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Environment and daily life in the *Campagna Romana* of the late Lower Palaeolithic: the case-study of La Polledrara di Cecanibbio (Latium, Italy)

Eugenio Cerilli [1,*], Cristina Lemorini [2], Ernesto Santucci [3], Ivana Fiore [4], Federica Marano [5], Grazia Maria Bulgarelli [6], Maria Rita Palombo [7], Salvatore Milli [7,8]

[1] collaborator Soprintendenza Speciale Archeologia, Belle Arti e Paesaggio di Roma, Roma, Italy
[2]Dipartimento di Scienze della Antichità, SAPIENZA Università di Roma, Roma, Italy
[3] collaborator Soprintendenza Speciale Archeologia, Belle Arti e Paesaggio di Roma, Roma, Italy
[4] collaborator Museo della Civiltà, Roma, Italy
[5] collaborator Soprintendenza Speciale Archeologia, Belle Arti e Paesaggio di Roma, Roma, Italy
[6] retired archaeologist Museo della Civiltà, Roma, Italy
[7] CNR-IGAG, Istituto di Geologia Ambientale e Geoingegneria, Area della Ricerca di Roma1, Roma, Italy
[8] Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy
** Corresponding author: cerillieugenio@gmail.com.*

ABSTRACT - The site of La Polledrara di Cecanibbio (Latium, Italy) is located about 22 kilometers northwest of Rome. Excavation campaigns conducted from 1985 to 2013 revealed 1200 square meters of deposits referable to a river that was active during the Middle Pleistocene. Two main sedimentary phases have been recognized. Initially, a fluvial episode led to the deposition of thousands of skeletal remains (mainly mammals, but also amphibians, reptiles, and birds) along with lithic and bone artifacts. Successively, a swampy phase occurred, during which some elephants (*Palaeoloxodon antiquus*) were trapped in muddy ponds. The skeleton of one of these individuals is surrounded by lithic implements that were carried at (and/or knapped on) the spot. The taphonomic analysis of the skeleton and artifacts context - including technology, refitting, use-wear, residues, and spatial analyses - indicates that the elephant carcass had been subjected to a butchering activity aimed at collecting meat and fat for food, possibly in more than one episode, as well as bones as raw material for making tools. The evidence collected at the site and the comparison with other relevant sites allow for some considerations about the daily dietary needs of the humans who frequented the site and the resources available there.

Keywords: *Homo heidelbergensis, Palaeoloxodon antiquus,* butchering activities, taphonomy, fluvial environment, daily energy expenditure.

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1. INTRODUCTION

Human-animal interaction and subsistence strategies during the Palaeolithic are intriguing topics that received the attention of several scientists. The possibility of reconstructing human subsistence strategies during the Lower Palaeolithic is linked to the availability of information from Pleistocene continental deposits. Focusing the analysis on the Middle Pleistocene, the Campagna Romana represents an ideal area for this type of analysis as it preserves numerous sites that yielded information on the interactions between humans and the surrounding environment, especially about subsistence strategies related to food procurement from animal sources.

Since the 18th century, and especially in the 19th century, professionals (e.g., S. Breislak, G.B. Brocchi, E. Clerici, M.S. De Rossi, R. Meli, A. Portis, U. Rellini, just to mention a few) and enthusiasts (e.g., Frére Indes, L. Ceselli, G. Ponzi, C. Rusconi) explored the territory north and south of Rome in search for prehistoric evidence, laying the foundations for our knowledge of geomorphological and palaeobiological features of this territory (Cerilli, 2014; Romano et al., 2021; Orombelli et al., 2023). Subsequently, the great urban transformations between and after the two World Wars of the last century, and the attention of other scholars (e.g., G.A. Blanc, A.C. Blanc, L. Cardini), brought to light several sites that still represent milestones in the reconstruction of the geological, palaeobotanical and paleontological evolution of Latium region (Romano et al., 2021; Orombelli et al., 2023). Finally, from the last twenty years of last century, with the improvement of survey and data processing technologies applied to these authentic repositories of information it has been possible to reconstruct, with greater precision and detail, the climate, landscape, animal, and plant life and, last but not least, the history of the human population in the Campagna Romana during the Pleistocene and Early Holocene (see the seminal paper by Conato et al., 1980). This research is still continuing. For a summary of the geological and palaeobiological evolution of the Campagna Romana see, Palombo and Milli (2010), Milli et al, (2011, 2016), Tentori et al. (2016), Milli et al. (2019), Buzi et al. (2021).

One of these deposits is La Polledrara di Cecanibbio, a notable example and an interesting case-study among the important palaeontological and archaeological Lower Paleolithic sites available in Italy, which preserves an example of a watercourse active during the final part of the Middle Pleistocene. The aim of this work is to attempt to reconstruct the daily dietary needs of the Middle Pleistocene hunter-gatherer bands frequenting the site and the surrounding area, and to determine whether the available animal resources could satisfy these needs.

2. SITE DESCRIPTION

2.1. GEOGRAPHIC SETTING

The site of La Polledrara di Cecanibbio is located approximately 22 kilometers northwest of Rome, in the north-western sector of the Campagna Romana (Fig. 1). The deposit was identified in 1984 during a survey promoted by the former Soprintendenza Archeologica di Roma (now Soprintendenza Speciale Archeologia Belle Arti e Paesaggio di Roma) which excavated the site, and built the museum, with the aim of taking a census of the archaeological evidence in the area under its jurisdiction. In 1985, based on a preliminary survey conducted by a surface sampling of the outcrops, a first excavation was carried out; it identified the right bank of a river and part of the riverbed where several remains of large mammal fossil bones associated with the lithic industry were detected. Since the following year, numerous excavation campaigns, completed in 2013, have revealed an area of approximately 1,200 square meters of a riverbed cut into a compact volcaniclastic deposit derived from the near Sabatini Volcanic Complex. The site has been musealized *in situ* by means of the construction of a building that covered the most interesting part of the deposit (approximately 900 square meters), preserving it and allowing it to be visited by the public since 2001 (see De Santis and Barone, in this volume for a description of the musealization history and related teaching aids).

2.2. GEOLOGICAL SETTING

The deposits of La Polledrara di Cecanibbio constitute part of the Pleistocene succession cropping out in the western sector of the Rome area between the Sabatini volcanic complex and the Tyrrhenian Sea (Fig. 1). Here this succession consists of several stratigraphic units representing low- and high-rank depositional sequences whose stratigraphic architecture reflected the strong interaction among three main processes: the volcanic activity and the tectonic uplift of the Latium Tyrrhenian margin and the glacio-eustatic sea-level variations related to the Quaternary climatic changes (Milli, 1997, 2006).

The deposits of the Polledrara di Cecanibbio site are part of the Ponte Galeria Sequence, a stratigraphic unit spanning from the Middle Pleistocene to the Present, within which depositional systems ranging from fluvial to palustrine-lacustrine, and from coastal-lagoon to shelf occur. Most of the fluvial and palustrine-lacustrine systems constitute the filling of several incised valleys hosting important mammal remains (Milli and Palombo, 2005; Milli et al., 2008; Palombo and Milli, 2010), thank of which has been possible to reconstruct both the depositional setting and the main paleoclimatic conditions of the Roman Basin during the Middle-Late Pleistocene.

The mammal remains of the La Polledrara site occur within fluvial and fluvio-palustrine deposits of volcaniclastic composition which derive from the Sabatini Volcanic District (Castorina et al., 2017). These deposits originally attribute to the Aurelia formation, an informal lithostratigraphic unit of the Campagna Romana (see Conato et al., 1980) has been successively ascribed to the PG6 low-rank sequence (Milli et al., 2008, 2011). Such mammal remains are included in the Aurelian Land Mammal Age (Palombo, 2018) and correlated with MIS 10 and 9 (Milli et al., 2008, 2011; Palombo and Milli, 2010). Recent ^{40}Ar/^{39}Ar dating indicates an age of the La Polledrara deposits of 325±2 Ka BP (MIS 9e) (Pereira et al., 2017) that agrees with what had already been highlighted by Anzidei et al. (2012).

2.3. DEPOSITIONAL SETTING

The morphology of the investigated river stretch where the La Polledrara site develop is about 45 m length and 40 m width. It is characterized by a left bank that is almost straight, while the right bank makes a wide curve. This morphology is due to the complex history of the watercourse (Anzidei et al., 2012; Santucci et al., 2016), an ephemeral stream showing locally a sinuous stretch that migrated laterally giving rise to the formation of a small point bar, just over a meter thick, which was later swamped (Fig. 2). The evolution of the area may be summarized in two main phases. The first phase was characterized by a markedly fluvial regime, with great seasonal variations in the flow discharge. During this phase a complex palimpsest accumulated on the bottom of the river during flood events; it included skeletal remains and lithic artifacts which, over time, were transported and deposited by stream during high and low flow stage conditions respectively, giving rise to a progressive accumulation of fossil remains. During the second phase the progressive abandonment of the

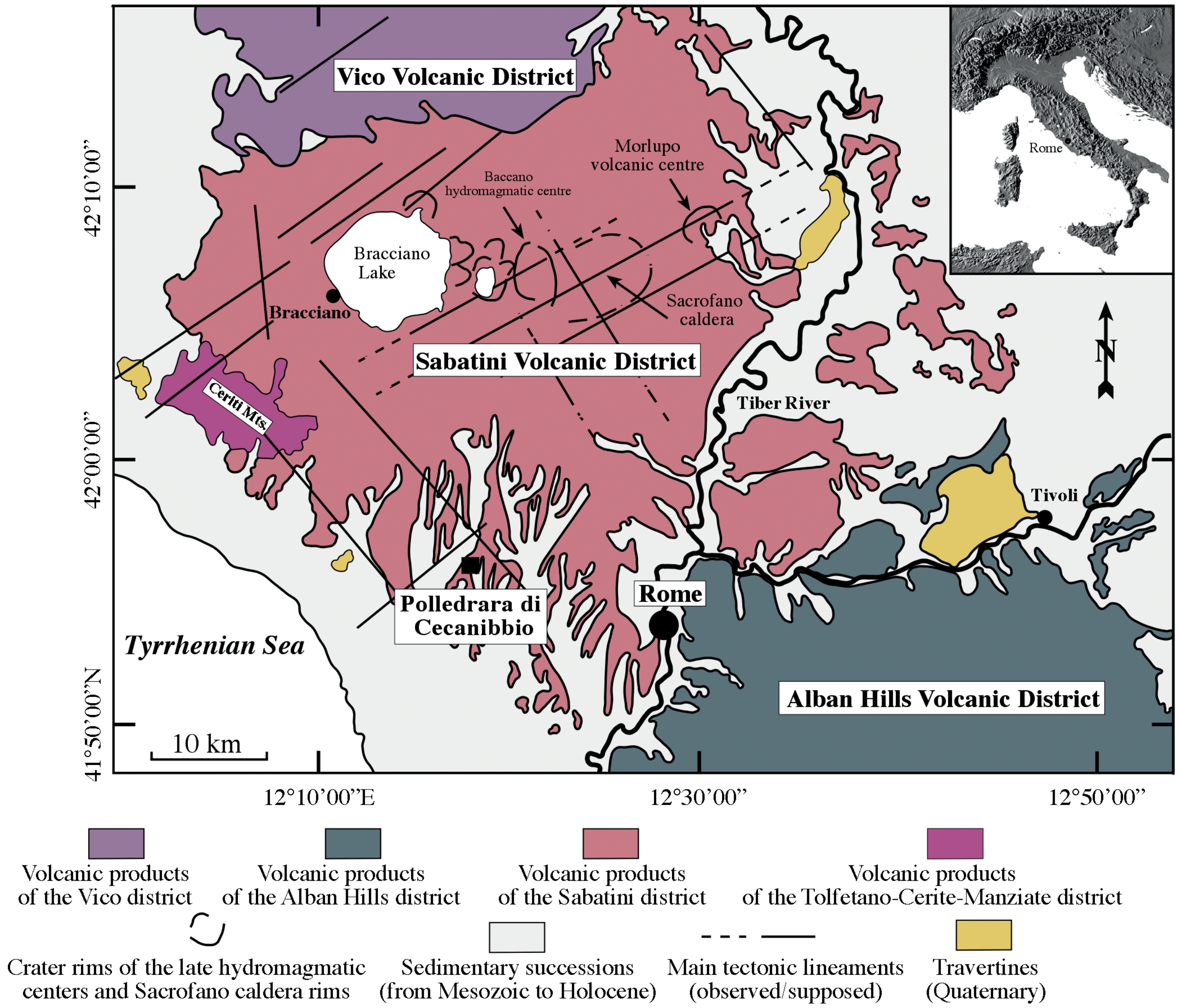

Fig. 1 - Geological sketch of the central-western Latium, central Italy showing the main volcanic districts of the area and the location of the Polledrara di Cecanibbio site (modified after Sottili et al., 2004).

curved channel segment, probably due to the decrease in floods frequency and amplitude, caused the filling of channel and its transformation into a swampy area with stagnant and muddy water, where at least three elephants were trapped. In several sectors of the riverbed, the depositional context documents the action of the fluvial current. In this area, it is possible to distinguish two zones separated by a step of approximately 80 centimeters, the height of which progressively decreases towards the center of the watercourse until it disappears. Upstream of the step, the river bottom appears very irregular, with raised and depressed areas. The latter, related to the effect of turbulence, constitute several scours filled with small skeletal remains, whose disposition locally influenced the directions and intensities of the fluvial currents. In this area, faunal remains have mostly accumulated in the depressed areas, while they are scarce in the embanked portions, which were more exposed to the hydraulic action of the current. Moreover, the tops of many of the highest areas are flat in shape and show evident mud cracks, reflecting their sub-aerial exposure due to seasonal fluctuations in river level. Downstream of the step, due to the increase in the width of the channel, the riverbed is flat, and the faunal remains are distributed almost uniformly. For example, in some areas, the long, narrow skeletal elements, such as the large elephant tusks, were arranged parallel or transverse to the direction of the stream and formed a barrier that favored the accumulation of smaller remains. In some cases, whirlpools associated with the acceleration of the flow around an obstacle produced under-excavation around a skeletal element (crescent scour structures).

With few exceptions, the faunal remains deposited on the riverbed, but often also the lithic artifacts represented by more than 500 specimens, present strongly striated surfaces, and a high degree of fluitation of the upper face, exposed to the current. Such features are not found in the lower face, resting on the bottom of the

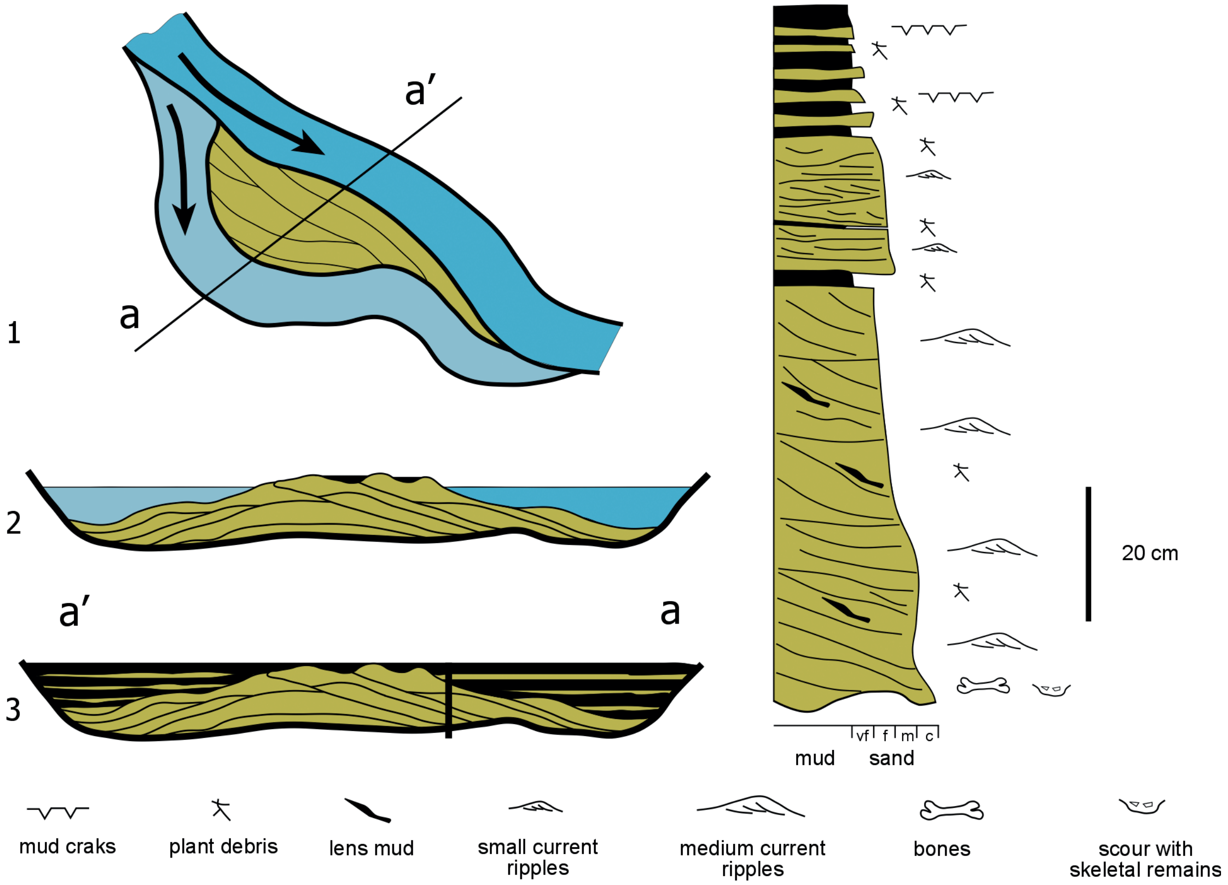

Fig. 2 - A) Paleo-environmental reconstruction of the Polledrara site. 1) Sketch of plan view of the two stream channel paths before and after the channel cutoff; 2) Cross-section showing the two channels just after the chute cutoff; 3) Cross-section showing the final stage of channel fills and waterlogging that is characterized by alternance of muddy (black beds) and sandy deposits. Vertical line indicates the position of the stratigraphic log (B). B) Stratigraphic log showing the depositional facies sequence of the point bar recognised in the fluvial deposits of the Polledrara site (note the fining-upward trend). The muddy deposits, which trapped the elephant described in the paper, constitute the upper part of the channel fill (modified from Anzidei et al., 2012).

riverbed, which is instead very often strongly eroded due to the chemical action caused by contact with the base sediment. Furthermore, traces of roots, impact fractures, or trampling are evident on the riverbed remains, and several traces of intentional anthropic fracturing for the extraction of marrow are present (Anzidei and Cerilli, 2001). Finally, there is a marked differential preservation of anatomical parts according to the density of their bone tissue: on the bottom of the channel, the hardest portions of elements belonging to adult individuals of large animals are more frequent, while skeletal elements derived from young or small animals, or with more abundant spongy tissue or thinner compact bone, are rare. Furthermore, on the bottom of the riverbed, skeletal elements in anatomical connection are very rare, whereas they are well represented in the later swampy phase, as are the skeletal parts of small animals.

These taphonomic arrangements (Cerilli and Fiore, 2018) indicate that the skeletal elements, and probably also the lithic artifacts, were essentially transported as bed load during flood events and that, once deposited on the bottom, they generally no longer moved significantly from their primary position, so remaining exposed to the flow of water for a prolonged interval of time. In contrast, the finds deposited in the subsequent channel abandonment show still traces of wear indicating that, after their transport and the subsequent deposition, they were almost immediately protected by further sediment deposition.

2.4. THE FAUNAL ASSEMBLAGE

More than 22,000 skeletal remains belonging mainly to large mammals, hundreds of lithic artifacts, and some bone-tools are preserved in the sediments deposited in various phases by the watercourse (Anzidei et al., 2012; Santucci et al., 2016; Cerilli et al., 2019; and references therein). The state of preservation of the skeletal elements is on the whole good, also due to reduced chemical-physical variations induced by their permanence in the sediment: X-ray diffraction analyses on bone samples show that the main mineral phase is hydroxyapatite, but fluorapatite and barite phases have also been identified (Marano et al., 2016, 2021).

In the faunal association of La Polledrara (Anzidei et al., 2012), *Palaeoloxodon antiquus* and *Bos primigenius* are the most represented species, while *Macaca sylvanus, Meles meles*, *Vulpes vulpes*, *Canis lupus*, *Felis silvestris*, *Stephanorhinus* cf. *S. hemitoechus, Equus ferus*, *Sus scrofa*, *Cervus elaphus*, and *Bubalus murrensis*, are less numerous. The assemblage also includes bird bones (mainly Anseriformes), rodent remains, both Muridae (*Apodemus sylvaticus*, *Microtus (Iberomys)* cf. *M. (I.) breccensis*) and Arvicolidae (*Pliomys* cf. *P episcopalis*, *Arvicola* sp.), as well as scarce elements of *Lepus* sp., as well as amphibian, and reptile specimens, which are currently under study. The faunal assemblage taxonomic composition, as well as the isotopic data and the results of the microwear analysis of the elephant molars, suggest that the landscape surrounding the watercourse was characterized by a large forest cover interspersed with open spaces and moderately humid and temperate climate conditions (Filippi et al., 2001; Palombo et al., 2005). The lack of pollen and plant fossil remains does not allow further confirmation this hypothesis.

2.5. THE ANTHROPIC PRESENCE

A single fossil tooth and the artifact material evidence the presence of Paleolithic humans. The human fossil is a deciduous upper second molar belonging to an individual aged around 11 years, whose morphometric analysis places it at the edge of the variability of modern humans and outside the Neanderthal range; this supports the hypothesis of a chrono-specific attribution to an "Anteneanderthal" or *H. heidelbergensis* (Buzi et al., 2021; Bondioli et al., 2022).

The Paleolithic evidence consists of a considerable number of artifacts found in the river deposit and numerous traces of anthropogenic impact on animal bones. The assemblage includes around 500 artifacts, with the addition of approximately 600 items associated with the carcass of one of the elephants trapped in the mud (Anzidei et al., 1999, 2004, 2012; Santucci et al., 2016; Lemorini et al., 2022). The lithic tools were made using small siliceous and rarely calcareous-siliceous pebbles, like those found in some levels of the Ponte Galeria Formation (Anzidei et al., 1999). Cores, flakes, and tools on pebbles and on flakes (denticulates, notches, scrapers and numerous multiple tools) are represented, as well as debris, the latter more frequent in the marshy phase. On some artifacts, both retouched and unretouched, use-wear attributable to the cutting of soft tissues, such as skin and meat, and woodworking, have been identified. There are no bifaces, in contrast to other roughly coeval sites located in the same geographic area, such as Castel di Guido (Radmilli and Boschian, 1996; Boschian and Saccà, 2015; Villa et al., 2021), Torre in Pietra (Piperno and Biddittu, 1978); Malagrotta-Capanna Murata (Radmilli, 1985).

Some artifacts were made using large fragments of elephant diaphysis as blanks (Anzidei, 2001). The use of so-called expedient tools is also well-represented. In addition to flint and bone artifacts, anthropic frequentation is also evidenced by a conspicuous number of bones intentionally fractured for marrow extraction (Villa et al., 1999; Anzidei and Cerilli, 2001), a practice linked to the recovery of nutrients contained in the marrow (i.e., Lupo, 1998).

2.6. THE HUMAN-ELEPHANT INTERACTION

As mentioned above, at La Polledrara, three elephants were trapped in the mud marsh sediments deposited during the last depositional phase (Anzidei et al., 2012; Santucci et al., 2016). The skeletal remains of one individual consist of the almost anatomically positioned tusks, the cervical vertebrae, and part of the hind limbs. Those of a second individual, found at a short distance from the first one, consist of a complete and anatomically connected right forelimb, and a left *manus*. The remains of the third individual, was found in an area close to the right bank, are of particular interest since the skeleton is in close spatial relation to human artifacts (Santucci et al., 2016; Lemorini et al., 2022).The skeleton is in partial anatomical connection: the skull, lacking of the neurocranium, and part of the postcranial skeleton are preserved; the forelimbs are flexed below the thorax and are missing the right humerus; the hind limbs are almost complete with the left one extended posteriorly and the right one partially flexed with both autopods arranged with the plantar surface facing upwards. Both femurs preserving the distal portion with traces of intentional fracturing of anthropogenic origin, likely aimed at the acquisition of large portions of bone to extract the marrow and perhaps also to obtain blanks for the manufacture of large bone-tools.

The axial skeleton is missing, though five cervical vertebrae, found near the skeleton could belong to this individual. The skeleton belongs to an adult elephant, possible a male had dead at about 31-47 years (following Laws, 1966), had a wither height ranging from 3.450 m (following Osborn, 1942) to 3.631 m (following Larramendi, 2016) and a body mass estimate of 8322-10580 kg, following Christiansen (2004) 8457-10150 kg, following Larramendi (2016).

The analysis of chipped stone tools found in the area of the elephant (Lemorini et al., 2022) allowed us to document various episodes of exploitation of the carcass by humans. The entire lithic assemblage was made of local flint pebbles of small size. No lithic bifaces were recovered during the excavation. The integration of the use-wear and residues analyses with the technological, refitting, and spatial analyses, combined with an excellent preservation of the lithic surface and a low degree of dispersion of the lithic items, documented the activities carried out with a spatial and chronological perspective.

The human group that arrived first at the site carried a lithic toolkit ready to be used, as suggested by the absence of refitting, which would have otherwise documented knapping activities on the spot. Use-wear and residues highlighted their use in butchering, which occurred especially on the right side of the elephant. The contact with fleshy tissues and hide testifies that at that time, the carcass was already intact; the meat was cut in pieces, and fat was possibly collected by scarping the inner part of the elephant skin. A second arrival was characterized by the knapping on the spot, as testified by the refitting, and the use of some of the knapped tools for butchering and, in a single case, for bone scraping, possibly to clean the bone from the periosteum and to prepare it for the breakage. Still, hominis found a carcass preserving exploitable soft tissues. Finally, humans were active around the carcass also when the skeleton was abandoned. They were knapping around the carcass, and they possibly stored the lithic products in a small area between the incisive bone and the left tusk, suggesting that the elephant carcass was also considered a sort of landmark for caching lithic tools for future uses (Santucci et al., 2016; Lemorini et al., 2022).

Striae were found on some elephant bones, but the effect of sediment abrasion prevents their resolution through microscopic analysis. The fractured femurs and the presence of a number of elephant-long bone diaphyses in the same area indicate fractures and flake detachments. These occurrences, in terms of quantity, location, concentration, and overlapping cannot be attributed to simple butchery activities. Instead, they support the hypothesis of raw material shaping actions and suggest an intensive exploitation of this area (Cerilli and Fiore, 2018).

2.7. THE DAILY FOOD EXPENDITURE AND THE DIETARY NEEDS OF *H. HEIDELBERGENSIS*

In the attempt to reconstruct the potential resources available in the La Polledrara site area, it is necessary to establish the hypothetical energy and food needs of the Anteneanderthal individuals who frequented this area of the Campagna Romana.

The total energy expenditure (TEE) or daily energy expenditure (DEE) required to support the basal metabolic rate (BMR), physical activity, and thermoregulation, as well as to ensure production, which includes growth, fat storage, and reproduction, constitutes a living organism's daily needs (Snodgrass and Leonard, 2009). The DEE, or TEE, can be calculated directly from the individual's weight using the appropriate formulae, or first calculating the BMR or RMR (Resting Metabolic Rate) (BMR and RMR are two conceptually similar values, but they differ in the measurement procedure), taking into account the Physical Activity Level (PAL), assignable to the individuals in a specific environmental context and way of life, varying between 1.55 and 2.1 (Panter-Brick, 2002). The value of this latter parameter was set at 2.0, in consideration of the surrounding environment, characterized by a morphology that is probably hilly or flat with a mosaic vegetation cover not overly dense, being characterized by wooded areas interspersed with open spaces, in a moderately humid and temperate climate, with good availability of water and food resources. The formulas used to calculate DEE are reported in table 1.

In terms of body weight, the choice of reference sample fell on the set of individuals that can conservatively be assigned to the informal group of Afro-Asiatic specimens defined as Middle Pleistocene *Homo* (Athreya, 2007; Wang, 2011; Manzi, 2011, 2016, 2021; Mounier, 2012; Xiao et al., 2014; Roksandic et al., 2018; Lacruz et al., 2019; Harvati and Reyes-Centeno, 2022) that could represent the Last Common Ancestor of *H. neanderthalensis* and *H. sapiens* (e.g., Rightmare, 1998, 2008; Mounier, 2009; Manzi, 2016; Wood and Boyle, 2016; Lacruz et al., 2019; Meneganzin et al., 2022) and, most likely, also of the so-called "Denisovans" (Manzi, 2016; Di Vincenzo et al., 2017). This group includes the specimens found at Sima de Los Huesos (Atapuerca, Spain), that were initially ascribed to *H. heidelbergensis* (Arsuaga et al., 1997) and more recently, even to *H. neanderthalensis* (Arsuaga et al., 2014; Meyer et al., 2016; Quam et al., 2023). As a matter of fact, their taxonomic attribution is still under debate (Manzi, 2016; Lacruz et al., 2019; Profico et al., 2023), especially in light of the genetic analyses carried out on them (Meyer et al., 2014, 2016) and the morphological observations made on their skulls, some of which display

Tab. 1 - Formulae used to calculate the Daily Energy Expenditure (DEE) (RMR: Resting Metabolic Rate; BMR: Basal Metabolic Rate; TEE: Total Energy Expenditure).

Formula	**Reference**
DEE (kcal) = 725+31xWeight (male, 20°C)	Altman and Dittmer, 1968
DEE (kcal) = 525+27xWeight (female, 20°C)	
RMR = Weight$^{0.75}$x70	Kleiber, 1961
log(RMR) = 1.839+0.778xlog(Weight)	Leonard and Robertson, 1992
log(RMR) = 1,845+0,750xlog(Weight)	Kleiber, 1961
RMR = 69.1xWeight$^{0.761}$	Leonard and Robertson, 1997
TEE = 86xWeight$^{0.792}$	
BMR = 10.56xWeight+744	Froehle and Schoeninger, 2006
DEE (kcal) = RMRx1.77	Ben-Dor et al., 2011

features that differ from those typical for the so-called "classic Neanderthals", while others are closer to the Neanderthal ones (Lacruz et al., 2019).

If the Mauer mandible (Shoetensach, 1908) is included in this group, then the appropriate name for this species is *H. heidelbergensis* (Rightmare, 1998, 2008; Mounier, 2009; Mounier et al., 2011; Manzi, 2016; Mounier and Mirazon, 2016; Pagano et al., 2022; Profico et al., 2023), although "this species subsumes a substantial morphological variety, possibly even suggesting the presence of more than one hominid morph" (Schwartz and Tattersall, 2010).

The body weights estimated by the authors on the basis of different methodological approaches for *Homo* specimens collected in several sites (Tab. 2), or calculated as the mean of some chronological groups of Middle Pleistocene *Homo* (Tab. 3), may differ even for the same specimen or same group, depending on the methodology proposed (Ruff et al., 1997; Wood and Collard, 1999; Bonmatí et al., 2010; Ruff, 2010; Cunnane and Crawford, 2003; Rosenberg et al., 2006; Robson and Wood, 2008; Ben-Dor et al., 2011; Fonseca-Azevedo and Herculano-Houzel, 2012; Dingwall et al., 2013; Gallagher, 2013; Grabowski, 2016; Will et al., 1017, 2021; Püschel et al., 2021).

Using the body weight values of the *Homo* specimens with a sound geographical and chronological constraint, the minimum, average, and maximum values were calculated for the total sample, the male sample, the female sample, and the sample of indeterminate gender attribution (Tab. 4). The means of these values, approximated to the nearest kilogram, range from 66 kg to 78 kg, with an average of 70 kg. Using three of these values (66, 70, and 78 kg), the DEE was calculated, according to the formulas proposed by various authors (Tab. 5; Fig. 3). The mean of the values obtained is 2931 kcal for the total sample and 2885 kcal for the sample corresponding to 70 kg of body weight. Therefore, for the following considerations, a rounded DEE value of 3000 kcal will be considered for ease of calculation.

The daily diet of a human being consists of plant food (underground storage organs, leaves, fruit, and seeds), animal proteins, and fat. The maximum intake of plant food is limited due to the seasonal and territorial availability of plant resources, the physiological tolerance in the metabolism of fibers and toxins, the technological capabilities and the time required to process this type of food resource before its consumption, or a combination of the three factors (Ben-Dor et al., 2011). From a physiological point of view, the ability to metabolize plant resources basically depends on the masticatory capacity and the length of the gut. To estimate the physiological limitation due to the digestion of fibrous plants, Ben-Dor and coauthors (2011) proposed the linear equation $Y= 0.583MQ-0.208$, where MQ is the McHenry's megadontia quotient, equal to =0.9 for *H. heidelbergensis* (McHenry, 2009), and Y is the maximum percentage of a long-term daily intake of plant food. For *H. heidelbergensis* this equation provides a DEE value of 31.67%, corresponding to 950 kcal/day.

Protein intake is also subject to physiological restrictions, due to the ability to metabolize these substances and excrete their waste products, without affecting the function of certain organs, e.g., the kidneys (Metges and Barth, 2000). Although 3.8 g/kg bodyweight/day of protein can be consumed for brief periods (Rudman et al., 1973), it is currently recommended that a daily protein intake of 1.7 g/kg bodyweight/day be maintained to remain healthy (Eades and Eades, 1996). Recent studies indicate a long-term protein intake of 2 g/kg bodyweight/day (Metges and Barth, 2000). According to the latter value, the maximum amount of protein that an individual of *H. heidelbergensis* weighing 70 kg can consume daily for long periods would correspond to 140 g, which in energy terms corresponds to 560 kcal, the energy value of protein being 4 kcal/g. In terms of the amount of meat, if protein came only from animal sources, these values would correspond to approximately 500-700 g of meat depending on the animal (mammals) and on the meat cuts (Crea website, 2023), but it should be remembered that plants can also be a source of essential amino acids, although not always of high quality, as well as invertebrate animals.

These calculations show that a maximum of 1510 kcal of protein and plant food must be consumed in one day. The remaining part of the daily 3000 Kcal, equal to 1490 kcal, is easily attainable through fat eating (Ben-Dor et al., 2011). Considering that the fat has an energy value of 9 kcal/g, the amount required to satisfy approximately half of the DEE would only be 166 g. Such an amount is easily attainable, as shown below. Furthermore, the consumption of fat is also an advantage for the protein metabolism because the proper assimilation of proteins requires the intake of carbohydrates, vegetables, or fat (e.g., Richards and Trinkaus, 2009; Ben-Dor et al., 2011; Reshef and Barkai, 2015), in addition to water.

The balance between the energy costs of obtaining and preparing various foods and the energy costs of digesting and metabolizing them should also be considered when choosing a viable subsistence strategy. The energy return from collecting plant food varies depending on whether it is seeds and nuts (841÷1554 kcal/h) or roots and tubers (450÷1462 kcal/h), while the energy return from the large game is considerably higher (15,142 kcal/h) (Stiner and Kuhn, 2009). About small game hunting, the need to pursue several small, fast, and elusive animals increases the daily caloric requirement, which could only be efficiently met by fat intake in order to maintain a favorable balance between intake and expenditure (Ben-Dor et al., 2011). Finally, it must also be considered that plant food and meat protein digestion is costlier compared to fat, a larger percentage of fibers and proteins escapes digestion, while fat digestion is nearly complete. Therefore, animal fat is a very efficient energy source (Ben-Dor et al., 2011; Ben-Dor, 2013; Barkai, 2019; and references therein), and marrow is also a relatively safe food because fewer bacteria grow on marrow than on meat (Smith et al., 2015).

Tab. 2 - Body weight of selected specimens of Middle Pleistocene *Homo* calculated by several authors (1: Rosenberg et al., 2006; 2: Bonmatí et al., 2010; 3: Ruff, 2010; 4: Gallagher, 2013; 5: Will et al., 2017; 6: Will et al., 2021).

Specimen	**Localization**	**Age Myr**	**Gender**	**Body weight (kg)**					
		(1-4-6)		**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Jinniushan 1	China	0.23	F	78.6		77.1	75-79		77.4
Broken Hill (Kabwe) E689	Zambia	0.30				75.2		75.8	75.8
Broken Hill (Kabwe) E691	Zambia	0.30	M?						90.1
Broken Hill (Kabwe) E719	Zambia	0.30				75.6			73.7
Broken Hill (Kabwe) E907	Zambia	0.30				82.1		82.6	82.6
Sambungmacan 2	Java	0.40						61.9	68.2
AT-1004	Sima Huesos; Spain	0.43	F	62.2		65.3		66.2	66.2
AT-1480	Sima Huesos; Spain	0.43						72.4	72.4
AT-1832	Sima Huesos; Spain	0.43						65.8	65.8
AT-1930	Sima Huesos; Spain	0.43	F					66.1	66.1
AT-2350	Sima Huesos; Spain	0.43	M	75.1		74.7		75.8	75.8
AT-2803	Sima Huesos; Spain	0.43	M					80.3	80.3
AT-3132	Sima Huesos; Spain	0.43	F					75.6	75.6
AT-3133	Sima Huesos; Spain	0.43						58.5	58.5
AT-4425	Sima Huesos; Spain	0.43	F					72.1	72.1
AT-575	Sima Huesos; Spain	0.43						64.8	64.8
AT-800	Sima Huesos; Spain	0.43	M	75.1		74.7		75.8	75.8
AT-835+AT-2501	Sima Huesos; Spain	0.43	M	77.5		76.9		77.8	77.8
AT-859	Sima Huesos; Spain	0.43						63.8	63.8
AT-860	Sima Huesos; Spain	0.43	F					62.5	62.5
SH Coxal 1	Sima Huesos; Spain	0.43	F	69.9				56.9	56.9
SH Pelvis 1	Sima Huesos; Spain	0.43	M			78.1		78.7	78.7
SH Femur X	Sima Huesos; Spain	0.43	M		90.3-92.5			83.3	83.3
SH Femur XII	Sima Huesos; Spain	0.43	M						
SH Femur XIII	Sima Huesos; Spain	0.43	M						
SH Femur IV/V	Sima Huesos; Spain	0.43						69.0	69.0
SH Femur XI	Sima Huesos; Spain	0.43	F					58.3	58.3
SH Femur XII/XIII	Sima Huesos; Spain	0.43	M					73.8	73.8
SH Femur XVI	Sima Huesos; Spain	0.43	F					56.9	56.9
SH foot association 1	Sima Huesos; Spain	0.43	M					73.0	73.0
SH foot association 2	Sima Huesos; Spain	0.43	F					57.6	57.6
SH foot association 5	Sima Huesos; Spain	0.43	M					90.7	90.7
SH foot association 8	Sima Huesos; Spain	0.43	M					65.7	65.7
SH foot association 9	Sima Huesos; Spain	0.43	F					62.6	62.6
Arago 44	France	0.438				80.4		79.6	79.6
ThI94-UA28-7	Thomas Quarry, Morocco	0.50						59.8	59.8
Boxgrove	England	0.50	M					82.8	82.8
KNM-BK 66	Kenya	0.51							55.9
Trinil I	Java	0.54	M						51.7
Trinil II	Java	0.54							50.0
Trinil III	Java	0.54							49.3

Tab. 2 - Continued...

Specimen	Localization	Age Myr	Gender	Body weight (kg)					
		(1-4-6)		(1)	(2)	(3)	(4)	(5)	(6)
Trinil IV	Java	0.54							51.8
Ain Maarouf 1	Morocco	0.70							53.3
OH 28	Olduvai Gorge; Tanzania	0.70	F			72.3			62.2
Gesher Benot Ya'acov 1	Israel	0.75							52.0
Zhoukoudian Femur 1	China	0.77							54.8
Zhoukoudian Femur 4	China	0.77							54.3
Zhoukoudian VI	China	0.77							51.6
TD6 Hominin 10	Gran Dolina; Spain	0.85	M						76.0
OH 34	Olduvai Gorge; Tanzania	0.90							55.3

Tab. 3 - Body weight means of Middle Pleistocene *Homo* calculated by several authors for species categories and species/chronological categories (1: Ruff et al., 1997; 2: Wood and Collard, 1999; 3: Cunnane and Crawford, 2003; 4: Rosenberg et al., 2006; 5: Robson and Wood, 2008; 6: Ben-Dor et al., 2011; 7: Fonseca-Azevedo and Herculano-Houzel, 2012; 8: Gallagher, 2013; 9: Dingwall et al., 2013; 10: Grabowski, 2016; 11: Püschel et al., 2021).

Specimen	Age Myr	Body weight (kg)										
	(4-8-9-10-11)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Homo heidelbergensis (mean)	0.7-0.2		62	66.7		71		70		67	70.6	70.6
Homo heidelbergensis (mean males)						84	77					
Homo heidelbergensis (mean females)						78	56					
Late Middle Pleistocene *Homo* (mean)	0.2-0.3	65.6										
Middle Middle Pleistocene *Homo* (mean)	0.55-0.4	67.9										
Late Middle Pleistocene *Homo* (mean males)	0.2-0.3				65.6							
Late Middle Pleistocene *Homo* (mean females)	0.2-0.3				54.1							
Middle Middle Pleistocene *Homo* (mean males)	0.55-0,4				71.2							
Middle Middle Pleistocene *Homo* (mean females)	0.55-0,4				64.6							
Later Middle Pleistocene *Homo* (*H. heidelbergensis* /*Homo rhodesiensis*)	ca. 0.428-0.138								70-90			

Tab. 4 - Minimum (min), mean and maximum (max) calculated on body weight values of selected localized specimens of Middle Pleistocene *Homo* (n: numbers of body weight values calculated by several authors, see table 2).

Categories	n	Body weight (kg)		
		min	mean	max
Total localized specimens	99	49.3	69.82	92.5
Male localized specimens	33	51.7	77.52	92.5
Female localized specimens	28	56.9	65.52	78.6
Unidentified gender localized specimens	38	49.3	66.31	90.1

Tab. 5 - Daily Energy Expenditure (DEE) of *H. heidelbergensis* calculated for three body weight categories (utilized formulae: 1: Kleiber, 1932, 1961 + Ben-Dor et al., 2011; 2: Altman and Ditter, 1968; 3: Leonard and Robertson, 1992 + Ben-Dor et al., 2011; 4: Kleiber, 1961 + Ben-Dor et al., 2011; 5: Leonard and Robertson, 1997 (TEE); 6: Leonard and Robertson, 1997 (RMR) + Ben-Dor et al., 2011; 7: Froehle and Schoeninger, 2006 + Ben-Dor et al., 2011).

Body weight (kg)	**DEE (Kcal)**						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
66	2869	2415	3181	2868	2375	2966	2550
70	2998	2655	3330	2998	2488	3101	2625
78	3252	3143	3623	3251	2710	3368	2775

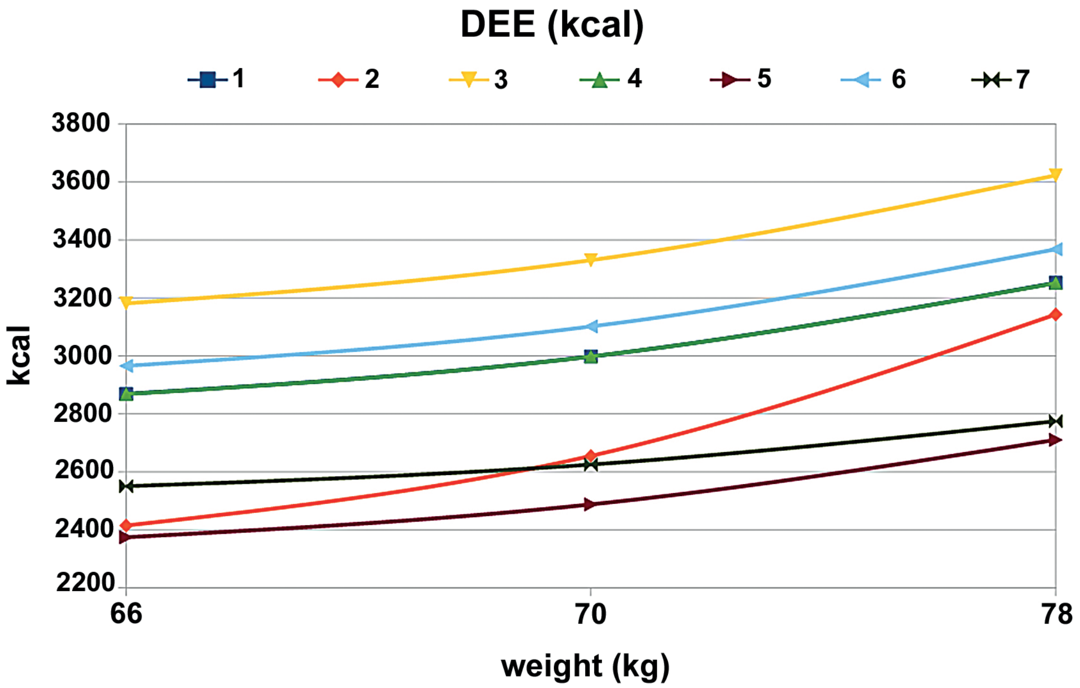

Fig. 3 - Graph of Daily Energy Expenditure (DEE) values of H. heidelbergensis calculated for bodyweights of 66, 70 and 78 kg (see Tab. 5), using formulae proposed by different authors (see Tab. 1). (1): Kleiber, 1932, 1961 + Ben-Dor et al., 2011; (2): Altman and Ditter, 1968; (3): Leonard and Robertson, 1992 + Ben-Dor et al., 2011; (4): Kleiber, 1961 + Ben-Dor et al., 2011; (5): Leonard and Robertson, 1997 (TEE); (6): Leonard and Robertson, 1997 (RMR) + Ben-Dor et al., 2011; (7): Froehle and Schoeninger, 2006 + Ben-Dor et al., 2011.

3. DISCUSSION

The presence of large and medium-sized mammals, whose meat and fat may have made an excellent food source for the Anteneanderthal hunter-gatherer bands that frequented La Polledrara di Cecanibbio area, is evidenced by the faunal association of this site, despite being represented by species and anatomical selected parts accumulated by natural processes (water transport or entrapment in the mud). The nutritional characteristics of the straight-tusked elephant (*P. antiquus*) have been calculated in terms of the number of calories, meat, and fat (e.g., Ben-Dor et al., 2011), but such information is not always available in the literature for the other animals of the La Polledrara faunal association. Accordingly, data available for animals of similar body weight and structure were used (Tabs. 6-8). As a result, the available data (Grizmek, 1975; Binford, 1978; Scott, 1985; Blumenshine and Madrigal, 1993; Ben-Dor et al., 2011; De Esteban and Kohle, 2011; Ballarin et al., 2016; Saarinen et al., 2016; Benoit et al, 2019) for African buffalo (*Syncerus caffer*) can be used to estimate the nutritional characteristics of aurochs (*B. primigenius*), and those for gemsbok (*Oryx gazella*), or wildebeest (*Connochaetes* sp.), or caribou (*Rangifer tarandus*) can be used to estimate the nutritional characteristics of deer individual of different size (*C. elaphus*). Finally, the data available for the common warthog (*Phacochoerus africanus*) can be used to estimate the nutritional characteristics of wild boar (*S. scrofa*).

The results (Tabs. 6-8) indicate that the herbivores recorded at La Polledrara are excellent sources of proteins and fat, understood as intramuscular fat, brain, and bone marrow fat (e.g., Ben-Dor et al., 2011; Agam and Barkai, 2015; Boschian et al., 2019; and references therein).

Tab. 6 - Fat and protein resources available from modern animals, or from taxa similar in weight to those identified at La Polledrara (data from Ben-Dor et al., 2011).

Species	liveweight[1] (kg)	% fat liveweight[2]	fat (kcal)	protein (kcal)
Palaeoloxodon antiquus	6952	4.1%	2117322	2182300
Syncerus caffer (male)	753	4.1%	229297	236400
Oryx gazella	168.5	4.9%	49151	68000

[1] excluding brain, heart, liver, tongue.

[2] excluding cancellous fat, seasonally variable.

Tab. 7 - Fat source: marrow in grams (*) available from taxa similar in weight to those identified at La Polledrara (hum: humerus; rad: radius; mc: metacarpus; fem: femur; tib: tibia; mt: metatarsus) (data from: Binford, 1978; Blumenshine and Madrigal, 1993; Ben-Dor et al., 2011).

Species	weight (kg)	hum*	rad*	mc*	fem*	tib*	mt*	Total*
Syncerus caffer (male)	753				143	176	46	(365)
Connochaetes sp.	165	39	37	11	38	61	13	364
Rangifer tarandus	110	76	72	42	104	128	42	574
Phacochoerus africanus	88	10	8	2	12	12	2	134

Tab. 8 - Fat source: brain available from modern animals, or from taxa similar in weight to those identified at La Polledrara.

Species	weight (kg)	brain (g)	References
Paleoloxodon antiquus	6979	6391	Benoit et al., 2019
Bos primigenius	700-1000	492-526	Grizmek, 1975, Scott, 1985, De Esteban and Kohle, 2011, Ballarin et al., 2016; Saarinen et al., 2016
Rangifer tarandus	110	362	Binford, 1978

Therefore, the animals living in the territory through which the river flowed and the portions of animal carcasses carried by the current, as well as the elephants trapped in the mud, likely represent an excellent food source for the bands of hunter-gatherers who frequented that area.

In a purely speculative exercise, it is possible to determine, by default, how each individual animal could have been sufficient to meet the dietary needs of the group of *H. heidelbergensis* that frequented the region where the La Polledrara site is located for several days by assuming that the group consisted of 10 individuals and ignoring the obvious structural distinction between males and females and age classes (Tab. 9). Since we do not know whether or to what extent humans of the Middle Pleistocene were aware of the processes of meat and fat preservation, which in the absence of the latter undergo putrefaction, fat rancidity, and saponification, changing the lipid profile (Forbes and Carter, 2016; Forbes et al., 2004, 2005, 2017), this calculation is, as was already mentioned, purely speculative. Given that fire should most probably have been mastered (Roebroeks and Villa, 2011; MacDonald et al., 2021; and references therein), one can certainly assume the use of cooking processes for food, which not only reduces the energy expenditure required for digestion, with a consequent decrease in daily requirements (Boback et al., 2007; Carmody and Wrangham, 2009), but also eliminates pathogenic germs (Ben-Dor et al., 2011; Smith et al., 2015).

On the other hand, we have no data on Anteneanderthals' ability to use fire to carry out preservation processes such as smoking, nor do we have data on its knowledge of drying processes by exposure to the sun and/or wind. However, alongside these, there are other processes of preservation, involving meat fermentation and fat autoxidation by lactic acid bacteria (LAB) fermentation, which prevent fats from becoming rancid and create important B-complex and other vitamins (Speth, 2017). There are several examples of these procedures. By simply

Tab. 9 - Hypothetical days covered by the fat/meat yield available from modern animals, or from taxa similar in weight to those identified at La Polledrara, for 10 individuals of *H. heidelbergensis*.

Species	fat	meat
Palaeoloxodon antiquus	142	390
Syncerus caffer (male)	15	42
Oryx gazella	3	12

storing meat and fat in pits dug into the ground (Jones, 2006), under piles of rocks in specially made seal-skin 'pokes' (Frink and Giordano, 2015), or submerging them in bogs, rivers, or shallow ponds (Fisher, 1995), they can be kept fresh, or fermented, for weeks or months and consumed without posing any health risks (Speth, 2017). Several examples can be given of the use of these procedures. For instance, seventeenth-century Khoisan hunter-gatherers of Namibia and South Africa scavenged the beached whales and put the meat in pits along the shore (Budack, 1977; Raven Hart, 1971), as did the Maori of New Zealand (Cawthorn, 1997) and natives of Tierra del Fuego (Darwin, 1982, p. 286). Eighteenth-century Native Americans of Pennsylvania ate putrid and maggot-infested deer or elk (Walton, 1790). Hadza in Tanzania often eats very rotten, week-old meat they scavenge from carnivores (Marlowe, 2004). Finally, modern hunters and gatherers throughout the Arctic and subarctic deliberately putrefy meat, fish, and fat (Speth, 2017). Therefore, it is possible that also the hunter-gatherers who frequented La Polledrara buried the edible parts of carcasses found in the river or marsh, either as a means of avoiding predation by antagonistic animals or as a means of preserving meat and fat.

Although palaeobotanical analyses at La Polledrara have so far been inconclusive since the sediment examined did not contain any plant fossil remains regarding the role of plant food, the plant food sources should have been extremely accessible near the river and could have been utilized in any circumstance. Regarding the procurement of animal resources, while hunting is certainly conceivable for small taxa, it is important to consider the organizational capacity of hunter-gatherer bands in the region and their capacity to hunt large animals, or rather, whether the latter species were exploited through scavenging when considering the procurement of large animal resources. (e.g., Blumenschine, 1986 a,b; Shipman, 1986; Selvaggio, 1987; Bickerton and Szathmáry, 2011; Nakamura et al., 2019).

Taking *P. antiquus* as an example, hunting patterns are potentially different (e.g., Agam and Barkai, 2018; Anzidei et al., 2021) and depend essentially on the number and organizational capacities of hunters, prey availability, vegetation cover, and the geomorphological conformation of the territory. The interaction between humans and proboscideans (mainly representatives of the families Deinotheridae, Elephantidae, and Mammutidae) is a long-lasting relationship and was witnessed during the Palaeolithic at numerous sites worldwide (Santucci et al., 2016; Anzidei et al., 2021; Palombo and Cerilli, 2021; Haynes, 2021). At La Polledrara, as already illustrated, exploitation through scavenging of water-borne portions or complete individuals trapped in the mud is certainly conceivable (Anzidei et al., 2012, 2015; Santucci et al., 2016; Lemorini et al., 2022). The characteristics of these sites indicate that over a very long period of time, opportunistic subsistence strategies based on the exploitation of carcasses of animals that died of natural causes were more frequently adopted, while the possible use of hunting, generally directed towards young individuals, seems to have been practiced in mainly more recent chronological periods, characterized by a social and technological organization that could allow such practice (Palombo and Cerilli, 2021; and references therein).

This hypothesis seems to be supported by both the statistical analysis of the characteristics of numerous archaeological sites and ethnographic comparisons with modern traditional societies, which demonstrate that elephant hunting requires a large group of hunters along with careful planning and organization because this activity is not without dangers. Even today, when the opportunity arises, the scavenging of elephants that died of natural causes is still practiced (Anzidei et al., 2021; and references therein).

Regarding other large mammals, such as *B. primigenius*, *B. murrensis*, and *E. ferus*, or medium-sized ones, such as *C. elaphus* and *S. scrofa*, it is possible to imagine a mixed supply strategy with both scavenging animal portions transported by the river and active hunting, the latter, especially towards medium-sized animals. Such mixed behavior can be found at several Middle Pleistocene sites, such as Terra Amata (France) (Cerilli, 2016; and references therein).

Finally, other likely sources of food through the so-called small game would still include small animals such as small carnivores, monkeys, lagomorphs, rodents, birds, and even herpetofauna. Contemporary ethnographic data (e.g., Lee and De Vore, 1976; Yellen, 1991) document that young individuals, old men, and occasionally women pursue small animals, especially fast-moving species, despite the potentially energy-consuming pursuit.

Based on these observations, some authors (e.g., Yellen, 1977; Stiner et al., 2000, 2009) have speculated that the presence of small animal species at several Palaeolithic sites is an indication of such "modern" behavior. Hence, it could be hypothetically suggested that also at La Polledrara, age classes and gender groups may have contributed to the meat component of the diet. In this regard, it should be remembered that, as already illustrated, the presence of at least one juvenile individual of *H. heidelbergensis* at La Polledrara is shown by the finding of the upper deciduous tooth.

4. CONCLUSIONS

Similar to other sites, the archaeological and palaeontological record of La Polledrara di Cecanibbio represents a tangible archive of past environments and life. By analyzing the deposit context, it is possible to reconstruct the geological and geomorphological evolution, paleoenvironmental characteristics, and the activities of the humans who frequented the regions surrounding the site.

The archeo-palaeontological evidence available at La Polledrara di Cecanibbio highlights and extends our knowledge about human-environment relations during the Middle Pleistocene and the subsistence strategies of *H. heidelbergensis* or, more generally, to humans of the Middle Pleistocene. Although it is unquestionable that, at La Polledrara, the main agents of bone accumulation were related to the successive activity phases of the river water, it is certainly undeniable that this site attracted the hunter-gatherer groups that frequented the area, for the formidable possibilities of exploiting the resources necessary to satisfy their daily needs even for long periods, both for food (animal meat and fat, but possibly also vegetables) and for the recovery of hard animal material to be used in the manufacture of artifacts.

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