Elsevier Editorial System(tm) for Journal of Anthropological Archaeology
Manuscript Draft

Manuscript Number: YJAAR-D-15-00127R1

Title: Reflections on Gravettian firewood procurement near the Pavlov Hills, Czech Republic

Article Type: Full length article

Keywords: Gravettian; Firewood; Fire; Charcoal; Resource management; Upper Paleolithic.

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Abstract: This paper draws attention to firewood as a natural resource that was gathered, processed and consumed on a daily basis by Palaeolithic groups. Using Gravettian occupation of the Pavlovské Hills as a case study (dated to around 30,000 years B.P.), we investigate firewood availability using archaeological, palaeoenvironmental and ecological data, including making inferences from charcoal in Pavlovian hearths. The collated evidence suggests that while dead wood was likely readily available in woodland areas where humans had not recently foraged, longer term occupations - or repeated occupation of the same area by different groups - would have quickly exhausted naturally-occurring supplies. Once depleted, the deadwood pool may have taken several generations (~40-120 years) to recover enough to provide fuel for another base camp occupation. Such exhaustion of deadwood supplies is well attested ethnographically. Thus, we argue that Pavlovian groups likely managed firewood supplies using methods similar to those used by recent hunter-gatherers: through planned geographic mobility and by deliberately killing trees years in advance of when wood was required, so leaving time for the wood to dry out. Such management of fuel resources was, we argue, critical to human expansion into these cold, hitherto marginal, ecologies during the Late Glacial.

*Highlights (for review)

Highlights

- Firewood strongly influenced mobility and basecamp location in the Palaeolithic
- Unexplored wooded areas likely contained substantial firewood supplies
- Depleted deadwood pools required generations (40-120 years) to recover naturally
- Groups managed their deadwood supply by deliberately killing trees years in advance.

Reflections on Gravettian firewood procurement near the Pavlov Hills, Czech Republic

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Introduction

The changing role of fire in different periods of the Palaeolithic remains hotly debated, with some authors suggesting that Neanderthals and their forebears did not need or habitually use fire to survive in northern latitudes of Europe (Sandgathe et al., 2011), while other recent papers have continued to highlight the benefits of fire and its probable impact in the evolution of modern human behaviour (Gowlett and Wrangham, 2013; Roebroeks and Villa, 2011; Wiessner, 2014). By Upper Palaeolithic times, however, and especially in European mid-upper latitudes, it is clear that fire was fundamental to a diverse range of activities and capabilities relevant for life, potentially including lighting, heating, cooking, transformation of raw materials such as lithics, manufacturing items of material culture, smoking of food, curing of skins, hunting, scaring away dangerous scavengers attracted by hunting and processing activities, repelling insects, felling trees, making smoke for technological, medicinal or hallucinatory purposes, conducting various rituals or communicating (e.g. smoke signals)(Beers, 2014; Binford, 1967; Olive and Taborin, 1989; Pullen, 2005; Tindale, 1974). Indeed if a group had expected to have access to fire but at short notice did not (e.g. Tindale, 1974:71), the consequences are likely to be bad (cold, inability to cook food or dry clothes, use fire-dependent technologies etc.). Key to fire success is provisioning sufficient fuel to burn. Palaeolithic fuel provisioning has previously been considered from a range of perspectives (Perlés, 1977; Théry-Parisot et al., 2009), including the selection and character of different wood fuels (Basile et al., 2014; Solé et al., 2013; Théry-Parisot, 2002b; Villa et al., 2002), green wood and dead wood mixing (Théry-Parisot and Henry, 2012) and mixing fuels such as wood, bone and dung from large herbivores (Beresford-Jones et al., 2010; Heizer, 1963; Rhode et al., 1992; Théry-Parisot, 2002a). Rare examples of other Palaeolithic fuels include coal (Klíma, 1956) and lignite (Théry-Parisot, 2002b), and a survey of ethnographic literature attests to a range of other fuel possibilities including driftwood (Alix and Brewster, 2004; Weitzner, 1979:270), heather (Heizer, 1963:190; Stefansson, 1919:46), and shrubs mixed with strips of animal fat (Boas, 1888:577).

For many Palaeolithic sites, however, the widespread occurrence of charcoal found in association with hearths indicates that wood was a primary fuel component, almost certainly due to its availability and superior raw material properties compared to other possible fuels. Wood gathering will therefore have been an important part of everyday life during the Palaeolithic, requiring more transportation labour per capita due to its bulk than most other supplies such as lithic raw materials, or animal carcasses that provided several resources in one package (MacLeod, 1925). Modelling firewood collection strategies thus offers another potential window through which Palaeolithic occupation strategies and resource utilisation across a landscape may be reconstructed and understood. Key to this is availability and distribution of wood fuel. If firewood was widely and readily available to Palaeolithic groups, firewood collection could have occurred incidentally as part of daily foraging activities near a campsite, straight-forward calculations made to forward-plan fuel supplies for the duration of stay, and little thought given to securing supplies when moving to a new campsite location. Conversely, if firewood was a scarce resource, the location of firewood supplies would have been an integral part of decision-making regarding the positioning of sites within a landscape just as other resources such as water, prey or lithic raw materials, with supplies deliberately managed or 'curated' through time (Heizer, 1963; Henry and Théry-Parisot, 2014).

This paper draws together varied evidence to reconsider this question of fuel availability and explore its likely impact on European Upper Palaeolithic hunter-gatherers. The chosen case study is the cluster of Gravettian occupations surrounding the Pavlovské Hills, Czech Republic where large numbers of people appear to have gathered in residential basecamps burning wood-fuelled fires. Using a combination of archaeological, ecological, palaeoclimatic and ethnographic data, we argue that while dead wood was clearly available near the Pavlov Hills, repeated and/or long-term occupation of basecamp sites for periods of several months or more would likely have quickly exhausted naturally-occurring dead wood supplies in the vicinity of these sites. A common response to this problem among modern hunter-gatherer groups is the deliberate killing of healthy trees and branches (e.g. by ring-barking), which are then left for a period of years for the wood to dry out before felling and burning the tree as firewood (e.g. Alix and Brewster, 2004). Such a strategy is used by groups that plan to return to a specific location in future years, requiring the complex logistical forward-planning and organised movement over long timescales that is a hallmark of modern humans (Gamble, 1998). We propose that Pavlovian groups may have practiced this strategy of deliberate firewood curation as one important part of a range of adaptations enabling the formation of the long-term settlement deposits that cover the northern slopes of the Pavlovské Hills. We further highlight the role of firewood availability more generally in determining site location in a landscape, and the relevance of firewood curation strategies for group mobility. We begin with some general perspectives on fuel gathering in hunter-gatherer communities before introducing our Pavlovian Hills case study.

Procuring firewood

Ethnographic reports indicate that firewood collection strategies generally follow a principle of least effort model (Marston, 2009; Théry-Parisot, 2002b), involve planning and social cooperation to a considerable extent and are inherently risk averse (Pullen, 2005). Different activities requiring fire use flame, heat and smoke to varying degrees, which directly affects which fuel is best suited to the job (Kephart, 1906); for example rotten wood may be used to generate smoke for smoking hides, or a mix of green and dead wood may be used to slow a fire down. There is thus a range of wood types that may be burned for different purposes with no single characteristic for ‘good wood fuel’ (Henry and Théry-Parisot, 2014). When selecting firewood that will combust easily, however, the single most important factor mentioned cross-culturally in determining ‘good firewood’ is the low moisture content of the wood (i.e. dead and dried out wood)(Picornell Gelabert et al., 2011). Other factors include heat yield, quality of the smoke, and branch/log diameter (typically between 5-20cm; Picornell Gelabert et al., 2011), while botanical species is the last thing normally considered unless specific cultural factors (e.g. species avoidance) come into consideration (Kibler and Mehalchick, 2010).

The range of purposes and activities requiring fire implies that hearths were probably used on a daily basis at larger basecamp sites during the Upper Palaeolithic. Indeed a survey of hunter-gatherer ethnographic literature makes clear that, once lit, fires are generally maintained continuously while a site is occupied, though often banked down when not in immediate use (e.g. Gayton, 1948:185; Pullen, 2005:63-74; Weitzner, 1979:270). Some activities are particularly firewood-intensive. For example, cooking meat or tubers by hot-rock boiling uses vastly more firewood than is required for roasting these foods over hot embers, because of the need to reheat the rocks continuously for over an hour (Kibler and Mehalchick, 2010 and references therein; Picornell Gelabert et al., 2011:379). Basecamp sites must therefore be continuously provisioned with fuel, a time-consuming activity that is mentioned frequently in ethnographic accounts and captured succinctly by Helge Ingstad in his descriptions of daily life among the Nunamiut:

> “*The burning question at every new encampment is how to get fuel. Sometimes we camp by a patch of willows where the Eskimos have recently been, and then the place is usually cleaned out; not a dry stick is to be seen… Once in a way it happens that we stumble upon a virgin patch of willows with an abundance of dry bushes. Then we feel that we have struck it rich. But most often we have to search both long and hard to find enough…… This inexorable demand is continually made on me: Wood must be found, carried, or driven. A lot of fuel is needed to warm my draughty tent. A load is consumed in a short time, and more has to be fetched. I get no peace.*"”(Ingstad, 1954:211).

Suitable sources for gathering dead wood include still-attached and shed branches, snags (standing dead trees), fallen trunks and stumps and rotting roots. These may be generated by natural processes such as natural death, bad weather, browser damage, fungal and insect attacks that continuously create and renew supplies. Even low-density habitats such as savannahs or park woodlands in arid and semiarid regions will include some dead wood (e.g. Shackleton, 1998), while climatic changes leading to the local extinction of trees in marginal habitats may create large deadwood pools locally (Grayson and Millar, 2008)In riparian environments driftwood collection also can be an important source of firewood where it might collect naturally in certain places, including in areas where trees grow locally (Alix and Brewster, 2004). In conifer woods dead twigs and small branches are typically uniformly and continuously distributed and can therefore be collected continuously and systematically. The availability of larger branches related to traumatic loss caused by meteorological incidents (wind, thunderstorms, snow accumulation, etc.) may occur more episodically and must be searched for. Deadwood production does not appear to vary much with inter-annual climatic fluctuations as live biomass production does, but instead is rather stable year-to-year (Shackleton, 1998). Stable deadwood productivity implies that fuel supplies and harvesting patterns can be predicted, and thus managed (Picornell Gelabert et al., 2011:381-382).

The Dolní Věstonice-Pavlov case study

The Dolní Věstonice-Pavlov-Milovice basecamps form a chain of sites stretching along the lower northern slopes of the Pavlovské Hills, a Jurassic limestone outcrop that rises to a height of 550 m (Figure 1). This rocky outcrop forms a distinctive landmark in an otherwise relatively flat or gently rolling steppic plain that links the Danube river corridor sites of Austria, Slovakia and Hungary with the Polish North European Plains, via the Moravian Gate. Three large Gravettian aggregation sites are known (Dolní Věstonice I, Pavlov I and the northern/upper part of Dolní Věstonice II), with several smaller occupations found nearby (Dolní Věstonice II western Slope, Dolní Věstonice III, Pavlov II-VI, and Milovice I-IV amongst others). Stratigraphic analyses and radiocarbon dating suggest most of these occupations occurred within a relatively short time window around the time of Greenland stadial 5 (approximately 32,000-29,000 BP)(Beresford-Jones et al., 2011; Svoboda et al., 2011), although differences in lithic typology (Polanská and Novák, 2014; Polanská pers. comm.), artistic styles and modes of production (Farbstein, 2011) have been detected between the sites.

Collectively, the evidence from the Pavlov Hills sites indicates either many repeated visits or fewer longer-term occupations at locations across the same hillside within a relatively short period of time. Indeed, some have postulated year-round settlement at Pavlov I and Dolní Věstonice I based on the exceptionally large quantities of lithics and fauna recovered at these sites (Wojtal and Wilczyński, in press). For example, excavations in the south-eastern part of Pavlov I (years 1952-1956) revealed remains of 536 individual animal skeletons including 56 reindeer, 7 mammoth, 10 horse, 192 hare and 123 red/polar fox (Wojtal et al., 2012); over 11,000 retouched lithics were also discovered in the same area (Svoboda, 2005b), along with personal ornaments, bone and ivory art, scattered human bones and evidence for 11 apparent dwelling structures. Renewed excavations in 2014 produced further remains that are now undergoing analysis (Svoboda et al., In press). Other parts of the Pavlov I site contained similarly large cultural assemblages and, along with Dolní Věstonice I and II (the latter the site of a triple human burial; Klíma, 1987), these sites are best seen as logistical basecamps (*sensu* Binford, 1980) repeatedly occupied by large groups of hunter-gatherers (Soffer, 1989). Excavations at the Pavlov Hills sites also revealed large numbers of charcoal-rich features described as hearths (Figure 2), for example: 56 at Pavlov SE, 11 at Pavlov NW, and 81 from the hilltop area of DVII ('agglomeration 1') (Klíma, 1995; Klíma, 1997; Svoboda, 2005b). These hearths typically occur as the centre-point of scattered material remains defining distinct settlement units (e.g. Svoboda, 1991, 2005b), with further randomly distributed hearths in the larger sites (e.g. Klíma, 1995; Svoboda, 1997, 2005b). The hearths are characterised by burned areas up to 1m in diameter, and rarely up to 2m diameter, generally containing 10-40 cm depth of ash and charcoal (Klíma, 1954; Klíma, 1995; Oliva, 2009; Svoboda, 2005a; Svoboda et al., 2009; Verpoorte, 2001). Excavation plans and photographs from Pavlov I also show stones used to line some of the hearths, and some hearths were clearly repeatedly reused (Svoboda, 2005a:33), also demonstrated by micromorphological data from a hearth from Dolní Věstonice II-05 (Beresford-Jones et al., 2011). Large charcoal assemblages discovered at the Pavlov Hills sites attest to the systematic burning of conifer wood in these hearths (e.g. Beresford-Jones et al., 2010), alongside bone and potentially other fuels as well.

FIGURE 1 AROUND HERE [MAP OF PAVLOV HILLS]

FIGURE 2 AROUND HERE [PICTURES OF HEARTHS]

Evidence for trees – the palaeoecological evidence

Databases of radiocarbon dated plant macrofossils demonstrate the long-term regional presence of conifer species in Central Europe during marine isotope stage 3 (approximately 60,000-27,000 BP) together with a small number of other arboreal taxa including *Salix*, *Alnus*, *Populus* and *Betula* (Binney et al., 2009; Damblon and Haesaerts, 2002; Willis and van Andel, 2004). Considered together with macrocharcoal remains (including radiocarbon dated pine cones) and pollen spectra from more recently published local Moravian assemblages, *Picea*, *Larix* and *Pinus* stand out clearly as the regularly dominating taxa (Jankovská and Pokorný, 2008 and references therein; Nádor et al., 2011; Pokorný, 2009; Rybníčková and Rybníček, 2014; Vlačiky et al., 2013). Pollen records also show clear evidence for the same three conifer genera on the Hungarian Plain, and at times on the Polish Plain (Feurdean et al., 2014; Magyari et al., 2014; Sümegi et al., 2013), while the full glacial survival of *Pinus sylvestris*, *Picea abies* and *Larix decidua* in Carpathian refugia is demonstrated by genetic evidence and species distribution modelling (Cheddadi et al., 2006; Ravazzi, 2002; Svenning et al., 2008; Wagner, 2013). Based on this evidence Jankovská and Pokorný (2008) have argued for the existence of a closed hemiboreal forest biome across Slovakia and the westernmost ranges of the Carpathians (E Czech Republic), situated altitudinally in between a dry open lowland loess steppe and an alpine grassland belt, analogous to the mixed conifer-dominated woodland of present-day Siberian continental taiga (see also photographs of the types of landscape envisaged by these authors in Pokorný, 2009). How far this forest biome extended west towards the Pavlov Hills, and how much it fluctuated with the Dansgaard-Oeschger cycles and other longer-term climatic variations, is not currently clear (Fletcher et al., 2010; Magyari et al., 2014). However the general picture of mixed forest-steppe landscapes – Guthrie's (2001) so-called mammoth steppe biome posited widely as covering much of northern and central Europe during the last glacial – agrees well with both the pollen spectra recovered from a sediment core taken close to the Pavlov Hills at Bulhary (Rybníčková and Rybníček, 2014), and with predictions from new net primary productivity models for the last glacial (Huntley et al., 2013). Together then, these data suggest a mixed local environment in the vicinity of the Pavlov Hills, similar to that which existed throughout much of the wider Moravian region.

Evidence for trees – the archaeological evidence

In agreement with the regional palaeoenvironmental evidence and the data from nearby Bulhary, the archaeological sites themselves contain abundant charcoal from pine and spruce/larch species which dominate almost all analysed assemblages (Beresford-Jones et al., 2011; Čulíková, 2011; Damblon, 1997; Klíma, 1995:31; Opravil, 1994; Svoboda et al., 2015). *Larix decidua* and *Picea abies* charcoal cannot normally be distinguished archaeobotanically on the basis of wood anatomy (Schweingruber, 1990), yet the heavy pollen of larch found at Bulhary strongly suggests this species was growing locally near the sites (Damblon, 1997).

Landscape-scale reconstructions of the mammoth steppe biome predict that trees would have grown in river valley settings near water sources and in places sheltered from the wind (Allen et al., 2010; Guthrie and van Kolfschoten, 2000; Opravil, 1994; Pokorný, 2009; Sümegi et al., 2013). Applying these criteria to the Pavlov Hills suggests that conifers will almost certainly have grown close to the site locations, in habitats proximal to the Dyje River and on the slopes of the Pavlovské Hills themselves. Indeed, given the open and treeless steppe-tundra environments that seemingly prevailed more widely at this time (Guthrie and van Kolfschoten, 2000), the Pavlov Hills themselves were probably unusually rich in wood fuel resources in comparison with that wider environment. Regardless of such reconstructions, however, it is perfectly clear from the charcoal evidence that abundant woody resources were available to groups occupying the Dolní Věstonice-Pavlov sites and it is therefore likely that trees were present in the vicinity.

Table 1 around here [CHARCOAL FROM PAVLOV HILLS ARCHAEOLOGICAL SITES]

Modelling firewood supply in the Pavlov Hills

The following sections draw together a range of data pertinent to firewood provisioning during the Pavlovian which we argue are sufficient for drawing some general conclusions about fuel wood abundance and supply near the Pavlov Hills. As per the palaeoenvironmental and archaeological evidence our analysis assumes the conifers pine, spruce and larch were the main source of firewood available to Gravettian groups. Additionally, while it is expected that some green wood was harvested and burned, we assume that dead wood was the primary fuel because of its superior combustion qualities (see earlier text), and concentrate on this. Indeed the burning of decayed dead wood is indicated at Pavlov I by charcoal fragments containing tunnels or holes caused by wood parasites (Damblon, 1997), and at the nearby Pavlovian site of Krems Wachtberg by degradation of charcoal cell walls (Cichocki et al., 2014). The presented data focus on the rate of deadwood production in modern forests; the size of the deadwood pool in natural environments (i.e. areas unaffected by, or completely recovered from, human foraging for dead wood supplies); and charcoal data from the firewood actually burned by Pavlovian groups. An analysis is then given of the probable challenges facing Pavlovian groups in their search for firewood. We begin by considering how much firewood may have been required by Pavlovian groups.

Firewood requirements at Pavlov-Dolní Věstonice II

The quantities of fuel needed at Palaeolithic basecamps are unknown and difficult to estimate from archaeology alone, while ethnographic data for recent hunter-gatherers are surprisingly sparse, given the historic importance of fire in traditional cultures (Heizer, 1963; Picornell Gelabert et al., 2011). Many ethnographic descriptions mention simply that obtaining sufficient firewood was a constant daily struggle, while a lack of firewood is frequently cited as a reason for moving camp to a new location (Binford, 1978b:425-427; Henry and Thompson, 1897; Ingstad, 1954:211; Theler and Boszhardt, 2006). Rare quantitative data for a contemporary Evenki group from east Russia records the use of chainsaws to cut 15 m^3 of stacked fresh larch wood (*Larix cajanderi*) each year, expecting this to fulfil the needs of one family for the first two months of the following winters occupation when burnt in a metal stove (Henry et al., 2009:26), equating to ~90 m^3 per year assuming stable consumption rates. This is broadly comparable to experimental data measured for an open hearth in a reconstructed Viking longhouse during summer burning dried local birch and used for cooking and warmth, suggesting a burn rate of 2.3 kg per hour and annual consumption rates of around 100 m^3 (Trbojević et al., 2011). Detailed data for African farmers living on Lake Malawi and in Tanzania demonstrates firewood usage rates exclusively for cooking and heating water of between 5-25 kg per day (260-1300 kg per person per year)(Biran et al., 2004). Meanwhile experiments replicating Middle Palaeolithic hearths from El Salt in Spain showed that 5-16 kg of fuel burned in ambient summertime temperatures of 28-33 ^{o}C for approximately 1.7-7.0 hours in different conditions (Mallol et al., 2013). These data give variable usage rates of 1.4-6.4 kg hr^{-1} with a mean of 3.6 kg hr^{-1}, or >31 tonnes per year, equivalent to 105 m^3 of stacked wood per year (figures converted throughout this paper where necessary using a weight-volume conversion of 450 kg m^{-3} and solid-wood to stacked-wood conversion factor of 1.5 (Lindroos, 2011)). Large hearths of c.1m diameter, such as the one from Beeches Pit in England, are estimated to need 50-100 kg of firewood per day (Gowlett et al., 2012:705).

Actual rates of fuel consumption clearly depend on a large number of variables including weather, hearth size, burn-hours per day, moisture content and density of the wood fuel, the specific fuel mix, hearth construction, etc., and it is difficult to know how the measured consumption rates might have compared with fuel use in the Palaeolithic. Better data on contemporary and historic hunter-gatherer fuel consumption rates would show how consumption varies between groups in different environments and seasons, and make clear how typical or otherwise the existing estimates might be. For the moment, however, we draw attention to the large numbers of hearth features found at the Pavlov Hills sites, together with evidence for substantial basecamp occupations at which a full range of domestic activities took place including: cooking; sleeping; manufacturing composite tools, personal ornaments and art including fired-clay figurines; curing hides; ritual activities including human burial. We also point out that multiple hearths may have been lit simultaneously for unknown periods at any one time. Wood-fuelled fires were clearly essential to the energetics of the groups who stayed at the Pavlov Hills, so that obtaining and sustaining a daily supply of firewood was also critical, however much or little was needed.

Dead wood availability in contemporary forest

Deadwood production: Tree mortality rates in contemporary unmanaged old-growth boreal forests have been calculated at between 1.6-3.8 trees per hectare per year (ha^{-1} yr^{-1})(Aakala et al., 2011; Jonsson, 2000), or eight to nineteen trees per hectare in every 5-year period (Jonsson, 2000). However these rates increase markedly during mortality episodes caused by storms or disease, for example to as much as 42 trees ha^{-1} yr^{-1} or 21% of living trees within five years (Aakala et al., 2011), compared to just 0.3% to 1.12% of living trees per annum under normal conditions (Aakala et al., 2011:330). These figures are broadly consistent with a maximum age of 250-350 years for European *Pinus*, *Picea* and *Larix* species (Vaganov et al., 2006), and estimates for canopy turnover rate in European conifer forests of 167-330 years (Aakala et al., 2011), although a vast majority of trees die before reaching this upper age range. Alongside deadwood input from tree mortality, wood from dead branches also contributes significantly to the dead wood pool, together equating to 15-50% of the total biomass increment over a 60-year period (Krankina and Harmon, 1995). Estimates of annual deadwood production never fall below 0.5 m^3 ha^{-1} yr^{-1} of solid wood or at least 3 logs per hectare (Jonsson, 2000), equivalent to 225 kg ha^{-1} and 0.75 m^3 of stacked wood.

Deadwood pool: Snap-shot estimates of the total extant deadwood pool in mature undisturbed woodland reveal a distinct south-north gradient, reflecting slower tree growth near the northern timberline (Table 2; Siitonen et al., 2000). Typical quantities of coarse woody debris including all dead branches, snags (standing dead trees), stumps, etc. in old-growth spruce-dominated forests range between 100-200 m^3 ha^{-1} in southern boreal zones, decreasing to around 20 m^3 ha^{-1} in the northern boreal zone (Sippola et al., 1998); similar values were obtained for pine-dominated forests (Siitonen et al., 2000). Disturbance factors such as fire, drought, pests, disease and wind damage generally increase the quantity of dead wood detritus. For example, sites affected by severe windstorms and given 10 years to recover were found to have deadwood stores equivalent to 43-57% of total biomass at that time, while the quantity of deadwood immediately following the windstorms was estimated to be 59-69% of total biomass (Krankina and Harmon, 1995:233). Mean volume among 647 dead *Picea abies* logs >15 cm diameter in north Sweden was found to be 0.35 m^3, while mean snag volume was 0.17m^3 (Jonsson, 2000); whole dead conifer trees near the timberline account for 11-12 m^3 ha^{-1} while snags and dead branches account for around 7 m^3 ha^{-1} (Sippola et al., 1998).

Only a portion of this deadwood pool is readily available to humans for collection by hand; for example a study considering South African savannah environments found that on a per tree basis, 77% of the total deadwood standing crop was unavailable for harvesting by hand without tools such as an axe or saw because it was too big, too high or too small (Shackleton, 1998). However ethnographic descriptions of hunter-gatherer firewood collection include a range of strategies for harvesting inaccessible wood supplies; illustrative examples include the NW Coast Indians who felled large trees with stone axes and fire (Day, 1953:330 and references therein), the Yokuts of Central California who set fires at the base of trees to fell them (Gayton, 1948:78), and the Haush of Tierra del Fueguo who split firewood into manageable pieces using bone wedges (Chapman and Hester, 1973:194). Further examples include methods used by Blackfoot Indians of the Great Plains who threw ropes attached to stones over high up branches and jerked on the rope to break them off, or burnt through roots of large trees to bring the whole tree down to make the high up branches more accessible (Wissler, 1910:32-33). Given the range of potential wood gathering methods, we therefore assume that most if not all extant dead wood was accessible to Palaeolithic humans should they have chosen to collect it.

TABLE 2 and FIGURE 3 AROUND HERE [VOLUME OF DEADWOOD BY LATITUDE]

Dead wood from trees and large branches may typically persist in boreal environments for around 65-90 years (Krankina and Harmon, 1995:236; Moroni et al., 2010 and references therein). However, actual decay rates vary significantly between species and are affected by factors such as starting density of the wood and the primary agent of decay (bacterial, fungal, weathering etc.). For example snags (standing trees) can retain the density of live trees for over a decade following death (Krankina and Harmon, 1995:232-233), and may stand for around 25 years before a loss of structural integrity causes them to fall over while logs on the ground will decay faster (Moroni et al., 2010:456). Conversely, buried wood in boreal forest conditions has been recorded as surviving for much longer periods, at least 250-500 years after death (Moroni et al., 2010); the main burial agent in this latter study was bryophyte groundcover growth, which forms a dense mat in many boreal forests that decreases temperature, increases moisture content and reduces nutrient availability in soils, thus slowing wood decay (bryophyte spores are recorded in pollen spectra from the Pavlov Hills; Svobodová, 1991).

These data make clear that today, small trees growing slowly in marginal environments produce substantially less deadwood and are associated with smaller extant deadwood pools than trees growing in more favourable climes, visible in the latitudinal gradient in Swedish spruce-dominated woods today (Siitonen et al., 2000: Figure 3). This is despite the fact that deadwood can remain in the environment for many decades after death in certain conditions.

Driftwood

Driftwood can be an important component of river systems, impeding water flow, altering patterns of riverbank erosion or alluvial deposition, and stimulating overbank flooding (Wohl, 2013). Once located, the wood may be valuable for fuel, construction, or for other purposes (Alix and Brewster, 2004). Seasoned deadwood is dry, buoyant and will float, easily being collected from the river as it passes, but wood that is waterlogged, damaged or too decomposed is heavy, will not travel far, and is often left behind (Alix, 2005; Alix and Brewster, 2004). In cold boreal environments most driftwood enters river systems either during the spring melt, or during summer floods, as a consequence of riverbank undercutting and erosion, or from direct tree fall (Alix, 2005; Wohl, 2013). Winter ice plays an important role in this seasonal cycle, hampering progression of deadwood downstream while helping to break larger branches apart and dislodge them from riverbanks (Alix, 2005). Periods of high water levels at other times of the year will have a similar effect, dislodging both fresh and dead wood materials all along the riverbank. Driftwood collection in boreal riparian environments is therefore strongly seasonal, defined by the timing of the spring melt and summer floods (Alix, 2005:93). Larger river systems flowing through such environments may carry vast quantities of wood at these times, when an annual supply of fuel wood may be collected relatively quickly and stored (Alix and Brewster, 2004). Alternatively, driftwood may be collected year-round from certain locations where debris has formed jams in a river, as smaller branches become lodged against larger logs that have become stranded on channel beds or banks. These locations will vary between flood events and must be searched for.

While driftwood was probably obtainable near the Pavlov Hills, the quantities available were almost certainly small. The Dolní Věstonice-Pavlov sites are located on slopes above the confluence of three medium-sized rivers, the Dyje, the Svratka and the Jihlava (Figure 1). While today's landscape has been altered from that of the Gravettian by the deep loess deposits that bury and preserve these sites, it is and was rather gentle and flat. Almost the only topography in the vicinity is the Pavlov Hills themselves, which rise a mere 200 m above the Dyje River floodplain. The three rivers rise *c.*130-160 km distant to the west and north-west, in the uplands of the Bohemian Massif, before reaching the lower-lying Moravian Plain between 30 km and 60 km from the Pavlov Hills. The available evidence indicates that the uplands of the Bohemian Massif were cold and harsh during the Gravettian period, being partially glaciated along their southern edge (Ehlers et al., 2011; ložek, 1996), so that trees would not likely have grown there. Along their 30-60 km stretches across the Moravian Plains, however, these rivers were part of the mammoth steppe ecosystem, and likely supported some boreal woodland in sheltered parts along their banks. Clearly, the quantities of any driftwood derived from these trees would have depended on the density of the riverine woodland, river channel width and depth, floodplain form, and the degree of bank erosion (Wohl, 2013); yet it is clear that small rivers send less driftwood downstream than larger rivers, due to smaller river catchment zones and increased jamming of wood against riverbanks and other obstructions. Thus, while driftwood may have been an important fuel source for Gravettian occupations located along major rivers such as the Morava or Danube, which potentially carried large supplies of driftwood (e.g. see Cichocki et al., 2014), here we argue that small rivers flowing across a flat topography with short stretches likely to sustain woodlands mean that driftwood was unlikely to have played an important role.

Charcoal data on Pavlovian firewood

Clues about tree growth around the Pavlov Hills may be gleaned from charcoal recovered at the occupation sites themselves. At Dolní Věstonice II (DVII), charcoal recovered in 2005 showed strong tree ring curvature indicative of fragments derived from thin-stemmed branches or trees (Beresford-Jones et al., 2011). However Opravil (1994) reports charcoal from other areas of DVII showing a range of ring curvatures, which he used to reconstruct stems/branches with diameters varying from 5 mm to 200 mm, and one *Picea*/*Larix* fragment from a trunk possibly 30-40 cm in diameter. Notwithstanding the inherent uncertainty in Opravil's calculations (García Martínez and Dufraisse, 2012), these estimates demonstrate clearly that at least some trees survived to a significant size and age. Indeed research at the nearby Gravettian site of Krems Wachtberg found that around one third of >2000 charcoal fragments studied contained between 50-100 rings, while 10% had more than 100 rings and the largest fragment had 328 rings, again indicating trees of significant age (Cichocki et al., 2014).

And yet, despite tree ring studies providing clear evidence that some trees survived for several decades or hundreds of years (Cichocki et al., 2014; Damblon, 1997), these same investigations have repeatedly shown that the wood burned by Gravettian hunters was dense and took a very long time to grow. For example, the charcoal fragments studied at Krems Wachtberg contained long sequences of rings less than 0.1 mm wide, containing only a couple of new cells per ring (Cichocki et al., 2014). Meanwhile growth rings averaging 0.58 mm in *Picea* were reported at Pavlov I (Damblon, 1997), <0.1 mm to 0.7 mm in *Larix*/*Picea* at DVII-05 including only one or two latewood cells, generally with very little cell wall thickening (Beresford-Jones et al., 2011), and as low as 0.25 mm (but up to 1.2 5mm) in *Larix*/*Picea* and *Pinus sylvestris* from the upper part of DVII near the triple burial (Opravil, 1994:178). Narrow growth rings were also reported in charcoals from Pavlov II, Pavlov VI and Milovice IV (Čulíková, 2011), while charcoal from Pavlov I presently under study at the University of Southampton shows the same narrow rings (Figure 4). Occasional wider rings have also been noted, for example up to 2.4 mm in *Picea* from Pavlov I (Damblon, 1997), but these growth rings are rare and distinctly atypical within a context which Beresford-Jones et al. (2011:1959) describe as experiencing "delayed springs, cool summers and early onset of cold autumns", generally poor living conditions for the trees. It should be emphasised that tight growth rings characterise charcoals from both large and small diameter stems, indicating this is not a function of the size of the wood collected but is true generally of the wood available to hunter-gatherers at the time (Beresford-Jones et al., 2011). Clearly, while the trees harvested for firewood in the Gravettian could and did grow old, they were also living at the edge of their survival limits and extremely slow-growing.

No tools suitable for wood-chopping have been reported among Pavlovian lithic assemblages, which are characterised by tools made on narrow blades and microliths

(Svoboda, 1996). Fuel was therefore probably gathered and burnt as found, or was brittle enough to break manually by hand.

FIGURE 4 AROUND HERE [PAVLOV I CHARCOAL CURRENTLY UNDER STUDY]

Deadwood production in the Pavlovian

Narrow growth rings in trees are consistent with a strong negative impact on plant photosynthesis (i.e. metabolism/growth), caused by the unique climatic conditions of the last glacial including lower temperatures, shortened day length and – especially significantly – lower concentrations of atmospheric CO_2 in combination with increased aridity (Gerhart et al., 2012; Temme et al., 2013). Slow plant growth is also reflected in Net Primary Productivity (NPP) estimates for the Moravian mid-Upper Palaeolithic, which show substantial reductions to conifer-dominated plant functional types relative to modern values (Allen et al., 2010; Huntley and Allen, 2003; Huntley et al., 2013). NPP for boreal woodland in the Czech Republic region at 32,000 has recently been modelled at 50-150 g m^{-2} yr^{-1} (Huntley et al., 2013), below that recorded in northern Scandinavian boreal forests in Sweden and Finland today (Zheng et al., 2004), emphasising again the slow growth rates and unfavourable conditions for trees at this time. It has already been noted that trees growing slowly due to poor climatic conditions produce dead wood more slowly, and form forests with a smaller total deadwood pool, than do fast-growing trees living in better conditions (Table 2; Siitonen et al., 2000). Given the clear climatic barriers to tree growth during the Pavlovian, it follows that dead wood must also have been produced relatively slowly at the time the sites were occupied.

Uncertainties concerning the extent and density of tree cover in the mammoth steppe mean it is beyond the scope of this paper to produce quantitative estimates of deadwood abundance, although we suggest this is a potential avenue for future modelling research. Nonetheless, it is illustrative to consider deadwood availability in contemporary north Scandinavian boreal forests near the timberline which experience harsh growing conditions resulting in low NPP in boreal woodland, similar to the Pavlov Hills case study (i.e. environments containing 20-60 m^3 of coarse woody debris per hectare, with minimal annual deadwood production rates of around 0.5 m^3 ha^{-1} yr^{-1} of woody stems >5 cm diameter (Jonsson, 2000; Siitonen et al., 2000; Sippola et al., 1998)). Assuming usage rates of 3.6 kg per hour (~105 m^3 of stacked wood per year), naturally-produced deadwood from a 1 ha area of Scandinavian boreal woodland could have sustained a single continuously-burning fire for 260 days; if three campfires were alight simultaneously for 16 hours per day and banked down over night using no extra fuel this halves to 130 days. Fuelling the same three campfires for 16 hours a day for 1 year would consume 63 tons of dead wood scavenged from between

2.3 and 7 hectares depending on tree stand density. Natural annual deadwood production per hectare would generate fuel for less than 2 days of human occupation per year, and once the deadwood pool was fully depleted it would take between 40-120 years for the deadwood pool to fully replenish.

While we do not suggest these figures are typical for the Pavlovian case study, the example illustrates two key points that are evident from the amassed data. First, the long residence-time of dead trees and branches in the deadwood pool means that even lightly wooded areas experiencing harsh climatic conditions may contain significant quantities of naturally-produced dead wood; this implies that firewood was probably readily available in wooded areas of mammoth steppe environments, but only in places where Palaeolithic groups had not recently scavenged for fuel. More important, however, is the second point, which highlights the fuel-supply challenge facing Upper Palaeolithic hunter-gatherers: slow-growing trees take many decades to fully replenish the deadwood pool. This is important because it suggests that *once groups had foraged an area for firewood, it will have taken many years before deadwood supplies were replenished sufficiently to again meet the firewood needs of a basecamp occupation***.** Groups remaining in one place for a prolonged period of time, or returning to the same campsite in several successive seasons faced dead wood fuel shortages that were both predictable and inevitable in the Central European Upper Palaeolithic world.

Discussion

Progressive exhaustion of local firewood supplies is a predictable and frequently mentioned problem in ethnographic accounts, leading to ever-increasing acquisition and transportation costs until a forced site abandonment occurs (Binford, 1978b; Bishop and Plew, 2016; Butler, 2014; Heizer, 1963; Ingstad, 1954:211; MacLeod, 1925; Theler and Boszhardt, 2006; Tindale, 1974). The Nunamiut, for example, expected most willow patches to sustain a single family for one or two winters, after which it would take around 45 years (i.e. 1-2 generations) to restore sufficient firewood supplies for the willow patch to be habitable again (Binford, 1978b:425-427). Rare larger patches could support several families simultaneously and these places were regarded as favoured locations, used regularly for winter camps (*ibid.*); only in areas of true boreal forest was firewood genuinely abundant. Meanwhile, northwest Athabascan Dénés also consumed all the locally available dead wood near their winter settlements annually, necessitating a new campsite location every year (Morice, 1895:184), while Australian Aborigines were forced to either reject basecamp locations near to water sources or carry firewood for long distances because recent ancestors had used up all the firewood (Tindale, 1974:55 and 65).

We take two main points from this ethnographic literature. First, *for groups that regularly burn wood-fuelled fires, access to firewood is equally important as access to food* *when choosing locations for residential basecamp settlements* (Binford, 1978b; Ingstad, 1954; Spier, 1928:369; Tindale, 1974:133). Applying this to the generally wood-poor landscapes of the Gravettian mammoth steppe, we therefore predict that large patches of trees would have been favoured as basecamp locations, attracting Pavlovian groups seeking to minimise the effort involved in gathering heavy, expendable firewood resources. These tree-rich locales provided a significantly larger starting deadwood pool, greater net annual deadwood production and could sustain the firewood needs of a larger population. The Pavlov Hills are a good candidate for such a location, given the coincidence of local geomorphology suitable for Gravettian-era tree survival (discussed previously) and the high density of settlement attested archaeologically.

Even in these firewood-rich locations, however, the ethnographic literature is unequivocal; longer-term or repeated occupations lead inevitably to diminishing naturally-occurring firewood supplies and ever-increasing acquisition and transportation costs. The second point we take from the ethnographic literature is, therefore, that *continued access to firewood at large and/or long-term settlements requires deliberate strategies for maintaining firewood supply*. This is particularly relevant for Gravettian occupations in the Pavlov Hills where the archaeological evidence indicates precisely the behaviours that would have created demand for fuel over an extended period of time: large basecamp sites with numerous hearths, representing repeated occupations by significant numbers of people, either in many smaller individual groups or fewer but larger groups. We concentrate on this second point for the remainder of the paper.

Forward-planning a firewood-provision system

Obvious potential responses to low deadwood supply include minimising consumption rates, mixing dead wood fuel with alternative fuels such as green wood, bone and dung (Beresford-Jones et al., 2010; Théry-Parisot, 2002a), or foraging for dead wood over a larger range. Indeed, maximum fuel foraging ranges vary widely between different sources and contexts, for example 250-800 m in a modern Evenki group (Henry et al., 2009), 90 m to 5 km for Aborinees in the Western Desert (Tindale, 1974:65) or 1-2km for two traditional African farming communities (Biran et al., 2004); meanwhile, Stefansson (1919:45) records Eskimo carrying driftwood inland for 10-13 km (6-8 miles) to their camps, and Ingstad (1954:211) mentions wood gathered from 48 km distant (30 miles). Other strategies include constructing rafts of firewood that were floated back to basecamps over unspecified distances (the Yukon River people, Heizer 1963:190). These transportation distances are clearly dependent on the choice of basecamp/site location, distribution of trees in the landscape, season and mode of transport, but the inherent bulkiness of firewood and high associated transport costs mean hunter-gatherers tend to move camp when local firewood supplies run out rather than increasing foraging distances to unmanageable levels (Heizer, 1963; Shackleton and Prins, 1992).

Guaranteeing deadwood fuel supplies in the long term within reasonable geographic distances to a campsite, however, requires more active management. This could involve planned geographic mobility over years and decades of the type already described allowing dead-wood pools to replenish naturally (Binford, 1978b; Spier, 1928), or mobility coupled with deliberate firewood curation – that is, deliberately killing trees months or years in advance of when the firewood will be needed, allowing time for the wood to dry out. This more invasive firewood management strategy is also widespread among hunter-gatherers from a range of different environments, including both planned and incidental tree-killing according to how certain groups are of returning to a given location (Alix and Brewster, 2004:55; Anderson et al., 2000; Day, 1953:330; Henry et al., 2009; Theler and Boszhardt, 2006). For example, trees killed quickly by ring-barking or 'girdling' may be left *in situ* indefinitely as 'insurance gear' (Binford, 1979:257) to be utilised whenever a future need arises and if this moment never comes, very little labour time is lost (Alix and Brewster, 2004). Alternatively if a group is more certain of returning, firewood may be collected, split and cached to dry at the site itself as 'site furniture' (Binford, 1978a), in readiness for immediate use when the group returns (Henry et al., 2009). Girdling conifer trees for firewood may also occur simultaneously with the gathering of other resources such as bark for manufacturing goods and clothing (Anderson et al., 2000:7; Zackrisson et al., 2000), and pitch which can be used for food or as an adhesive (Koller et al., 2001).

Firewood curation strategies – much like food storage – involve long-term logistical planning and structured mobility with an inherent expectation of returning to a given location, preparing resources in advance to ensure their future supply. The deliberate killing of trees alters both the physical and social character of a landscape, shaping living spaces and reflexively conditioning future decisions concerning basecamp location over months, years and generations. Explicit choices must be made about which trees to kill for fuel and which to leave as a future resource, while girdled trees left standing to dry or cut branches piled up may be considered 'owned' by those who left them, marking territory, and socialising the landscape and this physical resource within it (Anderson et al., 2000; Heffner and Heffner, 2012; Ingstad, 1954:212). Forward planning is essential to maintaining the supply of various raw material resources besides food and is integral to the lifeways of hunter-gatherers (Lightfoot et al., 2013); other examples of such practices might include the selection of specific prey animals within a herd to preserve herd structure and the collection of seasonal resources such as animal hides (Speth, 2013). This view is summarised by Keen (2004) speaking of the Australian Aborigines, who writes:

> "*According to one view, expressed by Robin Horton, foraging has a number of distinctive features. It involves minimal interference in, and control of, the reproduction of food species….. A contrasting view is that hunters and gatherers were not simply parasitic, killing and collecting opportunistically, but manipulated the environment and its resources. Aborigines* managed *lands, waters and their resources.*" (Keen, 2004:94 [Keen's emphasis]).

We maintain that Keen's description is equally applicable to the hunter gatherers of Upper Palaeolithic Europe and specifically here the Pavlovian, who will have engaged in a similar range of resource management activities to those observed today among contemporary hunter-gatherer communities – perhaps even more so given the energetics of life in a highly seasonal ice age climate.

Conclusion – Firewood supplies in the Pavlov Hills

We argue that groups living c.30,000 years ago at the Dolní Věstonice-Pavlov site cluster in the Pavlov Hills will have managed their fuel supply using similar methods to contemporary hunter-gatherers: by economising their fuel use; mixing different fuels where necessary (e.g. bone and dung); using green wood to supplement dead wood; and deliberately killing trees which were then left to dry out for periods of years prior to burning. We argue in particular that killing live trees and storing the wood *in situ*, or at the campsite, was likely essential for guaranteeing the availability of dry dead wood to burn, because it was unlikely that the charcoal-rich hearths found in the Pavlov Hills could have been sourced from naturally occurring deadwood alone. This is particularly true for the old-growth, large-diameter stems represented in hearth charcoal assemblages at Pavlov I (Cichocki et al., 2014; Opravil, 1994). There is currently no direct archaeological evidence that Pavlovian groups engaged in firewood management strategies. Indeed such evidence may not preserve archaeologically. Nonetheless, we argue that this behaviour must be inferred from:

1. Palaeoclimatic data indicating sparse tree growth restricted to favourable places in the landscape.
2. Archaeological data for intense occupation of the Pavlov Hills sites including large numbers of wood-fuelled hearths.
3. Charcoal ring-width data from Pavlovian sites, indicating that the firewood they burned grew very slowly but reached large-diameter branches/trunks.
4. The inference, based on deadwood production in modern forests and ethnographic data, that several generations were required for deadwood supplies to regenerate

naturally following residential occupations by hunter-gatherers in the neighbouring area.

Understanding settlement patterns and mobility in the Upper Palaeolithic requires proper consideration of fuel supply management. Firewood was not merely an optional resource in the Upper Palaeolithic to be collected casually when convenient. Rather, its procurement was fundamental to subsistence strategies and thus dictated human movement through the landscape and settlement within it. The crucial role of fuel provisioning is widely accepted for later archaeological periods (Bishop et al., 2015; Dufraisse, 2006; Johnson et al., 2005; Simpson et al., 2003; Theler and Boszhardt, 2006), and should, we argue, be properly incorporated into our understanding of Palaeolithic campsite locations at which large quantities of firewood were burnt. Without ready, reliable access to fuel, large aggregation sites around wood-fuelled hearths such as those of the Pavlov Hills would simply not have been possible. This argument is entirely consistent with ethnographic descriptions of firewood management practices by groups living in similar environmental settings today, but it was surely even more important in the freezing Pleistocene mammoth steppe environments of central and eastern Europe. Finally, this case study of fuel procurement is but one example of many potential landscape management practices that may have been employed by Upper Palaeolithic hunter-gatherers (Lightfoot et al., 2013), and which contributed to shaping the environments in which they lived.

Acknowledgements

We are grateful to the many people who discussed firewood supply with us and offered thoughts and comments on the ideas contained in this article including Brian Huntley, Martin Jones, Philip Nigst, Alex Wilshaw, Luc Moreau, William Davies and colleagues in the Centre for the Archaeology of Human Origins, University of Southampton. We also especially thank Amber Johnson for facilitating fruitful email discussions with colleagues based in the US, and Don Bragg, Greg Cleveland, Robert Jarvenpa, Marvin Jeter, Alice Kehoe, Jan Loovers, Carolina Mallol, Robert Wishart and Ben Pennington for their correspondence. AJEP is grateful to The Leverhulme Trust that funded this research, which was undertaken as part of the project *Seasonality, Mobility and Storage in Palaeolithic hunting societies* (RPG-2013-318).

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Figure 1: Map showing location of the Pavlovske Hills sites (marked 'X') and the Bulhary pollen core. Topography (shading), approximate location of rivers (thick lines) and associated floodplains are indicated. Trees may have grown as riparian woodland on the floodplain, or in sheltered locations in the valleys around the Pavlov Hills. 1 - Dolní Věstonice sites; 2 - Pavlov sites; 3 - Milovice sites.

Figure 2 – Images of hearths excavated at the Pavlov Hills sites. A) Photograph from the excavation archives of B. Klíma showing a hearth from Pavlov I in cross-section. B) Two hearths excavated in 1987 at Dolní Věstonice II, Western Slope. Photographs taken by J. Svoboda.

Figure 3 – Graphical plot of data listed in Table 2. Total deadwood volume is substantially lower in northern areas where tree growth is slower.

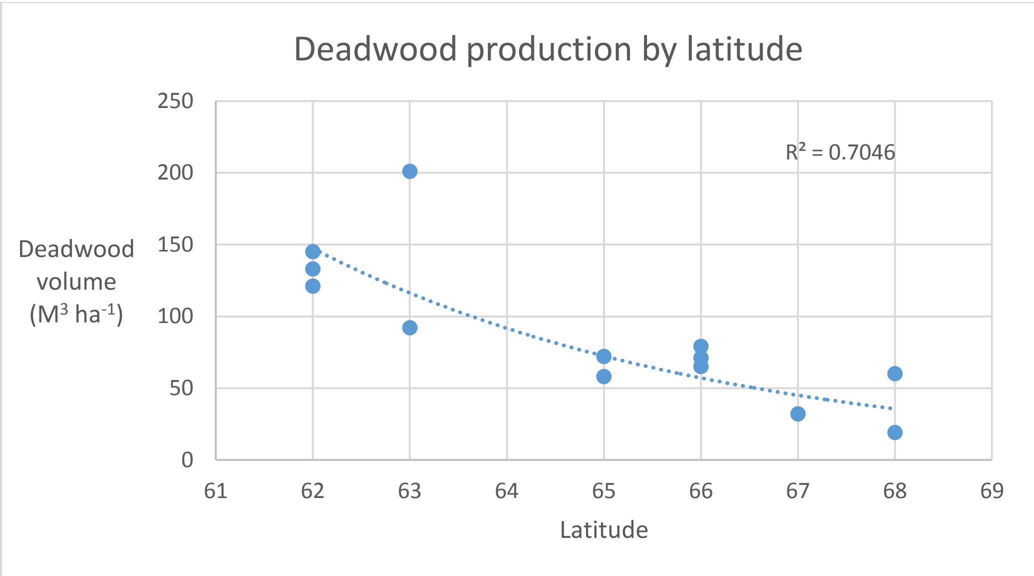


Figure 4 – Charcoal from Klima's 1963 and 1964 excavations at Pavlov I currently under study at the University of Southampton. A – Mostly narrow rings between 0.2 mm to 0.3 mm wide. This fragment shows 11 annual growth rings in 2.8 mm of charcoal. B – persistently narrow growth rings a few cells wide and mostly lacking late wood. This fragment shows 11 annual growth rings in 2.49 mm of charcoal.

Table 1

Arboreal taxa identified in macrocharcoal assemblages from Pavlovian sites near the Pavlov Hills. Numbers indicate quantities of fragments recorded. Where quantitative data are not available assemblages were summarised as follows: X – small quantities; XX – moderate quantities; XXX – large quantities.

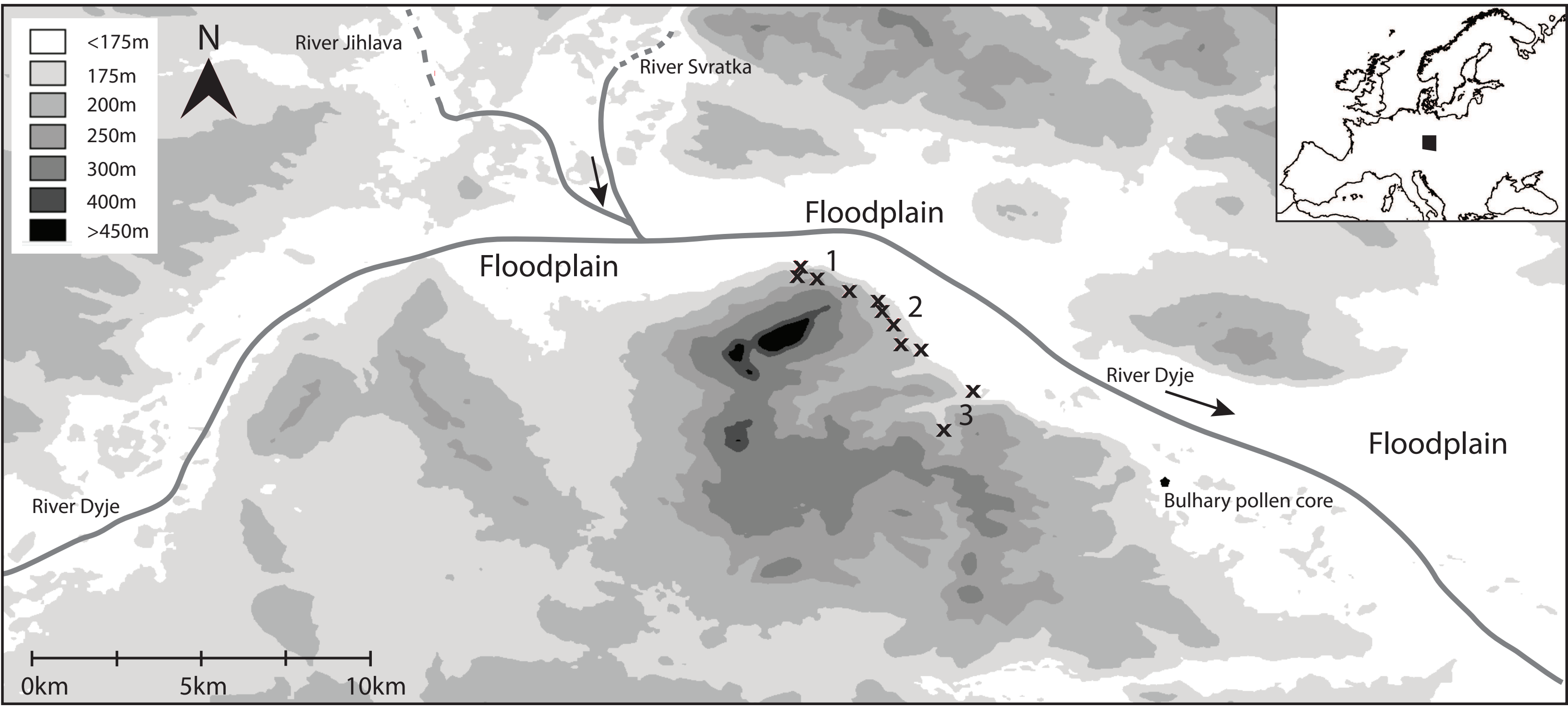
	Pine				Larch		Spruce		Fir			Broad leaved taxa							
Site (and researcher)	*Pinus sylvestris*	*Pinus t. cembra*	*Pinus mugo Turra*	*Pinus* sp.	*Larix/Picea*	*Larix decidua*	*Picea abies*	*Picea* sp.	cf. *Abies*	*Abies alba*	*Juniperus communis*	*Populus*	*Salix* sp.	*Fagus sylvatica*	*Quercus* sp.	*Taxus baccata*	cf. *Ulmus*	*Fraxinus*	Reference
Pavlov I (Opravil)	15	1	19		7		100		1	242									Opravil 1994
Pavlov I (Damblon)		125			7			526				1					1		Damblon 1997
Pavlov II (Čulíková)	6	2			48	86	82		4				5						Čulíková 2011
Pavlov VI (Čulíková)	3				26	19	61								1				Čulíková 2011
DVII (Opravil)	3				10	1		XXX	2	41									Opravil 1994
Milovice IV (Čulíková)	24				11	4	18		3				2						Čulíková 2011
Pavlov II (Opravil)										XXX									Klima 1976
DVI (researcher unknown)	XXX	XX	X	X		X	XX			X	X		X	X			X		Klíma 1954
DVII (other authors)	XXX			X	XXX	X				X	X					X			Mason et al. 1994; Klíma 1995; Beresford-Jones et al. 2011
Milovice I (Opravil)				X	X			XXX		XXX								X	Oliva 1988; Oliva 2009

Table 2

Volume of dead wood in old-growth undisturbed conifer forests at different latitudes, reproduced from data compiled in Siitonen et al. (2000). References for each entry in the table can be found in Siitonen et al. (2000).

Forest type	Stand age (years)	Location	Longitude (°E)	Latitude (°N)	Smallest measured diameter (cm)	Deadwood volume (m^3 ha^{-1})
Picea abies, Pinus sylvestris	196	Sweden	15	62	10	133
Picea abies	133	Sweden	16	62	10	121
Picea abies, Abies sibirica	~500	Russia, Komi	58	62	1	145
Picea abies, Pinus sylvestris	~200	Russia, Karelia	37	63	5	92
Picea abies	245	Sweden	18	63	10	201
Picea abies	140	Sweden	18	65	10	58
Picea abies	151	Sweden	19	65	10	72
Picea abies	~500	Sweden	16	66	5	79
Picea abies	176	Sweden	18	66	10	71
Picea abies	245	Sweden	22	66	10	65
Picea abies, Betula pubescens	~500	Finland	24	67	5	32
Picea abies, Betula pubescens	~500	Finland	25	68	1	19
Picea abies, Betula pubescens (moist)	~500	Finland	25	68	1	60

Figure 1



Map showing location of the Pavlovske Hills sites (marked 'X') and the Bulhary pollen core. Topography and approximate location of rivers (thick lines) and associated floodplains are indicated. Trees may have grown as riparian woodland on the floodplain, or in sheltered locations in the many valleys around the Pavlov Hills. 1 - Dolní Věstonice sites; 2 - Pavlov sites; 3 - Milovice sites.

Figure 1

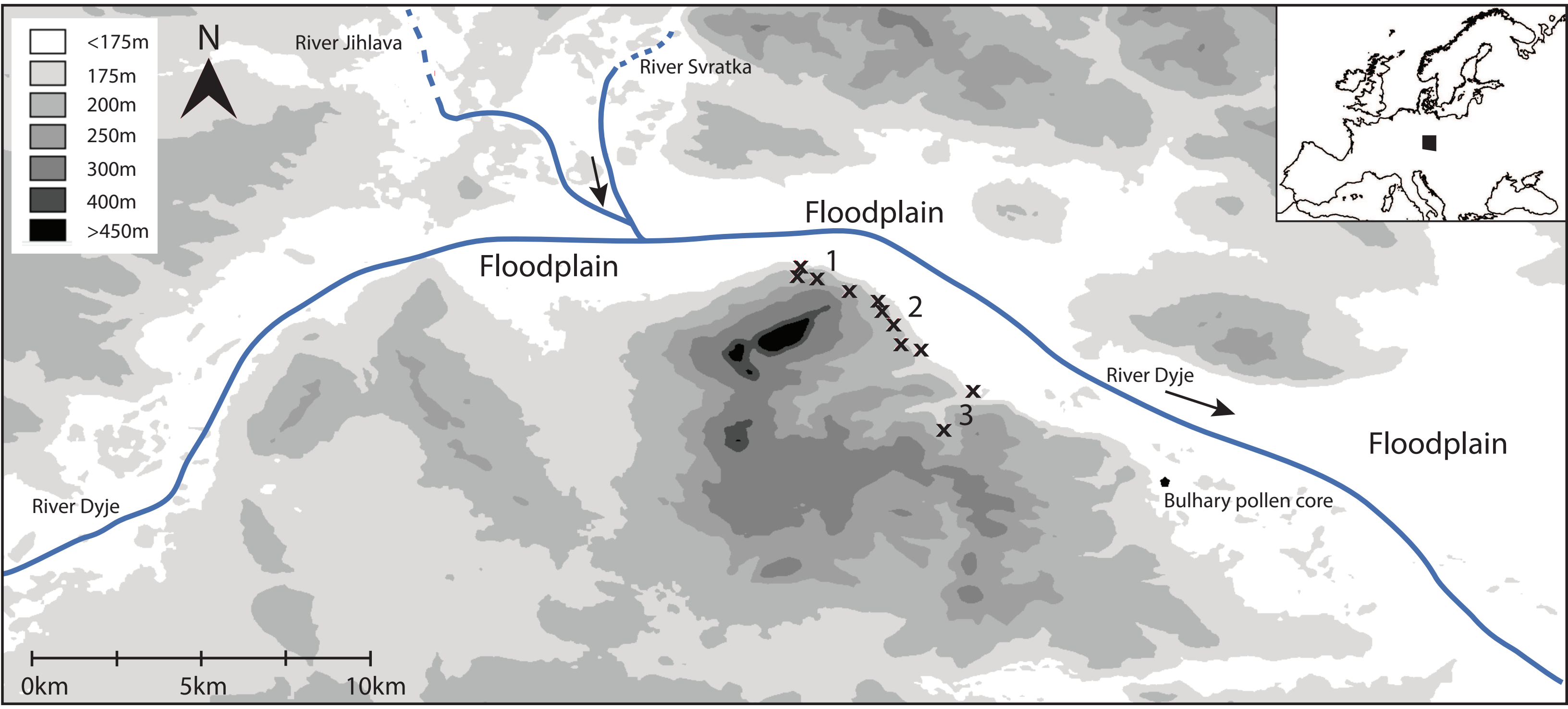


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Figure 2

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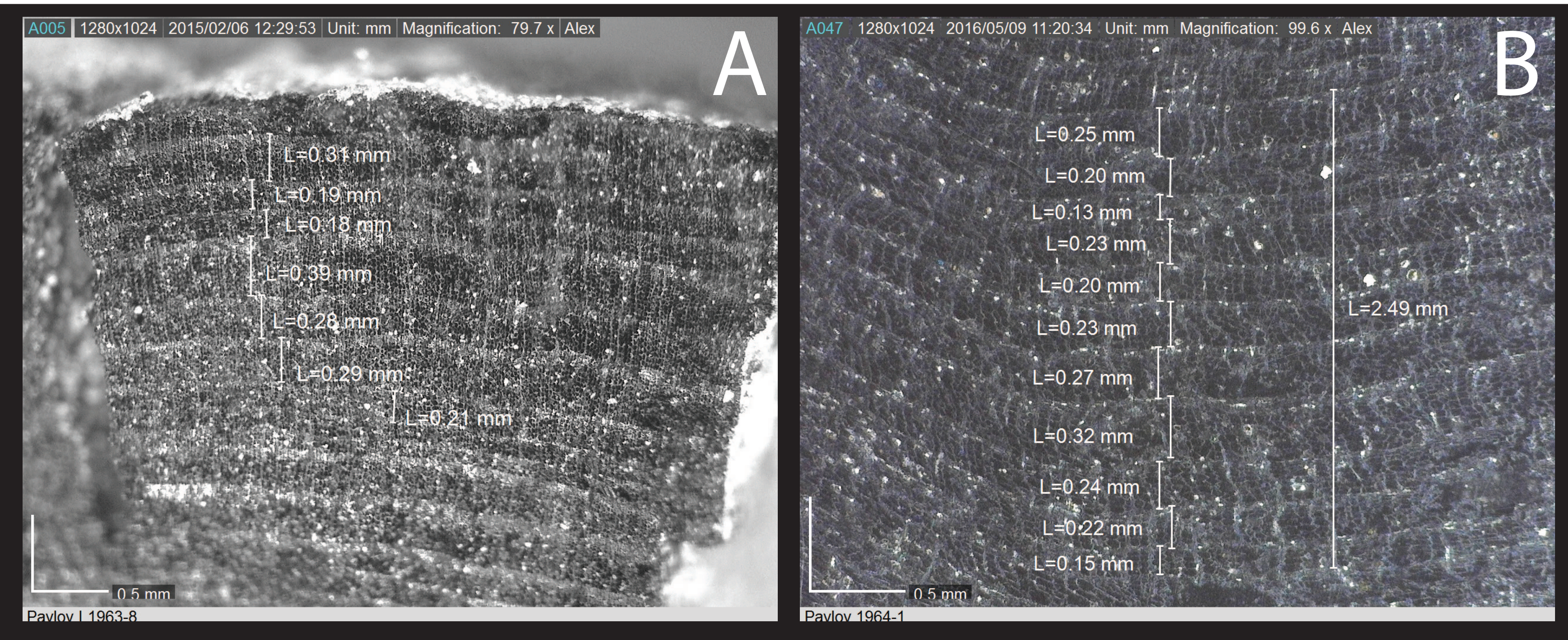
Figure 4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