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# Forensic entomology research and application in southern Africa: A scoping review

The use of forensic entomology is well established in the northern hemisphere, but is still emerging in the southern hemisphere, where most of the current research is not explicitly undertaken in the context of forensics. In this review, we provide an update on the current status of forensic entomology research and its application in relation to estimation of post-mortem interval in various criminal investigations ranging from murder cases, cases of human neglect and the poaching of wildlife in southern Africa, among other issues. A literature search was conducted using Google Scholar, PubMed, Scopus and EBSCOhost databases. The studies reviewed were focused on arthropod diversity during different stages of carcass decomposition, effect of seasons on the abundance and diversity of carrion feeding arthropod species during carcass decomposition, and diurnal and nocturnal oviposition of forensically important insect species during carcass decomposition. It was further observed that arthropod species that established on a decomposing carcass are potentially useful in the estimation of post-mortem interval and determining clues in cases of criminal investigations. The review confirmed the paucity of research in forensic entomology, and its application in southern Africa. Future studies on the research and application of forensic entomology in various criminal investigation scenarios – such as murder cases, human neglect, and wildlife poaching in southern Africa – are therefore needed.

**Significance:**

- Forensic entomology research and its application is lagging in southern Africa.
- There is seasonal variation in the arthropod species used for estimation of post-mortem intervals in southern Africa.
- Identification of arthropod species diversity in the region has potential for application in forensic investigations.

## Introduction

Forensic entomology has been applied in forensic investigations for decades[1-3] and is now recognised as an important investigative tool[3,4]. Forensic entomology can be classified into urban, stored-product and medico-legal divisions.[5,6] According to Goff[5], urban forensic entomology involves civil actions regarding insect activity associated with construction as in cases of termite damage. Stored-product forensic entomology deals with cases involving commercial property that is infested or damaged by insects. Medico-legal forensic entomology deals with insect evidence collected at a crime scene.[5-7] Such evidence is commonly used to estimate the time of death or post-mortem interval (PMI) of the decomposing remains of animals or humans.[5,8] This field has been gaining more recognition than have urban and stored-product forensic entomology worldwide.[5,9] Therefore, we focus on medico-legal forensic entomology in this review.

Insects have been used mainly for estimating PMI[4,10-12], drug verification[9,11,13], determination of ante-mortem trauma, and confirmation of the relocation of carcasses[9,14,15]. This is achieved by analysing the carrion-feeding insect communities recovered from crime scenes and on the carcasses to produce evidence in forensic investigation cases such as human neglect, suicide, homicide, animal poaching and accidental death.[16-20]

The stage of decomposition as well as other processes that lead to complete decomposition and that are likely to affect the remains of a person or animal, all need to be considered for the accurate estimation of PMI.[16,21,22] Harvey et al.[3] note that the application of forensic entomology to estimate the PMI requires accuracy and consideration of several factors, such as the ability to correctly identify the insect species colonising the carcass (i.e. insect community)[10,20]; the understanding of the role of different insect species and their colonisation process throughout carcass decomposition[20,23]; the effect of temperature, seasons and climatic zones; and the presence of toxins[11,24].

Forensically significant insects and other arthropods vary among regions due to varying geographical conditions. Therefore, data obtained from the northern hemisphere cannot be applied to the southern hemisphere.[16,20] The application of forensic entomology has been successfully explored mainly in developed countries such as the USA, Britain and Australia[20,25,26] as well as some European countries, while only a few studies have been conducted in African countries, including South Africa, Cameroon, Egypt, Ghana and Nigeria[26,27].

Although Villet[20] reported that the southern hemisphere is recognised as home to many forensically important insect species not found in the northern hemisphere, there is a paucity of information on the geographical distribution and abundance of these forensically important insect species.[3,20] These species have not been fully studied and exploited to determine their importance and role in forensic investigations[3,28]; the majority of research on carrion insects conducted in southern Africa was not undertaken in the context of forensic investigation[28]. Consequently, lack of information on the importance of these insects in forensics limits the application of entomology in forensic investigation.

According to Villet[20], African scientists have been aware of the potential application of entomology in forensic investigation for several years. For example, in South Africa and Zimbabwe, there have been cases in which entomological evidence was used in solving criminal cases.[3,16,28] To date, southern African forensic entomology research has been carried out on animals (i.e. pigs) as models for solving human cases.[5] In the study of Smith[15], the

carcasses of several vertebrates were used as models to study different insect communities on a decaying human body but there have been no applications in cases of animal poaching or neglect.[5,16,20] As such, the application of forensic entomology in cases that involve animal remains is still needed, given the high rate of wildlife poaching taking place in southern Africa.[16]

Research conducted in southern Africa to date has generated useful results that can be used as evidence in forensic investigations if assessed carefully. Consequently, research in forensic entomology in southern Africa has great potential as a complementary investigative technique in criminal investigations taking place in countries in southern Africa. According to Villet et al.[6], southern African research has focused more on species that are useful for urban or stored-product forensic entomology cases than on insects that are important in medico-legal cases.[6] This calls for more research on insects of medico-legal importance to assist in solving criminal cases.

Molecular research in species identification in forensic entomology is established[19,29,30] but an understanding of the role of quantitative genetics in the development and behaviour of arthropods found at crime scenes has been less appreciated in forensic entomology[19]. Quantitative genetics is used to identify and analyse differences in phenotypes[19,31], which reduces error in estimating the PMI with insects as evidence because each insect species has its own unique phenotype and developmental profile[28,32,33]. Hence, it is essential to accurately identify the insect species collected as evidence in solving criminal cases.[19,32]

In view of the above, the present review aims to provide an update on the current status of forensic entomology research and its application in relation to estimation of PMI in various criminal investigations such as murder cases, human neglect, and poaching of animals in the southern Africa region.

## Materials and methods

### *Scoping review*

The results of this scoping review address the question: What is known from the existing literature about forensic entomology research and its application in relation to estimation of PMI in various criminal investigations in southern Africa? Peer-reviewed research articles from southern Africa that explicitly report on forensic entomology research in a country or countries within southern Africa were collected through a comprehensive approach in order to answer this question. The procedure followed was consistent with a scoping review approach, which is to synthesise what is known about a particular matter across various literature forms in order to achieve clarity about the state of knowledge and evidence that exists.[34] The scoping review approach outlined by Arksey and O' Malley[35] was followed: (1) identify the research question; (2) identify relevant literature; (3) select the literature; (4) chart the data; and (5) collate, summate and report the results.

### *Search strategy and selection of the literature*

A literature search was conducted by one of the authors (D.T.) on four databases – Google Scholar, PubMed, Scopus and EBSCOhost – and the search was executed using the Boolean operators AND, OR and the following search terms: forensic entomology, post-mortem interval and/or index, forensic entomology research in southern Africa (Angola, Botswana, Madagascar, Mozambique, Namibia, South Africa, Zambia and Zimbabwe), identification of forensically important insects and southern Africa, and application and limitations of forensic entomology in southern Africa. Selected search terms were relevant to the scoping question and were developed in consultation with a librarian. Articles that were identified were then screened by reading through their titles and abstracts. Consistent with the scoping review protocol, post-hoc inclusion criteria were developed.[35] Two exclusion criteria were also identified: (1) no focus on forensic entomology research, such as articles that dealt with identification or distribution of arthropods in southern African countries, but not undertaken in the context of forensic entomology; (2) no information points that contributed to answering the scoping question.

Once the titles and abstracts had been reviewed, articles meeting the criteria were reviewed in full. Some articles were screened for any additional relevant information to be included in the review by manually scanning the reference lists.[34] Additional inclusion criteria were developed during the full review stage: peer-reviewed research articles from southern Africa explicitly reporting on forensic entomology research in a country or countries from southern Africa, including (1) colonisation and succession pattern of arthropods during different stages of decomposition; (2) variation spectrum of carrion-feeding insects; and (3) diversity and/or abundance of arthropods colonising a carcass during different seasons. The selection process and search flow are shown in Figure 1.

### *Charting, collating and summarising the data*

A spreadsheet was created to chart the data extracted from the articles which contributed to answering the research question. Details regarding

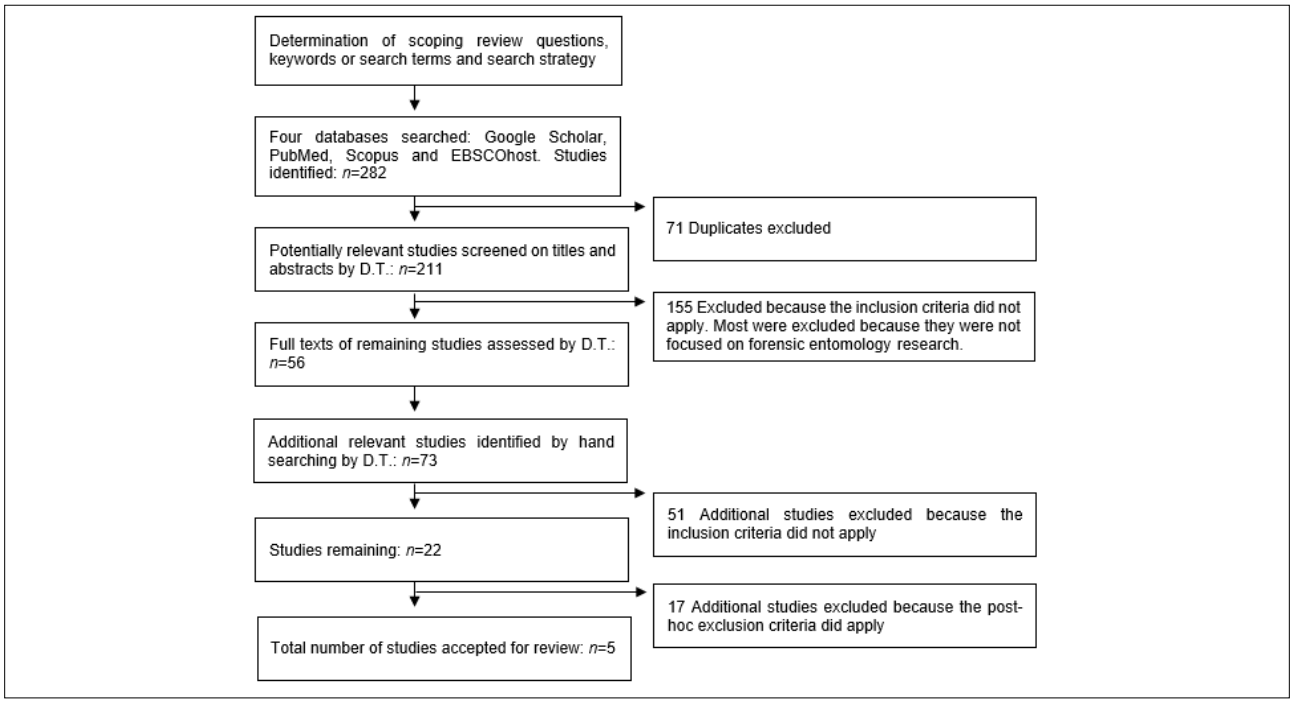


**Figure 1:** Selection process and search flow.

publication information, aims and objectives of the study, the country in which the study took place, outcomes of the study and data pertinent to the scoping question were recorded in this spreadsheet. This process was carried out by one of the authors (D.T.). The information extracted was discussed with the second author (S.M.) in order to work towards an overall perspective on the factors emerging from the literature reviewed. The final step was to work together to identify key knowledge or research gaps resulting from the reviewed articles that have direct relevance to the scoping review question. The verification of the data set used in the final analysis was done by S.M.

## Results

### Search flow

As shown in Figure 1, the literature search yielded a total of 282 hits from the databases searched, of which 277 were excluded because they were either duplicates or not focused on forensic entomology research. At the end of the selection process, only five peer-reviewed articles fulfilled the inclusion criteria (Figure 1); these are shown in Tables 1–3. The review included literature from 1934 to 2017.

### Arthropod diversity during different stages of carcass decomposition

Only two articles reported on the diversity of arthropods colonising decomposing carcasses from the southern African region[26,36] (Table 1). Kelly et al.[36] observed that during the fresh stage of a pig carcass, only *Musca* spp. were found, and they persisted during the bloated stage, where seven new species (*Calliphora vicina*, *Chrysomya chloropyga*, *Chrysomya marginalis*, *Chrysomya albiceps*, *Lucilia* spp., *Sarcophagidae* and *Hydrotaea capensis*) visited the carcass, but did not persist past this stage. Instead four new species (*Dermestes maculatus*, *Necrobia rufipes*, *Thanatophilus micans* species and one unidentified species) visited the carcass during the decay stage and only *D. maculatus* and *Necrobia rufipes* persisted on a carcass (Table 1). Mabika et al.[26] compared the pattern of arthropod colonisation between a rabbit carcass left to decompose in the sun and one left in the shade. During the fresh stage of a carcass exposed to the sun, *Lucilia cuprina*, *C. albiceps* and *Musca domestica* visited the carcass; they persisted during the bloated and decay stages and only disappeared during the dry stage. *Saprinus* spp. and *Dermestes* spp. were recorded only during decay and dry stages of the carcass exposed

**Table 1:** Summary of studies (1934–2017) reporting on different arthropods colonising carcasses during different stages of decomposition in southern Africa

| Study | Country of study | Location of study | Objectives of study | Host animal | Outcome of study | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Arthropods | | | Insect species collected at different stages of decomposition | | | |
| | | | | | Order | Family | Genus/species | Fresh | Bloated | Decay | Dry |
| Kelly et al.[36] | South Africa | Bloemfontein | Determine the influence of clothing and wrapping on carcass decomposition and arthropod succession to provide data to enable estimated post-mortem interval in homicide investigations | Pig | Diptera | Muscidae | *Musca* spp. | * | * | | |
| | | | | | Diptera | Calliphoridae | *Calliphora vicina* | | * | | |
| | | | | | Diptera | Calliphoridae | *Chrysomya chloropyga* | | * | | |
| | | | | | Diptera | Calliphoridae | *Chrysomya marginalis* | | * | | |
| | | | | | Diptera | Calliphoridae | *Chrysomya albiceps* | | * | | |
| | | | | | Diptera | Calliphoridae | *Lucilia* spp. | | * | | |
| | | | | | Diptera | Sarcophagidae | *Sarcophagidae* | | * | | |
| | | | | | Diptera | Muscidae | *Hydrotea capensis* | | * | | |
| | | | | | Coleoptera | Piophilidae | Unidentified | | | * | |
| | | | | | Coleoptera | Dermestidae | *Dermestes maculatus* | | | * | * |
| | | | | | Coleoptera | Cleridae | *Necrobia rufipes* | | | * | * |
| | | | | | Coleoptera | Silphidae | *Thanatophilus micans* | | | * | |
| Mabika et al.[26] | Zimbabwe | Harare | Investigate insects visiting sun exposed and shaded decomposing rabbit carcasses and establish the relationship between insects and carcasses which may be of forensic importance | Rabbit | Diptera | Calliphoridae | *Lucilia cuprina* (S) | 4 | 2 | 6 | 0 |
| | | | | | Diptera | Calliphoridae | *C. albiceps* (S) | 1 | 4 | 8 | 0 |
| | | | | | Diptera | Calliphoridae | Unidentified (S) | 1 | 1 | 5 | 0 |
| | | | | | Diptera | Calliphoridae | Unidentified (S) | 0 | 0 | 0 | 37 |
| | | | | | Diptera | Muscidae | *Musca domestica* (S) | 4 | 55 | 47 | 0 |
| | | | | | Diptera | Muscidae | *Hydrotaea* sp. (S) | 0 | 0 | 0 | 8 |
| | | | | | Diptera | Phoridae | Unidentified (S) | 0 | 0 | 1 | 0 |
| | | | | | Diptera | Sarcophagidae | *Sarcophagidae* sp. (S) | 0 | 0 | 1 | 0 |
| | | | | | Diptera | Drosophilidae | *Drosophilia* sp. (S) | 0 | 0 | 1 | 0 |
| | | | | | Coleoptera | Histeridae | *Saprinus* sp. (S) | 0 | 0 | 9 | 8 |
| | | | | | Coleoptera | Cleridae | *N. rufipes* (S) | 0 | 0 | 0 | 9 |
| | | | | | Coleoptera | Dermestidae | *Dermestes* sp. (S) | 0 | 0 | 18 | 65 |
| | | | | | Hymenoptera | Formicidae | *Pheidole* sp. (S) | 22 | 29 | 19 | 34 |
| | | | | | Diptera | Calliphoridae | *L. cuprina* (s) | 1 | 11 | 1 | 0 |
| | | | | | Diptera | Calliphoridae | *C. albiceps* (s) | 2 | 12 | 1 | 0 |
| | | | | | Diptera | Calliphoridae | Unidentified (s) | 1 | 27 | 0 | 0 |
| | | | | | Diptera | Calliphoridae | Unidentified (s) | 0 | 0 | 0 | 17 |
| | | | | | Diptera | Muscidae | *M. domestica* (s) | 2 | 276 | 40 | 0 |
| | | | | | Diptera | Muscidae | *Hydrotaea* sp. (s) | 0 | 1 | 1 | 0 |
| | | | | | Diptera | Phoridae | Unidentified (s) | 0 | 0 | 1 | 0 |
| | | | | | Diptera | Anthomyiidae | Unidentified (s) | 0 | 0 | 1 | 0 |
| | | | | | Coleoptera | Histeridae | *Saprinus* sp. (s) | 0 | 0 | 2 | 4 |
| | | | | | Coleoptera | Cleridae | *N. rufipes* (s) | 0 | 0 | 3 | 8 |
| | | | | | Coleoptera | Dermestidae | *Dermestes* sp. (s) | 0 | 0 | 31 | 141 |
| | | | | | Hymenoptera | Formicidae | *Pheidole* sp. (s) | 30 | 14 | 18 | 30 |

*S, carcasses exposed to sun; s, carcasses exposed to shade; *arthropod species identified*

**Table 2:** Summary of studies (1934–2017) on the diversity and abundance of carrion-feeding arthropods collected during different seasons in southern Africa

| Study | Country of study | Location of study | Objectives of study | Host animal | Outcome of study | | |
|---|---|---|---|---|---|---|---|
| | | | | | Order/family/species | Average number of carrion-feeding arthropods | |
| | | | | | | Dry season | Rainy season |
| Braack[37] | South Africa | Kruger National Park | To collect and identify the species found on the large mammal carcasses during both summer and winter | Impala | *Anisolabis* sp. | – | <10 |
| | | | | | *Bormansia meridionalis* Burr | – | <10 |
| | | | | | *Euborellia annulipes* (Lucas) | – | <10 |
| | | | | | *Fusius rubricosus* (Stal) | – | <10 |
| | | | | | *Lisarda rhodesiensis* Miller | – | <10 |
| | | | | | *Rhinocoris albopunctatus* (Stal) | – | <10 |
| | | | | | *R. violentus* (Germar) | – | <10 |
| | | | | | *Xylocoris (Proxylocoris) afer* Reuter | – | ±60 |
| | | | | | *Solenostethium liligerum* | – | <10 |
| | | | | | *Metagonum* sp. | – | <10 |
| | | | | | *Platymetopus curtulus* (Peringuey) | – | <10 |
| | | | | | *Xenodochus melanarius* (Boheman) | 662 | <10 |
| | | | | | *Histeridae* | – | – |
| | | | | | *Fabricius* | – | 265 |
| | | | | | *Staphylinidae* | – | 625 |
| | | | | | *Trogidae* | – | 422 |
| | | | | | *Allogymnopleurus thalassinus* (Klug) | – | <30 |
| | | | | | *Anachalcos convexus* (Boheman) | – | 164 |
| | | | | | *Aphodius* sp. | – | <100 |
| | | | | | *Caccobius convexifrons* (Roth) | – | <30 |
| | | | | | *C. nigritulus* (Klug) | – | <30 |
| | | | | | *Catharsius philus* (Kolbe) | – | <30 |
| | | | | | *Copris amyntor* (Klug) | – | <30 |
| | | | | | *C. elphenor* (Klug) | – | <30 |
| | | | | | *C. evanidus* (Klug) | – | <30 |
| | | | | | *C. mesacanthus* (Harold) | – | <30 |
| | | | | | *Garreta nitens* (Olivier) | – | <30 |
| | | | | | *Gymnopleurus virens* (Erichson) | – | <30 |
| | | | | | *Metacatharsius opacus* (Waterhouse) | – | <30 |
| | | | | | *Milichus* sp. *probably apicalis* (Fahraeus) | – | <30 |
| | | | | | *Onitis fulgidus* (Klug) | – | <30 |
| | | | | | *O. granulisetosus* (Ferreira) | – | <30 |
| | | | | | *O. inversidens* (van Lansberge) | – | <30 |
| | | | | | *O. obenbergeri* (Balthasar) | – | <30 |
| | | | | | *O. picticollis (Boheman)* | – | <30 |
| | | | | | *Onthophagus (Proagoderus) dives* (Klug) | – | 670 |
| | | | | | *Pedaria* sp. | – | <30 |
| | | | | | *Phaeochrous madagascariensis* (Westwood) | – | 486 |
| | | | | | *Phalops ardea* (Klug) | – | <30 |
| | | | | | *Sarophorus costatus* (Fahraeus) | – | 304 |
| | | | | | *Scarabaeus ebenus* (Klug) | – | <30 |
| | | | | | *Sisyphus calcaratus* (Klug) | – | <30 |
| | | | | | *S. goryi* (Harold) | – | <30 |
| | | | | | *S. impressipennis* (van Lansberge) | – | <30 |
| | | | | | *S. injuscatus* (Klug) | – | <30 |
| | | | | | *S. seminulum* (Gerstaecker) | – | <30 |
| | | | | | *Sybax distortus* (Schaum) | – | <30 |
| | | | | | *Tiniocellus spinipes* (Peringuey) | 191 | <30 |
| | | | | | *Dermestes maculatus* (De Geer) | – | – |
| | | | | | *Necrobia rufipes* (De Geer) | – | 572 |
| | | | | | *Phloeocopus* sp. | – | 1 |
| | | | | | *Carpophilus* nr. *quadrisignatus* Er. | – | <10 |
| | | | | | *Carpophilus* sp. | – | <10 |
| | | | | | *Bactria* sp. | – | <10 |
| | | | | | *Euscelidia rapax* (Westwood) | – | <10 |
| | | | | | *Hoplistomerus nobilis* Loew | – | <10 |
| | | | | | *Neolophonotus (Lophopeltis)* sp. | – | <10 |
| | | | | | *Ommatius* sp. | – | <10 |
| | | | | | *Stichopogon caffer* (Hermann) | – | <10 |

Table 2 continues...

...Table 2 continued

| Study | Country of study | Location of study | Objectives of study | Host animal | Outcome of study | | |
|---|---|---|---|---|---|---|---|
| | | | | | Order/family/species | Average number of carrion-feeding arthropods | |
| | | | | | | Dry season | Rainy season |
| | | | | | *S. punctus* (Loew) | – | <10 |
| | | | | | *Crossopalpus* n. sp. | – | <10 |
| | | | | | *Hypocerides spinulicosta* (Beyer) | – | <10 |
| | | | | | *Megaselia curtineura* | – | <10 |
| | | | | | *Megaselia* sp. n. *pauculitincta* | – | <10 |
| | | | | | *Plethysmochaeta* sp. | – | <10 |
| | | | | | *Australosepsis niveipennis* (Becker) | – | <50 |
| | | | | | *Paratoxopoda depilis* (Walker) | – | 97 |
| | | | | | *Xenosepsis* sp. | – | <50 |
| | | | | | *Piophilidae* | – | 849 |
| | | | | | *Cestrotus* n. sp. | – | <10 |
| | | | | | *Homoneura (Keisomyia)* n. sp. | – | <10 |
| | | | | | *Curtonotum cuthbertsoni* (Duda) | – | <10 |
| | | | | | *Sphaeroceridae* | – | 223 |
| | | | | | *Chlorichaeta albipennis* (Loew.) | – | <10 |
| | | | | | *Discomyza eritrea* (Cresson) | – | <10 |
| | | | | | *Mosillus beckeri* (Cresson) | – | <10 |
| | | | | | *Apotropina* n. sp. | – | <40 |
| | | | | | *Chloropsina* sp. | – | <40 |
| | | | | | *Conioscinella* sp. | – | <40 |
| | | | | | *Oscinella* sp. | – | <40 |
| | | | | | *Siphunculina ornatifrons* (Loew) | – | 250 |
| | | | | | *S. punctifrons* (Sabrosky) | – | <40 |
| | | | | | *Siphunculina* sp. | – | <40 |
| | | | | | *Desmometopa m-nigrum* (Zetterstedt) | – | <40 |
| | | | | | *Leptometopa latipes* (Meigen) | – | <40 |
| | | | | | *Leptometopa* n. sp. | – | <40 |
| | | | | | *Meoneura* n. sp. | – | 574 |
| | | | | | *Milichiella lacteipennis* (Loew) | – | <40 |
| | | | | | *Muscidae* | – | 289 |
| | | | | | *Fannia leucosticta* (Meigen) | – | 1 |
| | | | | | *Graphomya leucomelas* (Wiedemann) | – | 1 |
| | | | | | *Gymnodia mervinia* (Walker) | – | 5 |
| | | | | | *Gymnodia tonitrui* (Wiedemann) | – | 3 |
| | | | | | *Haematobosca latifrons* (Malloch) | – | 1 |
| | | | | | *H. spinigera* (Malloch) | – | 6 |
| | | | | | *H. thirouxi ssp. potans* (Bezzi) | – | 7 |
| | | | | | *Morellia nilotica* (Loew) | – | 3 |
| | | | | | *Ophyra capensis* (Wiedemann) | 47 | 303 |
| | | | | | *Lucilia* sp. | – | – |
| | | | | | *Nasonia vitripennis* | – | <40 |
| | | | | | *Trichopria lewisi* (Nixon) | – | >35 |
| | | | | | *Lardoglyphus* sp. | – | <100 |
| | | | | | *Macrocheles muscaedomesticae* | – | <100 |
| | | | | | *Pygmephorus* sp. | | <100 |
| Ellison[38] | South Africa | Klaserie Private Nature Reserve | The effect of scavenger mutilation on the subsequent rate of decomposition and insect colonisation of such carcasses | Impala | *Saprinus* spp. | 1.3 | – |
| | | | | | *Necrobia rufipes* | 6.6 | – |
| | | | | | *Dermestes maculatus* | 9.2 | – |
| | | | | | *Aleochara* spp. | <1 | – |
| | | | | | *Thanatophilus* spp. | <1 | – |
| | | | | | *Mycetophagidae* spp. | <1 | – |
| | | | | | *Onthophagus* spp. | <1 | – |
| | | | | | *Piophila* spp. | 36.5 | – |
| | | | | | *Ophyra capensis* | 3.4 | – |
| | | | | | *Musca* spp. | 10.9 | – |
| | | | | | *Chrysomya albiceps* | 3.4 | – |
| | | | | | *Chrysomya chloropyga* | <1 | – |
| | | | | | *Chrysomya marginalis* | 4 | – |
| | | | | | *Chrysomya putoria* | <1 | – |
| | | | | | *Tricyclea* spp. | 9.7 | – |
| | | | | | *Lucilia* spp. | 11 | – |
| | | | | | *Sarcophaga* spp. | 0.75 | – |
| | | | | | *Auchmeromyia luteola* | 0.25 | – |
| | | | | | *Ceratophaga vastella* | <1 | – |
| | | | | | *Brachynieria* spp. | <1 | – |
| | | | | | *Acrididae* spp. | <1 | – |

*–, None present or identified*

to the sun, whereas *Pheidole* spp. persisted throughout the four stages of decomposition on the carcass exposed to the sun. Similarly, *L. cuprina*, *C. albiceps* and *M. domestica* species visited the carcass in the shade during the fresh stage and persisted during the bloated and decay stages, but then disappeared during the dry stage. *Saprinus* spp. and *Dermestes* spp. visited the carcass in the shade only during the decay and dry stages, whereas *Pheidole* spp. visited the carcass in the shade throughout the four stages of decomposition. It was further observed that *N. rufipes* only visited the carcass exposed to the sun during the dry stage but persisted during both decay and dry stages on the carcass in the shade. Similarly, *Hydrotaea* spp. appeared on the carcass exposed to the sun during the dry stage only, but during both bloated and decay stages of the carcass in the shade. However, *Sarcophangidae* spp. and *Drosophilia* spp. persisted during the decay stage only on the carcass exposed to the sun. In the study of Kelly et al.[36], *L. cuprina* and *C. albiceps* visited the carcass only during the bloat stage, whereas in Mabika et al.'s[26] study, *L. cuprina* and *C. albiceps* persisted during the fresh, bloated and decay stages. Furthermore, in both studies, *Dermestes* spp. visited the carcass during decay and dry stages only.

### *Seasonal abundance and diversity of carrion-feeding arthropods*

There was an observed difference in the abundance and diversity of arthropods colonising impala carcasses during different seasons (Table 2). More arthropod species were identified during the rainy season[37] than the dry season[38]. *Necrobia rufipes* was found on the carcass during the dry season by Ellison[38]; however, Braack[37] found and identified the same species during the warm season. In both studies, *D. maculatus and Lucilia* spp. were found on decomposing carcasses during the dry season only.

### *Diurnal and nocturnal oviposition of forensically important insect species*

While attempting to determine the nocturnal oviposition behaviour of blowflies in the southern hemisphere, Williams et al.[39] found that *Lucilia* spp., *Chrysomya putoria* and *C. chloropyga* laid eggs during the day and night (Table 3). However, *Chrysomya megacephala* laid eggs only during the day and at a lower rate than the above-mentioned species. For all species, oviposition rate was generally higher during the day than at night.

## Discussion

To date, there has been limited research published on forensic entomology in southern Africa – a finding supported by the review by Villet et al.[6] on the history of forensic entomology Available studies are limited to identification of insect taxa found on carcasses during different stages of decomposition, and presumably this information can then be used in determining PMI.[26] Several factors affect the rate and pattern of decomposition, and thereby influence the abundance and diversity of arthropod species found colonising the carcass[40], which in turn affects the accuracy of PMI and consequently any legal investigation[11]. These factors include season, temperature, geographical distribution and vertebrate class (category) studied.[26,41]

### *Arthropod diversity during different stages of carcass decomposition*

Different stages of decomposition of a carcass attract different arthropod species. Kelly et al.[17] observed and described these stages as follows:

1. Fresh stage – the stage commencing directly after the animal is killed, characterised by a soft torso and flexible limbs. This stage is very short and associated with no odour.
2. Bloat/bloated stage – this stage is when the torso begins to harden and the abdomen becomes inflated as a result of a build-up of gases. The carcass appears like a balloon, and the body colour changes. Oviposition by arthropods takes place during this stage.
3. Decay stage – at the beginning of this stage, the carcass is deflated as a result of maggots feeding on the carcass tissue which consequently allows gases to be released. Limbs collapse into the resting position, and the skin begins to peel, allowing maggots to feed underneath. At the end of this stage, little tissue remains on the carcass and thus the bones of the skull, ribs and legs are often visible.
4. Dry stage – this stage is characterised by little to no moisture. The gut contents are dried out, with only hair and small patches of skin remaining.

Mabika et al.[26] observed that *L.a cuprina*, *C. albiceps* and *M. domestica*, from the families Calliphoridae and Muscidae, were the first to colonise rabbit carrion during the first three stages of decomposition (fresh, bloat and decay stages). However, these species were found only during the bloated stage of a pig carcass.[36] Results were consistent with a report by several authors that species from the Calliphoridae and Muscidae families are the first to colonise any carcass as the tissue is still soft[41-44], and the arthropod species from these two families can potentially be useful in the estimation of PMI and determining clues in cases of criminal investigations[41]. The difference in arrival pattern and colonisation time of the same arthropod species on different carcasses of different animal species as observed by Kelly et al.[36] and Mabika et al.[26] could be associated with the difference in body size[22]. According to Sutherland et al.[45], smaller animals decompose faster than larger animals and this faster decomposition leads to earlier attraction of arthropods. This in turn influences the sequence of arthropod colonisation, hence, *L. cuprina*, *C. albiceps* and *M. domestica* were found during the fresh, bloat and decay stages of a rabbit[18] but only at the bloating stage of a pig carcass[36].

The environmental or physical conditions (sun, shade, buried, housed) under which a carcass is disposed of also influence the type of arthropods arriving and colonising the carcass.[40] For instance, Mabika et al.[26] observed that *N. rufipes* colonised a carcass exposed to the sun during the dry stage but were found during both decay and dry stages of a carcass in the shade. *Hydrotaea* spp. were also found on the carcass exposed to the sun during the dry stage but were found during both bloated and decay stages of the carcass in the shade. This variation in insect arrival and colonisation pattern may be because of the difference in relative temperature and humidity – higher temperature and lower humidity lead to chemical reactions that often result in faster decomposition of the carcass.[41] *Pheidole* spp. (Family: Formicidae) were found throughout the decomposition stages.[26] Although Morreti et al.[46] showed that these species feed on both carcasses and maggots, they do not affect the decomposition process[26].

### *Seasonal abundance and diversity of carrion-feeding arthropods*

The abundance and diversity of arthropod species seem to vary with seasons.[37] Braack[37] collected and identified more arthropod species during the rainy (summer) season than during the dry (winter) season.

**Table 3:** Summary of the diurnal and nocturnal oviposition by forensically important arthropods on pig carcasses in southern Africa

| Study | Country of study | Location of study | Objective of study | Host animal | Outcome of study | | |
|---|---|---|---|---|---|---|---|
| | | | | | Species identified | Day | Night |
| Williams et al.[39] | South Africa | Grahamstown | To determine the nocturnal oviposition behaviour of blowflies in the southern hemisphere | Pig | *Chrysomya megacephala* | 1 | 0 |
| | | | | | *Lucilia sericata* | 8 | 1 |
| | | | | | *Chrysomya putoria* | 7 | 1 |
| | | | | | *Chrysomya chloropyga* | 2 | 1 |

This observation is congruent with that of Kelly et al.[36] and Parry et al.[47], who observed more arthropod species colonising carcasses during summer as compared to winter. The authors also observed that there were no other factors influencing the difference in abundance and the diversity of these arthropod species other than the change in season, which subsequently influenced temperature. For instance, the dry season is characterised by low temperatures, which consequently result in reduced arthropod activity, subsequently leading to a gradual decrease in the number of arthropods colonising carcasses.[48] Although PMI can still be estimated during the winter (dry) seasons, the reduction in the number of arthropod species present in this season often leads to difficulties in estimating the PMI accurately.[36]

The absence of certain species during a particular season is expected, as many species are specific to a season and geographical area or locality.[20] Arthropod species colonising an impala carcass, as observed by Braack[37] and Ellison[38], varied from season to season, with few exceptions. Ellison[38] surprisingly found *N. rufipes* colonising an impala carcass during the dry season, which was previously found by Braack[37] on an impala carcass during the warm (wet) season. Kelly et al.[36] found this species during both seasons. It can be suggested that the presence of this species during both seasons might be because it occurs throughout the year, as was observed and reported by Bensaada et al.[49] in Turkey. Furthermore, Ellison[38] and Kelly et al.[36] found *Dermestes maculatus* DeGeer *and Lucilia* spp. on decomposing carcasses during the dry season only. This observation contradicts that of Villet[20] who stated that although other *Dermestes* species such *D. peruvianus* and *D. haemorrhoidalis* are common in winter, *D. maculatus* and *Lucilia* spp. are typically common and more active in summer, and rare in winter. Therefore, knowledge of the seasonal occurrence of arthropod species is important as it provides useful information about which insect to expect during a given season, and is thus essential in determining PMI in forensic investigations.[24]

### *Diurnal and nocturnal oviposition of forensically important insect species*

Knowledge of the developmental stages of breeding arthropods on the carcass, estimating the date and time of egg or larva deposition, and taking into consideration the influence of environmental factors, can all assist in estimating the PMI of a carcass.[24,39] Williams et al.[39] observed that *Lucilia* spp., *C. putoria* and *C. chloropyga* species laid eggs during both the day and night, and *C. megacephala* only laid during the day. The authors observed that oviposition was higher during the day than night. This observation may have been due to the fact that ambient temperatures were very low at night, and according to Digby[50] and Nicholson[51], temperature is one of the important factors influencing flying activity. Williams[24] also observed that numerous blowfly species are unable to fly in ambient temperatures below 15 °C, and Richards et al.[52] observed that *C. marginalis*, *C. albiceps* and *C. chloropyga* were unable to fly in temperatures below 20.8 °C, 21.7 °C and 23 °C, respectively. Therefore, William et al.[39] concluded that the low number of species of arthropods colonising the carcass, and low oviposition at night, may have been due to lower temperatures and less light, which hindered the arthropod's ability to fly and lay eggs on the carcass. However, those species which were closer to the body were able to walk to the carcass, which explains why eggs from other arthropod species were found during the night.

In view of the above studies, arthropods can be an excellent source of evidence in forensic investigations. For instance, if the stage of a decomposing body is not known, it can be easily estimated by observing the species of arthropods colonising the carcass (i.e. *Dermestes* species can only be found during decay and dry stages). Furthermore, knowledge of seasonal occurrence of certain arthropod species provides useful information in determining PMI because arthropod species vary with season. Animal species also play a significant role in determining which arthropod species are attracted to them during different stages of decomposition. As such, there is need to document the variation of arthropod species attracted to different animal species in different geographical regions/locations. Lack of ideal tools for identification of arthropods to species level in southern African countries might have hampered the wide use of insects in forensic investigations. Although morphological tools have been widely used to identify important arthropod species for forensic studies, there are limitations. For example, morphological techniques require expertise in taxonomy and the ability to identify and differentiate arthropod species using identification keys which are lacking in many southern African countries. Furthermore, differentiation of some species at larval stage, using morphological approaches, is challenging. With the current advances in DNA technology, molecular tools are now available to facilitate species identification based on genetic examination. In view of the above, we can anticipate that estimates of PMI based on arthropod evidence will become more accurate and probably contribute to accurate interpretation and application of entomology data in medico-legal forensic investigation in southern Africa. Forensic entomology data or research have not been incorporated in cases of poaching, which are reported frequently in southern African countries including South Africa. Therefore, more studies need to be conducted and incorporated with available research so that research can be applied to solve cases of poaching of game animals. Additionally, occurrence of diurnal oviposition by carrion-feeding insects is well known, whereas there is still great debate about the occurrence of nocturnal oviposition, as most forensic entomologists assume that flies are nocturnally inactive. Therefore, future studies on nocturnal oviposition may be necessary, because a high number of deaths occur at night and nocturnal oviposition may be used in the determination of PMI.

## Conclusion

Although forensic entomology is useful in criminal investigations, it is still an emerging field in southern Africa. Studies completed to date have been limited to identification of insect taxa found on carcasses during different stages of decomposition, and this information can subsequently be used to determine PMI. Some of the research conducted in southern African on carrion-feeding insects was not undertaken in a forensic context; however, it has generated useful results which can be used as evidence in forensic investigations and improve the current status of forensic entomology in southern Africa. Nonetheless, future studies on the application of forensic entomology in various criminal investigation such as murder cases, human neglect, and the poaching of animals in southern Africa are recommended. Additionally, few studies have investigated nocturnal oviposition in southern Africa, despite many of deaths occurring at night and nocturnal oviposition therefore being applicable for the estimation of PMI.

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## Authors' contributions

D.T.: Collected the data and wrote the manuscript. S.M.: Conceptualised the idea, verified the data set used in the final analysis and participated in the revision of the manuscript.

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