

9. INVESTIGATING THE SPATIO-TEMPORAL DIMENSION OF PAST HUMAN-ELEPHANT INTERACTIONS: A SPATIAL TAPHONOMIC APPROACH

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ABSTRACT

Human-proboscidean interactions are key nodes of complex ecological, cultural and socio-economic systems. In the last decades, evidence has been provided in support of an early human exploitation of proboscidean carcasses, offering further insights into past human behaviors, diet and subsistence strategies. Nevertheless, the mode of acquisition of the carcasses, the degree of exploitation, its timing relative to carnivore scavenging and to the decomposition of the carcass, its ecological and socio-economical role are hitherto not fully understood and a matter of debate. By summarizing the empirical evidence for human-elephant interactions in Early and Middle Pleistocene open-air sites of western Eurasia, this contribution elaborates on the need for a more rigorous, spatially explicit inferential procedure in modeling past human behaviors. A renewed analytical approach, namely spatial taphonomy, is introduced. In its general term, spatial taphonomy refers to the multiscale investigation

of the spatial properties of taphonomic processes. Building upon a long lasting tradition of taphonomic studies, it seeks for a more effective theoretical and methodological framework that accounts for the spatio-temporal dimension inherent to any complex system. By bridging into a spatio-temporal framework the traditional archaeological, geo-archaeological and taphonomic approaches, spatial taphonomy enhances our understanding of the processes forming archaeological and palaeontological assemblages, allowing a finer comprehension of past human behaviors.

9.1 INTRODUCTION

Human-elephant interactions comprise complex and interdependent ecological, cultural and socio-economic aspects. While such a manifold relationship might still be observed in relatively few modern hunter-gatherer societies —e.g., among the BaYaka, the Mbuti and the Baka (respectively



see Lewis, this volume; Ichikawa, this volume; Yasuoka, this volume)—, the origin of it, at least in the form of human exploitation of proboscidean carcasses, could be dated back to the Early Pleistocene. An elephant butchering event was reported to occur as early as ~ 1.75 Ma at the Oldovai site of FLK North, level 6, Upper Bed I (Leakey, 1971; Bunn, 1981; Potts, 1988) —although the anthropogenic origin of the accumulation was later questioned on the basis of several taphonomic observations (Binford, 1981a; Domínguez-Rodrigo et al., 2007a). Yet, other indications of proboscidean exploitation come from the Early Pleistocene of Africa and Europe: e.g., HWK EE, Olduvai Bed II (de la Torre et al., 2017), FLK North, Olduvai Lower Bed II (Domínguez-Rodrigo et al., 2007b) and BK4b, Olduvai Upper Bed II, Tanzania (Domínguez-Rodrigo et al., 2014b); Barogali, Djibouti (Berthelet and Chavaillon, 2001); Olorgesailie Member 1, Site 15, Kenya (Potts et al., 1999); Fuente Nueva 3, Spain (Espigares et al., 2013); Barranc de la Boella, Spain (Mosquera et al., 2015). Such evidence significantly increases in quantity and archaeological resolution during the Middle and Late Pleistocene (e.g., Villa, 1983, 1990; Goren-Inbar et al., 1994; Piperno and Tagliacozzo, 2001; Gaudzinski et al., 2005; Villa et al., 2005; Müller and Pasda, 2011; Anzidei et al., 2012; Aureli et al., 2012; Rabinovich et al., 2012; Saccà, 2012; Pawłowska et al., 2014; Konidaris et al., 2018; Tournaloukis et al., 2018; Aranguren et al., 2019; Yravedra et al., 2019).

Being the largest terrestrial mammals during the Pleistocene, proboscideans ideally constituted optimal sources and reserves of food (Ben-Dor et al., 2011; Reshef and Barkai, 2015; Agam and Barkai, 2016, 2018) and raw material (Gaudzinski et al., 2005; Boschian and Saccà, 2015; Zutovski and Barkai, 2016) —albeit the nutritional/energy return in megafauna exploitation remains debated and non-dietary utilization of proboscidean carcasses might have had more importance than previously thought (Hawkes et al., 1991; Hawkes, 2000; Speth, 2010; Lupo and Schmitt, 2016; Barkai, 2019). Certainly, in the broader, long-last-

ing debate about the role of meat consumption in the biological and cultural evolution of hominins (e.g., Leakey, 1971; Isaac, 1978; Binford, 1981b, 1984; Potts, 1982; Binford et al., 1988; Blumen-schine, 1988; Speth, 1989, 2010; Domínguez-Rodrigo, 2002; Domínguez-Rodrigo et al., 2007b, 2014a, 2017a; Pante et al., 2012, 2015; Thompson et al., 2019), evidence of elephant exploitation, if confirmed, provides further insights into past human behaviors, diet and subsistence strategies.

In this respect, the discovery in recent years of a number of new sites with indications of anthropogenic exploitation of proboscideans (e.g., Aureli et al., 2012; Panagopoulou et al., 2018) and the re-examination of older ones (e.g., Villa et al., 2005; Boschian and Saccà, 2010; Sánchez-Romero et al., 2016; Santucci et al., 2016; Ceruleo et al., 2019) have definitely provided new data and information, but have little increased our knowledge on the mode (hunting or active/passive scavenging), degree (systematic or occasional) and purpose of human exploitation of elephant carcasses. A key research question (among others debated in the scope of this symposium) is: What would elephant hunting and processing sites look like and what kind of archaeological evidence is to be expected?

Tackling this research question is not always straightforward. The empirical evidence might not meet the expectations. First, the spatial association of proboscidean remains with artifacts does not necessarily imply causation. Spatial association, or the degree to which archaeological material occurs in spatial proximity, is a measurable condition of correlation (not causality) and a cornerstone analytical concept in archaeological science (Hodder and Orton, 1976). Nonetheless, it is inaccurately often used as a key, self-explanatory evidence in modeling past human behaviors, set forth by simple exploratory data analyses that mostly involve subjective visual methods (Bevan et al., 2013). As such, spatial association conveys an intuitive perception of spatial interaction and temporal contiguity. However, the observed spatial patterns are rarely distinct snapshots in time and space of human activities and more likely the

result of a spatio-temporal palimpsest of natural and cultural processes (Bailey, 2007). As a consequence of the interaction of the archaeological deposit with the biosphere, the atmosphere and the hydrosphere, syn- and post-depositional processes occur and may interact at different spatio-temporal scales. Accordingly, multi-scale spatio-temporal patterns are generated by a variety of anthropogenic (e.g., site re-occupation, recycling), biological (e.g., trampling, carnivore ravaging, burrowing), geological (e.g., deflation, erosion, swelling and shrinking of clay) and chemical processes (e.g., weathering, oxidation). Each process depends on the outcome of the other processes, and has the potential to rework, obliterate or preserve it (Karkanias and Goldberg, 2019). Moreover, different processes may achieve similar outcomes (equifinality) and a single process may lead to different outcomes (multifinality), introducing further pitfalls in the inferential procedure (Lyman, 1994, 2004). In such a complex open system, multiple entities (processes) interact with each other in non-linear, adaptive ways, so that the outcome patterns cannot be easily inferred.

Hence, capturing the complexity of past human-elephant interactions (and past human behavior in general) is highly dependent on solid multidisciplinary analyses. Among others, taphonomic and spatial analyses are certainly of primary importance. Since the first works on early hominid evolution (Behrensmeier, 1975; Boaz and Behrensmeier, 1976; Hill, 1976; Gifford and Behrensmeier, 1977; Brain, 1981), taphonomy has developed a wider theoretical and methodological framework, to the extent that the ephemeral dichotomy between taphonomy and the study of site formation processes, based on the nature of the object of interest, eventually has dissolved in the last decades towards an integrative and multi-disciplinary investigation of the processes, both natural and cultural, that modify the original properties of organic and inorganic material (Domínguez-Rodrigo et al., 2011; but see Lyman, 2010). Moreover, from different spatial perspectives, the analysis of orientation patterns, as well as refitting

patterns, size sorting and vertical distributions as indicators of syn- and post-depositional processes, have largely benefit from improved data collection and sampling strategies, advanced analytical methods and enriched experimental/neo-taphonomic references (e.g., Bertran and Texier, 1995; Lenoble and Bertran, 2004; McPherron, 2005, 2018; Anderson and Burke, 2008; Arriaza et al., 2018; Benito-Calvo and de la Torre, 2011; Bertran et al., 2012; Domínguez-Rodrigo and García-Pérez, 2013; Cobo-Sánchez et al., 2014; Ullah et al., 2015; García-Moreno et al., 2016; Clark, 2017; Vaquero et al., 2017). These analyses have been at different levels widely applied in studies of human-elephant interactions (e.g., Villa, 1990; Alpersen-Afil et al., 2009; Boschian and Saccà, 2010; Müller and Pasda, 2011; Sánchez-Romero et al., 2016; Santucci et al., 2016). Nevertheless, the integration of spatially-explicit analytical methods in taphonomic studies is not yet fully developed. Especially the study of the spatial distribution and the multiscale spatial correlation of different taphonomic markers is still under-developed. Moreover, it largely lacks a shared and extensive frame of references.

By summarizing the empirical evidence for human-elephant interactions in Early and Middle Pleistocene open-air sites of western Eurasia, this contribution aims to elaborate on the need for a more rigorous, spatially explicit inferential procedure in modeling past human behaviors. A renewed analytical approach, namely spatial taphonomy, is introduced. In its general term, spatial taphonomy refers to the multiscale investigation of the spatial properties of taphonomic processes. Building upon a long lasting research tradition of taphonomic studies, its goal is to move beyond the self-explanatory, indirect evidence provided by the spatial association of faunal remains and artifacts, and to seek for a more effective theoretical and methodological framework that accounts for the spatio-temporal dimension which is inherent to any complex system. By complementing the traditional archaeological, geoarchaeological and taphonomic approaches, spatial taphonomy en-

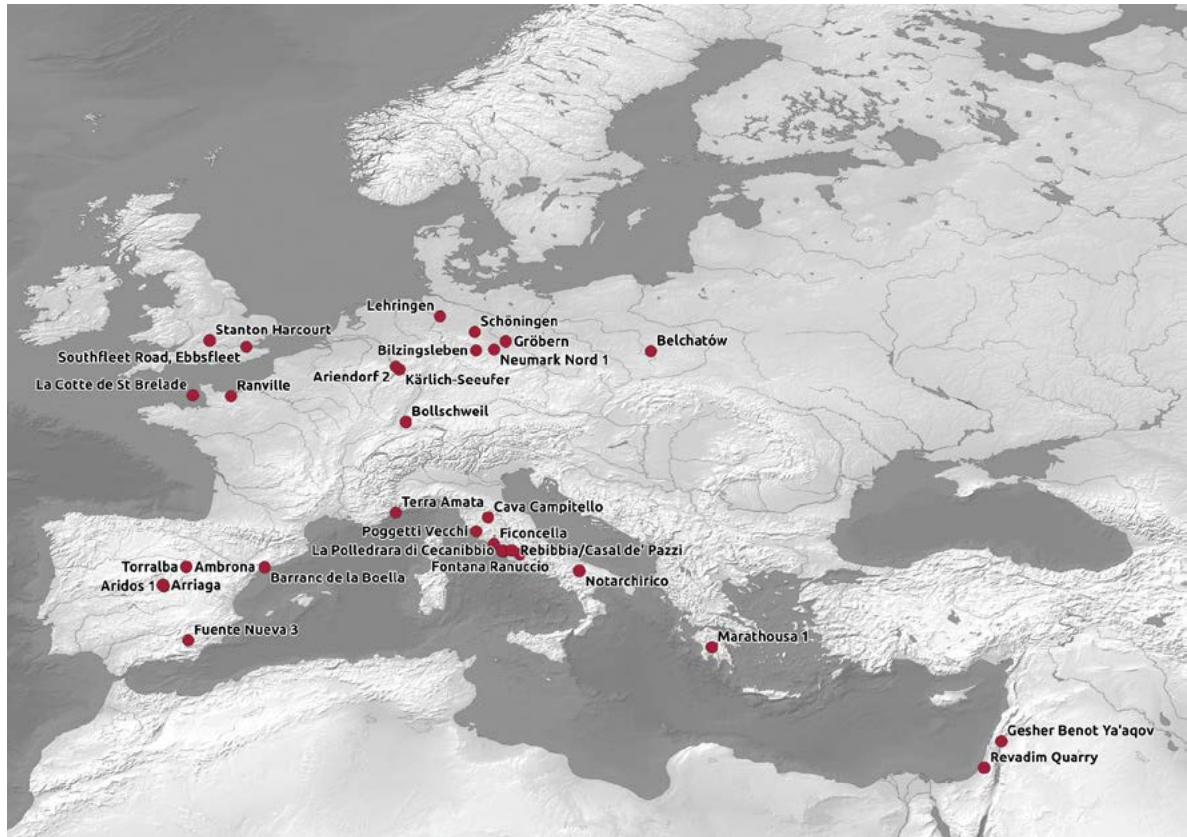


Figure 9.1: Geographical distribution of the sample of Early and Middle Pleistocene open-air sites in western Eurasia with direct or indirect evidence of human-elephant interactions (made using Natural Earth public domain data – [naturalearthdata.com](https://www.naturalearthdata.com)).

hances our understanding of the processes forming archaeological and palaeontological assemblages, allowing a finer comprehension of the mode and degree of human involvement in the acquisition and processing of elephant carcasses.

9.2 HUMAN-ELEPHANT INTERACTIONS

9.2.1. DIRECT AND INDIRECT EVIDENCE

The following synthesis is not intended to question current interpretations, but rather to stimulate the discussion on the need for compelling taphonomic and spatial studies for a better understanding of human-elephant interactions. The frequency of direct and indirect evidence, and the composition of the faunal assemblages are discussed for a sample of 35 Early and Middle Pleistocene open-air sites in western Eurasia with a single or multiple

elephant carcasses, or with important proboscidean remains in their diverse faunal assemblages (Fig. 9.1).

In these sites, human-elephant interactions are reported on the basis of direct (i.e., cut-marks, proboscidean bone tools or breakages for brain/marrow extraction, tools embedded in proboscidean bones) and/or indirect evidence (i.e., spatial association with artifacts and/or human fossils, tool use-wear and residues patterns, refitting patterns). Like in legal terms, a direct evidence is defined as an evidence that directly proves a fact, without an intervening inference. On the other hand, an indirect evidence, or circumstantial evidence, consists of a fact or set of facts which, if proven true, will support the formulation of an inference. Therefore, in the absence of verified direct evidence, the assessment of human-elephant interactions primarily relies on the accuracy of the indirect evidence and the validity of the inferential procedures.

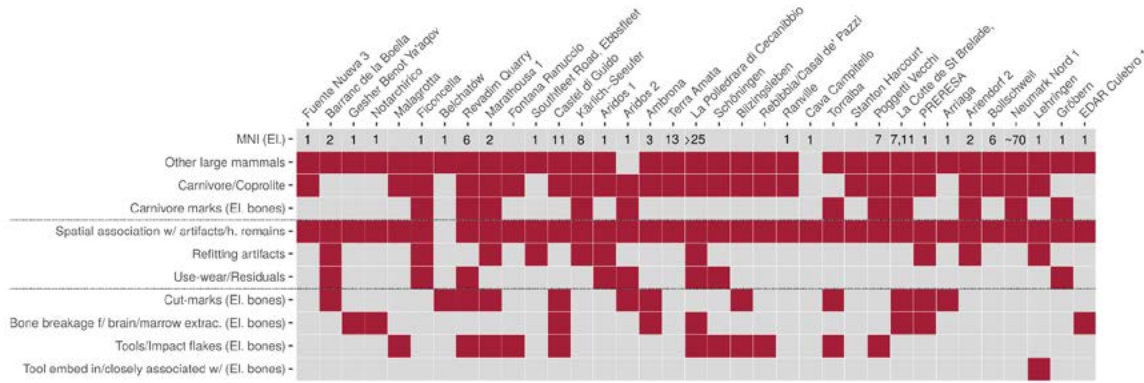


Figure 9.2: Geographical distribution of the sample of Early and Middle Pleistocene open-air sites in western Eurasia with direct or indirect evidence of human-elephant interactions (made using Natural Earth public domain data – [naturalearthdata.com](https://www.naturalearthdata.com)).

Yet, despite the primary importance of direct evidence in proving human-elephant interactions, it only offers a relative contribution to the narrative. The place and intensity of cut-marks are considered to be good indicators of the relative timing and aiming of the human access to the carcass (Blumenschine, 1988, 1995). However, cut-mark frequency is observed to be rather low in extant proboscideans due to the thickness of the periosteum and articular cartilage (Haynes, 1991). Moreover, due to a relatively high variability in cut-mark morphology and the lack of a shared, effective methodological framework, their interpretation might be less clear-cut than suggested (Lupo and O’Connell, 2002; Domínguez-Rodrigo et al., 2017b). Breakages for brain or marrow extraction are also relatively rare. The presence of marrow cavities in proboscidean bones seems to be random and not predictable (Villa et al., 2005; Yravedra et al., 2012; Boschian et al., 2019) and it is not clear which breakages were exclusively functional to tool production and which were concurrent to marrow extraction (Zutovski and Barkai, 2016; Boschian et al., 2019). Artifacts made of proboscidean bones are generally rare during the Lower Palaeolithic, although they were quite abundant in very few sites (e.g., Gaudzinski et al., 2005; Rabinovich et al., 2012; Saccà, 2012; Boschian and Saccà, 2015). Regardless of their presence, in the absence of any use-wear/residues evidence, it is still to be assessed whether they had a functional role or not (Zutovski and Barkai, 2016;

Barkai, 2019). Tools embedded in proboscidean bones are rather rare and actually absent in the Early and Middle Pleistocene (Wojtal et al., 2019 and references therein). In the absence of other lines of evidence, weapons closely associated with proboscidean bones, such as that at the site of Lehringen (Germany), cannot be considered unequivocal evidence for elephant hunting, likewise any other spatially associated artifacts.

Figure 9.2 shows the presence (in red) and the absence (in gray) of direct and indirect evidence of human-elephant interactions in the sampled sites. In addition, the graph shows the MNI (Minimum Number of Individuals) of proboscideans and the presence/absence in the same assemblage of other medium-to-large-sized herbivores (e.g., hippos, rhinos, Bovidae, Cervidae). The presence of large carnivores is marked positive by the occurrence in the same stratigraphic context of carnivore remains (e.g., big cats, Hyaenidae, Canidae, Ursidae) or carnivore coprolites. Carnivore marks on the elephant bones are also reported. For a complete summary list of the faunal assemblages see Konidaris and Tourloukis (this volume).

Direct evidence of proboscidean exploitation is relatively rare in the sampled Early and Middle Pleistocene record. Specifically, cut-marks are reported in 12 out of 35 sites (34%); bone breakages for brain or marrow extraction in 8 sites (23%); bone tools or impact flakes in 11 sites (31%); not a tool fragment embedded in elephant bones is reported, except for the wooded lance “between the

ribs of the elephant” at the site of Lehringen —although the original documentation is rather poor (Weber, 2000). Overall, 63% of the sites reported at least one type of direct evidence; 26% of them reported more than one. Indirect evidence such as tool use-wear and residues (23%) or refitting (29%) patterns are not more frequent than direct evidence. On the other hand, the spatial association of faunal remains with lithic artifacts is certainly the most common evidence in support of human-elephant interactions (in some cases also the only one, in lack of any direct evidence). Interestingly, only few sites rely on a positive combination of multiple direct and indirect evidence. Yet, also in those cases, interpretations are often limited by the complex palimpsest nature of the deposits (e.g., Boschian and Saccà, 2010).

Consequently, the mode of acquisition of proboscidean carcasses and its range of variability in the spectrum of hunting/scavenging strategies, the degree of exploitation (complete, random and partial, selective), its timing relative to carnivore scavenging and to the decomposition of the carcass, its ecological and socio-economical role are hitherto not fully understood and a matter of debate. In the attempt to better comprehend human-elephant interactions, both direct and indirect evidence should be cautiously considered with reference to the depositional context. For instance, an ideal set of evidence in support of butchering activities would include cut-marks, reliable spatial association with tools suitable for butchering, proboscidean protein residues on tools and consistency of use-wear patterns (Haynes and Klimowicz, 2015). For the purpose of this contribution, I will elaborate more on the role of spatial associations in the inferential process. Critical insights might come from the multi-level and multi-scale analysis of spatial patterns.

9.2.2. SPATIO-TEMPORAL PALIMPSESTS

The archaeological record, “at best a static pattern of associations and covariations among things dis-

tributed in space” (Binford, 1980: p. 4), nonetheless retains information about the interactions between the past cultural system and its surrounding environment. With reference to human-elephant interactions, we are most likely dealing with human-carnivore-megafauna interactions. Besides the frequency of direct and indirect evidence in the sample of sites, Figure 9.2 shows in addition the presence in the same assemblages of medium-to-large herbivores (including other elephants) and carnivores (also inferred by the presence of coprolites). Carnivore marks on elephant bones are reported in 11 of 35 cases (31%), whereas large carnivore remains or hyena coprolites are reported in 25 sites (71%). Thus, only 8 out of the 35 sampled sites do not include carnivore remains/coprolites or carnivore marks on elephant bones, albeit at least in 2 of them (Barranc de la Boella, Gesher Benot Ya’aqov) the presence of carnivores is attested by carnivore marks on bones other than elephant, and nevertheless occurring in the same stratigraphic layer with the elephant bones and the artifacts. Other medium-to-large herbivores are likely ubiquitous (94%), and sites with an MNI of elephants greater than 1 are 13 (37%). Hence, most of the localities, where human-elephant interactions have been documented, have yielded rich faunal assemblages marked by a significant presence of other medium-to-large herbivores and large carnivores. Both may have played major roles in the formation and modification of the fossil accumulations.

As an example, while the elephants’ repeated use of migration trails or paths leading to water sources might have facilitated humans in the practice of particular hunting strategies (Haynes, 2012; Agam and Barkai, 2018), it might have as well triggered intensive trampling especially in those places where accumulations of elephant carcasses usually occur. As a consequence of trampling and kicking (by elephants and other megaherbivores), stratigraphy may be reworked, bones and artifacts may be dispersed and reoriented, edge-damages may occur on stone tools and marks and fractures may be variably produced on bones to the extent of mim-

icking cut-marks or intentional breaking (Fiorillo, 1984; Andrews and Cook, 1985; Gifford-Gonzalez et al., 1985; Behrensmeyer et al., 1986; Haynes, 1988, 2012; Olsen and Shipman, 1988; Nielsen, 1991; Domínguez-Rodrigo et al., 2009; Gaudzinski-Windheuser et al., 2010; Benito-Calvo et al., 2011; McPherron et al., 2014; Courtenay et al., 2019a, 2020; Pizarro-Monzo and Domínguez-Rodrigo, 2020). Since direct evidence of elephant trampling, such as ichnofossils, are rarely preserved (Palombo et al., 2018; Serangeli et al., 2020), inferences are substantially drawn from the indirect evidence.

Furthermore, the significant presence of carnivores at elephant exploitation sites might have as well considerably increased the system entropy. Carnivore-hominin interactions are traditionally evaluated on the basis of the frequency and distribution of carnivore and anthropogenic modifications on bones (Lupo and O'Connell, 2002; Domínguez-Rodrigo et al., 2007b; Faith et al., 2007; Egeland, 2014), upon their unambiguous definition (James and Thompson, 2015; Domínguez-Rodrigo et al., 2017b) and confident classification. Recent technological advances in the digital acquisition and multivariate analysis of bone modifications (e.g., microscope image acquisition, geometric morphometrics analysis, Bayesian modeling and machine learning algorithms; Bello and Soligo, 2008; Boschian and Crezzini, 2012; González et al., 2015; Harris et al., 2017; Pante et al., 2017; Domínguez-Rodrigo and Baquedano, 2018; Domínguez-Rodrigo, 2019; Courtenay et al., 2019b; Moclán et al., 2019) have overcome much of the biases of more subjective and qualitative approaches and have significantly increased the accuracy in their classification. Nevertheless, the equifinality issue and the spatio-temporal resolution of carnivore-hominin interactions are still major issues affecting the taphonomic interpretation of many sites (e.g., McPherron et al., 2010; Baquedano et al., 2012; Pante et al., 2012, 2015; Domínguez-Rodrigo et al., 2014a; Domínguez-Rodrigo and Alcalá, 2016; Rosell et al., 2019a, b; Saladié and Rodríguez-Hidalgo, 2019).

This issue is equally valid for Early and Middle Pleistocene sites. The mode and degree of human access to and exploitation of animal carcasses might have likely changed with a change in the carnivore guild (see Konidaris and Turloukis, this volume), and yet the presence of carnivores, similarly attracted by food and water resources, have not overall limited the presence of hominins, and vice versa (e.g., Espigares et al., 2013; Pineda et al., 2017). By creating site structures and assemblage compositions that closely resemble anthropogenic ones, or by modifying at different spatio-temporal scales anthropogenic accumulations, carnivores definitely represent a critical element of uncertainty (Binford, 1981a; Gifford-Gonzalez, 1989; O'Connell et al., 1992; White and Diedrich, 2012; Camarós et al., 2013; Arriaza et al., 2018; Arilla et al., 2020). A formal quantification of such an uncertainty in probabilistic terms marks future direction of analysis (Harris et al., 2017).

Geological processes might as well likely contribute to the building of complex palimpsests. Most of the Early and Middle Pleistocene open-air sites considered here occur in fluvio-lacustrine and palustrine environments. These are known to be attractive locations to animals and to favor archaeological preservation in specific depositional settings. Nevertheless, they are also open, dynamic systems in which diverse syn- and post-depositional geogenic processes take place that might at different spatio-temporal scales rework, erode or preserve the archaeological record (Karkanas and Goldberg, 2019). As an example, White and Diedrich (2012) report that, in addition to primary scavenging by large carnivores and secondary scavenging by smaller carnivores, final disarticulation and scattering of the bones of a modern day elephant carcass were further influenced by the seasonal flooding of the lake shore. Notably, some type of flooding event has been reported in many of the sites discussed here (e.g., Boschian and Sacà, 2010; Marder et al., 2011; Sánchez-Romero et al., 2016; Karkanas et al., 2018).

Indeed, among the variety of natural processes that can contribute to the building of archae-

ological palimpsests, water flows are certainly the most important and largely studied. Especially in terrestrial alluvial environments, anisotropy (the preferential orientation of fossils or artifacts along the flow direction) is one of the proxies traditionally used to discriminate primary (*in situ*) vs. secondary (reworked) contexts (e.g., Toots, 1965; Isaac, 1967; Voorhies, 1969; Behrensmeyer, 1982, 1988; Nash and Petraglia, 1987; Petraglia and Nash, 1987; Petraglia and Potts, 1994). Consequently, fabric analysis, or the analysis of the orientation of archaeological material as clasts within a sedimentary matrix, has been widely applied in studying human-elephant interactions (e.g., Boschian and Saccà, 2010; Müller and Pasda, 2011; Sánchez-Romero et al., 2016; Peters and Kolfshoten, 2020). However, it is by itself not sufficient to unequivocally discriminate the depositional context and should therefore be integrated with the analysis of other diagnostic features (Lenoble and Bertran, 2004). As an example, anisotropy has been equally documented in autochthonous lag assemblages undergoing minimal re-sedimentation in a modern lake floodplain (Cobo-Sánchez et al., 2014). Moreover, besides water-flow processes, anisotropy has also been observed in association with a wide range of other processes, such as slope processes (Bertran and Texier, 1995), trampling (Benito-Calvo et al., 2011) and carnivore ravaging (Arriaza et al., 2018).

In such a complex, dynamic system, the human exploitation of an elephant carcass might occur at different spatio-temporal scales as well. As an example, contrary to the usually limited extension of archaeological excavations, Hadza kill sites have been observed to be sometimes marked by such a large-scale spatial distribution of associated bone debris and features that largely exceeds that of archaeological sites (O'Connell et al., 1992). Moreover, it is worth considering that, because larger animals such as elephants retain food value for a long time, they can be exploited longer than smaller species (Behrensmeyer, 1987). Recycling of raw material (e.g., bone) and delayed exploitation

of elephant meat, fat and marrow might have been more common than traditionally thought (Lemorini, 2018; Boschian et al., 2019).

All these natural and cultural processes, working in such a dilated spatio-temporal framework, variably contribute to the building of complex spatio-temporal palimpsests, with an increase of the system entropy both in terms of amount of disorder (chaos) and loss of information. In this context, spatial association of proboscidean remains with artifacts should undergo scrupulous investigation before being used as evidence of human-elephant interactions.

9.3 SPATIAL TAPHONOMY: THEORETICAL AND METHODOLOGICAL FRAMEWORKS

Unraveling spatio-temporal palimpsests has always been a critical task in archaeology. Despite recent theoretical and methodological advances in palimpsest dissection (e.g., Malinsky-Buller et al., 2011; Vaquero et al., 2012; Barton and Riel-Salvatore, 2014; Davies et al., 2016; Mallol and Hernández, 2016; Martínez-Moreno et al., 2016; Rezek et al., in press), a subtle, diffuse misconception is that it is possible to remove the negative veil of natural post-depositional processes and reveal the original, pristine archaeological occurrence; thus implying the presence of a linear, homogeneous, predictable “background noise” to be erased. On the contrary, cultural and natural processes, working at different scales, frequencies and intensities, are dynamically linked within a spatio-temporal framework. They are so intertwined that it is not possible to remove one without stripping away components of the other.

Borrowed from complex system theory, the concept of “emergence” describes well this property of archaeological palimpsests (Goldstein, 1999; Holland, 2000 and, for a more recent archaeological application, Rezek et al., in press). Emergence is defined as the “the arising of novel and coherent structures, patterns and properties

during the process of self-organization in complex systems” (Goldstein, 1999: p. 49). Thus, emergent spatio-temporal structures are patterns that arise in the system as a whole from the interactions in space and time between its components—patterns not otherwise produced by the systemic processes alone. Because emergent patterns are neither predictable, nor reducible to their parts alone, explanation of the system dynamics in term of its elements alone is insufficient. On the other hand, understanding such a complex system is possible by focusing on across-system associations and interactions among its components (Goldstein, 1999). Hence, capturing the complexity of past human-elephant interactions (and past human behavior in general) requires the rejection of the binary, hierarchical opposition between cultural and natural layers; it demands a change of focus from the system components themselves to the whole archaeological record as scale-dependent, emergent interactions between its parts. Variations in the observed patterns can be explained by the system dynamics and the randomness, unpredictability of interactions between its components, which often inherit a spatial dimension. Indeed, the spatio-temporal dimension of emergent patterns has long been universally recognized to be paramount in the investigation of the archaeological record (e.g., Whallon, 1973, 1974; Hodder and Orton, 1976; Clarke, 1977; Butzer, 1982, 2008; Kintigh and Ammerman, 1982; Orton, 1982; Hietala and Larson, 1984; Lyman, 1994; Petraglia and Potts, 1994; Dibble et al., 1997; Wheatley and Gillings, 2002; Conolly and Lake, 2006; Rapp and Hill, 2006; Gillings et al., 2020). With reference to human-elephant interactions, this is especially valid in multi-car-cass sites where the archaeological record emerges from complex dynamics of anthropogenic and natural processes (e.g., Boschian and Saccà, 2010; Anzidei et al., 2012).

Therefore, can we attempt to explain such complex systems in terms of the multifaceted interactions between their components, more than as the sum of their parts? Can we estimate uncer-

tainty and account for the observer’s bias¹ and the biases derived from missing, time/space-averaged data and spatially uneven sampling strategies? Assuming a spatial dimension of time (Wandsnider, 1992), I argue that the spatial distribution of entities and their attributes is among the most informative aspects of the archaeological variability and that understanding the dynamics of past complex systems requires spatially explicit, multi-scale analytical methods and adequate inferential approaches. Surely, drawing sound inferences highly depends also on accurate data collections, sampling strategies consistent with the scale of the research question, and adequate frames of references with respect to the specific context under study.

Following a long tradition of research in site formation processes—a systemic (processualist) approach that emerged in the ’60s from general system theory and strongly advocated the use of quantitative data and hypothetico-deductive models (Binford and Binford, 1968; Clarke, 1968; Flannery, 1968; and Kohler, 2012 for a review), system theory still provides an adequate framework for developing sound methodological approaches to investigate the spatio-temporal dimension of past complex systems such as human-elephant interactions. Many of the lessons of the processualist approach have been nowadays largely assimilated, albeit, a half-century after, many other intuitions have still to find full recognition and application (Shennan, 1989; Lycett and Shennan, 2018). For instance, the call for a multiscale and multilevel analysis of the spatio-temporal dimension of past cultural systems (Clarke, 1968) was possibly ahead of the technology of the time, while it could nowadays generously benefit from the more recent technological advances in GIS, AI and agent based

1 On the concept of emergence as a function of the epistemological bias of the observer, Crutchfield (1993: p. 3) noted: “the detected patterns are often assumed implicitly by analysts via the statistics they select to confirm the patterns’ existence in experimental data. The obvious consequence is that ‘structure’ goes unseen due to an observer’s biases”. An issue related to the natural tendency to seek confirmation, rather than rejection, of our assumptions.

modeling (which in turn are connected to the development of complexity theory).

Nevertheless, the analysis of spatial patterns still lacks a more formal, quantitative framework, being on the contrary mostly based on visual examinations and intuitive interpretations of distribution maps and cross-sectional plots alike (Bevan and Wilson, 2013). Even though such an “eye-balling” technique to read spatial distributions has long been criticized², it is still largely used to search for evidence of spatial association and co-variation. Similarly, for many of the sites considered here, a functional association of artifacts with elephant remains has been inferred on the basis of simple visualizations of distribution maps. On the other hand, moving beyond this basic exploratory analysis, more compelling spatial analyses of taphonomic and technological attributes in higher dimensional space might open new research perspectives. Indeed, multiple taphonomic or techno-economic proxies could be eventually spatially defined in order to investigate not only the spatial extension and intensity of taphonomic and behavioral processes, but also the multiscale interactions between them.

In spatial point pattern analysis, points are defined as the location of events generated by a point process (natural or cultural). The intensity of a spatial process, generally evaluated by means of kernel density estimation (Diggle, 1985), informs about its rate of occurrence (uniform or spatially varying across the study area). Although instructive, intensity does not provide sufficient information to reliably infer interactions between processes, which are instead of interest in the analysis of emergent patterns. On the other hand, multiscale inter-point interactions are measured by less common, higher-order statistics, such as the Ripley’s K correlation function (Ripley, 1977). In investigating the spatio-temporal dimension of past complex systems, such multiscale and multivariate statistics

are extremely useful to determine the type of spatial dependence (i.e., random, positive or negative association) between multiple processes, quantify its strength and spatial range. As an example, with reference to human-elephant interactions, it might be of interest to investigate the three-dimensional spatial dependence between behavioral and taphonomic processes by cross-analyzing techno-functional (e.g., raw material units, artifact types, use-wear/residue traces) and taphonomic proxies (e.g., bone surface modifications, bone breakage patterns, skeletal part profiles, dimensional classes). Furthermore, simulation techniques, such as Monte Carlo methods (Robert and Casella, 2004), might be employed in an hypothesis testing framework in order to build statistical significance and bypass with confidence the equifinality/multifinality inferential pitfalls. Statistical modeling is yet another, less common, but more powerful way to build statistical inference. Indeed, statistical modeling allows one to explicitly fit different explanatory variables to the empirical data. Thus, by building different statistical models and by using model selection techniques, it is possible to choose the best fitting model from among different competing hypotheses (e.g., Eve and Crema, 2014 for an application to archaeological settlement analysis). Moreover, contrary to the frequentist null hypothesis testing, Bayesian inference allows one to estimate model parameters in a probabilistic fashion, taking into account both prior knowledge and empirical data (e.g., Crema et al., 2014; Harris et al., 2017). By using such a probabilistic approach, it is possible to build best predictions starting from incomplete observations (such as the archaeological record), thus acknowledging a certain degree of uncertainty.

Interestingly, in his review of spatial statistics for the study of cultural processes, Orton (1982) beforehand discussed the utility of univariate and multivariate spatial point pattern statistics (e.g., K-function; Ripley, 1977) and the use of Monte Carlo simulations in hypothesis-testing frameworks. Nonetheless, only a relatively small number of scholars have continued to adopt advanced spa-

² “There is a widespread belief that we should go beyond the ‘eyeballing’ of spatial distributions and develop more objective approaches to the recognition of spatial patterns” (Kintigh and Ammerman, 1982: p. 31).

tial statistics to unravel past human behaviors from scatters of material culture (e.g., Orton, 2004; Bevan and Conolly, 2006, 2009; Crema et al., 2010; Bevan and Wilson, 2013; Crema and Bianchi, 2013; Eve and Crema, 2014; Crema, 2015; Negre et al., 2016, 2017; Reeves et al., 2019). Although these studies acknowledge post-depositional effects, they nevertheless lack explicit consideration of the spatial structure of natural processes. Besides well-developed quantitative methods for the analysis of orientation patterns, advanced spatial statistics are still insufficiently applied to the study of taphonomic processes. Therefore, spatial taphonomy aims to fill this gap. It refers to the multiscale and multilevel investigation of the spatial properties of taphonomic processes. It seeks for a more effective way to investigate past complex system, by bridging the traditional archaeological, geoarchaeological and taphonomic approaches into a spatio-temporal analytical framework.

An early attempt to adopt a specific taphonomic perspective in the analysis of spatial distributions dates back to the early '80s (Hivernel and Hodder, 1984). More recently, only a relatively small number of studies have answered the need for a more robust spatial analysis of taphonomic processes (e.g., Lenoble et al., 2008; Domínguez-Rodrigo et al., 2014b, c, 2017a; Giusti and Arzarello, 2016; Romagnoli and Vaquero, 2016; Organista et al., 2017; Discamps et al., 2019; Giusti et al., 2019; Mendez-Quintas et al., 2019). Applications to the study of past human-elephant interactions are also relatively few (Sánchez-Romero et al., 2016; Giusti et al., 2018; Mackie et al., 2020; Peters and Kolf-schoten, 2020). In these works, a spatially explicit, multi-scale analytical approach allowed to capture the spatial dimension of the processes forming the archaeological record; hypothesis-testing methods were also used to build sound statistical inferences. As an example, Giusti et al. (2018) used a comprehensive set of spatial statistics in order to disentangle the depositional processes at the elephant-butcher site of Marathousa 1 (Greece). Besides orientation patterns and vertical distributions, the authors analyzed spatial trends in either

the assemblage intensities and the associations between different classes of remains (e.g., the spatial dependence between two depositional units separated by an erosional contact). All together, these spatial analyses allowed the authors to reliably draw inferences about the autochthonous origin of the assemblage.

Hence, spatial point pattern analysis results particularly useful to investigate the spatio-temporal dimension of taphonomic processes and their multiscale and multilevel interactions with emergent behavioral processes. Moving forward, spatial taphonomy would also benefit from the integration of the spatial dimension in machine learning algorithms (ML) and agent based models (ABM). During the last few years, ML has been successfully applied in taphonomic studies of bone surface modifications, bone breakage patterns and skeletal part profiles (Arriaza and Domínguez-Rodrigo, 2016; Domínguez-Rodrigo and Baquedano, 2018; Byeon et al., 2019; Cifuentes-Alcobendas and Domínguez-Rodrigo, 2019; Courtenay et al., 2019a, b; Domínguez-Rodrigo, 2019; Moclán et al., 2019). These studies employed advanced multivariate statistics and classification methods in order to bypass the equifinality inferential pitfall and to objectively discriminate the human/carnivore agency in fossil accumulation. Likewise, ML allows a through investigation of spatial patterns. For instance, the combination of unsupervised, hybrid and supervised learning has already proved to be effective in the analysis of spatial data and in the identification of discrete fossiliferous levels in palaeontological sites (Martín Perea et al., 2020). Furthermore, by complementing the spatial data with other crucial archaeological, geological and taphonomic attributes, ML would likely allow us to objectively and efficiently reveal the complex interactions that lead to the emergence of archaeological spatio-temporal patterns.

Being understood that the appropriate choice of an analytical technique depends on the context of application, these recent advances in computer science and mathematics are definitely pushing forward our understanding of archaeological pa-

limpsests, promoting a more objective analysis of spatial patterns. Nevertheless, the interpretation of emergent patterns requires valid theory-based models tailored to specific theoretical problems and forms of information. In this regard, ABM provides a convenient framework for developing formal models of complex archaeological systems. ABM, and simulations in general, are primary tools for studying the emergent properties of complex systems, allowing the investigation of changes and interactions in space and time (see Crabtree et al., 2019; Davies et al., 2019; Romanowska et al., 2019 and references therein). For instance, a spatially explicit ABM has been successfully used to model a palimpsest deposit in a fluvial landscape, thus aiding interpretations of the archaeological deposit (Davies et al., 2016).

Nonetheless, drawing sound statistical inferences highly depends as well on references grounded on empirical observations. In order to consolidate the spatial taphonomic approach, it is therefore necessary to build a rich, exhaustive frame of references from actualistic, archaeological or palaeontological cases, where the spatial and taphonomic signatures might be more explicitly recognizable and attributable to particular sets of circumstances. On a side note, the building of effective frames of references would greatly benefit from a broader application of open science practices in archaeology (Marwick et al., 2017). Open access to raw taphonomic data (including spatial coordinates) should be facilitated and promoted if we aim to develop a spatial taphonomic referential framework for both archaeological and palaeontological assemblages (Giusti et al., 2019).

9.4 CONCLUSION

Human-elephant interactions represent key nodes of complex ecological, cultural and socio-economic systems. In the last decades, evidence has been provided in support, to some degree, of the existence of such interactions since the Early Pleistocene and their intensification in the Middle and

Late Pleistocene. Nevertheless, the nature of early human-elephant interactions are yet to be fully understood —the mode (hunting or active/passive scavenging), degree (systematic or occasional), purpose of human exploitation of proboscideans and its relation to other systemic agents are hitherto a matter of debate. Models are commonly built by using inductive reasoning from a set of observations that is, for its archaeological nature, very fragmented.

What would elephant hunting and processing sites look like and what kind of archaeological evidence is to be expected? Tackling this kind of research questions would require a high level of generalization that should nevertheless derive from consolidated knowledge about specific processes (Villa et al., 2005). At the site-scale of analysis, there is no single evidence that can lead to a certain solution; but the combination of many, examined within the specific context of each site, might allow probabilistic inferences. This is due to the palimpsest nature of the archaeological record and its extremely high variability generated by the non-linear interactions among different agents (human/carnivore/other megaherbivore) within different dynamic environments. Such interactions inherit an ineluctable spatio-temporal dimension that emerge in spatio-temporal patterns. Thus, on a site-by-site basis, if we tentatively want to shed light on the vast complexity of human-elephant interactions, we should move beyond a reductionist understanding of the whole system in the mere terms of its constituent parts, and instead investigate, within a spatio-temporal analytical framework, the emerging interactions between the different biotic and abiotic components of such a complex system of the past. Spatial taphonomy aims to answer this need by bridging the traditional archaeological, geoarchaeological and taphonomic approaches into a spatio-temporal analytical framework.

In the broad sense, this approach is hardly new —from different perspectives (e.g., orientation and refitting patterns), the spatial dimension of taphonomic processes has long been investigated.

Nevertheless, the study of the spatial distribution and the multiscale spatial correlation of different taphonomic and technological markers is still under-developed. Only a relatively small number of recent studies has successfully investigated the spatial properties of taphonomic processes adopting more compelling spatial statistics and hypothesis-testing methods. Few have applied such methods in studies of human-elephant interactions. In these works, multiscale and multilevel spatial point pattern statistics allowed to draw more reliable inferences about the site formation processes and the human involvement in the exploitation of elephant carcasses. Nevertheless, despite these recent methodological advances, much work has still to be done. Unraveling complex systems such as past human-elephant interactions requires a thorough investigation of the multiscale interactions between taphonomic and behavioral processes. Besides the use of robust spatial statistics, the analysis of such a complex system might further benefit from the critical adoption of other powerful, less common analytical techniques, such as machine learning algorithms and agent based models. Nonetheless, building exhaustive and shared frames of references from theory-based simulations or empirical cases remains a crucial step for the future development of a spatial taphonomic approach to the study of archaeological palimpsests.

On the other hand, the increasing use of an array of advanced quantitative methods and techniques of analysis does not represent any scientific progress if methods and techniques do not follow an epistemological shift. Is the old paradigm “Man the hunter” still projecting its long shadow on the current debate about past human-elephant interactions? After decades of research, much of the discussion is still largely revolving around the hunting vs. scavenging models, while a real shift of perspective towards a more holistic approach is still an ongoing process. By emphasizing the mode of meat acquisition, the risk is to underestimate other important issues, such as the degree of proboscidean exploitation and its relative role with respect to other taxa exploitation, non-animal resources and non-dietary behaviors.

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