One of the most important questions to be answered in the investigation of a homicide is the time since death. The answer has tremendous implications both for a suspect's alibi and the progression of the case overall, so accuracy is essential. In the past 30 years, forensic entomology has emerged as a prominent and powerful investigative tool, acting as a surprisingly accurate "biological clock" that begins ticking as soon as the first insects arrive at a corpse. This paper is an exploration of the history and methodology of forensic entomology, as well as some prominent issues that are of great concern to forensic entomologists at present.

Forensic entomology is a specialized extension of the broader study of the behaviour, evolution, and anatomy of insects. Insects make up more than half of all species in the world, exceeding all other groups of organisms combined. To date, there are roughly one million described species worldwide, but anywhere from 3-30 million species of insects may exist.[1] Insects are excellent forensic indicators because of their specialized habits and predictable life cycles. Consequently, a trained forensic entomologist can uncover detailed evidence pertaining to time of death, as well as the place, and even the manner in which the death occurred. This is so important because medical examiners cannot estimate the time of death with accuracy through conventional analysis once the *post-mortem interval* (PMI) exceeds 72 hours,[2] meaning that careful study of the insects found at the body can yield vital information.

While it is not a new idea to consider insect evidence in legal investigations, forensic entomology was seldom practiced before the last half of the 20th century. The firs recorded use of insect evidence in a criminal investigation comes from China in the year 1235. A "death investigator" by the name of Sung T'zu wrote a book called The Washing Away of Wrongs, in which he discusses a number of murders. One such story took place in a village in which the victim had been slashed repeatedly.[3] The local magistrate suspected that a sickle had been used, but repeated questioning of witnesses proved fruitless. Finally, the magistrate ordered all the local men to assemble, each with his own sickle. It was a hot summer day, and eventually the minute traces of blood and tissue on one sickle attracted a number of flies to it. Confronted with such

[1] B.D. Turner, "Forensic Entomology," Forensic Science Progress, vol. 5 1991 at p. 132.
[2] G.S. Anderson, "Forensic Entomology: The Use of Insects In Death Investigations" (1999) School of Criminology, Simon Fraser University at p. 1.
[3] M.L. Goff, A Fly for the Prosecution (Cambridge: Harvard University Press, 2000) at p. 10.

evidence, the sickle's owner confessed to the murder.

Undoubtedly, one of the reasons that insect evidence was absent from western investigations even as other forensic sciences like ballistics and toxicology gained recognition in the 19th century is because the development and behaviour of insects were so poorly understood. It was not until the late 17th century that the West even realized that maggots were immature flies. Previously, it was simply believed that maggots were worms that spontaneously emerged from rotting meat.[4] In 1668, Francesco Redi studied the fly infestations of decomposing meat and first documented the connection between fly eggs and maggots. At the time, he was able to describe four species of blow flies that landed on the putrefying carcasses. In 1767, C. Linnaeus observed of the industrious insects that "three flies consume the corpse of a horse as quickly as a lion did."[5]

Unfortunately, even as fly biology became known, maggots remained associated with filth and decay, and have usually been treated by investigators as something disgusting to wash away from the more important evidence. Forensic anthropologists and medical examiners are all too familiar with the unpleasantness of maggots; during autopsies, mature maggots will migrate away from the corpse and climb the walls in search of a safe place to develop. Inevitably, the maggots reach the ceiling and "rain" down on the disgusted scientists.[6] Another impediment was that entomologists could only very recently devote a significant amount of their time to researching the association between insects and human corpses. Research was usually only conducted sporadically during the course of a murder investigation, and then set aside. This meant that the field advanced very slowly and in a piecemeal fashion.

The first time insects were used to help in a forensic investigation was in 1855 in Paris.[7] The renovation of a house there uncovered the mummified body of an infant from behind the mantelpiece. The couple in the house were immediately suspected, until an autopsy performed by Dr. Bergeret d'Arbois concluded that the child had died at least two years earlier -- before the couple moved in. In the autopsy, Dr. Bergeret d'Arbois noted that flesh flies had exploited the body during the first year, and subsequently mites laid their eggs on the dried-out corpse the

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[4] Ibid. at p. 10.
[5] Smith, K.G.V. A Manual of Forensic Entomology (London: Cornell University Press, 1986) at p. 11.
[6] A. Underwood, "The Witness Was a Maggot," Newsletter of the Michigan Entomological Society, December 1990 at p. 10.
[7] M.L. Goff, *supra*, at p. 11.

following year. These conclusions were based on an understanding that different insects colonize a body at different times, because they are specifically adapted to live and reproduce in different, but predictably specific conditions. J.P. Mégnin, universally recognized as the "father" of forensic entomology, identified eight stages of decomposition of a human body, and the insects associated with each stage in 1894.[8] These patterns of succession were formally outlined by Jerry Payne in the 1960s, with the number of stages reduced to six. Together with Mégnin, his work remains the basis for forensic analysis of decomposition and succession to this day.[9] The succession method is discussed in more detail later in this paper.

Throughout the first half of the 20th Century, the investigation of some particularly grisly murders advanced the knowledge base and status of the emerging science of forensic entomology. In 1935, a woman found a severed human arm under a bridge in Scotland, where a later search ultimately turned up 70 pieces of two badly dismembered corpses. The bodies were those of Isabella Ruxton, the wife of a local doctor, and her maid, Mary Rogerson. Such a gruesome discovery is apt to leave a mark, and not surprisingly the area has since been known as the "Devil's Beef Tub."[10] As with many famous cases, however, the tragic circumstances and public fascination with the murders have contributed to the status of a new aspect of forensic science.

Among the evidence collected at the scene was a group of maggots feeding on the decomposing body parts. These were identified as the larvae of a blow fly, *Calliphora vicina*, and estimates placed them at between 12-14 days old. This meant that the bodies had also lain near the stream for a minimum of 12 days.[11] Suspicion fell on Dr. Ruxton, husband of one of the victims, both because the evidence pointed to a time he was home, and because the bodies had been dismembered with surgical skill. Additionally, a cleaning woman reported blood stains and foul odours in the Ruxton home on the day after the evidence had indicated the two women were killed. With the help of the entomological evidence, Dr. Ruxton was convicted and hanged for the

[8] B. Greenberg, "Flies as Forensic Indicators," (1991) Journal of Medical Entomology, vol. 28, no. 5 at p. 566.
[9] M.L. Goff, *supra*, at p. 15.
[10] Ibid. at p. 12.
[11] Ibid. at p. 11.

murders.[12]

Within the past thirty years, forensic entomology has become a broadly recognized science in its own right, with a professional association regulating its members. Most members of the American Board of Forensic Entomology are trained entomologists holding a Ph.D. degree,[13] and this careful regulation serves to maintain professional and ethical integrity. In addition, professional regulation avoids the proliferation of too many "hired guns," or unqualified lay practitioners. Forensic entomologists are typically called upon to uncover evidence indicating post-mortem interval (or time since death) in homicide investigations. Insect evidence can also be used to detect child or elder neglect. Specifically, unchanged diapers quickly attract flies, and the presence of maggots prove that a minimum period of 2 days has elapsed since the victim was cared for.[14,15] Additionally, by running chemical tests on adults or larvae found at crime scenes, traces of drugs or other toxins that the insects ingested helps determine the circumstances of the death.[16]

In Canada, forensic entomology as evidence in court is governed by the same rules of admissibility as the opinion evidence from any expert scientific witness.[17] Scientific witnesses may draw inferences and state their opinions in matters that require specialized skills or knowledge. As the Supreme Court of Canada has stated, "An expert's opinion is admissible to furnish the Court with scientific information which is likely to be outside the experience and knowledge of a judge or jury."[18] As per the comments of Sopinka J. in R. v. Mohan, forensic experts will be allowed to testify only if it can be demonstrated that their testimony is that of a qualified expert and will indeed be relevant, as well as being of necessity to assist the judge or jury in reaching a verdict.[19] Finally, there must not be any exclusionary rule against such evidence.

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[12] Ibid. at p. 11.
[13] R.D. Hall, "Introduction: Perceptions and Status of Forensic Entomology," in J.H. Byrd and J.L. Castner, eds. Forensic Entomology: The Utility of Arthropods in Legal Investigations (New York: CRC Press, 2001) at p. 7.
[14] M.L. Goff, *supra*, at pp. 154-157.
[15] G.S. Anderson, *supra, at pp. 7-8.*
[16] E.P. Catts and M.L. Goff, "Forensic Entomology in Criminal Investigations," (1992) Annual Review of Entomology, vol. 33 at p. 263.
[17] G.M. Chayko and E.D. Gulliver, eds., Forensic Evidence in Canada (Aurora: Canada Law Book Inc.) 1999 at p. 7.
[18] Ibid. at p. 7, quoting R. v. Abbey (1982) where Dickson J. quotes from R. v. Turner (1974) *per* Lawton L.J.
[19] Ibid. at p. 8.

Outside the trial setting, however, the investigative requirements are less stringent. Accordingly, forensic entomologists may (and, indeed, *should*) be routinely called upon by police and forensic pathologists to assist in the determination of the post-mortem interval.[20]

Arguably, the most exacting and arduous task facing the forensic entomologist is to identify the different species collected from a body. Even the misidentification of one fly in the place of another can skew estimates of their activity by hours or days.[21] Opposing counsel in criminal cases frequently challenge the accuracy of species identifications, to the extent that molecular tests are being developed to reduce the possibility of expert error when making what are usually microscopic distinctions.[22] In most cases, species diagnoses must be confirmed with specialists (for example, the Systematic Entomology Unit of Agriculture Canada in Ottawa), as the distinctions between two closely related species of insects are often subtle.[23] Generally, however, there are four families of insects most commonly associated with corpses: the Calliphorid flies, the Sarcophagid flies (or "flesh flies"), the Silphid beetles, and the Dermestid beetles.

Blow flies of the family Calliphoridae are almost always the first to arrive at a body. The blow fly family includes the familiar green and blue bottle flies. These colourful, shimmering flies are frequently mentioned in the literary imagery of death and decay.[24] There are some 1000 known species of blow flies, comprising one of the largest groups of flies in the world. They can be found on almost every continent, and are intimately associated with death. Blow flies actively search for carrion upon which to lay their eggs, and are remarkably attracted to blood and bodily fluids.[25] While their activity is generally limited to daylight hours, blow flies aggressively seek out

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[20] Ibid. at p. 125.

[21] R.D. Hall, "The Forensic Entomologist as Expert Witness," in J.H. Byrd and J.L. Castner, *supra*, at p. 383.

[22] R.D. Hall, "The Forensic Entomologist as Expert Witness," in J.H. Byrd and J.L. Castner, *supra*, at p. 383.

[23] In K.G. V. Smith A Manual of Forensic Entomology (London: Cornell University Press, 1986) at p. 105. Smith includes an identification key to carrion flies, where the distinguishing characteristics between the species *Calliphora subalpina* and *C. loewi* include: "Facial dusting golden [versus silver], male eyes separated above by width equal to that of third antennal segment [versus distance between male eyes above equal to 2.0-2.5 times width of the third antennal segment]." It is safe to say that such distinctions require microscopic examination of very particular details.

[24] See, for example, Romeo's soliloquy in Act III, Scene III of The Tragedy of Romeo and Juliet: *"… more courtship lives / In carrion flies than Romeo. They may seize / On the white wonder of dear Juliet's hand And steal immortal blessing from her lips, / Who, even in pure and vestal modesty, / Still blush, as thinking their own kisses sin; / But Romeo may not- he is banished. / This may flies do, when I from this must fly."*

[25] G.S. Anderson, "Forensic Entomology: The Use of Insects in Death Investigations," (1999) School of Criminology, Simon Fraser University at p. 2.

remains in almost any environment, rural or urban. Blow flies are extremely important as forensic indicators because of their predictable life cycles and nearly ubiquitous association with death. Not only will blow flies follow the scent of death for miles, but they will readily enter buildings, even high-rise apartments.[26] They are usually the first insects to arrive at a body, often within *minutes* of death.[27] Indeed, any body that is not completely wrapped, sealed or otherwise contained will generally host blow fly activity.[28,29]

When ovipositing (laying eggs), blow flies exploit any accessible openings on the body (specifically, the nose, ears, genitals, anus, eyes and mouth) as well as any wounds. The eggs are laid in large numbers (usually a clutch of about 250),[30] and hatch after 12-18 hours.[31] The larvae that emerge are voracious eaters, doing little else during the first three stages (instars) of growth, and must shed their skins (cuticles) at each instar to accommodate their greatly increased size. Eggs laid in clusters at wound sites frequently result in maggot masses. These occur when the larvae converge during their single-minded gorging on the flesh and fluids inside body cavities. Flesh flies, which arrive shortly after the first blow flies, lay tiny, live first instar larvae that behave and feed in much the same way.

Larvae use their dark mouth hooks for shredding tissue, simultaneously secreting salivary enzymes that "predigest" flesh into a semi-liquid suitable for consumption.[32] Maggot masses have the dual advantage of being extremely efficient at breaking down tissue, and the cold-blooded larvae benefit from the marked increase in temperature that results from collectively writhing

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[26] G.S. Anderson, "Insect Succession on Carrion and Its Relationship to Determining Time of Death," in J.H. Byrd and J.L. Castner, *supra*, at p. 152.
[27] J.H. Byrd and J.L. Castner, "Insects of Forensic Importance," in J.H. Byrd and J.L. Castner, *supra*, at p. 45.
[28] A. Underwood, "The Witness Was a Maggot," Newsletter of the Michigan Entomological Society, December 1990 at p. 10. *"They [flies] are the first witnesses arriving at the scene of the crime, and any corpse dumped in the woods, stashed in the attic, or concealed beneath the floorboards attracts them." She quotes Kenneth Smith, who remarks: "Unless a corpse is bricked up, if flies could reasonably have access, they will be there."*
[29] Also see G.S. Anderson, "Insect Succession on Carrion and Its Relationship to Determining Time of Death," in J.H. Byrd and J.L. Castner, *supra*, at p. 159. Here, she remarks that blow flies and other insects can even enter a locked car with little difficulty, entering through drainage holes in the trunk (as well as any rusted areas, or a window that was slightly open) so long as fluids or an odor plume are available to attract them.
[30] B. Greenberg, *supra*, at p. 567.
[31] M.L. Goff, *supra*, at p. 44.
[32] Ibid. at p. 45.

through decomposing remains.[33] When the larvae have reached the final growth instar, they leave the remains for a safe location to complete their development. Gradually, the larval skin shrivels and hardens into a tough shell (known as the puparium), inside of which the mature larva rests as it metamorphoses into an adult fly. The adult emerges from its puparium after a typical developmental period ranging between 400-500 hours (roughly 16 days) since hatching.[34]

Carrion beetles, another forensically important group of insects, belong to the family Silphidae.[35] These beetles typically arrive at a death scene weeks to months after flies have already colonized the remains, as a consequence of the beetles' particular feeding preferences. Carrion beetles and their larvae are both scavengers (feeding on dead tissue) and predacious (feeding on the maggots of flies).[36] As a result of this predictable, secondary arrival, a pattern of succession can be derived from the activity of the beetles relative to blow flies and other early colonizers (like flesh flies). This is particularly relevant when considering remains more than a few months old, when succession models yield the best estimates of the PMI. Adult beetles are almost totally black (with small orange markings along the tip of the elytra) and can secrete an offensive odour for defense when disturbed. The predacious, quick-moving larvae have a characteristic, "trilobite-like" shape and armored appearance and are often found at human remains. Like flies, the larvae of beetles pupate before emerging as adults.

Dermestid beetles, also known as "hide beetles" because of their rapacious affinity for dried skin, are much smaller insects, generally reaching 2-12 mm in length.[37] They are round in shape and covered with scales (sclerites) that form distinctively colourful patterns. These tiny but voracious beetles have been known to skeletonize a human body in only 24 days. For this reason, they have been employed for decades in the removal of flesh from museum specimens.[38] They

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[33] For example, see B. Greenberg, *supra*, at p. 568. The temperature rises even in very confined colonization sites. In one experiment, Dr. Greenberg packed an adult human skull with 1400 grams of ground beef. Some 10 000 eggs were deposited within 24 hours by the blow fly *Phormia regina*. Within a week, the larval activity within the skull had raised its internal temperature by 18 degrees Celsius above ambient. In other observations, temperatures recorded in goat carcasses reached 49 degrees C as a result of maggot activity.
[34] L.G. Higley and N.H. Haskell, "Insect Development and Forensic Entomology," in J.H. Byrd and J.L. Castner, *supra*, at p. 296.
[35] J.H. Byrd and J.L. Castner, "Insects of Forensic Importance," in J.H. Byrd and J.L. Castner, *supra*, at p. 62.
[36] Ibid. at p. 62
[37] Ibid. at p. 66.
[38] Ibid. at p. 66.

are also notorious pests, capable of reducing leather or precious museum specimens (*especially* mounted insects, as my employer, Dr. James O'Hara at Agriculture Canada, can ruefully attest)[39] and mummies to little more than dust.

Dermestid beetles typically arrive at human corpses during the dry and skeletal stages of decomposition, long after other insects have departed.[40] This is also a well-established pattern of succession that can be useful in determining the PMI. Expert consultation is recommended, however, as dermestid beetles have been known to arrive at any point from 4 months to 10 years after death. The larvae of dermestid beetles are covered in dense tufts of hair, and prefer dark, hidden cavities and recesses that are away from light when feeding. In the course of feeding, both adults and larvae leave holes in the dry skin of corpses that are frequently mistaken for trauma sites (such as bullet or stab wounds). This is another potentially confounding area that underscores the importance of obtaining expert advice.

In order to obtain the most accurate results from entomological evidence, it is imperative that investigators at crime scenes observe proper collection protocols -- and, ideally, that they defer to the expertise of an entomologist where one is available. It is, of course, obvious that a crime scene must be disturbed as little as possible while evidence is gathered, but investigators all too often do not recognize the importance of entomological evidence or do not know how to collect it properly. Eggs, for instance, are frequently disregarded as "sawdust" (or something equally inconsequential) because they resemble a powdery substance that can be easily brushed away.[41] Before instructing FBI agents on proper collection techniques, M. Lee Goff first urges them to make a procedure of calling the local university and determine whether an entomologist is available to assist. Not only are entomologists trained to consider the smallest of details, but they are familiar with local species, and can easily isolate insects likely to *eat* one another during

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[39] Personal conversation, October 2001. *Indeed, at one point, he pointed out a small pile of fragments on a counter, which contained some freshly-shed beetle skin, and what little remained of a pinned specimen he had been working with only the day before. All specimens must be kept sealed for storage, and the 1400 cabinets lining the corridors here are filled with mothballs in order to protect the 16 million specimens within the Canadian National Collection of Insects, Arachnids, and Nematodes from their ravenous cousins.*

[40] J.H. Byrd and J.L. Castner, "Insects of Forensic Importance," in J.H. Byrd and J.L. Castner, *supra*, at p. 66.

[41] J.H. Byrd, "Laboratory Rearing of Forensic Insects," in J.H. Byrd and J.L. Castner, *supra*, at p. 122.

transport to a lab.[42]

Both live and preserved samples of all specimens must be collected. This includes eggs, larvae, adults, as well as empty *and* occupied pupal cases. Preserved samples are important because they remain at precisely the same stage of development as when they were collected. This effectively "stops" the biological clock that was set into motion when the victim died. Larvae in particular grow quickly, and if there were no preserved specimens for comparison, the maturing maggots would appear older and skew estimates.[43] Conversely, live specimens of larvae and pupae are necessary because the immature stages of insects are notoriously difficult to identify. They are, quite simply, too small and too similar in appearance to reliably distinguish. By rearing specimens of all species to the adult stage, identification becomes comparatively straightforward and precise.

Prior to the removal of any specimens from a crime scene, however, an enormous amount of extremely precise data must be meticulously recorded.[44] This is not glamorous work, but such painstaking measurements and observations make a detailed reconstruction of events possible later on. They are also necessary for entry into court records.[45] When approaching the scene, it is important to remember to approach slowly so that flying and fast-moving adults are not disturbed and scared away. Then, the investigator must note all visible insect activity (such as adult flies buzzing about, as well as the presence of beetles, and especially any feeding or post-feeding larvae), their locations relative to the body, and then record these observations on a forensic entomology data form. The position and condition of body is carefully recorded, particularly with respect to any covering, sites of injury, any mutilation or burning, and whether the body is in contact with sunlight or it is (even partially) shaded.

One of the most essential requirements is to note the weather conditions at the crime scene -- such as ambient air temperature, ground temperature, internal body temperature (obtained with a rectal thermometer or an abdominal stab), the temperature under the body, the

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[42] M.L. Goff, *supra*, at p. 184.
[43] G.S. Anderson, *supra*, at p. 4.
[44] N.H Haskell, W.D. Lord and J.H. Byrd, "Collection of Entomological Evidence During Death Investigations," in J.H. Byrd and J.L. Castner, *supra*, at p. 82.
[45] Ibid. at p. 82.

maggot mass temperature, and soil temperature.[46] It will ultimately be necessary to obtain the meteorological data for the area for the past few weeks or months from weather services. Weather conditions figure prominently in entomological calculations of PMI. Temperature is so important because insects are cold blooded. Warm temperatures will accelerate their development, and cooler temperatures will impede it.[47] Larval growth rates are the central variable of most estimates of the post-mortem interval. Precise temperature readings are essential if the calculations are to be accurate.

Once enough information has been recorded to allow for an accurate reconstruction of conditions at the undisturbed scene, collection can finally commence. Having obtained the permission of the authorities in charge of the scene,[48] the entomologist should begin by taking close-up photos of the body. This accurately captures the infestation patterns on the body, and may provide important details on subsequent examination. As flying species are the most likely to flee from human activity, these are the first insects netted.[49] This is done by quickly swatting a collecting net down over the remains in a tight, repeated swings, trapping the insects as they are disturbed into flight.[50] The net is then emptied into a killing jar, which contains either saturated plaster of Paris or cotton balls that have been soaked in ethyl acetate (which is common nail polish remover, and typically kills insects within 5 minutes).[51] Beetles, conversely, can be collected with gloved fingers or forceps as they scurry about the body,[52] but are killed and preserved in the same manner as flies. It is less important to keep live adults because they do not grow, and can be identified from preserved specimens. The dead adults of both species are deposited in a standard preserving solution of 75% ethyl alcohol, and labels are applied both to the collection vial and directly into the alcohol.[53] These labels should be filled out in pencil, as the solution would wash ink away.

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[46] N.H Haskell, W.D. Lord and J.H. Byrd, "Collection of Entomological Evidence During Death Investigations," in J.H. Byrd and J.L. Castner, *supra*, at p. 86.
[47] J.L. Castner, "General Entomology and Arthropod Biology," in J.H. Byrd and J.L. Castner, *supra*, at p. 35.
[48] N.H Haskell, W.D. Lord and J.H. Byrd, "Collection of Entomological Evidence During Death Investigations," in J.H. Byrd and J.L. Castner, *supra*, at p. 96.
[49] Ibid. at p. 92.
[50] Ibid. at p. 92.
[51] Ibid. at p. 92.
[52] Ibid. at p. 93.
[53] Ibid. at p. 92.

On the other hand, collecting larvae requires a more thorough and invasive search, and most of them must be kept alive so that they can be reared to adulthood. Depending on the opinion of the primary investigator, this will either be done at the scene, or after the body has been removed for examination. If indeed collection takes place after the body has been removed, though, the length of time the body has spent in refrigeration must be recorded.[54] Refrigeration will cause the insects to become dormant, and greatly slow their development (making them appear younger than they are). The body, the clothes, and the surrounding area must be searched for eggs, larvae and pupae.[55] Insects will congregate in the wounds and natural orifices,[56] so this is the best place to start.

Large numbers of larvae should be collected from all species present. If possible, approximately 100 specimens of each size and species should suffice, with the majority kept alive. Roughly half of the larvae collected can be killed and preserved to provide baseline developmental comparison (e.g. what instar were the larvae found at the scene, and at what level of progression were they?).[57] Of course, if there are not many larvae present, then as many as possible should be kept alive. In this case, only 10% should be preserved. Within 24-48 hours after larval death, the larvae should be "fixed" in order to allow the preserving alcohol to penetrate deep into the larval body. When larvae are fixed (usually by immersing them in boiling water for about 30 seconds before transferring them to a fresh alcohol solution), the bacteria within the insect gut are killed and prevented from decomposing the delicate larval body.[58]

Live larvae are placed in vials or specimen containers with beef liver so they can continue feeding. If no meat is available, a small amount of the remains can be used instead.[59] This is an unpleasant but necessary task, since the larvae will quickly starve, die, and desiccate without food and moisture. When storing live larvae, of course, it is *critically* important to separate beetle larvae from fly larvae. This is because many beetles, especially carrion beetles, are also predacious. The beetle larvae will eat any maggots in the container with them, meaning that on

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[54] Ibid. at p. 106.
[55] Ibid. at pp. 96-101.
[56] Ibid. at p. 107.
[57] G.S. Anderson, *supra*, at p. 4.
[58] J.H. Byrd, "Laboratory Rearing of Forensic Insects," in J.H. Byrd and J.L. Castner, *supra*, at p. 128.
[59] G.S. Anderson, *supra*, at p. 4.

return to the lab, one will only have a few very fat, very satisfied predators to examine.[60] Eggs usually appear in clusters, and have a characteristic oblong shape and are creamy white or yellowish in colour.[61] Any eggs that are collected (usually from the ears, eyes, nose, genital areas, and wounds)[62] should be treated similarly to the larvae.[63] Approximately half should be immediately preserved. The remainder should kept alive, stored separately, and provided food because the larvae will often hatch within a few hours.

Mature larvae that are ready to pupate prefer to leave the wet remains for a dry safe area, so the clothes and the scene around the body must be searched thoroughly for 3rd instar larvae and pupae.[64] Of particular note are cuffs, collars, seams, and pockets -- typically, these are both dry and relatively concealed, making them havens as far as the mature larvae are concerned. As many puparia should be collected as possible. In most cases, puparia should be kept alive. They do not grow, consequently are not susceptible to false indications of aging if they are recovered quickly[65] (although the colour should be noted at the time of collection, as a new puparium is much lighter in colour than one which is hours older).[66] Additionally, it is almost impossible to determine the species from preserved puparia, even if the dissection of some samples is useful in determining the degree of development. Nevertheless, empty, preserved pupal cases are also important artifacts to be collected, as they indicate enough time has passed at the scene for adults to emerge, and thus lengthens the probable duration for which insects have been active at the scene.

Once the specimens have safely arrived at the forensic laboratory, all live specimens should be reared to the adult stage. For ideal conditions, larvae should be fed pork or beef liver and incubated at a constant temperature of 26 degrees Celsius through to the emergence of the last adults.[67] Whenever possible, the larvae should be separated into small, isolated batches so

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[60] M.L. Goff, *supra*, at p. 38.
[61] J.H. Byrd, "Laboratory Rearing of Forensic Insects," in J.H. Byrd and J.L. Castner, *supra*, at p. 123.
[62] Ibid. at p. 123.
[63] N.H Haskell, W.D. Lord and J.H. Byrd, "Collection of Entomological Evidence During Death Investigations," in J.H. Byrd and J.L. Castner, *supra*, at p. 101.
[64] Ibid. at p. 102.
[65] G.S. Anderson, *supra*, at p. 5.
[66] J.H. Byrd, "Laboratory Rearing of Forensic Insects," in J.H. Byrd and J.L. Castner, *supra*, at pp. 131-132.
[67] Ibid. at p. 124.

that they cannot form larval masses and generate additional heat (which would, obviously, greatly increase their developmental rates and throw off the entomologist's estimate of the PMI).[68] Dates of pupation are taken for each larva. The adults will emerge several days later, which they accomplish by inflating a balloon-like organ (called the ptilinum) on their heads, splitting open one end of the puparium.[69] Newly emerged adult flies are remarkably distinct -- they are pale and gray in colour, and have not yet extended their wings. It is only later that the wings expand, and the body will harden and attain the normal adult colours.[70] The dates (and rates)[71] of emergence can be taken for each pupae gathered at the scene and from larvae reared to pupation in the lab. Together, these figures help determine the age of each specimen at the time of collection.

Estimating the post-mortem interval can be done two ways: based either on succession models, or by using maggot age and development.[72] Calculating the PMI from insect succession is the least accurate of the two models, usually limited to a month or season, but in cases where the body is more than two months and several years old, this may be the only method available. The succession method is based on well-documented patterns that insects follow when colonizing remains. For example, blow flies are usually attracted first, and are *especially* quick to arrive when bodily fluids like blood are present.[73] As was stated previously, the predacious carrion beetles eagerly feed on maggots as well as necrotic tissue, so they typically arrive several weeks after death in order to better exploit both food sources. Other species are not interested in fresh bodies, and will only appear after it has decomposed for a period of weeks or months. These late arrivals include cheese skippers,[74] which arrive after 3-6 months of decomposition, during protein fermentation.[75] According to the evidence of which groups of insects have colonized the body (determined by the presence of larvae/adults and empty or occupied pupal cases of many

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[68] Ibid. at p. 129.
[69] Ibid. at p. 132.
[70] Ibid. at p. 133.
[71] Ibid. at p. 132.
[72] G.S. Anderson, *supra*, at pp. 1-2.
[73] Ibid. at p. 2.
[74] see M.L. Goff, *supra*, at pp. 4-6. Cheese skippers are so named because they prefer to eat stored foods like cheese, and bacon. Their maggots have evolved a unique method of locomotion, in addition to crawling, which they use when leaving their food source to pupate. The cheese skipper larvae arches backwards and clasps the fleshy lobes near the anus with its powerful mouth hooks. Flexing its muscles, the maggot releases its grip, thus flinging itself into the air in a process known as "popping."
[75] G.S. Anderson, *supra*, at p. 2.

species), an approximate indication of the post-mortem interval can be ascertained.

Calculations based on maggot development are a more precise means of determining a date of death, usually to a day or less, or at the most a range of days.[76] Of course, Kenneth Smith makes an excellent point when he cautions us that it is always the *insects* that are being aged, and this may or may not perfectly coincide with the post-mortem interval.[77] Ultimately, the PMI rests on a number of assumptions, and a skilled forensic entomologist controls for this by explicitly taking as many confounding variables into account when reaching an estimate.[78] Additionally, all development is contingent on the availability of food and especially the ambient crime scene temperature. With these qualifications in mind, however, it is certainly possible to determine how old preserved larvae were by dissecting them and noting their development. The precise stage of development is determined by noting the maggot's size and weight (which is why "fixing" them is so essential, since it maintains them in pristine condition), and counting and noting the shape of posterior spiracles (or breathing holes) and setae (bristles) present on the larvae.[79] Each instar lasts a set period of time for each species. The live larvae are reared to adulthood, making species identification exact, and once the species is known, it is possible to contrast the level of larval development with known growth rates and calculate their age. Again with our qualifications in mind, the age of the maggots will offer a highly accurate minimum length of time for which the body was exposed.

Once the age of the larvae is known, calculations must be made to take into account the actual temperatures at the crime scene, which may vary greatly from the controlled temperatures of the forensic lab. To adjust for this, the known mean temperatures for each day at the scene are multiplied by 24. This gives us the *accumulated degree hours* (ADH) for that day.[80] Insects that are reared in controlled conditions develop at consistent times, so entomologists know the *total* degree hours necessary for a larva to hatch, reach the first, second, and third

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[76] Ibid. at p. 2.
[77] Quoted in B.D. Turner, *supra*, at p. 139.
[78] As E.P. Catts and M.L. Goff, *supra*, point out at p. 256, "[T]he key assumption made is that insects, usually flies, will discover the corpse soon after death or time of corpse exposure [i.e., "dumping"]. Sometimes this assumption is specious, and it must be evaluated carefully in estimating the PMI. This is especially true for indoor and closed-container death scenes, or where weather conditions are extreme."
[79] M.L. Goff, *supra*, at pp. 58-59.
[80] Ibid. at p. 59.

instars, and finally pupate and emerge as an adult. Since cooler temperatures lengthen the developmental period, and warmer temperatures shorten it, multiplying the actual scene temperatures by 24 hours results in an accurate and proportionate conversion to the required developmental duration.[81] Adding up each day's ADH and comparing the total to the normal number of accumulated degree hours required to achieve a given level of development provides the true interval.

Consider the following example:[82] early second instar larvae have been recovered from a body. Fortunately, they can be immediately identified as belonging to the species *Phormia regina.* It is known that *P. regina* larvae need 908 Accumulated Degree Hours to complete the egg stage and all of the first instar. Since second instar larvae were collected from a crime scene, then the available data informs us that roughly 908 ADH have already passed. Using the temperatures at the scene, we can count backwards in order to calculate the elapsed time. If the mean temperatures of the previous two days were both 20 degrees, then those days (24 hours x 20 degrees x 2 days) provide a total of 960 ADH. This figure exceeds the 908 required ADH, so we can subtract the extra three hours to conclude that the eggs were laid approximately 45 hours prior to the body being discovered. Thus the minimum time of death was 45 hours ago. This is a very precise figure, and the level of confidence in this interval goes up as more variables are taken into consideration. In this case, if we suppose that the body was discovered at 9am on October 15, our calculations tell us that the murder likely took place at noon on October 13.

The following case[83],[84] further demonstrates how accurate and essential entomological evidence can be when properly applied. In 1984, a nine-year-old girl named Vernita Wheat went missing. She was allegedly last seen walking with Alton Coleman, who would later embark on a seven-week six-state serial murder spree that left at total of eight people dead. Before this rampage, the girl's mother had allowed Alton Coleman to take Vernita to a carnival. When Vernita did not return, Coleman became a suspect. Her body was found three weeks later in the

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[81] Ibid. at p. 59.

[82] Based on M.L. Goff, *supra*, at pp. 60-61. The ADH constants are the same as Goff provides, but the mean temperatures used in this paper's calculations have been altered for clarity and simplicity for the purposes of this brief example.

[83] see B. Greenberg, "Forensic Entomology: Case Studies" (1985) Bulletin of the Entomological Society of America 31(4) at pp. 27-28.

[84] see also A. Underwood, *supra*, at p. 11.

bathroom of an abandoned building in Waukegan, Illinois. A loop of wire was still around her neck, and ticket stubs from the roller coaster and Ferris wheel were still in her pocket. Her body was badly decomposed, and heavily infested with maggots of the blow flies *Phormia regina*, *Phaenicia sericata*, and *Calliphora vicina*. Indeed, identification was only possible because fingerprints left at the scene matched those on classroom papers that Vernita had handed in.

Due to the advanced state of decomposition, the coroner found it difficult to make a reasonable estimate of the time of death. This estimate would be critical in making a more compelling connection to Alton Coleman, who argued convincingly that the circumstantial evidence found at the scene did not necessarily imply his guilt. The rich information provided by a forensic entomologist would therefore be indispensible. Larvae, pupae, and adults from various species of insects were collected at the scene and submitted for analysis. Complicating the entomological analysis, however, was the fact that *Phormia regina* had already completed at least one life cycle at the scene. What this meant was that adults from the first generation were at the scene, as well as the larvae of a second. In a sense, the "biological clock" had been running too long. Relying on evidence from this species alone would provide an imprecise estimate of the PMI.

Fortunately, there were no young larvae of *Calliphora vicina* present. Additionally, no adults had yet emerged from the pupae collected on the bathroom floor, meaning that this species was still in its *first* generation. *Calliphora vicina* has a longer developmental time than the other blow flies collected, and the majority of the adults reared from the collected pupae proved to be of this species. Using established developmental rates (33-34 days) at a temperature of 15 degrees Celsius (which was approximately the temperature during the time the girl was missing), Dr. Greenberg was able to arrive at the date of midnight, Tuesday May 29, 1984, as the likely time of death. This meant that she was alive no later than the night of the carnival. This evidence was highly persuasive to the jury, and Coleman was convicted.

One of the newest applications of forensic entomology involves the use of insects as toxicological indicators. As the techniques used to extract traces of drugs and other toxins from body tissue and hair become more precise, insects have emerged as a potentially rich source of information. This is because insects often absorb, and store, concentrated levels of toxins as they feed on contaminated carrion. Not only are detectable deposits found in the bodies of larvae and adults, but insect fecal matter and pupal cases will also yield chemical traces.[85] This means that toxicological evidence can be available *long* after death (perhaps even for years afterwards), even when the only evidence that remains with a skeleton are dry, empty pupal cases, or the bodies of dead adults.[86]

Presently, a diverse cocktail of compounds can be extracted from insects. Prescription drugs, mercury, cocaine, cannabis, heroin, and 3,4-methylenedioxymethamphetamine have all been detected in maggots by the use of gas chromatography and thin-layer chromatography.[87] The presence of these drugs often help determine the circumstances of death -- specifically, whether it was an accident, a suicide, or a murder. The main caution offered in the literature is that where the presence of drugs is confirmed or suspected, PMI estimates made with the aid of insect evidence should be carefully evaluated. Little data exists on how drugs and toxins affect maggot development,[88] but M. Lee Goff has conducted experiments with cocaine, and reports that its presence significantly impacts larvae. Maggots exposed to cocaine exhibit greatly increased feeding activity, develop faster, and appear older than control specimens. Goff concludes that the variations would skew estimates of PMI by several days if the entomologist did not know the drug was present.[89]

As useful and informative as insects can be in the context of a criminal investigation, they are also frustratingly adept at making such investigations more difficult. This is especially true in the discipline of bloodstain analysis. Insects, especially blow flies, find blood irresistably attractive. When blood has been shed in any quantity at a crime scene, the insects will find it. To a skilled and well-trained investigator, the size, shape, and pattern of a bloodstain tell a detailed story of the violence that left a blood pattern behind.[90] Unfortunately, the tiny, bloody footprints of a fly or beetle that has casually strolled through a pool of blood can greatly *alter* that story by changing the

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[85] M.L. Goff and W.D. Lord, "Entomotoxicology: Insects as Toxicological Indicators and the Impact of Drugs and Toxins on Insect Development," in J.H. Byrd and J.L. Castner, *supra*, at p. 332.
[86] Ibid. at p. 332.
[87] Ibid. at pp. 332-336.
[88] M.L. Goff, *supra*, at p. 139.
[89] Ibid. at p. 142.
[90] R.E. Brown, R.I. Hawkes, M.A. Parker, and J.H. Byrd, "Entomological Alteration of Bloodstain Evidence," in J.H. Byrd and J.L. Castner, *supra*, at p. 353.

patterns, particularly by leaving the impression that spatters or droplets surround the larger pool.[91] With care, these alterations can be distinguished by their relative size. Blood droplets are larger than the feet of flies, but smaller than those of roaches, which tend to drag or "smear" the blood as they walk.[92]

Extreme care must consequently be taken to determine when a blood pattern is the result of a blow, or when it is an artifact of the inevitable activity of insects. Flies, for example, can easily move from a pool of blood to another surface, such as a wall. Fly footprints are not always distinct, because they may land on six feet, or only four. They are also less likely to leave directional tracks than an insect that walks. In these instances, they can leave the false impression that a high-velocity blood "spatter" has been left on the wall merely by flying back and forth.[93] In one case, a body found in a bathtub appeared to be a suicide, because empty pill bottles and razor blade packages were found next to the bathtub, along with a suicide note written in the victim's handwriting.[94] The one confounding piece of evidence was a bloodstain pattern. It was concentrated on the bathroom closet doors and mirrors, and each stain had a very small diameter. They were consistent with a very high-impact spatter, of the type caused by a gunshot. To the confusion of the investigators, however, there was no evidence of gunfire, nor were any guns found at the scene. It was only when a forensic entomologist was consulted (and able to carefully examine the exceedingly well-documented and superbly photographed evidence) that it was at last determined that the patterns originated with the insects present at the scene.[95]

Although the careful practice of forensic entomology cna yield accurate and reliable information, we must refrain from assuming that experts are infallible, or that the data provided will not be misinterpreted (or worse, misused). The scientific basis of forensic entomology is sound and empirically well-validated, but there are a number of technical, procedural, and legal issues that must be taken into consideration if the inferences drawn by practicing experts are to be accepted as legitimate evidence and hold up under scrutiny. As many of these issues have been broadly outlined here as is possible, but far more research would be necessary to rigorously

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[91] Ibid. at pp. 353-354.
[92] Ibid. at p. 361.
[93] Ibid. at p. 361.
[94] Ibid. at p. 375.
[95] Ibid. at p. 376.

account for them all. Additionally, it cannot be overemphasized that investigators must be taught the protocol required at crime scenes where entomological evidence is present. Of the utmost importance is the proper collection of live and preserved specimens at all stages of development. While entomologists may frequently be called to testify as expert, they must not work as the advocate of the side paying them. Nor should payment *ever* be contingent upon the outcome of the case. Instead, the entomologist must carefully and independently follow evidence where it leads.