Revised Title Page (with Author Details)

A detailed analysis of the spatial distribution of Schoningen 13II-4 'Spear Horizon' faunal remains

García-Moreno, Alejandro*[1], Hutson, Jarod M.[1,2], Villaluenga, Aritza[1,3], Turner, Elaine[1], and Gaudzinski-Windheuser, Sabine[1,4]

[1] MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution, Römisch-Germanisches Zentralmuseum, Neuwied, Germany

[2] Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington D.C., USA

[3] Consolidated Research Group on Prehistory (IT-1223-19), University of the Basque Country, Vitoria-Gasteiz, Spain

[4] Institute of Ancient Studies, Johannes Gutenberg University, Mainz, Germany

*Corresponding author.

E-mail address: garcia@rgzm.de (A. García-Moreno)

Abstract

The Middle Pleistocene Schöningen 13II-4 'Spear Horizon' (Germany) is a key site for the study of human evolution, most notably for the discovery of Paleolithic wooden weaponry and evidence for developed hunting strategies. On the other hand, the 'Spear Horizon' offers an excellent opportunity to approach hominin spatial behavior, thanks to the richness of the archaeological assemblage, its exceptional preservation, and the vast expanse of the excavated surface. Analyzing how space was used is essential for understanding hominin behavior at this unique open-air site and, from a wider perspective, for approaching how humans adapted to interglacial environments. In this paper, we present an exhaustive spatial study of the complete Schöningen 13II- 4 'Spear Horizon' faunal assemblage and its archaeological context, combining zooarchaeology and spatial analysis through the extensive application of Geographic Information Systems. Our results indicate the existence of different activity areas related to changes in the position of the shoreline due to fluctuations of water table levels of the Schöningen paleo-lake. These activity areas were likely used on a seasonal basis, whereas the spatial patterning observed in the distribution of faunal remains suggests a diversity of behavioral strategies in terms of intensity and/or duration of occupations. This study refines previous interpretations of the site and reconstructs human behavioral adaptations and the occupational changing lakeland environment during the Middle Pleistocene in Europe.

Keywords: Intrasite spatial archaeology; Middle Pleistocene; Zooarchaeology; Geographic Information Systems; Human spatial behavior

1. Introduction

The Middle Pleistocene archaeological site of Schöningen 13II-4 became known worldwide in the 1990s with the appearance of a series of wooden spears, considered among the oldest hunting weapons ever documented (Thieme, 1997; Schoch et al., 2015). These spears, which led to the site being known as the 'Spear Horizon', were recovered alongside a large assemblage of faunal remains and a comparatively small lithic collection within Middle Pleistocene interglacial lacustrine deposits (Lang et al., 2015; Stahlschmidt et al., 2015a; Urban and Bigga, 2015). The site was originally interpreted as the result of a single mass-killing event of horses along the lakeshore (Thieme, 2005), but that interpretation was later revised in favor of multiple horse hunting events (Voormolen, 2008; van Kolfschoten, 2014; van Kolfschoten et al., 2015a; Hutson et al., 2020). The exceptional preservation of the archaeological finds and the high resolution of the sedimentary deposit qualify Schöningen 13II-4 as one of the key sites of Paleolithic archaeology (Gaudzinski-Windheuser and Roebroeks, 2000; Conard et al., 2015), notable not only for the wooden spears (Thieme, 2007; Schoch et al., 2015) but also the early use of bone tools (van Kolfschoten et al., 2015b; Hutson et al., 2018) and sophisticated hunting strategies (Thieme, 2005; Voormolen, 2008; van Kolfschoten et al., 2015a; Hutson et al., 2020).

Despite its exceptional record, only recently have some of the first spatial analyses been presented (Böhner et al., 2015; Hutson et al., 2020; Peters and van Kolfschoten, 2020). Analysis of spatial patterning in the open-air Schöningen 13II-4 archaeological assemblage poses a particular challenge due to the lack of evident features providing points of spatial reference comparable to those found at other Pleistocene sites (Farizy, 1994), such as habitation structures (Stapert, 1990; Yar and Dubois, 1996; Jaubert and Delagnes, 2007; Jaubert et al., 2016) and hearths (Vaquero and Pastó, 2001; Vaquero et al., 2004; Henry, 2012; Shahack et al., 2014). In contrast to earlier suggestions (Thieme, 2005), long lasting hearths were not used at Schöningen 13II-4 (Stahlschmidt et al., 2015b). On the positive side, the

51 'Spear Horizon' faunal assemblage covers a vast expanse and includes thousands of well-
52 preserved faunal remains, together offering an excellent opportunity for detailed spatial
53 analysis of hominin activities specific to open-air lakeshore settings.

54 Analyzing the spatial patterning of the 'Spear Horizon' can contribute to our understanding
55 of when and in which contexts human spatial behaviors evolved. The rational use of space,
56 meaning the allocation of specific activities in differentiated areas, is a distinctive human trait,
57 and may be indicative of hominin social structure and settlement dynamics (Otte, 2012; Clark,
58 2016; Domínguez-Rodrigo and Cobo-Sánchez, 2017; Kuhn and Stiner, 2019). In this sense,
59 much of the debate has focused on the emergence of spatial behaviors prior to the
60 appearance of modern humans, mainly during the Middle Pleistocene (Kolen, 1999; Conard,
61 2007; Henry et al., 2012; Villa and Roebroeks, 2014). The unique characteristics of Schöningen
62 13II-4 provide the kind of high-resolution archaeological archive necessary to understand the
63 contexts in which our human ancestors organized their immediate environments.

64 This work constitutes part of a multidisciplinary project to analyze the entire Schöningen
65 13II-4 'Spear Horizon' faunal collection from a spatial perspective (Hutson et al., 2020). Spatial
66 analysis of the 'Spear Horizon' was designed around several goals: 1) to analyze the spatial
67 patterning of the taxonomic composition of the faunal assemblage, with special attention to
68 the main prey taxa; 2) to locate traces of hominin hunting and butchery activities along the
69 former Schöningen lakeshore; and 3) to reconstruct hominin occupations at Schöningen 13II-4
70 in fine detail, attempting to narrow down the temporal resolution of the history of occupations
71 by identifying discreet hunting events. The major aim of the spatial analysis is to contribute to
72 a comprehensive interpretation of this complex and unique site, leading to a better
73 understanding of how hominins used space and adapted to lakeshore interglacial
74 environments during the Middle Pleistocene (Gaudzinski-Windheuser et al., 2015, 2016; García
75 Moreno et al., 2020).

1.1. The Schöningen 13II-4 'Spear Horizon' archaeological site

Open cast lignite mining works led to the discovery of a series of archaeological sites near the town of Schöningen (Lower Saxony, Germany; Fig. 1). Many of these sites are contained within a series of laterally-stacked erosional features defined as 'channels', marking the location of a former lake. Among the sites, Schöningen 13II-4 (site 13, channel II, level 4) contained the richest deposit of archaeological finds. The level 4 'Spear Horizon' was divided into four sedimentological layers (4a, 4b, 4b/c, and 4c), but most of the finds were recovered from layer 4b, a 20–40 cm thick layer of dark brown, organic-rich, silt (Böhner et al., 2015; Serangeli et al., 2015). The presence of some archaeological materials in other layers can be explained by percolation from layer 4b, due to the wet depositional context or trampling. Böhner et al. (2015) noticed the correlation between the thickness of layers 4b, 4b/c, and 4c and the distribution of faunal remains, whose preservation was likely to have been favored in these organic deposits. In any case, the homogeneity of the archaeological assemblage through the different layers, the reduced thickness of the sedimentary package, and the documentation of bone refits between layers indicate that the entire 'Spear Horizon' can be considered and analyzed as a single archaeological unit (Böhner et al., 2015; Hutson et al., 2020). The 'Spear Horizon' was originally dated to around 400 ka (Thieme, 1997), but later was given a maximum age of 337–300 ka (MIS 9; Richter and Krbetschek, 2015) based on thermoluminescence (TL) dating on heated flints from underlying layer 13I-1. Thus, the Schöningen 13II-4 'Spear Horizon' was likely deposited during MIS 9 or a younger temperate period.

FIGURE 1

Excavations at Schöningen 13II-4 from 1995 to 2007 extended over an area of ca. 3,900 m^2 and produced some 15,000 archaeological remains (Serangeli et al., 2015). Alongside the wooden spears, a rather small lithic collection and a large, exceptionally well-preserved faunal

assemblage were recovered. The lithic industry is composed of around 1,500 finds, mainly flakes and debris, with only a few retouched tools and no hammerstones documented (Serangeli and Böhner, 2012). Recent zooarchaeological studies (Voormolen, 2008; van Kolfschoten, 2014; van Kolfschoten et al., 2015a; Hutson et al., 2020) indicate that the faunal assemblage, a total of more than 14,000 bones and bone fragments, is largely dominated by horse (*Equus mosbachensis*; see Table 1 and Supplementary Online Material [SOM] Table S1 for the complete species list). Aurochs (*Bos primigenius*), bison (*Bison priscus*) and red deer (*Cervus elaphus*) remains are common but significantly less abundant than horse. Other taxa, such as giant deer (*Megaloceros giganteus*), roe deer (*Capreolus capreolus*), and two different species of rhinoceros (*Stephanorhinus hemitoechus, Stephanorhinus kirchbergensis*; Welker et al., 2017) are present but rare. Altogether, the large mammalian fauna suggests a mosaic, interglacial environment composed of open grassland with nearby forests around the lake (Urban and Bigga, 2015). Carnivores, small mammals, birds, and fishes have also been documented (SOM Table S1). Carnivores are represented by wolf (*Canis lupus*), fox (*Vulpes vulpes*), badger (*Meles meles*), and a large felid, possibly extinct cave lion (*Panthera spelaea*) based on zooarchaeology by mass spectrometry analysis of a thoracic vertebra (Frido Welker, pers. comm.).

TABLE 1

Several lines of evidence indicate that most of the faunal assemblage was recovered in primary position: the presence of intact laminations and the absence of coarser grained materials indicate low fluvial activity and limited wave action (Stahlschmidt et al., 2015a); and the excellent state of preservation and minimal weathering of the zooarchaeological remains imply quick burial, whereas the absence of rounding of fracture edges denotes little erosion and transport of the assemblage (Hutson et al., 2020). Finally, the fact that many bones were found in anatomical connection during excavation (Voormolen, 2008; van Kolfschoten et al.,

2015a; Hutson et al., 2020) precludes a significant reworking of the deposit. Collectively, this evidence confirms that post-depositional processes had little influence on the actual distribution of the archaeological assemblage at Schöningen 13II-4.

The available data on the orientation of finds (Böhner et al. 2015; Peters and van Kolfschoten, 2020) indicate that finds from the 'Spear Horizon' seem to follow bimodal lineal orientations, mostly in the north-south and east-west axes. It is noteworthy that none of these axes follow the natural slope of the lake basin, but on the contrary they fit with the excavation grid. Orientation of finds was not recorded during excavation, so it was calculated from fieldwork drawings, which may result in an over-representation of this kind of perpendicular orientations (McPherron, 2005; Domínguez-Rodrigo et al., 2014), whereas the lack of data on the tipping of the finds make fabric analysis unfeasible. In any case, considering the absence of evidence for high-energy taphonomic and post-depositional processes, such anisotropic patterns may have derived from low-energy processes resulting in an in-situ reorientation of finds (Cobo-Sánchez et al., 2014; Domínguez-Rodrigo et al. 2014; García-Moreno et al., 2016), with a minor impact on the spatial distribution of the assemblage.

Sedimentary analysis (Lang et al., 2015; Stahlschmidt et al., 2015a), paleobotany (Urban and Bigga, 2015; Bigga, 2018), and actualistic experiments (Turner et al., 2018) indicate that the site formed in a delta environment, under wet and organic-rich conditions, similar to those found in shallow water and grass covered lake margins. Finally, carnivores played a limited role at Schöningen 13II-4, either as infrequent predators (van Kolfschoten, 2014) or as scavengers (Voormolen, 2008; Hutson et al., 2020). In either case, considering the scale of the site, carnivore influence on the distribution of the faunal assemblage would have been minimal.

All in all, the 'Spear Horizon' formed in a dynamic setting, where a certain degree of impact by taphonomic and post-depositional processes cannot be completely excluded.

However, the lack of evidence for high-energy processes indicates that even if some minor alterations may have occurred, these had a minimal influence on the spatial distribution of the archaeological assemblage. Therefore, the archaeological finds accurately reflect the spatial patterning of hominin activities at Schöningen 13II-4.

Most of the finds (faunal remains, lithics, spears and other wooden fragments) concentrate along a 10 m wide strip running in a north-south direction (Böhner et al., 2015; Fig. 2). Based on the density of finds and the slope of the basin, this strip has been interpreted as the former shoreline of the lake, where most hominin activities likely took place (Thieme, 2005). The paleosurface of the 'Spear Horizon' is highest in the western portion of the site (~104.5 meters above sea level [m.a.s.l.]), slopes gently to the proposed shoreline (~101 m.a.s.l.), and descends further to the east to the lowest area (~98.5 m.a.s.l.; Böhner et al., 2015; Fig. 2). This 6 m drop in elevation spans a distance of approximately 80 m west-to-east across the site. The area descending downslope to the east of the main concentration of finds, roughly below 101 m.a.s.l., was originally interpreted as the main body of the lake basin (Thieme, 2005). However, changing water table levels might have resulted in the lakeshore moving back and forth, together with hominin activity. A second activity area has been proposed in the eastern part of the site, where a significant number of finds were recovered (Turner et al., 2018). Only a few archaeological remains were found to the west of the main strip. This area was likely dry land during site formation, primarily based on the poor preservation, weathered condition of the faunal remains (Turner et al., 2018), and the extent of the organic sediment layer (Böhner et al., 2015).

FIGURE 2

2. Materials and Methods

The database created as an integral part of the Thieme excavations by the Niedersächsisches Landesamt für Denkmalpflege (Lower Saxony State Office for Heritage)

formed the basis for analyzing the spatial distribution of faunal remains from the 'Spear Horizon'. Two different sources of spatial data were implemented for Schöningen 13II-4—point data and polygon data (Böhner et al., 2015). First, the main database records the provenance of every find recovered from the excavations at Schöningen 13II-4. Finds were identified as single-point features, defined by Cartesian locations within a three-dimensional local reference system. In most cases, coordinates were recorded at the site during fieldwork; for finds where no coordinates were directly recorded (*n* = 2,553; 17.6%), artificial coordinates were assigned based on their location within the excavation grid, using the center point of a 1 m x 1 m excavation unit. A total of 14,506 faunal remains was three-dimensionally recorded. Second, digitalized excavation maps included major finds as polygons. Each find corresponded to a single polygon, and 9,206 bones and bone fragments were represented this way.

Each dataset offered different analytical possibilities. Even if a simplification of the actual finds, point data were used to plot almost the entire faunal assemblage. Polygon data, although not available for all the finds, accurately represented the shapes and sizes of many large faunal elements, especially in the case of large bones, which are not accurately represented by a single, central point.

Representation, visualization, and analysis of the data was performed using ArcMap 10.6 (ESRI, 2017) GIS software. Data ~~was~~ were plotted over the excavation grid for point-pattern distribution analysis. Point distribution provides a first impression of the spatial layout of the assemblage (Orton, 2004; Bevan et al., 2013); moreover, it constitutes the basis for extended analyses, such as density analysis or number of finds per unit of area. Zooarchaeological and taphonomical data resulting from zooarchaeological analysis (Hutson et al., 2020) were~~was~~ added to the spatial datasets, including taxonomy, skeletal parts representation, age and season of death, and bone surface modifications, providing detailed information regarding species distribution, seasonality of occupations, and anthropic activity. In contrast, little data

are~~is~~ available up to now for the lithic industry (Serangeli and Böhner, 2012; Serangeli and Conard, 2015). Therefore, our analysis focused on zooarchaeological remains, whereas lithics could not be considered for a detailed spatial analysis. Once data ~~was~~ were plotted, the number of faunal remains by area was calculated, counting the number of finds in each 1 m x 1 m squares of the original excavation grid.

The distribution of the faunal assemblage was analyzed in order to 1) define whether the distribution of finds followed aggregated, dispersed, or random patterns (Lloyd and Atkinson, 2004) and 2) identify significant concentrations of finds, if any. In the absence of major post-depositional processes reordering an assemblage, the presence of find clusters may reflect traces of anthropic activity, since finds ideally tend to appear closer to the place where actions originally took place (Carr, 1984; Barceló and Maximiano, 2013). To check the degree of clustering of the assemblage, Ripley´s K function (Barceló and Maximiano, 2008; Sánchez Romero, 2019) and Average Nearest Neighbor analysis (Blankholm, 1990; Kintigh, 1990) were used. Both procedures measure the type and intensity of a spatial distribution by comparing an assemblage against a randomly generated sample. Ripley's K function also allows measuring the evolution of such distribution with increasing distance (Maximiano, 2007). K-Means (Blankholm, 1990) was applied to group the assemblage into clusters and to identify areas with significant concentrations of finds. In both cases, a confidence interval of 95% ($p < 0.05$) was chosen to reject the null hypothesis. Finally, the density of finds throughout the site was calculated to create interpolated probability density maps using Kernel density (Baxter et al., 1997; Barceló, 2002).

3. Results

To simplify the presentation of the data and to clarify the terminology, the site was divided into three different zones (Fig. 3), based on different find densities (see below), the paleo-

topography of the 'Spear Horizon' (see Fig. 2; Böhner et al., 2015), and visual inspection of the point pattern distribution. Zone A comprises an area where the density of finds is higher than the mean density for the entire site. This corresponds to the long strip running north-south where the main find accumulation was recovered, interpreted as the shoreline of the lake (sectors 2–4 in Böhner et al., 2015). Zone B corresponds to the area located downslope to the east of Zone A. Here, faunal remains are more scattered over what is usually considered to have been underwater (sector 5 in Böhner et al., 2015). The boundary between Zone A and Zone B is clearer in the northern part due to a step in the slope of the basin, whereas it becomes more diffuse to the south where the slope is gentler and more continuous (Fig. 2; SOM Fig. S1). Zone C is the surface to the west of Zone A, likely corresponding to dryland based on the poor preservation of finds from this area (sector 1 in Böhner et al., 2015). These zones illustrate common general trends in the spatial patterning and density of finds in different areas of the site rather than constrained spaces. This division is consistent with that proposed by Böhner et al. (2015), but instead of dividing Zone A into several sectors, we defined the different clusters appearing within this zone using the above-mentioned statistical methods.

Zone A contains 9,310 bones and bone fragments located along an 820 m^2 band running north-south across the site; this represents 64.23% of the entire faunal record yet only 21% of the excavated surface. In contrast, 4,831 finds (33.3%) were deposited in Zone B in an area comprising 1,865 m^2 (47.82%). Only 365 (2.46%) faunal remains were scattered across the 1,250 m^2 (32.02%) surface of Zone C. In other words, almost two thirds of the faunal assemblage concentrate in a reduced portion of the site (Zone A, interpreted as the main shoreline), whereas the surface corresponding to dry land is significantly poorer in archaeological finds (Fig. 3). This aggregated pattern is confirmed by Average Nearest Neighbor analysis and by Ripley's K function (SOM Fig. S2).

FIGURE 3

3.1. Taxonomic spatial patterning

Spatial patterns differ according to taxon (Fig. 4). The three most abundant taxa at the 'Spear Horizon' are horse (*Equus mosbachensis*, *n* = 8,890), red deer (*Cervus elaphus, n* = 340), and bovids (*n* = 282), which included the combined sample of bison (*Bison priscus*) and aurochs (*Bos primigenius*). Horse is by far the most abundant taxa and its distribution mirrors that of the entire assemblage; 70.07% of horse remains appear in Zone A, another 28.33% are spread over Zone B, and only 1.60% come from Zone C. In contrast, red deer is most abundant in Zone B (59.94%), with only 26.81% appearing in Zone A and 13.25% in Zone C. Bovid remains show a more balanced distribution over the site: 41.99% in Zone A, 37.37% in Zone B, and 20.64% in Zone C.

FIGURE 4

The proportional representation of each taxon in each zone is also different. Of the faunal remains from Zone A, 96.79% belong to horse, whereas only 1.83% are from bovids and 1.38% from red deer. In Zone B, horse is again dominant (89.24%) and red deer remains (7.05%) are more abundant than bovid (3.72%). Proportions are more even in Zone C, where 58.20% of the remains are from horse, 23.77% from bovid, and 18.03% from red deer. According to Average Nearest Neighbor analysis, the three main taxa follow an aggregated pattern, but horse remains are more clustered (z-score: -91.74, $p < 0.001$) than bovid (z-score: -15.80, $p < 0.001$) and cervid (z-score: -12.21, $p < 0.001$). However, Ripley's K function shows that while horse remains are aggregated regardless of the distance between elements (SOM Fig. S3), bovid (SOM Fig. S4) and cervid (SOM Fig. S5) bones shift from an aggregated pattern to a dispersed pattern beyond a threshold distance of ~15 m for bovids and ~13.5 m for red deer.

The difference in the distributional pattern of each taxa is also evident when considering the distances between their remains. Bones and bone fragments belonging to

horse are separated from each other by a mean distance of 0.169 m (s.d.: 0.213 m), which shows how densely packed horse bones are in some areas. Almost 50% (*n* = 4,340) of horse remains are at a distance of ≤10 cm from their closest Neighbor. The average distance between horse remains is significantly different from that of the other taxa (Student's t: 3.154; *p* = 0.010). The significantly lower quantity of remains from the other taxa results in greater average distances between their elements. Bovid bones are separated by a mean distance of 0.918 m (s.d.: 1.316 m), and red deer remains are located 1.023 m (s.d.: 1.161 m) from each other.

Considering the number of finds per 1 m x 1 m unit area (following the original excavation grid), 1,746 (44.55%) units contained zooarchaeological remains. The maximum number of bone fragments per unit is 133, with a mean value of 7.97 ± 12.43 (Table 2). Regarding the presence of the three main taxa per unit, horse remains are widely represented, as can be expected from the high number of finds, appearing in 1,523 units (Fig. 4). Red deer and bovid remains are considerably more restricted. The high standard deviation of the mean number of finds per unit highlights the variability in the distribution of the zooarchaeological assemblage, with a maximum of 114, 24, and 10 bones per unit for horse, bovids, and cervids, respectively (Table 2). However, it must be noted that fragmentation at Schöningen 13II-4 is low, with many complete or nearly complete bones from all portions of the skeleton present. Therefore, even in cases of units with few bone fragments, the volume of finds per unit of area may be substantial when taking into consideration the size of these bones. It is noteworthy that red deer remains appear in 247 units, compared to the 148 units containing bovid remains, even though the mean number of bones per unit is similar in both taxa, and gives an idea of how remains of red deer are more scattered than those of bovids (see below).

TABLE 2

Besides these three main taxa, other animals are present at the 'Spear Horizon' in very low numbers (SOM Table S1). These taxa are substantially less abundant but follow more or less the same general pattern of distribution, with some notable differences (Fig. 5). Fish, bird, and micromammal remains are dispersed over Zones A and B, mirroring the distribution of the overall faunal assemblage, but carnivores only appear in the northern half of these two zones. Rhinoceros remains appeared in two small groupings, one in Zone C and another one at the southern convergence of Zones A and B.

FIGURE 5

3.2. Clustering and grouping of the assemblage

Kernel density analysis reveals two large clusters of horse remains in the northern portion of Zone A (Fig. 6). Other clusters appear in the southern part of Zone A and in Zone B. Bovids show a similar pattern, with a significant concentration of finds in the northern part of Zone A. Some bovid clusters appear in both Zones B and C, many of which correspond to semi-articulated skeletal elements from a single individual. Red deer remains appear more dispersed, with many small 'clusters' spread throughout both Zones A and B. Again, we must keep in mind the substantial difference in the number of finds of bovids and cervids when compared to horse remains. Overall, clusters of bovid and red deer bones are substantially less dense than those of horse. In fact, in areas with concentrations of bovid (or cervid) bones, horse bones may actually be more abundant.

K-Means analysis highlights the presence of different clusters, especially within Zone A (Fig. 6). According to Pseudo F-Statistic estimation, the three main prey taxa each can be divided into 14 or 15 groupings. In the case of horse bones, several circular groups of finds appear along Zone A, whereas bovid and cervid remains form only two dense clusters in the northern part of this zone. In general, groupings are more diffuse across Zone B and almost non-existent in Zone C for the three main taxa. The exceptions are three small, highly clustered

groupings: one located in the far west of Zone B (bovid) and two (one bovid, one cervid) in Zone C. These groups correspond to semi-articulated skeletal elements from single individuals.

FIGURE 6

3.3. Activity areas and traces of human activity

As stated previously, there is no direct evidence that the assemblage of large mammal remains resulted from anything other than hominin activity. Evidence of butchery and carcass processing at Schöningen 13II-4 derives from the presence of numerous cut marks, scraping marks, and impact damage on many of the bones (Hutson et al., 2020). The spatial distribution of these finds is similar to that of the entire assemblage (Fig. 7): 85.10% of bones showing cut marks and 85.77% of fragments showing impact damage are from Zone A; the rest of the remains are scattered throughout Zone B, with only a few fragments in Zone C. Hominin activity is also reflected in the presence of a significant number of bone tools, notably retouchers and soft hammers (van Kolfschoten et al., 2015b; Hutson et al., 2018). Retouchers were used for stone tool manufacture and maintenance; bone hammers were likely employed in heavy percussive activities, including stone working and bone breaking tasks. The spatial distribution of bone tools (Fig. 7) parallels the spatial patterning of the faunal and lithic assemblages (Table 3), probably because these were expedient tools selected from the bones of freshly butchered carcasses or from the bones of recent butchery episodes at the same location. Due to the availability of raw material, these tools were probably discarded after immediate use, at or next to the location where they were used.

FIGURE 7

TABLE 3

Zooarchaeological analysis indicates that at least 46 horses were killed at Schöningen 13II-4 (Hutson et al., 2020) and multiple horses possibly died during each hunting episode. Thirteen of these horse individuals can be identified based on thirteen complete or almost complete skulls recovered during excavation. Each skull derives from a single carcass and may provide an additional layer of spatial structure to the site. These elements were probably found *in situ*, as there is no evidence to suggest that the skulls were transported over long distances by humans, carnivores, or otherwise. Four of the skulls show cut marks suggesting the removal of the mandible or possible skinning marks. Three skulls preserve light carnivore tooth scoring on the nasal bones. This type of damage is typical of wolf kills and scavenging, in which skulls are among the least likely elements to be transported long distances away from original carcass sites (Haynes, 1982). All these crania are located in Zone A (Fig. 8), but their distribution is not uniform. One of these finds (nº 17018), was recovered in the northernmost part of Zone A, close to one of the main clusters of finds. To the south, within the densest cluster of finds, a second group of skulls appears, comprising three crania aligned from west to east (nº 4367, 5877 and 6756) and separated by 2.55 m and 2.71 m. At the southern edge of the main accumulation in Zone A, we find another four skulls: three align southwest-to-northeast (nº 6860, 7137, 7416), each separated by 2 m, and a fourth skull is located 2.4 m to the NW (nº 6569). Further to the south, and still in Zone A, four more crania emerge. Three (nº 9798, 10433 and 10865) follow a north-south alignment at the contact between Zones A and B, separated by 6.39 m and 5.97 m. The fourth skull (nº 10190) appears to the west of this alignment at 4.28 m to skull nº 10865. The last cranium (nº 11726) appears at the southernmost edge of Zone A, near the limit of the excavated surface, at 13.3 m from the previous group (nº 10865).

FIGURE 8

4. Discussion and Conclusions

As a result of the vast excavation surface and the exceptional preservation, the Schöningen 13II-4 'Spear Horizon' offers a unique opportunity to analyze hominin spatial activity in a Middle Pleistocene interglacial lakeshore landscape. Zooarchaeological analyses indicate that repeated hunting events took place at Schöningen 13II-4 (Voormolen, 2008; van Kolfschoten et al., 2015a; Hutson et al., 2020), and considering the density of finds in some areas of the site, a detailed spatial analysis is needed to unravel the spatiotemporal framework of those events.

As stated above, three different areas can be defined within the 'Spear Horizon' based on the distribution and concentration of finds: the former shore line with the main accumulation of finds (Zone A); the eastern portion of the site, descending downslope from the main accumulation and considered to be the former lake basin (Zone B); and dry land to the west where very few finds were recovered (Zone C). The detailed analysis of the spatial patterning of the complete faunal collection has revealed several differences between these zones beyond the density of finds, allowing for the identification of at least two occupation surfaces at Schöningen 13II-4.

Zone A constitutes the main and most characteristic area of accumulation at Schöningen 13II-4, and where the famous spears appeared. Zone A hosts two thirds of the zooarchaeological assemblage in a well-defined, 10 m wide and 60 m long band, yet only accounts for about 21% of the excavated surface. However, the distribution of faunal remains is not homogenous, but tends to concentrate in the northern half of the strip. In this northern area, two large clusters are clearly visible, with some smaller clusters in the southern half. In these large clusters, find density reaches its maximum values. The dense accumulation of faunal remains, lithics, bone tools, and wooden artefacts identifies Zone A as the main activity area within the 'Spear Horizon'.

The different clusters within Zone A likely relate to areas of intensive hominin activity. The lack of evidence for high-energy post-depositional processes that could have aggregated the assemblage indicates that the large concentration of bones in these spots is likely the result of anthropic hunting and carcass exploitation. The distribution of lithic and bone tools, which also accumulate within these clusters, supports this idea. This area of intense activity in the northern part of Zone A was delimited to the east by a step in the slope of the paleo-lake basin (Fig. 2; SOM Fig. S1), which probably reflects the location of the main shoreline during high water levels (see below). On the contrary, in areas where the slope is gentler and more continuous, such as the southern part of Zone A (as well as Zone B), minor fluctuations of the lake level would result in the shoreline shifting back and forth more frequently and, consequently, human activity was not so constrained by the lake margins, expanding over a wider surface. This pattern, along with more intense occupations during high water scenarios, may explain the high clustering observed in the northern half of Zone A.

Zone B, the wide area traditionally considered to be the lake basin and permanently under water (Thieme, 2005; Böhner et al., 2015), contains a significant number of zooarchaeological remains, even if in lower number and more scattered than in Zone A, suggesting that hominin occupations in this area of the site were more sporadic. Finds from Zone B show the same state of preservation and black staining observed on finds from Zone A, indicating deposition in Zone B occurred under similarly saturated and organic-rich conditions (Turner et al., 2018). Moreover, large and heavy bones and fragments appear in this area, and even some skeletal elements were found in semi-articulation (Hutson et al., 2020), all of which dismiss the possibility of a significant movement and reworking of the assemblage. Low-energy taphonomic processes, such as lake level fluctuations, can result in anisotropic orientation patterns due to an in-situ reorientation of finds (Cobo-Sánchez et al. 2014; Domínguez-Rodrigo et al., 2014, 2018), as those observed in finds from Zone B (Peters and van Kolfschoten, 2020). Accordingly, the faunal assemblage from Zone B was likely deposited in near-shoreline shallow

waters when the lake level was lower, after which the bones were rapidly covered by organic-rich sediments and dying grassy vegetation (Turner et al., 2018). The appearance of micromammal remains in Zone B suggests that this area was a stable surface where burrowing activities could take place, as was Zone A. On the other hand, the remains of fish were also found in both areas, demonstrating that these surfaces were also covered by water at some point. These alternating scenarios are supported by sedimentological analyses (Lang et al., 2012, 2015; Stahlschmidt et al., 2015a).

Altogether, these patterns indicate fluctuations in the lake level that resulted in a continuous shifting of the shoreline. Combined evidence from stable isotopes and equid dental wear (Julien et al., 2015; Kuitems et al., 2015; Rivals et al., 2015) confirm the presence of several horse populations in the assemblage, thus multiple hunting events, representing similar environmental regimes but different life histories and seasons of death. We can now introduce an element of space to ~~this~~ these data on shifting shorelines and multiple hunting events in order to bring into focus the temporal resolution of the site.

Fluctuations of the water table level could be due to seasonal oscillations of the stream flow feeding the lake, resulting in higher water levels in the warm season due to increased runoff, and lower levels in the spring and winter months with reduced stream flow. Subsequently, human activity tracked the ebb and flow of the shoreline between Zones A and B, which resulted in different activity areas during the year, depending on the water level. Seasonality data based on horses age-at-death estimates (Hutson et al., 2020; Fig. 9; SOM Table S2) suggest that most of the summer and autumn activities at the site took place in Zone A, whereas evidence of spring occupations appear in Zone B; winter occupations occur in both zones and even in Zone C. Based on ~~this~~ these seasonality data, it is possible to postulate a general trend in the seasonal use of the differing areas of the site, with most hunting events in Zone A taking place during summer-autumn, whereas Zone B saw mixed-season occupations.

Sporadic oscillations in seasonal water levels may result in occupations occurring off the expected season. Similar seasonal data ~~is~~ are not available for the much smaller bovid and cervid assemblage, so there are currently no indications of seasonal patterns for bovid and cervid hunting.

FIGURE 9

When the distribution of ungulates is considered, horse is overwhelmingly dominant in Zone B, as it is in Zone A. Bovids follow a similar distribution to horse, but red deer remains are more abundant in Zone B. The higher presence of red deer bones in Zone B and lower numbers of bovid remains may correspond to differences in prey selection strategies during periods when a lower lake level shifted the activity area downslope into Zone B. During these episodes, cervids may have been targeted more intensively than bovids for a variety of reasons, including a greater seasonal availability of cervids in the region, different foraging behaviors, and different duration and/or intensity of human occupations. In any case, we have to keep in mind that red deer remains constitute about 7% of the zooarchaeological assemblage in Zone B, whereas horse is by far the best represented taxa, as it is in Zone A. Following this, exploitation of cervids would be supplementary to equids overall.

The spatiotemporal relationship between these two zones is hard to establish, since no direct evidence connecting them has been found. Ongoing research on refitting faunal remains has thus far identified 37 breakage refits, connecting conjoinable bone fragments belonging to the same bone element, as well as 118 anatomical refits, pairing two or more articulating skeletal elements (Hutson et al., 2020). Most refits occur within Zone A, some at the boundary with Zone B, but none of the them clearly connect both zones (SOM Fig. S6). On the other hand, the homogeneity between the archaeological assemblages from Zones A and B suggests a close temporal relationship between them (e.g., consistent butchery patterns, few stone tools, extensive use of bone tools). Seasonality data indicate~~s~~ use of the site throughout the

year, with potentially increased activity over the summer months. The clustering of the faunal assemblage and the thinness of the find layer imply the site deposited within a narrow time frame; the excellent preservation, the appearance of many bone elements in anatomical articulation, and the low incidence of carnivores and their gnawing, indicate a quick burial of the assemblage.

Based on these results, it is feasible to propose a theoretical model of occupation for the 'Spear Horizon', with two hypothetical alternating scenarios. Phases of high-water level would correspond to short, intense summer-autumn occupations taking place in Zone A, involving repeated hunting and butchering events, essentially restricted to horse killings. Occupations during phases of low water would have happened in Zone B, when the lowered water table level would have shifted the shoreline to a lower area of the lake basin. In this scenario, hominin occupations would have been more sporadic yet still targeted at hunting horses around the lake. Red deer would have been targeted more intensively during the low water scenario, but always as secondary to horse hunting. In both scenarios, large bovids would have been supplemental prey. Although it is difficult to estimate the duration of accumulation, occupations at the 'Spear Horizon' lasted from a minimum of one year to probably some decades at maximum, since the observed patterns in Zones A and B would hardly be preserved over very longer periods of time.

These scenarios put previous interpretations of the site into perspective, providing a reconstruction of human occupations on a finer spatiotemporal resolution. We demonstrate that even if the main accumulation (Zone A) constitutes the primary activity area, human occupations shifted (possibly seasonally) between this area and downslope toward the lake basin (Zone B) during low water table levels. Combining both scenarios suggests that hominins potentially occupied the Schöningen landscape year-round, repeatedly visiting the lakeshore at different seasons during the year.

Tracking human activity on a finer scale throughout the vast expanse of the 'Spear Horizon' requires identifying specific activity areas where individual prey carcasses were exploited. This is especially relevant when considering the possibility that remains from repeated hunting episodes could have deposited on top of previous events. In this sense, the presence of thirteen almost complete horse skulls could be used as spatial references for structuring space, much like habitation structures or hearths are used as reference loci at other sites. In this case, each horse skull would indicate the location of an activity area, where a horse carcass would have been butchered. All thirteen skulls documented were recovered in Zone A, seven within the densest northern clusters (Fig. 8). Ongoing detailed spatial analyses on the distribution of faunal remains around these skulls will allow identifying specific activity areas at Schöningen 13II-4.

Despite the lack of hearths or other evident structures, the spatial patterning of the zooarchaeological assemblage reveals the use of different activity areas, based on the fluctuation of the shoreline and its associated littoral zone. The 'Spear Horizon' reflects how Middle Pleistocene human hunters adapted to this dynamic, interglacial landscape, taking advantage of the most profitable conditions for ambush hunting, as top predators do. Our results indicate that humans visited the Schöningen paleo-lake repeatedly, most likely on a seasonal basis, suggesting a year-round occupation of the surrounding landscape. Owing to its excellent preservation, the hominin occupations at Schöningen 13II-4 can be used as a model for the human use of open-air, interglacial lakeshore environments during the Middle Pleistocene.

Acknowledgements

The MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution is part of the Römisch-Germanisches Zentralmuseum Mainz, a

member of the Leibniz-Gemeinschaft. This research is part of the 'Hominin subsistence strategies during the Middle Pleistocene in Schöningen' project, funded by the Deutsche Forschungsgemeinschaft (GA 683/9-1). The spatial data used in this work ~~was~~ were provided by the Niedersächsisches Landesamt für Denkmalpflege. We would like to thank Thomas Terberger and Stefan Winghart of the Niedersächsisches Landesamt für Denkmalpflege, and especially Utz Böhner, for their support. We are grateful to the editors and reviewers for their suggestions and stimulating comments, which notably improved the original manuscript.

References

Barceló, J.A., 2002. Archaeological thinking: Between space and time. Archaeol. e. Calcolatori. 13, 237–257.

Barceló, J.A., Maximiano, A., 2008. Some notes regarding Distributional Analysis of Spatial Data. In: Posluschny, A., Lambers, K., Herzog, I. (Eds.), Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin, 2.-6. April 2007. Dr. Rudolf Habelt GmbH, Bonn, pp. 1–6.

Barceló, J.A., Maximiano, A., 2013. The mathematics of domestic spaces. In: Kovacs, G., Madella, M., Briz, I., Berzesenyi, B. (Eds.), The Archaeology of Household. Oxbow Books, Oxford, pp. 6–22.

Baxter, M.J., Beardah, C.C., Wright, R.V.S., 1997. Some archaeological applications of Kernel Density Estimates. J. Archaeol. Sci. 24, 347–354.

Bevan, A., Crema, E., Li, X., Palmisano, A., 2013. Intensities, interactions and uncertainties: some new approaches to archaeological distributions. In: Bevan, A., Lake, M. (Eds.),

547 Computational Approaches to Archaeological Spaces. Left Coast Press, Walnut Creek, pp.
548 27–52.

549 Bigga, G., 2018. Die Pflanzen von Schöningen. Botanische Makroreste aus den
550 mittelpleistozänen Ablagerungen und das Nutzungspotential einer interglazialen
551 Paläoflora. Verlag des Römisch-Germanischen Zentralmuseums, Mainz.

552 Blankholm, H.P., 1990. Intrasite Spatial Analysis in Theory and Practice. Aarhus University
553 Press, Aarhus.

554 Böhner, U., Serangeli, J., Richter, P., 2015. The Spear Horizon: First spatial analysis of the
555 Schöningen site 13 II-4. J. Hum. Evol. 89, 202–213.

556 Carr, C., 1984. The nature and organization of intrasite archaeological records and spatial
557 analytic approaches to their investigations. Adv. Archaeol. Method Theory. 7, 103–222.

558 Clark, A.E., 2016. Time and space in the middle Paleolithic: Spatial structure and occupation
559 dynamics of seven open-air sites. Evol. Anthropol. 25, 153–163.

560 Cobo-Sánchez, L., Aramendi, J., Domínguez-Rodrigo, M., 2014. Orientation patterns of
561 wildebeest bones on the lake Masek floodplain (Serengeti, Tanzania) and their relevance
562 to interpret anisotropy in the Olduvai lacustrine floodplain. Quat. Int. 322–323, 277–284.

563 Conard, N.J., 2007. Cultural evolution in Africa and Eurasia during the Middle and Late
564 Pleistocene. In: Henke, W., Tattersall, I. (Eds.), Handbook of Paleoanthropology. Springer,
565 Berlin, pp. 2001–2037.

566 Conard, N.J., Serangeli, J., Böhner, U., Starkovich, B.M., Miller, C.E., Urban, B., van Kolfschoten,
567 T., 2015. Excavations at Schöningen and paradigm shifts in human evolution. J. Hum.
568 Evol. 89, 1–17.

569 Domínguez-Rodrigo, M., Uribelarrea, D., Santonja, M., Bunn, H.T., García-Pérez, A., Pérez-

González, A., Panera, J., Rubio-Jara, S., Mabulla, A., Baquedano, E., Yravedra, J., Diez-Martín, F., 2014. Autochthonous anisotropy of archaeological materials by the action of water: Experimental and archaeological reassessment of the orientation patterns at the Olduvai sites. J. Archaeol. Sci. 41, 44–68.

Domínguez-Rodrigo, M., Cobo-Sánchez, L., 2017. The spatial patterning of the social organization of modern foraging *Homo sapiens*: A methodological approach for understanding social organization in prehistoric foragers. Palaeogeogr. Palaeoclimatol. Palaeoecol. 488, 113–125.

Domínguez-Rodrigo, M., Cobo-Sánchez, L., Yravedra, J., Uribelarrea, D., Arriaza, C., Organista, E., Baquedano, E., 2018. Fluvial spatial taphonomy: A new method for the study of post-depositional processes. Archaeol. Anthropol. Sci. 10, 1769–1789.

ESRI, 2017. ArcGIS Desktop 10.6. Environmental Systems Research Institute, Redlands.

Farizy, C., 1994. Spatial Patterning of Middle Paleolithic Sites. J. Anthropol. Archaeol. 13, 153–160.

García-Moreno, A., Smith, G.M., Kindler, L., Pop, E., Roebroeks, W., Gaudzinski-Windheuser, S., Klinkenberg, V., 2016. Evaluating the incidence of hydrological processes during site formation through orientation analysis. A case study of the middle Palaeolithic Lakeland site of Neumark-Nord 2 (Germany). J. Archaeol. Sci. Rep. 6, 82–93.

García-Moreno, A., Hutson, J.M., Smith, G.M., Kindler, L., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S., 2020. Human behavioural adaptions to interglacial lakeshore environments: An introduction. 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. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 1–4.

Gaudzinski-Windheuser, S., Brasser, M., García-Moreno, A., Hutson, J.M., Kindler, L., Smith, G.M., Villaluenga, A., Turner, E., 2015. Forschungsthema: Menschliche Verhaltensstrategien in warmzeitlichen Umwelten. In: RGZM Jahresbericht 2013. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 15–21.

Gaudzinski-Windheuser, S., García-Moreno, A., Huebinger, T., Hutson, J.M., Jöris, O., Kindler, L., Noack, E., Schunk, L., Smith, G.M., Turner, E., Villaluenga, A., Weber, K., 2016. Menschliche Verhaltensstrategien in warmzeitlichen Umwelten. In: RGZM Jahresbericht 2015. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 22–25.

Gaudzinski-Windheuser, S., Roebroeks, W., 2000. Adults only. Reindeer hunting at the Middle Palaeolithic site Salzgitter Lebenstedt, northern Germany. J. Hum. Evol. 38, 497–521.

Haynes, G., 1982. Utilization and skeletal disturbances of North American prey carcasses. Arctic. 35, 266–281.

Henry, D., 2012. The palimpsest problem, hearth pattern analysis, and Middle Paleolithic site structure. Quat. Int. 247, 246–266.

Henry, D., Hietala, H.J., Rosen, A.M., Demidenko, Y.E., Usik, V.I., Armagan, T.L., 2004. Human behavioral organization in the Middle Paleolithic: Were Neanderthals different? Amer. Anthropol. 106, 17–31.

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., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), The Origins of Bone Tool Technologies. Verlag des Römisch-Germanischen Zentralmuseums, Mainz, pp. 53–91.

Hutson, J.M., Villaluenga, A., García-Moreno, A., Turner, E., Gaudzinski-Windheuser, S., 2020. A zooarchaeological and taphonomic perspective of hominin behaviour from the

618 Schöningen 13II-4 “Spear Horizon.” In: García-Moreno, A., Hutson, J.M., Smith, G.M.,
619 Kindler, L., Turner, E., Villaluenga, A., Gaudzinski-Windheuser, S. (Eds.), Human
620 Behavioural Adaptations to Interglacial Lakeshore Environments. Verlag des Römisch-
621 Germanischen Zentralmuseums, Mainz, pp. 43–66.

622 Jaubert, J., Delagnes, A., 2007. De l’espace parcouru à l’espace habité au Paléolithique moyen.
623 In: Vandermeersch, B., Maureille, B. (Eds.), Les Néandertaliens. Biologie et Cultures.
624 Editions du CTHS, Paris, pp. 263–281.

625 Jaubert, J., Verheyden, S., Genty, D., Soulier, M., Cheng, H., Blamart, D., Burlet, C., Camus, H.,
626 Delaby, S., Deldicque, D., Edwards, R.L., Ferrier, C., Lacranmpe-Cuyaubère, F., Lévêque, F.,
627 Maksud, F., Mora, P., Muth, X., Régnier, É., Rouzaud, J.-N., Santos, F., 2016. Early
628 Neanderthal constructions deep in Bruniquel Cave in southwestern France. Nature. 534,
629 111–114.

630 Julien, M.-A., Rivals, F., Serangeli, J., Bocherens, H., Conard, N.J., 2015. A new approach for
631 deciphering between single and multiple accumulation events using intra-tooth isotopic
632 variations: Application to the Middle Pleistocene bone bed of Schöningen 13 II-4. J. Hum.
633 Evol. 89, 114–128.

634 Kintigh, K.W., 1990. Intrasite spatial analysis: A commentary on major methods. In: Voorrips, A.
635 (ed.), Mathematics and Information Science in Archaeology: A Flexible Framework. Holos,
636 Bonn, pp. 165–200.

637 Kolen, J., 1999. Hominids without homes: on the nature of Middle Palaeolithic settlement in
638 Europe. In: Roebroeks, W., Gamble, C. (Eds.), The Middle Palaeolithic Occupation of
639 Europe. University of Leiden, Leiden, pp. 139–175.

640 Kuhn, S.L., Stiner, M.C., 2019. Hearth and home in the Middle Pleistocene. J. Anthropol. Res.
641 75, 305–327.

642 Kuitems, M., van Der Plicht, J., Drucker, D., van Kolfschoten, T., Palstra, S.W.L., Bocherens, H.,
643 2015. Carbon and nitrogen stable isotopes of well-preserved Middle Pleistocene bone
644 collagen from Schoningen (Germany) and their palaeoecological implications. J. Hum.
645 Evol. 89, 105–113.

646 Lang, J., Böhner, U., Polom, U., Serangeli, J., Winsemann, J., 2015. The Middle Pleistocene
647 tunnel valley at Schöningen as a Paleolithic archive. J. Hum. Evol. 89, 18–26.

648 Lang, J., Winsemann, J., Steinmetz, D., Polom, U., Pollok, L., Böhner, U., Serangeli, J., Brandes,
649 C., Hampel, A., Winghart, S., 2012. The Pleistocene of Schöningen, Germany: A complex
650 tunnel valley fill revealed from 3D subsurface modelling and shear wave seismics. Quat.
651 Sci. Rev. 39, 86–105.

652 Lloyd, C.D., Atkinson, P.M., 2004. Archaeology and geostatistics. J. Archaeol. Sci. 31, 151–165.

653 Maximiano, A., 2007. Teoría geoestadística aplicada al análisis de la variabilidad espacial
654 arqueológica intrasite. Ph.D. Dissertation, Universidad Autónoma de Barcelona.

655 McPherron, S.P., 2005. Artifact orientations and site formation processes from total station
656 proveniences. J. Archaeol. Sci. 32, 1003–1014.

657 Orton, C., 2004. Point pattern analysis revisited. Archaeol. e Calcolatori. 15, 299–315.

658 Otte, M., 2012. The management of space during the Paleolithic. Quat. Int. 247, 212–229.

659 Peters, C., van Kolfschoten, T., 2020. The site formation history of Schöningen 13II-4
660 (Germany): Testing different models of site formation by means of spatial analysis, spatial
661 statistics and orientation analysis. J. Archaeol. Sci. 114, 105067.

662 Richter, D., Krbetschek, M., 2015. The age of the Lower Palaeolithic occupation at Schöningen.
663 J. Hum. Evol. 89, 46–56.

664 Rivals, F., Julien, M.-A., Kuitems, M., van Kolfschoten, T., Serangeli, J., Drucker, D., Bocherens,

665 H., Conard, N.J., 2015. Investigation of equid paleodiet from Schöningen 13II-4 through
666 dental wear and isotopic analyses: Archaeological implications. J. Hum. Evol. 89, 129–137.

667 Sánchez Romero, L., 2019. Desarrollo y aplicación metodológica para el análisis espacial de
668 yacimientos paleolíticos al aire libre y en cueva. Ph.D. Dissertation, University of Burgos.

669 Schoch, W.H., Bigga, G., Böhner, U., Richter, P., Terberger, T., 2015. New insights on the
670 wooden weapons from the Paleolithic site of Schöningen. J. Hum. Evol. 89, 214–225.

671 Serangeli, J., Böhner, U., 2012. Die Artefakte von Schöningen und deren zeitliche Einordnung.
672 In: Behre, K.-E. (Ed.), The Chronological Setting of the Palaeolithic Sites of Schöningen.
673 Römisch-Germanisches Zentralmuseum, Mainz, pp. 23–38.

674 Serangeli, J., Böhner, U., van Kolfschoten, T., Conard, N.J., 2015. Overview and new results
675 from large-scale excavations in Schöningen. J. Hum. Evol. 89, 27–45.

676 Serangeli, J., Conard, N.J., 2015. The behavioral and cultural stratigraphic contexts of the lithic
677 assemblages from Schöningen. J. Hum. Evol. 89, 287–297.

678 Shahack, R., Berna, F., Karkanas, P., Lemorini, C., Gopher, A., Barkai, R., 2014. Evidence for the
679 repeated use of a central hearth at Middle Pleistocene (300 ky ago) Qesem Cave, Israel. J.
680 Archaeol. Sci. 44, 12–21.

681 Stahlschmidt, M.C., Miller, C.E., Ligouis, B., Goldberg, P., Berna, F., Urban, B., Conard, N.J.,
682 2015a. The depositional environments of Schöningen 13 II-4 and their archaeological
683 implications. J. Hum. Evol. 89, 71–91.

684 Stahlschmidt, M.C., Miller, C.E., Ligouis, B., Hambach, U., Goldberg, P., Berna, F., Richter, D.,
685 Urban, B., Serangeli, J., Conard, N.J., 2015b. On the evidence for human use and control
686 of fire at Schöningen. J. Hum. Evol. 89, 181–201.

687 Stapert, D., 1990. Middle Palaeolithic dwellings: Fact or fiction? Some applications of the ring

688 and sector method. Palaeohistoria. 32, 1–19.

689 Thieme, H., 1997. Lower Palaeolithic hunting spears from Germany. Nature. 385, 807-810.

690 Thieme, H., 2005. The Lower Palaeolithic art of hunting: the case of Schöningen 13II-4, Lower
691 Saxony, Germany. In: Gamble, C., Porr, M. (Eds.), The Hominid Individual in Context.
692 Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and
693 Artefacts. Routledge, London/New York, pp. 115–132.

694 Thieme, H., 2007. Die Schöninger Speere. Mensch und Jagd vor 400000 Jahren. Konrad Theiss
695 Verlag, Sttutgart.

696 Turner, E., Hutson, J.M., Villaluenga, A., García-Moreno, A., Gaudzinski-Windheuser, S., 2018.
697 Bone staining in waterlogged deposits: a preliminary contribution to the interpretation of
698 near-shore find accumulation at the Schöningen 13II-4 'Spear-Horizon' site, Lower
699 Saxony, Germany. Hist. Biol. 30, 767–773.

700 Urban, B., Bigga, G., 2015. Environmental reconstruction and biostratigraphy of the late Middle
701 Pleistocene lakeshore deposits at Schöningen. J. Hum. Evol. 89, 57–70.

702 van Kolfschoten, T., 2014. The Palaeolithic locality Schöningen (Germany): A review of the
703 mammalian record. Quat. Int. 469–480.

704 van Kolfschoten, T., Buhrs, E., Verheijen, I., 2015a. The larger mammal fauna from the Lower
705 Paleolithic Schöningen Spear site and its contribution to hominin subsistence. J. Hum.
706 Evol. 89, 138–153.

707 van Kolfschoten, T., Parfitt, S.A., Serangeli, J., Bello, S.M., 2015b. Lower Paleolithic bone tools
708 from the 'Spear Horizon' at Schöningen (Germany). J. Hum. Evol. 89, 226–263.

709 Vaquero, M., Pastó, I., 2001. The definition of spatial units in Middle Palaeolithic sites: The
710 hearth-related assemblages. J. Archaeol. Sci. 28, 1209–1220.

711 Vaquero, M., Rando, J.M., Chacón, M.G., 2004. Neanderthal spatial behaviour and social
712 structure: hearth-related assemblages from the Abric Romaní Middle Palaeolithic site. In:
713 Conard, N.J. (Ed.), Settlement Dynamics of the Middle Paleolithic and Middle Stone Age II.
714 Kerns Verlag, Tubingen, pp. 367–392.

715 Villa, P., Roebroeks, W., 2014. Neandertal demise: An archaeological analysis of the modern
716 human superiority complex. PLoS One 9 (4), e96424.

717 Voormolen, B., 2008. Ancient hunters, modern butchers: Schöningen 13II - 4, a kill-butchery
718 site dating from the northwest European Lower Palaeolithic. Ph.D. Dissertation, Leiden
719 University.

720 Welker, F., Smith, G.M., Hutson, J.M., Kindler, L., García-Moreno, A., Villaluenga, A., Turner, E.,
721 Gaudzinski-Windheuser, S., 2017. Middle Pleistocene protein sequences from the
722 rhinoceros genus *Stephanorhinus* and the phylogeny of extant and extinct Middle/Late
723 Pleistocene Rhinocerotidae. Peer J DOI 10.7717/peerj.3033.

724 Yar, B., Dubois, P., 1996. Les structures d'habitat au Paléolithique inférieur et moyen en
725 France: entre réalité et imaginaire. Bull. de la Soc. Préhist. Française. 93, 149–163.

726

727 **Figure Legends**

728

729 **Figure 1**. Location of the town of Schöningen in Germany and view of the excavated surface
730 corresponding to the 'Spear Horizon'.

731

732 **Figure 2**. Map of the excavated surface at Schöningen 13II-4 showing the overall distribution of
733 the archaeological assemblage. Each square corresponds to a 10 m x10 m area. Background

734 represents the paleo-surface of the ‘Spear Horizon’ based on the contact between layers 4b/c
735 and 4c (see Böhner et al. 2015).

736

737 **Figure 3**. Division of faunal remains from Schöningen 13II-4 ‘Spear Horizon’ into three zones
738 based on the density of finds, paleotopography, and point pattern distribution.

739

740 **Figure 4**. Spatial distribution of the three main taxa at Schöningen 13II-4: horse (left),
741 *Bison*/*Bos* (middle) and red deer (right). Figures represent individual finds (upper) and number
742 of finds per 1 m x 1m square (lower). The background represents Kernel density of the entire
743 bone assemblage.

744

745 **Figure 5**. Spatial distribution of minor taxa at Schöningen 13II-4 (see SOM Table S1 for detailed
746 faunal list). The background represents Kernel density of the entire bone assemblage.

747

748 **Figure 6**. Distribution patterns of the Schöningen 13II-4 faunal assemblage for horse (left),
749 *Bison*/*Bos* (middle) and red deer (right), based on Kernel density (upper) and K-Means (lower).

750

751 **Figure 7**. Distribution of bone surface modifications and artefacts at the Schöningen 13II-4
752 ‘Spear Horizon’: (top left) cut marks and scraping marks (*n* = 1396); (top right) impact and
753 percussion marks (*n* = 1026); (bottom left) lithic tools and debris (*n* = 1500); (bottom right)
754 bone tools, including retouchers (*n* = 169) and bone hammers (*n* = 47).

755

Figure 8. Distribution of horse crania along Zone A. The background represents the Kernel density of faunal remains.

Figure 9. Distribution of seasonality data within the 'Spear Horizon', based on horse age-at-death estimates (see SOM Table S2 for details on seasonality data).

Figure 1

Click here to access/download;Figure;Fig. 1.tif

Figure 2

Click here to access/download;Figure;Fig. 2.tif

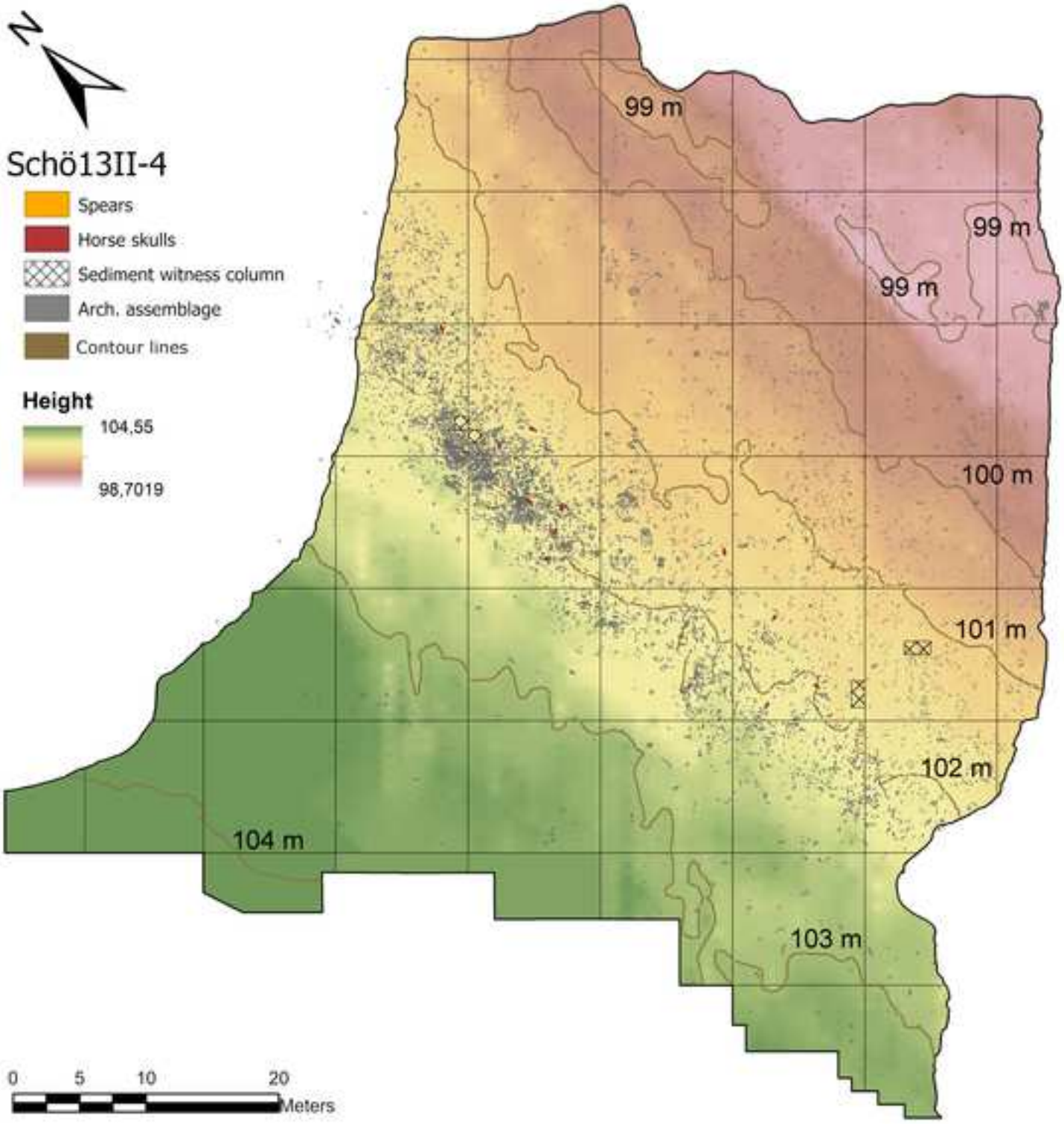


Figure 3

Click here to access/download;Figure;Fig. 3.tif

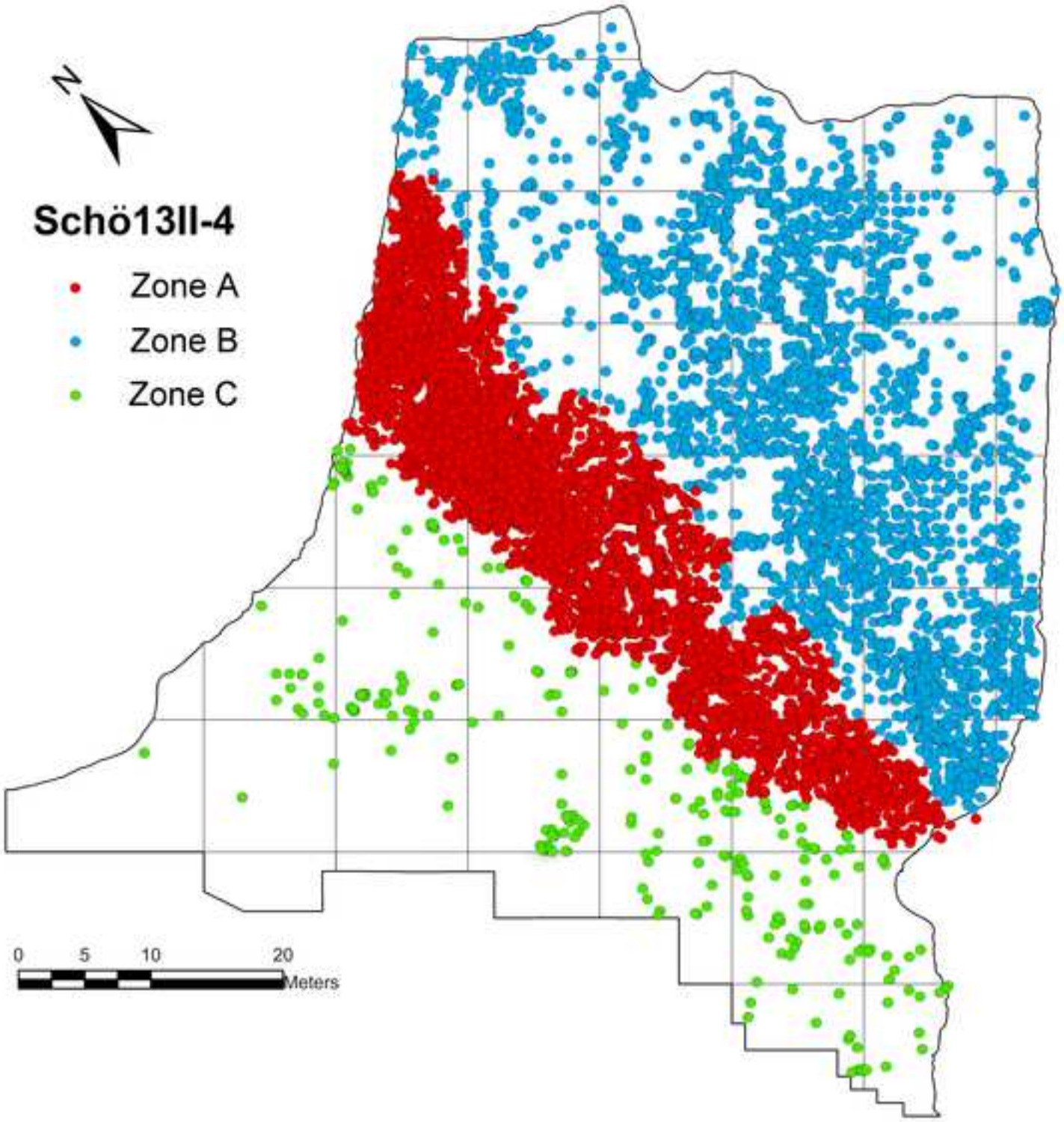


Figure 4

Click here to access/download;Figure;Fig. 4.tif

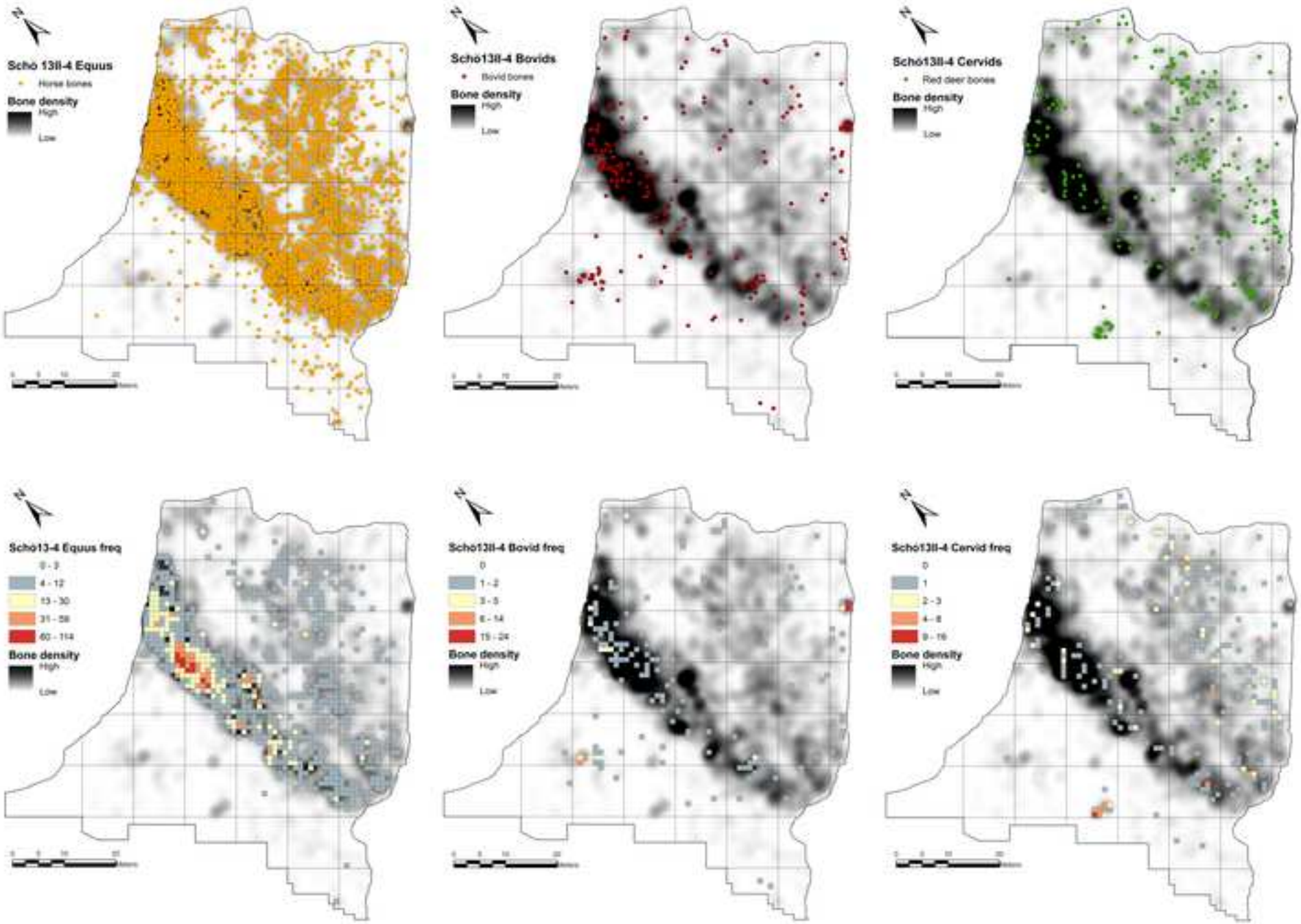


Figure 5

Click here to access/download;Figure;Fig. 5.tif

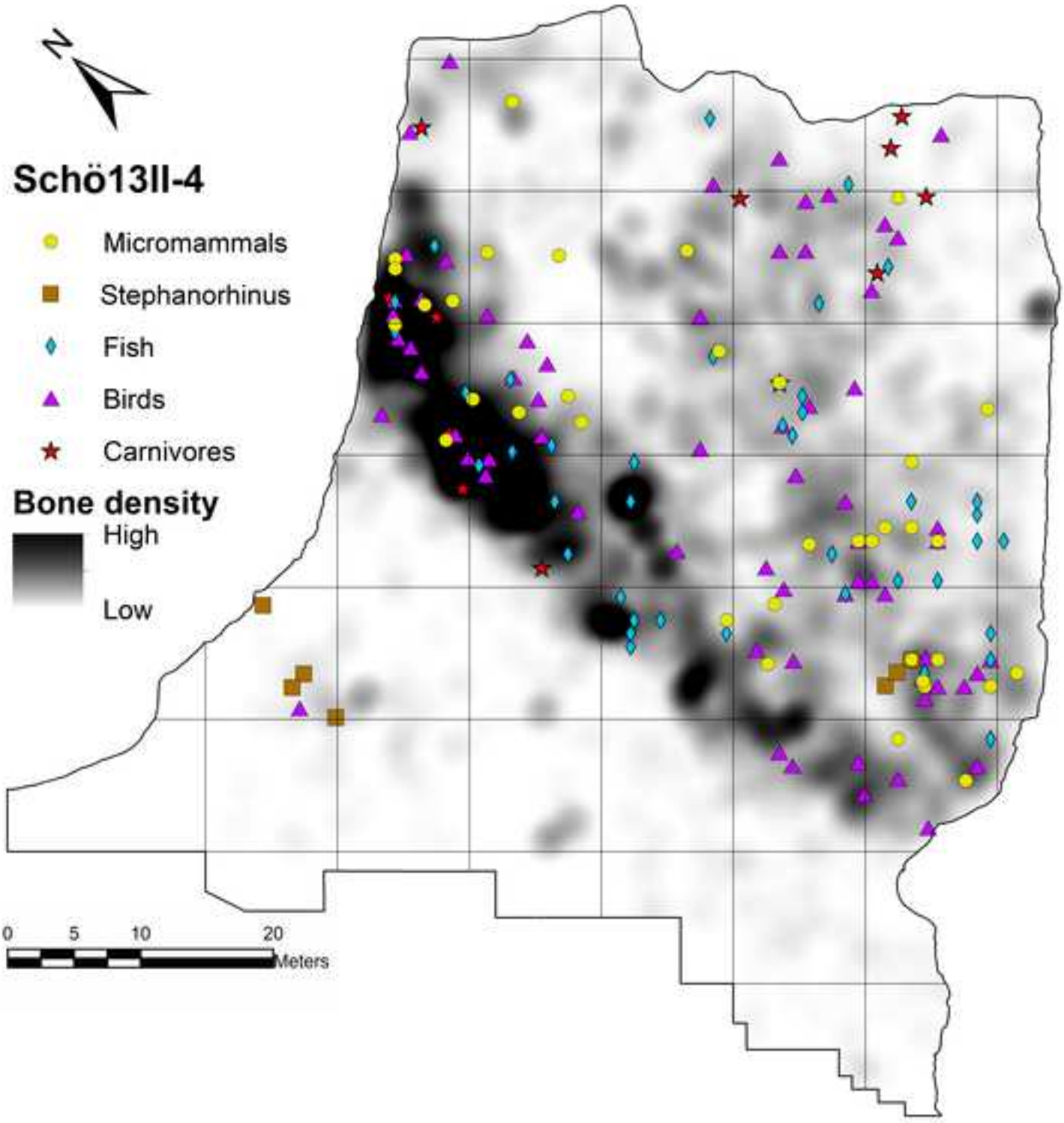


Figure 6

Click here to access/download;Figure;Fig. 6.tif

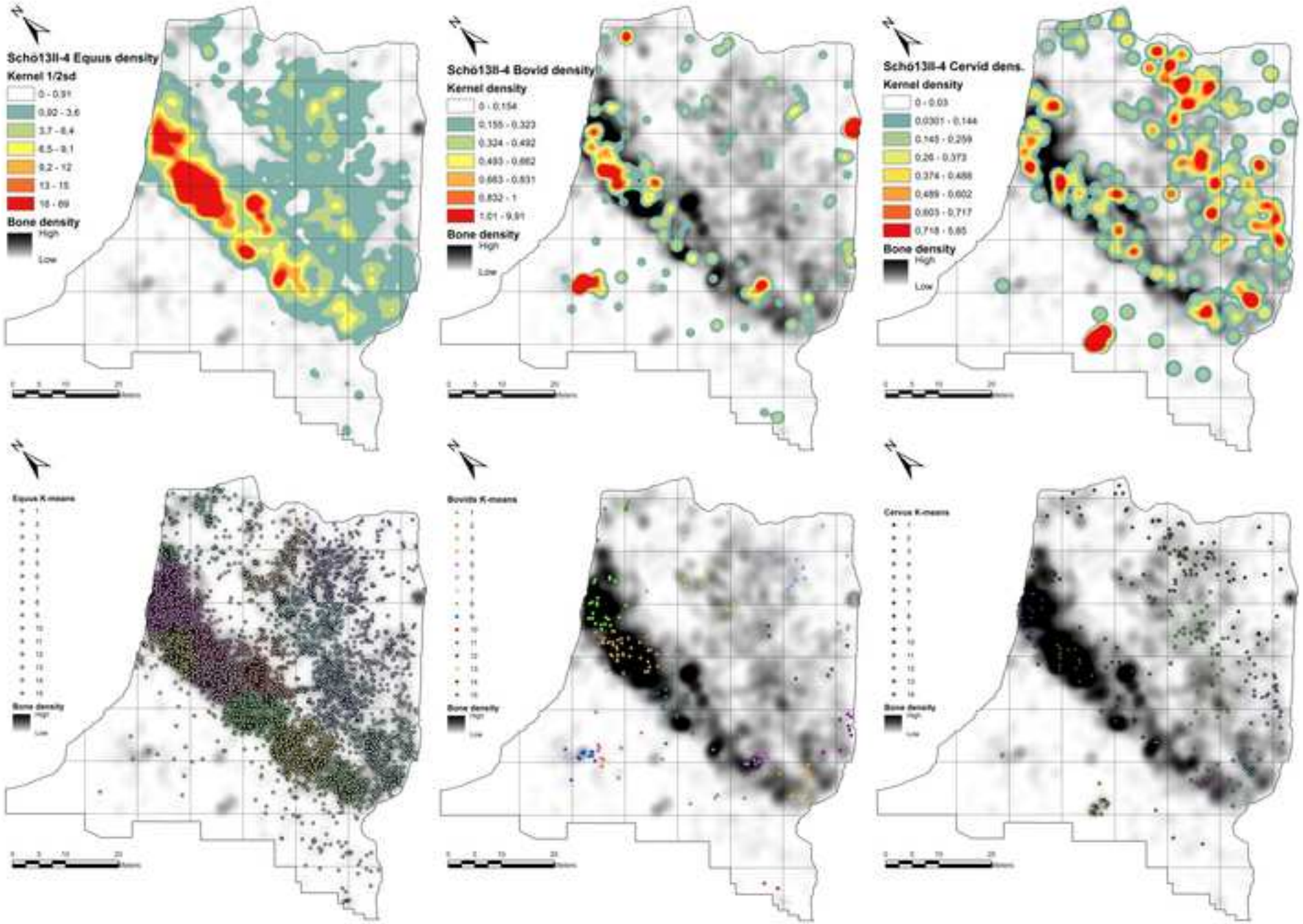


Figure 7

Click here to access/download;Figure;Fig. 7.tif

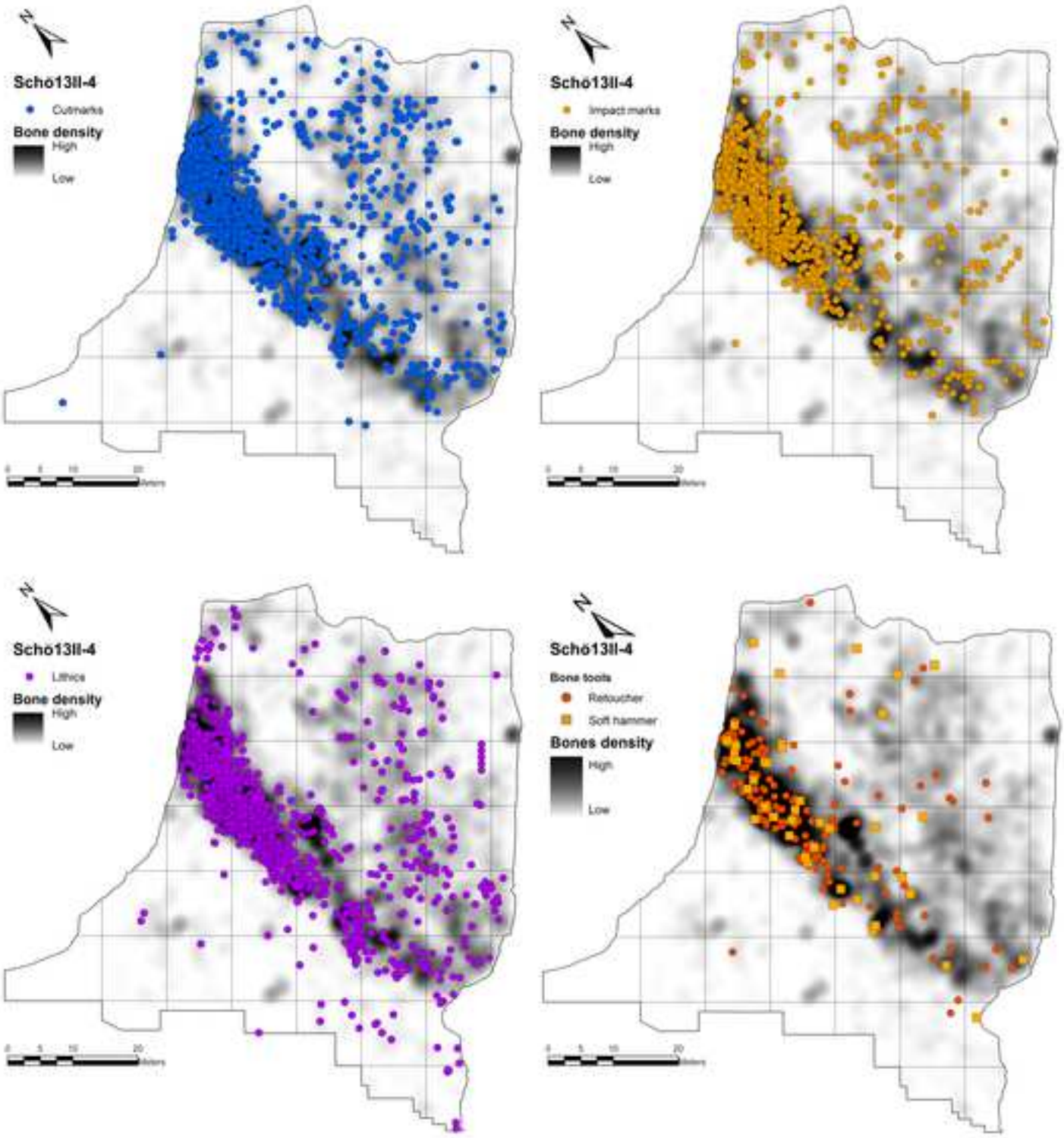


Figure 8

Click here to access/download;Figure;Fig. 8.tif

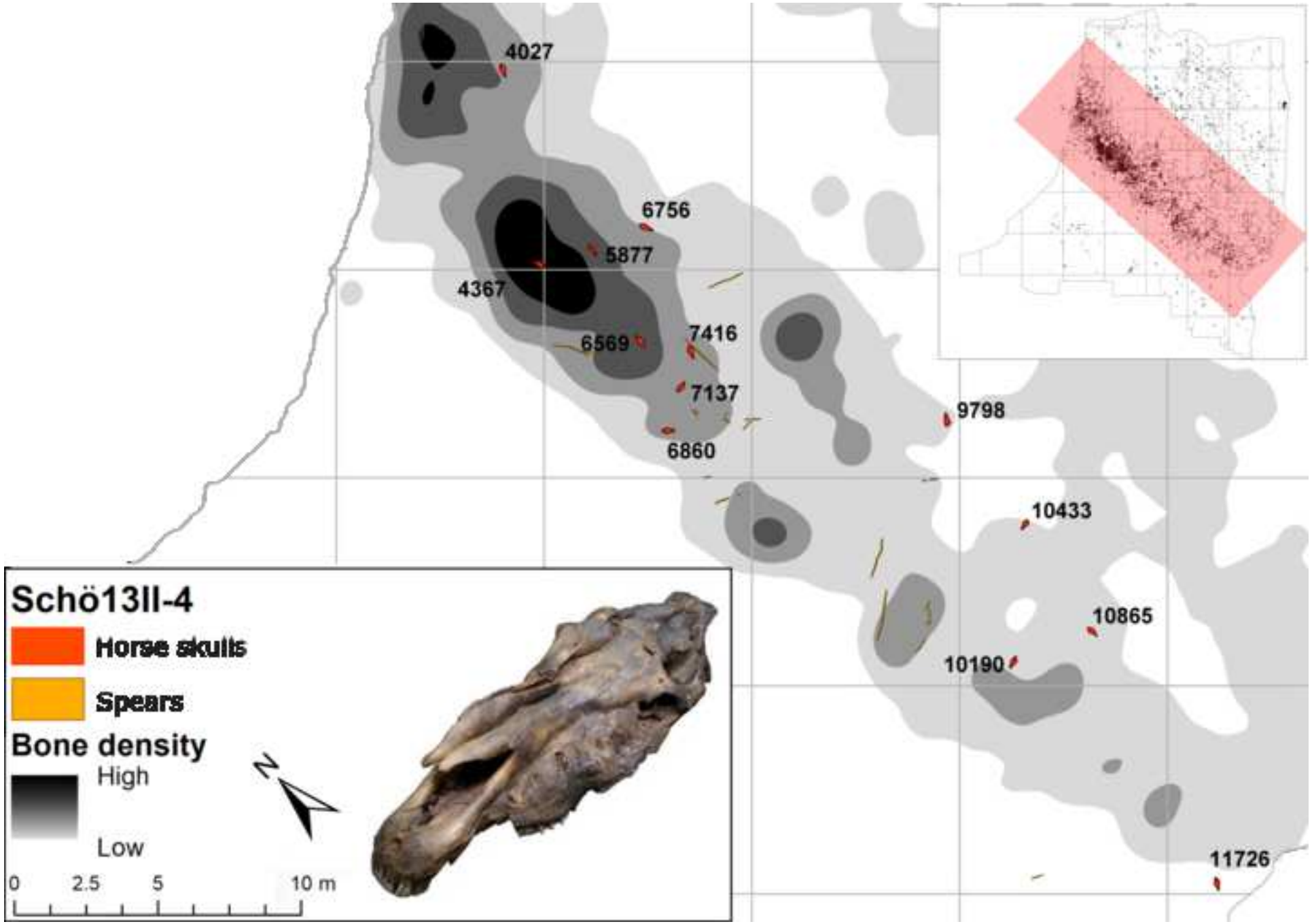
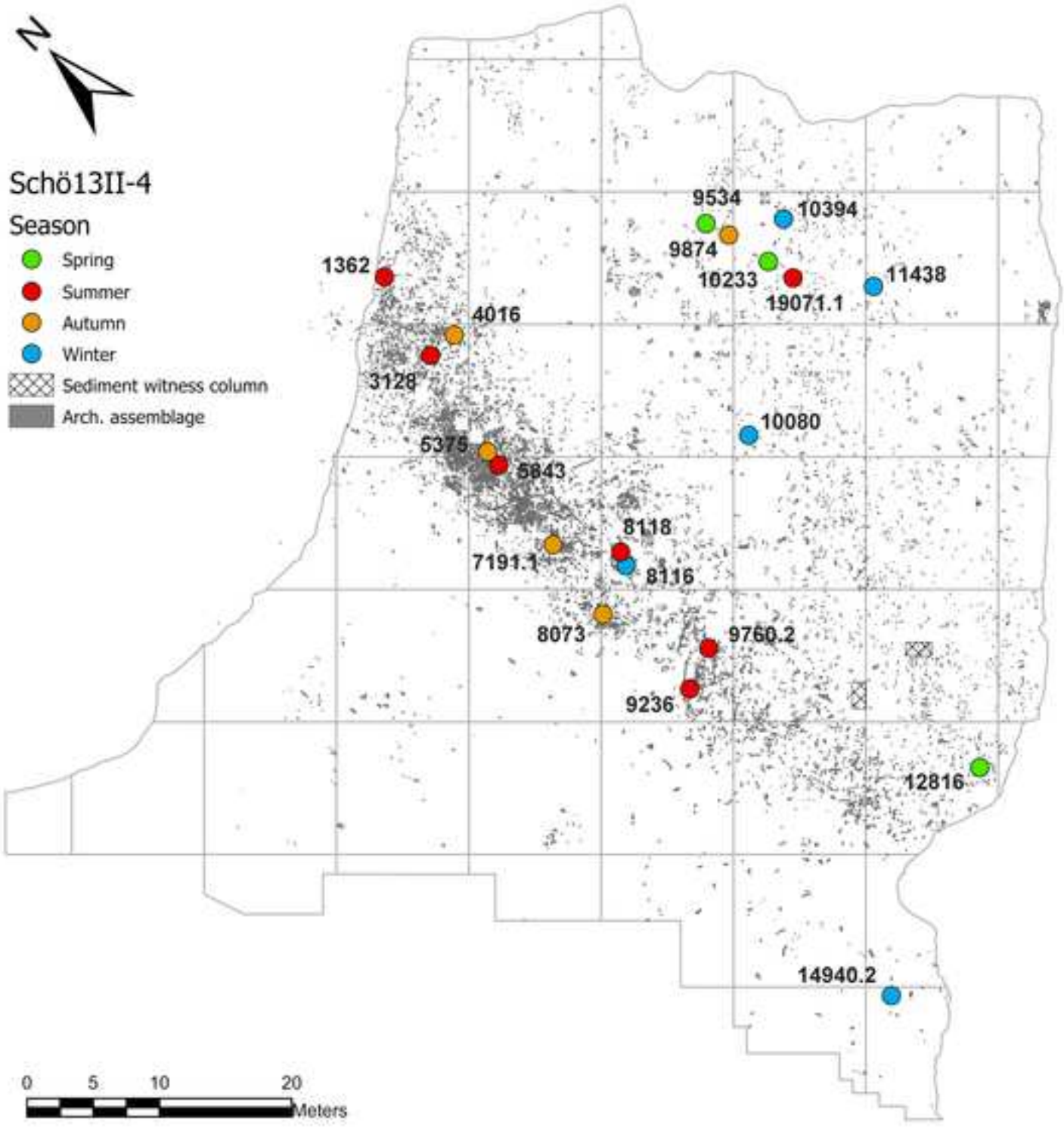


Figure 9

Click here to access/download;Figure;Fig. 9.tif



Supplementary Online Material (SOM):

A detailed analysis of the spatial distribution of Schoningen 13II-4 'Spear Horizon' faunal remains

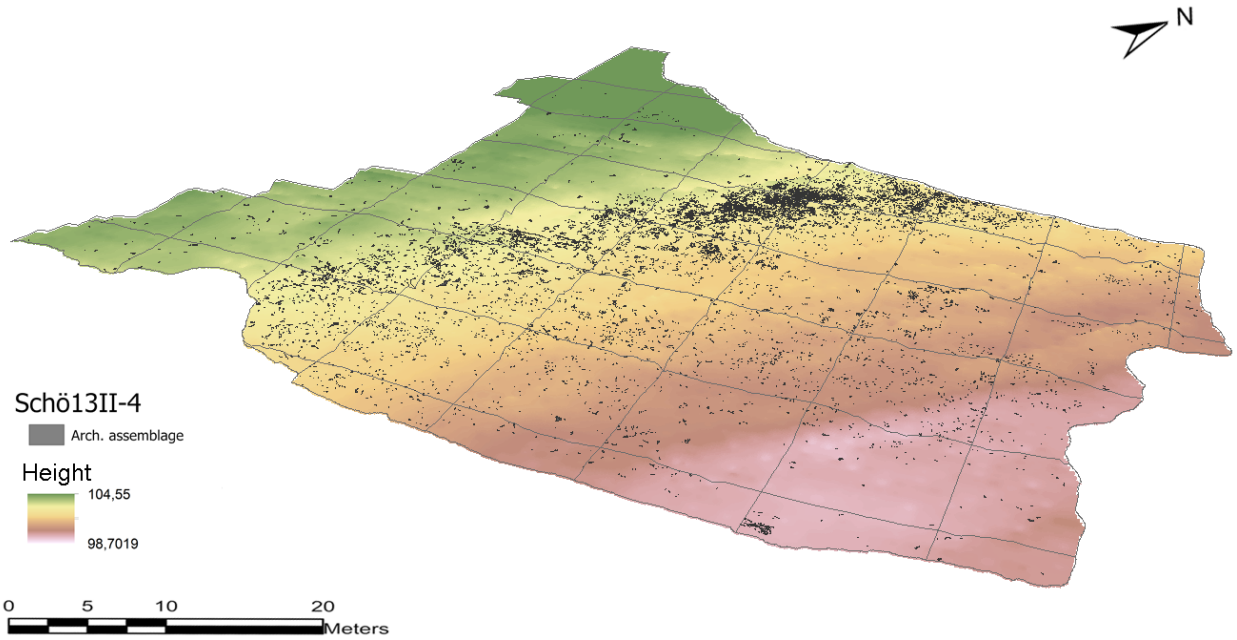
García-Moreno, Alejandro[1], Hutson, Jarod M.[1,2], Villaluenga, Aritza[1,3], Turner, Elaine[1], and Gaudzinski-Windheuser, Sabine[1,4]

[1] MONREPOS Archaeological Research Centre and Museum for Human Behavioural Evolution, Römisch-Germanisches Zentralmuseum, Neuwied, Germany

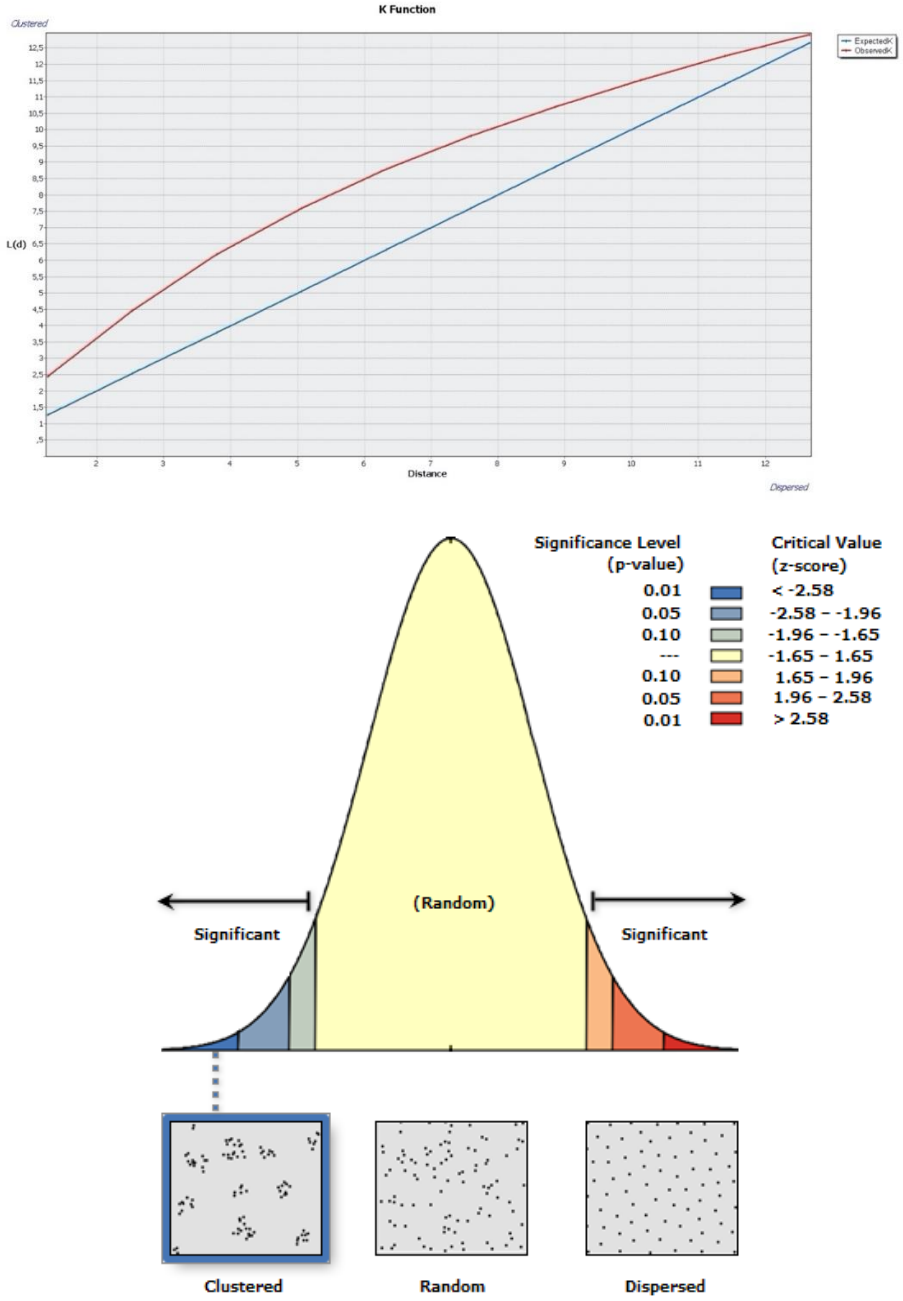
[2] Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, Washington D.C., USA

[3] Consolidated Research Group on Prehistory (IT-1223-19), University of the Basque Country, Vitoria-Gasteiz, Spain

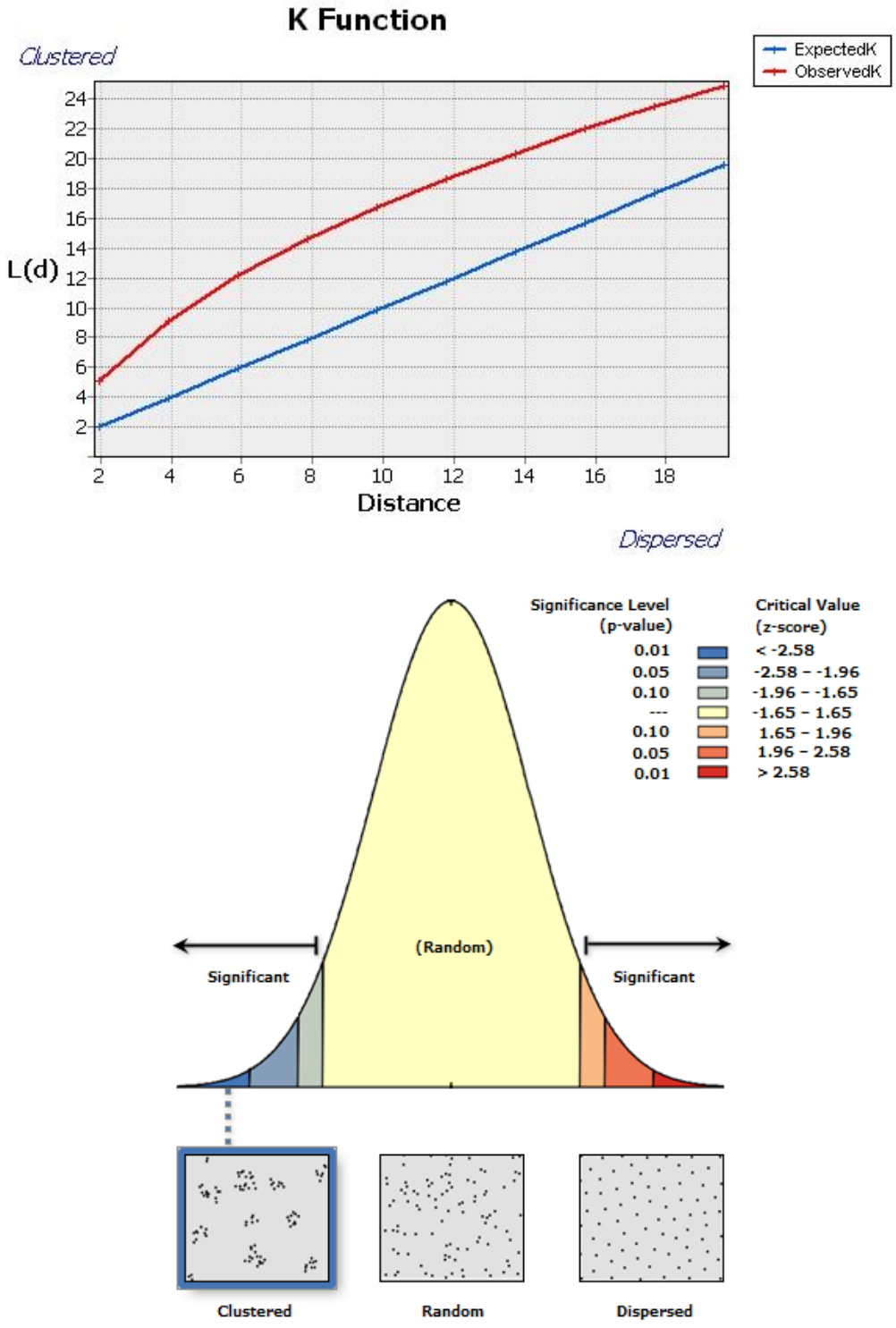
[4] Institute of Ancient Studies, Johannes Gutenberg University, Mainz, Germany



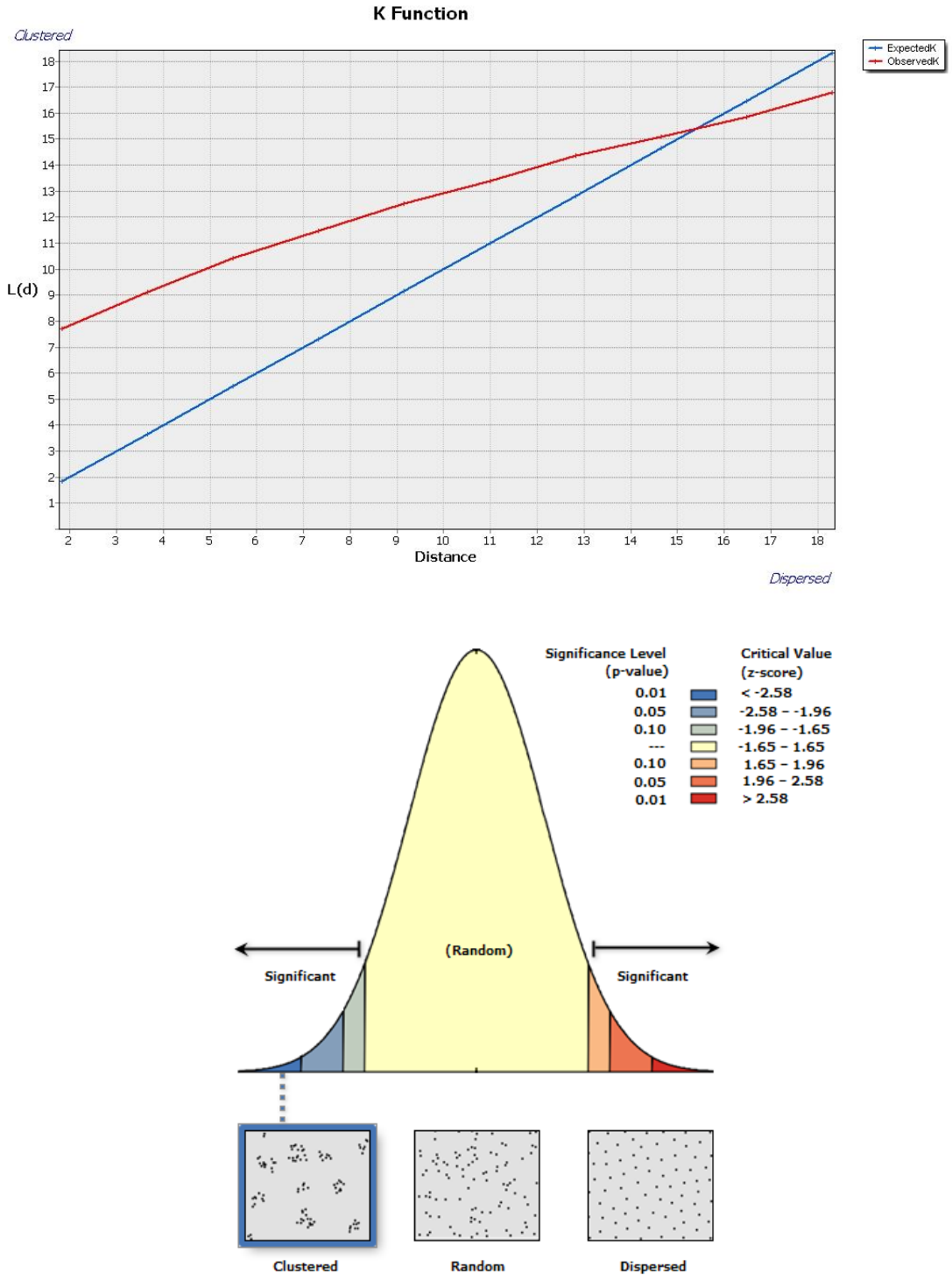
SOM Fig. S1. Isometric view showing the distribution of finds from Schöningen 13II-4 compared to the paleo-topography of the 'Spear Horizon'. Paleotopography was interpolated using Inverse Distance Method, based on heights recorded during fieldworks indicating the contact between layers 4b/c and 4c. Notice that the edge of the main accumulation band (Zone A in this paper) is indicated by a step in the slope of the basin, especially in its northern part, whereas it is more continuous in its southern part. This step likely reflects the limit of the low water scenario and separates the two main activity areas.



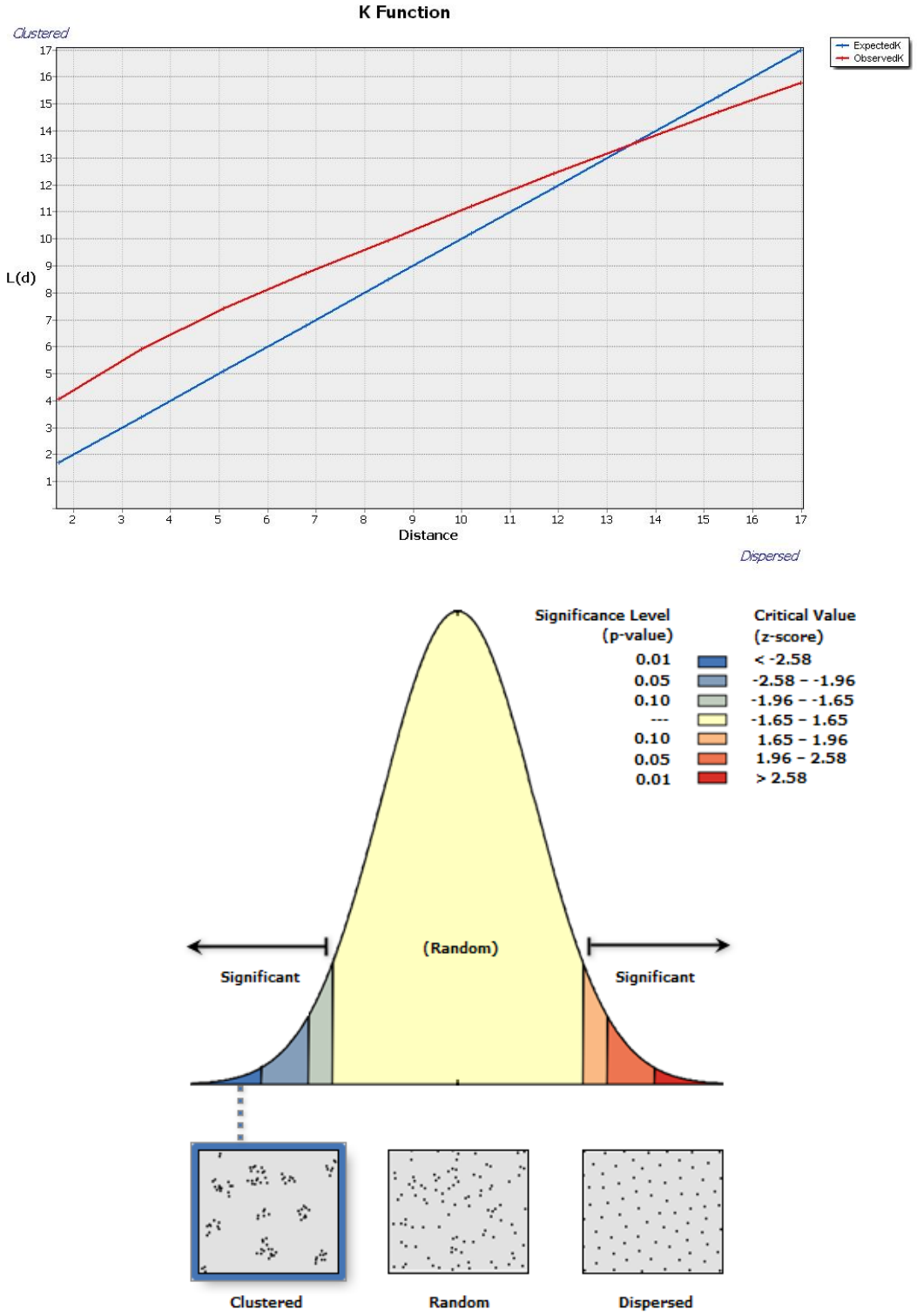
SOM Figure S2. Ripley's K function (upper panel) and Average Nearest Neighbor (ANN, lower panel) results for faunal remains from Zone A. In Ripley's K, the blue line represents the expected function for a random distribution, whereas the red line indicates the sample analyzed follows an aggregated pattern. ANN analysis shows that the faunal assemblage from 'Spear Horizon' follows a statistically significant aggregated pattern.



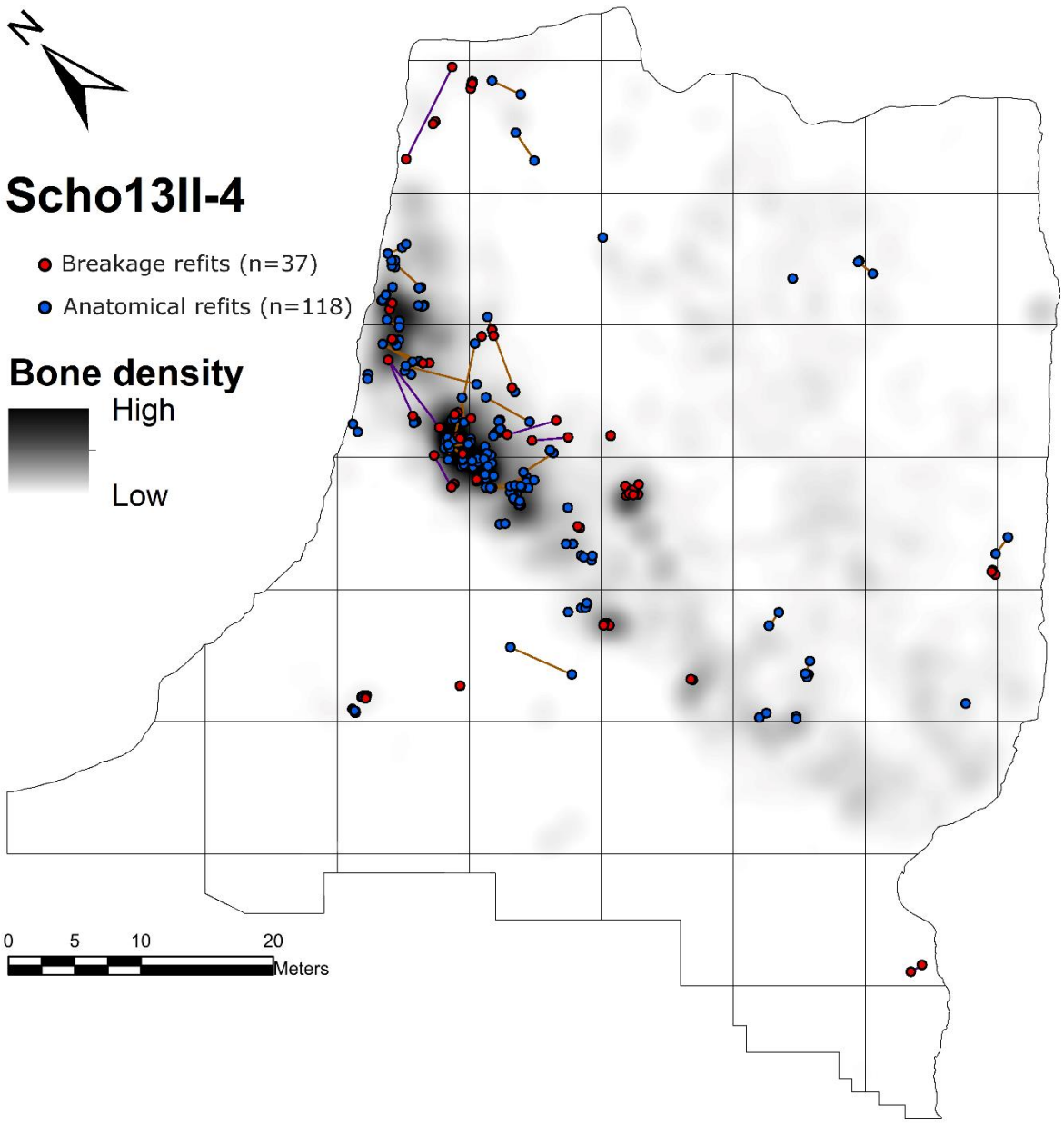
SOM Figure S3. Ripley's K function (upper) and Average Nearest Neighbor (lower) results for horse (*Equus mosbachensis*) remains from Schöningen 13II-4 'Spear Horizon'.



SOM Figure S4. Ripley's K function (upper) and Average Nearest Neighbor (lower) results for bovid remains (including *Bison priscus*, *Bos primigenius* and *Bos/Bison* indet.) from Schöningen 13II-4 'Spear Horizon'.



SOM Figure S5. Ripley's K function (upper) and Average Nearest Neighbor (lower) results for red deer (*Cervus elaphus*) remains from Schöningen 13II-4 'Spear Horizon'.



SOM Figure S6. Refitting analysis from Schöningen 13II-4 faunal assemblage. Breakage refits (*n* = 37) refers to conjoinable bone fragments belonging to the same bone element; anatomical refits (*n* = 118) refers to groups of two or more articulating skeletal elements.

SOM Table S1

Complete species list from Schöningen 13II-4, including number of identified specimens (NISP) and number of modified bones per taxon. Faunal remains without accurate provenience are not included. Some bones show both cut and impact marks, so they are counted in both categories.

Taxon	NISP	Cut	Impact	Retouch	Soft hammer
Equid					
Equus mosbachensis	8890	1053	644	129	42
Equus hydruntinus	8				
Bovid				3	2
Bison priscus	59	3	1		1
Bos primigenius	78	8	5	14	
Bison/Bos indet.	145	26	19		
Cervid				3	2
Capreolus capreolus	7	1			
Cervus elaphus	340	15	12		
Megaloceros giganteus	7				
Rhinoceros					
Stephanorhinus hemitoechus	1				
Stephanorhinus kirchbergensis	1				
Stephanorhinus indet.	7				
Carnivore					
Canis lupus	7				
Vulpes vulpes	3				
Meles meles	5				
Mustela sp.	5				
cf. *Panthera leo spelaea*	1				
Carnivora indet.	4				
Micromammal					
Arvicola terrestris cantiana	3				
Castor fiber	4				
Desmana sp.	2				
Microtus gregalis	1				
Sicista sp.	-				
Talpa europea	3				
Rodentia indet.	41				
Chiroptera indet.	1				
Bird					
Anas acuta	2				
Anas crecca	4				
Anas platyrhynchos	3				
Aythya fuligula	2				
Bucephala clangula	1				
Cygnus olor	1				
Rallus aquaticus	1				
Tadorna tadorna	1				
Anatidae indet.	31				

Phasianidae indet.	1
Aves indet.	55
Fish	
Esox lucius	64
Gasterosteus aculeatus	-
Perca fluviatilis	2
Cyprinidae indet.	3
Pisces indet.	5
Elephantidae	
Palaeoloxodon antiquus	4
Amphibian	
Pelobates fuscus	1
Rana sp.	4
Salamandridae indet.	-
Insect	
Coleoptera indet.	3

SOM Table S2

Age and season of death for subadult horses (*Equus mosbachensis*) based on crown height measurements of lower right dp3 teeth (Bignon, 2006) and May–June birth season.

ID nº	Season of death	Age (months)	Crown height	Comments
8118	Summer	2	-	estimated, slightly less wear than ID 3128
3128	Summer	2.2	32.00	
5843	Summer	2.9	31.22	
9236	Summer	4	-	estimated from maxillary teeth of same individual
9760.2	Summer	4.1	29.95	
1362	Summer	16	-	estimated from crown height of dp2 in same mandible
7119.1	Autumn	4.8	29.23	
4016	Autumn	5.1	28.92	
19071.1	August	5.2	28.75	
5375	Autumn	5.3	28.63	
9874	Autumn	7.2	26.70	
8073	Autumn	17.1	16.13	
10080	Winter	7.7	26.16	
11438	Winter	8.1	25.66	
10394	Winter	9.1	24.64	
8116	Winter	10	-	estimated from erupting M1 in same mandible
14940.2	Winter	20	12.99	estimated from broken crown height
10233	Spring	10.7	22.90	
12816	Spring	11.1	22.48	
9534	Spring	11.5	22.04	

Table 1

Number of identified specimens (NISP) of the main taxa identified at Schöningen 13II-4 and number of modified bones per taxon included for analysis. Faunal remains without accurate provenience are not included. Some bones preserve multiple types of modifications and are counted in more than one modification category.

Taxon	NISP	Cut	Impact	Retouch	Soft hammer
Equid					
Equus mosbachensis	8890	1053	644	129	42
Bovid					
Bison priscus	59	3	1	3	2
Bos primigenius	78	8	5	-	1
Bison/*Bos* indet.	145	26	19	14	-
Cervid					
Cervus elaphus	340	15	12	3	2

Table 2

Number of faunal remains per unit of area (1 m x 1 m).

Taxon	*n*	Cells with finds	% Cells with finds	Maximum finds per cell	Mean per cell	Standard deviation per cell
Horse	8890	1523	38.86%	114	5.72	±9.16
Bovids	282	148	3.78%	24	1.79	±2.89
Red deer	340	247	6.30%	10	1.32	±0.87
Faunal remains	14506	1746	44.55%	133	7.97	±12.43

Table 3

Number of bone tools identified in each zone at Schöningen 13II-4.

Bone tool	Zone A	Zone A%	Zone B	Zone B%	Zone C	Zone C%
Retoucher[a]	143	84.62%	23	13.61%	3	1.77%
Soft hammer	38	80.85%	8	17.02%	1	2.13%

[a]Including 1 retoucher from *Megaloceros giganteus* and 19 from indeterminate ungulates.