Involvement of larder beetles (Coleoptera: Dermestidae) on human cadavers: a review of 81 forensic cases

D. CHARABIDZE[1], T. COLARD[1], B. VINCENT[2], T. PASQUERAULT[2], V. HEDOUIN[1]

1 Univ Lille Nord de France, UDSL, Forensic Taphonomy Unit, F-59000 Lille, France
2 Institut de Recherche Criminelle de la Gendarmerie Nationale, Entomologie department, 93111 Rosny Sous Bois Cedex, France

Corresponding author: damien@forenseek.org, tel: +0033320623501, fax: +0033320623512

Abstract

From 1994 to 2013, French forensic entomology laboratories investigated 1093 cases. Larder beetles (Coleoptera: Dermestidae) were observed in 81 (7.5%) of these cases. To describe and analyze these 81 cases, Eight parameters were used: city, location (indoor or outdoor), decay stage (fresh, decay or dry), dermestid species and instar (adults and/or larvae), presence of living calliphorid larvae, presence of calliphorid pupae or adults and presence of other necrophagous species.

Eight Dermestidae species were observed: *D. frischii* (42% of cases), *D. undulatus* (35.8%), *D. peruvianus* (12.3%), *D. lardarius* (9.9%), *D. haemorrhoidalis* (8.6%), *D. maculatus* (7.4%), *D. bicolor* (3.7%) and *D. ater* (1.2%). Larder beetles primarily developed on human cadavers in outdoor locations in areas with a dry climate and were never reported in oceanic areas (which are characterized by frequent rainfall and high ambient humidity).

The number of dermestid species on a single corpse never exceeded 3. Typically, one species was found per corpse. Species differed between indoor and outdoor cases, with *D. frischii* and *D. undulatus* dominant in outdoor cases while *D. peruvianus* was dominant in indoor cases. Calliphoridae were found in 88% of the cases, while Hydrotaea and Piophilidae were observed 40% of the time. Regarding Coleoptera, *Necrobia spp*. (Coleoptera: Cleridae) were observed in 46% of the cases.

Lastly, we observed a typical decomposition pattern, with preferential feeding areas on the face, hands and feet (i.e. the extremities). Pupation chambers on or inside the bones were not observed.

Keywords

Forensic entomology; skeletonization; indoor corpses; colonization; dry remains

Introduction

The significance of larder beetles (Coleoptera: Dermestidae) in indoor or outdoor taphonomic processes has been poorly studied and remains generally misunderstood. Although many authors have cited these species [1–4], only a few case reports describing the activity of larder beetles on human corpses have been identified in the literature [5–9]. This study describes 81 unpublished forensic cases involving larder beetles and highlights the specific characteristics of these species in a forensic context.

Decomposition changes a fresh human body into a complete skeleton. These postmortem changes are highly complex and variable and depend on the environmental conditions [10, 11]. Several processes, such as cellular autolysis, putrefaction and insect activity, contribute to this skeletonization. Given this complexity, the time required for a body to become a skeleton can vary from days to years. The decomposition rate depends primarily on two key factors specific to the local environment: temperature/humidity and accessibility to insects [12, 13]. Several authors have identified outdoor patterns of decomposition in hot arid climates [14, 15], in hot and moist climates [13] and in cold climates [16]. Although the outdoor patterns are well studied, the indoor decomposition patterns are the focus of only a few publications [17–19]. If death occurs at home, in a socially isolated environment, the postmortem interval can be extended [20]. Such indoor corpses are exposed to specific external factors that can disrupt the traditional taphonomic processes. For example, it is quite common to observe hundreds of dermestids feeding on the cadaver [6, 8, 9].

Larder beetles (Coleoptera: Dermestidae) are small (0.5 to 1 cm long) necrophagous beetles with a worldwide distribution. The adults have a characteristic oval shape and dark coloration and larvae are even more characteristic with long setae all along the body (figure 1). These species are well described, as they are common pests in poultry houses, fish or meat smokehouses, tanneries and natural history museums [21]. Indeed, dermestids can feed on the dried muscle tissue and skins of animals and can cause severe damage to stored products. In a forensic context, a recent study of 46 forensic cases in France has placed dermestid larvae in a group of insects occurring late in the decay process, when the corpse was dry [22]. However, the use of these species as indicators of the time or season of the death needs further investigations [23].

Fig. 1: development instars of *Dermestes maculatus* (De Geer 1774). Clockwise from top right: first instar larvae, fully developed larvae before pupation, nympha and adult

One of the first detailed case studies involving dermestids feeding on human remains was reported by Voigt in 1965 [8]. The author describes the case of a mummified/skeletonized body discovered in a Copenhagen (Denmark) flat. The tissues were completely replaced by a *“network of slender, dry, brownish and whitish, fairly long fibres”*. This material was subsequently identified as frass, i.e., fecal material wrapped in peritrophic membrane. Two larder beetle species were identified: *Dermestes lardarius* and *D. haemorrhoidalis*. No other insect species were reported on the corpse. Medico-legal experts and subsequent inquiries estimated the PMI as 1-2 years.

Shroeder et al. (2002) have reported a similar case in Germany [6]. The mummified corpse of a man was discovered in an apartment with significant heat (25°C) and all of the windows closed. The head was totally skeletonized and had fallen from the corpse (figure 2). The hands were also skeletonized, and the muscles and organs were transformed into frass. Molts, larvae and adults of *Dermestes maculatus* were found in large quantities in and all around the corpse. Empty pupae and dead flies were also found. The victim was seen alive for the last time 5 months previously. The authors concluded that skeletonization had occurred extremely rapidly due to the accelerating effect of high temperature (heater turned on) on the drying of the corpse and the development of larder beetles. Finally, a recent study by Kumara et al. (2009) reported an infestation of *Dermestes ater* in Malaysia [9]. Only a few specimens (larvae and adults) were present, primarily on the face or crawling around the corpse. As the PMI was established as 14 days, the authors emphasized the unusually rapid arrival of dermestids, most likely due to the warm climate of the country. Other less detailed cases involving dermestid species can also be found in the literature [1–3, 24, 25].

Fig. 2: Skeletonized head of a 78-year-old man discovered dead on the floor in his flat. The victim was seen alive for the last time 6 months previously (PMImax). The corpse was surrounded by larder beetle molts and frass, and the cadaver was partially skeletonized. Mummified skin with marks produced by larder beetle feeding was still visible.

Dataset and methodology

This study is based on the analysis of 1093 forensic entomology cases that we investigated from 1994 to 2013; the results reflect the trend and patterns observed in the study of these cases. However, as forensic entomology cases are inherently not homogeneously or even randomly distributed over space and time, they constitute a biased sample of necrophagous entomofaunal colonization patterns. Furthermore, the present analysis is based on the material that was sampled when the corpse was discovered and, thus, do not reflect the ongoing temporal processes. Finally, despite the training of the crime scene technicians, sampling bias cannot be excluded. These limitations should be noted in the context of this study.

Eight parameters were examined in this study: city, location (indoors, including, e.g., cars and barns, or outdoors), larder beetle species, instar (larvae and molts or adults), presence of living calliphorid larvae, presence of calliphorid pupae or adults, presence of other (non-calliphorid) necrophagous species and decomposition stage. However, as different people described the decomposition in different terms, this parameter was unreliable. Thus, only 3 categories were considered to describe decomposition stages: fresh, decay and dry/skeletonization. Lastly, as some cases were documented with detailed pictures and reports, the decomposition patterns of certain corpses were visible and were included in the study.

Location and seasonality

Over 20 years, larder beetles have been observed in 7.5% of the forensic entomology cases analyzed in France (n=81). All of these cases occurred in metropolitan France (including Corsica); 2 additional cases from the overseas territories were not considered. In all, 70% were outdoor cases, 30% indoor cases. This distribution did not differ significantly from that observed for the entire dataset that we analyzed (1093 French forensic cases: outdoor=61.8%, indoor= 38.2%, χ^2 test, $p=0.1$).

Among cases involving dermestids, larvae or exuviae were observed in 75% of indoor cases but only in 44% of outdoor ones. In contrast, the occurrence of adults was the same in indoor and outdoor cases (71% vs. 74%) (table 1). The species distribution also differed significantly between indoor and outdoor cases (χ^2 test, $p<0.01$). Total species diversity did not vary (6 species), but *D. frischii, D. maculatus* and *D. undulatus* were dominant in the outdoor cases, whereas other species were dominant in the indoor cases (figure 3). Interestingly, *D. undulatus,* the most frequent outdoor species (42%), was never observed indoors.

Tab. 1: Occurrence of larder beetles (adults and larvae or molts) according to the location of the cadaver. The percentage is based on the total number of cases in a given location. As both larvae and adults can be simultaneously observed on a corpse, the sums differ from 100%. Numbers of cases involving a given instar are reported in brackets.

	indoor (n=24)	**outdoor (n=57)**	**Total (n=81)**
adults	71% (17)	74% (42)	73% (59)
larvae or molts	75% (18)	44% (25)	53% (43)

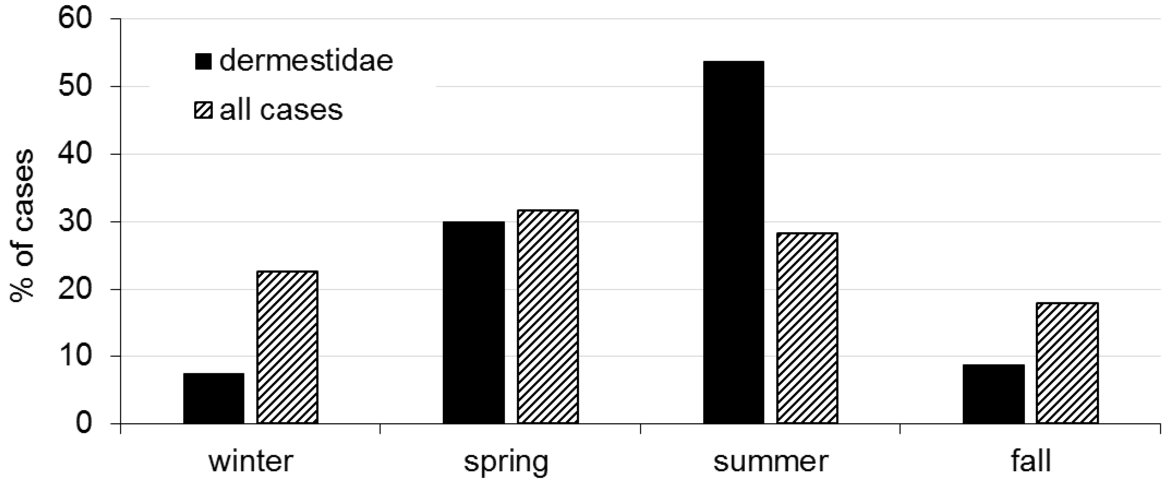

Fig. 3: Distribution over seasons of 1093 forensic cases examined in France from 1994 to 2013 (oblique lines) compared to the 81 cases involving larder beetles (Coleoptera: Dermestidae) during the same period (black). These two seasonal distribution differed significantly (χ^2 test, $p<0.001$). Values are reported as the percentage of total cases.

More cases were observed during spring and summer, with 15% of total cases in May, 9.8% in June, 18.8% in July and August and 16.3% in September (figure 4). The same seasonal trend was observed for the outdoor cases alone (18% in May, 10% in June, 17.6% in July and September and 13.7% in August). These seasonal patterns differed significantly from the distribution observed for the total dataset of 1093 French forensic cases that we analyzed (χ^2 test, $p<0.001$) but does not appear to be species-specific. Indeed, distribution over month of the two main species, *D. frischii* and *D. undulatus*, did not differ and were the same than global larder-beetles cases distribution (χ^2 test, $\alpha=0.05$) (figure 5). Distribution over months of other species was not tested due to the low number of cases involved.

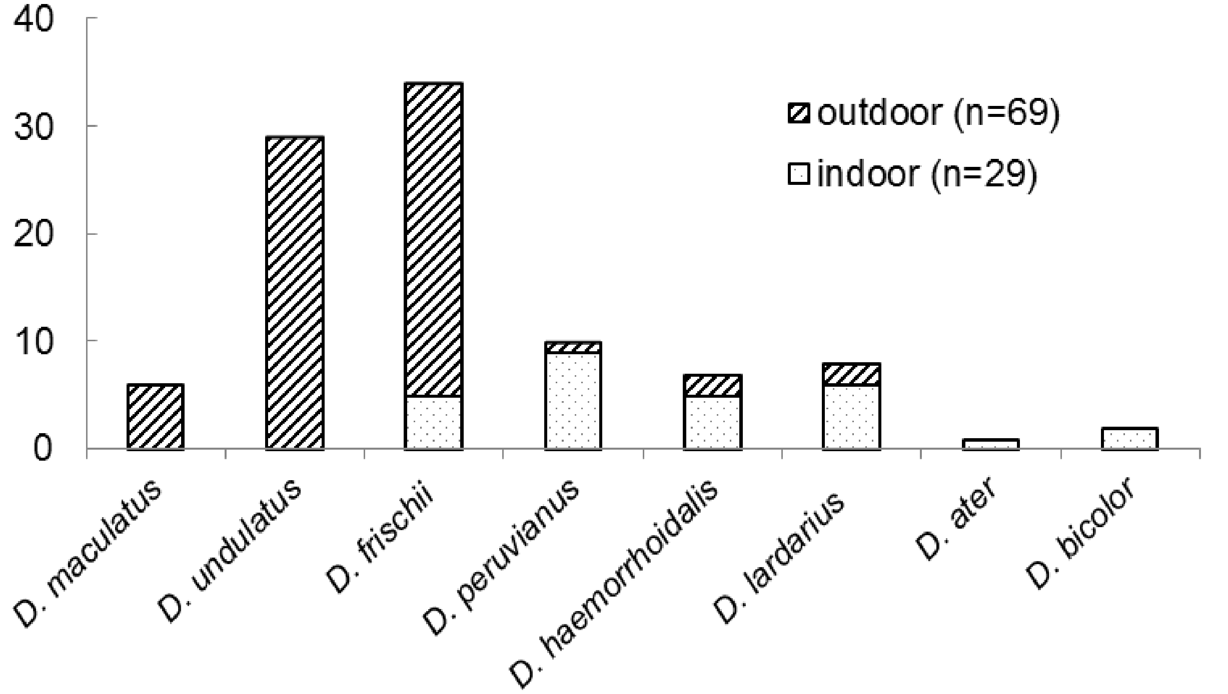

Fig. 4: Larder beetles species found in indoor (dotted black) and outdoor (oblique lines) cases (n=81). Values are reported as the number of cases involving a given species. Total number of indoor cases: 29; outdoor cases: 69. The species distribution differed significantly between indoor and outdoor location (χ^2 test, $p<0.01$).

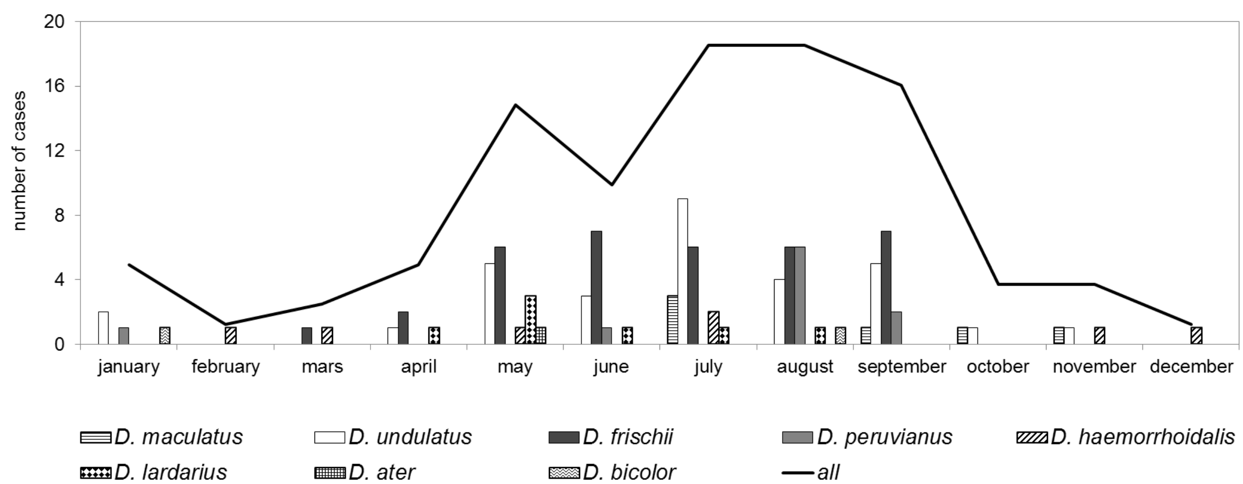

Fig. 5: Distribution over months of the occurrence of larder beetles (Coleoptera: Dermestidae) in forensic cases. Global trend (all species together) is reported with black curve. The distribution of *D. frischii* (black) and D. *undulatus* (white) did not differ among themselves and from this global distribution (χ^2 test, α=0.05). Due to the low number of cases involved, distribution over months of other species was not tested..

Post-mortem interval and decomposition

The date on which the victim was seen alive for the last time was known in 25% of the cases. Among these cases, the maximum post-mortem interval (PMImax, *i.e.,* the number of days between the day on which the victim was seen alive for the last time and the discovery of the cadaver) ranged between 9 days and more than 2 years (figure 6). The decomposition of the corpse varied among the cases, ranging from fresh cadavers to skeletonized bodies.

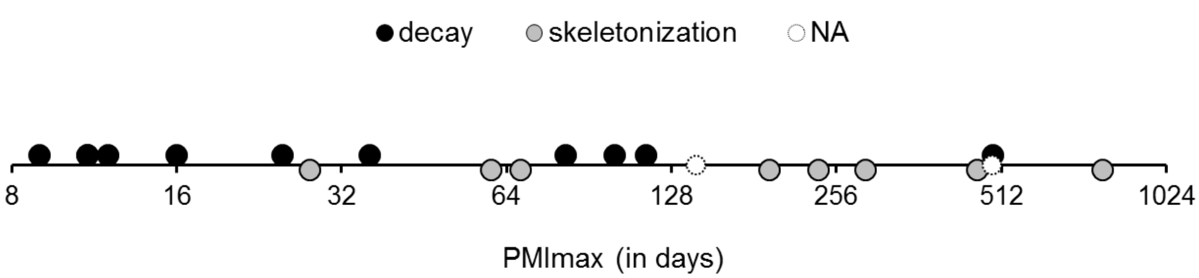

Fig. 6: PMImax values (number of days between the day on which the victim was seen alive for the last time and the discovery of the cadaver, log2 scale) for 21 forensic cases involving larder beetles (1994-2013, France). NA: not available.

Three decomposition stages were used in this study: fresh, decay or dry, skeletonization. Among the 81 cases involving larder beetles, fifty percent of the cadavers were in the active decay stage while 35% were dry or skeletonized. Only one was reported as fresh. Finally, two corpses were burned and the decomposition stage was not reported for 10 cases (12.3%). No correlation was found between species and decomposition stage (χ^2 test, $\alpha=0.05$) (figure 7).

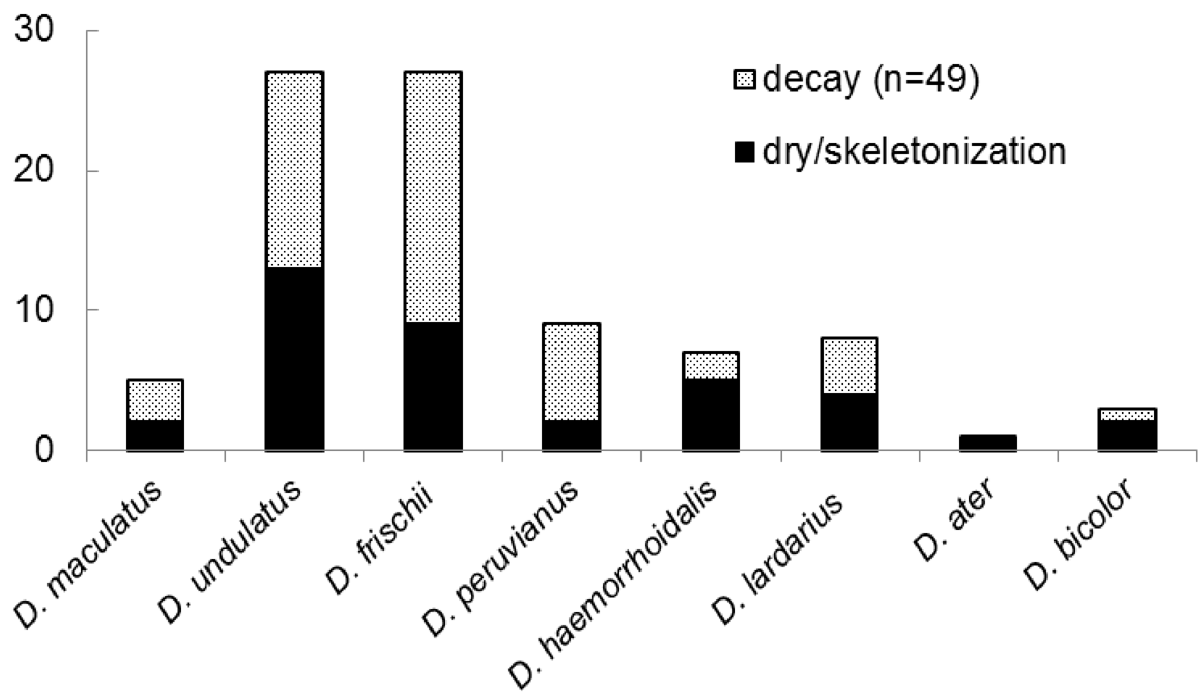

Fig. 7: Species according to decomposition stage (decay or skeletonization, fresh cadavers not shown (n=1)). Values are reported as the number of cases involving a given species. Total number of decay stages: 49; skeletonization stages: 38. The species did not differed significantly between decaying and skeletonized cadavers (χ^2 test, $\alpha=0.05$).

For 14 cases of indoor dry/skeletonized cadavers, the pictures taken and reports made by the medical examiner were available and allowed to characterize the decomposition patterns produced by larder beetles. According to these few cases, the extremities appear to be the preferential feeding area of larvae and adults (figures 1 and 8). On 10 corpses, the head, hands and feet were skeletonized, with complete disarticulation. The chest, thighs and arms appeared to be the last body parts to be consumed with only 4 cases of total skeletonization. We observed in these cases that the abdominal cavity and the surroundings of the corpses were full of light-brown humus composed of frass (feces) and molts from several generations.

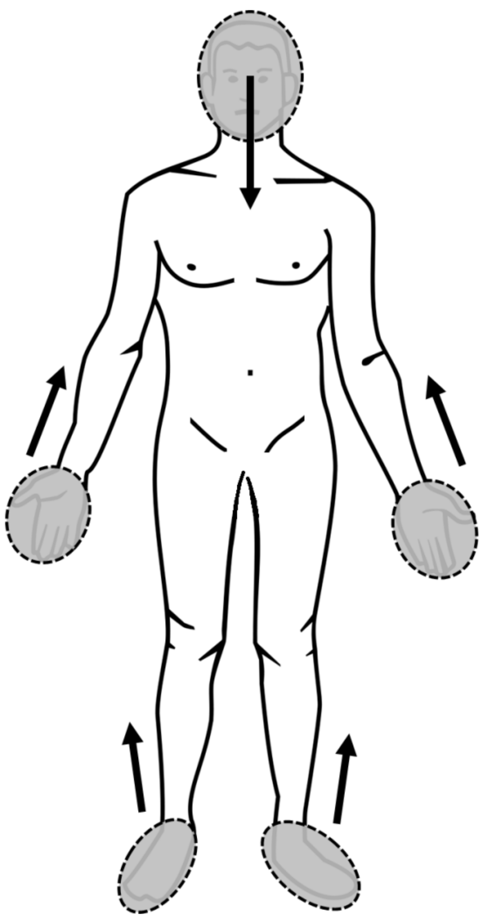

Fig. 8: Decomposition pattern due to larder beetles activity inferred from 14 cases of skeletonized cadavers discovered in France.

Species and specific associations

Eight dermestid species were observed: *D. frischii* (42%), *D. undulatus* (35.8%), *D. peruvianus* (12.3%), *D. lardarius* (9.9%), *D. haemorrhoidalis* (8.6%), *D. maculatus* (7.4%), *D. bicolor* (3.7%) and *D. ater* (1.2%, *i.e.,* a single case). According to the French National Institute of Agronomical Research (INRA), all these species shows widespread distribution in France and Europe [26]. However, we never observed more than 3 different species on a corpse, and only one species of larder beetle was usually found on a given corpse (table 2). If more than one species was involved, the *D. undulatus* + *D. frischii* association was the most common (11 cases in a total of 18).

Tab. 2: Occurrence of 1, 2 or 3 different larder beetle species on a single corpse according to the location of the cadaver.

	all **% (n)**	**indoor** **% (n)**	**outdoor** **% (n)**
1 species	77.8 (63)	70.8 (17)	80.7 (46)
2 species	19.8 (16)	25 (6)	17.5 (10)
3 species	2.4 (2)	4.2 (1)	1.8 (1)
total	**81**	**24**	**57**

One or more other insect species (Diptera and Coleoptera) were observed in 99% of the cases (figure 9). The most common coleopteran species associated with dermestids were *Necrobia* spp. (Coleoptera: Cleridae). These beetles were observed in 46% of the cases, especially outdoor ones (30 cases on 37), with 2 or 3 different species present simultaneously in most cases. With a total of 26 cases (32%), *Necrodes littoralis* (Coleoptera: Silphidae) was also frequently associated with larder beetles. Most likely due to the size and biology of this species, *Necrodes littoralis* was primarily found outdoors (22 cases).

Among the dipterans found, calliphorids (larvae, pupae or adults) were found on the corpse in 88% of the cases. However, living calliphorid larvae were observed in only 48% of the cases. Among Muscidae, *Hydrotaea spp.* were the most common species and were observed in 41% of the cases. Piophilidae were observed in 40% of the cases, primarily due to *Stearibia nigriceps,* which was observed in 30 cases. Finally, Phoridae were observed in only 4 cases (5%).

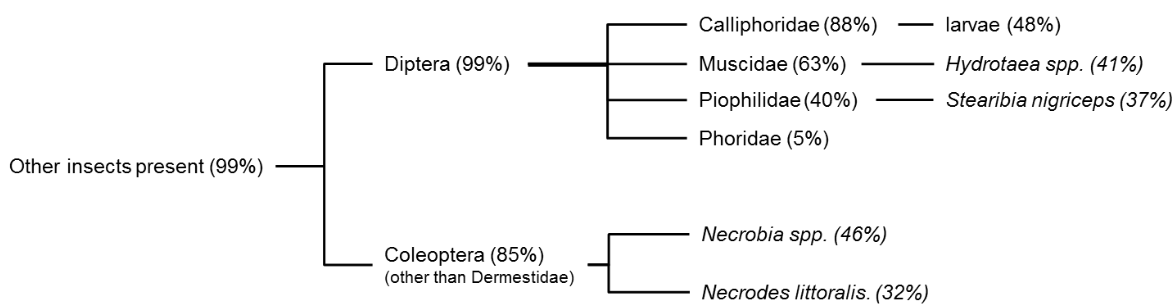

Fig. 9: Main taxa and instar sampled with Dermestidae on human cadavers. Values are reported as the percent of the total cases where a given taxa was observed. For example, Calliphoridae flies were present in 71 cases on 81 (88% of cases). Only main relevant taxa have been reported.

Discussion

Hundreds of dermestid species have been reported worldwide, but less than 10 of them are commonly observed on human remains [2, 27]. In France, 8 species have been observed in forensic cases during the past 20 years. Note, however, that this study only focused on forensic cases that have been analyzed by French entomology laboratories.

Although larder beetles are considered common, they have been observed in only 81 cases since 1994. Such a low number of cases could be due to a lack of sampling (sampling is not always performed by forensic entomologists) [28, 29]. However, larder beetles (adults and larvae) are mostly large and highly mobile species and are thus easy to see (figure 1). Accordingly, a specific lack of sampling of these species appears highly unlikely. Another explanation could be the strong selectivity of these species. Indeed, larder beetle larvae are well known to feed on dry organic materials, especially on vertebrate remains [27, 30]. Such substrates are associated with recruitment and mating behavior and provide the best food source for both adults and larvae [30–32]. Accordingly, we suppose that larder beetles are selective in their choice of feeding and breeding substrates. Thus, as dry/mummified human cadavers represent only a small fraction of forensic (and, moreover, forensic entomology) cases [14, 20], observations of larder beetles on human cadavers should be rare.

Location and seasonality

An important question raised by the cases reported in this (and the previous) study is the significance of indoor/outdoor locations for the abundance of larder beetles [6, 33]. In the present dataset, feeding larvae were observed in 75% of indoor cases involving larder beetles but in only 44% of outdoor cases. This skewed distribution was not observed with adults. Larvae and adults being equally visible (figure 1), sampling effects can reasonably be excluded. On the other hand, it is well known that dermestid larvae feed on dry organic material and avoid excessive humidity [30, 34] and light [35]. Thus, climate should play an important role in laying and larvae development, especially on outdoor corpses. Accordingly, we observed a strong seasonality in cases: 83% occurred during spring and summer, i.e. dry and hot months. Focusing on cases in which the development of larder beetles occurred (i.e., living larvae or molts), we reported the indoor and outdoor cases on a map (figure 10). Although indoor cases were located throughout France (except Bretagne - Brittany), no outdoor cases were reported from the west coast during the 20-year study period. As this part of the country has a typical oceanic climate (in which small temperature ranges and frequent rainfall create a high relative humidity), these conditions are inconsistent with the drying and mummification of outdoor corpses. Thus, rainfall/humidity appears to be the key climatic factor affecting the settlement and subsequent development of dermestids on corpses. This hypothesis is reinforced by the total lack of forensic cases (indoor or outdoor) involving larder beetles in Bretagne, a part of France that is surrounded by the sea and has a strongly oceanic climate (true oceanic climate) (figure 10) [36]. On the contrary, as many outdoor cases were reported from usually cold areas such as the east of France, it is probable that temperature plays a few role (figure 10).

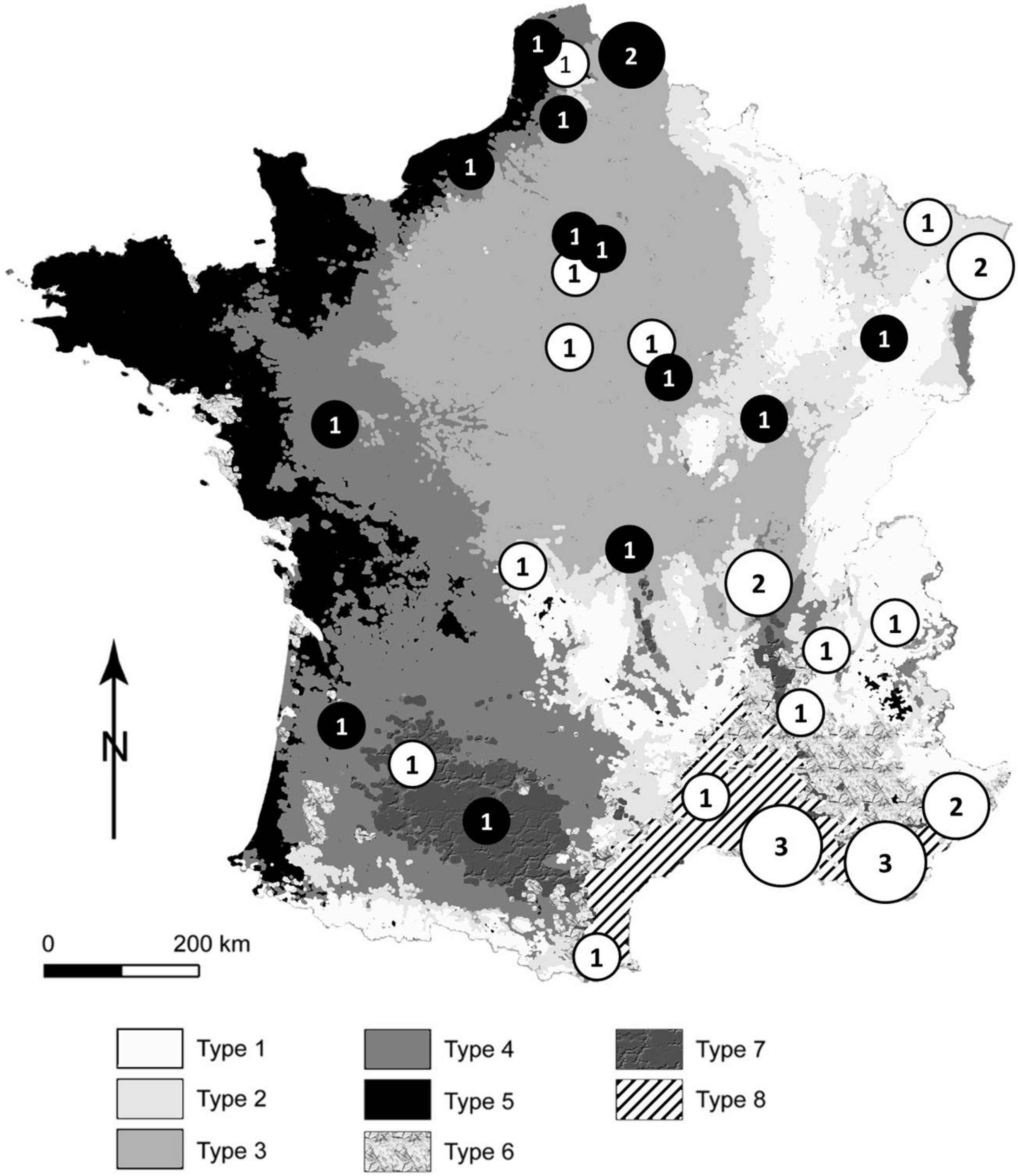

Fig. 10: Number (inside circles) and location of indoor (black circles) and outdoor (white circles) forensic entomology cases involving larder beetle larvae or molts. For convenience, locations have been grouped by department. In 20 years, no outdoor

cases involving larder beetle larvae were observed in type 4 and 5 climate areas (oceanic climate with frequent rainfalls and high humidity). Climatic areas are reported from Joly et al. (2010) as follows: Type 1: mountain climate, 2: semi-continental climate, 3: center-oceanic climate, 4: oceanic-modified climate, 5: true oceanic climate, 6: Mediterranean-modified climate, 7: south-west climate, 8: true Mediterranean climate.

In contrast to outdoor cases, cadavers discovered inside dwellings should offer relevant conditions for the multiplication of larder beetles [6]. Indeed, a hot and dry environment contributes to a rapid mummification of the corpse and limits active decomposition stages that are attractive to many other necrophagous species (especially Diptera) [12, 17, 33]. Furthermore, indoor locations prevent predation and offer many suitable places for pupation [34-36]. However, of the 81 dermestids cases analyzed in this study, only 24 were located indoors. This distribution was consistent with the skewed dataset (two-thirds of the 1093 forensic entomology cases were outdoor cases) and does not indicate a preference of larder beetles for indoor locations. For example, *D. undulatus* was very common outside but was never observed in indoor environments. This result could reflect two principal mechanisms. First, due to the rapid discovery of cadavers (e.g., by neighbors), the average PMI of indoor cases may be too short to attract larder beetles [20, 41]. In this study, however, the mean value of the maximum PMI did not differ between indoor and outdoor cases (191±255 vs. 160±179 days). The second hypothesis is the poor ability of larder beetles (or at least some species) to locate and/or access concealed corpses. Although previous studies have demonstrated the ability of larder beetles to detect odors from decomposed remains and to fly toward such a food source [31, 32, 42], their ability to detect small openings, to fly and land with accuracy and to crawl inside buildings is uncertain. Such a mechanism could explain the lack of some common outdoor species (e.g. *D.*

undulatus) on indoor cadavers. This difference may also result from species-specific location preferences (figure 4).

Post-mortem interval and decomposition

We observed a typical decomposition pattern, with preferential feeding areas on the extremities (face, hands and feet); such a pattern is consistent with the findings of previous studies [6, 8]. However, the potential use of the chronology of these specific post-mortem changes to establish a post-mortem interval is still uncertain. It is probable that the skeletonization of the head results from the feeding of both blowflies and dermestids larvae, whereas the skeletonization of the hands and feet was, most likely, due only to the dermestids. Indeed, as hands and feet are primarily composed of bones, muscles and skin, they dry more rapidly than other parts of the body. It is probable that such drying prevents feeding by the larvae of necrophagous blowflies and restricts consumption to dry-tissue-specific species, such as dermestids [43].

This decomposition pattern and the estimation of a PMI based on the development time of several generations of larder beetles may be useful tools for forensic entomologists in the future [23]. However, more research is needed and forthcoming cases should be better documented. Along other forensic entomology investigations, extensive on-site sampling of dermestidae, including larvae, nympha and adults, should be realized (figure 1). As larvae usually burrow galleries in soft materials around the corpse (e.g. wood pieces or mattress) to molt and pupate, presence of such galleries should possibly be investigated by crime-scene examiners and reported to forensic entomologist. Lastly, detailed pictures of skeletonized body parts should be provided (e.g. figure 2).

Finally, bone damage due to larder beetle activity was not observed within our dataset. Schroeder (2002) report a typical “larva-shaped” feeding defect on the humerus of a 5 month cadaver discovered inside an apartment, but this artifact was not clearly documented. Marks attributed to larder beetles have also been reported on dinosaur bones [44–48]. The authors of those reports observed circular, semi-circular or semi-elliptical structures that were attributed to the construction of pupation chambers by larder beetle larvae. The dimensions described ranged from 5 mm to 15.8 mm. However, neither studies describing the use of larder beetles to deflesh human bones [49–51] nor cases analyzed in this study mentioned such marks. This issue remains to be studied more closely.

Species and specific associations

We only exceptionally observed more than a single species of larder beetle species on a single corpse. In 78% of the cases reported in this study, only a single species was observed. Furthermore, we never observed more than 3 species on the same corpse, even in places where four different species had previously been observed (e.g., Paris or Strasbourg). The same trend has been observed in previously published cases [1, 3, 6, 9, 52] and within unpublished cases and data (personal communication). Such limitations on the number of species could result from the colonization process or could be due to exclusion mechanisms.

According to the first hypothesis, the number of species would simply be the result of the probability that n different species would discover and settle on the same corpse. After reaching the corpse, the first adults would start feeding and emit sexual pheromones [31, 32]. These pheromones are highly attractive to both males and females, especially if associated with decomposition odors. Such a mechanism could allow a rapid increase of the population. Furthermore, under favorable conditions, dermestids are rapid breeders. According to published development data, a pair of larder beetles developing in dry and warm conditions with sufficient food can give birth to hundreds of larvae in a few months [34, 53–56]. Thus, large populations (several generations, up to thousands of larvae feeding at the same time) can be the progeny of only a few initial settlers. However, although this hypothesis can explain the colonization of concealed cadavers by one or two species, it fails to explain similar observations on outdoor corpses, where access is not physically restricted. Furthermore, as the probability that n different species settled would increase with time, a correlation should be observed between the PMImax and the number of species; such a correlation was not observed in our dataset.

The second hypothesis postulates one or several mechanisms linked to the presence of one species and decreasing the probability that additional species would subsequently colonize the corpse. These mechanisms could involve repulsion, competition or predation. Case data do not allow testing such interspecific interactions; experiments under controlled conditions would be necessary to determine the mechanism involved. However, note that the species distribution was clearly more balanced in indoor cases than in outdoor ones. This result suggests that the indoor environment could act as a refuge for species with lower competitive abilities and thus supports the hypothesis of exclusion mechanism. Such a result could be used to highlight corpse displacement between indoor and outdoor location.

Several other necrophagous species were closely associated with larder beetles. These associated species included *Necrobia spp.*, which have feeding habits and a way of life similar to those of dermestids [57]. Interestingly, these species have been reported as predatory of larder beetles larvae and thus may limit the proliferation of dermestidae on cadavers [58]. Their particular abundance on outdoor cases may explain the limited number of different dermestidae species. However, specific predation of *Necrobia spp.* against certain dermestidae species is still to be documented.

The close association with *Necrodes littoralis* was surprising, as this species usually feeds during active decay, i.e., before the drying of the tissues [59]. This result suggest that similar decomposition odours, e.g. benzyl butyrate, may act as attractant for both dermestidae and *N. littoralis* [31, 60]. Furthermore, a body can simultaneously be putrefied and partially mummified or skeletonized depending on the body part [61]. This observation is particularly valid for clothed corpses, for which mummification of exposed parts, such as the face or the hands, can occur while covered parts (e.g., the abdomen) are still in an active state of decay. Among Diptera, Piophilidae and Hydrotaea were frequently found with larder beetles. Both of these taxa are common in France and can be found on human corpses, from the fresh stage until the beginning of mummification [2, 62–64]. In contrast to adults or pupae, living calliphorid larvae were recovered in less than one-half of the cases. The most likely explanation of this finding is that the blowfly larvae had already finished their development when the corpses were discovered. Indeed, calliphorids are usually pioneer species and lay eggs on fresh cadavers. Furthermore, larder beetles and *Necrobia spp.* are predators of fly larvae and, most likely, decreased the populations of dipteran larvae [39].

Acknowlegement

The authors would like to thanks the region Nord Pas de Calais for their financial support, the actual and former personals from the Forensic Entomological department of Institut de Recherche Criminelle de la Gendarmerie Nationale (IRCGN) for sharing of their cases database.

Bibliography

1. Megnin JP (1894) La faune des cadavres: application de l'entomologie à la médecine légale. Gauthier-Villars et fils.

2. Smith KGV (1986) A manual of forensic entomology. Trustees of the British Museum (Natural history), London.

3. Gennard D (2007) Forensic Entomology: An Introduction, 1st ed. Wiley.

4. Byrd DJH, Castner JL (2009) Forensic Entomology: The Utility of Arthropods in Legal Investigations, 2nd Revised edition. CRC Press Inc.

5. Reibe S, Strehler M, Mayer F, et al. (2008) [Dumping of corpses in compost bins--two forensic entomological case reports]. Arch Für Kriminol 222:195–201.

6. Schroeder H, Klotzbach H, Oesterhelweg L, Puschel K (2002) Larder beetles (Coleoptera, Dermestidae) as an accelerating factor for decomposition of a human corpse. Forensic Sci Int 127:231–236.

7. Suláková H, Markvartová J, Beran M (2013) [Insect and a dead man in his flat. Case report]. Soud Lékarství Cas Sekce Soud Lékarstvi Cs Lékarské Spolecnosti J Ev Purkyne 58:2–5.

8. Voigt J (1965) Specific post-mortem changes produced by larder beetles. J Forensic Med 12:76–80.

9. Kumara TK, Abu Hassan A, Che Salmah MR, Bhupinder S (2009) The infestation of Dermestes ater (De Geer) on a human corpse in Malaysia. Trop Biomed 26:73–79.

10. Aturaliya S, Lukasewycz A (1999) Experimental forensic and bioanthropological aspects of soft tissue taphonomy: 1. Factors influencing postmortem tissue desiccation rate. J Forensic Sci 44:893–96.

11. Simmons T, Adlam RE, Moffatt C (2010) Debugging Decomposition Data—Comparative Taphonomic Studies and the Influence of Insects and Carcass Size on Decomposition Rate. J Forensic Sci 55:8–13. doi: 10.1111/j.1556-4029.2009.01206.x.

12. Campobasso CP, Di Vella G, Introna F (2001) Factors affecting decomposition and Diptera colonization. Forensic Sci Int 120:18–27.

13. Mann RW, Bass WM, Meadows L (1990) Time since death and decomposition of the human body : variables and observations in case and experimental field studies. J Forensic Sci 35:103–111.

14. Galloway A, Birkby WH, Jones AM, et al. (1989) Decay rates of human remains in an arid environment. J Forensic Sci 34:607–616.

15. Parks CL (2011) A study of the human decomposition sequence in central Texas. J Forensic Sci 56:19–22. doi: 10.1111/j.1556-4029.2010.01544.x.

16. Komar D, Beattie O (1998) Effects of carcass size on decay rates of shade and sun exposed carrion. Can Soc Forensic Sci J 31:385–43.

17. Campobasso CP, Falamingo R, Grattagliano I, Vinci F (2009) The Mummified Corpse in a Domestic Setting. Am J Forensic Med Pathol 30:307–310. doi: 10.1097/PAF.0b013e318187df4b.

18. Zhou C, Byard RW (2011) Factors and processes causing accelerated decomposition in human cadavers – An overview. J Forensic Leg Med 18:6–9. doi: 10.1016/j.jflm.2010.10.003.

19. Anderson GS (2011) Comparison of decomposition rates and faunal colonization of carrion in indoor and outdoor environments. J Forensic Sci 56:136–142. doi: 10.1111/j.1556-4029.2010.01539.x.

20. Archer MS, Bassed RB, Briggs CA, Lynch MJ (2005) Social isolation and delayed discovery of bodies in houses: The value of forensic pathology, anthropology, odontology and entomology in the medico-legal investigation. Forensic Sci Int 151:259–265. doi: 10.1016/j.forsciint.2005.02.016.

21. Rajendran S, Hajira Parveen KM (2005) Insect infestation in stored animal products. J Stored Prod Res 41:1–30. doi: 10.1016/j.jspr.2003.12.002.

22. Lefebvre F, Gaudry E (2009) Forensic entomology: a new hypothesis for the chronological succession pattern of necrophagous insect on human corpses. Ann Soc Ent Fr 45:377–392.

23. Amendt J, Richards CS, Campobasso CP, et al. (2011) Forensic entomology: applications and limitations. Forensic Sci Med Pathol 7:379–392. doi: 10.1007/s12024-010-9209-2.

24. Haskell N, Catts EP (1990) Entomology and Death, a Procedural Guide.

25. Byrd JH, Castner JL (2001) Forensic entomology : the utility of arthropods in legal investigations,. CRC Press LLC, Boca Raton, Florida.

26. INRA Coleoptera: Dermestidae, http://www1.montpellier.inra.fr/CBGP/insectes-du-patrimoine.

27. Zhantiev R (2009) Ecology and classification of dermestid beetles (Coleoptera, Dermestidae) of the Palaearctic fauna. Entomol Rev 89:157–174. doi: 10.1134/S0013873809020055.

28. Gaudry E, Myskowiak JB, Chauvet B, et al. (2001) Activity of the forensic entomology department of the French Gendarmerie. Forensic Sci Int 120:68–71.

29. Amendt J, Campobasso CP, Gaudry E, et al. (2006) Best practice in forensic entomology—standards and guidelines. Int J Legal Med 121:90–104. doi: 10.1007/s00414-006-0086-x.

30. Woodcock L, Gennard D, Eady P (2013) Egg laying preferences and larval performance in Dermestes maculatus. Entomol Exp Appl n/a–n/a. doi: 10.1111/eea.12089.

31. Von Hoermann C, Ruther J, Reibe S, et al. (2011) The importance of carcass volatiles as attractants for the hide beetle Dermestes maculatus (De Geer). Forensic Sci Int 212:173–179. doi: 16/j.forsciint.2011.06.009.

32. Von Hoermann C, Ruther J, Ayasse M (2012) The attraction of virgin female hide beetles (Dermestes maculatus) to cadavers by a combination of decomposition odour and male sex pheromones. Front Zool 9:18. doi: 10.1186/1742-9994-9-18.

33. Frost CL, Braig HR, Amendt J, Perotti MA (2010) Indoor Arthropods of Forensic Importance: Insects Associated with Indoor Decomposition and Mites as Indoor Markers. In: Amendt J, Goff ML, Campobasso CP, Grassberger M (eds) Curr. Concepts Forensic Entomol. Springer Netherlands, pp 93–108.

34. Coombs CW (1979) The effect of temperature and humidity upon the development and fecundity of Dermestes haemorrhoidalis Küster and Dermestes peruvianus Laporte De Castelnau (Coleoptera: Dermestidae). J Stored Prod Res 15:43–52.

35. Rąkowski G (1988) Effect of illumination intensity on the response of the hide beetle, Dermestes maculatus, to aggregation pheromone. J Insect Physiol 34:1101–1104. doi: 10.1016/0022-1910(88)90211-9.

36. Joly D, Brossard T, Cardot H, et al. (2010) Les types de climats en France, une construction spatiale. Cybergeo Eur J Geogr. doi: 10.4000/cybergeo.23155.

37. Pohjoismäki JLO, Karhunen PJ, Goebeler S, et al. (2010) Indoors forensic entomology: Colonization of human remains in closed environments by specific species of sarcosaprophagous flies. Forensic Sci Int 199:38–42. doi: 10.1016/j.forsciint.2010.02.033.

38. Ahmad NW, Lim LH, Dhang CC, et al. (2011) Comparative insect fauna succession on indoor and outdoor monkey carrions in a semi-forested area in Malaysia. Asian Pac J Trop Biomed 1:S232–S238. doi: 10.1016/S2221-1691(11)60161-5.

39. Menezes LCCR, Rossi MN, Godoy WAC (2006) The Effect of Refuge on Dermestes ater (Coleoptera: Dermestidae) Predation on Musca domestica (Diptera: Muscidae): Refuge for Prey or the Predator? J Insect Behav 19:717–729. doi: 10.1007/s10905-006-9056-x.

40. Menezes LCCR, Rossi MN, Reigada C (2005) Consequences of refuge for the functional response of Dermestes ater (Coleoptera: Dermestidae) to Musca domestica (Diptera: Muscidae). Popul Ecol 47:213–219. doi: 10.1007/s10144-005-0227-y.

41. Hönigschnabl S, Schaden E, Stichenwirth M, et al. (2002) Discovery of decomposed and mummified corpses in the domestic setting--a marker of social isolation? J Forensic Sci 47:837–842.

42. Rakowski G, Sorensen KA, Bell WJ Responses of dermestid beetles, Dermestes maculatus, to puffs of aggregation pheromone extract (Coleoptera: Dermestidae). Entomol Gen 14:211–215.

43. Archer MS, Elgar MA (2003) Female breeding-site preferences and larval feeding strategies of carrion-breeding Calliphoridae and Sarcophagidae (Diptera): a quantitative analysis. Aust J Zool 51:165–174.

44. Bader KS, Hasiotis ST, Martin LD (2009) Application of Forensic Science Techniques to Trace Fossils on Dinosaur Bones from a Quarry in the Upper Jurassic Morrison Formation, Northeastern Wyoming. PALAIOS 24:140–158. doi: 10.2110/palo.2008.p08-058r.

45. Britt BB, Scheetz RD, Dangerfield A (2008) A Suite of Dermestid Beetle Traces on Dinosaur Bone from the Upper Jurassic Morrison Formation, Wyoming, USA. Ichnos 15:59–71. doi: 10.1080/10420940701193284.

46. Roberts EM, Rogers RR, Foreman BZ (2007) Continental insect borings in dinosaur bone: examples from the late cretaceous of Madagascar and Utah. J Paleontol 81:201–8.

47. Saneyoshi M, Watabe M, Suzuki S, Tsogtbaatar K (2011) Trace fossils on dinosaur bones from Upper Cretaceous eolian deposits in Mongolia: Taphonomic interpretation of paleoecosystems in ancient desert environments. Palaeogeogr Palaeoclim Palaeoecol 311:38–47. doi: 10.1016/j.palaeo.2011.07.024.

48. Laudet F, Antoine P-O (2004) Des chambres de pupation de Dermestidae (Insecta : Coleoptera) sur un os de mammifère tertiaire (phosphorites du Quercy) : implications taphonomiques et paléoenvironnementales. Geobios 37:376–381. doi: 10.1016/j.geobios.2003.04.005.

49. Graves R (2005) Beetles & Bones: Care, Feeding, and Use of Dermestid Beetles. Jillett Publications, South Berwick.

50. Hefti E, Trechsel U, Rüfenacht H, Fleisch H (1980) Use of dermestid beetles for cleaning bones. Calcif Tissue Int 31:45–47. doi: 10.1007/BF02407166.

51. Offele D, Harbeck M, Dobberstein RC, Wurmb-Schwark N, Ritz-Timme S (2007) Soft tissue removal by maceration and feeding of Dermestes sp.: impact on morphological and biomolecular analyses of dental tissues in forensic medicine. Int J Legal Med 121:341–348. doi: 10.1007/s00414-006-0116-8.

52. Pasquerault T, Vincent B, Chauvet B, Dourel L, Gaudry E (2008) Répartition des espèces du genre Dermestes L., 1758 récoltées sur des cadavres humains (Coleoptera Dermestidae). Entomol 64:221–224.

53. Coombs CW (1981) The development, fecundity and longevity of Dermestes ater Degeer (Coleoptera: Dermestidae). J Stored Prod Res 17:31–36.

54. Woodroffe GE, Coombs CW (1979) The development of several species of Dermestes (Coleoptera: Dermestidae) on various vegetable foodstuffs. J Stored Prod Res 15:95–100.

55. Amos TG (1968) Some laboratory observations on the rates of development, mortality and oviposition of Dermestes frischii (Kug.) (Col., Dermestidae). J Stored Prod Res 4:103–117. doi: 10.1016/0022-474X(68)90001-5.

56. Richardson MS, Goff ML (2001) Effects of Temperature and Intraspecific Interaction on the Development of Dermestes maculatus (Coleoptera: Dermestidae). J Med Entomol 38:347–351. doi: 10.1603/0022-2585-38.3.347.

57. Lambkin TA, Khatoon N (1990) Culture methods for Necrobia rufipes (Degeer) and Dermestes maculatus Degeer (Coleoptera: Cleridae and Dermestidae). J Stored Prod Res 26:59–60. doi: 10.1016/0022-474X(90)90038-T.

58. Knull JN (1951) The checkered beetles of Ohio (Coleoptera: Cleridae). Ohio Biol Surv Bull 8:268–350.

59. Matuszewski S (2011) Estimating the pre-appearance interval from temperature in Necrodes littoralis L. (Coleoptera: Silphidae). Forensic Sci Int 212:180–188. doi: 10.1016/j.forsciint.2011.06.010.

60. Dekeirsschieter J, Stefanuto P-H, Brasseur C, et al. (2012) Enhanced Characterization of the Smell of Death by Comprehensive Two-Dimensional Gas Chromatography-Time-of-Flight Mass Spectrometry (GCxGC-TOFMS). PloS One 7:e39005. doi: 10.1371/journal.pone.0039005.

61. Braack LE (1987) Community dynamics of carrion-attendant arthropods in tropical african woodland. Oecologia 72:402–9.

62. Wyss C, Cherix D (2006) Traité d'entomologie forensique. Presses Polytechniques et Universitaires Romandes (PPUR), Lausanne.

63. Martín-Vega D (2011) Skipping clues: Forensic importance of the family Piophilidae (Diptera). Forensic Sci Int 212:1–5. doi: 10.1016/j.forsciint.2011.06.016.

64. Farkas R, Hogsette JA, Börzsönyi L (1998) Development of Hydrotaea aenescens and Musca domestica (Diptera: Muscidae) in Poultry and Pig Manures of Different Moisture Content. Environ Entomol 27:695–699.