FORENSIC ENTOMOLOGY LITERATURE REVIEW

by

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Abstract

Forensic entomology is a rapidly advancing field within forensic science, providing critical insights into post-mortem interval (PMI) estimations and aiding in criminal investigations. Despite its increasing significance, there are still considerable gaps in the understanding of insect colonisation under different conditions, as well as inconsistencies within research methodologies and protocols, all of which limit its broader application. This study offers a comprehensive overview of the historical development of forensic entomology, examines recent advancements, and identifies persistent challenges that hinder the field's full potential. By addressing these gaps, this paper outlines key areas for future research to enhance the utility and reliability of forensic entomological studies.

This research highlights several issues, including the need for improved insect species identification, inconsistent methodological reporting, and a lack of consideration for environmental factors, which can significantly influence insect activity and subsequent PMI estimations. It is additionally recommended that future studies focus on observing the wider entomofauna, rather than concentrating on insects traditionally considered as forensically significant. This broader perspective has potential to provide a more comprehensive understanding of ecological dynamics and how local and temporal condition affect insect activity.

Improving the current understanding of the processes involved in decomposition and insect succession, including the effects of different cadaver conditions and weather patterns, will directly enhance the applicability of PMI estimations. By refining species identification methods through the incorporation of molecular techniques, standardising insect collection protocols, prioritising thorough scientific reporting, and formulating global and local databases, future research will lead to the development of more reliable forensic methods, enhancing accurate PMI estimations that can aid in criminal proceedings.

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<u>Chapter 1: Introduction</u>

1.1 Forensic Entomology

Forensic entomology is the use of insects or arthropods present at a crime scene to draw reasonable conclusions about the crime in question (Singh et al., 2022), particularly in the context of death and decomposition. By analysing insect arrival, succession, and development, entomologists can estimate roughly how much time has elapsed between a person's death and the discovery of the body, referred to as the post-mortem interval (PMI) (Acosta et al., 2021).

This specialised area of research can be further divided into three sub-disciplines: urban, stored product, and medicolegal forensic entomology (Vanin & Huchet, 2017). Urban forensic entomology pertains to civil cases involving structural weaknesses associated with insects, while stored-product forensic entomology focuses on biosecurity risks in products intended for human consumption (Bambaradeniya et al., 2023). Medicolegal forensic entomology, the most widely recognised of the three, involves the study of insects that colonise on decomposing organic matter, often in connection with criminal investigations, related to violent crimes or unexpected deaths (Bugelli et al., 2023). The types of insects and their life cycle stages provide insights into the time of death, the conditions surrounding the crime, and potentially link a suspect to a victim (Byrd and Sutton, 2020; Amendt et al., 2011).

The foundations of forensic entomology reside in the understanding and predictability of insect colonisation and succession on decomposing bodies (Sardar et al., 2021). However, the rate of insect development and decomposition is directly influenced by a variety of factors, such as climactic conditions and condition of the body, making it essential to understand these factors for accurate PMI estimations (Corotti et al., 2024).

By observing these variables and analysing species development, forensic entomologists can assist in criminal cases, especially in cases where other forensic methods are less reliable.

Forensic entomology has become an essential tool in modern criminal investigations, helping to solve cases of homicide (Obafunwa et al., 2024), neglect (Volckaert, 2020), and abuse (Mashaly and Al-Khalifa, 2024). Recent advancements in the field have improved accuracy of PMI estimations, primarily through molecular techniques such as DNA barcoding (Chimeno et al., 2018) and radiocarbon (C-14) dating (Franceschetti et al., 2023), allowing for more precise insect identification and the assessment of developmental stages (Bambaradeniya et al., 2023). Furthermore, the fusion of toxicology and forensic entomology has given rise to the specialised field of forensic entomotoxicology. In this discipline, insects are not only utilised for PMI estimations, but also for the identification of toxins (Bhardwaj et al., 2020). Research into how these chemicals affect insect development (Jain et al., 2025) and subsequent implications to PMI can provide critical insights into cases regarding drug overdoses (Introna et al., 2001), poisoning, (Chakroborty and Sharma, 2023) and other drug-related deaths.

As the field of forensic entomology continues to evolve, ongoing research, interdisciplinary collaboration, and technological advancements hold great potential for refining its applications in criminal investigations (Bansode et al., 2025). New methods are enhancing the precision of PMI estimations (Shao et al., 2023), expanding the scope of entomological evidence that can be utilised from crime scenes and aid in criminal proceedings. Additionally, by further understanding the intricate relationships between insects, environmental factors, and decomposition, forensic entomologists can provide even more accurate and insightful contributions to criminal investigations (Obafunwa et al., 2024), ultimately strengthening the role of entomology in modern forensic science.

1.2 PMI

The post-mortem interval (PMI) refers to the period of time that has elapsed since death and the discovery of the body (Haas et al., 2021). Determining the time of death is crucial in criminal proceedings as it can prove or disprove a person's alibi as well as reveal other details surrounding the timeline of events (Pereira et al., 2024). Furthermore, the role of PMI extends beyond this as it can also aid in the identification of possible key individuals related to a crime (Pai et al., 2007). However, when the exact time of death is unclear, contributions from other disciplines, such as forensic entomology, can provide additional support (Baldino et al, 2023).

The determination of a precise PMI is complex, as bodies undergo a range of physiological, chemical, and biological changes after death, referred to as decomposition. Rates of decomposition differ from one geographical location to another and also differ in the same location from one season to another (Almulhim and Menezes, 2023). This process can also be affected by bacteria activity (Hyde et al., 2014), and scavenger activity (Indra et al., 2023), further complicating PMI estimations.

1.3 Stages of Decomposition and Insect Activity

Decomposition occurs in several stages, each attracting different insect species that play a role in the breaking down of the body. The stages of decay are generally accepted as being subjective and used as artificial boundaries for a continual process for descriptive purposes (Eberhardt and Elliot, 2008). These stages can be loosely classified into the fresh, bloat, active decay, advanced decay, and dry remains/skeletal stages (Lee Goff, 2009; Rai, Pickles and Perotti, 2021).

There are several factors that can hinder the arrival of insects to a corpse. This can be the accessibility of a corpse (Charabidze et al., 2015), season or time of year (Hernandez, 2022), temperature (Lutz et al., 2022), and corpse location (Campobasso et al., 2001), to name a few. Additionally, the state of the body will also have an impact on the decomposition process, for example, if the body has been victim to burning (Vanin et al., 2013) or drowning (Caruso, 2016).

In each stage, the type of insect attracted is influenced by the decomposition process, with different species feeding on specific body components that are available at each stage (Benecke, 2005). The presence and activity of these insects provide valuable information for PMI estimations.

<u>1.3.1 Fresh Stage</u>

The point of death is the moment that the fresh stage of decay begins (Lee Goff, 2009), with the function of the heart, lungs and brain stopping (Shedge et al., 2023). This then leads to livor mortis (the levelling of blood in the body), rigor mortis (stiffening of the muscles caused by chemical alterations within the myofibrils) (D'Souza et al., 2011), algor mortis (natural cooling of the corpse due to the stoppage of thermoregulation) (Rattenbury, 2018), and autolysis (the destruction of tissue by their own enzymes) (Hyun et al., 2012).

Flies (Diptera) are typically the first insects present on a corpse, colonising the body withing minutes of death (Brundage, 2020). Calliphoridae species (blow flies) are most commonly reported colonising the body within the first stages of decomposition, as shown in studies of Voss et al (2011), and Maisonhaute and Forbes (2022). During the process of decay, gases are released, and the odour emitted by a corpse is what attracts these flies to it (Mondor et al., 2012). Orifices such as the mouth, nose, ears and open wounds are typically the first sites to be colonised by flies (Munro and Munro, 2008) depending on accessibility.

1.3.2 Bloat Stage

During the bloated stage of decomposition, bacteria, such as species belonging to Clostridium and Bacillus, will consume bodily minerals and begin to produce gases which inflate the body, causing bloating (Hyde et al., 2013). The increase in pressure caused by the extensive gas production by bacterial colonies leads to the escape of fluids from the body's natural openings, such as the nostrils, anus, and mouth (Janaway, Percival and Wilson, 2009). Additionally, changes in the skin being to appear, such as blistering, changes in colour, and degloving of the extremities (Almulhim and Menezes, 2023). The greatest number of adult flies is most commonly seen during this stage, followed closely by instar or larval stages (Joseph et al., 2011) as the bloat stage progresses.

1.3.3 Active Decay Stage

During the active decay stage, the body begins to lose mass as soft tissues are broken down and consumed by maggots. Beetles, particularly Dermestidae, Silphidae, and Staphylinidae families, are attracted to the body at this stage (Prado e Castro et al.,

2013) especially as the remains become more exposed. Some beetle species feed directly on the decomposing tissue, while others consume the maggots or other insect larvae that are present on the body (Nadeau et al., 2015). Additionally, literature on Coleopteran species has shown that these insects also prey on Hemipteran insects (Leschen, 2000). The feeding habits of beetles vary amongst insect family. For instance, those belonging to Carabidae have been detailed as feeding on a rage of insects including slugs and caterpillars (Reich et al., 2020), while Staphylinidae and Silphidae beetles have been documented feeding on other colonising insects present on a corpse (Aluja et al., 2005).

1.3.4 Advanced Decay Stage

By the point at which the advanced decay stage is reached, peeling and drying of the skin occurs, as well as the considerable loss of soft tissues (Tembe and Mukaratirwa, 2021), and the migration of the Dipteran larvae away from the body (Carter et al., 2023). During this time, Sepsidae and Piophilidae families become more abundant as they being to colonise the body (Skopyk and LeBlanc, 2024). Beetles from the Dermestidae (Hu et al., 2023) and Staphylinidae (Khalil et al., 2024) families become more prominent at this stage, feeding on dried tissue, skin and hair. In addition to this, the remaining flesh quickly dries out, decreasing the nutritional value of the corpse, leading to the decline in necrophagous insect abundance and an increase in Coleoptera presence (Lokhande and Hankare, 2021).

1.3.5 Dry Remains Stage

The final stage of decomposition is the dry remains stage, often referred to as skeletonisation, and is reached when there is a significant level of skeletal exposure (Cockle & Bell, 2017). Unlike the previous stages, the dry remains stage has no definitive end, lasting until the hair and bones are completely decomposed (Payne, 1965). During this stage, typically only adult Diptera (Phoridae and Sciaridae) and Coleoptera (Histeridae, Dermestidae, and Staphylinidae) species are observed, with no larval stages being present (Bonacci et al., 2021). Female Diptera do not lay eggs on bodies that are in the dry remains stage as the eggs and larvae need moisture for successful development (Amendt et al., 2004).

1.4 Insects and PMI Estimations

1.4.1 Insect Life Cycles

In forensic entomology, the lifecycle of insects, particularly Diptera and Coleoptera, are well documented as being essential for estimating PMI. This is because their lifecycles follow a predictable and consistent sequence of development (Harvey et al., 2016). These lifecycles are often compared to biological clocks (Faran et al., 2018), allowing forensic entomologists to determine an approximate time of death depending on present insect activity and life cycle stages. Flies, specifically blowflies, are most commonly the first to arrive on a corpse (Amendt et al., 2004), signifying a level of freshness. Unlike flies, beetles are more commonly observed during the later stages of decomposition (Bala and Singh, 2015), particularly in the dry remains stage.

1.4.1.1 Fly Life Cycle

The first stage within a fly's lifecycle is the egg stage. Within minutes of death, adult female flies will lay their eggs on exposed orifices such as the eyes, mouth, and ears, as well as any accessible open wounds (Rivers et al., 2023). Under favourable conditions, female C. megacephala can arrive at a carcass within an hour of death and lay a cluster of 220-325 eggs (Badenhorst and Villet, 2018). The developmental duration of immature insects is species-specific (Donovan et al., 2006), with eggs typically hatching within a few hours to several days (Oldroyd, 2025), depending on the environmental conditions in which they develop.

The larval stage follows the egg stage. Once hatched, fly larvae (maggots) enter the first instar stage. Larvae will feed on the decomposing tissues, growing rapidly as they progress through the second and third instar stages (Sharma et al., 2015). Each instar stage has a set growth period, with the third and final instar stage being the largest and most noticeable (Bunchu et al., 2012). With the duration of the third instar and pupal stages being longer than the previous stages, this makes accurately aging insects increasingly difficult than compared to the earlier lifecycle stages (Tarone & Foran, 2010). The rate of development is directly affected by environmental conditions, for example, *Chrysomya Rufifacies (*Calliphoridae) produce smaller pupae and adults with increased temperatures (Tomberlin et al., 2009). Entomologists can utilise local weather data and known temperature-dependant growth rates to estimate how long the maggots have been feeding on a body, providing a relatively accurate prediction of PMI.

The next life cycle stage is known as the pupal stage. After completing the third instar stage, the larvae begin to migrate away from the body towards a more sheltered environment where they can begin pupation (Joseph et al., 2011). During this stage, the larvae encase themselves in a protective casing called a puparium and transform into pupae. The pupal stage has the longest duration of all the stages, representing half of the total life cycle (Defilippo et al., 2013).

The final stage within a fly's lifecycle is the adult stage. This is when the pupa transforms into an adult fly, mating, laying eggs and beginning the life cycle all over again. The entire lifecycle stages, from egg to adulthood, lasts approximately two to four weeks (Amendt et al., 2021), however, some Dipteran species' oviposition and egg hatching rates, as well as the occurrence of pupation, have been shown to fluctuate during varying temperatures (Kinjo et al., 2014). It is because of these specific timeframes, and an ongoing petition to understand how variables, such as local climates, affect insect colonisation and development, that researchers can utilise fly species for PMI estimations (Singh et al., 2022).

1.4.1.2 Beetle Life Cycle

Much like a fly's life cycle, beetles also have an egg stage, larval stage, pupal stage, and adult stage. The egg stage begins once adult beetles have laid eggs on the decomposing remains, typically into the active decay or dry remains stage (Wolff et al., 2001). Alternatively, some species, *Creophilus maxillosus* for example, will lay singular eggs in clumps of soil (Frątczak-Łagiewska et al., 2020), making them more difficult to detect during investigations.

When eggs have hatched, beetle larvae, referred to as grubs, begin to feed on the decomposing tissues (Nadeau et al., 2015). The larvae will then proceed to go through several instar stages, which may last from several days to week, depending on temperature and food resources. Beetle larvae development, similarly, to fly larvae development, is highly temperature-dependant (Montoya-Molina et al., 2021) and can account for up to 70% of total development time for some species (Wang et al., 2021). The morphological features of beetle larvae are easier to distinguish than those of fly larvae (Shao et al., 2024), making for clearer identification and utilising species-specific growth pattern to help forensic entomologists estimate PMI. Once the larvae have consumed a sufficient amount of food, they migrate from the bodily remains in search of other shelter (Burges, 1959) in preparation of pupation (Gruszka & Matuszewski, 2022). The final stage of the beetle life cycle is the adult stage. Adult beetles will emerge from their pupal casing, ready to begin the life cycle again.

Often, beetles colonise a body much slower than flies but demonstrate an important role for PMI estimations during the later stages of decomposition (Benecke et al., 2004). It is valuable to note that the developmental stages of beetle species can differ greatly, for example, *Creophilus maxillosus* has been documented as having a far longer developmental duration compared to species belonging to Calliphoridae and Sarcophagidae (Wang et al., 2016). This demonstrated the importance of further research into species specific development as well as research into factors affecting development.

1.4.1.3 Other Insects Associated with Forensic Entomology

While not as commonly associated with carrion feeding as flies, some wasp species (Hymenoptera) have been documented as having necrophagous habits and influencing the duration of decomposition (Simões et al., 2013). In addition to this, wasp species, such as *Vespula germanica*, have been known to directly kill necrophagous flies, impacting the roles of flies on a deceased body (Cairncross et al., 2022). These documented behaviours of wasps will impact the rate of decomposition and subsequently affect PMI estimations. Therefore, wasp activity should be considered when observed during forensic investigations.

Ants (Hymenoptera) are another group of insects that aren't typically considered within forensic investigations but do hold potential to aid in PMI estimations. Ant colonies are often observed rapidly colonising near decomposing bodies (Siva Prasad & Aneesh, 2022) in all stages of decomposition (Campobasso et al., 2009) and have been observed directly feeding on decaying bodies (Singh et al., 2020), therefore making them forensically significant. In addition to affecting the duration of decay, a 2023 study has proposed a classification for improved accuracy of early postmortem events reconstruction based on bloodstain patterns caused by ant activity, which can also provide clues surrounding the circumstances surrounding the death (Kumar et al., 2023).

A diverse range of insects beyond flies and beetles, can contribute valuable information in forensic entomology. All of the aforementioned insects play a role in the decomposition process and can help provide evidence for PMI estimations. Moreover, these insects provide additional data that can contribute to a comprehensive understanding of the timeline of events, and the conditions surrounding death.

1.4.2 How PMI is Calculated

Post-mortem interval (PMI) refers to the time that has passed between death and the discovery of the body. A variety of natural processes related to decomposition, such as rigor mortis and livor mortis, can be used to estimate PMI. However, many of these processes cause PMI estimations to become less accurate over time, with their applicability becoming more limited after the first 72 hours after death Campobasso et al., 2001). In more advanced stages of decomposition, when a significant amount of soft tissue has been consumed, or when insect activity lessens, it becomes more difficult to accurately determine PMI (Sutton and Byrd, 2020), typically only being estimated within a range of several days, weeks, or more. Nonetheless, insects can still serve as a highly effective tool for estimating the minimum time since death (Amendt et al., 2011) and aid in criminal investigations.

The first step to calculate PMI using forensic entomology is to collect insect samples from the crime scene. Guidelines for collecting insect specimens specify that death scene samples must accurately reflect the cadaver's entomofauna, meaning that it must be representative of all life stages of each forensically significant species (Matuszewski, 2021). The types of insects found, along with the developmental stages (eggs, larvae, pupae, or adults), can provide important clues about the time that has elapsed.

The next stage in PMI estimations is the identification of insect species and the developmental stage. Different species of insects colonise the body at different times, therefore by identifying the species, as well as the developmental stage, researchers can condense the potential PMI window. Accurately identifying the species of insect samples is the first step in determining the age of the larvae found. Different insect larvae have varying growth rates and characteristics. For example, *Lucilia sericata* larvae develop more quickly at 25 °C than those of *Calliphora vicinia* (Amendt et al., 2004). Furthermore, blowflies typically arrive to a body first, laying eggs directly on the body (though there are exceptions), while all flesh flies (Sarcophagidae) give birth to live larvae (Skevington & Dang, 2002). These differences highlight that larvae at the same developmental stage found on a corpse may not have the same age or time of colonisation.

Methods of identification include the use of taxonomic keys to morphologically identify insects, as well as the use of molecular techniques such as DNA barcoding (Patle et al., 2024), and C-14 dating (Franceschetti et al., 2023). Additionally, as insects are typically more difficult to identify to species rank while in their juvenile stages due to inadequate larval taxonomic keys (Dittrich-Schröder et al., 2010), collected juveniles are often reared in a laboratory to adulthood to aid in the identification process. It is important to note that rearing protocols can vary for different insects and continued research into improved protocols is necessary for accurate PMI estimations. For example, a 2021 study on Necrodes littoralis demonstrated that group rearing improved the accuracy of developmental data used in forensic entomology, as opposed to individual rearing protocols that are often utilised for Coleopteran rearing (Gruszka & Matuszewski, 2021). Furthermore, laboratory rearing should be used with caution, as a significant portion of the specimens may die or experience slowed development while in the laboratory (Matuszewski and Mądra-Bielewicz, 2024).

It is important to consider the environmental conditions, such as temperature, humidity, geographic location, and rainfall, when calculating PMI, since these can have a significant effect on insect activity and development (García-Rojo et al., 2013). However, once the developmental stage of the insect specimens is known and the environmental factors have been accounted for, the minimum PMI can be estimated. The basis of these estimations is the assumption that by determining the age of the developing insects on a body, it is possible to estimate the time of colonisation, which provides a minimum PMI (Amendt et al., 2006).

1.4.3 How Accurate are Current PMI Estimations

The accuracy of PMI estimations, particularly those based on forensic entomology, can vary significantly depending on several factors. While entomological evidence can provide relatively precise estimations under ideal conditions, there are limitations that can affect the accuracy of PMI. PMI estimations are heavily reliant on correct identification of the insects present on the body and use the appropriate developmental models. Many insect's species follow a predictable pattern of colonisation and development, but there is a variability in how quickly they mature, depending on the species, geographic location, and environmental conditions (Obafunwa et al., 2024). Therefore, for accurate insect sample age calculations, forensic entomologists must first correctly identify the species found on the body, followed by reconstructing crime scene temperatures, and lastly model the development of rate of present immature insects (Amendt et al., 2011).

Weather conditions, such as temperature and humidity (Franceschetti et al., 2021), can complicate PMI estimations due to the effects these variables have on insect behaviour. In regions with unstable temperatures or where local accurate weather data is unavailable, PMI estimations cannot be precisely and reliably estimated. Furthermore, even in places with accessible weather data, there can be great contrasts between the ambient temperatures recorded by the weather station and the temperature at the crime scene (Archer, 2004). For this reason, it is recommended that ambient temperature is monitored at the crime scene for several days after the discovery of the body, allowing for the establishment of a regression relationship between these temperatures and the weather station temperature data (Amendt et al., 2006). Additional complications remain in criminal cases where the body is not exposed to weather conditions, such as being underground or inside buildings, the accuracy of PMI estimation will be significantly reduced.

The condition of the body itself plays an impotent role in accurate PMI estimations. Lack of exposure to the elements, movement, or protection from insect activity affects colonisation rates. PMI estimations are more accurate when a body is in an open environment with minimal disturbance, allowing for typical insect colonisation. If a body is moved, covered, or otherwise shielded from insect activity, PMI estimations may be less reliable, with the estimation window becoming broader.

Another important factor to consider is the possibility of insecticide or toxin exposure. If the body is exposed to insecticides or toxins, insect colonisation may be delayed or inhibited. Insecticides can lead to reduced insect activity, changes in insect succession and the presence of non-typical insect species, all of which negatively affect the accuracy of PMI estimations, resulting in underestimations.

PMI estimations using forensic entomology can be highly accurate under optimal conditions, especially in the early stages of decomposition. However, the accuracy of these estimations diminishes with advanced decay or when external factors complicate insect colonisation (Kotzé et al., 2021). As with all forensic methods, entomological evidence is typically used alongside other methods, such as autopsy and toxicology, to triangulate the most accurate PMI possible.

1.5 Forensic Entomology: Past and Present

Insect classification, established in the 18th century by Carl Linnaeus (Egerton, 2007), laid the foundation for modern taxonomy through the creation of the binomial nomenclature system. While there have been refinements to Linnaeus's original system, this structure of classification remains essential for the grouping of related species into genealogical trees that reflect their evolutionary lineage from shared common ancestors.

The first documented case of forensic entomology comes from the 13th century, as recorded by the Chinese lawyer and death investigator Sung Tźu in his medico-legal textbook Hsi yüan chi lu (commonly translated as "The Washing Away of Wrongs") (Giles, 1924). In this case Sung Tźu describes a stabbing that took place near a rice field. The day after the stabbing, workers were instructed to place their sickles on the ground. Blowflies were attracted to one sickle in particular, due to invisible traces of blood that remained on the blade (Benecke, 2001). When confronted, the owner of the sickle confessed to the crime. This case shows how insect colonisation was used to connect a suspect to a crime.

Prior to the 17th century, the theory of spontaneous generation prevailed, which suggested that maggots would naturally spawn out of decaying flesh (Parke, 2014). This belief was widely accepted until Italian physician, Francesco Redi, demonstrated the connection between maggots and flies. Two groups of meat were exposed to insects, with one left unprotected and the other covered by gauze. The meat protected by the gauze had no maggots on it, but eggs were observed on the protective outer surface of the gauze. The uncovered meat had eggs on it, which eventually hatched into maggots (Weiss, 1926), debunking the theory of spontaneous generation. Redi's work laid the foundation for modern forensic entomology by demonstrating the connection between insect reproduction and the decomposition process.

In the 19th century, forensic entomology began to emerge as a formal discipline. French physician Dr Louis François Étienne Bergeret became the first to apply entomological evidence to estimate PMI (Bergeret, M. 1855), a practice that would become the core of forensic entomology. In one notable case, he was called to investigate the remains of a mummified new-born, found behind a chimney of a boarding house. Upon his inspections, he found Sarcophaga larvae and Tineidae pupae. Having previous knowledge of insect life cycles, Bergeret hypothesised what the entomological activity may propose evidence for the case and how the life cycles of the specimens may indicate a period that the remains had been there for (Benecke, 2001).

In 1881, German medical doctor, Hermann Reinhard, reported the first systematic study within the field of forensic entomology (Reinhard, 1882). Reinhard collected numerous Phorid flies from a buried corpse and concluded that specific insects were associated with it. Additionally, French physician Paul Camille Hippolyte Brouardel identified numerous arthropods on the body of a new-born child during autopsy. Being beyond his expertise, he enlisted the help of Monsieur Perier, from the Paris Natural History Museum, and Dr Jean Pierre Mégnin, an army veteran, and transformed anecdotal data in verified crime scene evidence (Rivers & Dahlem, 2014). Dr Jean Pierre Mégnin continued to contribute to the field of forensic entomology and identified the eight distinct waves of insect succession on corpses exposed to air, as well as two distinct insect succession waved on buries corpses (Balcombe, 2021). Insect succession refers to the process of insect invasion onto a corpse soon after death, with different insect species being attracted to different stages of decomposition (Magni et al., 2019).

Advances in forensic entomology since the 20th century has made it one of the most accurate methods for establishing later stages of PMI (Lutz et al., 2021). Dr. Marcel Leclercq maintained methods in central Europe between the 1960s and 1980s (Benecke, 2001) when entomological research was scarce. Dr. Leclercq's work includes 132 entomological cases involving 141 corpses found in a variety of death scenes with approximately 100 insect species associated with a dead body having been identified by Dr. Leclercq. In addition to this, there was growing recognition of the critical role that temperature plays in insect development, allowing for entomologists of the time to refine PMI estimations. By the late 20th century, forensic entomology became a multidisciplinary field, increasing integrating with other scientific disciplines to aid in accurate PMI determination.

In 1984, genetics professor at the University of Leicester, Alec Jeffreys, discovered that patterns in regions of DNA could distinguish individuals. DNA profiling, sometimes referred to as forensic genetics or DNA fingerprinting, focuses on the 0.9% of the human genome that is not shared by everyone else, allowing the identification of individuals based on these DNA variations (Giardina, 2013). The use of DNA within forensics has since extended to forensic entomology. DNA based methods within forensic entomology most commonly include those used for species identification, insect gut contents and the characterisation of the population genetic structure of a forensically important insect species. In 1994, Sperling et al amplified specific insect DNA fragments using PCR, followed by direct DNA sequencing of the amplification products. Their results found abundant DNA sequence differences, unambiguously identifying immature larval stages of three blowfly species: *Phormia regina, Phaenicia sericata* and *Lucilia illustris* (Sperling et al., 1994). This biotechnological development is a great advancement in the field for criminal cases as it eliminates the need for larval rearing for identification purposes, saving valuable time. Additionally, these methods can be used in cases where samples are damaged (Picard et al., 2023) and morphological identification is no longer an option. However, this is not a cheap alternative for those studying the insects, calling for the need for this technology to be more accessible if this is to be the new normal for insect identification. Furthermore, studies have called for more research in order to form comprehensive databases and standardised protocols (Mahakalkar & Bhoyar, 2024).

Forensic entomology in the 21st century continues to develop, becoming ever more useful for criminal cases. Recent improvements and collaborations with molecular and DNA biology have enabled investigators to benefit from the use of molecular identification methods (Bhuyan et al., 2025). The most common practice for insect identification is through taxonomic keys, which heavily rely on the insects' morphological characteristics and correct practice by the user (Gemmellaro et al., 2019). Identification keys can be difficult or impractical to use however due to the unavailability of local keys (Kotzé et al., 2021) or the time-consuming nature for large scale investigations (Mehle & Trdan, 2012), as examples.

Recent research has increasingly focused on the impact of climate change and global warming on insect behaviour (Hwang et al., 2022; Englmeier et al., 2022; Amendt, 2021), which could have significant implications for current PMI estimation protocols (Strack & Smith, 2023), and their applicability to criminal cases. Temperature plays a vital role in regulating the development and life cycles of insects, especially those used for PMI investigations. As global temperatures rise due to climate change, it is expected that insect behaviour and activity will change, with potential shifts in typical colonisation behaviours (Amendt, 2021), extinction (Lencioni & Gobbi, 2021), and insect distribution (Atencio-Valdespino & Collantes-González, 2022). Insect development rates can increase or decrease depending on temperature thresholds, which creates a significant challenge for forensic entomologists as current PMI estimation methods heavily rely on established temperature-based models, which may become less reliable as global climate pattern shift (Strack & Smith, 2023). If insect behaviour and decomposition rates are altered due to global warming, the accuracy of PMI calculations used in criminal investigations could be compromised, potentially impacting the outcomes of criminal cases. Therefore, it becomes increasingly crucial to incorporate clime change considerations into forensic entomology research, ensuring that PMI estimations remain accurate of contemporary environmental conditions.

1.6 Current Application and Limitations of Forensic Entomology

In recent years, the advancements in molecular techniques have significantly enhanced the accuracy of forensic entomology. DNA barcoding has improved the identification of insect species (Kotzé & Martín-Vega, 2025), allowing entomologists to more precisely classify specimens that might have been previous difficult to identify due to being damaged or having limited access to necessary keys (Gemmellaro et al., 2019). Furthermore, the integration of molecular identification techniques has enabled entomologists to more accurately estimate the developmental age of insects (Asokan et al., 2012), which can be essential in cases involving bodies that have been exposed to environmental extremes or that have been buried for an extended period. However, databases for specific insects are still limited (Durango-Manrique et al., 2024) and require additional research and collaboration to enhance applicability. Additionally, the emerging field of forensic entomotoxicology has opened up new avenues for understanding how insects can be used to identify poisons, drugs, or other toxic substances present in the body at the time of death (Groth et al., 2024).

Despite these advancements, forensic entomology faces several limitations that can affect its reliability and application within criminal proceedings. One of the most significant challenges is the environmental variability that can influence insect activity (Silva et al., 2024), such as temperature, humidity, and geographic location. These factors can alter the rate of insect development (Maradi et al., 2024), making PMI estimations difficult in certain conditions. To account for these differences, researchers must develop region-specific models for insect behaviour. However, this requires extensive data collection, which can be time consuming and resource intensive. In addition to this, the nature in which a person has died, for example by burning, drowning, or hanging, and the characteristics of the body, such as age, size, and trauma, can significantly influence insect activity and the decomposition process (Bambaradeniya et al., 2023). The complex interactions between insects and decomposition presents numerous challenges for forensic entomologists, especially when accounting for climatic conditions in addition to bodily characteristics and nature of death (if known).

While significant progress has been made in enhancing the precision and scope of entomological applications, challenges related to environmental factors, insect behaviour, and contamination continue to limit its broader use. However, ongoing research, advancements in technologies, and interdisciplinary collaboration will aid in refining entomological methods (Kotzé & Martín-Vega, 2025), potentially overcoming many of these limitations and expanding the field’s utility in forensic science.

Chapter 2 – Literacy Summary

Pitter et al. (2020) conducted a field study in rural Germany to evaluate PMI estimations during advanced stages of decomposition. The study utilised pigs as a proxy for human decomposition, with some pigs being either partially covered, fully covered, or completely uncovered. The study focused on conditions where insect activity had significantly diminished, complicating their applicability to PMI estimations. Despite a reduced insect presence, only identifying 29 Dipteran species across three families (Calliphoridae, Sarcophagidae, and Muscidae), the research reinforces the use of species such as *Calliphora vicinia* and *Lucilia sericata* as forensically important for PMI estimations. Insects were collected through the use of aerial nets and manual collection techniques, with species identification being achieved through morphological keys. The study concluded that while entomological methods for PMI estimations remain useful, the accuracy of these are impacted by environmental factors, such as temperature and humidity, and the advancing stages of decomposition. The authors of this study recommended the integration of entomological data with other forensic methods for enhances applicability. This research highlights the potential of forensic entomology in challenging cases of advanced decay and also underlines its limitations, with an emphasis on a need for collaborative approaches.

The 2009 study by Wang et al. was conducted in Southern China, with the aims of investigating insect succession and development on pig carcasses, and their significance in estimation PMI. The research utilised uncovered pig carcasses, protected from scavengers with wired cages, in different environments and monitored insect colonisation over time. The study identified 6 insect orders (Diptera, Coleoptera, Hymenoptera, Orthoptera, Acari, and Dermaptera), with a total of 43 insect species (including 9 unidentified to species rank). Typical insect colonisation patterns were observed, with blowflies being the first to arrive. They noted that the specific insect succession and development stages of larvae could provide useful data for estimating PMI in South China, where the environmental conditions, including temperature and humidity, significantly influenced insect activity. By documenting these patterns, the study emphasised the importance of local insect datasets for forensic use. This research is valuable for PMI estimations in regions with similar climatic conditions and contributes to the understanding of entomological methods in different geographical locations. However, the study's result may have limited applicability in regions with different environmental factors.

Griffiths, Krosch, and Wright (2020) conducted a study in a dry tropical climate of Northern Australia to examine the variation in decomposition stages and carrion insect succession, and its impact on estimating PMI. The researchers placed pig carcasses in an open area and monitored the decomposition process and insect colonisation over time. They identified two insect orders (Diptera and Coleoptera), as well as three unidentified orders. In addition to this, no insects were identified to the genus or species level, with the family rank being the highest level of classification. Despite this, the study does highlight how environmental factors in dryer environments affects insect activity and the accuracy of PMI estimations. The authors did acknowledge that differences in local climate could limit the generalisability of the findings to other regions with varying conditions.

The 2024 study by Hamid et al. investigated the use of insect diversity in estimating PMI through examining the variety of insects found on decomposing bodies. The study was conducted in Pakistan, where uncovered rabbit carcasses (Oryctolagus cuniculus) were laid at surface level, protected from scavengers by a wire cage. Insects were collected at various decomposition stages using manual techniques as well as areal sweep nets. It is important to note that the insect identification method was not explicitly mentioned. This research only identified four Dipteran species, *Calliphora vicina*, *Calliphora vomitoria, Sarcophaga carnaria*, and *Musca domestica*. The research echoed that the diversity and succession of these insect species were critical factors in improving the accuracy of PMI estimations. The study also emphasised the importance of accurately identifying species and understanding their specific developmental stages. The authors suggested that insect diversity, when combined with other forensic techniques, could offer a more precise PMI estimation. However, the study acknowledged that environmental factors, such as temperature and humidity, could influence insect activity and affect the consistency of PMI predictions across different regions. This research underlined the need for a comprehensive approach, considering both insect diversity and environmental variables, to enhance forensic entomology's role in determining PMI.

Ahmad and Omar (2023) investigated the colonisation of *Pheidole megacephala* on small and medium-sized mammal carcasses and its implications for forensic entomology. The study was conducted in Malaysia, where carcasses of rats and monkeys were placed in an outdoor environment to observe the colonisation patterns of insect species involved with the decomposition process. The study identified four species belonging to Hymenoptera (including two unidentified to species specific rank) and 18 Dipteran insects, 13 of which were not identified to species level. The authors emphasised that ants, such as *P. megacephala*, should be considered in forensic investigations, as their presence and behaviour could provide useful insights into estimating PMI, especially in regions where ants are prominent decomposers. The study also highlighted the role of local environmental factors, such as temperature and humidity, in influencing insect activity and the accuracy of PMI estimations for uncovered, surface remains. This research contributes to the growing understanding of the role of ants in forensic entomology, particularly in tropical regions.

Dawson et al. (2022) investigated how the quality of carrion affects insect colonization patterns on vertebrate remains. The study, conducted in Southeastern Australia, used pigs and humans as the primary vertebrate carcasses. These carcasses were placed in outdoor environments to observe how their quality (e.g., size, condition, and stage of decomposition) influenced insect species diversity and abundance. The researchers found that higher-quality carrion (fresher, larger, or less decomposed carcasses) attracted a greater number of insect species, particularly blowflies (Calliphoridae) and beetles belonging to Dermestidae, while lower-quality carrion (more decomposed or smaller carcasses) saw fewer insect species and lower insect abundance. A total of three insect orders were observed (Diptera, Coleoptera, and Hymenoptera), with a total of 18 insects across the orders. Insects were collected through manual sampling techniques and the use of sweep nets and pitfall traps. Identification was achieved through the use of taxonomic keys. This study highlighted the significant role carrion resource quality plays in influencing insect colonisation and succession, which is critical when estimating the post-mortem interval (PMI). The authors additionally emphasised that understanding carrion quality variation can improve the accuracy of PMI estimations, especially in cases where insect activity is sparse or inconsistent.

Matuszewski et al. (2010) investigated insect succession and carrion decomposition in Western Poland, focusing on the composition and residency patterns of carrion insects in forests. The study utilised pig carcasses placed in various forested environments to observe insect colonisation patterns across different stages of decomposition. The research identified numerous insect species that were attracted to the carcasses, including blowflies (Calliphoridae), flesh flies (Sarcophagidae), and Silphidae beetles, which are commonly associated with different decomposition stages. The researchers found that blowflies were typically the first to colonise the carcasses, followed by flesh flies and beetles, with each species arriving at different stages of decay, consistent with findings echoes by numerous other studies. Insects were collected with the use of sweep nets, pitfall traps and manual collection techniques. Insect identification was achieved through the use of morphological keys. The study highlighted that the residency patterns of these insects varied based on environmental factors such as temperature and humidity, which influenced insect development and the timing of colonisation. This work emphasised the importance of understanding insect succession patterns in specific environments, particularly forests, for PMI estimations. The paper also reiterated the necessity for localised research on insect activity in different ecosystems to improve the accuracy of PMI estimations in different regions.

Voss, S.C., Cook, D.F., and Dadour, I. R. (2011) studied the effects of clothing on decomposition and insect succession on vertebrate carcasses in Western Australia. The study used pig carcasses, both clothed and unclothed, to observe and compare the patterns of insect colonisation and decomposition in different environmental conditions. The carcasses were placed in an outdoor environment, and the researchers tracked the insect species that arrived at various decomposition stages. A total of 20 insect species were observed within this study across the orders of Diptera and Coleoptera, three of which were not identified to species level. The study found significant differences in decomposition rates between clothed and unclothed carcasses, with clothing acting as a barrier to insect access, slowing the colonisation process and altering the succession patterns. The research highlighted that the presence of clothing can significantly impact PMI estimation, as the insect colonisation timeline and decomposition process are delayed when the body is covered. This study emphasises the importance of considering environmental and external factors such as clothing when using forensic entomology to estimate PMI.

Eberhardt, T.L., and Elliot, D.A. (2008) conducted a preliminary investigation into insect colonisation and succession on remains in New Zealand. The study used pig carcasses that were both clothed (T-shirts and pants) and unclothed to simulate a homicide scenario and observed the effects of clothing on decomposition and insect colonisation patterns. The researchers identified Coleopteran, Dipteran, and Hymenopteran species, although the identification method was not specified in this study. The study aimed to establish baseline data on insect activity in New Zealand for PMI estimations and found that clothing slowed the colonisation process, delaying insect activity, which can complicate PMI estimations. However, the study also highlighted that climatic conditions in New Zealand influenced the rate of decomposition and insect development. Although the research provided valuable insights into insect colonisation patterns within New Zealand, it acknowledged the need for further studies to better understand regional differences and develop more accurate PMI estimation models specific to New Zealand’s environmental conditions.

Voss, S.C., Spafford, H., and Dadour, I.R. (2009) investigated annual and seasonal patterns of insect succession on decomposing remains in Western Australia. The study used guinea pig carcasses to simulate human remains in across two outdoor sites. The researchers focused on how different seasons and environmental conditions influenced insect colonisation and subsequent decomposition rates. Similarly to the studies of Eberhardt, T.L., and Elliot, D.A. (2008), and Dawson et al. (2022), Diptera, Coleoptera, and Hymenoptera were the only insect orders recorded in this study. A total of 26 insects were observed, with 7 of these not being identified to species rank. Identification was completed through the use of taxonomic keys, as well as the use of external specialists for confirmation. This study revealed that seasonal variation had a significant impact on insect species composition and succession, with temperature and rainfall being the key environmental factors influencing the rate of decomposition and insect activity. The research also highlighted how the location of the carcasses affected insect communities, as the two study sites displayed different climatic conditions. The study concluded that seasonal and geographic variations must be considered when using insects for PMI estimation, as these factors can significantly alter the patterns of insect succession.

Ortloff, Peña, and Riquelme (2012) conducted a preliminary study in central Chile, examining the succession pattern of necrophagous insects on pig carcasses for forensic applications. The study aimed to identify the insect species involved in decomposition and their larval stages to assist with PMI estimations. Pigs were laid at surface level, concealed by only a metal cage to protect from scavengers. A total of 12 insects, belonging to Diptera and Coleoptera, were observed in this study, with only one insect not being identified to species-specific level. Identification was completed through the use of morphological keys. The researchers noted that environmental factors like temperature and humidity significantly influenced insect colonization and species succession. By studying the larval development of the insects, the authors echoed that *Lucilia sericata* larvae could be a reliable PMI indicator during early decomposition stages, though they emphasised the importance of considering seasonal variations and accurate species identification for improved PMI accuracy. The findings suggest that geographical and environmental conditions should be factored into forensic entomological practices to refine future PMI estimations.

Skopyk and LeBlanc (2024) conducted a study in Southern Ontario, Canada, to examine the insect colonisation, succession, and decomposition of domestic pig carcasses for forensic applications. The study aimed to identify the specific insect species involved in the decomposition process and assess their potential for estimations of PMI. Domestic pig carcasses were placed at two different locations, and insect samples were collected at various stages of decomposition. Sampling was completed through the use of pitfall traps and manual sampling techniques. The researchers identified the collected insects through morphological keys, as well as the use of external specialists, ensuring accurate species identification for their analysis. Although a total of 39 individual insect species were recorded, only six of these (all belonging to Diptera) were identified to species level. This study did also record the presence of not only Diptera, Coleoptera, and Hymenopters, but also Lepidoptera, Hemiptera, Orthoptera, Odonata, as well as one other unidentified insect order. The study also highlighted how temperature and seasonal conditions influenced the colonisation patterns of insects, with significant variation in insect activity across different months. By analysing the development of insect larvae and the species succession, the authors emphasised the importance of accurate insect identification and the consideration of local environmental factors when using entomological evidence for PMI estimation. The findings reinforce that pig carcasses provide a useful model for forensic entomology, particularly in Canadian climates where temperature fluctuations play a key role in insect activity and decomposition processes.

Bonacci et al. (2021) conducted a study in southern Italy to investigate arthropods associated with different decay stages of buried pig carcasses. The study involved burying pig carcasses and monitoring the decomposition process over several weeks, using a wire cage to protect the carcasses from scavenging. They collected insect samples at regular intervals using manual sampling techniques and identified these specimens with the use of taxonomic keys. A total of 85 different insects were recorded in this investigation, 42 Diptera, 30 Coleoptera, four Araneae, one Dermaptera, five Hymenoptera, two Hemiptera, and one Geophilomorpha. The results provided insights into the colonisation patterns of different arthropods, and how these patterns could be used to estimate PMI in forensic cases, particularly in scenarios where the remains were buried.

Zeariya and Kabadaia (2019) conducted a study on the seasonality of insect succession and the decomposition of dog carcasses in different habitats in Egypt, with the aim of understanding how environmental factors influence the decomposition process and insect colonisation. The researchers placed dog carcasses in both urban and rural areas, monitoring the decomposition over time. Insect samples were collected through the use of nets and direct collection methods at various intervals throughout the decomposition process. The insects were identified using morphological techniques as well as through external specialists. A total of 20 insects were identified within this study, belonging to Coleoptera, Diptera, and Hymenoptera. The study revealed significant seasonal variation in insect succession, with different insect species colonising the carcasses at different stages of decomposition, depending on environmental factors such as temperature, humidity, and habitat type. This research provides valuable insights into how seasonality and habitat influence the decomposition process and could contribute to forensic entomology, especially in determining the PMI in regions with varying environmental conditions.

Al-Mekhlafi et al. (2024) conducted a study to investigate the decomposition of buried rabbit carcasses and the pattern of insect colonisation and succession. Rabbit carcasses were buried in shallow graves, and insect samples were directly collected from the carcasses over the course of the decomposition process through manual collection. The researchers identified insect species based on morphological keys as well as through external specialists. Across the two reordered orders, Diptera and Coleoptera, just 15 species were identified, with all but one being identified to the species level. The study highlights the role of environmental factors such as temperature and humidity, which influenced the timing and species involved in the decomposition process. The research contributes to the understanding of insect succession on buried carcasses, with potential applications in forensic entomology, particularly in estimating PMI for cases where bodies are buried.

Shaalan et al. (2016) conducted a preliminary study on insect succession in the Eastern Region of Saudi Arabia. The study aimed to explore the patterns of insect colonisation on uncovered rabbit carcasses in a hot desert climate. The researchers placed the carcasses in open fields for observation, using a wire mesh cage to protect from scavengers, and collected insect samples using pitfall traps, sweep nets, and direct manual collection of larvae and adult insects. The insects were identified based on morphological features using keys. This study recorded 13 insects across four orders: Diptera (n=8), Coleoptera (n=3), Hymenoptera (n=1), and Araneae (n=1). In total, the study provided insights into the seasonal variation of insect species and their association with the different stages of decomposition. By studying the patterns of insect colonisation and succession, this study contributes to understanding how insect activity can help estimate PMI in arid regions, especially when climatic conditions like temperature fluctuations are a critical factor in insect behaviour. However, the study's generalisability to other regions might be limited, given the specific environmental conditions of the location, and further research in different areas would be valuable.

Taleb et al. (2022) investigated the impact of plastic wrapping on carcass decomposition and arthropod colonisation in northern Africa during the spring season. The study was conducted in an outdoor setting, using rabbit carcasses wrapped in plastic to simulate homicide scenarios and assess the effects of plastic covering on insect colonisation patterns and subsequent decomposition rates. The researchers observed and recorded the decomposition stages of the carcasses, along with the presence of insects and arthropods, including Diptera, Coleoptera, and Hymenoptera. In addition to this the orders of Araneae, Acari, Isopoda, and Hemiptera were identified. Insect samples were collected through direct manual collection and trapping, and species identification was carried out using both keys and DNA barcoding techniques. The study found that plastic wrapping significantly delayed decomposition and altered insect colonisation patterns, particularly influencing the types and abundance of insects and arthropods that colonised the carcasses. Furthermore, DNA barcoding provided a more accurate and reliable method for species identification, especially in cases where morphological identification might have been challenging. The findings highlighted the potential challenges that plastic-wrapped bodies may pose in forensic investigations, as the reduced insect activity could complicate PMI estimations. This research offers valuable insights into the forensic implications of plastic wrapping in crime scene investigations. However, as the study is specific to the environmental conditions of northern Africa, further research in different regions may be needed to understand the broader applicability of these results.

Zanetti, Visciarelli, and Centeno (2015) conducted a study to investigate the trophic roles of scavenger beetles in relation to decomposition stages and seasons, using pig carrion as their model. The study was carried out in Argentina, where the researchers aimed to better understand the role of scavenger beetles in the decomposition process across different stages of decay. Sampling was conducted using both manual collection techniques and pitfall traps to capture the insect fauna. Throughout the study, the researchers observed the colonisation and succession patterns of beetles, noting how different beetle species were associated with specific stages of decomposition. Although the study did not provide specific details on the methods used for insect identification, 52 Coleopteran species were recorded. Results from this study showed that scavenger beetles are key players in the decomposition process, with different species linked to distinct stages of decay. Additionally, seasonal variations in beetle colonisation patterns were observed, highlighting the influence of environmental factors such as temperature and humidity on beetle abundance and diversity. Although insect identification methods were not explicitly stated, the findings of this study offer valuable insights for forensic entomology, particularly regarding the role of scavenger beetles in the estimation of PMI.

Sharif and Qamar (2021) conducted a study on insect faunal succession on a buried goat carcass in Aligarh, India, with forensic entomology implications. The study aimed to observe insect colonisation patterns and their role in the decomposition of the carcass to aid in PMI estimations. Insect samples were collected using manual techniques, including sieving and sweep nets, to capture the insects present on the carcass at different decomposition stages. A total of 10 insects across four orders were observed: five Diptera, three Coleoptera, one Hymenoptera, and one Hemiptera. All insects except the Hymenoptera and Hemiptera species were identified to species level. The study demonstrated predictable patterns of insect succession on the goat carcass and concluded that these patterns could be used to estimate PMI in regions with similar climatic conditions. The research also noted the influence of environmental factors, such as temperature and humidity, on the insect colonisation and decomposition process. Although the study did not go into detail about the precise species identification process, the use of external morphological features to identify the collected specimens was key in establishing the insect succession patterns across the decomposition stages. This study contributes valuable information for forensic entomology in similar ecological and geographical contexts, especially in relation to cases where remains are buried.

In the study by Maisonhaute and Forbes (2022), the researchers explored decomposition and insect succession on human cadavers in Quebec, Canada, specifically within a humid, continental climate. The study focused on the identification of the insect species associated with decomposition at different stages of the process. The researchers used pitfall traps and nets to collect insect samples. Although the identification of these samples was carried out using morphological keys, 38 of the total 57 insects failed to be identified to the species level. In addition to this, 16 separate insect orders were recorded, however three of these are different unidentified orders. Of the 13 identified, Isopoda, Acari, Opiliones, Thysanura, Psocoptera, Lepidoptera, and Trichoptera had no identification passed order. This study contributes to a deeper understanding of insect succession within a humid, continental climate and emphasises the importance of identifying a diverse range of insects to more accurately estimate the PMI.

Chapter 3 – Research Aims and Study Design

3.1 Research Aims

This research aims to critically evaluate forensic entomology literature to identify and highlight weaknesses and inconsistencies in the current methods and data. By comparing multiple studies, this research seeks to propose solutions that address gaps in the current knowledge, ultimately enhancing the reliability and applicability of forensic entomological evidence in legal contexts.

While PMI estimations are important in criminal investigations, especially when insect evidence is involved, their reliability is often compromised by a range of practical, environmental and methodological challenges. The aspects of interest within the studies collected were the type of cadaver used, the location and season in which studies were conducted, how specimens were collected, and what insects were identified. In addition to this, key missing information, such as cadaver weight or sample collection method, was also highlighted. Overcoming these obstacles and filling missing information requires ongoing research and better standardisation of procedures, allowing for consistency in its application.

3.2 Study Design

Research papers that specifically focused on observing necrophages insects during the process of decomposition were compared in this study, all of which are detailed in Chapter 2 of this study. Papers that didn't specifically conduct research into rural, buried or surface remains were not utilised in this comparison as it was not deemed relevant to this research and would introduce too many variables.

20 papers ranging from the years 2008 to 2025 were collected and compared on a variety of factors. Papers were kept to this time frame as it ensures that the current methodologies and standards are being reflected, making the comparison more accurate and aligned to current practise within the field. The inclusion of papers that failed to detail important aspects of research, such as identification method, was for the purpose of demonstrating the frequency of missing key information.

The literature used in this study was found using Google Scholar with the following key words and phrases: forensic entomology, insect colonisation and PMI estimations, carrion feeding insects and decomposition, the use of insects for PMI estimations, and the effects of temperature on insect colonisation. These key words and phrases evolved over the course of this research to help discover relevant literature to incorporate in this study.

Papers used in this study were compiled into an excel spreadsheet and broken down into the following components: cadaver type and weight, covered or uncovered cadaver, surface or buried remains, geographic location and if climactic conditions were observed, time of year and season, insect taxa (from order to species), insect collection method, and identification method. It is important to note that all manual sampling methods (e.g. use of tweezers, brushes, and forceps) have been grouped together. Similarly, any covering mentioned falls into the “covered” category, however this does not include wire cages to protect from scavengers. Furthermore, although Acari is classified as a subclass of species, the choice to include it with the other species orders was made for comparative and discussion purposes.

Chapter 4: Results

This review critically examines recent forensic entomology studies, drawing comparisons across various aspects within research to identify gaps in our current understanding. This review seeks to explore the potential reasons behind these gaps, proposes strategies for addressing them, and highlights how expanding our understanding of forensic entomology could contribute to the advancement of this emerging field. This study emphasises the importance of ongoing research to expand the scope and depth of forensic entomology, ultimately strengthening its application in criminal justice and forensic science.

It is important to clarify that the total number of variables was counted across categories. For instance, if a study included both monkeys and rats, they would each be categorised separately – monkeys as mammals and rats as rodents. This approach was consistent across all categories in this study. Therefore, the results reflect the frequency of appearance in literature, rather than the number of individual studies.

4.1 Cadaver

Animal cadavers used in the collected literature were categorised into mammals and rodents. The mammal category includes pigs, monkeys, dogs and goats, while the rodent category includes rats, rabbits and guinea pigs. In addition to animal models of decomposition, human bodies were also used within some studies, detailed in *Figure 1*.

The total percentage of cadavers used in the compiled studies that fall into the mammal category is 63.6% (n=14). Within this category, 78.6% were pig (n=11), with the remaining 21.3% being equally comprised of monkey (n=1), dog (n=1), and goat (n=1) cadavers. Amongst the total literature used in this study, 50% (n=11) of the total cadaver used were pig. The total percentage of cadavers used in the collected research that fall into the rodent category is 27.3% (n=6). Within this, 66.7% of rodents used in within research were rabbits (n=4), with the following 33.3% being either rat (n=1) or guinea pig (n=1) cadavers. Human bodies made up the smallest portion of cadavers, with just 9.1% (n=2).

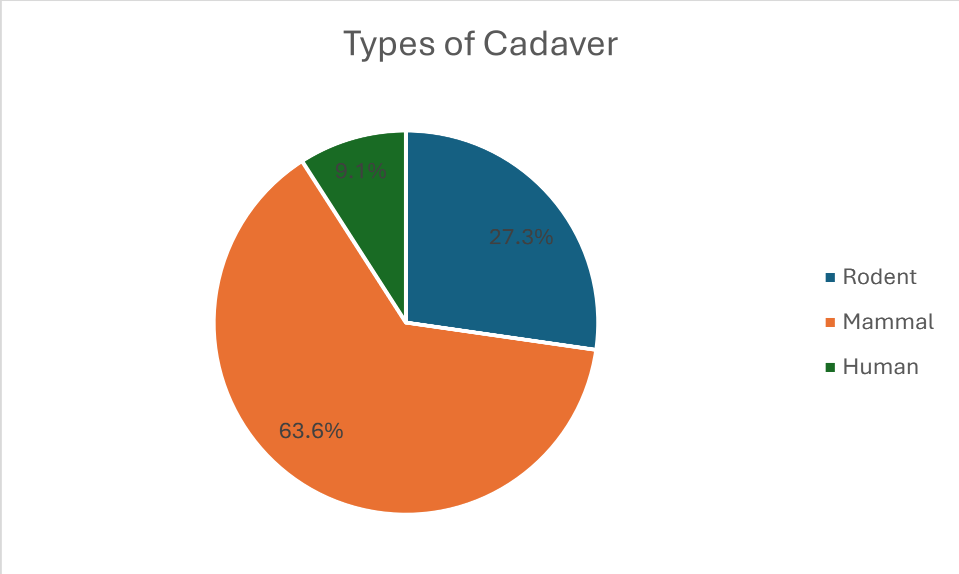

Figure 1 – Pie chart detailing the percentage of rodent, mammal, and human cadavers.

4.2 Cadaver Weight

The weight of the cadavers used in the studies ranged from 0.423kg-120kg, with 14.3% of cadavers having no specified weight (n=3). Of the cadavers whose weight was specified, the recorded weight of each cadaver was categorised into seven classifications, shown in *Figure 2*. The majority of cadavers weighed between 1-10kg, with 33.3%. The second largest weight class was 41-50kg, with 16.7% of cadavers falling into this category. The smallest category, making up 5.6% of all cadavers, is the 51kg+ classification. The remaining 44.4% of cadavers equally belong to 11-20kg, 21-30kg, 31-40kg, and the below 1kg categories, with each having 11.1%. Additionally,

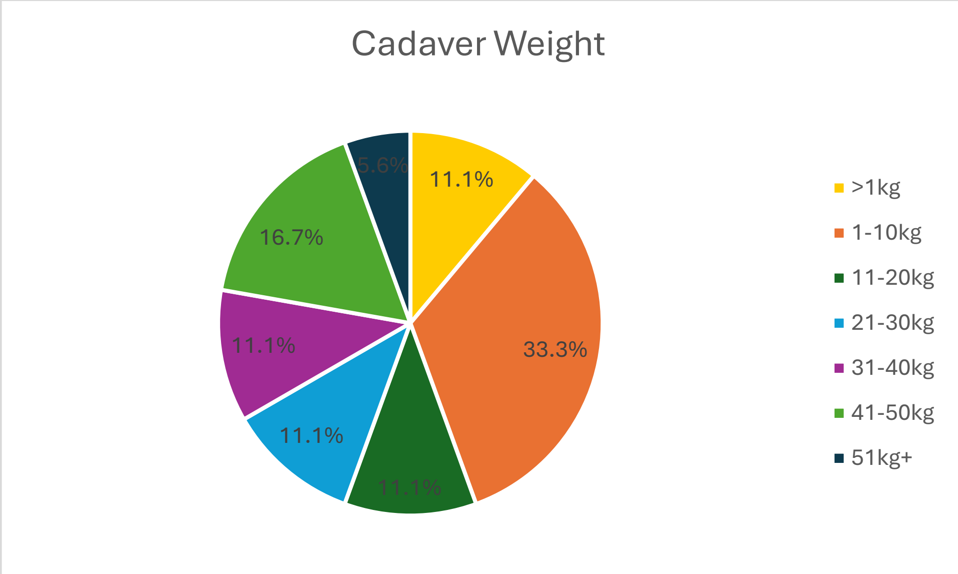

Figure 2 -Pie chart displaying the seven weight class classifications of cadavers, alongside the percentage of cadavers that met the weight class ranges.

4.3 Buried or Surface Remains

Of the papers collected in this study, 85% of them conducted research into surface remains (n=17), with the remaining 15% observing the effects on buried remains (n=3), detailed in *Figure 3*. No papers in this study detailed comparative research between these two variables.

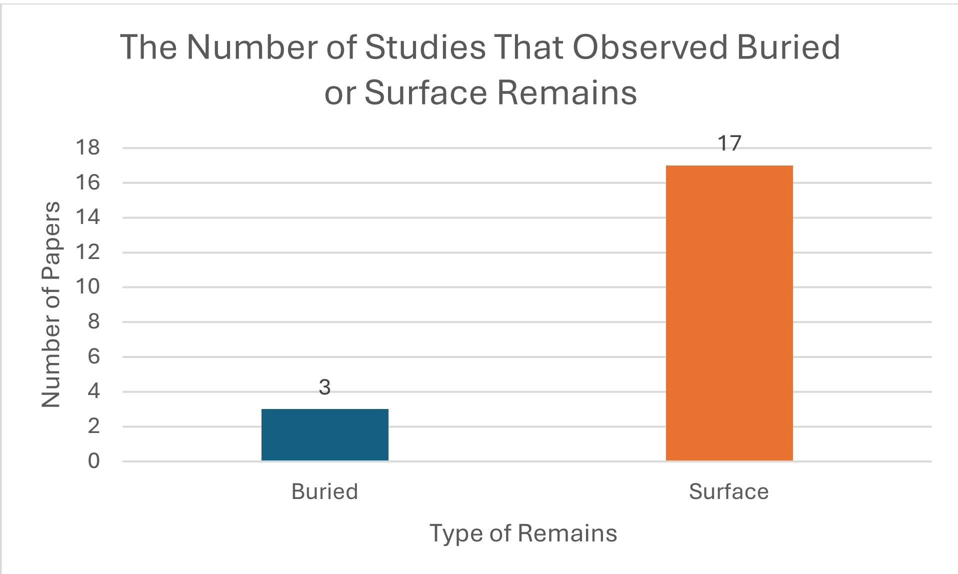

Figure 3 – Bar graph displaying the number of studies that investigated insect colonisation on buried or surface remains.

4.4 Covered or Uncovered Remains

When referring to a cadaver being covered, this includes being fully covered in plastic wrap or being partially covered in clothes or by twigs and foliage. Uncovered refers to a completely bare cadaver. Additionally, cages used to protect cadavers from scavengers were not included in the covered classification, as this does not directly impact the colonisation of insects but rather prevents scavengers from interfering in the study.

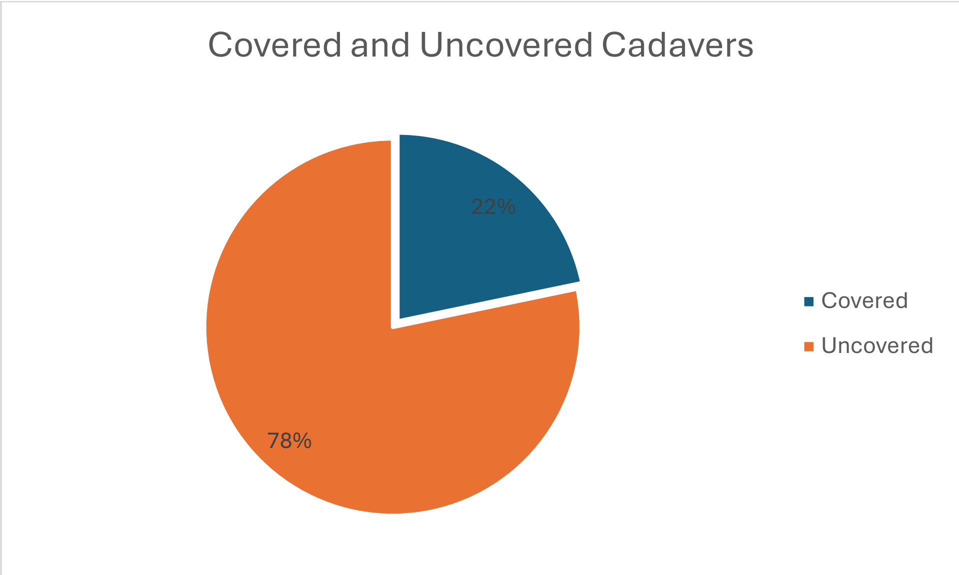

Figure 4 – Pie chart displaying the percentage of covered and uncovered cadavers.

Within the literature, 22% of cadavers were covered (n=5), and 78% were uncovered (n=18). Of the covered cadavers, 40% were covered with clothing (n=2), 40% were covered with branches and twigs (n=2), and 20% were completely covered in plastic wrap (n=1). In addition, 90% of studies utilised wire cages to protect cadavers from scavengers (n=18).

4.5 Geographical Location

The papers included in this research were spread across six regions: Europe (15%), Oceania (25%), Asia (30%), South America (10%), North America (10%), and Africa (10%), shown in *Figure 5*.

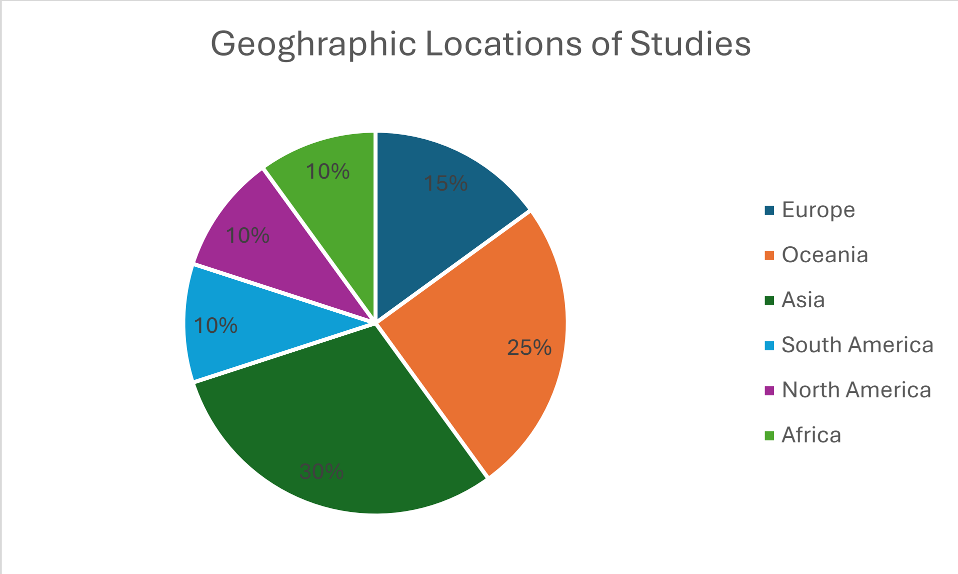

Figure 5 - Pie chart showing the percentage of research that came out of Europe, Oceania, Asia, South America, North America, and Africa.

When further specified, these papers can be classified into the following regions: Central Europe, Southeast Asia, South Asia, Oceania, South America, North America, Southern Europe, Northeast Africa, West Asia, and North Africa, refer to *Figure 6*.

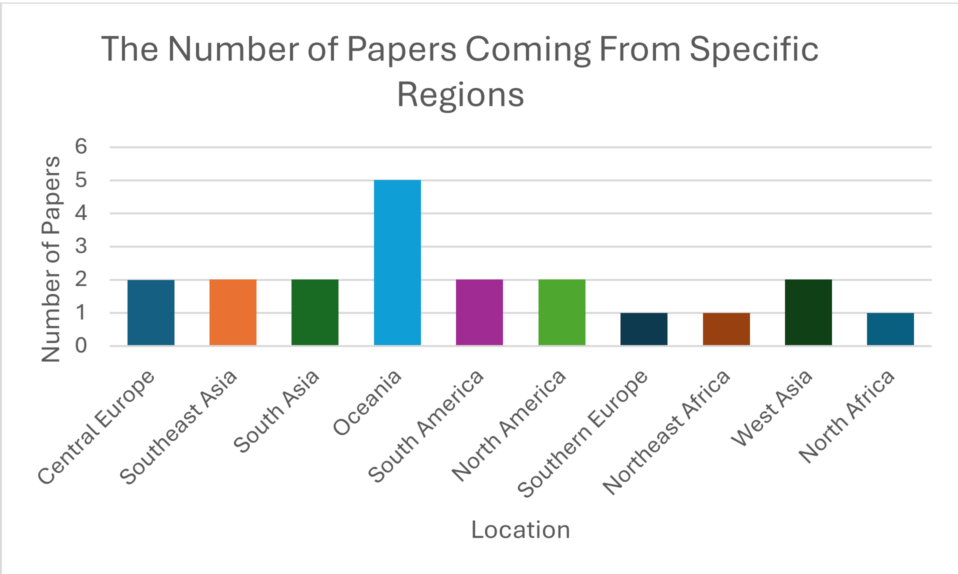

Figure 6 -Bar graph detailing the number of papers that came from central Europe, southeast Asia, south Asia, Oceania, south America, north America, northeast Africa, west Africa, and north Africa.

There are 18 specific geographic locations that studies came from: northern Germany, southern China, northeast Australia, Pakistan, Malaysia, southeastern Australia, western Poland, western Australia, New Zealand, central Chile, central Canada, southern Italy, Egypt, Saudi Arabia, northern Algeria, Argentina, northern India, and eastern Canada. Each location is associated with one research paper except western Australia and Saudia Arabia, both of which had two papers from these locations.

4.6 Climate

Amongst the literature, 90% confirmed that they observed weather conditions within their research (n=18). Of these 18 papers, 17 papers observed the effects of more than one climatic variable, shown in *Figure 7*. The weather variables detailed in these papers were temperature, rainfall, and humidity. The most commonly observed weather condition in these studies was temperature (45%), followed by humidity (35%). The least commonly observed weather condition was rainfall with 20%.

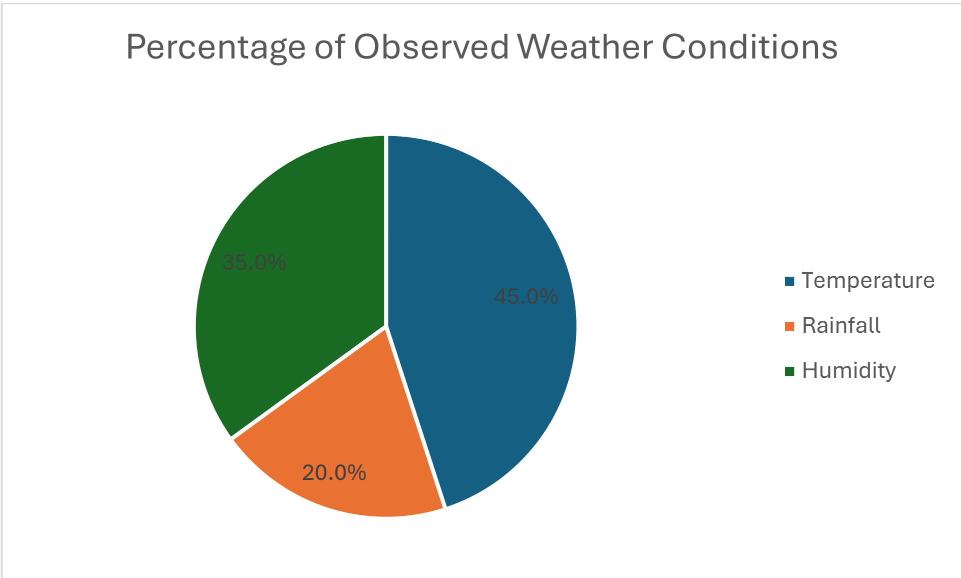

Figure 7 – Pie chart showing the percentage of observed weather conditions across literature.

4.6.1 Seasons

Due to the nature of the research in the compiled literature, studies typically took place across multiple seasons. The majority of studies did not conduct experiments across all four seasons (65%, n=13), but were more likely to observe insect succession across two or more seasons instead. The majority of studies took place during the summer months (29%), followed by autumn (27%), spring (24%), and winter (20%).

4.7 Insects Present

In total, 623 insects were reported across the 20 papers featured in this study, with 85% of papers (n=17) recording observing more than one type of insect during their research.

Of the 15% of papers that reported on just one type of insect (n=3), the insects featured were either Diptera (n=2) or Coleoptera (n=1).

4.7.1 Order

In total, 17 different insect taxonomic orders were identified and categorised, alongside a category for unidentified insect orders. There were 623 individual insect species belonging to these orders, with the top 5 being Diptera (47.4%), Coleoptera (38.4%), Hymenoptera (7.5%), Hemiptera (1.3%), and Araneae (1.3%). The remaining 4.1% of insects belonged to the unidentified category, Acari, Orthoptera, Dermaptera, Lepidoptera, Isopoda, Odonata, Geophilomopha, Opiliones, Neauroptera, Trichoptera, Psocoptera, and Thysanura, detailed in *Figure 8*.

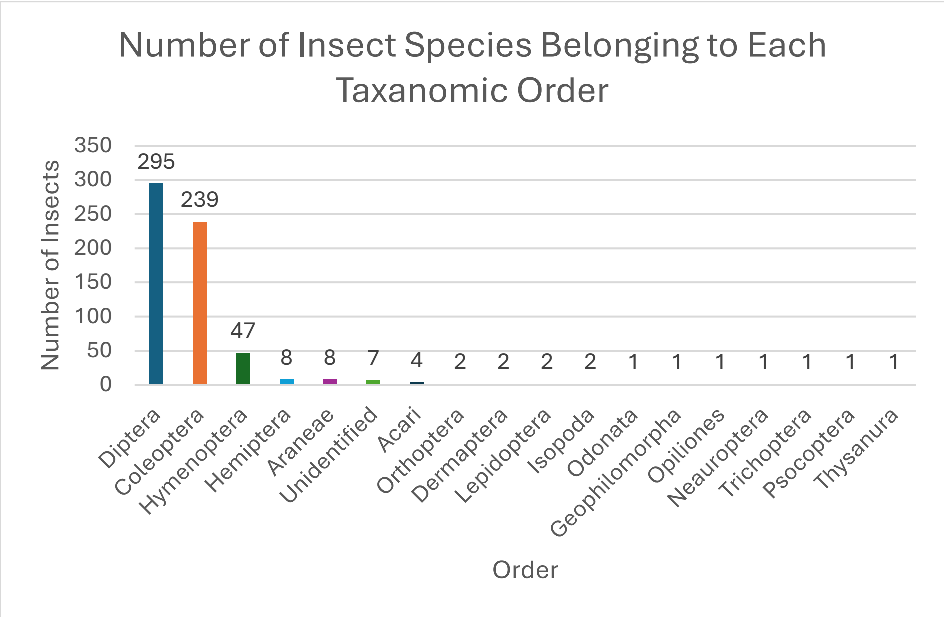

Figure 8 – Bar graph showing the number of insects belonging to each category of taxonomic order, including the unidentified category.

4.7.2 Family

Across literature, there were 93 insect families, including the unidentified classification. In total, 57% of these families appeared just once within literature, with these familied being comprised of 8.5% of the total reported insects. Unidentified insect families made up 3.2% of the total reported insects. There was a total of 81 Diptera families, 27

Coleoptera, 9 Hymenoptera, 7 Hemiptera, 7 Araneae, 2 Acari, 1 Oniscidae, 1 Forficulidae, 1 Gryllidae, and 1 Hemerobiidae. Insects that failed to be identified to the family rank featured a total of 20 times across literature.

The most common families are shown in *Figure 9,* with Diptera families making up 40%, Coleoptera families making up 50%, and Hymenoptera families making 10%. The Diptera families were Calliphoridae, Muscidae, Sarcophagidae, and Piophilidae. The Coleoptera families were Histeridae, Staphylinidae, Silphidae, Scarabaeidae, and Cleridae. The only Hymenoptera family to appear in the top ten insect families was Formicidae.

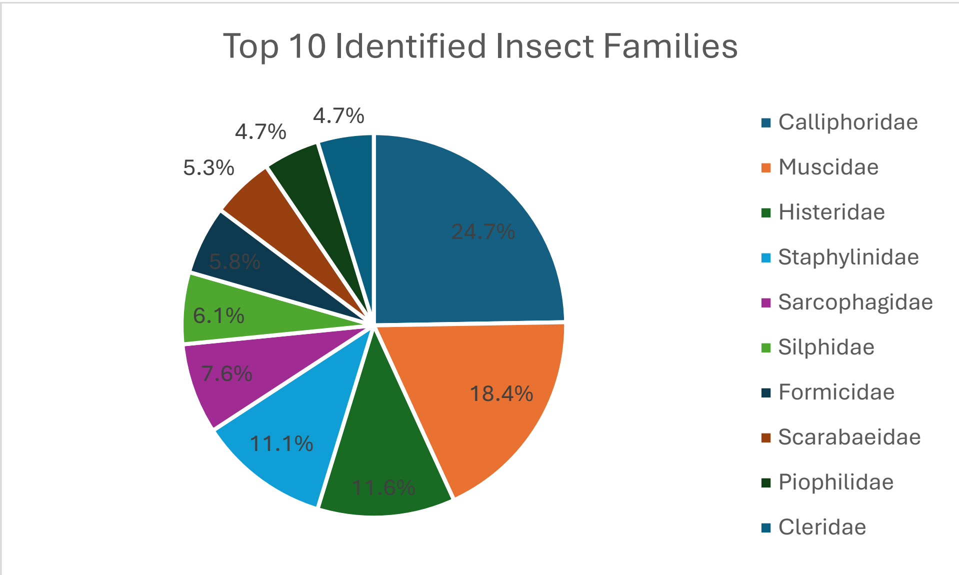

Figure 9 -Pie chart showing the top 10 identified insect families across all insect orders.

The top 10 most common Diptera families, were Calliphoridae, Muscidae, Sarcophagidae, Piophilidae, Phoridae, Spesidae, Fanniidae, Anthomyiidae, Sphaeroceridae, and Drosphilidae. Of the total insects, these families made up 41.7%, with 15.1%, 11.2%, 4.7%, 2.9%, 1.9%, 1.6%, 1.6%, 1.1%, 0.8% and 0.8% respectively.

The top 10 most common Coleoptera families were Histeridae, Staphylinidae, Silphidae, Scarabaeidae, Cleridae, Dermestidae, Carabidae, Tenebrionidae, Trogidae, and Nitidulidae. These 10 families made up 34% of all insect families, with 7.1%, 6.7%, 3.7%, 3.2%, 2.9%, 2.6%, 2.4%, 2.4%, 1.6%, and 1.4% respectively.

Out of 93 families, 9 of these were Hymenopteran families (9.7%). A total of 47 insects belong to Hymenoptera, split between Formicidae, Vespidae, Pteromalidae, Braconidae, Encytidae, Diapriidae, Apidae, Aphidiidae, and Ichneumonidae. These families make up a total of 7.7% of insects featured across literature, with 3.5%, 1.5%, 0.8%, 0.6%, 0.5%, 0.2%, 0.2%, 0.2%, and 0.2% respectively.

All other insect families featured make up 21.5% of families (n=20). Within these families, just 3.5% of insects are represented. All except Foficulidae and Delphacidae appeared just once across literature, with Foficulidae and Delphacidae each occurring twice. All identified families belonging to Dermeptera, Hemiptera, Araneae, Arcari, Isopoda, Neauroptera, and Orthoptera are represented in this section.

4.7.3 Genus

At genus level, the percentage of unidentified insect species increased from 3.2% (n=20) at Family rank to 22.8% (n=142). A total of 172 different insect genera were observed across research, this includes the unidentified category. All of the most common genera are comprised of either Diptera (n=6) or Coleoptera (n=4). Of the identified insect genera, the top 10 most frequently occurring were Chrysomya, Calliphora, Lucilia, Hydrotaea, Sarcophaga, Musca, Necrobia, Creophilus, Dermestes, and Saprinus, shown in *Figure 10*. These top ten genus make up 30.5% of all insect species.

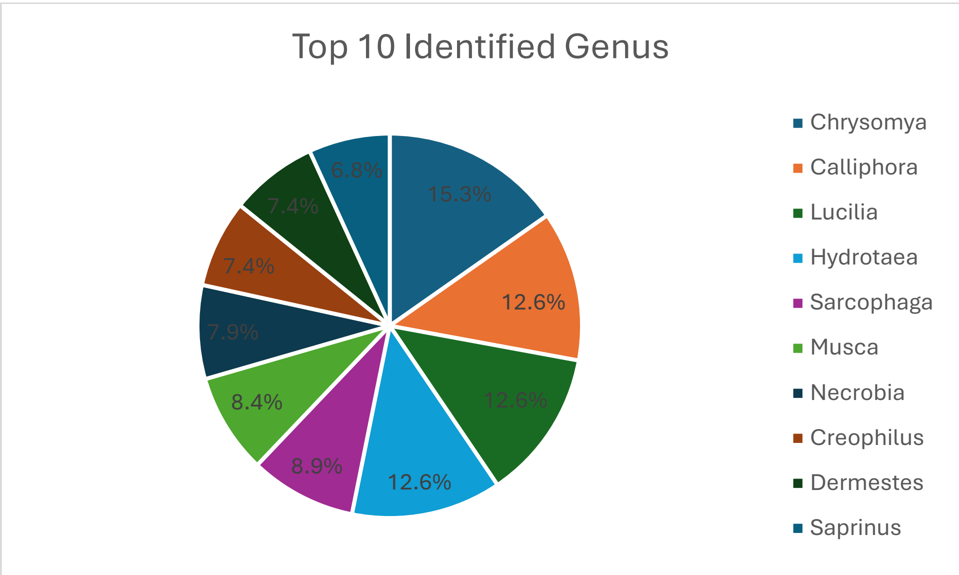

Figure 10 -Pie chart showing the top 10 identified insect genera.

The top 10 Diptera genera identified in this study were Chrysomya, Calliphora, Lucilia, Hydrotaea, Sarcophaga, Musca, Fannia, Muscina, Phormia, and Piophilia. These combined genera make up 26% of total insects.

The top 10 identified Coleoptera genera were Necrobia, Creophilus, Dermestes, Saprinus, Euspilotus, Onthophagu, Margarinotus, Nicrophorus, Thanatophilus, and Philonthus. These combined genera make up for 15.9% of total insects.

Just 9 Hymenoptera genera featured more than once across literature. These were Nasonia, Vespa, Vespula, Pheidole, Camponotus, Crematogast, Tachinaepha, Messor, and Cataglyphis. These combined genera make up for 1.5% of all identified insects.

A total of 105 insect genera appeared just once across literature, making up 16.9% of all recorded insets. Amongst these, all insects belonging to Hemiptera, Isopoda, Dermaptera, and Araneae were featured. Additionally, there were 14 Hymenoptera genus, 58 Coleoptera genus, and 27 Diptera genus that occurred just once within all papers.

4.7.4 Species

A total of 623 insects were accounted for across the papers used in this study. Of the total number of insects, 37.9% (n=236) were unidentified to species rank.

The most common identified species were *Lucilia sericata, Musca domestica, Calliphora vicina, Chrysomya megacephala, Necrobia rufipes, Chrysomya rufifacies, Creophilus maxillosus, Calliphora vomitoria, Phorma regina, Chrysomya albiceps, Dermestes maculatus,* and *Piophila casei,* shown in *Figure 11*.

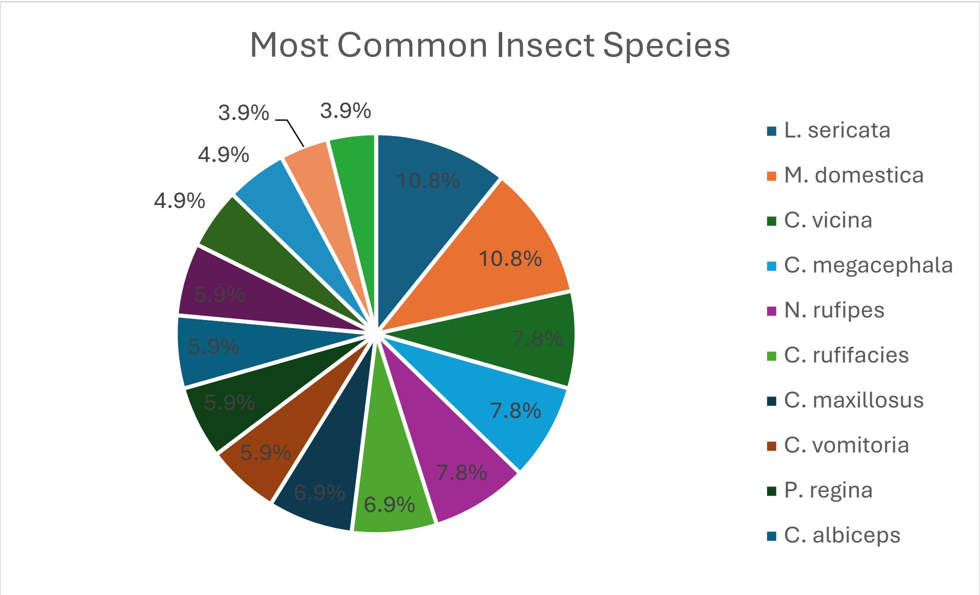

Figure 11 – Pie chart showing the top 10 most common insect species.

4.7.4.1 Diptera

209 of the total 387 identified insects belonged to Diptera (54%), with 110 distinct Diptera species identified.

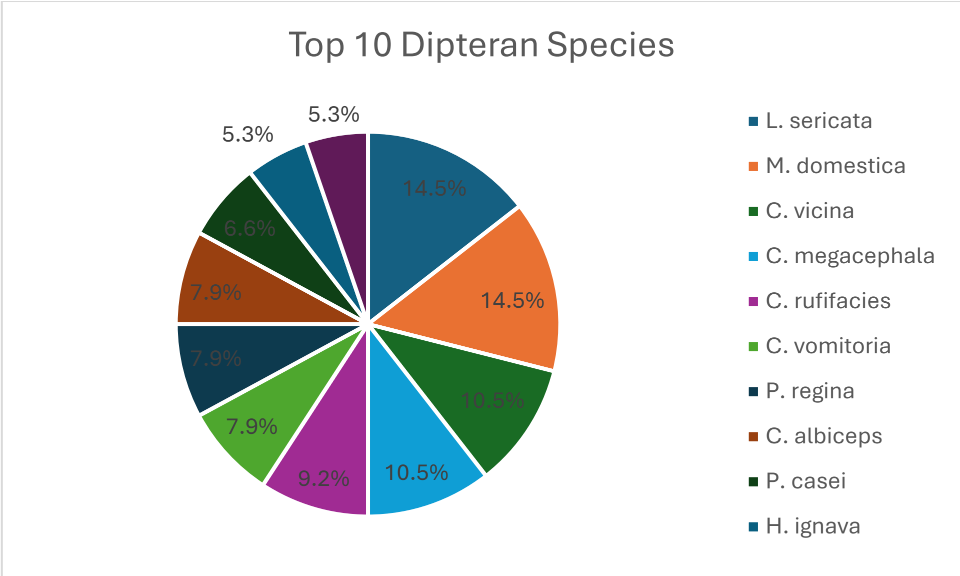

Figure 12 – Pie chart displaying the top 10 identified Dipteran species.

4.7.4.2 Coleoptera

Of the total insect species, 151 were Coleoptera, with 110 distinct Coleoptera species identified.

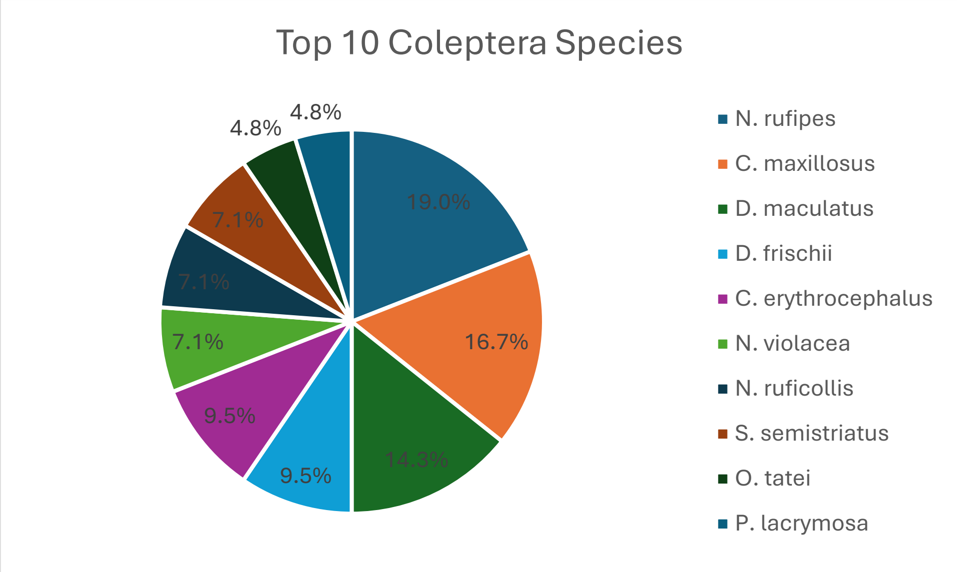

Figure 13 – Pie chart showing the top 10 identified Coleoptera species.

4.7.4.3 Hymenoptera

A total of 25 (6.5%) insects belonging to Hymenoptera were identified across literature. These 25 insects belonged to 18 different species, most commonly *Nasonia vitripennis, Pheidole megacephala, Vespula germanica*, and *Tachinaephagus zealamdicus*. The remaining 66% is made up by 14 other insect species, each appearing only once across all literature compiled.

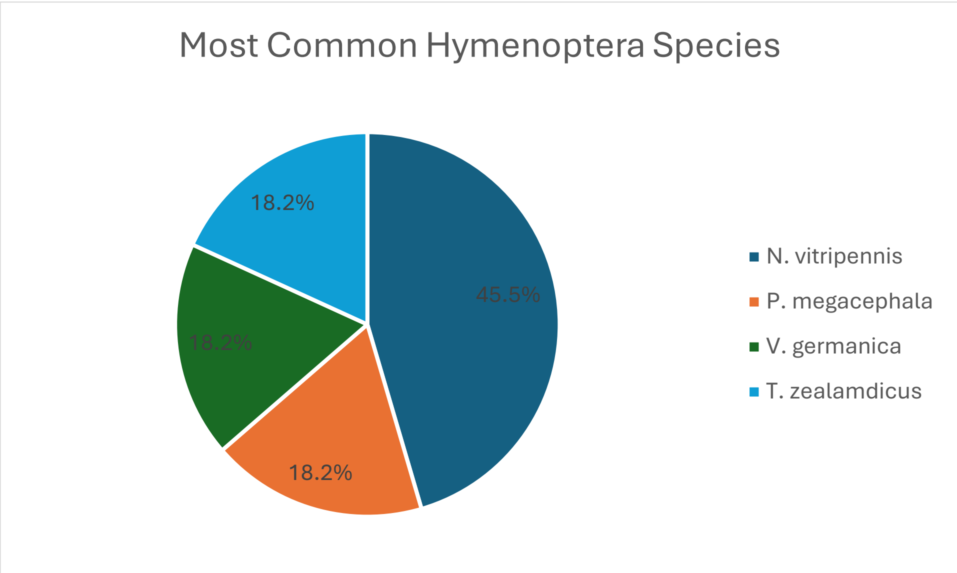

Figure 14 – Pie chart showing the most common Hymenopteran species.

4.7.4.4 Other Species

The remaining 0.5% of species belonged to the orders of Dermaptera and Araneae, each having just one identified species. These being *Forficula auricularia* (Dermaptera) and *Tegenaria domesticus* (Araneae). Of the total 20 distinct insect orders, 70% of these had zero insects identified to species level. Insects belonging to Orthoptera, Acari, Lepidoptera, Hemiptera, Odonata, Geophilomorpha, Isopoda, Opiliones, Neauroptera, Trichoptera, Psocoptera, or Thysanura were not identified to species rank.

4.8 Species Identification Method

There were three different forms of identification methods utilised throughout the gathered research: morphological keys (57.1%), molecular techniques (3.6%), and verification through external specialists (25%). In addition, there is a fourth classification for papers that failed to mention how specimens were identified (14.3%). Of the papers that specified identification methods, 43.75% used more than one method for species identification, with 56.25% only using one. It is important to note that although the 14.3% of unspecified methods would alter these percentages, they are included to highlight a crucial gap in scientific reporting in a significant number of studies.

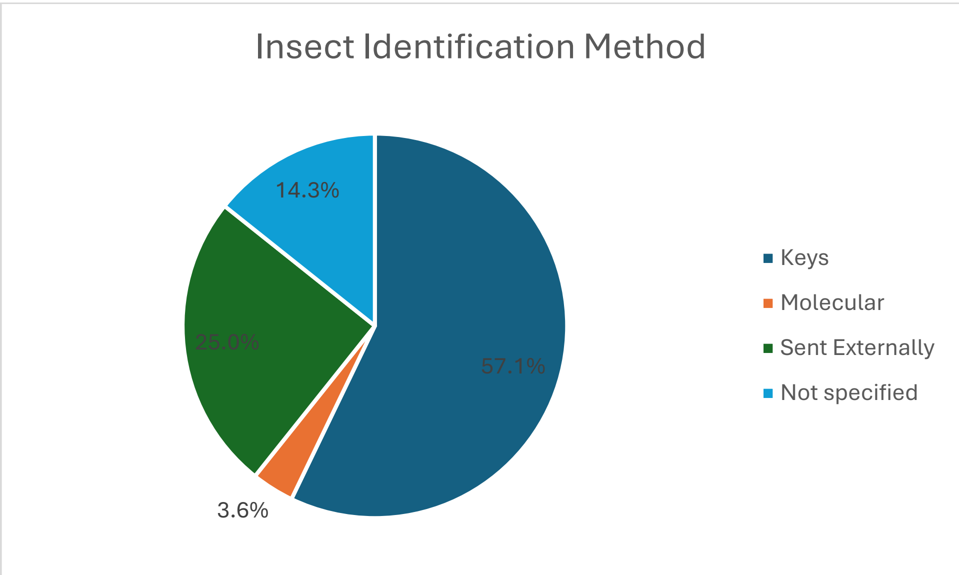

Figure 15 – Pie chart showing the percentage of insect identification methods used.

4.9 Insect Collection Method

There were six classifications of insect collection methods identified within this research: nets (34.1%), manual collection (43.2%), sticky traps (2.3%), pitfall traps (18.2%), sieving (2.3%). Additionally, 85% of research utilised more than one collection method, with 15% using only one method through their experiments.

When insects were collected, 75% of papers detailed that infant specimens were reared to adulthood for later identification.

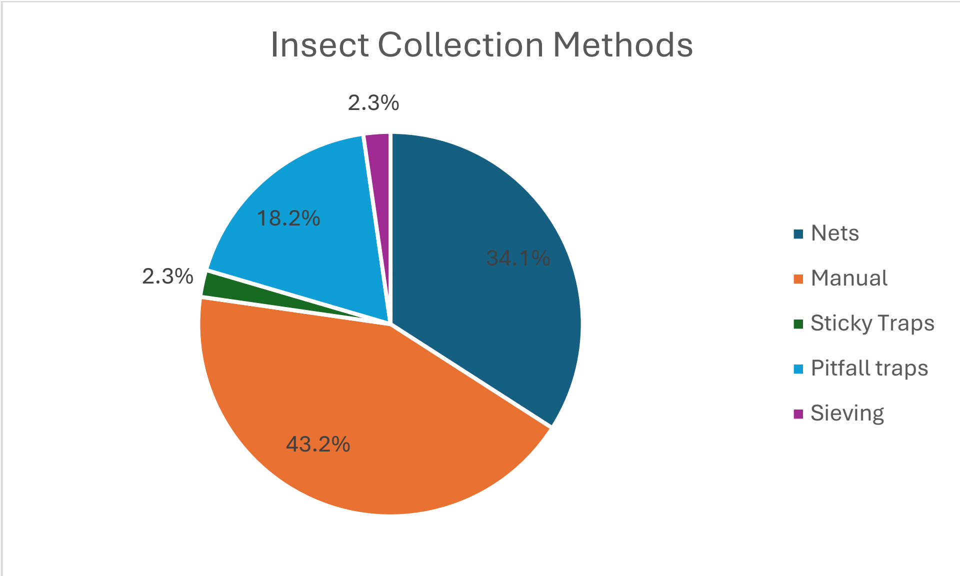

Figure 16 – Pie chart showing the percentages of insect collection methods used throughout the papers used in this study.

Chapter 5: Discussion and Conclusions

5.1 Cadaver

Forensic studies often rely on animal cadavers when replicating studies of human decomposition. The type of cadaver used for forensic experiments can have a significant impact on the results gathered. Different types of cadavers are used to represent human decomposition, including human bodies and animal models. Each type of cadaver has its advantages and disadvantages, particularly with regards to the accuracy of human decomposition replication, ethical concerns, and feasibility.

The results of this research align with the view that pigs have long been favoured amongst researchers due to the ease of replication and practicality for controlling confounding factors (Matuszewski et al., 2020) as well as allowing for the gaining of general trends and patterns seen in human decomposition (Miles, Finaughty and Gibbon, 2020). Pigs and humans share a range of physiological and anatomical similarities. For example, pigs' body size, and digestive system are comparable to humans, making them useful for identifying generalised decomposition trends. Comparative studies between pig, rabbit and human remains have been previously conducted, and ultimately concluded that the decomposition of pig tissue was that most similar to human decomposition (Dautartas et al., 2018). With this in mind, it is not surprising to see that pigs made up 50% of the total cadavers used.

Animal cadavers are often more accessible and come with fewer ethical obstacles to overcome compared to human bodies. Additionally, animals are more affordable, meaning that for large-scale studies, animals are favourable due to the reduced cost and availability. For studies that are specifically observing how different factors affect decomposition, the accessibility of animal cadavers means that it is easier to study and manage controlled variables, such as temperature, humidity, and insect exposure. For example, one study compared the insect colonisation rates on clothed and unclothed pigs over two separate years, finding that insect's colonisation and decomposition differed between the clothed and unclothes carcasses, with the presence of clothing prolonging the active decay stage (Voss et al., 2011). Similarly, a 2021 study also utilised pigs to investigate the decomposition stages of buried remains over a period of 171 days, finding that burial at a depth of approximately 25cm could be adequate at preventing the colonisation of some insects (Bonacci et al., 2021). These studies demonstrate how animal models are used when researching the effects of different variables, allowing for extended experiments and repetitions to provide sufficient results in their respective studies.

However, there are some disadvantages for the use of animal models. Animal cadavers do not always undergo the same decomposition process as humans. For example, body temperature regulation, and microbial communities in animals can significantly differ from those in humans, leading to difference in insect colonisation patterns and decomposition rates (Dawson et al., 2020). While the use of pigs has been proven beneficial, there are still key limitations. It cannot be overlooked that the most accurate portrayal of human decomposition is obtained through the use of human cadavers. Especially regarding research within forensic entomology and PMI estimations, as research has demonstrated that the presence of insects on animal cadavers may not be as impactful for human remains as it is for pigs (Steadman, 2018). However, there are ethical and practical obstacles that hinder the use of human bodies for experiments, as depicted in the results of this study, with just 9.1% of research utilising them. Due to the protocols associated with human death, it is very unlikely for a corpse to be experimented on within the first moments of death as typically, bodies that have been donated to science are taken in within the first 6 days of death, and embalmed withing the first 3 days (Derbyshire, 2015).

In theory, the human cadaver is generally considered the best option for forensic entomology and PMI estimations, given that it provides the most accurate representation of the decomposition process of humans. While ethical and logistical challenges make human cadavers harder to use, they remain the ideal model due to their ability to replicate the complex biological, microbial, and ecological factors that influence the rate of decomposition. In practicality, animal cadavers, specifically pigs, are the best available cadavers for studies into human decomposition and PMI estimations. Pigs are a great compromise for studies where human cadavers are not available or feasible as they offer a reasonable approximation of human decomposition despite limitations in replicating every aspect.

5.2 Buried and Surface Remains

Although a mix between studies observing decomposition and insect colonisation on either buried or surface level cadavers, 85% of studies observed the effects of decomposition on bodies left on the surface. With a large proportion of studies focusing on surface remains, this leaves a gap in the understanding of buried corpse decomposition and therefore implies that current PMI estimations based on surface remains may not be sufficient for buried remains.

Soil entomofauna differs between buried and surface remains, typically with buried remains having a reduced abundance of insects (Whittington, 2019) than that of surface remains. The most frequently observed insects associated with buried decomposition belong to Phoridae and Muscidae (Diptera) (Lancu et al., 2018) With regards to Phoridae and Muscidae colonisation, this study also found that buried remains consistently reported the observation of these species, specifically *Megaselia scalaris* (Phoridae) and *Musca domestica* (Muscidae). Additionally, reports of *Chrysomya megacephala, Chrysomya albiceps, Chrysomya megacephala (*Calliphoridae*)*, and *Dermestes frischii* featured across multiple studies of buried remains. The occurrence of these Calliphoridae species is not surprising due to the significant documentation of their use in forensic investigations (Sharma et al., 2021; Henríquez-Valido et al., 2025; Monum et al., 2017)).

Furthermore, it has been well documented that buried corpses decompose in a significantly different manner than to those left on the surface, most likely due to the effects on accessibility that burial has on insect colonisation. There is a general sense of agreement that the rate of decomposition decreases in buried remains compared to those left on the surface (Spaulding, 2020). Therefore, guidelines for PMI estimation were proposed, especially for buried remains of a depth of approximately 0.75m. (Marais-Werner, Myburgh, Becker and Steyn, 2017) Overall, a varied focus in research is beneficial for the complete understanding of roles that different insects have on decomposition and PMI estimations for buried and surface remains.

5.3 Uncovered and Covered Remains

Similarly to a buried body, covered remains limit access to a body, consequently, affecting the rate of decomposition and subsequent PMI estimations. The majority of studies in this research (78%) focused on the effects of insect colonisation and decomposition on uncovered remains, while 22% investigated the effects of covering in this process.

It is generally agreed amongst researcher that coverings, such as clothes or wrappings, act as a physical barrier between insects and the body. However, the impact that this has on insect colonisation is conflicted. Taleb et al, (2022) found that while plastic wrapping did impact the rate of decomposition, it did not hinder its accessibility, nor delay the arrival of necrophagous insects. Alternatively, a 2023 study described that the type of covering was the most significant factor, as the choice of material influenced how long it took for blowflies to find and colonise the body (Brownlow et al., 2023). Given the conflicting data surrounding the effects of clothing on cadaver decomposition and insect colonisation, this creates challenges for forensic entomologists who rely on insect activity to estimate PMI. Variations in clothing and environmental conditions could account for discrepancies in study outcomes. Forensic entomology research would benefit from more controlled studies comparing the effects of covered versus uncovered remains, such as those conducted by Eberhardt & Elliot (2008). By ensuring that all variables are consistent across studies, future research could provide more reliable insights into the influence of coverings on decomposition and PMI estimations.

5.4 Geographical Location

The geographical location plays a crucial role in forensic entomology research because it directly impacts insect colonisation patterns, decomposition rates, and the factors influencing the PMI estimation. Insects involved in the decomposition process are highly sensitive to environmental factors, such as temperature, humidity, and seasons, all of which can differ significantly across geographical areas. The majority of research found in this study came from Asia (30%), specifically Southern China (Wang et al, 2008), Pakistan (Hamid et al, 2024), Malaysia (Ahmad & Omar, 2023), Saudi Arabia (AL-

Mekhlafi, 2024; Shaalan et al, 2016), and Northern India (Sharif & Qamar, 2021). Papers from South America, North America, and Africa were the least common, each making up just 10% of all locations, refer to *Figure 5*. The results of this study show a need for additional research from these locations in order to contribute to more accurate PMI estimations within these regions.

Environmental factors have been shown to affect the rate of decomposition and the types of insects that colonise remains. The species present in a particular area can vary based on local climate, with certain insects are more common in tropical or subtropical areas than in temperate zones (Janzen & Schoener, 1968). Different regions may support distinct insect species due to the varying climates, vegetation, and habitats (Hawkins & DeVries, 2009). By studying insect activity in different locations, researchers can develop region-specific models for PMI estimations (Oh et al., 2024). Furthermore, decomposition and insect colonisation patterns differ greatly depending on the season in which a body is left in (Gunawardena et al., 2023). Understanding the seasonal influence on decomposition is essential for accurate PMI estimations and the formation of region-specific PMI calculation protocols.

Forensic entomologists conducting research in different geographical areas should share findings, providing a global perspective on the effects of geography on decomposition and insect colonisation. This collaboration would help standardise the application of entomological methods in forensic investigations worldwide, allowing for more consistent and reliable PMI estimations across different environments.

5.5 Insects

Insects play a crucial role in forensic investigations, offering valuable insight into post-mortem interval estimations, cause of death conclusions, and evidence of disturbance to the body (Silva et al, 2024). The predictable succession of insect colonisation and their temperature-dependant development allow forensic entomologists to estimate PMI with varied levels of precision (Voss et al, 2014). The two primary insect order used during PMI estimations are Diptera (flies) and Coleoptera (beetles), but emerging research suggests that other insects, such as Hymenoptera (ants and wasps) (Al-

Qurashi et al., 2023) could provide valuable forensic insights based on the influence they have on Diptera abundance.

It is important to note that the failure of papers to identify to the species level (37.9% of total insects) would have inadvertently impacted the results of this study. Hypothetically, if all insects were identified to species rank, the ranking of common insects found in this study would have differed greatly, possibly highlighting new insects for forensic application considerations.

5.5.1 Diptera

Flies are the most significant forensic insect due to their rapid arrival times to a body. Blowflies (Calliphoridae) are one of the most important insect families in forensic entomology. This sentiment is emphasised in the results of this study, as Calliphoridae was the most common family of insects feature throughout literature, accounting for 15.1% of all recorded insects (including the unidentified classification). The families of Muscidae and Sarcophagidae were also amongst the most common Diptera families present in studies, making up 11.2% and 4.7% of total insects respectively.

It is important to note that two papers used in this study only recorded Diptera activity (Pittner et al., 2020; Hamid et al., 2024). Collectively, these papers contributed 12 Calliphoridae species, 13 Muscidae species, and 8 Sarcophagidae species. Despite this focus on Diptera, the inclusion of these species-specific studies did not significant affect the results of this study, as Calliphoridae and Muscidae would have remained as the two most frequently occurring insects across literature, with Sarcophagidae also still remaining in the top 10 most common insects, moving down the list by just two spaces

5.5.2 Coleoptera

Several beetle families, such as Silphidae, and Staphylinidae, are involved in the later stages of decomposition. These beetles feed on the decomposing flesh and are often used to help estimate the stage of decomposition and estimate PMI for later stages of decay. The established forensic significance was echoed in this research, with Staphylinidae and Siphidae insects being of the top 10 most common to feature across literature, as shown in *Figure 9*. Of all Coleoptera families, Histeridae was the most common, making up 7.1% of all insects recorded in this study (including the unidentified category). With regards to Histeridae and Staphylinidae, there were just two identified species that separated the two families. It is likely that the enhanced identification of insects would have impacted where these two families had places amongst the top identified families. In addition to this, one of the studies involved in this research focused solely on Coleopteran insects with regards to decomposition (Zanetti, Visciarelli & Centeno, 2015). This study alone contributed to 23% (n=52) of distinct Coleopteran species. The inclusion of this paper may have disproportionately contributed to the observations of less common species. Alternatively, the use of single insect focused studies hold potential to identify new species of forensically significant insects to consider.

5.5.3 Other Insects

More recent research has begun to recommend a variety insects as potentially forensically significant for PMI estimation applications (Al-Qurashi et al., 2023; M. Badawy et al., 2024; Adetimehin et al., 2023). Across the literature used in this study, the occurrence of insects other than Diptera and Coleoptera was reported in 60% of papers (Wang et al, 2008; Ahmad & Omar, 2023; Dawson et al., 2022; Eberhardt & Elliot, 2008; Voss, Spafford & Dadour, 2009; Skopyk & LeBlanc, 2024; Bonacci er al., 2021; Zeariya & Kabadaia, 2019; Shaalan et al., 2016; Taleb et al., 2022; Sharif & Qamar, 2021; Maisonhaute & Forbes, 2023), demonstrating the open considerations of all insects present. The most significant amongst these were wasps and ants (Formicidae), true bugs (Hemiptera)and moths (Lepidoptera), spiders (Araneae), grasshoppers and crickets (Orthoptera), mites and ticks (Acari), and earwigs (Dermaptera).

Ants and wasps accounted for 7.5% of all recorded insects across studies. The activity of these insects has been more actively reported in recent years (Ramos-Pastrana et al., 2018), enhancing the overall understanding of complex entomofauna interactions. *Nasonia vitirpennis* was the most common Hymenoptera species, however, the family that this species belongs to, Pteromalidae, was not the most common Hymenopteran family. The most common family for this order of insects was Formicidae, making up 46.9% of total hymenopteran families. Ants are often seen during all stages of decomposition, but their role in the decomposition process, and how this impacts the accuracy of PMI estimations, is not yet fully understood. With Hymenoptera being one of the most frequently occurring species across papers, there is an undeniable need for improved understanding of this insect's carrion behaviour. Furthermore, previous studies have discussed the potential link between Formicidae species and abundance on decomposition (Campobasso et al., 2009), further reinforcing the need for improved species identification, as these ant species may be useful for the creation or updating of region-specific PMI models.

In addition to this, Hemiptera and Araneae species each accounted for 1.2% of total insect species respectively. Araneae and Hemiptera have been previously identified amongst insects colonising a body, although not directly involved in the decomposition process (Czepiel-Mil et al., 2020). Despite not directly feeding on the body, these insects can still contribute to the acceleration or deceleration of the decomposition rate, ultimately impacting the accuracy of PMI estimations, however to what degree is still not understood. Future research should consider observing the entire entomofauna for the purposes of developing baseline data for less commonly reported insects present during decomposition, with the potential to identify patterns and relationships between insects that have not yet been observed due to underreporting of insects.

5.6 Species Identification Method

Insect identification is one of the most crucial steps within forensic entomology and PMI estimations. Insects are classified by their taxonomic ranks: order, family, genus, and species, increasing in specificity. Of the papers used in this study, 20% of them failed to specify how they carried out the identification of specimens. Incomplete methodological reporting significantly limits the reproducibility and applicability of data, thus, the desire for future research to clearly state identification methods, as well as who carried them out, has been emphasised (Packer et al., 2018).

Forensic entomologists will often compare collected insects against reference collections and databases, such as those compiled by entomological institutes or museums, to aid in the identification of species. This study showed that 44% of studies utilised more than method of species identification, most typically being the combination of morphological identification through the use of keys and further confirmation by external specialists. The results shown in *Figure 15* show the proportions of all identification methods used across the collected literature. The results of this study confirm the need for improved methods of identification. While the use of keys were the most common method (57.1%), just 3.6% of all methods used were molecular based. This is reflective of recent advancement in the field, as well as the limitations faced by molecular identification techniques, such as accessibility and cost.

The results of this study displays that the use of species-level data remains uncommon. This sentiment has been echoed across literature; however, species level identification is still as more of an exception than a norm (Bansode et al., 2025). This limitation highlights the need for alternative approaches or supplementary data sources to improve the precision of PMI estimations in forensic entomology. Accessibility to molecular techniques, as well as collaboration with other identification methods, holds the greatest potential for improvements to species level identification and subsequent enhancement of PMI estimations. Furthermore, the concept of global and regional datasets has been proposed by various studies, with aims to standardise how entomological data is analysed and discussed within reports (Kotzé et al., 2021).

5.7 Insect Collection Method

Proper collection methods of insects are critical for forensic entomology analysis. Forceps and tweezers are used for picking up insects carefully, ideally without causing damage (Michaud et al., 2012). Sifting screens or ground nets are also used to collect larvae and pupae from the ground or body (Reddy & Ronanki, 2023). Insects should be collected from several areas around the body to account for variations in insect colonisation. Typically, entomologists will collect from the body, specifically from areas like the eyes, mouth, and open wounds (Bhuyan et al, 2025). In addition to this, the environment surrounding the body will also be inspected and sampled, with specimens that colonise the ground and vegetation near the body also being collected to provide a broader picture of insect activity.

Chapter 6: Suggestions and Conclusions

Proper insect collection and rearing are essential for accurate PMI estimations in forensic entomology. Insects are collected from various locations on and around the body, including orifices, wounds, and surrounding soil, to account for variations in colonisation. The majority of studies used within this research (85%) typically used more than method of insect collection during their research. This helps to ensure a comprehensive sample and accurately reflect insects associated with the stages of decomposition. Manual sampling techniques (the use of forceps, tweezers, and brushes) were the most common method used within literature, making up 43.2% of all reported methods. However, these methods run the risk of damaging specimens which may lead to inaccurate identification.

The use of nets (aerial, entomological, and sweeping) were the second most frequently used collection method, making up 34.1% of total collection methods across literature. Nets allow for efficient sampling of flying species such as adult beetles and flies, although they may miss low flying insects. Pitfall traps are useful for collecting ground-dwelling insects, such as beetles and ants, while sticky traps help to collect flying insects without requiring consistent monitoring. However, there is a possibility that these methods may damage insect specimens, making morphological analysis difficult. Sieving and sifting screens effectively recover burrowed larvae and pupae, ensure late-stage decomposition insects are not overlooked.

A reliable forensic entomology collection protocol should incorporate multiple methods to maximise specimen recovery while minimising damage. Collected larval specimens should be preserved in ethanol for later identification, while a subset of larvae should be reared to adulthood under controlled conditions for later species identification and to ensure accurate developmental timelines. This integrated approach enhances the reliability of PMI estimations, accounting for environmental variables and ensuring precise forensic conclusions.

6.1 Region-specific Geographical, Seasonal and Meteorological Effects on Insect Colonisation

As current literature highlights the significant impact of climate on insect behaviour and colonisation patterns, future research should continue to explore details about temperature and humidity thresholds that affect different species of insects during decomposition. Additionally, future research should explore the implication of extreme weather events, such as heavy rainfall, heatwaves, and snow, on insect colonisation and decomposition. These events are likely to alter insect activity and influence possible PMI estimations. The role of weather-induced disturbances, such as insects washed away from heavy rainfall, should be studied, particularly in areas prone to such events.

Geographical features such as elevation, proximity to water, or the presence of dense vegetation can also affect decomposition and insect colonisation. Future research should investigate how these factors influence insect behaviour and how decomposition rates differ in areas with varying landscapes, such as mountains, forests, or wetlands.

6.2 Insects, Inter-species Interactions and Predators

Research has shown that insect succession typically follows predictable patterns, but variations exist depending on an array of factors. Future studies should continue to explore changes in the body's condition under specific conditions, such as burial, and how this affects succession patterns. Understanding how insects colonise bodies under varied environmental and physical conditions will lead to increased accuracy and applicability for PMI estimations.

While primary colonisers are well studied, there is less research on secondary colonisers and predacious species. Investigating inter-species relationships has the potential to help explain variations in insect presence and activity, and to provide better insights into decomposition rates.

6.3 Improving Identification and Collection Methods

As concluded in this study, current research often relies on the morphological identification of insects, which can sometimes lead to misidentifications, ambiguities, or failure to identify to the species taxonomic level. Future research should prioritise the development of more accurate, rapid DNA-based identification techniques, such as DNA barcoding, which could allow forensic entomologists to identify species to a greater taxonomic resolution. Molecular techniques could be used for identifying species at the egg, larval, pupal, and adult stages, reducing misidentifications and increasing the accuracy of PMI estimations. In addition to this, genetic databases specific to forensic entomology could be developed and expanded to support these identification techniques, allowing for easier collaboration between researchers.

The collection of insects from crime scenes must be conducted under standardised protocols to ensure consistency and accuracy. Future research should focus on developing more rigorous and uniform collection methods, particularly regarding the timing of collection, areas to be sampled, and the tools used. A standardised protocol would also ensure that insects are collected at the proper developmental stages and from different areas of the body and surrounding environment.

Future research in forensic entomology should address several critical areas to enhance the accuracy and applicability of insect-based evidence in criminal investigations. These include improving the current understanding of insect behaviour under various conditions, refining species identification and collection methodologies, and utilise molecular identification techniques. By addressing these areas, forensic entomologists will be better equipped to provide more precise and reliable PMI estimations, which are critical for multiple aspects of criminal investigations. Additionally, a multidisciplinary approach and standardised research methods will allow for more consistent and universally applicable forensic entomological practices.

Chapter 7: References

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Chapter 8: Appendices

8.1 Research Table

Below is the table that was used throughout this study to collect relevant information from various papers. Cadaver type, the use of buried or surface remains, if the body was covered or uncovered (and if covered, what with), location of the experiment, insects collected during the study, the method used to identify collected insects, how these insects were collected, along with the references were collected. In addition to this, extra information regarding these variables was collected, such as cadaver weight, if studies utilised more than one collected or identification method, as well as the seasons that studies took place in.

CADAVER	BURRIED / SURFACE	COVERED / UNCOVERED	LOCATION	INSECT TAXA				SPECIES ID METHOD	COLLECTION METHOD	REFERENCES
				SPECIES	GENUS	FAMILY	ORDER			
Pig	Surafce	Partially covered, fully uncovered, and fully covered - cage, clothes, twigs, uncovered	Northern Germany	C. vicina C. vomitoria	Calliphora	Calliphoridae	Diptera	Keys	Aerial nets and manual collection	Pittner, S. *et al.* (2020) doi:10.1007/s00414-020-02278-0.
				L. ampullacea L. bufonivora L. caesar L. illustris L. sericata L. silvarum	Lucilia					
				M. gentilis	Melinda					
				P. regina	Phormia					
				E. cyanicolor	Eudasyphora	Muscidae				
				G. maculata	Graphomya					
				H. aenescens H. armipes H. cyrtonurina	Hydrotaea					

				H. ignava						
				M. podagrica	Morellia					
				M. aenescens						
				M. autumnalis	Musca					
				M. domestica						
				M. pascuorum	Muscina					
				M. prolapsa						
				P. aratrix	Parasarcophaga					
				S. caerulescens	Sarcophaga	Sarcophagidae				
				S. hirtipes						
				S. incisilobata						
				S. melanura						
				S. silmilis						
				S. variegata						
Pig	Surface	Uncovered - wire cage	Southern China	C. megacephala	Chrysomya	Calliphoridae	Diptera	Not specified	Manual	Wang, J. et al. (2008) doi:10.1016/j.forsciint.2008.04.014.
				C. rufifacies						
				C. pinguis	Ceylonomyia					
				C. nigripes						
				L. sericata	Lucilia					
				L. cuprina						
				L. bazini						
				P. ruficornis	Parasarcophaga	Sarcophagidae				
				P. albiceps						
				P. taenionota						
				M. domestica	Musca	Muscidae				
				M. ventrosa						
				H. spinigera	Hydrotaea					
				H. chalcogaster						

Unidentified	Unidentified	Sepsidae	
Unidentified	Unidentified	Phoridae	
H. illucens	Hermetia	Stratiomyidae	
S. splendens	Saprinus	Histeridae	Coleoptera
S. optabilis			
M. jekeli	Merohister		
A. depister	Altholus		
N. rufipes	Necrobia	Cleridae	
N. ruficollis			
C. maxillosus	Creophilus	Staphylinidae	
Unidentified	Platydracus		
Unidentified	Unidentified		
D. osculand	Diamesus	Silphidae	
D. maculatus	Dermestes	Dermestidae	
O. taurus	Onthophagus	Scarabeidae	
O. proletarius			
Unidentified	Unidentified	Carabidae	
C. obscuripes	Chiagosnius	Elateridae	
Unidentified	Unidentified	Nitidulidae	
V. bicolor	Vespa	Vespidae	Hymenoptera
V. affinis			
V. velutina			
V. flaviceps	Vespula		
H. venator	Harpegnathos	Formicidae	
P. affinis	Pheidologeton		
C. variegatus	Camponotus		
Unidentified	Unidentified	Gryllidae	Orthoptera
Unidentified	Unidentified	Unidentified	Acari
Unidentified	Unidentified	Forficulidae	Dermaptera

Pig	Surface	Uncovered - wire cage	Northeast-ern Aus-tralia	Unidentified	Unidentified	Calliphoridae	Diptera	Keys	Manual, sticky traps and aer-ial sweep nets	Griffiths, K., Krosch, M.N. and Wright, K. (2020) doi:10.1080/20961790.2020.1733830.
				Unidentified	Unidentified	Sarcophagidae				
				Unidentified	Unidentified	Muscidae				
				Unidentified	Unidentified	Piophilidae				
				Unidentified	Unidentified	Histeridae	Coleoptera			
				Unidentified	Unidentified	Dermestidae				
				Unidentified	Unidentified	Staphylinidae				
				Unidentified	Unidentified	Cleridae				
				Unidentified	Unidentified	Trogidae				
				Unidentified	Unidentified	Scarabeidae				
				Unidentified	Unidentified	Unidentified	Unidentified			
				Unidentified	Unidentified	Unidentified	Unidentified			
				Unidentified	Unidentified	Unidentified	Unidentified			
Rabbit	Surface	Uncovered - wire cage	Pakistan	C. vicina	Calliphora	Calliphoridae	Diptera	Not speci-fied	Manual and aerial sweep nets.	Hamid, E. et al. (2024) doi:10.1080/00450618.2024.2359427.
				C. vomitoria						
				S. carnaria	Sarcophaga	Sarcophagidae				
				M. domestica	Musca	Muscidae				
Rats and Monkeys	Surface	Uncovered - wire cage	Malaysia	P. megacephala	Pheidole	Formicidae	Hymenoptera	Keys, ex-ternal	Sweep nets, manual, pitfall traps	Ahmad, A. and Omar, B. (2023) doi:10.1007/s42690-023-01072-w.
				Unidentified	Heteroponera					
				Unidentified	Crematogaster					
				D. gigas	Dinomyrmex					
				H. spinigera	Hydrotaea	Muscidae	Diptera			
				Unidentified	Morellia					
				Unidentified	Unidentified	Piophilidae				
				Unidentified	Ptecticus	Stratiomyidae				
				C. megacephala	Chrysomya	Calliphoridae				
				C. rufifacies						
				C. villeneuvi						
				C. nigripes	Ceylonomyia					
				Unidentified	Scholastes	Platystomatidae				

				Unidentified	Unidentified	Sphaeroceridae				
				Unidentified	Unidentified	Sepsidae				
				Unidentified	Unidentified	Neridae				
				Unidentified	Unidentified	Micropezidae				
				Unidentified	Unidentified	Dolicopodidae				
				Unidentified	Unidentified	Drosophilidae				
				Unidentified	Unidentified	Phoridae				
				Unidentified	Unidentified	Anthomyiidae				
				Unidentified	Unidentified	Ulidiidae				
Humans and Pigs	Surface	Uncovered - wire cage	Southeast-ern Aus-tralia	Unidentified	Calliphora	Calliphoridae	Diptera	Keys	Sweep nets, manual, pitfall traps	Dawson, B.M. et al. (2022) doi:10.1007/s00442-022-05145-4.
				C. nigripes	Chrysomya					
				C. incisuralis						
				C. varipes						
				C. rufifacies						
				P. casei	Piophila	Piophilidae				
				Unidentified	Unidentified	Phoridae				
				A. rostrata	Australophyra	Muscidae				
				Unidentified	Dichaetomyia					
				N. rufipes	Necrobia	Cleridae	Coleoptera			
				C. lanio	Creophilus	Staphylinidae				
				C. erythroceph-alus						
				S. cyaneus	Saprinus	Histeridae				
				O. quadrin-odosus	Omorgus	Trogidae				
				N. vitripennis	Nasonia	Pteromalidae	Hymenoptera			
				R. metallica	Rhyidoponera	Formicidae				
				A. longiceps	Aphaenogaster					
				Unidentified	Crematogaster					
Pigs	Surface	Uncovered - wire cage	Western Poland	C. vicina	Calliphora	Calliphoridae	Diptera	Keys	Sweep nets, manual, pitfall traps	Matuszewski, S. et al. (2010) doi:10.1016/j.forsciint.2009.11.007.
				C. vomitoria						

	C. albiceps	Chrysomya		
	C. mortuorum	Cynomya		
	L. caesar	Lucilia		
	P. regina	Phormia		
	D. flaveola	Dryomyza	Dryomyzidae	
	F. canicularis			
	F. coracina	Fannia	Fanniidae	
	F. manicata			
	H. aenescens			
	H. armipes			
	H. cyrtonurina			
	H. dentipes	Hydrotaea		
	H. ignava		Muscidae	
	H. meteorica			
	H. pilipes			
	H. similis			
	T. simplex	Thricops		
	P. vulgaris	Parapiophila	Piophilidae	
	S. nigriceps	Stearibia		
	N. nitidula	Nemopoda		
	N. speiseri		Sepsidae	
	T. nigricornis	Themira		
	N. rufipes	Necrobia	Cleridae	
	N. violacea			
	D. frischii			
	Unidentified	Dermestes	Dermestidae	Coleoptera
	D. murinus			
	A. stercorosus	Anoplotrupes	Geotrupidae	
	T. vernalis	Trypocopris		
	M. brunneus	Margarinotus	Histeridae	

				M. marginatus						
				M. ruficornis						
				M. striola						
				M. ventralis						
				Unidentified						
				S. planiusculus						
				S. semistriatus	Saprinus					
				Unidentified						
				C. grandicollis	Catops	Leiodidae				
				S. fumatus	Sciodrepoides					
				O. colon						
				O. depressa	Omosita	Nitidulidae				
				O. discoidea						
				N. littoralis	Necrodes					
				N. humator						
				N. vespillo	Nicrophorus					
				N. vespilloides		Silphidae				
				O. thoracicum	Oiceoptoma					
				T. rugosus						
				Unidentified	Thanatophilus					
				T. sinyatus						
				C. maxillosus	Creophilus					
				Unidentified	Omalium	Staphylinidae				
				Unidentified	Philonthus					
				T. sabulosus	Trox	Trogidae				
				T. scaber						
				L. sericata	Lucilia					
				C. dubia						
Pigs	Surface	Covered - T-shirt and trousers - and uncovered - metal cages	Western Australia	C. albifrontalis	Calliphora	Calliphoridae	Diptera	Keys, external	Sweep nets, manual	Voss, S.C., Cook, D.F. and Dadour, I.R. (2011) doi:10.1016/j.forsciint.2011.04.018.
				C. megacephala	Chrysomya					

				C. rufifacies						
				C. varipes						
				A. rostrata	Australophyra	Muscidae				
				M. domestica	Musca					
				M. vetustissima						
				Unidentified	Unidentified	Sarcophagidae				
				P. casei	Piophila	Piophilidae				
				Unidentified	Dermestes	Dermestidae	Coleoptera			
				Unidentified	Saprinus	Histeridae				
				C. erythroceph-alus	Creophilus	Straphylinidae				
				H. castar	Helea	Tenebrionidae				
				N. rufipes	Necrobia	Cleridae				
				N. ruficollis						
				P. lacrymosa	Ptomaphila	Silphidae				
				O. tatei	Omorgus	Trogidae				
				O. binodis	Onothphagus	Scarabeidae				
Pig	Surafce	Covered - T-shirt and pants - metal cages	New Zea-land	C. stygia	Calliphora	Calliphoridae	Diptera	Not speci-fied	Sweep nets and manual	Eberhardt, T.L. and Elliot, D.A. (2008) doi:10.1016/j.forsciint.2007.09.010.
				C. quadrimacu-lata						
				C. vicina						
				C. rufifacies	Chrysomya					
				L. sericata	Lucilia					
				H. rostrata	Hydrotaea	Muscidae				
				Unidentified	Fannia	Fanniidae				
				Unidentified	Unidentified	Piophilidae				
				Unidentified	Unidentified	Sphaeroceridae				
				Unidentified	Unidentified	Psychodidae				
				Unidentified	Sylvicola	Anisopodidae				
				V. germanica	Vespula	Vespidae	Hymenoptera			
				Unidentified	Unidentified	Encyrtidae				

				T. zealamdicus	Tachinaephagus					
				Unidentified	Unidentified	Braconidae				
				C. oculatus	Creophilus	Staphylinidae				
				Unidentified	Necrobia	Cleridae	Coleoptera			
				Unidentified	Unidentified	Agyrtidae				
				L. sericata	Lucilia					
				C. dubia	Calliphora					
				C. albifrontalis		Calliphoridae				
				C. megacephala						
				C. rufifacies	Chrysomya					
				C. varipes			Diptera			
				H. rostrata	Hydrotaea					
				M. domestica	Musca	Muscidae				
				M. vetustissima						
				Unidentified	Unidentified	Sarcophagidae				
				Unidentified	Unidentified	Piophilidae				
Guinea Pig	Surface	Metal Cage	Western Australia	D. ater	Dermestes	Dermestidae		Keys, external	Sweep nets and manual	Voss, S.C., Spafford, H. and Dadour, I.R. (2009) doi:10.1016/j.forsciint.2009.08.014.
				D. maculatus						
				Unidentified	Saprinus	Histeridae				
				C. erythrocephalus	Creophilus	Staphylinidae				
				Unidentified	Aleochara		Coleoptera			
				N. rufipes	Necrobia	Cleridae				
				P. lacrymosa	Ptomaphila	Silphidae				
				O. tatei	Omorgus	Trogidae				
				O. taurus	Onthophagus	Scarabeidae				
				H. castar	Helea	Tenebrionidae				
				N. vitripennis	Nasonia	Pteromalidae				
				T. zealamdicus	Tachinaephagus	Encyrtidae	Hymenoptera			
				Unidentified	Aphaereta	Braconidae				

				Unidentified	Spilomicrus	Diapriidae				
				Unidentified	Iridomyrmex	Formicidae				
Pig	Surface	Metal cage	Central Chile	L. sericata	Lucilia	Calliphoridae	Diptera	Keys	Sweep net and manual	Ortloff, A., Peña, P. and Riquelme, M. (2012) doi:10.1016/j.forsciint.2012.04.022.
				C. macellaria	Cochliomyia					
				C. vicina	Calliphora					
				V. almeidai	Villegasia	Sarcophagidae				
				M. domestica	Musca	Muscidae				
				F. scalaris	Fannia	Fanniidae				
				Unidentified	Unidentified	Phoridae				
				A. obscuripennis	Atheta	Staphylinidae	Coleoptera			
				A. lata	Aleochara					
				C. maxillosus	Creophilus					
				C. erythrocephalus						
				E. bisignatus	Euspilotus	Histeridae				
Pig	Surface	Uncovered - no cage	Central Canada	P. regina	Phormia	Calliphoridae	Diptera	Keys, external	Pitfall traps and manual	Skopyk, A.D. and LeBlanc, H.N. (2024) doi:10.4039/tce.2024.17.
				L. illustris	Lucilia					
				L. sericata						
				L. coeruleiviridis						
				C. macellaria	Cochliomyia					
				P. terraenovae	Protophormia					
				Unidentified	Sarcophaga	Sarcophagidae				
				Unidentified	Unidentified	Muscidae				
				Unidentified	Unidentified	Phoridae				
				Unidentified	Unidentified	Sepsidae				
				Unidentified	Unidentified	Heleomyzidae				
				Unidentified	Unidentified	Piophilidae				
				Unidentified	Unidentified	Stratiomyidae				
				Unidentified	Unidentified	Tabanidae				
				Unidentified	Unidentified	Anthomyiidae				

				Unidentified	Unidentified	Sphaeroceridae				
				Unidentified	Unidentified	Drosophilidae				
				Unidentified	Unidentified	Scaridae				
				Unidentified	Unidentified	Staphylinidae	Coleoptera			
				Unidentified	Unidentified	Cleridae				
				Unidentified	Unidentified	Histeridae				
				Unidentified	Unidentified	Carabidae				
				Unidentified	Unidentified	Silphidae				
				Unidentified	Unidentified	Amphizoidae				
				Unidentified	Unidentified	Leiodidae				
				Unidentified	Unidentified	Trogidae				
				Unidentified	Unidentified	Elateridae				
				Unidentified	Unidentified	Coccinelidae				
				Unidentified	Unidentified	Currulionidae				
				Unidentified	Unidentified	Scolytidae				
				Unidentified	Unidentified	Unidentified	Lepidoptera			
				Unidentified	Unidentified	Vespidae	Hymenoptera			
				Unidentified	Unidentified	Braconidae				
				Unidentified	Unidentified	Apidae				
				Unidentified	Unidentified	Formicidae				
				Unidentified	Unidentified	Pentatomidae	Hemiptera			
				Unidentified	Unidentified	Unidentified	Orthoptera			
				Unidentified	Unidentified	Unidentified	Odonata			
				Unidentified	Unidentified	Unidentified	Unidentified			
Pig	Buried	Uncovered - wire cage	Southern Italy	C. vicina	Calliphora	Calliphoridae	Diptera	Keys	Manual, entomological net	Bonacci, T. et al. (2021) doi:10.3390/insects12040311.
				C. vomitoria						
				C. albiceps	Chrysomya					
				L. caesar	Lucilia					
				L. sericata						
				F. canicularis	Fannia	Fanniidae				

F. lineata				
H. aenescens	Hydrotaea			
H. capensis				
H. dentipes				
H. ignava				
M. domestica	Musca			
M. levida	Muscina	Muscidae		
M. prolapsa				
M. stabulans				
P. subventa	Phaonia			
P. meridionalis	Polietes			
Unidentified	Azelia			
Unidentified	Helina			
Unidentified	Thricops			
M. scalaris	Megaselia	Phoridae		
C. tibialis	Conicera			
Unidentified	Chaetopleu-rophora			
P. casei	Piophila	Piophilidae		
S. nigriceps	Stearibia			
Unidentified	Prochyliza			
S. duplicata	Sepsis	Sepsidae		
S. cynipsea				
Unidentified	Anthomyia	Anthomyiidae		
Unidentified	Sarcophaga	Sarcophagidae		
Unidentified	Unidentified	Cecidomyiidae		
Unidentified	Unidentified	Drosophilidae		
Unidentified	Unidentified	Dryomyzidae		
Unidentified	Unidentified	Ephydridae		
Unidentified	Unidentified	Heleomyzidae		

Unidentified	Unidentified	Lauxaniidae	
Unidentified	Unidentified	Psychodidae	
Unidentified	Unidentified	Scatopsidae	
Unidentified	Unidentified	Sciaridae	
Unidentified	Unidentified	Sphaeroceridae	
Unidentified	Unidentified	Tipulomorpha	
Unidentified	Unidentified	Simulidae	
N. ruficollis	Necrobia	Cleridae	Coleoptera
N. violacea			
D. frischii	Dermestes	Dermestidae	
A. stercorosus	Anoplotrupes	Geotrupidae	
M. brunneus	Margarinotus	Histeridae	
M. ventralis			
S. semistriatus	Saprinus		
S. lunatum	Sphaeridium	Hydrophilidae	
N. flavomacu-lata	Nitidula	Nitidulidae	
N. littoralis	Necrodes	Silphidae	
T. rugosus	Thanatophilus		
C. maxillosus	Creophilus	Staphylinidae	
Unidentified	Anotylus		
Unidentified	Carpelimus		
Unidentified	Heterothops		
Unidentified	Paederus		
Unidentified	Platystethus		
Unidentified	Philonthus		
Unidentified	Quedius		
Unidentified	Aleocharinae		
Unidentified	Piestinae		
Unidentified	Abax	Carabidae	

				Unidentified	Acinopus					
				O. cribricollis	Ophonus					
				Unidentified						
				T. quadristriatus	Trechus					
				Unidentified	Unidentified	Buprestidae				
				Unidentified	Unidentified	Chrysomelidae				
				Unidentified	Unidentified	Currulionidae				
				Unidentified	Unidentified	Scarabaeidae				
				Unidentified	Unidentified	Amaurobiidae	Araneae			
				Unidentified	Unidentified	Lycosidae				
				Unidentified	Unidentified	Thomisidae				
				Unidentified	Unidentified	Salticidae				
				F. auricularia	Forficula	Forficulidae	Dermaptera			
				Unidentified	Unidentified	Braconidae	Hymenoptera			
				Unidentified	Messor	Formicidae				
				Unidentified	Camponotus					
				Unidentified	Pheidole					
				N. vitripennis	Nasonia	Pteromalidae				
				Unidentified	Eupteryx	Cicadellidae	Hemiptera			
				Unidentified	Unidentified	Delphacidae				
				Unidentified	Unidentified	Unidentified	Geophilomorpha			
Dogs	Surface	Uncovered - wire cage	Egypt	C. albiceps	Chrysomya	Calliphoridae	Diptera	Keys, external	Manual, net	Zeariya, M. and Kabadaia, M. (2019) doi:10.21608/eajbse.2019.36659.
				C. megacephala						
				L. sericata	Lucilia					
				Unidentified	Calliphora					
				P. regina	Phormia					
				M. domestica	Musca	Muscidae				
				M. sorbens						
				S. calcitrans	Stomoxys					
				S. carnaria	Sarcophaga	Sarcophagidae				

				W. magnifica	Wohlfahrtia					
				M. scalaris	Megaselia	Phoridae				
				P. casei	Piophila	Piophilidae				
				D. maculatus	Dermestes	Dermestidae	Coleoptera			
				Unidentified	Hister	Histeridae				
				C. maxillosus	Creophilus	Staphylinidae				
				N. rufipes	Necrobia	Cleridae				
				N. vetripennis	Nasonia	Pteromalidae	Hymenoptera			
				C. bicolor	Cataglyphis	Formicidae				
				M. pharoensis	Monomorium					
				Unidentified	Doli-chovespula	Vespidae				
Rabbit	Buried	Uncovered - wire mesh	Saudi Ara-bia	W. nuba	Wohlfahrtia	Sarcophagidae	Diptera	Keys, ex-ternal	Manual	AL-Mekhlafi, F.A. *et al.* (2024) doi:10.1007/s42690-024-01203-x.
				D. marginella	Dolichotach-ina					
				S. dux	Sarcophaga					
				M. domestica	Musca	Muscidae				
				M. scalaris	Megaselia	Phoridae				
				C. albiceps	Chrysomya	Calliphoridae				
				C. rufifacies						
				C. megacephala						
				H. pulchra	Hemipyrellia					
				Unidentified	Rhyncomya					
				P. alceae	Physiphora	Ulidiidae				
				D. frischii	Dermestes	Dermestidae	Coleoptera			
				M. puncticollis	Mesostena	Tenebrionidae				
				S. chalcites	Saprinus	Histeridae				
				N. eremita	Nitidula	Nitidulidae				
Rabbit	Surface	Uncovered - wire mesh	Saudi Ara-bia	C. vicina	Calliphora	Calliphoridae	Diptera	Keys	Manual, pitfall trap, aeial sweep net	Shaalan, E.A. et al. (2016) doi:10.1111/1556-4029.13252.
				C. albiceps	Chrysomya					
				C. bezziana						

				C. megacephala						
				P. regina	Phormia					
				L. sericata	Lucilia					
				M. domestica	Musca	Muscidae				
				Unidentified	Sarcophaga	Sarcophagidae				
				B. sulcata	Blaps	Tenebrionidae	Coleoptera			
				Unidentified	Hymenorus					
				D. maculatus	Dermestes	Dermestidae				
				P. megacephala	Pheidole	Formicidae	Hymenoptera			
				T. domesticus	Tegenaria	Agelenidae	Araneae			
Rabbit	Suface	Covered - plastic wrap, wire cage	Northern Algeria	A. pluvialias	Anthomyia	Anthomyiidae	Diptera	Keys and DNA barcoding	Manual, pitfall traps,	Taleb, M. et al. (2022) doi:10.1016/j.scijus.2021.11.005.
				Unidentified	Delia					
				Unidentified	Unidentified					
				C. vicina	Calliphora	Calliphoridae				
				C. vomitoria						
				C. albiceps	Chrysomya					
				L. sericata	Lucilia					
				Unidentified	Unidentified	Chloropidae				
				Unidentified	Culex	Culicidae				
				Unidentified	Drosophilia	Drosophilidae				
				F. canicularis	Fannia	Fanniidae				
				F. monilis						
				Unidentified	Azelia	Muscidae				
				G. maculata	Graphomya					
				H. dentipes	Hydrotaea					
				H. ignava						
				M. domestica	Musca					
				M. prolapsa	Muscina					
				M. stabulans						
				S. calcitrans	Stomoxys					

P. subventa	Phaonia		
P. casei	Piophila	Piophilidae	
P. nigriceps			
P. rudis	Pollenia	Polleniidae	
P. vagabunda			
S. africa	Sarcophaga	Sarcophagidae	
S. argyrostoma			
S. pendellei			
S. teretirostris			
S. tibialis			
Unidentified	Sepsis	Sepsidae	
Unidentified	Unidentified	Tachinidae	
Unidentified	Thereva	Therevidae	
Unidentified	Tipula	Tipulidae	
Unidentified	Timarcha	Chrysomelidae	Coleoptera
C. bankii	Chrysolina		
N. rufipes	Necrobia	Cleridae	
N. violacea			
D. frischii	Dermestes	Dermestidae	
D. maculatus			
S. semistriatus	Saprinus	Histeridae	
H. bipunctatus	Hister		
Unidentified	Choleva	Leiodidae	
N. humator	Nicrophorus	Silphidae	
S. tristis	Silpha		
T. sinuatus	Thanatophilus		
C. maxillosus	Creophilus	Staphylinidae	
Unidentified	Philonthus		
Unidentified	Aleochara		
Unidentified	Sepidium	Tenebrionidae	

				Unidentified	Pachychila					
				Unidentified	heliotaurus					
				Unidentified	Trox	Trogidae				
				Unidentified	Onthophagus	Scarabeidae				
				Unidentified						
				T. squalida	Tropinota					
				Unidentified	Rhagonycha	Cerambycidae				
				Unidentified	Aphidius	Aphidiidae	Hymenoptera			
				C. viatica	Cataglyphis	Formicidae				
				Unidentified	Messor					
				N. vitripennis	Nasonia	Pteromalidae				
				V. germanica	Vespula	Vespidae				
				V. canescens	Ventura	Ichneumonidae				
				Unidentified	Pholcus	Pholcidae	Araneae			
				Unidentified	Unidentified	Zodariidae				
				Unidentified	Unidentified	Oribatida	Acari			
				Unidentified	Unidentified	Gamasida				
				Unidentified	Oniscus	Oniscidae	Isopoda			
				Unidentified	Unidentified	Miridae	Hemiptera			
Pig	Surface	Uncovered - wirecage	Argentina	A. topali	Archeocrypticus	Archeocrypticidae	Coleoptera	Not specified	Manual and pitfall traps	Zanetti, N.I., Visciarelli, E.C. and Centeno, N.D. (2015) doi:10.1016/j.rbe.2015.03.009.
				Unidentified	Astylus	Melyridae				
				P. egenus	Pelmatellus	Carabidae				
				B. viduus	Bradycellus					
				S. punctulatus	Selenophorus					
				T. laevigatus	Tetragonoderus					
				C. platensis	Carbonellia					
				A. oblitus	Argutoridius					
				N. posticalis	Notaphus					
				Unidentified	Carcinops	Histeridae				

Unidentified		
E. caesopygus		
E. connectens		
E. lacordairei		
E. niger	Euspilotus	
E. ornatus		
E. parenthesis		
E. patagonicus		
E. pavidus		
Unidentified	Phelister	
X. diptychus	Xerosaprinus	
Unidentified	Dendrophil-inae	
Unidentified	Unidentified	
Unidentified		
B. punctulatus	Blapstinus	Tenebrionidae
G. platensis	Gondwa-nocripticus	
H. tentyroides	Hylitus	
L. strangulata	Leptynoderes	
S. clathratus	Scotobius	
S. millaris		
S. muricatus		
A. chaconus	Archophileu-rus	Scarabaeidae
A. fodiens		
A. militaris	Aphodius	
A. pseudolividus		
A. platensis	Ataenius	
C. ornatus	Canthon	
Unidentified	Degallieridium	
Unidentified	Pseudocan-thon	

				Unidentified	Onthophagus					
				O. batesi	Omorgus	Trogidae				
				P. gemmingeri	Polynoncus					
				Unidentified	Aleocharinae	Staphylinidae				
				Unidentified	Creophilus					
				Unidentified	Carpelimus					
				Unidentified	Haematodes					
				H. bicolor						
				P. flavolimbatus	Philonthus					
				D. maculatus	Dermestes	Dermestidae				
				Unidentified	Unidentified	Anthicidae				
				N. rufipes	Necrobia	Cleridae				
				N. carnaria	Nitidula	Nitidulidae				
Goat	Buried	Uncovered	Northern India	M. scalaris	Megaselia	Phoridae	Diptera	external	Manual, sieving, sweep net	Sharif, S. and Qamar, A. (2021) doi:10.1186/s41935-021-00235-5.
				O. capensis	Ophyra	Muscidae				
				S. nudiseta	Synthesiomyia					
				C. megacephala	Chrysomya	Calliphoridae				
				C. erythrocephala	Calliphora					
				S. quadriguttatus	Saprinus	Histeridae	Coleoptera			
				S. splendens						
				O. quadridemtatus	Onthophagus	Scarabaeidae				
				Unidentified	Dorylus	Formicidae	Hymenoptera			
				Unidentified	Cydnus	Cydnidae	Hemiptera			
Human	Surface	Uncovered - wire cage	Eastern Canada	C. livida	Calliphora	Calliphoridae	Diptera	Keys	Nets, pitfall traps	Maisonhaute, J. -E. and Forbes, S. L. (2022). doi:10.1007/s00414-022-02903-0
				C. vomitoria						
				C. macellaria	Cochliomyia					
				L. illustris	Lucilia					
				L. silvarum						
				P. regina	Phormia					

Unidentified	Unidentified	Sarcophagidae	
Unidentified	Hydrotaea	Muscidae	
Unidentified	Unidentified	Fanniidae	
Unidentified	Unidentified	Anthomyiidae	
Unidentified	Unidentified	Ceratopogo-nidae	
Unidentified	Unidentified	Drosophilidae	
Unidentified	Unidentified	Dryomyzidae	
Unidentified	Unidentified	Heleomyzidae	
Unidentified	Unidentified	Phoridae	
P. xanthostoma	Prochyliza		
P. latipes	Protophormia	Piophilidae	
S. nigriceps	Stearibia		
Unidentified	Unidentified	Sepsidae	
Unidentified	Unidentified	Sphaeroceridae	
N. americana	Necrophila		
N. orbicollis			
N. tomentosus	Nicrophorus		
Unidentified		Silphidae	
O. novebora-cense	Oiceoptoma		
N. surinamensis	Necrodes		
Unidentified	Unidentified	Carabidae	
Unidentified	Unidentified	Cleridae	Coleoptera
Unidentified	Unidentified	Dermestidae	
Unidentified	Unidentified	Histeridae	
Unidentified	Unidentified	Geotrupidae	
Unidentified	Omosita	Nitidulidae	
G. quadrisigna-tus	Glischrochilus		
Unidentified	Unidentified	Leiodidae	
Unidentified	Unidentified	Scarabaeidae	

B. blandus	Bisnius	Staphylinidae	
C. maxillosus	Creophilus		
O. cingulatus	Ontholestes		
P. cyanipennis	Philonthus		
Unidentified	Unidentified	Ptiliidae	
Unidentified	Unidentified	Unidentified	Acari
Unidentified	Unidentified	Unidentified	Araneae
Unidentified	Unidentified	Unidentified	Opiliones
Unidentified	Unidentified	Formicidae	Hymenoptera
Unidentified	Unidentified	Vespidae	
Unidentified	Unidentified	Aphididae	Hemiptera
Unidentified	Unidentified	Cicadellidae	
Unidentified	Unidentified	Heteroptera	
Unidentified	Unidentified	Unidentified	Lepidoptera
Unidentified	Unidentified	Hemerobiidae	Neauroptera
Unidentified	Unidentified	Unidentified	Trichoptera
Unidentified	Unidentified	Unidentified	Psocoptera
Unidentified	Unidentified	Unidentified	Thysanura
Unidentified	Unidentified	Unidentified	Isopoda
Unidentified	Unidentified	Unidentified	Unidentified
Unidentified	Unidentified	Unidentified	Unidentified
Unidentified	Unidentified	Unidentified	Unidentified