ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 9 , September 2015

Historical approach of Forensic Entomology: A review

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I. INTRODUCTION

Forensic entomology is the analysis of insect evidence for forensic and legal purposes [1]. The most important task in the forensic investigation is the estimation of the minimum time since death [2,3]. Forensic entomology is the branch of forensic science in which information about insects is used to draw conclusions when investigating legal cases relating to both humans and wildlife, although the term may be occasionally expanded to include other arthropods as well. Insects can be used in the investigation of a crime scene both on land and in water [4-8]. The majority of cases where entomological evidence has been used are concerned with illegal activities which take place on land and are discovered within a short time of being committed. Gaudry *et al.* [9] commented that in France 70% of cadavers were found outdoors and of these 60% were less than 1 month old.

II. HISTORY OF FORENSIC ENTOMOLOGY

In China (13^{th} century), insects were first used in a forensic context. A farmer had been killed in a rice field with a sharp weapon. All the suspects were asked to assemble together and were told to place their sickles on the ground. No obvious evidence could be seen, but one sickle attracted numerous blow flies, apparently because of invisible traces of blood on the blade. The owner of the sickle, when confronted with this entomological evidence, confessed to the killing [10].

The applications of forensic entomology are numerous, encompassing any situation that may involve an interaction between insects and other arthropods, and the law. Therefore, the utility of the field is categorized under three separate headings: urban, stored product and medico legal forensic entomology [11,12].

Urban forensic entomology generally deals with the interaction of insects with man-made structures and other aspects of human society and may include the infestation of buildings by termites, cockroaches etc. [11], and the breeding of flies in livestock and similar facilities [13].

The stored product aspect of forensic entomology involves the infestation of stored commodities by insects. Infestations may include the harvesting and storage of crops and subsequent invasion by an insect pest and domestic invasion of kitchen products. This aspect also encompasses the infestation of food sold by retailers to the public, which may result in prosecution and substantial fines [13].

III. POST MORTEM INTERVAL (PMI)

The most accepted aspect of forensic entomology is assuredly the medico legal aspect. Forensic entomology intends to establish the time of death, known as postmortem interval (PMI), or more precisely, how long a carrion has been exposed in the environment. By analyzing the parameters like, body temperature or *livor* and *rigor mortis*, time since death can only be correctly estimated for the first 2 to 3 days after death. On the other hand, by calculating the age of insect immature stages feeding on a corpse and analyzing the necrophagous species present on a cadaver, PMI from the first day to many days can be calculated [14]. Hall and Haskell [15] and Megnin [16] proposed that PMI can be determined by knowing the life cycle of insect species and by evaluation the insect succession waves present on the corpse at any given time.

During medieval times, beyond the medical and legal experts, sculptors, painters and poets have closely observed the decomposition of human bodies and made realistic and detailed illustrations of corpse containing maggots [17]. Redi [18] studied the colonization of rotting meat by flies. He concluded that the generally accepted spontaneous generation of maggots from meat was actually a result of infestation by adult flies, based on observations of rotting meat whether open to or protected from fly activity. This represented a significant breakthrough in our understanding of insect involvement in decomposition [11]. Yovanovich [19] and Megnin [16] were the first forensic examiners who tried to evaluate insect succession on corpses, establishing properly the science of forensic entomology [20]. Megnin [16] published his most important book *La Fawne des Cadavers*: *Application de l'Entomologie à la Médicine Légale* in which he explained his theory of eight successions. He also described the morphological features of various classes of insects that helped in their identification [21].

ISSN: 2350-0328

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Reinhard [22] reported the first systematic study in forensic entomology on 6th April, 1881. Dealing with exhaumated bodies from Saxonia, he collected mainly Phorid flies. He also described beetles in graves older than 15 years. In some instances, he found the insects breeding within cracks of adipocire. However, he concluded that their presence may have more to do with their feeding on plant roots protruding into the graves rather than any direct association with the corpse. Reinhard's work remained well known for a long time and an extensive citation of his paper appeared in the work of the Phorid fly expert Schmitz [23] and elsewhere [24-26]. The metamorphosis of insects had become more commonly understood during the 17th century [27] and in the beginning of the 19th century it was observed that flies were attracted to corpses at a very early stage of decomposition. Mende [28] compiled a list of necrophagous insects, including flies and beetles as well as other taxa. Orfila and Lesueur [29] provided a more precise account, but did not link flies to the time of death. Krahmer [30] described the opportunities and problems associated with using insects for the estimation of the PMI, many of which are still relevant today [20].

The first application of forensic entomology in a French courtroom (in 1850) can be viewed as a breakthrough for this discipline [31]. Skeletonized remains of a child were found behind a chimney by workmen during redecoration. Insect evidence was accepted as proof that the current occupants of the building could not have been the murderers. However, in that case, the forensic examiner was of the opinion that the development of the adult flies took about one year; clearly his results would be questionable today. At that time, forensic examiners had only a poor understanding of insect biology and their knowledge was based largely on casual observations. Although Weismann [32] published development data for two necrophagous fly species at that time this was not widely noted by the forensic community. In the following years, side issues such as grave fauna [22,23], the skeletonizing of corpses [33,34], or modification of corpses caused by insects [35] were explored, but data concerning the biology, ecology and succession of necrophagous insects were not applied to forensic cases [36]. Leclercq and Leclercq [37], Leclercq [38,41], Nuorteva [42,43], Nuorteva *et al*. [44,45], Leclercq and Brahy [46] and Leclercq *et al*. [47] were among the first to use forensic entomology for the determination of the PMI in Europe.

In the 20th century, insects were shown to be of value in court cases involving insect colonization of body parts recovered from water and not just whole corpses found on land. On 29 September 1935, several body parts, later identified as originating from two females, were recovered from a Scottish river near Edinburgh. The identities of the deceased were determined and the women were named as Mrs Ruxton and Mary Rogerson, 'nanny' for the family. The presence of larvae of the blowfly *Calliphora vicina* Robineau-Desvoidy, in their third larval instar, indicated that the eggs had been laid prior to the bodies being dumped in the river. This information, combined with other evidence, resulted in the husband, Dr Ruxton, being convicted of the murder of his wife and Mary Rogerson [3].

The field of forensic entomology was revived by researchers such as Reiter and Wolleneck [48-50] and Reiter [51] in studies of the development of the common necrophagous fly *Calliphora vicina* and by several others [3,52-62]

Keh [63] reported in his review paper that forensic entomology was introduced as corroboration to methods used by forensic pathologists for approximating the time of recent death, as other methods such as body temperature, *livor* or *rigor mortis* and stages of decomposition are limited in their power. In 1992, a second review on forensic entomology was published [64]. At that time, two books dealt specifically with forensic entomology [65,66]. The book published by Smith [65] is till today one of the most important books on the topic including an identification key to several arthropod families associated with carcasses. Catts [2] states that several case reports were published since 1985, showing the applicability of the field.

IV. SUCESSIONAL PATTERNS OF INSECTS AND PMI

Norris [67] observed that experiments are inevitably carried out under conditions different from those in nature and that small differences can significantly alter the outcome. Blow flies respond differently to butchered meat as compared to natural carrion. The size of carrion and the species of animal used may also affect blow fly behavior. Animals with fur are oviposited on by blow flies more readily than are bare pieces of meat [68]. Insects are often reared in laboratories under constant temperature and humidity to determine time required for their development, but in nature fluctuating temperature, which may hasten, retard, or have no effect on speed of development, are more often encountered [63,69]. Payne [70] placed thawing carcasses of baby pigs outdoors in summer in rural South Carolina, sarcophagids were on the carcasses within five minutes and calliphorids, chiefly *Cochliomtia macellaria*, within 10 minutes [71]. Payne and King [72] recorded 202 species of Coleoptera alone from pig carcasses located in a limited geographic area. Studies of arthropods associated with animal carcasses consistently omitted concurrent observations on ectoparasites [65,73]. Payne and Mason [74] showed that certain species of Hymenoptera that were recovered from pig carcasses were determined according to the carcasses being exposed to air (on ground or in tree), buried or in water,

ISSN: 2350-0328

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an observation that shows that certain species may be ecological indicators of where the animal was placed [63]. Broadhead [75] found the nematoceran, *Trichocera saltator* in a corpse during an extremely cold period of the year. No trichocerids were known as necrophages until Erzinclioglu [76] studies the larvae of *T. annulata* found in a corpse, determined their developmental time, and established these flies as possible indicator of the time of death of a person during winter months when few other insects are active. Predators and parasitoids are very mixed group of arthropods whose potential for forensic information has not been well studied. Predators may be so voracious as to eliminate competing species. A hymenopterous parasitoids of Diptera *Nasonia vitripennis*, was found in fly pupae taken from a corpse [77].

Insects are usually the first organisms to arrive on a dead body, and they colonize in a predictable sequence. A dead body, whether human or animal, is a large food resource for a great many creatures and supports a large and rapidly changing fauna as it decomposes [78]. Dead body progresses through a recognized sequence of decomposing stages, from fresh to skeletal, over a period of time. A corpse goes through physical, biological and chemical changes during its decomposition [79-81].

There is an organized pattern in the successional development of insect fauna on carrion worldwide, but way of the pattern may vary enormously between geographical regions and from one locality to another [82,83]. Carrion, dead or decaying flesh, serves as a breeding and feeding habitat for carrion feeding insect species; therefore, when an organism dies, it remains form an important habitat [84,85]. The most common fly species is the blow fly [86,87], in addition to the blow fly, flesh flies (*Sarcophaga* sp.) also feed on carrion and lay live larvae on decaying matter [88,89] and are found everywhere in various environmental conditions. There are number of studies on carrion breeding Diptera which shows that species specialize along niche dimensions of season, carcass size, or state of decomposition [88,89].

Insects colonize a corpse in a definite fashion; so, both the presence and absence of a species may indicate PMI [90-95]. Factors that appear to influence succession pattern include the illumination of the scene, size of the cadaver, time of the year and type of habitat [20,96-98]. Succession research is extremely labor intensive. It is difficult to produce replicated data suitable for a traditional type of statistical confidence interval about a PMI estimate [99,100]. Computer resampling methods [100,101] may overcome this limitation. Therefore, there is a great opportunity to increase such computer intensive applications in succession research. It has long been observed that the adults of different carrion fly species differ in preference for habitat type [67,99]. Therefore, it may be possible to determine that a corpse was moved following death, if the immature insects in a corpse are not typical of the site where the body occurs [20,100].

Amendt *et al*. [99] moved piglet carcasses between rural and urban sites in Germany, following one week of exposure to insect colonization, while leaving others in place. Although no carrion insect species was unique to a habitat, habitat specific difference in the proportion of each species infesting a piglet could identify the habitat in which a carcass was first colonized. However, the experiments demonstrate that caution must be used in determining whether remains have been moved based solely on entomological evidence.

PMI refers to the time between the death and discovery of a corpse [2,3]. There are several natural processes associated with decomposition, such as *rigor mortis* or *livor mortis*, that can be used to estimate the PMI [3,100,101], but many of these are reciprocal functions and become inaccurate in application very quickly [3,102]. Furthermore, they are limited to the first 72 h after death [3,100]. However, during that 72 h and well beyond, insects can be a very powerful tool for estimating the minimum time since death. Depending on the level of accessibility and environmental conditions, necrophagous insects will promptly colonize a fresh corpse.

Usually the first taxa to arrive on a body are flies (Diptera), mainly blow flies and flesh flies. They can locate an odor source with great spatial precision and deposit their eggs on a corpse within few minutes [79,103] or even few seconds [104] after death.

By the beginning of the 21st century, forensic entomology had been accepted in many countries like Australia [105-110], Brazil [111], Canada [112], China [113-118], France [119], Germany [120-121], Hungary [122], India [123], Italy [124,125], Japan [126], Korea [127,128], Malaysia [129,130], Pakistan [131], Poland [132], Portugal [133], South Africa [134], Thailand [135], Taiwan [136], UK [137] and USA [138-143], as an important forensic tool. Singh *et al.* [144] have provided an extensive review of forensic entomology. Apart from the two books mentioned already more books have been published dealing extensively with the subject [78, 97,145-150].

ISSN: 2350-0328

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V. INDIAN HISTORY OF FORENSIC ENTOMOLOGY

Forensic entomology in India as authors emphasized in its infancy state and very few workers are pursuing their research in this field. Mackenzie (Indian Medical Gazette, 1889) has done the earliest work, in which he made observations on dead bodies about the times of appearance of eggs and maggots. Dr. Pankaj Kulshrestha of Medico Legal Institute, MP has published few papers in case studies of post mortem interval estimation based on flies infesting human corpses [151-153]. Dr. Devinder Singh (Second author) has done a lot of work on various aspects of this field. He worked with Dr. Bernard Greenberd, pioneer in the field of Forensic entomology, at University of Illinois at Chicago. Singh and Greenberg [154,155] identified the blow flies on the basis of egg morphology and studied the survival after submergence in five species of blow flies. Senior author has been the Principal Investigator in a major research project sponsored by Department of Science and Technology, Government of India (1998-2001).

Life history, bionomics and reproduction behavior of blow flies *C. megacephala*, *C. rufifacies* and *Lucilia cuprina* was studies by Subramanian and Mohan [156]. Rao et al. [157] carried out experiments on the developmental stages of the maggots to estimate time since death. Kashyap and Pillay [156,159] proved that entomological method is important than other methods for estimating post mortem interval by observing sixteen infested cadavers.

Bharti and Singh [160] carried out insect faunal succession on decaying rabbit carcasses at Punjabi University, Patiala (Punjab), India, from March 1997 to December 1999. They recognized four stages of decomposition, i.e., fresh, bloated, decay and dry. A total of 38 insect species belonging to 4 orders and 13 families were recorded. Diptera, Coleoptera and Hymenoptera dominated the carrion fauna. Calliphorids were the first to arrive in all the seasons of the year. Five species of Calliphoridae, four of Sarcophagidae, ten of Muscidae, and one each from Anthomyiidae and Otitidae were observed on rabbit carcasses. Representatives of six Coleopteran families, i.e., Staphylinidae, Histeridae, Cleridae, Dermestidae, Tenebrionidae, and Silphidae, were recorded. Eight species belonging to family Formicidae (Hymenoptera) and only one species of order Lepidoptera were recorded on carrion. Gupta and Setia [21] described the past, present and future status of Forensic entomology in India. Singh and Bharti [161] studied the nocturnal oviposition behavior of Indian species blow flies. Bharti and Singh [162] demonstrated the succession pattern of insect species on rabbit carcasses.

VI. CONCLUSION

It is evident from the foregoing discussion that the field of molecular forensic entomology has been rapidly growing around the world for the last fifteen years. Forensic entomology has a better position in countries like America, Canada, Europe, Australia and South East Asia. The status of forensic entomology in India is quite encouraging and it is desirable to focus on this field in future. A lot of work still has to be done in India to make this field good enough to be utilized in the medico-legal investigations. So, future workers from Science and Law background are hereby strongly encourage to choose this wonderful field in their respective research endeavors.

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