Yew wood, would you? An exploration of the selection of wood for Pleistocene spears

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Wood, perishable as it is, likely played a central role in Pleistocene societies and their material culture. This paper is an exploration of the use of wood species by hominins at three key European sites that yielded evidence of hominin manufacture of wooden spears. The sample includes the Clacton Spear point, found in interglacial freshwater deposits at Clacton-on-Sea (UK) dated to Marine Isotope Stage (MIS) 11, the collection of wooden spears and spear fragments found at Schöningen 13 II-4 (Germany) dated to MIS 9, and the single complete wooden spear discovered with a butchered elephant at Lehringen (Germany), dated to MIS 5e. Material properties of wood may have influenced the manufacture, performance and durability of these early weapons. This paper collates data on some commonly measured properties of wood, with a focus on the wood species likely available at each site. It explores the use of wood for the spears at these archaeological sites and seeks to understand whether these species were deliberately selected for their material properties. The thought experiment is supported by data from previously published experimental replications, alongside ethnographic data on manufacture and use of wooden tools. The evidence suggests hominins were aware of the material properties of different species of wood, and selection may have been influenced by economic as well as social factors.

1. INTRODUCTION

Of all the categories of Pleistocene wooden technologies, wooden spears are among the best-studied (e.g. Oakley et al. 1977; Thieme & Veil 1985; Veil 1991; Thieme 1997; Haidle 2009; Garofoli 2015; Schoch et al. 2015; Milks et al. 2016; Gaudzinski-Windheuser et al. 2018; Milks, Parker & Pope 2019). Complete and fragmented wooden spears are most often proposed to have been used for thrusting and/or throwing by hand, and archaeological examples have been preserved in sites in Europe, South America and Australia dating to between ~400,000 and ~10,000 years before present (BP) (Warren 1911; Adam 1951; Oakley et al. 1977; Luebbers 1978; Thieme & Veil 1985; Dillehay 1997; Thieme 1997; Schoch et al. 2015). This paper poses questions about whether Pleistocene hominins deliberately selected particular species of wood for these weapons, and if so, what material properties they were selecting for. The idea that Middle and early Late Pleistocene hominins selected wood for their spears according to specific properties has been often repeated (e.g. Oakley et al. 1977; Thieme & Veil 1985; Schoch et al. 2015; Hosfield 2020, p. 225), but this has not been explored in detail. In order to evaluate the potential for selection of wood, the paper compares likely tree species available at sites from which Middle and early Late Pleistocene wooden spears are evidenced, making interspecies comparisons of some commonly measured material properties of wood that would influence manufacture, performance and durability. From an economic perspective, hominins may have sought to maximise ease of manufacture, longevity of use, performance of the tool, or a combination of these. Different species of wood have different densities, affecting ease of manufacture, resharpening, and mass of the spear. Differences in material properties also mean that different species of wood perform differently under stress and strain, affecting resistance to breakage and deformation. Thus, variability in wood properties would influence not only the time required to make a spear, but also its effectiveness, ease of use, curation, and durability.

Comparing properties of wood species used by Pleistocene hominins for their spears with other species of wood available at the time helps better understand whether hominins were likely differentially selecting wood for these tools at all, and if they were, whether these choices reflect economic decisions. By posing such questions, we can explore to what extent Middle Pleistocene and early Late Pleistocene hominins were aware of the properties of the raw materials underpinning this early weapon technology. This thought experiment helps to reflect on the cultural biography of these spears, and of the wider category of

Pleistocene wood technologies.

We know that during the Pleistocene epoch, between about 2,580,000 and 11,700 years ago, hominins used a diversity of raw materials for both expedient and formal tools, including stone from ~3.3 million years ago (MYA), and bone as early as ~1.8 MYA (e.g. Harmand et al. 2015; Stammers et al. 2018; Pante et al. 2020). Although wood is much less likely to preserve than other organic materials such as bone and antler (Hurcombe 2007, pp.142-43), residues on stone tools dated to ~1.7 MYA suggest that hominins in Africa may have also been exploiting wood from around the same period (Domínguez-Rodrigo et al. 2001). The earliest purported wood artefact is a plank of willow with possible traces of polish, found in association with Acheulean lithic and faunal remains dated to ~780,000 years ago (Belitzky et al. 1991).

As a category, wooden artefacts comprise a small, but remarkable, dataset for understanding human technological and behavioural evolution. Wooden implements modified by multiple species of *Homo* are known from Pleistocene and early Holocene sites in Africa, Australia, Eurasia and South America. In addition to the spears that will be discussed in detail in this paper, Pleistocene and early Holocene wooden artefacts include a wide variety of objects that may have been functional objects, tools or tool components. These include artefacts interpreted as possible planks (Belitzky et al. 1991; Dillehay 1997; Nadel et al. 2006), digging sticks (Luebbers 1978; Dillehay 1997; Clark 2001; d'Errico et al. 2012; Aranguren et al. 2018; Rios-Garaizar et al. 2018), fire drills (Oakley 1955; Jolie et al. 2011), tool handles (Dillehay 1997; Thieme 1997), a poison applicator (d'Errico et al. 2012; but see A. Evans 2012), pegs (Gilbert et al. 2008), a lozenge-shaped spear tip (Gaspari et al. 2011), boomerangs and throwing sticks (Luebbers 1975; Thieme 1997; Bamford & Henderson 2003; Conard et al. 2020), fragments of bows and arrows (Rosendahl et al. 2006; Rozoy 1978), and structural wood and containers (Tyldesley & Bahn 1983; Beyries & Hayden 1993; Dillehay 1997; Sandgathe & Hayden 2003; Vallverdú et al. 2005; Solé et al. 2013; Bigga et al. 2015). In addition there are a number of sites with imprints or 'pseudo-morphs' of wood, or wood artefacts that were so poorly preserved that clear human modification based on shape or surface marks is significantly more difficult to determine (e.g. D. Mania & Toepfer 1973; Carbonell & Castro-Curel 1992; Castro-Curel & Carbonell 1995; Wagner 1995; D. Mania & U. Mania 1998; Koller et al. 2001; Vallverdú et al. 2005; Nadel et al. 2006). Human modification of Pleistocene wooden implements, including many of those listed above, is often disputed, in part due to a lack of established methodological protocols to identify diagnostic signs of manufacturing and/or use. Taphonomic processes can also alter surfaces of objects so much that even those with a shape consistent with modification are disputed (cf. Gaspari et al. 2011; Schoch et al. 2015). Until improved methodological approaches can be taken, interpretations of human modification and functional uses of many of these artefacts need to be treated with great care.

Like Pleistocene hominins, chimpanzees (*Pan troglodytes*), the closest extant relatives to *H. sapiens*, also use wood for proto-cultural tools for a variety of purposes including termite fishing, honey extraction, nut cracking and hunting (e.g. Pruetz & Bertolani 2007; Boesch et al. 2009; Luncz et al. 2012; Pascual-Garrido 2018). Most relevant to this paper are the savannah-dwelling chimpanzees in Fongoli (Senegal), who shape wooden sticks into points and repeatedly jab them into hollow trunks with sufficient force to injure prey within the cavity, leading the authors to suggest that these are hunting tools that function as 'spears' (Pruetz and Bertolani 2007, p.413; Pruetz et al. 2015). It does appear that chimpanzees preferentially select different materials for different needs: for instance they will use either stone or wood for nut cracking depending on the hardness of the nuts (Luncz et al. 2012) and more often use bark than other plant parts for termite fishing (Pascual-Garrido 2018). However, it remains unclear to what extent this reflects an awareness by the chimpanzees of the properties of the materials they use, as opposed to the availability and proximity of a resource. Together this brief summary of primatological and archaeological evidence suggests that *Homo* likely exploited wood for a wide variety of technological purposes, potentially for well over a million years before the earliest known archaeological wooden spears were made.

2. PLEISTOCENE WOODEN SPEARS AND THE HUMANS WHO MADE THEM

The best-known archaeological sites with untipped wooden spears, and the subject of a detailed exploration in this paper, include the Pleistocene sites of Clacton-on-Sea (UK), dated to approximately 400,000 BP, Schöningen 13 II-4 (Germany), dated to approximately 300,000 BP and Lehringen (Germany), dated to approximately 120,000 BP (Warren 1911; Jacob-Friesen 1949; Thieme & Veil 1985; Oakley et al. 1977; Thieme 1997; Schoch et al. 2015). In addition to these well-accepted examples, the MIS 7 (ca. 243,000–191,000 BP) site of Cannstatt I (Germany) had a poorly-preserved 2.2 m long wooden artefact that may have been a spear (Wagner 1995). Pointed wood fragments from Kärlich-Seeufer (Germany) and Torralba (Spain) were also proposed to be spear fragments, but the modification of these objects is disputed (Biberson 1964; Freeman 1975; Bosinski 1995; Gaudzinski et al. 1996; Bosinski 2006; Santonja 2013).

While the above examples all come from sites prior to the arrival of *H. sapiens* in Eurasia, archaeological sites pertaining to our own species have also yielded wooden spears. The terminal Pleistocene/early Holocene sites of Monte Verde II (Chile) and Wyrie Swamp (Australia) have examples of shaped wooden tools interpreted as untipped spears for thrusting or throwing by hand (Luebbers 1975; Dillehay 1997). At Monte Verde II, the proposed spears were manufactured from mañio (*Podocarpus* sp.), while at Wyrie Swamp the wood species of the untipped wooden spear is likely to be sheoak (*Casuarina stricta*) (Luebbers 1978). Unfortunately, the Monte Verde II and Wyrie Swamp artefacts have not been comparatively analysed so their status as spears remains unclear. Use of wooden spears in recent small-scale societies has been well-documented in North America, South America, Africa and Oceania for terrestrial and aquatic hunting and fishing, in violence, and as training spears for children (Milks 2020a).

Unfortunately, none of the three sites considered in detail in this paper, Clacton-on-Sea, Schöningen 13 II-4, and Lehringen, contain hominin remains, and therefore a clear association between these artefacts and a species of *Homo* remains problematic. Hominin cranial fragments from Swanscombe (UK) dated to MIS 11 are roughly contemporaneous with the Clacton deposits, and show early Neanderthal features (Stringer and Hublin 1999). Also located in western Europe and placed in MIS 11, hominin fossils from Sima de los Huesos (Spain) have been morphologically and genetically placed on the Neanderthal lineage (Arsuaga et al. 2014; Meyer et al. 2014; Roebroeks & Soressi 2016), calling into question the status of *Homo heidelbergensis* (Stringer 2012). While the makers of the Clacton and Schöningen artefacts could have been early Neanderthals (see also Conard et al. 2015), they could also have been late *H. heidelbergensis,* or even Denisovans, a species about which very little is currently known but who may also have been present in western Eurasia (Skov et al. 2020). Lehringen, based on its date and contemporaneous Neanderthal sites, is less controversially attributed to Neanderthals (e.g. Gaudzinski 2004; Gaudzinski-Windheuser et al. 2018). Given this current area of debate, this paper avoids attributing Clacton and Schöningen spears to a hominin species, and uses the term 'Neanderthal' only in the context of sites that previous publications have clearly designated as such.

Conceivably, fire could have been involved in the manufacture of wooden spears, either to make the wood more workable or to somehow alter its functional properties. However, while recent discoveries do demonstrate the use of fire on Eurasian Middle Pleistocene wooden tools interpreted as digging sticks (Aranguren et al. 2018; Aranguren et al. 2019; Revedin et al. 2019; Rios-Garaizar et al. 2018) there is at present no clear indication that any Pleistocene wooden spears underwent thermal alteration. Proposed traces of fire on the Schöningen wooden weapons have been questioned (Stahlschmidt et al. 2015) and Oakley and colleagues (1977) argue that the lack of sealing of tracheids on the Clacton spear point strongly suggests this artefact was not burnt. Although dark patches on the Clacton and Lehringen spears could indicate thermal alteration (Milks 2018; Schoch 2014), they more likely represent humification or possibly the effects of conservation treatments. Resolving this issue would require further investigation involving the removal of conservation treatments, and the use modern techniques. With no clear evidence of the use of fire in relation to Pleistocene spears, this paper will not further consider the effects of fire on manufacture or use of wooden spears.

3. METHODS

Data on the presence of tree species from Clacton-on-Sea, Schöningen, and Lehringen come from published pollen and macrofossil data (Reid & Chandler 1923; Pike & Godwin 1952; Turner 1970; Thieme & Veil 1985; Bridgland et al. 1999; Gaudzinski-Windheuser & Roebroeks 2011; Bigga et al. 2015; Urban & Bigga 2015). Hypotheses about favourable material properties for the manufacture and use of spears (section 4) are formed on the basis of published and unpublished experiments with replica Pleistocene wooden artefacts and are cited accordingly in the text. Ethnographic data comes from a published systematic review of the use of wooden spears in recent small-scale societies and an accompanying open access database (Milks 2020a; Milks 2020b).

Wood is an orthotropic material (a subset of anisotropic materials) with three planes on which properties can vary (Kretschmann 2010). The density, strength, stiffness and ductility of wood vary by and within species and are dependent on the direction and type of stress (e.g. Tsoumis 1991, p.118-121 and 172-181; Pirinen 2014, p. 3, 19, 21, 29, 35). The three directions that can be measured in wood include axially (i.e. parallel to the grain), radially, and tangentially (Tsoumis 1991, p. 160). Axially, wood has more strength and stiffness than it does across the grain (Pirinen 2014, p. 21).

Density, measured in grams per cubic centimetre (g/cm^3), is a measurement of the mass of wood divided by the volume with a given moisture content, while specific gravity is the relative density, and is the ratio of the density of the wood to the density of water (Hoadley 1990, p.47). These two measures, density and specific gravity, are interchangeable (Tsoumis 1991, p.111). The higher the density measurement, the denser the material; the hardness of wood is also proportional, and the higher the density and specific gravity, the harder the wood (Hoadley 1990, p.49). Modulus of Rupture, measured in megapascals (Mpa), is one measurement of the strength of wood in bending (Fig. 1: B), reflecting the maximum load-carrying capacity. A higher value reflects greater resistance to rupture (Kretschmann 2010). Modulus of Elasticity,

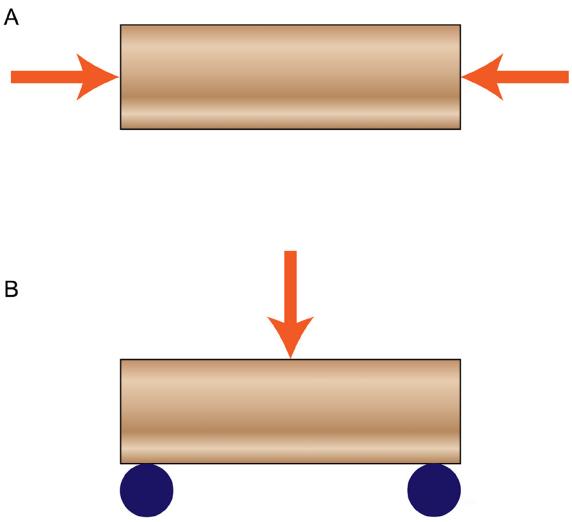

Figure 1. Schematic illustration of the direction of forces applied in A: testing of compression strength parallel to the grain, and B: testing modulus of rupture and modulus of elasticity on wood. The arrows represent the direction of forces in each testing scenario.

measured in gigapascals (GPa) is a measurement of the resistance of wood to being deformed elastically, in other words non-permanently (Kretschmann 2010). If loaded higher than its given Modulus of Elasticity, wood will not completely recover, and failure occurs. Stiffer materials have a higher elasticity value. Both Modulus of Rupture (MoR) and Modulus of Elasticity (MoE) are measurements of static bending. Finally, compression strength parallel to the grain, measured in megapascals (MPa) is the ability of wood to withstand loads parallel to the grain that tend to reduce the material in size (Fig. 1: A) (Kretschmann 2010). Of all strength measurements of wood, compression strength is the material property most affected by moisture content, although moisture content also affects density and elasticity (Wiedenhoeft 2010; Aicher & Stapf 2016).

The data on wood densities, MoR, MoE, and compression strength parallel to the grain (Comp) provided (Tables 1 to 3) come from the Global Wood Density Database (Zanne et al. 2009), The Wood Database (Meier 2007) and Nusret & Korkut (2016). Values represent averages for a given species, and properties vary by individual specimen. Therefore these values are for comparative purposes and are not intended to indicate specific values for Pleistocene artefacts discussed. Values are based on the following species: *Salix alba, Abies alba, Picea abies, Pinus sylvestris, Tilia europaea, Alnus glutinosa, Corylus avellana* (density) and *Corylus colurna* (for MoR, MoE and Comp), *Betula pendula, Taxus baccata* (density, MoE and Comp) and *Taxus brevifolia* (for MoR value), *Ulmus hollandica, Quercus robur, Carpinus betulus, Larix decidua, Rhamnus cathartica* (*Frangula alnus*), and *Juniperus communis.*

4. MATERIAL PROPERTIES AND THE MANUFACTURE AND USE OF WOODEN SPEARS

4.1 Manufacturing wooden spears

Evidence gathered during a systematic review of wooden spears in recent small-scale societies (Milks 2020a) shows a diversity of materials used to work and shape wood. Stone tools were used to execute initial cutting of wood, bark removal, and shaping, but in some instances this initial shaping was done using shells and teeth (e.g. Deacon & Wedgwood 1934, p.215; Gould 1969, p.98). The ethnographic literature also records a diversity of materials used for smoothing and polishing of spears, including sandstone, limestone, pumice, tree trunks, river weed, and sea sponges (Best 1924, p.245; Deacon & Wedgwood 1934, p.215; LeBar 1964, p.263). Handfuls of small chips of debitage were recorded in the polishing of wooden arrows (MacCalman & Grobbelaar 1965), a technique that could also be applicable to polishing wooden spears. Eurasian late Middle and early Late Pleistocene sites have evidence of lithic tools with residues and/or use-wear consistent with wood working (e.g. Rots 2009; Hardy & Moncel 2011; Rots et al. 2015), and Neanderthal populations in the Mediterranean also utilised shell technology, including potentially for woodworking (Romagnoli et al. 2017; Romagnoli 2018).

Hypothetically, optimal material properties of wood for manufacturing wooden tools will favour lower density woods, as in general the higher the wood density, the harder the wood, and the more difficult it is to work. Experiments replicating the manufacture of Pleistocene wooden spears using stone tools have focused on shaping yew (*Taxus baccata*) (e.g. McNabb 1989; Veil 1991; Fluck 2015). Veil (1991) manufactured a complete yew spear using stone tools, which took between 4.5 to 5.5 hours, not including the manufacture in advance of the stone tools required to cut down the small tree and shape the spear (see also Hosfield 2020, p.224). Hayden (1979, p.75) noted in an ethnographic study that Aboriginal Australian wooden fighting spears involved a considerable time investment and these tools therefore had significant prestige value. Making wooden spears is a considerable time investment compared with the mere minutes needed to manufacture unretouched flakes and chipped stone tools (e.g. Rasic & Andrefsky 2001; Putt 2015).

4.2 Material properties of wood in relation to function

Depending on whether spears were used for thrusting into prey, for throwing by hand, in self-defence, or multifunctionally, different material properties of

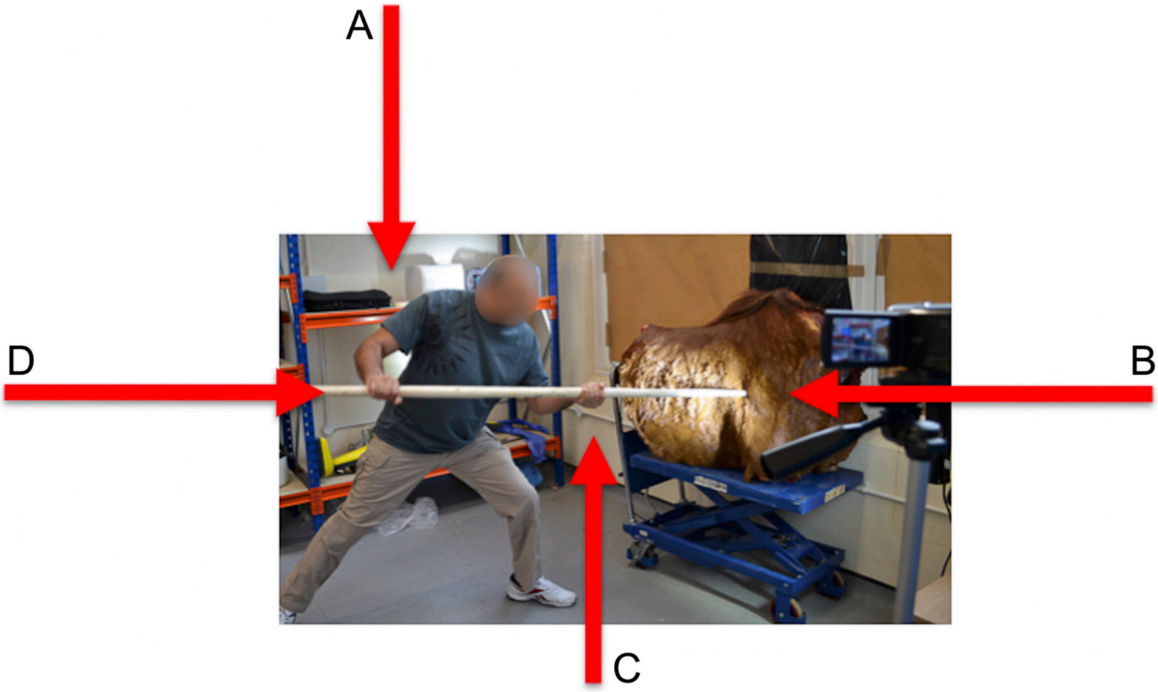

Figure 2. Experimental use of a wooden spear as a thrusting weapon on an animal carcass, with red arrows showing directions of forces acting on the spear during use. Arrow A: Downward force applied by the thruster in two-handed forward grip. Arrow B: Resistant force of the target. Arrow C: Upward force applied by the thruster in two-handed forward grip. Arrow D: Force applied on the spear against the target by the thruster's two arms and body mass. From Milks 2018.

wood for spears may have been selected for. Because wood is orthotropic, when used in weaponry, the points will fracture macro- and microscopically in different ways than weapons tipped with stone or bone. Stone is typically isotropic (Holdaway & Stern 2004; Andrefsky 2005 p. 24) while bone is anisotropic, differing on two planes (Knecht 1997). Ethnographic descriptions of the use of wooden spears do not often provide data on wood species, but many sources describe a selection for 'hard' wood (Milks 2020b). When species have been named they include those with high densities such as manuka (*Leptospermum scoparium*), woolly teatree (*Leptospermum lanigerum*) and desert oak (*Allocasuarina decaisneana*) (e.g. Smith 1893; Spencer & Gillen 1899; Noetling 1911; Clastres 1972; Alvarsson 1988). These ethnographic sources suggest that functionality and resistance to fracture during use was more important than ease of manufacture, although distance to raw material sources may play an important role in such choices.

4.3 Wood for thrusting spears

Wooden spear replicas have been experimentally tested as thrusting weapons, recording both high impact energies and forces (Milks et al. 2016; Coppe et al. 2019; but see Gaudzinski-Windheuser et al. 2018). During thrusting, wooden spears undergo forces from a number of directions, dependent in part upon hand positioning and grip. In a two-handed forward grip (Fig. 2), the grip chosen most frequently in two separate spear thrusting experiments with different participants (Milks et al. 2016; Milks 2018), forces acting on the spear come from different directions including the person's hands and body weight and the resisting forces of the target (Fig. 2). These different directions apply compression force on the tip of the spear while also placing bending forces along the shaft. Spears sustain compression and macrofracture damage to the point (Fig. 3: B), and broke experimentally along the shaft during spear thrusting (Fig. 4). Therefore, it is hypothesised that optimal properties for the wood selected for spear thrusting would include high compression strength to counteract tip compression, a high MoR and a low MoE to counteract fracturing of the tip and shaft. and a low MoE.

4.4 Wood for throwing spears

Experimental work confirmed that when thrown by skilled throwers, Schöningen Spear II replicas fly accurately and can hit a target at velocities over 20 m/s with kinetic energy at impact as high as 179 joules (Milks et al. 2019). The velocity with which a person throws an object is affected by its mass, with velocities decreasing with increases in mass (Toyoshima & Mitsumasa 1973). The mass of a spear is determined by its size, and also by the density and moisture content of the wood. Eleven replicas of Schöningen Spear II made of spruce (*Picea abies*) were created

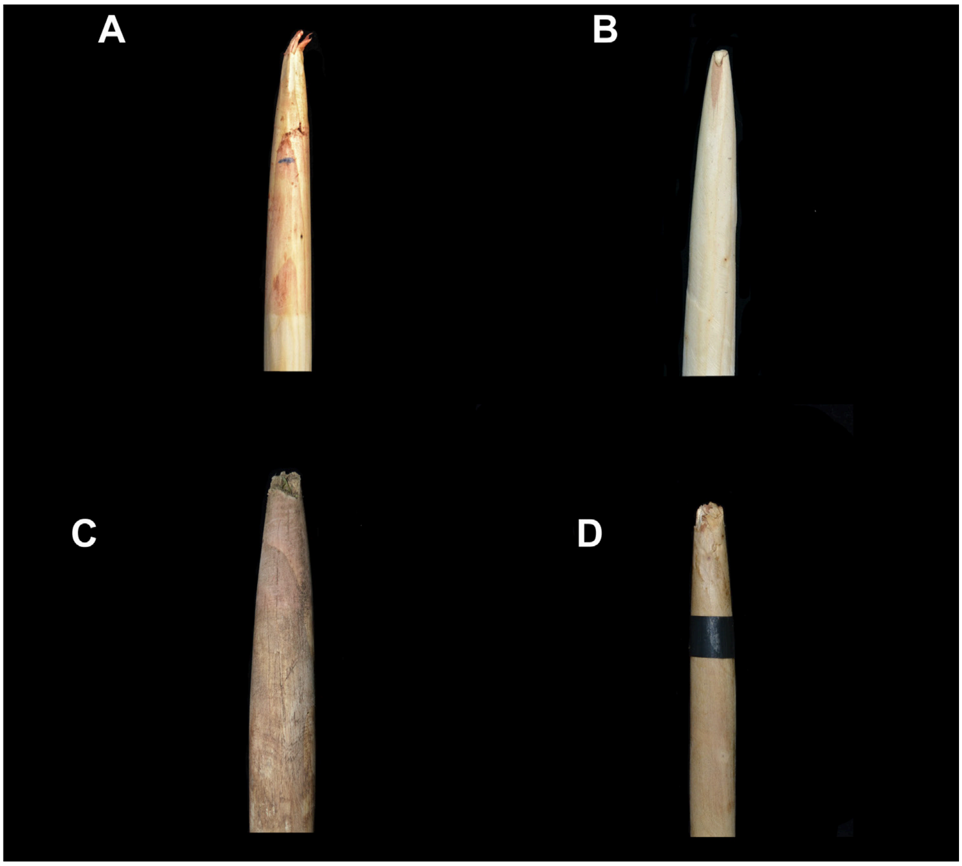

Figure 3. A selection of some of the types of tip damage from experimental use of wooden spears. A) Thrusting spear impacting an animal carcass resulting in tip splitting B) Thrusting spear impacting an animal carcass resulting in tip compression C) Throwing spear impacting turf resulting in complete tip fracture D) Throwing spear impacting an animal carcass resulting in complete tip fracture. Images not to same scale. From Milks 2018.

Figure 4. Example of a spear shaft breaking between the two hands during experimental use as a thrusting spear on ballistics gelatine (Milks et al. 2016). This spear shaft broke after 22 thrusts, at a point where several knots converged in the wood, representing a weak area in the wood.

for experimental purposes (Milks et al. 2016; Milks 2018; Milks et al. 2019). These replicas, made to match measurements of the original, had a wide range of masses from 597 grams (g) to 1020 g (mean=787 g). Although ethnographic throwing spears weigh as little as 242 g (Milks 2018) and as much as 1800 g (Spencer 1914), lighter spears might be favourable for longer distance throwing, while heavier spears may function better at closer distances.

Modern javelins are distance rated, with the stiffest javelins reserved for elite throwers (Johnson 1987). Stiffer javelins reduce vibration in flight, reducing drag and improving distance, but they take more power to throw. Elite javelin athletes who threw replicas of Schöningen Spear II reported that their stiffness conforms to the stiffest, highest distance-rated javelins used in modern competitions (Harry Hughes and Bekah Walton, pers. comm.). Thrown spears have forces acting upon them from a number of different directions, including the initial force at release and the opposing forces of drag, gravity, and lift during flight (Fig. 5). These forces can cause the spear to flex during flight. The stiffness of the wood affects amount of vibration at release and during flight; a stiffer material improves the release velocity and aerodynamics, but requires greater power from the thrower (Johnson 1987; see also Milks et al. 2019, SI).

A successful spear impact involves the spear landing point first, penetrating the target. Still photographs taken from high speed video footage demonstrate that if a thrown spear lands badly and/or fails to penetrate the target, it experiences force at both ends simultaneously, creating bending stresses (Fig. 6). Like thrusting spears, replica spears thrown experimentally at both soft ground and animal carcasses can sustain tip compression, and fractures to the tip and shaft, particularly after multiple throws (Fig. 3: C, D).

Considering the above, a balance of material properties for wooden throwing spears would be optimal. A relatively low density wood makes for a lighter spear, facilitating distance throwing, as the lighter the mass of the spear the faster it can be thrown. Similar to thrusting spears, a high parallel compression strength and high MoR would be favourable to prevent tip and shaft damage. Finally while wood with a high MoE, resulting in a stiffer spear, could have been used by the strongest and most experienced throwers, a lower MoE value would require less power to throw but might be more limited in distance. Given that spruce

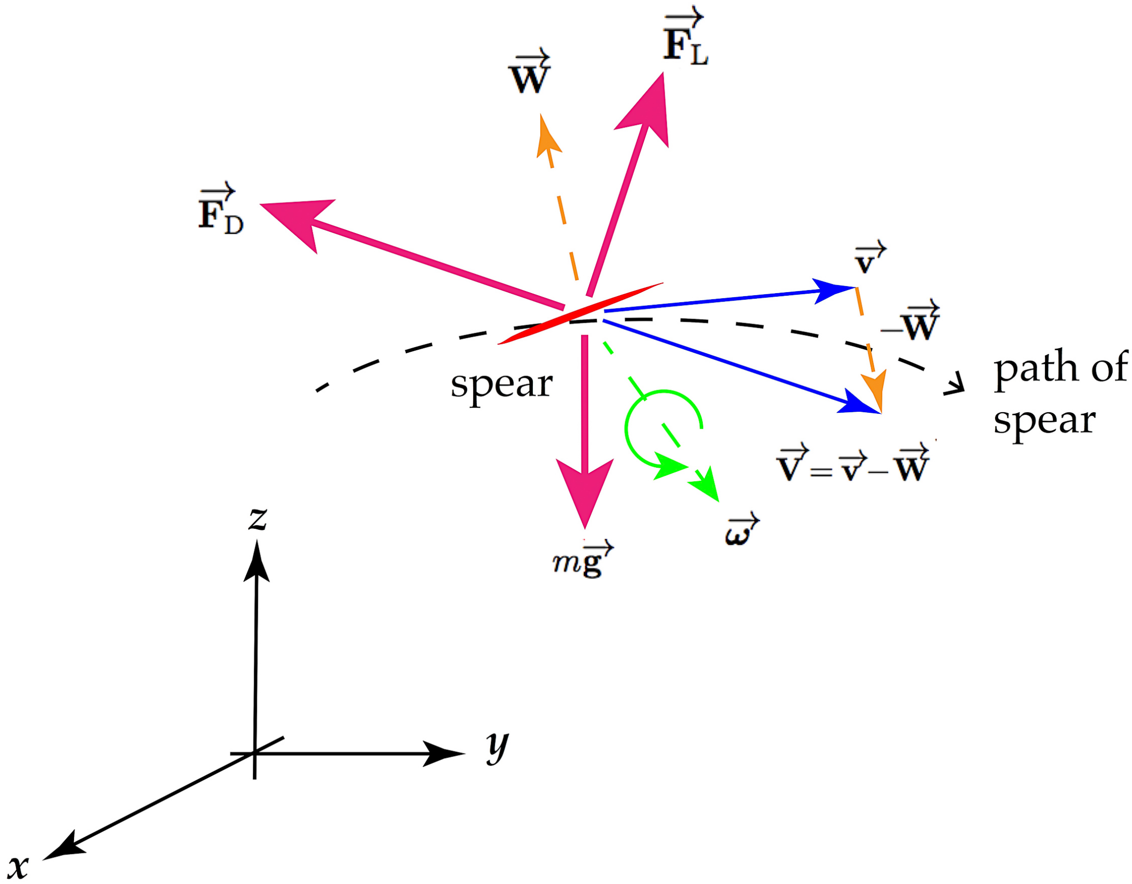

Figure 5. Schematic illustration of a spear during flight, with the pink arrows showing the forces of lift, drag, and gravitational acceleration. F_D represents the drag force, F_L the lift force, and *mg* the gravitational force. W represents the wind velocity and v the projectile velocity in relation to the coordinates. V = v – W represents the projectile velocity relative to the air, while $\vec{w}$ is the projectile angular velocity. From Milks et al. 2019, redrawn and recaptioned after Robinson & Robinson 2013.

Figure 6. Sequence of three still shots from high speed video footage of a failed spear impact during a throwing experiment. The final frame demonstrates the bending of the spear when it experiences impact at both ends simultaneously, and thus the importance of the resistance of wood to rupture during throwing.

was reported by athletes to be equivalent in stiffness to javelins used by elite male javelin athletes, it may be that wood with MoE any higher than this would become increasingly difficult to impart velocity that would be high enough to be viable as distance weapons.

5. AVAILABILITY AND SELECTION OF TREE SPECIES FOR SPEARS

Pleistocene sites rarely have the preservation of organics or chronological resolution of later prehistoric sites (e.g. López-Bultó & Piqué Huerta 2018), making recognition of the exploitation of wood, and of the reconstruction of the environment and availability of tree species more challenging. This highlights the value of sites such as Schöningen, not only in relation to its exceptional organic preservation, but also to the modern excavation and analytical methods used.

5.1 Clacton-on-Sea

The 'Clacton spear point', dated to Marine Isotope Stage (MIS) 11 (ca. 424,000–374,000 Before Present) is a broken yew branch (*Taxus baccata*) with clear evidence of shaping and tool marks (Warren 1911; Oakley et al. 1977; Bridgland et al. 1999; Roe et al. 2009; Milks 2018). It was found in sediments eroding out of the foreshore at Clacton-on-Sea (UK), and although its context therefore remains somewhat obscure, subsequent research on MIS 11 deposits in the region provide a broad idea of the characteristics of this interglacial (e.g. Turner 1970; Reid and Chandler 1923; Pike & Godwin 1952; Bridgland et al. 1999). Mammal remains from the Clacton deposits show the presence of cervids, equids, proboscideans, rhinoceros and bovids, suggesting a temperate interglacial climate (Warren 1923; Singer et al. 1973; Bridgland et al. 1999). A study of plant macrofossils from Clacton deposits show a mix of woodlands and scrublands associated with the Upper Freshwater Beds (Bridgland et al. 1999).

The Clacton spear point has been interpreted as the tip of a thrusting spear, or possibly a game stake or even a snow probe (Oakley et al. 1977; Gamble 1987). Its classification as a thrusting spear was partly made on the basis of its thick diameter in comparison with ethnographic spears (Oakley et al. 1977). However, a more recent morphometric analysis of archaeological and ethnographic wooden spears did not uphold that conclusion, as there was significant overlap in length and diameters between thrusting and throwing spears and the diameter of the Clacton spear point exceeds all examples in a comparative sample of ethnographic spears (Milks 2018, p. 216). Although it is a fragment, the diameter of the Clacton spear point does fit into the range of archaeological spears, with Schöningen Spears I and VI and the two possible spears from Monte Verde II all having larger maximum diameters (Milks 2018, p. 138; Schoch et al. 2015; Dillehay 1997, pp. 156-158).

Oakley and colleagues (1977) argued that the Clacton hominins deliberately selected yew due to its material properties, including its resistance to fracture. Yew has a special combination of properties that make it both hard and elastic, which gives it a reputation for durability (Uzquiano et al. 2015). Partly due to its narrow growth rings and high amounts of extractives (e.g. Keunecke 2008, pp. 14, 36, 52), yew wood has high density, a high MoR, a relatively low MoE showing resistance to deformation, and also has the highest compression value of any of the potentially available tree species (Table 1). It features heavily as a wood exploited for prehistoric weaponry: in addition to the Clacton and Lehringen spears, it was also used for the aforementioned lozenge-shaped spear point (Gaspari et al. 2011), and in later prehistory for bows (e.g. Clark 1963; Oeggl & Schoch 1995; Uzquiano et al. 2015 and references therein). The use of yew for the Clacton spear point is especially interesting in light of the fact that spruce and pine, the wood used to manufacture the younger Schöningen spears, were both potentially available to the Clacton hominins (Table 1).

Offsetting of the tip to avoid the softer central pith, such as can be seen on the Schöningen and Lehringen spears, was not observed on either the surface or the X-radiographs of the Clacton spear (pers. obs.; Allington-Jones 2015). Oakley et al. (1977, p.15) argue that the break on the spear fragment occurred when the wood was 'probably well seasoned' as it would be unlikely to have ruptured while green. They describe the force necessary for such a break as 'considerable' (Oakley et al. 1977, p.19) but hypothetically this could be the case for both throwing and thrusting. In experiments using spruce replicas, shafts broke during both spear thrusting and spear throwing, and in two cases they broke in such a way as to create a point roughly similar in length to the Clacton spear point (Milks 2018, pp.391-394). No experimental studies have focused explicitly on fracture patterns of wooden spears, and therefore our ability to relate breaks to delivery method is limited. Hominins at Clacton likely had a wide selection of trees with lower densities that would have been easier to make a spear from. Therefore, although because it is just a fragment we cannot say for certain how the Clacton spear point was used, the use of yew for the spear was likely preferentially selected for its performance properties (Uzquiano et al. 2015), allowing it to be resistant to fracturing during use as a penetrating tool of some kind.

5.2 Schöningen 13 II-4

Schöningen (Germany) represents a series of Pleistocene sites, with the locality 13 II-4, known as the 'Spear Horizon', dating to around 300,000 Before Present (BP) (Thieme 1997; Conard et al. 2015). The Spear Horizon has a remarkable collection of up to ten complete spears and spear fragments (Thieme 1997; Schoch et al. 2015). Genus and species identification of wood for the Schöningen artefacts was made on the basis of a macro- and microscopic analysis that included making comparisons of thin sections and macroscopic photographs with recent reference material (Schoch et al. 2015). Nine of the spears were made from spruce (*Picea* sp.), and one spear was made of pine (*Pinus sylvestris*) (Schoch et al. 2015). In addition to the spears at Schöningen, two double pointed sticks, proposed to have been designed to be used as rotational throwing sticks, were also made of spruce (Thieme 1997; Conard et al. 2020).

The wood used for the Schöningen spears is unlikely to have originated from the site itself, as few spruce pollen are present (Urban & Bigga 2015; Bigga et al. 2015). Hundreds of additional macrowood remains at the site are undergoing further analysis and may improve current understanding of hominin activities at the site (Böhner et al. 2015). The Schöningen spears were manufactured from the trunks of slow-grown trees, which increases the density and hardness of wood (Thieme 1997; Schoch et al. 2015). The hominins manufactured the tips of the spears from the base of the trees, which is also a harder, denser wood (Schoch et al. 2015). Another notable feature of the design of the Schöningen spears reflecting an awareness of wood properties is the offsetting of the softer central pith from the centre of the tip (Schoch et al. 2015). This avoidance of the softer pith wood being located at the very point where the spear would penetrate prey reduces the chance of fracture.

Most of the Schöningen spears taper on both ends (Schoch et al. 2015). Calculations and replicas of spears also show that the balance points on at least some of the spears are located in front of the middle, a feature that is essential for successful flight as this prevents the spears from turning back to front (Thieme 1997; Rieder 2001; Schoch et al. 2015; Milks et al. 2019). Together these features suggest that at least some of the Schöningen spears were intentionally designed for flight (Thieme 1997; Milks et al. 2019; Conard et al. 2015). In contrast to the double-tapering on most of the Schöningen spears, Spear VI is unlikely to have been utilized as a thrown weapon because it has a natural kink and does not taper at the back (Schoch et al. 2015). The spears may have been multifunctional including use as weapons for hunting and self-defence (Serangeli et al. 2015).

Macrofossils and pollen from the site of 13 II-4b/c show a range of different tree species from which the hominins could have made the spears (Table 2). Buckthorn (*Frangula alnus*) has a mixture of favourable properties, but it is a relatively low-growing shrub, making it a poor choice for spears. The most likely species of Juniperus based on distribution would be *Juniperus communis*, which usually grows as a shrub or small tree and is not a popular wood today for tools or lumber (Farjon 2013). Birch (*Betula*) could have made a good choice in terms of density, MoR and compression strength. Birch was widely used for modern Finnish javelins before the shift to steel and aluminium (Johnson 1987). Schöningen hominins may have avoided birch for a few reasons. First, the potential terrestrialisation of the lakeshore at the period when the Spear Horizon was formed may have led to a decrease in birch (Urban & Bigga 2015). Alternatively, because the MoE of birch is exceptionally high, this would make it stiffer and therefore more difficult to throw. Similarly larch (*Larix*) may have been avoided due to its stiffness in relation to spruce and pine. If thrown, the priority may have been for a lower density wood than birch, resulting in a lighter spear mass, making throwing easier. Considering that most of the Schöningen spears were made from slow-growing spruce, the density and potentially the parallel compression strength were likely higher than average values presented in Table 2. Spears made from a higher density spruce may have suffered macrofractures less readily than those used experimentally (Milks 2018).

Evidence of re-sharpening on Schöningen Spear X shows that spears were not immediately discarded when damaged (Schoch et al. 2015). However, at Schöningen it is not always clear whether breaks to the spears were pre- or post-depositional. Of the entire collection of spears and throwing sticks, only the first throwing stick was discovered in one piece

	Salix	*Abies*	*Picea*	*Pinus*	*Tilia*	*Alnus*	*Corylus*	*Betula*	***Taxus***	*Ulmus*	*Quercus*	*Carpinus*
Density (g/cm³)	0.28	0.35	0.37	0.42	0.42	0.44	0.52	0.53	0.55	0.55	0.56	0.71
MoR (MPa)	56.2	66	63.0	83.3	85.4	75.9	98.5	114	105	68.7	97.1	110
MoE (GPa)	7.76	8.28	9.70	10.1	11.7	9.0	8.27	13.9	9.10	7.52	10.6	12.1
Comp (MPa)	26.9	41.0	35.5	41.5	44.8	42.2	19	51.4	55.9	32.0	46.3	50.5

Table 1. Trees evidenced from MIS 11 deposits at Clacton-on-Sea, in order of lowest to highest wood density. The wood utilised for the spear, *Taxus baccata*, is in bold, and was identified on the basis of a thin section and comparison with modern reference collections (Oakley et al. 1977). Tree profile based on pollen and macrofossil data (Turner 1970; Reid and Chandler 1923; Pike & Godwin 1953; Bridgland et al. 1999). Tree silhouettes not to scale.

	Salix	***Picea***	***Pinus***	*Alnus*	*Larix*	*Frangula*	*Juniperus*	*Betula*	*Carpinus*
Density (g/cm³)	0.28	0.37	0.42	0.44	0.47	0.49	0.52	0.53	0.71
MoR (MPa)	56.2	63.0	83.3	75.9	90.0	60.0	*	114	110
MoE (GPa)	7.76	9.70	10.1	9.0	11.8	6.62	*	13.9	12.1
Comp (MPa)	26.9	35.5	41.5	42.2	52.0	41.9	*	51.4	50.5

Table 2. Trees evidenced at Schöningen 13 II-4b/c, in order of lowest to highest wood density. The wood utilised for the spears, *Picea* sp. and *Pinus sylvestris*, is in bold and was determined on the basis of thin sections and reference collections (Schoch et al. 2015). Tree profile based on pollen and macrofossil data (Urban & Bigga 2015; Bigga et al. 2015; Schoch et al. 2015). Tree silhouettes not to scale.

(Schoch et al. 2015; Conard et al. 2020). The positioning of some, for example Spear II and Spear VI, does suggest that many breaks could be post-depositional, but in other cases such as Spear V, the broken distal section has been rotated towards the shaft of the rest of the spear (Schoch et al. 2015; Conard et al. 2020). Apart from pre-depositional breakage trampling could also have been a factor in both breaking and re-orientation of the point (Schoch et al. 2015). Further examination of the breaks in a comparative analysis with experimentally produced use and post-depositional breaks may be able to resolve some of

	Tilia	*Ulmus*	*Corylus*	***Taxus***
Density (g/cm³)	0.48	0.44	0.52	0.55
MoR (MPa)	85.4	68.7	98.5	105
MoE (GPa)	11.71	7.52	8.27	9.10
Comp (MPa)	44.8	32.0	19	55.9

Table 3. Trees likely to have been available at Lehringen, in order of lowest to highest wood density. The wood utilised for the spear, *Taxus baccata*, is in bold. Tree profile based on pollen and macrofossil data (Thieme & Veil 1985; Gaudzinski-Windheuser & Roebroeks 2011). Tree silhouettes not to scale.

the questions about the use-lives and discard of these weapons. With the discard of some seemingly complete or potentially repairable tools, and in particular the first throwing stick which is in one piece (Schoch et al. 2015), from an economic perspective it seems that the Schöningen hominins saw wooden tools as relatively expedient tools (Conard et al. 2015). If wooden tools were expedient, the priority would be to use wood that was easier to work. In this case spruce and pine are the best choices available, with willow (*Salix*) being functionally unsuitable for spears due to its tendency to shrubby growth, poor compression strength, low MoR and low density. On balance, because many of the Schöningen spears look likely to have been designed to be thrown, spruce and pine are also relatively lightweight with elastic properties, both of which would facilitate throwing. Therefore the choice of spruce and pine would have facilitated initial manufacture and resharpening, in comparison to other wood species available, and would be a good choice for flight weapons.

5.3 Lehringen

The early Late Pleistocene site of Lehringen (Germany), dated to ~120,000 BP, yielded one complete spear worked from yew (Adam 1951; Thieme & Veil 1985; Gaudzinski 2004). The spear (Fig. 7) could have been manufactured either from a trunk or a branch with 39 side branches removed; it tapers at the front only and on that basis usually interpreted as a thrusting spear (Adam 1951; Jacob-Friesen 1959; Oakley et al. 1977; Thieme & Veil 1985; Veil 1991;

Figure 7. The tip of the Lehringen spear. As can be seen here the tip is asymmetrically shaped in comparison with the rest of the spear. The exposed central pith is bracketed.

Schoch 2014). In fact the wood at the base of the spear looks rounded and polished, leading Thieme & Veil (1985) to suggest that such wear could have developed while using the spear multifunctionally as a walking stick, a feature that points to this being a tool with a relatively long use-life. Like at Schöningen, the central pith of the wood is avoided at the very tip of the Lehringen spear (Veil 1991). Discovered with the bones of a straight-tusked elephant (*Palaeoloxodon antiquus*) and in association with lithic tools, the recovered yew spear at Lehringen may have been one of two spears, the second of which was potentially destroyed before the significance of the site and artefacts was recognised (Thieme & Veil 1985). Although no drawings or photographs of the spear in situ exist, testimonials describing the removal of the spear describe its discovery amongst the ribs of the elephant carcass (Thieme & Veil 1985). Its location and deformation into a C-shape suggests it had been pushed upwards through the abdomen, potentially causing it to bend when the animal fell on the spear (Thieme & Veil 1985). Although it was discovered in 6 or 7 pieces and is now in 13 pieces (pers. obs.; Schoch 2014), the breaks are very straight and are clearly post-depositional, testifying to the elasticity of yew to be bent in such a position but not fracture until much later.

The finds at Lehringen come from a blue-grey marl, assigned to the linden-elm-hazel (*Tilia-Ulmus-Corylus*) pollen zone, with flora and fauna indicating a warm temperate interglacial climate, and a densely forested lake basin (Thieme & Veil 1985 and references therein; Gaudzinski 2004). The spear was well preserved due to its submersion in the water-soaked marl layers that excluded air, fungi, and bacteria (Schoch 2014). Although the context for this artefact is relatively poor, we can look at the three other tree species, other than yew, potentially available to the Lehringen Neanderthals. Compared with yew, lime (*Tilia*) has a very high MoE, poor compression strength and poor MoR, making it an unlikely candidate for a thrusting spear as it would be much more likely to fracture during use. Hazel (*Corylus*) tends to not grow particularly tall, and due to its low compression strength and typical growth as a shrub would make it an unlikely candidate for weaponry. Elm (*Ulmus hollandica*) has a similar density to yew, and with a lower MoE is actually more elastic, but it has significantly lower MoR and parallel compression strength, and therefore like lime, it would have been more susceptible to fracturing than yew (Table 3). The hypothesis that Neanderthals at Lehringen preferentially selected yew to optimise functionality is supported on the basis that it has the highest density of evidenced wood types, and therefore would be more difficult to work with. The properties of yew that made it attractive to later prehistoric humans for weaponry are likely the same ones that the Lehringen Neanderthals were aware of.

6. DISCUSSION

I have argued in this paper that Pleistocene humans likely selected yew for thrusting spears from Clacton-on-Sea and Lehringen to take advantage of its elastic and durable properties. This choice would be a costly one in terms of the time to manufacture the spear, and therefore may reflect a desire to maximise durability and use-life of weapons. Schöningen is the site that has the clearest evidence that hominins were selecting wood in the first instance, as nine out of 10 spears, and both of the throwing sticks were made of spruce, even though this wood was likely not available at the site itself, and with many other tree species evidenced to have been available. At Schöningen, hominins may have sought wood that was both relatively elastic and light weight, facilitating distance throwing. Alternatively, it is possible that the makers of the Schöningen spears were expert woodworkers, and that spears were seen as relatively expedient tools. In this case, the selection of a lower density wood, particularly when considering the slow-grown nature of the trees used, may reflect a desire to reduce manufacturing time, which could help explain the discard of so many wooden tools at Schöningen. The choice to create the tips of the spears from the base of the trees, as well as the avoidance of the soft pith demonstrates that whatever they were maximising overall – manufacture or performance – they were likely making decisions with performance in mind.

The manufacture of wooden spears by Middle and early Late Pleistocene *Homo* suggests an awareness of a range of different aspects of material properties, not just in relation to the workability of a material, but also its functional performance. A clear understanding of the properties of different raw materials involves mental flexibility and abstraction (Mithen 1996; Wadley 2013). Furthermore the orientation and exploitation of an orthotropic material in relation to specific qualities that perform differently in three directions requires both a deep understanding of the organisation and structure of wood and of how it behaves under varying stresses and strains. There are some indications from Eurasian sites that date before the first known wooden spear at Clacton, that hominins were not simply using raw materials that were immediately available in the landscape. For example, hominins at Arago (France) were making use of exotic lithic materials that they transported to the site, suggesting that knapping quality factored into decisions (Hosfield 2020, p. 247), and at Boxgrove there is evidence that flint was tested prior to knapping (Austin et al. 1999). The selection of wood on the basis of material properties by these hominins is hardly surprising in light of the fact that extant great apes are also selective and aware of material properties of plants (e.g. Huffman 2001; Boesch et al. 2009) and the mounting evidence that there were not substantial cognitive differences between Neanderthals and ourselves (e.g. Roebroeks & Soressi 2016).

Throughout most of this paper, I have focused almost exclusively on economic perspectives in relation to material selection for wooden spears, such as how the use of wood might affect time budgeting, durability and use-lives of these hunting tools. The artefact record of Pleistocene wood technologies is not remotely quantitatively comparable to the lithic record, and as such we are not in a position to distinguish different wood technological 'cultures' by looking at patterning across sites. Sites that have yielded wooden spears are separated by hundreds of thousands of years, and could potentially even be attributed to different species of *Homo*. On the one hand, this paper therefore explores these important artefacts on the microscale, and as Pope (2015, p.64) argues, we "must understand the complexity of each artefact in isolation before attempting to relate artefacts to each other". However, we can also further develop our understanding of wood technology from the Middle and early Late Pleistocene if we contextualise it within the wider hominin techno-complexes. Stone, bone and wood technologies are demonstrably intertwined: stone, bone and conceivably wood were used to shape stones (e.g. Serangeli & Conard 2015; Van Kolfschoten et al. 2015; Martellotta et al. 2020; Pope, Roberts & Parfitt 2020), stone was used to cut and shape wood and bone (e.g. Rots et al. 2015), wood and stone were used to wound animals (e.g. Gaudzinski-Windheuser et al. 2018; Smith et al. 2020), and so on. These entangled technologies were socially learned, socially made and socially used, so looking at signatures of manufacture and use are a means of understanding the decisions of those who made them (e.g. Gamble 2007; Hosfield et al. 2018; Garofoli 2015; Conard et al. 2015; Pope 2015; Pope, Roberts & Parfitt 2020). As Hosfield and colleagues (2018) point out, raw material constraints do sometimes appear to have affected these hominins' technological choices, but there are many additional factors that need consideration, including social ones. Material cultures cannot be disentangled from the societies that made them. Although we may never be certain what exactly hominins were selecting for, these choices may have been affected by economics, but also by ideological relationships between these hominins and their natural world. We can begin to envision wood technology, perishable as it is, as a keystone of Pleistocene societies and their material culture.

The difficulties in preservation have negatively impacted the recognition of the role of wood for Pleistocene hominins, but there also remains a bias against collecting wood macroremains during excavation. Without clearly developed methodologies for the recovery, recognition and analysis of humanly modified wood prior to the Mesolithic, we are missing out on exciting opportunities to understand Pleistocene technologies and societies. Seemingly non-modified and natural wood remains need to be systematically sampled in Pleistocene excavations, and doing so whilst developing innovative methodologies to help recognise human exploitation of wood will create exciting challenges and opportunities in the coming decades.

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