t of copper found in the Uluburun ship wreck 50,000 artefacts can be produced. This means that the ship carried almost as much copper as the Mitterberg main lode produced in one year.

For the extraction of copper ores and the annual production of the above mentioned artefacts wood is required as fuel (see above). The energy expenditure calculations make it possible to calculate the demand for wood from the ore-wood-ratio taken from the experimental data (see above). Keeping the above mentioned constraints in mind, the demand for wood – specified in tons (Fig. 7) and hectare (Fig. 8) – illustrates the human impact on the environment. In the Copper and Early Bronze Age, a wood consumption of 870 t or 6 ha was calculated for the annual production of 7,500 artefacts from Ai Bunar copper and 2,025 t or 14 ha for the annual production of 17,500 artefacts from Saint-Véran copper. The annual production of 250 artefacts from Mount Gabriel copper in the Early and Middle Bronze Age only consumes 30 t or 0.2 ha of wood. For the Middle and Late Bronze Age a wood consumption of 6,980 t or 50 ha was calculated for the annual production of 70,000 artefacts from Mitterberg copper (main lode) and 9,975 t or 70 ha for the annual production of 100,000 artefacts from Mitterberg copper (whole region). Furthermore, for the annual production of 250,000 artefacts from the copper of the Mitterberg area, Tirol and the Salzburg region 24,935 t or 175 ha of wood are required. This

Figure 8. Required wood resources in hectare for the annual production of the artefacts in Fig. 6; for references see Tab. 1 (source: author).

demand is only surpassed by the amount of wood needed for the annual production of the 335,000 artefacts from Cypriot copper which is 33,410 t or 234 ha. In comparison, the production of the possible 50,000 artefacts from the 10 t of copper found in the Uluburun ship wreck requires 4,990 t or 35 ha of wood and, thus, almost as much wood as the annual artefact production from the Mitterberg main lode copper.

With the diagrams in mind, it becomes clear that the output amounts strongly increase with the beginning of the Middle Bronze Age. Therefore, an increasing demand for wood as fuel and, consequently, a deforestation of the environment near the mining and smelting areas can be expected. In comparison to that, the environmental data from the surroundings of studied alpine mining areas show only small clearings of the forest in the Late Bronze Age with a more or less intact forest vegetation. An extensive deforestation of the alpine environment before the beginning of the Iron Age is highly unlikely (Heiss and Oeggl 2008, 220). It must be kept in mind that the Middle and Late Bronze Age smelting sites were constructed at high altitudes (see *e.g.* the northern Tyrol copper production sites of Mauken which are located at an altitude of 900-1200 m and the copper smelting site of Hechenberg at Jochberg which is located at an altitude of 1320 m; Goldenberg *et al.* 2011*a*, 67; Goldenberg 2004, 168), because in this area sufficient amounts of wood were available. It has to be noted that although smelting is the most wood consuming manufacturing step, casting and post-processing also require large amounts of wood (see Fig. 3). These two last-mentioned steps were probably not carried out in close proximity to the mines and smelting sites, but in the vicinity of the settlements, as indicated *e.g.* by findings of buckled tuyères (*geknickte Düsen*) (Töchterle *et al.* 2013, 6).

Conclusion

It has been shown that the calculation of the energy expenditure provides information about economic aspects of Bronze Age life, like the demand for resources and the expenditure invested in certain activities. In this case, the energy expenditure calculation produces comparative data concerning the production of copper and bronze artefacts. That way it is possible to compare the expenditure required for the different manufacturing steps and for different artefacts and object categories from a diachronic perspective. The calculation process involves the estimation of the required wood resources. Thus, it has been shown that the differences in the production processes in the working area in the Early Bronze Age in contrast to the Middle and Late Bronze Age are reflected in the energy expenditure. The introduction of a new smelting process at the end of the Early Bronze Age (ca. 1600 BCE) results in a comparatively lower energy expenditure for the manufacturing of copper and bronze artefacts from that point on. In addition to that, at the end of the Early Bronze Age tin bronze occurs on a regular basis (Kienlin 2010, 823-824, 831-834). The published estimation of the copper output from different sites in Europe, relying on the archaeological features of these sites, show that with the beginning of the Middle Bronze Age the copper output increases as well. The estimations allow the calculation of the number of artefacts produced from the estimated amount of copper of the sites, *e.g.* about 100,000 artefacts from 20 t of copper mined at the Mitterberg region in Austria. Furthermore, it was possible to calculate the amount of wood required for the production of the mentioned artefacts using the ore-wood-ratio of the underlying experiments. These calculations show that the needed amount of wood decreases with the change in smelting technology at the end of the Early Bronze Age (ca. 1600 BCE). This means that with the end of the Early Bronze Age the new reducing smelting process allows for the production of larger amounts of metals with a lower investment of resources. The increased total copper output at the beginning of the Middle Bronze Age in turn would have resulted in an increased demand for wood required in metallurgy. It is beyond the scope of this article to examine the impact of Bronze Age metallurgy on the environment in detail (this is done using natural scientific methods like the analysis of macro-remains and pollen data: *e.g.* Heiss and Oeggl 2008; Breitenlechner *et al.* 2011; Oeggl 2015). However, it has been shown that energy expenditure calculations can give a hint on the degree of resource consumption during this period and illustrate how changes in technological processes are reflected in the requirement of resources.

Outlook

Although the ore beneficiation and smelting was conducted at specialized sites, the casting and post-processing was presumably carried out in the settlement areas alongside other domestic activities, as indicated by sparse features of casting facilities (see above: Säckingen, Baden-Württemberg; Taltitz, Saxony; Parchim, Mecklenburg-West Pomerania). Bronze Age metallurgy therefore had a direct impact on the living conditions, as the growing demand for bronze and, thus also wood – among other factors – changed the natural environment, which probably affected Bronze Age people. In addition, there are numerous negative effects of metallurgy which could not be examined in this article. Amongst others, these are water pollution, shortage of fuelwood caused by over-exploitation of wood resources and toxic fumes originating from smelting and casting processes. At this point of time, a change can be noticed which further developed in the following periods, revealing a growing human intervention in the environment.

Energy expenditure calculations have been demonstrated to be a valid tool for the analysis of economic decisions in past societies. Overall, the results of the energy expenditure calculations and the estimations regarding the copper output and the demand for wood correspond to the archaeological record, which shows an increasing amount of evidence for metallurgical activities with the beginning of the Middle Bronze Age, alongside with the use of a more effective manufacturing process. At the same time, the copper output and, thus the number of produced artefacts increased, together with the demand for wood and the energy expenditure invested in metallurgy. This implies that with the beginning of the Middle Bronze Age more people had to be involved in metallurgical activities. However, conclusions about the social aspects and implications of Bronze Age Metallurgy are limited, because a lot of context information is missing from the archaeological record. Many scholars have discussed the social implications of metallurgy (see O'Brien 2015, 245-278 with further literature) and it clearly goes beyond the scope of this article to examine them in detail. However, it is important to mention that presumptions regarding *e.g.* the organisation of labor or the structure of society influence the interpretation of metallurgical processes. A prominent example is the influence of the Bronze Age metallurgy on the development of hierarchic societies in the eastern alpine copper mining areas. In this area hilltop settlements with small-sized evidence of metallurgical activities appear in the Neolithic and Early Bronze Age (*e.g.* Mariahilfbergl, Götschenberg, Kiechlberg, Buchberg and Klinglberg). Scholars (*e.g.* Krause 2009), who favour the idea of an emergence of a hierarchically structured society, interpret these hilltop settlements as central places in a hierarchical settlement system whose control derives from the exploitation of the surrounding copper resources and the trade of copper. In this perspective, metallurgy required control by emergent elites (Kienlin 2013, 424). On the other hand, scholars who reject the hierarchical model (Shennan 1995; Kienlin and Stöllner 2009; Stöllner 2012; Tomedi 2015) assume that the population of these settlements practised metallurgy in a communal or kinship-based mode of operation (Kienlin 2013, 424-425). This small excursus shows that the interpretation of social implications of Bronze Age metallurgy largely depends on the underlying presumptions. The calculation of energy expenditure as well is an interpretation of the archaeological record, presuming that the comparative analysis of energy expenditure allows conclusions about changes in Bronze Age metallurgy. A future comparison of the energy expenditure for other domestic activities would help to estimate the expenditure spend on metallurgy on a daily or annual basis (a compilation by Kerig on the annual time requirement of a *Bandkeramik* household shows that 41 % of the annual available time is occupied with working activities: Kerig 2010, 242). In future research the results of energy expenditure calculations may also be used and compared with demographic data to get a better idea of the expenditure invested by communities in order to carry out particular activities and possibly of the structure of society.

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References

Anemüller, U. 1999. *Metallkundliche Untersuchungen an Bronzebeilen – ein Beitrag zur Technologie der Bronzezeit.* Düsseldorf: VDI Verlag.

Becker, D. 1989. Bronzezeitliche Schmelzofenreste von der Gemarkung Parchim. *Ausgrabungen und Funde*, 129-132.

Bernbeck, R. 2009. Wertschöpfungstheorien von Marx und Mauss zu Baudrillard und Bourdieu. in: Hildebrandt, B and Veit, C. (eds.), *Der Wert der Dinge – Güter im Prestigediskurs: Formen von Prestige in Kulturen des Altertums*. Graduiertenkolleg der DFG an der Ludwig-Maximilians-Universität München. Münchner Studien zur Alten Welt 6. München: Utz, 29-71.

Binggeli, M. *et al.* 1996. Bronzegiessen im Garten des Museums. *Archäologie der Schweiz. Mitteilungsblatt der schweizerischen Gesellschaft für Ur- und Frühgeschichte* 19, 2-8.

Bourgarit, D. *et al.* 2008. The beginning of copper mass production in the western Alps. The Saint-Véran mining area reconsidered. *Historical Metallurgy* 42/1, 1-11.

Boyadziev, Y. 1995. Chronology of Prehistoric Cultures in Bulgaria, in: Bailey, D.W. and Panayotov, I. (eds.) 1995, *Prehistoric Bulgaria*. Monographs in world archaeology 22. Madison: Prehistory Press, 149-191.

Breitenlechner, E. *et. al.* 2011. Der paläoökologische Nachweis von prähistorischen Bergbauaktivitäten in Tirol und Salzburg. in: Oeggl, K. *et al.* (eds.). *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten*. Proceedings zum 5. Milestone-Meeting des SFB HiMAT vom 7. – 10.10.2010 in Mühlbach. Innsbruck: Innsbruck University Press, 33-40.

Brinkmann, J. in prep. *Arbeitsaufwandsberechnungen zu Bronzeartefakten – Diachroner Vergleich von Aufwand und Wert in Mitteleuropa*.

Darvill, T. 2008. *The concise Oxford dictionary of archaeology*. Oxford: Oxford University Press.

Dieck, P. 2014. Aufwandsberechnungen zum Hausbau im Neolithikum, in: Müller, J. (ed.), *Denghoog, Großeibstadt, Rastorf. Studien zu neolithischen Gräbern und Häusern*. Frühe Monumentalität und soziale Differenzierung 5. Bonn: Habelt, 253-280.

Dobres, M.-A. 2000. *Technology and social agency: outlining a practice framework for archaeology.* Oxford: Blackwell Publishers.

Doonan, R. 1994. Sweat, fire and brimstone: pre-treatment of copperore and the effects on smelting techniques. *The Journal of the Historical Metallurgy Society* 28, 211-258.

Dörfler, W. 1995. Versuch einer Modellierung des Energieflusses und des Rohstoffverbrauchs während der römisch-kaiserzeitlichen Eisenverhüttung in Joldelund, Ldkr. Nordfriesland. *Probleme der Küstenforschung im südlichen Nordseegebiet* 23, 175-185.

Eibner, C. 1979. Zum Stammbaum einer urzeitlichen Kupfererzaufbereitung. *Berg- und Hüttenmännische Monatshefte* 124, 157-161.

Eibner, C 1982. Kupfererzbergbau in Österreichs Alpe, in: Hänsel, B. (ed.), *Südosteuropa zwischen 1600 und 1000 v. Chr. Prähistorische Archäologie in Südosteuropa 1*. Berlin: Moreland Editions, 399-408.

Eibner, C. 2005. Die Entwicklung der Kupfergewinnung aus Ostalpinen Lagerstätten vom 4. bis zum 1. Jahrtausend vor Chr. Ein archäologischer Überblick, in: Dal Ri, L. and Tecchiati, U. (eds.). Abstracts of the International workshop: Der spätkupferzeitliche Schmelzplatz von Milland bei Brixen im Rahmen der beginnenden Metallurgie im alpinen Raum. Bozen: Istituto Italiano di Preistoria e Protostoria, 37-39.

Faoláin, S.Ó. and Northover, J. P. 1998. The Technology of Late Bronze Age Sword Production in Ireland. *Journal Irish Arch.* 9, 69-88.

Fasnacht, W. 1994. Viertausend Jahre Kupfer- und Bronzeguß im Experiment. Experimentelle Archäologie Bilanz. *Archäologische Mitteilungen aus Nordwestdeutschland Beiheft* 8, 237-246.

Freudenberg, M. 2009. Steingeräte zur Metallbearbeitung – Einige neue Aspekte zum spätneolithischen und frühbronzezeitlichen Metallhandwerk vor dem Hintergrund des Schleswig-Holsteinischen Fundmaterials. *Archäologisches Korrespondenzblatt* 39, 341-359.

Ganslmeier, R. 2011. Wind und Wohlstand – Zur Kenntnis der Metallurgie, in: Friedrich, S. and Meller, H. (eds.). *Kultur in Schichten: Archäologie am Autobahndreieck Südharz (A 71)*. Archäologie in Sachsen-Anhalt Sonderband 14. Halle an der Saale: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, 119-126.

Gersbach, E. 1969. *Urgeschichte des Hochrheins* (Funde und Fundstellen in den Landkreisen Säckingen und Waldshut). Badische Fundber. Sonderh. Freiburg: Kehrer.

Goldenberg, G. 2004. Ein Verhüttungsplatz der mittleren Bronzezeit bei Jochberg (Nordtirol), in: Weisgerber, G. and Goldenberg, G. (eds.). *Alpenkupfer – Rame delle Alpi.* Tagung Urgeschichtliche Kupfergewinnung im Alpenraum an der Universität Innsbruck vom 4. – 8. Oktober 1995. Anschnitt Beiheft 17. Bochum: Vereinigung der Freunde von Kunst und Kultur im Bergbau e.V., 165-176.

Goldenberg, G. *et al.* 2011a. Prähistorischer Kupfererzbergbau im Maukental bei Radfeld/Brixlegg, in: Goldenberg, G. *et al.* (eds.), *Forschungsprogramm HiMAT – Neues zur Bergbaugeschichte der Ostalpen*. Archäologie Österreichs Spezial 4. Wien: Verlag der Österreichischen Gesellschaft für Ur- und Frühgeschichte, 61-110.

Goldenberg, G. *et al.* 2011b. Das Nepal Experiment. Experimentelle Archäologie mit ethnoarchäologischem Ansatz, in: Oeggl, K. *et al.* (eds.). *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten*. Proceedings zum 5. Milestone-Meeting des SFB HiMAT vom 7. – 10.10.2010 in Mühlbach. Innsbruck: Innsbruck University Press, 83-90.

Goldenberg, G. 2015. Prähistorische Kupfergewinnung aus Fahlerzen der Lagerstätte Schwaz-Brixlegg im Unterinntal, Nordtirol, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 151-163.

Hanning, E. 2012. Reconstructing Bronze Age Copper Smelting in the Alps: an ongoing process. *Experimentelle Archäologie in Europa. Bilanz* 11, 2012, 75-86.

Hauptmann, A. and Weisgerber, G. 1985.Vom Kupfer zur Bronze: Beiträge zum frühsten Berg- und Hüttenwesen, in: Born, H. (ed.). *Archäologische Bronzen, antike Kunst, moderne Technik*. Berlin: Reimer, 16-36.

Haustein, M. and Pernicka, E. 2008. Verfolgung der bronzezeitlichen Zinnquellen Europas durch Zinnisotopie – eine neue Methode zur Beantwortung einer alten Frage. *Jahresschrift für Mitteldeutsche Vorgeschichte* 92, 387-417.

Heiss, A.G. and Oeggl, K. 2008. Analysis of the fuel wood used in Late Bronze Age and Early Iron Age copper mining sites of the Schwaz and Brixlegg area (Tyrol, Austria). *Vegetation History and Archaeobotany* 17, 211-221.

Herdits, H. 1993. Zum Beginn experimentalarchäologischer Untersuchungen einer bronzezeitlichen Kupferverhüttungsanlage in Mühlbach, Salzburg. *Archaeologia Austriaca* 77, 31-38.

Herdits, H. 1996. Experimentalarchäologische Untersuchungen zur bronzezeitlichen Verhüttung sulfidischer Kupfererze. Experimentelle Archäologie in Deutschland. Bilanz. *Archäologische Mitteilungen aus Nordwestdeutschland Beiheft* 13, 21-31.

Herdits, H. and Löcker, K. 2004. Eine bronzezeitliche Kupferhütte im Mitterberger Kupferkies-Revier (Salzburg), in: Weisgerber, G. and Goldenberg, G. (eds.). *Alpenkupfer – Rame delle Alpi.* Tagung Urgeschichtliche Kupfergewinnung im Alpenraum an der Universität Innsbruck vom 4. – 8. Oktober 1995. Anschnitt Beiheft 17. Bochum: Vereinigung der Freunde von Kunst und Kultur im Bergbau e.V., 177-188.

Holdermann, C.-S. and Trommer, F. 2010. Verfahrenstechniken und Arbeitsaufwand im frühbronzezeitlichen Metallhandwerk – Technologische Aspekte der Himmelsscheibe von Nebra – Ein Erfahrungsbericht, in: Meller, H. and Bertemes, F. (ed.). *Der Griff nach den Sternen. Wie Europas Eliten zu Macht und Reichtum kamen*. Tagungen des Landesmuseums für Vorgeschichte 5. Halle an der Saale: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, 791-806.

Höppner, B. *et. al.* 2005. Prehistoric copper production in the Inn Valley (Austria), and the earliest copper in Central Europe. *Archaeometry* 47, 293-315.

Iaia, C. 2015. Smiths and Smithing in Bronze Age "Terramare", in: Kelm, R. (ed.), *Archeology and crafts: Experiences and Experiments on Traditional Skills and Handicrafts in Archaeological Open-Air Museums in Europe*. Proceedings of the VI. OpenArch-Conference in Albersdorf, Germany, 23.-27. September 2013. Albersdorfer Forschungen zur Archäologie und Umweltgeschichte 5. Husum: Husum Druck- und Verlagsgesellschaft, 78-93.

Jansen D./Nelle O. 2011. Neolithic wood usages: examples from the lowlands of Germany. *Saguntum* 11, 85-86.

Jansen D./Nelle O. 2014. The Neolithic woodland – archaeoanthracology of six Funnel Beaker sites in the lowlands of Germany. *Journal of Archaeological Science* 51, 154-163.

Kerig, T. 2010. Der Faktor Arbeit im Neolithikum: Steinbearbeitung, Feldbestellung, Schwertransport. in: Lichter, C. (ed.). *Jungsteinzeit im Umbruch. Die "Michelsberger Kultur" und Mitteleuropa vor 6000 Jahren.* Darmstadt: Badisches Landesmuseum, 236-242.

Kerig, T. 2013. Wirtschaft: Struktur und Leistung in frühen Gesellschaften, in: Eggert, M.K.H. (ed.), *Theorie in der Archäologie: zur jüngeren Diskussion in Deutschland*. Tübinger Archäologische Taschenbücher 10. Münster: Waxmann, 137-188.

Kerig, T. 2016. Ein Instrument vergleichender Bilanzierung: Das Kölner Tableau (KöTa) Version 12/2015, in: Kerig, T., *Einfache und komplexe Wirtschaften. Studien zur Urgeschichte des Faktors Arbeit im mitteleuropäischen Neolithikum*. Habilitationsschrift angenommen von der Fakultät für Geschichte, Kunst- und Orientwissenschaften der Universität Leipzig. Leipzig: unpublished.

Kienlin T.L. and Stöllner T. 2009. Singen Copper, Alpine Settlement and Early Bronze Age Mining: Is There a Need for Elites and Strongholds?, in: Kienlin, T. L. and

Roberts, B. W. (eds.), *Metals and societies. Studies in honour of Barbara S. Ottaway.* Universitätsforschungen zur prähistorischen Archäologie 169. Bonn: Habelt, 67-104.

Kienlin, T.L. 2010. Zu Herstellung, Eigenschaften und chronologischer Stellung der frühbronzezeitlichen Randleistenbeile des Sächsischen Typs, in: Meller, H. and Bertemes, F. (eds.), *Der Griff nach den Sternen. Wie Europas Eliten zu Macht und Reichtum kamen*. Tagungen des Landesmuseums für Vorgeschichte 5/1. Halle: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, 823-843.

Kienlin, T.L. 2013. Copper and Bronze: Bronze Age Metalworking in Context, in: Fokkens, H. and Harding, A (eds.). *The Oxford Handbook of the European Bronze Age*. Oxford: Oxford University press, 414-436.

Klemm, S. 2015. Bronzezeitliche Kupfergewinnung in den Eisenerzer Alpen, Steiermark, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/ Westfalen: Leidorf, 195-200.

Knapp, A.B. 2013. *The archaeology of Cyprus. From earliest prehistory through the Bronze Age*. Cambridge world archaeology. Cambridge: University Press.

Krause, R. 2003. *Studien zur kupfer- und frühbronzezeitlichen Metallurgie zwischen Karpatenbecken und Ostsee*. Vorgeschichtliche Forschungen 24. Rahden/ Westfalen: Leidorf.

Krause, R. 2009. Bronze Age copper production in the Alps: organisation and social hierarchies in mining communities, in: Kienlin, T. L. and Roberts, B. W. (eds.), *Metals and societies. Studies in honour of Barbara S. Ottaway.* Universitätsforschungen zur prähistorischen Archäologie 169. Bonn: Habelt, 47-66.

Leach, G. 1976. *Energy and food production*. Guildford: IPC Science and Technology Press for the International Institute for Environment and Development.

Leroi-Gourhan, A. 1964. *Le Geste et la Parole – Technique et langage*. Paris: Michel.

Lewis, A. 1990. Firesetting Experiments on the Great Orme, 1989, in: Crew, P. and Crew, S. (eds.). *Early mining in the British Isles*. Proceedings of Early Mining Workshop at Plas Tan y Bwlch, Snowdonia National Park Study Centre, 17-19 November, 1989. Occasional Paper 1. Plas Tan y Bwlch: Snowdonia National Park Study Centre, 55-56.

Lorscheider, F. *et al.* 2003. Frühe Kupferproduktion – archäologischer Befund und Experiment: Versuche zur Fahlerzverhüttung in einem einzigen Ofengang, in: Stöllner, T. *et al.* (eds.). *Man and Mining*. Studies in honour of Gerd Weisgerber on occasion of his 65th birthday. Der Anschnitt Beiheft 16. Bochum: Deutsches Bergbau-Museum, 301-307.

Mathieu, J.R. 2002. Introduction – Experimental Archaeology: Replicating Past Objects, Behaviors, and Processes, in: Mathieu, J.R. (ed.), *Experimental archaeology. Replicating past objects, behaviors, and processes*. Britisch Archaeological Reports (International Series) 1035. Oxford: Archaeopress, 1-11.

Martinek, K.-P. 1995. Archäometallurgische Untersuchungen zur frühbronzezeitlichen Kupferproduktion und -verarbeitung auf dem Buchberg bei Wiesing, Tirol. *Fundberichte aus Österreich* 34, 575-584.

Martinek, K.-P. and Sydow, W. 2004. Frühbronzezeitliche Kupfermetallurgie im Unterinntal (Nordtirol). Rohstoffbasis, archäologische und archäometallurgische Befunde, in: Weisgerber, G. and Goldenberg, G. (eds.). *Alpenkupfer – Rame delle Alpi.* Tagung Urgeschichtliche Kupfergewinnung im Alpenraum an der Universität Innsbruck vom 4. – 8. Oktober 1995. Anschnitt Beiheft 17. Bochum: Vereinigung der Freunde von Kunst und Kultur im Bergbau e.V., 199-211.

Marx, K. 1981. *Das Kapital. Kritik der politischen Ökonomie*. Band I: Der Produktionsprozeß des Kapitals. Frankfurt am Main 1981: Ullstein GmbH.

Marx, K. and Engels, F. 1990. *Gesamtausgabe (MEGA). Zweite Abteilung. „Das Kapital" und Vorarbeiten. Band 9.* Karl Marx. Capital. A Critical Analysis of Capitalist Production. London 1887. Text. Berlin: Dietz Verlag.

Modl, D. 2004. Gedanken und Erfahrungen bei der Rekonstruktion prähistorischer Kupferverhüttungsanlagen in der Steiermark, Österreich. *Experimentelle Archäologie in Europa. Bilanz* 3, 115-126.

Müller, J. 1990a. Arbeitsleistung und gesellschaftliche Leistung bei Megalithgräbern. Das Fallbeispiel Orkney. *Acta Praehistorica et Archaeologica* 22, 9-35.

Müller, J. 1990b. Die Arbeitsleistung für das Großsteingrab Kleinenkneten. in: Fansa, M. (ed.), *Experimentelle Archäologie in Deutschland. Begleitschrift zu einer Ausstellung des Staatlichen Museums für Naturkunde und Vorgeschichte Oldenburg*. Archäologische Mitteilungen aus Nordwestdeutschland Beiheft 4. Oldenburg: Isensee, 210-219.

Newton *et al.* 2005, Die Datierung des Schiffswracks von Uluburun, in: Yalçın, Ü. *et al.* (eds.). *Das Schiff von Uluburun. Welthandel vor 3000 Jahren.* Katalog der Ausstellung des Deutschen Bergbau-Museums Bochum vom 15. Juli 2005 bis 16. Juli 2006. Veröffentlichungen des Deutschen Bergbau-Museums 138. Bochum: Deutsches Bergbau-Museum, 115-116.

O'Brien, W. 2015. *Prehistoric copper mining in Europe: 5500-500 BC*. Oxford: Oxford University Press.

Oeggl, K. 2015. Vegetationsgeschichte und Landnutzung, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 43-49.

Oeggl, K. and Schwarz, A.S. 2015. Aspekte der Versorgung bronzezeitlicher Bergbaugebiete, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 255-262.

Ottaway, B.S. 1994. *Pr*ähistorische Archäometallurgie. Espelkamp: Leidorf.

Pichler, T. *et al.* 2012. Analysen zum prähistorischen Erzabbau in der Grube Mauk E, Radfeld. Dendro-Daten, Holzbedarf und Waldnutzung, in: Oeggl, K. and Schaffer, V. (eds.). *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten*. Proceedings zum 6. Milestone Meeting des SFB HiMAT vom 3. – 5.11.2011 in Klausen/Südtriol. Innsbruck: Innsbruck University Press, 85-89.

Pittioni, R. 1951. Prehistoric copper mining in Austria. Problems and facts. *Annual Report and Bulletin Institute of Archaeology* 7, 16-43.

Popov, H. *et al.* 2014. Feuersetzen beim Abbau der goldhaltigen Quarzgänge im spätbronzezeitlichen Goldbergwerk auf dem Ada Tepe, Südbulgarien. *Experimentelle Archäologie in Europa. Bilanz* 13, 27-44.

Primas, M 2008*. Bronzezeit zwischen Elbe und Po. Strukturwandel in Zentraleuropa 2200 – 800 v. Chr.* Universitätsforschungen zur prähistorischen Archäologie 150. Bonn: Habelt.

Pulak, C. 2005. Das Schiffswrack von Uluburun, in: Yalçın, Ü. *et al.* (eds.). *Das Schiff von Uluburun. Welthandel vor 3000 Jahren.* Katalog der Ausstellung des Deutschen Bergbau-Museums Bochum vom 15. Juli 2005 bis 16. Juli 2006. Veröffentlichungen des Deutschen Bergbau-Museums 138. Bochum: Deutsches Bergbau-Museum, 55-102.

Ricardo, D. 1817. *On the Principles of Political Economy, and Taxation*. London: John Murray.

Rieser, B. and Schrattenthaler, H. 2002. *Prähistorischer Bergbau im Raum Schwaz-Brixlegg. Urgeschichtliche Bergbauspuren, Werkzeugfunde, Experimente, Mineralien.* Reith im Alpbachtal: Ed. Tirol.

Rostoker, W. *et al.* 1989. Direct reduction to copper metal by oxide-sulfide mineral interaction. *Archeomaterials* 3, 69-87.

Roux, V. 2017. Ceramic Manufacture: The chaîne opératoire Approach, in: Hunt, A. (ed.). *The Oxford handbook of archaeological ceramic analysis*. Oxford: Oxford University Press, 1-17.

Shennan, S. J. 1995. *Bronze age copper producers of the eastern Alps. Excavations at St. Veit-Klinglberg.* Universitätsforschungen zur prähistorischen Archäologie 27. Bonn: Habelt.

Shennan, S.J. 1999. Cost, benefit, and value in the organization of early European copper production. *Antiquity* 73, 352-363.

Siedlaczek, M. 2011. Der experimentelle Nachguss von bronzezeitlichen Schwertern. *Experimentelle Archäologie in Europa. Bilanz* 10, 109-119.

Silvestri, E. *et al.* 2015. Bronzezeitliche Kupferverhüttung in Trentino, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 201-208.

Simon, K 1992. Ein Schmelzofen der späten Bronzezeit aus dem sächsischen Vogtland. *Arbeits- und Forschungsberichte zur sächsischen Bodendenkmalpflege* 35, 51-82.

Stein, F. 1976. *Bronzezeitliche Hortfunde in Süddeutschland. Beiträge zur Interpretation einer Quellengattung.* Saarbrücker Beiträge zur Altertumskunde 23. Bonn: Habelt.

Stöllner, T. 2012. Mining and Elites: A Paradigm Beyond the Evidence in European Metal Ages, in: Kienlin T. L and Zimmermann, A. (eds.), *Beyond elites. Alternatives to hierarchical systems in modelling social formations.* International conference at the Ruhr-Universität Bochum, Germany, October 22 – 24, 2009. Universitätsforschungen zur prähistorischen Archäologie 215. Bonn: Habelt, 433-448.

Stöllner, T. 2015. Die alpinen Kupfererzreviere: Aspekte ihrer zeitlichen, technologischen und wirtschaftlichen Entwicklung in zweiten Jahrtausend vor Christus, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 99-105.

Stöllner, T. *et al.* 2011a. Der Mitterberg – Der Großproduzent für Kupfer im östlichen Alpenraum während der Bronzezeit, in: Goldenberg, G. *et al.* (eds.), *Forschungsprogramm HiMAT – Neues zur Bergbaugeschichte der Ostalpen*. Archäologie Österreichs Spezial 4. Wien: Verlag der Österreichischen Gesellschaft für Ur- und Frühgeschichte, 113-144.

Stöllner, T. *et al.* 2011b. Überlegungen zur Funktionsweise des mittelbronzezeitlichen Nassaufbereitungskastens vom Troiboden, in: Oeggl, K. *et al.* (eds.). Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten. Proceedings zum 5. Milestone-Meeting des SFB HiMAT vom 7. – 10.10.2010 in Mühlbach. Innsbruck: Innsbruck University Press, 141-156.

Stöllner, T. *et al.* 2012. Feuersetzen im frühsten Metallerzbergbau und ein Experiment im frühbronzezeitlichen Goldbergbau von Sakdrissi, Georgien, in: Oeggl, K. and Schaffer, V. (eds.). *Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten*. Proceedings zum 6. Milestone Meeting des SFB HiMAT vom 3. – 5.11.2011 in Klausen/Südtriol. Innsbruck: Innsbruck University Press, 65-76.

Tecchiati, U. 2015. Frühe Siedlung und Kupfermetallurgie in Südtirol: Milland bei Brixen, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 83-88.

Töchterle, U. *et al.* 2013. Spätbronzezeitliche Verhüttungsdüsen aus dem Bergbaurevier Mauken im Unterinntal, Nordtirol: Typologie, mineralogisch-petrographische Zusammensetzung und experimentelle Rekonstruktionsversuche. *Der Anschnitt* 65, 2-19.

Tomedi, G 2015. Eliten der Früh- und Mittelbronzezeit und ihre Beziehungen zum Kupferbergbau der Ostalpen, in: Stöllner, T. and Oeggl, K. (eds.). *Bergauf, bergab. 10.000 Jahre Bergbau in den Ostalpen*. Wissenschaftlicher Beiband zur Ausstellung im Deutschen Bergbau-Museum Bochum vom 31.10.2015 – 24.04.2016. Veröffentlichungen des Deutschen Bergbau-Museums Bochum 207. Rahden/Westfalen: Leidorf, 265-271.

Vorlauf, D. 1991. Die technologisch-typologische Methode. Anmerkungen zu Charakter und Aussagekraft der Experimentellen Archäologie im Hinblick auf Handwerk und Technik. *Archäologische Mitteilungen aus Nordwestdeutschland Beiheft* 6, 83-90.

Werner, A. and Barth, R. 1991. Versuche zu prähistorischen Bronzegußtechniken. Experimentelle Archäologie. Bilanz. *Archäologische Mitteilungen aus Nordwestdeutschland. Beiheft*, 299-304.

Yalçın, Ü. *et al.* (eds.) 2005. *Das Schiff von Uluburun. Welthandel vor 3000 Jahren*. Katalog der Ausstellung des Deutschen Bergbau-Museums Bochum vom 15. Juli 2005 bis 16. Juli 2006. Veröffentlichungen des Deutschen Bergbau-Museums 138. Bochum: Deutsches Bergbau-Museum.

Warriors' lives: the skeletal sample from the Bronze Age battlefield site in the Tollense Valley, north-eastern Germany

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Abstract

Research on the Bronze Age battlefield site in the Tollense Valley (Mecklenburg-Western Pomerania, 13th century BCE) has uncovered remains of more than 140 individuals thus far, predominantly those of young adult men. These remains represent a very special Bronze Age skeletal sample due to the large number of individuals and their mortality profile. The bones show perimortem as well as healed lesions, documenting the actual fighting in the valley, but in some cases also violent encounters in previous life situations, raising the question whether violence played a more than occasional role in some of these men's lives, and whether special activities possibly associated with a warrior lifestyle – routine use of weapons (*e.g.* shooting a bow), riding horses, marching long distances – may have left discernible traces on the bones. The paper presents the possibilities but also the problems that arise in accessing these questions on the basis of the Tollense Valley material.

Keywords: Tollense Valley, Bronze Age battlefield, skeletal sample, morphological traits, activity pattern, enthesial changes

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Introduction

The Tollense Valley in north-eastern Germany (Fig. 1) was the scene of a large-scale, violent encounter in the first half of the 13th century BCE. Remains of, up to now, more than 140 individuals, mostly young adult males, many of them with traces of perimortem injuries, have been documented from several sites in the river valley, together with some remains of horse and several types of weapons, among them wooden clubs as well as flint and bronze arrowheads. The finds testify to a battle occurring around 1300-1250 BCE in which at least several hundred and perhaps more than 2000 men participated.

Figure 1. Aerial view of the Tollense Valley, looking north (photo: J. Tirgrath, copterdrone.com).

As of mid-2018, archaeological research along and in the river has yielded more than 12,000 human remains, representing at least 140 individuals (MNI). The re-assessment of these individuals – *i.e.* the men participating in the battle in the Tollense Valley – will be the focus of this paper.

Archaeological research in the river valley

The Tollense Valley is situated in north-eastern Germany, in the federal state of Mecklenburg-Western Pomerania (Fig. 2). The river Tollense originates from a lake, the Tollensesee; it still meanders naturally over large parts of its course, but dredging of the riverbed and other draining measures changed the appearance of the river valley during the last decades of the 20th century (Lorenz *et al.* 2014). The Tollense Valley is characterised by a low moorland environment; meadows close to the river are nowadays mainly used as pasture. Neighbouring ground moraine areas have been favoured settlement areas since the Neolithic.

Until the 1990s, human skeletal remains were repeatedly discovered during dredging works, which took place at several sites in the Tollense Valley. The valley had also been known for its outstanding bronze finds even before the discovery of the battlefield site (Dombrowsky 2014). In 1996 a wooden club was found in the riverbank at the site of Weltzin 20, together with several human remains, among them a humerus with an embedded flint arrowhead. During test excavations a finds layer with disarticulated bones, mainly human but also a few horse, was discovered underneath a layer of peat close to the river. The human bones represented several human individuals, but there were no indications for a burial context. One skull showed a large, unhealed impression fracture, again indicating a violent background to the formation of the finds layer.

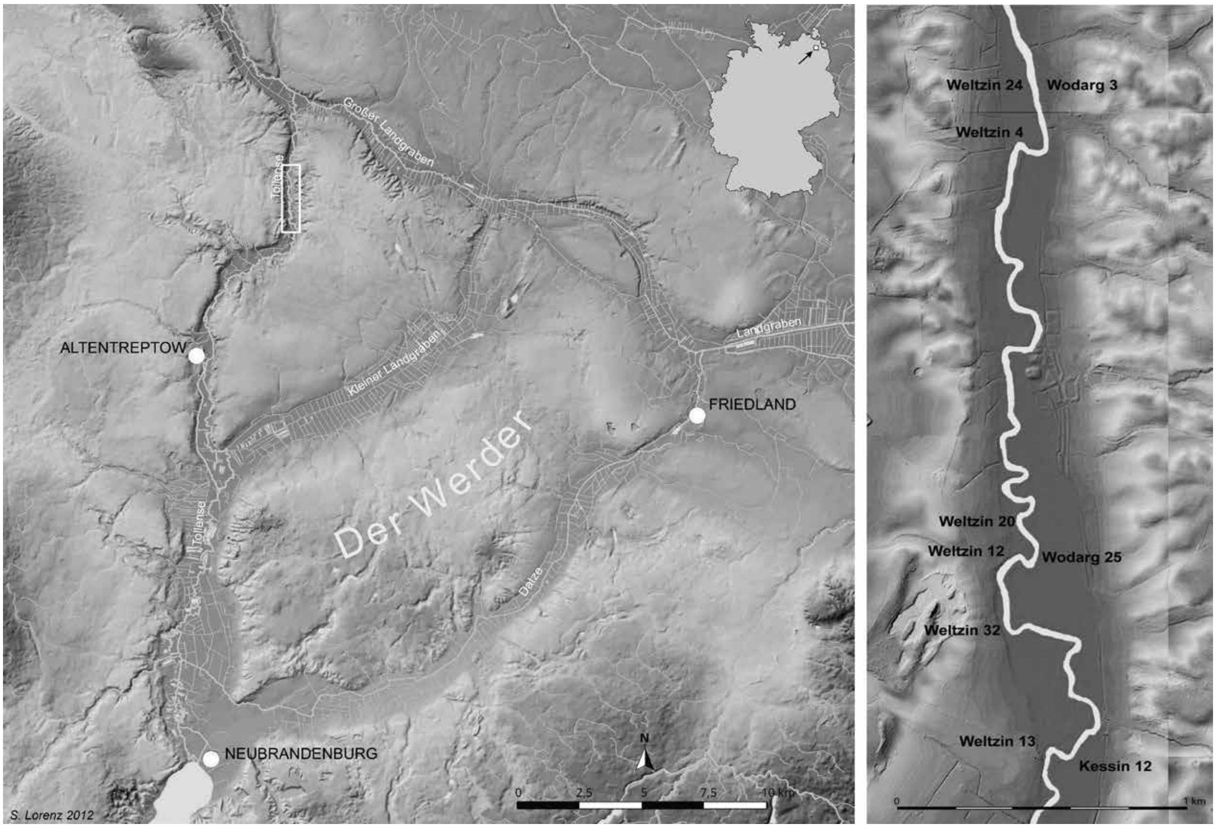

Figure 2. Location of the Tollense Valley (left) and the principal Bronze Age sites in the middle section of the river valley (right). The location of the inset to the right is indicated by the white frame in the map to the left (graphic: S. Lorenz & J. Dräger, using data from LAIV M-V © GeoBasis DE/MV 2012).

In 2007 extensive systematic archaeological research in the valley was initiated, including excavations, underwater surveys, and metal detector surveys, as well as scientific analyses on bones and other finds materials. Based on a series of more than 100 radiocarbon dates on skeletal and wooden remains from the Tollense Valley, the finds horizon of the Bronze Age battle can now be dated to the first half of the 13th century BCE (Terberger and Heinemeier 2014a). The human skeletal remains stem from a stretch of river more than 2.5 km long (linear distance) between the sites of Weltzin 4 and Weltzin 24 to the north and the sites of Weltzin 13 and Kessin 12 to the south (see Fig. 2; see also Terberger *et al.* 2014; Jantzen, Lidke, Brinker *et al.* 2014; Jantzen, Lidke, Dräger *et al.* 2014). From 2009 to 2015, extensive excavations of the bone finds layer were conducted at Weltzin 20 (exposing an area of *c.* 462 m^2), less extensive excavations were conducted at Weltzin 32; in both cases supported by comprehensive underwater surveys. In 2015 additional human skeletal remains dating to the battlefield horizon were discovered hundreds of metres north of sites Weltzin 4 and 24, possibly indicating an even larger spatial extent of the finds layer.

The spatial distribution of the bronze finds in the Tollense Valley is even more extensive than that of the skeletal remains. Weapons, tools, and jewellery have been found along a stretch of river several kilometres long, often in sediments dredged from the river decades ago, but also during diving surveys and – albeit rarely – during excavation. Most finds from the river valley – among them several weapons, such as a Riegsee-type sword, spearheads, and a Bohemian-type palstave – belong typologically to Period III of the Nordic Bronze Age (Dombrowsky 2014). They may thus relate to the battlefield horizon, but could also have come into the valley before or after the battle. A direct connection with battlefield activities is to be assumed only for those objects found directly in the bone finds layer or finds that can be directly dated. Up to now, this direct connection has been established for more than 50 bronze arrowheads, which were partly discovered during underwater surveys and excavations in the finds layer, but mostly during metal detecting, and which can often be dated via wooden shaft remains preserved in their sockets (Terberger and Heinemeier 2014a; Terberger *et al.* 2018). A case in point here is a bronze arrowhead still embedded in a human occipital bone, indicating a shot from behind (Lidke *et al.* 2018, Fig. 6.5).

Jewellery and weapons include local types as well as imported ones. The Bohemian-type palstave, the Riegsee-type sword, and several types of dress pins indicate more southerly or south-easterly regions of origin, and the bronze arrowheads are often thought to represent influences from the south. AMS results on wooden shaft remains indicate that the typologically diverse arrowheads were used together in the battle (Terberger and Heinemeier 2014a; Terberger *et al.* 2014, Fig. 15; 2018); they have close parallels in sites to the south also connected to fighting, *e.g.* Velim (Hrala 2000), Reisberg near Burgellern (Abels and Haberstroh 2001/2002), or Rachelburg (Möslein 2001; Möslein and Winghart 2001).

The excavated finds layer yielded very few items other than the skeletal remains. Weapons are documented from several sites, ranging from wooden clubs to flint and bronze arrowheads. Arrowheads not embedded in human bone may still have been originally deposited contained within the bodies of the dead. Other objects detected among the bones at Weltzin 20 include a bone dress pin, two small bone discs, and a bronze finger-ring. At this site the dead were obviously easily accessible for looting after the battle. At Weltzin 32, where the finds layer is situated in fluvial sediments of an old river bed, some valuables have been found: a gold spiral ring, four bronze spirals, and two tin spiral rings (Krüger *et al.* 2012). Probably at least some of the bodies escaped looting at this site, perhaps because they had fallen into the river or been thrown into it during the battle.

A possible conflict scenario

Structures that are very likely quite important for the interpretation of the development of the battle in the Tollense Valley were discovered approximately 1 km south of Weltzin 20, at Kessin 12/Weltzin 13. Finds material indicating a river crossing that was likely in use for millennia led to the discovery of a causeway in the eastern floodplain of the river valley, originally built in the 19th century BCE and probably still in use in the 13th century BCE. This structure made the crossing of the swampy area possible year-round, and it was likely an important feature in the communication and trade network of the region at that time (Jantzen, Lidke, Dräger *et al.* 2014).

A hypothetical reconstruction of the violent events in the Tollense Valley sees a first encounter of opponents at the probably widely known river crossing. The fighting then proceeded downstream in the form of a 'running battle'. Archers will have played an important role, as indicated by the many finds of projectiles at different sites. At several sites along the river these are found in places where numerous human remains also indicate skirmishes with various casualties. The floodplain of the river Tollense – being wet, swampy, and in parts covered with reeds – was not an ideal battle ground. A crossing of the river at a place other than the causeway track may have been prevented by tactical movements by one side, or it may just have been impossible due to the state of the riverbed and the riverbanks.

Conditions at Weltzin 20 were a bit better, as the alluvial fan here presented a slight, likely drier, elevation in the ground level. Here there seems to have been heavy fighting, indicated by a large number of perimortem lesions in the skeletal material indicative of long-range as well as close-range weapons. Some combatants likely died close to or in the river, whereas others may have drowned or have fallen or been thrown into the water.

The role of the horses that are represented in the skeletal material remains unclear. Were these beasts of burden, or were there mounted horsemen involved in the battle? So far no traces indicating riding have been detected on the horse bones (Benecke and Dräger 2014). The horse remains are as disarticulated as the human bones, indicating a direct connection to the development of the finds layer. But horses (minimum number of individuals [MNI] = 4) are clearly fewer in number than humans at the present state of research.

After the battle, at least hundreds of corpses must have littered the valley and the river. Those accessible to the victors were obviously thoroughly looted; in this process bodies will have been moved. Whether any other actions were undertaken concerning the dead – stacking or covering them, ritual act, or even execution of prisoners – is still open to debate.

The absence of gnawing marks from scavenging animals on the bones suggests that a protective covering – perhaps in the form of flooding or ice – may have been in place. Afterwards, the bodies decomposed; in shallow areas the skeletons became

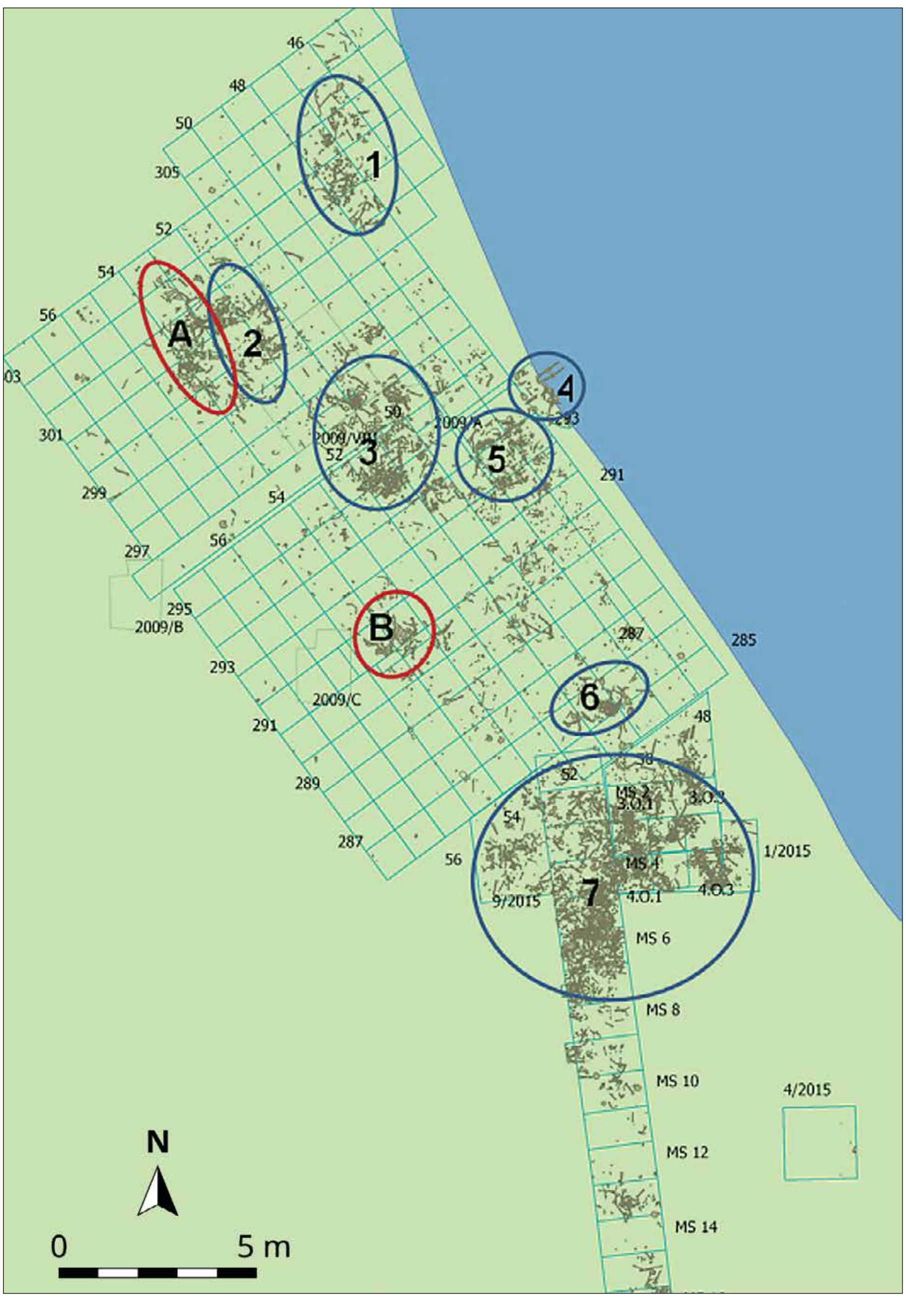

Figure 3. Map of Weltzin 20, showing the northern part of the excavated area with bone concentrations 1-7 (mainly human remains) and A-B (horse remains) (graphic: U. Brinker).

disarticulated and skeletal elements became displaced and commingled. The fact that the bones discovered in the excavated areas are usually in an excellent state of preservation suggests that sedimentation must have been relatively quick. Later flood events in the river valley, indicated by branches and other pieces of unworked wood dated to the Iron Age sometimes detected on top of the bone finds layer, may have disturbed the uppermost areas of the finds layer without commingling it as a whole; thus far, no later wood has been discovered within or under the Bronze Age bone finds layer.

Osteoarchaeological research on the human skeletal remains

The skeletal remains from the Tollense Valley – mostly human, more rarely horse – were most often discovered in a disarticulated state (Fig. 3). Only rarely were anatomical connections of limbs or other body parts recognisable already during excavation. Further connections – in some cases even leading to reconstructions of individuals ('anthropological re-association') – can be determined through osteoarchaeological analyses (*e.g.* Brinker *et al.* 2014). Analyses have shown that skeletal remains of individuals are not strewn across the valley over several sites, but are distributed over small areas of few square metres within each site. Disarticulation will thus have mostly taken place in a restricted environment.

Using 'visual pair-matching', a method generally applied in commingled bone assemblages (Konigsberg and Adams 2014, 201), paired skeletal elements (*e.g.* arm or leg bones) are matched (Fig. 4), if possible, by means of morphological similarities, including length, robusticity, muscle markings, epiphyseal shape, general symmetry between elements, and, where the state of preservation of the bones allows it, sometimes also other features, such as state of preservation or age and sex (*e.g.* Konigsberg and Adams 2014, 201; Adams and Byrd 2006).

In a next step, further associated bones of single individuals are identified by examining the congruence and character of joints and articular surfaces ('articulation'). This is a technique routinely used in commingled bone assemblages (*e.g.* Puerto *et al.* 2014), and under certain conditions the reconstruction of parts of bodies or even of more complete individuals is possible. According to Puerto *et al.* (2014, 328), under ideal circumstances, more than 90 per cent correct classifications of related skeletal elements are possible via pair matching or reassociation of fixed joints of the axial plane (vertebrae, sacrum-pelvis). Skulls and mandibles can be matched via the temporo-mandibular joint, and the upper and forearm bones can be matched via the elbow joint, both with a reliability of 60-90 per cent. For the Tollense Valley material, the method offers a possibility to identify matching elements and to conduct further analyses on the basis of these findings. Tollense Valley 'individuals' will therefore be represented mostly by matching pairs of either femora or arm bones, but in some cases (*e.g.* individual 16, see below) a more thorough identification has already proved possible.

Detailed information on the skeletal remains from the Tollense Valley are accumulated in databases, which, in combination with an AutoCAD-GIS programme, enables queries on all data – including skeletal elements identified as belonging together – within a virtual excavation surface. In this way, paired elements or partial bodies identified according to morphological-osteological analyses can be studied in their spatial relations to other remains, indicating how far elements of (partial) bodies have become dislocated from one another, and enabling investigations as to whether other skeletal remains in the vicinity may also belong to identified (partial) bodies (which latter elements are then again analysed morphologically to check for individual congruence).

Figure 4. Weltzin 20. Pair-matched femora of a single individual, found a few metres apart from each other in different parts of the excavation area (photo: S. Suhr).

Using these methods, it was possible to identify a nearly complete individual in one of the bone concentrations (bone concentration 6) at Weltzin 20, in addition to a few partial bodies of other individuals of different life stages (Fig. 5) and many more single disarticulated bones. The proportion of larger and smaller elements varies from site to site in the Tollense Valley, but also within a few square meters on the same site. Dense bone concentrations which, during analysis, were shown to consist in part of individual connections, are mingled with unrelated single bones of other individuals, suggesting that fluvial processes likely played a role in arranging and re-arranging the skeletal material.

As of mid-2018, the MNI for all Bronze Age sites relating to the battlefield horizon in the Tollense Valley is 144 (based on the left femur). Of these, 94 come from Weltzin 20, where the most extensive excavations (area of *c.* 462 square metres) have taken place so far.

Osteoarchaeological analyses have shown that a large majority of the individuals (>97 per cent) were young adult males (Brinker, Flohr *et al.* 2015). Many skeletal

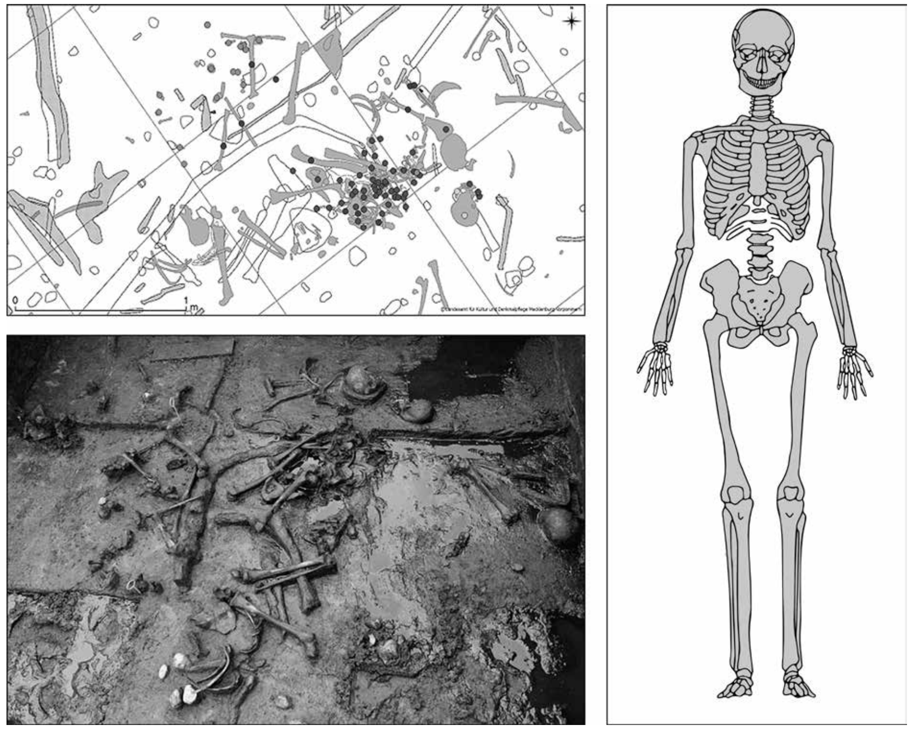

Figure 5. Weltzin 20. Detail of excavation area with bone concentration 6. Top left: schematic representation of the excavation area, with bones belonging to individual 16 marked with black dots; bottom left: photo of excavation area; right: skeletal representation of individual 16 (photo: G. Lidke; graphics: U. Brinker).

Figure 6. Examples of healed lesions from the Tollense Valley. Left: skull from Welzin 32 (ALM 2008/462, 165) with frontal blunt-force lesion; middle: skull from Weltzin 13 (ALM 2000/1382, 2) with stab wound or arrowhead lesion in the left parietal; right: detail of Weltzin 13 stab wound or arrowhead lesion (photos: S. Suhr & H. Lübke).

remains from all sites show perimortem lesions (n = 90), but some show healed ones, too (n = 40). Of the healed fractures, two thirds are unspecific fractures of ribs, claviculae, and arm, leg, hand, or foot bones, and one third appear to have been inflicted with a weapon (Jantzen *et al.* 2011, 424-426) and therefore indicate interpersonal violence. These are impression fractures on skulls, arrow or spearhead lesions (see Fig. 6), and parry fractures.

These healed lesions are located mainly on the front of the body, in the thorax region, and on the skull (see also Brinker *et al.* 2016, 49-51), thereby showing a similar distribution to the unhealed lesions (see below). At Weltzin 20, healed blunt-force lesions are concentrated on the skull, whereas unspecific lesions are seen mainly in the thorax region and the limbs (Fig. 7). All in all, the spectrum of healed lesions seen at different sites indicates that the affected individuals participated in violent conflicts long before the battle in the Tollense Valley.

Perimortem injuries (n = 79 at Weltzin 20) consist mainly of stab wounds and arrowhead lesions, but there are also injuries caused by sharp-force blows and cuts, as well as blunt-force injuries. Cases include arrowheads still embedded in bone, large impression fractures, as well as small cuts and funnel-shaped lesions that are partly rhombic, partly triangular. The latter likely represent mainly arrowshot wounds, as they show patterns typical of shooting lesions, in the form of impressed

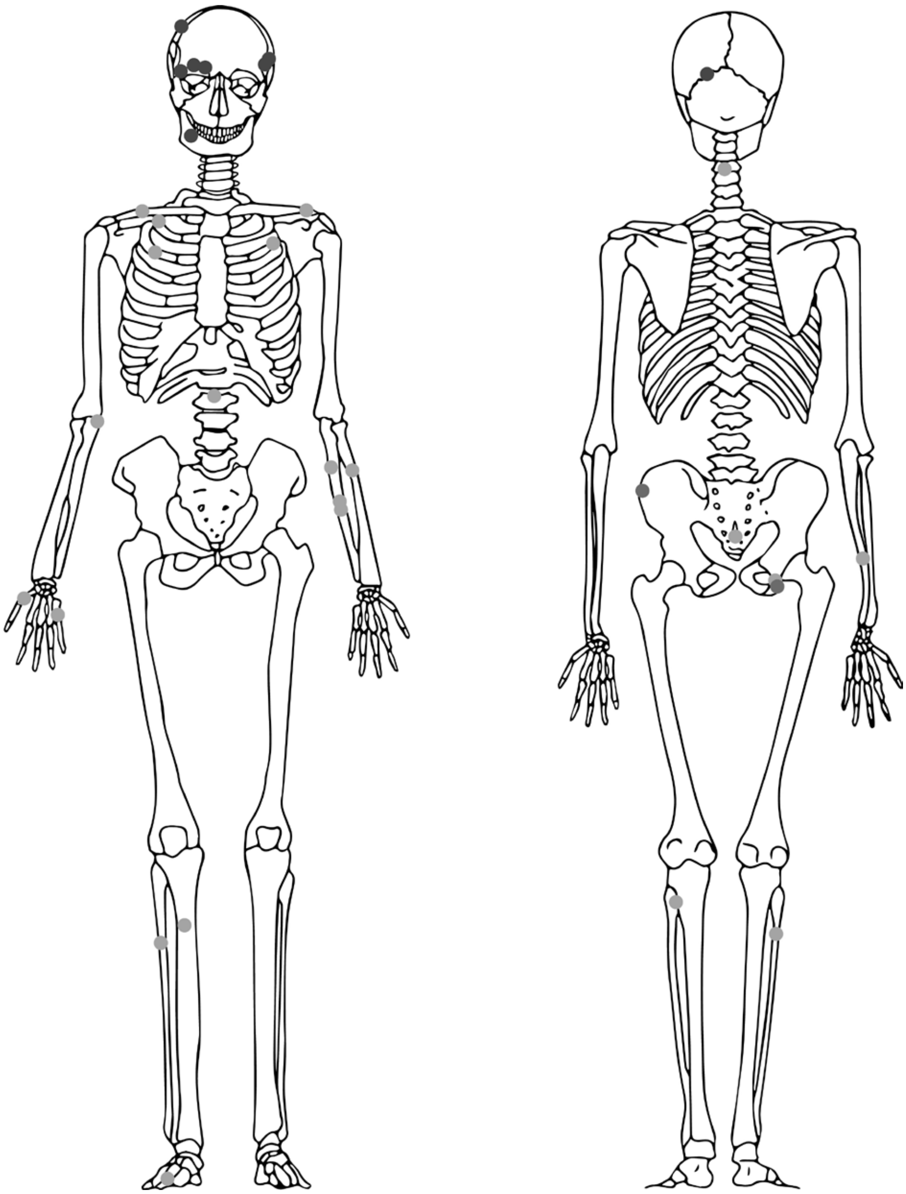

Figure 7. Weltzin 20. Locations of healed lesions (graphic: U. Brinker).

bone fragments at entry, and characteristic fracture lines, *e.g.* hinge fractures, funnel-shaped extensions, or chip fractures at entry or exit (Kneubuehl *et al.* 2008; see Brinker, Flohr *et al.* 2015; Brinker, Schramm *et al.* 2015; Brinker *et al.* 2016; 2018). The majority of perimortem lesions (>50 per cent) are found in the thorax region, but in general their distribution covers the entire body (Brinker, Schramm *et al.* 2015, 348-349, Fig. 3). Again in general, the front part of the body is affected most (*ibid.*), likely indicating close combat, but arrowhead lesions are often documented in the back of the body (Fig. 8), indicating that fleeing individuals were also targeted.

A femur fracture which initially was thought to represent a riding accident (without excluding other possibilities; Brinker *et al.* 2014, 199) could recently be shown to be a perimortem injury, probably caused by a spearhead (Schwinning *et al.* in prep.). So this weapon type is represented not only in the spectrum of finds from the Tollense Valley, but also in the spectrum of lesions.

In general, stereo and digital microscopy were applied to obtain information on the trauma and the objects (weapons) that caused them. Bronze Age weapons known from the Tollense Valley were impressed in florist foam in order to compare

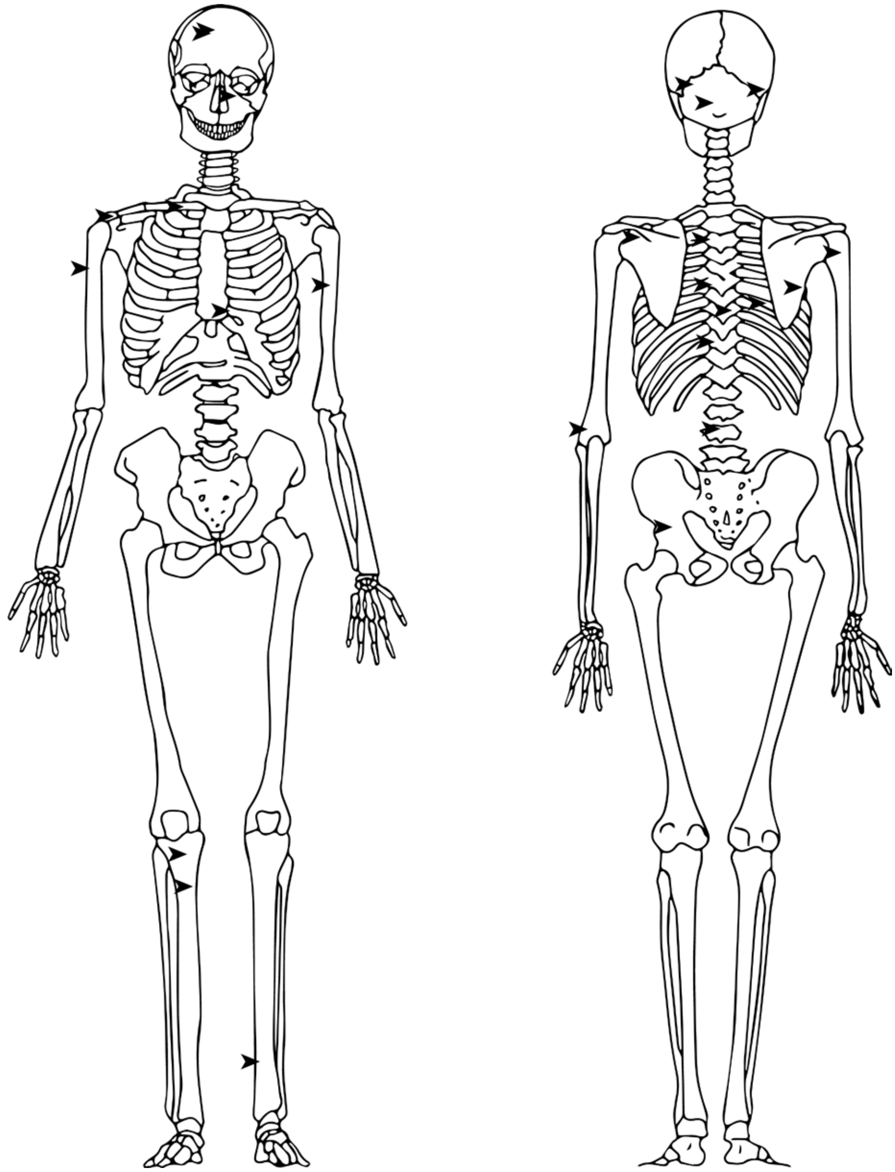

Figure 8. Weltzin 20. Locations of perimortem arrowhead lesions (graphic: U. Brinker).

the cross sections with those of the lesions on bones. This time-saving and simple method can give a first impression, but a more exact differentiation has to be based on modern imaging techniques (*e.g.* Brinker 2018). Therefore, Micro-CT analyses were conducted at the Bundesanstalt für Materialforschung und -prüfung (BAM) in Berlin to display and differentiate entry channels of, for example, arrowheads and dagger blades. Archaeological experiments with replica weapons (*e.g.* flint and bronze arrowheads, a bronze sword, knife and dagger blades, as well as spearheads made of bronze, flint, and bone) were conducted on pig half-carcasses to procure comparative osteological material for the identification of fracture patterns caused by different objects.

First results of these experiments (Lidke *et al.* 2014) allow comparisons between lesions on pig bones and those on Bronze Age human bones. The lesions observed in the human bone material were caused by a variety of weapons, with arrowhead lesions and stabbing lesions caused by daggers, knives, and/or spearheads being the most common, followed by blunt injuries and cutting lesions. Injuries caused by sword or axe blows are also quite likely, according to comparisons with the experimental osteological material.

The number of documented injuries alone points to a violent incident of unusual dimensions. Taking into account that a large number of lesions will have left no traces on the skeleton, an even greater total number of injuries is likely. Even the documented arrowhead lesions are just a minimum number, as only approximately one third of shots will have resulted in marks on bone (*e.g.* Milner 2005).

Initially, it was hypothesised that the fighting in the Tollense Valley may have dragged on over a longer period (Jantzen *et al.* 2011, 425), based on interpretation of clinical CT images of the humerus with embedded flint arrowhead, which showed a zone of higher density close to the projectile that was interpreted as a first healing reaction. However, micro-CT images taken subsequently show that this radiation zone does not go back to a bone reaction, but is caused by an accumulation of crushed trabecular bone tissue. The lesion therefore is now classified as an unhealed, perimortem one (Flohr *et al.* 2015).

The state and composition of the skeletal material discovered at Weltzin 32, where bones were mainly uncovered in a section of the river bank more than 60 m long, as well as the spectrum of lesions documented there, are more or less the same as at Weltzin 20. A causal and chronological connection of the development of the finds layer at both sites – as well as at other sites with evidence of the battlefield horizon in the Tollense Valley – is very likely. This also supports the hypothesis that all sites from the 'battlefield horizon' relate to just one major violent event and do not represent various minor incidents (Terberger *et al.* 2018).

Results of isotope (Sr, C, N) and aDNA analyses indicate a heterogeneous population with partly differing areas of origin (Price *et al.* 2017) and varying modes of nutrition (Terberger and Heinemeier 2014b). Isotopic signatures indicating the consumption of millet by some individuals do not necessarily indicate a geographical origin for these men in southern Europe, as millet cultivation has also been documented for Mecklenburg-Western Pomerania (Filipovic et al. 2018; Lübke 2011; Terberger and Heinemeier 2014b).

The number of individuals excavated in the Tollense Valley thus far points to an incident of more than local dimension. By extrapolating the number of individuals found in the small areas excavated so far to the entire find area of the Tollense Valley, we can estimate the total number of dead from the battle. Cautiously assuming 250-500 dead all in all, together with a death rate of 25 per cent of all battle participants, the number of fighters in the valley may have been as large as 1000-2000. Even if a higher death rate, of up to 50 per cent, is proposed, following the total rout of one side, a total number of up to 1000 fighters is still possible.

Individual traits and activity patterns?

Osteoarchaeological research also documents and analyses skeletal markers that may help to characterise the Bronze Age warriors from the Tollense Valley in more individual ways.

Measurements on bones, or morphometrics (*i.e.* the quantitative measurement and analysis of morphological traits), yield individual data for comparing morphological similarities and differences that can also be used, for instance, for the reconstruction of body height. Based on measurements on the most commonly represented skeletal element in the Tollense Valley material, the left femur, individuals at Weltzin 20 were on average 1.66 m tall (ranging from 1.60 m to 1.73 m; calculation after Pearson 1899), a value comparable to results obtained for other Bronze Age sites (Siegmund 2010).

Metrical analyses can also say something about the robusticity of the bones and, hence, about the preferred use of one side of the body by comparing paired elements, *e.g.* upper arm bones. The adult humeri found at Weltzin 20 show a preferred use of the right hand, which may indicate a primarily one-handed use of weapons.

Morphological analyses give also hints concerning physical strain. Changes at muscle attachment spots can be recognised and evaluated, based on the assumption that such changes indicate long-lasting activity of the muscle, and therefore also of the individual.

Research into so-called enthesial changes, or musculoskeletal stress markers, represents a relatively new osteoarchaeological method. Together with other parameters, such as degenerative changes in joints, these stress markers may indicate patterns of movement and physical strain from habitual activities in skeletal elements, for instance, the repeated use of certain weapons. However, confident differentiation among certain activities is rather difficult, as, for instance, muscle strain in using a bow and arrow or throwing a spear is different as a whole, but each activity partly involves the same muscles. A reconstruction of individual activities is made more difficult in the Tollense Valley material, as the skeletal remains are mainly found disarticulated. Nevertheless, it is possible to indicate tendencies for strain and activity for single limbs.

Comparisons between left and right body sides are based on reconstructed partial bodies. The analyses for muscle strain on the humeri from the Tollense Valley sample conducted so far did not show relevant differences in the use of left and right arms – in contrast to the results of morphometric measurements mentioned above. A habitual use of bow and arrow should have led to a disparate strain on muscles of the left and right arms, due to the differences in movement required for holding the bow and drawing it, respectively (Haidn *et al.* 2010). On the other hand, just about half of the ulna pairs from the Tollense Valley analysed so far exhibit a more pronounced attachment of the Musculus brachialis in the right ulna. As the sample is rather small and only this one muscle showed this more pronounced attachment, the results must be considered preliminary. Pronounced muscle attachments in the right ulna were documented in skeletons from Neolithic burials in France, where the burial furnishings are interpreted to indicate archers (Thomas 2014).

The attachment of the Musculus pectoralis on the humerus is also often quite pronounced in the Tollense Valley sample, indicating a slight preference for the right side. Together with Musculus brachialis, this muscle is in use when a person is carrying heavy weights.

Professional archery would also lead to a bilateral, symmetrical overstraining of the elbow and shoulder joints. The Tollense Valley skeletal material shows no grave arthritic changes. But small osteochondral lesions, which today occur in (young) people who are very active in throwing sports (Weigelt 2013; Weber and Streich 2017, 113), were diagnosed.

The majority of lower limbs from the Tollense Valley exhibit facets, such as squatting facets in the tibia or Poirier's facets in the femur, but these changes can only generally be interpreted as behavioural stress markers, without indicating special activities.

According to results obtained so far, the skeletal material does not support the hypothesis of professional archers in the Tollense Valley. Rather, the morphological traits observed so far together indicate routine, habitual activities without proving very specific activities. The long limb bones from the Tollense Valley show many morphological similarities, which could indicate comparable activity patterns. The men were likely very active, but were not engaged in overly strenuous activities for a longer time span. It is the activity level in general that characterises the population from the Tollense Valley.

The large variability in the results of osteoarchaeological measurements, when related to the results from strontium isotope analysis, may indicate 'foreigners' within the population group, which, in turn, could hint at a warrior community or *Männerbündnis* (men's alliance).

The re-association of individual 16 and his life history

Analyses of the skeletal material from excavations at Weltzin 20 have shown the viability of re-assessing at least parts of bodies, and in some cases even more complete individuals as well, despite the mostly disarticulated state in which the remains were found. Further research into these persons can yield individual information and thus lead to the formation of a more conclusive picture – one that could not necessarily be obtained from just single bones – as to place of origin, nutrition, physical stress markers, pathological conditions, and traumas, especially multiple ones in different parts of the body. These possibilities will be illustrated here in the case of individual 16, which was discovered in bone concentration 6 (see Figs. 3; 5) at Weltzin 20, in a disarticulated state, mingled with skeletal elements of other individuals. The nearly complete skeleton is that of a male aged 35-45, with

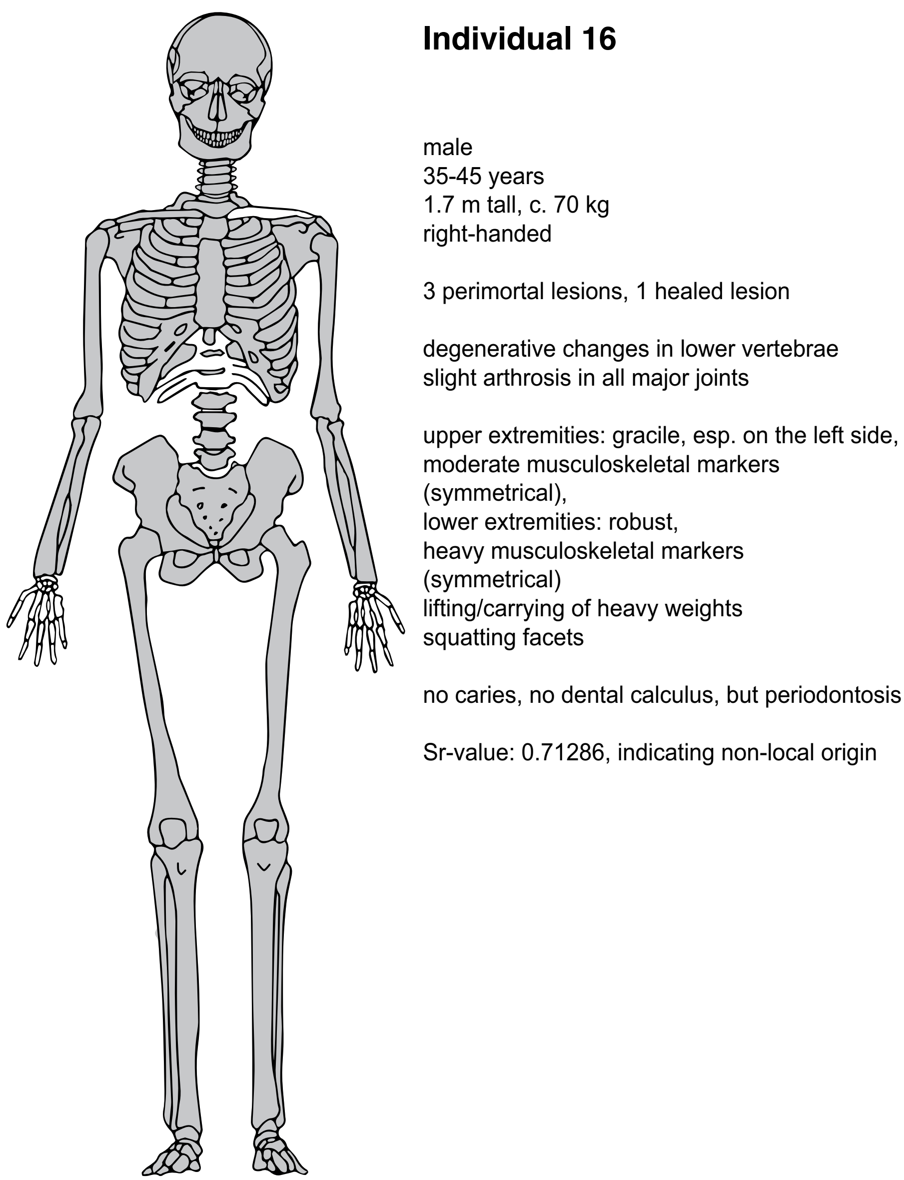

Figure 9. Skeletal representation of individual 16, together with biographical information (graphic: U. Brinker).

three perimortem lesions (in the left scapula, right humerus, and right tibia), likely caused by arrowheads, and an unspecific healed rib lesion. Furthermore, during excavation, a flint arrowhead was discovered in the sediment found close to the left radius (see Lidke 2014, 97, Fig. 14). It may once have stuck in the individual's arm without damaging the bone. The three perimortem lesions mentioned above were likely also caused by flint arrowheads, as indicated by distinctive traces. Although none of these lesions was lethal in itself, the man may nonetheless have died in a volley of arrows, or by some other wound that did not leave traces on his bones. Metrical analyses yielded more individual information: the man was about 1.7 m tall and had a body weight of about 70 kg (weight estimation after Ruff *et al.* 2012). Measurement results of the upper extremities indicate right-handedness. All major joints show changes due to arthrosis; the ribs and vertebrae also display degenerative changes. The postcranial skeleton exhibits traits that go back to high physical strain in general, such as changes in muscle attachment spots, but a preference for one side of the body was not visible here. The symmetrically manifested attachment spots of the thigh adductors and of Musculus brachialis and Musculus pectoralis, as well as the degenerative changes in the vertebrae, may indicate the continued lifting and carrying of heavy weights. The man's teeth showed neither caries nor dental calculus, but a degenerative reduction of the peridontium was visible. The Sr values measured for this individual (0.71286; see Price *et al.* 2017) indicate a non-local origin. In summary, this research shows that an individual profile with relevant information can be compiled (Fig. 9), and that an individual can thus be re-assessed.

Specialised fighters or even professional warriors in 13th century BCE societies in northern and central Europe?

Apart from contributing to the discussion on the differences in social dimensions and societal organisation between 'tribes' and 'chiefdoms' and the existence of retinues and *Männerbündnisse* in the Bronze Age (Knöpke 2009, 203-254; Kristiansen and Larsson 2005), the finds from the Tollense Valley offer hints of at least a part-time specialisation in the use of weapons, in general, by part of the male population. These hints are, on the one hand, the unusual composition of the individuals discovered there, mainly young adult males, and, on the other, the demographic dimension of the conflict, with at least hundreds of participants and possibly up to or even exceeding 2000 participants, with a high number of perimortem injuries in the skeletal material, but also a remarkable number of healed lesions that relate to weapon use as well. All this makes the alternate explanation, that this was a small and purely local conflict involving just farmers who had never before taken part in violent activities, quite unlikely (see also Terberger *et al.* 2014).

The differentiated spectrum of lesions indicates the use of long-distance (bow and arrow) and various close-combat weapons, thus possibly hinting at a tactical use of certain weapon groups related to a strategic deployment of fighters. The use of swords, spears, clubs, and bow and arrow may also indicate a social differentiation within the group(s) of warriors, perhaps at an early stage of a development that would eventually result in more clearly discernible structures, with 'soldiers' and 'commanders', in the north European Iron Age (*e.g.* Randsborg 1995).

Furthermore, during the Bronze Age the wider area surrounding the Tollense Valley was integrated into a network of contact and long-distance exchange reaching as far as regions with historically documented conflicts. Weapon furnishings in male burials enhanced the martial image of Bronze Age men, and gold and other precious objects in male and female burials attest to the presence of an elite.

The sheer dimension of the conflict would have to have had its basis in a differentiated social order, with its respective power structures. Early Bronze Age burials in Mecklenburg-Western Pomerania often show rich furnishings in comparison with those from other regions (Endrigkeit 2014), and the number of sword graves here is surprisingly high (Schmidt 2004). Long-distance contacts are testified to by finds of glass beads from the Mediterranean, possibly even Egypt (Varberg *et al.* 2015), and wild silk from the Mediterranean (Scherping and Schmidt 2007). The importance of trade routes and contact networks (see Kristiansen and Suchowska-Ducke 2015) is also made clear by constructions such as the Tollense Valley causeway, which was built with considerable effort and enabled a reliable east-west crossing of the Tollense Valley during all seasons from the 19th century BCE onwards, at least up to the 13th century BCE.

How power and decision making were organised, whether there were central powers capable of organising and supporting large fighting units or even armies, whether sword bearers came together for such events, how 'retinues' were organised and logistically maintained, who took command in the case of conflict – none of these questions can be addressed through archaeological research at the moment. Members of the upper echelons of society will have been present in the Tollense Valley, as attested by prestigious finds, *e.g.* four gold spiral rings (John and Schirren 2014). Such gold rings are typical objects in especially well-furnished graves of men and women of Period III in the region (Schmidt 1997). It is not likely that elites with their retinues met in the Tollense Valley to engage in a mainly symbolic, non-lethal contest. The conflict that took place here is rather comparable with battles documented and described historically for the Mediterranean at that time, *e.g.* the battle of Kadesh, 1274 BCE (Köpp-Jung 2015).

Because there was cultural contact between the Mediterranean and north-eastern Europe (see above), it is possible that not only glass beads, silk, and other commodities were exchanged, but also knowledge about specialisations, fighting techniques, or even military innovations in strategy (Hansen 2015; Schrakamp 2015). Egyptian and Hittite armies were elaborate fighting tools, professional standing armies kept by the state; numbers of tens of thousands of soldiers are given by the sources, and these are not always thought to be exaggerated (Bryce 2007, 10-11). No direct parallels should be expected for northern or central Europe at that time, but hoard finds and special house structures ('men's houses') of the Early Bronze Age Unětiće Culture may indicate military structures on a certain level, with commanders and soldiers (Meller 2015; 2017). At the beginning of the Urnfield Culture, warrior communities, perhaps in the form of chiefly retinues, appear to be documented in burial structures (Knöpke 2015).

To be efficient, the handling and use of weapons has to be taught and trained, for individual use and, even more so, for use in groups or tactical units (Molloy 2007a, 13; 2007b). The number of men obviously present in the valley indicates an organised commitment. If the scenario of the battle in the Tollense Valley described above is accepted as a working hypothesis, then disciplined units of warriors (*e.g.* archers waiting on the slopes who entered the fighting at the appropriate moment) could be expected as at least part of the force. The differentiation of the weapons spectrum – from long-distance to close-range – could hint at different units with differing weapons and tactical functions. Within each unit, of course, weapons would have to have been rather uniform and actions coordinated. These forces were perhaps supplemented by a body of inexperienced or less-experienced men, whose primary, everyday occupation did not lie in the military realm at all.

Mycenaean infantry troops are thought to have displayed uniform equipment, with shields and spears, issued to the warriors by palace officials, and perhaps even special, uniform-like textiles. This will have gone hand-in-hand with a well-established system of command and logistics (Grguric 2005). Iberian warrior stelae show standardised-looking weapons (Harrison 2004, 5, 69), and 'chiefly war leaders with a retinue of lance warriors' (Kristiansen and Larsson 2005, 224) are thought to be visible in the European Bronze Age since the 16th century BCE, and 'armies numbering in the hundreds' (*ibid.*) were thought likely even before the Tollense Valley evidence had come to light.

The mobilisation of hundreds of people for a special purpose is attested to in other large-scale activities of the north European Bronze Age – the building of large burial mounds (Holst *et al.* 2013). Logistically, the organisation of a group of warriors could have followed similar principles.

In general, a profound potential for conflict is often proposed for the second half of the 2nd millennium BCE in northern and central Europe, connected to changes in weapon techniques and social organisation and the occurrence of fortified settlements (see Falkenstein 2006/2007; Jockenhövel 2004/2005; Schmidt 2004). These times of upheaval will not have passed the Tollense Valley by; the development of the finds layer present there reflects these changes. At the same time, the finds present the rare possibility to describe and characterise not only the dramatic scene of large-scale group violence, but also the individuals, the men at arms, acting in it.

Conclusion

Sometime after 1300 BCE, the Tollense Valley saw an armed conflict of a scale hitherto unimagined for the European Bronze Age. Likely more than 1000, perhaps even more, combatants fought each other in the river valley, with the battle likely starting at a causeway that marked a long-established east-west crossing of the valley, and then developing into a running battle moving downstream. Long-distance as well as close-range weapons were used, and the number of casualties, attested to by a large number of perimortem lesions, was high.

The skeletal material indicates an unusual, heterogeneous population, consisting mainly of young adult males, who – as attested by the sheer number of them, but also by Sr-isotope analyses – cannot all have been local. The combatants may at least partly represent professional or part-time specialised warriors, trained in weapon use and strategy, for whom the battle in the Tollense Valley will not have been the first incident of its kind in their lives, as is indicated by a number of healed lesions in the skeletal record that relate to weapon use. The differentiated spectrum of perimortem lesions described above may, at the same time, indicate a differentiated – and perhaps specialised – use of weapons. Such a use of swords, spears/lances, and bow and arrow by different groups of fighters could also imply a social differentiation of the combatants. This question is connected to the interpretation of the more prestigious metal objects, and also the horse remains found in connection to the find layer. Are these connected to an elite or command level participating in the battle?

The situation in the Tollense Valley is unique for Bronze Age Europe, not only in terms of the distribution of finds, but also in terms of the social implications arising from the hypothesised scenario. Future research into the participants of the battle will have to concentrate on their lives before their arrival in the Tollense Valley, their region(s) of origin, and their living conditions there. The characterisation of the (warrior?) population will have to include research into their general level of activity, health status, nutrition, and physical stress markers. The material from the sites in the Tollense Valley offers excellent preconditions for further research into these topics, which, in their turn, will perhaps also give insights into the larger processes connected to changes in the European Bronze Age linked with the rise of the Urnfield Culture.

References

Abels, B.-U. and Haberstroh, J. 2001/2002. Fundchronik Urnenfelderzeit/Burgellern. Ausgrabungen und Funde Oberfranken 12. Sonderdruck aus Geschichte am Obermain. *Jahrbuch Colloquium Historicum Wirsbergense* 23, 18.

Adams, B.J. and Byrd, J.E. 2006. Resolution of small-scale commingling: a case report from the Vietnam War. *Forensic Science International* 156, 63-69.

Benecke, N. and Dräger, J. 2014. Ergebnisse der archäozoologischen Untersuchungen, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 233-238.

Brinker, U., Flohr, S., Piek, J., Mittlmeier, T. and Orschiedt, J. 2014. Die menschlichen Skelettreste aus dem Tollensetal – Ein Vorbericht, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 191-208.

Brinker, U., Flohr, S., Piek, J. and Orschiedt, J. 2015. Human remains from a Bronze Age site in the Tollense Valley: victims of a battle?, in: Knüsel, C. and Smith, M.J. (eds.), *The Routledge Handbook of the Bioarchaeology of Human Conflict*. London: Routledge, 146-160.

Brinker, U., Schramm, A., Flohr, S. and Orschiedt, J. 2015. Die menschlichen Skelettreste aus dem Tollensetal, in: Meller, H. and Schefzik, M. (eds.), *Krieg. Eine archäologische Spurensuche*. Begleitband zur Sonderausstellung im Landesmuseum für Vorgeschichte Halle/S. Stuttgart: Theiss, 347-350.

Brinker, U., Schramm, A., Flohr, S., Jantzen, D., Piek, J., Hauenstein, K. and Orschiedt, J. 2016. The Bronze Age battlefield in the Tollense Valley, Mecklenburg-Western Pomerania, northeast Germany – Combat marks on human bones as evidence of early warrior societies in northern Middle Europe?, in: Coimbra, F., Delfino, D., Sirbu, V. and Schuster, C. (eds.), *Later Prehistory to the Bronze Age. 1. The emergence of warrior societies and its economic, social and environmental consequences. 2. Imports and Aegeo-Mediterranean influences on the continental European tombs in the Bronze and Iron Ages.* Proceedings of the XVII UISPP World Congress (1-7 September 2014, Burgos, Spain) 9. Oxford: Archaeopress, 39-56.

Brinker, U., Harten-Buga, H., Staude, A., Jantzen, D. and Orschiedt, J. 2018. Perimortem lesions on human bones from the Bronze Age battlefield in the Tollense Valley: An interdisciplinary approach, in: Dolfini, A., Crellin, R., Horn, C., and Uckelmann, M. (eds.), *Prehistoric Warfare and Violence. Quantitative and Qualitative Approaches.* Cham: Springer, 39-60.

Bryce, T. 2007. *Hittite Warrior*. Oxford: Osprey.

Dombrowsky, A. 2014. Bronzezeitliche Metallfunde aus dem Gebiet der mittleren Tollense unter besonderer Berücksichtigung der Flussfunde, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 131-180.

Endrigkeit, A. 2014. *Älter- und mittelbronzezeitliche Bestattungen zwischen Nordischem Kreis und süddeutscher Hügelgräberkultur. Gesellschaftsstrukturen und kulturelle Beziehungen.* Frühe Monumentalität und soziale Differenzierung 6. Bonn: Habelt.

Falkenstein, F. 2006/2007. Gewalt und Krieg in der Bronzezeit Mitteleuropas. *Bericht der Bayrischen Bodendenkmalpflege* 47, 33-52.

Filipovic, D., Meadows, J., Wiethold, J., Jahns, S., Bittmann, F. and Kirleis, W. 2018. Before and after: millet cultivation and the transformation of prehistoric crop production in northern Germany. *Antiquity* 92, 1–6.

Flohr, S., Brinker, U., Schramm, A., Kierdorf, U., Staude, A., Piek, J., Jantzen, D., Hauenstein, K. and Orschiedt, J. 2015. Flint arrowhead embedded in a human humerus from the Bronze Age site in the Tollense valley, Germany – A high-resolution micro-CT study to distinguish antemortem from perimortem projectile trauma to bone. *International Journal of Palaeopathology* 9, 76-81.

Grguric, N. 2005. *The Mycenaeans c. 1650-1100 BC*. Oxford: Osprey.

Haidn, O., Weineck, J. and Haidn-Tschalova, V. 2010. *Bogenschießen: trainings- und bewegungswissenschaftliche Grundlagen*. Balingen: Spitta.

Hansen, S. 2015. Krieg in der Bronzezeit, in: Meller, H. and Schefzik, M. (eds.), *Krieg. Eine archäologische Spurensuche*. Begleitband zur Sonderausstellung im Landesmuseum für Vorgeschichte Halle/S. Stuttgart: Theiss, 205-212.

Harrison, R.J. 2004. *Symbols and Warriors: Images of the European Bronze Age*. Bristol: Western Academic & Specialist.

Holst, M.K., Rasmussen, M., Kristiansen, K. and Bech, J.-H. 2013. Bronze Age 'Herostrats': ritual, political and domestic economies in Early Bronze Age Denmark. *Proceedings of the Prehistoric Society* 79, 265-296.

Hrala, J. 2000. Metal artefacts and artefacts of other materials, in: Hrala, J., Šumberová, R. and Vávra, M. *Velim. A Bronze Age fortified site in Bohemia*. Prague: Institute of Archaeology, Academy of Sciences of the Czech Republic, 219-256.

Jantzen, D., Brinker, U., Orschiedt, J., Heinemeier, J., Piek, J., Hauenstein, K., Krüger, J., Lidke, G., Lübke, H., Lampe, R., Lorenz, S., Schult, M. and Terberger, T. 2011. A Bronze Age battlefield? Weapons and trauma in the Tollense Valley, north-eastern Germany. *Antiquity* 85, 417-433.

Jantzen, D., Lidke, G., Brinker, U., Dombrowsky, A., Dräger, J., Krüger, J., Lorenz. S., Schramm, A. and Terberger, T. 2014. Das bronzezeitliche Fundareal im Tollensetal – Entstehung, Interpretation und Hypothesen, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 239-252.

Jantzen, D., Lidke, G., Dräger, J., Krüger, J., Rassmann, K., Lorenz, S. and Terberger, T. 2014. An early Bronze Age causeway in the Tollense Valley, Mecklenburg-Western Pomerania – The starting point of a violent conflict 3300 years ago? *Berichte der RGK* 95, 2014 (2017), 13-49.

Jockenhövel, A. 2004/2005. Zur Archäologie der Gewalt: Bemerkungen zu Aggression und Krieg in der Bronzezeit Alteuropas. *Anodos: Studies of the Ancient World* 4/5, 101-132.

John, S. and Schirren, M. 2014. Zum Einsatz von Metalldetektoren im Tollensetal, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal: Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 73-78.

Kneubuehl, B.P., Coupland, R.M., Rothschild, M.A. and Thali, M.J. 2008. *Wundballistik – Grundlagen und Anwendungen*. Heidelberg: Springer.

Knöpke, S. 2009. *Der urnenfelderzeitliche Männerfriedhof von Neckarsulm. Mit einem Beitrag von Joachim Wahl.* Forschungen und Berichte zur Vor- und Frühgeschichte Baden-Württembergs 116. Stuttgart: Theiss.

Knöpke, S. 2015. Der urnenfelderzeitliche Männerfriedhof von Neckarsulm, in: Meller, H. and Schefzik, M. (eds.), *Krieg. Eine archäologische Spurensuche*. Begleitband zur Sonderausstellung im Landesmuseum für Vorgeschichte Halle/S. Stuttgart: Theiss, 257-258.

Konigsberg, L.W. and Adams, B.J. 2014. Estimating the number of individuals represented by commingled human remains: a critical evaluation of methods, in: Adams, B.J. and Byrd, J.E. (eds.). *Commingled Human Remains: methods in recovery, analysis, and identification*. Amsterdam and Boston: Academic Press, 193-220.

Köpp-Jung, H. 2015. Der Pharao siegt (fast) immer – Die Schilderungen der Schlachten bei Megiddo und Kadesch im Spiegel altägyptischer Quellen, in: Meller, H. and Schefzik, M. (eds.), *Krieg. Eine archäologische Spurensuche*. Begleitband zur Sonderausstellung im Landesmuseum für Vorgeschichte Halle/S. Stuttgart: Theiss, 235-238.

Kristiansen, K. and Larsson, T.B. 2005. *The Rise of Bronze Age Society. Travels, Transmissions and Transformations*. Cambridge: Cambridge University Press.

Kristiansen, K. and Suchowska-Ducke, P. 2015. Connected histories: the dynamics of Bronze Age interaction and trade 1500-1100 BC. *Proceedings of the Prehistoric Society* 81, 361-392.

Krüger, J., Nagel, F., Nagel, S., Jantzen, D., Lampe, R., Dräger, J., Lidke, G., Mecking, O., Schüler, T. and Terberger, T. 2012. Bronze Age tin rings from the Tollense Valley in northeastern Germany. *Praehistorische Zeitschrift* 87, 29-43.

Lorenz, S. 2014. Das Tollensetal – Naturraum und Landschaftsgeschichte, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 15-20.

Lidke, G. 2014. Der bronzezeitliche Fundplatz im Tollensetal – Die Geländearbeiten 2010 und 2011, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 89-100.

Lidke, G., Terberger, T. and Jantzen, D. 2014. Tatort Tollensetal: Schussexperimente mit Pfeil und Bogen. *Archäologie in Deutschland* 2/2014, 62-63.

Lidke, G., Jantzen, D., Lorenz, S. and Terberger, T. 2018. The Bronze Age battlefield in the Tollense Valley, Mecklenburg-Western Pomerania, northeast Germany: conflict scenario research, in: Fernández-Götz, M. and Roymans, N. (eds.), *Conflict Archaeology. Materialities of Collective Violence in Late Prehistoric and Early Historic Europe.* EAA Themes in Contemporary Archaeology 5. Abingdon and New York: Routledge, 61-68.

Lübke, H. 2011. Eine urgeschichtliche Hockerbestattung in Friedland, Lkr. Mecklenburgische Seenplatte, Mecklenburg-Vorpommern. *Zentrum für Baltische und Skandinavische Archäologie, Jahresbericht*, 55.

Meller, H. 2015. Armeen in der Frühbronzezeit? In: Meller, H. and Schefzik, M. (eds.). *Krieg. Eine archäologische Spurensuche*. Begleitband zur Sonderausstellung im Landesmuseum für Vorgeschichte Halle/S. Stuttgart: Theiss, 243-252.

Meller, H. 2017. Armies in the Early Bronze Age? An alternative interpretation of Únětice Culture axe hoards. *Antiquity* 91, 1529-1545.

Milner, G.R. 2005. Nineteenth-century arrow wounds and perceptions of prehistoric warfare. *American Antiquity* 70, 144-156.

Molloy, B.P.C. 2007a. Introduction: the evil that men do … , in: Molloy, B.P.C. (ed.). *The Cutting Edge. Studies in Ancient and Medieval Combat*. Stroud: Tempus, 9-16.

Molloy, B.P.C. 2007b. What's the bloody point? Bronze Age swordsmanship in Ireland and Britain, in: Molloy, B.P.C. (ed.), *The Cutting Edge. Studies in Ancient and Medieval Combat*. Stroud: Tempus, 90-111.

Möslein, S. 2001. Die bronze- und urnenfelderzeitlichen Lesefunde von der Rachelburg bei Flintsbach am Inn, Lkr. Rosenheim. *Bericht der Bayrischen Bodendenkmalpflege* 39/40, 205-238.

Möslein, S. and Winghart, S. 2001. Die Rachelburg (Alt-Falkenstein) bei Flintsbach am Inn, Lkr. Rosenheim: eine vor- und frühgeschichtliche Höhensiedlung und mittelalterliche Burg am Alpenrand. *Bericht der Bayrischen Bodendenkmalpflege* 39/40, 145-154.

Pearson, K. 1899. On the reconstruction of the stature of prehistoric races. Mathematical contributions to the theory of evolution 5. *Philosophical Transactions of the Royal Society of London A* 192, 169-244.

Price, T.D., Frei, R., Brinker, U., Lidke, G., Terberger, T., Frei, K.M. and Jantzen, D. 2017. Multi-isotope proveniencing of human remains from a Bronze Age battlefield in the Tollense Valley in northeast Germany. *Archaeological and Anthropological Sciences*. DOI 10.1007/s12520-017-0529-y.

Puerto, M.S., Egaña, S., Doretti, M. and Vullo, C.M. 2014. A multidisciplinary approach to commingled remains analysis: anthropology, genetics, and background information, in: Adams, B.J. and Byrd, J.E. (eds.), *Commingled Human Remains: methods in recovery, analysis, and identification*. Amsterdam and Boston: Academic Press, 307-336.

Randsborg, K. 1995. *Hjortspring. Warfare and Sacrifice in early Europe*. Aarhus: Aarhus University Press.

Ruff, C.B., Holt, B.M., Niskanen, M., Sladék, V., Berner, M., Garofalo, E., Garvin, H.M., Hora, M., Maijanen, H., Niinimäki, S., Salo, K., Schuplerová, E. and Tompkins, D. 2012. Stature and body mass estimation from skeletal remains in the European Holocene. *American Journal of Physical Anthropology* 148, 601-617.

Scherping, R. and Schmidt, J.-P. 2007. Seide im Norden – die Textilreste am älterbronzezeitlichen Halskragen von Thürkow, Lkr. Güstrow (Mecklenburg-Vorpommern). *Archäologisches Korrespondenzblatt* 37, 207-220.

Schmidt, J.-P. 1997. Ein bronzezeitliches Frauengrab der Periode III aus Ludwigsburg, Lkr. Ostvorpommern. *Jahrbuch Bodendenkmalpflege in Mecklenburg-Vorpommern* 45, 129-161.

Schmidt, J.-P. 2004. Die Bewaffnung während der Bronzezeit, in: Jöns, H. and Lüth, F. (eds.), *Mythos und Magie. Archäologische Schätze der Bronzezeit in Mecklenburg-Vorpommern.* Archäologie in Mecklenburg-Vorpommern 3. Schwerin: Landesamt für Kultur und Denkmalpflege, 56-63.

Schrakamp, I. 2015. Militär und Kriegführung in Vorderasien, in: Meller, H. and Schefzik, M. (eds.). *Krieg. Eine archäologische Spurensuche*. Begleitband zur Sonderausstellung im Landesmuseum für Vorgeschichte Halle/S. Stuttgart: Theiss, 213-223.

Schwinning, M., Harten-Buga, H., Brinker, U., Staude, A., Hesse, E., Orschiedt, J., Nikulka, F. and Jantzen, D. in preparation. *Pertrochanteric* femur fracture from the Bronze Age battlefield in the Tollense Valley, north-eastern Germany: a new paleomechanical approach to the differential diagnostic simulation of the injury mechanism using 3D-reconstruction and finite element analysis.

Siegmund, F. 2010. *Die Körpergröße der Menschen in der Ur- und Frühgeschichte Mitteleuropas und ein Vergleich ihrer anthropologischen Schätzmethoden. Beiträge zur Archäologie des Lebensstandards*. Norderstedt: BoD - Books on Demand.

Terberger, T. and Heinemeier, J. 2014a. Die Fundstellen im Tollensetal und ihre absolute Datierung, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.*

Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 101-116.

Terberger, T. and Heinemeier, J. 2014b. Die Ernährungsweise der bronzezeitlichen Menschen aus dem Tollensetal im Spiegel ihrer 13C- und 15N-Isotopie – Erste Ergebnisse, in: Jantzen, D., Orschiedt, J., Piek, J. and Terberger, T. (eds.), *Tod im Tollensetal. Forschungen zu den Hinterlassenschaften eines bronzezeitlichen Gewaltkonfliktes in Mecklenburg-Vorpommern. Teil 1: Die Forschungen bis 2011.* Beiträge zur Ur- und Frühgeschichte in Mecklenburg-Vorpommern 50. Schwerin: Landesamt für Kultur und Denkmalpflege, 209-214.

Terberger, T., Dombrowsky, A., Dräger, J., Jantzen, D., Krüger, J. and Lidke, G. 2014. Professionelle Krieger in der Bronzezeit vor 3300 Jahren? Zu den Überresten eines Gewaltkonflikts im Tollensetal, Mecklenburg-Vorpommern, in: Link, T. and Peter-Röcher, H. (eds.), *Gewalt und Gesellschaft. Dimensionen der Gewalt in ur- und frühgeschichtlicher Zeit.* Internationale Tagung vom 14.-16. März 2013 an der Julius-Maximilians-Universität Würzburg. Universitätsforschungen zur prähistorischen Archäologie 259. Bonn: Habelt, 93-109.

Terberger, T., Jantzen, D., Krüger, J. and Lidke, G. 2018. Das bronzezeitliche Kampfgeschehen im Tollensetal – ein Großereignis oder wiederholte Konflikte?, in: Hansen, S. and Krause, R. (eds), *Bronzezeitliche Burgen zwischen Taunus und Karpaten / Bronze Age Hillforts between Taunus and Carpathian Mountains*. Universitätsforschungen zur prähistorischen Archäologie 319 = Prähistorische Konfliktforschung 2. Bonn: Habelt, 103-124.

Thomas, A. 2014. Bioarchaeology of the Middle Neolithic: evidence for archery among early European farmers. *American Journal of Physical Anthropology* 154, 279-290.

Varberg, J., Gratuze, B. and Kaul, F. 2015. Between Egypt, Mesopotamia and Scandinavia: Late Bronze Age glass beads found in Denmark. *Journal of Archaeological Science* 54, 168-181.

Weber, M.-A. and Streich, N. (eds.) 2017. *Kompendium orthopädische Bildgebung*. Berlin: Springer.

Weigelt, L. 2013. *Osteochondrale Transplantation am Ellenbogen: Langzeitergebnisse bei osteochondralen Schäden*. PhD dissertation, Technische Universität München. https://mediatum.ub.tum.de/doc/1120680/1120680.pdf.

Environmental imposition or ancient farmers' choice? A study of the presence of "inferior" legumes in the Bronze Age Carpathian Basin (Hungary)

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Abstract

Plants of the legume family (Fabaceae) often contain anti-nutritional compounds that can be toxic to both humans and animals if they are not processed adequately. As a result, some species of legumes have been regarded as "inferior" to human consumption. Two known examples are bitter vetch (*Vicia ervilia*) and grass pea (*Lathyrus sativus*), which from historical and ethnographic sources are mostly known to be consumed as human food by poor segments of society or by the general population during times of famine. Despite the suggested relationship of the two species of "inferior" legumes with poor living conditions, there has been increasing evidence for their importance in prehistoric food economy in the Balkans, the Aegean and the Levant. Both bitter vetch and grass pea have been observed in a macrobotanical assemblage from the Bronze Age fortified settlement Kakucs-Turján mögött in central Hungary. The aim of this paper is to indicate whether the presence of these two "inferior" legumes is related to poor living conditions in the Hungarian Carpathian Basin during the Bronze Age, and to investigate the potential use of such legumes within prehistoric food economy.

Keywords: Living conditions, "inferior" legumes, bitter vetch, grass pea, Bronze Age, Hungarian Carpathian Basin

Introduction

The study of domesticated legumes has long been overshadowed by the study of cereal remains in European archaeobotany (Sarpaki 1992). The archaeological and archaeobotanical invisibility of legumes has been attributed to several factors, such as the smaller chance of carbonisation due to the fact that they can be consumed in a green (and unripe) state; the interpretation of tools and implements as solely used to harvest, process and prepare cereals; and the infrequent use of by-products of legumes as temper in bricks and ceramics, as opposed to cereal by-products (Sarpaki 1992, 71-72).

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Plants of the legume family often contain anti-nutritional compounds that help to protect their seeds from predation and pest infestation. They can therefore be toxic to both humans and animals (Sadeghi *et al.* 2009, 92). As a result, some species of legumes have been considered as "inferior" to human consumption, of which two known examples are bitter vetch (*Vicia ervilia*) and grass pea (*Lathyrus sativus*). This view is mainly based on historical and modern (ethnographic) sources, which report on the use of these two legumes as famine crops, fodder and food for the poor (Zohary *et al.* 2012, 92 and 95).

In the last decade, however, there has been increasing evidence for the importance of both species of "inferior" legumes in prehistoric food economy in the Balkans, the Aegean and the Levant (*e.g.* Medović *et al.* 2011; Slasky and Kislev 2010; Valamoti *et al.* 2011). The presence of both legumes has also been attested in Bronze Age archaeobotanical assemblages in the Hungarian Carpathian Basin, including the recently excavated Middle Bronze Age (MBA) settlement Kakucs-Turján mögött, in central Hungary. This paper seeks to, first, present an overview of the presence of bitter vetch and grass pea in the Hungarian Carpathian Basin during the Bronze Age, and second, indicate whether their presence is related to specific living conditions that prevailed in the area during the period.

General charcateristics of bitter vetch and grass pea

Legumes have been important companions to cereals since the dawn of agriculture in many regions worldwide. They are especially high in protein, nearly two to three times compared to most species of cereals with the exception of einkorn and emmer (Körber-Grohne 1987, 27 and 101 Tables 1 and 2; Salunkhe and Deshpande 1991, 139). Legumes have therefore functioned as the main source of plant protein, often substituting meat, in agricultural communities world-wide (Zohary *et al.* 2012, 75). Proteins of legumes are rich in the essential amino acid lysine but low in sulphur essential amino acids, while those of cereals are rich in sulphur amino-acids but low in lysine. Due to these differences in protein quality legumes are supplementary to cereal-based diets. A mixed diet of legumes and cereals thus enhances the quality of the plant-protein that is consumed (Bahl 1999, 144-145; Salunkhe and Deshpande 1991, 139).

Another valued characteristic of legumes is their ability to contribute to soil fertility by fixating atmospheric nitrogen through symbiosis with species of *Rhizobium* bacteria. Nitrogen is an essential compound for the development of plant protein and most plants derive their nitrogen from decomposed organic matter in the soil. In the case of legumes, however, *Rhizobium* bacteria are able to invade the roots of the legumes and fix atmospheric nitrogen in so-called root nodules (Salunkhe and Deshpande 1991, 147-149). Legumes are therefore known to be cultivated in mix or in rotation with cereals in order to boost the fertility of the soil (Palmer 1997, 36; Salunkhe and Deshpande 1991, 155). A successful nitrogen fixation, however, depends on several factors. For one, the environmental conditions have to be met not only for the legumes, but also for the *Rhizobium* bacteria. Factors such as acidity, salinity and water stress might obstruct the development of root-nodules and consequently that of nitrogen fixation (Robson 1999, 220, Smartt 1990, 10-13). Moreover, not all legumes are equally suitable for nitrogen fixation. It is in particular forage legumes (*e.g.* species of *Medicago* and *Vicia*) that are suitable for restoration of soil fertility, as grain legumes are generally more demanding in nitrogen uptake. Especially when the hay is not removed during harvesting, nitrogen fixation in the soil is the most successful. When uprooting is practiced, however, fixation does not take place (Palmer 1997, 36-37; Robson 1999, 221; Salunkhe and Deshpande 1991, 155). Besides mixed cultivation for soil fertility, legumes are known to be cultivated in mix with some species of cereals (*e.g.* barley) in order to support their long, unstable culms (Fig. 1).

Figure 1. Mixed barley-pea cultivation for animal fodder at the organic farm of Schoolbek, Kosel in Northern Germany (photo: June/July 2015, W. Kirleis).

The earliest archaeological evidence for the presence of bitter vetch (Fig. 2) originates from Israel (Middle and Upper Paleolithic) and Syria (Epipaleolithic and Pre-Pottery Neolithic A). These finds consists of small concentrations of seeds that are problematic to distinguish from the wild progenitors due to the low numbers in which they occur. Larger deposits of cultivated bitter vetch first appear in agricultural settlements in Anatolia dating to the ninth millennium BC. Most prehistoric finds of bitter vetch originate from Neolithic and Bronze Age sites in Anatolia and the Balkans, which are the proposed areas of domestication of bitter vetch (Zohary *et al.* 2012, 93-95; Miller and Ennerking 2014, 259).

Bitter vetch grows on a wide range of low to medium fertile soils, providing that they are not too clayey or damp. During the vegetative stage it can be resistant to low temperatures, and it is known to tolerate arid conditions (El Fatehi *et al.* 2016, 717; Ennerking *et al.* 1995,143-144; Hernández Bermejo and León 1994, 281, Table 10). Like most plants of the legumes family, bitter vetch contains toxic compounds that help to protect the seeds from predation and pest infestation. Seeds of bitter vetch

Figure 2. Seeds of bitter vetch (Vicia ervilia) from the Middle Bronze Age settlement Kakucs-Turján mögött (photo: S. Filatova).

contain canavanine and tannin, two anti-nutrients that are known to have a negative influence on the digestive system and cause for a bitter taste of the seeds (Sadeghi *et al.* 2009, 92; Miller and Ennerking 2014, 256). These toxins are water-soluble and can be removed completely through a combination of removing the seed testa and subsequent soaking and boiling of the seeds (Ennerking 1994, 10; Valamoti 2009, 30; Valamoti 2011, 390).

Bitter vetch is presently cultivated as a minor crop in the Mediterranean and the Near East. The largest production area is Turkey, where it is produced as fodder (Zohary *et al.* 2012, 92). At least from the historical period onwards, bitter vetch has generally been viewed as an inferior crop for human diet, consumed only by the poor and by animals, or by the general population in times of famine. Several authors of the Greek and Roman eras warn of the toxic effects of bitter vetch, which can cause several ailments, such as headaches, vomiting and digestive problems (Flint-Hamilton 1999, 378; Miller and Ennerking 2014, 262; Zohary, *et al.* 2012, 92). Few ethnographic and historical records point towards the consumption of bitter vetch in traditional food culture in ancient Rome and modern Greece (Valamoti 2009, 30). Still today, bitter vetch is not consumed by humans and is considered a last resort in times of food shortage (Ennerking 1995, 144-145; Halstead 1990, 152).

Like bitter vetch, the earliest archaeological indications for the presence of grass pea (Fig. 3) consist of deposits of a few seeds, making it difficult to distinguish them from wild *Lathyrus* species. Large deposits of grass pea seeds occur from the seventh century BC onwards in Anatolia and the Balkans, the majority of early finds originating from Greece and Bulgaria. Grass pea seems to have been part of the

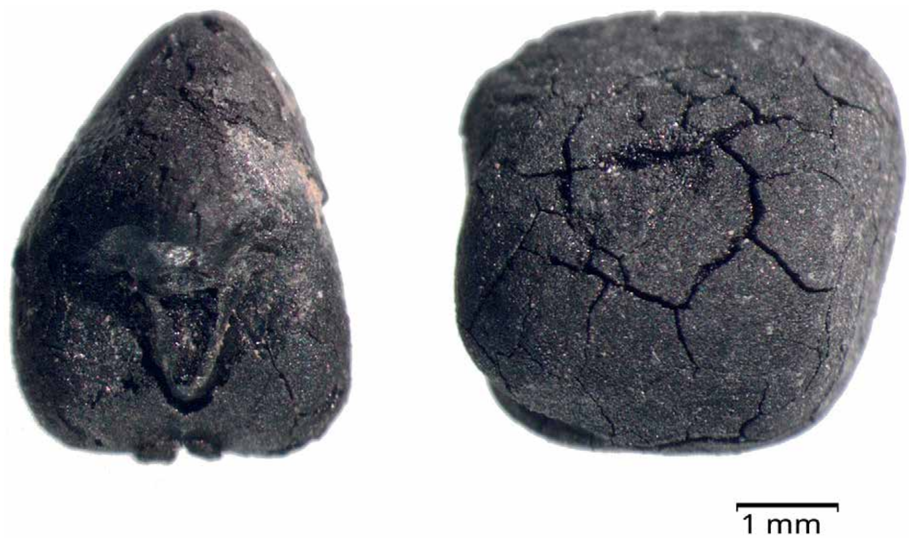

Figure 3. Seeds of grass pea (Lathyrus sativus) from the Middle Bronze Age settlement Kakucs-Turján mögött (photo: S. Filatova).

Neolithic founder crops assemblage, but it is also possible that it was added to the crop spectrum slightly later. Wild *Lathyrus* species are distributed over the entire Mediterranean basin, and the centre of domestication of grass pea has therefore not yet been identified. Based on the current evidence, grass pea was either domesticated in Anatolia or on the Balkan Peninsula (Kislev 1989; Zohary *et al.* 2012, 95-96).

Grass pea is able to grow in a variety of environments, resisting both drought and flooding, and in a wide range of soils, including poor as well as heavy, clayey soils (Butler *et al.* 1999, 124; Hernández Bermejo and León 1994, 281, Table 10; Kumar *et al.* 2013, 269; Slasky and Kislev 2010, 2479). The seeds of grass pea contain b-N-oxalyl-a,b-diaminopropionic acid (B-ODAP), a neurotoxin that, in case of excessive consumption, can cause a crippling disorder known as neurolathyrism and in some cases, even lead to death (Butler *et al* 1999, 123-124 ; Getahun *et al.* 2005, 169; Hansen 2000, 22; Peña-Chocarro and Peña1999, 51; Valamoti 2009, 29). Up to 80% of the toxin can be removed by ridding the seeds of their testa, leaching the seeds for at least 12 hours and subsequently boiling them and discarding the water prior to food preparation (Butler *et al.* 1999, p. 131; Peña-Chocarro and Peña1999, 51; Valamoti 2009, 29).

Today, grass pea is grown as a minor crop in the Mediterranean basin, south-west Asia, Ethiopia and India. While the main purpose of its production is for fodder, it is also cultivated for human consumption by poor segments of society in Ethiopia and India (Butler *et al.* 1999, 23-24; Zohary, *et al.* 2012, 95). The ability of grass pea to produce high yields despite poor growing conditions has made it an attractive crop during times of famine, causing for various neurolathyrism epidemics throughout history (Butler *et al.* 1999, 123-124; Getahun *et al.* 2005, 169; Halstead 1990, 152). Historic and ethnographic sources report on the use of grass pea as fodder as well as food for human consumption. The seeds are known to be particularly palatable and nutritious and are still part of traditional food culture on the Iberian Peninsula and in Greece (Hernández Bermejo and León 1994, 273; Peña-Chocarro and Peña 1999; Slasky and Kislev 2010, 2479; Valamoti 2009, 29).

Drivers for crop choice?

The choice to cultivate specific types of crops in agricultural societies is based upon a complex web of interrelated factors, which includes (changing) environmental, economic, political and social conditions. The environment is often viewed as the predominant factor, whereby periods of environmental stress (*e.g.* drought, flood

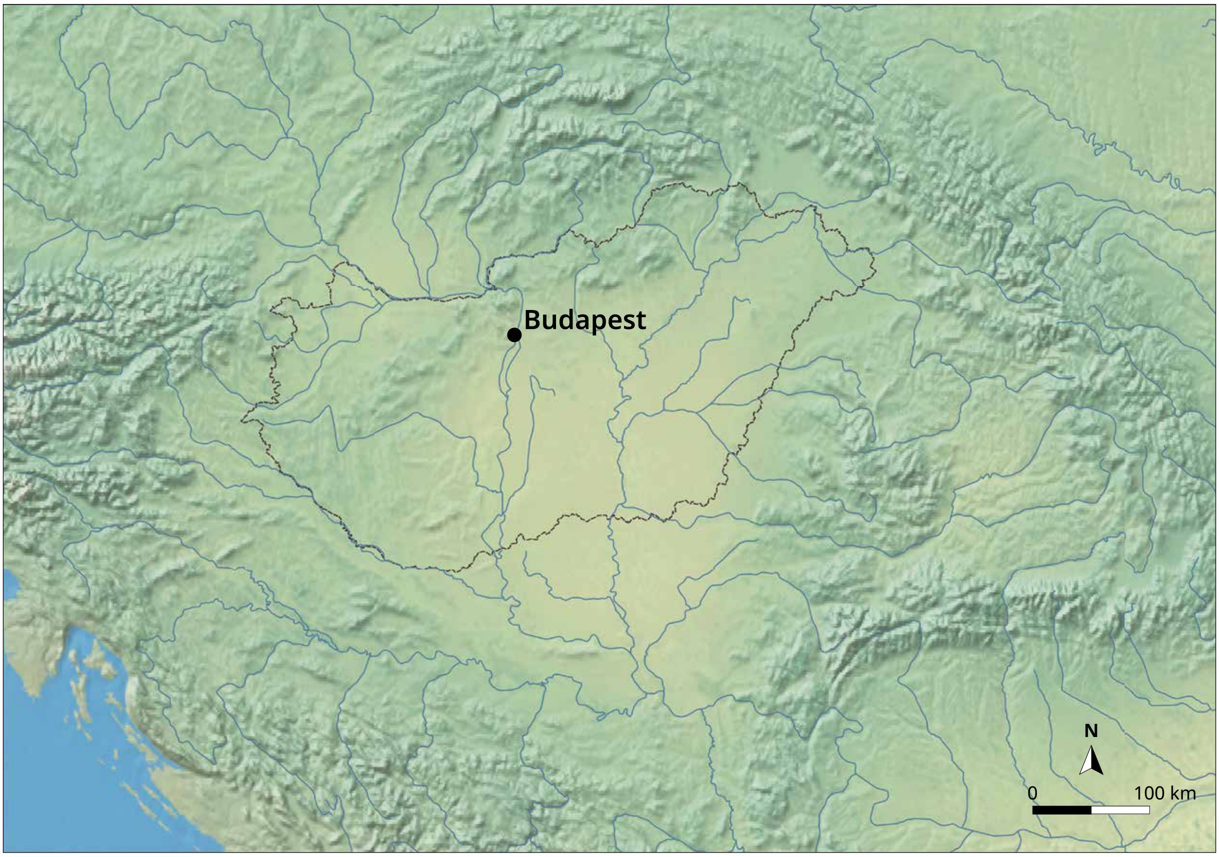

Figure 4. The area covered by present-day Hungary within the Carpathian Basin (Map: A. Kittler & S. Filatova; Basemap: Stamen Design; Map data: Open Street Map 2018; waterways: Geofabriek and Natural Earth data).

and soil depletion) influence economic, political and social choices, while periods of environmental stability leave room for choices governed by economic, political and social considerations (Riehl 2009, 96). According to Van der Veen (2010, 3), the choices of farmers in subsistence economies are mostly based on what is thought to contribute to security and stability. Cultivating specific crops is thereby not only related to the environment or the economy, but also to the prevailing ideology, which includes "*a society's willingness to challenge nature, the degree of openness to otherness and the existence of taboos and rules*" (Van der Veen 2010, 4).

A large body of historic and ethnographic data points towards the important role of bitter vetch and grass pea in the human diet in times of famine and their frequent consumption especially by poor segments of society. Consequently, the presence of the legumes is (indirectly) related to poor living conditions. The aim of this paper is to explore whether the presence of "inferior" legumes can be used to indicate such living conditions in the Hungarian Carpathian Basin during the Bronze Age. Living conditions are defined as those components that determine the quality of the livelihood of a community, household or individual. This not only includes the conditions posed by the environment (*e.g.* famine due to crop failure), but also those that are governed by political, economic and social considerations (*e.g.* social differentiation in diet or cultivation of specific crops for food security).

The archaeological and environmental setting of Hungarian Carpathian Basin in the Bronze Age

Present-day Hungary covers the vast majority of what is known as the Carpathian Basin (Fig. 4). The cultural transformations that define the Bronze Age (Tab. 1) in the

Chronology of the Hungarian prehistory			
Date: cal BC	**Archaeological period**	**Subperiod**	**Biozone**
450 – Late first century BC	Iron Age	Late Iron Age	Subatlantic
900/800 – 450 BC		Early and Middle Iron Age	
1500/1400 – 900/800 BC	Bronze Age	Late Bronze Age	Subboreal
2000/1900 – 1500/1450 cal BC		Middle Bronze Age	
2500/2400 – 2000/1900 cal BC		Early Bronze Age	
3600/3500 – 800/2700 BC	Copper Age	Late Copper Age	
4000 – 3600/3500 BC		Middle Copper Age	Atlantic
4500/4400 – 4000 BC		Early Copper Age	
5000/4900 – 4500/4400 BC	Neolithic	Late Neolithic	
5500/5400 – 5000/4900 BC		Middle Neolithic	
6000/5500 – 5400 BC		Early Neolithic	

Table 1. The chronology of prehistory in the Hungarian Carpathian Basin with a reference to the related biozones (after: Fischl et al., 504, Tab. 1b; Somogyi 1987, 30; Visy 2003).

Hungarian Carpathian Basin partially developed during the preceding Late Copper Age, but are most evident from the second part of the Early Bronze Age. This period gave rise to the formation of various cultural groups that are archaeologically distinguished on the basis of specific ceramic styles, creating a mosaic-like cultural landscape in the Carpathian Basin (for a recent overview, see Fischl *et al.* 2015, 504, Table 1b). A general characteristic of the period is the nucleation of settlements throughout the landscape, but with a variation in the settlement structures. The most significant type of settlement is the (fortified) tell, which reappeared during this period after being abandoned in the Late Neolithic (Fischl *et al.* 2015, 513; Gogâltan 2008, 59). These dwelling-mounds developed in the vicinity of rivers, the largest concentrations lying in central Hungary in the Danube and the Middle Tisza River regions. The settlements seem to concentrate in areas of the Basin with a prevailing sub-Mediterranean climate (Fischl *et al.* 2013, 356). Open and flat settlements were inhabited alongside tells, and a hierarchical arrangement of the settlements is assumed for the tell regions in central Hungary. In the western part of the Carpathian Basin, in Transdanubia, tells never formed and people inhabited (fortified) nucleated, flat settlements (Fischl *et al.* 2015, 514).

The habitation of the tell settlements continued and flourished during the Middle Bronze Age. The Early Bronze Age cultural groups were thereby replaced by several successive groups, keeping the mosaic-like arrangement of the landscape intact (Fischl *et al.* 2015, 504, Table 1b). The locations of the tells along the rivers enabled the development of extensive communication and exchange networks, stretching within as well as outside the Carpathian Basin (Fischl *et al.* 2013, 364). During the last phase of the Middle Bronze Age (1600/1500-1450 BC), referred as the Koszider period and known for the characteristic burials of bronze hoards, tell-settlements started to get abandoned and by the end of the period, the occupation of the tells had come to an end. A network of open settlements of the Tumulus culture developed in the Carpathian Basin, occurring in a lower density compared to those of the preceding period. It is assumed that these settlements do not reflect the same hierarchical structure that has been observed in tell-based settlements (Fischl *et al.* 2013, 360-361).

In 2013, the project 'Open Communities – Enclosed spaces' was initiated through a collaboration with Polish (UAM Poznań), Hungarian (Hungarian Academy of Sciences) and German (Kiel University) archaeologists. This research involved the excavation of a part of the settlement of Kakucs-Turján mögött in Central Hungary, lasting until the summer of 2016. The settlement is fortified by a ditch that divides it into three areas, resulting in a tripartite settlement structure (Fig. 5). The excavated area yielded evidence for occupation from the Early Bronze Age throughout the Middle Bronze Age, ending with the Koszider period. The Middle Bronze Age comprises the most intensive habitation phase, represented by the construction of two successive house structures and Vatya-style ceramics (Jaeger *et al.* 2018). During the excavations, a combination of systematic and judgemental sampling was employed to retrieve soil samples for macrobotanical analysis, which proved to contain carbonised macroremains. The first results seem to indicate a food economy that was based on the cultivation of a wide variety of crops, the most predominant crops being einkorn (*Triticum monococcum*) and lentil (*Lens culinaris*) (Tab. 2) (Filatova *et al.* 2018, 178). Both bitter vetch and grass pea are represented in the macrobotanical assemblage.

The cultivation of a wide variety of crops is characteristic for the Bronze Age in the Hungarian Carpathian Basin, in particular for the Middle and Late Bronze Ages (Fig. 6). Cereals predominate the archaeobotanical record, followed by legumes and oil-and fibre crops. Hulled barley (*Hordeum vulgare* var. *vulgare*), emmer (*Triticum dicoccon*) and einkorn are the most common cereals in Bronze Age settlements, and lentil and pea (*Pisum sativum*) are the most common legumes.

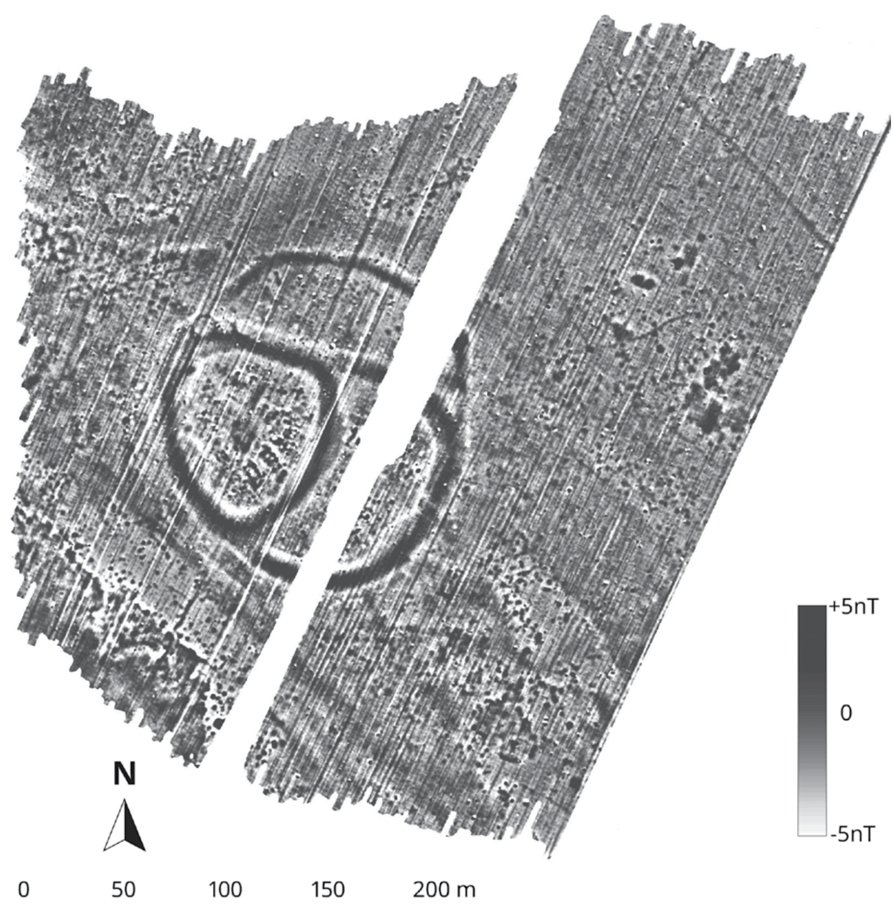

Figure 5. Geomagnetic survey image of the tripartite, fortified settlement Kakucs-Turján mögött (after: Szeverényi and Kulcsár 2012, 27).

The crop assemblage from Kakucs-Turján mögött		
Taxon	**Absolute quantity (n)**	**Common name**
Cereals		
Hordeum vulgare	944	Barley
Hordeum vulgare var. *nudum*	28	Free-threshing barley
Hordeum vulgare var. *vulgare*	546	Hulled barley
Triticum aestivum/durum	16	Free-threshing wheat
Triticum dicoccon	731	Emmer
Triticum monococcum	20283	Einkorn
Triticum spelta	3	Spelt
Panicum miliaceum	1	Broomcorn millet
Legumes		
Lathyrus sativus	8	Grass pea
Lens culinaris	15231	Lentil
Pisum sativum	203	Pea
Vicia ervilia	75	Bitter vetch
Oil and fibre crops		
Linum usitatissimum	23	Linseed/flax

Table 2. The first macrobotanical results of the crop spectrum from Kakucs-Turjan mögött. The results are presented based upon the absolute quantities of the remains.

Finds of oil and fibre crops are rare in the assemblages and are only attested from the Middle Bronze Age onwards.

The Carpathian Basin is characterised by the presence of four climatic zones: a continental climate from the east-west direction, an Atlantic climate from the west-east direction, a sub-Mediterranean climate from the south towards the north, and a sub-Carpathian/Carpathian climate in the northern mountains. The interaction of these zones, accompanied by a varying geology and morphology throughout the basin, has resulted in a patchy landscape with a varying vegetation cover (Nagy-Bodor *et al.* 2010, p. 121; Sümegi, Kertész and Hertelendi 2002, 51).

The Hungarian Bronze Age correlates with the Subboreal biozone, which runs from the Late Copper Age until the dawn of the Iron Age (Somogyi 1987, 30). In contrast to the Atlantic, the previous phase that witnessed the Holocene climatic optimum, the Subboreal is distinguished by cooler summer temperatures and high levels of humidity (Kordos 1987, 13-14, Figures 2 and 3).

In northeastern Hungary, paleo-environmental analysis of a sedimentary sequence from Sirok Nyírjes Tó show that the Early Bronze Age is marked by an expansion of *Carpinus betulus*, which declines during the end of the Middle Bronze Age, giving way to an expansion of *Fagus* (Gardner 2002, 547). In the Central-Eastern part, a compilation of previously published data and the analysis of a lake sediment core from the Sarló-hát oxbow lake, illustrates the expansion of *Carpinus betulus* until the first half of the Late Bronze Age, accompanied by a decrease in *Corylus* and an increase in *Fagus*. From the second half of the Late Bronze Age, *Fagus* pollen witness a peak value. The general wooden taxa pollen decrease, while

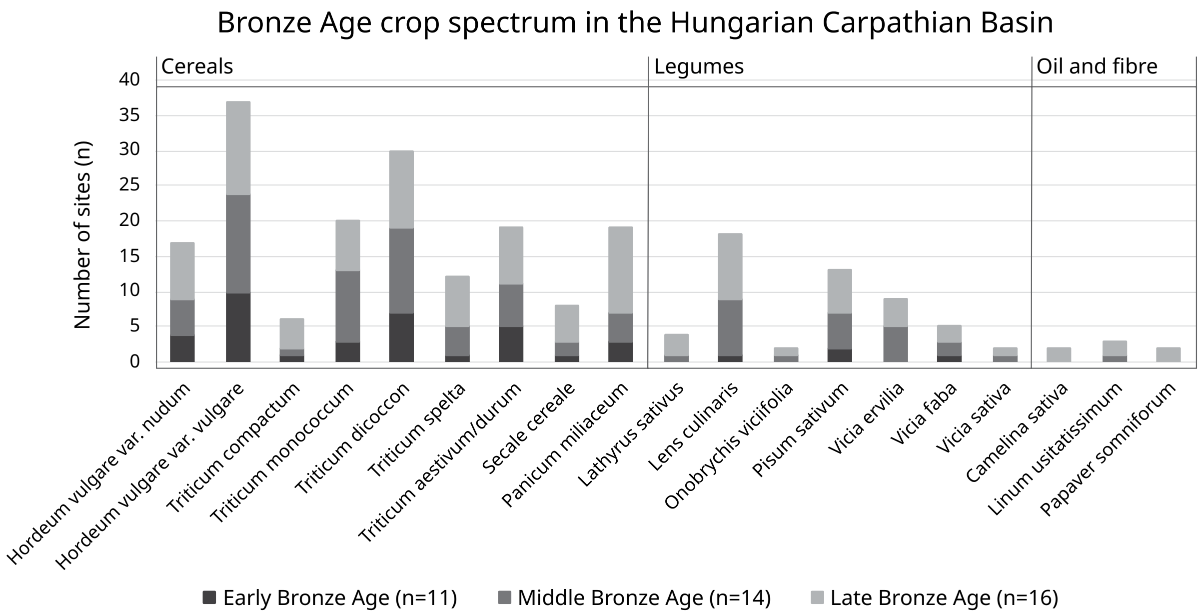

Figure 6. The crop spectrum in the Hungarian Carpathian Basin during the Bronze Age, based upon macrobotanical data published by Gyulai (2010, appendix macrobotanical database).

herbaceous species indicative of disturbance, pastoral activities and arable agriculture increase. The peak in *Carpinus betulus* might indicate relatively arid conditions, while the subsequent expansion of *Fagus* can point towards more humid conditions. The data have been related to the presence of temperate deciduous wooded steps throughout the Great Hungarian Plain, with varying ratios of tree cover distributed over the area (Magyari *et al.* 2010, 926-927).

In Transdanubia, palynological studies from several peat and lake sediments show that the Early Bronze Age and the beginning of the Middle Bronze Age are marked by the appearance of mixed oak forests, represented by *Quercus*, *Ulmus*, *Tilia* and *Fagu*s pollen. In the course of the Middle Bronze Age, the presence of *Vitis, Hedera* and *Castanea* is attested, indicating a milder and warmer summer temperature. Pollen of the non-woody, trampling tolerant species *Rume*x and *Plantago*, are suggested to demonstrate the presence of pastoral activities in the area. In the second part of the Middle Bronze Age and during the Late Bronze Age, pollen of *Quercus*, *Fagus* and *Carpinus* increase, while the remaining woody taxa decline. Anthropogenic markers appear to be more prominent during this period (Juhász 2007a, p. 34; Juhász 2007b, p. 47-49; Juhász and Szegvári 2007, 324).

Stable hydrogen, oxygen and carbon isotope data extracted from cave stalagmites in southern Hungary and bivalve shells from Lake Balaton reflect a short-term humid phase during the first part of the Middle Bronze Age, with a subsequent increase in humidity during the second part of the Bronze Age. After a humidity peak, precipitation decreases and gives way to a drier and warmer summer temperature during the second phase of the Late Bronze Age. These conditions have been interpreted to reflect a period of fluctuating humidity, but a relatively mild climate suitable for arable farming (Demény *et al.* 2019).

Overall, the above data illustrate the mosaic-like environment that prevailed in the Hungarian Carpathian Basin during the Bronze Age. Despite its patchiness, the climatic conditions can be said to be balanced, with some variations in (summer) temperatures, humidity and precipitation. As pointed out by Demény *et al.* (2019) and illustrated by the rich macrobotanical assemblages originating from Bronze Age sites, the environmental and climatic conditions were suitable for the cultivation of a wide range of crops.

Materials and methods

The compilation of regional archaeobotanical overviews that include information on the importance of crops in past food economies, is often complicated by the union of old and recent data that have been generated through different sampling strategies. Within older studies, macrobotanical remains were generally retrieved through judgemental sampling, while in more recent studies, the data are generally derived from a combination of judgemental and systematic sampling strategies. In the case of judgemental sampling, the samples are selected from features that are assumed to contain botanical remains (*e.g.* storage vessels or sediments rich in charcoal). Such a strategy is generally suitable for the reconstruction of (short-term) events that are related to the use of the sampled feature but they are not seen as representative for the proportions of crops that were once present at a site. In systematic sampling, no selection is made based upon an assumption of the macro-botanical content of a feature or layer. Samples are usually taken in grids and each grid has an equal chance of being selected for sampling. The results are suitable for the reconstruction of long-term processes that have led to the accumulation of macrobotanical remains. Long-term processes generally develop through the accumulation of short-term processes such as crop-processing and cooking, and result in the so-called settlement noise (Cappers and Neef 2012, 200-213; Van der Veen and Fieller 1982, 288-289). Although the true proportion of crops is always biased due to differential preservation, it is thought to be best reflected in the settlement noise, and thus in systematically sampled remains. Ideally, information on macrobotanical remains in a regional overview would thus consist of systematically and judgementally sampled data, but realistically, this is often not feasible. Excluding information from older macrobotanical studies would result in the loss of valuable information, which cannot be generated in any other way.

The calculation of the Representativeness Index (RI) was recently introduced by Stika and Heiss (2013) as part of an archaeobotanical compilation of cultivated crops across Europe during the Bronze Age. This semi-quantitative approach takes into account both the presence and the dominance of species in a site, and the total number of samples taken for the analysis (Stika and Heiss 2013, 190). First, the resulting RI can be used as a measurement of the representativeness of a given dataset during specific periods and/or in specific regions. It is assumed, that the higher the number of the RI, the more representative the dataset is for the period and/or region. Second, the approach unifies information on macrobotanical results that have been retrieved using different sampling strategies and enables the evaluation of the relevance of different crops during specific periods and/or in specific regions. As this suits both the dataset available for the Hungarian Carpathian Basin (see below) and the aim of this study, this approach was adopted in order to evaluate the presence and relative importance of "inferior" legumes in the area during the Bronze Age.

Selection of sites

Information on macrobotanical remains from archaeological sites in the Hungarian Carpathian Basin were extracted from a PDF database published by Gyulai (2010) as part of a regional work on archaeobotany in Hungary. The database consists of information collected from a vast body of macrobotanical studies conducted in Hungary from the late 19th century until present. It includes site-based records of macrobotanical finds and where known, the associated total number of samples taken per site. The remains are recorded per taxon, preservation condition and plant part. Finds are represented in absolute numbers, estimations of absolute numbers and measurements of volume or weight. Records of the sampling strategies applied to retrieve the remains and their associated archaeological features are not included in the database.

The selection of the sites was based on a number of criteria. First, burial sites and sites with an undefined chronology were excluded from the analysis. Second, only records of carbonised remains were included; imprints of plants were excluded due to the uncertainties related to the species identification of such finds. Third, only records of absolute numbers were accepted; estimations of numbers (*e.g.* 1-10, 10-100), weights and volumes were not taken into account. Lastly, uncertain identifications (*e.g.* those described as c.f.) were not considered.

The representativeness index

The calculation of the RI consists of two steps (Tab. 3). In the first step, each species is given a numerical score based upon its absolute quantity. A distinction is made between sites with less than 1000 crop finds, and sites with more than 1000 crop finds. The boundary of 1000 finds per site is set as a minimum that is required for identifying proportions of crops in plant food economies. Sites that have yielded less than 1000 finds can receive a score varying from 1-2, and sites that include more than 1000 finds can be scored 1-4 (Stika and Heiss 2013, 191-192). In the second step the scores can be multiplied by 2, 4 or 5, depending on the total number of samples that has been taken at the site. A minimum of 20 samples (or 10 000 finds per site) is required for a multiplication; sites with less samples or finds are excluded from this step.

Prior to the application of the semi-quantitative analysis in the current study, both steps of the method were reviewed according to the data at hand. The first step of the method was recently modified by Effenberger (2018), who applied it in her study on the food economy in Northern Europe during the Bronze Age. Effenberger thereby introduced a finer scaling of the scoring system, distinguishing between a larger variety of numbers of finds, resulting in a total of 7 scores. The reasoning behind the modification was that the dataset generally contained low numbers of finds and the majority of the sites (roughly 65%) did not exceed 1000 finds. The twofold scaling system applied to sites containing less than 1000 finds proved to be too coarse, resulting in an overrepresentation of species that occurred in low numbers and frequencies throughout the sites (Effenberger 2018, 66-67). A similar situation can be ascribed to the dataset in the current study. More than half of the selected sites contain less than 1000 finds and a vast majority of the finds are represented by absolute quantities lower than 10 (see Tab. 5). In order to prevent an overrepresentation of species that occur in low absolute numbers, the modified scoring system of Effenberger was applied.

In the second step of the method, Stika and Heiss set a minimum of 20 samples as a criterion for multiplying the obtained scores. In order to explore whether

Table 3. The semi-quantitative approach resulting in the calculation of the Representativeness Index value as introduced by Stika and Heiss (2013), (Figure after: Effenberger 2018).

	Step 1		Step 2	
	< 1000 finds	> 1000 finds		
Score	Absolute quantity		Factor	Total number of samples
1	< 100	< 100	x 2	> 20 samples
2	> 100	> 100	x 4	> 40 samples
3	-	Important crop (25- 50%)	x 5	> 100 samples
4	-	Predominant crop (> 50%)	x 2	> 10 000 finds

this minimum fits the current data, a scatter diagram was created wherein the number of legume seeds per taxon were plotted against the related number of samples, both variables being displayed in an ascending order. Information on the number of samples was not available for all finds of legumes selected for this study, and therefore a part of the finds was excluded from the graph. In addition, several high seed counts were excluded in order to enhance the visualisation of the results. The results of the graph in Figure 7 show a group of high absolute counts of bitter vetch and pea seeds located between 0 and 20 samples. From 100 samples onwards, there seems to be a gradual increase of absolute counts of lentil and pea seeds respectively. The absolute counts of seeds located between 20 and 100 samples are relatively low, all falling under a total of 50 counts per taxon. Although context-based data are not available from the current dataset, it is likely that the high seed counts at the start of the graph are mainly the result of a judgemental sampling strategy and thus mostly represent concentrations of seeds that were visible in the field. Although the same might be true for high seed counts related to higher numbers of samples in the dataset, it is assumed that the higher numbers of samples partially reflect a systematic sampling strategy. Taking this into consideration, it seems reasonable to keep the minimum of 20 samples as suggested by Stika and Heiss, and thereby prevent an overrepresentation of high

Table 4. The modified semi-quantitative approach resulting in the calculation of the Representativeness Index value (step 1 after: Effenberger 2018).

	Step 1		Step 2	
	< 1000 finds	> 1000 finds		
Score	Absolute quantity		Factor	Total number of samples
1	< 10	< 10	x 2	> 20 samples
2	10-49	10-49	x 3	> 40 samples
3	50-99	50-99	x 4	> 60 samples
4	> 100	100-499	x 5	> 80 samples
5	-	> 500	x 2	> 10 000 finds
6	-	Important crop (25- 50%)		
7	-	Predominant crop (> 50%)		

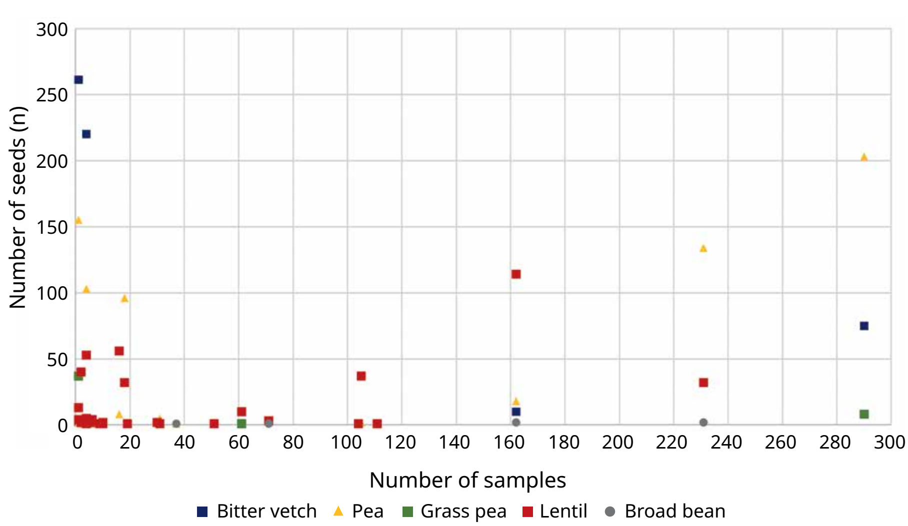

Figure 7. Scatter diagram depicting the relationship between the absolute quantities of legume seeds and the total number of samples. The results are represented per species of legume. The numbers of samples represent the total number of macrobotanical samples taken per site. The records of legumes excluded from the graph due to their high values are; Bitter vetch: n=990, 231 samples; Pea: n=1619, 6 samples and n=678, 1 sample; Lentil: n=15231, 290 samples.

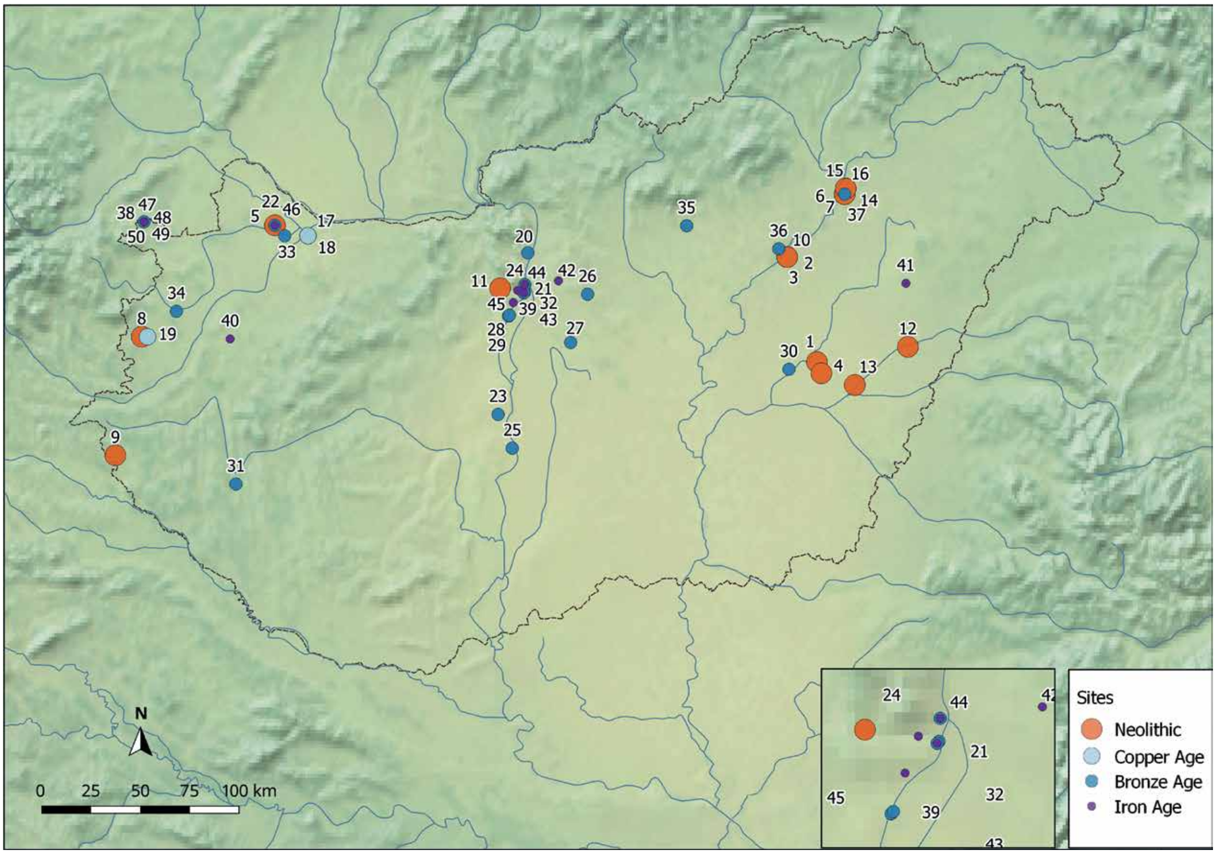

Figure 8. Map of the Hungarian Carpathian Basin with the sites included in the study. Neolithic: 1. Ecsegfalva; 2. Tiszaszőlős-Domaháza puszta; 3. Tiszaszőlős-Domaháza puszta (transitional); 4. Dévaványa-Réhelyi gát; 5. Mosonszentmiklós-Pálmajor; 6. Polgár site 31 (Polgár-Ferenci-hát); 7. Polgár site 31 (Polgár-Ferenci-hát; end of middle Neolithic) 8. Szombathely – Aranypatak lakópark; 9. Szentgyörgyvölgy-Pityerdomb; 10. Tiszaszőlős-Domaháza puszta; 11. Törökbálint Dulácska (Outlet storage); 12. Berettyóújfalu-Herpály; 13. Berettyóújfalu-Szilhalom; 14. Polgár site 6 (Polgár-Csőszhalom-dűlő); 15. Tiszapolgár-Csőszhalom tell I; 16. Tiszapolgár- Csőszhalom tell II. Copper Age: 17. Györ-szabadrétdomb; 18. Győr-Szabadrétdomb; 19. Szombathely -Aranypatak lakópark. Bronze Age: 20. Budakalász M0 motorway, 12; 21. Budapest, Albertfalva -Hunyadi J. u.; 22. Mosonszentmiklós-Pálmajor; 23. Baracs-Bottyánsánc; 24. Budapest, Bocskai-Fehérvári úti aluljáró; 25. Bölcske-Vörösgyír; 26. Mende-Leányvár; 27. Kakucs-Turján mögött; 28. Százhalombatta-Téglagyár; 29. Százhalombatta-Földvár; 30. Túrkeve- Terehalom; 31. Balatonmagyaród-Hídvégpuszta; 32. Budapest, Albertfalva-Kitérő út; 33. Börcs-Paphomlok; 34. Gór-Kápolnadomb; 35. Ludas, Varjú-dűlő; 36. Poroszló-Aponhát; 37. Polgár site 31; 38. Sopron-Krautacker site 1. Iron Age: 39. Budapest XI. Kőérberek-Tóváros (Kána village); 40. Celldömölk-Sághegy; 41. Ebes Zsong-völgy; 42. Rákoskeresztúr-Újmajor; 43. Budapest, Albertfalva-Kitérő út; 44. Budapest, Bocskai-Fehérvári úti aluljáró; 45. Budapest-Nagytétény "Campona"; 46. Mosonszentmiklós-Pálmajor; 47. Sopron-Krautacker site 3; 48. Sopron-Krautacker site 4; 49. Sopron-Krautacker site 5; 50. Sopron-Krautacker site 6 (Map: A. Kittler & S. Filatova; Basemap: Stamen Design; Map data: Open Street Map 2018).

seed counts that have been sampled from concentrations already visible in the field during excavation.

In the multiplication system presented by Stika and Heiss, there seems to be a different relationship between the first two factors and the related number of samples on the one hand, and the highest factor and the related number of samples, on the other hand. The first two factors appear to be related to a multiplication of 10, while the last factor seems to represent a multiplication of 20. In order to ensure that all the factors used in the multiplication represent an equal amount of samples, the second step was modified by taking 20 samples as the basis for each factor. The minimum and maximum factors by which a score can be multiplied were kept equal to the system of Stika and Heiss, but the number of samples determining the factor and the resulting number of factors by which a score can be multiplied were adapted. The semi-quantitative analysis applied to the dataset in the current study is presented in Table 4.

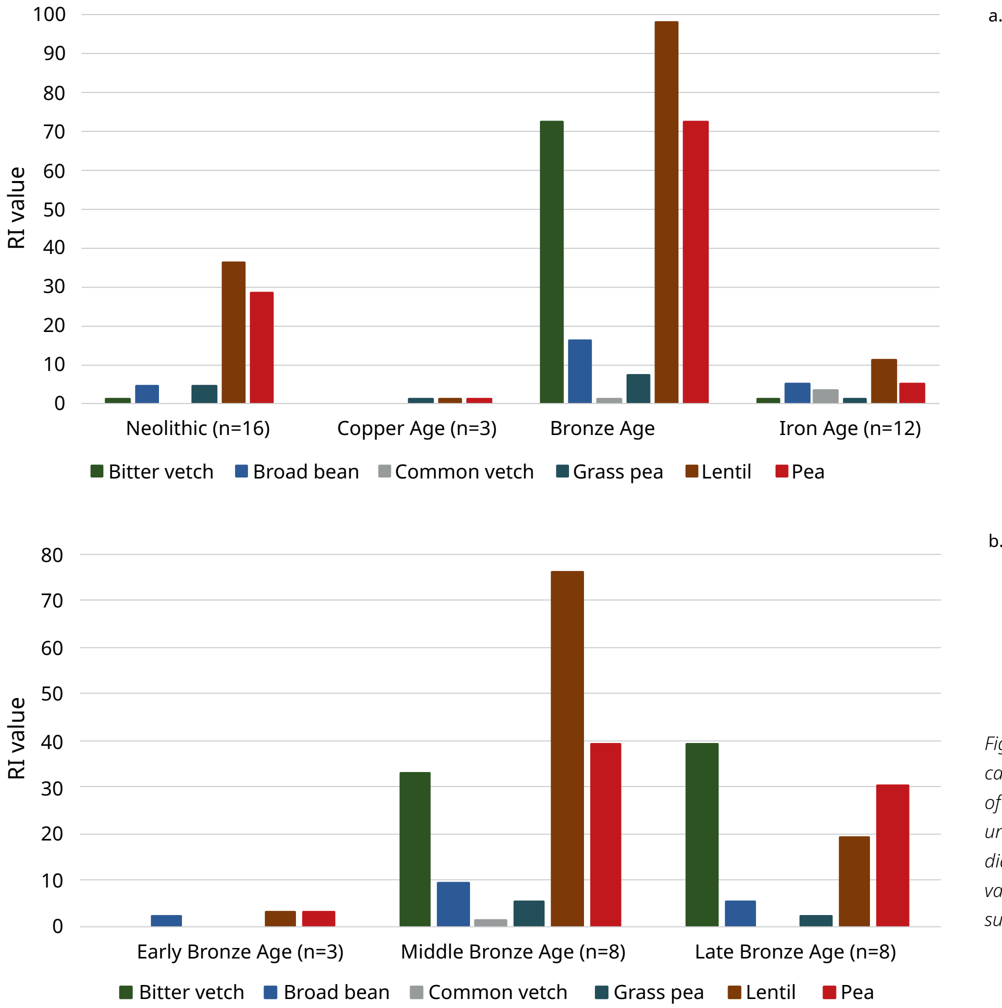

Figure 9. a: Stack diagram of the calculated RI values per species of legumes from the Neolithic until the Iron Age. b: Stack diagram of the calculated RI values per species of legume per subperiod of the Bronze Age.

Results

General characteristics of the dataset

The database published by Gyulai contains information on macrobotanical finds from a total of 204 archaeological sites dating to the Neolithic until the Iron Age (Gyulai 2010, appendix macrobotanical database). About 30% (n=32) of the total amount of sites include finds of legume seeds. 25% (n=50) of the total available sites was selected for the semi-quantitative approach (Fig. 8 and Tab. 2). The majority of the sites belong to the Bronze Age (n=19), followed by the Neolithic (n=16), the Iron Age (n=12) and lastly, the Copper Age (n=3). Most of the selected sites include information on the related archaeological culture and the total amount of botanical samples taken per site. About two-thirds of the sites (67%) are represented by less than a total of 1000 botanical finds.

The selected sites yielded a total of 6 species of legumes (Tables 6a and 6b). Bronze and Iron Age sites have the largest variety of legumes, followed by Neolithic and Copper Age sites. The highest absolute quantities of legumes are recorded for the Bronze Age sites. For all periods, lentil has been observed in the largest number of sites, followed by pea. While lentil is predominant in its absolute quantity for the total dataset, pea shows the highest absolute quantity during the Neolithic. Common

	Site	Archaeological period	Archaeological culture	Samples (n)	Bitter vetch (*Vicia ervilia*)	Broad bean (*Vicia faba*)	Common vetch (*Vicia sativa*)	Grass pea (*Lathyus sativus*)	Lentil (*Lens culinaris*)	Pea (*Pisum sativum*)	Total seeds legumes	Total crop finds
					Absolute quantity (n)							
1	Ecsegfalva	Early Neolithic	Körös-Starčevo	Unknown					1		1	1780
2	Tiszaszőlős-Domaháza puszta	Early Neolithic	Körös-Starčevo	111					1		1	544
3	Tiszaszőlős-Domaháza puszta (transitional)	Early Neolithic	Körös-Starčevo	71		1			3		4	234
4	Dévaványa-Réhelyi gát	Middle Neolithic	Szakálhát-Szilmeg group	4					5		5	105
5	Mosonszentmiklós-Pálmajor	Middle Neolithic	Linearbandkeramik	6						1	1	2
6	Polgár site 31 (Polgár-Ferenci-hát)	Middle Neolithic	Linearbandkeramik	105					37	2	39	2833
7	Polgár site 31 (Polgár-Ferenci-hát) (end of middle Neolithic)	Middle Neolithic	Linearbandkeramik	61				1	10	2	13	178
8	Szombathely - Aranypatak lakópark	Middle Neolithic	Linearbandkeramik	10					2		2	36
9	Szentgyörgyvölgy-Pityerdomb	Middle Neolithic	Linearbandkeramik	3						1	1	88
10	Tiszaszőlős-Domaháza puszta	Middle Neolithic	Linearbandkeramik	104					1		1	244
11	Törökbálint Dulácska (Outlet storage)	Middle Neolithic	Linearbandkeramik	6					2		2	100
12	Berettyóújfalu-Herpály	Late Neolithic	Herpály	1	2					155	157	157
13	Berettyóújfalu-Szilhalom	Late Neolithic	Esztár group and Herpály	6						1619	1619	2773
14	Polgár site 6 (Polgár-Csőszhalom-dűlő)	Late Neolithic	Tisza-Herpály-Csőszhalom	31					1	5	6	155
15	Tiszapolgár-Csőszhalom tell I	Late Neolithic	Tisza-Herpály-Csőszhalom	18					32	96	128	6657
16	Tiszapolgár-Csőszhalom tell II	Late Neolithic	Tisza-Herpály-Csőszhalom	19					1	2	3	11659
17	Győr-szabadrétdomb	Early Copper Age	Balaton-Lasinja	4					4		4	15
18	Győr-Szabadrétdomb	Late Copper Age	Baden-Boleráz	4				1			1	144
19	Szombathely -Aranypatak lakópark	Late Copper Age	Baden culture	6						1	1	71
20	Budakalász M0 motorway, 12	Early Bronze Age	Bell Beaker	51					1		1	64
21	Budapest, Albertfalva -Hunyadi J. u.	Early Bronze Age	Bell Beaker Csepel group	37		1				1	2	1950
22	Mosonszentmiklós-Pálmajor	Early Bronze Age	Lengyel	6						3	3	18
23	Baracs-Bottyánsánc	Middle Bronze Age	Nagyrév and Vatya	1			4		13		17	895
24	Budapest, Bocskai-Fehérvári úti aluljáró	Middle Bronze Age	Vatya	6					3	2	5	378
25	Bölcske-Vörösgyír	Middle Bronze Age	Nagyrév and Vatya	Unknown	325	19			4688	11	5043	36878

					Bitter vetch (*Vicia ervilia*)	Broad bean (*Vicia faba*)	Common vetch (*Vicia sativa*)	Grass pea (*Lathyus sativus*)	Lentil (*Lens culinaris*)	Pea (*Pisum sativum*)		
	Site	Archaeological period	Archaeological culture	Samples (n)	Absolute quantity (n)						Total seeds legumes	Total crop finds
26	Mende-Leányvár	Middle Bronze Age	Vatya	4					1		1	1
27	Kakucs-Turján mögött	Middle Bronze Age	Vatya	290	75			8	15231	203	15517	45046
28	Százhalombatta-Téglagyár	Middle Bronze Age	Vatya	6	1						1	5
29	Százhalombatta-Földvár	Middle Bronze Age	Vatya	162	10	2			114	18	144	5201
30	Túrkeve-Terehalom	Middle Bronze Age	Ottományi	4	220				53	103	376	788
31	Balatonmagyaród-Hídvégpuszta	Late Bronze Age	Tumulus	1	261			37	4	678	980	1641
32	Budapest, Albertfalva-Kitérő út	Late Bronze Age	Urnfield c	4					2	1	3	256
33	Börcs-Paphomlok	Late Bronze Age	Urnfield	10					1		1	209
34	Gór-Kápolnadomb	Late Bronze Age	Urnfield	16					56	8	64	18928
35	Ludas, Varjú-dűlő	Late Bronze Age	Kyjatice	231	990	2			32	134	1158	44752
36	Poroszló-Aponhát	Late Bronze Age	Gáva-Holigrady	2					40		40	399
37	Polgár site 31	Late Bronze Age	Tumulus	6					4		4	41
38	Sopron-Krautacker site 1	Late Bronze Age	Urnfield	1						2	2	11
39	Budapest XI. Kőérberek-Tóváros (Kána village)	Early Iron Age	Hallstatt	3	2			2	4		8	212
40	Celldömölk-Sághegy	Early Iron Age	Hallstatt	5		203			3		206	807
41	Ebes Zsong-völgy	Iron Age	Scythian	30					2		2	2427
42	Rákoskeresztúr-Újmajor	Iron Age	Scythian	9					1		1	302
43	Budapest, Albertfalva-Kitérő út	Late Iron Age	La Tène	2						1	1	28
44	Budapest, Bocskai-Fehérvári úti aluljáró	Late Iron Age	La Tène D	2					2		2	30
45	Budapest-Nagytétény „Campona"	Late Iron Age	Celtic	1					3	2	5	254
46	Mosonszentmiklós-Pálmajor	Late Iron Age	Celtic	6					2		2	8
47	Sopron-Krautacker site 3	Late Iron Age	Celtic	Unknown		7	1		14	1	23	177
48	Sopron-Krautacker site 4	Late Iron Age	Celtic	Unknown						1	1	37
49	Sopron-Krautacker site 5	Late Iron Age	Celtic	Unknown			1				1	6
50	Sopron-Krautacker site 6	Late Iron Age	Celtic	Unknown			2		1	1	4	26

Table 5. The sites selected for the analysis with the related total number of samples, absolute quantities of legumes and total crop finds per site (after: Gyulai 2010, appendix macrobotanical database).

a.

	Neolithic (n=16)			Copper Age (n=3)			Bronze Age (n=19)			Iron Age (n=12)			Total (n=50)			
Taxon	Abundance	Absolute quantity	RI	Abundance	Absolute quantity	RI	Abundance	Absolute quantity	RI	Abundance	Absolute quantity	RI	Abundance	Absolute quantity	RI	Common name
Lathyrus cicera/ sativus	1	1	4	1	1	1	2	45	7	1	2	1	5	49	13	Grass pea
Lens culinaris	12	96	32	1	4	1	15	20243	99	9	32	11	37	20375	143	Lentil
Pisum sativum	9	1883	28	1	1	1	12	1164	72	5	6	5	27	3054	106	Pea
Vicia ervilia	1	2	1	0	0	0	7	1882	72	1	2	1	9	1886	74	Bitter vetch
Vicia faba	1	1	0	0	0	0	4	24	16	2	210	5	7	235	21	Broad bean
Vicia sativa	0	0	0	0	0	0	1	4	1	3	4	3	4	8	4	Common vetch
Total	16	1983	65	2	2	3	19	23365	267	7	248	19				

b.

	Early Bronze Age (n=3)			Middle Bronze Age (n=8)			Late Bronze Age (n=8)			
Taxon	Abundance	Absolute quantity	RI	Abundance	Absolute quantity	RI	Abundance	Absolute quantity	RI	Common name
Lathyrus cicera/ sativus	0	0	0	1	8	5	1	37	2	Grass pea
Lens culinaris	1	1	3	7	20103	76	7	139	19	Lentil
Pisum sativum	2	4	3	5	337	39	5	823	30	Pea
Vicia ervilia	0	0	0	5	631	33	2	1251	39	Bitter vetch
Vicia faba	1	1	2	2	21	9	1	2	5	Broad bean
Vicia sativa	0	0	0	1	4	1	0	0	0	Common vetch
Total	3	6	8	21	21104	163	16	2252	95	

Table 6. a: The six species of legumes from the Neolithic until the Iron Age in the Hungarian Carpathian Basin, with the related abundance (presence per site), absolute quantities and calculated Representativeness Index values. b: The six species of legumes per subperiod of the Bronze Age in the Hungarian Carpathian Basin, with the related frequency (presence per site), absolute quantities and calculated Representativeness Index values.

vetch and grass pea represent the rarest species of legumes throughout the dataset, both in the abundance in which they occur in the sites, as well as in their absolute quantities. In accordance with the described results, the results of the semi-quantitative analysis show that lentil and pea have the highest combined RI values, while the lowest values are represented by common vetch and grass pea.

The results of the analysis have been visualised in two stack diagrams in Figures 9a and 9b. The first diagram, which contains the RI values of legumes from a diachronic perspective, shows that the highest RI values for legumes are represented in the Bronze Age. The RI values of the Neolithic come second, followed by the values from the Iron Age and lastly, the Copper Age. The RI values for the Bronze Age illustrate the predominance of lentil, while pea and bitter vetch share a second place. Grass pea and common vetch are the rarest legumes according to the RI.

A more detailed picture of the RI values of legumes in the Bronze Age (Fig. 9b) shows that the highest total number of values are recorded for the Middle Bronze Age, followed by the Late Bronze Age and subsequently, by the Early Bronze Age. In the Middle Bronze Age, lentil shows the highest RI values, followed by pea and bitter vetch. The Late Bronze Age values show a predominance of bitter vetch, followed by pea and lentil. During the Early Bronze Age, the RI values for all legumes are equal.

Interpretations

Limitations of the dataset and the applied methodology

Before making an attempt at interpreting the RI values, it is of importance to point out a number of limitations that have been observed with regard to this particular dataset and the application of the semi-quantitative analysis. First, not every period is represented by an equal number of sites. While the number of sites from the Neolithic, Bronze Age and Iron Age are relatively equal, those representing the Copper Age are notably smaller. The original dataset published by Gyulai (2010) includes archaeobotanical information from a total of 24 Copper Age sites. The selection criteria applied to form the current dataset have not excluded any records of legumes from the Copper Age and it is therefore representative for the original dataset of the Copper Age as a whole. As this paper focusses on the Bronze Age, no attempt will be made to interpret the low records of legumes in the Copper Age.

A second limitation can be noted in the application of the analysis to the dataset. From the results concerning the Late Bronze Age, bitter vetch has a higher RI value than pea, despite the fact that seeds of pea have been uncovered from a larger number of sites during this period (Tab. 6b). The high RI value of bitter vetch can especially be attributed to one site, Ludas Varjú-dűlő, which is represented by a high number of samples and absolute quantity of bitter vetch and also includes (lower) records of pea (Tab. 5). A second site, Balatonmagyaród-Hídvégpuszta, contains records of both bitter vetch and pea, but in this case the remains originate from a single sample. Additional records of pea are low in their absolute quantities and represent sites with low numbers of samples. Consequently, the calculated RI value of bitter vetch exceeds that of pea for the period due to the high absolute quantity from a single site with a high number of samples.

That being said, the resulting RI has also demonstrated the strength of the method. An example is the RI value of pea and lentil during the Neolithic. The RI value of lentil is higher compared to that of pea, despite the fact that pea is represented by a significantly higher absolute quantity. This is related to the fact that the bulk of the absolute quantity of pea originates from a site with a low total number of samples, and thus most likely mainly represents a storage supply or a concentration of seeds visible in the field. In this respect, the method has met its goal very well, by avoiding an overrepresentation of records originating from a lower number of samples despite the high absolute quantity.

Cappers and Neef (2012, 397) point out that the analysis of the contribution of legumes to past diet is complicated by a preservation bias related to the morphological characteristics of different species of legumes. In samples taken outside of the context of storage supplies, small-seeded legumes (*e.g.* lentil and bitter vetch) are generally overrepresented compared to large-seeded legumes (*e.g.* pea and grass pea). Small-seeded legumes have a larger variation in seed size compared to large-seeded legumes. During the sieving stage of processing the harvest, a proportion of both small and broken seeds are lost from small-seeded legumes, while mainly broken seeds are lost from large-seeded legumes.

When related to the current dataset, the above complication proves to apply only to a part of the group of small-seeded legumes. On average, lentil is indeed recovered in much higher amounts compared to pea in cases where a larger number of samples have been taken, while this is not the case for records of bitter vetch (Fig. 7). It is problematic to distinguish whether this observation results from a preservation bias or whether it can, to some extent, be related to the proportion of the crops at the sites. This is complicated even further by the fact that no context-based data are available for the sites in the current study, and it is therefore not possible to relate the records to storage supplies or food preparation activities (in which case the difference between large- and small-seeded legumes would not apply). No attempt will therefore be made to include such a discussion.

"Inferior" legumes in the Bronze Age

Putting the problems arising from preservation biases aside, the results show a general increase in the presence of legumes during the Bronze Age, particularly during the Middle Bronze Age, as opposed to the previous and following periods. Common vetch makes its appearance for the first time and bitter vetch and broad bean show an increase in their presence. For the Bronze Age as a whole, bitter vetch and pea have equal RI values.

It is clear that during the Bronze Age, both species of the supposedly inferior legumes, bitter vetch and grass pea, are represented in the archaeobotanical record, the latter being a rare find and the former a relatively frequent find. Archaeobotanical analyses have related the presence of both crops to changing environmental conditions, specifically periods of drought in Syria and the Levant (*e.g.* Merret and Meiklejohn 2015; Riehl 2008). The climatological and palynological data presented above cannot be taken as representative for the whole Hungarian Carpathian Basin due to the patchiness of its environment. Despite this, it might be assumed that the changes to the environment during the Bronze Age were not so dramatic that the cultivation of famine crops was necessary. In general, the climate has been described as relatively mild and suitable for crop growing throughout the Bronze Age and there is no indication for periods of drought. On the contrary, the climate has been suggested to have been more humid compared to the preceding Atlantic biozone.

It is problematic to argue whether famines did or did not occur in the Carpathian Basin during the Bronze Age. Famines can occur on an annual basis due to crop failure and the macrobotanical and palynological records used in the current analysis do not reflect annual fluctuations in harvests. The results of the Bronze Age crop spectrum presented in Figure 7, however, indicate the presence of a rich variety of crops as opposed to a shortage of food, and it is therefore carefully assumed that there were no famines in the region during this period. A second factor that should be kept in mind is that this study did not consider whether soil degradation could have led to the adaptation of these tolerant and fertilising legumes in the Bronze Age. One thing that can be concluded with certainty is that the legumes were not introduced in order to buffer periods of drought, as has been indicated by the studies discussed above.

A frequent description of the use of bitter vetch and grass pea is as fodder for domestic animals. In archaeobotanical research, it has been demonstrated that making a distinction between crops intended for fodder and those intended for human diet can be problematic (and even more so when dealing with site-based data). Ethnographic studies by Jones (1996) and Halstead (1990) indicate that the boundary between food and fodder is flexible in traditional agricultural communities: during periods with a favourable climate and high yields specific crops are used as fodder, while during periods with environmental stress and low yields the same crops are consumed by humans. Moreover, one and the same crop can be used for multiple purposes simultaneously: seeds can be used as human food while hay can be used as animal fodder, which is also common for cereals. A flexible boundary between food and fodder is therefore assumed in this study. Consequently, it must be considered whether the presence of these legumes in the diet of Bronze Age communities in the Hungarian Carpathian Basin might have posed a risk for their health, as both legumes are known to be potentially toxic.

Not much is known about the common consumption of bitter vetch in traditional agricultural communities and most information is related to the consumption of the legume as a famine crop. The consumption of bitter vetch thereby resulted in symptoms such as headaches and drowsiness (Ennerking *et al.* 1995, 144; Halstead 1990, 153). In the case of grass pea, consumption during times of famine has led to epidemics of neurolathyrism on multiple occasions throughout history (Getahun *et al.* 2005, 169; Halstead 1990, 152). These records can, however, not be taken as a reference for the Hungarian Carpathian Basin during the Bronze Age, as there is no strong indication for famines in the area. None of legumes would have made up the bulk of the daily diet, as would have been likely in the case of a famine. Grass pea is known to be toxic only in those cases when it represents more than 30% of the daily diet for at least one month (Hansen 2000, 22; Tassede and Bekele 2003, 315). The relationship between abnormal consumption and toxicity is true for all legumes that contain anti-nutrients (Liener 1969, 5).

The toxicity of legumes can be reduced not only by processing, but also by consuming the legumes in combination with cereals (Valamoti 2009, 30). In the case of the Hungarian Carpathian Basin, the broad range of crops recorded for the area during the (Middle) Bronze Age would have allowed for a balanced diet between potentially toxic legumes and harmless crops. Moreover, the frequent presence of both bitter vetch and grass pea during the Bronze Age has been attested in archaeobotanical assemblages from, amongst others, Croatia, Greece, Bulgaria and Israel (Kreuz and Marinova 2017; Kroll 1991; Marinova and Valamoti 2014; Reed 2013; Slasky and Kislev 2010). In Northern Greece, bitter vetch has even been reported to overshadow legumes that were represented in the area during the Neolithic (Valamoti 2011, 388-389).

"Inferior" legumes as part of subsistence strategy and culinary practice?

The bulk of bitter vetch finds originate from archaeobotanical assemblages from Middle Bronze Age settlements inhabited by Vatya communities (Tab. 5). Grass pea only consists of two records during the Bronze Age, one from a Vatya settlement, and the second from a Tumulus settlement. These observations might indicate a preference for the legumes, particularly bitter vetch, by Vatya communities in the Hungarian Carpathian Basin. Besides being perceived as tasty, which is problematic to argue based upon the current study, several reasons can be considered for such a preference.

First, the increased presence of legumes in general during the Bronze Age can be an indication for the application of specific farming techniques, such as green manuring (*i.e.* nitrogen fixation) or intensive farming. The latter is defined as a system that requires a high input of labour and is usually characterised by small land plots that are located close to the place of residence. It is therefore suited to nucleated, sedentary family groups in which childcare plays a central role (Bogaard 2005, 179-182; Van der Veen 2005, 158-159). Legumes are furthermore known to be suitable for intensive farming strategies (Halstead 1981, 320; Halstead 1987, 82; Jones 2005, 166). According to Nicodemus (2014, 110), tell building communities typically occupied small houses, indicative for (extended) nuclear families. In such a case, the practice of intensive farming (most likely combined with extensive farming) would have been suitable to the habitation structure of Vatya communities.

Second, the cultivation of a wide range of legumes might have been a method of risk management. As among others Martson (2011) points out, a diversification of a crop assemblage can be interpreted as a way to ensure the availability of food at all times. One part of the spectrum is thereby cultivated for fodder and the other part is cultivated for human diet. As the boundary between food and fodder is flexible, such a strategy ensures the availability of food in cases of yield loss (Martson 2011, 191-192). Kreuz and Marinova (2017, 653-654) and Valamoti (2011, 388-389) have suggested that during the Bronze Age in Bulgaria and Northern Greece respectively, legumes were cultivated for storage as a buffer, as both species are known to be hardy crops that can cope with environmental stress.

Last, the presence of bitter vetch and grass pea might be related to cultural (*e.g.* culinary practice) and social (*e.g.* exchange) factors prevailing in Vatya communities. Besides being an essential aspect of survival, satisfaction and potential economic prosperity, food plays a significant role in establishing social relationships and it has been described as a universal form of communication (Hastorf 2017, 312; Palmer and Van der Veen 2002, 196). The presence of "exotic" foods can therefore be a sign of interaction between distant communities (Valamoti 2005, 281). As has been described above, both bitter vetch and grass pea have been demonstrated to be part of Balkan and Aegean plant food economies during the Bronze Age. In addition, the broad bean, which is increasingly represented in the Carpathian Basin during the Bronze Age, is also first attested in macrobotanical assemblages in Northern Greece during the same period. Finds of broad bean from preceding periods are only recorded for the Aegean Islands (Valamoti 2009, 27). The presence of bitter vetch, grass pea and broad bean in archaeobotanical assemblages in the Carpathian Basin and the notable similarity with macrobotanical assemblages from the Balkans and the Aegean, might therefore indicate the existence of social relationships between the regions. Such relationships might have involved the exchange of plant foods and the related knowledge on how to process and prepare them.

Final remarks

The results presented in this study show an increased presence of legumes in the Hungarian Carpathian Basin during the Bronze Age, in particular during the Middle Bronze Age. Both the variety of species as well as the quantity of finds is higher compared to the preceding periods. This might be interpreted as an increased importance of legumes within the food economy prevailing in the area during this period. Both species of "inferior" legumes are represented from the Middle Bronze Age onwards, grass pea being a rare find, while bitter vetch seems to be of greater significance.

Based upon the results presented in this paper, the cultivation of bitter vetch and grass pea in the Hungarian Carpathian Basin during the Bronze Age should most likely not be seen as an indication for poor living conditions. From an environmental perspective there seems to have been no need for the cultivation of drought resistant crops and there is no strong evidence for the presence of famines. On the contrary, the crop spectrum of the Bronze Age suggests a rich food economy in the Hungarian Carpathian Basin, with a variety of choice of crops for both food and fodder. Moreover, there is no reason to assume that the health of the population would have been affected by the consumption of the legumes, as it is unlikely that the legumes made up the bulk of the diet during the period. This can, however, only be speculated on based upon the current study, and it requires more detailed macrobotanical data, as well as additional data from skeletal analysis to further indicate the health status of individuals (as exemplified by Merret and Meiklejohn 2015). That being said, it is also important to underline that what is perceived as good or bad with respect to living conditions, might have been different in the past compared to the present.

The same can be said with regard to which crops are viewed as "inferior" and which are not. As mentioned previously, the boundary between food and fodder is flexible and these definitions might change annually. Likewise, what is considered "good" food, and what is considered "bad" food is prone to the same variability. It is sensible to assume that during times of prosperity certain crops might get undervalued, while during times of shortage the value for the same crops might increase. The status of crops as a whole can thus be described as flexible, varying not only on a temporal scale, but also between and within different communities and regions.

One aspect that could not be investigated in the current study, is whether the consumption of "inferior" legumes can be related to a low social status, as is suggested by ethnographic and historical records. Such a consideration would require context-based data from various sites and include multiple households with a presumed social differentiation. Unfortunately, such data are currently not available to the authors.

The "inferior" legumes in the Hungarian Carpathian Basin can especially be related to the agricultural practices of Vatya communities that inhabited the central part of the basin during the Middle Bronze Age. The presence of bitter vetch and grass pea might be related to specific agricultural strategies practiced by these communities, and/or social ties with the Balkans and the Aegean. A more detailed study of botanical assemblages from Vatya settlements would be favourable for a better understanding of what aspect(s) of society governed the choice to cultivate these legumes in the past.

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References

Bahl, P.N. 1999. The role of food legumes in the diets of the populations of Mediterranean areas and associated nutritional factors, in: Osman, A.E, Ibrahim, M.H. and Jones, M.A. (eds.). *The role of legumes in the farming systems of the Mediterranean areas*. Dordrecht/Boston/London: Kluwer Academic Publishers, 143-151.

Bogaard, A. 2005. 'Garden Agriculture' and the Nature of Early Farming in Europe and the near East. *World Archaeology*, 37/2, 177-196.

Butler, A., Tesafy, Z., D'Andrea, C. and Lyons, D. 1999. The Ethnobotany of Lathyrus sativus L. in the Highlands of Ethiopia, in: Van der Veen, M. (ed.). *The Exploitation of Plant Resources in Ancient Africa*. New York: Springer Science+Business Media, 123-136.

Cappers, R.T.J. and Neef, R. 2012. *Handbook of Plant Palaeoecology*. Eelde/Groningen: Barkhuis publishing/Groningen University Library.

Demény, A., Kern, Z., Czuppon, G., Németh, A., Schöll-Barna, G., Siklósy, Z., Leél-Össy, S., Cook, G., Serlegi, G., Bajnóczi, B., Sümegi, P., Király, Á., Kiss, V., Kulcsár, G. and Bondár, M. 2019. Middle Bronze Age humidity and temperature variations, and societal changes in East-Central Europe. *Quaternary International*, 504, 80-95.

Effenberger, H. 2018. The plant economy of the Northern European Bronze Age – more diversity through increased trade with southern regions. *Vegetation history and archaeobotany*, 27, 65-74.

El Fatehi S., Béna G., Filali-Maltouf, A. and Ater M. 2016. Genetic diversity of Moroccan bitter vetch *Vicia ervilia* (L.) Willd. landraces revealed by morphological and SSR markers. *Australian Journal of Crop Science*, 10/5, 717-725.

Ennerking, D. 1994. *The toxicity of Vicia species and their utilisation as grain legumes*. Adelaide: University of Adelaide.

Ennerking, D., Lahlou A., Noutfia, A. and Bounejmate, M. 1995. A note on Vicia ervilia cultivation, utilisation and toxicity in Marocco. *Al Awamia*, 89, 141-148.

Filatova, S., Gissel, C., Filipović, D. and Kirleis, W. 2018. The plant economy at the Bronze Age site of Kakucs-Turján: first archaeobotanical results, in: Jaeger, M., Kulcsár, G., Taylor, N. and Staniuk S. (eds*.). Kakucs-Turján: A Middle Bronze Age multi-layered fortified settlement in Central Hungary.* Bonn: Dr. Rudolf Habelt GmbH, 175-187.

Fischl, K., Kiss, V., Kulcsár, G. and Szeverényi, V. 2013. Transformations in the Carpathian Basin around 1600 B.C, in: Meller, H., Bertemes, F., Bork, H. and Risch, R. (eds.), *1600 – Cultural change in the shadow of the Thera-Eruption? Tagungen des Landesmuseums für Vorgeschichte Halle (9).* Halle: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt/Landesmuseum für Vorgeschichte, 355-370.

Fischl, K., Kiss, V., Kulcsár, G. and Szeverényi, V. 2015. Old and new narratives for Hungary around 2200 BC, in: Meller, H., Arz, H.W., Jung, R. and Risch, R. (eds.). *2200 BC – Ein Klimasturz als Ursache für den Zerfall der Alten Welt? 2200 BC – A climatic breakdown as a cause for the collapse of the old world? 7. Mitteldeutscher Archäologentag vom 23. bis 26. Oktober 2o14 in Halle (Saale).* Halle: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt/Landesmuseum für Vorgeschichte, 503-524.

Flint-Hamilton, K.B. 1999. Legumes in Ancient Greece and Rome: Food, Medicine, or Poison? *The Journal of the American School of Classical Studies at Athens*, 68/3, 371-385.

Gardner, A.R. 2002. Neolithic to Copper Age woodland impacts in northeast Hungary? Evidence from the pollen and sediment chemistry records. *The Holocene*, 12/5, 541-553.

Getahun, H., Lambein, F., Van Hoorne, M. and Van der Stuyf, P. 2005. Neurolathyrism risk depends on type of grass pea preparation and on mixing with cereals and antioxidants. *Tropical Medicine and International Health,* 10/2, 169-178.

Gogâltan, F. 2008. Fortified Bronze Age tell settlements in the Carpathian Basin: a general overview, in: Czebreszuk, J., Kadrow, S. and Müller, J. (eds.). *Defensive structures from Central Europe to the Aegean in the 3rd and 2nd millennia B.C.* Bonn: Habelt, 39-56,

Gyulai, F. 2010. *Archaeobotany in Hungary: seed, fruit, food and beverage remains in the Carpathian Basin from the Neolithic to the late Middle Ages.* Budapest: Archaeolingua.

Halstead, P. 1981. Counting sheep in Neolithic and Bronze Age Greece, in: Hodder, I., Isaac, G. and Hammond, N. (eds.). *Patterns of the past: studies in honour of David Clarke*. Cambridge: Cambridge University Press, 307-339.

Halstead, P. 1987. Traditional and Ancient Rural Economy in Mediterranean Europe: Plus ça Change? *The Journal of Hellenic Studies*, 107, 77-87.

Halstead, P. 1990. Waste not want not: traditional responses to crop failure in Greece. *Rural History*, 1/2, 147-164.

Hansen, J. 2000. Palaeoethnobotany and palaeodiet in the Aegean region: notes on legume toxicity and related pathologies, in: Vaughn S.J. and Coulson W.D.E (eds.). *Palaeodiet in the Aegean*. Oxbow Books: Oxford, 13-27.

Hastorf, C.A. 2017. *The social archaeology of food: thinking about eating from prehistory to the present*. New York: Cambridge University Press.

Hernández Bermejo, J.E. and León, J. 1994. *Neglected crops: 1492 from a different perspective.* Rome: Food and Agriculture Organisation of the United Nations.

Jaeger, M., Kulcsár, G., Taylor, N., Staniuk, R. (eds.) 2018. Kakucs-Turján, a Middle Bronze Age multi-layered fortified settlement in Central Hungary. Studien zur Archäologie in Ostmitteleuropa 18. Bonn: Dr. Rudolf Habelt GmbH.

Jones, G. 1996. Distinguishing Food from Fodder in the Archaeobotanical Record. *Environmental Archaeology*, 1, 95-98.

Jones, G. 2005. Garden cultivation of staple crops and its implications for settlement location and continuity. *World Archaeology*, 37/2, 164-176.

Juhász, I. 2007a. The pollen sequence from Alsópáhok, in: Zatykó, C., Juhász, I. and Sümegi, P. (eds.). *Environmental Archaeology in Transdanubia.* Budapest: Archaeological Institute of the Hungarian Academy of Sciences, 29-35.

Juhász, I. 2007b. Comparison and correlation of four pollen sequences from the Little Balaton region (Alsópáhok, Föneyd, Keszthely and Zalavár), in: Zatykó, C., Juhász, I. and Sümegi, P. (eds.). *Environmental Archaeology in Transdanubia.* Budapest: Archaeological Institute of the Hungarian Academy of Sciences, 36-50.

Juhász, I. and Szegvári, G. 2002. The pollen sequence from Mezőlak, in: Zatykó, C., Juhász, I. and Sümegi, P. (eds.). *Environmental Archaeology in Transdanubia.* Budapest: Archaeological Institute of the Hungarian Academy of Sciences, 316-325.

Kislev, M.E. 1989. Archaeobotanical findings on the origin of Lathyrus sativus and L. cicera, in: Kaul, A.K. and Combes, D. (eds.). *Lathyrus and Lathyrism*. New York: Third World Medical Research foundation, 46-51.

Körber-Grohne, U. 1987. *Nutzpflanzen in Deutschland : Kulturgeschichte und Biologie*. Stuttgart: Theiss.

Kordos, L. 1987. Climatic and ecological changes in Hungary during the last 15,000 years, in: Pésci, M. and Kordos, L. (eds.). *Holocene environment in Hungary: contribution of the INQUA Hungarian National Committee to the XIIth INQUA Congress*. Budapest: Geographical Research Institute Hungarian Academy of Sciences, 11-24.

Kreuz, A. and Marinova, E. 2017. Archaeobotanical evidence of crop growing and diet within the areas of the Karanovo and the Linear Pottery Cultures: a quantitative and qualitative approach. *Vegetation History and Archaeobotany*, 26/6, 639-657.

Kroll, H. 1991. Südosteuropa, in: Van Zeist, W., Behre, K.E. and Wasylikowa, K. (eds.). *Progress in Old World Palaeoethnobotany: A Retrospective View on the Occasion of 20 Years of the International Workgroup for Palaeoethnobotany*. Rotterdam: Balkema.

Kumar, S., Gupta, P., Barpete, S., Amri, A.S.A, Mathur, P.N. and Baum, M. 2013. Grass pea, in: Singh, M., Upadhyaya, H.D. and Bisht I.S. (eds.). *Genetic and Genomic Resources of Grain Legume Improvement.* Amsterdam: Elsevier, 269-292.

Liener, E.I. 1969 (ed.). *Toxic constituents of plant foodstuffs*. New York: Academic Press.

Magyari, E.K., Chapman, J.C., Passmore, D.G., Allen, J.R.M., Huntley, J.P. and Huntley, B. 2010. Holocene persistence of wooded steppe in the Great Hungarian Plain. *Journal of Biogeography*, 37, 915-935.

Marinova, E. and Valamoti, S.M. 2014. Crop diversity and choice in prehistoric southeastern Europe: cultural and environmental factors shaping the archaeobotanical record of northern Greece and Bulgaria, in: Chavalier, A., Marinova, E. and Peña-Chocarro, L. (eds.). *Plants and people: choices and diversity through time.* Oxford: Oxbow books.

Martson, J.M. 2011. Archaeological markers of agricultural risk management. *Journal of Anthropological Archaeology,* 30, 190-205.

Medović, A., Mikić, A., Ćupina, B., Jovanović, Ž, Radović, S., Nikolić, A. and Stanisavljević, N. 2011. Pisum & Ervilia Tetovac – Made in Early Iron Age Leskovac. Part One. Two Charred Pulse Crop Storages of the Fortified Hill Fort Settlement Hissar in Leskovac, South Serbia. *Field and Vegetable Crops Research*., 48, 219-226.

Merret, D.C. and Meiklejohn, C. 2015. Living in a Marginal Environment: Climate Instability and Possible Lathyrism in the Syrian Neolithic, in: Kerner, S., Dann, R.J. and Bangsgaard, P. (eds.). *Climate and Ancient Societies*. Copenhagen: Museum Tusculanum Press and University of Copenhagen, 245-266.

Miller, N.M. and Ennerking, D. 2014. Bitter vetch (*Vicia ervilia*): ancient medicinal crop and farmers' favorite for feeding livestock, in: Minnis, P.E. (ed.). *New lives for ancient and extinct crops*. Arizona: The University of Arizona Press, 254-268.

Nagy-Bodor, E., Járai-Komlódi, M. and Medve, A. 2010. Late glacial and post-glacial pollen records and inferred climatic changes from Lake Balaton and the Great Hungarian Plain, in:

Hart, M.B. (ed.). *Climates: Past and Present. Geological society special publications, no. 181.* London: Geological Society, 121-133.

Nicodemus, A.J. 2014. *Bronze Age economies of the Carpathian Basin: trade, craft production, and agro-pastoral intensification*. Dissertation, University of Michigan.

Palmer, C. and Van der Veen, M. 2002. Archaeobotany and the social context of food. *Acta Palaeobotanica*, 42, 2, 195-202.

Palmer, C. 1997. An Exploration of the effects of crop rotation regime on modem weed floras. *Environmental Archaeology*, 2,1, 35-48.

Peña-Chocarro, L. and Peña, Z.L. 1999. History and traditional cultivation of *Lathyrus sativus* L. and *Lathyrus cicera* L. in the Iberian Peninsula. *Vegetation History and Archaeobotany*, 8, 49-52.

Reed, K. 2013. *Farmers in Transition: The archaeobotanical analysis of the Carpathian Basin from the Late Neolithic to the Late Bronze Age (5000-900 BC).* Dissertation, School of Archaeology and Ancient History University of Leicester.

Riehl, S. 2008. Climate and agriculture in the ancient Near East: a synthesis of the archaeobotanical and stable carbon isotope evidence. *Vegetation History and Archaeobotany*, 17, Suppl 1, S43-S51.

Riehl, S. 2009. Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient Near East. *Quaternary International*, 197, 93-114.

Robson, A.D. 1999. The role of self-regenerating pasture in rotation with cereals in Mediterranean areas, in: Osman, A.E, Ibrahim, M.H. and Jones, M.A. (eds.). *The role of legumes in the farming systems of the Mediterranean areas.* Dordrecht/Boston/London: Kluwer Academic Publishers, 217-236.

Sadeghi, G.M., Pourreza, J. and Samei, A. 2009. Chemical composition and some anti-nutrient content of raw and processed bitter vetch (Vicia ervilia) seed for use as feeding stuff in poultry diet. *Tropical Animal Health and Production*, 41, 85-93.

Salunkhe, D.K. and Deshpande, S.S. 1991 (ed.). *Foods of plant origin: production, technology, and human nutrition*. New York: Springer Science+Business Media.

Sarpaki, A. 1992. The palaeoethnobotanical approach: The Mediterranean triad or is it a quartet?, in: Wells, B. (ed.). *Agriculture in ancient Greece. Proceedings of the Seventh International Symposium at the Swedish Institute at Athens, 16-17 May, 1990*. Stockholm: the Institute, 61-76.

Slasky, Y.M and Kislev, M.E. 2010. Lathyrus consumption in late Bronze and iron age sites in Israel: an Aegean affinity. *Journal of Archaeological Science*, 37, 2477-2485.

Smartt, J. 1990*. Grain legumes: evolution and genetic resources*. Cambridge: Cambridge University Press.

Somogyi, S. 1987. Relationship between environmental changes and human impact until the 9th century, in: Pécsi, M. and Kordos, L. (eds.). *Holocene environment in Hungary: contribution of the INQUA Hungarian National Committee to the XIIth INQUA Congress.* Budapest: Geographical Research Institute Hungarian Academy of Sciences, 25-36.

Stika, H.P. and Heiss, A.G. 2013. Bronzezeitliche Landwirtschaft in Europa: Der Versuch einer Gesamtdarstellung des Forschungsstandes. In: Willroth, K.H. (ed.). *Studien zur nordeuropäischen Bronzezeit, Band 1.* Neumünster: Wachholtz, 189-222.

Sümegi, P., Kertész, R. and Hertelendi, E. 2002. Environmental change and human adaptation in the Carpathian Basin at the late glacial/postglacial transition, in: Jerem, E. and Biró, K. (eds.). *Proceedings of the 31st International Symposium on Archaeometry.* Oxford: Archaeopress, 171-177.

Szeverényi, V. and Kulcsár, G. 2012. Middle Bronze Age settlement and society in Central Hungary, in: Jaeger, M., Czebreszuk, J. and Fischl, K.P. (eds.). *Enclosed space – open society: contact and exchange in the context of Bronze Age fortified settlements in Central Europe*. Poznań: Wydawnictwo Poznanskie, 287-351.

Tassede, W. and Bekele, E. 2003. Variation and association of morphological and biochemical characters in grass pea (Lathyrus sativus L.). *Euphytica*, 130, 315-324.

Valamoti, S.M. 2005. Grain versus chaff: identifying a contrast between grain-rich and chaff-rich sites in the Neolithic of northern Greece. *Vegetation History Archaeobotany*, 14, 259-267.

Valamoti, S.M. 2009. Plant food ingredients and 'recipes' from Prehistoric Greece: the archaeobotanical evidence, in: Morel, J.P. and Mercuri, A.M. (eds.). *Plants and Culture: Seeds of the Cultural Heritage of Europe*. Bari: Edipulia, 25-38.

Valamoti, S.M., Moniaki, A. and Karathanou, A. 2011. An investigation of processing and consumption of pulses among prehistoric societies: archaeobotanical, experimental and ethnographic evidence from Greece. *Vegetation History Archaeobotany*, 20, 381-396.

Van der Veen, M and Fieller, N. 1982 Sampling seeds. *Journal of Archaeological Science*, 9, 287-298.

Van der Veen, M. 2005. Gardens and fields: the intensity and scale of food production. *World Archaeology*, 37, 2, 157-163.

Van der Veen, M. 2010. Agricultural innovation: invention and adoption or change and adaptation? *World Archaeology*, 42, 1, 1-12.

Visy, Z. 2013 (ed.). *Hungarian archaeology at the turn of the millennium*. Budapest: Department of Monuments of the Ministry of National Cultural Heritage.

Zohary, D., Hopf, M. and Weiss E. 2012. 4th ed. *Domestication of plants in the Old World: the origin and spread of domesticated plants in south-west Asia, Europe and the Mediterranean Basin*. Oxford: Oxford University Press.

The fossil plant remains from the Early Bronze Age site of Rothenkirchen on the island of Rügen: spatial distribution patterns as a reflection of household activities

Almuth Alsleben[1]

Abstract

Until about three decades ago, the study of the North European Bronze Age Culture was an archaeology of the dead, focusing on single or groups of grave mounds – landmarks visible even today in many of the regions. In southern Scandinavia and the Netherlands, research on Bronze Age settlements improved because of the many excavated farmsteads and other settlement forms. In contrast, the comparable knowledge for northern Germany is limited. Early Bronze Age settlement structures have been uncovered in the course of rescue excavations, but only some were analysed archaeobotanically. The investigation of the prehistoric plant economy requires close collaboration with archaeology, and archaeologists have increasingly recognised this. According to the data compiled here on plant macrofossils from Bronze Age northern Germany, emmer wheat and barley were the basis of cereal cultivation in the entire area. The less frequently recovered crops, such as spelt wheat and naked or hulled barley, exhibit regional distribution patterns. The study of crop processing within a household, through patterns of spatial distribution, requires systematic sampling of excavated deposits. At Rothenkirchen, on the island of Rügen, excavations of a two-aisled house dated to about 1900 cal BCE generated an assemblage of plant macrofossils suitable for such analysis, which indicated different activity zones related to crop-processing and the preparation of plant foods. The western room was probably reserved for living, as suggested by the lack of plant remains, whereas the economic sphere was located in the central and eastern rooms.

Keywords: northern Germany, Rügen, Early Bronze Age, archaeobotany, crops, crop processing, two-aisled house

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Introduction

For a long time, research on the North European Bronze Age Culture was dominated by the study of burial mounds. The materials recovered from graves allow for the reconstruction of the private and social life of a community. Because grave mounds are highly visible landmarks even today, it is these archaeological features that have garnered most of the archaeologists' attention, and many of them have been excavated. Settlement structures were neglected, mostly due to the fact that it is difficult to detect traces of houses. Within the past few decades, however, the state of research has improved, most notably in southern Scandinavia and the Netherlands. This is one of the findings of a conference held in Kiel 2013, with the subject 'The Third Food Revolution … in Bronze Age Europe'. Many trends in economic and subsistence strategies only become apparent in northern Europe from the 16th century BCE onwards (Kneisel *et al.* 2015, Fig. 1, 2). From about the 13th or 12th century BCE, an expansion of the crop spectrum is observed. In particular, spelt wheat (*Triticum spelta)* has an early focus in the North (Effenberger 2018, Fig. 47). Bronze Age archaeology in northern Germany still lags behind. Some progress has been made over the course of investigations financed by the Akademie der Wissenschaften und der Literatur Mainz (Meier 2013; Klems in preparation). In addition, rescue excavations as part of the linear projects in Schleswig-Holstein and Mecklenburg-Vorpommern, such as the construction of a motorway or the north European gas pipeline, revealed mainly small portions of settlement structures but nonetheless gave interesting results (Schmidt 2013).

The discoveries show that the two-aisled house-type known from the Late Neolithic continued to be prevalent until Period I of the Early Bronze Age, resp. Older, Nordic Bronze Age,[3] that is, until 1500 BCE. In Denmark and Schleswig-Holstein, the transition to Period II is characterised by the appearance of a new house-type, the three-aisled building, which combined residential areas and a house-barn under one roof (Bech and Haack Olsen 2013; Ethelberg 2000, Fig. 15, 16, 22.1-4, 22.5). Similarities in construction types across the entire area of the North European Bronze Age Culture makes it appropriate to use the term *Hauslandschaft* (house landscape), according to Harsema (1997) (cited in Arnoldussen 2008, Fig. 5.17). Cattle stalling is archaeologically traceable through the preserved elements of cattle boxes (Bech and Haack Olsen 2013, Fig. 11a, b; Kučan 2007, Fig. 22). In the case of the Late Bronze Age house at Rodenkirchen, Landkreis Wesermarsch (Lower Saxony), the archaeobotanical remains allowed a clear distinction between the outdoor area, the indoor area of the barn and the residential area (Kučan 2007, Table 16-24). The remains (subfossil seeds and fruit) indicating grassland vegetation and the vegetation of fields and ruderal areas derived mainly from the outdoor area and, to some extent, from the area of the barn. The living space was more or less devoid of plant remains, and the few fossil grains and chaff remains were not taken as indicators of crop processing inside the house.

The main aim of analysing fossil and subfossil plant material from archaeological sites is to learn about the plants that were cultivated or gathered and how they were used by the community under study. For Bronze Age northern Germany, a broad understanding of these aspects has been achieved through some recent work (see below). The growing number of sites in the area that have undergone archaeobotanical study have offered a better-resolution picture of the occurrence and dis-

3 The terminology used for the chronology in different regions of the North might cause confusion. In the case of Rothenkirchen (Mecklenburg-Vorpommern), the following terms are used: Early Bronze Age (2200-1600 BCE), Middle Bronze Age (1600-1250 BCE), and Late Bronze Age (1250-800 BCE). In the case of Schleswig-Holstein and southern Scandinavia, the following terms are used: Late Neolithic/Earliest Bronze Age (SN/Period1, 2200-1500 BCE), Older Bronze Age (Period II-III, 1500-1050 BCE) and Younger Bronze Age (Period IV-VI, 1050-550 BCE).

tribution of certain crops in space and time. With regard to innovations in the plant economy, particularly in agriculture, intercultural contact zones may be defined. However, insights into crop processing practices on a micro level have remained limited, mostly because they very much depend on the varying preservation conditions at individual sites.

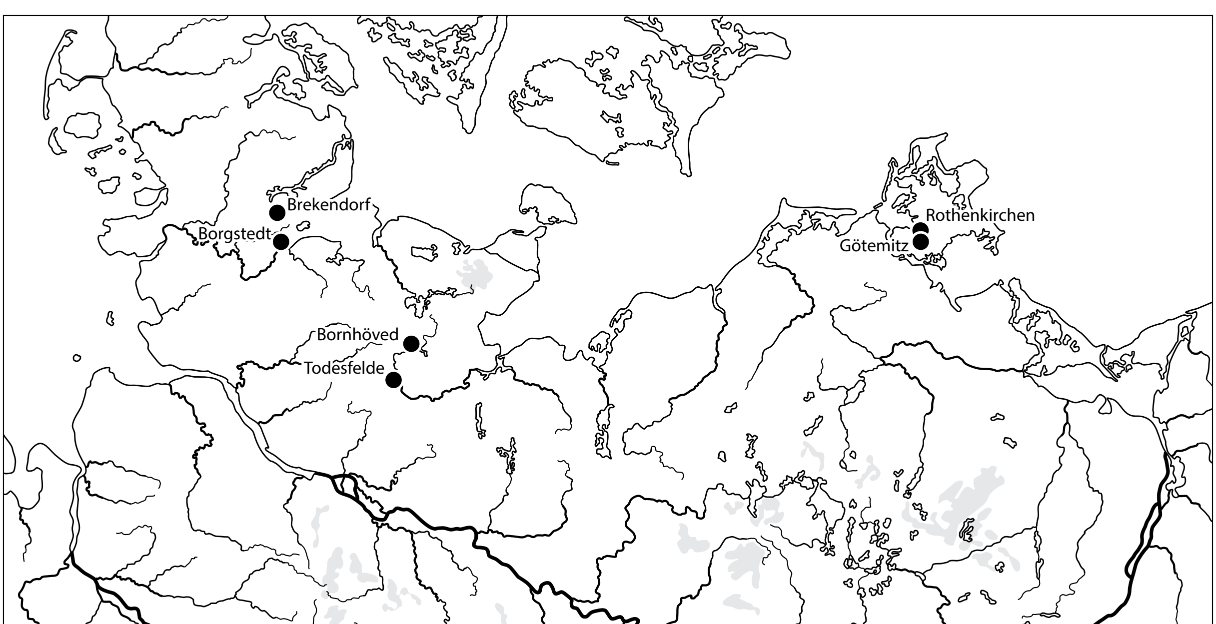
What are the possibilities offered by archaeobotanical data to address questions at the micro level? Assemblages composed of subfossil plant remains usually include many different species and, therefore, provide a good source for detailed qualitative considerations. Charred plant assemblages are less diverse because of the relatively small number of remains and because of the bias toward plants and plant parts that had a chance to come in contact with fire. Even more problematic are multi-phase sites where features from different phases abut or overlap. Here, taphonomic processes heavily reduce the level of detail possible in interpretation. This was, for example, the case with the site of Brekendorf, in Schleswig-Holstein (Alsleben 2013). The study undertaken by Robinson (2000, Fig. 6-9) on plant macrofossils from House IV at the site of Brødrene Gram, in Vojens, Denmark, represents a promising attempt at analysing the spatial distribution of charred plant remains. Robinson mapped discrete concentrations of grains and spikelets, as well as diaspores of wild plants (growing in arable fields and grassland), and this mapping revealed distinct distribution patterns. Inspired by this work, this paper presents the spatial distribution of archaeobotanical material within the Early Bronze Age house at Rothenkirchen, on the island of Rügen, and interprets it in terms of the location of zones where different plant-related activities likely took place.

The site of Rothenkirchen

The local landscape

It is worth considering the landforms and vegetation of the island and their development, since they may have influenced the plant economy of and resource availability for the prehistoric community of Rothenkirchen. The island of Rügen is located

Figure 1. Map showing the Bronze Age sites in Schleswig-Holstein and Mecklenburg-West Pomerania, northern Germany, discussed in the text.



on the south coast of the Baltic Sea (Fig. 1). Its landscape was transformed by the processes of transgression and isostatic land uplift, which led to great variation in coastal landforms, seen in the presence of cliffs, beaches, promontories, and lagoons. Just west of the peninsula of Jasmunder Bodden, a ground moraine of the last glaciation extending north-west-south-east divides Rügen into a hilly zone to the east and a mostly flat to gently undulating zone in the west. Boulder clay and marl plates alternate with areas under sandy soils and these support mixed woodland vegetation, including such species as hazel, lime, elm, and oak. The soil fertility values (Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern 2003: Fig. 3.6) show that the soils are of medium to good quality. Precipitation is highest in the upland areas, whereas the relatively dry lowlands along the coast receive 520-620 mm of water per annum (Lange *et al.* 1986, Fig. 1). Overall, the region would have been favourable for human occupation and would have offered a wide range of plant resources.

The archaeology of the island of Rügen and the site

More than 1200 grave mounds serve as evidence for the dense occupation of the island of Rügen during the Early Bronze Age (EBA). Until recently, however, little was known about the settlement with which the mounds were presumably linked. For the Late Bronze Age, different settlement patterns were proposed. The dense settlement of the peninsula of Jasmunder Bodden appeared to contrast with the lack of settlement in the areas to the west and near the south coast of Rügen. However, during salvage excavations in preparation for the construction of a motorway, the B96n, connecting the mainland with the island, archaeologists uncovered several sites in these areas, pointing to human use of the landscape also in the south-west (Saalow and Schmidt 2009, 69). These results offered new insights into the life of people on the island around 1900 BCE. Two of the excavated sites – Rothenkirchen and Götemitz – are situated at the western edge of a slightly rising plateau and in the immediate vicinity of the previously discovered nine grave mounds (known as the Neun Berge) that are today partly destroyed (Schmidt 2013, 129).

Most of the excavated sites are multi-phased, meaning that, in addition to the ground plans of EBA houses, the site also revealed more recent features, dated to the Pre-Roman and Roman Iron Age and to the early medieval period. Schmidt (2013) recorded and published layouts and absolute dates of the houses at Rothenkirchen and Götemitz. At Götemitz, four ground plans of houses from the Early Bronze Age and at least four from the Roman Iron Age were documented. Highly remarkable at this site is the cluster of 31 fireplaces south-west of EBA House 1, separated from it by an empty space. Despite the close vicinity, there is no direct connection between these two types of structures, because the fireplaces were dated to the Late Bronze Age (Schmidt 2013, 126-128, Fig. 7). The EBA house at Rothenkirchen was surrounded by pits created during the Late Bronze Age for the purpose of extracting clay. Additionally, inhumation graves from the Slavonic period (9th to 11th century AD) caused disturbance in the eastern part of this house (Schmidt 2013, 123-126, Fig. 4).

At both Rothenkirchen and Götemitz, the EBA houses were two-aisled and oriented north-west-south-east. The C14 dates – on charred wood from Götemitz and on charred grains of barley and emmer wheat and a rachis fragment of spelt wheat from Rothenkirchen – suggest that they were in use during the period 1900-2000 cal BCE (Schmidt 2013, Table 1, Fig. 6).

Analysis of the plant macro-remains

The archaeobotanical samples from both Götemitz and Rothenkirchen were made available for analysis. Unfortunately, the sampling of House 1 at Götemitz was not carried out systematically; in addition, the material consisted only of the residue larger than 5 mm (*i.e.* retained by a 5 mm sieve). Only a few grains of cereals, some pulses, and wild plant seeds embedded in the matrix were recovered, but these numbered too few to allow for interpretation. In total, there were nine hulled barley grains, two emmer wheat grains, six unidentified cereal grains, one unidentified pulse seed, two *Chenopodium album* seeds, and three *Vicia* spec. seeds.

Thanks to the systematic and careful sampling conducted by Klaus Hirsch at Rothenkirchen, a rich fossil assemblage of seeds and fruits was recovered from the EBA house, reflecting the plant economy of the members of this household. In total, 178 samples of unknown volumes were processed by manual flotation. No plant remains were found in 73 of these samples; the other 105 did yield material, ranging from many to few finds. The samples originate from the holes of the wall and roof posts, as well as from pits and structures of unspecified nature adjacent to the house. The samples from the 'outside' structures contained few or no plant remains. Postholes in the north half of the house were preserved as patches of dark soil visible on the surface, but it proved impossible to take soil samples from these features. Poor preservation of plant material is typical of Bronze Age settlements on dry soils in this region. Still, when taken as a whole, the remains can offer a useful picture of the plant economy of the time.

The seeds and fruits were identified to the species level where possible and counted; the results are listed in Table 1. The taxa are grouped into cultivated plants, *i.e.* cereals, other food plants, wild plants of anthropogenic habitats (arable and ruderal), and wild plants characteristic of grassland vegetation. The nomenclature follows Oberdorfer (1990). More than half (n=62) of the remaining samples were very poor in palaeobotanical remains. In Table 1, they were combined and considered as two groupings. The first (subtotal 1) combines those samples with at least some identifiable cereal grains; the second (subtotal 2) combines those samples containing only grains that could not be further identified. The assemblages of these two combined samples fit into the EBA cereal spectrum, but they are not suitable for any further interpretation. For each taxon, absolute (n) and relative (n%) numbers and frequency of occurrence are given in the table. Over 40 per cent of the cereal grains could not be identified to species level due to their poor state of preservation. The Cerealia indeterminata grains were added to the more precisely identified cereal grain categories according to their proportional representation in the plant material (n% corr.).

Cultivated plants

Pulses, oil plants, vegetables, herbs, fruits, and nuts form an important part of many human diets, but this diversity is hardly ever fully reflected in the amount and composition of fossil plant material from prehistoric sites. In the samples from Rothenkirchen, only one pea, six hazelnuts and one raspberry were discovered, an important indication of their presence but not of their place in the plant food menu (Table 1). However, one can assume that many more edible wild fruits, encompassing a greater diversity of species, were collected by the site's occupants.

In order to come close to understanding the plant economy of the Bronze Age residents of Rothenkirchen, one has to turn to the much more prominent remains of cereals (Table 1, Fig. 2). As shown in Table 1, it appears that emmer wheat (*Triticum dicoccum*) played the role of the major cultivated crop. It occurs in nearly half of the examined features, and it dominates the overall crop content, comprising over

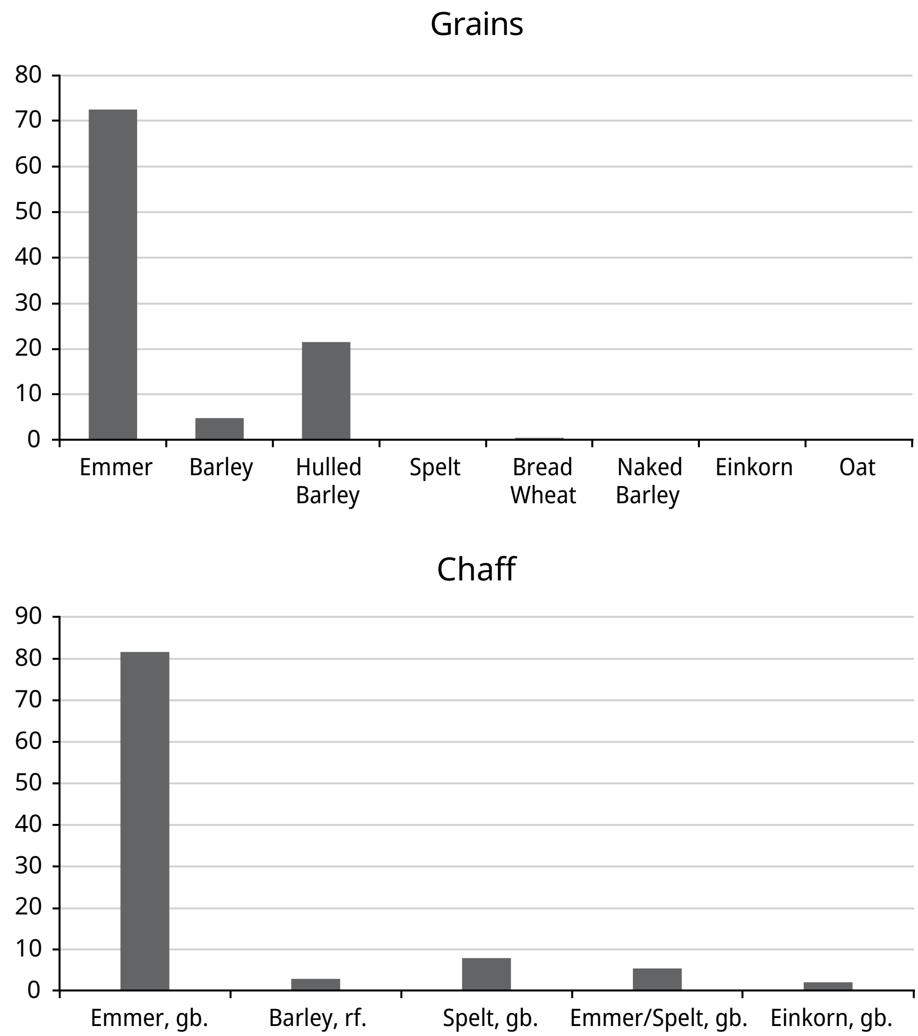


Figure 2. Rothenkirchen, Rügen. Relative proportions of cereal remains (gb = glume bases, rf. = rachis fragments).

70 per cent of it. In terms of both quantity and frequency, hulled barley (*Hordeum vulgare vulgare*) comes second. Both cereals were typical for the Neolithic in northern Europe, and their role as principal cereals seems to have also characterised the economy of the Bronze Age. Naked barley (*Hordeum vulgare nudum*) and einkorn (*Triticum monococcum*) seem to have always been of lesser importance. This distinguishes northern German plant husbandry from Scandinavian plant husbandry of the period, since naked barley was the dominant crop in Scandinavia, and it continued to have this status even in the Younger Bronze Age (Effenberger 2017, Fig. 5).

There were also grains of free-threshing wheat in the samples, most likely bread wheat (*Triticum aestivum*). Cultivation of durum wheat (*Triticum durum/turgidum*) cannot be excluded, since findings of the fossil rachis fragments have been reported for some Funnel Beaker culture sites in Denmark and northern Germany (Kirleis and Fischer 2014, Table 1). However, rachis fragments, which are the only parts of the plant that allow for clear differentiation between these two types of free-threshing wheat, are lacking at Rothenkirchen. Bread wheat is almost ubiquitous at prehistoric sites in the North, but it is present only in very low numbers. It is a highly demanding crop in terms of the quality of the soil in which it can grow, and this may have limited its cultivation potential in the wider region, although soils on Rügen would likely have ensured successful farming.

Spelt wheat (*Triticum spelta*) is as productive as free-threshing wheat, but less demanding in terms of growing conditions (*e.g.* soil properties). For instance, freezing temperatures have no negative effect on the growth of this plant. Therefore it can be cultivated in the north, where late spring frosts are to be expected. Also, unlike is the case with free-threshing wheat, crop rotation is not necessary; it is possible to crop the same field with spelt for several years in a row. Grains of spelt are poor in diagnostic morphological characteristics, and spikelet forks or glume bases are needed for accurate taxonomic identification. At Rothenkirchen, glume bases of spelt make up 8 per cent of the chaff (glume bases and rachis fragments), which can be taken as an indication of the importance of spelt in the plant economy from very early on in this period. The finds are dated to 1984-1876 cal BCE (glume base of spelt wheat, KIA37002, 3571±30 BP) and represent the earliest appearance of spelt on the southern Baltic coast known to date. This may coincide with the early appearance of spelt in Denmark and southern Sweden (Effenberger 2018, Fig. 31, 32). The temporal distribution of spelt in northern Germany is uneven. The ^{14}C dates on spelt remains from Todesfelde and the nearby site of Bornhöved, both located in southern Schleswig-Holstein (Fig. 1), differ by several hundreds of years. Rich finds of fossil spelt in two houses at Todesfelde were dated to the Late Neolithic/Early Bronze Age Period I (Effenberger 2018, Table 3). In Bornhöved, the burial mound (LA18) covered postholes containing remains of emmer and spelt dated to Period II, *i.e.* the Early Bronze Age (Alsleben unpublished data, 2013, 236). In northern Schleswig-Holstein, the site of Borgstedt (Period I/II), where five houses were excavated, did not yield any spelt remains (Alsleben unpublished data; Klems in preparation). Spelt was part of the cereal assemblage retrieved from three large houses at the site of Brekendorf of Period II/III (Alsleben 2013, Fig. 5).

Wild plants

Cultivated plants are often subjected to intensive care by humans and, therefore, do not need to compete with the native flora. That is why they could extend their habitat beyond the areas of their ecological optimum. Wild plants are more sensitive to variable climatic and edaphic conditions. In an anthropogenically modified environment, the latter factor determines the distribution and success of wild species. Changes in the fertility and moisture of soils, combined with the frequency and timing of disturbance of the soil, led to the development of certain plant communities adapted to the new growing conditions. Many annual plants are able to survive in highly disturbed environments, such as intensively cultivated arable fields, whereas perennials, which spread via adventitious roots or rhizomes, can survive in the gaps between the furrows created for sparsely sown crops.

Compared with the other Bronze Age sites in the region, the fossil plant material from Rothenkirchen is extremely poor in the diaspores of wild plants (Table 1). At Brekendorf, for instance, wild plants represented 40 per cent of the entire assemblage (Alsleben 2013, Table 2), whereas their proportion at Rothenkirchen is below 10 per cent. Crop processing – threshing, sieving, and winnowing – must have been done outside the house, and only the semi-cleaned crop product was brought to the house, meaning grains in the case of barley and spikelets in the case of emmer and spelt wheat (Jacomet and Kreuz 1999, Fig. 11.10, 11.11).

The wild plants identified from the site commonly occur in areas affected by human activity, such as fields and paths and the ground in and around farmsteads. The dominant species are fat hen *Chenopodium album* and redshank *Polygonum persicaria*. Both appear regularly in fossil plant assemblages. Some of the annuals documented at Rothenkirchen may indicate nutrient-poor and sandy soils; these are red sorrel *Rumex acetosella,* green foxtail *Setaria viridis,* annual knawel *Scleranthus annuus,* and corn spurry *Spergula arvensis*. Rothenkirchen is located in the area of transition from the boulder clay zone to the morainic sandy plains, and this could perhaps explain the presence of these particular plants. On the one hand, working the soil in such areas tends to be much easier than it is in areas covered with heavy clay; on the other, rapid eluviation of nutrients can cause problems, and crop fields often have to be relocated. Even so, the Bronze Age communities in the North seem to have preferred this border zone between the two distinct geological areas, at least based on the high number of sites found here, as indicated in the map showing the excavated Bronze Age sites in Schleswig-Holstein published by Effenberger (2018, Fig. 1).

The distribution of crops in Early Bronze Age House 1

In the study of fossil cereal assemblages, it is necessary to bear in mind that spelt wheat and free-threshing cereals require different post-harvest processing procedures. After the harvest, probably ears and straw (*i.e.* not separated) were brought to threshing floors, potentially located in courtyards. Products of the threshing are grains in or out of the husks, spikelets, rachis, and straw. In the case of free-threshing wheat and barley, grain is released from the husk during threshing, whereas in spelt wheat, grains remain in the spikelet after threshing. After winnowing and coarse sieving, straw and chaff would have been left outdoors. The grain/spikelets would have been brought into the house and stored there. Preparation of plant food likely took place indoors and involved dehusking (in the case of spelt wheat), sieving, hand cleaning, and then possibly grinding of grain and baking of bread, cooking of groats or mush, and so on. These processes may have taken place on a daily basis, whereby small quantities of semi-cleaned grain were taken from storage before the meal was prepared. By-products of crop cleaning were most likely thrown into domestic fires. Glume bases are quite hard, and they tend to survive exposure to fire. Therefore, charred spikelet forks and glume bases are frequent elements of plant macrofossil assemblages.

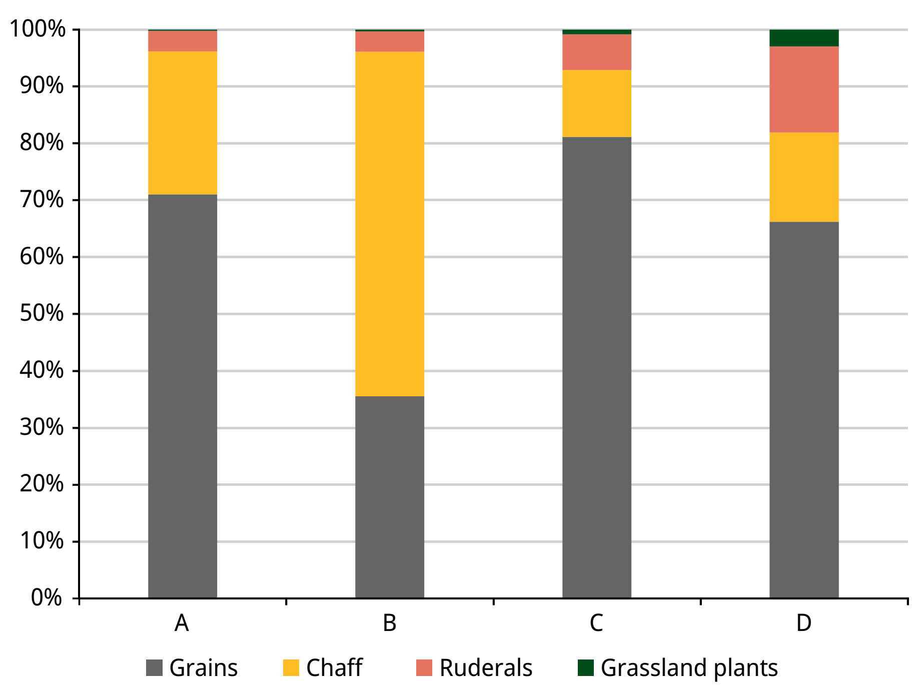


Figure 3. Rothenkirchen, Rügen. Relative proportions of different groups of plant macrofossils. A: Samples rich in grains of emmer; B: Samples rich in chaff fragments of emmer and spelt; C: Samples rich in grains of barley; D: samples with very small numbers of remains.

The fossil plant material from Rothenkirchen can be classified into four groups according to the proportions of grain, chaff, and diaspores of ruderals and grassland plants (Fig. 3). Samples in group A are dominated by grains and chaff of emmer, while they also contain small amounts of spelt and barley. Group B is characterized by a high percentage of chaff of emmer, spelt, and barley. In Group C, as well as the omnipresent emmer, barley grains are also abundant. Group D combines some 62 samples that are poor in remains and thus do not offer any additional information (as described above). The bar charts (Fig. 3) also clearly show a minor presence of the remains of wild plants.

Only two thirds of the features in the EBA house at Rothenkirchen contained some seed and fruit material (Table 1). With the exception of a single, very deep posthole, little archaeobotanical material was recovered from the north-west half of the excavated area, offering few archaeobotanical information for this part of the house. At Rothenkirchen, five samples containing more than 500 cereal remains can be understood as traces of former storage deposits. The argument for this is based on two observations. Compared with the usual very low absolute numbers of finds, the presence of 500 items in a single sample stands out and therefore requires an explanation. The calculated weight of 1000 grains (WTG) is also noticeable high. Two of these samples (from features 115 and 170) did not derive directly from the area of House 1. In both, emmer was the main component, accompanied by a small quantity of barley. The WTG of the emmer grains is 17.1, resp. 18.3 g. The samples consist of emmer grains and glume bases in a ratio of *c.* 3:1, suggesting that this crop was stored in the form of spikelets. Another three storage deposits were found inside the house. In the samples from features 67 and 344, emmer is mixed with spelt. Again, the emmer product consists of spikelets, whereas the spelt was left as glume bases. Due to identification difficulties, grains of spelt are hardly ever documented in Bronze Age crop assemblages. But it can be assumed that they were there. The ratio of spelt to emmer glume bases (1:5, resp. 1:4) can be used to calculated the proportion of these two grains. The two crops may have been mixed accidentally, but it is more likely that a combination of the two grew in the same field – with spelt being an accidental but tolerated inclusion in a standing crop of emmer. The possibility that spelt may have been cultivated as a crop in its own right has been highlighted for this period, and the situation may have differed among the sites (Effenberger 2018, 96-97). The last big grain deposit is a store of barley with an admixture of emmer. Here, the weight of emmer grains (WTG 11.3 g) is lower, likewise indicating that emmer was not the main crop.

Between the two extremes – the samples very poor in macro-remains and the possible crop stores – a group of 17 samples was selected that yielded enough material to allow for an analysis of the plant economy within the household under study. For the analysis of their spatial distribution, the samples were grouped according to the zone from which they originated within House 1 (Table 2). The richest of these samples come from the holes for roof posts and the holes for posts of the south-west and north-east walls. Emmer grain and glume bases predominate. The other crops show a distinctive distribution pattern within the house plan (Fig. 4). The central area of the house is characterised by a significant presence of emmer and an absence of barley. The greatest numbers of emmer remains are found in posthole 67 and the combined holes 344/345. Spelt wheat, represented only in the form of glume bases, is also found in the central area (features 67 and 344/345), as well as in the hole of a post making up the south wall (Feature 51). The concentration of barley is located in a posthole in the northern part of the building (feature 337), and this is the only such find in this house. Another, but smaller barley accumulation was found near the south-east wall. The most interesting observations relate to the part of the north-east wall between two of the entrances to the house. Here, numerous glume bases of emmer and spelt wheat were found (with emmer being the more numerous) and

	Emmer wheat, spelt wheat rich in grains and chaff							Emmer wheat, spelt wheat rich in chaff									Barley rich in grains							
Feature	**67**	**115**	**170**	**344**	**345**	**55**	**51**	**70**	**73**	**71**	**72**	**50**	**52**	**207**	**322**	**49**	**337**	**347**	**57**	**53**	**58**	**201**	**34**	**191**
Number of taxa	13	11	8	13	6	17	10	11	7	11	10	9	8	7	5	6	10	8	6	5	8	8	6	16
Total plant macrofossils (n)	1400	742	658	632	304	409	311	535	195	191	98	151	146	75	66	57	569	106	82	84	114	74	45	46
Subtotal cereals (n)	1381	729	655	617	301	297	299	525	187	177	95	145	137	71	65	53	555	99	76	79	89	70	42	28
Subtotal wild plants (n)	19	12	3	14	3	110	12	10	8	14	3	6	9	4	1	4	14	7	6	5	25	4	3	16
A: Cereals, grain																								
Triticum dicoccum	485	294	233	224	137	89	88	12	8	14	3	48	39	19	33	31	77	18	14	18	29	24	2	1
Hordeum vulgare	.	.	.	.	2	.	9	6	3	13	4	.	11	8	1	1	.	.	.	.	12	7	23	.
Hordeum vulgare vulgare	36	35	18	23	.	67	4	.	.	.	5	7	.	.	.	.	296	37	19	17	6	.	.	13
Triticum spelta	.	cf.2	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Triticum aestivum s.l.	cf.3	cf.1	.	cf.4	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	cf.2	.
Hordeum vulgare nudum	.	.	3	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Triticum monococcum	.	.	.	.	.	.	.	.	2	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Avena spec.	.	.	.	cf.1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2
Cerealia indet.	375	203	298	217	128	81	102	12	10	24	9	72	67	29	26	16	115	35	26	33	25	31	14	10
Sum of grains	**899**	**535**	**552**	**469**	**267**	**237**	**203**	**30**	**23**	**52**	**22**	**129**	**117**	**56**	**60**	**48**	**488**	**90**	**59**	**68**	**72**	**62**	**42**	**26**
Cereals, chaff																								
Triticum dicoccum, gb.	290	172	88	117	33	56	74	466	153	83	65	16	15	14	5	5	42	7	17	11	17	7	.	2
Hordeum vulgare, rf.	2	19	.	1	.	.	.	14	4	2	2	.	.	.	.	.	20	.	.	.	.	.	.	.
Triticum spelta, gb.	52	cf.1	11	30	.	cf.1	17	15	7	31	4	.	3	.	.	.	5	2	.	.	.	.	.	.
Triticum dicoccum/spelta, gb.	122	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Triticum monococcum, gb.	cf.16	2	4	.	1	4	5	.	.	9	cf.2	.	2	cf.1	.	.	.	.	.	.	.	cf.1	.	.
Sum of chaff	**482**	**194**	**103**	**148**	**34**	**61**	**96**	**495**	**164**	**125**	**71**	**16**	**20**	**14**	**5**	**5**	**67**	**9**	**17**	**11**	**17**	**8**	**0**	**2**
B: Further food plants																								
Pisum sativum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Leguminosae sativae indet.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Corylus avellana	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Rubus idaeus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sambucus nigra, subfoss.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sum of further food plants	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
C: Wild Plants																								
Plants of arable fields + ruderals																								
Chenopodium album	6	3	.	5	1	36	5	1	.	.	1	2	3	2	.	2	3	3	.	.	16	.	.	.
Polygonum persicaria-type	8	.	2	5	2	25	.	2	.	9	.	1	.	1	1	1	5	.	1	1	5	1	.	1
Polygonum convolvulus	2	1	.	2	.	2	2	1	.	1	.	.	.	.	.	.	.	2	.	.	.	1	.	.
Vicia-type	1	.	.	.	.	.	1	3	3	1	1	2	.	.	.	.	.	.	1	.	.	.	.	2
Rumex acetosella	2	.	.	1	.	38	4	1	.	.	.	.	5	.	.	.	.	1	4	4	3	.	.	4
Polygonum aviculare	.	.	1	.	.	2	.	.	.	1	.	1	1	.	.	.	1	.	.	.	1	.	.	.
Galium spurium	.	.	.	.	.	2	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	4
Polygonaceae	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Setaria viridis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	cf.1
Trifolium-type	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.
Plantago lanceolata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rumex crispus-type	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poa annua	.	.	.	.	.	.	.	1	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scleranthus annuus	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Spergula arvensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Atriplex spec.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sum of arable fields + ruderals	**19**	**4**	**3**	**14**	**3**	**106**	**12**	**9**	**8**	**12**	**3**	**6**	**9**	**3**	**1**	**3**	**11**	**7**	**6**	**5**	**25**	**2**	**0**	**14**
Grassland plants																								
Poaceae	.	.	.	.	.	1	.	.	.	2	.	.	.	.	.	1	3	.	.	.	.	1	.	1
Bromus spec.	.	8	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	3	1
Lolium spec., small-seeded	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex 2 spec.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex 3 spec.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cladium mariscus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eleocharis spec.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Molinia caerulea, rhizome	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stellaria palustris-type	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Sum of grassland plants	**0**	**8**	**0**	**0**	**0**	**4**	**0**	**1**	**0**	**2**	**0**	**0**	**0**	**1**	**0**	**1**	**3**	**0**	**0**	**0**	**0**	**2**	**3**	**2**

Table 1. Rothenkirchen, Rügen. Absolute and relative number of fossil plant remains, frequency of occurrence, and number of taxa per sample. gb. = glume base, rf. = rachis fragment.

	Non-specific cereal collections relatively poor																			Subtotal 1	Subtotal 2	Frequency	Total (n)	n%	n% corr.
Feature	**48**	**56**	**59**	**60**	**61**	**65**	**66**	**68**	**74**	**75**	**76**	**145**	**165**	**166**	**205**	**206**	**208**	**209**	**346**	**31 samples**	**31 samples**	**105 samples**	**105 samples**		
Number of taxa	4	6	3	4	5	8	4	4	4	5	2	6	4	6	5	3	6	3	5						
Total plant macrofossils (n)	23	43	3	10	10	78	8	36	14	5	4	33	11	24	23	8	46	5	14	123	114		7724	=100%	
Subtotal cereals (n)	22	36	3	10	9	75	8	35	13	2	4	28	10	22	21	7	43	4	9	100	55		7287	94.3	
Subtotal wild plants (n)	1	7	0	0	1	3	0	1	1	2	0	5	1	2	2	1	3	1	5	19	59		426	5.5	
A: Cereals, grain																									
Triticum dicoccum	12	16	.	4	2	11	3	14	1	.	.	.	3	9	6	2	13	.	3	24	.	49	2063	41.0	72.8
Hordeum vulgare	.	.	1	.	.	12	.	.	.	1	.	.	1	1	1	.	.	2	1	17	.	32	137	2.7	4.4
Hordeum vulgare vulgare	1	5	.	3	.	.	1	2	.	.	.	.	.	.	.	.	5	.	.	13	.	26	613	12.2	21.7
Triticum spelta	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	0.1	0.1
Triticum aestivum s.l.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	13	0.3	0.5
Hordeum vulgare nudum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	4	0.1	0.1
Triticum monococcum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	3	0.1	0.1
Avena spec.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	4	0.1	0.1
Cerealia indet.	9	12	1	2	4	41	3	12	4	1	2	3	6	7	7	5	18	2	4	34	55	84	2190	43.5	-
Sum of grains	**22**	**33**	**2**	**9**	**6**	**65**	**7**	**28**	**5**	**2**	**2**	**3**	**10**	**17**	**14**	**7**	**36**	**4**	**8**	**88**	**55**		**5030**	**=100%**	
Cereals, chaff																									
Triticum dicoccum, gb.	.	3	1	1	2	10	1	7	8	.	2	25	.	5	7	.	7	.	1	9	.	44	1843	81.7	
Hordeum vulgare, rf.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	10	66	2.9	
Triticum spelta, gb.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	13	179	7.9	
Triticum dicoccum/spelta, gb.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	122	5.4	
Triticum monococcum, gb.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11	47	2.1	
Sum of chaff	**0**	**3**	**1**	**1**	**3**	**10**	**1**	**7**	**8**	**0**	**2**	**25**	**0**	**5**	**7**	**0**	**7**	**0**	**1**	**12**	**0**		**2257**	**=100%**	
B: Food plants																									
Pisum sativum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1		
Leguminosae sativae indet.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2		
Corylus avellana	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	2	.	6	6		
Rubus idaeus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	1		
Sambucus nigra, subfoss.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	1		
Sum of food plants	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**0**		**11**		
C: Wild Plants																									
Plants of arable fields + ruderals																									
Chenopodium album	.	4	.	.	.	.	.	.	.	1	.	2	.	1	1	1	1	.	4	9	6	34	119	31.5	
Polygonum persicaria-type	.	2	.	.	1	1	.	1	.	.	.	.	1	1	.	.	.	.	1	1	4	27	84	22.0	
Polygonum convolvulus	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	1	.	.	.	5	15	22	5.6	
Vicia-type	.	.	.	.	.	.	.	.	1	.	.	.	.	.	1	.	.	.	.	1	2	14	20	5.3	
Rumex acetosella	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	12	69	18.3	
Polygonum aviculare	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	11	12	3.2	
Galium spurium	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	17	9	26	6.9	
Polygonaceae	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	6	6	1.6	
Setaria viridis	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	2	.	3	4	1.1	
Trifolium-type	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1	3	4	1.1	
Plantago lanceolata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	0.5	
Rumex crispus-type	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	2	2	0.5	
Poa annua	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	6	1.6	
Scleranthus annuus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	2	0.5	
Spergula arvensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	0.3	
Atriplex spec.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	0.3	
Sum of arable fields + ruderals	**1**	**7**	**0**	**0**	**1**	**2**	**0**	**1**	**1**	**1**	**0**	**4**	**1**	**2**	**2**	**1**	**3**	**1**	**5**	**15**	**47**		**380**	**=100%**	
Grasland plants																									
Poaceae	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	1	8	11	24.4	
Bromus spec.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	4	4	13	23	48.9	
Lolium spec., small-seeded	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	2.2	
Carex 2 spec.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	1	2.2	
Carex 3 spec.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	2.2	
Cladium mariscus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	2	4.4	
Eleocharis spec.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	2	4.4	
Molinia caerulea, rhizome	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1	3	6.7	
Stellaria palustris-type	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2	4.4	
Sum of grassland plants	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**12**		**46**	**=100%**	

Table 1 (continued). Rothenkirchen, Rügen. Absolute and relative number of fossil plant remains, frequency of occurrence, and number of taxa per sample. gb. = glume base, rf. = rachis fragment.

	Roofbearing postholes						South-west wall								North-east wall			
Feature	**65**	**67**	**322**	**344/345**	**337**	**347**	**50**	**51**	**52**	**207**	**53**	**55**	**57**	**58**	**70**	**71**	**72**	**73**
Total plant macrofossils (n)	78	1400	66	936	569	106	151	311	146	75	84	409	82	114	535	191	98	195
Subtotal cereals (n)	75	1381	65	918	555	99	145	299	137	71	79	297	76	89	525	177	95	187
Subtotal wild plants (n)	3	19	1	17	14	7	6	12	9	4	5	110	6	25	10	14	3	8
Grains																		
Triticum dicoccum	11	485	33	361	77	18	48	88	39	19	18	89	14	29	12	14	3	8
Hordeum vulgare	12	.	1	2	.	.	.	9	11	8	.	.	.	12	6	13	4	3
Hordeum vulgare vulgare	.	36	.	23	296	37	7	4	.	.	17	67	19	6	.	.	5	.
Triticum spelta	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.
Triticum aestivum	1	cf.3	.	cf.4	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Cerealia indet.	41	375	26	345	115	35	72	102	67	29	33	81	26	25	12	24	9	10
Chaff																		
Triticum dicoccum, gb.	10	290	5	150	42	7	16	74	15	14	11	56	17	17	466	83	65	153
Hordeum vulgare, rf.	.	2	.	1	20	.	.	.	.	.	.	.	.	.	14	2	2	4
Triticum spelta, gb.	.	52	.	30	5	.	.	17	3	.	.	cf.1	.	.	15	31	4	7
Triticum dicoccum/spelta, gb.	.	122	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.
Triticum monococcum, gb.	.	cf.16	.	1	.	.	.	5	2	cf.1	.	4	.	.	.	9	cf.2	.

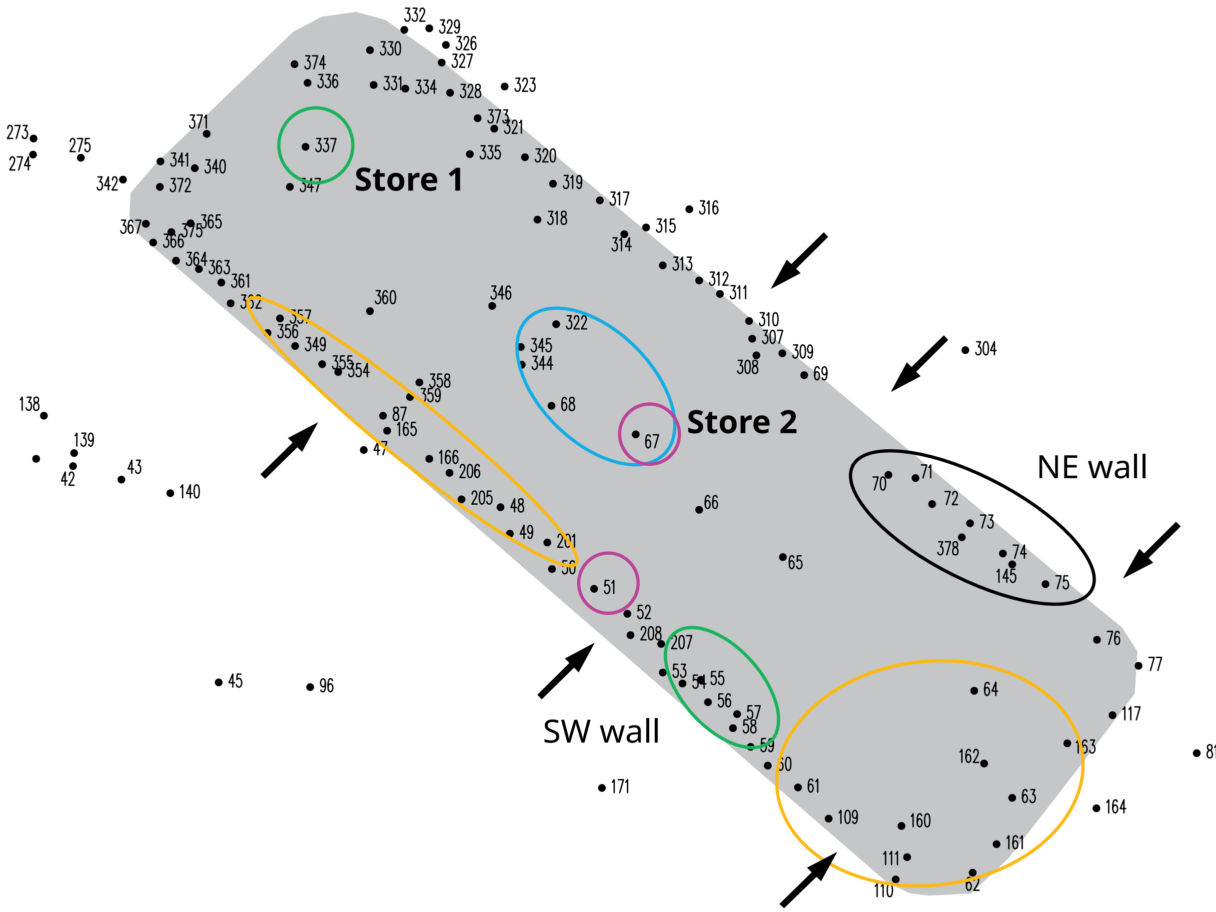
Table 2. Rothenkirchen, Rügen. Samples rich in cereal remains grouped according to their location of origin in House 1. gb. = glume base, rf. = rachis fragment.

almost no grains. Even rachis segments of barley, which are rare in the assemblage, are present in the samples from this zone.

In summary, plotting of the archaeobotanical data onto the plan of the house shows that (1) emmer is evenly distributed; (2) spelt in grain-rich samples is confined to the central area of the house, and spelt in chaff-rich samples is confined to the north-east wall; (3) small amounts of barley are generally distributed, and concentrations of it are found at the northern and south-western ends of the house; (4) chaff of emmer, spelt, and barley is concentrated along the north-east wall (Fig. 5).

Discussion

North European longhouses of the Older/Early Bronze Age were, with some minor variations, very similar in design. They were two-aisled and had two or more entrances in each of the long outside walls. Often a division into three 'rooms' is discernible. The development of the three-aisled house, around 1500 BCE, led to uniformity in the architecture. The most significant change was the inclusion of a byre in the eastern part of the house, which may be evidenced archaeologically, by elements of cattle boxes, or physically, by increased soil phosphate levels. At Brekendorf, Schleswig-Holstein, Meier (2013, Fig. 12) uses measured phosphate values to argue for the existence of a barn in House 4. In theory, it can also be evidenced by archaeobotanical remains. However, the chances of fodder plants and straw being preserved archaeologically are low, because their taphonomic pathway rarely



involves the necessary charring or subfossil preservation. An exception is the site of Rodenkirchen, which had subfossil preservation (Kučan 2007, Fig. 22, Table 16-24).

As material culture evidence and furnishing is missing, it is unknown if internal organisation of households followed the trend of uniformity in architecture. Andreasen (2011, cited in Grundvad *et al.* 2015) addressed that question when she compared Bronze Age houses of periods I to III in Jutland, Denmark. Jutland has a long tradition of settlement investigation, which has resulted in a large amount of archaeobotanical data. Spatial distribution within houses was analysed for the sites of Nørre Holsted (Grundvad *et al.* 2015), Kongehøj (Andreasen 2011), Frejlevgård (Jensen 2017), Brødrene Gram (Robinson 2000), and Bjerre (Henriksen *et al.* 2018). Andreasen noted a lot of variability in the assemblages, which were comprised of cereal grains, chaff, and wild plant species, and she noted that this variability requires more detailed investigation. However, some general results can be extracted from her compilation. (1) The western part of the houses is poor in fossil plant remains. (2) The eastern part is rich in finds, mainly cereal grain and/or chaff (sunken floors are often present in this part, probably to enlarge storage facilities; this functional interpretation may be supported by the fact that, here, the density of fossil grains is often high. (3) The central room is often rich in grain, chaff, and wild plants.

At Todesfelde, Schleswig-Holstein, Effenberger (2018, 26-33) came up with similar results for House 2. Although this house had no sunken floor, it did have a thick burnt layer containing charred cereal grains. Effenberger assumes that, as a result of the fire, a collapsing wall buried the cereal that was stored on the upper floor. The other sites in Schleswig-Holstein, Brekendorf (Alsleben 2013) and Borgstedt (Alsleben unpublished data), yielded no data pertinent to this issue.

Figure 4. Rothenkirchen, Rügen. Distribution of cereal assemblages in House 1 (see Table 2). Yellow: samples poor in palaeobotanical remains; black: samples with a concentration of glume bases of emmer and spelt; turquoise: samples dominated by emmer; pink: samples with a relatively high quantity of spelt; green: samples with a relatively high quantity of barley. Traces of cereal stores were found in features 67 and 337. Orientation to the north. Arrows mark presumed entrances. House 1 measurements: length: 21m, width 6m.

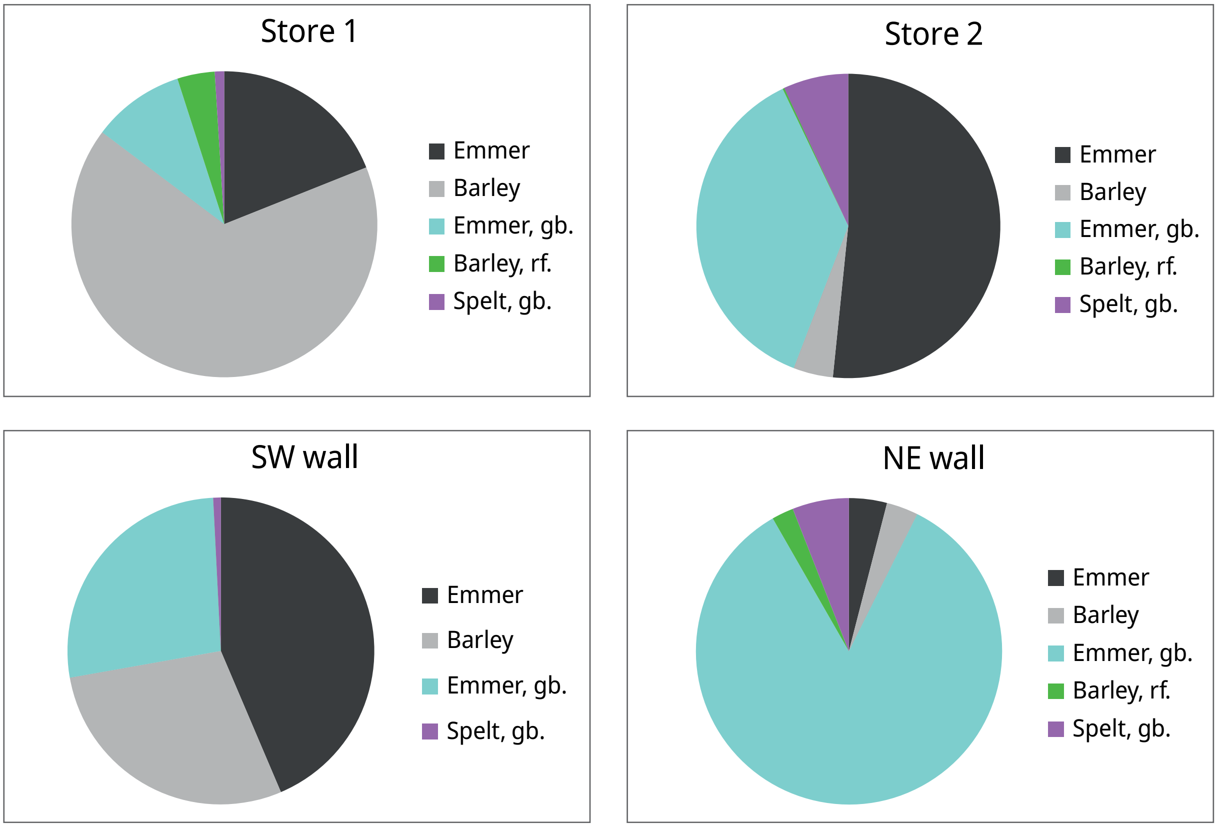


Figure 5. Rothenkirchen, Rügen. Selected cereal assemblages in House 1 (see Table 2). The pie charts combine grain and chaff. Black, grey: grains; turquoise, green, violet: chaff. gb. = glume base, rf. = rachis fragment.

The internal organisation of House 1 at Rothenkirchen shows some deviation from the other EBA houses. As is the case in the other houses, its western part lacks fossil plant remains, but it contained a single store of barley. The central part is similar to the Danish houses. Again, the eastern part differs, in that it has no evidence for a grain store, but it did contain chaff. There are several possible interpretations for the chaff, as residue of crop processing, either outside (but near) or inside the house, or as residue of straw covering the floor.

Summary and conclusions

House 1 at Rothenkirchen was classified as a two-aisled house typical of the Older/Early Bronze Age in Scandinavia, northern Germany, and the Netherlands. The available archaeological data did not reveal any details of the interior organisation of the household, such as the presence and/or location of fireplaces or pits. For this reason, the interpretation of the archaeobotanical data from a spatial/contextual perspective that is attempted here could not be tested against the information from archaeological features and the material culture evidence.

The primary information obtained from cereal remains from settlement sites gives an insight into the spectrum of crops grown and used by prehistoric communities and their potential importance in human diet. Cereal assemblages from individual houses, their density in the sampled deposits, and their spatial distribution can help draw an overall picture of crop production and consumption of the household that occupied the house, throughout the life of the house. For the residents of House 1 at Rothenkirchen, emmer wheat was a staple crop, while they also consumed variable quantities of barley and spelt. Over time, debris from the preparation of plant food accumulated in the holes of the roof and wall posts. The low density of plant remains recorded in the southern-most part of the house suggests that plant-related activities did not take place in this part of the building. In the northern part of the house, remains of two grain stores were detected. They included both grain and chaff, indicating that the harvested crop had not been fully cleaned. Rather, it probably went through the initial processing stages (threshing, winnowing, coarse sieving), which took place outdoors, and was then stored semi-cleaned, awaiting further cleaning prior to consumption. Activities such as sieving, hand cleaning, and grinding likely took place in the northern part of the house.

Another plant-related activity zone may have existed in the north-eastern part of the house, where numerous glume bases of emmer and spelt, as well as rachis fragments of barley, were found, but hardly any grain. This evidence may be interpreted in one of three ways. (1) The harvested cereals were threshed outside the house, but perhaps very close to it (although the fact that the residue from threshing is highly inflammable argues against the threshing area being located near the house). (2) It is the subsequent processing, *i.e.* dehusking (of hulled wheat) that took place in this part of the house. (3) The chaff remains in this zone do not result from crop processing, but from straw that may have covered the floor.

The compilation of data on houses from this site and others in the region shows that, using same construction type, the community of the Nordic Bronze Age culture expressed itself in the same way. This is reflected in the interior by a similar organisation of household activities: The western room was probably reserved for living, as suggested by the lack of plant remains, whereas the economic sphere was located in the central and eastern rooms.

References

Alsleben, A. 2013. Die fossilen Pflanzenreste des bronzezeitlichen Siedlungsplatzes Brekendorf in Schleswig-Holstein, in: Willrodt, K.-H. (ed.), *Siedlungen der älteren Bronzezeit: Beiträge zur Siedlungsarchäologie und Paläoökologie des zweiten vorchristlichen Jahrtausends in Südskandinavien, Norddeutschland und den Niederlanden: Workshop vom 7. bis 9. April 2011 in Sankelmark.* Studien zur nordeuropäischen Bronzezeit 1. Neumünster: Wachholtz, 223-237.

Andreasen, M.H. 2011. *HBV 1302, Kongehøj I og HBV 1275, Kongehøj II (FHM 4296/670 og 690): Makrofossil analyser fra en røse/gravhøj fra senneolitikum/ældre bronzealder og en række hustomer fra ældere bronzealder Periode II.* Konserverings- og Naturvidenskabelig Afdeling 3. Moesgård: Moesgård Museum.

Arnoldussen, S. 2008. *A living landscape: Bronze Age settlement sites in the Dutch river area (c. 2000-800 BC).* PhD dissertation, Rijksuniversiteit Leiden, 167-273.

Bech J.-H. and Haack Olsen, A.-L. 2013. Early Bronze Age houses from Thy, Northwest Denmark, in: Willrodt, K.-H. (ed.), *Siedlungen der älteren Bronzezeit: Beiträge zur Siedlungsarchäologie und Paläoökologie des zweiten vorchristlichen Jahrtausends in Südskandinavien, Norddeutschland und den Niederlanden: Workshop vom 7. bis 9. April 2011 in Sankelmark.* Studien zur nordeuropäischen Bronzezeit 1. Neumünster: Wachholtz, 9-32.

Effenberger, H. 2017. The plant economy of the northern European Bronze Age – more diversity through increased trade with southern regions. *Vegetation History and Archaeobotany* 27,1, 65-74.

Effenberger, H. 2018. *Pflanzennutzung und Ausbreitungswege von Innovationen im Pflanzenbau der Nordischen Bronzezeit und angrenzender Regionen.* Studien zur nordeuropäischen Bronzezeit 4. Neumünster: Wachholtz.

Ethelberg, P. 2000. Bronzealderen, in: Ethelberg, P., Jørgensen, E., Meier, D. and Robinson, D. (eds.), *Det Sønderjyske Landbrugs Historie: Sten- og Bronzealder.* Haderslev: Haderslev Museum, 135-280.

Grundvad, L., Poulsen, M.E. and Andreasen, M.H. 2015. *Et monumentalt midtsulehus ved Nørre Holsted i Sydjylland: Analyse af et langhus fra ældre bronzealder Periode I*. Aarhus: KUML: Årbog for Jysk Arkæologisk Selskab, 49-75.

Harsema, O.H. 1997. House form, farm stead and settlement structure in the northern Netherlands in the Middle and Late Bronze Age, in: Beck, H. and Steuer, H. (eds.), *Haus und Hof in ur- und frühgeschichtlicher Zeit*. Berichte über zwei Kolloquien der Kommission für Altertumskunde Mittel- u. Nordeuropas 1990 u. 1991. Abhandlungen der Akademie der Wissenschaften Göttingen, Philologisch-Historische Klasse 3, 218. Göttingen: Vandenhoeck and Ruprecht, 137-161.

Henriksen, P.S., Robinson, D.E. and Kelertas, K. 2018. Bronze Age agriculture, land use and vegetation at Bjerre Enge based on the results of archaeobotanical analyses, in: Bech, J.-H., Eriksen, B.V. and Kristiansen, K. (eds.), *Bronze Age Settlement and Land-Use in Thy, Northwest Denmark: Vol. II*. Museum Thy. Moesgård. Aarhus University Press, 387-458.

Jacomet, S. and Kreuz, A. 1999. *Archäobotanik*. 11.5.1 Getreide. Stuttgart. Ulmer, 261-276.

Jensen, P.M. 2017. ÅHM 6500, Frejlevgård etape V (FHM 4296/2272): Makrofossil analyse af to-skibet langhus fra overgangen mellem senneolitikum og ældre bronzealder. Konserverings- og Naturvidenskabelig Afdeling 23. Moesgård: Moesgård Museum.

Kirleis, W. and Fischer, E. 2014. Neolithic cultivation of tetraploid free threshing wheat in Denmark and northern Germany: implications for crop diversity and societal dynamics of the Funnel Beaker Culture. *Vegetation History and Archaeobotany* 23/supplement 1, 81-96.

Klems, V. in prep. Eine älterbronzezeitliche Siedlung bei Borgstedt, Kr. Rendsburg-Eckernförde.

Kneisel, J., Dal Corso, M., Kirleis, W., Taylor, N. and Tiedtke, V. 2015. The third food revolution? Common trends in economic and subsistence strategies in Bronze Age Europe, in: Kneisel, J., Dal Corso, M., Kirleis, W., Scholz, H., Taylor, N. and Tiedtke, V. (eds.), *The third food revolution? Setting the Bronze Age table: common trends in economic and subsistence strategies in Bronze Age Europe*. Universitätsforschungen zur prähistorischen Archäologie 283. Bonn: Habelt, 275-287.

Kučan, D. 2007. Archäobotanische Untersuchungen zu Umwelt und Landwirtschaft jungbronzezeitlicher Flussmarschbewohner der Siedlung Rodenkirchen-Hahnenknooper Mühle, Ldkr. Wesermarsch. *Probleme der Küstenforschung* 31, 17-83.

Lange, E., Jeschke, L. and Knapp, H.D. 1986. *Die Landschaftsgeschichte der Insel Rügen seit dem Spätglazial*. Landschaftsentwicklung und Siedlungsgeschichte der Ostseeinsel 1. Schriften zur Ur- und Frühgeschichte 38. Berlin: Akademie-Verlag.

Landesamt für Umwelt, Naturschutz und Geologie 2003. Böden in Mecklenburg-Vorpommern: Abriss ihrer Entstehung, Verbreitung und Nutzung, in: Ratzke, U. and Mohr, H.-J. (eds.), *Beiträge zum Bodenschutz in Mecklenburg-Vorpommern*. Güstrow: Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern.

Meier, D. 2013. Eine Siedlung der älteren Bronzezeit in Schleswig-Holstein, in: Willrodt, K.-H. (ed.), *Siedlungen der älteren Bronzezeit: Beiträge zur Siedlungsarchäologie und Paläoökologie des zweiten vorchristlichen Jahrtausends in Südskandinavien, Norddeutschland und den Niederlanden: Workshop vom 7. bis 9. April 2011 in Sankelmark*. Studien zur nordeuropäischen Bronzezeit 1. Neumünster: Wachholtz, 91-118.

Oberdorfer, E. 1990. *Pflanzensoziologische Exkursionsflora*. 6th revised edition. Stuttgart: Ulmer].

Robinson, D.E. 2000. Det slesvigske agerbrug i yngre stenalder og bronzealder, in: Ethelberg, P., Jørgensen, E., Meier, D. and Robinson, D. (eds.), *Det Sønderjyske Landbrugs Historie: Sten- og Bronzealder*. Haderslev: Haderslev Museum, 281-298.

Saalow, L. and Schmidt, J.-P. 2009. Mehr als nur Gruben und Scherben: die bronzezeitlichen Neufunde beim Bau der Bundesstraße B96n auf Rügen, in: Lehmann, T., Schmettow, H. Gräfin von and Schmidt, J.-P. (eds.), *Archäologische Entdeckungen in Mecklenburg-Vorpommern: Kulturlandschaft zwischen Recknitz und Oderhaff.* Archäologie in Mecklenburg-Vorpommern 5. Schwerin: Landesamt für Kultur und Denkmalpflege, 69-80.

Schmidt, J.-P. 2013. Bronzezeitliche Hausbefunde und Siedlungen in Mecklenburg-Vorpommern, in: Willrodt, K.-H. (ed.), *Siedlungen der älteren Bronzezeit: Beiträge zur Siedlungsarchäologie und Paläoökologie des zweiten vorchristlichen Jahrtausends in Südskandinavien, Norddeutschland und den Niederlanden: Workshop vom 7. bis 9. April 2011 in Sankelmark.* Studien zur nordeuropäischen Bronzezeit 1. Neumünster: Wachholtz, 119-136.

Waste disposal in the Bronze Age: plants in pits at Wismar-Wendorf, northern Germany

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Abstract

Development-led excavations in Wismar-Wendorf in the district of Nordwestmecklenburg, northern Germany revealed a site of prehistoric activity from the regional Late Bronze Age, as evident from the characteristics of the artefactual evidence. More precisely, the result of radiocarbon dating places the site in Period VI of the Northern European Bronze Age. Different types of features and finds were documented at the site and they indicate that a settlement was once located here. The most prominent features are pits – of different sizes and shapes but of a generally unclear function; the working interpretation includes categories such as storage pits and borrow pits. Archaeobotanical material recovered from pits can often shed light on a possible use of these structures. In the case of Wismar-Wendorf, it shows that the pits received discarded by-products of plant processing and possibly intentionally burnt fungi-infected stores of plant products.

In this report, the methods and results of the analysis of plant remains recovered from Wismar-Wendorf are presented in detail. The outcomes are briefly discussed in a broader regional and chronological context. The botanical assemblage from the site is used as a proxy in the reconstruction of the process of formation of the content (fill) of the pits and the depositional practices involving plant products and by-products. In this, the available archaeological information (for instance on other inclusions in the pit fill) are taken into account. The paper offers an insight into the possible ways in which plants were kept, processed and discarded at Bronze Age sites.

Keywords: Late Bronze Age, pits, Wismar-Wendorf, crop products, crop by-products, waste disposal

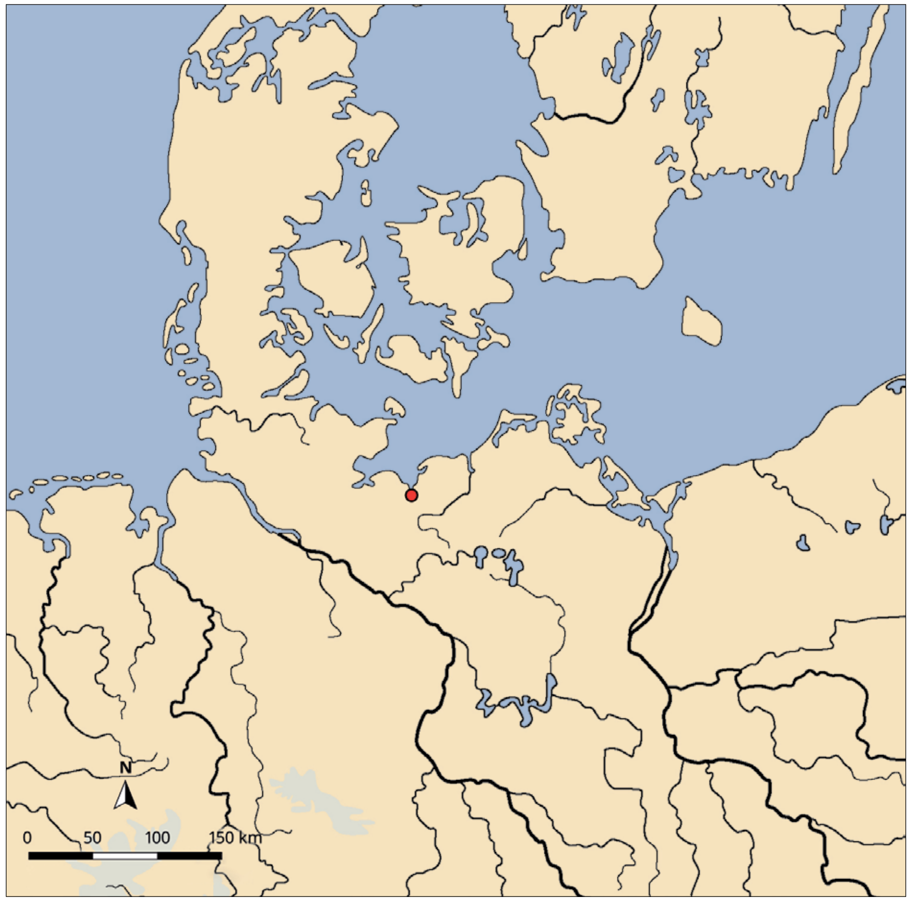

Figure 1. Map showing the location of Wismar.

Introduction

Whatever their original purpose, prehistoric pits are often found filled up with domestic waste that includes organics, sherds, lithics and other artefacts. Their role as dumps makes them a valuable source of information on day-to-day life in the past and the habit of rubbish disposal as well as on the production and consumption of a range of objects and materials, including plants. From an archaeobotanical perspective, residues from different plant-related activities and sources tend to be mixed and tossed in pits, though stratified pits may preserve individual episodes of discard of debris from discrete activities accumulated over short or extended periods. In both cases, the composition of the botanical assemblages can offer insight into the practice of disposal of waste resulting from handling plants and, beyond this, into certain aspects of plant processing and consumption.

This paper presents the methods and results of the archaeobotanical analysis of the contents of Bronze Age pits discovered at the site of Wendorf in Wismar, northern Germany and considers the depositional history of the botanical material, which it then uses to evaluate archaeological interpretation of the function of the pits. It also briefly discusses the regional and chronological context of the plant assemblage and highlights some relevant analogous botanical datasets from the region and period.

Summary of the site

In the course of 2016 and 2017, development-led archaeological excavations were carried out in the town of Wismar, in northwest part of the state of Mecklenburg-Vorpommern (Fig. 1), on the land where a new, 14 ha-large residential area of

Figure 2. Close-up of the location of the site of Wendorf in Wismar (map background: TK10, LAiV MV).

Figure 3. Cross-section through the grain-rich pit (Feature 145) at the site of Wendorf in Wismar (photo © LaKD-MV).

the seaside resort Wendorf (*Seebad Wendorf*) is to be constructed (Fig. 2).[3] The excavations took place in several sections of a wide flat zone on top of a very low, gentle rise overlooking the Bay of Wismar and situated 300-500 m away from the coast. They were conducted under the auspices of the *Landesamt für Kultur und Denkmalpflege* (State Office for the Preservation of Cultural and Historical Heritage) and were directed by Frank Mewis. About 21,000 m^2 of the extent of the site was cleared and examined. Machinery (wheeled excavator) was used to remove the top soil (*c.* 30 cm thick) as well as the sediment outside visible structures or features.

3 http://www.lge-mv.de/baugebiete/wohnhausgrundstuecke/wohngebiet-wismar-seebad-wendorf (accessed 22 January 2018).

Figure 4. Close-up view of the burnt grain concentration in pit (Feature 145) at the site of Wendorf in Wismar (photo © LaKD-MV).

The upper levels yielded traces of use of the site in modern and medieval times (14–18th century); underneath, remains of a Bronze Age settlement were discovered. They were recognised as areas of dark matrix in otherwise pale sandy loam and in the form of features (pits of various sizes and shapes, stone-lined hearths, postholes) and objects (*e.g.* tools made of stone and osseous materials and ceramic vessels).[4] Animal bones and plant remains were also encountered. For the majority of the dug features it was suggested that they could have served as borrow-pits, whereas a storage function was proposed for several of them.

With respect to the botanical material, the most stunning was the discovery of several dozen kilograms of charred grain in a large pear-shaped pit (Feature 145, Fig. 3-4). The first impression of the archaeologists has been that this find could represent an accident during drying of the grain. In the same pit, a large polished stone was also unearthed and has been considered a possible implement used for grinding grain.[5] In addition to plants and tools, animal bones and potsherds were present in the fill of the pit. The sherds come from pots typical of Period VI of the Northern Bronze Age including, for instance, storage vessels decorated with *Fingerkniffleisten* and vessels with fluted ornamentation.

4 http://www.lge-mv.de/aktuelles/spektakulaere-funde-im-neuen-wohngebiet-seebad-wismar-wendorf (accessed 22 January 2018).

5 http://www.ln-online.de/Lokales/Nordwestmecklenburg/Sensationelle-Funde-im-Seebad (accessed 22 January 2018).

	Context number	Context category	Sample number	Soil volume (L)
1	145	pit (storage pit? borrow pit?)	1	
2			3	
3			4	
4			5	
5			6	
6			9	
7			10	
8			A	10
9			A-rest	26
10			12+8	20
11			2+4+5	
12			16+3	
13			6+7	
14			B	10
15			11+7	
16			15	
17			13	
18	233	pits (storage pits?)	233	8
19	360		360a	12
20			360b	12
21	416		416	8
22	441		441	10
23	188	pits (borrow pits?)	188a	8
24			188b	12
25	250		250a	8
26			250b	8
27	257		257	8
28	270		270	5
29	280		280	11
30	330		330	10
31	362		362	6
32	366		366a	8
33			366b	10
34			366c	10
35	367		367	5
36	368		368	10
37	398		398	8
38	407		407a	5
39			407b	6
40	424		424	3
41	437		437a	15
42			437b	12
43			437c	7
44	372	pits	372	4
45	427		427	8
46	428		428	5
47	381	fireplaces	381	7
48	455		455	7
49	464		464	9
50	465		465	10
51	469		469	5

Table 1. The list of contexts at Wismar-Wendorf from which archaeobotanical samples were taken.

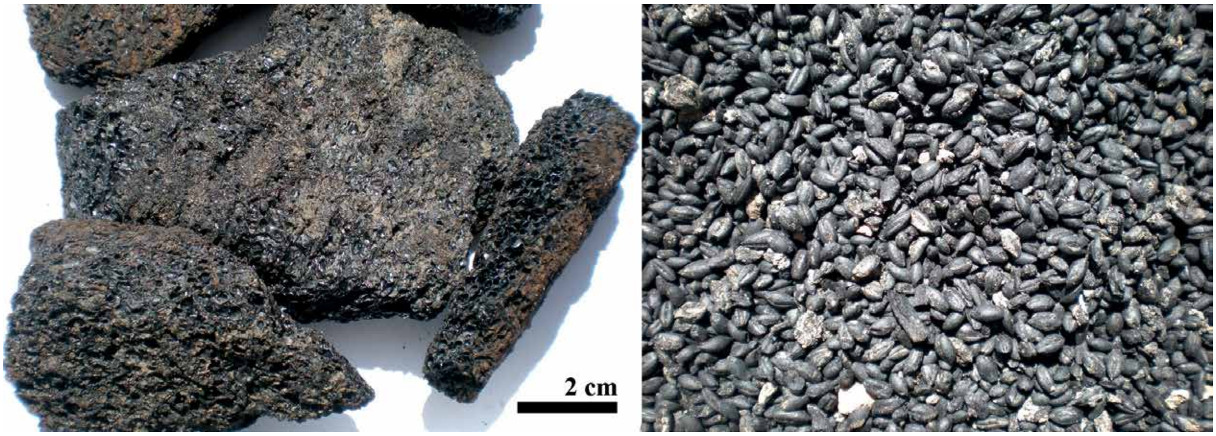

Figure 5. Charred grain from pit (Feature 145) at the site of Wendorf in Wismar: left – fused into hard chunks; right – loose.

Materials and methods

Collection and processing of archaeobotanical samples

The samples intended for archaeobotanical examination were collected by the excavators, in liaison with the archaeobotanists at the Institute of Pre- and Protohistory in Kiel. Around 10 litres of sediment were collected from the sampling locations/deposits chosen by the archaeologists, except in case of the grain-rich pit (Feature 145) where a larger amount of the pit fill was taken. From some of the pit-features, multiple samples were taken (up to three). Table 1 provides the list of contexts (features) from which a total of 51 archaeobotanical samples were derived (46 from pits and 5 from fireplaces), and shows the volume of the samples. Processing of the samples included flotation, drying, sieving and splitting. About a dozen samples from Feature 145 were manually floated in the field and their size was not recorded. The rest of the samples were hand-floated in Kiel, whereby the ones not originating from Feature 145 were processed by students participating in a weak-long training course in archaeobotanical field methods carried out at the Institute for Ecosystem Research in Kiel. The sediment from each sample was split into several buckets, to which water was then added; the sample was stirred and left to settle for few minutes, and then poured through a 0.3 mm sieve. Some of the samples were particularly clayey and required more water and multiple washing. This was especially the case with the fill of pit 145 from which several samples included large chunks of hard scorched earth with charred seeds embedded in it, or bearing impressions of grains (Fig. 5). The seed-containing blocks of earth were left to dissolve in water and then sieved; the ones carrying grain imprints only were left to dry and then stored.

Extraction, identification and quantification of plant remains

Save for the samples from pit 145, all other samples were fully sorted (and without prior sieving). The majority of the samples from pit 145 were very large and rich. In order to make the sorting process faster and easier, these samples were first sieved in order to separate the material of different size; sieves with apertures of 4 mm, 1 mm and 0.3 mm were used. The individual sieve-fractions were then split using a riffle-box (metal sample-splitter), so that a random subsample for each size-based fraction of each sample was obtained. Sample 'B' was, however, not sieved and was divided by hand to six more-or-less similarly sized portions, one of which was entirely sorted. Table 2 shows the different subsamples sorted from the fill of pit 145.

Pit 145	Subsample sorted		
Sample number	Sieve 4 mm	Sieve 1 mm	Sieve 0.3 mm
1		1/1	1/4
3	1/1	1/2	1/1
16+3		1/4	1/4
4		1/1	1/2
6	1/1	1/8	1/1
10		1/64	1/8
A	1/8	1/8	1/8
A-rest	1/1		
12+8		1/16	1/16
11+7		1/32	1/8
B	1/6	1/6	1/6
subsamples marked in red not included in this report			
2+4+5		1/64	1/8
5		1/1	1/8
9	1/1	1/28	1/8
13		1/16	1/4
6+7		1/32	1/8
15		1/1	

Table 2. The list of analysed subsamples from the grain-rich pit (Feature 145) at Wismar-Wendorf.

The extraction, identification and counting of plant remains was conducted for charred material only. Several pits contained mineralised seeds (mostly of Chenopodiaceae) and these were left out of the analysis. Charred wood remains were extracted but not identified. Botanical identification draws from the immense experience of Edeltraud Tafel, who processed the majority of the samples, whilst the help of Helmut Kroll was also available. The samples from pit 145 were processed by Edeltraud Tafel, Mark Hadyniak and Dragana Filipović; here, the identification and quantification procedure differed slightly between the analysts. For instance, in all but two of the samples (samples 'A' and 'B'), the 'asymmetrical' ('twisted') grains of barley were counted separately and determined as coming from the six-row barley variety. Further, the number of cereal (mostly barley) grains in these two samples was estimated based on their weight.[6] In all other cases, however, apical and embryo ends of cereal grains were counted and the larger count included in the total. This procedure secures more accurate quantification, but is more time-consuming and, so far, the counting has been completed for 11 out of the total of 17 samples from pit 145 (see Table 2). The non-quantified samples were not included in the analysis. Nevertheless, quick scanning of the material from these samples showed that the composition and amounts of different plant remains here are very

6 The weight of a certain number of whole cereal grains (*e.g.* 100) was measured and used as a basis for estimating the number of grains in a weighed combination of whole and fragmented grains.

similar to those seen in the completed samples from the respective layers/quadrants of the pit. Hence, the available results for pit 145 are taken as representative of the entire botanical archive recovered from this feature.

The counts of taxa identified in the subsamples from Feature 145 were multiplied and summed up to obtain the values for the whole samples;[7] these are the values reported here and used in the analysis. From several of the remaining pits, more than one sample was taken for the analysis (Table 1). In these cases, multiple samples from the same feature were analysed separately. Their composition turned out to be very similar. Also, the archaeological description does not suggest that they come from discrete deposits within the pit, even though they were taken at different depths through the pit fill. Because of this, the results (*i.e.* taxa counts) for the samples from the same feature were amalgamated and as such included here.

Data analysis and presentation

The following attributes are used as a basis for closer inspection of the botanical content of the features and their comparison: abundance and frequency of occurrence of individual taxa and groups of taxa; botanical density of the samples (number of items per litre of soil); botanical composition of the samples/contexts; archaeological layers or other units of excavation. Abundance and frequency of the remains are understood as reflecting the overall degree of presence and/or use of different taxa and, in turn, their potential importance and role for the Bronze Age occupants of the site. Botanical density is used as an indicator of the rate at which plant material was deposited, *i.e.* whether the material was deposited in a single event (*e.g.* large amounts of plant parts disposed all at once) or if the assemblage consists of several/many smaller botanical deposits accumulated over some time. Botanical composition helps reconstruct the formation of the assemblage and the processes involved in it (*e.g.* crop processing, food preparation). The details on archaeological context aid in investigation of the above-described parameters. Some of these characteristics are presented as univariate numerical data (given in the tables) and visualised using simple column and pie charts.

The archaeobotanical results for the same feature type are presented and discussed together. An exception to this is pit 145 because this particular feature contributed a greater number of samples and has yielded exceptional concentrations of plant remains (see below). Of the rest of the sampled features at Wismar-Wendorf, most represent pits (possibly of different function), whilst there are also several fireplaces. It is *a priori* assumed that the plant content of the former is of secondary origin, and of the latter – primary. This hypothesis is tested by looking at the composition of the botanical and, where available, other materials and the descriptions of structural elements of these features.

Results and discussion

The archaeobotanical assemblage

Table 3 gives a detailed list of the taxa encountered in the samples deriving from 26 sampled features. The results for pit-feature 145 are shown separately – in Table 4. Figure 6 presents proportions of crop *vs*. wild plant material across the 13 contexts (all of them pits) that yielded ≥30 counted items. Crop remains prevail in the majority of features suggesting that processing, use and discard of crop products

7 *e.g.* the totals for 1/8 of 0.3 mm fraction of sample 10 were multiplied by 8 and those for 1/64 of 1 mm by 64, and the products were summed to get the totals for 1/1 of sample 10.

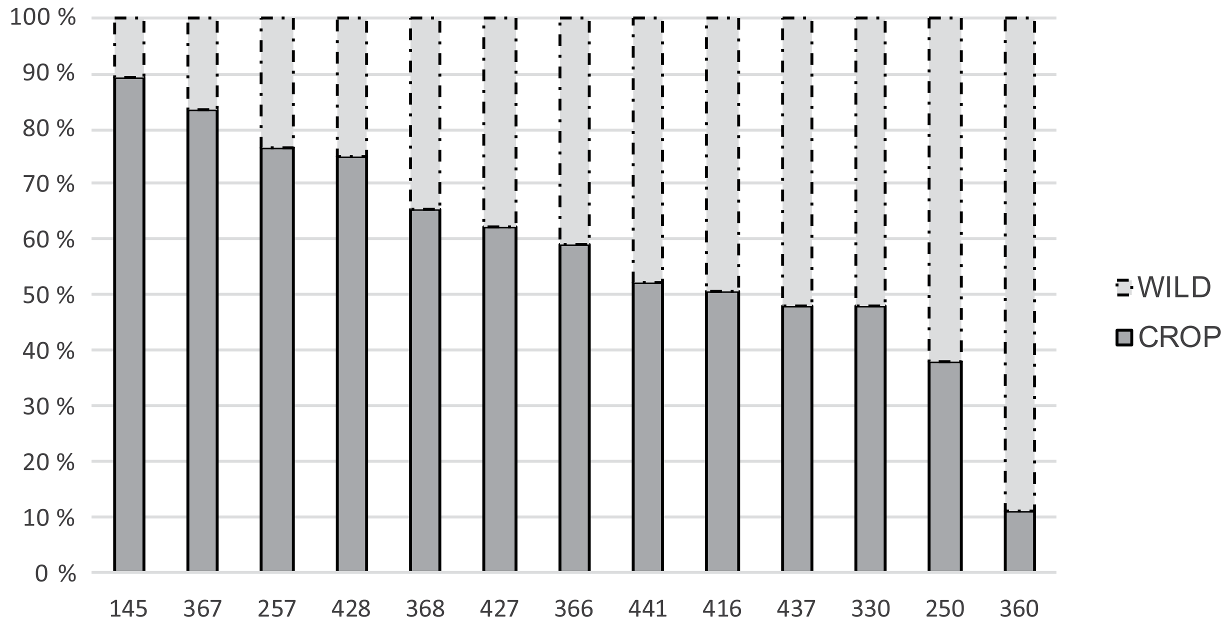

Figure 6. Relative proportions of crop and wild material from the contexts at Wismar-Wendorf that yielded thirty or more plant remains.

and by-products were the main activities that created the botanical assemblage. Several contexts contained more wild than crop remains. The wild plant assemblage also reflects crop processing, since the vast majority of wild taxa can be classified as potential arable weeds.

Crops

The spectrum of crop types identified is wide: two kinds of barley (*Hordeum vulgare*, hulled, *H. vulgare nudum* – naked), four types of wheat (*Triticum dicoccum* – emmer, *T. monococcum* – einkorn, *T. spelta* – spelt wheat, *T. aestivum, sensu lato* – free-threshing wheat), broomcorn millet (*Panicum miliaceum*), oat (*Avena sativa*), several pulses and oil/fibre plants. Not all of them may have been cultivated, and the abundance and frequency of their remains may be informative in this view, especially the relatively very high or very low values.

A quick look at the total item counts for crop taxa reveals that, among the generally plentiful (hulled and naked) barley remains those of the hulled variety are more abundant. Wheats are found in a lower quantity than barley (especially in pit 145) and emmer is the dominant type. The third on this list is broomcorn millet. Based on the relatively small number of remains of the other wheat types represented (einkorn, free-threshing wheat and spelt wheat), they could perhaps be considered less important or accidental inclusions in the grain of the staple (*e.g.* einkorn grain mixed in with emmer). Common oat was registered in only one sample, and this was a single floret base; the crop-status of this taxon is questionable. Of the three recorded oil/fibre plants, flax/linseed (*Linum usitatissimum*) is somewhat more visible compared to gold-of pleasure (*Camelina sativa*); poppy (*Papaver somniferum*) is represented by only several seeds and perhaps was not cultivated. The same could apply for instance, to foxtail millet (*Setaria italica*), here listed as a potential weedy inclusion. Its exclusive co-occurrence with millet in the samples can suggest that the two were sown, or otherwise grew together in arable plots. The identified legumes include pea (*Pisum sativum*), lentil (*Lens culinaris*) and faba bean (*Vicia faba*). The latter was documented only by two seeds, which, similarly to the above-mentioned taxa, may reflect its ambiguous crop status.

The frequency of crop remains (*i.e.* the percentage of samples in which they occur) offers an additional perspective of the degree of representation of different

		Context number		233	360	416	441	188	250	257	270	280	330	362	366	367	368	398	407	424	437	372	427	428	381	455	464	465	469
		Context category		pits (storage pits?)				pits (borrow pits?)														pits			fireplaces				
		Soil volume (L)		8	24	8	10	20	16	8	5	11	10	6	28	5	10	8	11	3	35	4	8	5	7	7	9	10	5
		Total remains		8	1877	63	69	12	42	81	13	3	76	10	161	30	156	1	28	16	525	15	56	32	7	0	20	1	0
		Density		1	78	8	7	1	3	10	3	0	8	2	6	6	16	0	3	5	15	4	7	6	1	0	2	0	0
TAXA	plant part (all charred)	Total remains	Frequency (%)																										
CEREALS																													
Hordeum vulgare, hulled	grain	99	15		48		11	1													39								
Hordeum vulgare nudum, naked	grain	7	4		7																								
Hordeum vulgare p.p.	grain	282	62	5		9		1	8	45			16	3	25	12	50		10		79	2	13	3			1		
Hordeum vulgare	rachis segment	7	4		7																								
Triticum dicoccum	grain	164	62		9	7	9		3	4			3		17	2	20		2	8	58	2	7	9			4		
Triticum dicoccum	glume base	66	42		33		4		2	1			13		3						1	4	2		1		2		
Triticum monococcum	grain	1	4													1													
Triticum spelta	grain	4	8		2																2								
Triticum aestivum (sensu lato)	grain	15	23						1											3	7		2		1		1		
Triticum aestivum (sensu lato)	rachis segment	1	4																					1					
Triticum sp.	grain	2	8	1															1										
Panicum miliaceum	grain	59	31		22								2		6		18		1	2	5			3					
Avena sativa	floret base	1	4				1																						
Cerealia indeterminata	grain estimate	200	50		50	15	10	3		10		1			35	5	10		1		45		10	5					
LEGUMES			0																										
Pisum sativum	seed	14	31		2	1							1		2		2				4		1				1		
Vicia faba	seed	2	8										1			1													
OIL / FIBRE PLANTS			0																										
Camelina sativa	seed	23	31		11				1					1	1	4					1			3			1		
Linum usitatissimum	seed	43	35		15		1		1	2	8				6		2				6	2							
Papaver somniferum	seed	6	8		1																5								
WILD GATHERED			0																										
Corylus avellana	shell fragment	11	35	1					1				3		1	1	1				1	1	1						
Prunus spinosa	stone fragment	1	4		1																								
Quercus sp., cf.	acorn fragment	1	4																				1						
ARABLE / RUDERAL PLANTS			0																										
Apera spica-venti	fruit	8	4		8																								
Avena sp.	fruit	57	46		18	1	1		1				1		8	2	6		1	1	15		2						
Avena sp.	floret base	31	23		22				1	3			2		2						1								
Bromus secalinus	fruit	38	35	1	8	1	2		1						4		6				11		4						
Chenopodium album	seed	296	69			9	9	3	12	3		1	13	4	20	1	24		2	1	183		6	1	3		1		
Echinochloa crus-galli	fruit	123	15		119		1								1		2												
Eleocharis sp.	fruit	4	4		4																								
Galeopsis sp.	seed	1	4		1																								
Galium aparine	seed	99	23		85		4	1					7	1							1								
Galium spurium	seed	147	42		106	6	3			1			9		2		2		2		13	1	2						
Malva sp.	seed	3	4		3																								
Plantago lanceolata	seed	3	8		2														1										
Polygonum aviculare	fruit	75	19		69	1									2		1				2								
Polygonum convolvulus	seed	65	50		35	3	2	1	1	3	1				4		2			1	10	1			1				
Polygonum persicaria	fruit	202	46		154	2			7	8			2		5		4		3		9			1			6	1	
Polygonum lapathifolium	fruit	73	12		71											1			1										
Rumex acetosella	fruit	43	27		30	1							1		7		1							2			1		
Rumex crispus type	fruit	25	27		17	1	2							1	1						1			2					
Scleranthus annuus	fruit	8	12		6			1	1																				
Setaria italica	grain	7	8		6												1												
Setaria viridis	fruit	408	12		404		3														1								
Solanum nigrum	seed	10	8		8	2																							

			Context number	233	360	416	441	188	250	257	270	280	330	362	366	367	368	398	407	424	437	372	427	428	381	455	464	465	469
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			Soil volume (L)	8	24	8	10	20	16	8	5	11	10	6	28	5	10	8	11	3	35	4	8	5	7	7	9	10	5
			Total remains	8	1877	63	69	12	42	81	13	3	76	10	161	30	156	1	28	16	525	15	56	32	7	0	20	1	0
			Density	1	78	8	7	1	3	10	3	0	8	2	6	6	16	0	3	5	15	4	7	6	1	0	2	0	0
TAXA	plant part (all charred)	Total remains	Frequency (%)																										
Spergula arvensis	seed	7	8		6												1												
Stellaria media	seed	120	12		118	1															1								
Thlaspi sp.	seed	15	15		11		1								1						2								
Trifolium sp. type	seed	11	15		8	1									1						1								
Vicia sp.	seed	50	42		28	2	2		1				1		2		1				9		2	1			1		
Asteraceae, cf.	seed fragment	1	4																					1					
Brassicaceae	seed	28	19		10		3								2						12		1						
Chenopodiaceae p.p.	seed	221	8		219																	2							
Fabaceae, small-seeded	seed	2	8									1							1										
Panicoideae p.p.	seed	1	4												1														
Plantaginaceae p.p.	seed	1	4		1																								
Poaceae, small-seeded	fruit	101	27		92					1	1				2		2						2				1		
Poaceae, large-seeded	fruit	1	4																						1				
culm/stem remains	fragment	1	4								1																		
'food' or fruit flesh remains	fragment	3	8								1								2										
bud/shoot		1	4										1																
indeterminate	seed/fruit	3	12					1			1							1											

Table 3. The list of botanical taxa and the number of remains found in different contexts at Wismar-Wendorf.

crops. Figure 7 shows percentage frequency of the most abundant taxa across all of the analysed contexts (27 in total). Barley is, by far, the most commonly occurring taxon (found in *c.* 70% of the contexts); however, in relatively few cases was it possible to determine whether it is of the hulled or naked type. Emmer grain is also common (found in *c.* 63% of the features), and so are emmer glume bases, which will be of interest in the discussion below on the deposition of crop products and by-products. Other considered taxa were detected in less than half of the contexts, but their frequency is still reasonably high – mostly over 30%. One observation deduced from this is that the best-represented crop taxa, in a quantitative sense, are also the ones widely distributed across the site. This confirms the impression that they played important roles in crop production and use. As the most frequent and abundant finds, emmer and barley likely were the mainstay of agriculture at Wismar-Wendorf.

Wild plants

Several taxa producing edible fruit and traditionally considered as gathered were encountered in some of the samples in small quantities. Hazelnut is somewhat more common; it is registered in about 30% of the features. It may have been in use more widely or more often compared to the other wild/collected fruit-candidates, wild plum (*Prunus spinosa*), Chinese lantern (*Physalis alkekengi*) and acorn (*Quercus* sp.). Although a minor component of the botanical archive from Wismar-Wendorf, these remains suggest that gathering still played a part in later prehistoric economy.

Over thirty wild taxa were characterised as associated with arable and/or ruderal habitats (crop fields, edges of cultivated plots, trampled areas, roadsides) and they potentially represent weeds harvested together with crops. Figure 8 shows the proportions of the most common crops/crop groups and wild taxa across the 13 contexts that yielded ≥30 counted items. In the contexts dominated by barley (145, 367 and 257), it is possible that the accompanying wild/weed taxa all derived from plots cropped with barley. The presence of other crops, however, leaves a possibility

Pit 145	Sample number		1	3	16+3	4	6	10	A+A-rest	12+8	11+7	B
	Layer		(Upper layer)	3-4	3-4	4	4	4-5	4-5	4-5	4-5	4-5
	Quadrant			A-D	B-D	A-D	A-D	A-D	A-D	B-D	B-C	B-C
	Total remains		395	1047	7856	38	13900	39520	117508	6096	9234	76950
	Density								4520	305		7695
TAXA	plant part (all charred)	Total remains	multiplied-up counts for subsamples (to obtain 100%)									
CEREALS												
Hordeum vulgare, hulled, six-row	grain	4859	2	20	20		137	3840	10	272	558	
Hordeum vulgare, hulled	grain	139642	4	364	96		413	13440	60400	1712	3441	59772
Hordeum vulgare nudum, naked, six-row	grain	192					176			16		
Hordeum vulgare nudum, naked	grain	44799		24			12852	1216	27226	416	527	2538
Hordeum vulgare nudum, naked	rachis segment	8						8				
Hordeum vulgare, six-row	grain	3	3									
Hordeum vulgare	grain	3108	4	10		7	117	1728	14	608	620	
Hordeum vulgare	rachis segment	56						40	8		8	
Triticum dicoccum	grain	28954	5	373	60			5440	13684	816	1922	6654
Triticum dicoccum	glume base	9660	1	88				3704	4455	96	422	894
Triticum monococcum	grain	3		2			1					
Triticum monococcum / dicoccum	grain	734		30				640	2		62	
Triticum sp., hulled	grain	366		26	20			320				
Triticum sp., hulled	glume base	1200	4	19	16		1	1136	24			
Triticum aestivum (sensu lato)	rachis segment	8						8				
Triticum aestivum (sensu lato)	grain	62							56			6
Triticum sp.	grain	155		18				64	11		62	
Triticum sp.	basal rachis segment	16						16				
Panicum miliaceum	grain	7811	3	2	7612			8	144			42
Cerealia indeterminata	grain	1598	3	34	8			1216	4	240	93	
LEGUMES												
Lens culinaris	seed	21	3			1	1		16			
Pisum sativum, cf.	seed	1	1									
Leguminosae sativae	seed	32							16	16		
OIL / FIBRE PLANTS												
Camelina sativa	seed	50	2						48			
Linum usitatissimum	seed	86	2		4				32	48		
WILD GATHERED		0										
Physalis alkekengi	seed	13	13									
fruit flesh	fragments	16					16					
ARABLE / RUDERAL PLANTS												
Apera spica-venti	fruit	20	20									
Avena fatua	floret base	809		4		4	23	216	316	48	24	174
Avena sp.	fruit	4233					54	904	1512	208	217	1338
Avena sp.	awn fragment	731	1	16		42	6	40	280	320	8	18
Avena sp.	floret base	160						144			16	
Brassica sp. / *Sinapis* sp.	seed	1	1									
Bromus secalinus	fruit	1829	1	10			8	568	362	48	124	708
Bromus sp.	fruit	27	1		4	3	2	16	1			
Capsella bursa-pastoris	seed	184						144	8	32		
Chenopodium album	seed	2429	53			4		32	1664	640		36

Pit 145	Sample number		1	3	16+3	4	6	10	A+A-rest	12+8	11+7	B
	Layer		(Upper layer)	3-4	3-4	4	4	4-5	4-5	4-5	4-5	4-5
	Quadrant			A-D	B-D	A-D	A-D	A-D	A-D	B-D	B-C	B-C
	Total remains		395	1047	7856	38	13900	39520	117508	6096	9234	76950
	Density								4520	305		7695
TAXA	plant part (all charred)	Total remains	multiplied-up counts for subsamples (to obtain 100%)									
Chenopodium cf. *ficifolium*	seed	14	12						2			
Chenopodium sp.	seed	184	24							160		
Echinochloa crus-galli, cf.	fruit	41	1						40			
Galium aparine	seed	22	16									6
Galium spurium	seed	58	7			3			48			
Galium mollugo type	seed	1					1					
Galium sp.	seed	1	1									
Hordeum sp.	grain	2		2								
Lapsana communis	seed	31				6	3		16			6
Linum sp., cf.	seed	16								16		
Lolium sp., small-seeded	fruit	2					2					
Lychnis sp. / *Silene* sp.	seed	8							8			
Medicago sp., cf.	seed	1	1									
Neslia sp. type	seed	1	1									
Plantago lanceolata	seed	32							32			
Plantago sp.	seed	8						8				
Poa trivialis type	fruit	12	12									
Polygonum convolvulus	nutlet	419	3	1			2	80	224		31	78
Polygonum lapathifolium	nutlet	3804	6	15	4	1	24	2056	588	16	806	288
Polygonum persicaria	nutlet	11123	13	2			48	752	5866		32	4410
Polygonum lapathifolia / persicaria	nutlet or endsperm	939	3	3		6	17	728	6	16	160	
Polygonum sp.	trigonous core	5	5									
Rumex acetosella type	nutlet	40						8	32			
Rumex crispus type	nutlet	2	2									
Setaria viridis / verticillata	fruit	1124	20					32	584	480	8	
Setaria sp.	fruit	24							24			
Spergula arvensis	seed	8							8			
Spergula sp.	seed	16						16				
Stellaria media	seed	72	72									
Veronica hederifolia	seed	1	1									
Vicia sp. / *Lathyrus* sp.	seed	25	1				8		16			
Brassicaceae	pod fragment	8	8									
Brassicaceae p.p.	seed	1028	28				8	960		32		
Caryophyllaceae p.p.	seed	48								48		
Chenopodiaceae p.p.	seed	32								32		
Chenopodiaceae/Caryophyllaceae	seed core	2				2						
Poacae p.p.	fruit	152				1	2	32		16	101	
Indeterminate	seed	117	40		12				1	64		
culm/stem remains	fragment	8						8				
OTHER												
Claviceps purpurea	sclerotia	26		2					24			

Table 4. The list of botanical taxa and the number of remains found in the grain-rich pit (Feature 145) at Wismar-Wendorf.

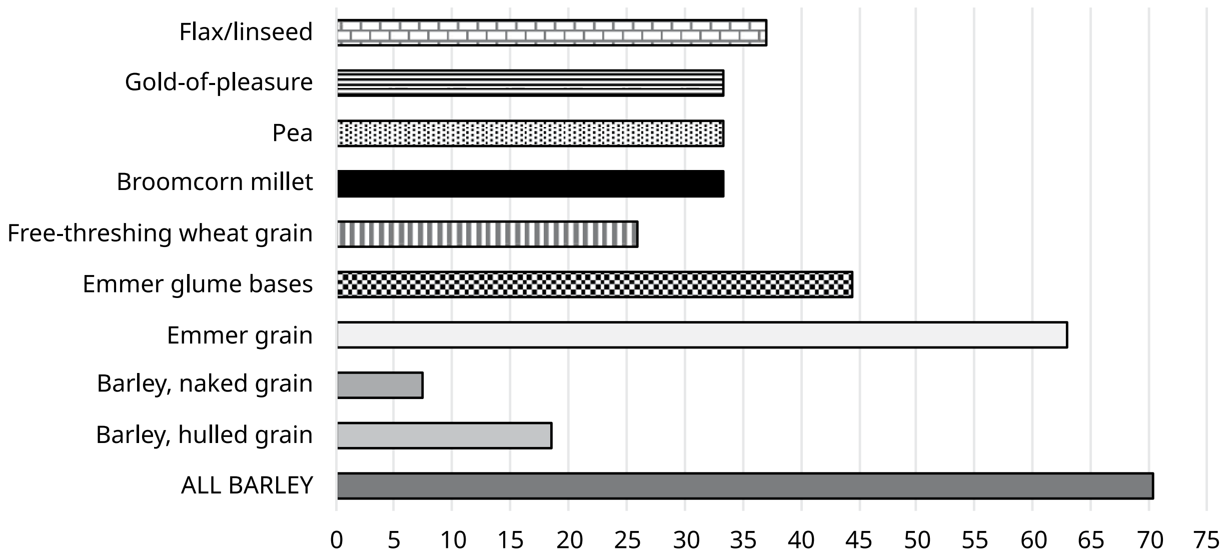

Figure 7. Proportion of the contexts at Wismar-Wendorf in which the most abundant taxa occur.

that some of the wild/weed taxa arrived from emmer or broomcorn millet fields. This is even more likely for the rest of the contexts, which appear 'mixed' – they contain similar proportions of the two main crops (barley and emmer) and small amounts of other crops, and significant amounts of wild/weed remains. This can be understood as indicating that the plant material was mixed prior to its deposition in the features.

The figures given in Tables 3-4 show that, among the most abundant wild/weed taxa are several types of grasses, such as large-seeded (*e.g. Avena*, *Bromus*) and panicoid grasses (*Echinochloa* and *Setaria*), some *Polygonum* species (*P. persicaria* and *P. lapathifolia* in particular), *Chenopodium* (*album* type), *Galium* (mostly *G. aparine* and *G. spurium*), few Caryophyllaceae and Brassicaceae species. The indeterminate Brassicaceae likely include some distorted and thus indeterminate *Camelina* seeds. Based on the morphology, a large number of the finds of *Avena* floret base could be identified as belonging to *Avena fatua* (cf. Pasternak 1991; Jacomet 2006). *Avena* grains occur quite frequently at the site and are for instance, highly abundant in pit 145, where a significant quantity of *Avena fatua* floret bases were discovered (grains in glumes were also encountered). It is possible that the oat grains from pit 145 also come from *Avena fatua*.

Plants in the archaeological context

In the sections that follow, the botanical content of different feature types is described and commented on. In the case of pits, the presence of non-botanical material in the fill is noted (*e.g.* pottery, animal bone, *etc.*) in an attempt to grasp the overall composition of the deposits in the pits and their history.

Fireplaces

Five fireplaces were available for the analysis. They were all of oval or kidney shape and located in very shallow to somewhat deeper depressions (*c.* 0.20-0.50 m). Their dimensions were 1.5-2 m in length and 1-1.5 in width. They all contained chunks of burnt/scorched earth, burnt stones and fragments of pottery. A flint tool (sickle piece) and a grinding ball were found in Feature 465.

The samples from fireplaces are very poor in, or void of, seed/fruit remains (see Table 3). In contrast, they yielded large-sized (*e.g.* >1 cm) wood charcoal pieces, Feature 469 in particular, demonstrating the use of wood as fire fuel. It is possible

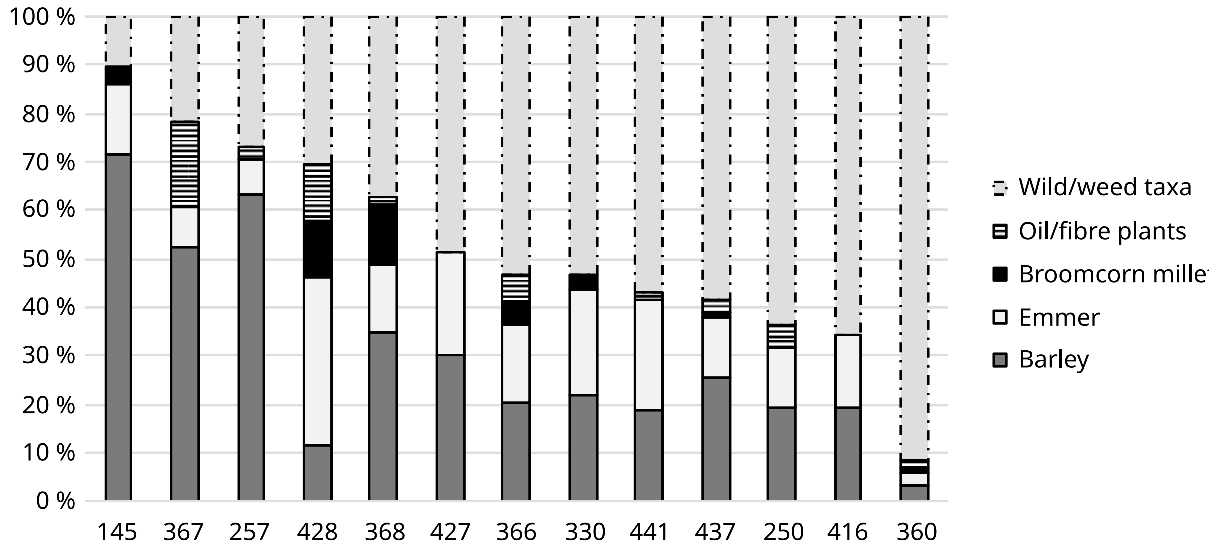

Figure 8. Relative proportions of the selected taxa in the contexts at Wismar-Wendorf that yielded thirty or more plant remains.

that other plant parts thrown into fires were mostly burnt away or removed if/when the fireplaces were swept. The few taxa identified based on the presence of their seed/fruit are the same ones documented in the pits, where some of them occur in much larger quantities. Further, the majority of the analysed pits contained some amount of wood charcoal. It looks like spent fuel from the hearths was deposited in the pits.

Pits filled with rubbish

The majority of the 21 analysed pits has a very low botanical density (up to *c.* 15 items per litre of soil), suggesting deposition of small amounts of plant parts, probably over an extended time interval, or a one-time infilling of the pit with the matrix that did not contain much plant material. Feature 360, however, stands out with 78 items per litre of soil; it is discussed in more detail below. Almost all of the pits yielded a mixture of cereal grain (mostly emmer and barley in co-occurrence) or seeds of other crops, wild/weed seeds and, occasionally cereal chaff, which is a combination of products and by-products of crop cleaning. It is thus difficult to differentiate between them taxonomically, regardless of the tentative archaeological characterisation (*e.g.* storage or borrow pits). Figure 9 provides a closer look at the relative proportions of some prominent crop types/groups in the twelve pits that yielded ≥30 counted items. The crop-product component (grain/seed), which prevails in several samples (left end of the graph) always includes several different crops. These remains were likely mixed after processing and/or consumption, and discarded together as waste. The rest of the samples contain small amounts of products and greater proportions of by-products, and they probably represent a combination of discard from processing of all of these crops. Feature 360, tentatively described as a storage pit, is almost entirely dominated by wild/weed taxa; this is also the context with the highest number and density of plant remains among the pits (beside pit 145). Almost all of the wild/weed taxa recorded at the site are found here, and the best represented are those recognised as the most abundant across the site. Nearly all of the crops are also present, in small numbers, and the arable weeds may have been associated with any or all of them, reflecting the general crop growing conditions at Wismar-Wendorf. From an archaeobotanical perspective, the fill of pit 360 consists of crop processing waste. The relatively large quantity of it is perhaps a result of more frequent or prolonged use of the pit for disposing of domestic rubbish.

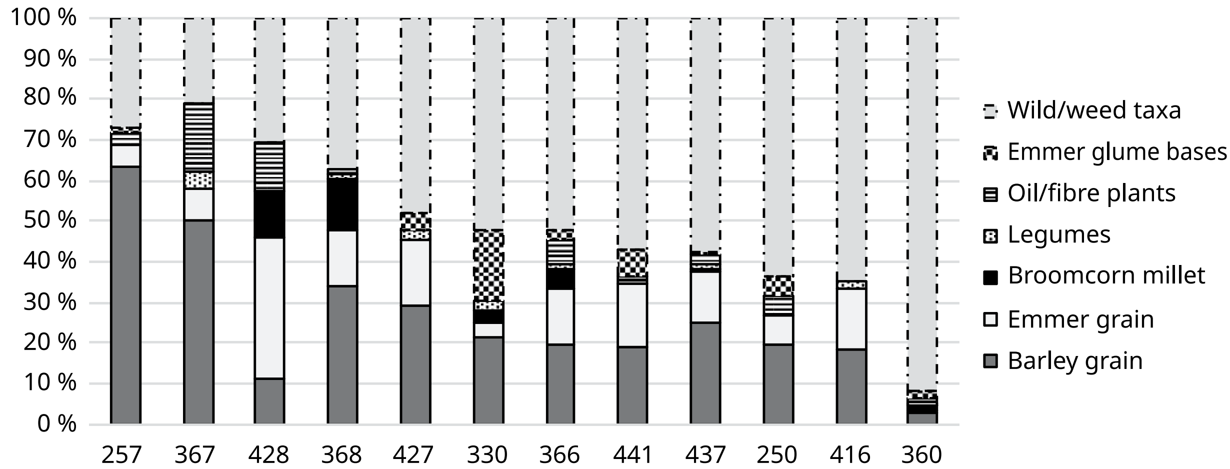

Figure 9. Relative proportions of the selected taxa in the twelve pits at Wismar-Wendorf that yielded thirty or more plant remains.

In sum, the botanical content of the pits is, without exception, made up of the waste resulting from handling and consumption of different crops, meaning that the analysed deposits from pits represent rubbish deposits. Their mixed nature applies also to other types of finds. Table 5 lists the categories of archaeological materials discovered in the pits, as well as the quantity of the crop types/groups considered here. The combination of the most frequently occurring categories of the material is standardised and mixing is pervasive. What varies between the pits is the quantity of each type of find. For instance, some yielded larger amounts of pottery or chipped stone pieces. Perhaps a future coordination of the archaeological and archaeobotanical data would enable a (meaningful) differentiation between the infills of these features.

A pit full of grains

Pit 145 yielded the greatest amount of plant material; its fill had the highest botanical density (see Table 4). A preliminary interpretation offered by the archaeologists was that it represented a borrow pit, whose secondary use was for waste disposal. The pit was located in the immediate vicinity of other features, such as two ovens, postholes and more pits. It had an oval base and was oblong in cross-section (Figure 3). Its dimensions were as follows: length 2.79 m, width 2 m and relative depth 0.98 m. In comparison to the other pits analysed (Table 5), this one was of medium size. The excavation of a section of it exposed six layers of infill differentiated by their colour, consistency and inclusions. Thus, the excavation proceeded by emptying the pit in six layers, each of which seems to have represented a discrete deposit. The top layer of the fill (Layer 1) was composed of greyish brown loose, sandy clay with charcoal fragments, pieces of scorched clay and potsherds. Below Layer 1, Layer 2 was of a similar composition, although charcoal pieces were much smaller. Layer 3 was made of homogeneous light brown sandy clay. Layer 4, which was about 20 cm thick, is of greatest interest here. This is where large pieces, in the form of slabs, were discovered of hardened, scorched clay bearing imprints of twigs. To the archaeologists they looked as if they could be fragments of (house/oven?) wall coated with what appears to be lime-rich slip. From this layer also, an abundance of fragments of charcoal, pottery, burnt bones and grain was recovered. This is chiefly where the archaeobotanical material analysed here comes from. Layer 5 was recognised as a grey ashy matrix. Layer 6 was composed of greyish to light brown, loose, sandy clay with inclusions such as small pieces of charcoal and scorched clay. Of other materials, chipped stone pieces, a grinding stone and a clay bead were encountered in the pit. A grain sample from Layer 4 was radiocarbon-dated at the laboratory in

Feature number	233	360	416	441	188	250	257	270	280	330	362	366	367	368	398	407	424	437	372	427	428
Shape of base	round	oval	oval	sub-oval	oval	sub-rectangular	sub-oval	oval; funnel-shaped profile	semi-circular	irregular; funnel-shaped profile	kidney-shaped	square to irregular	irregular	irregular	oval	kidney-shaped	oval	irregular, oblong	oblong	round to oval	oval
Length (m)		1.88	1.52	1.8	1.84	3.3	2.54	1.8	3.24	4.7	1.62	4.12	3.7	2.86	2.98	2.94	2.58	5.42	2.4	1.75	1.86
Width (m)		1	1.1	1.44	1	2.02	1.75	1.2	0.85	3.7	1	3.3	2.9	1.8	2.1	1.85	2.15	2.88	1.78	1.62	1.6
Relative depth (m)		0.98	0.46	1.08	1.22	0.88	0.6	0.62	0.48	0.96	0.68	1.16	0.6	0.62	0.6	0.86	0.54	1.25	0.42	0.25	0.36
charcoal	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
pottery	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
chipped stone	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
bone		x		x		x				x	x	x	x	x	x		x	x	x		
stone polisher		x	x	x	x	x					x	x	x			x		x			x
whetstone															x						
metal ring										x											
metal needle													x								
burnt stone						x															
brick						x															
ALL CROP	6	207	32	36	5	16	62	8	1	36	4	95	25	102		15	13	252	10	35	24
ALL WILD	2	1670	31	33	7	26	19	3	2	39	6	66	5	54	1	11	3	273	5	21	8
Barley grain	5	55	9	11	2	8	45			16	3	25	12	50		10		118	2	13	3
Barley, hulled grain		48		11	1													39			
Barley, naked grain		7																			
Emmer grain		9	7	9		3	4			3		17	2	20		2	8	58	2	7	9
Emmer glume bases		33		4		2	1			13		3						1	4	2	
Broomcorn millet		22								2		6		18		1	2	5			3
Legumes		2	1							2		2	1	2				4		1	
Oil/fibre plants		27		1		2	2	8			1	7	4	2				12	2		3

Table 5. The list of archaeological materials and the number of remains of crop types/ groups in the different archaeobotanically analysed pits at Wismar-Wendorf.

Poznan and it gave the date of 2505±35 BP (Poz-90213; 657 ± 89 cal BCE, calibrated with Calpal Online).

Figure 10 illustrates the overall composition of the pit fill, based on the results available so far. It is evident that all of the major crop types registered in other contexts at Wismar-Wendorf are also represented in pit 145. Moreover, just like elsewhere, here too hulled barley and emmer are the most prominent crops. Table 6 provides the counts of the main crop types/groups in the pit, from the three layers from which the samples were taken for archaeobotanical analysis. The high and

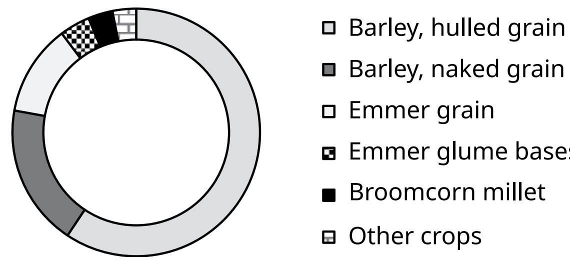

Figure 10. Relative proportions of crops in the fill of the grain-rich pit (Feature 145) at Wismar-Wendorf.

concentrated quantity of crops, principally of cereal grain, in a well-defined deposit clearly shows that the material represents stores of crop products. The significant presence of wild/weed taxa in the samples indicates that the crops were not cleaned prior to storage. This is, in case of emmer, also clear from the notable amounts of emmer glume bases co-occurring with emmer grain (or with broadly identified hulled wheat and cereal grain that may be emmer – see Table 4). That the emmer grain is always more numerous than the glume bases is to be expected given the grain-to-glume base ratio for this cereal but also because of the lower chances of chaff to survive charring, as demonstrated in the experimental work by Boardman and Jones (1990). Emmer was most probably stored in the spikelet, along with the weed seeds not removed in coarse-sieving (cf. Hillman 1981; Jones 1984). Barley was also stored without being fully cleaned, as again suggested by the presence of potential weeds in the barley-rich samples and the occurrence of barley rachis internodes. There are not many free-threshing cereal rachis remains in the samples and this is because they tend to be removed early in the crop processing sequence (Jones 1990). In contrast to emmer and barley, millet grain seems to have been deposited in a cleaned state. In the millet-dominated sample (sample 16+3), the wild/weed component is minor and may actually be associated with the small admixture of barley. The millet-sample comes from a concentration of pottery sherds; the pot may have held the cleaned grains (prior to/during the burning) and was likely crushed by the weight of the overlying layers of the pit fill.

The twigs, whose impressions were observed in pieces of scorched clay in Layer 4, perhaps derive from wickerwork potentially installed as lining for the pit, such as was the case with two pits ('silos') from the 3rd century AD discovered at the site of Feddersen Wierde in Lower Saxony, which were approximately 0.6 m deep and lined with wickerwork (Haarnagel 1979). That, at Wismar-Wendorf, twigs left imprints in clay suggests that the wickerwork was plastered with clay/mud, which was then covered with slip/whitewash preserved in traces on the surface of the pieces of burnt clay. Perhaps these remains in fact come from a mud-plastered basket, of the kind widely used in traditional storage systems of small-scale farmers in, for instance, Africa and India (Shepherd 1999; Nagnur *et al.* 2006). Very well-preserved archaeological examples of mud-plastered baskets, filled with barley and millet grain, were encountered in a house at a late La Tène settlement (1st century BCE) of Čarnok in Vojvodina, Serbia (Medović 2006).

The charred grain embedded in the burnt clay links the clay pieces with the concentration of grain discovered in the same deposit. The two categories of material evidently burned simultaneously. It is possible that the burnt bones and wood from this layer (and perhaps pottery, when it bears traces of secondary burning) represent elements of the same burning event. The burnt clay fragments were scattered through the grain-rich deposit and do not indicate an *in situ* layer/surface atop which the grain was burned, although such surface, if it existed, could have been truncated and disturbed following the burning. It, thus, remains unclear whether the slabs of burnt clay with twig imprints represent traces of constructional elements of the pit (*e.g.* lining, floor), or of objects (*e.g.* containers, ovens) intentionally placed or dumped into the pit.

Sample number		1	3	16+3	4	6	10	A+A-rest	12+8	11+7	B
Layer		(Upper layer)	3-4, transition		4		lower 4 and transition 4-5				
Quadrant			A-D	B-D	A-D		A-D		B-D	B-C	
	Total remains	multiplied-up counts for subsamples (to obtain 100%)									
Barley, hulled grain	144501	6	384	116		550	17280	60410	1984	3999	59772
Barley, naked grain	44991		24			13028	1216	27226	432	527	2538
Emmer grain	3108	4	10		7	117	1728	14	608	620	
Emmer glume bases	9660	1	88				3704	4455	96	422	894
Broomcorn millet	7811	3	2	7612			8	144			42
Legumes	54	4			1	1		32	16		
Oil/fibre plants	136	4		4				80	48		
ALL CROP	243424	37	1010	7836	8	13698	32824	106150	4240	7715	69906
ALL WILD	29120	358	37	20	30	202	6696	11358	1856	1519	7044
ALL REMAINS	272544	395	1047	7856	13938	157028	6096	86184			

Table 6. Quantity of the remains of the main crop types/groups in the three archaeobotanically analysed layers of the grain-rich pit (Feature 145) at Wismar-Wendorf.

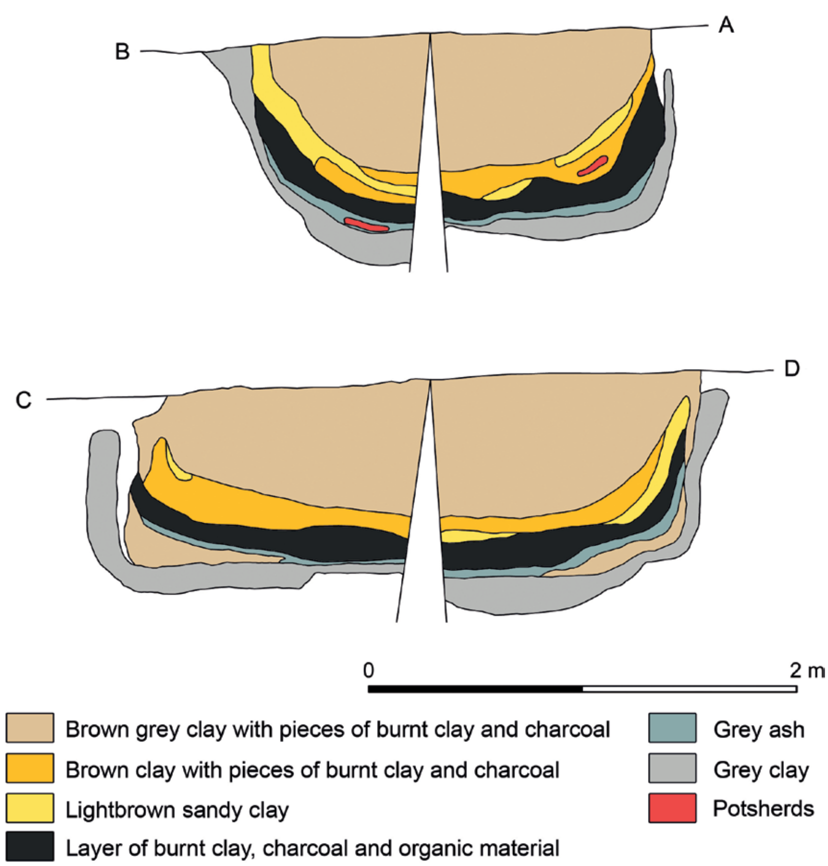

Figure 11. Simplified representation of the sections through layers of the fill of Feature 145 at Wismar-Wendorf, illustrating its varied composition.

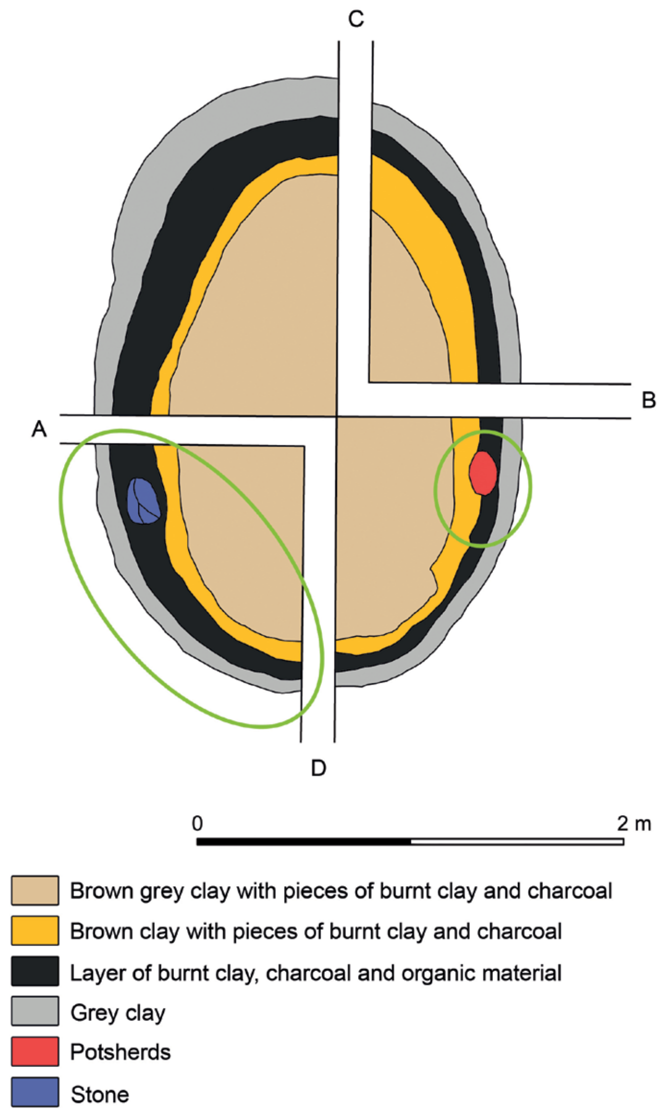

Figure 12a. Simplified view of the different deposits in the upper part of layer 4 of the fill of Feature 145 at Wismar-Wendorf; circled are the zones with the concentration of barley (left) and broomcorn millet (right).

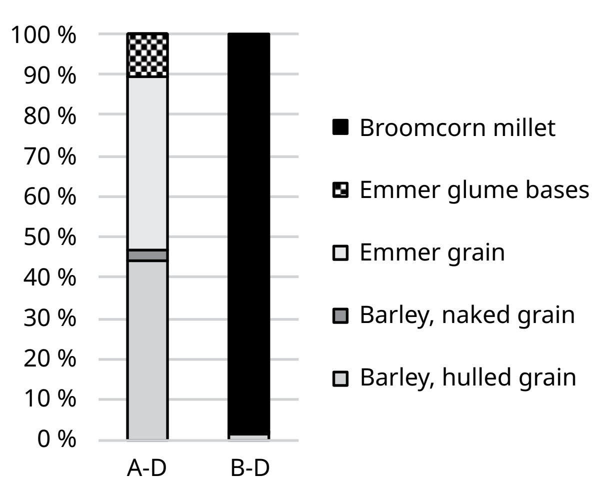

Figure 12b. Proportional representation of the main crops in the upper part of layer 4 of the fill of Feature 145 at Wismar-Wendorf (labels A-D and B-D refer to quadrants of the grid).

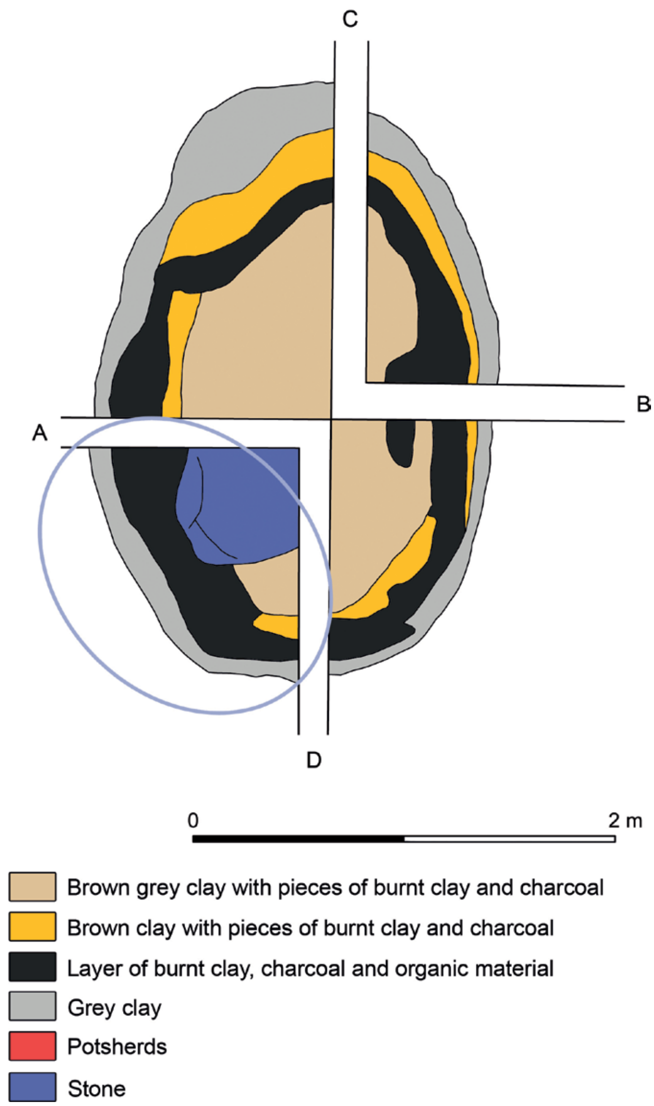

Figure 13a. Simplified view of the different deposits in the lower part of Layer 4 of the fill of Feature 145 at Wismar-Wendorf; circled is the zone with the concentration of naked barley.

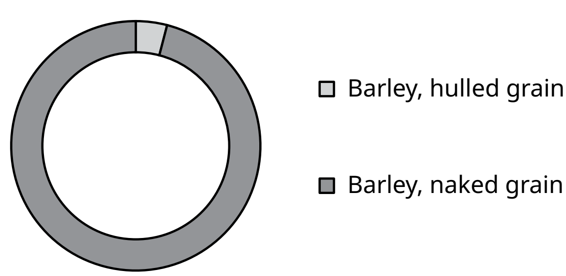

Figure 13b. Proportional representation of the two types of barley in the barley deposit in the lower part of Layer 4 of the fill of Feature 145 at Wismar-Wendorf.

It is also difficult to establish whether the burning occurred in the pit. There was no record, for example, of a fired surface at the base of the pit or traces on its sides that would point at *in situ* burning. It is, however, possible that the burning did take place in the pit, but that it was very localised and controlled – perhaps it occurred within a clay-plastered, basket-like, grain-filled container. If so, then there likely was more than one storage container, filled with varying amounts of different crops. This is indicated by the presence of 'sub-layers' or lenses of charred material registered within the grain-rich Layer 4. They differ in size/volume and were documented in some parts of the pit and not in others; hence, the distribution of plant remains through and across Layer 4 is uneven and discontinuous, as illustrated in Figure 11. The lenses are dominated by different crop types (see Table 6) and may represent separate crop stores and perhaps even separate burning events. The concentration of broomcorn millet grain was detected in the south-east part of the pit (Quadrant

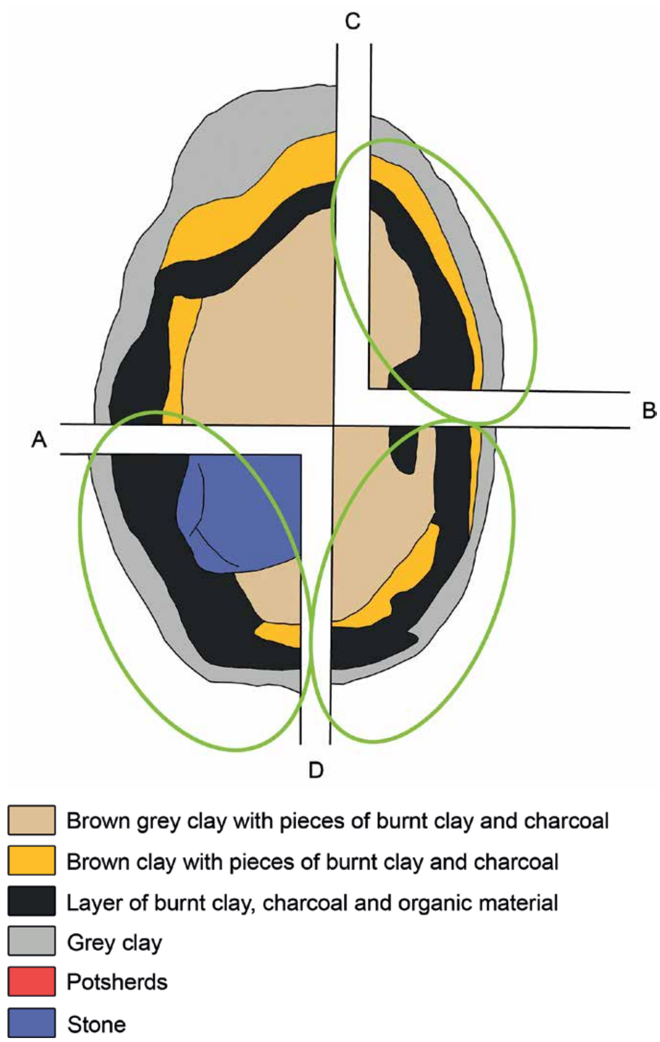

Figure 14a. Simplified view of the different deposits in the lower part of Layer 4 of the fill of Feature 145 at Wismar-Wendorf; circled are the zones from which the hulled barley-rich samples derived.

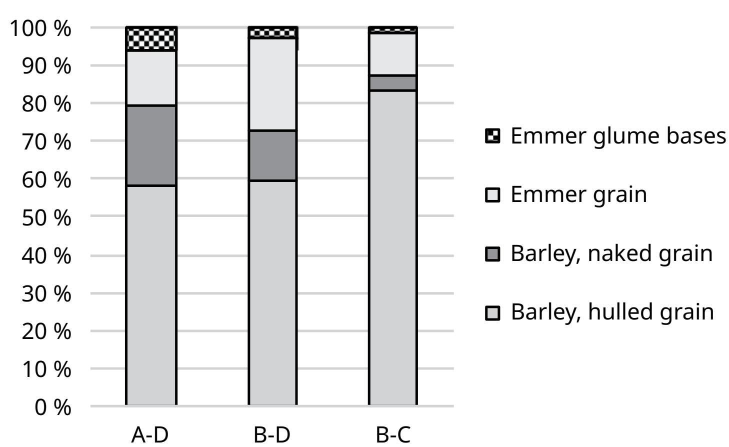

Figure 14b. Proportional representation of the two main crops found at the base of Layer 4/top of Layer 5 of the fill of Feature 145 at Wismar-Wendorf. (labels A-D, B-D and B-C refer to quadrants of the grid).

B-D), in the upper section of Layer 4 (base of Layer 3), contained within a cluster of pottery fragments and thus understood as a discrete deposition. At approximately the same depth, but in the south-west part of the pit (Quadrant A-D), a charred lens composed mostly of similar proportions of hulled barley and emmer (grain) was registered (Figures 12a-b). The likelihood is very low that these two crop types were kept together in a store in a semi-cleaned state, unless perhaps they were intended to be fed to animals. Emmer (hulled wheat) and barley (free-threshing cereal) have differing post-harvest processing requirements (Hillman 1984) and are in general sown, stored and processed separately. In sum, three distinct crop stores can be discerned at this level in the pit, two of which may have been combined at the time of deposition.

Below this level, in the south-west quarter of the pit, another lens of charred material was discovered, constituting mostly of grains of naked barley (Figure 13a-b). This could be interpreted as another discrete crop store. In the lower part and at the base of Layer 4 (and into Layer 5), a significant concentration of grain extended along the southern and eastern walls of the pit (Quadrants A-D, B-D and B-C; Figure 14a). The bulk of the material was encountered in the south-west quarter of the pit (A-D quadrant). This deposit was, for the greatest part, made up of grains of hulled barley, particularly in the north-east section of the pit (Figure 14b). The other components include crops from the two overlying deposits (naked barley and emmer) from which some of the content seeped into the hulled barley store.

The richest samples from Layer 4 derived from Quadrant A-D; this is where concentrations of three of the four major crop types were documented, the most remarkable being the hulled barley concentration. The bottom-top sequence of crop deposits here is as follows: hulled barley – naked barley grain – emmer/naked barley. This may reflect the order in which the crop stores were placed in the pit before or after burning. Perhaps hulled barley stood in a mud-plastered wicker container at the bottom, on top of which bags were stacked made of perishable materials (*e.g.* leather, textile, bark) and containing other crops. That the different crop stores were discovered as neat, more-or-less pure and exceptionally well-preserved deposits may mean that they got charred on the spot or that they were burned elsewhere (and separately) and then deposited into the pit one after another. In either case, there was little post-depositional disturbance in the pit – it looks like the grain-rich layer was sealed soon after its formation with a homogeneous layer (Layer 3) that was virtually find-free. The subsequent infilling of the pit seems to have continued at a slow pace and with detritus from every-day activities (*e.g.* weed seeds removed in crop cleaning).

Wherever it occurred, the burning destroyed a significant amount of stored crops. This could have been accidental, but may also have been done purposefully. Namely, a fair number (more than 20) of sclerotia of *Claviceps purpurea*, a parasitic plant fungus, were encountered in the hulled barley deposit. This is an ergot fungus that grows on ears of cereals (mainly rye) and reduces the yield. More importantly however, it contains toxic alkaloids that if consumed, can be extremely harmful and even deadly to humans and animals (Schuman and Uppala 2000). Perhaps the Bronze Age farmers at Wismar-Wendorf were aware of the detrimental effect of this pest and decided to dispose of the infested crop.

The plant spectrum at Wismar-Wendorf in a regional context

Recently, a detailed study was conducted of plant economy in the Bronze Age of northern Germany, Denmark and southern Sweden (Effenberger 2017, 2018; see also Kroll and Wiethold 2001 and Kroll 2011). Here, previous and newly produced

WILD / WEED TAXA	Neolithic sites in northern Germany (after Kirleis *et al.* 2012)	Grain-rich samples from Bronze Age sites in northern Germany, Denmark and southern Sweden (after Effenberger 2015: Tabelle 48)	Wismar-Wendorf
		presence / absence	
Atriplex patula	X		
Avena sp.	X		X
Bromus arvensis	X	X	
Bromus secalinus	X	X	X
Carex sp.	X		
Chenopodium album	X	X	X
Descurainia sophia	X		
Echinochloa crus-galli	X	X	X
Euphorbia helioscopia	X	X	
Galium aparine	X	X	X
Galium spurium	X	X	X
Hypericum sp.	X		
Lapsana communis	X	X	X
Lolium sp.	X		X
Phleum sp.	X		
Plantago lanceolata	X	X	X
Poa annua	X	X	
Polygonum aviculare	X	X	X
Polygonum convolvulus	X	X	X
Polygonum lapathifolium	X	X	X
Polygonum persicaria	X	X	X
Ranunculus sp.	X		
Rumex acetosella	X	X	X
Rumex crispus	X	X	X
Rumex sanguineus type	X		
Schoenoplectus sp.	X		
Solanum dulcamara	X		
Solanum nigrum	X	X	X
Spergula arvensis	X	X	X
Stellaria media	X	X	X
Urtica dioica / urens	X	X	
Vicia sp.	X	X	X
Agrostemma githago		X	
Aphanes australis		X	
Atriplex sp.		X	
Brassica nigra		X	
Bromus sp.		X	X
Bupleurum rotundifolium		X	
Capsella bursa-pastoris		X	X
Chenopodium ficifolium		X	X
Chenopodium hybridum		X	
Galeopsis sp.		X	X
Knautia arvensis		X	
Mentha arvensis		X	
Raphanus raphanistrum		X	
Scleranthus annuus		X	X
Setaria italica		X	X
Setaria viridis		X	X
Stachys annua		X	
Thlaspi arvense		X	X

WILD / WEED TAXA	Neolithic sites in northern Germany (after Kirleis *et al.* 2012)	Grain-rich samples from Bronze Age sites in northern Germany, Denmark and southern Sweden (after Effenberger 2015: Tabelle 48)	Wismar-Wendorf
Trifolium sp.		X	X
Vicia hirsuta / tetrasperma		X	
Viola sp.		X	
Apera spica-venti			X
Avena fatua			X
Brassica sp. / *Sinapis* sp.			X
Chenopodium sp.			X
Eleocharis sp.			X
Galium mollugo type			X
Galium sp.			X
Hordeum sp.			X
Linum sp., cf.			X
Lychnis sp. / *Silene* sp.			X
Malva sp.			X
Medicago sp., cf.			X
Neslia sp. type			X
Plantago sp.			X
Poa trivialis type			X
Polygonum sp.			X
Setaria sp.			X
Setaria viridis / verticillata			X
Spergula sp.			X
Veronica hederifolia			X
Vicia sp. / *Lathyrus* sp.			X

Table 7. List of wild/weed plants recorded at Wismar-Wendorf and wild/weed plants encountered at Neolithic and Bronze Ages sites in northern Germany.

archaeobotanical data for almost 160 sites[8] from the Bronze Age phases defined for northern Europe (2000-500 BCE – *e.g.* Rassmann 2004) were combined and analysed. The regional variations in the level of preservation and classes of archaeological features, as well as the differences in archaeobotanical field and laboratory methods, were successfully overcome using a number of different quantification steps and adjustments. The study offers a comprehensive overview of the archaeobotanical knowledge for this period in this part of the world.

The list of crop taxa provided in this work and documented throughout the study region is very similar to the one presented here for Wismar-Wendorf (Effenberger 2017: Table 2, Fig. 4). Furthermore, the cereal spectrum of Late Bronze Age Wismar-Wendorf is almost identical to the general one for Late Bronze Age sites in Mecklenburg-Vorpommern (*ibid.* Table 2). The exception is rye (*Secale cereale*), which was not registered at Wismar-Wendorf, and einkorn, that is absent from other Late Bronze Age sites in Mecklenburg-Vorpommern. The full range of pulses and oil/fibre plants recorded in Late Bronze Age northern Germany is represented at Wismar-Wendorf (*ibid*: Fig. 2). Thus, the assemblage from Wismar-Wendorf conforms to the regional pattern in terms of the very wide and diverse crop spectrum that also includes several (possible) species likely not cultivated prior to the Bronze Age (*e.g. Camelina sativa, Papaver somniferum, Vicia faba*). It also represents another example of the increased presence of *Panicum miliaceum*, characteristic of this phase and noted also in other parts of northern Europe. The notable quantity of naked barley that was seemingly absent from Mecklenburg-Vorpommern in the Early Bronze Age perhaps means that this crop made its (re-)appearance here in the Late Bronze Age (*ibid.* Figs. 2, 5).

8 See list of sites in Effenberger 2015: Table 44.

In Table 7, the repertoire of wild plants identified at Wismar-Wendorf is compared with the list of wild plants found in (cereal) grain-rich samples from Late Bronze Age sites in the area studied by Effenberger, as reported in her doctoral thesis (2015: Tabelle 48).[9] Virtually all of the potential weed taxa recognised as abundant-and-frequent at Wismar-Wendorf (see above) were also present in the wider region, and are found associated with, presumably, large quantities of cereals. Many of these taxa were recorded at Neolithic sites in northern Germany too (Table 7, and see Kirleis *et al.* 2012). Just as the regional 'Neolithic crop set' was carried on into the Bronze Age, it looks like the 'Neolithic arable weed set' also persisted. But it also seems that many new wild/weed taxa (such as *Setaria* species) were brought in during this period, and this process ran in parallel to the broadening and diversification of crop spectrum and other innovations in the agricultural regime (*e.g.* Willerding 1988) or the agricultural tool kit (Knörzer 1987). This is in line with the proposed changes in intensity of agricultural production in the Bronze Age in the region (*e.g.* Kroll 1997; Behre 1998; Harding 1989) or, perhaps the greater variability in the degree of intensity of cultivation (*e.g.* van der Veen 1992), that is – the possible co-existence of different cultivation regimes. The ecology of arable weed taxa identified in the different crop deposits in pit 145 is under study and will shed more light on the growing conditions in the crop fields cultivated by the residents of the Bronze Age settlement at Wismar-Wendorf.

Summary and conclusions

The site of Wendorf in the town of Wismar in north-eastern Germany is mostly characterised by a number of pits of various shapes and sizes. Other features include fireplaces and postholes indicating the existence of above-ground structures and a settlement. Based on the typology and style of pottery, the site was determined to have been occupied in the late phase of the Bronze Age; radiocarbon dating confirmed this impression.

Many of the pits, and a few fireplaces, were sampled for archaeobotanical remains. The fireplaces yielded little plant material, as did the majority of the examined pits. The assemblages from these contexts are, by default, composed of similar amounts of crop products (grain) and by-products (chaff and wild/weed seeds), and of a mixture of taxa. This, and the combination of crops that have dissimilar processing requirements demonstrate that, the fill of a large number of pits represents waste resulting from cleaning of crops and food preparation. Given that the Bronze Age settlement had areas designated for rubbish disposal, it appears that there was some waste management in place such as, in this case, landfilling.

One of the larger pits contained unusually high quantity (*i.e.* kilograms) of plant material, mostly cereal grain but also admixtures of various wild seeds. The analysis of different layers/sections of the pit fill revealed the sequence of 'dumps' of the remains of four different crops: hulled barley, naked barley, emmer and broomcorn millet. Each of the dumps likely represents stored crop; it is not quite clear whether the burning of the crop stores took place in the pit. There are no traces of burning inside the pit, though the presence of slabs of burnt clay, possibly parts of mud-plastered basket or another form of wickerwork, may indicate that the burning happened inside the pit, but was confined within a storage container. Equally possible is that the plant material was charred elsewhere and then deposited in the pit. The burning of the crops may have not been an accident. At least in the case of hulled barley, it may have been provoked by the ergot fungus infection.

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9 *Setaria italica* is not in the original list; it was added here as it is not considered cultivated taxon at Wismar-Wendorf. It occurs at few Bronze Age sites in the study region and is included with grown crops by Effenberger (2017).

The contents of the grain-rich and other pits at Wismar-Wendorf display the spectrum of crops grown and/or consumed at the site and the range of wild plants likely accompanying crops in arable fields. They also indicate that the crops were not brought to the site in a fully clean state, but that at least final processing prior to preparation took place on-site. The repertoire of crop and wild taxa registered at Wismar is comparable to the array of plants reported for other Bronze Age sites in the wider region of northern Germany. In comparison to the Neolithic, the Bronze Age crop spectrum is wider as some useful plants that previously seem to have been random inclusions, may have been brought into cultivation in this period.

Acknowledgements

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References

Behre, K.-E. 1998. Landwirtschaftliche Entwicklungslinien und die Veränderung der Kulturlandschaft in der Bronzezeit Europas, in: Hänsel, B. (ed.), *Mensch und Umwelt in der Bronzezeit Europas*. Kiel: Oetker-Voges-Verlag, 91-109.

Boardman, S. and Jones, G. 1990. Experiments on the effects of charring on cereal plant components. *Journal of Archaeological Science* 17, 1-11.

Effenberger, H. 2015. *Pflanzennutzung und Ausbreitungswege von Innovationen im Pflanzenbau der Nordischen Bronzezeit und angrenzender Regionen*. PhD thesis. Kiel: Kiel University.

Effenberger, H. 2017. The plant economy of the Northern European Bronze Age – more diversity through increased trade with southern regions. *Vegetation History and Archaeobotany* 27, 65-74.

Effenberger, H. 2018. *Pflanzennutzung und Ausbreitungswege von Innovationen im Pflanzenbau der Nordischen Bronzezeit und angrenzender Regionen*. Kiel: Wachholtz Verlag.

Haarnagel, W. 1979. *Die Grabung Feddersen Wierde. Methode, Hausbau, Siedlungs- und Wirtschaftsformen sowie Sozialstruktur. Feddersen Wierde*. Wiesbaden: Franz Steiner Verlag.

Harding, A. 1989. Interpreting the evidence for agricultural change in the Late Bronze Age in northern Europe, in: Nordstrom, H.-A. and Knape, A. (eds.), *Bronze Age Studies*. Stockholm: Statens Historiska Museum, 173-181.

Hillman, G.C. 1981. Reconstructing crop husbandry practices from the charred remains of crops, in: Mercer, R. (ed.), *Farming Practice in British Prehistory*. Edinburgh: Edinburgh University Press, 123-162.

Hillman, G.C. 1984. Interpretation of archaeological plant remains: Application of ethnographic models from Turkey, in: Casparie, W.A. and van Zeist, W. (eds.), *Plants and Ancient Man*: *Studies in palaeoethnobotany*. Rotterdam: Balkema, 1-41.

Jacomet, S. 2006. *Identification of cereal remains from archaeological sites*. Basel University: Archaeobotany Lab IPAS.

Jones, G. 1984. Interpretation of archaeological plant remains: ethnographic models from Greece, in: Casparie, W.A. and van Zeist, W. (eds.), *Plants and Ancient Man: Studies in palaeoethnobotany*. Rotterdam: Balkema, 43-61.

Jones, G. 1990. The application of present-day cereal processing studies to charred archaeobotanical remains. *Circaea* 6/2, 91-96.

Kirleis, W., Klooß, S., Kroll, H. and Müller, J. 2012. Crop growing and gathering in the northern German Neolithic: a review supplemented by new results. *Vegetation History and Archaeobotany* 21, 221-242.

Knörzer, K.-H., Gerlach, R. and Meurers-Balke, J. 1999. *Pflanzenspuren: Archäobotanik im Rheinland: Agrarlandschaft und Nutzpflanzen im Wandel der Zeiten*. Materialien zur Bodendenkmalpflege im Rheinland 10. Cologne: Rheinland Verlag.

Kroll, H. 1997. Zur eisenzeitlichen Wintergetreide-Unkraut-Flora von Mitteleuropa. Mit Analysenbeispielen archäologischer pflanzlicher Großreste aus Feudvar in der Vojvodina, aus Greding in Bayern und aus Dudelange in Luxemburg. *Prähistorische Zeitschrift* 72/1, 106-114.

Kroll, H. and Wiethold, J. 2001. Die Kulturpflanzenfunde von Jürgenshagen, Lkr. Güstrow. *Jahrbuch 2000*, Band 48. Bodendenkmalpflege in Mecklenburg-Vorpommern, 105-128.

Kroll, H. 2011. Der Getreidefund von Dolgelin, in: Peter-Röcher, H. (ed.), *Die spätbronze-/früheisenzeitliche Siedlung in Dolgelin. Lkr. Märkisch-Oderland. Ergebnisse der Grabungen in den Jahren 2000-2004*. Veröffentlichungen zur brandenburgischen Landesarchäologie 43/44, 2009/2010, 85-112.

Medović, A. 2011. Keltski silosi od bačkog pruća i panonskog blata. *Field and Vegetable Crops Research/Ratarstvo i povrtarstvo* 48, 429-438.

Nagnur, S., Channal, G. and Channamma, N. 2006. Indigenous grain structures and methods of storage. *Indian Journal of Traditional Knowledge* 5/1, 114-177.

Pasternak, R. 1991. Hafer aus dem mittelalterlichen Schleswig. *Offa* 48, 363-380.

Rassmann, K. 2004. Chronologie: Die zeitliche Ordnung der Dinge als Schlüssel zur Geschichte der Bronzezeit, in: Lehmann, T., von Schmettow, H. and Schmidt, J.-P. (eds.), *Mythos und Magie: Archäologische Schätze der Bronzezeit aus Mecklenburg-Vorpommern*. Ausstellungkatalog Schwerin. Lübstorf: Archäologisches Landesmuseum und Landesamt für Bodendenkmalpflege Mecklenburg-Vorpommern, 38-49.

Schumann, G.L. and Uppala, S. 2000. Ergot of rye. *The Plant Health Instructor.* DOI: 10.1094/PHI-I-2000-1016-01 (available at/accessed 7 May 2018: https://www.apsnet.org/edcenter/intropp/lessons/fungi/ascomycetes/Pages/Ergot.aspx;)

Shepherd, A.W. 1999. A guide to Maize Marketing for Extension Officers. *Marketing Extension Guide 1*. Rome: Food and Agriculture Organization of the United Nations.

van der Veen, M. 1992. *Crop husbandry regimes. An archaeobotanical study of farming in northern England 1000 BC – AD 500*. Sheffield Archaeological Monographs 3. Sheffield: J.R. Collis Publications.

Willerding, U. 1988. Zur Entwicklung der Ackerunkrautgesellschaften im Zeitraum vom Neolithikum bis in die Neuzeit. *Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg* 31, 31-41.

An overview of olive trees in the eastern Mediterranean during the mid- to late Holocene: Selective exploitation or established arboriculture?

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Abstract

The interaction between human activity and drier climatic conditions after the mid-Holocene initiated the 'Mediterranisation' of the landscape (Sadori *et al.* 2011), which resulted in the expansion of drought-tolerant Mediterranean-type taxa. The most striking indicators of expansion of Mediterranean-type taxa are olive trees, which have been used to define the boundaries of the present-day Mediterranean region (Carrión *et al.* 2010). While it seems that the growth of the olive was promoted by a warming climate, its abundance in the late Holocene could be interpreted instead as the first sign of large-scale management of wild olive trees or of the development of their cultivation. Even though there is no complete agreement on the timing and nature of olive cultivation/domestication, botanical data show good agreement with archaeological evidence from the Bronze Age onwards for economically significant, extensive use of olives, such as large numbers of olive stones, tools for processing olives for oil, and vessels for transporting and storing oil.

This paper reviews the patterns of vegetation changes in the eastern Mediterranean, with a particular focus on olive cultivation, the role of human impacts on the environment, and climate change through the mid- to late Holocene by integrating data from genetic, archaeological, archaeobotanical, palynological, and climatological archives. Our aim is to trace robust evidence for the timing and nature of olive arboriculture across the eastern Mediterranean by presenting the recent developments, strengths, and limitations of archaeobotanical methods in differentiating between cultivated and wild olive. By having improved spatial coverage (from numerous sites all over Turkey, Greece, and the Levant) compiled from a more diverse dataset than has previously been available, this study allows us to offer a new and more detailed way of addressing the question of whether transformation of the landscape through cultivation of olive trees occurred synchronically or diachronically across the eastern Mediterranean. We argue that olive cultivation was not a spatio-temporally uniform practice across the eastern Mediterranean, at least

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until the Late Bronze Age. Further evidence is needed to confirm our argument, but based on the current data, it looks like the story of olive domestication may have to be rewritten to include a more complex model, one in which humans played a prominent role in the Mediterranisation of the landscape.

Keywords: olive, cultivation, eastern Mediterranean, archaeobotanical, Bronze Age

Introduction

The coupled interaction of human and natural forces has played an important role in the anthropisation and transformation of landscapes surrounding the Mediterranean Sea. Being one of the earliest fruit trees to be cultivated (Zohary and Spiegel-Roy 1975), the olive is of palaeoecological, biogeographical, archaeological, and evolutionary interest. The development of cultural landscapes and increasing human activity during the Holocene can be tracked by detecting evidence for the cultivation and geographic expansion of olive trees, both in archaeological sites and in natural archives off-site.

Olive (*Olea europaea* L.)

Olive (*Olea europaea* L.) constitutes a typical component of the vegetation in the Mediterranean realm, where the climate today is characterized by rainy and cool winters and hot and dry summers. Olive is a long-lived, evergreen, thermophilic species that is well adapted to tolerate drought, salinity stress, and poor soils (Guerrero Maldonado *et al.* 2016). It is considered a sensitive thermal bioindicator for the Eu-Mediterranean vegetation zone (which extends from sea level to about 800 m ASL) represented mainly by evergreen shrubs (Zohary 1973). It is a widely cultivated species of significant agricultural value, for both fruit and oil production in the Mediterranean region, where 94 per cent of the world's olive oil is produced (IOC 2008; Punt *et al.* 1991). Nowadays, its cultivation has spread beyond its natural range both in latitude and altitude, and its pollen are amongst the most abundant airborne pollen in the Mediterranean region (*e.g.* Mercuri 2015; Tormo-Molina *et al.* 2010).

In the Mediterranean area, two varieties of the subspecies *europaea* exist: *Olea europaea* ssp. *europaea* var. *sylvestris* (wild oleaster, which forms part of the natural vegetation) and *O. europaea* ssp. *europaea* var. *europaea* (cultivated olive). The currently documented number of cultivars is likely an underestimate of the actual total due to incomplete knowledge on minor local varieties and ecotypes; it is thought that there are possibly more than 2000 cultivars in the Mediterranean basin (Muzzalupo *et al.* 2014; Rotondi *et al.* 2003). Both olive cultivars and wild oleaster olives are long-lived trees (taking hundreds of years for population turnover, see Ehrlich *et al.* (2017) that have overlapping geographical distributions and that share similar morphological features and ecological and climatic requirements in the Mediterranean basin (Lumaret *et al.* 1997; Zohary and Spiegel-Roy 1975).

Green (2002) has listed botanical criteria that can be used to distinguish oleaster olive trees from the cultivated ones. Compared with cultivated olives, wild olives have spiny juvenile shoots; shrubby growth; shorter leaves; and smaller fruits, with a less-fleshy mesocarp and a lower oil content. In addition, while wild olive has a taproot system, making the plant highly drought-tolerant and allowing a deep exploration of the soil and an easy implant on both sandy soils and rocks, cultivated olive has hairy roots (Sesli and Yegenoglu 2017). However, any olive offspring that is grown from seed generally exhibits the morphological characters specific to oleasters, regardless of parental origin (wild or cultivar) (Zohary and Spiegel-Roy 1975). Therefore, these olive offspring constitute a complex of wild-looking olives (*i.e.* phenotypically wild) potentially ranging from wild to feral forms (*i.e.* secondary sexual derivatives of the vegetatively propagated cultivated clones or products of hybridisation between cultivated trees and nearby oleasters) (Zohary and Spiegel-Roy 1975). Therefore, feral olive trees can be confused morphologically with genuine oleasters native to the Mediterranean.

The use of olives in prehistory

The olive has multiple uses. The fruit is a source of table food. The oil is used in cooking, as fuel for illumination, and in the manufacture of soap, ointments, perfume, and medicines, whereas the oil pressing residue is used as animal fodder. The wood is used as firewood or building material. The first use of the olive may have involved use of the wood as firewood and/or the oil as fuel, since olive wood produces high heat during burning and is long lasting and the oil produces little smoke during burning. The unprocessed fruits are very bitter, even when overripe, due to the presence of high amounts of oleuropein and other phenolic glucosides, so direct use of the fruits will have been limited (Marone and Fiorino 2012).

We know from many ethnographic studies that the basic method of extracting oil from the olive fruits has remained unchanged. It consists of crushing and pressing the fruits and then separating the resulting oil from the olive pressing residue. This residue, called *jift* in Arabic, consists of many crushed olive stones and pulp, which would have been useful as fuel or fodder (Galili *et al.* 1997; Rowan 2015). By removing most of the water, either by drying or by thermally degrading it through heating, *jift* can be turned into a lightweight, more effective fuel, which burns with a hotter flame and less smoke. This upgrading was practiced in Bronze Age settlements in the eastern Mediterranean basin (*e.g.* Akrotiri and Tell Tweini, Braadbaart *et al.* 2016).

Olive cultivation/domestication

Cultivation is defined as the intentional preparation of the soil for planting of wild or domesticated plants, and includes repeated planting and harvesting, whereas domestication refers to morphological or genetic changes in plant species brought about through artificial human selection or through adaptations to anthropogenic environments by the plant (Price and Bar-Yosef 2011). Domestication is generally considered to start with the exploitation of wild ancestors and to continue through the cultivation of plants (Harlan 1992; Zohary *et al.* 2012). Although domestication is generally considered to be the end point, a continuum exists between the wild and domesticated states (Ford 1985).

Disentangling the history of olive domestication is challenging, because it constitutes a long-term transformation process rather than an abrupt event and because wild populations are part of the natural environment of the Mediterranean – in the case of the eastern Mediterranean, in Greece, Turkey, and the Levant. In addition, trees are not 'domesticated' in the same way as annual plants are, and little is known about how genes and genomes evolve in long-lived plants during the process of domestication (Miller and Gross 2011). Ongoing crop-wild gene flow and clonal propagation in trees resulting from the long-term history of cultivation, selection, and human-mediated dispersion lead to a weak 'domestication syndrome', which is defined as the combination of phenotypic changes through which it has diverged from its wild ancestor(s) (Fuller 2007; Gros-Balthazard *et al.* 2016). The domestication history of annuals has been intensively studied, so the wild ancestor of annuals is well known and the domestication syndrome is well defined, such as increased fruit or seed size, non-shattering seed, changes in branching and height, and a change in reproductive strategy (Meyer *et al.* 2012 and references therein). These traits will help to determine the stages of the domestication process of annuals, from wild, to incipient domesticate, to cultivated, the latter of which cannot survive without human intervention. In contrast, there are no clear criteria regarding the domestication syndrome of the olive.

The cultivation of the olive may involve (but is not limited to) pruning, grafting, and soil management techniques, including weeding (elimination of potential competitors), tillage, irrigation, and application of fertilizer (IOC 2007). Cultivation and, subsequently, the process of domestication has caused the species to go beyond its natural bioclimatic limits and has enabled growth at higher altitudes and latitudes. Therefore, today's distribution of the olive does not reflect that of the oleaster (Carrión *et al.* 2010; Lumaret and Ouazzani 2001). Although evidence for grafting of olive trees based on archaeological record is absent until the Greco-Roman period, this practice is documented in texts and epigraphic data (Mudge *et al.,* 2009).

The early exploitation of the olive for its wood may have had advantages, including that the pruning of oleaster bushes would have had the unintended consequence or side effect of promoting increased flowering and thus increased fruit production. This can be considered as a pre-domestication step, even before the manipulation of fruit productivity by humans through the selection and intentional propagation of selected clones (Besnard *et al.* 2017; Margaritis 2013; Renfrew 1972).

It is presumed that today's olive cultivars derived from the oleaster as an ancestor, and then spread all around the Mediterranean as well as crossing between wild oleaster olives and the earliest cultivars, which led to new cultivars in different parts of the Mediterranean (Besnard *et al.* 2001). However, major questions about the timing and nature of olive cultivation/domestication across the Mediterranean remain unanswered due to conflicting interpretations, as will be explained in the following sections.

Materials and methods

This paper reviews the current state of knowledge on the emergence, development, and spread of olive cultivation in the eastern Mediterranean, until the establishment of intensive arboriculture, presumably during the Late Bronze Age (LBA). We present a comprehensive synthesis of past olive exploitation practices based on a large number of pieces of evidence compiled from diverse datasets, including genetic, archaeological, archaeobotanical, palynological, and climatic records taken from multiple sites in the eastern Mediterranean, representing a broad swath of space and time (Fig. 1). The data, summarised in Figures 2-4, present a more complete picture of the spatiotemporal patterns of olive cultivation in the eastern Mediterranean through the mid- to late Holocene. While this paper builds upon previous reviews (*e.g.,* in order of publication, Zohary and Spiegel-Roy 1975; Kaniewski *et al.* 2009; Kaniewski *et al.* 2012; Zohary *et al.* 2012; Weiss 2015; Besnard *et al.* 2017; Fuller 2018), most of which have focused on the earliest evidence for the domestication of olive trees, our emphasis differs in two respects: (a) we focus on seeking more clear evidence of established/intensive arboriculture by examining more detailed and interregional research on patterns of olive use across the eastern Mediterranean and (b) we assess the recent developments in and limitations of methods used to distinguish between cultivated olive and wild olive, as this is essential for avoiding misguided conclusions.

The applications, pros, and cons of approaches to detecting the use and cultivation of the olive in prehistoric times

The evidence for possible use of the olive in prehistoric times can be mainly grouped into the following three categories: (a) plant macrofossils, comprising mainly dry

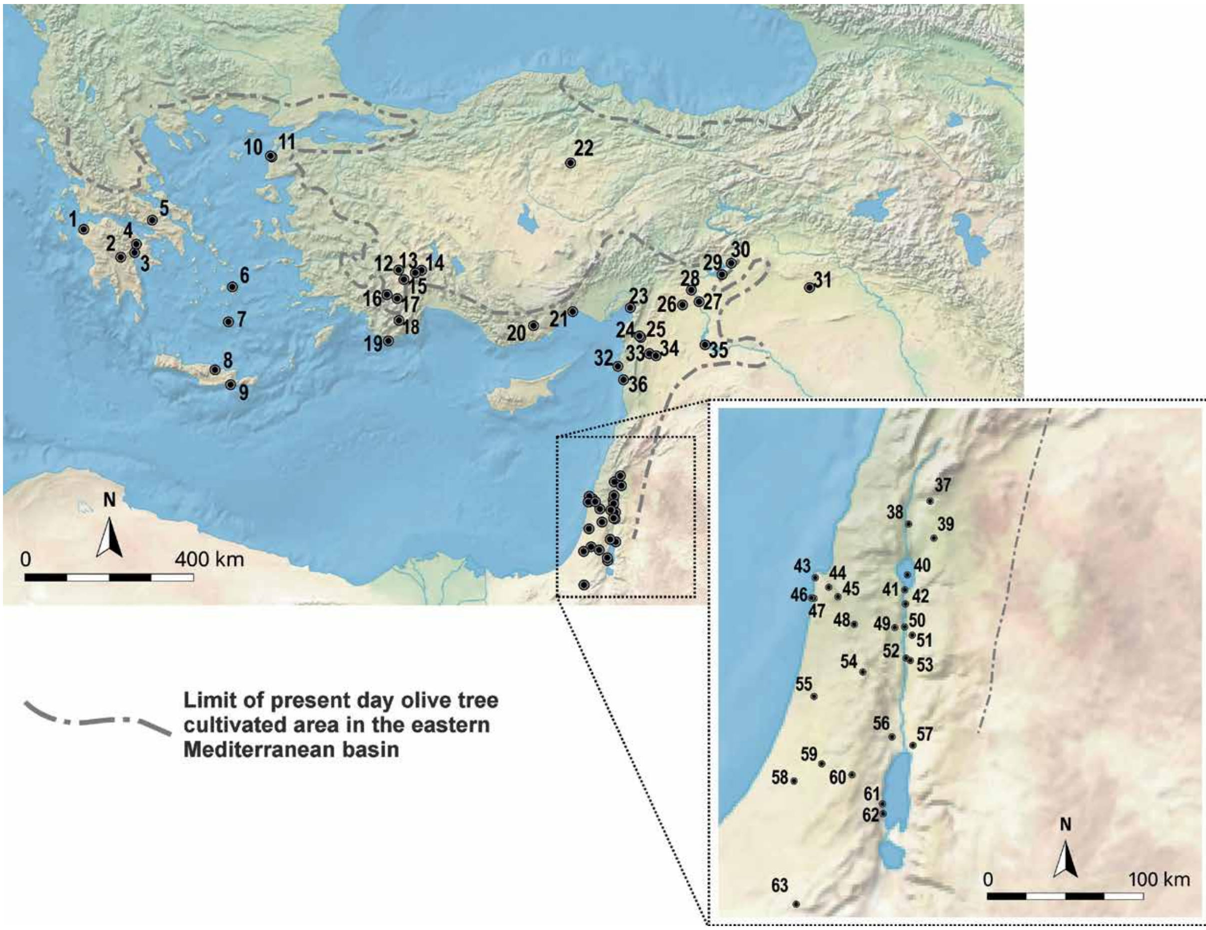

Figure 1. Map showing the major sites and regions mentioned in the text and the modern distribution of the olive tree (after Bottema 1991; Caudullo et al. 2017). 1- Kotihi lagoon; 2- Tsoungiza and Lerna; 3- Argive Plain; 4- Kleonai; 5- Boeotia; 6- Naxos; 7- Akrotiri; 8- Knossos; 9- Myrtos and Aphrodite's Kephali; 10- Kumtepe; 11- Troy; 12- Elmalı; 13- Gravraz; 14- Sagalassos and Çanaklı; 15- Pınarbaşı; 16- Gölhisar; 17- Söğüt; 18- Avlan; 19- Ulububrun shipwreck; 20- Kilise Tepe; 21- Yumuktepe; 22- Hattuşa; 23- Kinet Höyük; 24- Tell Tayinat; 25- Tell Atchana (Alalakh); 26- Tilbaşar Höyük; 27- Gre Virike; 28- Horum Höyük; 29- Titriş Höyük; 30- Hassek Höyük; 31- Tell Mozan; 32- Ugarit; 33- Mastuma; 34- Ebla Tell Mardikh; 35- Emar; 36- Tell Gibala-Tell Tweini and Tell Sukas; 37- Birkat Ram; 38- Hula Basin; 39- Golan Heights; 40- Sea of Galilee (Lake Kinneret); 41- Ohalo II; 42- Tell esh Shunah and Tell Rekhesh; 43- Kfar Samir; 44- Mount Carmel; 45- Tell Qashish (Tell Qasis); 46- Kfar Galim, Megadim and Tell Hreiz; 47- Carmel coast; 48- Tell Taannach; 49- Tell Rakan II; 50- Beisan; 51- Pella; 52- Jordan valley; 53- Abu Hamid; 54- Samaria highlands; 55- Aphek; 56- Jericho; 57- Teleillat Ghassul; 58- Tel Erani Tell elAreini; 59- Tel Yarmut Khirbet elYarmuk; 60- Judean highlands and Soreq Cave; 61- Ein Gedi; 62- Ze'elim; 63- Boker excavation.

or charred olive stones (endocarp, pit), and olive charcoal, which may give clues about pruning; b) plant microfossils (*i.e. Olea* pollen); c) artefacts associated with the processing of olives for oil production and storage. In addition, written sources can provide supportive information, despite various problems of interpretation.

Notwithstanding their increasing prominence and accuracy, biomolecular studies are still in their infancy. Condamin *et al.* (1976) distinguished fatty acids characteristic of olive oil through gas chromatography/mass spectrometry. Unfortunately, the distinction between animal fats and plant oils in archaeological residues is not always straightforward; particular organic compounds are difficult to recognise because of degradation or contamination of the original organic substances during post-depositional processes (Evershed 2008). In addition, the lipid composition of olive oil – which is composed mainly of triacylglycerols, including oleic acid, palmitic acid, linoleic acid, alpha-linolenic acid, and stearic acid – is similar to that of other vegetable oils (Gunstone 2004). For example, a higher proportion of oleic acid in particular, and also linoleic acid, may indicate olive oil, but it

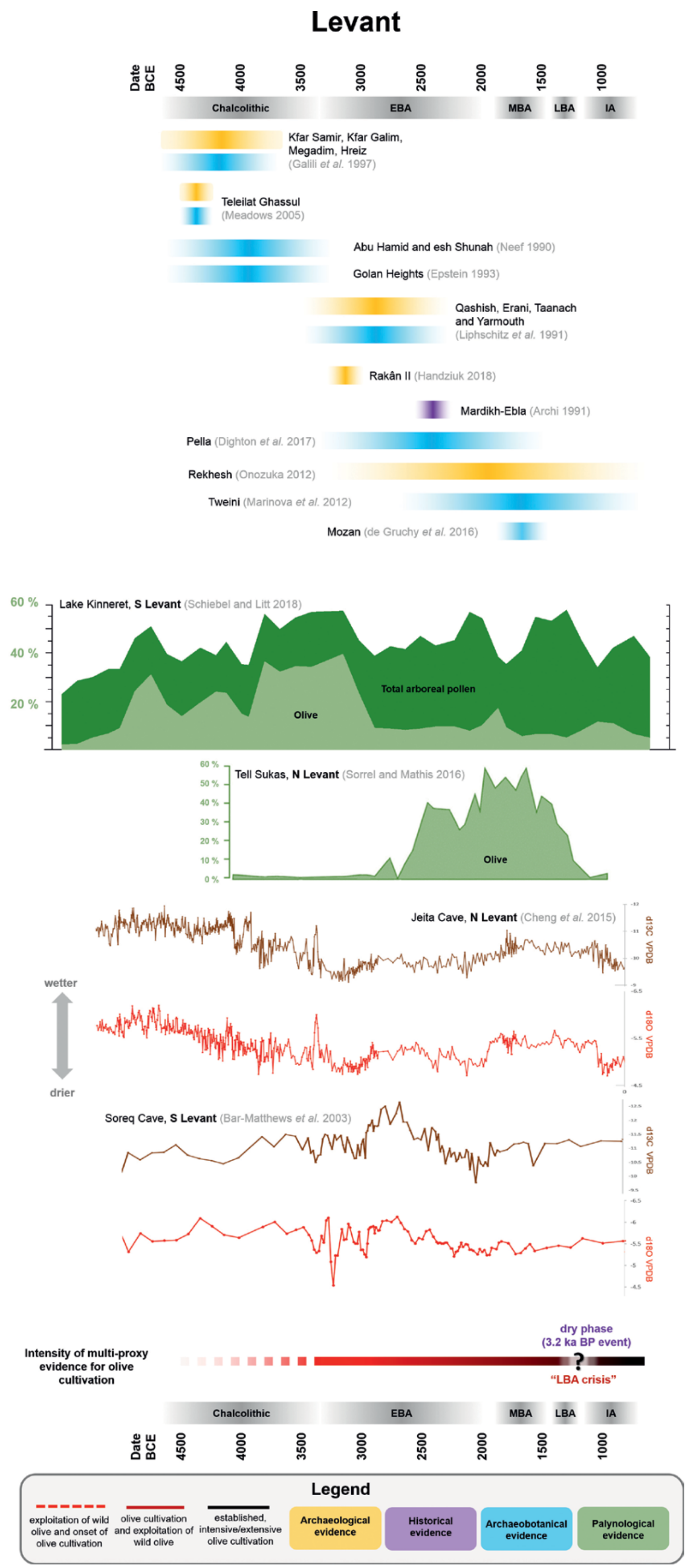

Figure 2. A schematic representation of the chronology and reconstruction of olive use based on multi-proxy evidence in the Levant (see text for discussion).

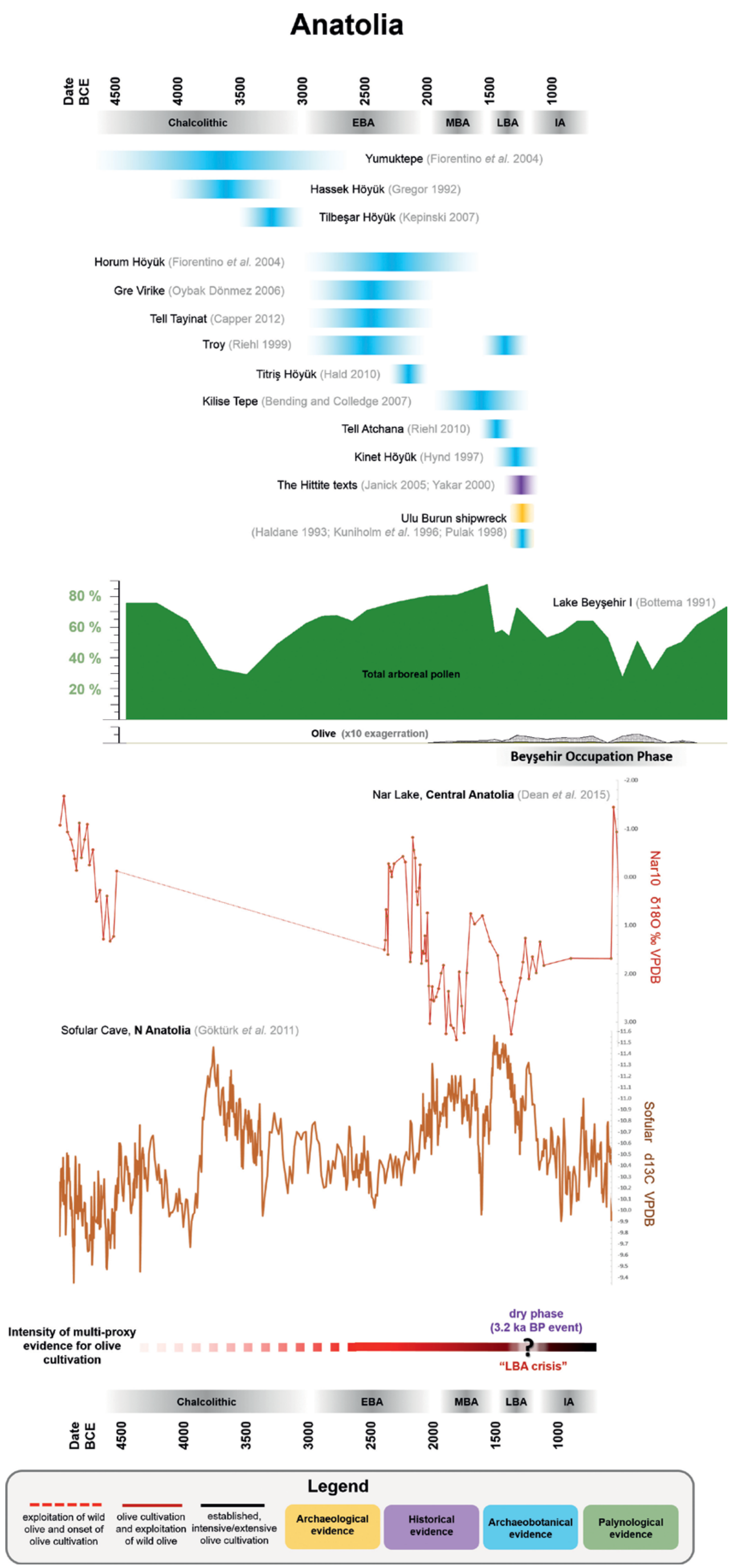

Figure 3. A schematic representation of the chronology and reconstruction of olive use based on multi-proxy evidence in Anatolia (see text for discussion).

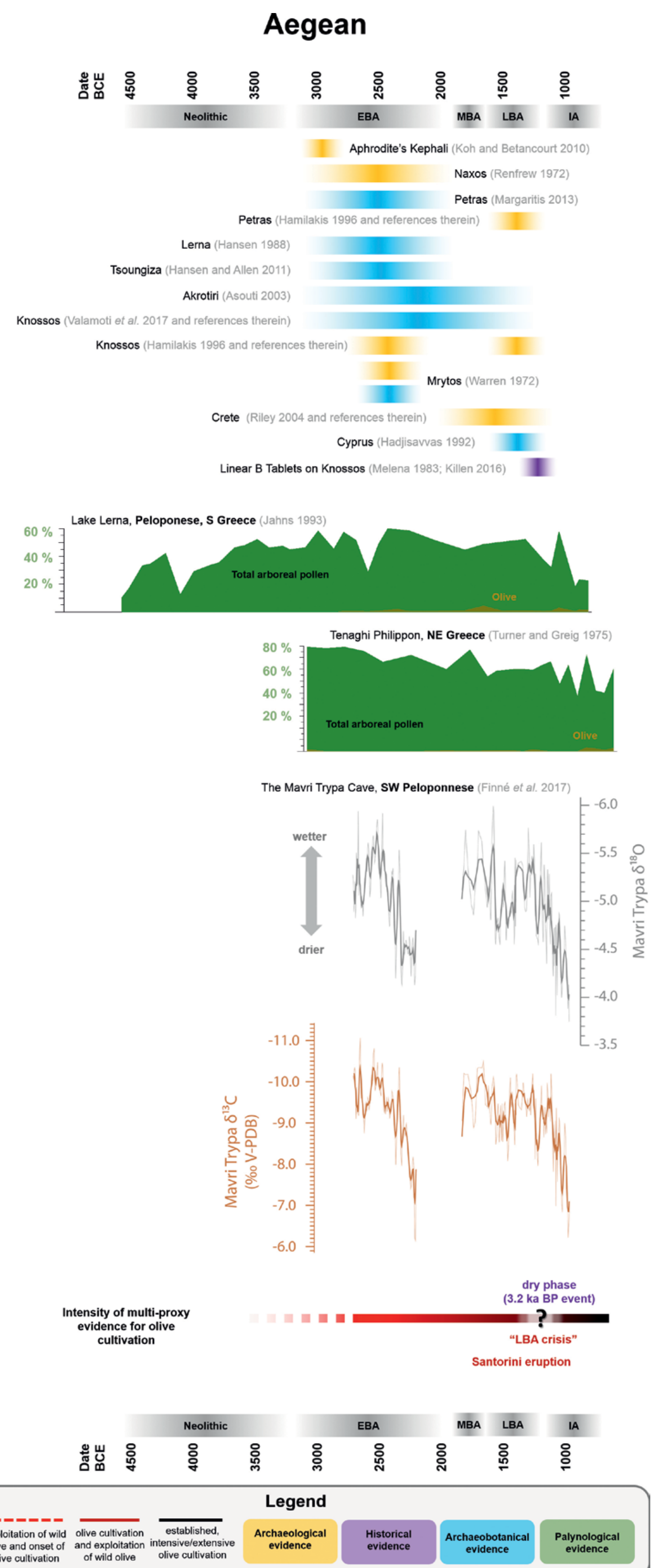

Figure 4. A schematic representation of the chronology and reconstruction of olive use based on multi-proxy evidence in the Aegean (see text for discussion).

Type of analysis/Type of material		Culinary use		Exploitation from wild olives	Cultivation practices (either from wild or domesticated forms)	Domestication
		Olive oil	Olive fruit			
Archaeobotanical analysis	Olive endocarps	+ (jift)	+	+/-	-	+/-
	Olive charcoal	-	-	+/-	+/-	-
Palynological analysis	*Olea* pollen	-	-	+	+/-	-
Biomolecular analysis	Olive processing residue	+/-	-	-	-	-
	Olive ancient DNA	+/-	+/-	+	-	+

Table 1. Potential of different types of analyses and materials for detecting possible use of olives, and to differentiate possible stages from exploitation of wild olives to cultivation and to infer domestication status of olive.

+ *proof; high-confidence*
+/- *probable proof; low confidence, risk of bias*
- *no proof*

may also indicate sunflower or safflower oil, both of which are also high in oleic and linoleic acids. Hansson and Foley (2008) isolated DNA from inside amphoras from Chios in an effort determine the products of ancient trade. Their work yielded DNA of olive together with that of oregano and an unspecified *Pistacia* species. However, it should be noted, as presented by Elbaum *et al.* (2006), that preservation conditions for olive DNA may not be favourable, especially for the eastern Mediterranean, due to post-depositional processes and pre-depositional processing by the original olive producers (*e.g.* salting and pickling).

Although most of the aforementioned evidence may indicate use of the olive, it is crucial to also determine the source whether wild or cultivated olive trees, in order to shed light on the origin of olive cultivation and the process of olive domestication (Table 1). In the archaeobotanical record, where olive remains consist of stones, charcoal, and/or pollen, differentiating between wild and cultivated forms on the basis of morphology can be very challenging.

Archaeobotanical evidence for domestication and/or cultivation of the olive tree: endocarps and wood charcoal

Archaeobotanical evidence, including frequent finds of olive wood charcoal or stones (accompanying other anthropogenic indicators of the diet of local people) from sites far outside the natural range of the oleaster, may provide indirect proof of the earliest cultivation practices and technological developments in agronomy (such as crop irrigation or seedling transplantation) (Neef 1990; Zohary *et al.* 2012). Because the fruits of the olive can be stored and transported over long distances, fruit fragments and endocarps can confirm only that olives were part of the diet; they cannot confirm their local cultivation (Liphschitz *et al.* 1991). Therefore, in comparison to endocarps, whose existence may indicate human transport, and to pollen grains, which may have been transported by natural agents over long distances, olive charcoal can be considered a relatively more reliable indicator of the species' local growth (for a discussion, see Valamoti *et al.* 2017).

Endocarps

Although the size of the endocarps of the fruits of wild olive trees and olive cultivars overlaps due to high taxonomic variation (Breton *et al.* 2006), morphometric methods are efficient in distinguishing between them because the morphometry of the endocarps has changed during the domestication process (Breton *et al.* 2012). It is generally accepted that lower variability in the dimensions of a sample of olive endocarps may be a sign of cultivation/domestication (see Dighton *et al.* 2017;

Meadows 2005; Newton *et al.* 2006, 2014; Terral *et al.* 2004). Conversely, great morphological heterogeneity in olive stones demonstrates exploitation of wild populations (Kislev 1994). Recently, Fuller (2018), having analysed 984 specimens from Cyprus, Egypt, Greece, Israel, and Jordan dated between 5500 BCE and 575 BCE, proposed size criteria based on plotting time series data of size, identifying episodes of largely directional change and estimating rates of phenotypic evolution to determine the domestic status of olive. Fuller (2018) recorded a gradual increase in the size of olive stones, accompanied by a pronounced increase in the L/W ratio, from the 5th millennium BCE onwards.

However, morphometric methods have limitations as they require large sample sizes, and complete endocarps, which are rarely recovered from archaeological sites, especially for early periods (Margaritis, 2013). In addition, it should be noted that the charring process affects the size and shape of carbonized endocarps.

Wood charcoal

Terral and Arnold-Simard (1996) studied archaeological wood charcoal from the Cardial Neolithic to the Roman period in eastern Spain to distinguish between wild and cultivated olive based on differences in anatomical characters (growth ring width, vessel surface, number of vessels per group, vessel density, and vulnerability ratio). According to their analysis, which combined detailed morphometric and statistical analyses and took into account the influence of ecological/climatic conditions on wood anatomy (distinguished by vulnerability ratio and vessel density), the wild olive is represented by narrower growth rings and a higher number of vessels per group than are the cultivated forms (Terral and Arnold-Simard 1996). In addition, Terral (1996) suggested that variation amongst wild/cultivated olives can be recognised through elemental composition analysis on wood charcoal, because improved fertilisation and greater vegetative growth in cultivated forms result in an increase in the inorganic elements such as nitrogen and phosphorus. In another study, Terral (2000) analysed charcoal samples from three archaeological sites from Spain and France (Cova de l'Espérit and Montou, in the Pyrénées, France, and Cova de les Cendres, in Levante, Spain) in order to differentiate immature wood (young branches and twigs, which have distinct growth rings) from mature wood (old branches and the trunk, which often have indistinct growth rings). Terral (2000) argued that different modes of olive tree exploitation can be detected by this anatomical approach. Intentional and selective management evidenced by a significant increase in the frequency of immature wood charcoal from the Neolithic to the Bronze Age could be interpreted as the earliest indicator of pruning, and thus of the development of olive cultivation and early selective practices for fruit production (Terral 2000).

Palynological evidence for olive cultivation

The mean dimensions of pollen grains of both wild oleaster and cultivated olive varieties, and of pollen grains of *Phillyrea latifolia* that inhabit the same geographic areas, are almost identical (Liphschitz *et al.* 1991). Beug (2004) suggested other criteria to differentiate *Olea* from *Phillyrea,* showing that *Olea* has a thicker exine and larger brochi. However, differentiation of fossil pollen is challenging due to variation in individual pollen grains. Therefore, slight differences in the morphology of the exine (*e.g.* variation in the shape of the lumina or in the width and fusion of the muri) can only be distinguished by means of a scanning electron microscope (SEM) (Liphschitz *et al.* 1991; Punt *et al.* 1991). Because identification of these pollen grains using only light microscopy is problematic, some studies report them under the family name Oleaceae, or at the type level only (*Olea*-type). Although palynological evidence cannot reveal whether domesticated or wild olive is represented, it will complement archaeobotanical and archaeological data because it provides information about landscape transformation at a more regional level.

Olea pollen was present sporadically and in minor amounts at the beginning of the Holocene in the Mediterranean basin, while the 'climatic optimum' of the early to mid-Holocene is generally characterised by maximum percentages of pollen of deciduous forests in the Mediterranean pollen records (possibly favored by the period with the highest winter precipitation) (Carrión *et al.* 2013; Peyron *et al.* 2011; Sadori *et al.* 2011). From the mid-Holocene onwards, *Olea* pollen started to be continuously present, while other drought-tolerant Mediterranean-type taxa (xerophytic sclerophyllous taxa, such as *Phillyrea, Pistacia,* and *Cistus*) expanded all over the Mediterranean area after the mid-Holocene-late Holocene transition (Sadori *et al.* 2011). By the late Holocene, deciduous vegetation was replaced by evergreen vegetation, a change that can be attributed either to human activity and/or to climatic trends (Jalut *et al.* 2009). The maximum percentage of *Olea* pollen is clearly detected in many late Holocene records of the Mediterranean basin, especially in terrestrial areas close to the coast, for example, in south-eastern Europe and the Near East (Bottema 1991), the central Mediterranean (Di Rita and Magri 2009, 2012; Sadori and Narcisi 2001), and in the circum-Mediterranean area (Jalut *et al.* 2009). It is similarly detected in marine records across the Mediterranean (Combourieu-Nebout *et al.* 2013; Desprat *et al.* 2013). This maximum percentage may be accepted as the first palynological sign of large-scale management of wild olive trees or the development of cultivation.

Olive pollen is generally recovered in high frequencies and high proportions from archaeological sites (Mercuri *et al.* 2013). In general, high values of *Olea* pollen may be evidence for human cultivation of olive (Walsh 2014). Huntley and Birks (1983) argue that values exceeding 5 per cent possibly indicate extensive olive cultivation within the catchment of a site, even though *Olea* pollen may travel long distances. Values of more than 5 per cent, which is much higher than modern pollen rain, were recorded in Greek Macedonia and south-western and eastern Turkey during the Beyşehir occupation phase (BOP) and are interpreted as an indication of arboriculture (Bottema 1991). However, higher values in fossil samples can be misleading due to (a) the presence of oleasters, which would amplify the *Olea* pollen signal; (b) the existence of a warming phase, which would have favoured plant growth and the expansion of the thermophilous olive (Florenzano *et al.* 2017); (c) the significant dispersal of *Olea* pollen due to its ability to be wind-transported over long distances. In spite of these limitations, *Olea* pollen can be accepted as an indicator of human activity, especially in the presence of other anthropogenic indicators (Bottema and Woldring 1990; Mercuri *et al.* 2013).

Vermoere *et al.* (2003) studied variation in olive pollen production and dispersal near various extant olive stands and then compared these modern pollen data with fossil pollen data (Hellenistic-Roman) from south-western Turkey (Sagalassos) through multivariate statistics. Although olive pollen representation in the modern surface samples was highly variable, the overall fossil pollen data, with their relatively high values for secondary anthropogenic indicators, show similarities with modern spectra relating to olive stands surrounded by annual crop agriculture (Vermoere *et al.* 2003). A similar methodology was applied by Florenzano *et al.* (2017), who compared pollen data of surface soil samples from modern olive groves in the Italian regions of Basilicata and Tuscany with pollen data from the Hellenistic to medieval archaeological layers in several sites in the same geographic area. Their results show that the highest percentages of *Olea* pollen are evidence of local cultivation in a given area (short distance to source), while low percentages are possibly due to long-distance transport. Langgut *et al.* (2014) conducted a field survey in the southern Levant (Galilee, Mount Carmel, the Samaria highlands, and the Judean highlands) and documented quantitative differences in the olive pollen production between a well-managed traditional olive orchard, an abandoned orchard, and an orchard rehabilitated after decades of abandonment. Their results indicate a strong decline in flowering and pollen production for decades following the end of cultivation and a strong increase following rehabilitation. The aforementioned studies suggest that *Olea* pollen, by having a very short response time, is a reliable marker for determining the extent of olive cultivation and oil production in pollen samples from sedimentary sequences throughout the Holocene.

Archaeological evidence for domestication/cultivation of the olive tree

The development of olive arboriculture for trade products in stratified societies is debated, because it requires long-term residential stability (sedentary lifestyle/permanent groves), long-term planning, technological development in agriculture, and an initial substantial investment in labour (Zohary *et al.* 2012). Olive trees must grow for 15-20 years before they produce a worthwhile crop, which they will do until they are about 80 years old, and they generally produce fruits once every two years (high and low yields in alternate years, with exceptional instances of two successive bad years). Therefore olive arboriculture is incompatible with short-term landlordship (Riehl 1999). Because the wait for sufficient fruit productivity is long, cultivation of the olive is an investment for the future. Potential economic problems related to the wait time can be reduced by the intercultivation of annual crops (vegetables and cereals) on the same plot of land, as is demonstrated by the palynological study conducted near Sagalassos by Vermoere *et al.* (2003). Because annual crops reach high yields and do so more easily and more quickly than the olive, they can be used as a form of risk buffering against the biennial fruiting of olive trees and years of poor olive production. In turn, the extensive root system of olive trees prevents erosion, favouring the cultivation of diverse crops, and the evergreen nature of the olive trees provides shelter to the annual seedlings (Neef 1990). Therefore, the cultivation of olive trees, requiring the investment of much time and energy, can be attributed to a stable economy (Vermoere *et al.* 2003).

Genetic evidence for the domestication of the olive

Olive domestication processes have involved a mixture of practices. While wild olives reproduce from seeds (they reproduce sexually via wind pollination, and their seeds are mainly dispersed by birds), cultivated varieties are maintained by the empirical selection of individual trees having better performance for fruit size and oil content, via repeated vegetative propagation over very long periods (as clones, either directly planted as cuttings or grafted onto indigenous oleasters) (Zohary and Spiegel-Roy 1975). In this process, through the selection of certain features, the anthropogenic practices that lead to an amplification of the selection pressure on plants have gradually modified the natural phenotypic variation (Terral 1996). Such long-standing processes aimed at optimising fruit production have continuously shaped the ecological, morphological, and genetic differentiation between wild and cultivated trees, from prehistoric times until today, throughout the Mediterranean basin (Besnard *et al.* 2017). However, the genetic distance between the wild tree and the cultivated lines still remains smaller than in other fruit trees, probably because of their long generation time (Zohary *et al.* 2012). Most of the Mediterranean olive cultivars are of uncertain pedigree (Bartolini *et al.* 2005). Tracking the genetic history of olives is challenging, as cloned, superior genotypes can spread by human migration over long distances and olive clones can interbreed with oleasters or feral trees (Diez *et al.* 2015).

According to the 'classic diffusionist model', a change from wild to cultivated olive populations started during the Chalcolithic, around 6000 BP, in the southern Levant and then spread through human-mediated migration (*e.g.* interaction/contact with the Phoenicians, Greeks, and Romans) from East to West, via both the northern and the southern coasts of the Mediterranean Sea (Galili *et al.* 1997; Kaniewski *et al.* 2012; Liphschitz *et al.* 1991; Zohary and Spiegel-Roy 1975). However, recent genetic studies indicate that patterns of genetic variation do not clearly support this hypothesis (Besnard *et al.* 2017 and references therein). Based on comprehensive sampling by independent research teams, three main clusters of the primary gene pools for the cultivated olive were identified: the eastern, central, and western Mediterranean (Besnard 2016 and references therein). This clear evidence reflects multiple centres of diversity of olive cultivars across the Mediterranean area (Baldoni *et al.* 2006; Besnard *et al.* 2001, 2017; Diez *et al.* 2015).

Opposing the predominant view of a single primary domestication in the eastern Mediterranean, Terral *et al.* (2004) and Diez *et al.* (2015) proposed that the diversification of the cultivated olive may have resulted from local, independent domestication in the central and western Mediterranean basin. Revisiting of the 'diffusionist model' based on archaeological and archaeobotanical records from the central and western Mediterranean has also provided evidence of olive exploitation/management earlier in time than previously thought, during the Chalcolithic/Bronze Age (2550-2050 BCE), which was probably initiated during the Neolithic (*e.g.* D'Auria *et al.* 2016; Margaritis 2013; Terral 2000 and references therein; Terral and Arnold-Simard 1996).

Several previous studies on the genetic history of olives based on both nuclear and cytoplasmic markers found high differentiation between the eastern and western Mediterranean oleaster populations (*e.g.* Besnard *et al.* 2001; Lumaret *et al.* 2004). In contrast, studies of the nuclear genetic diversity of the cultivated olive revealed that cultivars do not show such geographical separation, supporting the idea of multiple geographic origins of cultivars and diversification in the central and western Mediterranean basin (Diez *et al.* 2015; Doveri and Baldoni 2007).

Besnard *et al.* (2017) stated that about 90 per cent of present-day cultivars are characterised by the chlorotype *E1*, originated from oleaster populations in the eastern Mediterranean region, along the current border between north-western Syria and south-eastern Turkey. They argue that this genetic evidence supports a primary origin and spread of cultivated olive trees from the Near East to the western Mediterranean. Besnard *et al.* (2017) further suggest that the distinct genetic differences found in cultivated olives may have occurred due to secondary diversification via admixture (interbreeding of two or more previously isolated populations) between local, unselected, pre-domesticated oleasters, on the one hand, and cultivars introduced from the East, on the other. The role of westward human migrations in olive biodiversity in the western Mediterranean basin is also confirmed by morphometric analysis of olive stones from the LBA settlement of Ugarit, which indicates that the morphotypes typical of the eastern Mediterranean appear in the archaeological record of the western Mediterranean1000-1500 years later than they do in the record of the eastern Mediterranean (Newton *et al.* 2014). However, the lower genetic diversity of the eastern Mediterranean oleaster populations, as compared with the western populations, contradicts the idea of a primary origin in the eastern Mediterranean and suggests that further research is needed to fill the gaps in our knowledge on the historical biogeography of olive domestication in the central and western Mediterranean basin (Besnard *et al.* 2013 and references therein).

In general, evidence supports that the process of olive domestication consisted of multiple spatiotemporal steps that lasted several thousand years and that it is still ongoing. It remains to be explored whether the centre of diversity is caused by a single domestication event (the primary domestication taking place exclusively in the Near East, followed by secondary diversification in other parts of the Mediterranean basin) or multiple independent domestication events in different parts of the Mediterranean basin (Besnard *et al.* 2017). Until now, testing these alternative scenarios has been difficult due to limitations. For example, some genetic studies lacked a broad geographical coverage and focused instead on one country, namely, Turkey (Yoruk and Taskin 2014) or Spain (Belaj *et al.* 2010). As noted by Besnard and Rubio de Casas (2016), to disentangle the genetic history of olives requires a large number of genetic markers and a large number of samples from cultivated and uncultivated olives. In addition, multidisciplinary research that integrates molecular, archaeobotanical, archaeological, and historical data, especially from the central and western Mediterranean regions, will be crucial to improve our understanding of olive domestication.

A synthesis of past olive exploitation practices in the Levant

Archaeobotanical evidence from the Levant

It has been assumed that wild olives were exploited long before their cultivation, based on the sporadic appearance of charred pieces of olive wood or the presence of single olive stones in Levantine settlements, such as the Boker excavation (Liphschitz *et al.* 1991) and Ohalo II, on the shore of the Sea of Galilee (Lake Kinneret) (Kislev *et al.* 1992), at least since the Palaeolithic.

From the Late Neolithic/Chalcolithic onwards, olive stones start to increase in number and frequency in the southern Levant, at sites as the Golan Heights (Epstein 1993); the submerged Wadi Rabah sites, such as Kfar Samir, Kfar Galim, Megadim, and Hreiz (Galili *et al.* 1997); as well as Teleilat Ghassul (Bourke *et al.* 2004), Abu Hamid, and esh Shunah (Neef 1990). Therefore, it is generally thought that olive domestication began after this period (Fuller 2018; Galili *et al.* 1997; Liphschitz *et al.* 1991) (Fig. 2).

The submerged site of Kfar Samir is accepted as the most convincing early evidence for olive oil extraction/production, revealing two types of pits containing *jift*; stone basins, concave mortars, and grinding and chopping tools that were probably used to crush olives; and a woven basket, straw, and wood branches that may have been used together as a strainer (Galili *et al.* 1997). This appears to be the remains of a simple olive press that would have produced only small quantities of olive oil, since such an extraction process would be time consuming and very inefficient (Rowan and Golden 2009). Based on morphometric analysis, Kislev (1994) showed that the olive stones at the site, which show great morphological heterogeneity, were from wild populations growing near the site rather than from domesticated ones, which would be expected to have lower variability in olive stone dimensions, and he argued that olive oil production pre-dates domestication by several centuries.

The earliest definite morphological evidence for olive arboriculture and/or the emergence of domestication are the olive stones from Teleilat Ghassul. Based on morphometric measurements at Teleilat Ghassul, Meadows (2005) demonstrated a significant decrease in the variation in olive stone size from the Late Chalcolithic, with the earliest date estimated around 4400-4300 cal BCE, which may be the result of restricted growing conditions of cultivated olive trees and a loss of genetic diversity caused by clonal propagation. Moreover, Kislev (1994) stated that cloning of the best olive genotypes via vegetative propagation and grafting of olive trees led to a dramatic reduction in the variation of measured attributes. The olive stones were recorded in close association with cereal grains, dates, and pulses (Zohary and Spiegel-Roy 1975), suggesting that olives were an integral element of the diet in the Late Chalcolithic of the Jordan valley. Moreover, the remains of olive stones in Teleilat Ghassul (similar to the stones recorded at the site of Abu Hamid) consisted mostly of small fragments with rounded fractures along the edges, which may suggest breakage prior to deposition (*e.g.* Simchoni and Kislev 2006; see also discussion in Marinova *et al.* 2011), as differentiated from post-depositional breakage, represented by sharp edges on the broken faces of the stones (Neef 1990). Today, the Jordan valley, the region around Teleilat Ghassul, is outside of the geographical distribution of the Mediterranean wild olive as it is too dry for that plant to succeed. Thus, it was claimed that the olives at Teleilat Ghassul were the product of cultivation, probably having been raised under irrigation, analogous to today's olive cultivation in Jericho or Beisan (Zohary and Spiegel-Roy 1975). Lovell (2002) stated that other changes in the subsistence economy coincide with the emergence of the domestication of the olive. Similar to the case at Abu Hamid and esh-Shunah, no tools that may indicate processing of olives were found at the site of Teleilat Ghassul (Neef 1990). However, the relatively large amount of olive wood charcoal recorded in these sites may indicate possible use of olive branches for fuel after pruning (Neef 1990). It is argued that olive charcoal from sites in the Jordan valley supports domestication, as firewood would not have been carried far beyond the source tree's natural habitat (Rowan 2014). Olive timber was used for construction at the sites of Teleilat Ghassul and Abu Hamid (Neef 1990). A lamp with traces of soot recovered at Teleilat Ghassul may indicate use of oil for lighting (Epstein 1993). Although recent genetic evidence, which shows the north-eastern Levant territory (on the Syrian-Turkish border) as a centre of primary domestication in the eastern Mediterranean (Besnard *et al.* 2013; Besnard and Rubio de Casas 2016), is not consistent with the archaeological results from Teleilat Ghassul, which show a southern origin, in the hills around the Jordan valley, Teleilat Ghassul remains the earliest known site with explicit archaeobotanical evidence for domestication so far (Zohary *et al.* 2012).

At the site of Pella, in Jordan, Dighton *et al.* (2017) also revealed a decrease in the size variation of olive stones, as well as an increase in their length through time, after the Chalcolithic and before the LBA, possibly the result of selection pressure on trees experiencing increasingly intensive exploitation of their fruits. In another words, the domestication of the olive was initiated later at Pella than at Teleilat Ghassul. This evidence suggests that the process of olive domestication varies spatio-temporally (Dighton *et al.* 2017).

Starting in the Early Bronze Age (EBA) (around 3300-2200 BCE), olive stones and timber are recorded with greater frequency and in greater abundance in the dry farming regions of the Near East, especially at such sites as Tell Qashish, Tell Erani, Tell Taanach, and Tell Yarmouth, accompanied by pottery oil lamps, pottery containers for oil preservation, and olive oil installations (Liphschitz *et al.* 1991).

For the northern Levant, especially in Upper Mesopotamia, there is little archaeological or archaeobotanical evidence accompanying the genetic evidence to support an eastern Mediterranean origin for olive domestication, so, just like the fig (*Ficus* sp.), the olive may have had a minor economical and alimentary role (*e.g.* at Tell Mardikh Ebla and Tell Mozan) before the Middle Bronze Age (MBA) (de Gruchy *et al.* 2016; Janick 2005).

Apart from at the sites mentioned above, early finds are sporadic in other parts of the eastern Mediterranean until the MBA to LBA, when olive cultivation became established (*e.g.* Tell Rekhesh) (Onozuka 2012; Zohary *et al.* 2012).

Palynological evidence from the Levant

Starting in the Late Chalcolithic, olive pollen values rise markedly in comparison to earlier periods in the southern Levant, for example, in Lake Kinneret (Baruch 1986, 1990; Schiebel and Litt 2018), Ze'elim (Neumann *et al.* 2007a), Birkat Ram (Neumann *et al.* 2007b), Lake Hula (van Zeist *et al.* 2009), and Ein Gedi (Litt *et al.* 2012). Therefore, the palynological evidence supports to the aforementioned Levantine archaeological findings regarding early intensified exploitation of olive or an early episode of olive cultivation in the late Chalcolithic (Fig. 2).

Starting in the EBA, the drastic increase in *Olea* pollen reflects the spread of olive cultivation in the southern Levant. This is followed by a relatively later introduction to the northern Levant (*e.g.* at Tell Sukas and partly at Tell Tweini), around EBA II-III (around 3000-2500 BCE) (Kaniewski *et al.* 2010; Langgut *et al.* 2016 and references therein; Sorrel and Mathis 2016). After reaching their highest frequencies in EBA IB (around 3150-3000 BCE), the values of olive pollen decline dramatically in EBA II-III (around 3000-2500 BCE) of the southern Levant (Langgut *et al.* 2014). Langgut *et al.* (2014) suggest that the decline in *Olea* pollen during EBA II-III is probably linked to changes in geopolitical and trade conditions in the region, rather than climate change, since the other arboreal pollen percentages remained relatively high. *Olea* values stay significantly lower until the end of the LBA, with relatively high Mediterranean tree values in the southern Levant (Langgut *et al.* 2013). It should be noted that for the MBA and the LBA, the palynological data (especially from Lake Hula and Birkat Ram), which show much lower values of *Olea* pollen relative to the EBA, are not in agreement with the archaeological, historical, and archaeobotanical data in the southern Levant. At the end of the LBA, around 1250-1100 BCE, the lowest *Olea* pollen values, accompanied by a dramatic decrease in Mediterranean tree values, are recorded, suggesting a link to the aridity event called the 3.2 cal kyr BP abrupt climate change, which will be discussed further ahead (Langgut *et al.* 2014). However, the northern Levant olive record (the data covers the period from 3rd millennium to 1st millennium BCE) shows exactly the opposite trend, with maximum *Olea* values initially, culminating in the LBA, reflecting weakened networks between the southern Levant and Egypt, while an intensification occurred between Egypt and the northern Levant via the rise of maritime links (Langgut *et al.* 2016; Sorrel and Mathis 2016). Furthermore, periods of relatively low olive percentages in both the southern and the northern Levantine records have been interpreted to indicate cultivation mostly for local consumption, rather than for export-oriented production (Langgut *et al.* 2015).

After the severe dry phase at the end of the LBA, an increase in pollen percentages of both olive and Mediterranean trees is observed in Iron Age I, especially in the later phase (around 1050-950 BCE) (Langgut *et al.* 2015). Intensification of olive cultivation from the Iron Age onwards is also strongly supported by archaeological (increased settlement activity and oil press installations) and archaeobotanical (high percentage of olive charcoal and olive stones) evidence in the southern Levant (Finkelstein and Langgut 2018).

Archaeological evidence from the Levant

Lovell (2002) stated that the development and expansion of olive cultivation, oil production, and oil trade, as well as environmental changes, were important factors related to the rise of city states in the Levant during the transition from the Chalcolithic to the Early Bronze Age. Finkelstein and Gophna (1993) suggested that settlement expansion into the uplands from the Late Neolithic to the EBA probably related to the potential of marginal areas, where annual crops are unproductive, to be used for olive cultivation, as an alternative to using lowlands for agriculture. Joffe

(1993) stated that the production and subsequent trade in olive oil caused regular contact between the rural southern Levant and the highly centralised Egyptian state and thus prompted the urbanisation process in the Levant during the EBA. From the EBA onwards, olive is frequently mentioned in ancient texts and trade in olive oil (accompanying grape wine) is well documented in cuneiform sources (*e.g.* Tell Mardikh-Ebla, Syria, 2400 BCE) of the Levant (Riehl 2014). In the southern Levant, at the site of Tell Rakân II, the olive press (features cut into the bedrock, with interconnecting channels, vats, and silos constructed exclusively to produce olive oil), associated with *in situ* ceramic storage vessels (so-called hole-mouth jars), strongly indicate that a substantial volume of olive oil was produced in rural northern Jordan during EBA I (around 3300-3000 BCE) and, accordingly, that olive oil was significant to the local and regional economies during the EBA (Handziuk 2018). Although very important socio-political changes took place during the Middle Bronze Age-Late Bronze Age transition, cultivated crop species do not change, with the exception of the expansion of olive cultivation into the northern Levant and the upper Euphrates region (Riehl 2014). Starting in the Iron Age, olives are cultivated intensively throughout the Levant, represented mainly by oil press installations (Onozuka 2012).

A synthesis of past olive exploitation practices in Anatolia

Archaeobotanical evidence from Anatolia

While genetic evidence suggests the northern Levant along the border between north-western Syria and south-eastern Turkey as a possible centre of olive domestication, the earliest evidence of olive stones – typically associated with other botanical remains, including cereals, pulses, pistachio, almond, and fig – was found at Yumuktepe Tell, in the Cilician plain of Turkey, dating to around the first half of the 8th millennium cal BCE (Fiorentino 2004) (Fig. 3). Archaeobotanical analysis has revealed diversified exploitation of the environment related to a mixed farming economy during the Middle and Late Neolithic, while the Middle and Late Chalcolithic show an increase in the exploitation of tree fruits – represented by olive stones and figs – as well as the first appearance of grape pips (Fiorentino *et al.* 2014). In the EBA (around 2800 BCE), olives seem to have been exploited systematically at Yumuktepe, more so than grape vines (Fiorentino *et al.* 2014).

Hassek Höyük, which is outside of today's natural distribution area of the olive, is the earliest known site in Turkey with evidence related to the olive. A single olive stone was recorded, together with grape, barley, chickpea, and lentil, dating to the Uruk period (Late Chalcolithic to EBA, around 4000-3100 BCE) (Gregor 1992). So far, the earliest archaeobotanical evidence for exploitation of the olive from the other parts of Turkey has been dated to the EBA.

From south-eastern Anatolia, botanical studies at Tilbeşar Höyük suggest that it was a centre of olive oil and wine production in EBA III (around 2500 BCE), with a particularly good representation of wood remains of *Olea* and a few olive stones (Kepinski 2007). The nearby site of Horum Höyük shows the same trend of an increased presence of wood charcoal of the olive together with wood charcoal of other fruit trees (fig and vine) from the EBA to the MBA, with culmination in the MBA and returning to smaller proportions in the LBA (Deckers and Pessin 2010). At Gre Virike, small numbers and low densities of intact and fragmented olive fruit stones, as well as grape remains, are found in the EBA (Oybak Dönmez 2006). At Titriş Höyük, smaller quantities of olive and pistachio as well as high amounts of cereals, legumes, and grape are recorded at the end of the EBA (around 2200 BCE) (Hald 2010). Today, all of these south-eastern Anatolian sites are situated outside the natural distribution area of the olive. This evidence suggest either that olive products were imported or that the geographical distribution of olive trees was different in the past. The latter hypothesis, which favours local cultivation, can only be confirmed by the presence not only of olive stones but also of olive wood (Deckers and Pessin 2010).

From within the modern natural distribution area of the olive, near the Mediterranean coast of Turkey, evidence indicates more common use of olives. Although the numbers of individual olive stones are not extraordinarily high and they do not show signs of having been crushed for oil production, the fact that were found in nearly all EBA contexts at Tell Tayinat implies that olives were in common use at the time (Capper 2012). Other nearby sites with a climate like Tell Tayinat's, such as Kilise Tepe, also had less frequent quantities of olive (and of grape) throughout the Middle and Late Bronze Age deposits (Bending and Colledge 2007). In LBA samples from Kinet Höyük, olive stones were recovered together with remains of barley, wheat, lentil, and walnut (Hynd 1997). At Tell Atchana, a high number of olive pips with very low ubiquity were recovered from LBA contexts (1600-1500 BCE) (Riehl 2010).

In archaeological sites further inland from the Levant, especially in the upper Euphrates and upper Khabur regions, archaeobotanical data show low numbers of olive pips. These findings are in contrast to Bronze Age texts, for example, from Ugarit (Heltzer 1996), that mention olive groves – especially at Alalakh (Tell Atchana) and Emar, which are referred to as the centres of olive production – as well as the economic importance of olive oil (in addition to wine) (Riehl 2009, 2010; Riehl and Bryson 2007). The Hittite texts also demonstrate that olives were cultivated in Anatolia (especially in the Cilicia region) as an important component of the Hittite economy and that olive oil was exported to Egypt (around the 12th century BCE) and used for illumination and cosmetic purposes, namely, for skin protection (Janick 2005; Yakar 2000). Riehl (2010) argues that the olive was never a major cultivated species outside the natural range of the oleaster and that therefore the textual evidence may indicate that it was a trade item.

From western Turkey, the archaeobotanical record at Troy shows no evidence of large-scale olive oil production in any of the periods, but the counts of olive stones are much higher in the EBA than in the LBA (Riehl 1999). The olive was not cultivated during the MBA in Troy, and the olive is not recorded at Kumtepe (a site near Troy) in any of the periods (Riehl 1999; Riehl and Marinova 2008). From the south-western coast of Turkey, a Canaanite jar containing more than 2500 olive stones, which represents the largest single deposit of olive stones from the LBA in the Mediterranean, was discovered in the Ulu Burun shipwreck (which has been dated to around 1316 BCE), demonstrating the trade of olives (as well as luxury products, including copper, glass, tin ingots, terebinth resin, jewellery, gold, and silver) with nearby lands in the eastern Mediterranean (Haldane 1993; Kuniholm *et al.* 1996; Pulak 1998).

Palynological evidence from Anatolia

In most of the pollen diagrams from south-western Turkey, *Olea* pollen is sporadically identified until the LBA (Bottema and Woldring 1984; Eastwood *et al.* 1998; van Zeist *et al.* 1975). From the LBA onwards (around 1500 BCE) until the middle of the 1st millennium BCE, an abrupt increase in *Olea* pollen, together with a combination of different primary and secondary anthropogenic indicators for cereal cultivation, arboriculture, grazing, deforestation, and fire, is recorded in the numerous Anatolian records during the period referred to as the Beyşehir occupation phase (BOP) (Figure 3). The BOP, first identified by van Zeist *et al.* (1975) from a site on the shore of Lake Beyşehir, shows some of the most distinct evidence for increasing human impact and intensification of land use practices reflected in any of the pollen diagrams from the Mediterranean region, fuelling a discussion on the transformation of the Mediterranean landscape. BOP is clearly visible in the records from the upland valleys of south-western Turkey (the Oro-Mediterranean zone). It is also recorded partly in north-western and central Turkey, as well as in some parts of Greece, especially in Crete (Bottema and Sarpaki 2003); in Cyprus (Kaniewski *et al.* 2013); and in the Levant (*e.g.* Bottema 1991; Djamali *et al.* 2009; Neumann *et al.* 2010). However, the spatial and temporal extent of the BOP is ambiguous. A layer of tephra identified just before the onset of the BOP from several sites in Turkey, attributed to the Minoan eruption of Thera by Sullivan (1988), acts as a key stratigraphic marker horizon.

Oro-Mediterranean sites that record BOP are situated above the altitudinal limit for olive trees (1400 m ASL), so outside of natural geographical distribution of olive today (Kaniewski *et al.* 2007). Bottema *et al.* (1993) argued that the *Olea* pollen recorded in the BOP is the product of long-distance transport of olives cultivated in groves near the coast, in the Eu-Mediterranean vegetation zone. However, as Roberts (1990) notes, the mountain complex of the Taurus acts as a barrier between all these sites and olive groves on the Mediterranean coast. Moreover, other sites located both in the Oro-Mediterranean vegetation zone and close to the Mediterranean coast (*e.g.* Elmalı, Avlan) have smaller amounts of *Olea* pollen compared with inland Oro-Mediterranean sites (*e.g.* Gölcük, Söğüt, Pınarbaşı, Gölhisar, Gravraz, and Çanaklı) (Eastwood *et al.* 1998; Vermoere *et al.* 2003). In addition, surface sample data (Bottema and Woldring 1990; Eastwood 1997; van Zeist and Bottema 1991; van Zeist *et al.* 1975; Vermoere *et al.* 2000) demonstrate that today, lower pollen values of *Olea* are recorded regardless of extensive olive cultivation in the Eu-Mediterranean vegetation zone, in comparison to much higher values of fossil pollen values during the BOP.

The end of this occupation phase appears to have been marked by an abrupt decline in pollen of anthropogenic indicators, suggesting a strong decrease in agriculture followed by forest regeneration. The diversity of woodland composition (dominated by *Pinus*) is remarkably different from the preceding mid-Holocene (a mixed *Quercus*, *Pinus*, *Juniperus*, and *Cedrus* forest), and this also suggests a possible link with human disturbance, rather than environmental change (Dusar *et al.* 2011 and references therein). Moreover, this change was accompanied by land abandonment and population decline, at least in the countryside (Roberts *et al.* 2018).

A synthesis of past olive exploitation practices in the Aegean

Archaeobotanical evidence from the Aegean

Regional patterns of olive use through time and the timing of intensive cultivation in Greece are a topic of debate, especially in the context of 'Renfrew's model', which will be addressed further ahead. Recently, Valamoti *et al.* (2017) examined the distribution of olive stones and charcoal from numerous sites on mainland Greece and the Aegean islands dating from the Neolithic (7000-3300 BCE) to Hellenistic times (1st century BCE). They found that the olive was almost absent in northern and central mainland Greece as far south as Boeotia in the Neolithic, and that its presence was limited to some islands in the Aegean and Ionian seas at the end of the Neolithic.

From the EBA onwards (3300/3100 BCE), the visibility of the olive in the archaeobotanical record, especially in southern Greece, including predominantly Crete (*e.g.*

at Petras, Knossos, and Myrtos) and the Peloponnese (*e.g.* at Tsoungiza and Lerna), but also the Cyclades and the north-eastern Aegean islands, starts to increase (in comparison to its scarcity in the Neolithic) and culminating during the LBA (Foxhall 2007; Hansen 1988; Hansen and Allen 2011; Margaritis 2013; Renfrew 1972; Riley 2002, 2004; Sarpaki 2012; Valamoti *et al.* 2017 and references therein) (Fig. 4).

The charcoal from Akrotiri (Thera), which is present in large quantities and high frequencies, suggest widespread exploitation of the fruit (wild and/or domesticated) and regular harvesting of the wood for firewood during the EBA (Asouti 2003). Although this evidence supports Renfrew's thesis on EBA use of the olive (possibly wild oleaster), it does not imply early domestication or cultivation. Mavromati (2017) argues that the presence of degenerate growth rings, which may suggest pruning of cultivated olive trees, is not enough for secure conclusions about cultivation due to the small sample size of specimens. However, it is clear that the archaeobotanical macroremains, together with the anthracological evidence, suggest cultivation at least during the LBA.

In sum, while the use of olives and olive oil during the EBA is still debated in terms of cultivation/domestication status and the scale of production/economic importance (small, perhaps household-scale) (Margaritis 2013; Runnels and Hansen 1986), evidence for larger-scale olive processing is much stronger by the LBA, for example, in Cyprus (Hadjisavvas 1992) and in Crete (Hamilakis 1996).

Palynological evidence from the Aegean

For most areas of Greece, olive pollen values increased relatively later than they do in the Levant (Runnels and Hansen 1986). *Olea* is quite sporadic in the pollen records from central and southern Greece before the EBA (Carrión *et al.* 2010). Moreover, the visibility of *Olea* in the pollen records from Greece is not pronounced in comparison to that of the Levant.

In Crete, *Olea* pollen appears to be more clearly visible in the Late Neolithic, which suggests that the olive was present before olive pollen became frequent on the Greek or Turkish mainland (Bottema and Sarpaki 2003; van Zeist and Bottema 1991).

By the EBA, *Olea* pollen starts to display continuous curves by becoming a regular element of the Aegean landscape, especially in Crete (reaching about %40, Moody *et al.,* 1996), and interpreted as the cultivation of the tree (Gennett, 1982). In the Peloponnese, higher *Olea* pollen values are registered during the LBA, especially in the Argive plain (Jahns 1993; see Fig. 4), Kleonai (Atherden *et al.* 1993), and the Kotihi lagoon (Lazarova *et al.* 2012). For northern Greece, the earliest evidence for the olive is recorded in the LBA pollen record (*e.g.* Limni Kopais and Tenaghi Philippon), while there is no indication in the archaeological and archaeobotanical records (Greig and Turner 1974; Turner and Greig 1975).

A second peak in *Olea* pollen values is recorded in different parts of Greece from around 1000-800 BCE until 550-200 BCE, indicating extensive cultivation from the Late Protogeometric until the Hellenistic period (Bottema 1982; Greig and Turner 1974; Jahns 1993).

Archaeological evidence from the Aegean

Available evidence indicates that the emergence of olive cultivation happened later in the Aegean region than in the Levant. The olive and olive oil play an important role in prehistoric Aegean communities, as these, together with cereals and wine, are the components of the so-called 'Mediterranean polyculture', also termed the 'Mediterranean Triad' by Renfrew (1972) and later modified to the 'Mediterranean Quartet' with the addition of pulses by Sarpaki (1992). There is a long-standing debate regarding the beginning of intensive cultivation of the olive in the Aegean and its relationship with the economic transformation in the 3rd millennium BCE. In the highly influential, 'anti-diffusionist' book *The Emergence of Civilisation*, Colin Renfrew (1972) discussed the possible relationship between the establishment of agricultural diversification and the rise of the Aegean civilisation in the EBA. He proposed that the plains and the valleys were more suitable for grain cultivation, while the foothills and the highlands were better for horticulture/arboriculture. According to Renfrew, the use of marginal land for intensive cultivation of the olive induced important socio-economic changes, including the creation of production surpluses, the growth of inter-regional exchange, and population increase. The usage of different topographical features led to an increased economic interdependence among various regions and the emergence of a stratified society. Renfrew's model has attracted some criticism (*e.g.* Halstead 1988), especially about the timing of intensive cultivation (see Runnels and Hansen 1986) on the basis of the limited visibility of the olive in the archaeobotanical record from Greece as discussed earlier. Residue analysis by gas chromatography on pottery sherds from the site Aphrodite's Kephali shows strong oleic acid peaks thought to suggest the presence of olive oil in the EBA (around 3200-2700 BCE) (Koh and Betancourt 2010). Moreover, the process for the extraction of oil from olive fruits seems to have been known by the EBA. For example, at Myrtos, spouted clay tubs possibly used for separating the oil from the residue were recorded together with olive stones and olive wood remains showing possible evidence of pruning (Warren 1972), and a jug containing traces of oil and two oil lamps were found on the island of Naxos (Renfrew 1972).

However, Boardman (1976) emphasised that the olive was not the most significant economic factor in the EBA. Moreover, the available evidence is not enough to support a widespread use of olive oil for culinary purposes before the LBA (around the first half of the 2nd millennium BCE). In contrast to Renfrew, Hamilakis (1996) argued that oil production had increased in the LBA on Crete and that olive oil as well as wine were consumed as luxury products (the oil being used as a perfume and unguent, possibly for anointing) by the elites based on the fact that the majority of the evidence comes from high-status sites and palaces. The number of olive trees presumably of distinct types or possessing distinct qualities are also mentioned in the written LBA sources (*e.g.* clay Linear B tablets on Knossos and Pylos) (Killen 2016; Melena 1983). Based on more abundant archaeological evidence, including stone olive presses, storage containers for oil, and clay spouted tubs, accompanied by epigraphic evidence, it is becoming clear that olive cultivation and oil production were well established in the southern Aegean region, especially in Crete, by the LBA (Riley 2002, 2004). From the LBA to the Hellenistic period (around the end of the 1st millennium BCE), the spread of the olive was at its maximum extent, extending from the warm lands of southern Greece to the more marginal areas for olive growing of northern Greece, an extension that is assumed to be due to the increased need for olive oil accompanying Greek colonisation (Valamoti *et al.* 2017).

Climatic implications of the expansion of the olive after the Late Bronze Age-Iron Age transition: the 3.2 cal kyr BP abrupt climate change event

The olive tree is cold-intolerant and limited to climates where the mean temperature of the coldest month (the January isotherm) is no lower than approximately 3°C (Polunin and Huxley 1965). Therefore, growth of the olive would have been promoted by the warming of the climate after the mid-Holocene-late Holocene transition (Sadori *et al.* 2011). However, flowering productivity is reduced with less rainfall and dry conditions. Thus, in warm weather, olive groves on high hills or slopes are probably less stressed than those on low altitudes or coasts, where olives may become less productive (Ozdemir 2016).

At the Bronze Age-Iron Age transition (1200-1000 BCE), most eastern Mediterranean urban centres (especially in Greece, Turkey, and the Levant) were destroyed, abandoned, or under stress (see Cline 2014). This occurred following a large-scale shift to more arid conditions (a drop in precipitation/palaeo-rainfall; a drop in sea-surface temperatures), reconstructed from multi-proxy records from various regions, termed the 3.2 cal kyr BP abrupt climate change event (around 1550-550 BCE), especially in the eastern Mediterranean (Boyd 2015; Cheng *et al.* 2015; Dean *et al.* 2015; Drake 2012a, 2012b; Finné *et al.* 2011; Finné *et al.* 2017; Göktürk *et al.* 2011; Issar 2003; Jalali *et al.* 2016; Mayewski *et al.* 2004; Schilman *et al.* 2002; Schimmelpfennig *et al.* 2012;Wick *et al.* 2003). The following period in the Aegean region (from the Early Iron Age until around 700 BCE), referred to as the 'Greek Dark Ages', is characterised by rural settlements, population migration, and limited long-distance trade (Drake 2012b). Kaniewski and van Campo (2017) argue that the 'LBA crisis' coincided with the onset of an approximately 300 year megadrought (see also Kaniewski *et al.* 2015). This is supported by textual evidence in tablets found at Hattuşa, Ugarit, Emar, and Aphek indicating droughts and famine at the end of the LBA (Langgut *et al.* 2013 and references therein). However, how changes in settlement patterns as well as political, economic, and climatic factors influenced agricultural organisation at the end of the LBA is still unclear due to a paucity of archaeological and archaeobotanical evidence. Moreover, the climate proxies available for the eastern Mediterranean are based on low-resolution data with chronological uncertainties, making it difficult to pinpoint correlations with archaeological data (for a further discussion, see Knapp and Manning 2016). As olive trees require at least 400 mm of annual precipitation to be profitable, reduced precipitation may lead to a decrease in productivity (Langgut *et al.* 2016). The seeds, fruits, charcoal remains, and palynological data from Tell Mastuma indicate that the prosperity seen at the site in EBA – which was based on the cultivation of the olive (in addition to that of wheat and barley) – abruptly ended in the LBA due to drought, which was accompanied by the abandonment of many sites in north-western Syria around 1600 BCE (Yasuda 1997). Yasuda (1997) stated that these sites were re-occupied by the Iron Age due to a shift towards wetter conditions. As we have mentioned above, although the palynological data from the Levant indicate a reduction in *Olea* pollen, confirming the occurrence of a dry phase at the end of the LBA, discrepancies resulting from low sampling coverage and dating resolution preclude the identification of the exact time and duration of the dry event at the end of the LBA (Langgut *et al.* 2013). In contrast to the situation in the Levant, in Turkey, the pollen data suggest the flourishing of oleiculture during the BOP, over an exceptionally long duration of more than a millennium. In addition, the vegetation composition suggests that the economic system was sustainable without any specific signal despite climate change suggesting a dry period and drought spikes between the second half of the 2nd millennium BCE and start of the 1st millennium BCE in Turkey (Kuzucuoğlu 2012; Lespez *et al.* 2016).

Although there is general agreement from different proxies regarding more arid conditions in the last centuries of the 2nd millennium BCE in the eastern Mediterranean region (Roberts *et al.* 2011), there is a lack of information about the nature and temporal extent of this complex climate event to infer precipitation changes throughout the circum-Mediterranean that might enable us to correlate it precisely with archaeological and historical data. Clear conclusions about the climatic implications of the 3.2 cal kyr BP abrupt climate change on olive cultivation and on the expansion of olive growing cannot be drawn, due to the low resolution and the high level of uncertainties in the chronology of the available sedimentary records from the eastern Mediterranean.

Conclusions

Unlike is the case for other crops, genetic evidence demonstrates that for the olive, domestication is an ongoing, regionally and temporally diverse process (Besnard *et al.* 2017). Therefore, tracking the early origins of olive domestication and the establishment of olive cultivation is a challenging task. As there is a rich corpus of archaeological evidence for human exploitation and usage of the olive, the southern Levant region remains the putative place of origin for domestication at the moment (see summaries by Kaniewski *et al.* 2012; Weiss 2015; Zohary *et al.* 2012). Temporal differences in the origins of olive domestication across the Levant indicate that the process of domestication and, correspondingly, cultivation was not spatially uniform throughout the eastern Mediterranean.

For the Levant, available information from the archaeobotanical, archaeological, and palynological records suggests that olives (mostly from wild oleasters) were exploited from the Chalcolithic period onwards, especially in the southern coastal region, where oleaster forms a natural component of the vegetation. The evidence from the Chalcolithic in the southern Levant, with the exception of Teleilat Ghassul, suggests manipulation and nurturing of already existing olive trees, rather than established cultivation. Therefore, the Chalcolithic in the southern Levant can be accepted as the period of the onset of olive cultivation, accompanied by a continuation of the exploitation of wild trees. The visibility of olives in the archaeobotanical, archaeological, and palynological records increases during the EBA in the southern Levant, indicating a widespread existence of olive trees (especially represented by the highest peak of *Olea* in the palynological record), the systematic exploitation of olives, and possible intensive olive oil production in the southern Levant starting in the EBA.

However, the available data still remain patchy and unconvincing regarding the cultivation status of the olive. Although it is clear that the EBA saw a boost in the selective exploitation and management of already existing wild oleasters, it is difficult to infer the existence of established arboriculture during the EBA based on both archaeological and archaeobotanical data. On the other hand, all evidence (especially when complemented by epigraphic sources) peaks in the LBA, indicating that by then the olive had spread outside of the natural distribution area of oleaster, especially into the western part of northern Mesopotamia, suggesting the cultivation of the olive tree.

For the Aegean, there is no concrete evidence that olive cultivation was practiced before the EBA. Similarly, the available data are inconclusive regarding the idea of extensive cultivation and the production of olive oil during the EBA. Starting in the LBA, the olive seems to have been economically significant and olive oil production was common practice.

For Anatolia, there is very sparse evidence regarding olive use for the early periods of prehistory. Although archaeobotanical research in Turkey has increased, available data in support of the cultivation of the olive are temporally and spatially fragmentary, and they are inconclusive before the LBA. Archaeobotanical evidence indicates an increased presence of olives starting in the EBA, which is mostly restricted to areas of the natural geographical distribution of olive trees near the Mediterranean coast of Turkey, especially in Cilicia, but the data are not enough to support cultivation of olive trees or production of olive oil before the LBA, when the palynological data strongly indicate olive arboriculture, during the Beyşehir occupation phase.

Hitherto, based on multi-proxy evidence from the Levant, Anatolia, and the Aegean region, there is no concrete data to support the hypothesis of a westward diffusion or adoption of olive cultivation. The question of when and where olive cultivation first took place will have to remain unanswered until more data (especially archaeological evidence) become available from EBA and MBA contexts. Moreover, the geographical and temporal distribution of archaeobotanical data in the eastern Mediterranean are limited, especially in Turkey. Further studies are needed with a focus on high-resolution palynological reconstructions from or near archaeological sites and more archaeobotanical data with absolute dates in order to fill significant gaps of knowledge on the history of olive cultivation.

Although the Persians, the Greeks, and especially the Romans were well acquainted with gardening traditions, the existence of knowledge and the availability of the necessary technology regarding olive cultivation (ranging from simple cuttings to more advanced grafting) before classical times cannot be excluded. However, the available data are insufficient to make reliable, conclusive statements about the status of the existing technology, it is unlikely to assume the existence of a widespread olive oil 'industry' in the eastern Mediterranean before the Iron Age.

In sum, the cultivation of the olive in the eastern Mediterranean region commenced at different times in different places, but from the Late Bronze Age onwards, the archaeobotanical evidence, especially when complemented by palynological, archaeological and textual data, is in good agreement regarding the existence of well-established olive arboriculture in the whole of the eastern Mediterranean region. We suggest that researchers should consider the possibility that climatic conditions until the end of the LBA may have provided optimal conditions for the expansion or cultivation of the olive in areas outside its original range of distribution.

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References

Archi, A. 1991. Culture de l'olivier et production de l'huile à Ebla, in: Charpin, D. and Joannès, F. (eds.), *Marchands, Diplomates et Empereurs. Etudes sur la Civilisation Mésopotamienne Offertes à Paul Garelli*, Paris: Recherche sur les civilisations, 211-222.

Asouti, E. 2003. Wood charcoal from Santorini (Thera): New evidence for climate, vegetation and timber imports in the Aegean Bronze Age. *Antiquity* 77, 471-484.

Atherden, M., Hall, J., and Wright, J.C. 1993. A pollen diagram from the northeast Peloponnese, Greece: Implications for vegetation history and archaeology. *The Holocene* 3, 351-356.

Baldoni, L., Tosti, N., Ricciolini, C., Belaj, A., Arcioni, S., Pannelli, G., Germana, M.A., Mulas, M., and Porceddu, A. 2006. Genetic structure of wild and cultivated olives in the central Mediterranean Basin. *Annals of Botany* 98, 935-942.

Bar-Matthews, M., Ayalon, A., Gilmour, M., Matthews, A., and Hawkesworth, C. J. 2003. Sea-land oxygen isotopic relationships from planktonic foraminifera and speleothems in the eastern Mediterranean region and their implication for paleorainfall during interglacial intervals. *Geochimica et Cosmochimica Acta* 67/17, 3181-3199.

Bartolini, G., Prevost, G., Messeri, C., Carignani, C., Carignani, G. 2005. *Olive germplasm: cultivars and world-wide collections*. Rome: FAO.

Baruch, U. 1986. The Late Holocene vegetational history of Lake Kinneret (Sea of Galilee), Israel. *Paléorient* 12, 37-48.

Baruch, U. 1990. Palynological evidence of human impact on the vegetation as recorded in Late Holocene lake sediments in Israel, in: Bottema, S., Entjes-Nieborg, G., and van Zeist, W. (eds.), *Man's role in the shaping of the eastern Mediterranean landscape*. Rotterdam: A.A. Balkema, 283-293.

Belaj, A., Muñoz-Diez, C., Baldoni, L., Satovic, Z., and Barranco, D. 2010. Genetic diversity and relationships of wild and cultivated olives at regional level in Spain. *Scientia Horticulturae* 124, 323-330.

Bending, J. and Colledge, S. 2007. The archaeobotanical assemblages, in: Postgate, N. and Thomas, D. (eds.), *Excavations at Kilise Tepe 1994-98, from Bronze Age to Byzantine in Western Cilicia: Volume 1 Text*. London: British Institute at Ankara, 583-596.

Besnard, G. 2016. Origin and domestication, in: Rugini, E., Baldoni, L., Muleo, R., and Sebastiani, L. (eds.). *The olive tree genome*. Basel: Springer, 1-12.

Besnard, G., Baradat, P., and Bervillé, A. 2001. Genetic relationships in the olive (*Olea europaea* L.) reflect multilocal selection of cultivars. *Theoretical and Applied Genetics* 102, 251-258.

Besnard, G., Khadari, B., Navascues, M., Fernandez-Mazuecos, M., El Bakkali, A., Arrigo, N., Baali-Cherif, D., Brunini-Bronzini de Caraffa, V., Santoni, S., Vargas, P., and Savolainen, V. 2013. The complex history of the olive tree: From Late Quaternary diversification of Mediterranean lineages to primary domestication in the northern Levant. *Proceedings of the Royal Society B: Biological Sciences* 280, 20122833-20122833.

Besnard, G. and Rubio de Casas, R. 2016. Single vs multiple independent olive domestications: The jury is (still) out. *New Phytologist* 209, 466-470.

Besnard, G., Terral, J.F., and Cornille, A. 2017. On the origins and domestication of the olive: A review and perspectives. *Annals of Botany* 121, 385-403.

Beug, H.J. 2004. *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete*. München: Verlag Dr. Friedrich Pfeil.

Boardman, J. 1976. The olive in the Mediterranean: Its culture and use. *Philosophical Transactions of the Royal Society of London: Series B* 275, 187-196.

Bottema, S. 1982. Palynological investigations in Greece with special reference to pollen as an indicator of human activity. *Palaeohistoria* 24, 257-288.

Bottema, S. 1991. Pollen proxy data from southeastern Europe and the Near East, in: Frenzel, B. (ed.), *Evaluation of climate proxy data in relation to the European Holocene*. Stuttgart, Jena, New York: G. Fisher, 63-79.

Bottema, S. and Sarpaki, A. 2003. Environmental change in Crete: A 9000-year record of Holocene vegetation history and the effect of the Santorini eruption. *The Holocene* 13, 733-749.

Bottema, S. and Woldring, H. 1984. Late Quaternary vegetation and climate of southwestern Turkey: Part II. *Palaeohistoria* 26, 123-149.

Bottema, S. and Woldring, H. 1990. Anthropogenic indicators in the pollen record of the eastern Mediterranean, in: Bottema, S., Entjes-Nieborg, G., and van Zeist, W. (eds.), *Handbook of man's role in the shaping of the eastern Mediterranean landscape*. Rotterdam: A.A. Balkema, 231-264.

Bottema, S., Woldring, H., and Aytuğ, B. 1993. Late Quaternary vegetation history of northern Turkey. *Palaeohistoria* 35-36, 13-72.

Bourke, S., Zoppi, U., Meadows, J., Hua, Q., and Gibbins, S. 2004. The end of the Chalcolithic period in the south Jordan valley: New14C determinations from Teleilat Ghassul, Jordan. *Radiocarbon* 46, 315-323.

Boyd, M. 2015. Speleothems from warm climates – Holocene records from the Caribbean and Mediterranean regions. PhD dissertation, Stockholm University.

Braadbaart, F., Marinova, E., and Sarpaki, A. 2016. Charred olive stones: Experimental and archaeological evidence for recognizing olive processing residues used as fuel. *Vegetation History and Archaeobotany* 25/5, 415-430.

Breton, C., Tersac, M., and Bervillé, A. 2006. Genetic diversity and gene flow between the wild olive (oleaster, *Olea europaea* L.) and the olive: Several Plio-Pleistocene refuge zones in the Mediterranean basin suggested by simple sequence repeats analysis. *Journal of Biogeography* 33, 1916-1928.

Breton, C.M., Warnock, P., and Bervillé, A.J. 2012. Origin and history of the olive, in: Muzzalupo, I. (ed.), *Olive germplasm: The olive cultivation, table olive and olive oil industry in Italy*. London: InTechOpen, 3-22.

Capper, M. M. 2012. Urban subsistence in the Bronze and Iron Ages: The palaeoethnobotany of Tell Tayinat, Turkey. Master's thesis, Simon Fraser University.

Carrión, Y., Ntinou, M., and Badal, E. 2010. *Olea europaea* L. in the north Mediterranean basin during the Pleniglacial and the Early-Middle Holocene. *Quaternary Science Reviews* 29, 952-968.

Carrión, Y., Ntinou, M., and Badal, E. 2013. Neolithic woodland in the north Mediterranean basin: A review on *Olea europaea* L., in Damblon F. (ed.), *Proceedings of the Fourth International Meeting of Anthracology*. British Archaeological Reports International Series 2486. Oxford: Archaeopress, 31-40.

Caudullo, G., Welk, E., and San-Miguel-Ayanz, J. 2017. Chorological maps for the main European woody species. *Data in Brief* 12, 662-666.

Cheng, H., Sinha, A., Verheyden, S., Nader, F.H., Li, X.L., Zhang, P.Z., and Edwards, R.L. 2015. The climate variability in northern Levant over the past 20,000 years. *Geophysical Research Letters* 42/20, 8641-8650.

Cline, E.H. 2014. *1177 B.C.: The year civilization collapsed.* Princeton, Princeton University Press.

Combourieu-Nebout, N., Peyron, O., Bout-Roumazeilles, V., Goring, S., Dormoy, I., Joannin, S., Sadori, L., Siani, G., and Magny, M. 2013. Holocene vegetation and climate changes in the central Mediterranean inferred from a high-resolution marine pollen record (Adriatic Sea). *Climate of the Past* 9, 2023-2042.

Condamin, J., Formenti, F., Metais, M. O., Michel, M. and Blond P., 1976. The application of gas chromatography to the tracing of oil in ancient amphorae. *Archaeometry* 18, 195-201.

D'Auria, A., Buonincontri, M.P., Allevato, E., Saracino, A., Jung, R., Pacciarelli, M., and Di Pasquale, G. 2016. Evidence of a short-lived episode of olive (*Olea europaea* L.) cultivation during the Early Bronze Age in western Mediterranean (southern Italy). *Holocene* 27/4, 605-612.

de Gruchy, M., Deckers, K., and Riehl, S. 2016. A diachronic reconstruction of the northern Mesopotamian landscape (4th to 2nd millennia BCE) from three separate sources of evidence. *Journal of Archaeological Science: Reports* 8, 250-267.

Dean, J.R., Jones, M.D., Leng, M.J., Noble, S.R., Metcalfe, S.E., Sloane, H.J., Sahy, D., Eastwood, W.J., and Roberts, N. 2015. Eastern Mediterranean hydroclimate over the late glacial and Holocene, reconstructed from the sediments of Nar Lake, central Turkey, using stable isotopes and carbonate mineralogy. *Quaternary Science Reviews* 124, 162-174.

Deckers, K. and Pessin, H. 2010. Vegetation development in the middle Euphrates and upper Jazirah (Syria/Turkey) during the Bronze Age. *Quaternary Research* 74, 216-226.

Desprat, S., Combourieu-Nebout, N., Essallami, L., Sicre, M.A., Dormoy, I., Peyron, O., Siani, G., Bout Roumazeilles, V., and Turon, J.L. 2013. Deglacial and holocene vegetation and climatic changes in the southern central Mediterranean from a direct land-sea correlation. *Climate of the Past* 9, 767-787.

Di Rita, F. and Magri, D. 2009. Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: A 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy. *Holocene* 19, 295-306.

Di Rita, F. and Magri, D. 2012. An overview of the Holocene vegetation history from the central Mediterranean coasts. *Journal of Mediterranean Earth Sciences* 4, 35-52.

Diez, C.M., Trujillo, I., Martinez-Urdiroz, N., Barranco, D., Rallo, L., Marfil, P., and Gaut, B.S. 2015. Olive domestication and diversification in the Mediterranean basin. *New Phytologist* 206, 436-447.

Dighton, A., Fairbairn, A., Bourke, S., Faith, J.T., and Habgood, P. 2017. Bronze Age olive domestication in the north Jordan valley: New morphological evidence for regional complexity in early arboricultural practice from Pella in Jordan. *Vegetation History and Archaeobotany* 26, 403-413.

Djamali, M., de Beaulieu, J.L., Andrieu-Ponel, V., Berberian, M., Miller, N.F., Gandouin, E., Lahijani, H., Shah-Hosseini, M., Ponel, P., Salimian, M., and Guiter, F. 2009. A late Holocene pollen record from Lake Almalou in NW Iran: Evidence for changing land-use in relation to some historical events during the last 3700 years. *Journal of Archaeological Science* 36, 1364-1375.

Doveri, S. and Baldoni, L. 2007. Olive, in: Kole, C. (ed.), *Genome mapping and molecular breeding in plants: Volume 4: Fruits and nuts*. Berlin, Heidelberg: Springer, 253-261.

Drake, B.L. 2012a. New paleoclimate reconstruction techniques in archaeology: Applications in Greece, New Mexico, and Portugal. PhD dissertation, University of New Mexico. https://digitalrepository.unm.edu/anth_etds/8

Drake, B.L. 2012b. The influence of climatic change on the Late Bronze Age Collapse and the Greek Dark Ages. *Journal of Archaeological Science* 39/6, 1862-1870.

Dusar, B., Verstraeten, G., Notebaert, B., and Bakker, J. 2011. Holocene environmental change and its impact on sediment dynamics in the eastern Mediterranean. *Earth-Science Reviews* 108, 137-157.

Eastwood, W.J. 1997. The palaeoecological record of Holocene environmental change in southwest Turkey. PhD dissertation, University of Wales, Aberystwyth.

Eastwood, W.J., Roberts, N., and Lamb, H.F. 1998. Palaeoecological and archaeological evidence for human occupance in southwest Turkey: The Beyşehir occupation phase. *Anatolian Studies* 48, 69-86.

Ehrlich, Y., Regev, L., Kerem, Z., and Boaretto, E. 2017. Radiocarbon dating of an olive tree cross-section: New insights on growth patterns and implications for age estimation of olive trees. *Frontiers in Plant Science* 8, 1918.

Elbaum, R., Melamed-Bessudo, C., Boaretto, E., Galili, E., Lev-Yadun, S., Levy, A. A., and Weiner, S. 2006. Ancient olive DNA in pits: Preservation, amplification and sequence analysis. *Journal of Archaeological Science* 33/1, 77-88.

Epstein, C. 1993. Oil production in the Golan Heights during the Chalcolithic period. *Tel Aviv* 20, 133-146.

Evershed, R.P. 2008. Organic residue analysis in archaeology: The archaeological biomarker revolution. *Archaeometry* 50/6, 895-924.

Finkelstein, I. and Gophna, R. 1993. Settlement, demographic, and economic patterns in the highlands of Palestine in the Chalcolithic and Early Bronze periods and the beginning of urbanism. *Bulletin of the American Schools of Oriental Research* 295, 1-22.

Finkelstein, I. and Langgut, D. 2018. Climate, settlement history, and olive cultivation in the Iron Age southern Levant. *Bulletin of the American Schools of Oriental Research* 379, 153-169.

Finné, M., Holmgren, K., Shen, C.C., Hu, H.M., Boyd, M., and Stocker, S. 2017. Late Bronze Age climate change and the destruction of the Mycenaean palace of Nestor at Pylos. *PLoS ONE* 12/12, e0189447.

Finné, M., Holmgren, K., Sundqvist, H.S., Weiberg, H., and Lindbolm, M. 2011. Climate in the eastern Mediterranean, and adjacent regions, during the past 6,000 years: A review. *Journal of Archaeological Science* 38, 3153e3173.

Fiorentino, G. 2004. The botanical view of food and landscape at Yumuktepe, in: Caneva, I. and Sevin, V. (eds.), *Mersin-Yumuktepe: A reappraisal.* Lecce: Congedo Editore, 159-161.

Fiorentino, G., Primavera, M., and Caracuta, V. 2014. Archaeobotanical analysis at Mersin-Yumuktepe: Food habits from Neolithic to Medieval period, in: Milano, L. and Bertoldi, F. (eds.), *Paleonutrition and food practices in the ancient Near East: Towards a multidisciplinary approach*. Padova: S.A.R.G.O.N., 85-94.

Florenzano, A., Mercuri, A.M., Rinaldi, R., Rattighieri, E., Fornaciari, R., Messora, R., and Arru, L. 2017. The representativeness of *Olea* pollen from olive groves and the Late Holocene landscape reconstruction in central Mediterranean. *Frontiers in Earth Science* 5, 85.

Ford, R. I. 1985. The processes of plant food production in prehistoric North America, in Ford, R. I. (ed.), *Prehistoric Food Production in North America,* Anthropological Papers, No. 75, Ann Arbor: Museum of Anthropology, University of Michigan, 1-18.

Foxhall, L. 2007. *Olive cultivation in ancient Greece: Seeking the ancient economy*. Oxford: Oxford University Press.

Fuller, D.Q. 2007. Contrasting patterns in crop domestication and domestication rates: Recent archaeobotanical insights from the old world. *Annals of Botany* 100, 903-924.

Fuller, D.Q. 2018. Long and attenuated: Comparative trends in the domestication of tree fruits. *Vegetation History and Archaeobotany* 27, 165-176.

Galili, E., Stanley, D.J., Sharvit, J., and Weinstein-Evron, M. 1997. Evidence for earliest olive-oil production in submerged settlements off the Carmel coast, Israel. *Journal of Archaeological Science* 24, 1141-1150.

Gennett, I. 1982. Three Holocene pollen records from southern Greece. *Palynology* 6, 282.

Göktürk, O.M., Fleitmann, D., Badertscher, S., Cheng, H., Edwards, R.L., Leuenberger, M., and Kramers, J. 2011. Climate on the southern Black Sea coast during the Holocene: Implications from the Sofular Cave record. *Quaternary Science Reviews* 30/19-20, 2433-2445.

Green, P.S. 2002. A revision of *Olea* L. (Oleaceae). *Kew Bulletin* 57, 91-140.

Gregor, H.J. 1992. Paläobotanische Untersuchungen zur antiken Pflanzenwelt des Hassek Höyük im Tal des oberen Euphrat und ein Versuch zur Rekonstruktion der dortigen Ökosystems für den Übergang von der späten Urukzeit zur frühen Bronzezeit, in: Behm-Blancke, M.R. (ed.), Hassek Höyük: Naturwissenschaftliche Untersuchungen und lithische Industrie. Tübingen: Ernst Wasmuth, 34-67.

Greig, J.R.A. and Turner, J. 1974. Some pollen diagrams from Greece and their archaeological significance. *Journal of Archaeological Science* 1, 177-194.

Gros-Balthazard, M., Newton, C., Ivorra, S., Pierre, M.H., Pintaud, J.C., and Terral, J.F. 2016. The domestication syndrome in *Phoenix dactylifera* seeds: Toward the identification of wild date palm populations. *PLoS ONE* 11/3, e0152394.

Guerrero Maldonado, N., López, M.J., Caudullo, G., and de Rigo, D. 2016. *Olea europaea* in Europe: Distribution, habitat, usage and threats, in: San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., and Mauri, A. (eds.), *European atlas of forest tree species*. Luxembourg: Publication Office of the EU, e01534b.

Gunstone, F.D. 2004. *The chemistry of oil and fats sources composition properties and uses*. Oxford: Blackwell.

Hadjisavvas, S. 1992. *Olive oil processing in Cyprus from the Bronze Age to the Byzantine period*. Göteborg: P. Åströms Förlag.

Hald, M.M. 2010. Distribution of crops at late Early Bronze Age Titriş Höyük, southeast Anatolia: Towards a model for the identification of consumers of centrally organised food distribution. *Vegetation History and Archaeobotany* 19, 69-77.

Haldane, C. 1993. Direct evidence for organic cargoes in the Late Bronze Age. *World Archaeology* 24, 348-360.

Halstead, P. 1988. On redistribution and the origin of Minoan-Mycenaean palatial economies, in: French, E. and Wardle, K. (eds.). *Problems in Greek prehistory*. Bristol: Bristol Classical Press.

Hamilakis, Y. 1996. Wine, oil and the dialectics of power in Bronze Age Crete: A review of the evidence. *Oxford Journal of Archaeology* 15/1, 1-32.

Handziuk, N. 2018. Ceramic anatomy of a Bronze Age olive press, in: ICAANE – 11th International Congress on the Archaeology of the Ancient Near East Conference abstract-book. München: Ludwig-Maximilians-Universität, 214.

Hansen, J.M. 1988. Agriculture in the prehistoric Aegean: Data versus speculation. *American Journal of Archaeology* 92/1, 39-52.

Hansen, J.M. and Allen, S. 2011. The palaeoethnobotany of Early Helladic Tsoungiza, in: D. Pullen (ed.), *Nemea Valley Archaeological Project, Volume I: The Early Bronze Age village on Tsoungiza Hill*. Athens: American School of Classical Studies and Hesperia, 805-891.

Hansson, M. and Foley, B. 2008. Ancient DNA fragments inside Classical Greek amphoras reveal cargo of 2400-year-old shipwreck. *Journal of Archaeological Science* 35, 1169-1176.

Harlan, J.R. 1992. *Crops and man*. Madison: Crop Science Society of America.

Heltzer, M. 1996. Olive growing and olive oil in Ugarit, in: Heltzer, M. and Eitam, D. (eds.), *Olive oil in antiquity: Israel and neighbouring countries from Neolithic to Early Arab period*. History of the Ancient Near East 7. Padova: Sargon, 77-89.

Huntley, B. and Birks, H.J.B. 1983. *An atlas of past and present pollen maps for Europe 0-13000 years ago*. Cambridge: Cambridge University Press.

Hynd, A. 1997. A model of local continuity: The 1995 archaeobotanical assemblage from Kinet Höyük, Hatay. MSc thesis, University of Sheffield.

IOC (International Olive Council) 2007. Production techniques in olive growing. Madrid: International Olive Council.

IOC (International Olive Council) 2008. *Olive Products Market Report Summary* 30, 1-3.

Issar, A.S. 2003. *Climate changes during the Holocene and their impact on hydrological systems*. Cambridge: Cambridge University Press.

Jahns, S. 1993. On the Holocene vegetation history of the Argive plain (Peloponnesus, southern Greece). *Vegetation History and Archaeobotany* 2, 187-203.

Jalali, B., Sicre, M.A., Bassetti, M.A., and Kallel, N. 2016. Holocene climate variability in the north-western Mediterranean Sea (Gulf of Lions). *Climate of the Past* 12, 91-101.

Jalut, G., Dedoubat, J.J., Fontugne, M., and Otto, T. 2009. Holocene circum-Mediterranean vegetation changes: Climate forcing and human impact. *Quaternary International* 200, 4-18.

Janick, J. 2005. The origin of fruits, fruit growing, and fruit breeding. *Plant Breeding Reviews* 25, 255-320.

Joffe, A.H. 1993. *Settlement and society in the Early Bronze Age I and II, southern Levant*. Sheffield: Sheffield Academic Press.

Kaniewski, D., and Van Campo, E. 2017. 3.2 ka BP megadrought and the Late Bronze Age collapse, in: Weiss, H. (ed.), *Megadrought and collapse: From early agriculture to Angkor*. Oxford: Oxford Scholarship Online, 161-182.

Kaniewski, D., Guiot, J., and Van Campo, E. 2015. Drought and societal collapse 3200 years ago in the eastern Mediterranean: A review. *Wiley Interdisciplinary Reviews: Climate Change* 6, 369-382.

Kaniewski, D., Paulissen, E., De Laet, V., Dossche, K., and Waelkens, M. 2007. A high-resolution Late Holocene landscape ecological history inferred from an intramontane basin in the western Taurus mountains, Turkey. *Quaternary Science Reviews* 26, 2201-2218.

Kaniewski, D., Paulissen, E., van Campo, E., Al-Maqdissi, M., Bretschneider, J., and Van Lerberghe, K. 2008. Middle East coastal ecosystem response to middle-to-late Holocene abrupt climate changes. *Proceedings of the National Academy of Sciences of the United States of America* 105, 13941-13946.

Kaniewski, D., Paulissen, E., van Campo, E., Bakker, J., van Lerberghe, K., and Waelkens, M. 2009. Wild or cultivated *Olea europaea* L. in the eastern Mediterranean during the middle-late Holocene? A pollen-numerical approach. *Holocene* 19, 1039-1047.

Kaniewski, D., Paulissen, E., van Campo, E., Weiss, H., Otto, T., Bretschneider, J. 2010. Late second-early first millennium BC abrupt climate changes in coastal Syria and their possible significance for the history of the Eastern Mediterranean. *Quaternary Research* 74, 207-215.

Kaniewski, D., Van Campo, E., Boiy, T., Terral, J.F., Khadari, B., and Besnard, G. 2012. Primary domestication and early uses of the emblematic olive tree: Palaeobotanical, historical and molecular evidence from the Middle East. *Biological Reviews* 87, 885-899.

Kaniewski, D., Van Campo, E., Guiot, J., Le Burel, S., Otto, T., and Baeteman, C. 2013. Environmental roots of the Late Bronze Age crisis. *PLoS ONE* 8, e71004.

Kepinski, C. 2007. Dynamics, diagnostic criteria and settlement patterns in the Carchemish area during the Early Bronze period, in: Peltenburg, E. (ed.), *Euphrates River valley settlement: The Carchemish sector in the third millennium BC*. Levant Supplementary Series 5. Oxford: Oxbow Books, 152-163.

Killen, J. 2016. Wheat, barley, flour, olives and figs on Linear B tablets, in: Halstead, P. and Barrett, J.C. (eds.), *Food, cuisine and society in prehistoric Greece*. Oxford: Oxbow Books, 155-173.

Kislev, M.E. 1994. Wild olive at submerged Chalcolithic Kfar Samir, Haifa, Israel. *Journal of the Israel Prehistoric Society* 26, 134-145.

Kislev, M.E., Nadel, D., Carmi, I. 1992. Epipalaeolithic (19,000 BP) cereal and fruit diet at Ohalo II, Sea of Galilee, Israel. *Review of Palaeobotany and Palynology* 73, 161-166.

Knapp, A.B. and Manning, S.W. 2016. Crisis in context: The end of the Late Bronze Age in the eastern Mediterranean. *American Journal of Archaeology* 120/1, 99.

Koh, A. and Betancourt, P. 2010. Wine and olive oil from an early Minoan hilltop fort. *Mediterranean Archaeology and Archaeometry* 10, 15-23.

Kuniholm, P.I., Kromer, B., Manning, S.W., Newton, M., Latini, C.E., and Bruce, M.J. 1996. Anatolian tree rings and the absolute chronology of the eastern Mediterranean 2220-718 BC. *Nature* 381, 780-783.

Kuzucuoğlu, C. 2012. The rise and fall of the Hittite state in central Anatolia: How, when, where, did climate intervene?, in: Henry, O., Beyer, D., and Tibet, A. (eds.), *La Cappadoce Méridionale de la préhistoire à la période byzantine*. İstanbul: Ege Yayinevi, 37-41.

Langgut, D., Adams, M.J., and Finkelstein, I. 2016. Climate, settlement patterns and olive horticulture in the southern Levant during the Early Bronze and Intermediate Bronze Ages (c. 3600-1950 BC). *Levant* 48/2, 117-134.

Langgut, D., Finkelstein, I., and Litt, T. 2013. Climate and the Late Bronze collapse: New evidence from the southern Levant. *Tel Aviv* 40, 149-75.

Langgut, D., Finkelstein, I., Litt, T., Harald Neumann, F., and Stein, M. 2015. Vegetation and climate changes during the Bronze and Iron Ages (~3600-600 BCE) in the southern Levant based on palynological records. *Radiocarbon* 57/2, 217-235.

Langgut, D., Lev-Yadun, S., and Finkelstein, I. 2014. The impact of olive orchard abandonment and rehabilitation on pollen signature: An experimental approach to evaluating fossil pollen data. *Ethnoarchaeology* 6, 121-135.

Lazarova, M., Koutsios, A., and Kontopoulos, N. 2012. Holocene vegetation history of the Kotihi lagoon (northwest Peloponnesus, Greece). *Quaternary International* 261, 138-145.

Lespez, L., Carozza, L., Berger, J.F., Ghilardi, M., Kuzucuoglu, C., Carozza, J.M., and Vannière, B. 2016. Rapid climatic change and social transformations: Uncertainties, adaptability and resilience, in: Thiébault, S. and Moatti, J.P. (eds.), *The Mediterranean region under climate change: A scientific update*. Marseille: IRD Éditions, 35-45.

Liphschitz, N., Gophna, R., Hartman, M., and Biger, G. 1991. The beginning of olive (*Olea europaea*) cultivation in the Old World: A reassessment. *Journal of Archaeological Science* 18, 441-453.

Litt, T., Ohlwein, C., Neumann, F.H., Hense, A., and Stein, M. 2012. Holocene climate variability in the Levant from the Dead Sea pollen record. *Quaternary Science Reviews* 49, 95-105.

Lovell, J. 2002. Shifting subsistence patterns: Some ideas about the end of the Chalcolithic in the southern Levant. *Paleorient* 28, 89-102.

Lumaret, R. and Ouazzani, N. 2001. Ancient wild olives in Mediterranean forests. *Nature* 413, 700.

Lumaret, R., Ouazzani, N., Michaud, H., and Villemur, P. 1997. Cultivated olive and oleaster: Two very closely connected partners of the same species (*Olea europaea*): Evidence from enzyme polymorphism. *Bocconea* 7, 39-42.

Lumaret, R., Ouazzani, N., Michaud, H., Vivier, G., Deguilloux, M.F., and Di Giusto, F. 2004. Allozyme variation of oleaster populations (wild olive tree) (*Olea europaea* L.) in the Mediterranean basin. *Heredity* 92, 343-351.

Margaritis, E. 2013. Distinguishing exploitation, domestication, cultivation and production: The olive in the third millennium Aegean. *Antiquity* 87/337, 746-757.

Marinova, E., van der Valk, J.M.A., Valamoti, S.M., and Bretschneider, J. 2011. An experimental approach for tracing olive processing residues in the archaeobotanical record, with preliminary examples from Tell Tweini, Syria. *Vegetation History and Archaeobotany* 20, 471-478.

Marone, E. and Fiorino, P. 2012. Oleiculture in progress. *Advances in Horticultural Science* 26, 163-175.

Mavromati, A. 2017. Landscape and wood-fuel in Akrotiri (Thera, Greece) during the Bronze Age. *Quaternary International* 458, 44-55.

Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlén, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., and Steig, E.J. 2004. Holocene climate variability. *Quaternary Research* 62, 243-255.

Meadows, J. 2005. Early farmers and their environment: Archaeobotanical research at Neolithic and Chalcolithic sites in Jordan. PhD dissertation, La Trobe University.

Melena, J.L. 1983. Olive oil and other sorts of oil in the Mycenaean tablets. *Minos* 18, 89-123.

Mercuri, A.M. 2015. Applied palynology as a trans-disciplinary science: the contribution of aerobiology data to forensic and palaeoenvironmental issues. *Aerobiologia* 31, 323-339.

Mercuri, A.M., Bandini Mazzanti, M., Florenzano, A., Montecchi, M.C., and Rattighieri, E. 2013. *Olea*, *Juglans* and *Castanea*: The OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. *Quaternary International* 303, 24-42.

Meyer, R.S., DuVal, A.E., and Jensen, H.R. 2012. Patterns and processes in crop domestication: An historical review and quantitative analysis of 203 global food crops. *The New Phytologist* 196/1, 29-48.

Miller, A.J. and Gross, B.L. 2011. From forest to field: Perennial fruit crop domestication. *American Journal of Botany* 98, 1389-1414.

Moody, J., Rackham, O., and Rapp, G. 1996. Environmental archaeology of prehistoric NW Crete. *Journal of Field Archaeology* 23, 273-297.

Mudge, K., Janick, J., Scofield, S., and Goldschmidt, E. 2009. A history of grafting. *Horticultural Reviews* 35, 437-493.

Muzzalupo, I., Vendramin, G.G., and Chiappetta, A. 2014. Genetic biodiversity of Italian olives (*Olea europaea*) germplasm analyzed by SSR markers. *Scientific World Journal* 2014, 1-12.

Neef, R. 1990. Introduction, development and environmental implications of olive culture: The evidence from Jordan, in: Bottema, S., Entjes-Nieborg, G., and van Zeist, W. (eds.), *Man's role in the shaping of the eastern Mediterranean landscape*. Rotterdam: A.A. Balkema, 295-306.

Neumann, F.H., Kagan, E.J., Leroy, S.A.G., and Baruch, U. 2010. Vegetation history and climate fluctuations on a transect along the Dead Sea west shore and their impact on past societies over the last 3500 years. *Journal of Arid Environments* 74, 756-764.

Neumann, F.H., Kagan, E.J., Schwab, M.J., and Stein, M. 2007*a*. Palynology, sedimentology and palaeoecology of the late Holocene Dead Sea. *Quaternary Science Reviews* 26/11-12, 1476-1498.

Neumann, F., Schölzel, C., Litt, T., Hense, A., and Stein, M. 2007*b*. Holocene vegetation and climate history of the northern Golan Heights (Near East). *Vegetation History and Archaeobotany* 16/4, 329-346.

Newton, C., Lorre, C., Sauvage, C., Ivorra, S., and Terral, J.F. 2014. On the origins and spread of *Olea europaea* L. (olive) domestication: Evidence for shape variation of olive stones at Ugarit, Late Bronze Age, Syria: A window on the Mediterranean basin and on the westward diffusion of olive varieties. *Vegetation History and Archaeobotany* 23, 567-575.

Newton, C., Terral, J.F., and Ivorra, S. 2006. The Egyptian olive (*Olea europaea* subsp. *europaea*) in the later first millennium BC: Origins and history using the morphometric analysis of olive stones. *Antiquity* 80, 405-414.

Onozuka, T. 2012. Keeping up with the demand for oil? Reconsidering the unique oil presses from Late Bronze Age IIB to Iron Age IIA in the southern Levant. *Orient* 47, 67-90.

Oybak Dönmez, E. 2006. Prehistoric and medieval plant remains from two sites on the Euphrates, south-eastern Turkey. *Turkish Journal of Botany* 30, 11-38.

Ozdemir, Y. 2016. Effects of climate change on olive cultivation and table olive and olive oil quality. *Scientific Papers: Series B: Horticulture* 60, 65-69.

Peyron, O., Goring, S., Dormoy, I., Kotthoff, U., Pross, J., de Beaulieu, J.L., Drescher-Schneider, R., Vanniére, B., and Magny, M. 2011. Holocene seasonality changes in the central Mediterranean region reconstructed from the pollen sequences of Lake Accesa (Italy) and Tenaghi Philippon (Greece). *Holocene* 21/1, 131-146.

Polunin, O. and Huxley, A. 1965. Flowers of the Mediterranean. London: Chatto and Windus.

Price, T.D., Bar-Yosef, O. 2011. The origins of agriculture: New data, new ideas. *Current Anthropology* 52/S4, S163-S174.

Pulak, C. 1998. The Uluburun shipwreck: An overview. *International Journal of Nautical Archaeology* 27, 188-224.

Punt, W., Bos, J.A.A., and Hoen, P.P. 1991. Oleaceae, in: Punt, W. and Blackmore, S. (eds.), *The northwest European pollen flora VI*. Amsterdam: Elsevier, 23-47.

Renfrew, C. 1972. *The emergence of civilisation: The Cyclades and the Aegean in the third millennium BC*. London: Methuen.

Riehl, S. 1999. *Bronze Age environment and economy in the Troad: The archaeobotany of Kumtepe and Troy.* BioArchaeologica 2. Tübingen: Mo-Vince-Verlag.

Riehl, S. 2009. Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient Near East. *Quaternary International* 197, 93-114.

Riehl, S. 2010. Flourishing agriculture in times of political instability: The archaeobotanical and isotopic evidence from Tell Atchana, in: Yener, K.A. (ed.), *Tell Atchana, Ancient Alalakh: Volume 1: The 2003-2004 Excavation Seasons*. Istanbul: Koç Üniversitesi Yayinlari, 123-136.

Riehl, S. 2014. Agriculture in the ancient Near East, in: Selin, H. (ed.), *Encyclopaedia of the history of science, technology, and medicine in non-Western cultures.* 2nd edition. Basel: Springer, 1-15.

Riehl, S. and Bryson, R. 2007. Variability in human adaptation to changing environmental conditions in Upper Mesopotamia during the Early and the Middle Bronze Age, in: Kuzucuoglu, C. and Marro, C. (eds.), *Sociétés humaines et changement climatique à la fin du troisième millénaire: Une crise a-t-elle eu lieu en Haute Mésopotamie?* Paris: De Boccard, 523-548.

Riehl, S. and Marinova, E. 2008. Mid-Holocene vegetation change in the Troad (W Anatolia): Man-made or natural? *Vegetation History and Archaeobotany* 17/3, 297-312.

Riley, F.R. 2002. Olive oil production on Bronze Age Crete: Nutritional properties, processing methods and storage life of Minoan olive oil. *Oxford Journal of Archaeology* 21/1, 63-75.

Riley, F.R. 2004. The olive industry of Bronze Age Crete: Evidence for volcanic damage to olive groves and property in central and eastern Crete. *Akroterion* 1-6.

Roberts, N. 1990. Human-induced landscape change in south and southwest Turkey during the later Holocene, in: Bottema, S., Entjes-Nieborg, G., van Zeist, W. (eds), *Man's role in the shaping of the eastern Mediterranean landscape*. Rotterdam: A.A. Balkema, 53-67.

Roberts, N., Cassis, M., Doonan, O., Eastwood, W., Elton, H., Haldon, J., and Newhard, J. 2018. Not the end of the world? Post-Classical decline and recovery in rural Anatolia. *Human Ecology* 1-18.

Roberts, N., Eastwood, W.J., Kuzucuoğlu, C., Fiorentino, G., and Caracuta, V. 2011. Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-holocene environmental transition. *Holocene* 21, 147-162.

Rotondi, A., Magli, M., Ricciolini, C., and Baldoni, L. 2003. Morphological and molecular analyses for the characterization of a group of Italian olive cultivars. *Euphytica* 132, 129-137.

Rowan, E. 2015. Olive oil pressing waste as a fuel source in Antiquity. *American Journal of Archaeology* 119/4, 465-482.

Rowan, Y.M. 2014. The southern Levant (Cisjordan) during the Chalcolithic period, in: Steiner, M.L. and Killebrew, A. (eds.), *The Oxford handbook of the archaeology of the Levant (ca. 8000-332 BCE).* Oxford: Oxford University Press, 223-236.

Rowan, Y.M. and Golden, J. 2009. The Chalcolithic period of the southern Levant: A synthetic review. *Journal of World Prehistory* 22, 1-92.

Runnels, C. and Hansen, J. 1986. The olive in the prehistoric Aegean: The evidence for domestication in the Early Bronze Age. *Oxford Journal of Archaeology* 5, 299-308.

Sadori, L., Jahns, S., and Peyron, O. 2011. Mid-Holocene vegetation history of the central Mediterranean. *The Holocene* 21, 117-129.

Sadori, L. and Narcisi, B. 2001. The postglacial record of environmental history from Lago di Pergusa, Sicily. *The Holocene* 11, 655-670.

Sarpaki, A. 1992. The palaeoethnobotanical approach: The Mediterranean triad or is it a quartet? in: Wells, B. (ed.), *Agriculture in ancient Greece*. Stockholm: Åströms Förlag, 61-76.

Sarpaki, A. 2012. The taming of an island environment: Crete from dawn to noon (Neolithic to the end of the Bronze Age), in: Cadogan, G., Iacovou, M., Kopaka, K., and Whitley, J. (eds.). *Parallel lives: Ancient island societies in Crete and Cyprus.* London: British School at Athens, 35-45.

Schiebel, V. and Litt, T. 2018. Holocene vegetation history of the southern Levant based on a pollen record from Lake Kinneret (Sea of Galilee), Israel. *Vegetation History and Archaeobotany* 27, 577-590.

Schilman, B., Ayalon, A., Bar-Matthews, M., Kagan, E.J., and Almogi-Labin, A. 2002. Sea-land paleoclimate correlation in the eastern Mediterranean region during the late Holocene. *Israelian Journal of Earth Sciences* 51, 181-190.

Schimmelpfennig, I., Schaefer, J.-M., Akçar, N., Ivy-Ochs, S., Finkel, R.-C., and Schlüchter, C. 2012. Holocene glacier culminations in the western Alps and their hemispheric relevance. *Geology* 40, 891-894.

Sesli, M. and Yegenoglu, E.D. 2017. Genetic relationships in wild olives (*Olea europaea* ssp. *oleaster*) by ISSR and RAPD markers. *Biotechnology and Biotechnological Equipment* 31/5, 897-904.

Simchoni, O. and Kislev, M.E. 2006. Charred by-products of olive-oil production in the Iron Age, in: Mazar, A. (ed.), *Excavations at Tel Beth-Shean1989-1996 vol.1*. Jerusalem: The Israel Exploration Society and the Institute of Archaeology, 679-685.

Sorrel, P. and Mathis, M. 2016. Mid- to late-Holocene coastal vegetation patterns in Northern Levant (Tell Sukas, Syria): Olive tree cultivation history and climatic change. *Holocene* 26, 858-873.

Sullivan, D.G. 1988. The discovery of Santorini Minoan tephra in western Turkey. *Nature* 333, 552-554.

Terral, J. 1996. Wild and cultivated olive (Olea europaea L.): a new approach to an old problem using inorganic analyses of modern wood and archaeological charcoal. *Review of Palaeobotany and Palynology* 91 (1-4), 383-397.

Terral, J.F. 2000. Exploitation and management of the olive tree during prehistoric times in Mediterranean France and Spain. *Journal of Archaeological Science* 27, 127-133.

Terral, J.F., Alonso, N., Buxò i Capdevila, R., Chatti, N., Fabre, L., Fiorentino, G., Marinval, P., Jordá, G.P., Pradat, B., Rovira, N., and Alibert, P. 2004. Historical biogeography of olive domestication (*Olea europaea* L.) as revealed by geometrical morphometry applied to biological and archaeological material. *Journal of Biogeography* 31/1, 63-77.

Terral, J.F. and Arnold-Simard, G. 1996. Beginnings of olive cultivation in eastern Spain in relation to Holocene bioclimatic changes. *Quaternary Research* 46, 176-185.

Tormo-Molina, R., Gonzalo-Garijo, M.A., Silva-Palacios, I., and Muñoz-Rodríguez, A.F. 2010. General trends in airborne pollen production and pollination periods at a Mediterranean site (Badajoz, southwest Spain). *Journal of Investigational Allergology and Clinical Immunology* 20/7, 567-574.

Turner, J. and Greig, J.R.A. 1975. Some Holocene pollen diagrams from Greece. *Review of Palaeobotany and Palynology* 20, 171-204.

Valamoti, S.M., Gkatzogia, E., and Ntinou, M. 2017. Did Greek colonisation bring olive growing to the north? An integrated archaeobotanical investigation of the spread of *Olea europaea* in Greece from the 7th to the 1st millennium BC. *Vegetation History and Archaeobotany* 27, 177-195.

van Zeist, W., Baruch, U., and Bottema, S. 2009. Holocene palaeoecology of the Hula area, northeastern Israel, in: Kaptijn, E. and Petit, L.P. (eds.), *A timeless vale: Archaeological and related essays on the Jordan valley*. Leiden: Leiden University Press, 29-64.

van Zeist, W. and Bottema, S. 1991. *Late Quaternary vegetation of the Near East*: *TAVO Beihefte zum Tübinger Atlas des Vorderen Orients 18.* Wiesbaden: Dr Ludwig Reichert Verlag.

van Zeist, W., Woldring, H., and Stapert, D. 1975. Late Quaternary vegetation and climate of southwestern Turkey. *Palaeohistoria* 17, 53-144.

Vermoere, M., Smets, E., Waelkens, M., Vanhaverbeke, H., Librecht, I., Paulissen, E., and Vanhecke, L. 2000. Late Holocene environmental change and the record of human impact at Gravgaz near Sagalassos, southwest Turkey. *Journal of Archaeological Science* 27/7, 571-595.

Vermoere, M., Vanhecke, L., Waelkens, M., and Smets, E. 2003. Modern and ancient olive stands near Sagalassos (south-west Turkey) and reconstruction of the ancient agricultural landscape in two valleys. *Global Ecology and Biogeography* 12, 217-235.

Walsh, K. 2014. *The archaeology of Mediterranean landscapes: Human-environment interaction.* New York: Cambridge University Press.

Warren, P. 1972. Myrtos: An Early Bronze Age settlement in Crete. London: British School at Athens.

Weiss, E. 2015. Beginnings of fruit growing in the old world: Two generations later. *Israel Journal of Plant Sciences* 62, 75-85.

Wick, L., Lemcke, G., and Sturm, M. 2003. Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: High-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. *Holocene* 13/5, 665-675.

Yakar, Y. 2000. *Ethnoarchaeology of Anatolia: Rural socio-economy in the Bronze and Iron Ages.* Jerusalem: Institute of Archaeology of Tell Aviv University.

Yasuda, Y. 1997. The rise and fall of olive cultivation in northwest Syria: Palaeoecological study of Tell Mastuma. *Japan Review* 8, 251-273.

Yoruk, B. and Taskin, V. 2014. Genetic diversity and relationships of wild and cultivated olives in Turkey. *Plant Systematics and Evolution* 300, 1247-1258.

Zohary, D., Hopf, M., and Weiss, E. 2012. *Domestication of plants in the Old World: The origin and spread of domesticated plants in southwest Asia, Europe and the Mediterranean basin*. Oxford: Oxford University Press.

Zohary, D. and Spiegel-Roy, P. 1975. Beginning of fruit growing in the old world. *Science* 187, 319-327.

Zohary, M. 1973. *Geobotanical foundations of the Middle East*. Stuttgart: Fisher.

On-site palaeoecological investigations at the Hünenburg hillfort-settlement complex, with special reference to non-pollen palynomorphs

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Abstract

To highlight the potential of non-pollen palynomorphs as an additional source of information within archaeological contexts, palynological samples from settlement layers of the Hünenburg hillfort-settlement complex were analyzed. In addition, some new non-pollen palynomorph types, mostly fungal spores, are described, illustrated, and discussed. The study provides new on-site data relating to the living conditions during the Late Bronze Age/Early Iron Age. Samples taken from the horizons of two superimposed pits show microscopic evidence for stockpiling, plant processing, waste management, and hygienic conditions within the settlement area, whereas samples taken from the ancient watercourse deposits provide insights into local land use, water quality, and fire management.

Keywords: NPPs, pollen, ancient watercourse, pits, Late Bronze Age/Early Iron Age

Introduction

With the establishment of the analysis of non-pollen palynomorphs (NPPs: fungal spores, eggshells of parasitic worms, algae, cyanobacteria, dinoflagellate cysts, remnants of invertebrates, *etc.*) in palynology, new opportunities have been opened up for more detailed reconstructions of the archaeological contexts. Many of the NPPs occur only under certain circumstances, such as the presence of decaying plant matter, wood, and dung (*e.g.* Dietre *et al.* 2012; Prager *et al.* 2012; van Geel and Aptroot 2006); under specific moisture, nutrient, and salinity conditions (*e.g.* Haas and Wahlmüller 2010; Marret *et al.* 2009; van Geel 1976); during parasitic infestation (*e.g.* Le Bailly *et al.* 2007; Maicher *et al.* 2017; Rácz *et al.* 2015); or after fire or erosion events (*e.g.* Hillbrand *et al.* 2014; Innes *et al.* 2004; van Geel *et al.* 2003). Furthermore, in contrast to pollen, most of these microfossils are of autochthonous origin, making them valuable indicators for on-site characterizations (Blackford

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et al. 2006; Marinova and Atanassova 2006; van Geel 2001). With regard to archaeological stratigraphies, the analysis of NPPs can provide information about temporal and/or spatial changes in specific conditions, thus helping to reconstruct how structures and settlement areas were used in the past. Another characteristic of NPPs is their strong resistance to decay. Especially in minerogenic deposits of archaeological sites, NPPs often remain preserved when pollen grains have disappeared as a result of corrosion and oxidation (*e.g.* Medeanic *et al.* 2008; Prager *et al.* 2006). This makes them an important alternate source of information when there is a scarcity of pollen in the settlement layers.

Despite all these advantages, NPPs are still given too little attention, as shown by the small number of studies of NPP assemblages from archaeological sites (*e.g.* Bosi *et al.* 2011; Brinkkemper and van Haaster 2012; Chichinadze and Kvavadze 2013; Kvavadze and Kakhiani 2010; Revelles *et al.* 2016; Święta-Musznicka *et al.* 2013; van Geel *et al.* 1986, 2003).

As demonstrated by previous, off-site palynological investigations, the surroundings of the Late Bronze Age/Early Iron Age Hünenburg hillfort-settlement complex exhibited quite intensive land-use in the past (Heske and Wieckowska 2012). In order to complete the picture, at the local level, and to take advantage of the potential of the analysis of NPPs, samples were taken from archaeological features of the outer settlement of the Hünenburg hillfort and from an ancient watercourse at the foot of the hill. The palynological investigations of these samples were aimed at bringing new insights into the living conditions during the occupation phases, that is, crop, waste, and fire management; hygienic conditions; and water quality. The overall, additional objective was to obtain new information or support existing information on the ecological significance of NPPs in order to increase the potential for reconstructions associated with archaeological contexts.

Archaeological setting

The Hünenburg, located on the hill called the Heeseberg, near Watenstedt, central Germany (Fig. 1), is a Late Bronze Age/Early Iron Age hillfort-settlement complex in the northern foreland of the Harz Mountains. Since 1998, the area of the western plateau of the Heeseberg has been investigated as part of the project titled 'The Hünenburg near Watenstedt, Kr. Helmstedt – A prehistoric hillfort and its associated area', by archaeologists from the state museum of Braunschweig (Braunschweigisches Landesmuseum) and the Georg-August-Universität Göttingen (Heske 2003, 2006). In this framework, both a hillfort and an outer settlement of about 400,000 m^2 have been prospected. During this project, particular emphasis was placed on the building history of the rampart and the use of the interior space of the hillfort. In the framework of the succeeding project, 'Periphery and centre: the Hünenburg near Watenstedt, Helmstedt district – A hillfort in the contact zone between the Lusatian culture and the Nordic Bronze Age', which started in 2005, a settlement area of about 3,500 m^2 was investigated by means of excavations (Heske 2016a). According to the ceramic chronology and a series of ^{14}C dates, a small settlement was built as early as the 14^{th} century BCE. After the erection of the rampart, around 1130 cal BCE (Heske 2006, 2017), the hillfort was used continuously until the 7^{th} century BCE, whereby the highest intensity of the settlement was reached between 900 and 750 BCE (Period V of the Northern Bronze Age). During this time, new contacts with the northern European region are evidenced in the finds of the settlement, and also in new features near the river Soltau (Heske 2013, 2015), located at the foot of the Heeseberg.

The areas below the hillfort excavated thus far show a picture of an open settlement with a large number of settlement pits located close to each other. In general, the multiple settlement pits yielded stone tools, bronze objects, and bones, as well as

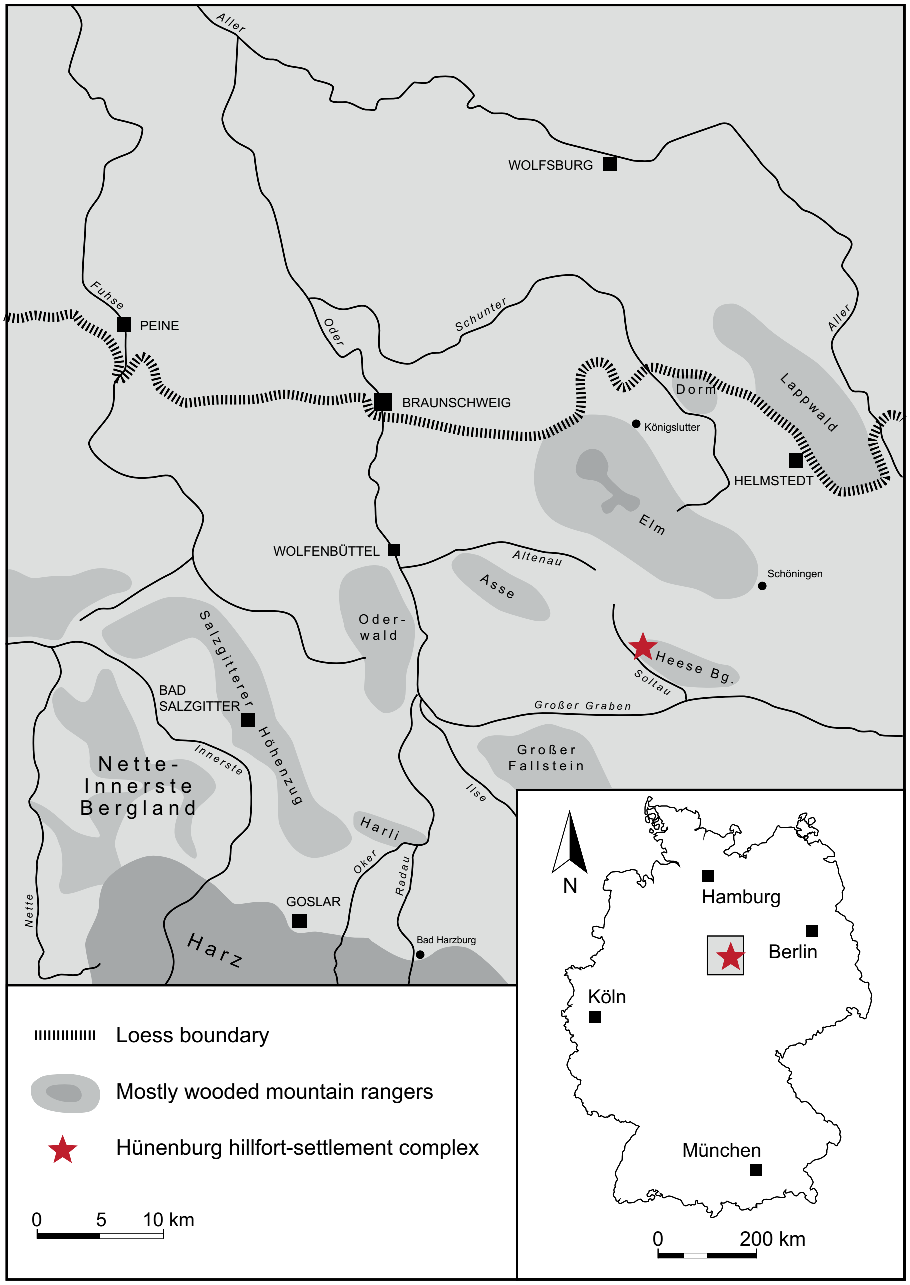

Figure 1. Map showing the northern Harz area with the hill called the Heeseberg (Heese Bg. on the map). The Hünenburg is situated at the western edge of the Heeseberg (after Meibeyer 1997, modified by H. Marx and the authors).

plant remains, including cereal grains, legumes, and associated crop weeds (Heske *et al.* 2010). Beyond that, the cultural layer included evidence of a plurality of similar post houses, pointing to a dense construction of buildings. Further finds are indicative of metal workers and ritual depositions.

Geomagnetic surveys found evidence for an ancient watercourse under the recent agricultural surface (Fig. 2). In the Bronze Age, this stream ran through the upper and lower settlement areas and then flowed into the Soltau. During excavations within the ancient watercourse in the lower part of the outer settlement area, pottery, decorated pieces of wood, and animal bones were found. In addition, some metres east of the stream, hundreds of cooking pits aligned in rows were detected. Some of them were excavated, too. The cooking pits are interpreted as the remains of ritual celebrations (Heske *et al.* 2012).

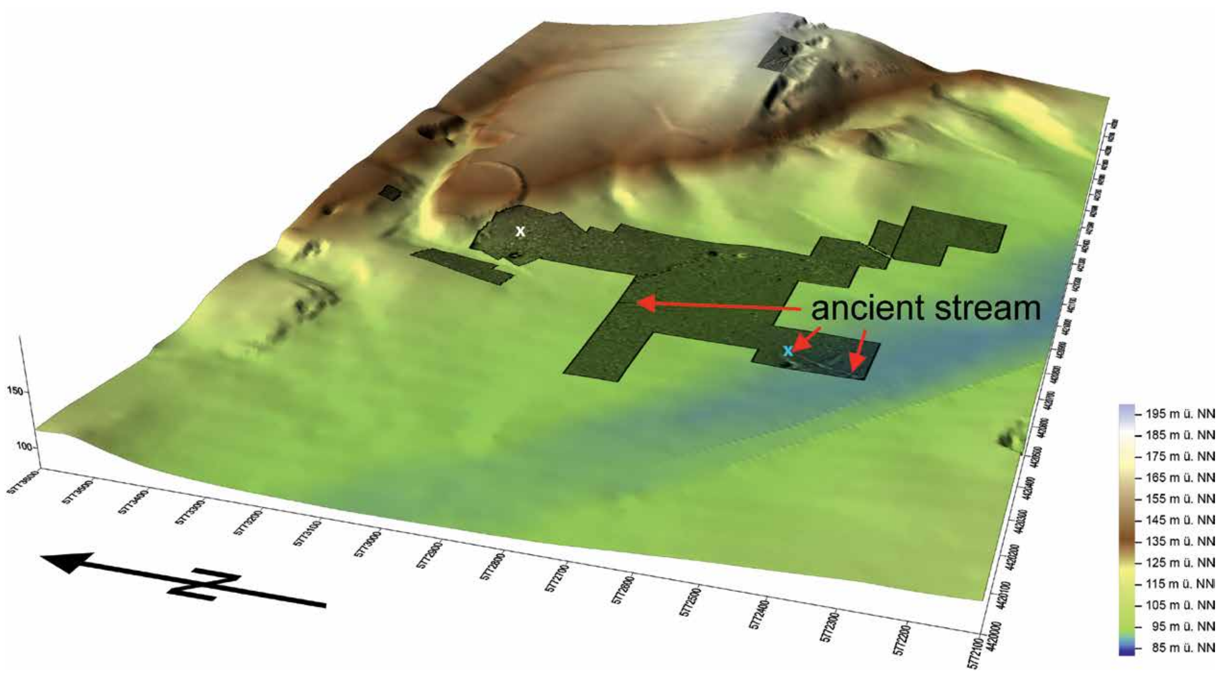

Figure 2. Map showing the western plateau of the Heeseberg and the wet depression of the Soltau. The rampart of the Hünenburg hillfort is still visible today on the western spur. The figure also shows the location of geomagnetic surveys within the outer settlement area. The crosses mark the approximate location of the samples taken for palynological investigations (blue cross: ancient water stream; white cross: pit context) (graphic: M. Posselt and H. Marx, modified by the authors).

The settlement activity at the Hünenburg ended around 650 BCE, in the middle of the Iron Age, once new resources and additional living space were needed. During this time, long-distance communication, connections for the trade in metals, and the exchange of other resources, such as salt and livestock, become less important in the entire region and beyond (Grefen-Peters and Heske 2018; Heske 2018).

Materials and methods

In order to obtain information on the living conditions during the use of the Hünenburg hillfort-settlement complex, microfossil analyses were conducted on the stratigraphies of two archaeological contexts, the ancient river course and two superimposed pits in the occupation layer of the outer settlement area.

Several samples were extracted from two overlapping sediment profiles (WAT I/II) taken from the cross-section of the ancient watercourse (S IV M 646-645 north profile), within the ceremonial area, at intervals of 10 cm (Fig. 3). The profile originated from the gently rising, western part of the stream. The two lowermost samples came from a sediment layer below the stream bed, which contained Late Neolithic pot shards (late 4th–3rd millennium BCE). The next six samples above them in the sequence were obtained from natural infill layers of the stream comprising Late Bronze Age/Early Iron Age pottery fragments (Period IV–VI of the Northern Bronze Age: 1100-550/530 BCE), wood, and bone (Heske *et al.* 2012). Radiocarbon dating of one these bones revealed an age of 1005–889 cal BCE (Heske in preparation). Located just above this bone find was a burial urn dating to the Early Iron Age (Period VI of the Northern Bronze Age: 730/720–550/530 BCE) (Heske 2016b). The next samples were taken from shore zone deposits (two samples) and subsequent natural infillings of the stream (two samples), containing bones dating from the Roman Iron Age (1st–2nd centuries AD). The six uppermost samples came from artificial infilling of medieval and modern date.

Eight sediment samples were taken from occupation layers within the outer settlement area, again at intervals of 10 cm. Apart from the uppermost two samples (30-40 cm), which originated from younger cultural layers, all the others were

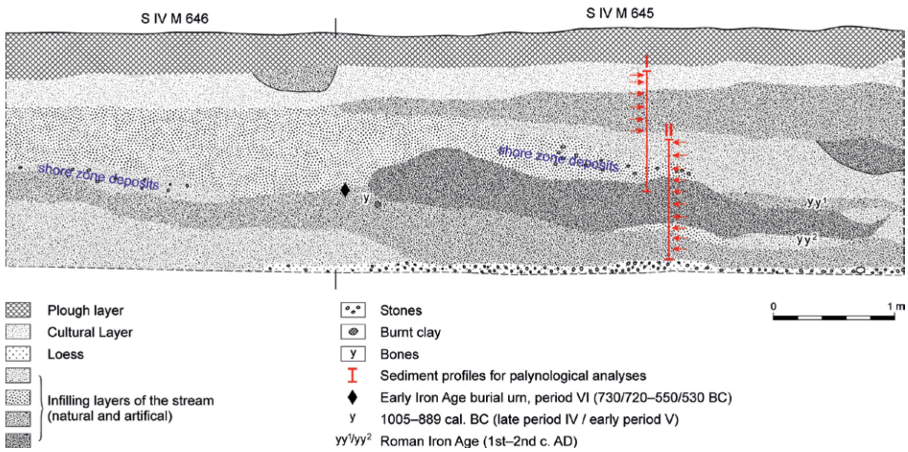

Figure 3. Cross-section through the ancient watercourse with its several layers, showing the location of archaeological finds and the overlapping sediment profile WAT I/II. The red arrows mark the position of palynological samples (graphic: H. Marx, modified by the authors).

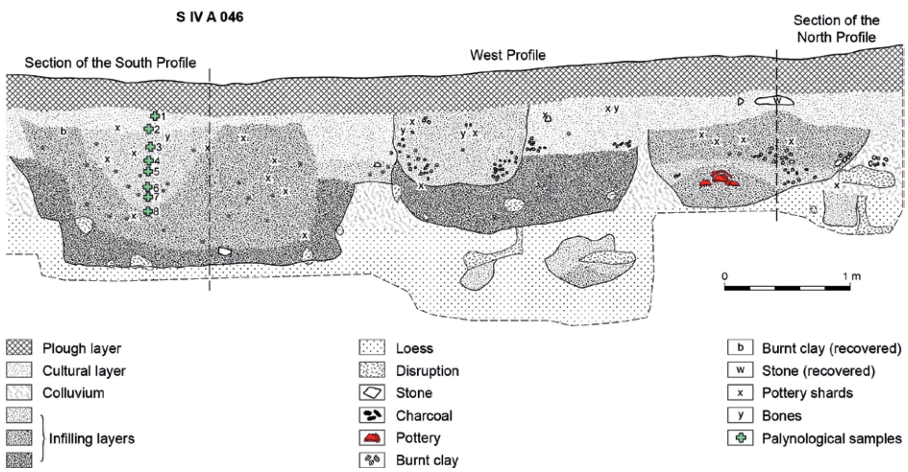

Figure 4. Profile S IV A 046, showing the positions of palynological samples (green pluses) taken from the pit contexts (graphic: H. Marx, modified by the authors).

extracted from two archaeological contexts (profile S IV A 046). Samples 3 to 7 (50-90 cm) were taken from a pit located next to a house. The lowermost sample, 8 (100 cm), originated from a second pit, which was below the first one (Fig. 4).

All samples were prepared for pollen and NPP analysis according to the standard techniques outlined by Moore *et al.* (1991). The calculation of pollen percentages is based on the total terrestrial pollen sum (TTPS: trees, shrubs, and dwarf-shrubs + pollen of herbaceous terrestrial plants). The TTPS averages 600 pollen grains in the samples from the WAT I/II profile and 150 pollen grains in the samples from the pit. The latter are considered very low pollen concentrations. Tablets containing a known number of *Lycopodium* spores were added to enable calculation of pollen and NPP concentrations (following Stockmarr 1971). The data from the microscopic charcoal analysis are expressed as concentration per cm^2 of sediment. The pollen and NPP diagrams were produced with the help of the program C2, version 1.7.7 (Juggins 2014). Nomenclature of pollen types follows Beug (2004) and that of spores follows Moore *et al.* (1991). NPPs were identified using a reference catalogue at Kiel University and available literature (Booth *et al.* 2010; Carrión and Navarro 2002; Florenzano *et al.* 2012; Gelorini *et al.* 2011; Guarro *et al.* 2012; Jones *et al.* 2016; Menozzi *et al.* 2010; Schlütz and Shumilovskikh 2017; van Geel and Aptroot 2006; van Geel *et al.* 1981, 1983, 2003; Vánky 2013). Nomenclature of NPP types follows the HdV-no. system (Miola 2012). The results of the pollen and NPP analysis from the ancient watercourse and the outer settlement area are presented in Figures 5 and 6, respectively. During the microfossil analysis, some not previously recorded NPPs were documented. These types are described in the present paper for the first time and termed using the code KIU-xxx, whereby KIU stands for Kiel University,

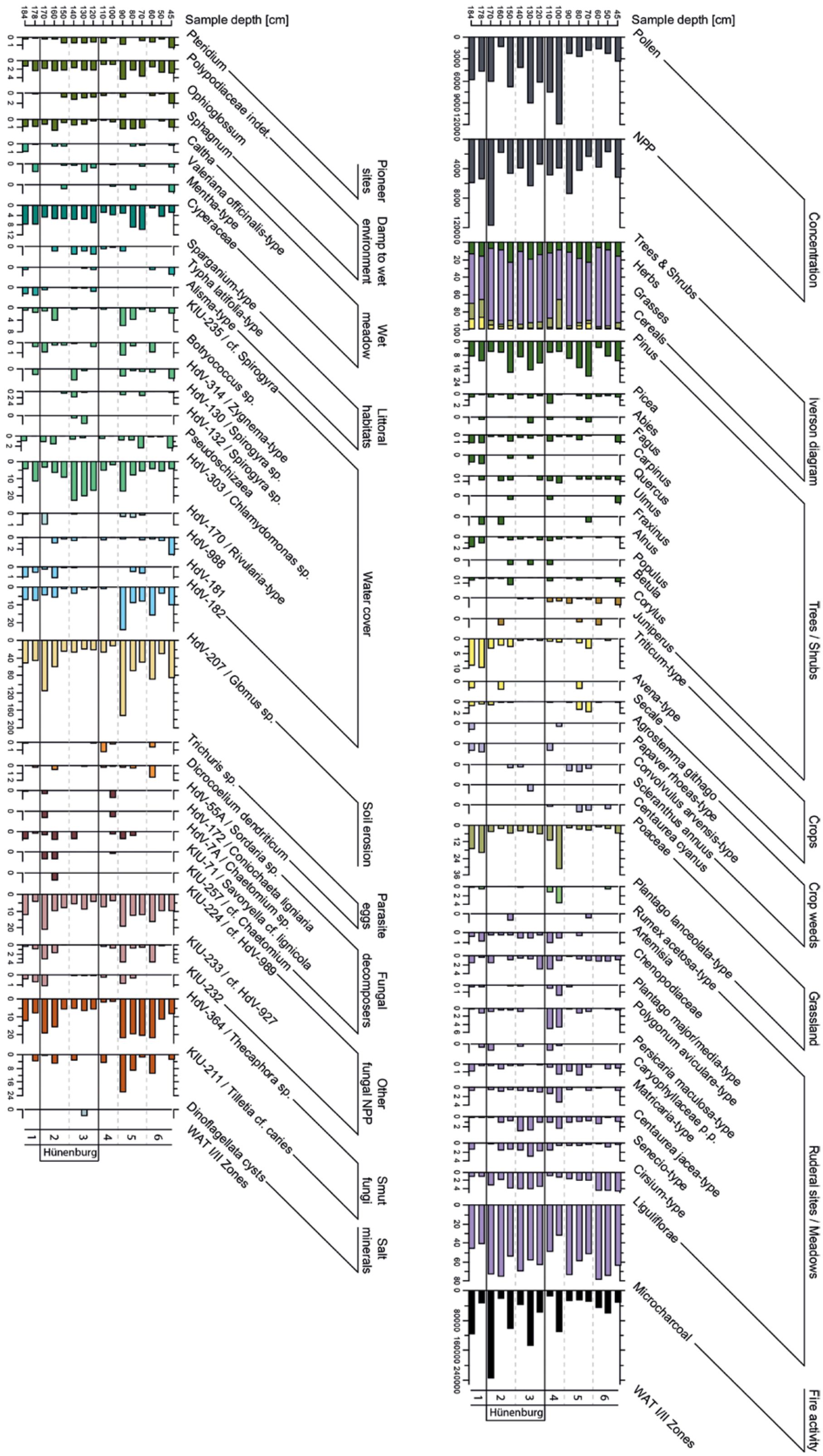

Figure 5. Pollen and non-pollen palynomorphs diagram for the ancient watercourse, showing selected taxa (graphic: M. Wieckowska-Lüth).

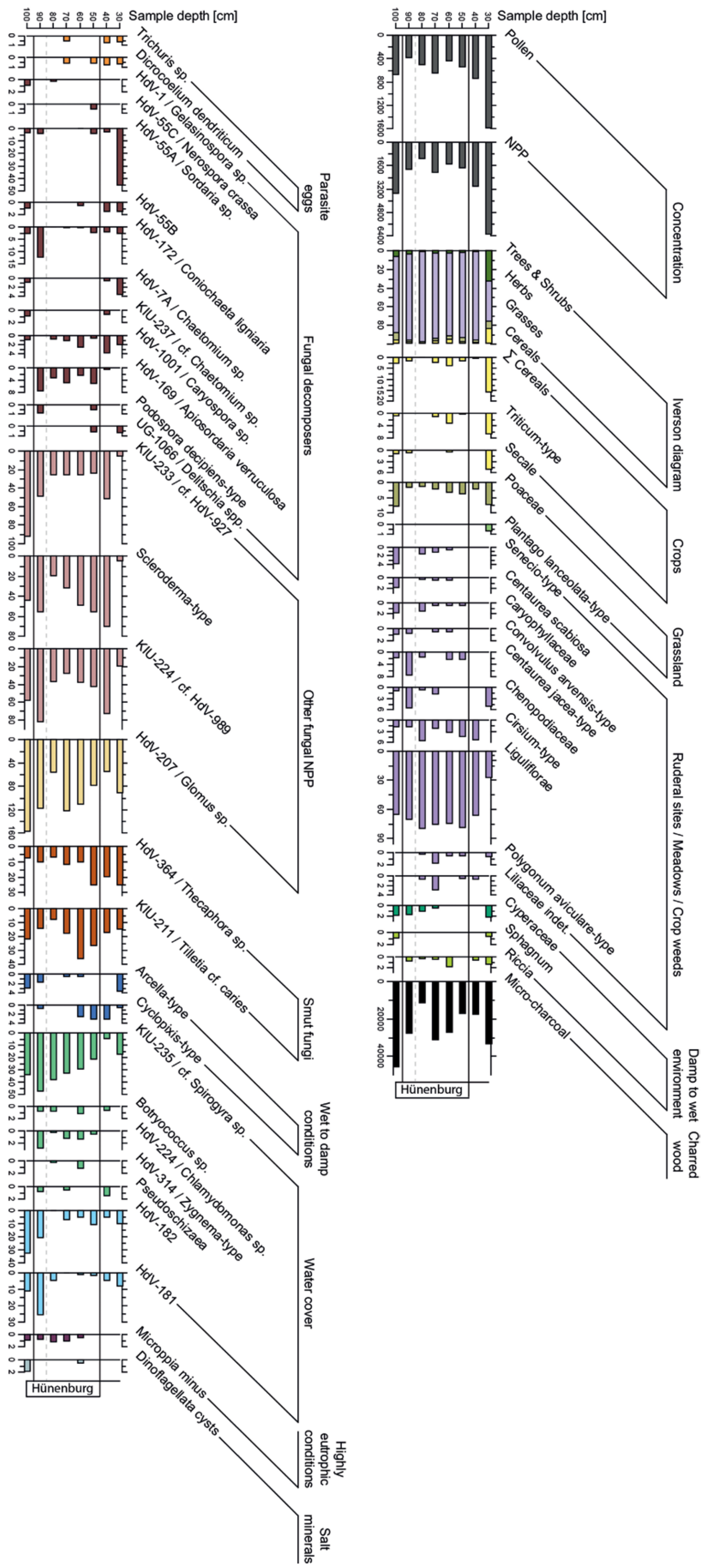

Figure 6. Pollen and non-pollen palynomorphs diagram for the pit contexts within the outer settlement area, showing selected taxa (graphic: M. Wieckowska-Lüth).

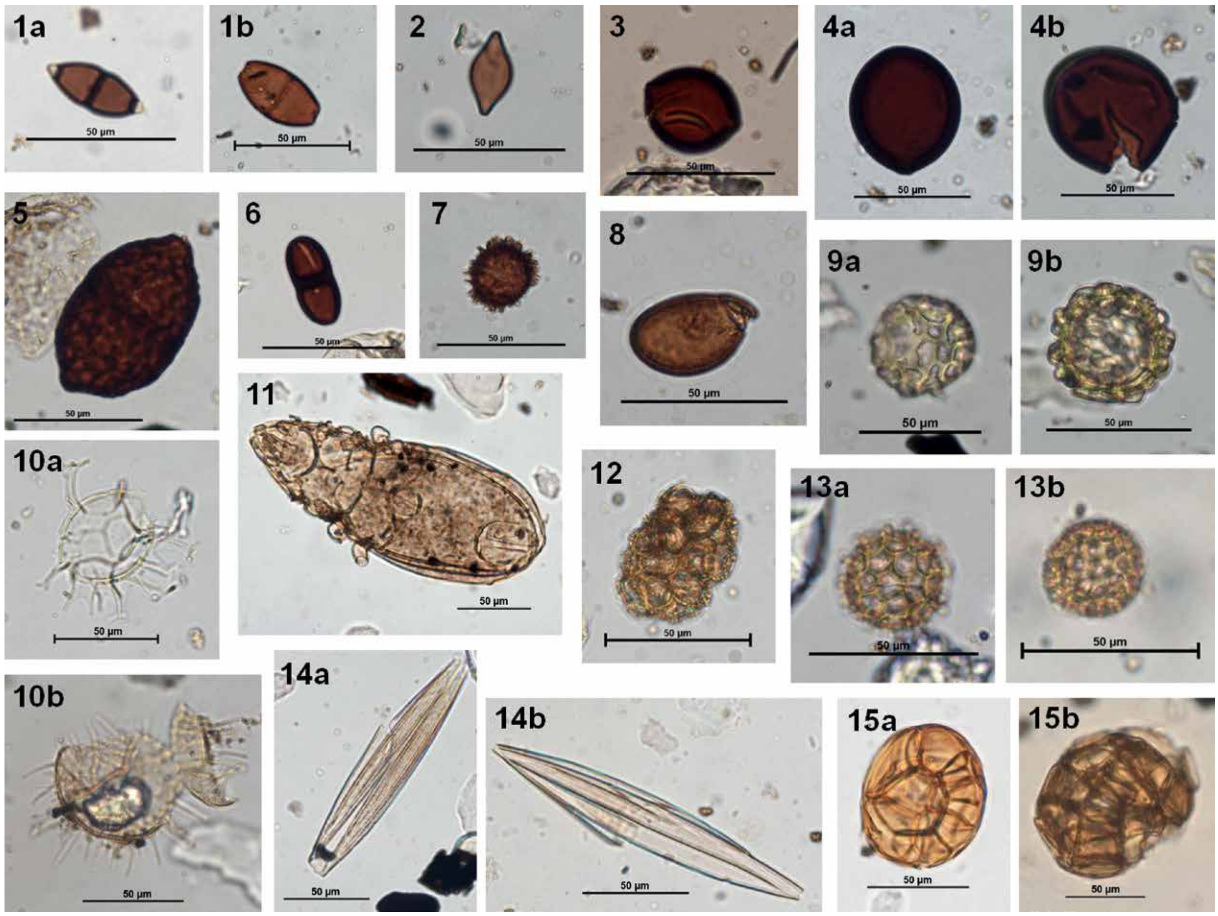

Figure 7. Non-pollen palynomorphs types from settlement layers of the Hünenburg hillfort-settlement complex. (1a,b) KIU-71 (Savoryella cf. lignicola); (2) KIU-237 (cf. Chaetomium); (3) KIU-257 (cf. Chaetomium); (4a,b) KIU-233 (cf. HdV-927); (5) HdV-1001 (Caryospora sp.); (6) HdV-1066 (Delitschia sp.); (7) Scleroderma-type; (8) Dicrocoelium dendriticum; (9) KIU-224 (cf. HdV-989); (10a,b) Dinoflagellate cysts; (11) Microppia minus; (12) HdV-364 (Thecaphora sp.); (13a,b) KIU-211 (Tilletia cf. caries); (14a,b) KIU-235 (cf. Spirogyra); (15) KIU-232 (photos: M. Wieckowska-Lüth).

Germany, and -xxx is a sequential number. The new NPP finds (KIU-71, KIU-211, KIU-224, KIU-232, KIU-233, KIU-235, KIU-237, and KIU-257) are illustrated in Figure 7, together with selected, already known microfossils occurring in the settlement layers of the Hünenburg hillfort-settlement complex.

Results

The deposits of the ancient watercourse

In the profile from the ancient watercourse, six local microfossil assemblage zones (WAT I/II 1-6) were distinguished based on major changes in microfossil proportions (Fig. 5). The pollen ($1.4\text{-}9.2 \times 10^3$ types/cm^3) and NPP ($1.9\text{-}11.8 \times 10^3$ types/cm^3) concentrations are roughly equal, but the diversity of the pollen (22-36 taxa) is higher than that of the NPPs (14-26 taxa).

The lowermost part of the palynological record – WAT I/II 1 – displays the environmental conditions at the Heeseberg during the Late Neolithic period. Since this zone is not relevant to the scope of the paper, this section will not be described in detail here. The same is true for zones WAT I/II 4–6, representing the environmental development from the Roman Iron Age to modern times.

WAT I/II 1 is characterized by maximum values of pollen of deciduous trees (up to 4.8%), among which *Alnus* is the most common taxon, but saccate pollen of conifers (*Pinus* and *Picea*: up to 12%) dominates the microfossil assemblages. Compared with the subsequent zones, WAT I/II 1 is also distinguished by markedly higher proportions of cereals, mainly represented by *Triticum*-type. These finds are accompanied by crop weeds, such as of *Agrostemma githago* and *Papaver rhoeas*-type. At the same time, the Poaceae, as the representatives of grassland, show relatively high proportions amounts (up to 20.4%). Among the ruderal plants, the Liguliflorae are the dominant taxon (up to 46.6%). The values of microcharcoal vary distinctly (3.5-11.8 × 10^3 particles/cm^3). In addition, WAT I/II 1 features slightly elevated values of the elements of wet meadows, as well as of plants of littoral habitats, such as *Catha*, *Valeriana officinalis*-type, Cyperaceae and *Alisma*-type, along with some unknown water-inhabiting NPPs, such as HDV-182 and HdV-182.

The Bronze Age and the early pre-Roman Iron Age settlement layers are reflected in the pollen/NPP diagram by the local microfossil assemblage zones WAT I/II 2-3 (Fig. 5), which are characterized by relatively low amounts of arboreal pollen (16.9-22.7%). Both zones are still dominated by conifers (*Pinus* and *Picea*: up to 19.5%), but deciduous taxa (*Quercus*, *Fagus*, *Carpinus*, and *Betula*: up to 3.3%) and riparian trees (*Ulmus*, *Fraxinus*, *Alnus*, and *Populus*: up to 0.7%) are also present. Shrub pollen reaches minimum values (*Corylus* and *Juniperus*: up to 0.3%). Among the non-arboreal pollen, Liguliflorae show the highest proportions (up to 76.3%). Further elements of meadows and ruderal sites are *Cirsium*-type, *Senecio*-type, *Centaurea jacea*-type, *Matricaria*-type, Caryophyllaceae, *Persicaria maculosa*-type, *Polygonum aviculare*-type, *Plantago major*/*media*-type, Chenopodiaceae, *Artemisia*, and *Rumex acetosa*-type (up to 13.3%). Compared with these taxa, the Poaceae display rather low values (up to 6.7%). Concomitantly, *Plantago lanceolata*-type was recorded only once, in WAT I/II 3, and single finds of the representatives of crop weeds, such as *Convolvulus arvensis*-type and *Scleranthus annua,* also occur in both zones. Regarding cereal pollen grains, of which *Triticum*-type is the predominant taxon, their evidence drops slightly from WAT I/II 2 (up to 4.7%) to WAT I/II 3 (up to 1.2%). Microcharcoal particles display the highest levels in the lowermost part of WAT I/II 2. Their values, however, fluctuate strongly throughout the zones (1.9-11.6 × 10^3 particles/cm^3).

WAT I/II 2 features evidence of fern and moss spores (*Pteridium*, Polypodiaceae indet. *Ophioglossum*, and *Sphagnum*) indicative of the presence of damp to wet sites as well as pioneer habitats, which increase in WAT I/II 3. The same is true for the representatives of both wet meadows and littoral habitats (*Valeriana officinalis*-type, Cyperaceae, *Sparganium*-type, *Typha latifolia*-type, and *Alisma*-type). In parallel, there is a rise of stagnant, shallow water-inhabiting algal taxa from the Zygnemataceae family (van Geel 1976), such as HdV-314 (*Zygnema*-type), HdV-130 (*Spirogyra* sp.), and HdV-132 (*Spirogyra* sp.). In WAT I/II 3, HdV-303 (*Chlamydomonas* sp.) also increases, representing a green alga (*e.g.* Andreev *et al.* 2014; Haas, pers. comm.; Miola *et al.* 2006) that colonizes every kind of aquatic habitat, sometimes forming blooms, especially in extremely nutrient-rich waters. Some members of this genus, however, are also found on soil and terrestrial surfaces, snow, and ice (van Vuuren *et al.* 2006). In contrast, other algal and unknown water-inhabiting palynomorphs, such as *Botryococcus* sp., KIU-235 (cf. *Spirogyra*), HdV-988, HdV-181, HdV-182, and *Pseudoschizaea*, show elevated proportions in WAT I/II 2. According to Grenfell (1995), the latter could belong to the hydro-terrestrial green algae of the Zygnemataceae family. At the same time, finds of cyanobacteria (*Rivularia*-type) were registered, which are known to be dominant in more eutrophic systems (Hutchinson 1957; van Geel 1994).

Additional NPP assemblages of these zones are fungal spores, of which the soil erosion indicator HdV-207 (*Glomus* sp.) (van Geel *et al.* 2003) reaches its highest amounts in WAT I/II 2, along with KIU-224, KIU-233, and KIU-238. The presence of decomposing fungi, such as HdV-55A (*Sordaria*-type), HdV-172 (*Coniochaeta ligniaria*), HdV-7A (*Chaetomium* sp.), KIU-257 (cf. *Chaetomium*), and KIU-71 (*Savoryella* cf. *lignicola*), is also mostly restricted to this zone. What stands out is that these are lignicolous fungi, found on different woody substrates (van Geel and Aptroot 2006). Of particular importance is that *Savoryella* species have been reported from submerged wood in aquatic habitats (Jones *et al.* 2016). Other representatives of NPPs are smut fungi, such as HdV-364 (*Thecaphora* sp.) and KIU-211 (*Tilletia* cf. *caries*), representing plant pathogens (Vánky 2013). Both types, like the other fungal spores, display elevated abundance in WAT I/II 2. Beside this, WAT I/II 2–3 are characterized by the occurrence of eggs of the parasite fluke *Dicrocoelium dendriticum*, of which ruminants are the main definitive hosts (Florenzano *et al.* 2012). In addition, a find of an eggshell of *Trichuris* sp. was made in WKS I/II; this is an intestinal parasite with a significant number of species affecting humans and many other animals (Maicher *et al.* 2017). In WAT I/II 3, there was also a single occurrence of a dinoflagellate cyst, which has been identified as marine (Marret-Davies, pers. comm.).

In the deposits of the Roman Iron Age, reflected by WAT I/II 4, there is a distinct change within the microfossil assemblages. The pollen spectra now show a distinct increase in Poaceae (up to 32.3%), together with *Plantago lanceolata*-type (up to 3.8%). In addition, elements of ruderal sites, which had up till now played a minor role, such as *Plantago major/media*-type and *Polygonum aviculare*-type, gain in importance, whereas Liguliflorae and *Cirsium*-type decrease temporarily. The proportions of microscopic charcoal particles continue to fluctuate strongly.

WAT I/II 4 is also characterized by a reduction in the representatives of a damp to wet environment, wet meadows, and littoral habitats. In accordance with this, the green algae almost disappear. In contrast, some fungal decomposers occur in this section of the microfossil diagram, such as HdV-55A (*Sordaria* sp.), HdV-172 (*Coniochaeta ligniaria*), HdV-7A (*Chaetomium* sp.), and KIU-71 (*Savoryella* cf. *lignicola*). At the same time, elevated finds of *Trichuris* sp. were registered, along with *Dicrocoelium dendriticum*. In general, however, the quantities of the NPPs are at a rather low level compared with the previous zones. In the two upper zones, WAT I/II 5–6, the amounts of Poaceae, *Plantago lanceolata*-type, *Plantago major/media*-type, and *Polygonum aviculare* decrease again markedly, whereas the values of Liguliflorae increase. Synchronously, the proportions of cereals rise slightly (up to 6%), as do those of crop weeds, such as *Centaurea cyanus* and *Convolvulus arvensis*-type. In WAT I/II 5–6, the quantities of microcharcoal particles decline (2.9-6.1 × 10^3 particles/cm^3) and do not show as strong a fluctuation as they do in the lower parts of the profile.

Within the lowland record, there is a renewed increase in the elements of a damp to wet environment, especially in WAT I/II 5. At the same time, the values of Cyperaceae rise, along with those of the representatives of green algae (KIU-235 (cf. *Spirogyra*), *Botryococcus*, HdV-314 (*Zygnem*a-type), HdV-130 (*Spirogyra* sp.), and HdV-303 (*Chlamydomonas* sp.)) and other aquatic organisms (HdV-170 (*Rivularia*-type), *Pseudoschizaea*, HdV-181, and HdV-182). This increase is accompanied by a distinct increase in the amounts of both the soil erosion indicator HdV-207 (*Glomus* sp.) and smut fungi, such as HdV-364 (*Thecaphora* sp.) and KIU-211 (*Tilletia* cf. *caries*). Other fungal NPPs (KIU-224, KIU-233, and KIU-232) also increase visibly, in particular in WAT I/II 5.

The pits

The archaeological layers of the pit contexts are reflected in the pollen and NPP spectra of the samples taken at 50–100 cm (Fig. 6). The palynological results show that the pit record includes a high quantity (1.1-3.5 × 10^3 types/cm^3) of different NPP types (26-30 taxa), distinctly exceeding the amount (0.4-0.7 × 10^3 grains/cm^3) and diversity of pollen (13-18 taxa). Many of these microfossils are of unknown origin.

If we consider the pollen record from the pits as it stands, we can see that all of the samples are characterized by extremely high values of non-arboreal pollen, of which herbs of relatively dry ruderal sites and crop weeds, such as Liguliflorae, *Cir-*

sium-type, *Centaurea scabiosa*, *Senecio*-type, *Centaurea jacea*-type, Caryphyllaceae p.p., Chenopodiaceae, *Convolvulus arvensis*-type, *Polygonum aviculare*-type, and Liliaceae indet. have the highest proportions (up to 97.8%). The amounts of Poaceae reach their highest levels (8.2%) in the lowermost sample. All samples contain finds of cereals, of which *Triticum*-type is the most common (up to 3.5%). Beside this, low palynological signals of the representatives of damp to wet locations, such as *Riccia* (2.1%), *Sphagnum* (up to 1%), and Cyperaceae (up to 2.1%), were recorded. The deposits of the pits are also distinguished by high quantities of microcharcoal, whereby the maximum concentration was noted in the lowermost sample (46×10^3 particles/cm^3).

With respect to the NPP record, all samples are characterized by a high proportion of fungal spores (up to 248.2%), followed by algal palynomorphs (up to 53.2%). The lowermost sample (100 cm) shows an elevated presence of spores from soil fungi, decomposing dead plant remains, and wood, such as HdV-1 (*Gelasinospora* sp.), HdV-55A (*Sordaria* sp.), HdV-55B, HdV-172 (*Coniochaeta ligniaria*), HdV-1001 (*Caryospora* sp.), HdV-7A (*Chaetomium* sp.), and KIU-237 (cf. *Chaetomium*) (Guarro *et al.* 2012; van Geel and Aptroot 2006). Other fungal taxa, such as KIU-233 and *Scleroderma*-type, occur within this horizon in extremely high amounts. As for the latter, the members of the *Scleroderma* genus are ectomycorrhizic with several trees or shrubs and are found in sandy soils, in humus, in grasslands, and sometimes on rotten wood (Guzmán *et al.* 2013). Further fungal spores, such as KIU-224 and HdV-207 (*Glomus* sp.) – the latter of which colonizes roots of different plants (van Geel *et al.* 2003) – were present in great quantities, too. Furthermore, smut fungi, such as HdV-364 (*Thecaphora* sp.) and KIU-211 (*Tilletia* cf. *caries*), were also recorded. While *Thecaphora* species affect several herbs, *Tilletia caries* parasitises on grasses and cereals, such as *Triticum* and *Secale* (Vánky 2013). The lowermost sample also contains high quantities of KIU-235, which is probably a zygospore from the green algae genus *Spirogyra*. Finds of testate amoebae (*Arcella*-type), which appear, among other places, in moist soils and wetlands (Booth 2002; Lamentowicz and Michell 2005), were also noted, along with elevated quantities of shallow water indicators, such as HdV-181 and HdV-182 (van Geel *et al.* 1983). *Microppia minus*, which is a representative of mites that inhabit highly eutrophic milieus (Schatz, pers. comm.), makes its first appearance. The oldest horizon of the pit was also characterized by the occurrence of two types of dinoflagellate cysts (Fig. 7), which have been identified as marine (Marret-Davies, pers. comm).

In the next sample in the sequence (90 cm), the quantities of some fungal decomposers (*Sordaria* sp., *Coniochaeta ligniaria*) rise temporarily, and new types, such as HdV-169 (*Apiosordaria verruculosa*) and *Podospora decipiens*-type, occur, whereas others are no longer recorded. The saprobionts *Apiosordaria verruculosa* and *Podospora decipiens*-type are coprophilous; *Podospora decipiens* is an obligate dung inhabitant that is prevalent on cattle and horse droppings (Lundqvist 1972; Schlütz and Shumilovskikh 2017). Other representatives of fungi, such as *Scleroderma*-type and KIU-224, also increase in this horizon of the pit, along with some water-inhabiting organisms, such as KIU-235 (cf. *Spirogyra*) and HdV-181, whereas the values of KIU-233 drop visibly. Beside this, other hydro-terrestrial palynomorphs were recorded from this sample onwards, such as the green algae *Botryococcus*, HdV-224 (*Chlamydomonas* sp.), HdV-314 (*Zygnema*-type), and *Pseudoschizaea.* The latter NPP is also linked to seasonal drying (Carrión and Navarro 2002; Scott 1992).The subsequent samples (50–80 cm) initially show a decrease in decomposers and other fungal NPPs, before most of them increase again in the uppermost horizons of the pit, such as HdV-55A (*Sordaria* sp.), HdV-172 (*Coniochaeta ligniaria*), *Podospora decipiens*-type, *Scleroderma*-type, KIU-224, HdV-364 (*Thecaphora* sp.), and KIU-211 (*Tilletia* cf. *caries*). In addition, new taxa of decaying plant material-inhabiting fungi, such as HdV-55C (*Neurospora crassa*) (Guarro *et al.*

2012) and UG-1066 (*Delitschia* spp.), were documented in the uppermost sample. As for the latter, many *Delitschia* species are mostly coprophilous, occurring on various kinds of dung (Gelorini *et al.* 2011). The proportions of HdV-1001 (*Caryospora* sp.) and HdV-169 (*Apiosordaria verruculosa*), on the other hand, remain approximately the same as before. Furthermore, the samples included scattered finds of eggshells of parasitic worms, such as *Trichuris* sp. and *Dicrocoelium dendriticum*. A single dinoflagellate cyst of marine origin was also recorded in these samples. Beside this, there is a distinct reduction in some water cover indicators, such as HdV-181 and HdV-182, whereas the representatives of testate amoeba (*Cyclopixis*-type) increase in the youngest horizons of the pit.

The uppermost two samples (40–30 cm) represent horizons that post-date the settlement phase of the Hünenburg. Their NPP and pollen spectra are briefly characterized here in order to provide a complete overview of the sequence investigated. Both samples still show relatively high amounts of both the smut fungi (HdV-364 (*Thecaphora* sp.) and KIU-211 (*Tilletia* cf. *caries*)) and the erosion indicator HdV-207 (*Glomus* sp.). Furthermore, the NPP spectra of the lower sample (40 cm) show a rise in the amounts of fungal spores, such as KIU-233 (cf. HdV-927), *Scleroderma*-type, and KIU-224 (cf. HdV-989), while in the sample directly above it their values significantly decrease. Beside this, the number of finds of different fungal decomposers, such as HdV-55A (*Sordaria* sp.), HdV-55B, HdV-172 (*Coniochaeta ligniaria*), HdV-7A (*Chaetomium* sp.), KIU-237 (cf. *Chaetomium*), HdV-1001 (*Caryospora* sp.), HdV-169 (*Apiosordaria verruculosa*), and UG-1066 (*Delitschia* spp.), increases in the uppermost layers, with the topmost sample exhibiting the highest proportions (up to 54.6%). Both samples show the presence of eggshells of parasitic worms, such as *Trichuris* sp. and *Dicrocoelium dendriticum*. In addition, the abundance of hydro-terrestrial palynomorphs, in particular HdV-235 (cf. *Spirogyra*), decreases compared with the lower layers of the pit.

Regarding the pollen record, there is a marked rise in the values of arboreal pollen (up to 33.1%), together with those of cereals (in particular *Triticum*-type and *Secale*) (up to 16.2%), in the uppermost sample. At the same time, increased proportions of the Poaceae were recorded (up to 7.7%), along with the first finds of *Plantago lanceolata*-type. Synchronously, the values of Liguliflorae decline visibly, together with those of *Cirsium*-type.

Discussion

The local environment

The pollen record from the stream profile indicates that the surrounding forest had already been strongly opened and that cereal fields dominated the local landscape during the Late Neolithic settlement of the Heeseberg. In addition, the simultaneous relatively high proportions of grasses suggest woodland destruction by browsing cattle. Due to the open vegetation structure, the saccate pollen of pine (*Pinus*) and spruce (*Picea*), which can be subject to long-distance transport, in this case probably from the Harz Mountains, is overrepresented in the pollen diagram (*e.g.* Heske and Wieckowska 2012). Small stands of riparian forest vegetation were still present along the watercourse.

As shown in the present palynological study, the landscape away from the stream becomes treeless and the patches of riparian forest beside the stream almost disappear during the Late Bronze Age/Early Iron Age. The scarceness of trees in the surroundings of the Hünenburg may be related to local construction activities, metalworking, or even salt production.

There is hardly any evidence of pastures, as suggested by the low values of pastoral indicators, such as *Plantago lanceolata*. And although potentially coprophilous fungal spores (*Sordaria* sp., *Coniochaeta ligniaria*, and *Chaetomium* sp.) are present, in particular in the older deposits of the watercourse, these finds can also be attributed to the presence of other decaying plant material, such as wood. The simultaneous occurrence of the fungus *Savoryella* cf. *lignicola*, causing soft-rot decay of wood when wood is exposed to wet conditions (Jones *et al.* 2016), confirms this assumption. Hence, records of these fungi may possibly be linked to the wood found in the deposits of the stream. These pieces of wood may have washed out from the upper settlement, or they may have got into the stream as part of activities related to the use of the cooking pits. Eggshells of both the lancet liver fluke (*Dicrocoelium dendriticum*) and the whipworm (*Trichuris*) could suggest deposition of human excrement into the water. However, these intestinal parasites may also be associated with the consumption of ruminants or pigs (Heske 2016a). In this scenario, they would have entered the stream with the slaughter waste, probably also in the context of ritual celebrations. Alternatively, these parasites could have entered the stream as part of household waste.

The decreasing evidence of cereal pollen over the duration of the settlement suggests a landscape covered by extensive meadows and may indicate that agricultural activities were becoming less important. It is conceivable that agricultural products were just traded, but it is also possible that the arable fields were situated at a greater distance from the settlement complex. Nonetheless, the high evidence of microcharcoal, along with the erosion indicator *Glomus* sp., especially in the older phases of the settlement, shows that the area around the watercourse had been used intensively. The synchronous high amounts of plant pathogens (in particular *Thecaphora* sp.) and other fungal spores (KIU-224 and KIU-233) may also be related to soil erosion processes.

The rise in plant communities of damp and wet habitats during the younger occupation phase of the Hünenburg hillfort-settlement complex may refer to encroachment of terrestrial vegetation into the stream. This may have been due to progressive nutrient enrichment, as indicated by the occurrence of cyanobacteria (*Rivularia*-type) and the remains of the green alga *Chlamydomonas* sp. Strong eutrophication of the watercourse may have been related, for example, to the intensive use of the adjacent ceremonial area. It is likely that there was an increased disposal of the leftovers from ritual celebrations, which would have had a negative effect on the water quality. Alternatively, it is possible that the stream was about to run dry during that time, as shown by the reduction in several aquatic organisms (*Pseudoschizaea*, HdV-181, and HdV-182). In accordance with this, the increased evidence of green algae that colonize hydro-terrestrial environments (Zygnemataceae) suggests the existence of temporary pools of shallow, stagnant water.

After the demise of the Hünenburg hillfort-settlement complex, a change in land use is visible in the pollen record. During the Roman Iron Age, increased proportions of grasses, along with the grazing indicator *Plantago lanceolata*, suggest that the area of the Heeseberg was used as pasture land. As regards the watercourse, it seems to have dried up at that time. This is suggested by the almost complete disappearance of both hydro-terrestrial and aquatic microfossils.

At some point after the Roman Iron Age, cereal cultivation becomes more important for some centuries, before extensive meadows once more characterise the landscape. High signals of NPPs indicative of erosion may be associated with advanced soil degeneration in the recent past due to more intensive agricultural activities. Contemporaneously, the stream bed appears to have been fed by water again, at least temporarily, as indicated by the presence of different green algae and other aquatic organisms within the microfossil record.

On-site conditions

The changing microfossil spectra in pollen and NPP data from the two superimposed pit contexts indicate different functions of this structure over time. The oldest horizons, for example, are characterized by the presence of decomposing fungal spores, along with maximum quantities of microcharcoal, demonstrating the presence of charred organic material. At the same time, they contain marine dinoflagellate cysts. These cysts probably originate from salt-bearing minerals formed at the Jurassic/Cretaceous transition (Heunisch *et al.* 2007), which were subsequently dissolved in the form of salt springs. Today, the nearest salt spring rises at the western foot of the Heeseberg, between the villages of Watenstedt and Barnstorf (Lachmann 1827). Thus, the evidence of these microremains may be indicative for salt extraction from salt springs. Subsequently, salted food could have been stored in pits. Such supplies could have been kept in containers or baskets made of wood or other plant material that subsequently suffered a fungal attack, which would explain the occurrence of saprobiontic fungi. It should also be mentioned that the dinoflagellates could have their source in marine substrates that entered the pit horizons due to soil erosion and/or rainwater run-off. At the same time, the elevated abundance of pollen of cereals, grasses, and herbs suggests that herbal supplies may also been stored there. It is conceivable that these also suffered from fungal attack. One possible explanation for the high levels of microscopic charcoal particles documented in this horizon of the pit is that the storage pit caught fire, in turn providing an adequate substratum for pyrophilous fungi, such as HdV-1 (*Gelasinospora* sp.) (Lundqvist 1972; van Geel 1978). The simultaneous high proportion of HdV-207 (*Glomus* sp.) and *Scleroderma* may be related to increased soil erosion after such a fire event.

Later on, the pits apparently lost their (presumed) storage function. An indication of this is the presence of obligate coprophile fungal spores (*Podospora decipiens*-type and *Delitschia* sp.) in the layers that follow. This demonstrates that grazing livestock were present in the outer settlement area, and that their droppings were disposed of in the pit. Furthermore, the occurrence of intestinal parasitic eggs indicates that animal and/or human excrement was also disposed of there. Additionally, their occurrence reveals that both the livestock and the inhabitants of the settlement suffered from parasite infestation. The evidence for plant pathogenic fungi (*Thecaphora* sp. and *Tilletia* cf. *caries*) also points to the removal of plant material from the surroundings, which was possibly processed in the vicinity of the pit. The presence of fungal decomposers (*Apiosordaria verucculosa* and *Caryospora* sp.) attests to the existence of plant debris. The simultaneous appearance of pollen of cereals and crop weeds (*Convolvulus arvensis*-type) could indicate the remnants of the harvest. In addition, the presence of testate amoebae, green algae, and other water-inhabiting organisms suggests that the pit content was directly exposed to the elements. No device to cover the pit could be detected archeologically, but since such a pit cover would probably have been made of wood or other organic material, it would be difficult to detect it in archaeological deposits with dry preservation. The presence of a mite, being strongly dependent on nutrients in its life needs, illustrates a highly eutrophic deposition milieu. However, it is also possible that the various microfossils found in the pit ended up in it accidentally. As the study location is on a gently rising hillside, the pit may have trapped any material transported by rainwater running down the slope. Indeed, high proportions of spores of ecto- and endomycorrhizal fungi (*Scleroderma*-type and *Glomus* sp.) may be the result of rainwater run-off and/or soil erosion.

Finally, the uppermost horizon, in particular, reflects a completely different microfossil distribution compared with the lower levels of the pit. The strong presence of fungal decomposers, some of which have a coprophilous affinity (*Sordaria* sp., *Coniochaeta ligniaria, Chaetomium* sp., *Delitschia* spp.), along with the finds of parasitic worms and the increased amounts of Poaceae and *Plantago lanceolata*-type, point to the use of the area as pasture land. It is also conceivable that the NPPs registered indicate the use of manure that was applied to the soil to increase the crop yield. The relatively high quantities of cereal pollen grains show that, at the very least, arable fields were present in the immediate vicinity at that time.

Descriptions and interpretation of new NPP types from the Hünenburg hillfort-settlement complex

KIU-71: Ascospores three-septate, elliptic, constricted at the septa, psilate, middle cells brown, end cells pale white to hyaline and often totally destroyed, 45 × 21.4-36 × 16.5 µm. This type is similar to HdV-121 (Pals *et al.* 1980), EMA-108 (Prager *et al.* 2012), and UAB-35 (Revelles *et al.* 2016). KIU-71 was identified as *Savoryella* cf. *lignicola* (Jones *et al.* 2016).

KIU-211: Spores globose to subglobose, single-celled, yellow-green to reddish brown, coarse reticulate wall, 29.6-34.7 µm in diameter. KIU-211 was identified as *Tilletia* cf. *caries* (Vánky 2013).

KIU-224: Probably a fungal spore, single-celled, globose to subglobose, thick verrucose wall, yellowish green, 43-46 µm in diameter. This type is similar to HdV-989 (Carrión and van Geel 1999). KIU-224 occurs continuously in both records, along with the highest values of other fungal spores, but has much higher proportions in the deposits of the pits. This type may be indicative of soil erosion.

KIU-232: Probably a fungal spore ball, globose, ovoid, or irregular, composed of single, elongated to polyhedral cells, yellow to pale brown, 72-105 µm in diameter. This type is restricted to the deposits of the stream, where it occurs together with increased finds of green algae. This type may be related to an aquatic organism or may occur on organisms that colonize waterlogged habitats.

KIU-233: Fungal spore, single-celled, globose to subglobose, with a protruding pore of about 3.4–4.5 µm, often split, smooth, dark brown, 52-78 µm in diameter. KIU-233 is similar to HdV-927 (Garneau 1993). This type was documented from both sampling sites; however, it showed significantly higher amounts within the pit records. Its strongest evidence co-occurred with the highest values of *Glomus* sp. During our own observations on recent material, a similar type was recorded on charred wood.

HdV-235: Probably an algal zygospore (cf. *Spirogyra*), oblong with tapering ends, with longitudinal ribs, hyaline to slightly brownish, smooth or covered with fine granules, 140-200 µm in length. This type is similar to HdV-956 (Garneau 1993). KIU-235 was recorded at both sampling sites, but again in considerably higher quantities within the pit records. This type may be indicative of shallow water cover and highly eutrophic conditions.

KIU-237: Fungal ascospore, single-celled, fusiform, with two apical pores, smooth, light brown, 26-28 × 10-14 µm. This type is restricted to the pit samples, where it occurs together with fungi related to decomposition. KIU-237 may comprise some *Chaetomium* species (Guarro *et al.* 2012).

KIU-257: Fungal ascospore, single-celled, lemon-shaped, brown to dark brown, with two apical pores, 34.4-36.2 × 27.2-28.7 µm. This type is similar to UAB-4 (Revelles *et al.* 2016). KIU-257 is restricted to the deposits of the stream, where it was documented together with HdV-7A (*Chaetomium* sp.) and *Savoryella* cf. *lignicola*. KIU-257 may represent a fungal decomposer, probably a member of the genus *Chaetomium*.

Conclusions

Both the deposits from the ancient watercourse and those from the pit contexts include pollen and different known and unknown NPPs, providing important information on how settlement areas and former structures within the Hünenburg hillfort-settlement complex were used in the past. Their study also shows that the two archaeological contexts differ strongly in terms of pollen preservation, it being quite poor within the pit fill. The preservation of NPPs was, in contrast, extremely good in both archaeological settings. This illustrates, on the one hand, the significant value of NPPs and, on the other hand, the necessity of combining pollen and NPP data in archaeological contexts.

The NPP evidence shows that the pit may have been initially used as a storage pit, before it lost that function during the succeeding occupation phases. In the younger horizons, the occurrence of coprophilous fungi, along with eggshells of parasitic worms, points to the presence of herbivores within the outer settlement area and on-site removal of dung and/or animal and human excrement. In parallel, high amounts of both smut fungi and plant debris indicators, along with the presence of cereal pollen grains, suggest on-site processing of crops.

In terms of water quality, there is some evidence that this must have been quite poor, at least within the ceremonial area. The existence of both parasite eggs and wood-decomposing fungi in the deposits of the stream may be indicative of the disposal of habitation debris and/or leftovers from ritual celebrations into the water. At the same time, the appearance of cyanobacteria suggests progressive eutrophication, while huge proportions of microcharcoal demonstrate extensive fire activities, which may be related to the use of the cooking pits within the ceremonial area.

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References

Andreev, A.A., Tarasov, P.E., Wennrich, V., Raschke, E., Herzschuh, U., Nowaczyk, N.R., Brigham-Grette, J. and Melles, M. 2014. Late Pliocene and Early Pleistocene vegetation history of northeastern Russian Arctic inferred from the Lake El'gygytgyn pollen record. *Climate of the Past* 10, 1017-1039.

Beug, H.-J. 2004. *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete*. München: Pfeil.

Blackford, J.J., Innes, J.B., Hatton, J.J. and Caseldine, C.J. 2006. Mid-Holocene environmental change at Black Ridge Brook, Dartmoor, SW England: a new appraisal based on fungal spore analysis. *Palaeobotany and Palynology* 141, 189-201.

Booth, R.K. 2002. Testate amoebae as paleoindicators of surface-moisture changes on Michigan peatlands: modern ecology and hydrological calibration. *Journal of Paleolimnology* 28, 329-348.

Booth, R.K., Lamentowicz, M. and Charman, D.J. 2010. Preparation and analysis of testate amoebae in peatland paleoenvironmental studies: article 2. *Mires and Peat* 7, 1-7.

Bosi, G., Bandini Mazzanti, M., Florenzano, A., Massamba N'siala, I., Pederzoli, A., Rinaldi, R., Torri, P. and Mercuri, A.M. 2011. Seeds/fruits, pollen and parasite remains as evidence of site function: piazza Garibaldi – Parma (N Italy) in Roman and Mediaeval times. *Journal of Archaeological Science* 38, 1621-1633.

Brinkkemper, O. and van Haaster, H. 2012. Eggs of intestinal parasites whipworm (*Trichuris*) and mawworm (*Ascaris*): non-pollen palynomorphs in archaeological samples. *Review of Palaeobotany and Palynology* 186, 16-21.

Carrión, J.S. and van Geel, B. 1999. Fine-resolution Upper Weichselian and Holocene palynological record from Navarrés (Valencia, Spain) and a discussion about factors of Mediterranean forest succession. *Review of Palaeobotany and Palynology* 106, 209-236.

Carrión, J.S. and Navarro, C. 2002. Cryptogam spores and other non-pollen microfossils as sources of palaeoecological information: case-studies from Spain. *Annales Botanici Fennici* 39, 1-14.

Chichinadze, M. and Kvavadze, E. 2013. Pollen and non-pollen palynomorphs in organic residue from the hoard of ancient Vani (western Georgia). *Journal of Archaeological Science* 40/5, 2237-2253.

Dietre, B., Gauthier, É. and Gillet, F. 2012. Modern pollen rain and fungal spore assemblages from pasture woodlands around Lake Saint-Point (France). *Review of Palaeobotany and Palynology* 186, 69-89.

Florenzano, A., Mercuri, A.M., Pederzoli, A., Torri, P., Bosi, G., Olmi, L., Rinaldi, R. and Bandini Mazzanti, M. 2012. The significance of intestinal parasite remains in pollen samples from Medieval pits in the Piazza Garibaldi of Parma, Emilia Romagna, Northern Italy. *Geoarchaeology* 27, 34-47.

Garneau, M. 1993. *Reconstitution paléoécologique d'une tourbière en position littorale sur la rive sud de l'estuaire du Saint-Laurent, Isle-Verte, Québec, Canada*. PhD dissertation, University of Amsterdam.

Gelorini, V., Verbeken, A., van Geel, B., Cocquyt, C. and Verschuren, D. 2011. Modern non-pollen palynomorphs from East African lake sediments. *Review of Palaeobotany and Palynology* 164, 143-173.

Grefen-Peters, S. and Heske, I. 2018. Der bronzezeitliche Bauernhof ist komplett (inkl. Hütehund)! – Tierdeponierungen, Tierskelette und Tierbestattungen aus der Hünenburg-Unterstadt. *Archäologie in Niedersachsen* 21, in press.

Grenfell, H.R. 1995. Probable fossil zygnematacean algal spore genera. *Review of Palaeobotany and Palynology* 84, 201-220.

Guarro, J., Gené, J., Stchigel, A.M. and Figueras, M.J. 2012. *Atlas of soil Ascomycetes*. Utrecht: CBS-KNAW Fungal Biodiversity Centre.

Guzmán, G., Cortés-Pérez, A., Guzmán-Dávalos, L., Ramírez-Guillén, F. and del Refugio Sánchez-Jácome, M. 2013. An emendation of *Scleroderma*, new records, and review of the known species in Mexico/ Una emendación de *Scleroderma*, nuevos registros y revisión de las especies conocidas en México. *Revista Mexicana de Biodiversidad* 84/Supplement, 173-191.

Haas, J.N. and Wahlmüller, N. 2010. Floren-, Vegetations- und Milieuveränderungen im Zuge der bronzezeitlichen Besiedlung von Bruszczewo (Polen) und der landwirtschaftlichen Nutzung der umliegenden Gebiete, in: Müller, J., Czebreszuk, J. and Kneisel, J. (eds.). *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens*. Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt, 50-81.

Heske, I. 2003. Die Hünenburg bei Watenstedt, Ldkr. Helmstedt (Niedersachsen): Vorbericht über die Prospektionsgrabungen der Jahre 1998-2000. *Nachrichten aus Niedersachsens Urgeschichte* 73, 15-27.

Heske, I. 2006. *Die Hünenburg bei Watenstedt, Ldkr. Helmstedt: eine ur- und frühgeschichtliche Befestigung und ihr Umfeld*. Göttinger Schriften zur Vor- und Frühgeschichte 29. Neumünster: Wachholtz.

Heske, I. 2013. Waren und Leben: Skizzen zu einer Mobilität zwischen den Landschaften, in: Heske, I., Nüsse, H.-J. and Schneeweiss, J. (eds.). *Landschaft, Besiedlung und Siedlung: archäologische Studien im nordeuropäischen Kontext*: *Festschrift K.-H. Willroth*. Göttinger Schriften zur Vor- und Frühgeschichte 33. Neumünster and Hamburg: Wachholtz, 33-44.

Heske, I. 2015. Nordic by nature? Ideas about some inhabitants of the 'Hünenburg' hillfort near the Harz mountains in Periods V and VI, in: Suchowska-Ducke, P. Scott Reiter, S. and Vandkilde, H. (eds). *Forging identities: the mobility of culture in Bronze Age Europe*: *Vol. 1.* British Archaeological Reports International Series 2772. Oxford: Archaeopress, 65-72.

Heske, I. 2016a. *Die Hünenburg-Außensiedlung bei Watenstedt, Ldkr. Helmstedt: Funde und Befunde der Ausgrabungen 2005 bis 2010: mit Beiträgen von Silke Grefen-Peters zur osteologischen Auswertung des Fundmaterials*. Göttinger Schriften zur Vor- und Frühgeschichte 34. Neumünster and Hamburg: Wachholtz.

Heske, I. 2016b. Zwischen Feuer und Wasser: Schmuckensembles als Hinweis auf 'fremde Frauen' in der Frühen Eisenzeit. *Archäologie in Niedersachsen* 19, 50-54.

Heske, I. 2017. The rise of a chieftain: the initial phase of the Hünenburg-hillfort near Watenstedt in Lower-Saxony (Germany), in: *Fortifications: the rise and fall of defended sites in Late Bronze and Early Iron Age of south-east Europe*. International Conference 11-13th November 2015, Timisoara (RO). Berliner Beiträge zur Vor- und Frühgeschichte 21. Berlin : Staatliche Museen zu Berlin,15-32.

Heske, I. 2018. Das bronzezeitliche Herrschaftszentrum der Hünenburg in Watenstedt (Niedersachsen) zwischen regionaler Entwicklung und europäischer Einbindung, in: Hansen, S. and Schopper, F. (eds.). *Der Grabhügel von Seddin im norddeutschen und südskandinavischen Kontext. Internationale Konferenz 2014 in Brandenburg.* Brandenburgisches Landesamt für Denkmalpflege und Archäologisches Landesmuseum. Arbeitsberichte zur Bodendenkmalpflege im Land Brandenburg 33, 127-138.

Heske, I. and Wieckowska, M. 2012. The Bronze Age settlement chamber on the hill Heeseberg, Lower Saxony – An ecoregion in transition between the Únětice and the House-Urn Culture, in: Kneisel, J., Kirleis, W., Dal Corso, M., Taylor, N. and Tiedtke, V. (eds.). *Collapse or continuity? Environment and development of Bronze Age human landscapes.* Proceedings of the International Workshop Socio-Environmental Dynamics over the Last 12,000 Years: The Creation of Landscapes II (14th-18th March 2011) in Kiel, vol. 1. Bonn: Habelt, 133-142.

Heske, I., Grefen-Peters, S., Posselt, M. and Withold, J.2010. Die jungbronzezeitliche Außensiedlung der 'Hünenburg' bei Watenstedt, Lkr. Helmstedt: Vorbericht über die Ausgrabungen 2005−2007. *Prähistorische Zeitschrift* 85, 159-190.

Heske, I., Lüth, P. and Posselt, M. 2012. Deponierungen, Gargruben und ein verfüllter Wasserlauf: zur Infrastruktur der Hünenburg-Außensiedlung bei Watenstedt, Lkr. Helmstedt: Vorbericht über die Grabung 2011. *Prähistorische Zeitschrift* 87, 308-337.

Heunisch, C., Caspers, G., Elbracht, J., Langer, A., Röhling, H.-G., Schwarz, C. and Streif, H.J. 2007. Erdgeschichte von Niedersachsen – Geologie und Landschaftsentwicklung. *GeoBerichte* 6, 3-85.

Hillbrand, M., van Geel, B., Hasenfratz, A., Hadorn, P. and Haas J.N. 2014. Non-pollen palynomorphs show human- and livestock-induced eutrophication of Lake Nussbaumersee (Thurgau, Switzerland) since Neolithic times (3840 bc). *The Holocene* 24/5, 559-568.

Hutchinson, G.E. 1957. *A treatise on limnology: volume 1: geography, physics and chemistry*. New York: Wiley.

Innes, J.B., Blackford, J.J. and Simmons, I.G. 2004. Testing the integrity of fine spatial resolution palaeoecological records: microcharcoal data from near-duplicate peat profiles from the North York Moors, UK. *Palaeogeography, Palaeoclimatology, Palaeoecology* 214, 295-307.

Jones, E.B.G., To-anun, C., Suetrong, S. and Boonyuen, N. 2016. Mycosphere essays 12: progress in the classification of the water-cooling tower ascomycete *Savoryella* and a tribute to John Savory: a review. *Mycosphere* 7/ 5, 570-581.

Juggins, S. 2014. *C2 user guide: software for ecological and palaeoecological data analysis and visualisation.* Newcastle upon Tyne: University of Newcastle.

Kvavadze, E. and Kakhiani, K. 2010. Palynology of the Paravani burial mound (Early Bronze Age, Georgia). *Vegetation History and Archaeobotany* 19, 469-478.

Lachmann, H.W.L. 1827. *Flora Brunsvicensis: Aufzählung und Beschreibung der in der Umgegend von Braunschweig wildwachsenden Pflanzen.* Braunschweig: G.C.E. Meyer.

Lamentowicz, M. and Michell, E.A.D. 2005. The ecology of testate amoebae (protists) in *Sphagnum* in north-western Poland in relation to peatland ecology. *Microbial Ecology* 50, 48-63.

Le Bailly, M., Leuzinger, U., Schlichtherle, H. and Bouchet, F. 2007. 'Crise économique' au Néolithique á la transition Pfÿn-Horgen (3400 BC): contribution de la paléoparasitologie. *Anthropozoologica* 42, 175-185.

Lundqvist, N. 1972. Nordic Sordariaceae s. lat. *Symbolae Botanicae Upsalienses* 20, 1-374.

Maicher, C., Hoffmann, A., Côté, N.M.L., Palomo Pérez, A., Saña Segui, M. and Le Bailly, M. 2017. Paleoparasitological investigations on the Neolithic lakeside settlement of La Draga (Lake Banyoles, Spain). *The Holocene* 27/11, 1659-1668.

Marinova, E. and Atanassova, J. 2006. Anthropogenic impact on vegetation and environment during the Bronze Age in the area of Lake Durankulak, NE Bulgaria: pollen, microscopic charcoal, non-pollen palynomorphs and plant macrofossils. *Review of Palaeobotany and Palynology* 141, 165-178.

Marret, F., Mudie, P., Aksu, A. and Hiscott, R.N.. 2009. A Holocene dinocyst record of a two-step transformation of the Neoeuxinian brackish water lake into the Black Sea. *Quaternary International* 197, 72-86.

Medeanic, S., Zamora, N. and Corrêa, I.C.S. 2008. Non-pollen palynomorphs as environmental indicators in the surface samples from mangrove in Costa Rica. *Revista Geológica de América Central* 39, 27-51.

Meibeyer, W. 1997. Das Braunschweiger Land als Naturraum. *Führer zu Archäologischen Denkmälern Deutschlands* 34, 10-21.

Menozzi, B.I., Zotti, M. and Montanari, C. 2010. A non-pollen palynomorphs contribution to the local environmental history in the Ligurian Apennines: a preliminary study. *Vegetation History and Archaeobotany* 19/5-6, 503-512.

Miola, A. 2012. Tools for non-pollen palynomorphs (NPPs) analysis: a list of Quaternary NPP types. *Review of Palaeobotany and Palynology* 186, 142-161.

Miola, A., Bondesan, A., Corain, L., Favaretto, S., Mozzi, P., Piovan, S. and Sostizzo, I *et al.* 2006. Wetlands in the Venetian Po Plain (northeastern Italy) during the Last Glacial Maximum: interplay between vegetation, hydrology and sedimentary environment. *Review of Palaeobotany and Palynology* 141, 83-102.

Moore, P.D., Webb, J. A. and Collison, M. E. 1991. *Pollen Analysis*. Oxford: Blackwell Scientific Publications.

Pals, J.P. van Geel, B. and Delfos, A. 1980. Paleoecological studies in the Klokkeweel bog near Hoogkarspel (prov. of Noord-Holland). *Review of Palaeobotany and Palynology* 30, 371-418.

Prager, A., Barthelmes, A., Theuerkauf, M. and Joosten, H. 2006. Non-pollen palynomorphs from modern alder carrs and their potential for interpreting microfossil data from peat. *Review of Palaeobotany and Palynology* 141, 7-31.

Prager, A., Theuerkauf, M., Couwenberg, J., Barthelmes, A., Aptroot, A. and Joosten, H. 2012. Pollen and non-pollen palynomorphs as tools for identifying alder carr deposits: a surface sample study from NE-Germany. *Review of Palaeobotany and Palynology* 186, 38-57.

Rácz, S.E., Pucu de Araujo, E., Jensen, E., Mostek, C. and Morrow, J.J.2015. Parasitology in an archaeological context: analysis of medieval burials in Nivelles, Belgium. *Journal of Archaeological Science* 53, 304-315.

Revelles, J., Burjachs, E. and van Geel, B. 2016. Pollen and non-pollen palynomorphs from the Early Neolithic settlement of La Draga (Girona, Spain). *Review of Palaeobotany and Palynology* 225, 1-20.

Schlütz, F. and Shumilovskikh, L. 2017. Non-pollen palynomorphs notes: 1: Type HdV-368 (*Podospora*-type), descriptions of associated species, and the first key to related spore types. *Review of Palaeobotany and Palynology* 239, 47-54.

Scott, L. 1992. Environmental implications and origin of microscopic Pseudoschizaea Thiergart and Frantz Ex R. Potonie emend. in sediments. *Journal of Biogeography 19/4*, 349-354.

Stockmarr, J. 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13, 615-621.

Święta-Musznicka, J., Latałowa, M., Badura, M. And Gołembnik, A. 2013. Combined pollen and macrofossil data as a source for reconstructing mosaic patterns of the early medieval urban habitats – a case study from Gdańsk, N. Poland. *Journal of Archaeological Science* 40/1, 637-648.

van Geel, B. 1976. Fossil spores of Zygnemataceae in ditches of a prehistoric settlement in Hoogkarspel (The Netherlands). *Review of Palaeobotany and Palynology* 22, 337-334.

van Geel, B. 1978. A palaeoecological study of holocene bog section in Germany and The Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals. *Review of Palaeobotany and Palynology* 25/1, 1-120.

van Geel, B. 2001. Non-pollen palynomorphs. In: Smol, J.P., Birks, H.J.B. and Last, W.M. (eds.), *Tracking environmental change using lake sediments*: *volume 3: terrestrial, algal and silicaceous indicators*. Dordrecht: Kluwer, 99-119.

van Geel, B. and Aptroot, A. 2006. Fossil ascomycetes in Quaternary deposits. *Nova Hedwigia* 82/3-4, 313-329.

van Geel, B., Bohncke, S.J.P. and Dee, H. 1981. A palaeoecological study of upper Late Glacial and Holocene sequence from 'De Borchert', The Netherlands. *Review of Palaeobotany and Palynology* 31, 367-448.

van Geel, B., Hallewas, D.P. and Paks, J.P. 1983. A late Holocene deposit under the Westfriese Zeedijk near Enkhuizen (Prov. of Noord-Holland, The Netherlands): palaeoecological and archaeological aspects. *Review of Palaeobotany and Palynology* 38/3-4, 269-335.

van Geel, B., Bos, J.M. and Pals, J.P. 1986. Archaeological and palaeoecological aspects of a medieval house terp in a reclaimed raised bog area in North Holland. *Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek* 33, 419-444.

van Geel, B., Mur, L. R., Ralska-Jasiewiczowa, M. and Goslar, T. 1994. Anabaena as indicators for medieval phosphate-eutrophication of Lake Gosciaz (central Poland). *Review of Palaeobotany and Palynology* 83, 97-105.

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G. and Hakbijl, T. 2003. Environmental reconstruction of a Roman period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. *Journal of Archaeological Science* 30/7, 873-883.

Vánky, K. 2013. *Illustrated genera of smut fungi*. 3rd edition. St. Paul: American Phytopathological Society.

van Vuuren, S.J., Taylor, J., van Ginkel, C. and Gerber, A. 2006. *Easy identification of the most common freshwater algae: a guide for the identification of microscopic algae in South African freshwaters*. Pretoria: Resource Quality Services.

Creating an understanding of life in and around a Bronze Age house through science-based artist impressions

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Abstract

The house is often thought of as the basis for studying past living conditions. However, a "house" in archaeology is often nothing more than a collection of posthole features or an empty reconstruction. For subsistence to be successful, many activities and their related objects are needed, and they would be reflected in the house furnishings. In this paper, an overarching approach to subsistence and the research towards living conditions is presented which is applicable to any time period, geographical location or climate. By viewing subsistence as a form of survival, basic activities and objects were identified that form an expectation for what minimally must have existed in a household. As a case study for the study of the interior of a house, the large dataset available from Bronze Age West Frisia, The Netherlands was used. A catalogue of European Bronze Age finds was used to compare with the expected activities and objects, and to confirm find categories or recognise missing elements in the archaeological record. Finally, based on this comparison and other lines of evidence, five science-based artist impressions were constructed of the interior of a Bronze Age house. These and future (3D) reconstructions can be used to stimulate ideas and discussions on (pre)historic living conditions and hopefully remedy the simplified view about people in the past.

Introduction

When studying past living conditions, we often think of the house as a basis from which subsistence is practiced. A house in north-western European archaeology however, is often represented by nothing more than a collection of (digitalised) posthole features, sometimes superseded by a digital or life-size reconstruction. In many cases, such houses are portrayed empty, so that the audience viewing such reconstructions, be it lay or peer, gets a clear idea of the dimensions of the house and its different spaces, as well as the construction of the building itself. It is striking that the house is often shown as an empty space, since it forms the most important

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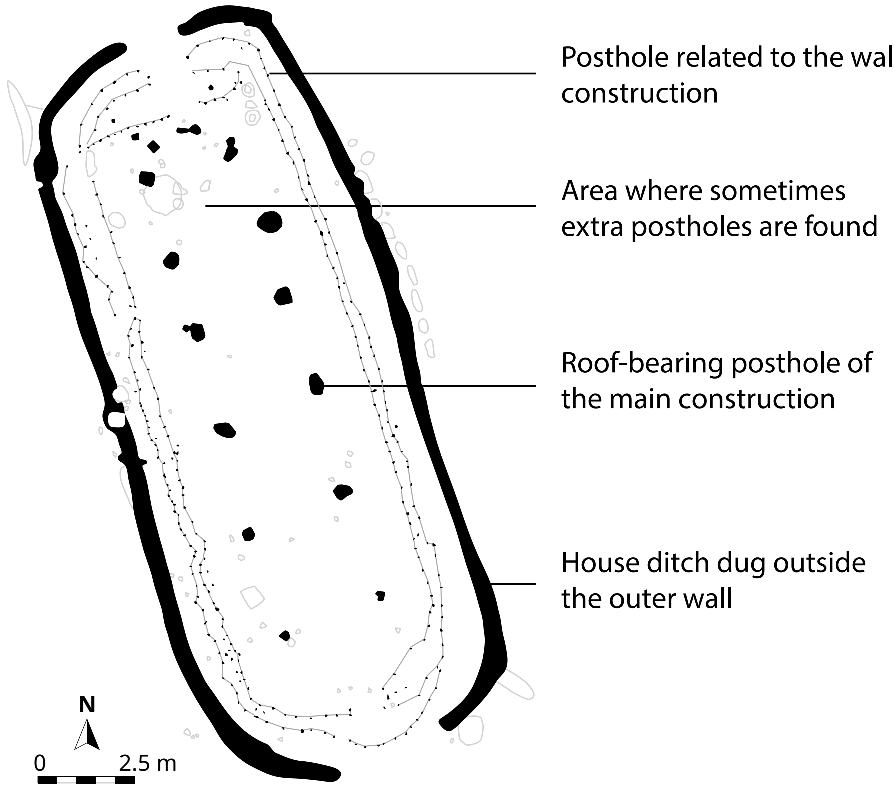

Figure 1. West Frisian Bronze Age house plan with the different types of features related to it (from: Roessingh 2018).

centre of any form of subsistence for people and would surely have contained many of their things, including the tools, equipment and furniture essential to daily life.

There exist five basic requirements for subsistence: procuring food, water, shelter, fire and clothing (United States Dept. of the Army 2009). The approach presented in this paper works under the assumption that subsistence in its purest form can be viewed as a form of survival, which means that it is certain that these five basic requirements must always be met. Even if in archaeology we deal with many different time periods, geographical locations and cultures, these five basic requirements could be used as an overarching basic approach that is applicable to any form of subsistence regardless of the aforementioned variables.

Approaching the research into living conditions and the house from this angle means that it is necessary to first study the tasks required on an annual basis to meet basic demands and make/keep subsistence successful. Then, according to these reconstructed activities, it is possible to define the objects and resources required for subsistence and create an expectation for the house inventory. Finally, through comparing the expectation with archaeological finds, more insight is gained into the actual content of past houses as well as missing elements.

As a case study for this research the Bronze Age houses of West Frisia, the Netherlands are used, since there is much data available on both this time period and this research area (Van Amerongen 2016 and references therein).

Methodology

Bronze Age West Frisia

The Bronze Age in The Netherlands lasted from *c.* 2000-800 BCE. During this time, several cultural groups existed within the Netherlands, of which the Hoogkarspel culture within the region of West Frisia is one. West Frisia is situated in the north-western part of The Netherlands. It is characterized by a clayey subsoil and a high water table, which results in excellent preservation conditions for organic remains. In the Bronze Age, West Frisia was surrounded by peat to the north and south, the North Sea to the west, and large freshwater/slightly brackish lakes to the east (see also Van Amerongen 2015). The Hoogkarspel culture is characterized by its unique style of pottery and houses in comparison to other cultures in the Netherlands. House-plans are clearly recognisable by the distinct configuration of their post-holes and surrounding house ditches (Figure 1). In some house plans, an extra set of post-holes is present in the western part of the house, between the roof-bearing posts.

Subsistence in Bronze Age West Frisia consisted of a mix of crop and animal husbandry, evidenced by the presence of many remains of several domestic animal species and the presence of numerous macro remains of cultivated crops and fields with ard marks. The combination of both crop and animal husbandry practiced by a limited number of residents of one farm results in a small-scale mixed farming subsistence. The sheer quantity of data supporting this farmer's lifestyle has long led people to believe that this was the only type of subsistence practiced. However, recent research (Van Amerongen 2016) has revealed that also hunting and in particular wild plant gathering were essential to life in the Bronze Age. The four subsistence strategies (*i.e.* crop and animal husbandry, hunting and gathering) within a small-scale mixed farming subsistence were used as a basis from which an expectation of related activities was made.

Expectation for the basic house inventory

The expectation for a basic set of activities and a basic house inventory was made based on the identified subsistence strategies mentioned in the previous paragraph. These established basic activities were then used to create the expectation of required objects for the West Frisian Bronze Age. It was subsequently established for each of the activities which tools would be needed to accomplish each task (Table 1). Waste and other by-products of practices of daily life are not included for clarity of the reconstruction, but these must of course also have been present in the house.

Archaeological finds

Archaeological finds provide a direct insight into prehistoric life. Numerous examples of furniture, household supplies, tools, and equipment have been discovered at several Bronze Age sites throughout Europe. Often however, a particular site does not yield enough data to justify a complete reconstruction of household furnishings, but the combined finds from Bronze Age sites together hold a wealth of information. The presence of objects shows that certain knowledge, skills and objects must have existed in the European Bronze Age as a whole, and can thus form a general basic set of objects used in daily life. Therefore, several sites with excellent preservation conditions were used to construct a catalogue of direct examples of a Bronze Age house inventory.[3]

The major site used for this purpose is Hauterive-Champréveyres, Switzerland. Must Farm, United Kingdom has many excellently preserved Bronze Age finds as well, but since the post-excavation is still taking place, only one find is added here. Several single finds from sites in The Netherlands, Germany, The

3 To prevent copyright issues of the images used in the catalogue, see Van Amerongen 2016a, 279-89.

	Tools	Equipment	Furniture
1. Diet			
1.1 Hunting	knife stick	net, **weir, trap,** spear, sling, **bow and arrow,** hook, *etc.*	
1.2 Animal husbandry	knife **cheese strainer** shearing tool?	**rope halter** **bit and bridle** milking container (bucket?)	
1.3 Crop husbandry	**sickle** digging stick, **hoe** pestle/mortar pounding tool sieves, winnows, **baskets** quern	**plough/ard** **yoke**	
1.4 Gathering (wild plants and animals)	**basket** digging stick knife		
1.5 Consumption	**pot** **whisk** **plate, cup, ladle, bowl**		hearth
2. Clothing (textiles and hides)	carding/combing tool **spindle whorl** **needle** **awl** scraper	**loom and related objects**	loom stool
3. Shelter	**axe** chisel hammer		benches/**chairs** beds (and bedding) stools shelves hearth hooks
4. General	**rope** **containers (wood, ceramic, baskets)** fire making tools **shovel** **boat** **cart** sweep/besom **ladder**		

Table 1. List of required basic tools for daily life in prehistoric small-scale mixed farms. Many objects which were expected to be necessary for daily life were also uncovered at many Bronze Age sites throughout the Netherlands and north-western Europe (in bold). In addition, many objects made from organic materials (highlighted in grey) are often not recovered at sites.

United Kingdom and Denmark were also included. The catalogue has been made as a starting point for future research into this subject and is therefore far from complete. Surely, when sites such as Must Farm are completely excavated and analysed, much more information can be added to improve prehistoric house reconstructions in the future.

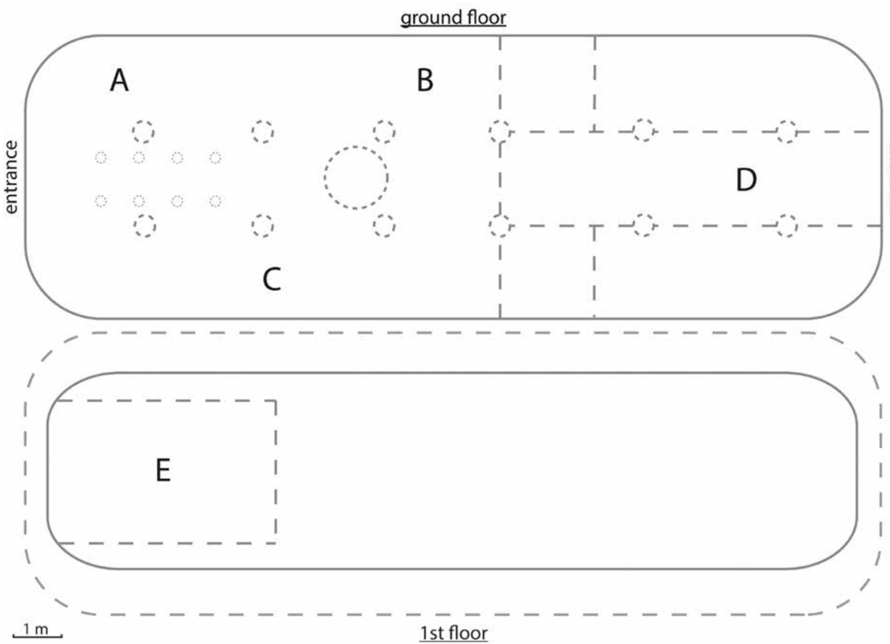

Figure 2. Top view of the simplified interior of a West Frisian Bronze Age house with ground floor (above) and first floor consisting of an attic (below). The first floor has a smaller surface area due to the slope of the roof. Dashed small circles indicate postholes, the dashed large circle the assumed location of the hearth, and dashed straight lines a possible division of living area/ stable/storage areas. A: textile production area; B: food production area and storage of related objects; C: sleeping area and storage of tools and valuable objects; D: barn and fodder storage; E: attic with food storage.

Results

Comparing expectation and finds

Only considering archaeological evidence in the reconstruction of the interior of a house means that much information is potentially missed: there will be many aspects of the house interior and of daily activities that will rarely or even never preserve because of taphonomy and other (archaeological) formation processes. For this reason, the expectation of objects was compared with the constructed catalogue of actual Bronze Age archaeological finds.

In Table 1 it can be seen from the expected furnishings, that only some objects are usually well represented by archaeological finds. These finds often include objects made from flint, stone and ceramics, and are related to activities such as processing of hides (flint awls and scrapers), textile production (stone or ceramic loom weights), food production (ceramic tableware) and active hunting (flint arrow heads). Only rarely are objects found made from organic material, which means that activities such as for example gathering, passive hunting (*i.e.* with (fish)traps), basketry/vessel making, and furniture making are highly underrepresented. Exceptional sites sometimes yield these rare organic objects, but on average it is safe to say that the majority of (essential) objects related to daily life is missed during and after excavation. Some finds, although essential to subsistence, have never been found or recognised and remain exclusively known (and are only missed) because an expectation was formed beforehand. An example of this is the consumption of vegetative wild plant parts.[4]

Reconstructing daily life in and around the Bronze Age house

The reconstruction of the Bronze Age West Frisian house interior[5] was made by using both the known finds from Bronze Age sites from the Netherlands

4 See Van Amerongen 2016b.

5 The architecture of the house was not the main focus of the paper and is therefore left comparatively vague in construction and outline.

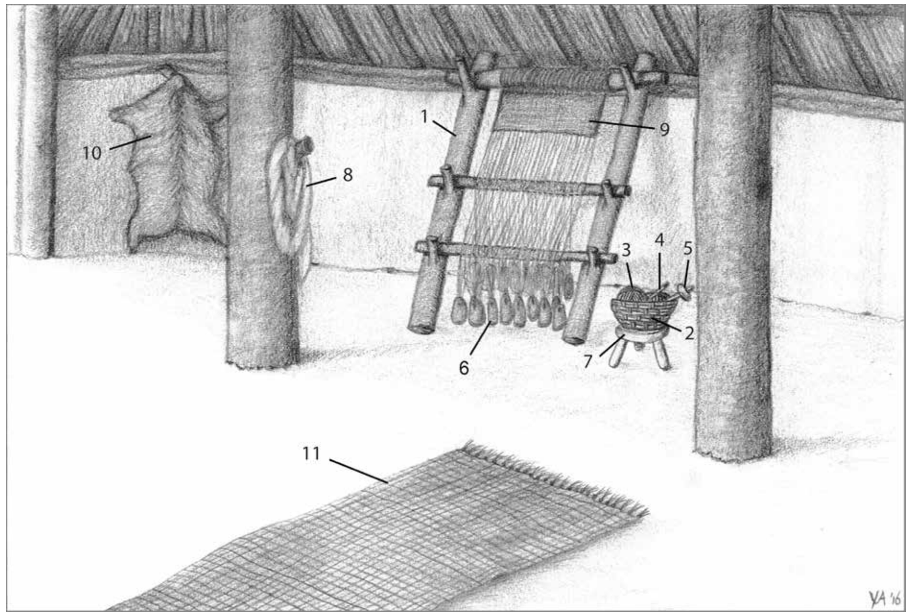

Figure 3. Area A: Textile production area. 1: warp-weighted loom; 2: basket; 3: ball of yarn; 4: needle; 5: spindle whorl; 6: loom weight; 7: stool*; 8: carded wool; 9: linen* (but flax was cultivated); 10: hide*; 11: mat. *Objects not found archaeologically.*

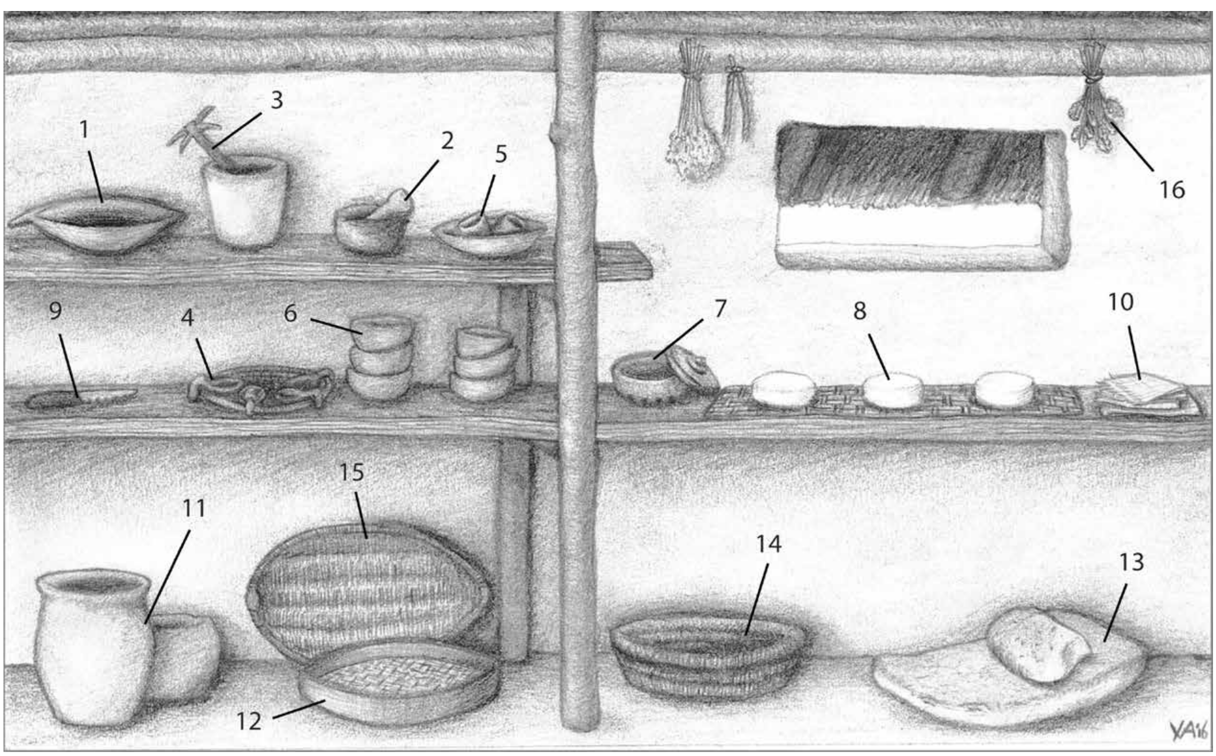

Figure 4. Area B: Cheese making area and storage of consumption related material. 1: bowl; 2: bone pestle; 3: whisk; 4: spoon; 5: miniature bowl; 6: ceramic container; 7: cheese strainer with lid; 8: cheese; 9: knife*; 10: cheese cloth*; 11: pot; 12: sieve*; 13: quern; 14: basket; 15: winnowing basket*; 16: dried herb. *Objects not found archaeologically.*

and north-western Europe, as well as the expectation of objects when no direct examples were available. The house interior reconstruction has ultimately resulted in the creation of science-based artist impressions (made by the author). Science-based in this respect means that most of the information portrayed on these images was supported by either archaeological, botanical, ethnographical and/or zoological studies, including the location of the different activity areas, the tools and equipment, and the different types of food that formed the diet. The artist's impression was used to create a plausible house interior and fill in existing gaps of knowledge until confirmations or contradictions with scientific evidence become apparent and changes are required.

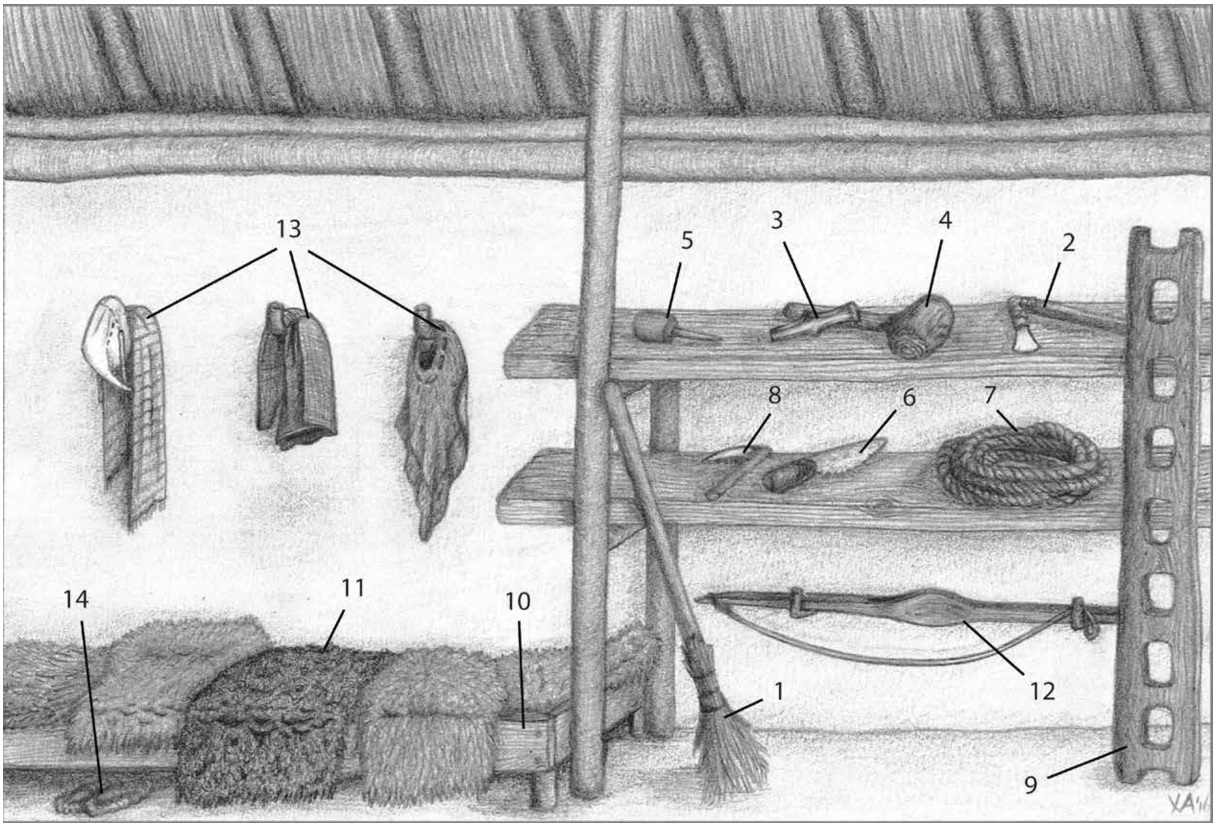

Figure 5: Area C: Sleeping and tool storage area. 1: broom*; 2: axe; 3: chisel; 4: wooden hammer; 5: awl; 6: slaughter knife*; 7: rope; 8: sickle; 9: adder; 10: bed*; 11: sheep skin*; 12: wooden bow; 13: clothing; 14: shoes. *Objects not found archaeologically.

Impressions were made of five different areas within the house (Figures 2-7), where actual Bronze Age archaeological finds from different areas in Europe are indicated with numbers.[6] Objects that were not found archaeologically in the list presented here are indicated with an asterisk.

The western part of the West Frisian Bronze Age house was most likely used as the human living area, whereas the eastern part was presumably used as a barn (assumption based on differences in distance between roof-bearing posts; Roessingh 2018). Area A is the potential textile production area of the house (Figure 3). This area is chosen to have been suitable for textile production because of the favourable light conditions during the day. So, when textile production took place inside the house, it was most likely in this area. Area B is located at the northern part of the house and is therefore the coolest location of the living area. It is therefore likely to have been used to produce food, such as cheese (Figure 4). Evidence for cheese production in West Frisia consists of the find of a ceramic cheese strainer and the presence of ruminant milk fat residue in pots (Roessingh and Lohof 2011). Possibly, the food production area was also used for the storage of tools and equipment related to consumption. The southern part of the living area, Area C, is the warmest section of the house, both due to the constant exposure to sunshine during the day and the close proximity to the hearth at night (Figure 5). This area is therefore well-suited for sleeping. Perhaps it was also used for the storage of valuable tools, that were kept close to people and therefore were safer during the night. In the eastern part of the house, Area D, is most likely where the barn was located (Figure 6). Here, there is enough room for both the storage of large tools as well as the stabling of different domestic animal species (cf. Kveiborg 2009a). Area E is located above the extra setting of

6 For references to actual finds, see Table 2.

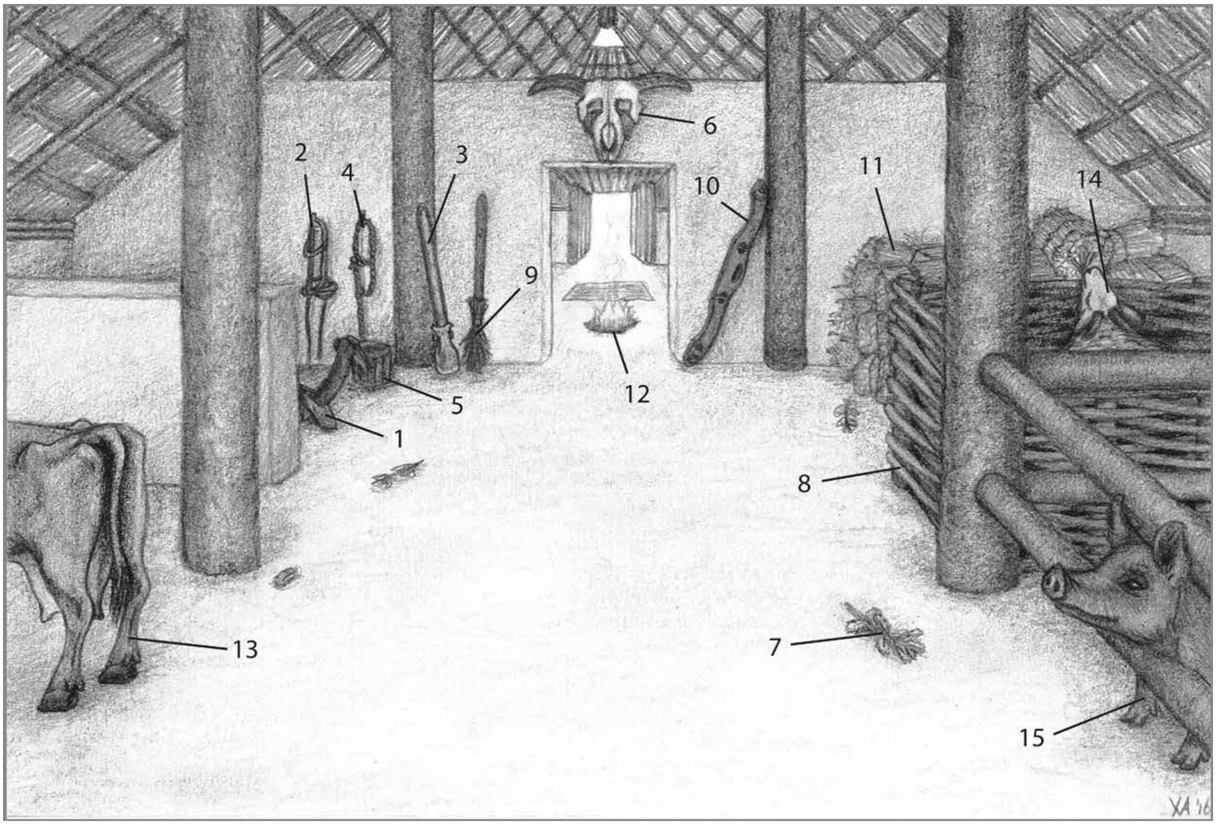

Figure 6. Area D: Barn. 1: ard; 2: bit and bridle; 3: shovel; 4: rope head gear 5: milking bucket*; 6: cattle skull hung from leather straps; 7: repellent (Mentha sp.); 8: wattle pen; 9: broom*; 10: yoke; 11: fodder; 12: hearth; 13: cow; 14: sheep; 15: pig. *Objects not found archaeologically.

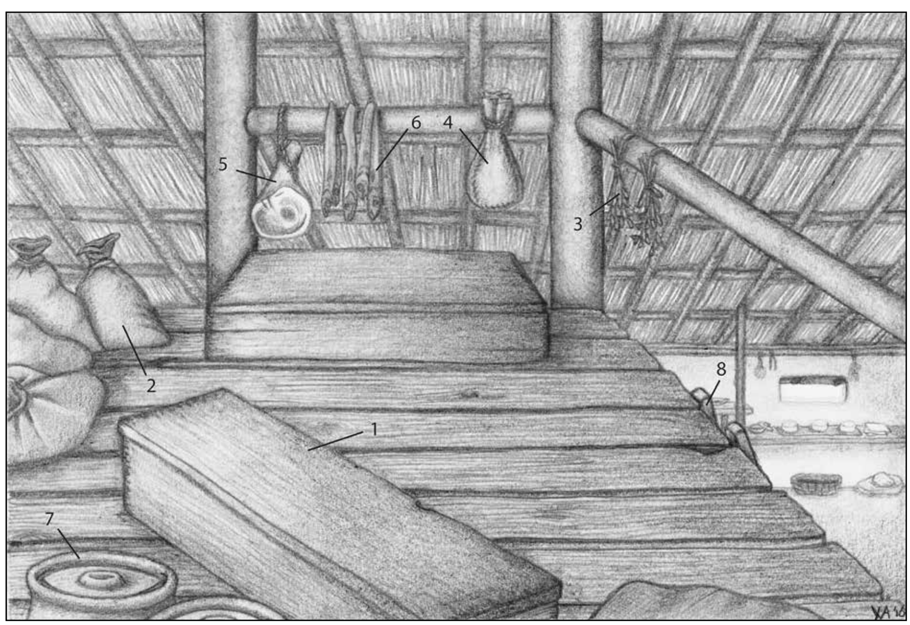

Figure 7. Area E: Attic with food storage. 1: wooden container; 2: linen sack*; 3: dried herb; 4: leather bag; 5: dried meat; 6: dried fish; 7: ceramic container; 8: ladder. *Objects not found archaeologically.

post-holes, and may have functioned as an attic for food storage (Figure 7). Food storage usually takes place above living areas, where it is dry and well-ventilated, and stored food is easily accessed.

Discussion

The primary aim of the reconstruction is to stimulate the discussion on (the appearance of) the interior of the house and its many challenges and opportunities for practicing daily activities. Such a reconstruction helps in creating new ideas for future research on daily life in (pre)history.

The applied overarching approach used in this paper mainly focuses on the survival side of life, since for survival it is possible to arrive at a basic set of needs. But of course, life consists of more than just survival, and includes activities and objects related to *e.g.* music, local appearances of people and objects, and religion. Research into aspects of life surpassing the survival threshold are left out of this paper on purpose, since they cannot be generalised in an overarching approach. When pottery is analysed on a functional level, this can plausibly be assumed to be similar between regions or cultures. However, when researching expressions of (local) identity such as specific pottery decorations and house ornamentations such as carving/painting it is important to use only finds from the site that is studied. In that manner, we stay as true to the studied culture in the reconstruction as possible. The construction of a general catalogue of archaeological finds is comparably focused on a basic set of house furnishings for survival. It would be very interesting to expand such a catalogue in the future when more finds related to subsistence are found. Perhaps a separate part should be made within this catalogue or even an entirely separate catalogue that includes finds related to aspects of daily life surpassing survival. Such an overview could add to the understanding of the range of possibilities of expressing (local) identity and create a more wholesome view of past daily life.

The science-based artist impressions presented in this paper were originally made with paper and pencil. Even though this should already raise many questions and points of discussion, a more malleable type of reconstruction is required to test research hypotheses more easily. Ideally, a digital reconstruction in the form of a 3D house should be made, in which many variables and layouts can be created. Testable variables could for example include temperature and light to assess the plausibility of activity areas. In addition, these digital reconstructions could allow for the substitution of furnishings from the general catalogue with local finds when they are uncovered. Another advantage of a 3D reconstruction is that it can easily be adapted to different house types and time periods, as well as geographical locations. Currently, a 3D house reconstruction is being made for Bronze Age West Frisia to test the plausibility of the here presented reconstruction.

A second aim of the reconstruction of the interior of the house is to attempt to fill gaps of knowledge about past practice and skill.

Our view of daily life in the past is limited when we solely rely on (rare) archaeological finds. At the moment, this view is probably the most important factor in our assessment of (pre)historic people's knowledge, skills and appearance. When including an expectation of what must have existed, as well as examples from other areas within the same time period, it is clear that people were able to create a range of tools, equipment and furniture that was paramount to daily life (and survival) in the past. Table 1 has illustrated this very clearly. The absence of many find(categorie)s may very well be related to issues with preservation, a lack of recognition by the excavator/specialist or a combination of both: and not the actual absence in the past. These problems are potentially the main reasons why house reconstructions usually remain empty.

The overarching approach and reconstructions presented in this paper, as well as future models and finds, will hopefully aid a better understanding of past daily life and its many tasks and objects. Eventually, it may help to remedy a potentially simplified existing view of the capabilities of prehistoric people by providing an image that is more nuanced and more scientifically proven.

Find	Location	Country	Reference
Loom weights	Zutphen Loöerenk	Netherlands	Bouwmeester *et al.* 2008
Ball of yarn	Emmererfscheidenveen	Netherlands	Van Amerongen 2016a
Awl and needle	Enkhuizen Kadijken, West Frisia	Netherlands	Roessingh and Lohof 2011
Spindle	Hauterive-Champréveyres	Switzerland	Pillonel 2007
Spindle whorls	Enkhuizen Kadijken, West Frisia	Netherlands	Roessingh and Lohof 2011
Cheese strainer	Zwaagdijk-Oost, West Frisia	Netherlands	Van Amerongen 2016a
Ceramic containers, bowls, small bowls and spoons	Enkhuizen Kadijken, West Frisia	Netherlands	Roessingh and Lohof 2011
Whisk	Hauterive-Champréveyres	Switzerland	Pillonel 2007
Wooden containers	Hauterive-Champréveyres	Switzerland	Pillonel 2007
Quern	West Frisia	Netherlands	Kleijne 2015
Baskets	Hoogkarspel, West Frisia/ Hauterive-Champréveyres	Netherlands/ Switzerland	Van Iterson Scholten 1977/ Pillonel 2007
Clothing and shoes	Emmererfscheidenveen	Netherlands	Van Amerongen 2016a
Axe	Hauterive-Champréveyres/ Must Farm	Switzerland/ United Kingdom	Pillonel 2007/Must Farm 2016
Hammer	Voorburg Park Leeuwenstein	Netherlands	Hagers *et al.* 1992
Chisel	Westwoud, West Frisia	Netherlands	Van Amerongen 2016
Sickle and holder	Heiloo/ Hauterive-Champréveyres	Netherlands/ Switzerland	Kleijne 2015/ Pillonel 2007
Rope	Hoogkarspel, West Frisia	Netherlands	Van Iterson Scholten 1977
Bow	Noordwijkerhout – De Zilk	Netherlands	Van der Wal 1952
Ladder	Enkhuizen Kadijken, West Frisia	Netherlands	Roessingh and Lohof 2011
Rope head gear	Siggård	Denmark	Kveiborg 2009b
Horse bridle-bit	Sigmaringen	Germany	British Museum 2016a
Ard	Donneruplund	Denmark	Denmark's history 2014
Shovel head	Hoogkarspel Tolhuis, West Frisia	Netherlands	Van Amerongen 2016a
Skull with straps	Tiel-Medel	Netherlands	Cavallo and Van Groenenstein 2005
Yoke	Flag Fen, Peterborough	United Kingdom	British Museum 2016b
Wattle pen	Nørre Tranders	Denmark	Kveiborg 2009a
Storage containers	Several locations	Denmark	Andreasen 2009 and references therein
Plants and animal species and their products	West Frisia	The Netherlands	Van Amerongen 2016

Table 2. Information about the actual archaeological finds and references to imagery of the finds used in the science-based artist impressions.

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References

Andreasen, M.H. 2009. *Agerbruget i enkeltgravskultur: senneolitikum og ældre bronzealder i Jylland belyst ud fra plantemakrofossiler*. Kuml, 9-55.

British Museum 2016a. *Horse bridle-bit dating to the Middle Bronze Age*. Available at: http://www.britishmuseum.org/research/collection_online/collection_object_details.aspx?objectId=814404&partId=1&searchText=bronze+horse+bit&page=1, accessed 24th June, 2018.

British Museum 2016b. Yoke dating to the Middle Bronze Age. Available at: http://www.britishmuseum.org/research/collection_online/collection_object_details/collection_image_gallery.aspx?assetId=790986001&objectId=814334&partId=1, accessed 24th June, 2018.

Bouwmeester, J., Fermin, N. and Groothedde, M. 2008. *Zutphen Looerenk*. Zutphen: BAAC bv.

Cavallo, C. and Van Groenesteijn, N.J.M. 2005. Zoöarcheologisch onderzoek, in: Van Hoof, L.G.L. and Jongste, P.F.B. (eds.). *Een nederzettingsterrein uit de midden- en late bronstijd te Tiel-Medel Bredesteeg*. Leiden: Archol Report 64, 134-45.

Denmark's history 2014. *Ard*. Available at: http://www. dandebat.dk/eng-dk-historie9.htm, accessed 24th June, 2018.

Hagers, J.-K., Hessing, W.A.M., Kooistra L.I., Schaepman, M.T.M. and Vermeeren C.E. 1992. *Nederzettingssporen uit de midden-bronstijd in Park Leeuwensteijn – Voorburg (Z-H),* Westerheem 41, 69-82.

Kleijne, J. 2015. Kennemerland in de Bronstijd: Inventarisatie en synthese van archeologische vindplaatsen. MAK Onderzoek en Advies.

Kveiborg, J. 2009a. *Bondens dyr – husdyrhold i ældre jernalder belyst ved fund af indebrændte dyr.* Moesgaard Museum Delrapport I, Nørre Tranders. Konserverings- og Naturvidenskabelig Afdeling 17. Højbjerg: Moesgård Museum.

Kveiborg, J. 2009b. Bondens dyr – husdyrhold i ældre jernalder belyst ved fund af indebrændte dyr. Moesgaard Museum Delrapport II. Siggård. Konserverings- og Naturvidenskabelig Afdeling 18. Højbjerg: Moesgård Museum.

Must Farm 2016. *Shafted bronze axe*. Available at: http://www.mustfarm.com/progress/site-diary-38-announcing-our-finds/, accessed 24th June, 2018.

Pillonel, D. 2007. *Hauterive-Champréveyres 14: Technologie et usage du bois au Bronze final.* Archéologie neuchâteloise 37. Neuchâtel: Musée cantonal d'archéologie de Neuchâtel.

Roessingh, W. 2018. *Dynamiek in Beeld: Onderzoek van West-friese nederzettingen uit de bronstijd*. PhD dissertation, Leiden University.

Roessingh, W. and Lohof, E. 2011. *Bronstijdboeren op de kwelders: Archeologisch onderzoek in Enkhuizen-Kadijken.* ADC ArcheoProjecten Monograph 11. Amersfoort: ADC ArcheoProjecten.

United States Department of the Army 2009. *The U.S. Army survival manual: Department of the Army field manual*. Berkeley: Ulysses Press, 21-76.

Van Amerongen, Y.F. 2015. Fish in Bronze Age West Frisia: a Proxy for the Reconstruction of Environment and Activity, in: Kneisel J., Dal Corso M., Kirleis W., Scholz H., Taylor, N. and Tiedtke, V. (eds.). *Third Food Revolution? Setting the Bronze Age Table: Common Trends in Economic and Subsistence Strategies in Bronze Age Europe: Proceedings of the International Workshop "Socio-Environmental*

Dynamics over the Last 12,000 Years: The Creation of Landscapes III (15th – 18th April 2013)" in Kiel. Bonn: Habelt Verlag, 227-235.
Van Amerongen, Y.F. 2016a. *Wild West Frisia: the role of domestic and wild resource exploitation in Bronze Age subsistence*. PhD dissertation Leiden University. Leiden: Leiden University Press.
Van Amerongen, Y.F. 2016b. *Expect the unexpected: the vital need for wild plants in a bronze age farmer's diet.* Open Journal of Archaeometry Special Issue 3, 1-6.
Van Iterson Scholten, F.R.1977. Rope and fishing tackle, in: Van Beek, B.L., Brandt, R.W. and Groenman-van Waateringe, W. (eds.). *Ex horreo: IPP 1951-1976*. Amsterdam: Amsterdam University, Albert Egges van Giffen Instituut voor Prae- en Protohistorie (IPP) 135-43.
Van der Wal, W.A. 1952. *Interessante archaeologica*. Westerheem 1.7-8, 74-9.

Case Study „How was life in Early Bronze Age Bruszczewo" – Archaeology and the View on Bronze Age in Reconstruction Images

Jutta Kneisel[1]

Abstract

This article concentrates on the comparison of reconstructed images of the past and the archaeological reality. Today archaeologists have a wealth of information that can be combined into reconstruction images of life in past societies. Even though these images are largely intended for a popular scientific audience, they contain all the information the archaeologist could provide about the past. Many pictures are made for a specific, singular purpose, *i.e.* to show houses, craftsmanship, or clothes worn in ancient times. The landscape is used as a decorative background while houses, cattle, and individuals are placed in focus. In addition, a large number of images or dioramas often leave an idyllic impression, especially of prehistoric times. The period from the Neolithic to the Bronze Age is therefore generally represented as peaceful. But do these images reflect the real life of past peoples? In the last several decades, a larger number of scientific analyses have yielded new insights about past environment, diet, and health conditions that have only slowly been adopted in the reconstruction images. Here, the site of Bruszczewo, Greater Poland, is used as an example of how a slightly different picture of the living conditions in an Early Bronze Age settlement could be designed.

Keywords: Reconstruction Images, Early Bronze Age, Living conditions

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Die Entwicklung der Menschheit

'*Einst haben die Kerls auf den Bäumen gehockt,*
behaart und mit böser Visage
Dann hat man sie aus dem Urwald gelockt
und die Welt asphaltiert und aufgestockt,
bis zur dreißigsten Etage.' (Erich Kästner 1932)

The development of humanity

'*Once guys perched in the trees,*
hairy with mean faces.
Then they were lured out of the jungle
and paved the world and built up
to the thirtieth floor.' (Erich Kästner 1932)

Introduction

This article focuses on the comparison of reconstructed images of the past and the archaeological reality in an Early Bronze Age site in Bruszczewo, Poland. Today, archaeologists have a wealth of information that can be combined into reconstruction images of life in past societies. Even though these images are largely intended for a popular scientific audience, they generally provide the information an archaeologist could give about the past. Looking at a large number of images or dioramas, they often have an idyllic impression; at least for prehistoric times. Houses, cattle and individuals are represented. A lot of pictures are only made for a single purpose, to show houses, craftsmanship or the ancient clothes that were worn. The landscape is used as a decorative background. Whereas for the Mesolithic hunting scenes are often staged as violent action scenes to illustrate the dangerous life of these people, and battle scenes are typical for the Roman period, the period from the Neolithic to the Bronze Age mostly appears as a peaceful period in these images (Mainka-Mahling 2008). But do these images reflect real life? Nowadays, a large number of scientific analyses have yielded new insights about past environment, diet, and health conditions that are only slowly adopted in the reconstruction images.

Archaeology does not only mean excavating, describing and cataloguing finds, and determining their chronological order. The aim today is rather to create an image of the past which is as complex as possible. As Alan Sorrell said after excavation and the following written report, the reconstruction is the third step in the scientific process (Sorrell 1977). Never before have the methods been as comprehensive as today. In addition to archaeozoology, physical anthropology and archaeobotany, the environment and climate are increasingly taken into account. Isotope research, aDNA and geological data allow us to make additional statements about people's origins, health status and nutrition, and environmental conditions. This rich selection of information available to archaeologists today can be combined into reconstruction images that contradict the ideas of the "noble savage" (Rousseau), "Once guys perched in the trees, hairy…". (E. Kästner 1932) or the "Bronze Age – The first Golden Age of Europe" (Council of Europe campaign, Hänsel 1998).

This insight into past life is not only important for our historical understanding, but also helps above all in public relations and education. The translation of expert knowledge into generally understandable language is of particular importance. Research into the past and current research questions are closely linked to current problems and the major socio-political debates of the present. Reconstruction images thus represent visualized, concentrated knowledge in which all the state-of-the-art expertise on the life history of past societies is incorporated. They are used in exhibitions, display boards, school books, popular books and science magazines, among others. Precisely because they are aimed at the public, and represent the public outreach of our profession it is important to understand and critically question the intentions behind the creation of these images.

However, reconstruction pictures are heavily ideologically loaded. The discussion about reconstruction pictures and their reflection is a rather new direction in archaeological research. The discussion has mostly taken place within French, English and German speaking countries since the end of the 1980s. There are only a few summarizing works and also the extent of the examined reconstruction pictures differs strongly from each other (Mainka-Mahling 2008). The authors usually deal with case studies on specific topics or periods of time. One of the early studies of this topic is on Palaeolithic finds (Moser 1992). Here, reconstruction images have been used to support theories and to propagate theories, as images are catchier than the written word. It is therefore important to understand that reconstruction images are a powerful weapon for our notions of the past. While in the 19th century pictures of the Palaeolithic were mainly used as a tool for theory formation (Moser 1996), in the early 20th century they were strongly political-ideological influenced. For example the Bronze Age, which at that time was still regarded as "Germanic", was heroized in idealized (Müller-Wille 1994). The depiction of the wild man with the club ultimately goes back to antique elements (*e.g.* vase paintings) (Stoczkowski 1997) and served to distinguish themselves geographically, culturally or chronologically from "others, strangers, barbarians, ancestors" and to emphasize the own level of culture (Mainka-Mahling 2008). Since entire generations have been shaped by the image of the "unkempt" prehistoric man or "heroic" warrior, it is time to put these images of the past into a modern form. We have to know that images of past life reflect the society which created them and its view of the past. And we want to create our picture of the past with all the information available to us. Even though these reconstructions are intended for a broad audience, they can contain more information about the past than it is usually the case. But new insights like health status or a more scientific based picture of the environment flow only slowly into the representations of the past. In the case study of the site of Bruszczewo, Greater Poland, a slightly different picture of the living conditions of an Early Bronze Age settlement could be designed which has little in common with the idyllic Bronze Age settlements in reconstructions of the last 100 years. This article therefore tries to discuss the latest findings from the settlement according the possibilities for creating a reconstruction of Bronze Age settlement life. The author is fully aware that this new approach is also ideologically influenced. Climate change, pollution and epidemics are current issues and an important part of our current societal discussion. Of course, our interest as archaeologists also focuses on these topics in the past. At the same time we have to ask ourselves to whom is the reconstruction picture directed and what purpose should it serve? Is it of showing the technological development of mankind as in an exhibition, or is it of showing the composition of traditional costume elements in an article? The aim for this paper is to create a picture of the living conditions and to incorporate a broad spectrum of information into this picture. The success and ideological background of this project may be judged by the readers of the next generations.

Reconstruction pictures of the Bronze Age

For Bronze Age there is a multitude of illustrations. Still today a lot of pictures are from the 1930ies and are heavily ideological loaded with the idea of the "Germanic heroized" Bronze Age (Müller-Wille, 1994). Surprisingly, these ideas of the "heroic Teuton" go back much further into the early modern period (16th-17th century), influenced by the then published writings of Tacitus (Andraschko 1992). School wall

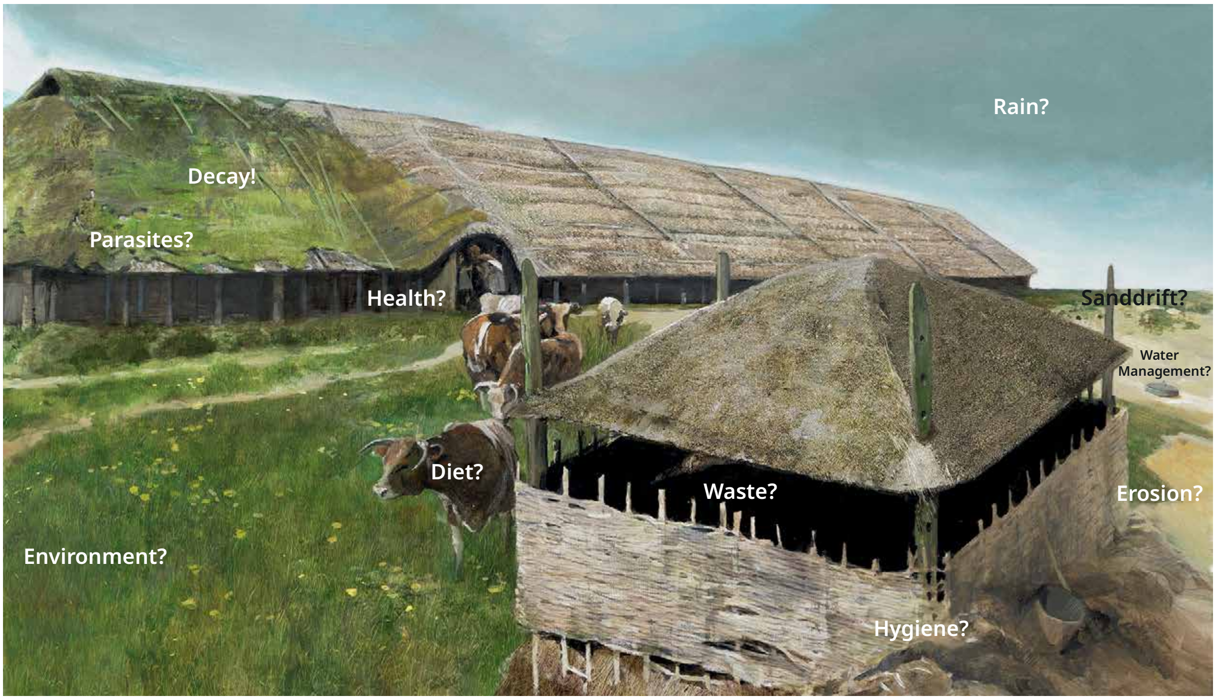
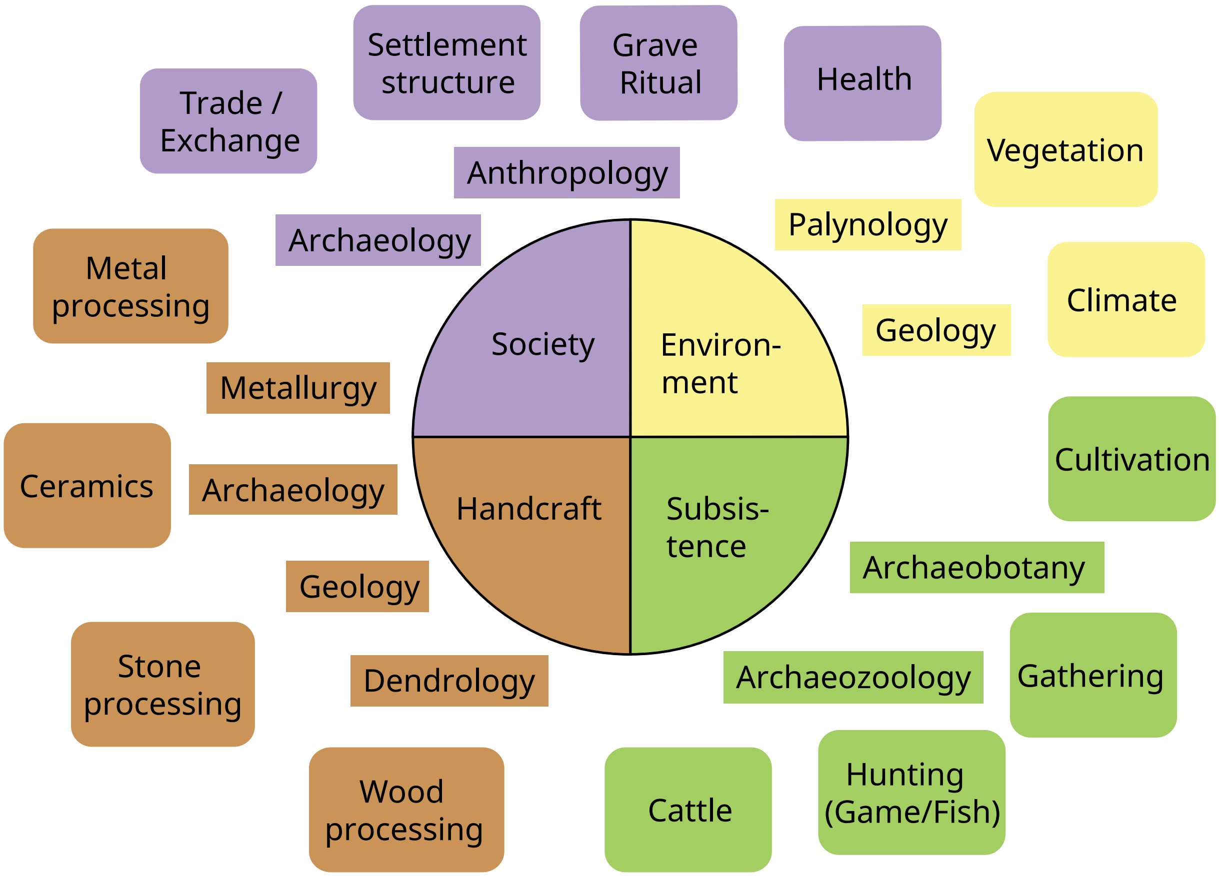


Figure 1. Picture of a Middle Bronze Age farmstead in the Netherlands (drawing by Kelvin Wilson, words added by the author).

pictures, as they still appear today on the Internet under the keyword "*Bronzezeit Lebensbilder*", were, on the other hand, a quick medium of propaganda during the 1930ies to be able to react to current political events (Müller 1983). These representations "were intended to lay the foundation for a 'Greater Germanic Empire' which also included Scandinavia" (Müller-Wille 1994, 33). And still today most Bronze Age pictures adopt the Scandinavian dress style, among others for the lack of other known prehistoric clothing. If we look into the reception of reconstruction pictures, it becomes clear, that there exist no depiction of prehistoric life which is free of ideology. However, they usually show an idealized landscape with houses, cattle and individual people. A. Mainka-Mahling has dealt extensively with reconstruction images in archaeology and has compiled an extensive catalogue. In her work she concludes that the landscape is often only the framework for architecture or technological achievements, *e.g.* metal casting in the Bronze Age (Mainka-Mahling 2008, 233). Although the landscape, in contrast to the Palaeolithic, is now anthropogenic, it mainly serves as a decorative background. But do these pictures represent real life (Fig. 1)? What does nutrition look like beyond agriculture and animal husbandry? What about hygiene? Where did the waste go? Were there any diseases and parasites? What was the drinking water like? What were the domesticated animals doing? And what about the environment? Did the sun always shine, as is so often indirectly suggested in images?

In the last 10 years, a large number of scientific analyses have yielded new insights that are slowly being incorporated into modern images of past life. The Alpine pile dwellings and their western European representations from the Belgian and French-speaking regions (*e.g.* ATELIER BUNTER HUND; http://bunterhund.ch 15.1.2018) are pioneers for the transfer of current scientific results into pictures. Although the landscapes in the background are generally stylized in the reconstruction images of Flemming Bau, some focus on the structures of settlements and agricultural as well forest ecosystems for different areas (*e.g.* in the Brandenburg State Archaeological Museum; http://bau.nu 15.1.2018). With the representation of a multitude of information on the reconstruction pictures this becomes more complex



and the viewer has to spend more time to study them. This, however, prevents the viewer from memorizing a picture of the past that is all too idealized.

Figure 2. Four aspects of living conditions and the scientific research cluster behind the reconstruction of the Early Bronze Age Bruszczewo.

The missing activities

Reconstruction pictures for exhibitions mostly follow a technological development from stone processing to iron production. Only new technologies are presented, although it is forgotten that, for example, flint processing still took place in later periods. Important Bronze Age themes include house building and burial customs, as well as the new technology of bronze casting, which can be found in countless depictions. Although bronze technology is new for this period, and it makes sense to base museum concepts on the technological progress that has been made in each period, there are many activities that are rarely or never depicted in large-scale image reconstructions. Activities such as pottery or weaving have been part of the pictures of the Neolithic, and are rarely found on depictions of the younger Bronze or Iron Age. Hunting is reserved to the Palaeolithic. Also the processing of flint, stone tools and bone artefacts is no longer depicted in the Bronze Age and remains limited to older periods. But what about the production of the folding chairs we know from the Danish graves, or shelves, roof tiles, woodcarvings, sewing, knotting, or tanning? Such activities are rarely found, although we are aware of them through the discovery of bone and wood artefacts from wetland settlements. After all, these different activities were also part of the past lifestyle. As well as the processing of grain, cooking of food, collecting of wild plants or hunting belong to Bronze Age life.

The Case Study: Bruszczewo

In order to answer the question "how was life" in Bruszczewo, it is not only sufficient to present the material culture, but also to implement the perception of modern research into man and the environment. The starting point for the case study are the various investigations and results of different disciplines (Fig. 2), which have been working together in the Bruszczewo team since 1991. (Müller and Czebreszuk 2003; Czebreszuk and Müller 2004; Müller *et al.* 2010; Czebreszuk and Müller 2015; Czebreszuk *et al.* 2015; Kneisel *et al.* 2008a).

Bruszczewo site 5 is located 60 km south of Poznań in Greater Poland, in an area of a lowland mire as late succession state of a former lake. The settlement of the Early Bronze Age (around 2200-1650 BCE) lies on a spur that is separated from the hinterland by a ditch and rampart, and protrudes into the lowland. Below the spur, directly on the lake shore, three rows of wattle-work fortifications and several remains of the Early Bronze Age settlement were excavated. Four houses were situated on the original lake shore, some of which survives under wet conditions. Particularly noteworthy are one house overlaid with colluvial material that eroded from the spur and preserved the house layers. Bruszczewo is one of the few fortified settlements of the northern Únětice groups located at the eastern rim of their distribution and the only one with wet area preservation. After a hiatus a late Bronze Age settlement started around 1000 BCE.

The following article concentrate on four major sources of living conditions, which are outlined in fig. 2, and are available for detailed information on the numerous finds and samples. Their analysis give information about life and living conditions in the Early Bronze Age settlement. In the following we will try to get an insight into the human way of life of an Early Bronze Age Únětice Culture site based on the findings of Bruszczewo. The selected examples are based on the available findings and from that six categories were selected: human bones, hygienic conditions, food remains, environmental data, the spectrum of different activities, and social differences. For the appearance of the humans remains from burials and pits provide information about the health and physical exertion of the inhabitants at that time. We know quite well how the houses have must look like in sense of a hygienic perspective and we can say something about the waste management. On the basis of the plant macro-remains, a good overview of the vegetal nutrition and the use of medicinal plants is given. Some pollen data from off-site and on-site allow us to reconstruct the landscape in the surrounding of the site. Pollen and macro remain analyses as well as dendrology allow statements about the intensity of human influence on the surrounding „nature". The numerous finds from the material culture provide us with evidence of a wide range of activities occurring locally from playing a flute up to an intensive nightlife. And we can see the social differences between the people according to their access to hunted animals or grave goods. And finally, the burial rituals illuminate the social structure and social hierarchy of this society.

The ancients

An important aspect of reconstruction images is the representation of people. Only rarely are items of clothing preserved. What we know in general are costume components (metal/bone/antler) from the graves. However, the human bones also allow conclusions to be drawn about the age distribution and the state of health of the population. Normally, people in the settlement context are usually visible through their legacies and activities. In the Early Bronze Age, nevertheless, human burials in settlement pits are not unusual (Hubensack, 2013). In addition to a single regular burial in Bruszczewo, there were also quite a large number of human bones found in pits and cultural layers. Of the more than 41,000 bones, about 146 fragments can be attributed to humans; 97 of which have been examined in more detail (Iwanek and Piontek 2015, 293). The bones partly originate from pits, where they were deposited together with ceramics and animal bones. Partly larger skeletal parts, ribs and skull fragments were scattered over the whole settlement. In addition a complete skeleton were found in a burial on-site (Jaeger *et al.* 2016, 52; Kneisel 2010c). The grave lay in the eastern wet area under one of the houses (see fig. 5). The anthropologists were able to determine a minimum number of 21 individuals (22 individuals including the burial) for the Early Bronze Age settlement phase. Twelve individuals were from the wet area close to the lake; 9 individuals were found from the spur. The age and gender distribution is as follows (according to Jaeger *et al.* 2016, 62 Table 1):

- 6 male; 0 female
- 2 Infans II; 1 Infans II/juvenile; 3 juveniles; 10 adults; 1 adult/mature; 5 mature
- + 1 settlement burial: juvenile male; 18-24 years; 168.8 cm tall

Despite the strong fragmentation, a number of morphological and pathological changes could be observed. They give us information about the state of health of the population in the settlement. These include:

- Degenerative lesions: on the spine (2 individuals), on the ribs (3 individuals), on the hand (1 individual).
- Porotic hyperostosis of the parietal bone was observed on bones from an elderly man; porotic hyperostosis could also be detected of the skeleton from the burial.
- At the skeleton from the burial, cribra orbitalia also appeared in the porous stage on humus and femur as well as other bones, Harris lines on the shins and thigh bones, and musculoskeletal stress in the spine, in the thoracic, lumbar and sacral areas were visible.
- Osterophytes (2 individuals including burial).
- In addition, caries and tooth loss were detected sporadically (one individual each).
- On bones from the burial occurred indicators for anaemia during the 8^{th}-13^{th} year of life. Further degenerative changes in the bones were observed that are triggered by heavy lifting and carrying (Iwanek *et al.* 2010, 737-742).

The grave in particular provides us with a lot of information about the state of health. In his early youth (8 to 13 years of age) the man suffered from anaemia. Further degenerative changes show great physical strain on the body. The signs of wear and bone changes indicate heavy lifting and carrying on the right side of the body, perhaps also with stabilisation through a carrying loop. It can be assumed that the strain also led to a limp in the right leg.

The anthropological findings indicate hard physical work that led to degenerative changes in the skeleton. Tooth loss and caries were also part of the disease pattern of the population at that time. In addition, there are times of lack of food, which left clear traces on the bones in adolescence.

The depiction of physical malnutrition or physical impairment is, so far, however, extremely rare in reconstruction pictures. (Mainka-Mahling 2008, 206). Translating the results of Bruszczewo into a reconstruction image, we should find different physical afflictions, bad teeth, people who are limping and bent by hard work or marked by hunger.

Hygiene – a concept for maintaining health and waste management

As already mentioned the sun shines on many pictures, the settlement and houses look almost like new and apart from some free running animals the open spaces are

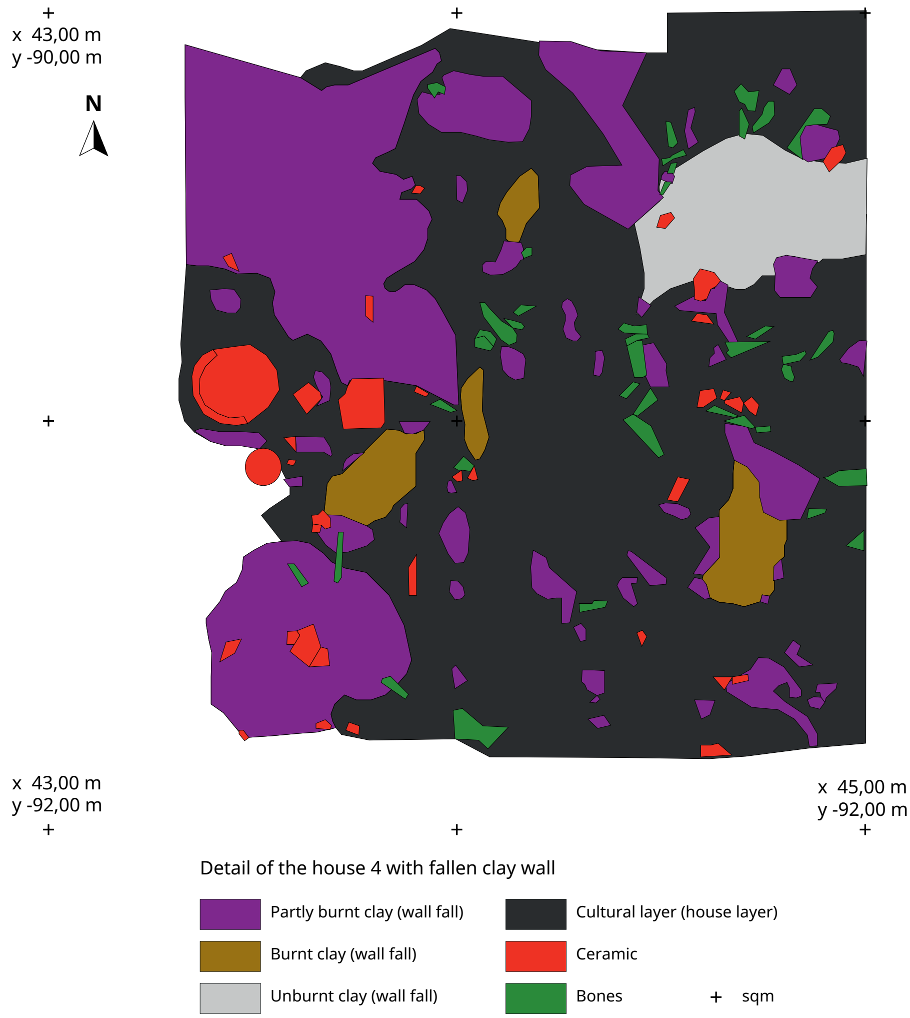


Figure 3. Section of the western house wall with a dense bone distribution (1.5 m² detail).

clean and tidy. The interior of the house corresponds according to A. Mainka-Mehling mostly to „prehistoric model homes“ (Mainka-Mehling 2008, 225). But how clean or hygienic were the houses really? Hygiene is a modern term in the history of medicine, which is primarily concerned with avoiding health-impairing dangers and combating diseases. Per definition of Max Rubner in 1911 Hygiene or health care is „the conscious avoidance of all dangers threatening health and the activity of health-promoting actions“ (Siefert 2005, 647). Is it possible to detect these avoidance of health threatening dangers also in the past? Or did people at that time know about diseases and knew avoidance strategies? However, the increasing hygiene standards of the Western world are also viewed critically, as they can lead to allergies and autoimmune diseases (Strachan 1989). Our current standard can, therefore, hardly be applied to past times. But even with the knowledge of a different standard of hygiene in the past, the features in Bruszczewo sometimes seem strange to the modern observer.

By the good preservation of a complete house floor with culture layer, which was buried after the destruction of the house by fire under a fallen clay wall, it is possible to describe the hygienic standard of this particular house interior. The excavation of house 4 in the wet area yielded revealing findings in this respect. The structure of the house, buried under a wall, made it possible to dig up the cultural layer in the house right down to the floor. On a floor lined with twigs lay shattered pots, charred grains and huge amounts of bones all buried by the collapsed wall (Fig. 3). These include not only small bone fragments, fish vertebrae and bones that

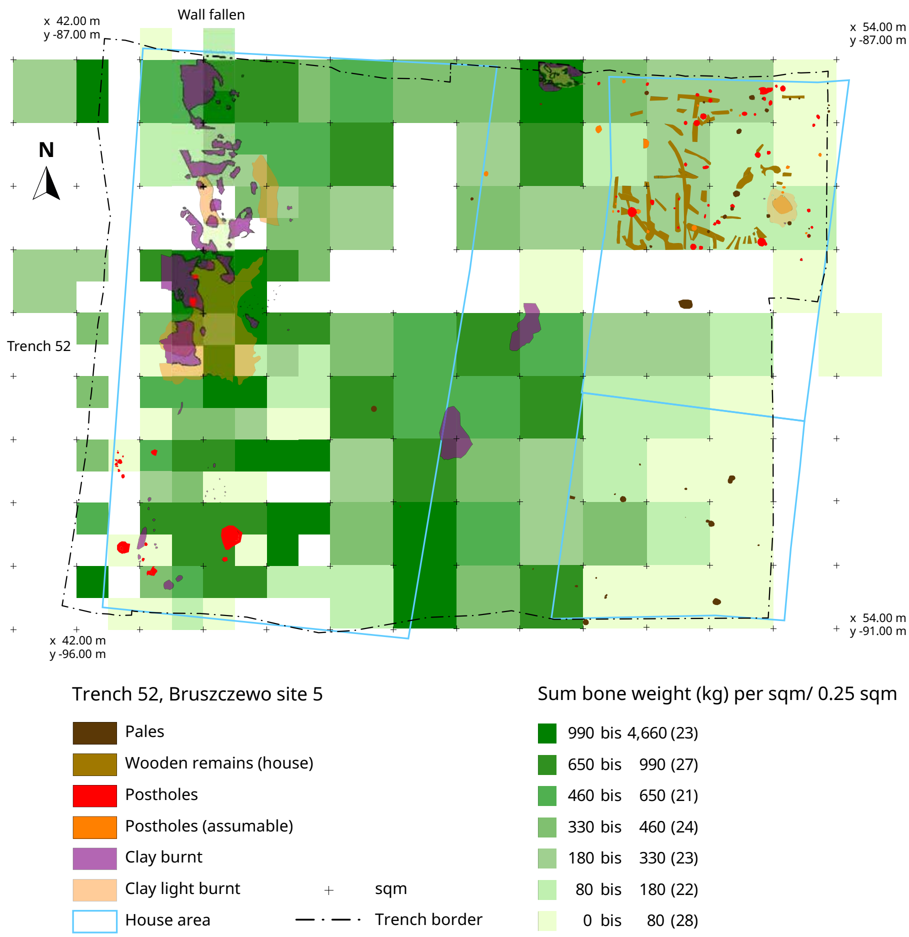


Figure 4. Distribution of total bone weights in the area of house 4 and house 3, Trench 52.

had accumulated in the corners and along the wall, but also fragmented extremities. Obviously, the remains of meals were disposed of inside the house 4. The concentration of the bones along the western wall (Fig. 4) with up to 4,6 kg bones per square metre underlines this. The waste disposal in the house contradicts the basic hygiene standards we know today.

In the house itself several coprolites were excavated, which, according to N. Erguez, were identified as from dogs (Erguez 2016). Beside a house further north (house 2, Trench 31), a 0, 10 m thick layer of dung was found, which was probably deposited around the house. The path between the houses and the fascine was muddy and full of waste. Stepping stones and larch pieces of oak barks testify a muddy surrounding (Fig. 5) close to the wattle-fence (Kneisel 2010b).

Not only there was there rubbish strewn around and within the houses, but also the lake shore, which was only a few metres away, was full of garbage. Broken tools, broken pots and large amounts of bone waste were found between reeds and washed up wood remnants (driftwood). In the early Bronze Age, some of the settlement waste was obviously disposed and thrown in the lake. While complete tools were mainly from the house layers, broken tools and antlers were deposited in the lake (Fig. 5). It is easy to imagine a man or woman angrily throwing a just broken antler hoe or hammer over the wattle-fence into the lake. The difference to some modern polluted lakes today and human behaviour is small. Plastic bags, bottles and driftwood at lake or sea shores is nowadays quite common; only that the organic and ceramic waste of the past is nowadays replaced by plastic.

The living space of the settlement Bruszczewo would be catastrophic according to today‘s hygiene standards. However, we must not forget that these living condi-

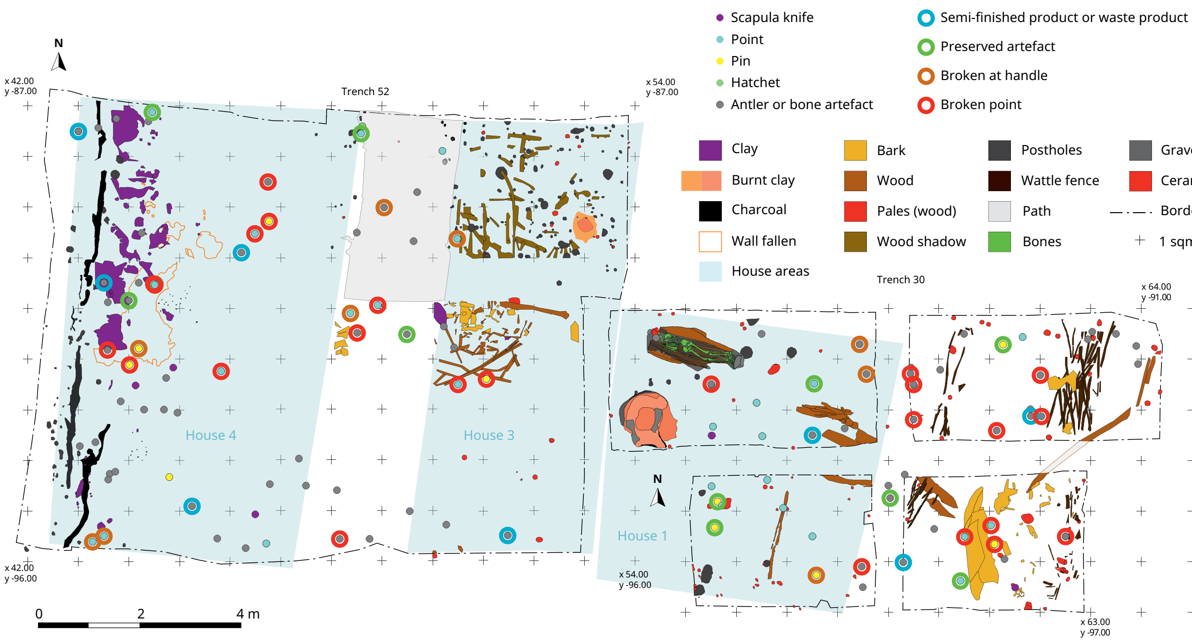


Figure 5. Distribution of the bone tools in trench 52 and 30, the broken ones are mostly situated east of the houses and wattle-fences.

tions were common in Europe well into the 19th century. Nevertheless the „hygienic" conditions are represented only on 1% of the reconstructions (Mainka-Mehling 2008, 226). To translate the results into a reconstruction image, refuse lies on the paths, the animals do their business everywhere, and waste is carelessly disposed at the lake shore and at the front door. And after heavy rains the ground must been so muddy that it went up to the ankles of men and animals.

Not everything gets eaten...

The botanical plant spectrum provides a good overview of some parts of the vegetal nutrition. Samples were taken from the pits on the spur and the culture layers in the wet area and a grain depot was preserved under the collapsed wall of the aforementioned house 4 (Kneisel *et al.* 2008b; Kroll 2010; Karg *et al.* 2004). For the Early Bronze Age, we mainly know two types of grain: emmer and barley. According to the weed composition, only the ears were harvested and stored; in addition, remains of barley ears were found in the house. In the northern Early Neolithic farming was first established with multiple cereal species (Kirleis and Fischer 2014) that already towards the Middle Neolithic were reduced to the two species emmer and barley as main crops. This tendency is continued into the Early Bronze Age and only in the Late Bronze Age this limitation was overcome again (Effenberger 2018; Effenberger 2017; Kneisel *et al.* 2015). Pulses are rare in the Early Bronze Age and only in the Late Bronze Age become more frequent, such as oil plants (Kneisel *et al.* 2015, 276 fig.1). This pattern from a monotonously vegetable nutrition in the Early Bronze Age to a more variable nutrition in the Late Bronze Age is also visible in the context of our site Bruszczewo (Kroll 2010).

However, evidence of Harris lines on the human bones shows that enough food not always was available for all, or that crop failures or long winters may have led to malnutrition. Whether the puristical diet on barley and emmer leads to deficiency symptoms has not yet been sufficiently investigated.

The large number of peeled acorns in the aforementioned EBA house 4 is striking (Wölfle 2017). They were obviously not used as animal fodder, but as food for humans. Acorns are known from numerous European sites of the Bronze Age, yet it is still unclear whether this is a regular foodstuff or whether it was only a food substitute and was used in times of food shortage (Šálková *et al.* 2011). Acorns need not to be bitter, and sweet acorn trees exists in Schleswig-Holstein, they can be consumed without further processing (personal comment V. Arnold 2018). In addition to cereal products, meat products from domestic and wild animals, as well as fish, are also part of the diet of the Bronze Age population in Bruszczewo (Makowiecki 2004; Makowiecki and Drejer 2010; Makowiecki 2014). Even if the latter are rarely found in bone material, the discovery of a fish trap proves that fish was caught (Müller 2004, 111 fig. 50). But hunting also played a role, at least for certain households, as the distribution of wild animal bones on the settlement is irregular (Kneisel 2010a).

Besides collected fruits such as hazelnuts and strawberries, rare plant species such as fennel (*Foeniculum vulgare*) or donkey thistle (*Onopordum acanthium* L.) were also found, whose use as food is well documented (Kroll 2012; Kroll 2010). These plants, rarely preserved in archaeological evidence, show that the collection spectrum was rather larger than suggested by the usual plant macro-remains preserved near the fire. In addition, there is also evidence for medicinal plants or hallucinogens such as black henbane (*Hyoscyamus niger*) or mistletoe. Both are known remedies against complaints (stomach cramps) and diseases (worm infection) which we were able to document in humans and animals in Bruszczewo (see below; Kroll 2010; Haas and Wahlmüller 2004).

Apart from hunting and agriculture, the procurement of food is rarely the focus of Bronze Age reconstruction images. Gathering is reserved for the Mesolithic. If we translate the results of Bruszczewo into a reconstruction image, we are able to detect a large number of gathered plants. These plants must be processed, stored and processed. We also have to take differences among the population into account when it comes to nutrition. Not every household had the same food resources. Staple foods have only a small variance. Times of hunger are a regular experience for the people of that time. But we should also take into account the use of rarely-discovered plant remains, and eating habits that are no longer comprehensible to us, such as the acorn or donkey thistle. The use of various wild herbs as medicinal plants or even hallucinogens also belongs in the pictures.

An idyllic environment?

The representation of the environment in the reconstruction images serves either as a decorative background or to illuminate the local flora and fauna. The landscape is idyllic, and bad weather simply does not exist. A dramatic sky serves only to underline a dramatic aspect of the scene, *e.g.* in armed conflicts (Mainka-Mahling 2008, 229-231). Only recently has the depiction of different environmental conditions found its way into the reconstruction pictures. In Bruszczewo, it is possible to obtain a detailed picture of the immediate surroundings of the site based on the environmental analyses. The information comes from two pollen profiles, one from centre of the former lake, another from the settlement layers directly on the lake shore (Haas and Wahlmüller 2004; Haas and Wahlmüller 2010). The pollen data indicate a clear eutrophication of the lake by algae growth for the Early Bronze Age period of settlement. In addition, NPPs (non-pollen palynomorphs) indicate the entry of manure and excrements (fungi – *cercophora*) into the lake. Increased erosion events are also visible (*Glomus fasciculatum*). In addition, the number of whipworm eggs (*Trichuris* sp) in the pollen profile proves that parasites were brought into the lake by excrement. This deterioration in water quality is not unusual in the immediate vicinity of a settlement. However, the aforementioned NPPs show peaks in the Early Bronze Age, which can only be found sporadically in the pollen profile during the Late Bronze Age use of the landscape (the settlement and cemetery). Erosion and manure indicators only reappear in large numbers during the medieval settlement

Figure 6. „Building and living (Neolithic)" in pile dwellings (Studio "Bunter Hund", Switzerland).

of the fortress complex at the northern end of the lake. In contrast, green and blue algae (*Pediastrum, Anabena* sp.) and whipworm eggs (*Trichuris* sp.) only occur during the Early Bronze Age settlement phase. The NPPs listed here prove that the lake was significantly polluted. The consequences for humans and animals when used as a source of drinking water (wells are still missing) can be mild to severe stomach complaints. The mistletoe also found in the profile in the Early Bronze Age is proven from ethnographic parallels as a remedy against worms, and the henbane found in large quantities is used in medicine for stomach complaints. According to this, the Early Bronze Age people knew about their problems and possibly also knew remedies for them.

The erosion that can be detected in the lake profile could have taken place partly through cattle movement. Cattle obviously also had free access to the lakeshore. In some cases, rainfall on the open slopes will have led to erosion. Erosion channels from the spur to the lake could be detected towards the end of the Early Bronze Age settlement (Hildebrandt-Radke 2015).

On the basis of the plant societies in the pollen profiles, the Early Bronze Age landscape appears as an open landscape. The wood used for the timber of the houses and palisades shows that not only was suitable wood used for construction, but also unsuitable wood such as poplar/willow. Obviously in the 18th century BCE there was already a lack of timber on site when the lake-side fortification was erected (Kneisel and Kroll 2010). Layers of windblown sand on the slopes of the moraines, erosion on open arable land and open areas through cattle movement must have been an everyday sight. Individual groups of trees and bushes formed the human-influenced environment of the settlement surrounding already in the Early Bronze Age.

If we translate these results into a reconstruction image, the shore was softened and muddy (and full of waste). Animals had direct access to the shore. Presumably the animals were running around freely, which would explain the dung layers in the settlement. Green and blue-green algae swam on the lake, at least during the summer months. The landscape was marked by individual groups of trees, where the oak and hazel decreased more and more in the course of time. The remaining trees were rather bushy, a sign of looping or coppicing (Klusek and Kneisel in print). The high number of cereal pollen indicates fields in the immediate vicinity of the settlement, probably on the surrounding moraine hills. But also larger erosion areas caused by cattle movement and agriculture must have been visible on the slopes. It is difficult to say whether the poor water quality severely affected humans and animals at that time. In any case, remedies for worms and stomach cramps were known. For Neolithic pile dwellings such a picture exists, which shows a lake in a morning atmosphere, but the shore is contaminated with alluvial wood and waste, and on closer inspection the idyllically-depicted lake turns out to be not quite so clean (Fig. 6).

Human activities (sports, fun and games or hard work?)

As already mentioned at the beginning, most of the activities of the Bronze Age reconstruction pictures refer to metal casting and perhaps still to weaving and ceramics production. Overall, the diversity of the representations decreases (Mainka-Mahling 2008, 114; 163). A. Mainka-Mehlig criticises the fact that reconstruction paintings from the Bronze Age on are mainly based on new techniques to the Bronze Age (*ibid.*). But other activities also belong to the normal settlement picture. On the basis of the material from Bruszczewo considerably more activities can be proven:

- The slaughter of animals and the tanning of skins can be proven by cutting traces on the foot bones of animals. In Bruszczewo, this was also obviously limited to certain areas (Kneisel 2010a).
- The production of tools and jewellery from antlers and bones obviously took place inside the houses based on the finds situation of semi-finished products.
- The finds of a presumed weaving sword and loom weights prove the presence of textile processing. Finds of flax and the age of the sheep prove that both fibres may have been used (Kroll 2010; Makowiecki 2004; 2014). The nettle cannot be ruled out as a textile raw material either, as its macro-residues were found in large quantities; in addition, H. Kroll points to the donkey thistle as a source of fibre (Kroll 2012). Textile impressions on ceramics prove different techniques of fabric production. Worn textiles were recycled for ceramic production, as the imprints show (Schaefer 2016; Kneisel and Schaefer-Di Maida in print).
- Of course, metal processing is also a must. Tuyères, casting moulds and small drops of bronze (cast bronze drops) on site prove these. Findings also show that experiments were made with various casting techniques, such as cast-on technique for pins (Rassmann 2010; Müller and Kneisel 2010, 773 fig. 14).
- In addition, less frequently proved activities like a wood processing area, with remainders of wood chips, thin wooden planks, a wooden ball of unknown function and a wheel hub belong to the diversity of wood handcraft on site. In the Bronze Age, timber construction was by no means limited to house building or palisade construction, but also produced much finer pieces of thin timber or decorative elements (Ważny 2010; Kneisel and Kroll 2010). Likewise, the cartwright or wagonry probably belongs to a settlement of this size.
- The wood chips in the area of the fascine prove that the piles were obviously worked directly on site (Trench 31, area 6). The splitting of trunks and the

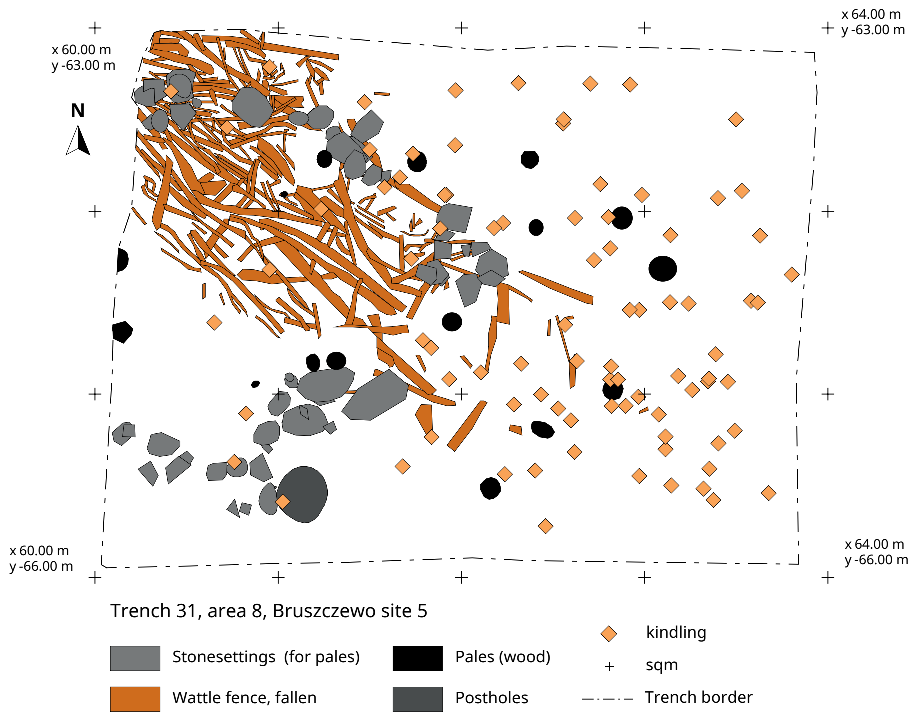


Figure 7. Distribution of burnt points used as torches (kindling) outside a house in Trench 31 area 8.

pointing of pales took place in the settlement. The marks on the woods found correspond to the width of the flanged axes also found on site (Kneisel and Kroll 2010).

- Waste disposal is also rarely seen; the digging of pits and the disposal of household waste, whether swept out of the door or pushed into a pit, is sought in vain in reconstruction pictures (Mainka-Mehling 2008, 226 Anm. 693).
- Also so-called „leisure activities", activities that do not contribute directly to securing basic needs, are missing. Although we are familiar with depictions of rituals such as burials or depositions, the discovery of a flute mouthpiece is evidence of music-making, whether for ritual purposes or just for fun (Kneisel *et al.* 2012, 85).
- Pine chips with burnt points were used as small torches (kindling), which were found in large numbers in the surroundings of house 2. They prove activities during darkness and testify to a lively nightlife (Fig. 7).
- Ceramic production is also proven. A piece of tempered clay with a handprint shows the portioning of clay and thus also the local production (Kneisel *et al.* 2012, 36).
- Exchange and trade would have also taken place. Copper and tin from the south and amber from the north prove the networking of this settlement within Central and Northern Europe (Müller and Kneisel 2010).
- Agricultural activities, field cultivation, ear harvesting, threshing and storage of cereals are also present in the Bronze Age, as are livestock farming and grazing, including animal husbandry.
- Even if bones of game and fish are rare, they prove hunting and fishing, the latter also by the discovery of a fish trap (Müller 2004, 111 fig. 50).

By translating the activities listed here into images, we have a much wider range of activities that go beyond the new technologies: Bronze Age life is not reduced to metal casting. In each settlement there were activities such as butchery, carpentry, tanning, an active nightlife and also music. Hunting may have been restricted to certain groups of persons or may have been carried out by certain persons only. Fishing, plus flint, bone, antler, and textile processing also existed during the Bronze Age. And certainly not only the adults were involved in these work processes.

All people are equal, but some are more equal than others

The Bronze Age was by no means a peaceful and idyllic time. Within the village community clear social differences could be depicted. A comparison of the settlement burial with other burials in the area reveals striking differences. The deceased in the settlement was wrapped in a willow mat and had only two hammer stones and a large sherd of a storage vessel as grave goods (Kneisel 2010b). On the other hand, the burials of the princely burial mounds in Łęki Małe (15 km in distance) or the grave of Przysieka Polska (only 1 km in distance on the other side of the lake), contain rich grave objects and have an elaborate tomb construction (Kowiańska-Piaszykowa 2008; Schwenzer 2004). It can be assumed that this inequality in access to materials and the right to an extraordinary burial is also reflected in everyday life and that these social differences are visible in a settlement like Bruszczewo. Apparently not every individual had access to an elaborate burial. The numerous scattered bones in the settlement testify to the fact that not even all individuals (or only not all men?) were entitled to a burial. There are two other possibilities for scattered distribution of single bones, of which a lot were found in the area or within the wattle-work fence. They are either graves destroyed by a flood and flushed out, or deceased people who could no longer be buried, for example after a battle or epidemic. Although the number of sexually determined individuals with six skeletons is very small, since they are all men, this would speak more for warlike activities. Further ^{14}C-dating could provide clarification here.

If we translate these results into a reconstruction image social inequality should also be visible in a settlement like Bruszczewo. Be it with different house sizes, different clothes or jewellery. Here, too, new reconstruction images from the „Bunter Hund“ studio show a clear social gap between the Early Bronze Age inhabitants in the Alpine region. People with worn clothes face people on horseback with elaborate clothing and jewellery (http://bunterhund.ch/Arbeiten/Geschichte/geschichte.html, fig. *Handel und Verkehr* 15. 1. 2018).

Summary

The description of the Bronze Age way of life and a comparison with the reconstruction pictures clarifies that we need to consider more the downside of these settlements. Maybe also a landfill beside the settlement or in the area of the lake shore, dung and waste in the corners, inside and between the houses. Hard working people and a wider spectrum of people with regards to age, health and poverty/richness. Besides the waste laying around everywhere, animals should be walking around and dogs doing the necessary. It would be interesting to see a rainy weather day with muddy paths and people and animals walking through the mud. A wider range of activities should be included and not only housebuilding, but also finer carpentry and furniture-building and the repair of things like wagons. But also daily activities like cooking or food preparation. And why do not someone play the flute? The landscape could look nice in some parts, but we should not deny that there are also eroded parts of the surface and that environmental pollution exists. In our first try to create reconstruction pictures, the Bronze Age world was still in order (Kneisel *et al.* 2012). Our second attempt, together with Samson Goetze (Schrader 2017), shows a livelier picture with a lot of different activities going on and a darker view inside a house, where not everything looked recently constructed (cover and fig. 8).

Figure 8. Reconstruction of life in an Early Bronze Age house in Bruszczewo Greater Poland (Samson Goetze).

We have to be opposed to the trend of decreasing information on such pictures as A. Mainka-Mehling already mentioned in her book (2008). Life on a prehistoric settlement is much more differentiated, as are the humans who inhabit it, and the sun does not always shine. To conclude, we need to think more about the wide range of living conditions, and acknowledge that life in the past was most often not easy. Diseases and physical handicaps were surely more often seen then than today. They have no doubt experienced a nice cool morning atmosphere at the lakeside, but such idyllic scenery as reflected in the pictures from Switzerland – atelier „Bunter Hund" most probably were exceptional moments in everyday life.

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References

Andraschko, F. M. 1992. Das Germanenbild im Wandel, in: Bernhardt, G. (ed.). *Bilder früher Menschen. Archäologie und Rekonstruktion.* Begleitbuch zur gleichnamigen Wanderausstellung des Westfälischen Museumsamtes, Münster 1992 – 1994. Westfalen-Lippe Museumsamt, 98-109.

Czebreszuk, J. and Müller, J. 2004. *Bruszczewo I.* Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens. Rahden/Westf.: Leidorf [u.a.].

Czebreszuk, J. and Müller, J. (eds.) 2015. *Bruszczewo III. The settlement and fortification in the mineral zone of the site*. Studien zur Archäologie in Ostmitteleuropa 13. Poznań: Dr. Rudolf Habelt GmbH.

Czebreszuk, J., Müller, J., Jaeger, M. and Kneisel, J. (eds.) 2015. *Bruszczewo IV*. *Natural resources and economic activities of the Bronze Age people*. Studien zur Archäologie in Ostmitteleuropa 14. Poznań: Dr. Rudolf Habelt GmbH.

Effenberger, H. 2018. *Pflanzennutzung und Ausbreitungswege von Innovationen im Pflanzenbau der nordischen Bronzezeit und angrenzender Regionen*. Büttelborn:Wachholtz Verlag.

Effenberger, H. 2017. The plant economy of the Northern European Bronze Age – more diversity through increased trade with southern regions. *Vegetation History and Archaeobotany*, 27, 65-74.

Erguez, N. 2016. *Micromorphological study of samples of Koprolites from Bruszczewo*, site 5. unpublished.

Haas, J.N. and Wahlmüller, N. 2004. Pollenanalytische Untersuchungen im Bereich der bronzezeitlichen Seeuferstation „Bruszczewo“ – Badania palinologiczne na stanowisku z epoki brazu w „Bruszczewie“, in: Czebreszuk, J. and Müller, J. (eds.), *Bruszczewo I. Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens. 1. Forschungsstand – Erste Ergebnisse – Das östliche Feuchtbodenareal.* Studien zur Archäologie in Ostmitteleuropa 2. Rahden/Westf.: Leidorf, 273-279.

Haas, J.N. and Wahlmüller, N. 2010. Floren-, Vegetations- und Milieuveränderungen im Zuge der bronzezeitlichen Besiedlung von Bruszczewo (Polen) und der landwirtschaftlichen Nutzung der umliegenden Gebiete, in: Müller, J., Czebreszuk, J. and Kneisle, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 50-81.

Hänsel, B. (ed.) 1998. *Mensch und Umwelt in der Bronzezeit Europas.* Abschlußtagung der Kampagne des Europarates: Die Bronzezeit: das erste goldene Zeitalter Europas an der Freien Universität Berlin, 17.-19. März 1997. Kiel: Oetker-Voges Verlag.

Hildebrandt-Radke, I. 2015. Geographical environment of the central Obra region and the geoarcheology of an Early Bronze Age settlement at Bruszczewo, in: Czebreszuk, J., Müller, J., Jaeger, M. and Kneisel, J. (eds.), *Bruszczewo IV. Natural resources and economic activities of the Bronze Age people*. Studien zur Archäologie in Ostmitteleuropa 14. Poznań: Wydawnictwo Naukowe UAM, 11-38.

Hubensack, V. 2013. Kontinuitäten und Wechselwirkungen des Bestattungsverhaltens in Gräberfeldern und Siedlungen des 3. bis 2. Jahrtausends v. Chr. im südlichen Sachsen-Anhalt und angrenzenden Gebieten anhand der Funde seit 1990. PhD, Ludwig-Maximilians-Universität München.

Iwanek, B., Piontek J. and Nowak O. 2010. Anthropologische Analyse des Skelettes aus Bruszczewo, in: Müller, J., Czebreszuk, J. and Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 730-753.

Iwanek, B. and Piontek, J. 2015. An anthropological study of human skeletal remains, in: Czebreszuk, J., Müller, J., Jaeger, M. and Kneisel, J. (eds.), *Bruszczewo IV Natural resources and economic activities of the Bronze Age people*. Studien zur Archäologie in Ostmitteleuropa 2. Rahden/ Westf.: Leidorf, 47-57.

Jaeger, M., Czebreszuk, J., Kneisel J. and Müller, J. 2016. Human remains from the Early Bronze Age fortified settlement in Bruszczewo. Preliminary report, in: Gogâltan, F., Ailincăi, S.-C. (eds.), *Settlements of Life and Death. Studies from Prehistory to Middle Ages. Proceedings of an International Colloquium Tulcea, 25th-28th of May 2016*. Cluj-Napoca: Editura MEGA, 51-70.

Karg, S., Bauer, S. and Fingerhut, D. 2004. Erste botanische Großrestanalyse aus dem östlichen Feuchtbodenareal, in: Czebreszuk, J. and Müller, J. (eds.), *Bruszczewo I. Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens. 1. Forschungsstand – Erste Ergebnisse – Das östliche Feuchtbodenareal.* Studien zur Archäologie in Ostmitteleuropa 2. Rahden/Westf.: Leidorf, 264-274.

Kirleis, W. and Fischer, E. 2014. Neolithic cultivation of tetraploid free threshing wheat in Denmark and Northern Germany: implications for crop diversity and societal dynamics of the Funnel Beaker Culture. *Vegetation History and Archaeobotany*, 23, 81-96.

Klusek, M. and Kneisel, J. in prep. Woodland management practices in Bronze Age, Bruszczewo, Greater Poland. Environmental Archaeology.

Kneisel, J. 2010a. Aktivitätszonen und Ressourcennutzung in der Bronzezeit Großpolens, in: Horejs, B. and Kienlin, T. (eds.). *Siedlung und Handwerk. Studien zu sozialen Kontexten der Bronzezeit.* Beiträge zu den Sitzungen der Arbeitsgemeinschaft Bronzezeit 2007 Schleswig und 2008 Mannheim. Bonn: Dr. Rudolf Habelt GmbH, 173–190.

Kneisel, J. 2010b. Die Grabungskampagnen Bruszczewo 2004-2006, in: Müller, J., Czebreszuk J. and Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 92-164.

Kneisel, J. 2010c. Eine Siedlungsbestattung der Frühbronzezeit, in: Müller, J., Czebreszuk J. and Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens*. Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 724-729.

Kneisel, J., Bork, H.-R., Czebreszuk, J., Dörfler, W., Grootes, P., Haas, J.N., Heußner, K.-U., Hildebrandt-Radke, I., Kroll, H., Müller, J., Wahlmüller, N. and Ważny, T. 2008a. Bruszczewo – Early Bronze Age Defensive Settlement in Wielkopolska. Metallurgy, peat zone finds and changes in the environment, in: Czebreszuk, J., Kadrow, S. and Müller, J. (eds.). *Defensive Structures from Central Europe to the Aegean in the 3rd and 2nd millennium BC*. Poznań: Wydawnictwo Poznańskie/Dr. Rudolf Habelt GmbH, 155–170.

Kneisel, J., Czebreszuk, J., Dörfler, W., Grootes, P., Haas, J.N., Heußner, K.-U., Karg, S., Kroll, H., Müller, J., Wahlmüller, N. and Ważny, T. 2008b. Die befestigte frühbronzezeitliche Siedlung Bruszczewo: Metallproduktion, Feuchtbodenbefunde und ökologischer Kollaps? *Nachrichtenblatt Arbeitskreis Unterwasserarchäologie*, 14, 51-58.

Kneisel, J., Dal Corso, M., Kirleis, W., Taylor, N. and Tiedtke, V. 2015. The Third Food Revolution? Common Trends in Economic and Subsistence Strategies in Bronze Age Europe, in: Kneisel, J., Kirleis, W., Dal Corso, M., Scholz, H., Taylor, N. and Tiedtke, V. (eds.), *The Third Food Revolution? Setting the Bronze Age Table: Common Trends in Economic and Subsistence Strategies in Bronze Age Europe*. Proceedings of the International Workshop „Socio-Environmental Dynamics over the Last 12,000 Years: The Creation of Landscapes III (15th-18th April 2011) in Kiel. Bonn: Dr. Rudolf Habelt GmbH, 275-287.

Kneisel, J. and Kroll, H. 2010. Die Holzanalysen aus dem östlichen Feuchtbodenareal, in: Müller, J., Czebreszuk, J. and Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 566-651.

Kneisel, J., Müller, J., Szmyt, M. and Czebreszuk, J. (eds.) 2012. [bruszcewo] *Momentaufnahmen einer bronzezeitlichen Siedlung*, Neumünster: Wachholtz.

Kneisel, J. and Schaefer-Di Maida, S. (in print). Loom Weights in Bronze Age Central Europe: Unravelling change in textile production, in: Sabatini, S. and Bergerbrandt, S. (eds.). *Textile production and Trade in Europe during the second millennium BC*. 12th-13th March 2015 Gothenburg.

Kowiańska-Piaszykowa, M. 2008. Cmentarzysko kurhanowe z wczesnej epoki brązu w Łękach Małych w Wielkopolsce, Poznań, Muzeum Archeologiczne w Poznańiu.

Kroll, H. 2010. Die Archäobotanik von Bruszczewo – Darstellung und Interpretation der Ergebnisse, in: Müller, J., Czebreszuk, J. & Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 250-287.

Kroll, H. 2012. Der Kaktus der Bronzezeit: Die Eselsdistel *Onopordum acanthium* L., in: Stobbe, A. and Tegtmeier, U. (eds.), Verzweigungen. Eine Würdigung für A. J. Kalis und J. Meurers-Balke. *Frankfurter Archäologische Schriften*. Bonn: Dr. Rudolf Habelt GmbH, 189–192.

Mainka-Mahling, A. 2008. *LebensBilder. Zur Darstellung des ur- und frühgeschichtlichen Menschen in der Archäologie*. Remshalden: Verlag Bernhard Albert Greiner.

Makowiecki, D. 2004. Archäozoologische Untersuchungen zu den frühbronzezeitlichen Tierknochen aus ausgewählten Befunden, in: Czebreszuk, J. and Müller, J. (eds.), *Bruszczewo I. Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens. 1. Forschungsstand – Erste Ergebnisse – Das östliche Feuchtbodenareal*. Studien zur Archäologie in Ostmitteleuropa 2. Rahden/Westf.: Dr. Rudolf Habelt GmbH, 281-290.

Makowiecki, D. 2014. Opatowice – Prokopiak's Mount: testing ground for evaluating Animal husbandry and natural environment: the multicultural settlement at Bruszczewo, site 5. A study of faunal remains 1996-2008, in: Czebreszuk, J., Müller, J., Jaeger, M. and Kneisel, J. (eds.), *Bruszczewo IV. Natural resources and economic activities of the Bronze Age people.* Studien zur Archäologie in Ostmitteleuropa 14. Poznań: Wydawnictwo Naukowe UAM, 111-186.

Makowiecki, D. and Drejer, A. 2010. Chronologische und chorologische Analyse der in Bruszczewo gefundenen Knochenreste aus den Jahren 1964-1968, in: Müller, J., Czebreszuk, J. & Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 288-314.

Moser, S. 1992. The visual language of archaeology. A case study of neanderthals. *Antiquity*, 66, 831-844.

Moser, S. 1996. Visual representation in archaeology: depicting the missing-link in human origins, in: Baigrie, B.S. (ed.). *Picturing Knowledge: Historical and Philosophical problems Concerning the Use of Art in Science.* Toronto: University of Toronto Press, 184-214.

Müller-Wille, M. 1994. Der politische Machtmißbrauch der skandinavischen Vor- und Frühgeschichte während der Jahre 1933-1945. *Offa*, 51, 25-35.

Müller, J. 2004. Die östlichen Feuchtbodenareale: Stratigraphien und Architektur, in: Czebreszuk, J. and Müller, J. (eds.), *Bruszczewo I. Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens. 1. Forschungsstand – Erste Ergebnisse – Das östliche Feuchtbodenareal.* Studien zur Archäologie in Ostmitteleuropa 2. Rahden/Westf.: Leidorf, 99-134.

Müller, J. and Czebreszuk, J. 2003. Bruszczewo – eine frühbronzezeitliche Siedlung mit Feuchtbodenerhaltung in Großpolen. Vorbericht zu den Ausgrabungen 1999-2001. *Germania*, 81, 443-480.

Müller, J., Czebreszuk, J. and Kneisel, J. (eds.) 2010. *Bruszczewo II. Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens*. Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH.

Müller, J. and Kneisel, J. 2010. Bruszczewo: Production, distribution, consumption and the formation of social differences, in: Kneisel, J., Müller, J. and Czebreszuk, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 756-782.

Müller, W. 1983. *Einleitung. Anschauung und Ideologie – Schulwandbilder der NS-Zeit aus Duisburg*. Begleitheft einer Ausstellung des Archivs „Schulisches Wandbild" der Univ. Duisburg im Niederrheinischen Museum der Stadt Duisburg 4. Mai bis 14. Aug. 1983, Duisburg, Dezernat für Kultur und Bildung.

Rassmann, K. 2010. Neue chemische Analysen von Kupferartefakten aus der Siedlung von Bruszczewo, in: Müller, J., Czebreszuk, J. and Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 712-722.

Šálková, T., Divišová, M., Kadochová, Š., Beneš, J., Delawská, K., Kadlčková, E., Němečková, L., Pokorná, K., Voska, V. and Žemličková, A. 2011. Acorns as a Food Resource. An Experiment with Acorn Preparation and Taste. *Interdisciplinaria archaeologica natural sciences in archaeology (iansa)*, 2, 139-147.

Schaefer, S. 2016. Die Textilkeramik im Kontext Nord- und Mitteleuropas am Fallbeispiel der befestigten Siedlung "Bruszczewo" (Kościan, Großpolen). Master-Thesis, Kiel University.

Schrader, C. 2017. Aufbruch in die Moderne. Abenteuer Bronzezeit. Frühe Städte, Handel, Krieg. Unsere Welt vor 4000 Jahren wird neu entdeckt. *National Geographic*, Oktober, 40-63.

Schwenzer, S. 2004. Przysieka Polska – Ein Grabfund in der Umgebung der frühbronzezeitlichen Siedlung von Bruszczewo, in: Czebreszuk, J. and Müller, J. (eds.), *Bruszczewo I. Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens. 1. Forschungsstand – Erste Ergebnisse – Das östliche Feuchtbodenareal.* Studien zur Archäologie in Ostmitteleuropa 2. Rahden/Westf.: Leidorf, 317-324.

Siefert, H. 2005. Hygiene, in: Gerabek, W.E., Haage, B.D., Keil, G. and Wegner, W. (eds.). *Enzyklopädie Medizingeschichte*. Berlin: De Gruyter, 647.

Sorrell, A. 1977. The Artist and Reconstruction. *Current Archaeology*, 41, 177-181.

Stoczkowski, W. 1997. The painter and prehistoric people, in: Molyneaux, B. L. (ed.). *The Cultural Life of Images. Visual Representation in Archaeology*. London: Routledge, 249-262.

Strachan, D.P. 1989. Hay fever, hygiene, and household size. *British Medical Journal*, 299, 1259-1260.

Ważny T. 2010. Bericht zur Dendrochronologischen Datierung von Bruszczewo, Grabungen 2004-2005, in: Müller, J., Czebreszuk, J. and Kneisel, J. (eds.), *Bruszczewo II – Ausgrabungen und Forschungen in einer prähistorischen Siedlungskammer Großpolens.* Studien zur Archäologie in Ostmitteleuropa 6. Bonn: Dr. Rudolf Habelt GmbH, 232-237.

Wölfle, S. 2017. *Archäobotanische Untersuchungen zum häuslichen Wirtschaften in der frühbronzezeitlichen Siedlung Bruszczewo, Polen.* Master-Thesis, Kiel University.

HOW'S LIFE? Living Conditions in the 2nd and 1st Millennia BCE

During the Bronze and early Iron Ages many developments occurred in metalworking, social structure, production, nutrition and diet. At the same time the networks in Europe were intensified and human impact on the environment changed in character. What influence did these transformations have on human daily life? Which proxies can researchers use to study such topics?

Scientific contributions from different fields of expertise within modern archaeology are presented here in order to investigate past living conditions through aspects related to production (e.g. of food and metal), well-being (e.g. diet, health), interrelations (e.g. violence) and the local environment (e.g. pollution, waste and water management). Further, modern graphic representation of Bronze Age living conditions are critically addressed.

This volume of proceedings compiles contributions from to the homonymous session organised for the international workshop of the Graduate School "Human Development in Landscapes", entitled "Socio-environmental Dynamics over the Last 12,000 Years: The Development of Landscapes IV", which took place in 2017 in Kiel. Following the publication of overarching core research on subsistence systems, societal transformations, and resilience versus disruption dynamics, this volume aims to take a closer look at the everyday life of past communities.

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