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Cover illustration: One adult *Chrysomya marginalis* and three adult *Chrysomya albiceps* feeding on a White Rhinoceros (*Ceratotherium simum*) carcass in Thomas Baines Nature Reserve, South Africa by Cameron Richards (Natural History Museum London).

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Preface

Forensic Entomology deals with the use of insects and other arthropods in medico legal investigations. We are sure that many people know this or a similar definition, maybe even already read a scientific or popular book dealing with this topic. So, do we really need another book on Forensic Entomology? The answer is 13, 29, 31, 38, and 61. These are not some golden bingo numbers, but an excerpt of the increasing amount of annual publications in the current decade dealing with Forensic Entomology. Comparing them with 89 articles which were published during the 1990s it illustrates the growing interest in this very special intersection of Forensic Science and Entomology and clearly underlines the statement: Yes, we need this book because Forensic Entomology is on the move with so many new things happening every year.

One of the most attractive features of Forensic Entomology is that it is multidisciplinary. There is almost no branch in natural science which cannot find its field of activity here. The chapters included in this book highlight this variety of researches and would like to give the impetus for future work, improving the development of Forensic Entomology, which is clearly needed by the scientific community. On its way to the courtrooms of the world this discipline needs a sound and serious scientific background to receive the acceptance it deserves.

This book does not ignore the forensic and entomological basics of the discipline, and gives an update in entomotoxicology, offering a survey about the decomposition of a cadaver (including a protocol for decomposing studies) and keys for identifying the difficult stages of immature insects. Especially the latter topic is an important one, as we believe that, despite the enormous progress made in bar-coding and identification of many taxa via DNA-analysis in recent years, one should not neglect the very basic skills - particularly because using these “easy lab-tools” could give you a speciously feeling of certainty.

Forensic Entomology and Blowflies are very often named in the same breath. We would like to attract the readers to some groups of animals which are neglected or even ignored such as, beetles and mites. Blowflies are much easier to handle in the lab than beetles, which could be the major reason why the majority of developmental studies are dealing with Diptera. If you have ever seen a cadaver infested by thousands of Silphidae or Dermestidae you soon realise that you must know more about them. Mites are not insects, nevertheless they belong traditionally to medical entomology since its early beginnings. So we should recognize them as a part of forensic entomology as well, keeping in mind that the great Mégnin includes them in his famous *Faune des Cadavres* in the late nineteenth century. These arthropods are especially abundant in buildings, which leads to another gap in our knowledge: Indoor scenarios. Interestingly the majority of experiments analysing the insect succession on cadavers take place outside in the field. However we should not ignore that vast amount of corpses found every year indoors. No doubt, it's much easier to conduct experiments out in nature, but we need indoor data sets as well for a better understanding of crime scenes which are located in a building.

Working as a forensic entomologist means mainly working with terrestrial ecosystems, but people die in the sea as well, or their dead bodies are dropped there after a homicide. What happens to those corpses? How do the bodies decompose? And are any arthropods or insects involved in this process? You will know this soon. From deep in the sea to down in the ground: It is surprising that our knowledge of forensic entomology of the soil is so incomplete. Dealing with cases where the bodies were buried always creates a lot of difficulties. Is there a succession in the soil as well as on the surface? Are the species found on the body able to colonize the buried cadaver or did they colonize him before?

Despite all of the scientific possibilities to improve the quality of entomological reports for the court, there are always pitfalls which cannot always be avoided. This book highlights certain caveats, bearing in mind that we are dealing with biological systems which do not always work in the same predictable manner. Due to the variability, we need statistics and probabilities in our expertises, which information is also covered in this book.

A topic such as climate change would not be expected in a book about Forensic Entomology, but the truth is simple: Climate change is everywhere and it will also influence a topic like the use of insects in forensic investigations. Last but not least we dedicate an own chapter to the field of myiasis, which is a well known subject for a veterinary. Insects also infest living humans and feed on them. A forensic entomologist should understand this process because it could bias his work, and at the same time he might be asked to estimate the time of negligence.

Curious? Then join us on our journey through the world of Forensic Entomology, but take care: after reading this book you may find you like this subject so much that perhaps you can find your own field of activity there: It is an exciting field of research.

Jens Amendt
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Chapter 1
Early Postmortem Changes and Stages of Decomposition

M. Lee Goff

1.1 Introduction

When faced with the task of estimating a period of time since death, there are generally two known points existing for the worker: the time at which the body was discovered and the last time the individual was reliably known to be alive. The death occurred between these two points and the aim is to estimate when it most probably took place. This will be an estimate since, it is generally accepted that there is actually no scientific way to precisely determine the exact period of time since death. What is done in the case of entomology is an estimation of the period of insect activity on the body. This period of insect activity will reflect the minimum period of time since death or postmortem interval (PMI) but will not precisely determine the time of death. In most cases, the later point is more accurately known than the former. Individuals tend to recall when they first encountered the dead body with considerable precision. This is typically not in their normal daily routine and it makes an impression, even on those accustomed to dealing with the dead.

Once the body is discovered, those processing the scene make meticulous (at least we hope meticulous) notes including times of arrival, departure, movement of the body and, finally, when the body is placed into the morgue. By contrast, the time at which the individual was last reliably known to be alive is often less precise. This is possibly due to the fact that those having the last contact most probably did not anticipate that this would be their last encounter with the individual and nothing of significance took place at the time. In the absence of something unusual, one rarely notes the time one said "good morning" to a neighbor or passed an acquaintance on the street. The last time the individual was reliably known to be alive may involve statements concerning the last time the individual was seen alive. It may involve hearing the individual or a telephone communication. Some instances may involve the touch or smell of the individual. Obviously there is some latitude possible in this determination and the time frame is often incorrect. For this reason, the precision

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of the time of discovery and collection of specimens become of major significance, as they are the anchor for the estimates. Estimation begins when the insects are collected and preserved, stopping the biological clock.

As the process of estimating the period of insect activity takes place, it must be kept in mind that the parameters of the estimate become progressively wider as the period of time since death increases. The changes to a body that take place immediately following death are often more rapid than those occurring later during the decomposition process. Thus the estimate begins, potentially, with a range of plus or minus minutes, goes to hours, days, weeks, months and finally "its been there a long time." The last is not the most popular with law enforcement agencies as they had already guessed that. It should also be kept in mind that the estimates presented, by their very nature, are not precise. I have found in my experience that it is typically the more inexperienced investigator who provides the most precise and unchanging estimates of the PMI.

Decomposition is a continuous process, beginning at the point of death and ending when the body has been reduced to a skeleton. Although this process is a continuum, virtually every study presented has divided this process into a series of stages. The number of stages has varied from one to as many as nine, depending on author and geographic region (Goff 1993) (Table 1.1). While the number of stages considered has varied, there does not appear to be a firm relationship between these and the total number of species observed in each study. For example, Cornaby (1974) working in Costa Rica using lizards and toads as animal models noted only 1 stage for

Table 1.1 Summary of selected decomposition studies giving numbers of recognized stages and taxa listed

Author and Ref.	Date	Locality	Animal model	# Stages	Total # of arthropod taxa
Avila and Goff	2000	Hawaii	Pigs(burnt)	5	68 species
Blacklith and Blacklith	1990	Ireland	Birds, mice	1	27 species
Bornemissza	1957	Australia	Guinea pig	5	45 groups listed
Braack	1986	Africa	Impala	4	227 species
Coe	1978	Africa	Elephants	3	No totals given
Cornaby	Cornaby, 1974	Costa Rica	Lizards, toads	1	172 species
Davisand Goff	2000	Hawaii	Pigs(intertidal)	5	85 species
Earlyand Goff	1986	Hawaii	Cats	5	133 species
Hewadikaram and Goff	1991	Hawaii	Pigs	5	46 species
Megnin	1894	France	Humans	9	No totals given
Payne	1965	South Carolina	Pigs(surface)	6	522 species
Reed	1958	Tennessee	Dogs	4	240 species
Rodriguez and Bass	1983	Tennessee	Humans	4	10 families listed
Shalaby et al.	2000	Hawaii	Pig(hanging)	5	35 species
Shean et al.	1993	Washington	Pig	–	48 species
Tullisand Goff	1987	Hawaii	Pig	5	45 species

decomposition but recorded 172 different species. By contrast, work in Hawaii by Early and Goff (1986), using domestic cats as the animal model, recognized five stages of decomposition but recorded 133 species. Other studies have recognized other numbers but with no real correlation between stages observed and numbers of taxa reported. To a certain extent, these differences may be related to sampling methods and taxonomic interests of those involved.

1.2 Early Postmortem Changes

As death proceeds, there are a series of early changes to the body that result in a definite change in the physical nature and/or appearance of the body prior to the onset of gross, recognizable decompositional changes. These changes have traditionally been used in estimations of the PMI and may be a source of confusion if not recognized. For that reason, they are described here.

1.2.1 Livor Mortis

One of the early changes observable is livor mortis, also referred to as lividity, postmortem hypostasis, vibices and suggilations. This is a physical process. While the individual is alive, the heart is functioning and circulating the blood. When death occurs, circulation stops and the blood begins to settle, by gravity, to the lowest portions of the body. This results in a discoloration of those lower, dependent parts of the body (Fig. 1.1). Although beginning immediately, the first signs of livor

Fig. 1.1 Livor

Fig. 1.2 Blanching

mortis are typically observed after a period of approximately 1 h following death with full development being observed 3–4 h following death. At this time, the blood is still liquid and pressing on the skin will result in the blood being squeezed out of the area (blanching), only to return once pressure is removed. This situation continues until 9–12 h following death, at which time the pattern will not change and the livor mortis is said to be "fixed." Any areas of pressure resulting from clothing or continued pressure during this period will not show discoloration (Fig. 1.2).

1.2.2 Rigor Mortis

This is a chemical change resulting in a stiffening of the body muscles following death due to changes in the myofribrils of the muscle tissues. Immediately following death, the body becomes limp and is easily flexed. As ATP is converted to ADP and lactic acid is produced lowering the cellular pH, locking chemical bridges are formed between actin and myosin resulting in formation of rigor. Typically, the onset of rigor is first observed 2–6 h following death and develops over the first 12 h. The onset begins with the muscles of the face and then spreads to all of the muscles of the body over a period of the next 4–6 h (Gill-King 1996). Rigor typically lasts from 24 to 84 h, after which the muscles begin to once again relax. The onset and duration of rigor mortis is governed by two primary factors: temperature and the metabolic state of the body. Lower ambient temperatures tend to accelerate the onset of rigor and prolong its duration while the opposite is found in warmer temperatures. If the individual has been involved in vigorous activity immediately prior to death, the onset of rigor is more rapid. Body mass and rates of cooling following

Fig. 1.3 Rigor

death also influence the onset and duration of rigor mortis. As rigor disappears from the body, the pattern is similar to that seen during the onset, with the muscles of the face relaxing first (see Fig. 1.3).

1.2.3 Algor Mortis

Once death has occurred, the body ceases to regulate its internal temperature and the internal temperature begins to approximate the ambient temperature. In most instances this involves a cooling of the body until ambient temperature is reached, most often in a period of 18–20 h (Fisher 2000). Although there are several different approaches, the rate of cooling is most often expressed by the equation:

$$PMI\,(hours) = \frac{98.6\ Body\ Temperature\ (^{\circ}F)}{1.5} \tag{1}$$

Any estimate of the postmortem interval obtained using this technique should be limited to the very early stages of death (18 h or less) and treated with care. There are several obvious factors involved in the cooling of the body that may easily influence the rate at which this occurs. The size of the individual is a major factor. A smaller individual will cool more rapidly than a larger individual in the same set of conditions. Exposure to sunlight or heating may also influence the rate of cooling as may clothing and a number of other factors. The most commonly used temperature in these calculations are from the liver although rectal temperature may also be employed.

Fig. 1.4 Glove

1.2.4 Tache Noir

Following death, the eyes may remain open and the exposed part of the cornea will dry, leaving a re-orange to black discoloration. This is termed tache noire (French for "black line") and may be misinterpreted as hemorrhage. Unlike hemorrhage, this will have symmetrical distribution, corresponding to the position of the eyelids (see Fig. 1.5).

1.2.5 Greenish Discoloration

As the body decomposes, gasses are produced in the abdomen and other parts of the body. While the exact composition of the gasses may vary from body to body, a significant component of these gasses is hydrogen sulfide (H_2S). This gas is a small molecule and readily diffuses through the body. Hydrogen sulfide will react with the hemoglobin in blood to form sulfhemoglobin. This pigment is greenish and may be seen in blood vessels and in other areas of the body, particularly where livor mortis has formed.

1.2.6 Marbling

As the anaerobic bacteria from the abdomen spread via the blood vessels, the subcutaneous vessels take on a purple to greenish discoloration, presenting a mosaic appearance, similar to what is seen in cracking of old marble statuary. Typically this is seen on the trunk and extremities (see Fig. 1.6).

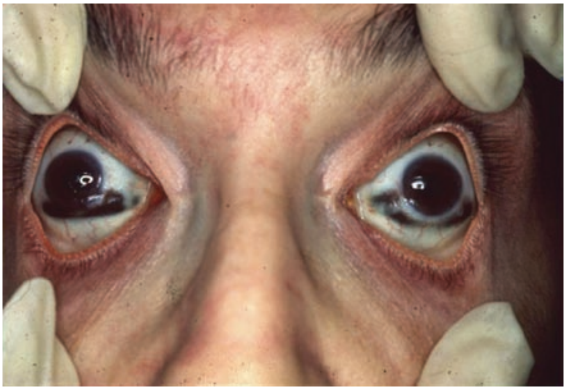

Fig. 1.5 Tache noir

Fig. 1.6 Marbling

1.2.7 Skin Slippage

Upon death, in moist or wet habitats, epidermis begins to separate from the underlying dermis due to production of hydrolytic enzymes from cells at the junction between the epidermis and the underlying dermis. This results in the separation of the epidermis which can be easily removed from the body. Slippage may first be observed as the formation of vesicle formation in dependent portions of the body. In some instances, the skin from the hand may separate from the underlying dermis as a complete or relatively complete unit. This is termed glove formation and can be removed from the hand s an intact unit. This skin can be used for finger printing, often with better results than if the skin remains on the hand (see Fig. 1.4).