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Forensic acarology: an introduction

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Abstract Mites can be found in all imaginable terrestrial habitats, in freshwater, and in salt water. Mites can be found in our houses and furnishings, on our clothes, and even in the pores of our skin—almost every single person carries mites. Most of the time, we are unaware of them because they are small and easily overlooked, and—most of the time—they do not cause trouble. In fact, they may even proof useful, for instance in forensics. The first arthropod scavengers colonising a dead body will be flies with phoretic mites. The flies will complete their life cycle in and around the corpse, while the mites may feed on the immature stages of the flies. The mites will reproduce much faster than their carriers, offering themselves as valuable timeline markers. There are environments where insects are absent or rare or the environmental conditions impede their access to the corpse. Here, mites that are already present and mites that arrive walking, through air currents or material transfer become important. At the end of the ninetieth century, the work of Jean Pierre Mégnin became the starting point of forensic acarology. Mégnin documented his observations in 'La Faune des Cadavres' [The Fauna of Carcasses]. He was the first to list eight

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distinct waves of arthropods colonising human carcasses. The first wave included flies and mites, the sixth wave was composed of mites exclusively. The scope of forensic acarology goes further than mites as indicators of time of death. Mites are micro-habitat specific and might provide evidential data on movement or relocation of bodies, or locating a suspect at the scene of a crime. Because of their high diversity, wide occurrence, and abundance, mites may be of great value in the analysis of trace evidence.

Keywords Carcass · Forensics · Animal decomposition · Trace evidence · Post mortem interval

Introduction

Mites are everywhere! Mites can be found in all imaginable terrestrial habitats, in freshwater, in salt water; mites can be found in our houses, on the curtains, in and on our mattresses, on our clothes, and even in the pores of our skin. Many mites feed on microorganisms associated with decay and they, in turn, form the diet of predatory species. Others are parasites and commensals of plants, vertebrates and invertebrates, with varying degrees of host specificity. Most of the time, we are unaware of them because they are small and easily overlooked.

Mites have colonised as many habitats as insects and have better exploited modern living and working conditions, especially those in temperate climates and developed countries. The storage of food in refrigerators and the common use of synthetic fabrics and carpets have successfully limited the number and diversity of insects to a point where the arrival of a single fly can cause surprise and annoyance. Our homes and means of transport contain a surprising variety of species, mostly unnoticed by us, and surveys of indoor environments have demonstrated the range of microhabitats exploited by them. Extensive and detailed work on so-called dust mites has clearly established that mite species on our bed linen are very different from the mite species below our beds. Mites on our clothes are different from the mites on our skin and the mites associated with the living room couch. Moving from habitat to habitat and room to room, mites inhabit an incredible variety of microhabitats, exhibiting considerable specialisation and spatial resolution in diversity (Frost et al. 2009).

Compared to the routine use of insect evidence, mites, despite their ubiquity and diversity, hardly feature in the field of forensics. In addition to problems associated with their small size, their use is inhibited by the difficulty of identification and lack of comprehensive knowledge about, for example, distribution, length of life cycle in natural habitats and, in the case of those transported by other invertebrates, the range of carrier species.

In this article we present an overview of mites in forensics and ask what capacity they have to make a greater contribution to modern investigations. The first mite associations observed in criminal cases were with human corpses. From investigations of mites on decomposing human and animal remains, there is a progression to mites as potential indicators of crime and as trace evidence to link objects or persons to a particular habitat at a certain point in time. Modern forensic entomology has now a record of at least 150 years of case studies and research. Forensic acarology should make good use of this and rapidly develop into a valuable alternate input into forensic analysis (Turner 2009).

Recognition and the first case

In recent years the importance of insects for forensic investigations has first been shown to the general public through popular science books such as ‘Maggots, murder, and men: Memories and reflections of a forensic entomologist’ (Erzinçlioglu 2000). ‘A fly for the prosecution: How insect evidence helps solve crimes’ (Goff 2001), ‘Corpse: Nature, forensics and the struggle to pinpoint time of death’ (Sachs 2001), ‘Death’s acre: Inside the legendary ‘Body Farm’’ (Bass and Jefferson 2003), ‘Murderous methods: Using forensic science to solve lethal crimes’ (Benecke 2005), and fictional novels like ‘The body farm’ (Cornwell 1994), ‘Blow fly’ (Cornwell 2003), ‘Shoofly pie: A Bug Man novel’ (Downs 2003), ‘Chop Shop’ (Downs 2004), ‘First the dead: A Bug Man novel’ (Downs 2008), to name a few. An even stronger impact comes from television shows as ‘Forensic Files’, ‘Dirty Jobs’ or ‘CSI: Crime Scene Investigation’, the latter one has been advised and inspired on some episodes by an acarologist who works on chigger mites.

However, the modern science of employing arthropods in forensic investigations started in the early 1800s in France, Germany, Italy and Spain (Benecke 2001; Amendt et al. 2004; Klotzbach et al. 2004). Only the second criminal case in France’s history that used arthropods for estimating a post mortem interval of a corpse employed mites. The corpse was that of a newborn baby girl found on waste ground of the rue Rochebrune in Paris, in January of 1878 (Brouardel 1879, 1895; Benecke 2001). It was covered in some kind of linen cloth soaked with moisture and rotten at the points that made contact with the soil. The body itself was completely mummified and sounded like cardboard according to the pathologist, Brouardel, performing the autopsy. The first case of using entomological evidence for the estimation of a post mortem interval, thirty years earlier (1848), was also a case of a mummified newborn baby (Bergeret 1855). The corpse in Brouardel’s case had caterpillars of the grease and fungus moth genus *Aglossa* (Pyralidae, Lepidoptera), which were already known to feed on fatty substances, in this case possibly on the precursors of grave wax or adipocere of the mummy. *Aglossa pinguinalis* and *A. caprealis* have been found near and on carcasses. No attempt was made to estimate the age of the moth larvae. The moths might have arrived early on the carcass because it takes several months before pyralid larvae start constructing characteristic silk tubes around themselves. However, there was no mention in the report of any such structures. Another possibility might be that the *Aglossa* species was rather recently attracted by the damp linen and so was a late arrival.

Also, the corpse was covered on the outside by a brownish layer, some 2 mm thick, composed exclusively of mite carcasses, exuviae and feces. Live mites were found in the interior of the child’s cranium. All mites belonged to a single species, the seed mite *Tyroglyphus longior*, now known as *Tyrophagus longior* (Acaridae, Astigmata), a species that is particularly active at lower ambient temperatures. It was known to feed on the fatty acids and soapy substances containing ammonia that form on carcasses during dry decomposition (Brouardel 1879). Other insects or arthropods, including *Dermestes* beetles (Dermestidae, Coleoptera), were noticeably absent. It was estimated that the corpse had a surface area of 3,000 cm^2 including the internal surface of the cranial cavity. Four mites, exuviae or eggs were counted per mm^3, resulting in a total of 2,400,000, mainly dead, mites on and in the entire corpse. Based on the then already published life histories of *T. longior* and *T. mycophagus* it was assumed that a few hypopial nymphs initially had arrived phoretically on the corpse. It was suggested that the mite arrived on flies, beetles or myriapods as transport hosts. *Aglossa* as a possible vector of the mite was not discussed, perhaps because moths and butterflies were not well known at that time as phoretic hosts of mites. *Aglossa costiferalis*, for example, is now known as a carrier for the mite *Blattisocius tarsalis* (Ascidae, Mesostigmata) (Treat 1975). However, there are some acarological problems. The species *T. longior* has lost the deutonymphal life stage at which the phoretic hypopi that attach to carrier hosts develop. Therefore, either *T. longior* arrived at the corpse by a different route or the mite species on the corpse was not *T. longior*. Details of this question are discussed in the article dedicated to this particular case, where the mite evidence is also re-analysed (Perotti 2009).

For the calculation of the post mortem interval of the mummified corpse it was assumed that every female of *T. longior* would give birth to 10 daughters and 5 sons, which would mature within 15 days. The original calculation was simply based on the following table:

1st generation after	15 days	10 Females	5 Males
2nd	30	100	50
3rd	45	1,000	500
4th	60	10,000	5,000
5th	75	100,000	50,000
6th	90	1,000,000	500,000

The minimum time necessary to achieve 1,500,000 mites is 3 months. Taking into account other factors, Brouardel estimated that the corpse was exposed to the air for 6–8 months. Brouardel, a professor of legal medicine, had asked for help with the mite identification from Mégnin, a veterinary surgeon in the French army who recently had become interested in mites. Mégnin continued later on to write, among other things, textbooks on parasitic mites and the fauna of corpses (Mégnin 1892, 1894). It took more than a hundred years before mites were recognised and used again to estimate a post mortem interval in a homicide case. As for many years in the case of insects, so many forensic scientists have been unaware of a potentially rich source of information for their investigations in the form of mites that has been right in front of their eyes.

Carcasses and time of death

During the first 72 h after death, medical parameters of the carcass are of most use to estimate the post mortem interval. Occasionally, a few eyelashes are plucked and examined microscopically for the presence of mites. The follicle mite, *Demodex folliculorum* (Demodicidae [Demodecidae], Prostigmata), is primarily found in the hair follicles of the eyelashes and eyebrows. If the mite is present, the chances of which increase with the age of the person, estimation of the time interval from death may be based on whether or not the mites are still alive. A second species, *D. brevis*, lives in the sebaceous glands of the follicles. Desch (2009) discusses the role of these mites in forensic studies.

The next stage in the decomposition of a corpse is most often covered by a complete cycle of blow flies (Calliphoridae) or flesh flies (Sarcophagidae). Life history data for the most common blow and flesh flies have been reasonably well established and can provide in many cases accurate estimations of a post mortem interval. After that, the successional colonisation of the remains by other insect groups provides a more coarse framework for the estimation of time. Lee Goff reviews the individual stages of decomposition of a human corpse in this issue (Goff 2009). Experimental studies on human decomposition are rare and so far have been limited to the University of Tennessee Forensic Anthropology Facility, frequently called the 'body farm', near Knoxville, Tennessee (Bass and Jefferson 2003). A new facility was opened in 2006 at the Western Carolina Human Identification Laboratory of the Western Carolina University in Cullowhee, North Carolina, while the Department of Anthropology of the Texas State University-San Marcos is currently considering a Forensic Anthropology Research Facility for Texas. Experiments on animal decomposition are slightly more numerous. Mites have been described on human and animal carcasses deposited in terrestrial habitats (Braig and Perotti 2009). A dominant and important group of mites associated with human and animal decomposition is the Astigmata (OConnor 2009). Mites can arrive in four principal ways at these carcasses, i.e., by walking, air currents, material transfer and biological transport as a phoront on another animal. The case of the mummified newborn baby described earlier may or may not have involved a phoretic mite species. Certain mite species have only been found attached to a specific species of insect for transportation, while others are phoretic on a wider range of taxa. Each different insect species might bring its own specific mite species to the dead body. The biology of phoresy of mites is important for the understanding of the behaviour and ecology of many mites associated with carcasses (Perotti and Braig 2009; Perotti et al. 2009).

Circumstances and stages of decomposition where mites might contribute valuable information to forensic investigations are manifold. Butyric fermentation and advanced decay will attract mites in such numbers that they become visible to the naked eye. However, they are often mistaken for mould, which is present at that time as well, or for fine sawdust, as has been emphasised by Haskell et al. (1997).

The most obvious contribution is to the area of long post mortem intervals, especially the dating of the later stages of dry decay or decomposition. During the drying stage, empty puparia are often employed for the identification of past insect species. These puparia might have many associated live mites (Haskell et al. 1997). These mites are not identified or used. Later, hardened exoskeletons of many beetles persist. These structures are often broken to a point where they become difficult to recognise. Dead mites are preserved as well but because of their much smaller size, they suffer considerably less damage than insects. Dead mites of many species can relatively easily be rehydrated, which will greatly facilitate their identification and thus potentially shed light on their manner and time of arrival. The well-sclerotized exoskeleton of members of the Oribatida, for example, persists for a long time after their death. Some species, e.g., of *Rostrozetes* (Haplozetidae), feed on dry skin in the later stages of decomposition.

Corpses deprived of blow or flesh flies, either through the absence of fly activity or increasingly through various forms of concealment of the body, constitute the biggest challenge for forensic entomology. Invasion of indoor corpses relies on the activity of outdoor flies, either blow or flesh flies. In many temperate countries, these flies are not available for colonisation for some months of the year. Remains are more and more being sheltered in a house or vehicle, or purposely concealed in a careful way restricting access by blow and flesh flies. In these cases, beetles will be one of the first major insect groups that might invade the corpse. Post mortem estimates based on beetle data are hampered by the fact that the number of instars, which is constant for fly species, varies for many beetle species depending on the stress environmental and nutritional conditions exert on the local population. The succession of mites might help resolve some of these problems. Recent forensic studies focus on tiny carrion-breeding scuttle flies (Phoridae) that still might get access where blow flies and other Calyptrata are successfully excluded from the corpse (Disney and Manlove 2005; Disney 2006). These scuttle flies might become even more valuable because they transport phoretic mites to the body to start a new succession of mite species (Fain and Greenwood 1991; Fain 1998a, b). Some of these species, for example *Macrocheles disneyi* (Macrochelidae, Mesostigma), have to date only been found on a phorid carrier (Fain and Greenwood 1991). In the absence of insects, decay is primarily a function of bacteria action. These are likely to attract a variety of bacteriophagous mites, which, in turn, will attract a variety of predatory mites. A complex food web of mites feeding on bacteria, algae, fungi, insect eggs and other mites will establish, starting a succession of different mite species. These mites are almost always overlooked, either because of their size, the lack of specific knowledge about them or they are not picked up using current forensic methods. Mite succession potentially constitutes a completely untapped resource for forensic purposes and could achieve greater resolution data in terms of time since death. Because mites have much shorter generation times and life spans than insects, the succession of mites might be faster than the succession of insects. This opens up the possibility of a higher resolution in estimating the post mortem interval.

The potential value of phoretic mites in terms of increased time resolution might be illustrated by the following factors. Many phoretic mite species are haplodiploid and the phoretic stage is female. In some species, the first generation after transport will be entirely male. Just by observing the sex ratio of a particular population, one might estimate a minimum time for that species on the body.

Mites have a greater diversity than insects in certain circumstances where carcasses come to rest. For example, few taxa of insects live in salt water (although they may be present in large numbers), whereas many aquatic mite species are present there. However, the question of whether or not mites contribute to the decomposition of submerged carcasses has never been addressed (Proctor 2009).

Forensic indicators

A wide range of biological material has been used to indicate circumstances surrounding actual or suspected criminal activity. Insects have been used as forensic indicators for as long as urban, medical and veterinary entomologists have investigated food spoilage, myiasis, stored product pests, and structural pests like termites or death watch beetles; the majority of cases being on the civil and litigation side, rather than on the criminal side. Davis (1928) suggested the presence of greenbottle flies of the genus *Lucilia* might indicate the approaching death of humans. Diatoms have been used to indicate whether a drowning victim might have been conscious, unconscious, already dead or might have experienced a sudden death when entering the water.

The use of insects like the false stable fly, *Muscina stabulans* (Muscidae, Diptera), and the lesser house fly, *Fannia canicularis* (Fanniidae, Diptera), in cases of child and elder neglect has brought insects and criminal forensic investigations more to the forefront of attention (Benecke and Lessig 2001; Benecke et al. 2004). Forensic investigations associated with animals in general, but focusing on animal cruelty investigations and with wildlife in particular, are becoming more prominent (Sinclair et al. 2006; Cooper and Cooper 2007; Merck 2007).

Mites have been used in archaeology as indicators of habitat type, human social and economic activities, and animal husbandry (Schelvis 1990, 1994; Ervynck 1999; Nielsen et al. 2000; Chepstow-Lusty et al. 2007). As with modern forensics, however, they have been much less used in analyses than have insects. Fossil soil mites are also used as indicators to reconstruct habitats (Solhoy and Solhoy 2000; Coetzee and Brink 2003). The abundance of soil mites and a respectable number of existing soil acarologists could contribute hugely to forensic soil analyses. In more damp soil near fresh water and in leaf litter, testate amoebae (rhizopods, thecamoebians), terrestrial species with a hard shell that remains intact, might provide additional forensic information (Gunn 2006).

On outdoor corpses, different blow fly species dominate in urban and in rural environments (Hwang and Turner 2005). Species composition also changes with latitude and season. Recent carrion succession studies, on open-air pigs in a European urban habitat, showed that two species considered to be biogeographic indicators for rural and shaded locations were dominant in the inner city. Also, a non-indigenous species, previously associated exclusively with southern tropical and subtropical habitats, has exhibited a range expansion (Grassberger and Frank 2004). The local and spatial resolution of blow flies for common crime locations might, therefore, become coarser in the years to come (Amendt et al. 2009). Mites in outside habitats are abundant and very diverse. The range of species of phoretic mites on insects that visit carcasses has not yet been appreciated. Determining the mite fauna associated with carcasses has the potential to significantly increase the amount of location-specific information and, hence, contribute immensely to questions of possible movements of bodies between less disparate habitats. Several groups of insects are known to visit carcasses at specific stages of decay but do not leave behind any recordable evidence that could be utilised. Butterflies and moths, for example, are well known to feed off the seepage from carcasses but are of no value for forensic evaluations. Yet, these insects might again contribute specific phoretic mites to the body and alter the succession of mite species.

Trace evidence

Forensic botany, particularly palynology, is a well-established discipline that primarily provides information on trace evidence, ecological information related to origin and identity, i.e., that which is present as a result of contact between people or objects and their surroundings. By determining the identity of pollen found, ecological information relating to origin can be given. Mites could also be used in such a way. Like pollen, they are small and light, and so have the capacity to be picked up unknowingly by humans, e.g., on their clothing or hair, and on other objects. Fibres of any kind have gained great importance as trace evidence in forensic investigations. Most mites are considerably smaller than fibres and may be more abundant under certain condition. These mites have DNA, whereas fibres do not, therefore they have the potential to provide complementary evidence. Some mites can even bite and leave forensically important information on a suspect (Turner 2009).

Insects have generally become less diverse in modern living quarters. Detailed studies of the causes of human allergies clearly show that this is not the case for mites. Often lumped together under the common name of ‘dust mites’, the omnipresence and diversity of these mites escapes the non-acarologist. A first record of the mites of stored food and houses in the UK has been assembled by Hughes (1976). Later, Van Bronswijk (1981) listed 147 mite species that had been recorded from house dust around the world. The taxa included species regarded to be visitors, e.g., plant and soil mites brought in with pot plants or on the shoes of people or the feet of pets, and disembarked parasites of pets and other animals. The permanent inhabitants comprised members of the Oribatida, Prostigmata, Mesostigmata and Astigmata; the greatest number of individuals and species belonging to the latter. Since

1981, many more detailed descriptions of the mites in domestic situations have been published, for example, those on bed linen, curtains, window sills, clothes, pets and in other indoor microhabitats (Colloff and Hopkin 1986; Horak et al. 1996; Arlian 2002; Frost et al. 2009). The work has clearly established that mite species on our bed linen are very different from the mite species below our beds. Mites on our clothes and the living room couch are different from the mites on our skin. Moving from habitat to habitat and room to room, mites inhabit an incredible variety of microhabitats, and exhibit specialisation and spatial resolution in diversity (Frost et al. 2009). Also, almost every detritivorous mite will attract its own predatory mite species, which in part explains the high diversity of the indoor mite fauna (Frost et al. 2009) .

House dust dwelling astigmatids include species that are also present in stored foods, e.g., members of the families Acaridae and Glycyphagidae (Hughes 1976), but the extensive literature on the fauna shows that the most abundant species belong to the family Pyroglyphidae, which feed on the skin flakes and other dander found in our homes. In a global survey, *Dermatophagoides pteronyssinus, D. farinae* and *Euroglyphus maynei* accounted for up to 90% of the house dust fauna (Blythe et al. 1974; Crowther et al. 2000).

New houses and homes might be colonised via the movement of mite-infested furniture or soft furnishings, the use of another arthropod for transport (phoresy), air currents or simply brought in by humans, e.g., on clothing, and their pets (Bischoff and Kniest 1998; Warner et al. 1999). House dust mites do not like to establish populations in new houses until humans are present (Warner et al. 1999). This is a very important point. The indoor acarofauna depends on the people living or working in these houses and homes. These indoor environments are important locations for forensic investigations, but this richness of mite biodiversity has not been exploited by forensic investigators. In this issue, Solarz (2009) focuses on the mites in a variety of indoor habitats.

Mites originating from outdoor habitats can also be useful trace evidence and give accurate evidence about movements or transportation of a body. For example, eggs and other immature stages of phytophagous mites can survive several days attached to decaying leaves associated with a body, while species such as *Cenopalpus pulcher*, which in Britain has only been found on unsprayed apple trees (Evans et al. 1961), have very restricted distributions. Plant parasitic mites show a much higher degree of diversity, polymorphism and spatial resolution than the host plant itself.

Mites also occur in artificial aquatic situations and contamination of corpses and other evidence of forensic interest. *Trimalaconothrus maniculatus* and *T. aquatilis* (Malaconothridae, Oribatida) and *Histiostoma ocellatum* (Histiostomatidae, Astigmata) have only been found in swimming pools or aquaria and complete their entire life cycle in water (Fain et al. 1986). Another oribatid, *Trhypochthoniellus crassus* (=*Hydronothrus aquariorum* and *H. crispus*, according to Seniczak et al. 1998) (Trhypochthoniidae), occurs in natural freshwater habitats, but also in swimming pools and aquaria. In a survey of 36 indoor swimming pools in Japan, 53% were positive for mites, whereas no mites were found in the four outdoor pools examined (Kazumi et al. 1992). *Trhypochthoniellus crassus* and *T. maniculatus* were found in a restricted geographical area, while *H. ocellatum* occurred widely throughout the country. Individual pools were mainly colonised by a single species.

The next step

To realise the potential of mites and forensic acarology, it is necessary to produce the data that clearly demonstrate how mites can contribute to investigations. At the same time, it will be important to raise the awareness of forensic scientists and investigators. However, ultimately for forensic acarology to take off, it will require that the forensic investigators collaborate with acarologists in a more open interaction. Even if the agencies and companies in charge of forensic investigations would have the resources to hire acarologists, there might not be enough acarologists left to fill the positions. Therefore, a following priority is to provide more user-friendly identification aids, such as picture-based keys, covering the diversity of mites (Baker 1999; Walter and Proctor 2001).

The ubiquity of mites means that there are few situations in which people and objects associated with crime will not be exposed to them. But, as well as being a potentially rich source of evidence, this has a disadvantage. If specimens found on a suspect or victim belong to a species that occurs in virtually every household, little information can be gained. DNA of the trace mites might provide a molecular fingerprint of the particular mite colony, thus immensely increasing the information content and resolution of mites as evidence. Since forensic laboratories are currently laid out to process molecular evidence, the future success of forensic acarology might depend on the adoption of molecular tools in the identification and characterisation of mites.

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