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Role of Forensic Entomology in Crime Investigation

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Forensic entomology is an important branch of science that uses insects and other arthropods to assist in legal and criminal investigations. In cases involving suspicious or unexplained deaths, insects that colonise a decomposing body can provide valuable clues about the time that has passed since death. Flies, beetles and other insects arrive at different stages of decomposition, and their developmental stages and patterns of occurrence can help investigators estimate the minimum post-mortem interval when appropriate environmental and species-specific information is available. The role of forensic entomology extends beyond estimating the time since death. Insect evidence may also provide clues about the possible movement of a body, the presence of drugs or toxic substances, and cases involving neglect or abuse. Recent advances such as DNA-based species identification and entomotoxicology have further expanded the scope of this field. This article discusses the biological basis of forensic entomology, important insect groups involved in forensic investigations, methods of estimating the post-mortem interval, evidence collection, recent scientific advances, and the major challenges associated with the use of insect evidence. Properly collected and carefully interpreted, forensic entomological evidence can provide valuable clues that complement pathological and other forensic evidence in criminal investigations.

Introduction

Forensic entomology is the branch of applied entomology that deals with the use of insects and other arthropods as evidence in criminal and civil legal proceedings (Tomberlin & Benbow, 2015). Its most widely recognised application lies in death investigations, where the arrival, colonisation and development of insects on a corpse follow a reasonably predictable pattern that can be used to estimate the time elapsed since death, commonly referred to as the post-mortem interval (Matuszewski, 2021). Because insects are among the first organisms to detect and colonise a dead body, often within minutes to hours of death under favourable conditions, their presence, abundance and developmental stage carry a wealth of information that is frequently unavailable through conventional pathological examination alone, particularly once decomposition has advanced beyond the stage at which body temperature and rigor mortis remain useful indicators (Amendt & Zehner, 2017).

The discipline draws upon principles from entomology, ecology, physiology and forensic science, and is generally divided into three interconnected sub-disciplines: urban forensic entomology, which addresses insect infestations relevant to civil litigation such as structural or stored-product pest disputes; stored-product forensic entomology, concerned with contamination of food and other commodities; and medico-legal forensic entomology, which deals with the use of insect evidence in cases of death, abuse or neglect (Hall & Wall, 2019). Medico-legal forensic entomology, being the most developed and frequently applied branch, forms the primary focus of this review (Sharma *et al*., 2022).

Historical Background

The use of insects in death investigation has a documented history extending back several centuries, with early accounts from thirteenth-century China describing the use of blowfly attraction to a bloodstained weapon to identify a murderer (Amendt & Zehner, 2017). Systematic scientific study began in earnest in the nineteenth century in France, where physicians studying exhumed remains observed a successional pattern of insect colonisation that varied predictably with the stage of decomposition (Matuszewski, 2021). Through the twentieth and early twenty-first centuries, the discipline matured considerably with advances in insect rearing, developmental biology and statistical methods, and forensic entomology is now recognised as an established forensic science with professional certification bodies, peer-reviewed journals and standardised protocols for evidence collection in many countries, including India (Sharma *et al*., 2022).

Biological Basis of Forensic Entomology

The biological foundation of forensic entomology rests on two related phenomena: insect succession and insect development (Matuszewski, 2021). As a body decomposes, it passes through a sequence of stages, commonly described as fresh, bloat, active decay, advanced decay and dry or skeletal remains, and each stage produces a distinct combination of odours, moisture and tissue conditions that attracts a characteristic assemblage of insect species (Pujol-Luz *et al*., 2018). Necrophagous flies of the families Calliphoridae, the blow flies, and Sarcophagidae, the flesh flies, are typically the first colonisers, arriving within minutes of death to oviposit or larviposit on the body, particularly around natural orifices and wounds (Hall & Wall, 2019). As decomposition progresses, these are followed by predators and parasites of the necrophagous species, then by omnivorous species such as certain beetles and wasps that feed on both the remains and the earlier insect colonisers, and finally, in the later stages, by species adapted to feed on drying tissue, skin, hair and bone, principally beetles of the families Dermestidae and Cleridae (Matuszewski, 2021).

The second pillar, insect development, is used to estimate the minimum post-mortem interval directly (Owings *et al*., 2014). Because the rate of insect growth from egg to adult is strongly temperature-dependent and follows well-characterised developmental curves for each species, the age of the oldest immature stages collected from a body, combined with local temperature records, can be used to calculate the minimum time that has elapsed since insects first colonised the remains (Matuszewski, 2021). This calculation typically relies on the accumulated degree hours or degree days required for a species to reach a particular developmental stage, data that have been experimentally determined for many forensically important species under controlled laboratory conditions (Kaur & Kaur, 2020).

Insects of Medico-Legal Importance

1. Diptera (Flies)

Flies are the most important insect order in forensic entomology because of their rapid detection of and response to a decomposing body (Hall & Wall, 2019). Blow flies such as Calliphora, Lucilia and Chrysomya species are typically the earliest and most abundant colonisers, and their eggs, larvae and puparia are the primary specimens collected for post-mortem interval estimation (Kaur & Kaur, 2020). Flesh flies of the genus Sarcophaga are also early arrivals and are distinguished by depositing live larvae rather than eggs. House flies, Musca domestica, and several other muscid species colonise later and can provide corroborating evidence of the succession timeline (Sharma *et al*., 2022).

2. Coleoptera (Beetles)

Beetles generally arrive later in the decomposition sequence and are particularly important for estimating longer post-mortem intervals, once the body has progressed beyond the stages primarily colonised by flies (Pujol-Luz *et al*., 2018). Carrion beetles of the family Silphidae and rove beetles of the family Staphylinidae are common predators of fly larvae during the active and advanced decay stages, while hide beetles and skin beetles of the family Dermestidae become dominant during the dry and skeletal stages, feeding on desiccated skin,

cartilage and remaining tissue (Matuszewski, 2021). The presence of dermestid beetle activity is often used as an indicator that a substantial period, typically weeks to months, has elapsed since death (Owings *et al*., 2014).

3. Other Arthropods

Although flies and beetles dominate forensic entomological casework, other arthropods including mites, particularly of the family Macrochelidae, ants, wasps and certain moth species have also been documented on decomposing remains and can provide supplementary evidence, particularly regarding the presence of predators or the disturbance of a body by scavengers (Perotti & Braig, 2019).

Methods of Post-Mortem Interval Estimation

1. Developmental Rate Method

The developmental rate method involves collecting the oldest immature insect specimens present, typically the largest larvae or the most advanced puparia, identifying them to species, and determining their age using published developmental data and local temperature records from the time of the body's discovery (Owings *et al*., 2014). This age, combined with an estimate of the pre-colonisation interval, the time between death and the arrival of the first colonising insects, provides an estimate of the minimum post-mortem interval (Matuszewski, 2021).

2. Successional Pattern Method

The successional pattern method is used primarily for longer post-mortem intervals, where the developmental rate method becomes less precise because insects present have already completed their development (Pujol-Luz *et al*., 2018). This approach relies on the characteristic sequence in which different insect species colonise a body as decomposition progresses, and comparison of the species assemblage present at the scene with published succession data for the relevant geographic region and season allows an estimate of the broader time window since death (Kaur & Kaur, 2020).

3. Accumulated Degree Day and Degree Hour Models

Because insect development is temperature-dependent rather than strictly time-dependent, forensic entomologists commonly use accumulated degree day or accumulated degree hour models, which sum the number of degrees above a species-specific developmental threshold over the relevant time period (Owings *et al*., 2014). These models allow the developmental data collected under one set of temperature conditions to be applied accurately to the different temperature conditions recorded at a crime scene, considerably improving the precision of post-mortem interval estimates (Matuszewski, 2021).

Evidence Collection and Analytical Protocols

Reliable forensic entomological analysis depends critically on the quality of evidence collection at the scene (Kaur & Kaur, 2020). Standard protocols require collection of both live and preserved insect specimens from multiple locations on and around the body, accurate recording of scene temperature over an extended period, photographic documentation of insect activity in situ, and careful preservation of specimens, with a portion killed and fixed immediately to halt development for measurement, and a portion reared to adulthood to confirm species identification (Hall & Wall, 2019). Chain of custody must be maintained throughout, and close collaboration between the forensic entomologist, the crime scene investigator and the forensic pathologist is essential to ensure that entomological findings are correctly integrated with other evidence (Sharma *et al*., 2022).

Advances in Molecular and Toxicological Applications

Molecular techniques, particularly DNA barcoding using the mitochondrial cytochrome c oxidase subunit I gene, have considerably improved the accuracy of species identification, especially for immature specimens that lack the morphological characters required for traditional taxonomic identification (Nelson *et al*., 2018). This is particularly valuable in regions with high species diversity or where closely related species have overlapping

developmental data but differ in ecological requirements or geographic distribution (Sharma *et al*., 2022).

Entomotoxicology, the analysis of drugs and toxins sequestered within the tissues of insects that have fed on a decomposing body, has emerged as a valuable extension of forensic entomology, particularly in cases where soft tissue suitable for conventional toxicological analysis is no longer available due to advanced decomposition (Gosselin *et al*., 2016). Because necrophagous larvae bioaccumulate certain substances present in the tissues on which they feed, analysis of larval or puparial tissue by techniques such as gas chromatography-mass spectrometry can reveal the presence of drugs, poisons or heavy metals in the body at the time of death, and in some cases the concentration of these substances in insect tissue can also be used to refine post-mortem interval estimates, since certain drugs alter larval developmental rates (Gosselin *et al*., 2016).

Insect evidence has also been used to address questions beyond the post-mortem interval, including whether a body has been relocated after death, based on discrepancies between the insect species present and those expected in the local habitat where the body was found (Perotti & Braig, 2019), and to substantiate cases of neglect involving living victims, most notably in cases of myiasis in the elderly, infirm or infants, where the extent of fly larval infestation on a living person can indicate the duration of neglect (Hall & Wall, 2019).

Challenges and Limitations

Despite its established value, forensic entomology continues to face several methodological and practical challenges:

- Post-mortem interval estimates can be confounded by factors that delay or accelerate insect colonisation, including burial, wrapping, extreme weather, or insecticide use at the scene (Matuszewski, 2021).
- Developmental and succession data exist for a limited number of species and regions, leaving gaps for many local faunas, including much of the Indian subcontinent (Sharma *et al*., 2022).
- Species-level identification of immature specimens remains technically demanding without molecular confirmation, and misidentification can introduce substantial error (Nelson *et al*., 2018).
- Temperature data used in degree day models must closely match the actual scene microclimate; reliance on distant weather stations can introduce inaccuracy (Owings *et al*., 2014).
- Shortage of trained forensic entomologists and standardised legal protocols in many jurisdictions limits routine use of entomological evidence (Kaur & Kaur, 2020).

Status and Prospects in India

Forensic entomology in India remains a comparatively young discipline relative to its established status in North America, Europe and parts of Southeast Asia, though interest and research activity have grown considerably in recent years (Sharma *et al*., 2022). Studies documenting insect succession patterns and developmental data for forensically important Calliphoridae and Sarcophagidae species under Indian climatic conditions have begun to build the region-specific baseline data essential for reliable post-mortem interval estimation (Kaur & Kaur, 2020). Strengthening collaboration between entomology departments, forensic science laboratories and law enforcement agencies, along with the generation of more comprehensive regional succession and developmental datasets, is likely to substantially enhance the practical application of forensic entomology in criminal investigations across the country (Tomberlin & Benbow, 2015).

Conclusion

Forensic entomology has evolved from a curiosity of historical criminal investigation into a rigorous, evidence-based forensic science capable of providing information that is frequently unobtainable through other means, particularly in cases involving advanced decomposition.

Its principal strength lies in the estimation of the post-mortem interval through the developmental biology and successional ecology of necrophagous insects, complemented increasingly by molecular identification and entomotoxicological analysis. Continued investment in region-specific baseline research, standardisation of evidence collection protocols, and training of specialist personnel will be essential to realise the full potential of this discipline, particularly in regions such as India where the necessary local data remain incomplete. When applied with appropriate methodological rigour and integrated with pathological and circumstantial evidence, forensic entomology offers a scientifically robust and increasingly indispensable tool for criminal investigation.

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