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Early evidence for bear exploitation during MIS 9 from the site of Schöningen 12 (Germany)

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ABSTRACT

A cutmarked bear metatarsal and phalanx from the German open-air sites of Schöningen 12 II-1 and 12 B, respectively, correlated with the interglacial optimum of MIS 9 (ca. 320 ka), provide early evidence for the exploitation of bear skins. Archaeological sites with evidence of bear exploitation from the Lower Paleolithic are rare, with only Boxgrove (United Kingdom) and Bilzingsleben (Germany) yielding cutmarked bear bones indicating skinning. We interpret these finds as evidence for bear hunting and primary access since bear skins are best extracted shortly after the animal's death. The very thin cutmarks found on the Schöningen specimens indicate delicate butchering and show similarities in butchery patterns to bears from other Paleolithic sites. The Eurasian Lower Paleolithic record does not show any evidence for the exploitation of bear meat; only Middle Paleolithic sites, such as Biache-Saint-Vaast (France; ca. 175 ka) and Taubach (Germany; ca. 120 ka), yield evidence for the exploitation of both skin and meat from bear carcasses. Bear skins have high insulating properties and might have played a role in the adaptations of Middle Pleistocene hominins to the cold and harsh winter conditions of Northwestern Europe.

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1. Introduction

The Lower Paleolithic sites of Schöningen (Germany) have played a major role in discussions of the origin of active and specialized hunting of large mammals. The presence of a kit of complete wooden hunting weapons (nine throwing spears, a thrusting lance, and two throwing sticks; Thieme, 2007; Conard et al., 2020), along with the Schöningen mammalian skeletal assemblage, have yielded clear indications of the exploitation of large herbivores for meat and marrow, bone for tool production, and potentially skins (Voormolen, 2008; Julien et al., 2015; van Kolfschoten et al., 2015a,b; Starkovich and Conard, 2015; Turner et al., 2017; Hutson et al., 2018). In the present study, we

describe new evidence for the exploitation of bears from Schöningen and compare this evidence to other published faunal assemblages with evidence of bear exploitation from open-air archaeological sites in Northwestern Europe dating to the Lower and Middle Paleolithic. We compare Schöningen only to open-air sites in this study, as cave sites are known to primarily yield bear skeletal remains from natural deaths during hibernation. We discuss the mode of exploitation and compare the sites based on three proxies that are regularly used as supporting evidence for the exploitation of bears: the relative occurrence of bears within an archaeological assemblage, the mortality profile of the population, and the presence of the anthropogenic marks that indicate their exploitation. The exploitation of bears, especially cave bears, has been an ongoing debate for over a century and is relevant not only in the context of hominin diets but also for the use of skins. Tracing the origins of hide exploitation can contribute to the understanding of survival strategies in the cold

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and harsh conditions of Northwestern Europe during the Middle Pleistocene.

1.1. Human-bear relationships in the Paleolithic of Europe

During the Palaeolithic occupation of Europe, bears were an omnipresent part of the Pleistocene fauna, both during warm and cold conditions, either with members of the cave bear or the brown bear lineage (Stiner, 1999). As omnivores and frequent cave dwellers, they shared their environments with humans, and interactions between humans and bears would likely have occurred. The nature of these interactions has been the subject of scientific debate for at least a century, with paradigms having shifted multiple times. In the first half of the 20th century, the discussion of bear hunting during the Paleolithic revolved around the 'cave bear cult' theory initiated by Bächler (1921, 1923, 1940). The accumulation of large masses of cave bear remains, sometimes found in peculiar constellations in cave sites where stone artifacts were also discovered, led to the interpretation that cave bears were actively hunted and worshiped as part of a cult. Even at the time, the theory was already contested and the accumulations were explained as a taphonomic phenomenon (Soergel, 1940), leading some authors to be skeptical of cave bear hunting under any circumstances (e.g., Koby, 1953). Over the past three decades, substantial new evidence of bear hunting during the Paleolithic was found and research on the relationships between bears and humans was reinitiated (Pacher, 1997, 2000; Tillet and Binford, 2002).

The clearest examples of cave- and brown-bear exploitation have been discovered from Upper Paleolithic sites, and among them are some true 'smoking guns' of bear hunting. From an Early Gravettian layer at Hohle Fels in Germany, dated to 29,000 BP, archaeologists found a thoracic vertebra with an imbedded flint fragment (Conard et al., 2001; Münzel and Conard, 2004). A large number of bear remains from the same horizon displays butchery marks, evidence of marrow fracturing, and burning, documenting the full exploitation of bears by humans for their meat, skins, marrow, and bones (Münzel and Conard, 2004; Kitagawa et al., 2012). Wojtal et al. (2015) describe additional evidence at open-air Gravettian sites from Poland and the Czech Republic with cutmarked bones from both cave bears and brown bears. Although the remains of bears at Gravettian open-air sites are always recovered in low numbers, the anthropogenic marks show that bear hunting in this time was a common phenomenon. In the late Upper Paleolithic site of Grotte du Bichon, Switzerland, a female brown bear skeleton was found with an imbedded flint fragment in the third cervical vertebra. It was discovered together with a skeleton of a man hypothesized to have died from a hunting accident (Morel, 1993; Chauvière, 2008). Damage patterns and imbedded flint particles on a brown bear rib from the Late Epigravettian site of the Cornafessa rock shelter in Italy have been experimentally shown to result from bow-and-arrow hunting (Duches et al., 2018).

Numerous cave sites show clear evidence of bear exploitation, even during the Middle Paleolithic. Romandini et al. (2018) published a comprehensive overview of Middle Paleolithic sites with evidence of cave bear exploitation, adding detailed taphonomic descriptions of new material from Rio Secco Cave and Fumane Cave (Italy). Their study highlights that Neanderthals not only exploited bears for their skins but also used them as a food source, demonstrated by filleting marks, burned bones, and potential human tooth marks. At the well-known Neanderthal site of Krapina (Croatia), at least a part of the adult-dominated bear assemblage shows cutmarks indicating human exploitation of cave bears (Miracle, 2007, 2008). The Eemian site of Lehringen (Germany), famous for the discovery of both a yew spear associated with a straight-tusked elephant skeleton and stone tools (Adam, 1951;

Thieme and Veil, 1985), yielded a distal femur fragment of a brown bear with cutmarks (Wenzel, 1998). Exceptional amounts of bear remains with clear anthropogenic modifications ($n = 2496$) were discovered at the open-air site of Biache-Saint-Vaast (France, MIS 7; Auguste, 1988, 1995, 2003). A reappraisal of the faunal material excavated in the 19th and early 20th century from Taubach (Germany, MIS 5) revealed cutmarks on a large number of bear bones, which Bratlund (1999) interpreted as the result of active hunting.

During the Middle Paleolithic, bear bones were also used as a raw material for tool production: in Scladina Cave, six long bone fragments were used as retouchers, of which four could be refitted as part of a femur shaft of a cave bear (Abrams et al., 2014). Similarly, in Biache-Saint-Vaast (Auguste, 2002, 2003), as well as in Fumane Cave and Rio Secco Cave (Romandini et al., 2018), archaeologists discovered bone retouchers made from ursid bones.

Evidence for bear exploitation in the Lower Paleolithic is much rarer: at the approximately 600 ka site of Isernia La Pineta (Molise, Italy), cutmarks related to skinning and scraping marks have been found on skeletal elements of bears (Thun Hohenstein et al., 2005). The earliest documented evidence in Northwestern Europe is an approximately 500 ka, cutmarked zygomatic arch from Boxgrove (UK) (Parfitt, 1999; Smith, 2012). A recent taphonomic study (Brasser, 2017, 2020) from a sample of the skeletal material from Bilzingsleben (Germany, ca. 400 ka) described several cutmarked bear metatarsals and skull fragments. Three associated metatarsals from Grays Thurrock (UK; MIS 9) show cutmarks on the dorsal side (Schreve, 1997; Schreve and Currant, 2003), but no detailed taphonomic description of the rather substantial bear assemblage ($n = 104$) has yet been published. The relationship between the artifacts found in the quarries at Grays Thurrock and the bear remains with cutmarks is unclear, as they originate from old excavations and stratigraphic and spatial data of the finds are scarce. Given the assigned age of the bone assemblage to MIS 9, it is unclear if they were associated with Lower or Middle Paleolithic industries. The new material from Schöningen described in this study is therefore a noteworthy addition to the scarce evidence of early bear exploitation during the Lower and early Middle Paleolithic.

1.2. The Schöningen site-complex

The Lower Paleolithic open-air site complex of Schöningen (Lower Saxony, Germany; Fig. 1A) is world-famous for the well-preserved organic archaeological finds including a series of wooden spears from the late Middle Pleistocene, dating to around 320–300 ka (Thieme, 1997; Conard et al., 2015; Serangeli et al., 2015a). The large mammal skeletal assemblages from Schöningen, currently comprising over 20,000 specimens, have yielded a wealth of data on the exploitation of large mammals by late Middle Pleistocene hominins (Voormolen, 2008; van Kolfschoten, 2014; Julien et al., 2015; Starkovich and Conard, 2015; van Kolfschoten et al., 2015a,b; Turner et al., 2017; Hutson et al., 2018). Among this large assemblage, a small subsample (<1%) consists of finds from species that belong to Carnivora (e.g., Serangeli et al., 2015b; Hutson et al., 2021; Verheijen et al., 2022). Most carnivore species are represented by only a few skeletal elements at Schöningen; however, bear remains from the lowermost levels of sites of Schöningen (Schö 12 II-1 and Schö 12 B) are relatively numerous ($n = 34$). Among these bear remains are two cutmarked specimens that are the focus of this article.

During large-scale mining operations east of the town of Schöningen, archaeological and geological monitoring revealed a long sequence of Quaternary deposits covering three glacial cycles (Elsterian, Saalian, and Weichselian glaciations) and four intercalated interglacial cycles (Holstein, Reinsdorf, Schöningen, and Eemian interglacial). In 1992, the first Lower Paleolithic

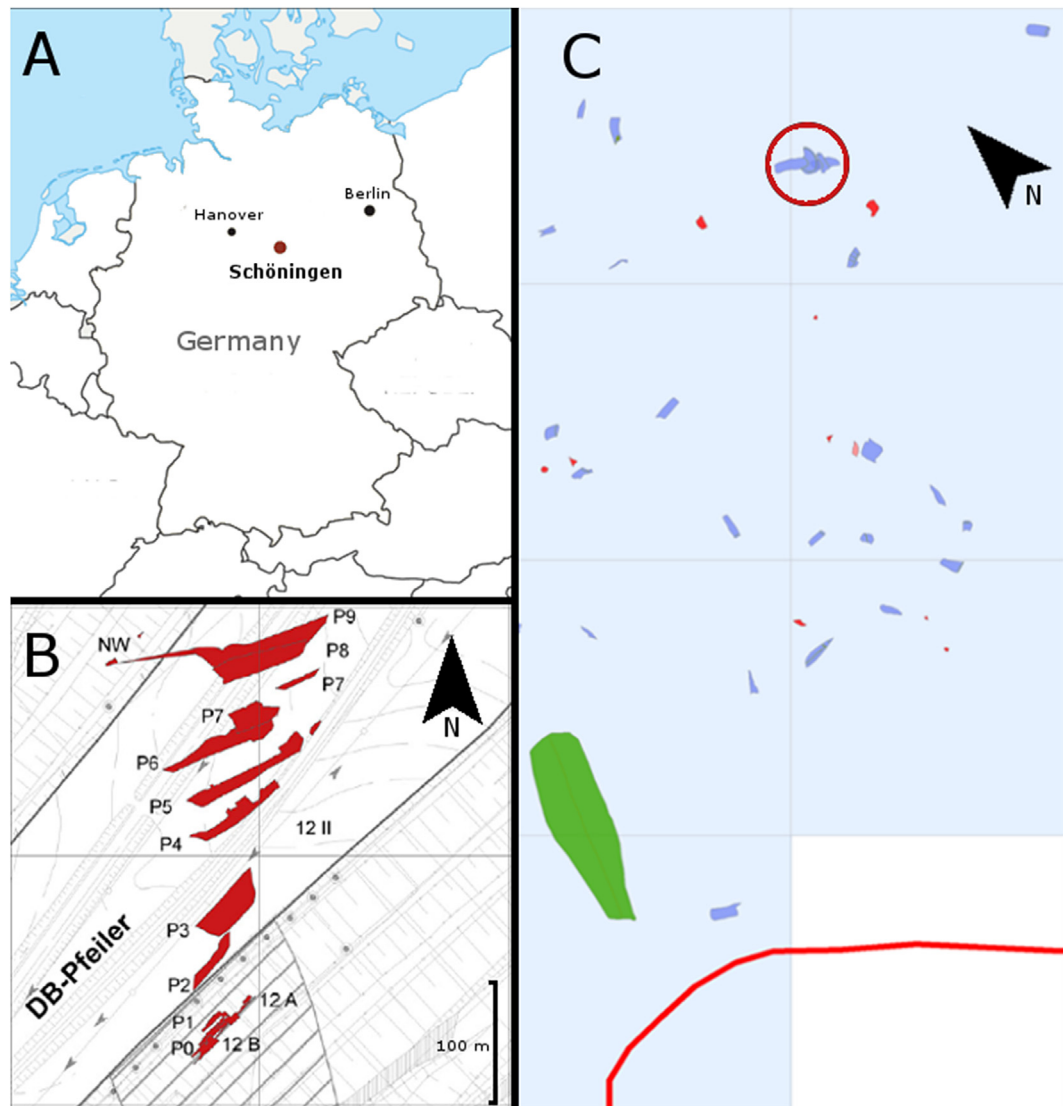


Figure 1. Site location Schöningen 12. A) Location of Schöningen in Northwestern Europe and B) the location of the site of Schöningen 12 (12 A, 12 B, 12 II P0–9) within the Schöningen lignite quarry. DB-Pfeiler is the former location of the railway track (modified from Serangeli et al., 2015). C) ArcGIS excavation map of the site of Schö 12 II-1, plateau 1 with the cutmarked bear metatarsal (ID 16985) indicated within the red circle. The red line represents the quarry section. The light blue boxes represent 1 × 1 m excavation squares; displayed area comprises coordinates: x 15–16, y 490–493. Find-types are color-coded: blue = bones; red = flint fragments and flakes; green = wood. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article).

archaeological and faunal remains were discovered in the quarry sections within Middle Pleistocene lacustrine sediments. The first rescue excavations at the sites of Schö 12 A, Schö 12 B, and Schö 12 C yielded a rich Middle Pleistocene mammalian fauna, associated with Lower Paleolithic flint tools and several potential wooden hafting tools (Thieme et al., 1993; Thieme and Maier, 1995; Thieme, 2007). At the site of Schö 12 B, the largest archaeological assemblage was recovered from a single find horizon (findlayer 1 or Fundschicht [FS] 1). Rescue excavations of a 150 m² surface yielded approximately 1000 finds (Serangeli et al., 2015a), of which 678 belong to large mammals (Voormolen, 1997). Although some aspects of the faunal assemblage from site 12 B, FS 1 have been published (Thieme et al., 1993; van Kolfschoten, 1993; 1995; van Zijderveld and Kirkels, 1996), a thorough taphonomic analysis of the entire assemblage was only reported in an unpublished doctoral essay by Voormolen (1997). Approximately 80% of the material originates from the 150 m² excavation area, whereas about 20% of the bones were collected from the spoil heaps belonging to

the FS 1 that were already removed by the mining company. Owing to time pressure during the rescue excavations, contextual information such as vertical distribution of the finds and their stratigraphic context was only partially recorded (Thieme et al., 1993). The assemblage contains a rich interglacial large mammal fauna, including several bear remains previously assigned to *Ursus spelaeus* and *Ursus thibetanus* (van Kolfschoten, 1995; van Zijderveld and Kirkels 1996).

In 2008 and 2009, rescue excavations at the site of Schö 12 II were executed during the mining of a ten-hectare area within the Schöningen lignite quarry (DB-Pfeiler), formerly separating the quarry in a northern and a southern part (Conard et al., 2015; Serangeli et al., 2015a). The excavations were done in a series of plateaus (0–9), sequentially numbered toward the north in the order of their excavation (Fig. 1B). The majority of the faunal remains from the 2008–2009 excavations at Schöningen site 12 II were published by Julien et al. (2015). The analysis focused on the occurrence of potential bone tools from site 12 II-4 and their

geoarchaeological context. The study highlighted the clearly archaeological nature of the assemblage, with the occurrence of bone retouchers, a horse metapodial used as a soft hammer, and several bones and an elephant tusk fragment with worn/polished ends that may relate to hominin use (Julien et al., 2015). In addition, the assemblage contained faunal remains with hominin butchery marks (cutmarks, marrow-fractured long bones; Julien et al., 2015), found together with flint artifacts (Serangeli et al., 2015a).

The stratigraphy at Schö 12 II incorporates five sedimentary cycles, interpreted as lake-level shallowing cycles. These shallowing cycles, characterized by calcareous marl grading up to organic mud deposits (Stahlschmidt et al., 2015) are correlated with the well-known archaeological site complex of Schö 13 II, located approximately 800 m from the site of Schö 12 II (Serangeli et al., 2015a). Schö 12 B and plateau 0–1 of the site of Schö 12 II are geographically adjacent (Fig. 1B). Schö 12 II-1 and Schö 12 B, FS 1 are both situated at the base of sedimentary channel II (Mania, 1995). Therefore, we interpret the faunal assemblages found in both sites as being broadly contemporaneous. This base is ascribed to the interglacial optimum of the Reinsdorf Interglacial based on the pollen assemblages that are indicative of a forested area around the lake dominated by *Alnus* (alder; Urban, 1995; Urban and Bigga, 2015) and faunal species corresponding to temperate, wooded environments (Thieme et al., 1993; van Kolfschoten, 1993; van Zijderveld and Kirkels, 1996). Thermoluminescence (TL) dating of heated flint from the underlying channel I deposits has established a maximum date of the channel II deposits of approximately 321 ± 16 ka (Richter and Krbetschek, 2015). Direct Uranium-series (U-series) dating of the peat deposits from channel II provided a date of approximately 300 ka (Sierralta et al., 2012). Based on relative dating (biostratigraphy) combined with the U-series dating (Sierralta et al., 2012) and TL-dating (Richter and Thieme, 2012; Richter and Krbetschek, 2015), the channel II Reinsdorf Interglacial deposits in Schöningen are currently correlated with MIS 9 (Richter and Krbetschek, 2015; Urban and Bigga, 2015).

2. Materials and methods

2.1. Materials

For this study, we analyzed the large mammal skeletal remains from Schöningen 12 II-1 and 12 B (FS 1). The total assemblage of large mammal remains from the site of Schö 12 B consists of 678 specimens (Voormolen, 1997) while the Schö 12 II-1 assemblage contains 295 specimens. The collections are currently housed in the Faculty of Archaeology, Leiden University (The Netherlands) and the Forschungsmuseum Schöningen (Germany).

2.2. Methods

Taxonomic identification For taxonomic identifications, we used the modern and fossil comparative collections at the Institute for Archaeological Sciences, University of Tübingen, and at the Faculty of Archaeology, Leiden University. In addition, to morphologically differentiate between different bear species, we used descriptions and metric data by Rode (1935) and Erdbrink (1953). Species identification of postcranial material was first done based on size and second by comparing morphological features with the fossil and recent comparative collections in Tübingen. A long bone fragment with presumable cutmarks (ID 13768; Fig. 5) from Schöningen has been previously published (Thieme and Maier, 1995; Thieme, 2007). The bone, previously identified by Boudewijn Voormolen (1997) as a tibia of a cave bear, shows a series of diagonal marks on the diaphysis. The taxonomic identification of the bone is uncertain, as both epiphyses are missing due to carnivore

gnawing. Therefore, this specimen was analyzed using ZooMS (Zooarchaeology by Mass Spectrometry) by Frido Welker and Liam Lanigan of the Globe Institute, University of Copenhagen, to verify its taxonomic identification.

Relative occurrence To determine the relative occurrence of bear remains from the Schöningen assemblages and other comparative sites, we used the Number of Identified Specimens (NISP; Lyman 1994) for all specimens that could be identified to taxa. All bone fragments with recent breaks belonging to a single skeletal element were counted as a single record. Therefore, the NISP used in this study differs from the NISP for Schö 12 II-1 published by Julien et al. (2015). To calculate the %NISP for the identifiable mammalian remains, we used the data collected by Voormolen (1997) and our own data collected from 2017 to 2020. We compared the relative occurrence of bears from these two Schöningen sites with published data from four Lower and Middle Paleolithic sites: Boxgrove (ca. 500 ka; NISP = 595; Parfitt and Roberts, 1999), Bilzingsleben (ca. 380–400 ka; Minimum Number of Individuals = 245; Mania, 1991, 2004; Turner, 2004; Brasser, 2017, 2020), Biache-Saint-Vaast (220–175 ka; NISP = 20,000; Auguste, 1995, 2003), and Taubach (ca. 120 ka; NISP = 4,363; Bratlund, 1999). For Bilzingsleben, the relative occurrence of all mammalian taxa was only available as the Minimum Number of Individuals (MNI; Mania, 2004), whereas the NISP published by Brasser (2017) only represents a selection of the large mammal species and not the whole assemblage from the site. Therefore, the data from Mania (2004) were used instead for Bilzingsleben, taking into consideration that the MNI might over-emphasize the presence of some of the rarer taxa that are only represented by a few elements.

Age profile reconstruction For the individual age-of-death determination of the Schöningen bears, we used only premolars and molars, as canines and incisors are more subject to individual variation (Stiner, 1998). We assessed all teeth as single records (NISP) without taking symmetry or association within a dentition into account, meaning that teeth with similar wear stages that could have belonged to the same individual were assessed separately. Therefore, the numbers used do not represent the MNI, but show a general view of the mortality structure of the population (Andrews and Turner, 1992; Turner, 2004). Wear stages of the premolars and molars, described by Stiner (1998), were used to differentiate between juvenile (stage I–III), prime adult (stage IV–VII), and old adult individuals (stage VIII–IX). The juvenile stage corresponds to an age of up to approximately one year old, whereas the division between prime adult and old adult is mainly based on an exceeded tooth wear with large areas of dentine exposure and is not connected to a specific individual age (Stiner, 1998).

We compared the mortality profile from Schöningen with the four other Middle Pleistocene sites referenced earlier (i.e., Boxgrove, Bilzingsleben, Biache-Saint-Vaast, and Taubach). We made small adjustments to the published age assessment to fit Stiner's (1998) method as follows. We used the tooth wear descriptions of each individual specimen from Boxgrove by Parfitt (1999) to determine the general age categories (juvenile, prime-adult, old-adult). For Biache-Saint-Vaast, Auguste (1995) used different age categories in his diagram, where 'J' and 'J/A,' correspond to Stiner's 'juvenile,' 'A' to 'prime adult,' and 'A/V and V' to 'old adult.' Minimum number of individuals was used instead of NISP for Biache-Saint-Vaast. Given the large sample size for Biache-Saint-Vaast (MNI = 107), using the MNI instead of the NISP does not notably affect the general division of age classes. To determine the age profile from Taubach, Bratlund (1999) only used the M^2 and M_3 , organizing them in four categories according to dental wear stages dissimilar to those of Stiner (1998): subadult 1, without wear; subadult 2 with slight wear (the cusps flattened and spots of dentine exposed); adult, with medium wear (the dentine exposed

on up to half of the surface); and old-aged/senile, with severe wear (more than half of the dentine exposed). For our present study, we adjusted Bratlund's age categories to match Stiner's categories, where Bratlund's 'subadult 1' corresponds to 'juvenile,' 'subadult 2' and 'adult' to 'prime adult,' and 'old aged/senile' to 'old adult.' To account for the differences in sample size, we present the results in a tripolar diagram with 95% confidence intervals calculated using the likelihood-based method by [Weaver et al. \(2011\)](#). This method visually represents the sample size within the tripolar diagram, where larger sample sizes have a higher precision and cover a smaller surface, whereas small sample sizes can be positioned with less confidence and therefore cover a larger surface within the diagram. Samples that have overlapping contours are likely of a similar origin, whereas samples with nonoverlapping contours are likely to have had different predepositional or postdepositional histories.

Taphonomic marks We analyzed all bear specimens from Schö 12 B and 12 II-1 for taphonomic marks with the use of incident light, either with the naked eye or a low-magnification hand-held lens. To study the morphology of individual marks, we used a low-magnification stereo microscope (Motic SMZ-171, 7.5–50× magnification). For the initial assessment of the taphonomic marks, we used taphonomy manuals by [Binford \(1981\)](#), [Lyman \(1994\)](#), and [Fernández-Jalvo and Andrews \(2016\)](#). To verify the cutmarks, we followed definitions by [Potts and Shipman \(1981\)](#), and [Shipman and Rose \(1983a,b, 1984\)](#): a sharp, v-shaped cross-section,

microstriations within the marks, the optional presence of a shouldering effect, with a secondary striated groove deviating from the first one. In addition, we took into account the location of the marks in relation to a butchery or skinning process. To further compare and potentially identify the taxa responsible for the carnivore damage on the bear specimens from Schöningen, we compared the marks to other carnivore gnawing damage from the site and several reference studies ([Binford, 1981](#); [Domínguez-Rodrigo and Piqueras, 2003](#); [Domínguez-Rodrigo and Barba, 2006](#); [Delaney-Riviera et al., 2009](#); [Andres et al., 2012](#)).

As parts of the assemblages were already analyzed and published, we also re-evaluated previous taphonomic interpretations, for example, a long bone shaft that was published as a cutmarked bear bone ([Thieme and Maier, 1995](#); [Thieme, 2007](#)).

In the discussion, the interpretation of the cutmark location found on the Schöningen specimens is compared to the interpretation of similar marks found in other archaeological studies.

3. Results

3.1. The Schöningen fossil bear record

We identified two taxa of bear in the assemblage from Schö 12 B and 12 II-1. We assigned one M₁, which is clearly smaller than other elements from the assemblage, to the Asiatic black bear, *U. thibetanus*. The tooth also has morphological features that, according to [Erdbrink](#)

Table 1
Bear dental and skeletal elements from Schöningen site 12 B and 12 II-1.^a

ID nr.	Site	Layer	Square	Fnr.	Taxon	Element	Taphonomy	Tooth wear stage ^b
13384	12 B	FS 1	9/10	9	<i>Ursus deningeri/spelaeus</i>	M ₁ dex.		III
13430	12 B	FS 1	12/11	2	<i>Ursus deningeri/spelaeus</i>	scapula dex.	carnivore gnawing	
13436	12 B	FS 1	12/12	2	<i>Ursus deningeri/spelaeus</i>	ulna dex.		
13449	12 B	FS 1	13/11	3	<i>Ursus deningeri/spelaeus</i>	P ⁴ dex.		V
13458	12 B	FS 1	13/11	12	<i>Ursus deningeri/spelaeus</i>	ulna sin.	carnivore gnawing	
13474	12 B	FS 1	13/12	12	<i>Ursus deningeri/spelaeus</i>	metacarpal III dex.	carnivore gnawing, cutmarks?	
13475	12 B	FS 1	13/12	13	<i>Ursus deningeri/spelaeus</i>	patella dex.		
13481	12 B	FS 1	14/9	1	<i>Ursus deningeri/spelaeus</i>	canine sup. sin.		
13522	12 B	FS 1	14/13	12	<i>Ursus thibetanus</i>	M ₁ sin.		VI
13523	12 B	FS 1	14/14	1	<i>Ursus deningeri/spelaeus</i>	ulna dex.	carnivore gnawing	
13533	12 B	FS 1	15/9	4	<i>Ursus deningeri/spelaeus</i>	phalanx I	cutmark	
13610	12 B	FS 1	17/10	4	<i>Ursus deningeri/spelaeus</i>	P ⁴ dex.		III/IV
13671	12 B	FS 1	18/9	4	<i>Ursus deningeri/spelaeus</i>	metacarpal IV sin.		
13731	12 B	FS 1	20/10	3	<i>Ursus deningeri/spelaeus</i>	M ₂ dex.		III
13768	12 B	FS 1	23/7	2	<i>Ursus sp.</i>	long bone shaft	trampling; carnivore gnawing	
13907	12 B	FS 1	26/15	3	<i>Ursus deningeri/spelaeus</i>	humerus dex. fragment		
13920	12 B	FS 1	27/13	1	<i>Ursus deningeri/spelaeus</i>	M ₃ dex.		V
13946	12 B	FS 1	31/13	2	<i>Ursus deningeri/spelaeus</i>	maxilla sin. with M ²		IV
13956	12 B	FS 1	31/13	12	<i>Ursus deningeri/spelaeus</i>	canine inf. sin.		
13958	12 B	FS 1	31/13	14	<i>Ursus deningeri/spelaeus</i>	M ₃ sin.		V/VI
13975	12 B	FS 1	31/13	31	<i>Ursus deningeri/spelaeus</i>	pisiform dex.		
14041	12 B	FS 1	10/5	50	<i>Ursus deningeri/spelaeus</i>	phalanx I		
14091	12 B	FS 1	10/5	100	<i>Ursus deningeri/spelaeus</i>	phalanx I		
no ID	12 B	FS 1	26/13	?	<i>Ursus deningeri/spelaeus</i>	phalanx II		
no ID	12 B	FS 1	14/12	?	<i>Ursus deningeri/spelaeus</i>	M ₁ sin.		VIII
no ID	12 B	FS 1	12/11	?	<i>Ursus deningeri/spelaeus</i>	M ¹ dex.		VI
15679	12 II-1	c1	18/470	1	<i>Ursus deningeri/spelaeus</i>	phalanx I	carnivore digestion	
15850	12 II-1	a	21/469	1	<i>Ursus sp.</i>	mandible fragment dex. with canine fragment		
15860	12 II-1	c1	21/472	2	<i>Ursus deningeri/spelaeus</i>	metapodial		
15861	12 II-1	c1	21/472	3	<i>Ursus deningeri/spelaeus</i>	canine		
15946	12 II-1	?	23/479	1	<i>Ursus sp.</i>	canine fragment		
16971	12 II-1	c1	16/491	3	<i>Ursus deningeri/spelaeus</i>	canine inf.(?)		
16977	12 II-1	c1	16/492	3	<i>Ursus deningeri/spelaeus</i>	M ₂ sin.		III
16985	12 II-1	c1	16/493	2	<i>Ursus deningeri/spelaeus</i>	metatarsal II dex.	cutmarks	

Abbreviations: ID nr. = identification number; fnr. = find number; dex. = dexter/right; sin. = sinister/left.

^a Three elements were collected from water-screened sediment samples and do not have an individual identification or find number.

^b Tooth wear stage based on [Stiner \(1998\)](#).

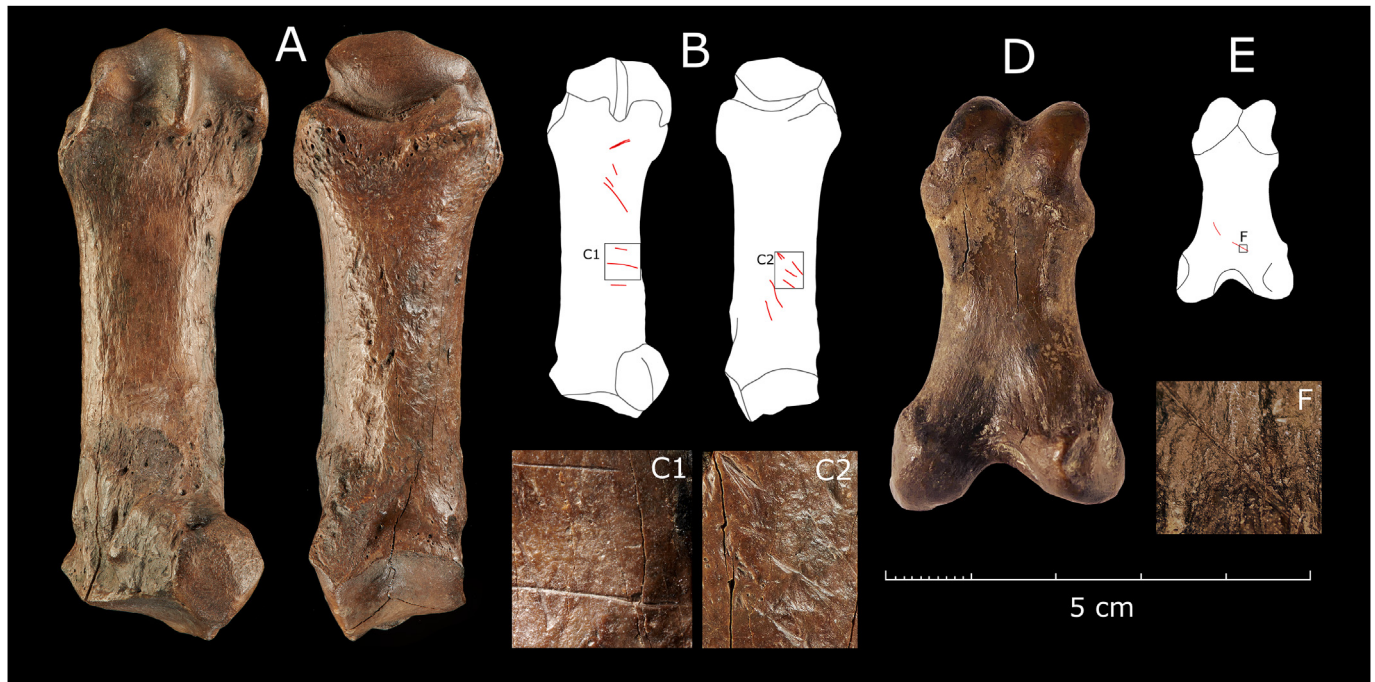


Figure 2. Bear remains with cutmarks from Schö 12. A–C: Metatarsal II (ID 16985) with cutmarks from the site of Schöningen 12 II-1. A) left = plantar view, right = dorsal view, B) schematic drawings with cutmarks in red; left = plantar view, right = dorsal view. C) Close-up of plantar (C1) and dorsal (C2) cutmarks. D–F: phalanx I (ID 13533) with potential cutmarks on the palmar/plantar side. D) photo of palmar/plantar view, E) schematic drawing with cutmarks in red, F) close-up of palmar/plantar cutmarks. Photos and drawings: A, C, Volker Minkus; B, D–F, Ivo Verheijen. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article).

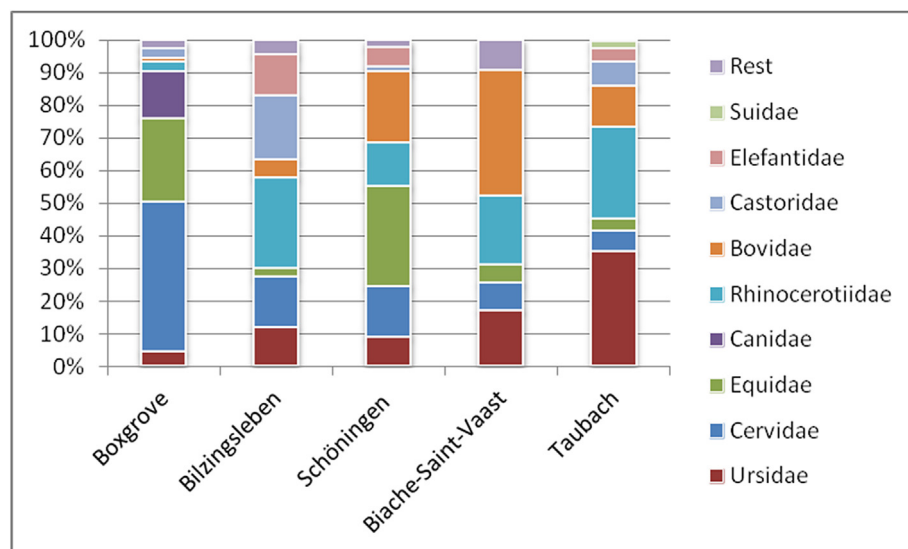


Figure 3. Relative occurrence in %NISP or %MNI of bears in relation to other large mammalian taxa within the Schöningen 12 II-1 and 12 B assemblages in comparison to the four other Lower and Middle Paleolithic sites with evidence of bear exploitation: Boxgrove (Parfitt and Roberts, 1999), Bilzingsleben (Mania, 2004), Blache-Saint-Vaast (Auguste, 1995), and Taubach (Bratlund, 1999).

(1953), distinguish it as *U. thibetanus*, for example, a narrow shape, a connected hypoconid and entoconid at the posterior side, and a typical longitudinal zig-zag groove (Mazza and Rustioni, 1994). This is the only element that we encountered from this species and therefore it was not used in the current analysis. All other bear remains belong to a larger species of bear that, based on dental and skeletal characteristics belongs to the lineage of cave bears, *Ursus* ex gr. *deningeri/spelaeus* (Erdbrink 1953). This species is characterized by relatively wide and robust metapodials, a lower M_2 where the anterior part is wider than the posterior part, and an upper M^1 with a

large paracone. Fragmented or weathered elements that clearly belong to a bear but could not be assigned with confidence to either of the two species are mentioned here as *Ursus* sp. All specimens are listed in Table 1. Table 1 also includes tooth wear stages for the postcanine teeth (following Stiner, 1998) and the occurrence of taphonomic marks such as cutmarks and carnivore gnawing marks. All postcranial elements have fully fused epiphyses, and therefore belong to adult individuals. No anatomical refits were found within the bear assemblage. Most remains are complete, except for a fragmented molar, several canine fragments, and some postcranial

elements as noted in Table 1. No impact marks related to anthropogenic bone fracturing for marrow procurement were found. All fractured edges display dry bone fractures, whereas some fracture edges show marks of carnivore gnawing (e.g., scapula ID 13430, ulna ID 13458, ulna ID 15323, tibia ID 13768), consisting of irregular edges and tooth pits near the fracture edge. This type of carnivore damage is very similar to what has been found in the Schöningen Spear Horizon assemblage, which has been assigned to wolves (Voormolen, 2008; van Kolfschoten et al., 2015; Hutson et al., 2021). One first phalanx (ID 15679) has an etched cortical surface, indicating it was digested by a carnivore. The MNI for the cave bear remains from Schö 12 II-1 and Schö 12 B is 2, based on the occurrence of two proximal right ulna fragments and two upper right fourth premolars.

The cutmarked second right metatarsal of a bear (ID 16985; Fig. 2A–C) was found in layer C1 of site Schö 12 II-1. Figure 1C shows the location of the bone within the find distribution map of plateau 1, with stone artifacts in close proximity, indicating its archaeological context. The proximal phalanx (ID 13533; Fig. 2D–F), with very fine cutmarks on the plantar/palmar side, was found at the site of Schöningen 12 B FS 1 in 1992. The complete find distribution data from the 1992 excavations are currently not available.

3.2. Relative occurrence of bears based on percentage number of identified specimens or percentage minimum number of individuals

Figure 3 shows the relative occurrence of bears in relation to other large mammalian species within the Schöningen 12 II-1 and 12 B assemblages in comparison to the four other Lower and Middle Paleolithic sites with evidence of bear exploitation. Taxa are summarized per family, where only the major taxonomic groups are represented. All other taxa that only play a minor role in the assemblages are placed in the 'rest' group. The abundance of bears varies markedly based on site, for example, between 4.5% at Boxgrove and 35.4% at Taubach. Only at Taubach are bears the most represented taxa, whereas at most sites large herbivores such as rhinos, bovids, cervids, and equids are more frequently represented. Bilzingsleben, Schöningen, and Biache-Saint-Vaast have similar abundances of bears of approximately 10–15%.

3.3. Mortality profile reconstruction

The mortality profile reconstruction for Schöningen and the four other Lower and Middle Paleolithic comparative sites are displayed in Figure 4. Schöningen has a very low number of dental elements ($n = 10$) for which age could be determined. This small assemblage contains two juveniles, one old-aged, and seven prime-aged animals; the posterior half of an M_1 (ID 13384) belongs to a yearling as it lacks any signs of wear, but has a fully developed root. Most other teeth show slight to moderate wear, representing prime-aged adult individuals. One M_1 shows extreme wear (Stiner's wear stage VIII–IX) and therefore is classified as an old individual. It is noteworthy that the wear is asymmetrical and more severe on the labial side. Therefore, it could be caused by a pathology in the corresponding upper dentition which would result in an overestimation of the individual's age. The mortality profile for bears at Schöningen overlaps both with the 'prime-dominated' and the 'living structure' area of the tripolar diagram (Fig. 4).

The assemblage from Boxgrove only yielded a small number of dental elements, with only seven molars and premolars that could be used for age estimation. The assemblage has a similar position to Schöningen in Figure 4, likely caused by the small sample size and the absence of juveniles. Specimen numbers are much higher for Bilzingsleben ($n = 695$), Biache-Saint-Vaast (MNI = 107), and Taubach ($n = 132$), which allow for a more accurate mortality

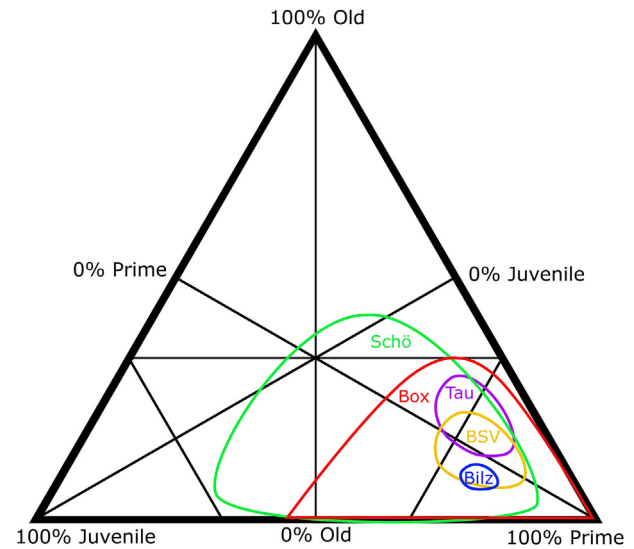


Figure 4. Triangular mortality pattern diagram, based on methods and tooth wear stages following Stiner (1990, 1998) dispersed over three main age categories: juvenile-, prime-, and old-aged individuals. Diagram and the 95% confidence intervals were calculated using the method and program by Weaver et al. (2011). Represented sites, symbols, sample sizes, and data sources: Boxgrove (red; $n = 8$; Parfitt, 1999), Bilzingsleben (blue; $n = 695$; Brasser, 2017), Schöningen (green; $n = 10$; this study), Biache-Saint-Vaast (yellow; $n = 107$; Auguste, 1995), Taubach (blue; $n = 132$; Bratlund, 1999). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article).

profile reconstruction. They all show a clear prime-dominated mortality profile, in which juveniles and old-aged individuals are underrepresented.

3.4. Anthropogenic modifications

A second metatarsal (ID 16985, Fig. 2A–C) contains three transverse, parallel cutmarks on the plantar side, a diagonal cutmark toward the distal half of the diaphysis, and a small cluster of cutmarks near the distal end. The first proximal mark has a small

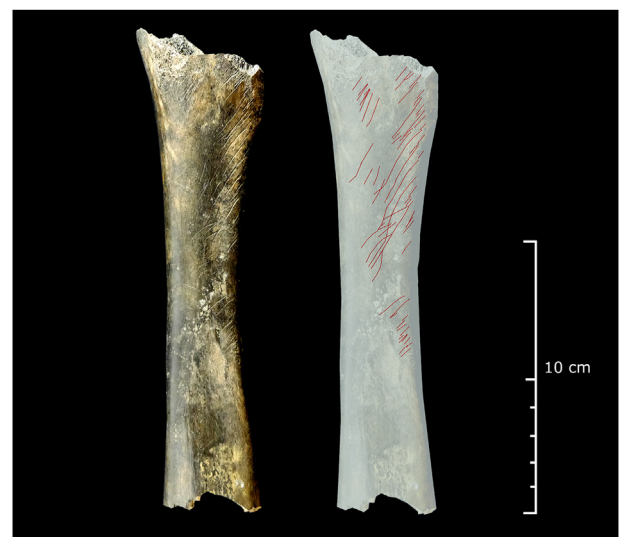


Figure 5. Ursid long bone shaft (ID 13768) from Schöningen 12 B (FS 1) with curvilinear taphonomic marks. The marks previously interpreted as cutmarks (Thieme and Maier, 1995; Thieme, 2007) are morphologically distinct from cutmarks and are interpreted here as originating from a natural cause, either as the result of trampling or carnivore gnawing.

barb at the end. On the dorsal surface, four short, diagonal cutmarks are present on the attachment area on the proximal shaft. All cutmarks are narrow and sharply incised, with v-shaped transects. Most of the marks show fine, parallel striations at the bottom of the groove and some of them also display a shouldering effect, as described by Shipman and Rose (1983a,b) as characteristic of cutmarks. A third metacarpal (ID 13474) from Schö 12 B FS 1 has some potential cutmarks on the dorsal surface, but they are covered by a preservative lacquer, masking essential details to verify the origin of the marks. On a first phalanx (ID 13533; Fig. 2D–F) from Schö 12 B FS 1, two potential cutmarks are present on the palmar/plantar side, within a hollow surface near the proximal epiphysis. Although very fine, the marks do show characteristics (shouldering effect, tapering at the ends) that correspond to cutmarks.

Analysis of the long bone fragment ID 13768 (Fig. 5) from Schöningen using ZooMS confirmed that the specimen indeed belongs to the genus *Ursus*, but identification to species level was not possible. The origin of the marks is nonetheless ambiguous; although they possess some characteristics that are often connected to cutmarks, other indicators suggest a natural cause. The location and especially the severity of the marks do not correspond to a typical butchery process. Marks for dismembering are usually short and positioned on attachment areas for muscles and ligaments near or on the epiphyses. Filleting marks from muscle-mass removal or scraping marks related to the removal of the periosteum, often encountered in Schöningen assemblage (Voormolen, 2008; van Kolfschoten et al., 2015b), are usually more shallow and parallel to the long axis of the bone. In addition, the marks are deep, but do not show a clear v-shaped transect. Most of the scratches are not straight, but curvilinear and vary in width. We interpret a natural (gnawing/trampling) instead of an anthropogenic cause for the marks.

4. Discussion

4.1. Bear accumulation at open-air sites

The mortality patterns for the open-air archaeological sites compared in Figure 4 show a similar, prime-dominated pattern. Neonates are absent from the open-air assemblages that we used as a comparison. This absence is often ascribed to taphonomic processes that have a larger effect on the fragile remains of bear neonates (Bratlund, 1999; Turner, 2004; Brasser, 2017). Normally, neonate mortality occurs during the hibernation period of the mother; therefore, their remains are usually found in dens, not at open-air sites. In addition to this, bear cubs shed most of their deciduous teeth (except for the deciduous canines) at a very young age, usually even before they emerge from the den during the hibernation season in which they were born (Kurtén, 1958; Andrews and Turner, 1992), accounting for their rarity at open-air sites. All other age categories are represented in the studied assemblages, but prime-adult individuals predominate. Therefore, the mortality patterns shown in Figure 4 are clearly different from assemblages formed by natural deaths during hibernation in caves (Stiner, 1998).

A prime-dominated mortality pattern is normally interpreted as the result of human hunting (Stiner, 1990). On some occasions, especially with bears, natural deaths can account for a similar mortality pattern (Wolverton, 2006). Skeletal assemblages from natural traps sometimes contain substantial remains of young adult bears that were trapped when looking for food (Wolverton, 2006). The scenario of a natural trap can be excluded for all sites in this study, given their location in the landscape near water sources and without geological features that can form a natural trap.

Among modern young adult bears, the second most common cause of death (after human hunting) is intraspecific violence (Bunnell and Tait, 1981). When the cubs leave their mothers after their second season of hibernation, they must find their own territory (Wolverton, 2006). The sometimes violent exclusion of young bears by older individuals from their territories (especially for young males during the mating season) can be the cause of death in early adulthood, as young bears may become injured or may need to retreat to areas with fewer food resources which might eventually lead to starvation (Stiner, 1999; Wolverton, 2006). Starvation caused by exclusion from a resource-rich landscape seems unlikely as well, as all sites are situated near bodies of water which are normally rich in nutrients. In the case of Schöningen, paleobotanical studies have shown a wide variety of edible plants in the area directly surrounding the lake (Bigga et al., 2015). Although cave bears mainly had a herbivorous diet, we speculate that occasional scavenging opportunities might have lured them to the Schöningen lakeside too in colder periods of the year when plant resources were less available. A similar scenario has been proposed to explain the attraction of bears to the site of Biache-Saint-Vaast (Auguste, 2003).

A final alternative cause for the prime-adult-dominated assemblage could be attacks from other carnivores. A rich large carnivore fauna is present at the Schöningen sites, including lion, wolf, and saber-toothed cat (van Kolfschoten, 2014; Serangeli et al., 2015b). Kurtén (1958) hypothesized that attacks by other solitary carnivores would have been exceptional because of the large size of cave bears, as both parties would have preferred avoidance instead of conflict. Wolves are ranked as the most dangerous predators to bears by Couturier (1954), and other group hunters like cave hyenas might also have formed a threat to cave bears. Normally, in open-air settings (as opposed to hibernation sites) other carnivores will hunt the young, the weak, or the old individuals instead of the prime-aged adults (Stiner, 1999). Therefore, carnivore kills are not a probable cause of the prime-dominated or living structure mortality profiles shown in Figure 4. The carnivore gnawing marks on the bear bones from Schöningen (Table 1) are likely the result of scavenging by other carnivores, such as wolves, as documented for the other faunal elements from the site (Voormolen, 2008; Starkovich and Conard, 2015; van Kolfschoten et al., 2015a). Thus, although we cannot exclude that some natural deaths might have contributed to the accumulation of bear remains in Schöningen and other open-air sites, the prime-dominated assemblages are likely the result of human hunting.

4.2. Mode of bear exploitation

The location of cutmarks on bones is informative for reconstructing human exploitation of animals in the past (e.g., Binford, 1981). Though it is likely that the different activities were not mutually exclusive, we compare evidence from different sites and the interpretation of the cutmarks made by previous investigators to distinguish between damage inflicted due to the exploitation of bears for their skin versus for their meat. With regard to cutmarks in the paw region in particular, different hypotheses have been proposed to explain how they were inflicted. Both cutmarked bear specimens from Schöningen are part of the paw and could therefore indicate either skinning, defleshing, or dismembering. The location of the cutmarks found on the plantar/palmar and dorsal side of bear metapodials has been recognized on other Paleolithic specimens. Auguste (1988) depicted two associated metatarsal bones (metatarsals I and II) with cutmarks on the plantar side, which the author interpreted as skinning marks. The location of the cutmarks is very similar to the Schöningen metatarsus, with several parallel marks on the proximal half of the shaft, perpendicular to the long axis of

the bone. Three associated metatarsals (III–V) from Grays Thurrock display several cutmarks on the dorsal side (Schreve, 1997), but no detailed description of the marks is given. A metatarsal (III) from Hohle Fels, dated to around 30 ka, shows cutmarks on both the plantar and dorsal sides of the shaft (Münzel and Conard, 2004). The plantar side also shows multiple separated marks perpendicular to the long axis of the bone, similar to the Schöningen specimen. The marks have been interpreted as the result of skinning and removing the feet (Münzel and Conard, 2004).

Cutmarks on the dorsal and lateral face of a first phalanx from Abri Castanet (32,400 BP; Dordogne, France) have been interpreted as the result of hide procurement (Armand, 2006; Mensan et al., 2012). In general, Armand (2006) ascribes cutmarks found on bear phalanges to the process of skinning, whereas the marks on the metapodials could originate from skinning and/or butchering of the paws. Others underline the nutritional value of the paws, as the palms are rich in fat and muscle tissue (Bez, 1995; Bratlund, 1999; Armand, 2006). In Taubach, the high number of metapodials and phalanges with cutmarks are ascribed by Bratlund (1999) to the meticulous filleting of the paws, whereas only a few marks are interpreted as skinning marks. Marks on the lateral and medial sides of metapodials (except for the metapodial I and V) cannot be explained from the skinning process, as these areas of the bone are inaccessible for a tool if the paw is still articulated during skinning. Contrarily, the repetitive occurrence of transverse or oblique cutmarks on the dorsal and plantar/palmar side of the metapodials can result from either skinning or filleting. Especially on the dorsal side, very little muscle tissue is present, and the skin is strongly attached to the dorsal face of the paw, requiring repetitive cutting during the skinning process. Similarly, the plantar/palmar side also has this connective tissue, in combination with the presence of a callus pad that needs to be removed during the skinning process through repetitive cutting. For those reasons, a variety of cutmarks are inevitable when skinning the paws that are not necessarily related to meticulous filleting.

Based on their morphology and anatomical location, the cutmarks on a fragment of the zygomatic arch from Boxgrove were interpreted by Parfitt and Roberts (1999) as a result of skinning or possible filleting. The cutmarks on the Bilzingsleben bear bones, described by Brasser (2017), are only found on the metapodials and the maxilla. She interpreted these as skinning marks. Additionally, Müller and Pasda (2011) reported on a bear femur with cutmarks from new excavations in Bilzingsleben between 2004 and 2007, but they are not sure of the assertion, as many bones with pseudo-cutmarks are found within the same area of the excavation. If the femur indeed has cutmarks, it can change the interpretation of the bear exploitation in Bilzingsleben from pure skinning to the exploitation of meat as well.

From the Middle Pleistocene onwards, a more complete exploitation of bears can be deduced from anthropogenic marks on bones. According to Romandini et al. (2018) a wide variety of anthropogenic modifications associated with different steps of exploitation can be identified on cave bear assemblages from the Middle Paleolithic sites of Fumane Cave and Rio Secco Cave: skinning, defleshing, disarticulating, percussion for marrow extraction, and burning of bones. Similar results of full exploitation have been obtained from the skeletal assemblages of Hohle Fels (Münzel and Conard, 2004; Kitagawa et al., 2012). From the Lower and Middle Paleolithic sites discussed in our study, evidence for this complete sequence of carcass exploitation is less visible, or in some cases not present. At Boxgrove, Bilzingsleben, and Schöningen, all modifications can be explained by skinning, but do not exclude the exploitation of the meat. Only at open-air archaeological sites with a later date, Biache-Saint-Vaast and Taubach, large numbers of cutmarks on a multitude of elements indicate a more complete

exploitation of the carcass, with signs of skinning, defleshing, and marrow exploitation.

4.3. Bear hunting versus scavenging

Although the evidence for bear exploitation in the Lower Paleolithic seems clear, the mode of procurement (hunting/scavenging) remains a source of debate. The discovery of the Schöningen spears together with the amassed bones of butchered large mammals indicate that hominins were capable of actively hunting large herbivores. Nonetheless, the bear remains discovered in Schöningen are far less numerous than those of large herbivores. Smith (2012) suggested that the limited modifications on the bear remains from Boxgrove argue for an opportunistic use of their carcasses rather than active hunting. Brasser (2017) argued for an anthropogenic influence on the accumulation of bears in Bilzingsleben, but added that the extent to which humans are responsible for the accumulation as a whole is unclear. According to Brasser (2017), this low number of cutmarks on a rather large assemblage indicates only incidental hunting or exploitation of bears. Large accumulations of bears, as observed in Biache-Saint-Vaast, Taubach, and possibly even part of the Bilzingsleben assemblage, could be a palimpsest of repeated hunting episodes at locations that were known to Paleolithic hunters to attract bears. Smaller assemblages, such as Schöningen and Boxgrove, might on the other hand represent more ephemeral, or opportunistic hunts. Currently, because of the absence of direct evidence for hunting (such as projectile impact marks), we can only substantiate the exploitation of bears, and not active hunting. The similarities in cutmarks on the paws nonetheless speak to a uniform extraction process of the hide, underlining the importance of hides.

If indeed skinning was the main goal of bear exploitation in the Lower Paleolithic, it is arguable that hominins had early access to the carcasses, in order for the skins to be in a good state for recovery. It is known among modern hunters that a bear must be skinned shortly after death (ranging from an hour to maximum of one day based on climatic conditions); otherwise, the skin will be spoiled through decomposition and 'slipping' of the hair (Boren and Hurd, 2004). Hence, Romandini et al. (2018) and Armand (2006) proposed that if the skin was used, early access and therefore active hunting would be a probable mode of procurement, although in the case of Schöningen, there is no direct evidence of hunting. Armand (2006) added that hide procurement was probably planned, but that the hunting of bears was still a marginal activity compared to the hunting of ungulates. Considering the relative rarity of bears in an ecosystem and their slow reproduction (Bunnell and Tait, 1981), bears could not have been a dominant contributor of nutrients to Paleolithic hunters (Armand, 2006).

The evidence from this study indicates that active hunting of bears could have taken place in the Lower Paleolithic, but not with the intensity documented in sites such as Biache-Saint-Vaast and Taubach. The similarity in mortality profiles of the five discussed sites in Figure 4 supports this notion, as it clearly shows a preference for prime-aged adults. Nonetheless, given that the number of specimens from Schöningen and Boxgrove is very low, the sites do not plot as tightly as the ones with larger samples.

In general, when bears are represented in open-air assemblages, teeth and elements from the feet are always well-represented. This is also the case for Schöningen. This type of skeletal part representation was interpreted by some researchers as the transportation to the camp site of skins with parts of the paws and the skull attached (Mania, 1991, 2004). It is noteworthy that these elements on the one hand are very solid and therefore easily survive, and on the other hand have a characteristic morphology and can be

easily identified. In addition to this, feet have a large number of elements based on NISP or MNE relative to most ungulates, given the fact that bears have five digits per foot. The percentage of Minimum Animal Units (%MAU) values give a much more representative view, as it takes into account the observed skeletal elements at a site normalized against the expected number of elements in a complete carcass. For example, at Bilzingsleben, although metapodials are often encountered, they only represent 35 percent of the %MAU (Brasser, 2017), whereas mandibular fragments are most numerous and long bones are underrepresented. Only in Biache-Saint-Vaast are almost all parts of the skeleton represented in the assemblage (Auguste, 1995). This could also have been the case at Taubach, but not all elements are now part of the collections due to selective curation during excavation (Bratlund, 1999). For Bilzingsleben, Schöningen, and Boxgrove, we see an underrepresentation of parts of the axial skeleton, as well as most long bones. For the latter two sites, this could be a result of the small sample size. For Bilzingsleben, the skeletal representation is most likely explained by taphonomic processes (Turner, 2004; Müller and Pasda, 2011) rather than hominin selection (Mania, 1991, 2004). The absence of the meat-rich parts of the skeleton from the assemblages potentially biases our interpretation toward skinning and away from the nutritional value of the rest of the carcass, which was unlikely to be left untouched by Paleolithic hunters.

4.4. The relevance of bear skins and early indications of hide working

One of the main obstacles for hominins to overcome in North-western Europe, even during interglacial conditions, was maintaining their body temperature. Year-round occupation without major seasonal migration implies that hominins were able to cope with these severe conditions and endure wind chill, low temperatures, reduced daylight hours, and snow cover (Hosfield, 2016). Although some physical adaptations of Middle Pleistocene hominins might have allowed them to better cope with these harsh conditions (e.g., Trinkaus et al., 1999), cultural solutions such as pyrotechnology, shelter, and increased insulation through clothing (Hosfield, 2016; MacDonald, 2018) were probably also required for survival. Direct evidence for such cultural solutions in the Middle Pleistocene record of Eurasia is scarce and often disputed. Nonetheless, there are several indications that the technology necessary to produce simple clothing (following the definition by Gilligan, 2007) was already present. This type of simple clothing probably constituted of animal skins that were wrapped around the body without elaborate tailoring. Carnivore pelts, and especially bear pelts have high insulating properties (Rodríguez et al., 2021), which would make them very suitable for constructing simple clothing and/or bedding. In light of the cutmarked bear bones from Schöningen, we discuss the relevance of this find and other indices for hide processing in Schöningen and other Middle-Pleistocene sites.

As demonstrated earlier, indications of skinning in the Lower Paleolithic are not restricted to Schöningen, but are also evidenced by cutmarks on bear bones from Bilzingsleben (Brasser, 2017) and Boxgrove (Parfitt and Roberts, 1999), and on a lion from Gran Dolina TD10.1 (Blasco et al., 2010). Other indicators (tools, materials) for hide preparation are also present in the Schöningen site complex, and known from other Middle Pleistocene archaeological sites. Two types of tools are normally associated with the preparation of a hide: scrapers and smoothers. Scrapers with steep retouch, suitable for removing scraps of meat and connective tissue from the hide, are a relatively common tool in the Schöningen assemblage (Serangeli and Conard, 2015). A combined use-wear and residue

analysis on a sample of the Schöningen flint artifacts has shown that at least one tool was used to cut animal skin. A side scraper on a flake (ID 18606; Schö 12 II-2) was identified as a 'dry hide knife,' with a use-wear polish from hide working, collagen residues, and hair fragments (Rots et al., 2015). In addition, a retouched flake (ID 17922; Schö 12 II-4) shows a use-wear pattern that is similar to hide working. Use-wear analysis on stone tools from other Lower Paleolithic sites demonstrates that hide working was already taking place well before the time of the Schöningen finds. Flint scrapers from the MIS 11 site of Hoxne, UK, display use-wear related to hide working (Keeley, 1993; Gilligan, 2010). These tools were found in post-Hoxnian layers associated with cooler climates in a boreal forested environment (Ashton et al., 2008). Additional evidence from use-wear through hide working on stone tools is present from Qesem Cave (Lemorini et al., 2006; Agam and Zupancich, 2020) and Gran Dolina TD10.1 (Pedergrana and Ollé, 2020).

Lissoirs, or smoothers, are one of the other essential tools for the stretching of skins to make them into soft, flexible hides. The earliest, unambiguous lissoirs are associated with the Neanderthal Mousterian of Acheulian Tradition sites Pech-de-l'Azé I (Pech I) and Abri Peyrony (Soressi et al., 2013) and differ from potential earlier versions of the tool as they are shaped before use and have a more standardized form. These earlier, expedient tools were among others found in Schöningen (Julien et al., 2015). They are normally produced from long bone fragments of large mammals, and only show rounded or polished tips, which could originate from both natural and anthropogenic processes, but could potentially be linked to hide production.

Macrobotanical remains of plant species with high levels of tannin show that plant-based tanning substances were readily available in the direct surroundings of the Schöningen lake shore (Bigga et al., 2015; Bigga, 2018). Although the presence of plants with tanning properties does not prove their use, there is at least one clear indication of the use of plants for tanning by Neanderthals: a residue of a tannic paste is present on both surfaces of an approximately 200,000-year-old flint blade from Neumark-Nord (Koller and Baumer, 2010). The chemical composition of the residue indicates that the wax-like substance originated from the bark of an oak (*Quercus suber*), interpreted to result from the cutting bark to produce a tanner for hides. The plant fiber residues found on the aforementioned retouched flake from Schöningen site 12 II-4 (ID 17922) could also be the relict of a plant-based tanner (Rots et al., 2015).

Animal-based tanning substances would also be available at the Schöningen lake shore. The exploitation of bone marrow through long bone fracture is very prevalent in the Spear Horizon assemblage (Voormolen, 2008; van Kolfschoten et al., 2015), but is also present in the underlying, older strata in Schöningen (Voormolen, 1997; van Kolfschoten et al., 2015; Julien et al., 2015). Apart from its nutritional value, bone marrow is a very suitable material for tanning hides. Besides that, the fat from the prey animal itself can be used for tanning. Bears, especially toward the hibernation season, are known to have large quantities of fat. Notably, in North America, bear fat was specifically used to water-proof leather clothing (Charles, 1997).

5. Conclusions

There is an increasing body of evidence for the exploitation of bears during the Lower and Middle Paleolithic (e.g., Auguste, 1995; Bratlund, 1999; Brasser, 2017; Romandini et al., 2018). The presence of skeletal remains of prime-aged adult bears with skinning marks at open-air archaeological sites seems to be an indicator for their exploitation. The fact that bear skins can only be collected shortly after death supports the hypothesis of active hunting by hominins.

The very thin cutmarks on the Schöningen specimens and the similarities found between the cutmark locations from different sites indicate that the processing of bear paws was a delicate and rather uniform process. The location of the marks on the skeletal remains from Schöningen, Bilzingsleben, and Boxgrove point toward skinning and do not necessarily support the exploitation of meat, though this might be the result of selective skeletal preservation. The circumstantial evidence for hide working in Lower Paleolithic contexts such as scrapers with use-wear from hides and bone tools for smoothing hides argues for a deep history of hide working. The insulating properties of bear skins rank them as a highly valuable resource for survival in cold conditions. Therefore, the procurement of bear skins might have been an important step in the year-round occupation of Northwestern Europe during the Lower Paleolithic.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Adam, K.D., 1951. Der Waldelefant von Lehringen, eine Jagdbeute des diluvialen Menschen. *Quartär* 5, 79–92.
- Abrams, G., Bello, S.M., Di Modica, K., Pirson, S., Bonjean, D., 2014. When Neanderthals used cave bear (*Ursus spelaeus*) remains: Bone retouchers from unit 5 of Scaldina Cave (Belgium). *Quat. Int.* 326–327, 274–287.
- Andres, M., Gidna, A., Yravedra, J., Domínguez-Rodrigo, M., 2012. A study of dimensional differences of tooth marks (pits and scores) on bones modified by small and large carnivores. *Archaeol. Anthropol. Sci.* 4, 209–219.
- Andrews, P., Turner, A., 1992. Life and death of the Westbury bears. *Ann. Zool. Fenn.* 28, 139–149.
- Agam, A., Zupancich, A., 2020. Interpreting the Quina and demi-Quina scrapers from Acheulo-Yabrudian Qesem Cave, Israel: Results of raw material and function analyses. *J. Hum. Evol.* 144, 102798.
- Armand, D., 2006. Abri Castanet (Dordogne, France): An Aurignacian site with bear procurement. Bear exploitation in Paleolithic time. *Sci. Ann., School of Geology, Aristotle University of Thessaloniki*.
- Ashton, N., Lewis, S.G., Parfitt, S.A., Penkman, K.E., Russell Coope, G., 2008. New evidence for complex climate change in MIS 11 from Hoxne, Suffolk, UK. *Quat. Sci. Rev.* 27, 652–668.
- Auguste, P., 1988. Apports paléontologiques et archéozoologiques de l'étude de la faune des grands mammifères de Biache-Saint-Vaast (Pas-de-Calais). *Rev. Archeol. Picardie* 1, 63–68.
- Auguste, P., 1995. Chasse et charognage au Paléolithique moyen: L'apport du gisement de Biache-Saint-Vaast (Pas-de-Calais). *Bull. Soc. Préhist. Française* 92, 155–167.
- Auguste, P., 2002. Fiche éclats diaphysaires du Paléolithique moyen: Biache-Saint-Vaast (Pas-de-Calais) et Kulna (Moravie, République Tchèque). In: Patou-Mathis, M. (Ed.), *Industrie de l'os préhistorique. Cahier X, Compresseurs, Percuteurs, Retouchoirs*. Éditions Société Préhistorique Française, Paris, pp. 39–57.
- Auguste, P., 2003. La chasse à l'ours au Paléolithique moyen: Mythes, réalités et état de la question. In: Patou-Mathis, M., Bocherens, H. (Eds.), *Le rôle de l'environnement dans les comportements des chasseurs-cueilleurs préhistoriques*, BAR International Series 1105, pp. 135–142. Oxford.
- Bächler, E., 1921. Das Drachenloch ob Vättis im Taminatale. *Jahrb. St. Gallische Naturwiss. Ges.* 57, 1920–1921. Band 1, 1–144.
- Bächler, E., 1923. Die Forschungsergebnisse im Drachenloch ob Vättis im Taminatale. *Jahrb. St. Gallische Naturwiss. Ges.* 59, 79–118.
- Bächler, E., 1940. Das Alpine Paläolithikum der Schweiz. In: *Monographien zur Ur- und Frühgeschichte der Schweiz* 2, pp. 1–263.
- Bez, J.-F., 1995. Traces de boucherie sur les restes de grands mammifères. In: Defleur, A., Cregut-Bonnoure, E. (Eds.), *Le gisement paléolithique moyen de la grotte des Cèdres (Var)*. D.A.F. 49, pp. 43–47.
- Bigga, G., 2018. Die Pflanzen von Schöningen. In: *Forschungen zur Urgeschichte aus dem Tagebau von Schöningen, Band 3*. Verlag des Römisch-Germanischen Zentralmuseums, Mainz.
- Bigga, G., Schoch, W.H., Urban, B., 2015. Paleoenvironment and possibilities of plant exploitation in the Middle Pleistocene of Schöningen (Germany). Insights from botanical macro-remains and pollen. *J. Hum. Evol.* 89, 92–104.
- Binford, L.R., 1981. *Bones: Ancient Men and Modern Myths*. Academic Press, New York.
- Blasco, R., Rosell, J., Arsuaga, J.L., Bermúdez de Castro, J.M., Carbonell, E., 2010. The hunted hunter: The capture of a lion (*Panthera leo fossilis*) at the Gran Dolina site, Sierra de Atapuerca, Spain. *J. Archaeol. Sci.* 37, 2051–2060.
- Boren, J., Hurd, B.J., 2004. How to Prepare Hides, Guide L-101. New Mexico State University.
- Bratlund, B., 1999. Taubach revisited. *Jahrb. Römisch-Ger. Zent.mus. Mainz* 46, 67–174.
- Brasser, M., 2017. Die Megafauna von Bilzingsleben. In: *Veröffentlichungen des Landesamtes für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte, Band 73*.
- Brasser, M., 2020. Big questions for big bones – evaluating the extent of human influence at the Lower Palaeolithic site of Bilzingsleben. In: García-Moreno, A., Hutson, J.M., Smith, G.M., Kindler, L., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), *Human Behavioural Adaptations to Interglacial Lakeshore Environments, RGZM-Tagungen*, vol. 37, pp. 5–29.
- Bunnell, F.L., Tait, D.E.N., 1981. Population dynamics of bears – implications. In: Fowler, C.W., Smith, T.D. (Eds.), *Dynamics of Large Mammal Populations*. John Wiley and Sons, New York, pp. 75–98.
- Charles, R., 1997. The exploitation of carnivores and other fur-bearing mammals during the North-western European Late and Upper Paleolithic and Mesolithic. *Oxford J. Archaeol.* 16, 253–277.
- Chauvière, F.-X., 2008. La grotte du Bichon: un site préhistorique des montagnes neuchâteloises. Office et musée cantonal d'archéologie de Neuchâtel.
- Conard, N.J., Langguth, K., Uerpman, H.-P., 2001. Die Ausgrabungen im Gravettien des Hohlle Fels bei Schellklingen, Alb-Donau-Kreis. In: Biel, J. (Ed.), *Archäologisches Ausgrabungen in Baden-Württemberg 2000*, pp. 18–22.
- Conard, N.J., Serangeli, J., Böhner, U., Starkovich, B.M., Miller, C.E., Urban, B., van Kolfschoten, T., 2015. Excavations at Schöningen and paradigm shifts in human evolution. *J. Hum. Evol.* 89, 1–17.
- Conard, N.J., Serangeli, J., Bigga, G., Rots, V., 2020. A 300,000-year-old throwing stick from Schöningen, northern Germany, documents the evolution of human hunting. *Nat. Ecol. Evol.* 4, 690–693.
- Couturier, M.A.J., 1954. L'ours brun. *Ursus arctos* L. Grenoble.
- Domínguez-Rodrigo, M., Barba, R., 2006. New estimates of tooth mark and percussion mark frequencies at the FLK Zinj site: The carnivore-hominid-carnivore hypothesis falsified. *J. Hum. Evol.* 50, 170–194.
- Domínguez-Rodrigo, M., Piqueras, A., 2003. The use of tooth pits to identify carnivore taxa in tooth-marked archaeofaunas and their relevance to reconstruct hominid carcass processing behaviours. *J. Archaeol. Sci.* 30, 1385–1391.
- Delany-Riviera, C., Plummer, T.W., Hodgson, J.A., Forrest, F., Hertel, F., Oliver, J.S., 2009. Pits and pitfalls: Taxonomic variability and patterning in tooth mark dimension. *J. Archaeol. Sci.* 36, 2597–2608.
- Duches, R., Nannini, N., Fontana, A., Boschin, F., Crezzini, J., Bernardini, F., Tuniz, C., Dalmeri, G., 2018. Archaeological bone injuries by lithic backed projectiles: New evidence on bear hunting from the Late Epigravettian site of Cornafessa rock shelter (Italy). *Archaeol. Anthropol. Sci.* 11, 2249–2270.
- Erdbrink, D.P., 1953. A Review of Fossil and Recent Bears of the Old World. With Remarks on Their Phylogeny, Based Upon Their Dentition, vol. 1. Jan de Lange, Deventer.
- Fernández-Jalvo, Y., Andrews, P., 2016. *Atlas of Taphonomic Identifications. 1001+ Images of Fossil and Recent Mammal Bone Modification*. Springer, Berlin.
- Gilligan, I., 2007. Neanderthal extinction and modern human behaviour: The role of climate change and clothing. *World Archaeol.* 39, 499–514.
- Gilligan, I., 2010. The Prehistoric development of clothing: Archaeological implications of a thermal model. *J. Archaeol. Method Theory* 17, 15–80.
- Hosfield, R., 2016. Walking in a winter wonderland? Strategies for Early and Middle Pleistocene survival in midlatitude Europe. *Curr. Anthropol.* 57, 653–682.
- Hutson, J.M., Villaluenga, A., García-Moreno, A., Turner, E., Gaudzinski-Windheuser, S., 2018. On the use of metapodials as tools at Schöningen 13II-4. In: Hutson, J.M., García-Moreno, A., Noack, E.S., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), *The Origins of Bone Tool Technologies: "Retouching the Palaeolithic: Becoming Human and the Origins of Bone Tool Technology"* Conference at Schloss Herrenhausen in Hannover, Germany, 21–23. October 2015. Verlag des Römisch-Germanisches Zentralmuseum, Mainz, pp. 53–91.
- Hutson, J.M., García-Moreno, A., Villaluenga, A., Gaudzinski-Windheuser, S., 2021. Dancing with wolves at Schöningen 13II-4. In: Gaudzinski-Windheuser, S.,

- Jöris, O. (Eds.), The Beef Behind all Possible Pasts. The Tandem-Festschrift in Honour of Elaine Turner and Martin Street, Monographien des RGZM, vol. 157.1. Propyläen, Heidelberg, pp. 49–85.
- Julien, M.-A., Hardy, B., Stahlschmidt, M.C., Urban, B., Serangeli, J., Conard, N.J., 2015. Characterizing the Lower Paleolithic bone industry from Schöningen 12 II: A multi-proxy study. *J. Hum. Evol.* 89, 264–286.
- Keeley, L.H., 1993. The utilization of lithic artifacts. In: Singer, R., Gladfelter, B.G., Wymer, J.J. (Eds.), *The Lower Palaeolithic Site at Hoxne, England*. University of Chicago Press, Chicago, pp. 129–149.
- Kitagawa, K., Krönneck, P., Conard, N.J., Münzel, S.C., 2012. Exploring cave use and exploitation among cave bears, carnivores and hominins in the Swabian Jura, Germany. *J. Taphon.* 10 (3–4), 439–461.
- Koby, F.E., 1953. Les Paléolithiques ont-ils chassé l'Ours des Cavernes?. In: *Actes de la Société jurassienne d'émulation* 57, pp. 157–204.
- Koller, J., Baumer, U., 2010. The organic traces on a silex blade from Neumark-Nord. In: Meller, H. (Ed.), *Elefantenreich, ein Fossilwelt in Europa*. Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt – Landesmuseum für Vorgeschichte Halle (Saale), pp. 553–562.
- Kurtén, B., 1958. Life and death of the Pleistocene cave bear: A study in paleoecology. *Acta Zool. Fenn.* 95, 4–59.
- Lemorini, C., Stiner, M.C., Gopher, A., Shimelmitz, R., Barkai, R., 2006. Use–wear analysis of an Amudian laminar assemblage from the Acheulo–Yabrudian of Qesem Cave, Israel. *J. Archaeol. Sci.* 33, 921–934.
- Lyman, R.L., 1994. *Vertebrate Taphonomy*. Cambridge University Press, Cambridge, England.
- MacDonald, K., 2018. Fire-free hominin strategies for coping with cool winter temperatures in North-Western Europe from before 800,000 to circa 400,000 years ago. *PaleoAnthropology* 2018, 7–26.
- Mania, D., 1991. Zur Paläontologie der mittelpleistozänen Travertine von Bilzingsleben. In: *Veröffentlichungen des Landesmuseums für Vorgeschichte Halle* 44, pp. 9–28.
- Mania, D., 1995. Die geologischen Verhältnisse im Gebiet von Schöningen. In: Thieme, H., Maier, R. (Eds.), *Archäologische Ausgrabungen im Braunkohlentagebau Schöningen, Landkreis Helmstedt*. Hansche Buchhandlung, Hannover, pp. 33–43.
- Mania, U., 2004. Special aspects of vertebrate fauna from the Middle Pleistocene find horizon of Bilzingsleben. In: Mania, D., Mania, U., Heinrich, W.-D., Fischer, K., Böhme, G., Turner, A., Erd, K., Mai, D.H. (Eds.), *Bilzingsleben V: Homo erectus – seine Kultur und Umwelt. Beiträge zur Ur- und Frühgeschichte Mitteleuropas* 40. Beier and Beran, Langenweißbach, pp. 197–200.
- Mazza, P., Rustioni, M., 1994. On the phylogeny of Eurasian bears. *Palaeontogr. Abt. A* 230, 1–38.
- Mensan, R., Bourrillon, R., Cretin, C., White, R., Gardère, P., Chiotti, L., Sisk, M., Clark, A., Higham, T., Tartar, É., 2012. Context and dating of newly discovered Aurignacian rock art from Abri Castanet (Dordogne, France). *PALEO* 23, 171–188.
- Miracle, P.T., 2007. The Krapina Paleolithic Site: Zooarchaeology, Taphonomy and Catalog of the faunal remains. Croatian Natural History Museum, Zagreb.
- Miracle, P.T., 2008. Sex and size of the Krapina cave bears. In: Toškan, B. (Ed.), *Fragments of Ice Age Environments: Proceedings in Honour of Ivan Turk's Jubilee*. Opera Instituti Archaeologici Sloveniae 2. ZRC Publishing, Ljubljana, pp. 85–110.
- Morel, P., 1993. Une chasse à l'ours brun il y a 12,000 ans: une nouvelle découverte à la grotte du Bichon (La Chaux-de-Fonds). *Archéol. Suisse* 16, 110–117.
- Münzel, S.C., Conard, N.J., 2004. Cave bear hunting in Hohle Fels Cave in the Ach Valley of the Swabian Jura. *Rev. Paléobiol.* 23, 877–885.
- Müller, W., Pasda, C., 2011. Site formation and faunal remains of the Middle Pleistocene site Bilzingsleben. *Quartär* 58, 25–49.
- Pacher, M., 1997. Der Höhlenbärenkult aus ethnologischer Sicht. In: *Wissenschaftliche Mitteilungen aus dem Niederösterreichischen Landesmuseum* 10, pp. 251–375.
- Pacher, M., 2000. Höhlenbär und Mensch: Tatsachen und Vermutungen. In: Rabeder, G., Nagel, D., Pacher, M. (Eds.), *Der Höhlenbär*. Jan Thorbecke Verlag, Stuttgart, pp. 82–104.
- Parfitt, S.A., 1999. Mammalia. In: Roberts, M.B., Parfitt, S.A. (Eds.), *Boxgrove, A Middle Pleistocene Hominid Site at Earham Quarry, Boxgrove, West Sussex*. English Heritage, London, pp. 197–290.
- Parfitt, S.A., Roberts, M.B., 1999. Human modifications on faunal remains. In: Roberts, M.B., Parfitt, S.A. (Eds.), *Boxgrove, A Middle Pleistocene Hominid Site at Earham Quarry, Boxgrove, West Sussex*. English Heritage, London, pp. 395–414.
- Pedergnana, A., Ollé, A., 2020. Use-wear analysis of the late Middle Pleistocene quartzite assemblage from the Gran Dolina site, TD10.1 subunit (Sierra de Atapuerca, Spain). *Quat. Int.* 569–570, 181–211.
- Potts, R., Shipman, P., 1981. Cutmarks made by stone tools on bones from Olduvai Gorge, Tanzania. *Nature* 291, 577–580.
- Rode, K., 1935. Untersuchungen über das Gebiß der Bären. *Monogr. z. Geol. Palaont.* 11/7.
- Rodríguez, J., Willmes, C., Mateos, A., 2021. Shivering in the Pleistocene. Human adaptations to cold exposure in Western Europe from MIS 14 to MIS 11. *J. Hum. Evol.* 153, 102966.
- Richter, D., Krbetschek, M., 2015. The age of the Lower Paleolithic occupation at Schöningen. *J. Hum. Evol.* 89, 46–56.
- Richter, D., Thieme, H., 2012. One first chronometric date for the Lower Palaeolithic occupation at Schöningen 13-I. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Forschung zur Urgeschichte im Tagebau von Schöningen 1*. Verlag der Römisch-Germanischen Zentralmuseums, Mainz, pp. 171–182.
- Romandini, M., Terlato, G., Nannini, N., Tagliacozzo, A., Benazzi, S., Peresani, M., 2018. Bears and humans, a Neanderthal tale. Reconstructing uncommon behaviors from zooarchaeological evidence in southern Europe. *J. Archaeol. Sci.* 90, 71–91.
- Rots, V., Hardy, B.L., Serangeli, J., Conard, N.J., 2015. Residue and microwear analyses of the stone artifacts from Schöningen. *J. Hum. Evol.* 89, 298–308.
- Schreve, D.C., 1997. Mammalian Biostratigraphy of the Later Middle Pleistocene in Britain. PhD Dissertation, University of London.
- Schreve, D.C., Currant, A.P., 2003. The Pleistocene history of the Brown Bear (*Ursus arctos* L.) in the western Palaearctic: A review. In: Kryštufek, B., Flajšman, B., Griffiths, H.I. (Eds.), *Living with Bears. A Large European Carnivore in a Shrinking World*. Ekološki forum LDS, Ljubljana, pp. 27–39.
- Serangeli, J., Conard, N.J., 2015. The behavioral and cultural stratigraphic contexts of the lithic assemblages from Schöningen. *J. Hum. Evol.* 89, 287–297.
- Serangeli, J., Böhner, U., van Kolfschoten, T., Conard, N.J., 2015a. Overview and new results from large-scale excavations in Schöningen. *J. Hum. Evol.* 89, 27–45.
- Serangeli, J., van Kolfschoten, T., Starkovich, B., Verheijen, I., 2015b. The European Saber-toothed cat (*Homotherium latidens*) found in the “Spear Horizon” at Schöningen (Germany). *J. Hum. Evol.* 89, 172–180.
- Shipman, P., Rose, R., 1983a. Evidence of butchery and hominid activities at Torralba and Ambrona: An evaluation using microscopic techniques. *J. Archaeol. Sci.* 10, 465–474.
- Shipman, P., Rose, J., 1983b. Early hominid hunting, butchering, and carcass processing behaviors: Approaches to the fossil record. *J. Anthropol. Archaeol.* 2, 57–98.
- Shipman, P., Rose, J., 1984. Cutmark mimics on modern fossil bovid bones. *Curr. Anthropol.* 25, 116–177.
- Sierralta, M., Frechen, M., Urban, B., 2012. ²³⁰Th/U dating results from opencast mine Schöningen. In: Behre, K.-E. (Ed.), *Die chronologische Einordnung der paläolithischen Fundstellen von Schöningen, Forschung zur Urgeschichte im Tagebau von Schöningen 1*. Verlag der Römisch-Germanischen Zentralmuseums, Mainz, pp. 143–154.
- Smith, G., 2012. Hominin-carnivore interaction at the Lower Palaeolithic site of Boxgrove, UK. *J. Taphon.* 10 (3–4), 373–394.
- Soergel, W., 1940. Das Massenvorkommen des Höhlenbären. Fischer, Jena.
- Soressi, M., McPherron, S.P., Lenoir, M., Dogandžić, T., Goldberg, P., Jacobs, Z., Maigrot, Y., Martisius, N.L., Miller, C.E., Rendu, W., Richards, M., Skinner, M.M., Steele, T.E., Talamo, S., Texier, J.-P., 2013. Neanderthals made the first specialized bone tools in Europe. *Proc. Natl. Acad. Sci. USA* 110, 14186–14190.
- Stahlschmidt, M.C., Miller, C.E., Ligouis, B., Berna, F., Urban, B., Conard, N.J., 2015. The depositional environments of Schöningen 13II-4 and their archaeological implications. *J. Hum. Evol.* 89, 71–91.
- Starkovich, B.M., Conard, N.J., 2015. Bone taphonomy of the Schöningen “Spear Horizon South” and its implications for site formation and hominin meat provisioning. *J. Hum. Evol.* 89, 154–171.
- Stiner, M.C., 1990. The use of mortality patterns in archaeological studies of hominid predatory adaptations. *J. Anthropol. Archaeol.* 9, 305–351.
- Stiner, M.C., 1998. Mortality analysis of Pleistocene bears and its paleoanthropological relevance. *J. Hum. Evol.* 34, 303–326.
- Stiner, M.C., 1999. Cave bear ecology and interactions with Pleistocene humans. *Ursus* 11, 41–58.
- Thieme, H., 1997. Lower Palaeolithic hunting spears from Germany. *Nature* 385, 807–810.
- Thieme, H., 2007. *Die Schöninger Speere, Mensch und Jagd vor 400 000 Jahren*. Konrad Theiss Verlag GmbH, Stuttgart.
- Thieme, H., Maier, R., 1995. *Archäologische Ausgrabungen im Braunkohlentagebau Schöningen, Landkreis Helmstedt*. Verlag Hahnsche Buchhandlung, Hannover.
- Thieme, H., Veil, S., 1985. Neue Untersuchungen zum eemzeitlichen Elefantenjagdplatz Leheringen, Ldkr. Verden. *Die Kunde* 36, 11–58.
- Thieme, H., Mania, D., Urban, B., van Kolfschoten, T., 1993. Schöningen (Nordharz-vorland) eine altpaläolithische Fundstelle aus dem mittleren Eiszeitalter. *Archäol. Korresp.* 23, 147–163.
- Thun Hohenstein, U., Di Nucci, A., Peretto, C., 2005. Lo sfruttamento di *Ursus deningeri* press oil giacimento del Paleolitico inferior di Isernia La Pineta (Molise – IS). In: Malerna, G., Visentini, P. (Eds.), *Atti del IV Convegno Nazionale di Archeozoologia (Pordenone, 13-15 Novembre 2003)*, Quaternari del Museo Archeologico del Friuli Occidentale 6, pp. 23–29.
- Tillet, T., Binford, L.R. (Eds.), 2002. *L'ours et l'Homme. Symposium d'Auberives-en-Royans - Isère- France (4-6 Novembre 1997)*. E.R.A.U.L. 100.
- Trinkaus, E., Stringer, C.B., Ruff, C.B., Hennessey, R.J., Mark, B., Roberts, M.B., Simon, A., Parfitt, S.A., 1999. Diaphyseal cross-sectional geometry of the Boxgrove 1 Middle Pleistocene human tibia. *J. Hum. Evol.* 37, 1–25.
- Turner, A., 2004. Bears and lions of Bilzingsleben: Palaeoecological implications. In: Mania, D., Mania, U., Heinrich, W.-D., Fischer, K., Böhme, G., Turner, A., Erd, K., Mai, D.H. (Eds.), *Bilzingsleben V: Homo erectus – seine Kultur und Umwelt, Beiträge zur Ur- und Frühgeschichte Mitteleuropas* 40. Beier and Beran, Langenweißbach, pp. 189–195.
- Turner, E., Hutson, J., Villaluenga, A., García-Moreno, A., Gaudzinski-Windheuser, S., 2017. Bone staining in waterlogged deposits: A preliminary contribution to the interpretation of near-shore find accumulation at Schöningen 13II-4 ‘Spear-Horizon’ site, Lower Saxony, Germany. *Hist. Biol.* 30, 767–773.

- Urban, B., 1995. Palynological evidence of younger Middle Pleistocene Interglacials (Holsteinian, Reinsdorf and Schöningen) in the Schöningen open cast lignite mine (eastern Lower Saxony, Germany). In: Mededelingen Rijksgeschiedkundige Dienst 52, pp. 175–186.
- Urban, B., Bigga, G., 2015. Environmental reconstruction and biostratigraphy of Upper Middle Pleistocene lakeshore deposits at Schöningen. *J. Hum. Evol.* 89, 57–70.
- van Kolfschoten, T., 1993. Die Vertebraten des Interglazials von Schöningen 12B. *Ethnogr.-Archäol. Z.* 34, 623–628.
- van Kolfschoten, T., 1995. Faunenreste des altpaläolithischen Fundplatzes Schöningen 12 (Reinsdorf-Interglazial). In: Thieme, H., Maier, R. (Eds.), *Archäologische Ausgrabungen im Braunkohlentagebau Schöningen, Landkreis Helmstedt*. Verlag Hahnsche Buchhandlung, Hannover, pp. 85–94.
- van Kolfschoten, T., 2014. The palaeolithic locality Schöningen (Germany): A review of the mammalian record. *Quat. Int.* 326–327, 469–480.
- van Kolfschoten, T., Buhre, E., Verheijen, I., 2015a. The larger mammal fauna from the Lower Paleolithic Schöningen Spear site and its contribution to hominin subsistence. *J. Hum. Evol.* 89, 138–153.
- van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015b. Lower Paleolithic bone tools from the ‘Spear Horizon’ at Schöningen. *J. Hum. Evol.* 89, 226–263.
- van Zijderveld, K., Kirkels, M., 1996. De Midden Pleistocene grote zoogdierresten uit de bruinkoolgroeve Schöningen (Schö 12B), Duitsland. *Cranium* 13, 31–38.
- Verheijen, I., Serangeli, J., Ramcharan, A., Starkovich, B.M., van Kolfschoten, T., 2022. The remains of the European sabre-toothed cat (*Homotherium latidens*) found in the Spear Horizon at Schöningen (Germany). In: Conard, N.J., Hillgruber, K.F., Serangeli, J., Terberger, T. (Eds.), *Die Homotherium-Funde von Schöningen 13 II-4 – Menschen und Raubkatzen des Eiszeitalters Beiträge des wissenschaftlichen Workshops am paläon (Schöningen) vom 05.06 – 07.06.2015, Forschungen zur Urgeschichte im Tagebau von Schöningen*, vol. 4, pp. 3–17.
- Voormolen, B., 1997. The vertebrate taphonomy of the Middle Pleistocene site Schöningen 12B, Niedersachsen, Germany. Unpublished doctoral essay, Leiden University.
- Voormolen, B., 2008. Ancient hunters, modern butchers. Schöningen 13II-4, a kill-butcher site dating from the northwest European Lower Paleolithic. *J. Taphon.* 6, 71–141.
- Weaver, T.D., Boyko, R.H., Steele, T.E., 2011. Cross-platform program for likelihood-based statistical comparisons of mortality profiles on a triangular graph. *J. Archaeol. Sci.* 38, 2420–2423.
- Wenzel, S., 1998. Die Funde aus dem Travertin von Stuttgart-Unterduckheim und die Archäologie der letzten Warmzeit in Mitteleuropa. Ph.D. Dissertation, University of Cologne.
- Wojtal, P., Wilczyński, J., Nadachowski, A., Münzel, S.C., 2015. Gravettian hunting and exploitation of bears in Central Europe. *Quat. Int.* 359–360, 58–71.
- Wolverton, S., 2006. Natural-trap ursid mortality and the Kurtén Response. *J. Hum. Evol.* 50, 540–551.