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A brief history of forensic entomology

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Abstract

Apart from an early case report from China (13th century) and later artistic contributions, the first observations on insects and other arthropods as forensic indicators were documented in Germany and France during mass exhumations in the late 1880s by Reinhard and Hofmann, whom we propose recognizing as co-founders of the discipline. After the French publication of Mégnin's popular book on the applied aspects of forensic entomology, the concept quickly spread to Canada and the US. At the time, researchers recognized that the lack of systematic observations of forensically important insects stood in the way of their use as indicators of postmortem interval. General advances in insect taxonomy, and ecology helped close this gap over the following decades.

Many early case reports dealt with alleged child homicides, including the suspected use of sulphuric acid. In this context, it was shown that ants, cockroaches, and freshwater arthropods could produce postmortem artifacts suggestive of child abuse.

After the World Wars, few forensic entomology cases entered the scientific literature. From the 1960s to the 1980s, Leclecq and Nuorteva were primarily responsible for maintaining the method in Central Europe, with a focus on case work. Since then, basic research in the US, Russia and Canada has opened the way to the routine use of entomology in forensic investigations. The following article gives a brief overview of historic developments in the field. A major focus is on the work done between 1850 and 1950. Since sources from that time remain difficult to track down, the article also includes a historic bibliographical overview on forensic entomology of that era.

Keywords: Forensic entomology; Diptera; Coleoptera; Maggots; History of medicine and natural sciences

1. Introduction

Hundreds of arthropod species are attracted by corpses, primarily flies (Diptera), beetles (Coleoptera), and their larvae, and also mites, isopods, opiliones, and nematodes. These animals feed, live, or breed in and on the corpse, depending on their biological preferences and on the state of decompostion (e.g. [1,24,38,43,46,59,69,63,74,82,103]).

Since arthropods are by far the largest and most important biological group on Earth (they outnumber even plants), they can be found in a wide variety of locations including crime scenes. This opens a wide range of applications for *forensic entomology*, the investigation of insects and other arthropods recovered from crime scenes and corpses.

The following article gives a brief review of the historic sources describing the development that led to the present state of the art. An attached bibliography[1] both documents the earliest efforts made in the field and facilitates access to early studies, research results, and case reports.

2. Medieval China to 19th century

The first documented forensic entomology case is reported by the Chinese lawyer and death investigator Sung Tźu in the 13th century in the medico-legal text book Hsi yüan chi lu (one possible translation: ''The Washing Away of Wrongs'') [97,98]. He describes the case of a stabbing near a rice field. The day after the murder, the investigator told all workers to lay down their working tools (sickles) on the floor. Invisible traces of blood drew blow flies to a single sickle. So confronted, the tool's owner confessed to his

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[1] Historic references until 1945 only. A searchable, extended version of the bibliographic data given in this article is available at http://www.benecke.com/fespecial.html.

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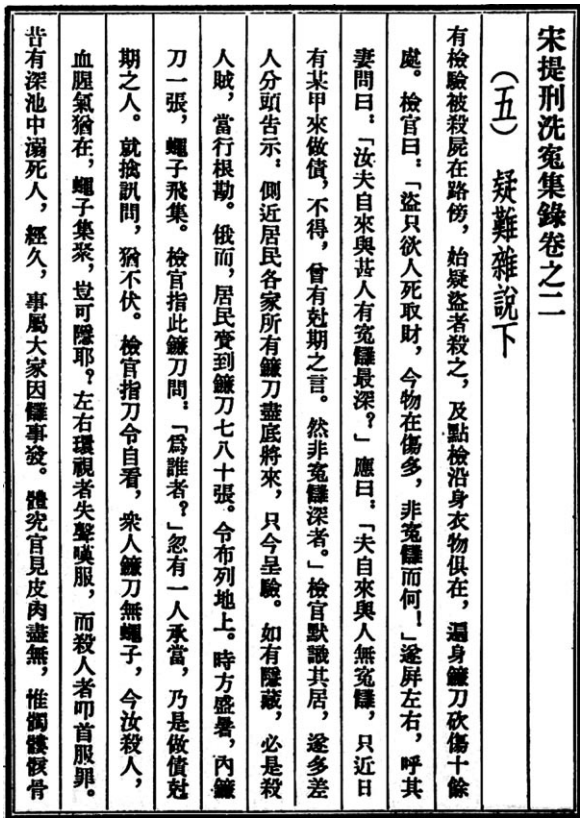

宋提刑洗冤集錄卷之二

（五）疑難雜說下

有檢驗被殺屍在路傍，始疑盜者殺之，及點檢沿身衣物俱在，遍身鐮刀砍傷十餘處。檢官曰：「盜只欲人死取財，今物在傷多，非冤讎而何！」遂屏左右，呼其妻問曰：「汝夫自來與甚人有冤讎最深？」應曰：「夫自來與人無冤讎，只近日有某甲來做債，不得，曾有爭期之言。然非冤讎深者。」檢官默識其居，遂多差人分頭告示：側近居民各家所有鐮刀盡底將來，只今呈驗。如有隱藏，必是殺人賊，當行根勘。俄而，居民賫到鐮刀七八十張。令布列地上。時方盛暑，內鐮刀一張，蠅子飛集。檢官指此鐮刀問：「爲誰者？」忽有一人承當，乃是做債爭期之人。就擒訊問，猶不伏。檢官指刀令自看，衆人鐮刀無蠅子，今汝殺人，血腥氣猶在，蠅子集聚，豈可隱耶？左右環視者失聲嘆服，而殺人者叩首服罪。

昔有深池中溺死人，經久，事屬大家因讎事發。體究官見皮肉盡無，惟獨髏骾骨

Fig. 1. Chapter 5 of Sung Tzu's Chinese book on Forensic Medicine deals with a case of stabbing solved by use of insects: adult flies detected blood on the killer's sickle (from [10]).

crime and ''knocked his head on the floor'' (Fig. 1). Leclercq and Lambert re-enforced the observed preference of certain blow flies for blood in 1976: they found *Calliphora vomitoria* on a corpse, 6 h after postmortem, laying eggs into blood (but not on the wounds) of the deceased.

In addition to medical and legal experts, sculptors, painters, and poets have closely observed the decomposition of human bodies, noting, in particular, the effects of feeding maggots. Early documents illustrating maggots on corpses date to the Middle Ages, including woodcuts from the ''Dances of the Death'' (15th century, Fig. 2), and the intricately cut ivory carving, ''Skeleton in the Tumba'' (16th century, Fig. 3, [11]). Such artwork accurately depicts the insect-mediated pattern of body mass reduction, particularly the early skeletonization of the skull and the reduction of internal organs, with large parts of the skin left intact (Figs. 2 and 3). The poem ''Une Charogne'' by the French poet Charles Baudelaire (1821–1867) must be mentioned in this context too, since it contains clear observations on the decay of human bodies, including an accurate reference to the sound of maggot masses on corpses: ''Like water and the wind running/Or corn that a winnower in rhythmic motion/ Fans with fiery cunning'' [9]. A century earlier, in 1767, the biologist Carl von Linné made the statement that three flies would destroy a horse as fast as a lion would (in the sense of them producing large masses of maggots) [75].

3. Early cases from France

During mass exhumations in France and Germany in the 18th and 19th centuries, medico-legal doctors observed that buried bodies are inhabited by arthropods of many kinds. In 1831, the famous French medical doctor Orfila observed a large number of exhumations [79,80]. He understood that maggots play an important role in the decomposition of corpses (Fig. 4).

The first modern forensic entomology case report to include an estimation of postmortem interval (PMI) was given by the French doctor Bergeret in 1855 [12]. The case dealt with blow fly pupae and larval moths. Though Bergeret was by profession a hospital physician (at the Hopital Civil d'Arbois), his interest in cadaver study is clear, as he states that a corpse dealt with by him resembled those he had observed found in other locations (i.e. ''in the hot and dry lands (''pays chauds'') on the cemetery of the Capucins of Palerme'', or ''in Toulouse''). His original report to the court was dated 28 March 1850. In his journal article, next to a long description of the criminalistic impact in the trial, he also describes the court proceedings: ''Within three years, four different tenants [i.e. families, M.B.] lived in the flat. The first of them left in December 1848, and the person examined started to live there at the end of 1844. I [i.e. Bergeret] was brought to the house of Mme. Saillard [i.e. the landlady] in rue du Citoyen, 4, (. . .) to examine the corpse of a child. (. . .) Length of corpse: [46 cm] [then details on measurements of bones, state of internal organs, etc. follow]. The questions we had to deal with now were: (1) was the child born regularly/at the right time; (2) was it alive when it was born; (3) how long did it live; (4) how did it die?; (5) what was the time interval between birth and death?'' Questions 1–4 were answered with classical forensic pathology. Question 5 was commented in the following way: ''To answer this question, legal medicine must check with another science, the Natural Sciences.'' However, Bergeret does not state whether he worked together with another person.

In his paper, Bergeret gives a brief overview on the life cycle of insects in general. He mistakenly assumes, however, that metamorphosis would generally require a full year (''une annee entiere''). Furthermore, he assumes that females generally lay eggs in summer, and that the larvae would transform to pupae (he calls them nymphes) the following spring and hatch in summer. Some details of Bergeret's calculation: ''The eggs of the larvae we found on the corpse in March 1850 must have been deposited there in the middle of 1849. Therefore, the corpse must have been deposited before this time interval. Next to the many living larvea there were numerous pupae present, and they must

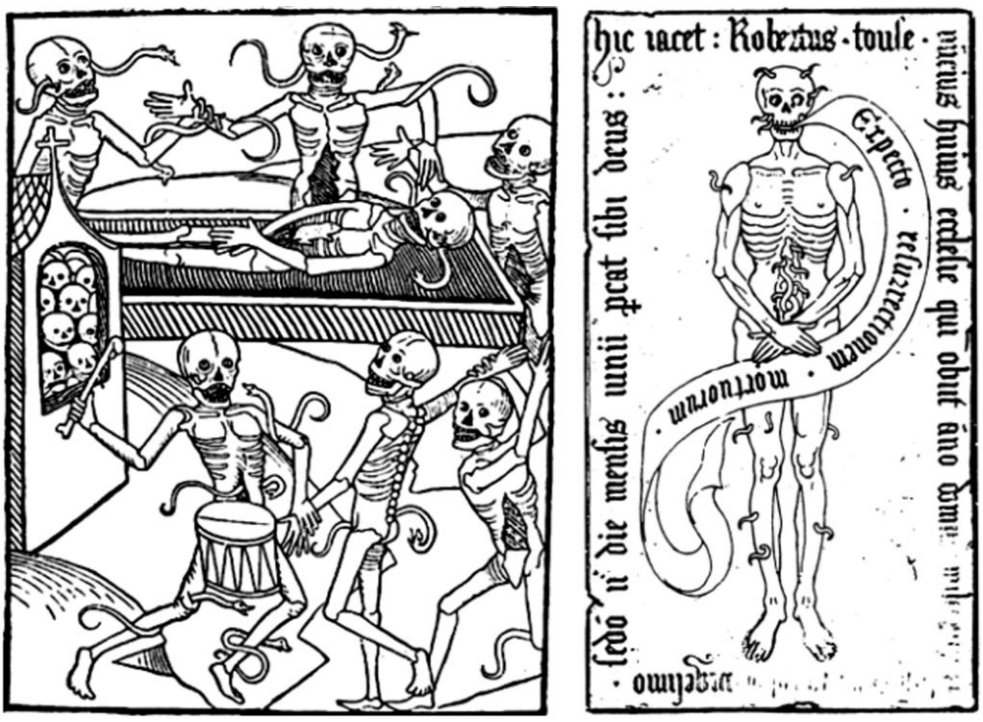


Fig. 2. Close observation of decomposition of human corpses built the basis for these figures: (left) ''Dance of the Death'' (ca. 1460, from: W. Stammler: *Der Totentanz*, Munich, 1948); (right) grave of Robert Touse who ''expects the resurrection of the dead'' (exact time of making unknown, from [11,54]). Note that maggots are displayed similar to snakes, or worms (on the left picture), and that all heads of the corpses are already skeletonized.

come from eggs that have been laid earlier, i.e. in 1848. (. . .) Could it be that the corpse was deposited even before that time [i.e. 1848]? The fly that emerges from the pupae that we found in the body cavities, is *Musca carnaria* L. that lays its eggs before the body dries out. We found other pupae of little butterflies of the night [i.e., moth] too, that attack bodies that are already dried out. If the body was deposited, say in 1846 or 1847, we would not have found those larvae [i.e., since they would have hatched]. In conclusion, two generations of insects were found on the corpse, representing 2 years postmortem: on the fresh corpse, the flesh fly deposited its eggs in 1848, on the dried out corpse, the moth laid their eggs in 1849''.

In retrospect, one should understand that Bergeret did not focus on forensic entomology in his report to the court but used entomology as one forensic tool among others. Indeed, the mummification of the cadaver appears to be his overriding issue of interest in this case. Bergeret references Orfila in the matters of both mummification and forensic entomology. He also clearly notes the lack of knowledge concerning insect succession on corpses in his days.

In 1879, the president of the French Society of Forensic Medicine, Brouardel reported another early case [15]. Paul Camille Hippolyte Brouardel, born in Saint-Quentin on 13 February 1837, became a member of the French Academy of Medicine in 1880. He worked on tuberculosis, vaccination, and legal medicine. His numerous medico-legal accounts include practical guidelines for his colleagues in the morgue. A contemporary said that ''his work is conscientious, clear, methodical, and serves as a model.''

In his report, after referencing the work of Bergeret, Brouardel describes the case of a newborn child that was autopsied by him on 15 January 1878 [15]. The mummified body was inhabited by several arthropods, including butterfly larvae and acari (i.e. mites), which led to a request for assistance from Monsieur Perier, Professor at the Museum of Natural History in Paris, and Army Veterinarian Pierre Mégnin. Perier reported that the body was most likely dried out before it was abandoned. The determination of mites was left to Mégnin whereas Perier determined the butterfly larvae as ''chenilles d'aglosses'', i.e. larvae from the genus *Aglossa* (small moth, family Pyralidae). From the state of preservation, and from the larvae found, Perier stated that the baby may have been born and died *the summer before* (''de l'éte dernier probablement''), i.e. around 6–7 months before the corpse was autopsied.

Mégnin reported that the whole body was covered with a brownish layer composed exclusively of mite skins and mite feces, but not living mites. Inside the cranium, he found large numbers of a single mite species. Initially, a few larval mites must have been carried to the corpse by other arthropods. Mégnin calculated that on the whole body, 2.4 million acari

Ponte de quelques insectes. Nous savons qu'en été, dans l'espace de temps pendant lequel les cadavres sont exposés à l'air, avant l'inhumation, quelques mouches pondent à la surface de la peau des œufs qui, éclos plus tard dans le cercueil, peuvent donner naissance à d'autres mouches; celles-ci, après s'être fécondées, peuvent encore reproduire sept ou huit fois des générations qui vont en se multipliant à l'infini.

Les insectes qui paraissent se repaître de préférence des cadavres, et dont les œufs sont déposés à la surface du corps, sont les suivans : *musca tachina simplex* de Meigen; *vomitoria, cæsarea, domestica, carnaria, furcata; scatophaga stercoria; thyreophora cynophila; anthrenus; dermestes; hister; necrophorus; sylpha; ptenus fur, imperialis; oxyporus, lathrobium; pœderus; stenus; oxytelus; tachinus; aleochara; noterus; scarites; harpalus; julus lepisma.*

Or, il est avéré que, dans les premiers temps après la mort, les mouches ne s'arrêtent pas autour des cadavres; que plus tard elles ne font que voltiger près d'eux, et qu'enfin, lorsque la putréfaction est plus avancée, elles s'appliquent sur eux et y déposent leurs œufs; bientôt en effet on voit des larves plus ou moins nombreuses ramper sur plusieurs de leurs parties. Que si l'on enterre maintenant deux cadavres, dont l'un offre à sa surface des milliers d'œufs, tandis que l'autre n'en présente pas encore, il est évident que le premier se pourrira beaucoup plus vite, toutes les autres circonstances étant les mêmes, parce que le propre des larves est de détruire nos tissus pour s'en nourrir. On ne saurait donc nier l'influence de la ponte des insectes à la surface du corps sur la marche de la putréfaction.

Fig. 3. Early account of insects on corpses that were already determined to the species. From Orfila's & Lesueur's *Handbook for the use at exhumations* [79].

were present dead or alive. He also calculated that after 15 days, the first generation with 10 females and five males had developed; after 30 days, 100 females and 50 males; after 45 days, 1000 females and 500 males. Finally, after 90 days, 1 million females and 500,000 males were present. Since this was the number of individual he estimated being on the corpse, he made a conservative guess and reported that the corpse must have been abandoned for at least 5 months (3 months of mite development, preceded by 2 months for desiccation) but more likely 7–8 months. This is the same case as Case no. 12 in Mégnins "La faune de cadavres" (see below), and Mégnin states that this is his "prémiere étude médico-légale" (*first medico-legal study*) [63].

This case also illustrates nicely how early researchers in the field investigated the use of molds, slime fungi, crustaceans, mites, and plants in addition to insects.

4. Further mass exhumations

On 6 April 1881, the German medical doctor Reinhard reported the first systematic study in forensic entomology [85]. Dealing with exhumated bodies from Saxonia, he collected mainly Phorid flies taxonomically identified by the entomologist Brauer in Vienna. He also described beetles in graves older than 15 years. In some instances, he found the insects breeding within cracks of adipocire. But Reinhard concluded that their presence may have more to do with their feeding on plant roots protruding into the graves rather than any direct association with the corpses. Reinhard's work remained well known for a long time, and in 1928 an extensive citation of his paper appeared in the work of the Phorid fly expert, Schmitz [88] and elsewhere [3,49].

Another entomological report of exhumations, this time from Franconia, was given by Hofmann in 1886 [41]. Hofmann found Phorids too, and identified them as *Conicera tibialis* Schmitz, today known as the "coffin fly".[2]

Around the same time, the 60-year-old doctor Jean Pierre Mégnin started to develop his theory of predictable, ecological waves of insect life on corpses. Mégnin, born in Herimoncourt (Doubs) on 18 January 1928, went to school at the Ecole d'Alfort from 1849 until his graduation in 1853. In 1855, he became an Army Veterinarian. His books include "Maladies de la Peau des Animaux" (*Animal Skin Diseases*, 1867–1882), and "Maladies parasitaires" (*Diseases caused by Parasites*, 1880). Mégnin likewise worked on Acari (publications in this matter date between 1876 and 1879), and reported some of his results in his book "Faune des Tombeaux" (*Fauna of the Tombs*, 1887) [60]. No affiliation to a university or a Museum of Natural History was mentioned in his articles, and because he became a member of the French Academy of Medicine in 1893, one might conclude that he considered himself primarily a medical doctor.

Mégnin drew on his 15 years of medico-legal experience with corpses in publishing 14, mostly brief, papers between 1883 and 1896 (e.g. [2,61,64]). He found fault in the dissertation of his younger French colleague George P. Yovanovitch, of the Faculty of Medicine, Paris, on the same subject (1888, [113]). Mégnin was under the impression that Yovanovitch's data were not sufficiently precise [62]. Previously, the two researchers had co-operated in the sense that Yovanovitch was allowed to use Mégnin's data, including tables of mites and the successional table of five cadaverous fauna waves that Yvanovitch titled *Toilers on the Dead* ("Les Travailleurs de la Mort", obviously being a pun related to the book *Toilers of the Sea* ("Les Travailleurs de la Mer" by French author Victor Hugo, 1866)).

Finally, in 1894, Mégnin published his most important book *La Faune des Cadavres* (Figs. 5 and 6). In it, he expanded his former theory of four insect waves for freely exposed corpses to eight successional waves. For buried corpses, he reported two waves. The book dealt with larval and adult forms of a number of families, and its drawings focused on wing venation, posterior spiracles, and overall

[2] The Phorid fly collection of Schmitz is now at the Museum Alexander König in Bonn, Germany.

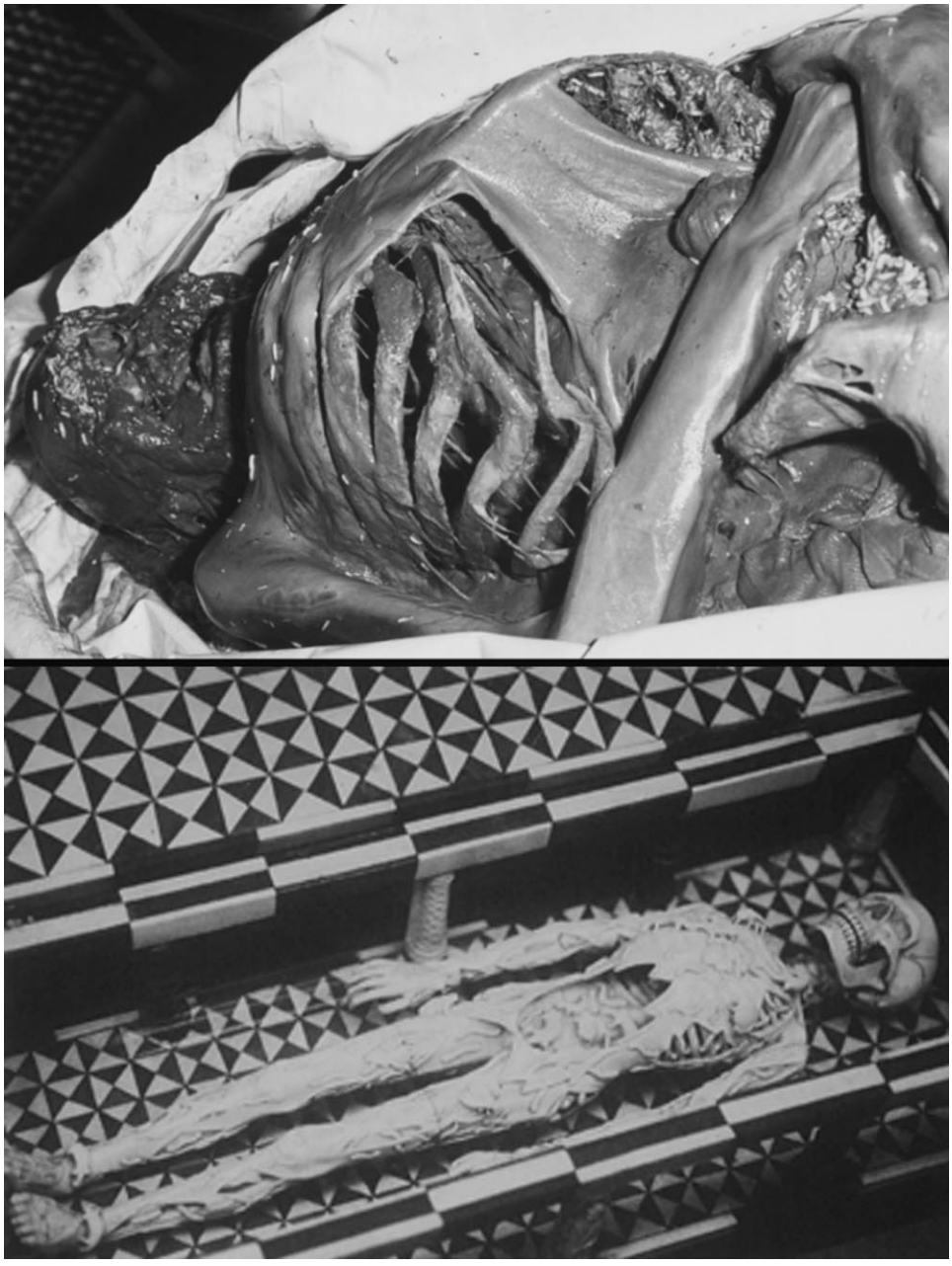


Fig. 4. (Top) Typical pattern of decay caused by maggots (head is left, rib case if partially skeletonized); (bottom) realistic artistic representation of the same postmortem decay as above (ivory ''Skeleton in the Tumba'', 16th century, Schnütgen Museum, Cologne, Germany).

anatomy of the insects for identification. Mégnin also described 19 case reports, including his own cases between 1879 and 1888 (some of the cases were in co-operation with Brouardel). He cites his original statements given in court as well as the basic questions asked of him as an expert witness.

In addition to advancing the science of forensic entomology, Mégnin's work greatly popularized the subject. His contributions to our knowledge of the arthropod fauna of graves and the general fauna and flora of mummified, or otherwise decayed, corpses was later honored in the naming of the mold *Endoconidium megnini* [45].

In 1895, inspired by Mégnin, the Canadian researchers Wyatt Johnston and Geoffrey Villeneuve, of Montreal, started a number of systematic entomological studies on human corpses [48]. The two scientists write of Mégnin: ''(. . .) in no single instance did the results of the inquiry go to

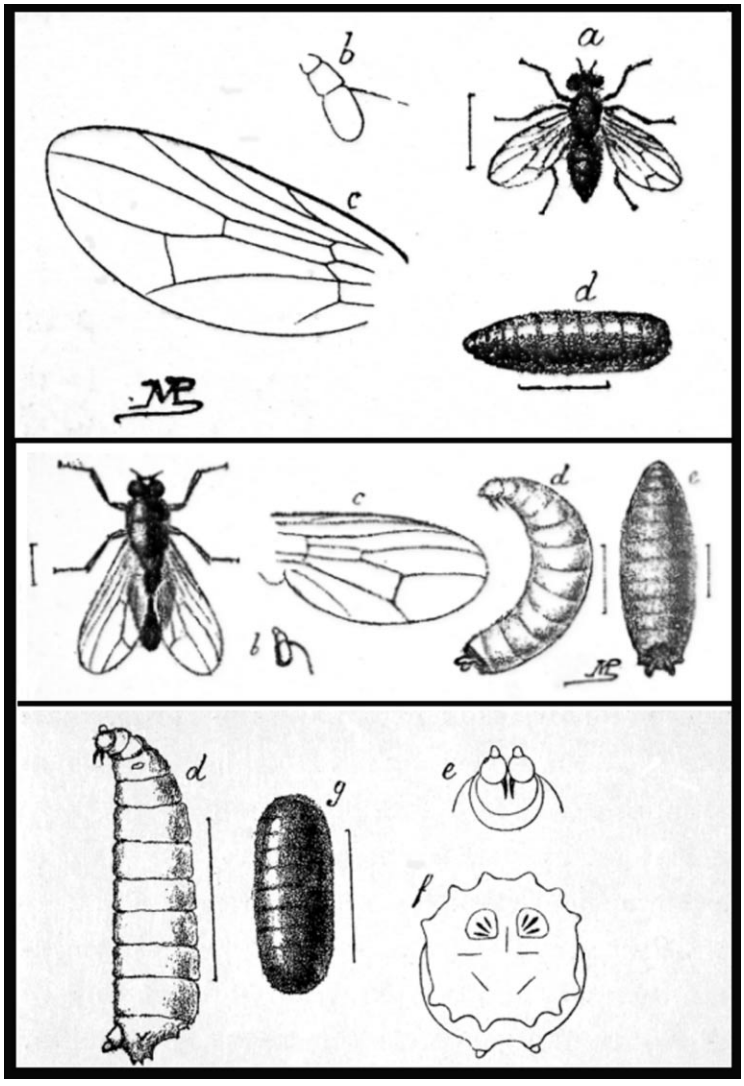


Fig. 5. Figures of flies from Mégnin's faune de cadavres [63]: (top) "*Pyophila petasionis* Duf.", middle: "*Sarcophage carnaria* Meig."; (bottom) "*Lucilia Caesar* Rob. D."

show that M. Mégnin's deductions were erroneous. (. . .) The chief danger to be feared from Mégnins imitators is that they might tend to indulge in guesses having no very solid basis and to apply rules to countries and climates where they were inapplicable." They aimed to refine the work of Mégnin, and to adapt it to their local faunas.

Another study on this subject had already been set up by Murray Galt Motter, "Volunteer in the United States Bureau

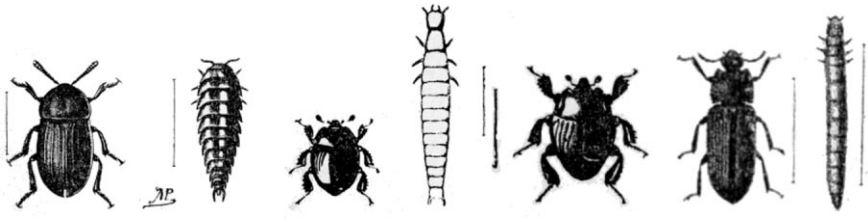


Fig. 6. Figures of beetles from Mégnin's *Faune de cadavres* [63]. From left to right: "*Silpha obscura*" (adult and larva), "*Saprinus rotondatus*" (adult and larva), "*Hister cadaverinus*" (adult), and "*Tenebrio obscurens*" (adult and larva).

for Animal Industry'', and his co-workers a few years previous. Shortly after, in the summers of 1896 and 1897, Motter's group systematically and critically checked more than 150 exhumed corpses from Washington, DC [74]. In his report, Motter provides brief descriptions of the entomological findings as well as brief comments on soil type, grave depth, etc. A speech that he ''read before the public section of the British Medical Association'' in 1897 carried the title ''Underground Zoology and Legal Medicine'' [73].

Another report in 1895 came from Sweden where Schöyen gave an overview of work that could be applied to the investigation of ''gravenes fauna'', or the fauna of graves [89]. However, he refers primarily to species already mentioned in Reinhard's and Mégnin's publications.

The only forensic entomology studies of that time no longer available are those performed by Hough in New Bedford from 1894 to 1897, as he never published his data.

5. Turn of the century

Previous forensic insect studies by the German doctors Klingelhöffer [51] and Maschka [58], and the forensic pathologist Stefan von Horoskiewicz from Krakau University (then Austria, now Poland) [44], had focused on the bite patterns of cockroaches and ants. Klingelhöffer, a district medical doctor responsible for the Frankfurt area, relates the case of a poor family whose 9-month-old sickly baby died on 26 May 1889, and was autopsied 3 days later, on 29 May. In the meantime, the local ''doctor responsible for the poor'' had filed a report to the police because he had observed patches in the face of the child, leading to the father's arrest. During the resulting autopsy, the ''patches'' were noted on the nose and lips and to proceed downwards from the child's mouth. The tongue was not discolored, but bleeding on the tip. Of particular interest to the police was confirmation of their suspicions that the father had tried to make the child drink sulphuric acid, a common method of poisoning (also self poisoning) at that time. However, Klingelhöffer found no signs of poisoning, and concluded that the abrasion-like patterns had most likely been caused by cockroaches. The father was released after 3 weeks in prison (see also [87]).

Horoszkiewicz dealt with a similar case, in which a child was autopsied in April 1899. The autopsy found no internal signs of violent death, however, numerous abrasions could be seen on the nose, cheeks, lips, and chin, with more obvious marks on the surface of the neck and backside of the left hand, fingers, genitals, and the inner thighs. When questioned by Horoszkiewicz, the mother stated that when she came home from preparing for the funeral, the body of her child had looked as if it was covered with a black shroud (''mit einem schwarzen Leichentuche bedeckt'') of cockroaches, but she did not see any abrasions at that time. To verify whether the cockroaches could be the sole cause for the abrasions, Horoszkiewicz put pieces of fresh tissue from human corpses in glasses filled with cockroaches. While no obvious signs of cockroach feeding were apparent immediately after the feeding activity, they became visible when the skin dried, explaining why the mother had not seen the abrasions but the medical examiners had.

Similar cases were reported by medical examiner Maschka from Austria who became involved in high profile cases in the modern sense of the phrase. In one case, he found abrasions on a child whose body was discovered in a well. It was believed that a sexual offender may have abused the child and then strangled, or throttled it before throwing it in the well. Maschka, however, concluded that the lesions must have been caused by arthropods. In another case, it was thought that a father may have killed his 3-day-old child by forcing it to drink sulphuric acid. The father, however, stated that he had put the child, after it had died of natural causes, near the window at 22.00 h on 14 April 1880. He reported that on 04.00 h the next day, the child's head, located under a blanket, was already covered with ants. Maschka's findings at autopsy were consistent with the father's account.

Another experimental account was given by Eduard Ritter von Niezabitowski, also a medical examiner at the Medico-Legal Insitute of Krakau University. His experiments were performed from May 1899 to September 1900, using aborted fetuses and cat, fox, rat, mole, and calf cadavers that he put on the windowsill of the institute as well as in a nearby vegetable garden [76]. His observations dealt primarily with flies: Calliphorids, *Lucilia caesar*, *Sarcophaga carnaria*, and ''*Pyophila nigriceps*'' (most likely, cheese skippers (*Piophila casei*)); and also beetles, mostly *Silpha*, *Necrophorus*, or *Dermestes*. His important contribution to the field was the experimental proof that human corpses share the same fauna with animal corpses, both vertebrate and invertebrate.

Meanwhile, turn-of-the-century France and Germany enjoyed a general increase in interest in zoological studies including invertebrate life. As evidence, we see the great success of two popular book series from that time, Alfred Brehm's *Thierleben* (*Life of The Animals*) [99], and even more Jean Henri Fabre's *Souvenirs entomologiques* (*Souvenirs of Insect Life*) [29], among other topics specifically dealing with carrion beetles and blow flies. These books, still well-known to the public in Central Europe, inspired an interest in entomology in large numbers of people. Among the lasting benefits of this popularity are numerous ecological studies that continue to be drawn upon in forensic case studies today.

In 1907, Claude Morley published an article in UK dealing with the question of which species should be classified as carrion beetles [72]. He stated that during 10 years of collecting he found that winter was ''almost the best time'' for carrion beetles and that there are (so-called) carrion beetles that are not carnivorous but ''act as final dissoluters to the ancient carcase (. . .). It is still a mystery to me what *N[ecrophorus] vespillo* feeds upon.'' Papers like this were the early basis for the systematic ecological studies that have influenced forensic entomology since the 1920s.

6. Circa the World Wars

Beginning in the 1920s, species lists and monographs on forensically important insects were finally published (e.g. [38,53,84,91]), with a focus on ecology, metabolism or anatomy, e.g. [8,14,19,20,22–25,27,31–34,39,40,46,50,52, 57,66–68,70–72,81,83,84,93,94,100–102,104–108,111,112]; see also [6,26]. Pest control, and ''maggot therapy'' were both of growing interest during this period, and many contributions stemmed from these fields (e.g. [5,7,35,36,37, 42,47,53,82,86,95,96,109,110]), creating a major scientific source for interpretation of forensic insect evidence. In the context of pest control, for instance, it was found that adult flies may be present near dying persons or animals before their actual death [21]. It also became popular to investigate the entomological status of ancient mummies [28].

The interest in maggots on corpses remained high in 1922, when Karl Meixner, professor at the Insitute for Legal Medicine in Vienna and Innsbruck reported cases of bodies that quickly disintegrated while being put into storage in the institute's basement [65]. This rapid disintegration was most dramatic with juvenile corpses. Apart from references to Orfila and Lesueur [79] and Mégnin [60–64], no further data was collected by Meixner.

A few years later, Hermann Merkel, professor at the Insitute for Legal Medicine in Munich, extended Meixners observations with case reports that demonstrated that the circumstances of death could influence the course of insect succession. In a case from summer 1919, a son had killed his parents and stored the bodies next to each other for 3 weeks. At autopsy, the bodies were found to be in different states of decomposition: the obese body of the mother (shot in the

Fig. 7. Influence of caddis-flies on a child's body; case investigated by Holzer (from [43]).

heart) was in full bloated decay, with both eyeballs destroyed by the actions of maggots and numerous maggots already present inside of the (liquifying) brain tissue. Her internal organs were comparably intact and no maggots were present inside of the fat layers. By contrast, the father's slim body had already been infested with numerous maggots in all cavities, with all internal organs destroyed, and pupae already developed. The reason for the increased maggot presence in the father's body was that he had not only been shot but also repeatedly stabbed. This attracted flies to deposit eggs not only in the facial area but also into the wounds [69]. In another case, Merkel found the mummified body of a person who died at home, with *not one single maggot being present*.

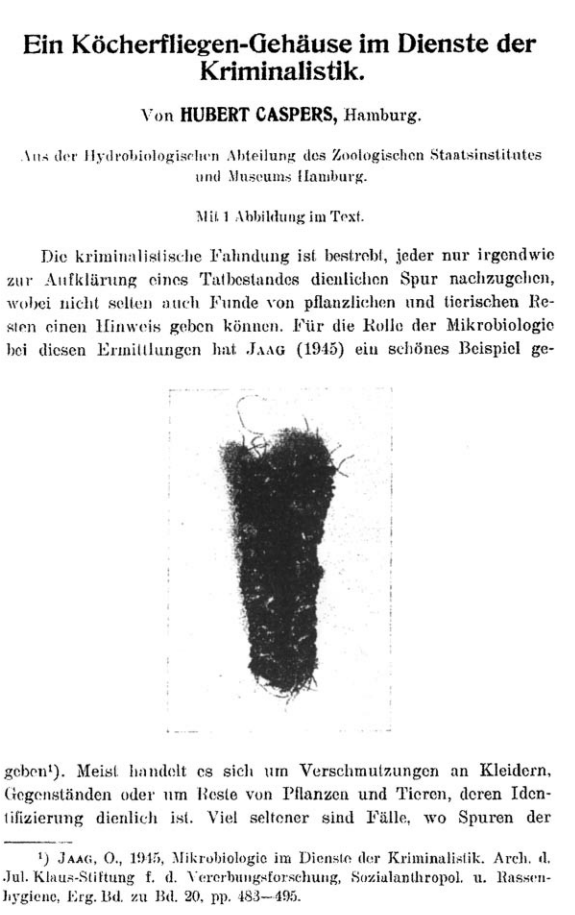
In Italy, G. Bianchini, director of the Institute for Legal Medicine of Bari University, wrote a ''contribution to the practical, and experimental study of the fauna of corpses'' in 1929 [13]. Bianchini's case report deals with the corpse of a 4-year-old child that had dried-out lesions of the skin on the ears, arms, the abdominal area, and the upper side of the thighs. Arthropods collected from the body included mites, ''very small scorpions'', small beetles, and ants. Identification of the ants was performed by professor Carlo Minozzi, and after further experimentation, Bianchini concluded that the lesions must have been caused by ants of the same species as found on the corpse within a period of around 24 h. A former case report of Raimoni and Rossi (1888; cited after [13]) dealt with the influence of *Gammarus pulex*, a freshwater crustacean, on corpses. The authors found that Gammarus can produce large numbers of small needle-like lesions. In their case report, it was concluded that a body had been stored in a freshwater containment.

The only case report during the 1930s seems to come from Josef Holzer, medical examiner at the Institute for Legal Medicine in Innsbruck, Austria. Holzer investigated the type of destruction caused by caddis-flies feeding on corpses submerged in freshwater. In an actual case from April 1937, he found that caddis-flies had destroyed all skin layers of the thighs up to the lower border of a pair of shorts as well as larger parts of the facial skin (Fig. 7). It was late winter/early spring with low temperatures, and there had clearly been no blow-fly maggots present. Holzer had never observed such patterns of destruction, even in cases where caddis-fly casings had actually been present on corpses. Therefore, he collected caddis-flies from the body of water in which the corpse had been found and put them in three aquariums containing an aborted fetus, a rat, and a guinea pig, respectively. In doing so, he demonstrated that caddis-flies were the cause of the lesions observed on the child [43].

K. Walcher from the Insitute for Legal Medicine in Munich also reports that he found maggots entering the spongiosa of long bones to reach the bone marrow (circumstances: suicide, postmortem interval 100 days outside). Since the skeleton was intact, Walcher suggested that the animals crept through *Foramina nutritia*, tiny gaps in the bones that allow blood vessels, and nerves to enter the bones [103].

7. After the World Wars

During the 1940s, only a note of Bequaert seems to deal with the use of insects to determine the postmortem interval [4], but see also [30]. In the 1950s, Hubert Caspers from the Zoological Institute and Museum of the State Hamburg introduced the use of caddis-fly casings as a tool for forensic investigation (Fig. 8). The body of a dead woman, naked except of a pair of red socks, and wrapped in a sack, had been found in 1948 in a moat of a windmill [16]. The question was if the body was disposed there immediately after the killing, or if it was stored elsewhere before it was dumped. In a caddis-fly casing (most likely of *Limnophilus flavicornis* L.) that was found on one sock, fibers of the red socks had clearly been used to build the casing. However, the fibers



Ein Köcherfliegen-Gehäuse im Dienste der Kriminalistik.

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Aus der Hydrobiologischen Abteilung des Zoologischen Staatsinstitutes und Museums Hamburg.

Mit 1 Abbildung im Text.

Die kriminalistische Fahndung ist bestrebt, jeder nur irgendwie zur Aufklärung eines Tatbestandes dienlichen Spur nachzugehen, wobei nicht selten auch Funde von pflanzlichen und tierischen Resten einen Hinweis geben können. Für die Rolle der Mikrobiologie bei diesen Ermittlungen hat JAAG (1945) ein schönes Beispiel ge-

geben[1]). Meist handelt es sich um Verschmutzungen an Kleidern, Gegenständen oder um Reste von Pflanzen und Tieren, deren Identifizierung dienlich ist. Viel seltener sind Fälle, wo Spuren der

[1]) JAAG, O., 1945, Mikrobiologie im Dienste der Kriminalistik. Arch. d. Jul. Klaus-Stiftung f. d. Vererbungsforschung, Sozialanthropol. u. Rassenhygiene, Erg. Bd. zu Bd. 20, pp. 483–495.

Fig. 8. ''*A caddis-fly casing as a tool in criminalistics*.'' The casing was not only used to suggest a possible postmortem interval but due to the fibers it was built of, it could also be connected to the socks of a dead woman (from [16]).

were only found at the very top, and the very bottom of the casing which meant that the fly had already built her case before she entered the sack. She then finished the casing (fibers on top), and attached it to the sock (fibers on bottom). Since the attachment procedure lasts at least some days, it was estimated that the body was laying in the water for at least 1 week. Further criminalistic evidence led to the conclusion that the entomological result indicated that the body had been stored elsewhere before it was dumped. With the description of Caspers' case, our historic survey on forensic entomology ends.

8. Final remarks

Between the 1960s and mid-1980s, forensic entomology was maintained primarily by medical doctor Marcel Leclecq (Belgium) [55,56] and professor of biology Pekka Nuorteva (first, Helsinki Zoological Museum, later, professor at the Department of Environmental Protection and Conservation, University of Helsinki, Finland) [77,78], with a focus on case work.

Since then, basic research and advanced application of forensic entomology in the US [4], Russia [3], Canada [1], France and Japan [2] as well as casework in other countries like England and India has opened the way to routine casework. By now, researchers worldwide use entomology in criminal investigations including murder and other high profile cases.

Note: During the process of publication of this paper, the following manuscripts were obtained; [17,18,90,92], P. Schneider, Leichenzerstörung durch Madenfraβ. Wie lange log die Leiche im Gebüsch? (Destruction of a corpse caused by the action of maggots. How long did the body lay in the bushes?). Arch. Kriminol 98 (1936) 216–221 and L.J. Monde, Ausfürliches Handbuch der gerichtlichen Medizin, Fünfter Teil, Dyk'schz Buchhandlung, Leipzig (1829) 220 (in German). Mende's book already mentions several arthropod species, amongst them orthoptera, hymenoptera, diptera, aptera, coleoptera, etc.

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References

[1] C.E. Abbott, The necrophilous habit in Coleoptera, Bull. Brooklyn Entomol. Soc. 32 (1937) 202–204.
[2] Anon., Report on P. Mégnin, Préparations, en partie microscopiques, de tous les restes d'insects trouvès sur ou dans un cadavre, Rev. Hyg. Pol. San. 5 (1883) 203–204 (in French).
[3] Anon., Report on C. Strauch C, Die Fauna der Leichen. In Verhandlungen der VII. Tagung der Deutschen Gesellschaft für Gerichtliche Medizin, Vjschr, Gerichtl. Med. 43 (Suppl. 2) (1912) 44–49 (in German).
[4] Anon., Report on J.C. Bequaert, Some observations on the fauna of putrefaction and its potential value in establishing the time of death, New Engl. J. Med. 227 (1945) 856.
[5] Anon., Report on Pemberton, Fly control in carrion, Proc. Hawaiian Entomol. Soc. 12 (1945) 213–214.
[6] E.E. Austen, Necrophagous diptera attracted by the odour of flowers, Ann. Mag. Nat. Hist. Zool. Bot. Geol. 18 (1896) 237–240.
[7] W.S. Baer, The treatment of chronic osteomyelitis with the maggot (larva of the blow fly), J. Bone Joint. Surg. 13 (1931) 438–475.
[8] W.V. Balduf, The Bionomics of Entomophageous Coleoptera, John S. Swift & Co., St. Louis, MO, Fig. 1–108, 1935, pp. 1–220.
[9] C. Baudelaire, in: M. Mathews, J. Mathews (Eds.), The Flowers of Evil, New Directions Publishing, New York, 1955 (in English and French).
[10] M. Benecke, Rechtsmedizinisch angewandte kerb und spinnentierkundliche Begutachtungen in Europa: eine kurze Übersicht über Ursprünge und den aktuellen Stand der Forschung (A short survey on the history, and current state of forensic entomology), Rechtsmedizin 8 (1998) 153–155 (in German).
[11] M. Benecke, M. Leclercq, Ursprünge der modern angewandten rechtsmedizinisch-kriminalistischen Gliedertierkunde bis zur Wende zum 20. Jahrhundert (Foundations of modern Forensic Entomology until the turn of the last century), Rechtsmedizin 9 (1998) 41–45 (in German).
[12] M. Bergeret, Infanticide. Momification naturelle du cadavre. Découverte du cadavre d'un enfant nouveau-né dans une cheminée où il s'était momifié. Détermination de l'epoque de la naissance par la présence de nymphes et de larves d'insects dans le cadavre, et par l'étude de leurs métamorphoses (Homicide of a new-born child found in a chimney, and its natural mumification. Determination of postmortem interval by the use of insect larvae and their metamorphosis), Ann. Hyg. Méd. Lég. 4 (1855) 442–452 (in French).
[13] G. Bianchini, Contributio practico e sperimentale allo studio della fauna cadaverica (Practical, and experimental contribution concerning the study of the fauna of cadavers), Bernardinno, Siena, 1929 (in Italian).
[14] F.S. Bodenheimer, Über die Voraussage der Generationenzahl von Insekten. III. Die Bedeutung des Klimas für die landwirtschaftliche Entomologie (On the prediction of the number of generations of insects: influence of the climate on entomological aspects of agriculture), Z. Angew. Entomol. 12 (1927) 91–122 (in German).
[15] P. Brouardel, De la détermination de l'epoque de la naissance et de la mort d'un nouveau-né, faite a l'aide de la présence des acares et des chenilles d'aglosses dans un

cadavre momifié (Determination of the postmortem interval/time of birth of a new-born child by use of larvae from the genus Aglossa on a mummified corpse), Ann. Hyg. Pub. Méd. Lég. 2 (1879) 153–158.

[16] H. Caspers, Ein Köcherfliegen-Gehäuse im Dienste der Kriminalistik (A caddis-fly casing in the service of criminalistics), Arch. Hydrobiol. 46 (1952) 125–127 (in German).

[17] R.K. Chapman, An interesting occurrence of *Musca domestica* L. larvae in infant bedding, Can. Entomol. 76 (1944) 230–232.

[18] C.U. Clark, On the food habits of certain dung and carrion beetles, J. N. Y. Entomol. Soc. 3 (1895) 61.

[19] C.P. Clausen, Entomophagous Insects, Mc-Graw Hill, New York, 1940.

[20] W.T. Davis, *Silpha surinamensis* and *Creophilus villosus* as predaceous insects, J. N. Y. Entomol. Soc. 23 (1915) 150–151.

[21] W.T. Davis, *Lucilia* flies anticipating death, Bull. Brooklyn Entomol. Soc. 23 (1928) 118.

[22] W.M. Davies, Hibernation of *Lucilia sericata*, Mag. Nat. 123 (1929) 759–760.

[23] W.M. Davies, Parasitism in relation to pupation in *Lucilia sericata*, Mag. Nat. 125 (1930) 779–780.

[24] C.C. Deonier, Carcass temperatures and their relation to winter blowfly populations and activity in the southwest, J. Econ. Entomol. 33 (1940) 166–170.

[25] C.K. Dorsey, A comparative study of the larvae of six species of *Silpha* (Coleoptera, Silphidae), Ann. Entomol. Soc. Am. 33 (1940) 120–139.

[26] L.H. Dunn, *Hermetia illuscens* breeding in a human cadaver, Entomol. News 27 (1916) 59–61.

[27] A.C. Evans, Studies on the influence of the environment on the sheep blow-fly *Lucilia sericata* (Mg.). II. The influence of humidity and temperature on praepupae and pupae, Parasitology 27 (1935) 291–298.

[28] H.E. Ewing, Lice from human mummies, Science 60 (1924) 389–390.

[29] J.H. Fabre, Souvenirs entomologiques. Etudes sur l'instinct et les moeurs des insectes, 10 Volumes (1879–1907), Paris, Delagrave, 1905–1909.

[30] G. Forbes, The brown house moth as an agent in the destruction of mummified human remains, The Police J. (Lond.) 15 (1942) 141–148.

[31] G. Fraenkel, Observations and experiments on the Blow-fly (*Calliphora erythrocephala*) during the first day after emergence, Proc. Zool. Soc. (Lond.) 103 (1935) 893–904.

[32] M.E. Fuller, The insect inhabitants of carrion: a study in animal ecology, Bull. Council Sci. Ind. Res. 82 (1934) 1–63.

[33] G.S. Graham-Smith, Observations on the habits and parasites of common flies, Parasitology 8 (1916) 440–544.

[34] E. Hartung, Untersuchungen über die Geruchsorientierung bei Calliphora erythrocephala (Experiments on the orientation by the use of smelling organs in *Calliphora erythrocephala*), Z. Vergl. Physiol. 22 (1935) 119–144 (in German).

[35] A. Hase, Über ein einfaches und billiges Verfahren, Fliegenmaden zu züchten (A cheap and simple method to breed maggots), Zool. Anz. 88 (1930) 286–287 (in German).

[36] A. Hase, Fliegenmadenzuchten und Fliegenhaltung für chirurgische Zwecke (Maggot breeding and maturing for the use in surgery), Naturwissenschaften 31 (1934) 523–525.

[37] A. Hase, Über Wärmeentwicklung in Massenzuchten von Insekten sowie über ein einfaches Verfahren, Stubenfliegen dauernd zu züchten (Heat development in mass cultures of insects, and a simple method to breed house flies), Zool. Anz. 112 (1934) 291–298 (in German).

[38] R. Heymons, H. von Lengerken, Studien über die Lebenserscheinungen der Silphini (Coleopt.) VII. *Oecoptoma thoracica* L. (Studies on the ecology of Silphini (Coleoptera): *Oecoptoma thoracica*), Z. Morph. Ökol. Tiere 20 (1931) 691–706 (in German).

[39] R.P. Hobson, Studies on the nutrition of blow-fly larvae. III. The liquefacation of muscle, J. Exp. Biol. 9 (1932) 359–365.

[40] R.P. Hobson, Studies on the nutrition of blow-fly larvae. IV. The normal role of micro-organisms in larval growth, J. Exp. Biol. 9 (1932) 366–377.

[41] O. Hofmann, Observations de larves de Diptères sur des cadavres exhumés (Observations on Diptera larvae on exhumated corpses), C. R. Séances Soc. Ent. Belg. 74 (1886) 131–132 (in French).

[42] F.G. Holdaway, Field populations and natural control of *Lucilia sericata*, Nature 126 (1930) 648–649.

[43] F.J. Holzer, Zerstörung an Wasserleichen durch Larven der Köcherfliege (Destruction of corpses submerged in water by Trichoptera (caddis-fly) larvae), Z. Ges. Ger. Med. 31 (1939) 223–228 (in German).

[44] S. von Horoszkiewicz, Casusistischer Beitrag zur Lehre von der Benagung der Leichen durch Insecten (A case report concerning the feeding of insects on human corpses), Vjschr. Ger. Med. (3 Folge) 23 (1902) 235–239.

[45] H. Hunziker, Über die Befunde bei Leichenausgrabungen auf den Kirchhöfen Basels. Unter besonderer Berücksichtigung der Fauna und Flora der Gräber (Observations during the exhumations on the graveyards of Basel. Under special consideration of the fauna and flora of the graves), Frankf. Z. Pathol. 22 (1919) 147–207 (in German).

[46] F.J. Illingworth, Insects attracted to carrion in southern, California Proc. Hawaiian Entomol. Soc. 6 (1926) 397–401.

[47] A.D. Imms, Dipterous larvae and wound treatment, Nature 144 (1939) 516–517.

[48] W. Johnston, G. Villeneuve, On the medico-legal application of entomology, The Montreal Med. J. 26 (1897) 81–90.

[49] F. Karsch, Über Leichenwürmer (On corpse worms), Naturwiss. Wochenschr. 3 (1888) 88–90 (in German).

[50] R.R. Kaufmann, Investigations on beetles associated with carrion in Pannal Ash, near Harrogate, I–III, Entomol. Monthly Mag. 73 (1937) 78–81, 227–233, 268–272.

[51] Klingelhöffer, Zweifelhafte Leichenbefunde durch Benagung von Insekten (Misinterpretation on the cause of death as a result of insects feeding on corpses), Vjschr. Gerichtl. Med. 25 (1898) 58–63 (in German).

[52] E.F. Knipling, A comparative study of the first instar larvae of the genus Sarcophaga (Calliphoriadae, Diptera), with notes on its biology, J. Parasitol. 22 (1936) 417–454.

[53] E.W. Laake, E.C. Cushing, H.E. Parish, Biology of the primary screw worm fly, *Cochliomya americana*, and a comparison of its stages with those of *C. macellaria*, Tech. Bull. US Dept. Agric. 500 (1936) 1–24.

[54] E.H. Langlois, Essai historique, philosophique et pittoresque sur les danses des morts (Historic, philosophic, and pittoresque essay on the daces of the dead), Lebrument, Rouen, 1852.
[55] M. Leclercq, Entomologie en Gerechtelijke Geneeskunde (Entomology and legal medicine), Tijdschr. Geneeskunde. 22 (1968) 1193–1198 (in Flamish).
[56] M. Leclercq, L. Quinet, Quelques cas d'application de l'entomologie a la détermination de l'époque de mort (Several cases concerning the application of entomology on determination of postmortem interval), Ann. Med. Lég. 29 (1949) 324–326 (in French).
[57] J.R. Malloch, A preliminary classification of Diptera, exclusive of puparia, based upon larval and pupal characters, with keys to imagines in certain families. Part 1, Bull. Illinois State Lab. Nat. Hist. 12 (1917) 161–409, and Plates 28–57.
[58] Maschka, Angeblicher Tod eines Kindes infolge von Verletzungen. Natürliche Todesart. Entstehung der Verletzung nach dem Tod durch Ameisenbisse (Alleged death of a child due to injuries. Natural cause of death. Injury patterns caused by ant bites), Vjschr. Ger. Med. N.F. 34 (1881) 193–197 (in German).
[59] A.G. Mearns, Larval infestation and putrefacation, in: S. Smith, J. Glaister (Eds.), Recent Advances in Forensic Medicine, 2nd Edition, Blakiston's, Philadelphia, 1939, pp. 250–255.
[60] P. Mégnin, La faune des tombeaux, in: M. Brown-Sequard (Ed.), C. R. Heb. Seances Acad. Sci. 105 (1887) 948–951 (in French).
[61] P. Mégnin, Entomologie appliquée a la médicine légale, Bull. Soc. Méd. Légale France 30 (1889) 249–251 (in French).
[62] P. Mégnin, Entomologie appliquée a la médicine légale à propos de la thèse de M. Georges Yovanovitch, Bull. Soc. Méd. Lég. France 21 (1889) 249–251 (in French).
[63] P. Mégnin, La faune de cadavres. Application de l'entomologie a la médicine légale, Encyclopdie scientifique des Aides-Mémoire, Masson, Paris Gauthier-Villars, Paris, 1894 (in French).
[64] P. Mégnin, Note sur une collection d' insectes des cadavres intéressants à connaître au point de vue médico-légal, offerte au Muséum, Bull. Mus. Hist. Nat. 10 (1896) 187–190 (in French).
[65] K. Meixner, Leichenzerstörung durch Fliegenmaden (Destruction of corpses caused by blow fly maggots), Z. Medizinalbeamte 35 (1922) 407–413 (in German).
[66] K. Mellanby, The influence of atmospheric humidity on the thermal death point of a number of insects, J. Exp. Biol. 9 (1939) 222–231.
[67] K. Mellanby, Diapause and metamorphosis of the blowfly, *Lucilia sericata* Meig. Parasitol. 30 (1938) 392–402.
[68] Melvin, *Lucilia sericata*, Ann. Entomol. Soc. Am. 34 (1934) 406-410.
[69] H. Merkel, Die Bedeutung der Art der Tötung für die Leichenzerstörung durch Madenfrass (The importance of the circumstances of death on the destruction of corpses), Dt. Z. Ges. Ger. Med. 5 (1925) 34–44 (in German).
[70] D.F. Miller, Determining the effects of change in temperature upon the locomotor movements of fly larvae, J. Exp. Zool. 52 (1929) 293–313.
[71] D.E. Minnich, The chemical sensitivity of the legs of the blow-fly, to various sugars, Z. Vergl. Physiol. 11 (1930) 1–55.
[72] C. Morley, Ten years' work among vertebrate carrion, Entomol. Monthly Mag. 43 (1907) 45–51.
[73] M.G. Motter, Underground zoology and legal medicine, J. Am. Med. Assoc. 29 (1897) 646, 810.
[74] M.G. Motter, A contribution to the study of the fauna of the grave. A study of on hundred and fifty disinterments, with some additional experimental observations, J. N. Y. Entomol. Soc. 6 (1898) 201–233.
[75] P.L.S. Müller, Des Ritters Carl von Linné (. . .) vollständiges Natursystem nach der zwölften lateinischen Ausgabe (. . .). 5. Theil, 1. Band, Von den Insecten. Raspe, Nürnberg, 1774 (in German).
[76] E. Niezabitowski, Experimentelle Beiträge zur Lehre von der Leichenfauna, Vjschr. Ger. Med. Oeffentl. Sanitätswesen BAND 1902 (1) 44–50 (in German).
[77] P. Nuorteva, M. Isokoski, K. Laiho, Studies on the possibilities of using blowflies (Dipt.) as medicolegal indicators in Finland. 1. Report of four indoor cases from the city of Helsinki, Ann. Entomol. Fenn. 33 (1967) 217–225.
[78] P. Nuorteva, H. Schumann, M. Isokoski, K. Laiho, Studies on the possibilities of using blowflies (Dipt., Calliphoridae) as medicolegal indicators in Finland. 2. Four cases where species identification was performed from larvae, Ann. Entmol. Fenn. 40 (1974) 70–74.
[79] M.J.B. Orfila, C.A. Lesueur, Traité des exhumations juridiques, et considérations sur les changements physiques que les cadavres éprouvent en se pourrissant dans la terre, dans l'eau, dans les fosses d'aisance et dans le fumier (Handbook for the use at legal exhumations, and notes on the physical changes of corpses buried in the earth, in water, in cesspools, and in the manure), Paris, Béchet Jeune, 1831, pp. 331–333 (in French).
[80] M.J.B. Orfila, C.A. Lesueur, Handbuch zum Gebrauche bei gerichtlichen Ausgrabungen und Aufhebungen menschlicher Leichname jeden Alters in freier Luft, aus dem Wasser, den Abtrittsgruben und Düngerstätten (Handbook for the use at legal exhumations from corpses of every age found at the free air, in the water, in cesspools, and in the manure), Übers. v. E.W. Güntz. Barth, Leipzig, 1835, pp. 292–294 (in German).
[81] A.A. Peredelsky, A. Pastuchova, Der Einfluß der Nahrungsmengen auf die Dynamik einiger Erscheinungen im Leben der Schmeißfliege, Biologia. Generalis. 6 (1930) 327–352.
[82] F. Pietrusky, A. Leo, Über Aasfresser und ihre gerichtsärztliche Bedeutung (On carion-feeding animals and their relevance for forensic medicine), Z. Desinfektion/Prakt. Desinfektor. 21 (4) (1929) 50–53.
[83] C.F. Porta, Contributo allo studio dei fenomeni cadaverici. Ĺazione della microfauna cadaverica terrestre nella decomposizione de cadavere, Arch. Antrop. Crim. Psichiatr. Med. Leg. 59 (1929) 1–55 (in Italian).
[84] E. Pukowski, Ökologische Untersuchungen an *Necrophorus* F. (Ecological investigations on *Necrophorus* F.), Z. Morphol. Ökol. Tiere. 27 (1933) 518–586.
[85] H. Reinhard, Beiträge zur Gräberfauna (Contributions on the fauna of graves), Verh. k. & k. Zool.-Bot. Ges. Wien 31 (1882) 207–210 (in German).

[86] W. Robinson, Surgical maggots in the treatment of infected wounds; culture of sterile maggots, J. Lab. Clin. Med. 18 (1933) 406–412.
[87] L.M. Roth, E.R. Willis, Cockroach Bites, in: The Medical and Veterinary Importance of Cockroaches, Smithon Miscellaneous Collection, Vol. 134, No. 10, 1957, Chapter IX, pp. 30–34.
[88] S.J. Schmitz, Phoriden in doodkisten (Phorid flies in coffins), Natuurhist. Maandblad 17 (1928) 150–153 (in Dutch).
[89] W.M. Schöyen, Et bidrag til gravenes fauna, Entomol Tidskr 5 (1895) 121–124 (in Swedish).
[90] D. Schranz, A legyek jelentösége törvényszéki orvosi szempontból (The meaning of flies from a medico-legal standpoint), Orvosi Hetilab 31 (1934) 716–719 (in Hungarian).
[91] E. Séguy, La vie des Mouches et des Moustiques, Delagrave, Paris, 1938 (in French).
[92] C.F. Selous, A preliminary note on the so-called carrion-feeding Coleoptera, Entomol. Monthly Mag. BAND (1911) 86–89, Also: Entomol. News 22 (1911) 324.
[93] E. Smirnov, A.N. Zhelochovtsev, Change of characteristics in *Calliphora erythrocephala* Mg. under the influence of shortened feeding periods of the larval stages, Wilh. Roux' Arch. Entwicklungsmechanik 108 (1926) 579–595.
[94] B.F. Steele, Notes on the feeding habits of carrion beetles, J. N. Y. Entomol. Soc. 35 (1927) 77–81.
[95] G. Steiner, Untersuchungen über die Kältewiderstandsfähigkeit der Eier und Larven von Fleischfliegen (Experiments on the resistance against cold of eggs, and larvae of flesh flies), Anz. f. Schädlingskunde Nachrbl, Dt. Ges. Angew. Entomol. 17 (1941) 133–139 (in German).
[96] G. Steiner, Eine Zuchtweise für Fleischfliegen (A method for the breeding of flesh flies), Zool. Anz. 138 (1942) 97–106 (in German).
[97] S. Tźu, The Hsi Yüan Lu or Instructions to Coroners (Version from 1843, compiled by Ťung Lien), Proc. R. Soc. Med. 17 (1924) 59–107 (H.A. Giles, Trans.)
[98] Sung Tźu, The Washing Away of Wrongs (Original title: Hsi yüan chi lu), Book 2, Center for Chinese Studies, University of Michigan, Ann Arbor, 1981 (Chapter 5) (B. von McKnight, Trans.).
[99] E.L. Taschenberg, Die Insekten, Tausendfüßer und Spinnen (The insects, millipedes, and spiders.), in: Brehms Thierleben, Vierte Abtheilung — Wirbellose Thiere, Erster Band, Bibliographisches Institut, Leipzig, 1877 (in German).
[100] E. Titschak, Experimentelle Untersuchungen über den Einfluß der Massenzucht auf das Einzeltier (Experimental studies on the influence of mass breeding on the individual [insect]), Z. Ang. Entomol. 23 (1937) 1–64 (in German).
[101] B.V. Travis, E.F. Knipling, A.L. Brody, Lateral migration and depth of pupation of the larvae of the primary screwworm, *Cochliomyia americana* C. & P., J. Econ. Entomol. 33 (1940) 847–850.
[102] R. Voris, Biologic investigations on the Staphylinidae, Trans. Acad. Sci. (St. Louis) 28 (1934) 233–261.
[103] K. Walcher, Das Eindringen von Maden in die Spongiosa der großen Röhrenknochen (Maggots entering the spongiosa of long bones), Dt. Z. Ges. Ger. Med. 20 (1933) 469–471 (in German).
[104] G.B. Walsh, Studies in the British necrophagous Coleoptera. I. The activity of carrion-feeding beetles during the year, Entomol. Monthly Mag. 67 (1931) 76–81.
[105] G.B. Walsh, Studies in the British necrophagous Coleoptera. II. The attractive powers of various natural baits, Entomol. Monthly Mag. 69 (1933) 28–32.
[106] R.A. Wardle, The seasonal frequency of calliphorine blowflies in Great Britain, J. Hyg. 26 (1927) 441–464.
[107] R.A. Wardle, Significant variables in the blowfly environment, Ann. Appl. Biol. 17 (1936) 554–574.
[108] G. Warnke, Experimentelle Untersuchungen über den Geruchssinn von *Geotrupes silvaticus* Panz. und Geotrupes vernalis Lin. Zugleich ein Beitrag zum Problem der Orientierung der Tiere im Raum (Experiments on the smelling senses, and orientation of Geotrupes), Z. Vergl. Physiol. 14 (1931) 121–199 (in German).
[109] H. Weidner, Beiträge zur Kasuistik des Ungezieferwahns. (Cases of entomophobia), Münchener Med. Wochenschr. 83 (1936) 1920–1921 (in German).
[110] H. Weidner, Die Großstadt als Lebensraum der Insekten, ihre Biotope und ihre Besiedlung (Large cities as habitats for insects), Int. Kongreß f. Entomol., Berlin (1939) 347–1361 (in German).
[111] E. Weinland, Über die Stoffumsetzungen während der Metamorphose der Fleischfliege (*Calliphora vomitoria*) (On the metabolism during metamorphosis of the flesh fly *Calliphora vomitoria*), Z. Biol. 47 (1906) 186–231 (in German).
[112] P.W. Whiting, Observations on blowflies; duration of the prepupal stage and colour determination, Biol. Bull. Marine Biol. Lab. Woods Hole 26 (1914) 184–194.
[113] G.P. Yovanovitch, Entomologie appliquée à la médicine légale (Entomology applied to legal medicine), Ollier-Henry, Paris, 1888.