

Chapter 69

Forensic Entomology

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Forensic entomology, in the broad sense, is the term applied to the use of entomological (insect) evidence in courts of law. This broad definition includes entomologists who are able to testify about subjects pertaining to proper uses of chemicals or other pesticides, control of fly populations in animal waste, damage to structures from insects, or the contamination of food by insects. These cases are usually adjudicated in civil courts. A more specific meaning of forensic entomology, and that which is focused on in this text, is the use of insects during investigation of crimes or other legal matters where the forensic entomologist will culminate his or her investigation with a report or testimony in court.

In most of these cases, the forensic entomologist becomes involved with the legal system after the initial discovery of a dead body or other crime. This is due to the insects being important in establishing time of death in many cases. It is when the medical examiner/coroner, police, or prosecutor needs additional information regarding insect evidence noticed on the body or at a crime scene, that the forensic entomologist is usually contacted. This is the most desirable scenario from the standpoint of the forensic entomologist, due to the ability of the insect expert to do his or her own recovery of insect evidence at the scene (if called in a timely fashion) or at the very least for a collection to be made during autopsy. The expert is able to gather supporting documentation and request other investigators for help in that quest, to calibrate the microenvironment where the insects were recovered (the scene) with weather stations, and to do additional laboratory studies using live insects freshly recovered from the remains or from the scene.

Secondly, the forensic entomologist may be contacted by the death investigators days, weeks, or even months after a crime has been committed. This is often the case when it was initially determined by the investigators that there was an obvious suspect, or the elements of the crime were known, but then they discovered later that little of the above was actually what had happened. When involved in this way, the forensic entomologist is faced with a greater challenge due to not having the opportunity to collect personally, thus being dependent on others who may have little or no training in recognition or recovery of insect evidence. When significant time has passed,

environmental conditions may have changed considerably, so confirmation of climatic conditions at the scene may be impossible. Also, if insects were collected, most often they will be dead, so laboratory rearing for species identification accuracy will be impossible.

The third means by which the forensic entomologist becomes involved is being hired as an expert witness by either the prosecution or defense after charges have been filed. In some cases, the interval of time between being retained and the trial may be as short as 1½ or 2 weeks. This situation presents even greater challenges for the forensic entomologist: first to come up to speed with the case itself, then to educate the trial attorneys on entomology. Insect evidence may be minimal or lacking, supporting documentation may be unobtainable, or time is just not adequate to do the necessary testing and research in order to obtain the most precise results possible. In addition, there may be an opposing forensic entomology expert who has had weeks or months to prepare for the case. Additional preparation of the attorneys regarding the opposing expert (his transcripts, publications, or presentations pertinent to his testimony) is essential if effective cross-examination of the witness is to be accomplished.

Whichever way the forensic entomologist is engaged for the case, the task is to determine what entomological evidence is present and what data are available from the literature or from personal experience for the kind of insects (groups or species) recovered. Once this information is obtained, the forensic entomologist must determine what results and conclusions may be drawn from the combination of the insects and the known information regarding those insect groups. A concise but detailed and well-written report is often the end of involvement in the case. However, continuation of the case as the forensic entomology expert in the courtroom may be an alternative role necessary to answer questions as to the guilt or innocence of a defendant.

It is essential that the forensic entomologist be unbiased regarding the analysis of the entomological evidence. This evidence is derived from a very powerful quantitative scientific methodology gathered by hundreds of researchers over decades of studies, observations, and testing. It must be emphasized that it is not the responsibility of the forensic entomologist to determine the guilt or innocence of the

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person on trial. The forensic entomologist's only responsibility is to present the conclusions as accurately, honestly, and clearly to the jury as is possible. The criminal justice system is responsible for the judgment.

BRIEF HISTORY

The use of entomology in death investigations dates originally to a thirteenth-century record of a murder where adult blowflies were attracted to the one hand sickle used to kill a Chinese peasant farmer among more than a dozen hand sickles placed upon the ground by other suspects. It became obvious in a matter of minutes which hand sickle retained bits of human tissue, blood, and hair because of the numerous flies orbiting around the murder weapon for a taste of the victim. The owner of the implement soon confessed to the murder.¹

Reliability in insect growth, development, behavior, and habit proved itself again and again over the following centuries in many experiments regarding questions of spontaneous generation,² insect colonization of decomposing human remains in a successional pattern,^{3,4} and studies on meat contamination and livestock loss due to parasitic blowflies.⁵⁻⁹

Documentation of human death studies records a case from France in the 1850s being solved using the colonization of beetles.¹⁰ A famous case from England in the 1930s gave prominence to the maggots that helped prove that Dr. Ruxton had ample opportunity and time to kill his wife and housekeeper and return to his home within an allotted time frame.¹¹ It became apparent during the early 1930s that solving murders would benefit by knowing specific information about certain insect groups. J. Edgar Hoover requested work to begin on a monograph focusing on what has become the chief insect indicator group, the blowflies (Diptera: Calliphoridae).¹² It was not until 1948, however, that this work was completed and published by D.G. Hall under the title of *The Blowflies of North America*.¹³ This volume satisfied two major needs in entomology, one being the use in death investigation and the other in reducing excessive livestock losses in the southern latitudes of the United States by the primary screw worm (*Cochliomyia hominivorax*).

Due to the pressures of the economic losses caused by this fly, increased research funding was applied to solving this major problem.^{6,7,14,15} Vast amounts of data were gathered on this specific species and many of the other closely related blowfly species that cohabitated with *C. hominivorax*. This progression of studies resulted in the most successful biological control and eradication of an insect species in history. After intensive study of the species, it was discovered that there were actually two species of flies (*Cochliomyia hominivorax* and *Cochliomyia macellaria*),⁵ in one of which (*C. hominivorax*) the female only mated once. This information indicated that if males could be sterilized, unfertilized eggs would result. This technique was tested in Florida in the mid-1950s and was a great success. A national plan was implemented where tens of millions of male *C. hominivorax* were produced, sterilized, and released.¹⁶ Within the past 40 years of this program's application,

the primary screw worm has now been eradicated as far south as Costa Rica. The serendipitous outcome of this intensive research over the past 70 years has been able to provide much knowledge regarding the blowflies, which just happen to be the first insects to colonize dead animal carrion (humans included). Because of this focus on the economic aspects of losses in our livestock industry, forensic entomology is now decades ahead of where it would have been without this early work.

SCIENTIFIC PERSPECTIVE AND PRINCIPLES OF APPLICATION

The basic principles used in most applications where insects are employed to answer questions at a death scene are decades-old, reliable principles of insect behavior, growth, development, and habit. This is due to nearly two and a half centuries of study by hundreds of naturalists, biologists, and entomologists. In a series of studies by Megnin in France in the late nineteenth century,³ it was observed that as a human body or other animal decomposed, there was a predictable progression to the decomposition. The body changes from a freshly dead condition into a bloated state, then to active decay where body fluids begin to seep from the remains. As more time passes, the body begins to dry out with the fluids becoming more greaselike, and eventually the body dries to the point where any tissues remaining are stiff and leathery. This last bit of mummified tissue eventually disappears until only dry bones remain. It was also noted by Megnin that along with these major physical changes in the human tissues, the tissues were also changing biochemically. These biochemical changes are the cause of another critical observation that Megnin made. As the biochemicals change, there is a corresponding change in the insect groups and species that appear on the body over the course of the decomposition.

Megnin identified eight specific seral (meaning sere) waves of insects coming to the body, colonizing it for a period of time, and then leaving. With this sequence of insects moving onto the body, feeding for their specific periods of time in the decomposition progression, and then leaving when the tissues had changed biochemically so as not to be attractive to that insect group any longer, it was possible to utilize the food resource entirely. Today, this is known as food (or resource) partitioning. Over the last century, many studies have been conducted on the progression of decomposition of humans and animals from a wide range of different environments and habitats.¹⁷⁻³⁴

This sequence or seral wave progression (insect succession) is used today as one of the two major methods of estimation of the time since death or postmortem interval (PMI). What has been learned from the many studies on insect succession is that the timing of the insect groups can be variable given the geographic location (which may be a function of temperature), season of the year (again temperature-related), and habitat. It is important to recognize that in nearly all the studies, even with differing temperatures, varying habitats, diverse geographic locations, and different seasons of the year, the sequence of the insect groups

and species (insect taxa) moving onto the carrion (decomposing soft tissues), colonizing the carrion, and then leaving the carrion, were consistent.¹⁷⁻³⁴ Therefore, if experiments are conducted during different seasons at specific geographic locations within specified habitats, it is possible to obtain very reliable time intervals on how long a dead body has been exposed to the insects. This insect succession method is used when remains have been exposed for long periods of time, such as for weeks or more during summers in the upper latitudes of the United States or for months of exposure during cooler times of the year. This method can be very accurate, but not as precise as the second method used for estimation of the PMI.

The second method used by entomologists for estimation of the time of death is the use of an insect's known growth and development time for a specific species. This is primarily applied to the fly group (Diptera), but not exclusively. As discussed in the historical section above, it is fortunate that much of the early twentieth-century research focused on the blowflies. Since those early years of fly biology research, a resurgence of fly research in the last 40 years has continued to focus on individual species growth and development rates for developing growth tables for several of the most common species of flies to colonize human and animal remains.³⁵⁻⁴¹ These later studies are becoming more sophisticated regarding temperature variability and the establishment of statistical limits. This area of research is still one of the most needed areas of data when considering cases from across North America.

The underlying principle in using this means of estimating the PMI is that the blowflies (most species in the group) will colonize immediately upon death if the remains are exposed for access by the flies and the temperatures are above the lower limit flight threshold for the species involved. Also, due to the successional preferences of the different groups, the blowflies will only have one generation developing from any given human or animal remains. This does not mean that there cannot be eggs deposited (oviposition) on a number of successive days or intervals of time where egg-laying by the adult females is inhibited. In the experience of this author, with 20 years of research observations, it has never been seen that a true second generation of blowflies has had the opportunity to colonize a body for the second time. The biochemical condition of the body will pass quickly, as decomposition moves forward, into a form that is not attractive as a food resource.

Specific species developmental time estimates are utilized when there is a shorter PMI in question, usually not longer than 25 to 30 days during warm summer temperatures. This method may be used for periods of weeks or even months if cooler or cold temperatures are prevalent and the specimens have not completed the full life cycle. Great precision can be achieved under this method, being within ± 12 hours in cases of 8 to 15 days duration and ± 48 hours with cases in the 20 to 25 day range.⁴²

In general, more advanced flies (evolution based), such as blowflies (Calliphoridae), house flies (Muscidae), flesh flies (Sarcophagidae), and many of the later colonizing flies (e.g. Sepsidae, coffin flies [Phoridae], skipper flies [Piophilidae]), have similar life cycles which include an egg

(flesh flies start with a first-stage [instar] maggot), a first-, second-, and third-instar (stage) larva (maggot), a migrating third-instar larva, a puparium (pupa), and finally hatching (eclosing) from the puparium as an adult male or female fly. Many of the beetles associated with carrion have a "complete" life cycle also, with the egg, larva, pupa, and adult, but many beetle species can vary the number of larval stages (instars) if stressed for food or from environmental pressures. Both groups of insects (flies and beetles) have the potential to be used to estimate elapsed time since death by using their individual species life cycles.

As stated earlier, our key insect indicator species group is the blowflies, which is used in the majority of death cases. From data sets (experiments on growth of the flies in the lab or field) on growth and development of the common species of blowflies found in both semitropical and temperate areas of the country, quantification of the temperatures driving that growth and development over time can be derived. The important factors relating to the species are the temperatures at which the specimens were raised to obtain the time it took to complete the different stages of their respective life cycles. In addition, the time is combined with the temperature (temperature \times time) to give a product in the units of growing degree days or growing degree hours. A base temperature is also introduced to reflect the lower limit threshold of growth. Below this base temperature there will be no growth or development; therefore in any period of time where the ambient temperatures are below this threshold, no growth occurs and it is denoted as a zero for that value. This method provides a means of dealing with fluctuating temperatures on either an hourly or a daily basis, adjusting for periods of cool temperatures when growth is slowed or for high temperatures when growth is quite rapid, all combined within the same data set of temperatures from any temperature recording station.

Other methods used by practicing forensic entomologists may include data sets that provide a rate of growth at a specified temperature over a given time period. For example, at 80°F it takes 3.5 days for *Phaenicia sericata* (Calliphoridae) to reach the third-instar larva. If you recover third-instar larvae (plural of larva) of *P. sericata* from a body, does that mean that the larva is 3.5 days old? Not necessarily, because the temperatures may be either higher or lower than the rearing data above, and this difference from 80°F has not been taken into account. If the overall average (mean temperature) for the days in question were 80°F even with lower temperatures at some periods and higher temperatures at others, then in this example it could be quite close to the 3.5 days. Therefore, it is critical to know at what temperature the developmental data were derived as well as at what temperature the case specimens are developing.

APPLICATIONS

As we have seen above, the primary application of insects answering questions in death investigation is to estimate when the victim died. This possibility exists due to the insects being the very first organisms to colonize dead animals.

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Some species within the blowfly group can be found on a dead body within seconds to minutes after the individual died. Eggs or larvae can be deposited within the first hour if temperatures are above the flight and oviposition (egg-laying) minimum temperatures for that particular species. Flight minimum temperatures are around 50°F for temperate climate blowflies and may be slightly higher for the tropical species. There is also a possibility of a delay in colonization after death if conditions are below minima or if there are barriers to the flies accessing the remains. In most cases, death will occur prior to the insect colonization (egg-laying), and the conclusion is that there is an established/calculated minimum of time for the remains to have been dead.

Another application of entomology is using the ranges of a specific insect species' geographic distribution (where it lives) to establish from where a body originated. In a case from California, the presence of a chigger species on the suspect proved that the suspect had deposited the murdered woman at a location where high populations of this chigger were present. This chigger species is very rare in central California and when found, it only occupies an area of a few hundred yards but is found in very dense aggregations. The chigger was not found in any other location in that part of central California except at the body dump site. This evidence, combined with other testimonial evidence, placed the suspect at the site where the victim was dumped. A conviction resulted in this case.⁴³ In another case, it was suspected that the murderer had driven from central Belgium to the coast to deposit the body in a tidal estuary, a distance of some 150 miles. Insect evidence (in this case mayflies) was collected from the grill and radiator of the suspect's car. As is customary with the mayflies, they are periodistic (due to their short life as adults) and can be very local in their distribution. Once the mayflies were identified, it was found that they were only found within 20 miles of the coast where the body was deposited and were only out as adults for 4 days. The death of the woman had occurred during this 4-day hatch. The suspect was convicted of the murder.

Carrion insects (primarily blowflies) can be used to identify areas of trauma on badly decomposed remains when major changes have taken place in the appearance of the soft tissues on the body. The larvae of the blowflies have only the nine natural body openings to access the remains, unless there is some means by which the skin of an adult human has been opened or damaged with exposure of underlying muscle or other soft tissue. It has been demonstrated during research that for the first several days of decomposition, the skin is a major barrier to the early-feeding maggots, keeping them from feeding on the underlying soft tissues of the body. Lacking trauma to a body, the preferred site for initial blowfly egg-laying is the face, with the eyes, nose, and mouth as specific locations for finding the first egg masses. This is due to the gases that are being generated within the body purging from the nose and mouth. Compounds carried within these gases are the primary attractants of the blowflies. Head hair that is moist with blood or other natural fluids, and which is close to or

in contact with the ground, may have quantities of eggs in as little time as an hour or so of death. The pelvic area will eventually attract female flies for egg laying, but there appears to be a considerable delay from the facial area if trauma to the pelvic area is not present.

Therefore, if a body of only a few days postmortem has colonies of blowfly maggots in locations other than the face or pelvic area, these areas, where there is underlying bone or intact soft tissue, should be examined closely for the presence of some type of wound that opened the skin and exposed the soft tissues to the blowflies. It has also been shown that when there are extensive colonies of maggots in the pelvic area of females, that are as old as or older than the colonies on the face, there is a strong likelihood that some type of trauma has occurred to that region of the body. In cases where there are early stages of maggots in the face and similar-sized maggots on the hands and fingers, and the hands are extended away from the body, an examination of the finger and hand bones (metacarpals and phalange) may reveal cut marks on the bones. Of course, with each case, there are differing circumstances that must be taken into account surrounding the position of the body and the duration of exposure to the blowflies. However, if those variables are considered, a forensic pathologist may discover and arrive at a conclusion in a more timely fashion than if these insect behavior patterns are not known or understood.

The maggots may be used to determine the presence or absence of drugs when human body tissues are too badly decomposed to do toxicology on the human tissues.⁴⁴⁻⁵² It has been found that maggots feeding on tissues containing many of the controlled drugs will ingest these chemicals and then store them in fat bodies in the insect or in the outer chitin covering of the specimen. Chitin is a protein-like substance that is arranged in a molecular matrix pattern that appears to be ideal for trapping and locking chemical substances within the molecular structure. Actively feeding maggots can hold a number of substances that can be tested for by using normal drug-testing techniques. In one case, empty puparial cases found with skeletal remains were tested and revealed cocaine, which was present in large quantities. The victim had been missing for 4 years, and it was suspected that the decedent had taken an overdose of the drug, but the body had never been found. This new evidence assisted the forensic pathologist in arriving at a cause of death.

Techniques for analyzing molecular DNA structures of insects for species identification⁵³⁻⁶¹ and the human DNA in insects that feed on humans^{62,63} have recently been developed. The major insect groups being studied for these tests include the mosquitoes, lice, fleas, and bed bugs. All of these insect groups may take human blood meals to furnish nourishment to eggs being produced in their bodies or as food for themselves. These human blood meals can be analyzed for individual human DNA testing. As an example, a woman was assaulted and raped by an unknown attacker. The attacker inadvertently transferred pubic lice that he was carrying onto the victim. Fortunately, the lice were collected as evidence and human DNA was extracted

and tested. Later, when suspects were being investigated, a match was made between one of the suspects and the DNA sample from the pubic lice recovered from the victim.

In addition to the blood-feeding insects, maggots feeding on decomposing humans have been tested for human DNA and found to retain testable levels.⁶² This can be important to an investigation when a body has been removed from a site where decomposition has been extensive enough to leave behind sizable maggots. Even if the remains are never recovered, maggots with a victim's DNA would be proof that the person was dead. Also, this technique could be used to prove if maggots alleged to have come from a crime scene were actually from the remains recovered from that scene and not switched by an opposing expert witness.

ADDITIONAL APPLICATIONS

Insects can also provide considerable information in cases of elderly neglect or child abuse. These types of cases usually involve living as opposed to dead individuals. Children or elderly persons who are under the care of others have been admitted as patients in emergency rooms or doctor's offices with maggots or other insects on them. Questions as to how long since the person has had a bath or how long since a diaper has been changed can often be answered by the presence of fly larvae on the person. The insect fly group is usually the house fly or its relatives. By knowing how long it is required to reach the stage of the fly life cycle collected from the patient, a time interval can be established. In a case from Indiana, house fly maggots of at least 5 days of age were collected from a 3-month-old baby girl. This was proof enough for the county prosecutor to force the parents to enroll in parenting classes. The father was 16 and the mother was 15 at the time of the diaper incident and the child was their second offspring. They truly did not know that a diaper should be changed more than once a week!

The blowflies can answer questions in civil matters such as time of death when payment of an insurance policy is in question. A case from Illinois illustrates this application of forensic entomology. The decedent was last seen around March 24 when he went on a camping trip by himself. He was found dead on approximately April 10. His insurance policy of \$100,000 expired on April 1. His 5-year-old child survived him and was the beneficiary of the policy. The county coroner contacted the forensic entomologist and requested assistance in determining when the man died. Blowfly larvae collected from the remains in combination with daily temperature data for the period of March 20 through April 15 proved that the father had died soon after he had last been seen leaving for the camping trip. A report from the forensic entomologist accompanied the coroner's report to the insurance company. The surviving son was awarded the value of the policy within days of the coroner submitting his report.

Yet another situation where blowflies may assist in finding answers to a complicated and horrific occurrence is the identification of human soft tissues in violent air crashes.

In recent years, several commercial air disasters have resulted in destruction of the human remains similar to high-velocity military air crashes. With these high-speed crashes, human bodies are literally shredded into small pieces of tissue. Aircraft wreckage and debris are closely intermingled with hundreds of pieces of body parts from the victims. After a few days, the human tissues became very difficult to distinguish from the wreckage (e.g., American Eagle crash, Roselawn, Indiana, October 31, 1994). A way to quickly identify the human soft tissues is to observe where the blowflies are actively feeding and depositing eggs. These insects will only be depositing their next generation on decomposing animal tissue, so recognition of the human remains should be apparent from that of the wreckage with these bright-green and blue flies as signals.

IMPORTANCE OF CLIMATOLOGICAL INPUT

The climatological data, and specifically the temperatures, but including intensity of rainfall, fog conditions, cloud cover, and time of sunrise and sunset, may be important when attempting to determine if insect colonization (especially blowflies) is immediate or if there has been a delay in the insects finding or laying eggs on the corpse. Usually, with bodies in outdoor environments, the data to determine whether there is a delay in colonization or not are available from weather data collected by the National Weather Service (NWS) (there are some private sources available also). The reliability of the NWS is due to the documented standards and protocol directed from oversight committees constantly monitoring the system. There are critical safety issues at stake with NWS data being used by the Federal Aviation Administration, the quality of scientists working for NWS, and the constant monitoring of the data-retrieval equipment all combining together to provide valid, accurate, and trustworthy data. These are the reasons why this author relies heavily on climatological data from this source.

The selection of a weather station or stations for data regarding a specific death scene is of great importance. In most instances, the NWS station will be located at a local or regional airport, in conjunction with the U.S. Forest Service, or at locks, dams, or on lakes as part of the U.S. Army Corps of Engineers, and at major U.S. military bases around the country. Most of the larger airports have data reported on an hourly basis, which can enhance the precision of a PMI estimate in a case. However, the most reliable results from a PMI estimate will come from a station that most closely represents the habitat where the remains were found. If this proximity is an extended distance, then reliance on weather data must accompany a calibration of the death scene and the weather station. This is accomplished by first collecting simultaneous temperatures from both the scene and the weather station and then completing a statistical analysis to calculate the adjustment necessary to make the two locations equal.⁶⁴ In many cases,

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using this method of calibration of the temperature would have nullified many hours of argument in court between the forensic entomologist or meteorologist and the opposing attorney (e.g., the Westerfield trial, San Diego).

The methodology of combining the time with the temperature has been discussed above, but some additional points need discussion regarding degree day and degree hour computations. The degree hour calculations are based upon hourly temperatures, with the degree day calculations based on daily maxima and minima. With the hourly data, a complete data set for a 24-hour period should be available. Therefore, if it is necessary to convert the units from degree hours to degree days, the procedure would be to identify the highest and lowest temperatures from the data set and use those two values as the values for the maxima and minima. This would then give degree day units and would be appropriate. However, *you cannot go the other way*, that is, calculate a daily mean and then multiply by 24. This can be illustrated by using an hourly data set and then taking the daily mean from that data set times 24. They will not be equal! It is incredible that in a case in California the forensic entomologist identified a value of daily temperature mean for what he called the daily temperature median. The median value of a distribution is the very middle number of the number set and has nothing to do with temperature calculations regarding degree days or degree hours. What was additionally interesting in this case was that he had made errors in this computation (of the mean) and the attorney for his side attempted to make up for his errors by stating that he had calculated the median. The end result is that even if he had calculated the "median," it was done incorrectly because he only had the daily maximum and minimum and the median of that data set was the "mean" (the exact middle number of the data).

Another point of degree day and degree hour calculations is the essential element of the base temperature. Again, this author has opposing forensic entomologists who claim that it is not necessary to use a base temperature for these calculations. These individuals have missed the very definition of degree days or degree hours. It is possible to calculate a "value" without a base temperature as long as all the temperatures are above the base. However, once temperatures drop below the base, an overestimation of the growth will result. What is even more interesting is that if the temperatures go below 0°C (32°F), and negative numbers are present, the calculations will suggest that the growing maggot is becoming younger the longer the numbers are in the negative column. This is not biologically possible and would appear as approaching the ridiculous. Could this discovery be the "Fountain of Youth"? (I think not!) However, these same forensic entomologists have insisted while under oath that this method is perfectly valid.

The above calibrations and calculations may require yet another variant. When the maggots are in an aggregation known as the maggot mass, they generate great amounts of exothermic heat.^{37,65-67} This is primarily seen during the entire third-instar duration until they move from the remains to initiate migration. Research has shown that

when given a range of temperatures to choose from, third-instar blowfly maggots will select a temperature of approximately 90°F.⁶⁸ This also is very close to the temperature that provides for the fastest growth. This effect may not be of major significance when ambient temperatures are in the 80s and 90s, but will be of great importance to consider when development is progressing with temperatures in the 30s and 40s. In cases where remains have been recovered and the body placed in the morgue cooler over a weekend prior to autopsy, maggot mass temperatures are still in the 85 to 90°F range after 48 hours of exposure to 40°F temperatures in the cooler.^{66,67,69} Therefore, factoring in a temperature of approximately 90°F for 24 hours or so may help compensate for these added energy units. In addition, if 90 to 95°F is at the fastest rate of development, then what has been calculated is the shortest period of time available for growth. Any other temperature would produce a longer period for the development of the maggot.

IMPORTANCE OF RESEARCH

It is fortunate for the forensic entomology community that so much detailed and species-specific research was conducted during the first half of the twentieth century on fly biology, behavior, growth, and development. Without these specific developmental studies, we forensic entomologists would have required another half century to be at the level of knowledge we have today.

Recent forensic entomology studies have been initiated in well-established and many new areas for investigation such as: aquatic insects,⁷⁰⁻⁷² succession of carrion insects from geographic areas not previously studied,^{17,34} comparison of human versus pig carrion,⁷³ fly DNA cataloging,^{58-61,74} human DNA in insects,⁶¹⁻⁶³ insect preservation,⁷⁵ and prehistoric recovery of insect remains on murdered humans,⁷⁶ to name just a few.

Still, decades of additional research are required if we are to reach the full potential of the insect evidence recovered from death scenes. Continued studies of growth and development for the forensically important species are needed, with refinements to life stage variability and temperature variations. Studies on variation of the PMI estimates and the influences of temperature data require continuous monitoring. There are many areas where expanding pilot studies must take place, such as the DNA of human blood or tissues in maggots and blood-feeding insects. The investigation into cockroach feeding on humans to determine if there are specific salivary proteins left behind by the cockroaches is yet another area where information is greatly needed. Field studies on the varying habitats and environments across North America must continually be conducted. Detailed population ecology studies on carrion insects are also needed to better understand the effects of insect abundance on colonization and growth rates.

The major drawback to this much-needed research is the limitations of funding for these studies. Very few studies have been funded through national efforts.^{73,77} Most studies have had minimal assistance, although whatever assistance is provided is always greatly appreciated, and have been

completed only by inventive and nontraditional means (through personal funds and low-budget experimental design). It is hoped that this will change in the near future with the direct link between the use of insects to answer questions in police investigations, the debate over the death penalty, and the direct connection with Homeland Security. It is essential that additional dollars be made available to forensic entomologists attempting to answer questions for science and in courts of law.

Some of the above aspects regarding forensic entomology are discussed in recent popular press publications such as: *Corpse*,⁷⁸ *Maggots, Murder, and Men*,⁷⁹ *Dead Reckoning*,⁸⁰ *A Fly for the Prosecution*,⁸¹ and *Entomology and the Law: Flies as Forensic Indicators*.⁸² Other, more technical works on forensic entomology include: *A Manual of Forensic Entomology*,¹⁰ *Entomology and Death: A Procedural Guide*,⁸³ *Forensic Taphonomy*,⁸⁴ and *Forensic Entomology: The Utility of Arthropods in Legal Investigations*.⁸⁵ A considerable understanding of the principles of forensic entomology, along with interesting case studies, can be derived from these publications.

QUALIFICATIONS OF THE FORENSIC ENTOMOLOGIST

If a criminal justice agency is in need of a forensic entomologist, the following discussion should help identify the qualifications necessary to select an expert knowledgeable in assessing the time of death of a human based upon insect colonization. First, the most reliable and qualified experts are individuals who possess degrees in entomology and board certification with the American Board of Forensic Entomology (ABFE).^{66,67} This board, organized through the American Academy of Forensic Sciences and based upon certification boards of other forensic science disciplines, requires in its certification at least 5 years of study and case involvement in forensic entomology with documentation of published research and case reports. A written test and laboratory practical examination are also necessary to complete with a passing grade before certification is granted. Additionally, board certification within the entomological profession as a board-certified entomologist would show a certain level of competence reached in specified disciplines of entomology. Specific study areas within entomology that would be preferred/required could include: Dipteran (flies) studies, medical and veterinary entomology, insect taxonomy, insect ecology, and, of course, study of forensic entomology. This certification requires several years in the entomological area of study and a 200 point examination with a 70% passing grade or higher to receive certification. An entomology degree at the bachelor's level, but definitely at the master's and PhD levels, in the above study areas would enhance the qualifications of the entomology expert being sought. The PhD-level education in the above-mentioned areas of study is the academic degree preferred if the expert is to draw conclusions and then testify to those conclusions in court. Under some conditions, a master's-level entomologist may

qualify as a forensic entomology expert in court and do quite well, but this person must show extensive study of the carrion insects with research, publications, and presentation in the forensic entomology arena.

The expert sought must have research areas in one or a combination of the following areas, including: study of carrion insects, fly DNA research, aquatic carrion research, research in carrion insect taxonomy, or specific ecological field studies of carrion and carrion insects. These study areas should generate research papers that would be presented at regional, national, or international entomological or forensic meetings. A track record for such presentations will indicate the individual is willing to share and interact with other participating forensic entomologists. Publication of these papers is also very important because it shows that the research has been reviewed and accepted by his or her scientific peers.

Membership within forensic science and entomological societies or other professional organizations is important. This provides the forum where new ideas can be discussed and old methods reviewed and improved. These are the very places where presentations, interaction with colleagues, and publications of your work as a forensic scientist will take place.

As with any area of expertise, much time, effort, training, education, and experience is foremost in ensuring that the person is truly an expert. This author has seen on a number of occasions where well-meaning college professors, who have studied biology, anthropology, microbiology, or entomology, but are inexperienced in carrion insects, become involved with case work where they have no business becoming involved. Most often these individuals had not put in the required time to study the carrion insects at the level necessary for a well-informed conclusion. They had not established a track record of forensic research, presentations, publications, or involvement with peers in the study of carrion insects. In addition, these academics had not participated in any case studies, either collaborating with an established practicing forensic entomologist or not. These people had only reviewed the entomological literature, but promoted themselves as expert forensic entomologists. In most cases, the results of their analyses were lacking in understanding of basic principles of forensic entomology, with some cases having wrong conclusions. Today, this should not happen due to the information present about qualifications of forensic entomologists with the needs for specialized education and training. This inappropriate selection process must stop for the sake of the courts, the defendants, and the science of forensic entomology.

CONCLUSION

Forensic entomology has a wealth of information to offer the criminal justice system and some of those applications have been presented above. We have been limited in attaining greater knowledge because of the lack of research funding, but that has not deterred us from doing the best we can do with existing resources to answer the most pressing

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questions facing us at the present time. It is hoped that this chapter has enlightened the reader to the uses of forensic entomology, our strong points, and even some of the areas needing further study.

Those entomologists qualified in the field of forensic entomology have worked for years in field research, spending many summer vacations sweating over the very offensive odors of decomposing humans, pigs, and other animal carrion, and have spent thousands of hours peering through a microscope searching for a hair on a fly or an outcropping on a maggot to identify to which species out of tens of thousands of specimens a fly belongs. We do not deserve the unfair criticism, the attacks, or the insults of "junk science," "voodoo science," or "weirdos" given by self-proclaimed analytical experts on television (e.g., the Westerfield trial, San Diego, 2002). Perhaps the most positive outcome of this undue criticism is that we forensic entomologists worldwide will concentrate renewed conviction, energy, and personal and professional resources in our challenge to seek the truths and understand the science of forensic entomology on a level never before imagined possible.

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