University of Reading

Fire in the round: a holistic approach to the Lower Palaeolithic record

Article

Accepted Version

Creative Commons: Attribution-Noncommercial-No Derivative Works 4.0

Scott, R. V. and Hosfield, R. ORCID: https://orcid.org/0000-0001-6357-2805 (2021) Fire in the round: a holistic approach to the Lower Palaeolithic record. Journal of Archaeological Science: Reports, 37. 102938. ISSN 2352-409X doi: https://doi.org/10.1016/j.jasrep.2021.102938 Available at https://centaur.reading.ac.uk/96890/

It is advisable to refer to the publisher's version if you intend to cite from the work. See Guidance on citing.

To link to this article DOI: http://dx.doi.org/10.1016/j.jasrep.2021.102938

Publisher: Elsevier

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the End User Agreement.

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

Author's Original Manuscript – Postprint

This is an Author's Accepted Manuscript of an article published as: Scott, R.V. & Hosfield, R. In press. Beyond arrows on a map: the dynamics of Homo sapiens dispersal and occupation of Arabia during Marine Isotope Stage 5. *Journal of Archaeological Science: Reports*.

Fire in the Round: A holistic approach to the Lower Palaeolithic record

Rebecca V. Scott[1,2*] and Rob Hosfield[1]

[1.] Department of Archaeology, Whiteknights, University of Reading, RG6 6AB, United Kingdom

[2.] Department of Archaeology, Streatham Campus, University of Exeter, EX4 4QE, United Kingdom

*Corresponding author

Email: rebecca.scott@pgr.reading.ac.uk Tel: +44 (0) 118 378 8132

Abstract

Whilst several explanations have been proposed for the absence of fire-related behaviours at well preserved Lower Palaeolithic sites, much of the emphasis of previous research has concentrated on our ability to find fire in the archaeological record. Furthermore, evolutionary models of early hominin fire engagement have often been developed and discussed in the context of early African hominins. Here we explore the role of fire in the behaviours, choices and lives of hominins during the earliest occupations of temperate regions, with a focus on Europe. We consider fire use in the context of Europe's specific palaeoenvironmental conditions and discuss whether a long or short fire chronology model best fits the current evidence for the use of controlled fire in these regions during the Lower Palaeolithic.

We propose two models for hominin fire behaviours in the temperate latitudes, using a heuristic 'macroscale to microscale' approach to understanding the needs for — and the use of — fire during this period. We argue that such holistic approaches must combine experimental work, experiential observations and cost-benefit approaches and should consider site context and function, fire function, social behaviour, and mobility, to evaluate the limited evidence for fire use in the Lower Palaeolithic. We highlight that, varying with seasonality, fire function (and the associated costs and benefits) was of particular importance and may explain the overall paucity of evidence for fire use in temperate regions prior to the Middle Palaeolithic. This has implications for other potential survival

strategies that are invisible in the early archaeological record, such as shelter, clothing, and the putrefaction of meat for later consumption.

Key words

Controlled use of fire, Lower Palaeolithic, hearths, Europe, hominin use of fire

Highlights

- Review of European Lower Palaeolithic fire evidence
- Posits two heuristic models of fire needs and likely settings
- Key issues for understanding the Lower Palaeolithic fire record are highlighted
- Recommends a 'holistic' approach to understanding the needs for and use of fire

1. Introduction

Understanding the use of fire before the later Middle Pleistocene (*c*. 478–130 thousand years ago [ka]) in the temperate latitudes (broadly defined as between 30–60° N and S of the equator) is fundamental to our understanding of hominin behavioural adaptions prior to the Middle Palaeolithic. Evidence of hominin occupation in northern Europe before *c*. 780 ka (e.g., in the Loire River basin, central France; Despriée et al., 2011; Moncel et al., 2013) is suggested to represent relatively brief forays into this region as opposed to sustained occupations (Dennell and Roebroeks, 1996; Hosfield and Cole, 2018; Roebroeks and Kolfschoten, 1994). The increasing size and number of lithic artefact assemblages post-500 ka suggest the development of new technologies and environmental adaptations associated with more substantial and/or sustained occupations (Lewis et al., 2019). One of these emerging new technologies is suggested to be the controlled use of fire (Davis and Ashton, 2019), with the earliest accepted European evidence for this in the form of hearths from sites at Vértesszőlős (Hungary), dated to MIS 13, and Beeches Pit (UK), Menez-Dregan and Terra Amata (France; Figure 1), dated to MIS 11 in the Middle Pleistocene (see Kretzoi and Dobosi, 1990; de Lumley, 2006; Moigne et al., 2015; Preece et al., 2006; Ravon et al., 2016).

Discussions of fire are complicated by terminology. Sandgathe (2017) has highlighted problems with the term 'control': namely that it overlooks the process of development of pyrotechnology, as it does not imply fire-making abilities (Sandgathe, 2017: S361). Here, we define 'control of fire' to mean an intentional act of manipulating fire, whether kindled at will or not. In contrast 'routine' (or 'habitual') fire use is defined here as when its use became a regular occurrence in the hominin technological repertoire. Extant fire studies have also varied markedly in scale. Villa and Roebroeks (2011) take a continental perspective to understanding the development of controlled fire use, whilst other research has focused on understanding the use of fire from a site-specific perspective (e.g., Tabun Cave, Israel; Shimelmitz et al., 2014; Roc de Marsal and Pech de l'Aze, France; Goldberg et al., 2012; Aldeias et al., 2012).

A variety of models have discussed the circumstances of the earliest hominin engagement with fire and its 'discovery' (e.g., Chazan, 2017; Gowlett, 2010, 2016 ; Parker et al., 2016; Wrangham, 2009). Yet models of fire discovery have often been developed and discussed in the context of early African hominins; there are few that consider the specific conditions of temperate latitudes, especially if an earlier (pre-500 ka BP) age for controlled fire use is favoured. A key ongoing debate is therefore whether a long fire chronology (beginning with early *Homo*, potentially *H. erectus*, e.g., Gowlett, 2016; Wrangham and Carmody, 2010) or shorter fire chronology model (arguing that habitual controlled fire use did not begin until the late Pleistocene, e.g. Sandgathe et al., 2011b) best fits the evidence for the use of controlled fire in temperate regions. Robustly evaluating these competing chronological hypotheses is critical for understanding the scale and scope of fire use in the earliest occupations of Europe.

We review the Lower Palaeolithic archaeological record of the temperate regions and models for the use of fire, illustrated with examples from central and western Europe. Using known archaeological and ethnographic examples as a basis for definition, we define a hearth as a *localised*, *spatially discrete* and *maintained* fire. With specific regard to size, both ethnographic and archaeological examples (e.g. de Lumley, 2006; Gowlett et al., 2000; Mallol et al., 2007) suggest hearth sizes from around 30 cm to *c*. 1 m in diameter. We aim to examine why the fire record for the European Lower Palaeolithic is so scarce and build a heuristic model of fire needs, likely settings, and potential fire 'signatures', contrasted against existing models of Middle Palaeolithic fire use by Neanderthals. We conclude by offering predictions of what this fire evidence may look like, and where and how we can develop our understanding in future. This review therefore posits new models for the use of fire in the European Lower Palaeolithic and aims to highlight the key issues and challenges in our understanding of the Lower Palaeolithic fire record in temperate environments.

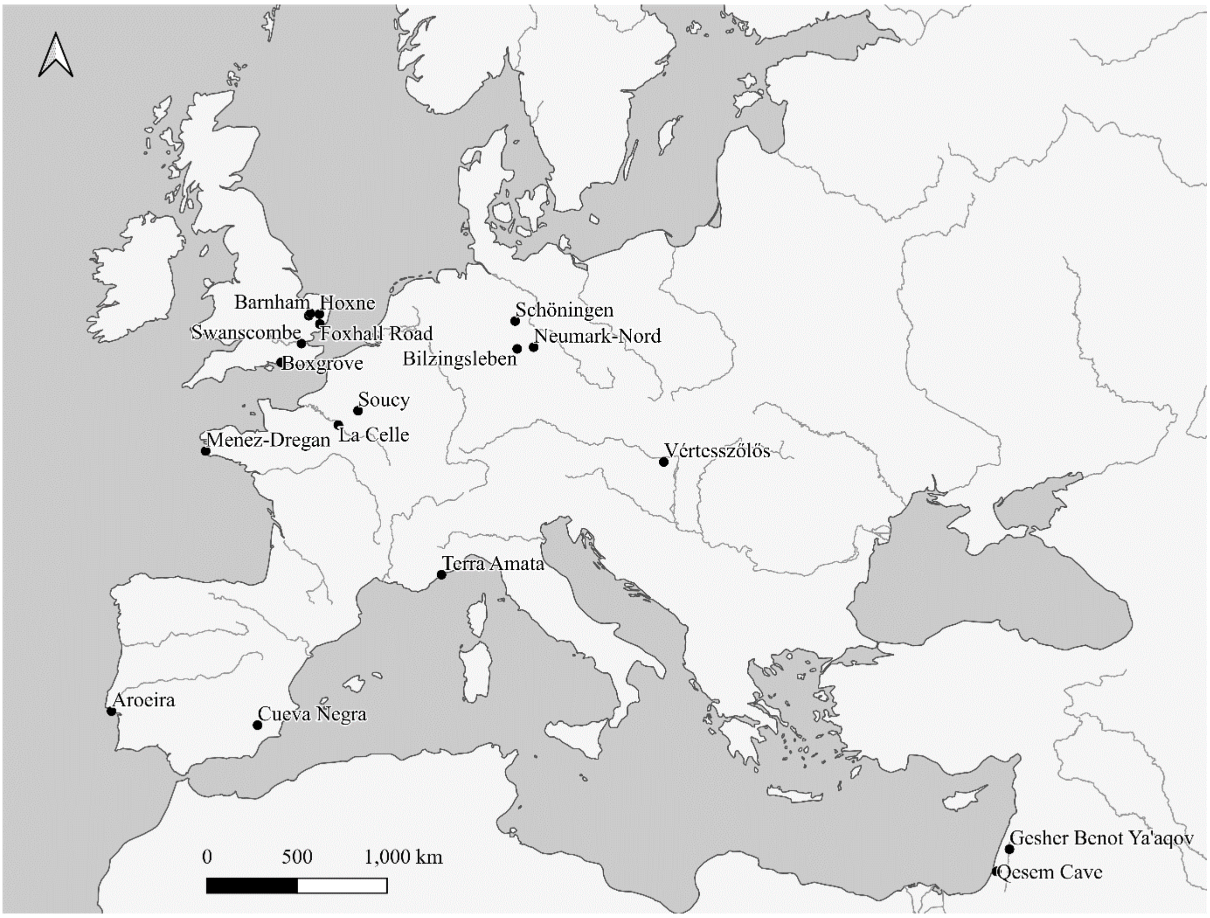

Figure 1: Map of Lower and Middle Palaeolithic sites mentioned in the text. Made with Natural Earth. Free vector and raster map data @ naturalearthdata.com

2. Fire use

2.1 A long or short chronology?

Roebroeks and Villa (2011) present a convincing argument that the routine use of fire became a part of hominin life from around MIS 9 (*c*. 330 ka), with a steady increase in both the frequency of fire evidence and the diversity of fire use from MIS 5 (*c*. 130 ka) onwards. It is suggested that routine fire use was not an essential pre-adaptation to the occupation of northwest Europe (Aldeias, 2017; Aldeias et al*.*, 2012; Dibble et al*.*, 2018; Sandgathe, 2017), although others have proposed that the sustained occupation of the high latitudes led to the routine use of fire as a cultural development (e.g., Attwell et al., 2015). The former view is broadly supported by Sandgathe et al*.*'s suggestion of a late date for *habitual* use of fire, perhaps even as late as MIS 3 (*c*. 60 ka) (Sandgathe et al., 2011b). The ability of Neanderthals to produce fire is also under debate with the evidence for fire use by Neanderthals variable across time and space (see Dibble et al., 2018; Sandgathe et al., 2011a, 2011b; Sorensen, 2017; Sorensen et al., 2018). These ongoing debates highlight the difficulties and complexities in understanding fire use, even in later contexts.

There is further opposition to the short chronology model for habitual fire use suggested by Sandgathe et al*.* (2011a; 2011b). The 'Cooking Hypothesis', proposed by Wrangham (2009) and Wrangham and Carmody (2010), advocates a long chronology for fire use by *Homo*, linked with the expansion of brain size and other biological changes (e.g., gut reduction). Optimal foraging models suggest energy gain is maximised through pre-digestion processing of food (e.g., by cooking, pounding, consumption of rotting or rotten foods, or gastrophagy; see Buck et al., 2016; Speth, 2017). Wrangham and Carmody (2010) argue that the small mandible, smaller post-canine tooth areas, reduced masticatory strain in the form of facial shortening, and the 'barrel-shaped' thoracic cage of *H. erectus* are evidence of an early cooked diet, with the use of fire in cooking developing from fire's initial role in providing night-time protection from predators. As Wrangham and Carmody (2010) state, this is a solution to the seemingly paradoxical human life history model as the efficiency of provisioning is increased, and extrinsic mortality is reduced (Wrangham and Carmody 2010: 193). However, archaeological evidence for Wrangham's hypothesis is weak, and other causes of brain expansion in hominins during this time have been suggested (e.g., Cornélio et al., 2016; Shipman, 2009; Wrangham, 2017). Gowlett (2010) also argues for a long chronology of fire use, linked with encephalisation and beginning over 1.5 Ma. He argues that its use is deeply tied both to our biological, social, and technological evolution (Gowlett, 2010: 342).

2.2 Beyond the site?

Discussions of controlled fire use, with their emphasis on cooking, toolmaking, and sociality, have sometimes ignored the geography of hominin fire. As Gowlett (2010) explicitly summarises, larger scale fire use, such as landscape burning, taking advantage of foraging in fire-prone environments, (Herzog et al., 2016; Hoare, 2019; Parker et al., 2016; Pruetz and Herzog, 2017), or niche construction (the process of modifying one's local environment; Odling-Smee et al., 2003) has been somewhat neglected within the archaeological community. As Gowlett argues, concentrating on the identification of preserved hearths likely misses a large part of the overall picture of fire use by Pleistocene hominins, since even if heat-altered materials such as flint and bone are not indicators of hearths, they infer the availability of fire in the wider landscape (Gowlett, 2010). Optimal models of foraging by extant species in fire-prone environments, using prey choice models (as highlighted by Hoare, 2019 and Pruetz and Herzog, 2017), indicates a reduction in biomass, which increases encounter rates with profitable resources, search efficiency for high ranked food items and energetic profitability of food items cooked in natural fires. In short, models of potential fire use by the earliest European hominins need to look beyond the hearth and the site and consider the importance of burnt landscapes within those discussions.

3. Where are the Lower Palaeolithic hearths?

The lack of evidence for the controlled use of fire in the form of hearths before the later Middle Pleistocene in the temperate latitudes, and the general paucity of the Lower Palaeolithic fire record, is fundamental to our understanding of hominin behavioural adaptions prior to the Middle Palaeolithic. It has implications for the likelihood, and relative importance, of other survival strategies that are largely invisible in the early archaeological record. These external 'cultural insulation features' (*sensu* Hosfield, 2016) such as shelter and clothing (Gilligan, 2010; Hosfield, 2016; MacDonald, 2018) would likely have been required for hominin occupation in these higher latitudes *in the absence of significant body hair* (see MacDonald, 2018; Hosfield, 2020). This would have been the case even during peak interglacials, as pronounced seasonality requires insulation from cool winter temperatures, regardless of the robust bodies indicated by the hominin fossil record (e.g., Trinkaus et al., 1999) and other potential physiological adaptations (e.g., Steegmann et al*.,* 2002). An absence of fire for cooking raises further questions with regards to the nutritional and processing challenges posed by raw foods, although the putrefaction of meat for later consumption may have been an alternative dietary behaviour in the northern latitudes (Speth, 2017).

There are two potential answers to the question of why there is such a limited record of controlled fire use evidence in Lower Palaeolithic Europe: the first is that hominins did not control fire during the Middle Pleistocene; the second is that preservation and sampling biases hinder the identification of fire behaviours (e.g. because these fires are small in scale, highly ephemeral, and/or because we are looking at locations in the landscape in which fire use is unlikely to have taken place; Table 1 illustrates the nature of the currently known Lower Palaeolithic evidence from northern Europe). Here we evaluate these two hypotheses by developing a holistic model of what pristine Lower Palaeolithic fire records *might* look like (whilst acknowledging that there is likely to be more than one *type* of record), and by generating predictions of the traces that we should be seeking, and where these might be located.

Table 1: Key sites with direct and indirect evidence for fire or fire use in northern Europe during the Middle Pleistocene. Data from Roebroeks and Villa (2011; Supplementary data). Note the paucity of sites and the predominance of sheltered locations (e.g., springs, rock shelters). There are also small numbers of other possible 'fire sites' in adjacent areas of Europe: e.g., Vértesszőlős (Hungary: Kretzoi and Dobosi, 1990), Terra Amata (southern France: de Lumley, 2006), Aroeira (Portugal: Sanz et al.*, 2020), and Cueva Negra (Spain: Rhodes* et al.*, 2016; Walker* et al.*, 2013).*

Site and location	Age	Nature of evidence	Landscape setting	Original source(s)
Beeches Pit (UK)	MIS 11	Direct and indirect (heated lithics, burned bone and sediment)	Spring	(Gowlett, 2006; Preece et al., 2006)
Bilzingsleben (Germany)	MIS 11-9	Direct and indirect (charcoal, reddened/cracked pebbles, and tufa)	Spring	(Mania and Mania, 2005)
Barnham (UK)	MIS 11	Indirect (dispersed charcoal, heated lithics)	Alluvial	(Ashton et al., 1994)
Menez-Dregan (France)	MIS 11-7	Direct and indirect (dispersed charcoal, heated lithics, quartz pebbles, and granite slabs)	Rock shelter	(Mercier et al., 2004; Ravon et al., 2016; Monnier et al., 2016; Ravon et al., 2019)
Foxhall Road (UK)	MIS 11	Indirect (? heated sediment and lithics)	Alluvial and lacustrine	(White and Plunkett, 2004)

3.1. Option A: Hominins occupying Europe during the Early and Middle Pleistocene did not control fire

Option A suggests that the hominin species present in Europe at this time (i.e. *H. heidelbergensis sensu lato* and/or early *H. neanderthalensis*) could not control fire, or that, despite the contemporary presence of fire traces in other parts of the Lower Palaeolithic/Early Stone Age world such as the Middle East (e.g. Gesher Benot Ya'aqov, Israel; Alperson-Afil, 2008; Goren-Inbar et al., 2004) and East Africa (e.g. Koobi Fora, Kenya; Hlubik et al., 2019), controlled fire use was not a necessary behavioural adaptation for Lower Palaeolithic hominins in this region. The latter seems unlikely given the position of Europe at the high latitude 'edge' of the Lower Palaeolithic world. The environmental context of hominin occupation in temperate regions, e.g., Europe, is significant for our understanding of fire use, particularly in relation to fire function. Table 2 summarises palaeoclimatic and palaeoenvironmental conditions for a selection of Lower Palaeolithic sites in north-central and north-western Europe, based on Ashton and Lewis (2012). This regionally specific list is not intended to be comprehensive but rather to convey the variable conditions associated with hominin occupations, and the environmental contexts of the significant changes that occur in occupation patterns and technological behaviours in northern Europe post-MIS 13 (Hosfield and Cole, 2018).

Table 2: Temperature estimates and environmental contexts for selected northern European Lower Palaeolithic sites highlighting the variety of conditions associated with hominin occupation of the region.

Site	Age	T_{min}(°C)	T_{max}(°C)	Landscape setting	Local vegetation	Regional vegetation	Evidence	Source
Happisburgh 3 (UK)	MIS 25/21	-3 – 0	16 – 18	Alluvial	Grassland	Coniferous	Coleoptera	Ashton and Lewis (2012); Parfitt et al., (2010)
Pakefield (UK)	MIS 19/17	-6 – 4	17 – 23	Alluvial	Grassland	Deciduous	Coleoptera	Coope (2006)
Boxgrove (Unit 4b and 4c) (UK)	MIS 13	-4 – 4	15 – 20	Spring, lagoon	Grassland/scrub	Mixed	Ostracods (MOTR), herpetofauna (MCR)	Ashton and Lewis (2012); Holman, (2000); Holmes et al., (2010)
Barnham (Unit 5c) (UK)	MIS 11	?	>17	Alluvial	Grassland	Deciduous	Herpetofauna	Holman (1998)
Beeches Pit (Bed 3b) (UK)	MIS 11	-8 – 15	9 – 24	Spring	Forest	Deciduous	Ostracods (MOTR)	Benardout (2015)
Swanscombe (Lower Loam) (UK)	MIS 11	-3 – 4	15 – 19	Alluvial	Grassland	Deciduous	Ostracods (MOTR)	White et al., (2013)
Soucy (France)	MIS 9	Temperate	Temperate	Alluvial	Forest	Deciduous	Molluscs	Limondin-Lozouet (2001)
Bilzingsleben (Germany)	MIS 11	-0.5 – 3	20 – 25	Spring	Grassland	Deciduous	Molluscs, ostracods	Mania and Mania (2005); Mania (1995)
La Celle (France)	MIS 11	Temperate	Temperate	Spring	Forest	? Deciduous	Molluscs	Limondin-Lozouet et al., (2010)

From a Lower Palaeolithic perspective, it is important to acknowledge the potential need for fire as cultural insulation in other, non-European, regions and settings, for example in the highlands of East Africa (e.g., between Nov-Jan at Addis Ababa, at c. 2350 m asl, average minimum temperatures for the period 1982–2012 were *c*. 7°C; Climate-Data.org, n.d.). The possibility that the 'discovery' and 're-discovery' of fire-making was a punctuated event that occurred multiple times in different regions and at different times during the Middle Pleistocene due to independent invention and/or cultural exchange behaviours could (at least in part) explain the sporadic on-site fire record, both in

Europe and elsewhere (Sandgathe, 2017). Moreover, an inability to reliably produce fire does not necessarily mean an inability to exploit it (i.e., obtain benefits), and so other fire signatures, e.g., hominin activity in association with wildfire traces, might still occur, particularly given the advantages of foraging in fire-prone landscapes (e.g., new plant growth, the opening of the landscape enabling different mobility strategies). The key challenge in evaluating this scenario concerns the identification of wildfire evidence and establishing whether traces of hominin activity are related to it.

3.2 Option B: Hominins occupying the Europe during the Early and Middle Pleistocene did control fire, but the record is hindered by poor preservation, identification and/or recovery

Option A has of course ignored the problems of preservation. Detection of fire-making and fire-altered materials on open air sites dated to the Lower Palaeolithic is rare (see Table 1) regardless of the range of techniques able to identify heated archaeological materials (e.g., FTIR, magnetic susceptibility and remanence, thermoluminescence, organic petrology, lipid analysis; see Goldberg et al., 2017; Mentzer, 2014 for a full list of analytical approaches). The most common fire proxies (products resulting from burning, *sensu* Aldeias, 2017) from fires are seldom preserved in open air sites since they are readily removed by wind and water (e.g., remains of fuel such as ash and charcoal). These problems are accentuated by the relatively small number of cave and rock shelter sites (e.g., Menez-Dregan, northern France), compared to temperate open-air sites for this period.

3.2.1 Preservation of direct fire proxies

Ash and charcoal are the primary solid products of burning. Their appearance in archaeological contexts is dependent on soil chemistry, weathering, and other biochemical processes. Ash is not always visible in archaeological contexts owing to its easy removal from the soil surface and poor preservation potential (Braadbaart et al., 2012): it is especially vulnerable to dissolution in temperate environments by percolating water, and in acidic soil conditions (Mentzer, 2014). Given this, the absence of Lower Palaeolithic fire evidence in some areas of the Mediterranean, with hot, dry summers, is potentially striking, although ash traces on open-air sites would be vulnerable to percolating water during mild, moist winters. In that regard, the sheltered context of the fire traces at Aroeira, Portugal and Cueva Negra, Spain is noteworthy (see Sanz et al., 2020; Rhodes et al., 2016; Walker et al., 2013). The occurrence of charcoal in archaeological contexts is dependent on fuel type (and condition), and the preservation and combustion conditions (Mentzer, 2014: 630). Although less subject to physical and chemical decompositions in soils compared to ash, charcoal degrades more quickly in alkaline environments due to oxidation processes (Cohen-Ofri et al., 2006), including being buried alongside ash (Huisman et al., 2012). Excavation and analysis introduce further methodological challenges; both ash and charcoal are vulnerable to trowelling, sieving and flotation (Matthews, 2010), and block sampling of sediments is usually required where ash is thought to be present (Braadbaart et al., 2012).

3.2.2 Preservation of indirect fire proxies

Owing to the challenging preservation of charcoal and ash, indirect proxies (fire-altered archaeological materials; Aldeias, 2017: S193) offer alternative means to identify past uses of fire. These include materials that were exposed to fire, such as heated flints, bone, or sediment (Aldeias, 2017). Heated flints are found occasionally at archaeological sites (e.g., Barnham, UK; Debenham, 1998), but they have also been identified in pre-Quaternary soils in France (Rolland, 2004) making their presence at some archaeological sites ambiguous since materials can be heated during natural landscape burning. This is a critical consideration when dealing with heated materials in contexts contemporary with a known presence of hominins in the local or regional landscape. Spatial analysis of heated flint assemblages has been undertaken at selected sites, e.g., at Gesher Benot Ya'aqov in Israel where it led to interpretations of 'phantom hearths' (Alperson-Afil, 2017, 2012, 2008; Goren-Inbar et al., 2004). The clustering of these artefacts across multiple layers may indicate repeated burning and re-visiting of the landscape by hominin groups, over a timescale of around 100,000 years (Goren-Inbar et al., 2000). As Gowlett (2010) highlights, even if these indirect proxies are not conclusive evidence of anthropogenic fire use, they do at the very least indicate the availability of fire in the wider landscape, forming a resource which humans could have taken advantage of (Herzog et al., 2016).

3.2.3 Variations in direct and indirect proxies

There are differences in the likelihood of finding traces of past fire-use in both 'off-site' and 'on-site' settings (see McCauley et al., 2020; Scherjon et al., 2015 for surveys of both on-and off-site fire use by modern hunter-gatherers). Experimental work, including ethno-geoarchaeological studies, have enabled a more nuanced understanding of the preservation of fires used for different functions and other variables controlling fire visibility (e.g., Aldeias et al., 2016; Bentsen, 2012; Canti and Linford, 2000; Liedgren et al., 2017; Mallol et al., 2007). Broadly speaking, the most visible fire features are those that are either protected from erosion, and/or have experienced burning at high temperatures, or for long durations of time (e.g., continuous burning for weeks or months; see Mallol et al., 2007). Both experimental and ethno-geoarchaeological studies have shown that the factors controlling the rubification (reddening) of sediments beneath hearths are unclear (Canti and Linford, 2000). It has been suggested that the amount and type of fuel has a strong influence on temperatures reached (and therefore the depth of hearth traces) beneath hearths (e.g. Liedgren et al., 2017), whilst in contrast, other experimental work suggests that there is little correlation between fuel load and the depth of hearth traces (Bentsen, 2012). Further research is required to determine the variables responsible for the visibility of past hearths, to fully assess the lack of evidence for small scale fire use in the Palaeolithic record.

4. What is a likely model of fire use?

Considering the above points, we propose two models for early fire use in Europe, dubbed habitual, or 'high fire' and opportunistic, or 'low fire'. Both propose hominin fire use, but within contrasting frameworks in terms of the types, purposes, locations, and frequencies of fire use (Table 3). The models are grounded in the idea that fire use has deep origins (in that sense they are in keeping with both Gowlett and Wrangham) and are also grounded in the current archaeological evidence for the use of fire in the Lower and Middle Palaeolithic periods. Whilst analysis of modern hunter-gatherers has shown a huge diversity in both on-and off-site fire use (e.g. McCauley et al., 2020; Scherjon et al., 2015) and is a potential source of insights, we are wary of using ethnographic comparisons which may not be sufficient to account for any differences between *Homo* species (see French, 2019). The 'high fire' model has a strong emphasis on habitual use, including for cooking, whilst the 'low fire' model is grounded in sporadic, opportunistic use and 'non-cooking' applications (i.e., cultural insulation, extending the day, foraging in fire-prone landscapes). The opportunistic, or 'low fire' model therefore follows the earlier stages of the Gowlett model (2010) and is based on a cost-benefit approach – i.e., an economic framework that compares the advantages of fire use to the costs associated with its control (e.g., Henry et al., 2018). Both models are intended as testable propositions that may be supported or refuted by future discoveries and further data.

Table 3: Two potential models for early fire use in Europe. Both models are intended as testable propositions that may be supported or refuted by future discoveries and further data.

Opportunistic or 'low fire' use	Habitual or 'high fire' use
Not for technology (e.g., mastics) or (or only rarely) for cooking; potentially for extending the day	Likely for cooking
Related to environmental conditions (i.e., keeping warm and dry)	Re-use of fire features
Not sustained	Sustained
Seasonal, geographically uneven patterns of use	Year-round, geographically even patterns of use

4.2 A habitual / 'high fire' model

In a long chronology model of controlled fire use (Section 2.1; e.g., Wrangham 2009), where control is both habitual and sustained and fire is explicitly linked to cooking, traces of past fire use are likely to be year-round and geographically even (assuming that Lower Palaeolithic hominins were residentially mobile through the year), with fire features likely to be re-used at residential sites. There is some evidence for the re-use of hearths in the Lower Palaeolithic, for example at the MIS 11 site of Beeches Pit it is suggested that there are several discrete, separate burning events at overlapping locations, based on the intersection of two burnt areas, interpreted as repetitive activities and evidence of repeated occupations (Gowlett et al., 2000; Preece et al., 2006). Longer term re-use of hearth locations, spanning separate occupation horizons, is also suggested at Menez-Dregan (MIS 11-7), Qesem Cave (MIS 11-9) and Gesher Benot Ya'aqov (MIS 19; Alperson-Afil, 2008; Karkanas et al., 2007a; Monnier et al., 2016; Shahack-Gross et al., 2014).

There is some claimed evidence for 'home bases' from sites such as Bilzingsleben, interpreted by Mania and Mania (2005) to indicate spatial differentiation, living structures and potential cleaning of the area, but differing interpretations of the patterns and the taphonomic complexities of the site have also been highlighted (Gamble, 1999; Müller and Pasda, 2011). Indeed, as Gamble writes, if the explicit aim is to identify shelters/home bases to outline Palaeolithic social behaviour then our analytical ingenuity means that we are likely to be able to find them (Gamble 1999: 169). Similar sentiments might perhaps be posited with respect to an over-focus on hearths as an on-site, social focus?

The fundamental current problem with the high fire model is that we simply do not have much evidence for fire and its use during the Early and Middle Pleistocene. Table 1 shows the landscape settings of the small number of northern European sites in which we do have some evidence. It is telling from these examples that the sites in which we do have evidence for controlled fire use are sheltered locations close to sources of water (e.g., springs and rock shelters).The number of well-preserved sites in which we do not find any evidence (e.g., Boxgrove, Hoxne, Schöningen) argues against our 'high fire' model, as otherwise we should expect to find fire traces in the other types of landscape settings represented at these latter sites.

4.2 An 'opportunistic' / low fire model

By considering the many ways and places in which fire can be accessed and used, we propose an alternative 'low fire' model which avoids casting early European hominins as truly 'fire free', but also recognises the current realities of the Lower Palaeolithic fire record. In this model, fire use is unlikely to be for technological (e.g., tool manufacturing) purposes since there is no evidence for mastics such as birch bark pitch in the archaeological record in this region at this time, with the earliest European evidence known from the site of Campitello Quarry, Italy, attributed to MIS 5 (the Late Pleistocene; Mazza et al., 2006). Whilst there is evidence for Lower Palaeolithic wooden tools (e.g., the Clacton spear point; Warren, 1911, Oakley, 1950, Oakley et al*.,* 1977), the earliest evidence for fire use in wooden tool manufacture comes from MIS 6 at Poggetti Vecchi (Italy; Aranguren et al*.,* 2018; but see also Fluck 2007). In this low fire model, the sporadic or 'opportunistic' nature of fire use implies that cooking occurred only rarely, or not at all. This view can be supported because of the potential for other mechanisms of pre-digestion (Speth, 2017), and because of the complex balance of costs/benefits with regards to cooking fires. Henry et al.'s calculations of the energetic costs of fuel gathering in different environments (e.g., forest, grassland), compared to energetic benefits (i.e., calories from cooked foods), suggests that at least some of the variability in the evidence of the use of fire may be due to hominins sometimes choosing not to make fire, i.e., when the costs would outweigh the benefits (Henry et al., 2018). Speth (2017) further highlights the potential importance of putrid meat and fish for Neanderthal diets with reference to modern Northern-forager diets, since in these high protein and fat-rich diets cooking is not required to preserve meat and fish, circumventing the need for fire where fuel is scarce, and/or bypassing the need to make fire at will. Fermentation and putrefaction of these foods could be undertaken by burial in shallow pits or by submerging under water, making it an energetically 'low-cost' method for softening and pre-digesting protein. It also allows for the preservation of these foods for weeks or even months, and produces and preserves essential vitamins (e.g., B-vitamins, vitamin C) that are often lost during cooking, drying or smoking processes (Speth, 2017: 56).

In this low fire model, the need for fire is not static and varies both with geography and changing seasonality. In the middle latitudes, including during peak interglacials, seasonality is pronounced, with cool winter temperatures that are often exacerbated by wind chill factors (Hosfield, 2016). In such a context the emphasis would be on fire as cultural insulation, although these benefits would be limited to the fire-side locations (see also Gilligan, 2017). Daylight hours are also reduced in winter, critically limiting the time for foraging during a period when the overall availability and quality of resources was low. Fire use would extend the day and enable all-day foraging, by backloading specific activities (e.g., socialising, eating) into the dark hours. To some extent this agrees with Gowlett's (2010) suggestion that the extension of daylight hours was a driving force for the controlled use of fire by hominins.

5. Where did fire use take place? Hominin habitats in the Early and Middle Pleistocene

One requirement of fully testing the low fire and high fire models is an assessment of where in the landscape fire traces are found. Unfortunately, such comparisons are complicated: Ashton et al*.* (2006) highlight the bias that impacts on landscape interpretations of hominin activity at interfluve, cave, and coastal localities in the British Lower Palaeolithic record of MIS 11 (the Hoxnian interglacial). Only detailed analysis of lake and river-edge habitats for Middle Pleistocene hominins in northwest Europe was possible, and this remains an ongoing probem (see also Pope et al*.,* 2016). As currently understood the majority of the Lower Palaeolithic archaeological record from Europe represents fluvial landscape settings (Santonja and Villa, 2006), although at least some of the material evidence may have been derived from interfluve areas. Fluvial locales provide a diverse landscape of animal, plant and lithic resources but are also important route-ways throughout these wider landscapes, although interfluve areas may have seen more regular visits from early *Homo* in periods characterised by cooler, more open conditions (Ashton et al., 2006). Since they currently dominate the record an important initial question concerns whether these fluvial locations were landscape settings within which fire use was likely to take place. These were relatively open environments in which hominins were likely to have experienced increased threats, e.g., from predators around water sources. This is not necessarily to say that these are locations in which fire use would not take place *at all* (e.g., as demonstrated by the burning traces at Barnham), but in our opinion any records are more likely to be ‘low fire’ traces of a highly ephemeral nature, and unlikely to be re-used hearths. Notably, the majority of those sites in which we do have some – often repeated – fire evidence (e.g., Menez-Dregan, Beeches Pit, and Bilzingsleben) are all located within either rockshelters (e.g., Menez-Dregan), or travertine/tufa outcrops (e.g., Beeches Pit and Bilzingsleben) indicating spring locations. The latter would have provided sheltered areas within ‘bowl-like’ depressions created by springs, as at Vértesszőlős (Fluck and McNabb, 2007: 63).

6. Finding fire: Testing the opportunistic / ‘low fire’ model

We have highlighted the key challenges to understanding the use of fire in the European Lower Palaeolithic record: 1) The amount of fire evidence and the location(s) of that evidence; 2) The fire use behaviours this evidence represents; and 3) The related question of fire function. Based on the evidence described in Sections 4 and 5, we tentatively propose that our opportunistic, or ‘low fire’, model is supported by the currently known archaeological record. To further test the ‘low fire’ model, a truly holistic approach is required. This should include experimental work, experiential observations, and cost-benefit analysis of the ‘micro-scale’ factors such as fuel provisioning (e.g., Henry et al., 2018), alongside further understanding of the wider archaeological and environmental context (the ‘macro-scale’ issues).

6.1 The quantity and location of fire evidence

We have shown that not only is the amount of evidence for fire use in the Lower Palaeolithic record of temperate regions limited to a very small number of sites (e.g., Beeches Pit, Menez-Dregan, Bilzingsleben and Vértesszőlős in central and north-western Europe; Table 2), but the location of these sites is focused on springs and rock shelters. The limited range of landscape settings represented by those sites in comparison to the wider archaeological record suggests either a) fire use was only taking place in selected locations within the landscape, or b) these landscape locations are those where fire is more likely to be preserved. Most plausible is a combination of both a) and b), leading to the currently observed bias in the overall Lower Palaeolithic fire record. Advancing our understanding of this issue will involve further, multi-disciplinary investigations of the taphonomy of fire proxies in a wider range of landscape settings (e.g., uplands and interfluvial areas). Whilst experimental work is key for understanding the taphonomic controls on the preservation and alteration of fire evidence in both open air and closed environments, ethnographic studies are potentially also useful in establishing the range of fire behaviours in these different locations, with the caveat that we are dealing with unique hominins for which we have no modern analogue (McNabb 2007: 348). Utilising ethno-geoarchaeological approaches to the visibility of anthropogenic fires in different geographic locations will certainly facilitate our understanding of fire preservation and how these differ between varying landscapes and climatic regimes (e.g., Mallol et al., 2007). As Mallol and Henry (2017: S227) have argued, experiments should not be replaced by ethno-archaeological research but rather the two approaches should be used in tandem to test hypotheses about archaeological contexts.

6.2 The type(s) of fire the evidence represents

The second key issue for our current understanding of the Lower Palaeolithic hominin fire record in temperate environments regards the nature of the evidence we do have, particularly the indirect evidence (e.g., heated lithics and bone) which are much more common in the temperate latitudes compared to direct proxies (see Section 4.2). The key issue here is understanding both how different types of fire use may (or may not) be preserved in the archaeological record (and what these traces may look like), and how other types of fire use might be distinguished from natural burning episodes. Sandgathe and Berna (2017) highlight Hlubik et al.,'s approach to the patterning of burned artefacts at Koobi Fora, Kenya (Cutts et al., 2019; Hlubik et al., 2019, 2017) which may be utilised for determining the likelihood of a natural fire as a cause of heated artefacts. Controlled wildfire experiments (e.g., Gowlett et al., 2017) and drawing on wildfire data from other disciplines should be a priority both for establishing a 'wildfire background' and understanding how different types of fire behaviour may (or may not) be preserved in the archaeological record. Similarly, the ethno-geoarchaeological approach highlighted in Section 6.3 will not only facilitate our understanding of fire preservation, but also what the traces of different types of fire may look like and how these may be identified in the archaeological record. Caution is advised when basing interpretations on macroscopic observations alone, as recent analysis of reddened patches formerly interpreted as hearths (now attributed to post-depositional iron precipitation and oxidation) at Schöningen 13 II-4 (Germany), has shown (Stahlschmidt et al., 2015). A reassessment of other known 'fire sites' using the micro-contextual approach undertaken in the analysis of Schöningen 13 II and 12 B should be a key future priority given the many approaches that can now be employed to assess whether sediments or artefacts have undergone heating. These micro-contextual approaches have already been applied to several sites (Qesem Cave, Israel; Schöningen, Germany; Wonderwerk Cave, South Africa, and Zhoukoudian, China; see Goldberg et al., 2017), but an assessment of more sites from the temperate latitudes is necessary. Where possible, a palaeoenvironmental approach should be used in conjunction with this micro-contextual analysis, assessing charcoal and microcharcoal assemblages, alongside palynological work. There are, of course, considerable difficulties with this approach, most importantly the potential time-averaging of Pleistocene deposits. Additionally, there are problems estimating the potential impacts of a wildfire background (e.g., transport of microcharcoal) as has been highlighted by Lebreton et al., (2019) for open-air Acheulean sites in Southern Italy.

6.3 Fire function

The third key outstanding question in our understanding of Lower Palaeolithic fire use relates to fire function. The desired function of a fire or hearth is important both for understanding the behaviours, choices and lives of hominins in the Lower Palaeolithic and because it is likely to determine the duration over which a fire burns, the location in the landscape a fire occurs at, the size of the fire, and the choice (type, amount, and state) of fuel collected (although a number of researchers suggest preferential use of dead, seasoned and/or partly decayed wood by both hunter-gatherers and early sedentary societies; see Delhon, 2018), all of which are factors affecting the archaeological visibility of past hearths (see Section 4.2.3). However, as Aldeias (2017) highlights, determining the function of a hearth is challenging for several reasons, including the fact that many functions are untestable, and light and warmth result from the burning of fuel, regardless of the intended function. Additionally, fires may serve more than one desired function at a time and the needs for different functions are likely to change seasonally and at shorter temporal intervals, depending on the environment and preferred hominin habitats. As Aldeias (2017) suggests, it might be possible to begin to assess fire function by using specifically targeted experiments, comparing evidence from multiple sites, and building testable hypotheses based on these comparisons (e.g., assessment of heat and light properties of different fuels; see Hoare, 2020). Utilising cost-benefit approaches, such as Henry et al. (2018)'s approach to cooking, for different fire functions will also be useful for advancing understanding of hominin fire behaviours.

Establishing local environmental conditions at Middle Pleistocene sites is slightly less elusive than determining fire function. However, exactly how these environmental conditions related to needs such as keeping warm and dry, extending the day, or cooking, and the likelihood of hearths being a manifestation of all (or any combination) of these functions is challenging. Interestingly, the correlation of the Beeches Pit sequence to the Marks Tey $\delta^{18}O$ record suggests the earliest examples of fire use identified at Beeches Pit (Bed 3b) took place during a period of climatic cooling. Similarly, the later evidence for fire in Beeches Pit (Beds 5 and 6) is associated with climatic deterioration at the end of the MIS 11 interglacial, tentatively suggesting that this particular use of fire was associated with keeping warm and dry during climatic deteriorations (Sherriff, 2016: 326). Fire use as niche construction has received much less attention to date than the use of hearths per se, although it has been considered for Neanderthals in forested environments during the last interglacial (e.g., at Neumark-Nord 2; see Roebroeks and Bakels, 2015). Nonetheless it is an important avenue to consider, although again truly interdisciplinary work will be required to establish whether any traces of larger-scale landscape burning is a) preserved and b) can be distinguished from natural burning episodes. Identifying the re-use of hearth features is also difficult, with re-use able to be identified only at those sites where fires have taken place in overlapping locations (e.g., Beeches Pit), or those that have undergone sediment deposition between burning episodes (e.g., Qesem Cave; Barkai et al., 2017; Karkanas et al., 2007b; Shahack-Gross et al., 2014). Other sites (e.g., Gesher Benot Ya'aqov, Menez-Dregan) indicate repeated visits, alongside associated burning events, but these represent re-use on a much longer timescale, over hundreds of thousands of years (Goren-Inbar et al., 2000; Monnier et al., 2016).

7. Conclusions and final comments

We have argued that the nature of fire records can be valuably understood using a holistic approach encompassing experimental, experiential, and cost-benefit approaches. Considering these aspects in combination allows us to build a more detailed understanding of the behaviours, choices, and lives of hominins during the earliest occupations in the temperate latitudes. We suggest that, in the absence of habitual cooking, fire was used for other purposes, such as niche construction through cultural insulation, but ultimately as an opportunistic technology. This is consistent with the current evidence for fire use in temperate regions prior to MIS 9 (*c*. 300 ka), as evidenced by indirect proxies at sites such as Barnham, Beeches Pit, Bilzingsleben, Menez-Dregan, and Vértesszőlős. Our analysis complements other long chronology models of hominin fire engagement, particularly that of Gowlett (2010, 2016) and Chazan (2017), where a long chronology of opportunistic fire use is favoured. Both models of fire use presented here have pertinent implications for understanding evolving hominin behaviours and human-environment interactions during the early spread of hominins through the temperate latitudes e.g., cultural insulation and dietary strategies in Europe prior to the Middle Palaeolithic.

It is not the intention of this paper to be pessimistic about research regarding the use of fire in the early archaeological record. Instead, we have aimed to highlight some of the complexities involved.

We have emphasised the various methods through which we can continue to interpret the archaeological record of fire us, underpinned by an evolutionary approach *sensu* Sandgathe and Berna (2017). Future research can only be improved by a 'holistic' approach to the archaeological record, which encompasses wider landscape-scale and contextual issues around the Palaeolithic record itself (the 'macroscale') and smaller-scale processes at the meso-and microscale.

Acknowledgements

This work was supported by the AHRC South, West and Wales Doctoral Training partnership (Grant AH/L50/3939/1). The authors would like to thank participants of the 2018 Palaeofire workshop held at the University of Reading (funded by the School of Archaeology, Geography and Environmental Science, University of Reading), and the 2019 Fire workshop held at the British Museum (funded by the British Museum – University of Reading Joint Development Fund) for fruitful discussions that helped develop several ideas in this paper. We also thank the 2019 Trial by Fire conference team and organisers, Professor Martin Bell, and Sam Nicholson for their helpful comments on earlier paper drafts, and two anonymous reviewers for their constructive comments.

References

Aldeias, V., 2017. Experimental Approaches to Archaeological Fire Features and Their Behavioral Relevance. Curr. Anthropol. 58, S191–S205. https://doi.org/10.1086/691210

Aldeias, V., Dibble, H.L., Sandgathe, D., Goldberg, P., McPherron, S.J.P., 2016. How heat alters underlying deposits and implications for archaeological fire features: A controlled experiment. J. Archaeol. Sci. 67, 64–79. https://doi.org/10.1016/j.jas.2016.01.016

Aldeias, V., Goldberg, P., Sandgathe, D., Berna, F., Dibble, H.L., McPherron, S.P., Turq, A., Rezek, Z., 2012. Evidence for Neandertal use of fire at Roc de Marsal (France). J. Archaeol. Sci. 39, 2414–2423. https://doi.org/10.1016/j.jas.2012.01.039

Alperson-Afil, N., 2017. Spatial Analysis of Fire: Archaeological Approach to Recognizing Early Fire. Curr. Anthropol. 58, S258–S266. https://doi.org/10.1086/692721

Alperson-Afil, N., 2012. Archaeology of fire: Methodological aspects of reconstructing fire history of prehistoric archaeological sites. Earth-Science Rev. 113, 111–119. https://doi.org/10.1016/j.earscirev.2012.03.012

Alperson-Afil, N., 2008. Continual fire-making by Hominins at Gesher Benot Ya'aqov, Israel. Quat. Sci. Rev. 27, 1733–1739. https://doi.org/10.1016/j.quascirev.2008.06.009

Ashton, N., Lewis, S.G., 2012. The environmental contexts of early human occupation of northwest Europe: The British Lower Palaeolithic record. Quat. Int. 271, 50–64. https://doi.org/10.1016/j.quaint.2011.10.022

Ashton, N., Lewis, S.G., Parfitt, S., White, M., 2006. Riparian landscapes and human habitat preferences during the Hoxnian (MIS 11) Interglacial. J. Quat. Sci. 21, 497–505. https://doi.org/10.1002/jqs.1032

Ashton, N., Lewis, S.G., Parfitt, S.A. (Eds.), 1998. Excavations at the Lower Palaeolithic site at East Farm, Barnham, Suffolk 1989-94. British Museum Occasional Paper Number 125. British Museum Press, London.

Ashton, N.M., Bowen, D.Q., Holman, J.A., Hunt, C.O., Irving, B.G., Kemp, R.A., Lewis, S.G., McNabb, J., Parfitt, S., Seddon, M.B., 1994. Excavations at the Lower Palaeolithic site at East Farm, Barnham, Suffolk 1989-92. J. Geol. Soc. London. 151, 599–605.

Attwell, L., Kovarovic, K., Kendal, J.R., 2015. Fire in the Plio-Pleistocene: The functions of hominin fire use, and the mechanistic, developmental and evolutionary consequences. J. Anthropol. Sci. 93. https://doi.org/10.4436/jass.93006

Barkai, R., Rosell, J., Blasco, R., Gopher, A., 2017. Fire for a Reason: Barbecue at Middle Pleistocene Qesem Cave, Israel. Curr. Anthropol. 58, S314–S328. https://doi.org/10.1086/691211

Benardout, G., 2015. Ostracod-based palaeotemperature reconstructions for MIS 11 human occupation at Beeches Pit, West Stow, Suffolk, UK. J. Archaeol. Sci. 54, 421–425. https://doi.org/10.1016/j.jas.2014.07.027

Bentsen, S.E., 2012. Size matters: Preliminary results from an experimental approach to interpret Middle Stone Age hearths. Quat. Int. 270, 95–102. https://doi.org/10.1016/j.quaint.2011.09.002

Braadbaart, F., Poole, I., Huisman, H.D.J., van Os, B., 2012. Fuel, Fire and Heat: An experimental approach to highlight the potential of studying ash and char remains from archaeological contexts. J. Archaeol. Sci. 39, 836–847. https://doi.org/10.1016/j.jas.2011.10.009

Buck, L.T., Berbesque, J.C., Wood, B.M., Stringer, C.B., 2016. Tropical forager gastrophagy and its implications for extinct hominin diets. J. Archaeol. Sci. Reports 5, 672–679. https://doi.org/10.1016/j.jasrep.2015.09.025

Canti, M.G., Linford, N., 2000. The effects of fire on archaeological soils and sediments: Temperature and colour elationships. Proc. Prehist. Soc. 66, 385–395. https://doi.org/DOI: 10.1017/S0079497X00001869

Chazan, M. (2017). Toward a Long Prehistory of Fire. Current Anthropology, 58(S16), S351–S359. https://doi.org/10.1086/691988mm

Climate-Data.org, n.d. Addis Abeba climate. https://en.climate-data.org/africa/ethiopia/addis-ababa/addis-abeba-532/ (Accessed 29/05/20).

Cohen-Ofri, I., Weiner, L., Boaretto, E., Mintz, G., Weiner, S., 2006. Modern and fossil charcoal: Aspects of structure and diagenesis. J. Archaeol. Sci. 33, 428–439. https://doi.org/10.1016/j.jas.2005.08.008

Coope, G.R., 2006. Insect faunas associated with palaeolithic industries from five sits of pre-Anglian age in central England. Quat. Sci. Rev. 25, 1738–1754.

https://doi.org/10.1016/j.quascirev.2006.01.015

Cornélio, A.M., de Bittencourt-Navarrete, R.E., de Bittencourt Brum, R., Queiroz, C.M., Costa, M.R., 2016. Human Brain Expansion during Evolution Is Independent of Fire Control and Cooking. Front. Neurosci. 10, 167. https://doi.org/10.3389/fnins.2016.00167

Cutts, R.B., Hlubik, S., Campbell, R., Muschinski, J., Akuku, P., Braun, D.R., Patterson, D.B., O'Brien, J.J., Garrison, E., Harris, J.W.K., 2019. Thermal curved-fragments: A method for identifying anthropogenic fire in the archaeological record. J. Archaeol. Sci. 106, 10–22. https://doi.org/10.1016/J.JAS.2019.03.006

Davis, R., Ashton, N., 2019. Landscapes, environments and societies: The development of culture in Lower Palaeolithic Europe. J. Anthropol. Archaeol. 56, 101107. https://doi.org/10.1016/j.jaa.2019.101107

de Lumley, H., 2006. Il y a 400 000 ans: La domestication du feu, un formidable moteur d'hominisation. Comptes Rendus - Palevol 5, 149–154. https://doi.org/10.1016/j.crpv.2005.11.014

Debenham, N., 1998. Thermoluminescence dating of burnt flint, in: Ashton, N., Lewis, S.G., Parfitt, S. (Eds.), Excavations at the Lower Palaeolithic Site at East Farm, Barnham, Suffolk, 1984-94. The British Museum, London, 175–178.

Dennell, R., Roebroeks, W., 1996. The earliest colonization of Europe: The short chronology revisited. Antiquity 70, 535–542. https://doi.org/10.1017/S0003598X00083691

Despriée, J., Voinchet, P., Tissoux, H., Bahain, J.J., Falguères, C., Courcimault, G., Dépont, J., Moncel, M.H., Robin, S., Arzarello, M., Sala, R., Marquer, L., Messager, E., Puaud, S., Abdessadok, S., 2011. Lower and Middle Pleistocene human settlements recorded in fluvial deposits of the middle Loire River Basin, Centre Region, France. Quat. Sci. Rev. 30, 1474–1485. https://doi.org/10.1016/j.quascirev.2011.02.011

Dibble, H.L., Sandgathe, D., Goldberg, P., McPherron, S., Aldeias, V., 2018. Were Western European Neandertals Able to Make Fire? J. Paleolit. Archaeol. 1, 54–79. https://doi.org/10.1007/s41982-017-0002-6

Fluck, H., McNabb, J., 2007. Raw material exploitation at the middle Pleistocene site of Vértesszölös. Lithics 28, 50–64.

French, J.C., 2019. The use of ethnographic data in Neanderthal archaeological research: Recent trends and their interpretative implications. Hunt. Gatherer Res. 4. https://doi.org/10.3828/hgr.2018.3

Gamble, C., 1999. The Palaeolithic societies of Europe. Cambridge University Press, Cambridge.

Gilligan, I., 2010. The Prehistoric Development of Clothing: Archaeological Implications of a Thermal Model. J. Archaeol. Method Theory 17, 15–80. https://doi.org/10.1007/s10816-009-9076-x

Goldberg, P., Miller, C.E., Mentzer, S.M., 2017. Recognizing Fire in the Paleolithic Archaeological Record. Curr. Anthropol. 58, S175–S190. https://doi.org/10.1086/692729

Goren-Inbar, N., Alperson, N., Kislev, M.E., Simchoni, O., Melamed, Y., Ben-Nun, A., Werker, E., 2004. Evidence of Hominin Control of Fire at Gesher Benot Ya`aqov, Israel. Science. 80. 304, 725-727. https://doi.org/10.1126/science.1095443

Goren-Inbar, N., Feibel, C.S., Verosub, K.L., Melamed, Y., Kislev, M.E., Tchernov, E., Saragusti, I., 2000. Pleistocene milestones on the out-of-Africa corridor at Gesher Benot Ya'aqov, Israel. Science (80-.). 289, 944–947. https://doi.org/10.1126/science.289.5481.944

Gowlett, J., 2010. Firing up the social brain, in: Dunbar, R., Gamble, C., Gowlett, J. (Eds.), Social Brain, Distributed Mind. Oxford University Press, Oxford, 344–360.

Gowlett, J.A.J., Los, J.H., Houn, S., Brant, V., De, N.C., 2000. Beeches Pit: Archaeology, Assemblage Dynamics and Early Fire History of a Middle Pleistocene Site in East Anglia, Uk. Eurasian

Prehistory 3, 3–38.

Gowlett, J.A.J., 2016. The discovery of fire by humans: A long and convoluted process. Philos. Trans. R. Soc. B Biol. Sci. https://doi.org/10.1098/rstb.2015.0164

Gowlett, J.A.J., 2006. The early settlement of northern Europe: Fire history in the context of climate change and the social brain. Comptes Rendus Palevol 5, 299–310. https://doi.org/10.1016/j.crpv.2005.10.008

Gowlett, J.A.J., Brink, J.S., Caris, A., Hoare, S., Rucina, S.M., 2017. Evidence of burning from bushfires in southern and east Africa and its relevance to hominin evolution. Curr. Anthropol. 58, S206–S216. https://doi.org/10.1086/692249

Henry, A.G., Büdel, T., Bazin, P.-L., 2018. Towards an understanding of the costs of fire. Quat. Int. 493, 96-105. https://doi.org/10.1016/j.quaint.2018.06.037

Herzog, N.M., Keefe, E.R., Parker, C.H., Hawkes, K., 2016. What's burning got to do with it? Primate foraging opportunities in fire-modified landscapes. Am. J. Phys. Anthropol. 159, 432–441. https://doi.org/10.1002/ajpa.22885

Hlubik, S., Berna, F., Feibel, C., Braun, D., Harris, J.W.K., 2017. Researching the nature of fire at 1.5 Mya on the site of FxJj20 AB, Koobi Fora, Kenya, using high-resolution spatial analysis and FTIR spectrometry. Curr. Anthropol. 58, S243–S257. https://doi.org/10.1086/692530

Hlubik, S., Cutts, R., Braun, D.R., Berna, F., Feibel, C.S., Harris, J.W.K., 2019. Hominin fire use in the Okote member at Koobi Fora, Kenya: New evidence for the old debate. J. Hum. Evol. 133, 214–229. https://doi.org/10.1016/J.JHEVOL.2019.01.010

Hoare, S., 2020. Assessing the function of Palaeolithic hearths: Experiments on intensity of luminosity and radiative heat outputs from different fuel sources. J. Paleolit. Archaeol. https://doi.org/10.1007/s41982-019-00047-z

Hoare, S., 2019. The possible role of predator–prey dynamics as an influence on early hominin use of burned landscapes. Evol. Anthropol. Issues, News, Rev. 28, 295-302. https://doi.org/10.1002/evan.21807

Holman, J.A., 2000. New herpetological records from the Middle Pleistocene Boxgrove hominid site, England. Cranium (Leiden) 17, 112–120.

Holman, J.A., 1998. The herpetofauna, in: Ashton, N., Lewis, S.G., Parfitt, S. (Eds.), Excavations at the Lower Palaeolithic Site at East Farm, Barnham, Suffolk, 1984-94. British Museum Occasional Paper Number 125. British Museum Press, London, 101–106.

Holmes, J.A., Atkinson, T., Fiona Darbyshire, D.P., Horne, D.J., Joordens, J., Roberts, M.B., Sinka, K.J., Whittaker, J.E., 2010. Middle Pleistocene climate and hydrological environment at the Boxgrove hominin site (West Sussex, UK) from ostracod records. Quat. Sci. Rev. 29, 1515–1527. https://doi.org/10.1016/j.quascirev.2009.02.024

Hosfield, R., 2016. Walking in a winter wonderland? Strategies for Early and Middle Pleistocene survival in midlatitude Europe. Curr. Anthropol. 57, 653–682. https://doi.org/10.1086/688579

Hosfield, R., Cole, J., 2018. Early hominins in north-west Europe: A punctuated long chronology? Quat. Sci. Rev. 190, 148–160. https://doi.org/10.1016/J.QUASCIREV.2018.04.026

Huisman, D.J., Braadbaart, F., van Wijk, I.M., van Os, B.J.H., 2012. Ashes to ashes, charcoal to dust: Micromorphological evidence for ash-induced disintegration of charcoal in Early Neolithic (LBK) soil features in Elsloo (The Netherlands). J. Archaeol. Sci. 39, 994–1004. https://doi.org/10.1016/j.jas.2011.11.019

Karkanas, P., Shahack-Gross, R., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A., Gopher, A., Stiner, M.C., 2007a. Evidence for habitual use of fire at the end of the Lower Paleolithic: site-formation processes at Qesem Cave, Israel. J. Hum. Evol. 53, 197–212. https://doi.org/10.1016/j.jhevol.2007.04.002

Karkanas, P., Shahack-Gross, R., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A., Gopher, A., Stiner, M.C., 2007b. Evidence for habitual use of fire at the end of the Lower Paleolithic: Site-formation processes at Qesem Cave, Israel. J. Hum. Evol. 53, 197–212. https://doi.org/10.1016/j.jhevol.2007.04.002

Kretzoi, M., Dobosi, V.T., 1990. Vértesszőlős. Site, man and culture. Akadémiai Kiadó, Budapest.

Lebreton, V., Bertini, A., Russo Ermolli, E., Stirparo, C., Orain, R., Vivarelli, M., Combourieu-Nebout, N., Peretto, C., Arzarello, M., 2019. Tracing fire in early European prehistory: Microcharcoal quantification in geological and archaeological records from Molise (Southern Italy). J. Archaeol. Method Theory 26, 247–275. https://doi.org/10.1007/s10816-018-9373-3

Lewis, S.G., Ashton, N., Field, M.H., Hoare, P.G., Kamermans, H., Knul, M., Mücher, H.J., Parfitt, S.A., Roebroeks, W., Sier, M.J., 2019. Human occupation of northern Europe in MIS 13: Happisburgh Site 1 (Norfolk, UK) and its European context. Quat. Sci. Rev. 211, 34–58. https://doi.org/10.1016/J.QUASCIREV.2019.02.028

Liedgren, L., Hörnberg, G., Magnusson, T., Östlund, L., 2017. Heat impact and soil colors beneath hearths in northern Sweden. J. Archaeol. Sci. 79, 62–72. https://doi.org/10.1016/j.jas.2017.01.012

Limondin-Lozouet, N., 2001. Une malacofaune nouvelle du Pléistocène moyen á Soucy (Yonne - France): Biogéographie et paléoécologie. Geobios 34, 303–313. https://doi.org/10.1016/S0016-6995(01)80078-4

Limondin-Lozouet, N., Nicoud, E., Antoine, P., Auguste, P., Bahain, J.-J., Dabkowski, J., Dupéron, J., Dupéron, M., Falguères, C., Ghaleb, B., Jolly-Saad, M.-C., Mercier, N., 2010. Oldest evidence of Acheulean occupation in the Upper Seine valley (France) from an MIS 11 tufa at La Celle. Quat. Int. 223, 299–311. https://doi.org/10.1016/j.quaint.2009.10.013

MacDonald, K., 2018. Fire-free hominin strategies for coping with cool winter temperatures in north-western Europe from before 800,000 to circa 400,000 Years Ago. PalaeoAnthropology 2018, 7–26. https://doi.org/10.4207/PA.2018.ART109

Mallol, C., Marlowe, F.W., Wood, B.M., Porter, C.C., 2007. Earth, wind, and fire: Ethnoarchaeological signals of Hadza fires. J. Archaeol. Sci. 34, 2035–2052. https://doi.org/10.1016/j.jas.2007.02.002

Mallol, C., Henry, A. (2017). Ethnoarchaeology of Paleolithic Fire: Methodological Considerations. Current Anthropology, 58(S16), S217–S229. https://doi.org/10.1086/691422

Mania, D., Mania, U., 2005. The natural and socio-cultural environment of Homo erectus at Bilzingsleben, Germany. In Gamble, C., Porr, M. (Eds.), The Hominid Individual in Context: Archaeological investigations of Lower and Middle Palaeolithic landscapes, locales and artefacts, 98–114.

Mania, U., 1995. Man and Environment in the Palaeolithic. ERAUL, Liège.

Matthews, W., 2010. Geoarchaeology and taphonomy of plant remains and microarchaeological residues in early urban environments in the Ancient Near East. Quat. Int. 214, 98–113. https://doi.org/10.1016/j.quaint.2009.10.019

Mazza, P.P.A., Martini, F., Sala, B., Magi, M., Colombini, M.P., Giachi, G., Landucci, F., Lemorini, C., Modugno, F., Ribechini, E., 2006. A new Palaeolithic discovery: tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed. J. Archaeol. Sci. 33, 1310–1318. https://doi.org/10.1016/J.JAS.2006.01.006

McCauley, B., Collard, M., Sandgathe, D., 2020. A cross-cultural survey of on-site fire use by recent hunter-gatherers: Implications for research on Palaeolithic pyrotechnology. J. Paleolit. Archaeol. https://doi.org/10.1007/s41982-020-00052-7

Mentzer, S.M., 2014. Microarchaeological Approaches to the Identification and Interpretation of Combustion Features in Prehistoric Archaeological Sites. J. Archaeol. Method Theory 21, 616–

668. https://doi.org/10.1007/s10816-012-9163-2

Moigne, A.-M., Valensi, P., Auguste, P., García-Solano, J., Tuffreau, A., Lamotte, A., Barroso, C., Moncel, M.-H., 2015. Bone retouchers from Lower Palaeolithic sites: Terra Amata, Orgnac 3, Cagny-l'Epinette and Cueva del Angel. Quat. Int. 409, 195-212. https://doi.org/http://dx.doi.org/10.1016/j.quaint.2015.06.059

Moncel, M.-H., Despriée, J., Voinchet, P., Tissoux, H., Moreno, D., Bahain, J.-J., Courcimault, G., Falguères, C., 2013. Early evidence of Acheulean settlement in northwestern Europe - La Noira site, a 700,000 year-old occupation in the center of France. PLoS One 8, e75529. https://doi.org/10.1371/journal.pone.0075529

Monnier, J.-L., Ravon, A.-L., Hinguant, S., Hallégouët, B., Gaillard, C., Laforge, M., 2016. Menez-Dregan 1 (Plouhinec, Finistère, France): Un site d'habitat du Paléolithique inférieur en grotte marine. Stratigraphie, structures de combustion, industries riches en galets aménagés. Anthropologie. 120, 237–262. https://doi.org/10.1016/J.ANTHRO.2016.05.003

Müller, W., Pasda, C., 2011. Site formation and faunal remains of the Middle Pleistocene site Bilzingsleben. Quartär, 58, pp.25-49. https://doi.org/10.7485/QU58_02

Odling-Smee, F.J., Laland, K.N., Feldman, M.W., 2003. Niche construction: the neglected process in evolution. Monographs in Population Biology 37. Princeton University Press, Princeton.

Parfitt, S.A, Ashton, N.M., Lewis, S.G., Abel, R.L., Coope, G.R., Field, M.H., Gale, R., Hoare, P.G., Larkin, N.R., Lewis, M.D., Karloukovski, V., Maher, B.A, Peglar, S.M., Preece, R.C., Whittaker, J.E., Stringer, C.B., 2010. Early Pleistocene human occupation at the edge of the boreal zone in northwest Europe. Nature 466, 229–233. https://doi.org/10.1038/nature09117

Parker, C.H., Keefe, E.R., Herzog, N.M., O'Connell, J.F., Hawkes, K., 2016. The pyrophilic primate hypothesis. Evol. Anthropol. 25, 54–63. https://doi.org/10.1002/evan.21475

Preece, R.C., Gowlett, J.A.J., Parfitt, S.A., Bridgland, D.R., Lewis, S.G., 2006. Humans in the Hoxnian:

Habitat, context and fire use at Beeches Pit, West Stow, Suffolk, UK. J. Quat. Sci. 21, 485–496. https://doi.org/10.1002/jqs.1043

Pruetz, J.D., Herzog, N.M., 2017. Savanna Chimpanzees at Fongoli, Senegal, Navigate a Fire Landscape. Curr. Anthropol. 58, S000–S000. https://doi.org/10.1086/692112

Ravon, A.-L., Monnier, J.-L., Laforge, M., 2016. Menez-Dregan I, layer 4: A transitional layer between the Lower and Middle Palaeolithic in Brittany. Quat. Int. 409, 92–103. https://doi.org/10.1016/J.QUAINT.2015.07.066

Ravon, A. L. 2019. Early human occupations at the westernmost tip of Eurasia: The lithic industries from Menez–Dregan I (Plouhinec, Finistère, France). Comptes Rendus - Palevol, 18(6), 663–684. https://doi.org/10.1016/j.crpv.2019.06.001

Rhodes, S.E., Walker, M.J., López-Jiménez, A., López-Martínez, M., Haber-Uriarte, M., Fernández-Jalvo, Y., Chazan, M., 2016. Fire in the Early Palaeolithic: Evidence from burnt small mammal bones at Cueva Negra del Estrecho del Río Quípar, Murcia, Spain. J. Archaeol. Sci. Reports 9, 427–436. https://doi.org/10.1016/j.jasrep.2016.08.006

Roebroeks, W., Bakels, C.C., 2015. ‘Forest furniture’ or ‘forest managers’? Neandertal presence in Last Interglacial environments. In: Coward, F., Hosfield, R., Pope, M., Wenban-Smith, F. (Eds.), Settlement, Society and Cognition in Human Evolution: Landscapes in mind, 174–188.

Roebroeks, W., Kolfschoten, T. Van, 1994. The earliest occupation of Europe: a short chronology. Antiquity 68, 489–503. https://doi.org/10.1086/204707

Roebroeks, W., Villa, P., 2011. On the earliest evidence for habitual use of fire in Europe. Proc. Natl. Acad. Sci. U. S. A. 108, 5209–14. https://doi.org/10.1073/pnas.1018116108

Rolland, N., 2004. Was the emergence of home bases and domestic fire a punctuated event? A review of the Middle Pleistocene record in Eurasia. Asian Perspect. 43, 248–280. https://doi.org/10.1353/asi.2004.0027

Sandgathe, D.M., 2017. Identifying and describing pattern and process in the evolution of hominin use of fire. Curr. Anthropol. 58, S360–S370. https://doi.org/10.1086/691459

Sandgathe, D.M., Berna, F., 2017. Fire and the Genus Homo: An introduction to Supplement 16. Curr. Anthropol. 58, S165–S174. https://doi.org/10.1086/691424

Sandgathe, D.M., Dibble, H.L., Goldberg, P., Mcpherron, S.P., Hodgkins, J., 2011a. On the role of fire in neandertal adaptations in western Europe: Evidence from Pech de l'Azé IV and Roc de Marsal, France. PaleoAnthropology 216–242. https://doi.org/10.4207/PA.2011.ART54

Sandgathe, D.M., Dibble, H.L., Goldberg, P., McPherron, S.P., Turq, A., Niven, L., Hodgkins, J., 2011b. Timing of the appearance of habitual fire use. Proc. Natl. Acad. Sci. U. S. A. 108, E298; author reply E299. https://doi.org/10.1073/pnas.1106759108

Santonja, M., & Villa, P. 2006. The Acheulian of Western Europe, in: Goren-Inbar and Sharon (Eds.), Axe Age Acheulian Toolmaking from Quarry to Discard. Equinox, London, 429-478.

Sanz, M., Daura, J., Cabanes, D., Égüez, N., Carrancho, Á., Badal, E., Souto, P., Rodrigues, F., Zilhão, J., 2020. Early evidence of fire in south-western Europe: the Acheulean site of Gruta da Aroeira (Torres Novas, Portugal). Sci. Rep. 10, 12053. https://doi.org/10.1038/s41598-020-68839-w

Scherjon, F., Bakels, C., MacDonald, K., Roebroeks, W., 2015. Burning the Land: An ethnographic study of off-site fire use by current and historically documented foragers and implications for the interpretation of past fire practices in the landscape. Curr. Anthropol. 56, 299–326. https://doi.org/10.1086/681561

Shahack-Gross, R., Berna, F., Karkanas, P., Lemorini, C., Gopher, A., Barkai, R., 2014. Evidence for the repeated use of a central hearth at Middle Pleistocene (300ky ago) Qesem Cave, Israel. J. Archaeol. Sci. 44, 12-21. https://doi.org/10.1016/j.jas.2013.11.015

Sherriff, J., 2016. The palaeoenvironmental context of Lower Palaeolithic occupation in southern Britain during Marine Oxygen Isotope Stage 11. Royal Holloway, University of London.

Shimelmitz, R., Kuhn, S. L., Jelinek, A. J., Ronen, A., Clark, A. E., & Weinstein-Evron, M. (2014). 'Fire at will': The emergence of habitual fire use 350,000 years ago. Journal of Human Evolution, 77, 196–203. https://doi.org/10.1016/J.JHEVOL.2014.07.005

Shipman, P., 2009. Cooking debate goes off the boil. Nature 459, 1059–1060. https://doi.org/10.1038/4591059a

Sorensen, A.C., 2017. On the relationship between climate and Neandertal fire use during the Last Glacial in south-west France. Quat. Int. 436, 114–128. https://doi.org/10.1016/j.quaint.2016.10.003

Speth, J.D., 2017. Putrid meat and fish in the Eurasian Middle and Upper Paleolithic: Are we missing a key part of Neanderthal and modern human diet? PaleoAnthropology 44–72. https://doi.org/10.4207/PA.2017.ART105

Stahlschmidt, M.C., Miller, C.E., Ligouis, B., Hambach, U., Goldberg, P., Berna, F., Richter, D., Urban, B., Serangeli, J., Conard, N.J., 2015. On the evidence for human use and control of fire at Schöningen 89, 181-201. https://doi.org/10.1016/j.jhevol.2015.04.004

Trinkaus, E., Stringer, C.B., Ruff, C.B., Hennessy, R.J., Roberts0, M.B., Parfitt, S.A., 1999. Diaphyseal cross-sectional geometry of the Boxgrove 1 Middle Pleistocene human tibia. Acad. Press J. Hum. Evol. 37, 1–25.

Walker, M.J., López-Martínez, M., Carrión-García, J.S., Rodríguez-Estrella, T., San-Nicolás del-Toro, M., Schwenninger, J.-L., López-Jiménez, A., Ortega-Rodrigáñez, J., Haber-Uriarte, M., Polo-Camacho, J.-L., García-Torres, J., Campillo-Boj, M., Avilés-Fernández, A., Zack, W., 2013. Cueva Negra del Estrecho del Río Quípar (Murcia, Spain): A late Early Pleistocene hominin site with an "Acheulo-Levalloiso-Mousteroid" Palaeolithic assemblage. Quat. Int. 294, 135–159. https://doi.org/10.1016/J.QUAINT.2012.04.038

White, M.J., Plunkett, S.J., 2004. Miss Layard Excavates: A Palaeolithic site at Foxhall Road, Ipswich, 1903-1905. Western Academic & Specialist Press, Bristol.

White, T.S., Preece, R.C., Whittaker, J.E., 2013. Molluscan and ostracod successions from Dierden's Pit, Swanscombe: Insights into the fluvial history, sea-level record and human occupation of the Hoxnian Thames. Quat. Sci. Rev. 70, 73–90. https://doi.org/10.1016/j.quascirev.2013.03.007

Wrangham, R., 2017. Control of fire in the Paleolithic: Evaluating the cooking hypothesis. Curr. Anthropol. 58, S303–S313. https://doi.org/10.1086/692113

Wrangham, R., 2009. Catching Fire: How Cooking Made Us Human. Profile Books Ltd., London.

Wrangham, R., Carmody, R., 2010. Human adaptation to the control of fire. Evol. Anthropol. Issues, News, Rev. 19, 187–199. https://doi.org/10.1002/evan.20275