

AN OVERVIEW OF THE ROLE OF FORENSIC ENTOMOLOGY IN CRIMINAL INVESTIGATION

Dr. Neetu Singh,

Assistant Professor

Shri JJT University, Jhunjhunu, Rajasthan
drneetu.singhrana03@gmail.com

Ms. Haritha R S,

Assistant Professor

Shri JJT University, Jhunjhunu, Rajasthan
harithrs94@gmail.com

Abstract

Forensic entomology is a distinct branch of forensic science that employs insect evidence to assist in criminal investigations. These insects that live on a dead body can be used as potential markers to establish the time of death, a regularly used reference. The term used to refer to the postmortem period is PMI. Over time, substantial progress in comprehending insect biology, behavior, life cycle, and their contribution to post-mortem decomposition has fundamentally transformed the forensic investigation process. This review article provides a thorough examination of the basic principles, historical context, stages of decomposition, and advanced techniques used in forensic entomology. It also discusses the practical applications of this field, including the use of DNA barcoding technology, gene expression aided PMI estimate. This review paper also examines the diverse obstacles and constraints linked to this developing topic.

Keywords: *Forensic entomology, insects, forensic evidence, PMI, blowfly, forensic indicator*

Introduction

Forensic entomology, a scientific discipline that examines insects and their arthropod cousins within the framework of legal inquiries, has become an indispensable resource in resolving criminal investigations. This specialized field plays a crucial role in various areas. Various facets of death investigations encompass a wide range of tasks, including the assessment of post-mortem interval (PMI) and assisting in determining the movement of the body after death.

The use of insects as forensic evidence can be traced back to ancient civilizations,

where different societies acknowledged the potential significance of insect observations at crime scenes. Forensic entomology gained scientific recognition and established systematic procedures in the previous century, emerging into a sophisticated and dependable field within the area of forensic science. The origins of forensic entomology can be traced back to ancient civilizations like China, where the behavior of insects surrounding dead bodies was recorded as early as the 13th century in the Song Dynasty (Benecke, 2001). Similarly, the ancient Egyptians documented observations of insects found near human remains, although their methods did not meet the scientific standards of current forensic entomology (Campobasso et al., 2001). These initial observations established the foundation for acknowledging the potential importance of insects in forensic investigations.

The field of forensic entomology, as it exists today, started to develop throughout the early 20th century. This progress was largely influenced by entomologists such as Jean Pierre Ménégnin, who made important contributions to the subject through his influential publications in the late 19th century. Nevertheless, the groundbreaking research conducted by Dr. Auguste Forel in 1884 was a pivotal moment in the utilization of entomology for criminal investigations. Forel's study

on fly larvae at crime scenes showcased the capacity of insects to offer significant insights in homicide investigations (Amendt et al., 2004). The systematic methodology and principles of forensic entomology originated in the mid-20th century, primarily via the contributions of forensic entomologists such as Dr. Bernard Greenberg. Greenberg's research during the 1950s and 1960s established the basis for the scientific examination of insect succession on decomposing carcasses, which is essential for estimating the postmortem interval (Greenberg, 1991). During this time, there was also progress in establishing uniform procedures for gathering and examining insect evidence, which improved the dependability and recognition of forensic entomology in court settings. Forensic entomology benefits from its multidisciplinary character, utilizing information and techniques from entomology, biology, and forensic science. The combination of these areas of expertise has resulted in the development of forensic entomology as a strong and essential tool for investigating crime scenes. Forensic investigators can use it to obtain vital information about the time of death, possible shifts in the body's position, and other essential details in criminal cases. Forensic entomology has progressed from ancient observations of insect behavior near dead bodies to a highly specialized and scientifically based discipline.

This review article seeks to offer a thorough summary of the historical progression, fundamental principles, research methods, and recent progress in forensic entomology, emphasizing its importance in contemporary forensic science.

HISTORICAL BACKGROUND OF ENTOMOLOGICAL STUDIES

The origins of forensic entomology can be traced back to ancient civilizations, where basic observations of insect behavior near dead bodies were recorded. Despite the absence of scientific rigor, these initial observations established the basis for acknowledging the potential importance of insects in forensic investigations (Catts et al., 1992). The employment of insects in forensics was first documented in the 13th-century in China under the Song Dynasty. The Chinese legal document, "Hsi Yu Chi" (The Washing Away of Wrongs), includes accounts of incidents when the presence of insects near dead bodies was utilized as evidence to establish the cause of death (Benecke, 2001). These historical records illustrate an early recognition of the correlation between insects and decomposition, however primarily based on personal stories and lacking scientific rigor. Ancient Egypt, known for its thorough record-keeping, contains references to observations of insects found in connection with human remains. The Ancient Egyptians were aware of the existence of insects such as flies and beetles in the vicinity of decomposing corpses. Nevertheless, these observations primarily centered on religious and cultural elements, including the significance of the scarab beetle in the process of rebirth (Campobasso et al., 2001). Although there are some early historical references, the field of forensic entomology did not become a systematic and scientifically rigorous science until the 19th and 20th centuries. The groundbreaking contributions of individuals such as Dr. Auguste Forel, a Swiss neurologist, signified a pivotal moment. In 1884, Forel conducted

research on the growth of blowfly larvae on human corpses, which yielded useful knowledge about the possible uses of entomology in forensic investigations (Amendt et al., 2004). Dr. Jean Pierre Mégnin, a French military physician, made notable advancements in the discipline during the late 19th century. Mégnin's meticulous and methodical observations and documenting of insect species that are connected with decaying corpses established the foundation for the scientific investigation of forensic entomology (Anderson, 2001). Dr. Bernard Greenberg played a pioneering role in developing the methodical methodology and concepts of forensic entomology throughout the mid-20th century. During the 1950s and 1960s, his research was mostly centered around comprehending the process of insect succession on decomposing carcasses, which is a fundamental aspect of estimating the postmortem interval (PMI). Greenberg's research boosted forensic entomology from casual observations to a rigorously established field of study (Greenberg, 1991). The historical viewpoint of forensic entomology emphasizes the enduring human obsession with insects and their connection to death. The origins of forensic entomology may be traced back to ancient China and Egypt, where initial observations were made. However, it was not until the 19th and 20th centuries that significant advancements were made, turning it into a crucial tool for contemporary forensic investigations.

ROLE OF INSECTS IN FORENSIC INVESTIGATION

Forensic entomology relies on a wide range of insect species to gather important information about the timing and circumstances of a death investigation.

Frequently encountered insects, such as the *Lucilia sericata*, commonly known as the Common Blowfly, the species *Calliphora* spp., *Lucilia* spp., and *Sarcophaga* spp. play a crucial role in determining the post-mortem interval by their involvement in the arrival, egg-laying, and larval development on a dead body. : Blow flies are the Gold Standard forensic indicators. These are most useful in estimating Time of Death, TOD. These are the ones that come in first, immediately after the body is dead and start to decompose. Hide Beetles (*Dermestes* spp.), Rove Beetles (*Staphylinidae* spp.), Hister Beetles (*Histeridae* spp.), Carrion Beetles (*Silphidae* spp.), and Scavenger Beetles (*Cleridae* spp.) play a crucial role in decomposition by consuming carrion and assisting in the pupation process. Predatory mites and ants play a role in the functioning of the ecosystem by preying on other insects found on dead bodies and aiding in the construction of nests, respectively. Wasps engage in scavenging and nesting activities, while Moths and Lepidoptera are responsible for depositing eggs on remnants, which initiates larval feeding. Beetles, which consist of several species, perform multiple functions such as feeding, undergoing pupation, and colonizing. Diptera, sometimes known as flies, play a crucial role in maintaining the balance of the ecosystem by laying eggs and developing larvae on decaying organisms (Oliveira & Vasconcelos, 2010). These insects are crucial in forensic entomology, providing valuable information on the timing of death investigations. They assist forensic experts in solving complicated cases by studying their behavior and life cycles in relation to decomposing bodies.

ENTOMOLOGICAL SUCCESSION ON CADAVER

The study of insect succession on decaying bodies is a crucial component of forensic entomology, as it offers essential data for determining the time since death (post-mortem interval, PMI). This complex process consists of multiple discrete stages, starting with the first study conducted by Mona et al. (2019) which observed a shift in the types of insects attracted to decomposing remains over time. Initially, blowflies and flesh flies were the primary attractants during the fresh stage. However, as the remains dried up, scavenging beetles became the dominant species. Insect succession has discernible patterns as species are attracted to particular stages of decomposition due to their ecological roles and feeding preferences. Environmental factors such as temperature, cadaver accessibility, insect competition, geographic location, and seasonal fluctuations can influence succession rates (Brandmayr et al., 2010). This comprehension of insect succession is crucial in forensic investigations, assisting in the estimation of postmortem interval (PMI) and providing vital insights to criminal cases.

PHASES OF DECOMPOSITION AND CORRESPONDING INSECT SPECIES

The decomposition of a human or animal body follows a series of distinct stages, each marked by unique alterations in the physical and chemical makeup of the remains. The stages are commonly classified as fresh, bloat, active decay, advanced decay, and dry or skeletal (Villet, 2011). Every phase provides a unique ecological habitat for many insect groups, and their arrival and departure may be accurately anticipated.

Fresh Stage: The fresh stage refers to the period immediately following death, typically lasting for a few hours to a few days, during which the body remains in its initial state. The blowflies (Diptera: Calliphoridae) and meat flies (Diptera: Sarcophagidae) are the initial insects to appear and deposit eggs on or in close proximity to the corpse. The larvae, referred to as maggots, consume the recently formed tissues and play a crucial role in determining the minimum postmortem interval (PMI) (Tomberlin & Benbow, 2015).

Bloat Stage: During the process of breakdown, gasses build up inside the body, resulting in its expansion and bloating. This stage is particularly attractive to flies, especially species such as the cheese fly (Diptera: Piophilidae) and coffin flies (Diptera: Phoridae), which have adapted to lay their eggs in swollen carcasses (Pohjoismäki et al., 2010).

Active Decay Stage: During this stage, tissues begin to break down, creating an optimal environment for various carrion beetles (Coleoptera: Silphidae) and predatory insects such as rove beetles (Coleoptera: Staphylinidae) and ants (Hymenoptera: Formicidae) (Catts & Goff, 1992).

Advanced Decay Stage: In the advanced decay stage, the majority of the body's soft tissues have undergone decomposition, resulting in the presence of dry skin, bones, and cartilage.

Scavengers, including dermestid beetles (Coleoptera: Dermestidae) and other types of mites (Acari), consume the residual organic matter (Matuszewski et al., 2008).

Dry or Skeletal Stage: During the last phases of decomposition, just the desiccated skeletal remnants remain. Insects exhibit reduced attraction towards

this particular stage, although specific species of carrion beetles, such as hide beetles (Coleoptera: Trogidae), might still contribute to the process of bone cleaning (Archer, 2004).

PATTERNS OF INSECT SUCCESSION

The Faunal Succession Model is a well-established pattern that characterizes the predictable sequence of insects on cadaver. This model elucidates the consecutive entrance and departure of several insect species on a decomposing cadaver as it undergoes various stages of decomposition. Comprehending these concepts, an understanding of patterns is crucial for forensic entomologists as it enables them to precisely estimate the post-mortem interval (PMI) and get vital insights into the biological dynamics of decomposing remains. (Martinez et al., 2007). The Faunal Succession Model can be categorized into distinct stages, each linked to certain insect species and their corresponding behaviors.

Fresh Stage: This is the first stage of decomposition, which occurs within a few hours to a few days following death. The presence of necrophagous flies, specifically blowflies (Diptera: Calliphoridae) and meat flies (Diptera: Sarcophagidae), is a defining characteristic. These flies are drawn to the scent of decay and deposit their eggs on or in close proximity to the corpse. The larvae, known as maggots, consume the recently formed tissues of the deceased body (Tomberlin & Benbow, 2015).

Bloat Stage: As decomposition advances, gasses generated by microbial activity result in the distension of the body. This phase specifically appeals to a distinct group of fly species, including cheese flies (Diptera: Piophilidae) and coffin flies

(Diptera: Phoridae), which have evolved to lay their eggs in swollen carcasses (Pohjoismäki et al., 2010).

Active Decay Stage: In this stage, the corpse decomposes quickly and becomes very appealing to a wider variety of insects. Carrion beetles, rove beetles, and ants are the main insects that inhabit the corpse during this stage. Carrion beetles belong to the Coleoptera family Silphidae, rove beetles belong to the Coleoptera family Staphylinidae, and ants belong to the Hymenoptera family Formicidae. Carrion beetles, such as those mentioned by Catts and Goff in 1992, consume decomposing meat and engage in competition with other insects to obtain this resource.

Advanced Decay Stage: During this stage of decomposition, the organism undergoes further breakdown, resulting in the consumption of the majority of its soft tissues. This leaves behind just dry skin, bones, and cartilage. This stage is favorable for the presence of scavengers such as dermestid beetles (Coleoptera: Dermestidae) and several types of mites (Acari), which consume the leftover organic matter (Matuszewski et al., 2008).

Dry or Skeletal Stage: This stage refers to the last phase of decomposition, during which only dry skeletal remnants remain. By this stage, the appeal of insects decreases considerably, although certain carrion beetles, specifically hide beetles (Coleoptera: Trogidae), may still contribute to the process of bone cleansing (Archer, 2004).

Comprehending these anticipated patterns of insect succession is essential for forensic entomologists when examining evidence from a crime scene. Through analyzing the species makeup and developmental stages of insects discovered

on a dead body, experts can accurately estimate the time since death (PMI) by determining the level of decomposition. This data assists law enforcement authorities in conducting criminal investigations and plays a role in the successful conclusion of cases.

POST MORTEM INTERVAL (PMI) ESTIMATION

Determining the post-mortem interval (PMI) is a crucial goal in forensic entomology, since it offers significant insights on the time that has elapsed since death, assisting investigators in criminal investigations. This section examines diverse approaches for the calculation of PMI involving several methods, such as temperature-based models, the accumulated degree-hours (ADH) approach, and new breakthroughs in molecular techniques (Shiva et al., 2022). The progress in molecular techniques has the capacity to supplement conventional methods for estimating the postmortem interval (PMI) and improve the precision of forensic entomology in criminal investigations.

Degree-day models: These models are used to compute the total amount of heat units, measured as degree-days or degree-hours, needed for insect larvae to develop from an egg to a specific stage (Sharma et al., 2015). The formula for degree-days is commonly expressed as: $DD = \sum (T_{max} - T_{min})/2$, where \sum denotes the summation over time intervals, and T_{max} and T_{min} indicate the daily maximum and minimum temperatures, respectively.

These models utilize temperature data obtained from the crime site or adjacent weather stations to calculate the age of the insect larvae discovered on the body.

Accumulated Degree-Hours (ADH) Approach: The ADH technique is an

enhanced version of the degree-day model that takes into accounts not just temperature but also the accumulated impact of temperature over a period of time. The process involves calculating the cumulative degree-hours by integrating temperature data over time, typically using specialized software. ADH models offer a more accurate assessment of insect development and can accommodate fluctuations in temperature during the day (Bala & Sharma, 2016).

DNA barcoding technology: It is a molecular method that entails determining the order of nucleotides in a particular section of an organism's DNA in order to ascertain its species. Forensic entomology has gained significance due to its ability to accurately determine the insect species present in decomposing remains, particularly in cases when standard morphological identification is challenging due to factors such as specimen damage or immaturity. One of the main benefits of DNA barcoding is its capacity to distinguish closely related insect species, a task that is typically difficult using standard morphological methods. Utilizing DNA sequencing of a standardized gene area, such as the mitochondrial cytochrome c oxidase subunit I (COI) gene, enables accurate identification of species. (Huang and colleagues, 2018).

Analysis of Gene Expression: Forensic entomology has seen a recent development in the analysis of gene expression. This entails the examination of gene expression in insects that are connected to the decomposition of organic matter. Researchers can obtain significant information about the age and physiological condition of insect larvae located on a body by examining the gene expression associated with development

and metabolism. This information is vital for appropriately determining the post-mortem interval (PMI). Genes involved in metamorphosis and growth exhibit higher levels of activity in younger insect larvae, but genes linked to energy metabolism can offer valuable information about the nutritional status of the insects. Gene expression analysis is valuable for establishing the timing of insect colonization, whether it occurred before or after death. The reference is from Cammack et al. (2020).

ENTOMOTOXICOLOGY

Entomotoxicology is the scientific study of how pharmaceuticals from a deceased person's body can be accumulated by the larvae of flies that feed on decaying carcasses. Examining the presence of harmful chemicals in highly developed organisms. Decomposition or skeletonization might provide a significant challenge. When faced with such situations, scientists have the ability to pulverize and analyze the larvae that have consumed the organism using a range of techniques such as thin-layer chromatography, gas chromatography, and mass spectrometry. The presence of toxins, such as cocaine and heroin, in the corpse might accelerate the development of larvae. Conversely, the presence of poisons like malathion in the decaying tissue can hinder the colonization of insects. The citation is from Gosselin et al. (2011).

FORENSIC ENTOMOLOGICAL EVIDENCE

Forensic entomology involves the application of insect-related data in legal investigations and criminal cases. Forensic entomology utilizes insects and other arthropods to gather significant evidence that assists in determining important

details of a crime scene, such the post-mortem interval (PMI), body displacement, and other factors related to a death. This section examines the categories of circumstances in which insect evidence is valuable, the methods of preserving and collecting entomological evidence, and the legal acceptability of such evidence (Campobasso & Introna 2001).

Legal Admissibility and Expert

Testimony:

The admissibility of entomological evidence in court proceedings differs according to the jurisdiction. Forensic entomologists frequently act as expert witnesses in court, offering their professional conclusions derived from scientific study. Their testimony can aid the judge and jury in comprehending the importance of the evidence and its ramifications for the case. In order to determine the acceptability of entomological evidence, forensic entomologists must follow defined procedures, keep precise documentation, and showcase their proficiency in the discipline (Hall, 2019). The admissibility of evidence in legal proceedings may be determined by applying either the Daubert or Frye standards, which evaluate the scientific validity and relevance of the evidence. Forensic entomology evidence is crucial in several categories of criminal prosecutions, offering useful insights into the date and circumstances surrounding a death. Preserving, collecting, and documenting entomological evidence correctly is crucial to guarantee its acceptance in court and its effectiveness in assisting investigators and legal experts in solving crimes (Said et al., 2018).

CHALLENGES & LIMITATIONS

Forensic entomology, although a vital tool in criminal investigations, is not devoid of

its obstacles and constraints. Comprehending these limitations is essential for forensic entomologists, law enforcement, and the legal system to effectively establish the utilization of entomological evidence in an informed and precise manner has been demonstrated by Chopi et al. (2019). This section examines some significant issues and constraints related to forensic entomology.

Insect Behavior Variability: The variability in insect behavior presents a substantial difficulty in the field of forensic entomology. Insects, being ectothermic species, exhibit a high degree of sensitivity to environmental factors, specifically temperature and humidity. Their developmental rates, including egg hatching, larval growth, and pupation, might significantly differ depending on these circumstances. Furthermore, the time and pattern of bug colonization can be further influenced by local ecological factors, including the presence of other scavengers, the ability to reach the body, and the availability of good locations for laying eggs. The intricate nature of the situation makes it challenging to accurately determine the post-mortem interval (PMI) in all instances, as one must carefully take into account the fluctuations in ambient circumstances and insect behavior. Forensic entomologists depend on established growth models and accumulated degree-hour computations. However, the accuracy of these estimations may be affected when conditions depart from the usual or when many insect species are present. Thus, although forensic entomology can offer valuable information about the timing of a death, the natural fluctuations in insect behavior emphasize the necessity of a multidisciplinary approach that integrates

entomological evidence with other forensic data to obtain more precise estimates of the postmortem interval (PMI) (Klotzbach et al., 2004).

Insufficient Standardization: The absence of uniformity in forensic entomology is a notable issue in the discipline. Regional disparities in climate, indigenous insect species, and accessible resources result in divergences in procedures, impacting the timing of insect colonization and the selection of specimens for examination. The quality and consistency of analyses can be further affected by limitations in resources and differences in experience among forensic laboratories. Differences in methodology, such as adjustments made to suit local conditions, preservation techniques, and collecting methods, result in discrepancies in how insect evidence is collected and processed. Moreover, the lack of standardized certification and training prerequisites, along with legal and regulatory inconsistencies, can impact the dependability of entomological analyses. The dynamic characteristics of the area and the presence of interdisciplinary difficulties also contribute to discrepancies in forensic entomology techniques (Tomberlin et al., 2012). It is essential to address these challenges by implementing standardization initiatives in order to improve the dependability of bug evidence in criminal investigations and judicial procedures.

Limited Accuracy in PMI Estimation: Forensic entomology is crucial for calculating the post-mortem interval (PMI), however it is essential to acknowledge that PMI estimates frequently have inherent limits. These estimates are commonly expressed as ranges instead of exact timings of death

because there are numerous variables involved. The accuracy of the findings relies on various elements, such as the caliber and amount of entomological evidence gathered, the accessibility and dependability of environmental data, and the proficiency in accurately identifying and studying the insect species implicated. Moreover, the absence of standardized processes and the presence of regional variances in practices can affect the uniformity of PMI estimations. When there are several insect species or unusual environmental conditions, estimating the postmortem interval (PMI) becomes much more difficult (Amendt et al., 2011). Therefore, forensic entomologists must be careful when presenting their findings and emphasize the possible uncertainties in their estimations. They should emphasize the significance of using a multidisciplinary approach that combines entomological evidence with other forensic data to create a more thorough and dependable assessment of the postmortem interval (PMI).

Limited Comprehension of Entomology:

A crucial factor in forensic entomology is the possibility of an inadequate comprehension of the biology and conduct of specific insect species, especially those that are uncommon or have been minimally studied by scientists. Although many bug species have been thoroughly examined in the context of forensic investigations, there exist numerous uncommon or recently found species that lack comprehensive documentation. The lack of expertise in this area can greatly restrict the precision of entomological evidence, as forensic entomologists depend on reliable data and life cycle information to precisely estimate post-mortem intervals (PMI). When dealing

with less-researched insects, there can be doubts regarding their rates of development, preferences for the habitat, or behaviours related to colonisation. The limited understanding of the subject highlights the significance of continuous entomological research to address these gaps and improve the precision and dependability in estimating PMI. Furthermore, it emphasises the importance of thoroughly evaluating the possible constraints and uncertainties associated with utilising entomological evidence in forensic inquiries, particularly in instances involving less commonly known insect species or distinctive ecological circumstances (Miller and Naples 2002).

Time of Insect Arrival v/s the Time of Death:

Forensic entomology provides significant information for measuring the time when insects first arrive on a decomposing body, which is a critical factor in defining the post-mortem interval (PMI). Nevertheless, it is crucial to acknowledge that the period when insects establish a colony does not necessarily align with the exact moment of death. Various circumstances can cause delays between the two occurrences, which can affect the accuracy of PMI estimations. These considerations encompass the duration it takes for insects to discover and reach a dead body, which can be affected by variables such as the body's positioning, burial, or concealment, as well as the existence of other scavengers. Occasionally, there may be a delay caused by environmental factors, such as severe cold, that can impede insect activity. Moreover, the developmental phase of the insect larvae discovered on the body can offer insights about the initiation of colonization, but it may not precisely determine the moment of death. Hence,

forensic entomologists must take into account these intricacies while analyzing insect evidence and collaborate with other forensic specialists to construct a thorough chronology of events related to a death inquiry (Bugelli et al., 2015).

Post-Mortem Movements: Forensic entomology faces a major obstacle when there have been post-mortem movements of a body. Under certain circumstances, the actual place of death may vary from the area where the body is found, which might result in issues when estimating the post-mortem interval (PMI). Relocating a deceased body can disturb the organic process of insect colonization and growth. Insects that were initially drawn to the original location of death may leave the body while it is being moved, and different insects may then establish a colony at the new location where the body is found. If not carefully handled, this change in insect activity might lead to inaccurate estimates of PMI. Forensic entomologists collaborate closely with investigators to reconstruct the chronological order of events, including the details of bodily movement, in order to obtain a more precise comprehension of the timeline. Integrating entomological evidence with other forensic data, such as witness statements, physical evidence, and scene analysis, is crucial in order to consider the complications caused by post-mortem movements and to offer a more thorough and dependable estimation of the time of death (Gupta & Setia, 2004).

Preservation and Contamination: Ensuring the correct gathering and safeguarding of entomological evidence is of utmost importance in forensic entomology, as the authenticity and dependability of specimens can be easily challenged. Insufficient preservation

methods or the introduction of impurities into specimens can result in incorrect findings when estimating the post-mortem interval (PMI). When insects are gathered from a crime scene or a body, they must be handled with care and stored in suitable containers to avoid any harm or pollution. Neglecting to comply with this requirement can lead to the forfeiture of crucial evidence or the inclusion of irrelevant materials, both of which can impede precise analysis. Contamination can occur due to inadequate storage conditions, such as being exposed to environmental elements like high temperatures and moisture, or through the transfer of contaminants between different specimens. In order to reduce these hazards, forensic entomologists strictly follow standardised procedures for gathering, conserving, and conveying insect evidence. By preserving the quality and authenticity of these samples, forensic entomology can remain a significant asset in criminal investigations and enhance the accuracy of post-mortem interval estimates (Mazzanti et al., 2010).

Forensic Collection of Insect Evidence in Indoor Cases: When decomposition happens indoors, forensic entomology encounters distinct difficulties in retrieving insect evidence. Indoor surroundings, in contrast to outdoor settings, offer a regulated climate that can influence the patterns of insect colonization. Indoor temperature and humidity levels can remain relatively constant, which may result in a decrease in insect activity compared to outdoor environments. Restricted entry to the body within enclosed indoor areas might also affect the capacity of specific insects to reach the cadaver, resulting in uneven colonization. In addition, human interference, such as

efforts to cleanse or hide the body, might disturb the natural course of insect activity and make it more difficult to determine the post-mortem interval (PMI). In order to surmount these obstacles, forensic entomologists must diligently record the details of the crime scene, such as the prevailing environmental conditions and the existence of any potential pollutants or obstacles that may hinder insect colonization. Collaborating with crime scene investigators and other forensic professionals is essential for accurately reconstructing the sequence of events and improving post-mortem interval estimations in indoor cases of decomposition (Brundage & Byrd, 2016).

Identification of Insect Species: Precise identification of insect species is a crucial component of forensic entomology, but it may be quite difficult, especially when working with damaged specimens or immature stages of insects. Conventional identification procedures frequently depend on the analysis of morphological characteristics, which may not always be clearly visible or distinguishable in specimens that are damaged or not fully developed. When faced with such situations, the use of molecular techniques such as DNA barcoding has proven to be quite beneficial in overcoming these restrictions. DNA barcoding entails the sequencing of a standardized segment of an organism's DNA and subsequently comparing it to a reference library of DNA sequences for established species. This method allows for accurate and dependable identification of insect species, even in cases where traditional morphological traits are not accessible or inconclusive. The use of DNA barcoding has greatly enhanced the precision of species identification in forensic

entomology, hence improving the field's capacity to give more dependable evidence in criminal investigations and aiding in more precise estimations of post-mortem interval. It is crucial to emphasize that DNA barcoding should be employed alongside other entomological approaches to guarantee thorough and strong analyses (Joseph et al., 2011).

Insects' Reaction to Chemicals and Pharmaceuticals: The existence of pharmaceuticals or chemicals in the body of a deceased individual can indeed exert a substantial influence on the behavior and growth of insects that feed on dead bodies, so introducing an additional factor.

The interpretation of insect evidence in forensic entomology is complicated by its intricacy. Substances, such as drugs or pharmaceuticals, have the ability to modify the decomposition process by impacting the scent characteristics of the body. These alterations have the ability to impact the allure and behavior of scavenging insects, which could result in changes to the way they colonize and the timing of their arrival. In addition, certain chemicals employed in embalming or preservation techniques might discourage or even intoxicate insects, hence adding complexity to the entomological examination. Forensic entomologists must take into account the possible impact of drugs and substances on insect behavior when determining the post-mortem interval (PMI). In order to accurately determine the timeline of events in a death investigation, it is crucial to have a close working relationship with toxicologists and a thorough understanding of the specific drugs involved. This collaboration and awareness are necessary to account for the intricacies involved in such investigations (Gennard, 2012).

Entomological evidence in Decayed

Corpse: In forensic cases when decomposition has reached an advanced level, resulting in merely skeletal remains, the usefulness of entomological evidence decreases dramatically. This is due to their preference for soft tissues; insects are less drawn to skeletal remnants, which provide fewer nutrients and organic matter. The lack of soft tissues limits the possibility of insects colonizing and the formation of significant entomological evidence. Forensic entomologists encounter constraints when attempting to estimate the post-mortem interval (PMI) exclusively from the analysis of insect behavior. Instead, investigators frequently depend more extensively on alternative forensic techniques, such as the examination of skeletal remains, taphonomic investigations, and contextual evidence, to ascertain the circumstances and timeline of the death. Although entomological evidence may have a reduced significance in advanced decomposition cases, it still highlights the necessity of a multidisciplinary approach in forensic investigations. Different forensic disciplines work together to enhance our understanding of the circumstances surrounding a death (Wang et al., 2019).

Ethical Factors Involved: Ethical difficulties arise when insects are used as evidence in forensic entomology, especially when it involves environmental conservation and disruption to ecosystems. Gathering insects for a forensic application has the potential to disturb the local ecosystem. Ecosystems can have detrimental effects on wildlife populations. Certain bug species have the potential to be endangered, protected, or playing vital roles in their native habitats, these

organisms pose ethical concerns when collected. Moreover, the disruption of these ecosystems can lead to a series of consequences on other organisms and the overall environment. In order to tackle these ethical difficulties, forensic entomologists must exhibit prudence and accountability while gathering insect evidence (Sandhi et al., 2023).

It is important for them to give priority to the employment of non-invasive techniques, minimize the negative effects on local ecosystems, and adhere to legal and ethical norms for the conservation of animals. Engaging in cooperation with conservationists and ecologists can effectively safeguard the ecosystem and protect endangered species from any adverse effects caused by insect gathering for forensic purposes. The challenge of maintaining ecological integrity and biodiversity while conducting criminal investigations is a crucial issue in forensic entomology. This emphasizes the significance of ethical considerations in the discipline (Blau, 2016).

It is essential to recognise and clearly convey the constraints of forensic entomology to investigators and legal professionals in order to uphold transparency and trust in the area. Through engaging in open discourse Forensic entomologists can assist in ensuring that the constraints posed by issues such as variable insect behavior, insufficient understanding of some species, and the potential impact of medicines or poisons are adequately taken into account during the investigative process. Furthermore, forensic entomologists should prioritize the recognition of the interdisciplinary aspect of their work, emphasizing the significance of collaborating with other forensic specialists in order to construct a

thorough and all-encompassing case. Moreover, it is important to acknowledge that the discipline of forensic entomology is characterized by constant change and development. In the future, difficulties related to insect evidence may be addressed and the accuracy and reliability of such evidence may be improved through ongoing study, technical developments, and the establishment of standardized processes (Byrd & Brundage, 2020). This encompasses enhancements in DNA analysis methodologies for the identification of insect species, the fine-tuning of insect development models, and progress in environmental monitoring and data gathering. As the field advances, forensic entomologists are in a position to make more contributions to criminal investigations and judicial proceedings, potentially decreasing the uncertainties related to insect evidence. Nevertheless, it is crucial to be watchful and proactive in recognising and minimizing constraints, as this is a basic element of ethical and efficient forensic entomology practice.

DISCUSSIONS

Forensic entomology, the application of insect biology in legal investigations, is on the verge of significant advancements in the near future. These promising opportunities are supported by a balanced interaction of the several factors contributing to the growth of this field. These include the continuous advancement of technology, a better understanding of insect behavior and ecological dynamics, and a growing recognition of the field's significant potential in both criminal justice and wildlife conservation. The advancements in DNA analysis tools are allowing us to remove and examine the contents of insect guts, which is significant. This innovative method offers

new opportunities for identifying certain organisms, potentially linking them to crime scenes or individuals involved. Furthermore, the incorporation of advanced machine learning algorithms has the potential for faster and more accurate data analysis, hence improving the precision of critical forensic decisions, such as determining postmortem intervals. Forensic entomology is increasingly gaining importance in wildlife crime and illicit trade cases, in addition to its conventional role in criminal investigations. This aligns well with the increasing global awareness of environmental issues. The interdisciplinary nature of this subject, which brings together entomologists, geneticists, and forensic experts, is promoting collaborative efforts that have the potential to provide new advances. Forensic entomology is poised to play a more significant role, both in the criminal justice system and worldwide, in combating wildlife crimes and protecting endangered species. These developments highlight the field's significant capacity to make substantial contributions to settling complex legal matters and protecting the valuable biodiversity of our planet in the promising years to come.

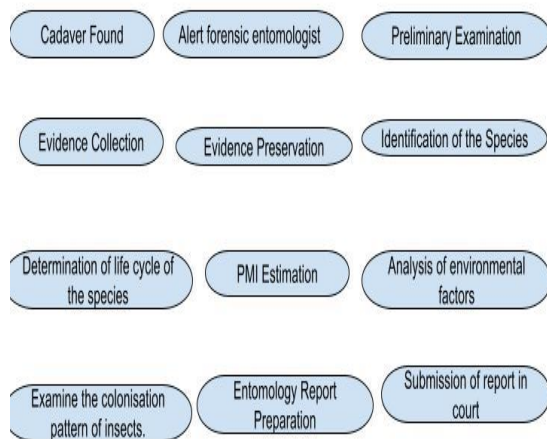


Fig 1: Workflow and Analysis Flow Chart for Forensic Entomology Investigation

REFERENCE

- Amendt, J., Campobasso, C. P., Gaudry, E., Reiter, C. & LeBlanc, H. N. 2004. Best practice in forensic entomology—standards and guidelines. *International Journal of Legal Medicine*, 118 (2): 90-104.
- Amendt, J., Richards, C. S., Campobasso, C. P., Zehner, R. & Hall, M. J. 2011. Forensic entomology: applications and limitations. *Forensic science, medicine, and pathology*, 7: 379-392.
- Anderson, G. S. 2001. Forensic entomology in British Columbia: a brief history. *Journal of the Entomological Society of British Columbia*, 98: 127-136.
- Archer, M. S. 2004. Carrion-flies (Diptera: Calliphoridae) and the "body farm": A 25-year study of insect succession and decomposition in central Texas. *Journal of Forensic Sciences*, 49 (4): 704-711.
- Bala, M. & Sharma, A. 2016. Postmortem interval estimation of mummified body using accumulated degree hours (ADH) method: a case study from Punjab (India). *J. Forensic. Sci. & Criminal Inves*, 1: 1-5.
- Benecke, M. 2001. A brief history of forensic entomology. *Forensic Science International*, 120 (1-2): 2-14.
- Blau, S. 2016. More than just bare bones: Ethical considerations for forensic anthropologists. In *Handbook of forensic anthropology and archaeology* (pp. 457-467).Routledge.
- Brandmayr, P., Greco, S., Brandmayr, T. Z. B., Bonacci, T., Tersaruolo, C. & Vercillo, V. 2010.
 - A preliminary investigation of insect succession on carrion in Calabria (southern Italy). *Terrestrial Arthropod Reviews*, 3 (2): 97-110.
 - Brundage, A. & Byrd, J. H. 2016. Forensic entomology in animal cruelty cases. *Veterinary pathology*, 53 (5): 898-909.
 - Bugelli, V., Forni, D., Bassi, L. A., Di Paolo, M., Marra, D., Lenzi, S., ... & Vanin, S. 2015. Forensic entomology and the estimation of the minimum time since death in indoor cases. *Journal of forensic sciences*, 60 (2): 525-531.
 - Byrd, J. H. & Brundage, A. 2020. Forensic entomology. In *Veterinary Forensic Medicine and Forensic Sciences* (pp. 67- 111).CRC press.
 - Cammack, J. A., Tan, A. J., Drijfhout, F. P. & Meier, R. 2020. Gene expression reflects temporal changes in the age, sex, and reproductive condition of blow fly (*Calliphora vicina*) larvae. *Forensic Science International*, 308: 110176.
 - Campobasso, C. P. & Introna, F. 2001. The forensic entomologist in the context of the forensic pathologist's role. *Forensic Science International*, 120 (1-2): 132-139.
 - Campobasso, C. P., Di Vella, G., Introna, F. & Dragone, P. 2001. Factors affecting decomposition and Diptera colonization. *Forensic Science International*, 120 (1-2): 18-27
 - Catts, E. P. & Goff, M. L. 1992. Forensic entomology in criminal investigations. *Annual Review of Entomology*, 37: 253- 272.
 - Chophi, R., Sharma, S., Sharma, S. & Singh, R. 2019. Forensic entomotoxicology: current concepts, trends and challenges. *Journal of forensic and legal medicine*, 67: 28-36.
 - Gennard, D. 2012. Forensic entomology: an introduction. John Wiley & Sons.
 - Gosselin, M., Wille, S. M., Fernandez, M. D. M. R., Di Fazio, V., Samyn, N., De Boeck, G. & Bourel, B. 2011. Entomotoxicology, experimental set-up and interpretation for forensic toxicologists. *Forensic science international*, 208 (1-3): 1-9.
 - Gupta, A. & Setia, P. 2004. Forensic entomology—past, present and future. *Anil Aggrawal's Internet Journal of Forensic Medicine and Toxicology*, 5 (1): 50-53.
 - Hall, R. D. 2019. The forensic entomologist as expert witness. In *Forensic Entomology* (pp. 333-348). CRC Press.