State of the art of the funerary archaeoentomological investigations in Italy

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Received: 25 June 2021 / Accepted: 16 February 2022 / Published online: 25 March 2022
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Abstract
Archaeoentomology is a branch of environmental archaeology focusing on insects and other arthropods contributing, with other disciplines, to reconstruct a more complete view of past events, climate and landscape. Funerary archaeoentomology focuses on the arthropods associated with human remains or with elements part of funerary rituals such as offerings. In the last years, several papers have been published on Italian material covering around 5000 years. Sardinian necropolis, Egyptian mummies and offerings stored in public collections are among the oldest samples in which insects have been evidenced. Mummified and skeletonised bodies of kings, Saints and common people are another important source of insects in addition to remains of WWI soldiers. The arthropod remains found during these investigations belong mainly to Diptera (flies), Coleoptera (beetles) and Arachnida (mites). The aim of this paper is to summarise the Italian data about insects associated with human remains of archaeological interest in order to increase the interest and the utilisation of a discipline too often underestimated.

Keywords Insects · Funerary archaeoentomology · Past reconstruction · Diptera

Introduction
Archaeoentomology is defined as the study of synanthropic insects and other arthropods recovered during archaeological excavations, with the aim to better understand and reconstruct past environmental and climatic conditions and/or cultural practices (Kenward 1978). Archaeoentomology deals with anthropic settlements where insects found microhabitats similar to their natural environments and benefit from their facultative or obligate association with humans (King 2014). This is the distinctive trait in respect to the other, although close, discipline known as paleoentomology that specifically refers to the study of insect remains collected from natural environments free from any kind of anthropic activity. Paleoentomology was promoted by Russell Coope, a geologist, and Peter Osborne, an entomologist at the Quaternary Research Laboratory at the University of Birmingham (UK) in the late 1950s (Ashworth et al. 1997).

Indeed, archaeoentomology is a branch of the environmental archaeology which is a large interdisciplinary subject involving other disciplines such as geology, geography, climatology, biology, history and anthropology (Kenward 2009), all collaborating and providing information field-specific in order to draw a scenario as much accurate and complete as possible about the human past. As stated by Kenward, “No archaeological project involving excavation can now be regarded as having been properly executed unless the full range of evidence has been properly examined...” (2009) and, among the range of evidence, insects represent an important source of information at different levels.

The use of insects in the interpretation of past environments had its beginnings in Egypt in 1842 when the entomologist Reverend F.W. Hope wrote a paper reporting beetle remains
found inside the gut of a mummified ibis (*Threskiornis aethiopica* Latham, 1790) (Hope 1842). Despite the skepticism of the ornithologists, Hope’s finding allowed clarifying the diet habits of the bird (Panagiotakopulu 2001).

What makes insects an exceptional, although often underestimated, evidence to be analysed also in the archaeological context is that they are the most ecologically diverse group of animals, capable to survive in a large variety of habitats characterised by the most diverse environmental/climatic conditions (Buckland et al. 2014). Therefore, not surprisingly, the archaeoentomological investigations are essentially based on the habitat preferences of species recovered from ancient deposits to infer past scenarios, considering that the majority of them did not evolve in the last 2 million years and still exist nowadays allowing the data comparison (Forbes et al 2013; Buckland et al. 2014). Upon the identification of taxa found within an archaeological assemblage, information about the following topics can be derived:

- **Past climate and environments**, both inland and marine (estuarine and coastal) (Ashworth et al. 1997; Elias 2014; Buckland et al 2016; Smith 2017);
- **Human diet** (Panagiotakopulu 2001);
- **Agricultural practices** even through the study of stable isotopes accumulated in the insects’ exoskeleton (King 2012);
- **Commercial trades**, as in the case of the finding of the khapra beetle (*Trogoderma granarium* Everts, 1898), recovered from grain seeds within the collection of Egyptian Museum of Turin, which may indicate an early contact with the Indian subcontinent (Panagiotakopulu 2003);
- **Human living conditions and attitudes to hygiene** (Kennard and Hall 1997; McCobb et al. 2004; Panagiotakopulu 2004). For examples, ectoparasites living on hosts’ body such as lice (*Pediculus humanus* Linnaeus, 1758), fleas (*Pulex irritans* Linnaeus, 1758) and bedbugs (*Cimex lectularius* Latreille, 1802) were found in archaeological sites in Europe, North and South America, and Near East. Although they are generally indicators of scarce sanitary conditions (Raoul et al. 2006; Forbes et al. 2013; Forbes et al. 2015), Bain (2004) points out that in making these assumptions we are imposing modern Western standards of hygiene on those living in the past;
- **Permanence of settlements** (Ponel et al. 2000; Panagiotakopulu et al. 2007; Panagiotakopulu and Buchan 2015).

**Archaeoentomology and funerary practices: archaeology of death**

While studying the entomofauna assemblage discovered during the archaeological investigation of a tenth century sarcophagus attributed to one of the members of the family of the Counts of Toulouse, the French entomologist Jean-Bernard Huchet coined the name *archéoentomologie funéraire*, funerary archaeoentomology (1996). Huchet announced the birth of a new line of research where knowledge about medico-legal entomology and archaeology, as well as history found themselves weaved together in a very original way that nobody before thought about, and that can be summarised in the sentence “application of the medico-legal forensic entomology to the study and interpretation of insect remains associated with graves in archaeological contexts” (Huchet 1996). It is worth mentioning that the study of the entomofauna associated with a body after the death is the bulk of the so-called medico-legal entomology that mainly deals with the estimation of the minimum post-mortem interval (min PMI) (Amendt et al. 2007). However, despite that the min PMI cannot be traced in archaeological context, the study of the arthropods remains collected from a grave, combined with the knowledge of their biology, can provide relevant information about the “history” of the cadaver, including peri- and post-mortem events such as the season of the death, the estimation of the corpse exposure duration, delayed burial, grave reopening, identification of secondary burials and other aspects concerning the reconstruction of the taphonomic process (Huchet and Greenberg 2010; Huchet et al. 2013a, b; Huchet 2014). Interestingly, the two sister disciplines mainly differ in their timelines and purposes (legal in one case, historical in the other one) but they share the same approach of collection, analysis, preservation and, for some aspects, the interpretation of the samples (Huchet 1996; Giordani et al. 2018a, b).

When analysing insect’s assemblages collected from archaeological burials, six ecological groups of taxa can be distinguished (Huchet 2014):

1) Taxa associated to the corpses (skeletonised or mummified) and strictly associated to the decomposition process as members of one of the “successional waves”. In regard of the “colonisation mode”, two groups of organisms can be identified in this category (Huchet 2014) (Fig. 1):

- **Pre-depositional phase taxa**, including necrophagous insects colonising corpses or carcasses shortly after death in a time period prior to burial (e.g. Diptera: Calliphoridae);
- **Post-depositional phase taxa**, specialised in colonising underground corpses only (e.g. Diptera: Muscidae and Phoridae) (Figs. 2 and 3).

This distinction is essential to reconstitute the taphocenosis (i.e. the assemblage of cadaveric organisms) post facto, as the biodiversity of the entomofauna of buried corpses is different and reduced when compared to the community colonising an exposed body (Figs. 2 and 3);
2) Taxa associated with offerings such as clothes, ornaments, personal artefacts or vegetal matter as in the case of the recovery of the cutting leaves ant *Acromyrmex versicolor* Pergande, 1894 from a Mexican funerary bundle (Huchet et al. 2013a, b);

3) Taxa resulting from subsequent contaminations (Huchet 2010);

4) Human ectoparasites that in some cases have been identified as vectors of pathogens as in the case of Napoleon’s soldiers corpses carrying lice from which the DNA of the gram-negative bacteria *Bartonella quintana* (Schmincke 1917) Brenner et al. 1993, the agent of trench fever, was retrieved (Raoult et al. 2006) (Fig. 4);

5) Ectoparasitism in animals used as offerings such as in mummies of dog and guinea pigs respectively from Egypt and South America where the brown dog tick *Rhipicephalus sanguineus* (Latreille, 1806), the louse fly *Hippobosca longipennis* Fabricius, 1805, from the dog, and fleas of the genus *Pulex* Linnaeus, 1758 from the guinea pigs were reported (Dittmar 2000; Dittmar, et al. 2003; Huchet et al. 2013a, b; Otranto et al. 2014);

6) Environmental indicators, taxa associated with the primary deposition site/s. These insects can be associated to specific habitat, or to specific locations. They may also provide information about climate and general envi-
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Environmental conditions. Their presence on the body can be occasional or due to a passive transport.

The aim of this paper is to describe the most important achievement in applying the study of insects from archaeological, mainly funerary, contexts in Italy. Authors worked to verify and to validate the hypothesis that insects and other arthropods are indeed an important source of information providing further level of description and interpretation of archaeological contexts. The analysis of the Italian data was listed depending on the question that insects may help in answering: paleosol, funerary practices, contamination, alteration, biodiversity and paleopathology reconstruction.

**Paleoenvironment reconstruction**

Compared to the European scenario, the archaeoentomology field has received scarce attention in Italy (Fig. 5 and Table 1). Only a small number of studies in fact report records either from high altitude (Foddai and Minelli 1994; Ponel and Richoux 1997) or from areas at the sea level (Sacchi and Petti 2008) (Table 1). In particular, the study of the entomofauna of two Italian glacial sites allowed to infer paleoenvironmental information, leading, for example, to the discovery that approximately 18,000 years ago the Alps were at least 1,000 m higher and the temperatures were significantly lower in accordance to the Last Glacial Maximum (LGM) occurring in that period. *Amara alpina* (Paykull, 1790), a ground beetle (Coleoptera, Carabidae), today only distributed in the Scandinavian peninsula, confirms the climate change (Foddai and Minelli 1994). Sacchi and Petti (2008) instead interestingly report the first and only finding of ichnofossils attributed to a “puparium chamber” — the space where beetles complete their metamorphosis from larva to adult — from Pleistocene paleosols in Santo Stefano Island (Fig. 5).

![Fig. 3 Puparia of Phoridae, the coffin flies, in ventral and dorsal view (scale bar: 1 mm)](image)

**Funerary archaeoentomology and funerary practices reconstructions**

The published records concerning funerary-archaeoentomological research in Italy are slightly more abundant compared with the studies dealing with reconstruction of paleoenvironment based on insect remains, and on the time scale, they cover a range approximately between 4000 and 100 years ago (Fig. 5 and Table 1). Beyond showing a quite wide distribution on the Italian peninsula, the studies offer several aspects of interpretation, including reconstruction of funerary practices of either natural or artificial mummies, as well as the embalming methods and trace of lice infestation of Renaissance noble and royal families. In addition, some studies focused their attention on the analysis of the WWI soldier remains in a project related with their identification.

The most ancient record concerns the findings of partially mineralised fly puparia — the fly puparium, called also pupal cage, is the hard barrel, composed by the larval cuticle, where the metamorphosis takes place — and two Coleoptera elytral remains on human bones in the necropolis of Filigosa, in the neighbour of Macomer in Sardinia. Some puparia were nested inside the bones, a clear indication of subsequent deposition. The entomological findings were also useful in testing other archaeological hypotheses about the body exposure, before the burial.
and the condition of the funerary chamber at the time of the depositions. The presence of puparia of Calliphoridae, a taxon belonging to the first wave of colonisation of an exposed body, clearly indicated a period of exposure of the body before burial. In addition, the presence of beetle able to colonise body in dry condition revealed that the chamber was, at the moment of the deposition, dry and not partially submerged as it appears in 1965 when it was excavated (Tuccia et al. submitted).

The second most ancient record is about the Egyptian mummy Namenkhet Amun conserved at San Lazzaro degli Armeni Monastery, a small island in the Venice lagoon (Northern Italy), and whose studies conducted by Huchet (2010) reveal insect taxa (e.g. Chrysomya albiceps (Wiedemann, 1819) (Diptera, Calliphoridae)) in accordance with the hypothesis that a short exposition of the body prior the evisceration was completed and the body treated for the mummification (Huchet 2010).
The study of insect fragments found in association to visceral remains and materials used for the preparation of corpse belonging to members of the Medici family, which presided over Florence between 1434 and 1737, allowed to better understand the funerary practices adopted by the De’ Medici family. Especially it has been suggested that the embalming jars, safeguarded at the San Lorenzo Basilica in Florence, were briefly exposed to the environment prior to be sealed and probably reopened once the dry stage was reached. However, the absence of larder beetles (Coleoptera, Dermestidae) supports the hypothesis that at certain point the jars were made unavailable after embalming (Morrow et al. 2016).

The hypogeal taxa, mainly Muscidae in the genus *Hydrothaeae* Robineau-Desvoidy, 1830 found in association to the natural mummies of the Franciscan friars in Azzio suggest that the corpses were prevented from external exposition and that the decomposition occurred completely in the *putridarium*, underground room of Catholic Churches used in some Italian monasteries as typical burial from the sixteenth until the early twentieth century (Pradelli et al. 2019).

The entomological investigations conducted on the artificial mummified body of the Blessed Antonio Patrizi from Monticiano in the province of Siena, Tuscany, allowed the authors of the study to suggest a short exposition of the body, likely in an indoor place, prior to be sealed in the sarcophagus, inferred upon the conspicuous abundance of *Hydrotaea capensis* (Wiedemann, 1818) (Diptera: Muscidae) and the lack of coffin flies (Phoridae) (Morrow et al. 2015). However, this conclusion is not supported by other evidence and by any other case study.

Studies on the tombs located in the Sacristy of the Basilica of Saint Domenico Maggiore (Naples) preserving the
bodies of King Ferrante II d’Aragona and other Renaissance nobles provided interesting information about the funerary practices of the period and about the event that occurred to the tombs in the last centuries (Loni et al. 2019).

If the previous mentioned works analysed the insects collected from a limited number of bodies — mummified, partially mummified and skeletonised — the studies carried out on the Capuchin catacombs of Palermo (Palla et al. 2011; Querner et al. 2018) and the studies still in progress on the human remains from the crypt of Roccapelago and Monsampolo (Vanin et al. 2020) deal with a huge amount of bodies providing a long list of species and a better understanding of the local saprophagous entomofauna. In addition, these studies are providing entomological records that allow comparison with the entomofauna nowadays to trace the effect of the climatic changes as well as of the hygienic conditions of the populations in the last centuries. The interest for the insects of the Palermo Capuchin cemetery was already mentioned by the French physician Louis François Étienne Bergeret — also known as Bergeret d’Arbois — in the nineteenth century (Benecke 2001) but only in the last years several papers have been produced on this topic revealing a very complex community of mites, pseudoscorpions and several taxa of insects, the majority of them saprophagous or saprophilous.

Palermo was also the location where the coffin of the Holy Roman Emperor Frederik II (1194–1250) was investigated from an entomological point of view describing the presence of not only the commonly found Muscidae and Fanniidae in the genera Hydrotaea Robineau-Desvoidy, 1830 and Fannia Robineau-Desvoidy, 1830 but also species in the families Carnidae and Milichidae (Leto Barone et al. 2002). It is worth mentioning that the same species of Milichidae, Leptometopha latipes (Meigen, 1830), found in the Frederik coffin was also collected few years ago from a body in a Maghreb country, in Northern Africa (Giordani et al. 2018a, b).

Roccapelago, with more than 30 species reported, represents the site with the highest saprophagous/saprophilous biodiversity described, but further work needs to be done before ending the list of the species from this site (Vanin et al. 2020).

### Funerary archaeoentomology and the season of the death

An interesting area of investigation has been the entomofauna associated with the remains of WWI soldiers from the Italian Front, called also the Alpine Front, in a project aiming to identify the remains and providing a proper worthy burial. In this case, insects were used to obtain information about the season of the death and to evaluate the exposure of the bodies before their burial (Gaudio et al. 2013) or be accidentally covered by soil (Vanin et al. 2010).

### Funerary archaeoentomology and contamination

Egyptian samples, stored in the museum of Turin, one of the largest and most interesting collections of Egyptian material outside Cairo, were analysed by Panagiotakopulu (2003). In this study, “victual mummies” and other materials were analysed in order to identify the presence of the entomological specimens (Panagiotakopulu 2003). In addition to useful and serious consideration dealing with “ancient versus modern infestation”, the study produces some of the earliest records of pest insects of stored products and the first evidence of early contact with the Indian subcontinent (Panagiotakopulu 2003).

Huchet analysed also the fragments of a beetle (Coleoptera, Scarabeidae) and of a parasitoid wasp (Hymenoptera, Ichneumonidae) from a Roman funerary urn discovered in the Tomb 40 I Pompei, but he concluded that they were the result of a secondary contamination and not related with any specific taphonomic process (Huchet 2013).

An entomological collection with traps, carried out in the Palermo Capuchin cemetery, allowed to identify pest insects active in the deterioration of the mummies and of material, such as wood, associated with them (Querner et al. 2018). This study, performed to collect living insects, allowed to better describe the past entomofauna associated with the mummies removing from the total records the species still active.

In a recent work, Vanin et al. (2021) focusing on the osteological collection of the University of Bologna report the co-presence on the bones of insects associated with the body decomposition (mainly Diptera puparia) but as well of museophagous species (mainly Coleoptera and Lepidoptera). In this work, the authors provide some suggestions to discriminate between these two insect categories.

### Funerary archaeoentomology and bone alterations

The Sardinian case of Pill’e Mattu Quartucciu necropolis, numbering more than 270 burials of Roman time period, is the unique study conducted on skeleton remains and proving that the osteolytic lesions — circular holes in bones — were caused by wild bees and solitary wasps (Hymenoptera). The analyses carried out by the archaeologist Emanuele Pittoni in cooperation with a team of entomologists revealed the presence of a variety of damages including round holes and irregular bone destruction caused by three species of Hymenoptera belonging to Sphecidae and Halictidae families (Pittoni 2009). Due to the regular shape of the holes and their wide presence in all the necropolis, other hypotheses such as plant root damage, chemical solution or microbial activity...
have been excluded, confirming the involvement of the solitary bee/wasp activity in the diagenesis bone process. The implications of this kind of observation about post-mortem bone injuries from archaeological samples are also useful in the interpretation of cases nowadays when unusual body alterations are examined by forensic anthropologists and pathologists (Viero et al. 2019).

Funerary archaeoentomology and paleopathology

The paleopathological studies conducted on the mummy of Ferdinando II of Aragon (King of Naples from 1504 to 1516) revealed a case of “royal pediculosis” (Fornaciari et al. 2009), while the examination of Capuchin monks’ mummies in Palermo revealed the infestation by the parasitic mite (Sarcoptes scabiei) which causes the scabies (Gutierrez 1990).

Funerary archaeoentomology and biodiversity study

The finding of Hermetia illucens (Linnaeus, 1758) (Diptera: Stratiomyidae) in the sarcophagus of the princess Isabella of Aragon led to questioning about the beginning of the spread of this fly from the American continent to Europe (Benelli et al. 2014). In fact this species was supposed to be having colonised the European continent during the twentieth century, whereas the Benelli’s finding backdates the introduction of the species in the Old continent to the sixteenth century.

On the other hand, investigations conducted on Castelsardo (Sardinia Island) mummies, reveal the presence of Phormia regina (Meigen, 1826) (Diptera: Phoridae) which is no longer present in Sardinia. Some hypotheses about the disappearance of the species have been suggested but further research needs to be performed to clarify this potential local extinction.

Some investigations carried out in Palermo about the interaction and relation between microbiome and entomofauna have been carried out revealing a complex food web of fungi, bacteria and insects (Palla et al. 2011).

Conclusion

Overall, the mentioned studies show the important implications that archaeoentomological studies can provide in support of other disciplines with the aim to recreate the whole picture of historical events and providing interesting information about past faunas. The communicating vessel system between funerary archaeoentomology and forensic entomology allows a better interpretation of the data of the past based on records nowadays as well as the interpretation of present forensic cases based on past data, especially in cases of mumified and concealed bodies. The checklist of the species of funerary and forensic interest is still far to be complete but several studies are ongoing in this field in Italy and abroad thanks to the increasing interest of some research groups. In addition, both the recent availability of descriptions and diagnostic keys for immature stages such as Diptera puparia (Giordani et al. 2018a, b, 2019; Giordani and Vanin 2020) and the more and more efficient molecular investigative techniques are providing useful tools for the identification of challenging specimens such as fragmented individuals and immatures. In conclusion, it is also important to highlight that, in some cases, the entomological findings can be the results of secondary contamination that happened in the past or are still active such as in the case of beetles associated with wood or clothes moths. For this reason, only a serious and critical examination and interpretation of the collected species based on a deep knowledge of their biology, ecology and distribution is fundamental to avoid any misinterpretation and false reconstruction.

Funding Open access funding provided by Università degli Studi di Genova within the CRUI-CARE Agreement. The work of F. Tuccia was funded by the Leverhulme Trust Doctoral Scholarship programme.

Declarations

Conflict of interest The authors declare no competing interests.

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