TEMPERATURE VARIATIONS OF DIPTERAN LARVAL MASSES ANALYZED ON FLORIDA BLACK BEAR CARCASSES

By

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This document is dedicated to my parents, Bob and Susan. They have always supported all the decisions I have made and left a clear pathway to follow. They have showed their love and passed on all their knowledge so I can continue to strive through life.

I also dedicate this work to Ron. He has provided the extra care and support I needed to achieve my dreams.

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The first colonizers of carrion are necrophagous flies from the families Calliphoridae and Sarcophagidae. The larvae grow in groups referred to as maggot masses that help enhance decomposition. The larvae produce heat that enables them to sustain continual growth despite ambient temperature. The maggot masses in North Central Florida are composed primarily of the species *Chrysomya rufifacies* (Macquart).

The objective of this experiment was to analyze the varying temperatures of the maggot mass on three different black bear carcasses. Temperature reading from the air, wet bulb, soil underneath the bear, and maggot mass were taken every 15 minutes. All four of the different temperature readings were compared to determine the role of the maggot mass in decomposition and how this effects Post Mortem Interval (PMI) determination.

CHAPTER 1
FORENSIC ENTOMOLOGY LITERATURE REVIEW

Introduction to Forensic Entomology

History Behind the Field

Entomologists have used carrion flies and sarcophagous beetles with the intent of solving criminal cases. Dating back to the 13th Century, this division of medical entomology was first understood and used in China by a leading criminalist trying to solve a mysterious murder-by-slashing in a small town (Hall 2001). With a basic knowledge of flies, it was possible to determine which of the villagers had committed the crime. From then on, the field of forensic entomology progressed slowly until the mid 1800s when it became of interest to Bergeret in Europe. Then in the late 1800s, J.P. Megnin was credited with focusing forensic entomology studies in the West (Hall 2001). Megnin identified eight stages in the decomposition of a human body in air; and determined the insects associated with each stage (Greenberg 1991). Since that time, entomological evidence has been used sporadically in several murder cases in Britain and more frequently on the North American continent with increasing success (Smith 1986).

Even with an increased interest in forensic entomology and extensive research being done, death investigators still regarded these insects as merely a sign of decay, to be washed away or otherwise disposed of as quickly as possible, rather than potentially significant evidence (Goff 2000). It was not until the last two decades that the value of insects found infesting corpses became apparent to those in the forensic field. Because the emphasis of forensic medical entomology has been placed on the use of arthropod

evidence for solving crimes, most often violent in nature, the name *medicocriminal entomology* has been coined for the field (Hall 1990). Forensic entomology contains the intrigue surrounding human death, the decay process with its grisly aspects, the detective work necessary to bring perpetrators to trial, the adversarial criminal justice system with its arcane terminology, and the drama of the courtroom (Hall 2001).

Description of Insects and the Law

Forensic entomology is the study of arthropods, especially insects, associated with crimes and other aspects of the court and judicial system. It involves the identification of insects and other arthropods associated with human remains as an aid to determine time and place of death (Mullen & Durden 2002). The exposed remains of an individual present a temporary habitat and food source for a wide variety of organisms, most importantly carrion insects (Goff & Odom 1987). As the initial colonizers they may arrive just minutes after death and lay eggs within a few hours (Greenberg & Kunich 2002). The insects provide information to scientists and investigators as to the time of death for that individual. They can also provide information on the location of death. When an insect is collected from a corpse that is not present in the region that the corpse was left, it can indicate possible movement of the body. The movement can be a distance from one town to the next one over or several states in between.

Insects are major players in nature's recycling effort, and in nature a corpse is simply organic matter to be recycled (Goff 2000). To further comprehend the lifestyle of these particular insects, entomologists have taken an interest in their temporary habitats, life cycle, and growth rates, which can be used in criminal investigations. The insects and other invertebrates feeding on carrion form a distinct faunal succession associated with the various stages of decay. Recognition of the immature stages of the species

involved in the succession, united with a knowledge of their rates of development, can give an indication of the age of the corpse (Smith 1986). Succession is the idea that as each organism or group of organisms feeds on the body, the corpse changes thereby making it more attractive to another group of organisms (Goff 2000). The first generation of initial colonizers can provide a biological clock that more precisely measures the time of death for up to two or more weeks; medical examiner's estimates are limited to about a day or two (Greenberg & Kunich 2002).

Forensic entomology is the study of arthropods most notably associated with crimes and used to solve matters of legal interest. "It's mostly a repeated tale of human tragedy combined with some remarkable insect ecology," says Dr. Jeffery Wells (Lewis 2001). The use of forensic entomology is utilized less when compared to the other scientific methods such as ballistics or blood splatter, hair, and fiber analyses for solving a crime (Lewis 2001). Although still viewed by the public as something of an oddity, insect evidence is recognized by the courts and increasingly introduced in cases involving accidents, homicides, and suspicious deaths, especially where time of death is a key issue (Greenberg & Kunich 2002). Forensic entomology is inextricably linked with the broader scientific fields of medical entomology, insect taxonomy, and forensic pathology (Hall 1990).

First Uses of Forensic Entomology

Following the introduction of arthropods to criminal studies in the United States several medical entomologists expanded their field of interest. Several different research studies were conducted to further understand the fly and its role in forensics. The most notable studies were conducted by Bernard Greenberg who is widely regarded as the father of forensic entomology (Goff 2000). He is now a world authority on the

Calliphoridae family due to all the time and work he has put into researching the biology and life cycles of many species (Goff 2000). In the mid-1960s Jerry Payne, a student of Greenberg, began to lay the groundwork for another aspect of forensic entomology: succession. In his landmark paper he detailed the changes that occurred during the decomposition of pig carcasses exposed to insects compared to pigs that were protected (Goff 2000). Forensic entomologists with the consciousness of insect succession patterns in carcasses and comparing this with corpses were able to determine the post mortem interval (PMI) the time elapsed since death. The ability to determine the PMI was the next big step forward for forensic entomology. It is accredited with giving entomologists a place in the criminal field.

The principal methodology used in medicocriminal entomology is application of the temperature-dependent development of insects, especially flies, for estimating a decedent's PMI (Hall 2001). Work conducted on the life cycle of the Calliphoridae and Sarcophagidae, the two families most likely be found on a decomposing corpse was used to figure out the time of death. The perception that the Calliphoridae and Sarcophagidae were found together on carcasses lead some researchers to examine how they managed to cultivate concurrently. Denno and Cothran (1976) explored the interaction between these two families. They examined experimentally the role that interspecific competition played in determining niche relationships within the fly guild. They determined that the only factor limiting Sarcophagidae populations was the calliphorids. When the calliphorid population was reduced, the sarcophagid population increased 6-fold.

Several of the first studies conducted looked at temperature and its relation to other variables. One of the earliest papers published involved experiments showing the

relationship between carcass temperature and the winter blow fly populations (Deonier 1940). It was found that blow flies of the southwestern United States feed extensively in carcasses and their development depends on temperature of the medium along with that of exposure to the sun. The ambient temperature combined with the temperature of the masses of blow fly larvae furnished favorable conditions for larval development during cool weather (Deonier 1940). In 1944, Davidson conducted a project "On The Relationship Between Temperature and Rate of Development of Insects at Constant Temperatures." He was able to write equations that showed the relationship between temperature and the time required for development in insects and other poikilothermic animals. The curves from these data represent the development trend rate of the insects for 85-90% of the temperature range at which development can occur. The 'peak' temperature is defined as the temperature at which the given stage of the animal develops the fastest.

In 1975, Ash and Greenberg researched the rate of development from two sibling Calliphorid species based on temperature. It was determined that *Phaenicia sericata* (Meigen) developed at a much slower rate than its sibling, with more variability at each stage and tended to diapause at both low and high temperatures. *Phaenicia pallescens* (Meigen) develops at a much faster rate, does not diapause and is found in sub-tropical regions.

Although entomologists in the United States had been introduced to forensic entomology in the late 1800s much of the research advances did not take place until the 1980s. Most of the literature does not date back earlier than 1975; however the earlier work set the groundwork for what was to follow.

Studies Since 1980

Succession

Succession of carrion insects has been studied for many years by an array of entomologists. To further understand the behavior of sarcophagous insects, whether beetles or flies, research has been conducted with several kinds of carcasses in a wide variety of locations to make this science as accurate and useful as it can be for law enforcement agencies. It is known that insects are usually the first organisms to arrive to a body after death, and they colonize in a predictable sequence. The body progresses through a recognized sequence of decompositional stages, from fresh to skeletal, over time. Each of these stages of decomposition is attractive to a different group of sarcosaprophagous arthropods, primarily insects (Anderson 2001).

Blow flies are the most common dipterans seen in abundance around carcasses, which serve as oviposition sites and larval food sources. Adult flies are attracted to the carrion until it is nearly dry, but other species visit the carcasses only during specific stages of decomposition; thus a succession of species can be observed (Goddard & Lago 1985). Blow flies are dipteran vultures with a keen ability to locate ephemeral resources in a large landscape (Greenberg 1991). When the sequence of insects colonizing carrion is known for a given area and a set of circumstances, an analysis of the arthropod fauna on a carcass can be used to determine the time of death (Anderson 2001). Arthropod succession on carrion during the decomposition process is generally divided into microseral stages, but there has been little agreement as to the number of stages (Goddard and Lago 1985).

Several factors can alter the succession process for a carcass: geographical differences, effects of season, effects of sun exposure, urban vs. rural scenarios, bodies

inside buildings, effects of burial, bodies in water, bodies in vehicles, bodies in enclosed spaces, hung bodies, burned remains, and wrapped remains (Anderson 2001). Succession studies have been conducted on a variety of carcasses ranging from small to very large animals and the data have been extrapolated to help law enforcement agencies solve crime. In 1991, Hewadikaram & Goff addressed this topic and found that there were no size-related differences between the carcasses with respect to the composition of the arthropod fauna or patterns of succession. A greater number of arthropods were attracted to the larger carcass and the rate of decomposition observed was more rapid. It has also been discovered that an exposed carcass will decompose at an increased rate compared to a shaded carcass. Temperature readings for the sun exposed site and the observed maggot masses are higher for most part throughout the day (Shean et al.. 1993).

Post Mortem Interval (PMI)

Insects, by their activities, begin a biological clock that will allow for an estimation of the PMI (Goff 1993). PMI is defined as the time from death to discovery of the corpse; it is the most familiar use of entomological evidence in criminal investigations (Schoenly et al. 1996). Entomologists have applied developmental and successional data of carrion-associated arthropods to assist medicolegal investigators in cases of homicide, suicide, and accidental death (Schoenly et al. 1996). Determining time of death is extremely important in a death investigation as it focuses the investigation into the correct time frame. This can support or refute a suspect's alibi and improves the efficiency of the criminal investigation (Anderson 1999).

The time of death is determined by an examination of the arthropod fauna surrounding a carcass or corpse. The insects are analyzed in detail and the entomologist will count backwards from collection date to pin point the PMI. The estimate is based on

either the period of time required for a given species to reach the stage of development that is collected from decomposing remains or an analysis of patterns of succession of a number of different species of arthropods onto the decomposing remains (Goff and Win 1997). Data from Hall and Doisy (1993) indicate that bodies dead between 0 and 96 h attract different assemblages of blow flies and flesh flies, depending upon the time lapsed since death.

Upon collection of arthropod fauna from a carcass/corpse, the instar and length of the most mature maggots will be determined and compared with data from laboratory rearing to see how long it took a similar maggot to reach that stage under controlled conditions (Goff 2000). The time period is then adjusted to fit the circumstances of the site where the body was found. This is done by converting the temperatures and times into accumulated degree hours (ADH) or accumulated degree days (ADD) by multiplying the time by the temperature in degrees Celsius. Since the time required for development decreases as the temperature increases, the total number of ADH required to develop to any given stage remains constant (Goff 2000). Once the total number of ADH is determined from laboratory rearing data, the entomologist works backward from the time that the biological clock of the maggots were stopped until the total number of ADH is reached (Goff 2000).

In rare cases insects can be used to determine more than the time of death. They can also lead to the assertion that a wound was inflicted after the time of death. Upon discovery of a mutilated body, it can be concluded whether death occurred after or prior to mutilation. One such case took place in Canada. With the discovery of a severed head and no body, the entomologist was able to conclude with the use of the few maggots

found on the neck that the individual was killed prior to mutilation (Anderson 1997). This was verified by the absence of maggots in the orifices but the presence of maggots on the wound created by the decapitation.

There have been a few rare recorded cases of using social insects to determine time of death but it is possible only if their behavior and lifestyle is completely understood. The developmental time for an *Anoplolepsis longipes* (Jerdon) (Hymenoptera: Formicidae) colony was used to calculate a post mortem interval for a set of human remains discovered in a metal toolbox in Hawaii (Goff and Win 1997).

A factor that can alter the estimated PMI is the nocturnal oviposition of certain blow flies. It has been stated that blow flies need sunlight and warmth to oviposit but in 1988 and 1989 three fly species – *Calliphora vicina* (Robineau-Desvoidy)*, Phaenicia sericata* and *Phormia regina* (Meigen) – were observed ovipositing in the dark hours of the night in the summer (Greenberg 1990).

Geographical diversity contributes to difficulties in estimating post mortem intervals because of physical factors in the environment, such as temperature, wind and rainfall or humidity. These may greatly alter the gross appearance of decomposing remains that have the same post mortem interval in different habitats (Goff et al. 1988). The wrapping of a dumped body causes difficulties in determining PMI because the wrap will delay oviposition. The delay in colonization of the remains by insects at the death scene due to wrapping in the blankets serves to emphasize the necessity for consideration of all the circumstances surrounding the remains when providing a post mortem interval estimate (Goff 1992). In determining the PMI other factors of interest must be considered such as the effect of sun on the carcass, bacterial effect, and maggot masses

which form on the carcass and cause increased temperatures that can affect developmental times (Greenberg and Kunich 2002).

Examining Forensically Important Flies

Research in forensic entomology has shown that the leading contributors for determining PMI are the flies and most notably the blow flies. The blow flies are of main interest because they are ubiquitous and typically the first to find a body, often before the police do. Because most bodies are discovered in the first few weeks after death, blow flies are encountered more frequently and can reveal time of death more accurately than their successors (Greenberg 1991). This has lead to the development of several new and extensive taxonomic keys for identifying the adult and immature larvae stages of blow flies. Scientists have colonized several species of forensically important blow flies in order to depict the eggs, three larval stages and puparia to aid in identification. Without this work it would still be difficult to identify the immatures, particularly the early instars of several species used to determine the PMI. This is crucial when eggs or early larval instars are the only available insect evidence after all specimens have been preserved (Lui and Greenberg 1989).

Extensive work has been done on the eggs from a few species of forensically important blow flies (Greenberg and Singh 1995). This is useful for identification in cases where only preserved specimens are available and can help lead to a positive identification. Identification of the eggs was confounded by three facts: (1) variability within and among populations of the same species, (2) similarities among some congeneric species, and (3) similarities between some species of different genera. Reliable separation based on morphology should take into account relevant aspects of

blow fly biology as it is affected by locality, climate, season, and weather (Greenberg and Singh 1995).

Some forensic entomologists use the maggot's weight to pin point its age. Using the spiracles and length is the most effective way to determine age of a maggot, but in some cases the maggots are not preserved correctly and the exact length cannot be recorded and the spiracles can be difficult to identify. Most techniques used today by uninformed individuals to preserve maggots can lead to shrinkage and deformation. The most appropriate way to preserve these specimens is to fix their internal protein by placing them in boiling water for approximately 10 seconds (Tantawi and Greenberg 1993). To use the weight of the maggot for age determination, a statistical model relating distributions of weights to age must be formulated and fit to the data. The weight of a larva of unknown age is then compared to the fitted model via inverse prediction to compute the confidence interval on age of the larva (Wells and LaMotte 1995).

Advancements in DNA

The study of DNA has become a breakthrough in science for many fields. Modern technology has given researchers the ability to isolate, amplify, and analyze minute quantities of human DNA (DiZinno et al. 2002). Within the past ten years, entomologists have employed this technique to rapidly and effectively identify insects used to determine the post mortem interval (Sperling et al. 1994).

A problem posed to entomologists is that for most cases the only insects present are early instar larvae, which are hard to identify and therefore need to be reared to adults for confirmation of species. This takes more time for species identification and PMI configuration; with the use of DNA analysis, the immature larvae can be identified to species correctly and more rapidly. DNA analysis is also helpful in distinguishing

between species that are very similar in appearance and nature such as *Cochliomyia macellaria* (Fabricius) and *Cochliomyia hominivorax* (Coquerel) (Roehrdanz and Johnson 1996).

The analysis of mitochondrial DNA (mtDNA) with restriction enzymes had proven to be a useful method in investigations of genetic variability and evolution within species as well as the systematic relationship of closely related species (Azeredo-Espin and Madeira 1996). Unambiguous species diagnoses with the use of mtDNA, particularly of immature stages of two very closely related species such as *Chrysomya rufifacies* (Macqaurt) and *C. albiceps* (Wiedemann), are of primary importance to forensic entomologists and will be invaluable for any future studies of the ecological and genetic interaction between them (Wells and Sperling 1999). Mitochondrial DNA analyses have been utilized to identify both the human remains upon which fly larvae have fed and the species of the larvae themselves. Preliminary work details for the first time the successful application of mtDNA sequencing techniques to the analysis of necrophagous beetle larvae that have fed on the bone remains of a human (DiZinno et al. 2002). It is also suggested that there is a possible use of mtDNA from fly feces deposits, which may contain DNA of the victim or perpetrator, critical to a case, after other sources are no longer available.

Miscellaneous

With all of the major work being conducted by forensic entomologists in the areas previously discussed there are still some individuals that take interest in other applications. One particular topic of interest looks at the effects various drugs ingested by a victim has on the growth and appearance of the maggots. In addition to their use in the estimation of post mortem intervals, insects may serve as reliable alternate specimens

for toxicological analyses in the absence of tissues and fluids normally taken for such purposes (Goff and Lord 1994).

In some cases when a victim is in the advanced stages of decomposition there are no tissues or fluids available to test for toxins, such as organophosphate insecticides, in the blood. It was found that the toxins could be extracted from the maggots present on the remains (Gunatilake and Goff 1989). It has also been discovered from case studies and confirmed with research that cocaine has an enhanced effect on the growth rate of the species *Boettcherisca peregrina* (Robineau-Desvoidy). In the presence of cocaine, the larvae develop 12-14 hours faster and pupation can occur up to 24 h earlier (Goff et al. 1989). This was also found to be true when the species was reared on carcasses that had their tissues ingested with heroin. The differences observed in the rates of development were sufficient to alter post mortem interval estimates based on larval development by up to 29 h and estimates based on pupal development by 18 to 38 h (Goff et al. 1991). Increased growth effects were observed with the drug 3,4-Methylenedioxymethamphetamine in a different species of Sarcophagidae, which were fed on carcasses with the drug. It was also noted that the larval growth was relative to the dosage of the drug from the carcass (Goff et al. 1997).

Other research conducted by forensic entomologists depicts the effects that temperature presents on several species of forensically important Diptera. Three studies in particular look at the effects that temperature had on the growth rate of three different fly species of interest, *Cochliomyia macellaria, Chrysomya rufifacies* and *Sarcophaga haemorrhoidalis* (Fallen) (Byrd and Butler 1996; Byrd and Butler 1997; Byrd and Butler 1998). Understanding the effects of temperature on several species of Diptera

corresponds with determining the post mortem interval. It is important to recognize the variations in growth that can occur due to temperature thus ensuring the PMI is calculated accurately and precisely. Because entomologists are participating more often in criminal investigations to assist in post mortem interval determinations, the availability of accurate developmental and successional data on sarcophagous insects is of primary importance (Byrd and Butler 1997).

Thermal Energy

A maggot mass originates in the collective oviposition site selection frenzy of female flies. After penetration of the body, the invading larvae become a feeding aggregation (Greenberg and Kunich 2002). Although insects are cold-blooded and generally must develop as a function of ambient temperature, the teeming, writhing mass of maggots that sometimes occurs during decomposition may produce significantly elevated temperatures (Greenberg 1991). These elevated temperatures have rarely been experimentally examined in order to completely understand the effects of the maggot mass on developmental time and the role it plays in determining post mortem interval. The experiment reported here examines the role the maggot mass has in decomposition and its thermal effects.

An extremely imperative topic of interest among forensic entomologists, thermal energy of the larvae and the carcass, is very rarely discussed and researched even less. Many of the leaders in forensic entomology (Greenberg 1991; Greenberg and Kunich 2002; Goff 2000; Byrd and Butler 1996; Byrd and Butler 1997; Byrd and Butler 1998; Campobasso et al. 2001; Hewadikaram and Goff 1991) talk about this phenomenon and refer to the event as the massing of the maggots, coining the name maggot mass. However, very few utilize it for research or have felt a need to further understand it. A

study conducted in 1990 by Cianci and Sheldon examined the thermal influence of the maggot mass on the decomposition of four pigs. The temperature dynamics of the maggots were studied to determine the thermal influence of the three larval instars, the magnitude of the temperature rise and the degree to which the elevated temperature remains independent of ambient temperature variation (Cianci and Sheldon 1990). Very little work has been done on the thermal energy of the maggot mass and therefore maggot mass has not been incorporated into determination of post mortem interval. The research experiment reported here examines the temperature produced by the maggot mass. The purpose of this experiment is to understand the maggot mass, observe the temperature produced by it, determine how this effects the growth rate of the maggots, and determine any effects this will have on the current ways of calculating the post mortem interval.

CHAPTER 2
EXAMINING THE MAGGOT MASS

Host Selection and Scope of Study

In any forensic experiment conducted, the proper host must be chosen before any research can begin. Several different types of hosts have been used to conduct forensic research, the most common being the pig (Goff 2000; Anderson 2001; Cianci and Sheldon 1990; Shean et al. 1993; Hewadikaram and Goff 1991; Carvalho et al. 2000; Komar and Beattie 1998; Goff 1992; Watson and Carlton 2003); others include domestic cats (Early and Goff 1986), human cadavers (Rodriquez and Bass 1983; Mann et al. 1990; Barreto et al. 2002; Grassberger and Reiter 2001; Anderson 1997; Goff et al. 1988), rabbit carcasses (Wells and Greenberg 1992; Denno and Cothran 1976; Goff et al. 1989; Goff et al. 1991; Goff et al. 1997), Leghorn chicken hens (Hall and Doisy 1993), large mouth bass (Goddard and Lago 1985) laboratory rats (Greenberg 1990), alligator, deer and bear (Watson and Carlton 2003). One of the major areas for concern in obtaining baseline data from decomposition studies has been the choice of the animal model used (Goff 1993). The domestic pig, *Sus scrofa* L., appears to be the most acceptable animal model and has been widely used in decomposition studies (Goff 1993). Researchers have determined the pig to be most closely related to a human in physical similarities such as skin texture and hair coverage.

For this experiment the researcher and committee chose the Florida black bear, *Ursus americanus floridanus,* instead of the conventional pig. The Florida black bear is one of three distinct subspecies of the American black bear recognized in the

southeastern United States (Florida Fish and Wildlife Conservation Commission 2001-2003). It is listed as a protected animal in the state of Florida. Mr. Walter McCown, from the Florida Fish and Wildlife Conservation Commission (FFWCC) office in Gainesville, FL, approved the use of dead bears for this experiment. All the bears used in the experiment were accidentally hit by a car at locations within a two-hour drive from Gainesville, FL and were picked up by Mr. McCown. The bears were placed in a wooded area of the FFWCC property upon retrieving them from the location where they were found.

The Florida black bear was chosen as the host because of some of the similar characteristics it has with humans in physical appearance. The Florida black bear is more closely related to a human in size than a pig, the thick hair has similar effects in decomposition that clothing would on a human, and the Florida black bear has more comparable eating habits to those of humans. The use of the Florida Black bear is beneficial to forensic studies related to humans and in cases of wildlife poaching.

These thesis objectives were to evaluate

- Insect species found on the Florida black bear hosts.
- Species succession.
- Development and movement of maggot masses of the host.

Methods and Materials

Bears were placed in a clearing in a semi-wooded area in heavy shade with barely visible sky. Much of the site was over grown with brush. The vegetation consisted of large pine and oak trees along with smaller oaks and vines. Bears were placed within a wooden fenced area surrounded by a chain-link fence that enclosed the entire facility. Bears were first observed within four hours of their arrival at the study site. Maggot

mass temperatures were collected daily from the largest dipteran larval mass present on the carcass. A HOBO™ external logger (Onset Computer Corporation, Bourne, MA, 1995-1999) was placed at the carcass site and set to record four different temperatures. The HOBO™ external logger was preprogrammed in the lab to take temperature readings every 15 minutes throughout the entire decomposition process. The base of the HOBO™ external logger was tied to the wooden fence while one of the probes was placed about 3 inches (7.62 cm) beneath the bear in the soil. The next probe was set out above ground out of direct sunlight, another was attached to a water bottle by cloth in order to record the wet bulb temperature. The wet bulb is used to record the relative humidity in the location of the bear and is done so with the cloth and water bottle. The last probe was moved daily to the largest maggot mass. It was placed first in the mouth of the bear until a maggot mass developed on the surface of the animal.

The bears were never moved after they were placed at the study site. Only one bear was present at a time; a total of three bears were used for the entire experiment. Each experiment occurred in a different month. A cage was not constructed to secure the carcass from vertebrate scavengers and there were never any signs of attempted removal of the carcass or pieces of it.

Adult and developing immature insects were collected daily with a sweep net, forceps and gloved hands at approximately 5-6 PM from day one continuing until the carcass decomposition was complete. Adult beetles and flies were killed in an ethyl acetate kill jar. Fly larvae were initially placed into empty vials, and returned to the lab for further processing. Photographs of the various insects and the growing maggot masses were taken every other day, along with photographs of the different carcass

decomposition stages. The photographs of the insects and masses were made with an Olympus 4T (MF9) 35mm camera with macro close up attachments. A separate camera, a Kodak Advantix, was used to photograph the carcass. An Olympus 1 35mm camera with an infrared filter was used to take daily photos of the maggot mass for observation of the heat spots. Sketches of the maggot mass locations and decomposition stages were made daily for visual reference.

After examination of the carcass, collections of the adult and immature insects were taken to the lab. The adults were removed from the kill jar, pinned and attached to date labels. Adults were then identified to species and properly labeled (James 1947; Smith 1986; Catts and Haskell 1990). The larvae were boiled for approximately 10 seconds in water to fix their internal proteins, then placed into vials of 70% ethyl alcohol for preservation and labeled. The larvae were identified by instar and species at a later date (Stojanovich et al. 1962; Wells et al. 1999). Larvae from each vial were chosen at random and measured to estimate the growth rate of the larvae in the carcass.

After decomposition was complete, the HOBO™ external logger was removed from the site and returned to the lab. The temperature data were downloaded from the HOBO™ onto a computer. This process stops the logger from recording and resets it for use at the next carcass. The data were stored in the BoxCar HOBO computer program (Onset Computer Corporation, Bourne, MA, 1995-1999) until analyzed further in the statistical program of Microsoft Excel 97 SR-2 (Copyright 1985 – 1997, Microsoft Corporation) and SAS (Windows NT Version 5.0 2195, 1999-2000 by SAS Instituite Inc, Cary, NC).

Bear 1, June 2002

The first experiment began on June 3, 2002. A female, approximately 160 lbs (75.57 kg) was hit accidentally by a car the previous night. The first visit to the bear occurred at 4:45 PM on June 3, 2002, upon which fly eggs and adults were collected. The HOBO™ external logger was set up and the probes were placed in their appropriate positions. Photographs were taken of the initial appearance of the bear and the insects present. Infrared (IR) photographs of the maggot mass were taken for observation of the heat spots. On the final day of observation, June 23, 2002, only a small amount of skin and filth fly larvae such as muscids and Stratiomyidae were present.

Bear 2, August 2002

On August 30, 2002, the second bear, a 195 lb (88.45 kg) female, was placed at the same study site as the bear from June, however, not in the exact spot. A car hit the bear at approximately 8 am that morning; the first visit occurred at 7:10 PM that evening. The HOBO™ external logger was set up and the temperature probes were put in their appropriate locations. Insects were collected and pictures were taken every other day. IR photographs of the maggot mass were taken for observation of the heat spots. October 2, 2002 was the last day data were recorded. On this date, the bear was completely skeletonized and only Stratiomyidae larvae were present.

Bear 3, November 2002

The third bear for the experiment arrived on November 1, 2002. It was a male cub, weighing approximately 38 lbs (17.24 kg). Upon visiting the bear at 12:30 PM on November 1, 2002, for the first time, the HOBO™ external logger was set up and the bear was moved onto a piece of screening. The screening was used to prevent unnecessary

overflow of insects from the other bears not used in these studies that had been placed in the area prior to November but had not completely their decomposed. By November 7, 2002, the bear was completely skeletonized and adult fly activity had concluded. Photographs were taken daily to show the insects and decomposition stages of the cub.

Species Composition

In forensic entomology, when a study is conducted there will be some collection of insects. For the most part the species collected will come from a few families and there might even be only a dozen or so different species. Even if the experiment is not based on succession or a species, a collection is useful to the researcher in many ways to help analyze the data (Goff 2000; Byrd and Castner 2001a; Greenberg and Kunich 2002). Sometimes there is not a designated use for the specimens at the time of collection but later they may have much to do with the underlying results.

For all three of the bear carcasses, insect specimens were randomly collected to get an idea of the species found in this region of Florida that are attracted to carrion. Adults of 20 different species were collected from the three bear carcasses, with some Sarcophagidae and Bibionidae that could only be identified to family. There were also some Dipteran adults that were not identified to species and grouped together as miscellaneous. Tables 2-1 to 2-3 shows the adult insects collected daily during the time of decomposition for each bear. Figures 2-1 to 2-3 show the larval succession pattern recorded during decomposition for each bear.

The larval species present varied depending on month, which is a reflection of the season. Bear 1 and Bear 2 had similar species diversity, but different species compositions. Bear 3 had little diversity of species present and the least amount of collected specimens.

Table 2-1. Adult insects collected from Bear 1, June 2002, cataloged by species per day for the hours of decomposition.

Catalog of Daily Collections of Adult Insects from Bear 1

Adults	Hours												
	0	48	72	96	120	144	168	192	216	240	264	312	408	480
Hydrotaea leucostoma	4	14	12	13		6			2		11	5	3	4
Chrysomya rufifacies		6				1							1	3
Chrysomya megacephala	5	2	2								1	2	2	1
Cochliomyia macellaria		1												
Sarcophagidae	3													
Phaenicia coeruleiviridis.	4	3									1			
Necrophila americana			2	2										
Nicrophorus carolinus		1		1	1									
Nicrophorus orbicollis		2	4	4	2						1			1
Creophilus maxillosus		5	7	9	6	5					1	1		1
Necrodes surinamensis		10	1	4	15									
Necrobia rufipes		1	1	1				1			1	5		6
Dermestes caninus		6	1	1		6					3	14		1
Dermestes maculates		5				4					3	9		1
Dermestes ater		4					1					2		
Trox suberosus		5	3	1	1	3			4			17		6
Saprinus pennsylvanicus					2	6					2	10		
Hister sp.	4	4			24	20	18		11		3	21		9

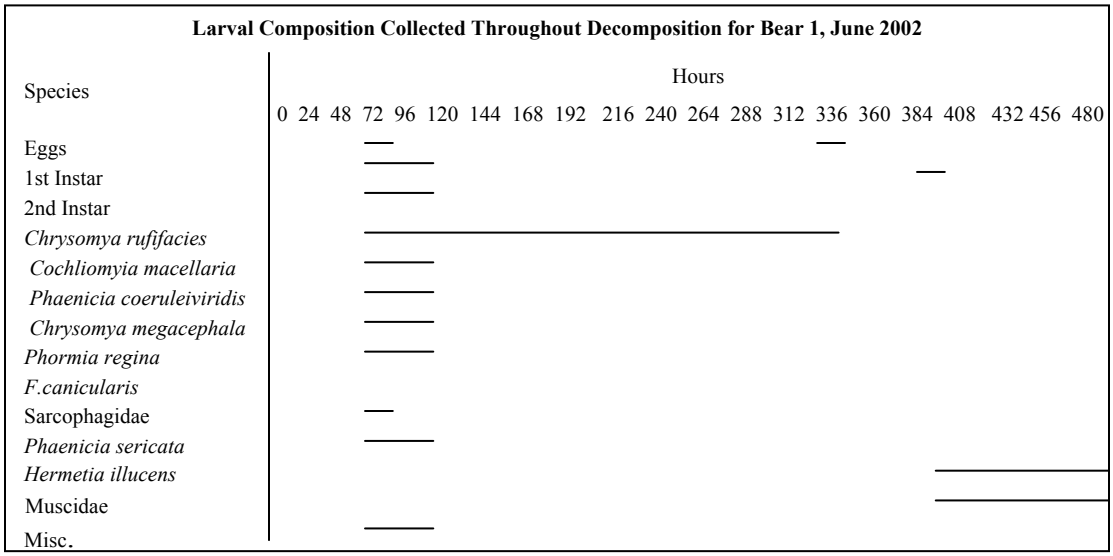

Figure 2-1. Bear 1, June 2002 larval succession pattern during decomposition

Table 2-2. Adult insects collected from Bear 2, August 2002, cataloged by species per day for the hours of decomposition.

Catalog of Daily Collections of Adult Insects for Bear 2

Adults	Hours														
	0	24	48	72	96	144	168	192	240	336	408	432	456	480	552
Chrysomya megacephala		4	4	1	1						1				
Chrysomya rufifacies			2	1								1			
Cochliomyia macellaria		1	3												
Hermetia illucens		2	1												
Hydrotaea leucostoma		2	7				1			4	2	13			2
Phaenicia sericata	2	6	1	1								1		1	
Sarcophagidae		1	1							1					
Creophilus maxillosus				6	4			2							
Dermestes caninus					5	4		2	1			1		2	2
Dermestes maculatus					2	1		8				6		3	7
Hister sp.		6	5	12	11	8	3	4	8			7		5	1
Necrobia rufipes								1						2	4
Necrodes surinamensis				8	6	1	1	1							
Nicrophoris carolinus					2										
Nicrophoris orbicollis														1	
Saprinus pennsylvanicus					1	1	1	5	1			1		6	3
Trox suberosus								1	3			1		3	3
Misc.		2	3							2	1	17		6	

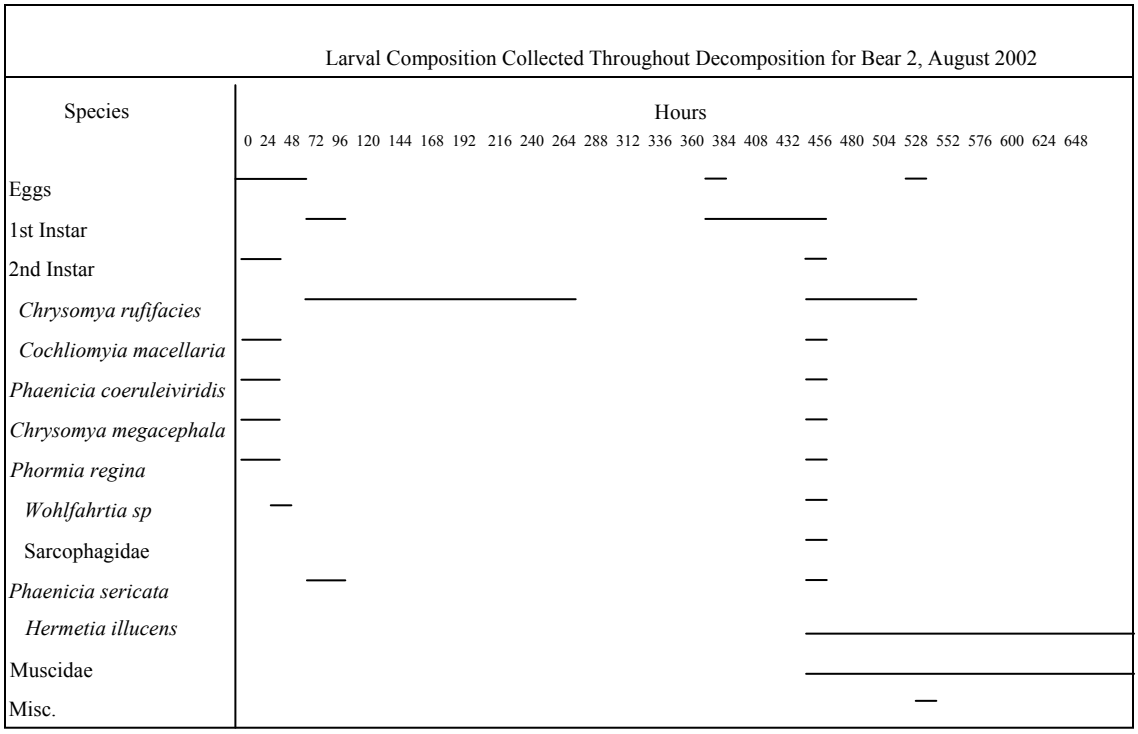

Figure 2-2. Bear 2, August 2002 larval succession pattern during decomposition

Table 2-3. Adult insects collected from Bear 3, November 2002, cataloged by species per day for the hours of decomposition.

Catalog of Daily Collections of Adult Insects for Bear 3

Adults	Hours			
	24	48	72	96
Chrysomya megacephala	3		1	12
Chrysomya rufifacies				4
Cochliomyia macellaria	1		3	2
Hydrotaea leucostoma		4	17	6
Phaenicia illustris				1
Phaenicia sericata	1			
Creophilus maxillosus			1	
Hister sp.		1	2	9
Necrobia rufipes				1
Necrodes surinamensis			3	
Necrophilia americana			1	
Trox suberosus			1	
Misc.		4		

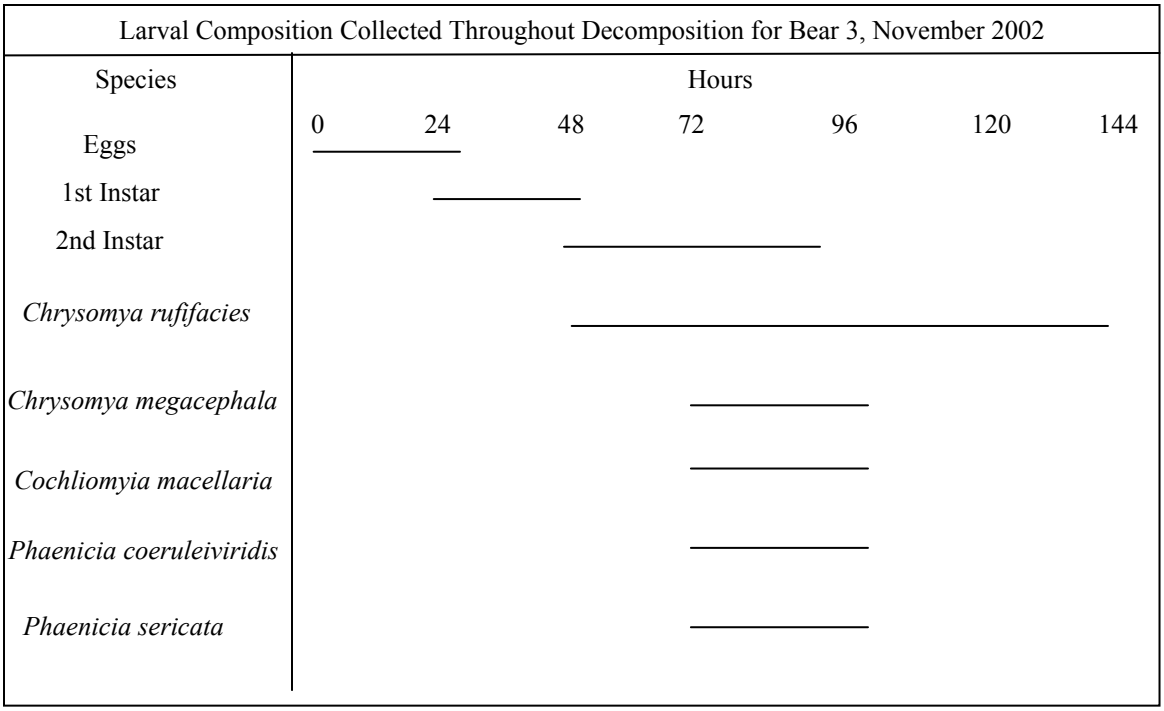

Figure 2-3. Bear 3, November 2002 larval succession pattern during decomposition

Species Pictorial

The small amount of variation in insect species that are attracted to carrion in the North Central region of Florida makes identification easier and the species diversity is not as broad as it is in other parts of the United States and around the world. In Louisiana a total of 93 species were collected from pig, alligator, bear and deer (Watson and Carlton 2003) and in Brazil 54 species were collected from pigs (Carvalho et al. 2000), but only 22 total species were collected in Hawaii from humans (Goff 1991), to name a few. The different species collected from all three bear carcasses are shown in Figures 2-4 to 2-29. The white arrow lines in the photographs represent the actual size of the insect.

Chrysomya rufifacies (Macquart), the Hairy Maggot Blow fly (Figures 4 & 5), is the most abundant of all the species collected in North Central Florida. Indigenous to the

Figure 2-4. Adult Hairy Maggot Blow fly, *Chrysomya rufifacies*

Australian Asian regions, it was introduced in to the U.S. after becoming established in Central America (Byrd and Castner 2001b). Found mostly in the southern U.S., it is slowly moving northward (Baumgartner 1993). Its method of entry into the American tropics is uncertain but it could have been through commerce, which continues to increase, especially by air (Gagne 1981). The larvae have a ferocious appetite and must consume live tissue from other developing larvae along with decaying flesh in order to complete their life cycle (Butler, personal communication; Goff 2000). The hairy maggot blow fly is an important indicator in forensic cases and is becoming the dominant species on carrion in North Central Florida (Byrd and Butler 1997).

Chrysomya megacephala (Fabricius), the Oriental Latrine Fly (Figures 6 & 7) originated from Australian and Pacific locations. So it migrated to Africa and then the Americas (Wells and Kurahashi 1994). The flies are attracted to carrion and sweet foods as well as urine and excrement (Byrd and Castner 2001b). They are known to transmit

Figure 2-5. Maggot mass of *Chrysomya rufifacies*

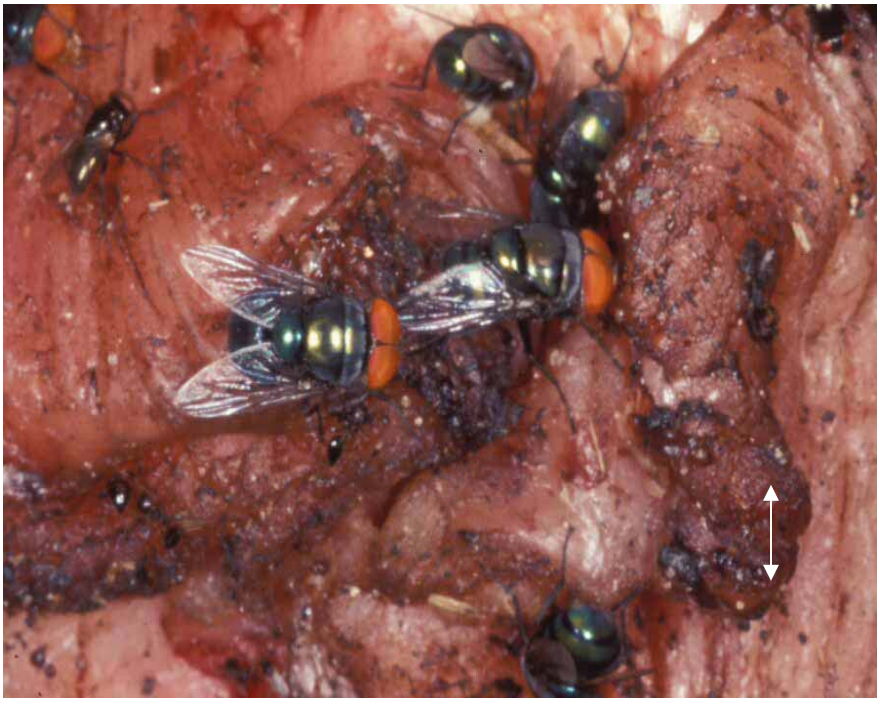

Figure 2-6. Adult *Chrysomya megacephala* ovipositing on fresh tissue

Figure 2-7. Maggot mass composed solely of *Chrysomya megacephala*

Figure 2-8. Adult Secondary Screwworm, *Cochliomyia macellaria*

enteric pathogens and parasites (Wells and Kurahashi 1994). Adults are common near human dwellings and thus likely to be encountered in forensic work. They are a great nuisance in open meat markets, slaughterhouses, and around latrines and cess pools (Smith 1986).

Cochliomyia macellaria (Fabricius), the Secondary Screwworm, (Figures 8 & 9) ranges throughout the U.S. and American tropics (Byrd and Castner 2001b). It is primarily a scavenger that is very abundant in carrion and also known to cause myiasis (Smith 1986). The Secondary Screwworm prefers humid weather and frequents carrion that is located in either shaded or sunny places (Byrd and Castner 2001b; Smith 1986).

Figure 2-9. Maggot mass composed of *Cochliomyia macellaria*

Figure 2-10. Adult *Phaenicia coeruleiviridis*

Phaenicia coeruleiviridis (Macquart), the Green Bottle Fly (Figure 10), has a Nearctic distribution and is very common in the southern U.S. (Byrd and Castner 2001b). The adults are attracted to almost all decaying animal matter and are one of the most common species attracted to fresh carrion. It is probably the most predominate blow fly in the southeastern U.S. during the spring and fall (Byrd and Castner 2001b).

Phaenicia sericata (Meigen), the Sheep Blow Fly (Figures 11 & 12), are typically found around both garbage and meat (Ash and Greenberg 1975). The larvae are best suited to feed on carrion. The Sheep Blow Fly arrives very early to the carrion and oviposition occurs within a few hours of death (Byrd and Castner 2001b).

Figure 2-11. *Phaenicia sericata* adult

Figure 2-12. *Phaenicia sericata* larva

Figure 2-13. Adult Sarcophagidae, Flesh Fly

Flesh Flies from the large family Sarcophagidae (Figure 13) are found throughout the U.S. with most species located in tropical regions (Byrd and Castner 2001b). The adults are attracted to nectar and are found on flowers. The family name refers to the larvae, which feed on some type of animal material: carrion and feces (Byrd and Castner 2001b).

Figure 2-14. Adult Red-Tailed Flesh Fly

Sarcophaga haemorrhoidalis (Fallen), the Red-Tailed Flesh Fly (Figure 14), adults are attracted to the excrement of carrion but are more commonly found on human corpses located indoors (Byrd and Castner 2001b). It is a follower of man and consequently has an almost worldwide distribution (Smith 1986). The females do not lay eggs but the larvae hatch within the abdomen and are laid as first instars therefore giving them an advantage over the blow flies.

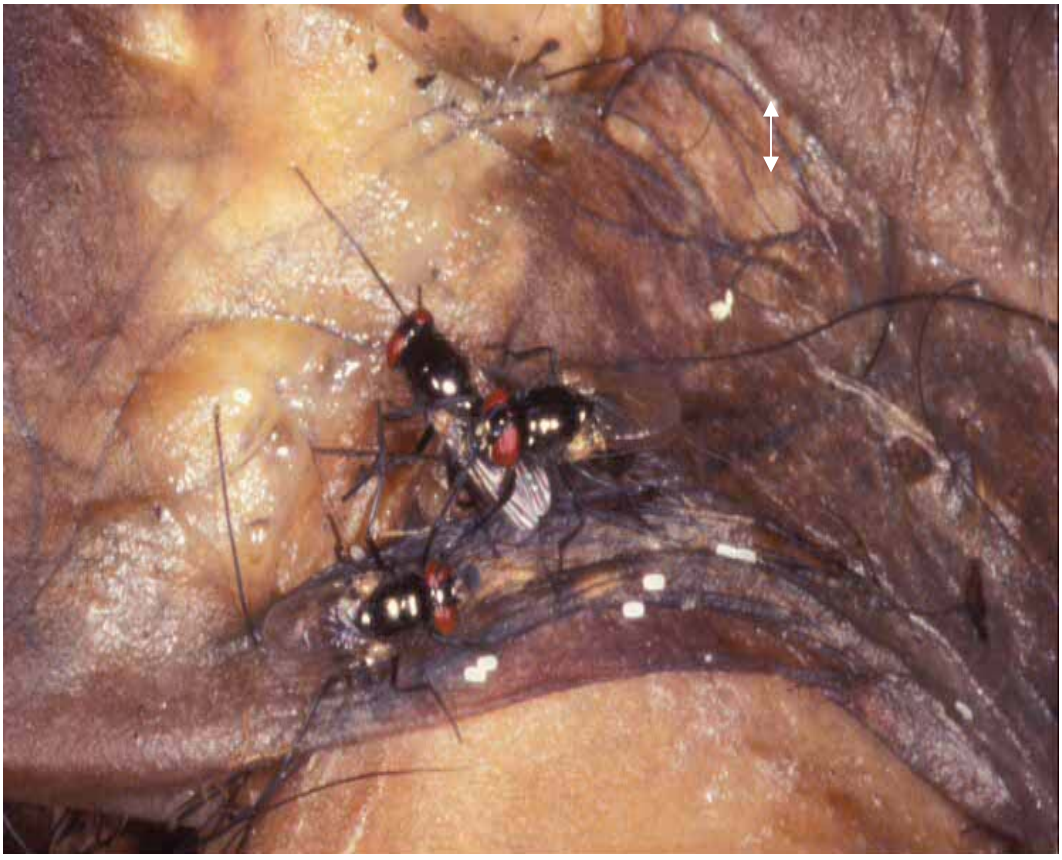

Figure 2-15. Adult Black Dump Fly, *Hydrotaea leucostoma*

Hydrotaea leucostoma (Wiedemann), the Black Dump Fly (Figure 15), is found throughout the U.S. The flies are attracted to carrion and excrement and the larvae are facultative predators (Byrd and Castner 2001b). Males can be seen hovering on calm days, and the larvae appear during late or active decay stages (Byrd and Castner 2001b).

Figure 2-16. Adult Black Soldier Fly, Stratiomyidae

Hermetia illucens (Linnaeus), the Black Soldier Fly (Figure 16), is Neotropical in origin, but now found in almost all temperate and tropical areas of the world where it probably arrived through distribution of contaminated food (Byrd and Castner 2001b). Larvae can be found in decaying fruit and vegetable matter, outdoor lavatories and carrion, and human cadavers (Smith 1986; Lord et al. 1994).

Adult *Necrodes surinamensis* (Fabricius), the Suriname Carrion Beetle (Figure 17), adults feed only on the maggots while present at the carrion. The immatures feed on the carrion and are present after the Dipteran larvae have left (Smith 1986). The adults and larvae are most commonly found on large carcasses such as bear, deer and human. The adults secrete an offensive odor as a mode of defense when disturbed (Byrd and Castner 2001b).

Figure 2-17. Suriname Carrion Beetle, adult

Figure 2-18. *Necrophilia americana* adult

Necrophilia americana (Linnaeus), the American Carrion Beetle (Figure 18), are found throughout the United States. The adults and larvae feed on carrion, fly larvae, and the larvae of other beetles (Byrd and Castner 2001b). They are found from spring to fall throughout the U.S. and the adults are diurnal (Byrd and Castner 2001b).

Figure 2-19. The Burying Beetle adult, *Nicrophorus carolinus*

Nicrophorus carolinus (Linnaeus), the Burying Beetle (Figure 19), is typically found in the Atlantic coastal states from Virginia to Florida and across the Gulf Coast states to Texas (Byrd and Castner 2001b). They feed on the developing maggots at the carcass.

Nicrophorus orbicollis (Say), the Sexton Beetle (Figure 20), are most abundant in the midsummer months and overwinters as adult. The adults feed on the maggots while the larvae feed on the decaying carrion. They are mainly nocturnal and most commonly found in wooded habitats (Byrd and Castner 2001b).

Figure 2-20. *Nicrophorus orbicollis* adult preserved

Figure 2-21. Adult *Dermestes ater*

Dermestes ater (DeGeer), the Black Larder Beetle (Figure 21), are very similar in appearance to *Dermestes maculatus* (DeGeer) (Figure 19). It is a serious pest of dried fish, mushrooms, and cheese, and is particularly attracted to the protein-rich tissues of decaying vertebrates (Byrd and Castner 2001b). The adults feed of the carcass skin and hide.

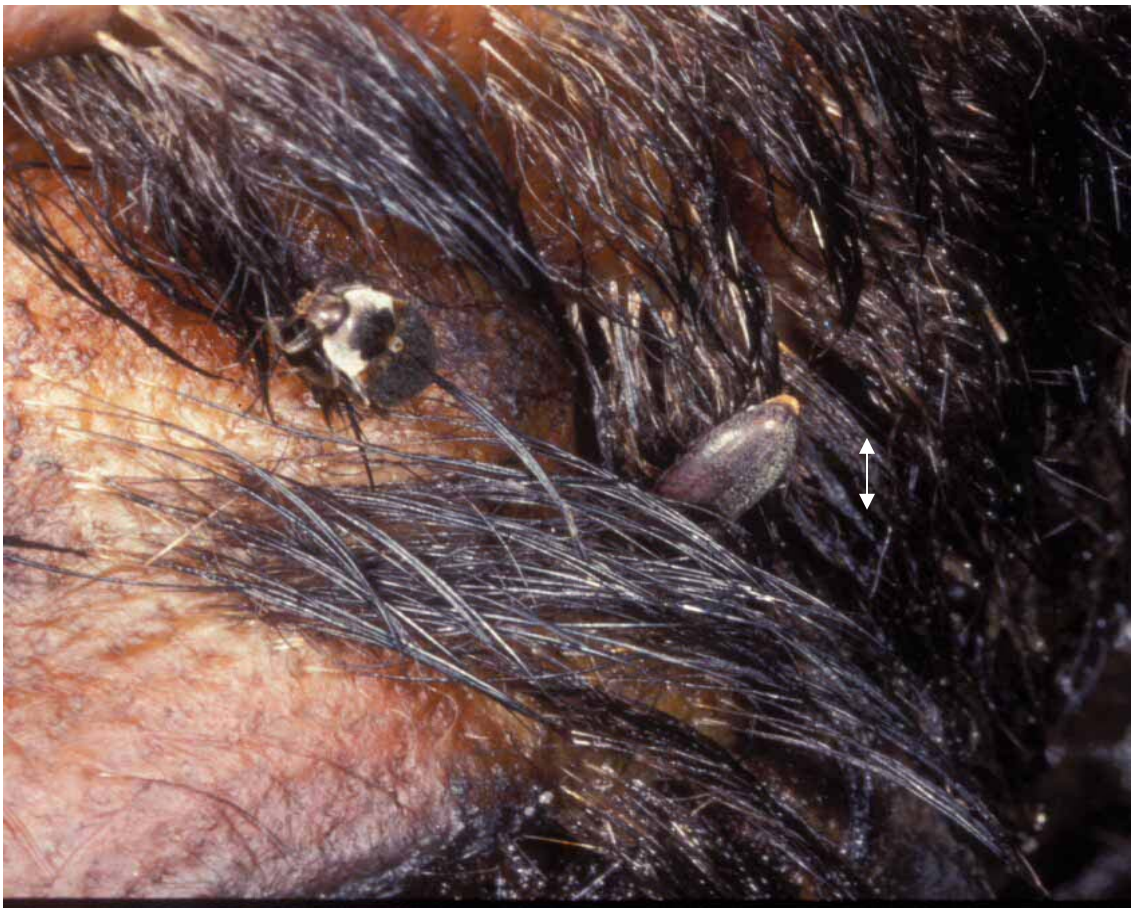

Figure 2-22. Adult *Dermestes maculates*

Dermestes maculatus (DeGeer), the Hide or Leather Beetle (Figure 22), has a worldwide distribution. The adults are cannibalistic and will eat young larvae. The larvae are typically found on human corpses and can reduce a human body to a skeleton in only 24 days (Byrd and Castner 2001b).

Figure 2-23. Preserved *Dermestes caninus* adult

Dermestes caninus (Germar) (Figure 23) is distributed throughout the U.S. except the Northwest Pacific region. It is attracted to stored food products and carrion of all types (Byrd and Castner 2001b). The adults are similar in appearance with *D. maculatus* (Figure 19) and *D. ater* (Figure 18) but the elytra are more densely covered with fine yellow hairs. The adults feed on the hide and skin of the carcass.

Creophilus maxillosus (Linnaeus), the Hairy Rove Beetle (Figures 24 & 25), is found throughout the eastern United States. The adults can be found on carcasses within hours after death as well as during the advanced stages of decomposition. The adults feed on the developing Dipteran larvae (Byrd and Castner 2001b).

Figure 2-24. Hairy Rove Beetle, *Creophilus maxillosus*

Figure 2-25. Adult *Creophilus maxillosus*

Figure 2-26. *Hister sp*, Clown Beetle adult

Figure 2-27. *Saprinus pennsylvanicus* adult specimen

Clown Beetle (Figure 26) adults have a worldwide distribution and are found on cadavers from bloat through the dry stages of decomposition (Byrd and Castner 2001b). They occur wherever there is decay and putrefaction and are reported to play a factor in the reduction of dipterous larvae (Smith 1986).

Saprinus pennsylvanicus (Paykull) (Figure 27) is one Histeridae species commonly recovered from carcasses. It has shiny green metallic elytra and is present throughout all stages of decay.

Figure 2-28. Red Legged Ham beetle adult

Necrobia rufipes (DeGeer), the Red-Legged Ham Beetle (Figure 28), is distributed worldwide and recovered throughout the U.S. It is known for infesting cured meat products. The adults and larvae are also predacious on fly eggs and maggots (Byrd and Castner 2001b). They are also found on dried bones, which are a source of food, and can be a nuisance for anthropologists if the bones are not preserved correctly.

Figure 2-29. Adult *Trox suberosus*

Trox suberosus Fabricius, the Hide Beetle (Byrd and Castner 2001b) (Figure 29), is usually associated with the nests of small mammals and birds, fungi, carcasses, decayed fish and occasionally dung (Smith 1986). *T. suberosus* is a carrion feeder and is present during advanced decomposition through the dry decay stages It is distributed throughout the U.S. and noted to be one of the last in the succession of insects on decomposing remains (Byrd and Castner 2001b). .

Decomposition

All the members of the animal kingdom go through the same decomposition stages when they die. The four most commonly reported stages of decomposition are fresh, bloated, decay and dry (Rodriquez and Bass 1983). The fresh stage begins upon the death of the individual and continues until the early stages of bloating. Bloat begins with the onset of bloating and ends with the cessation of bloating. The third stage

observed is decay. Decay begins with ceased bloating and ends when most of the remains are dry. The final stage is the dry stage and is particularly more difficult to identify cause it lacks precise characteristics (Rodriquez and Bass 1983).

The stages of decay are shown in the following figures for each of the three bears. The pictures shown begin at in the early stages of decay and continue to show the final dry stages observed during the experiment. Bear 1, June 2002, can be observed in Figures 27-33; Bear 2, August 2002, is represented in Figures 34- 40; and Bear 3, November 2002, is depicted in Figures 41- 47.

Bear 1, June 2002

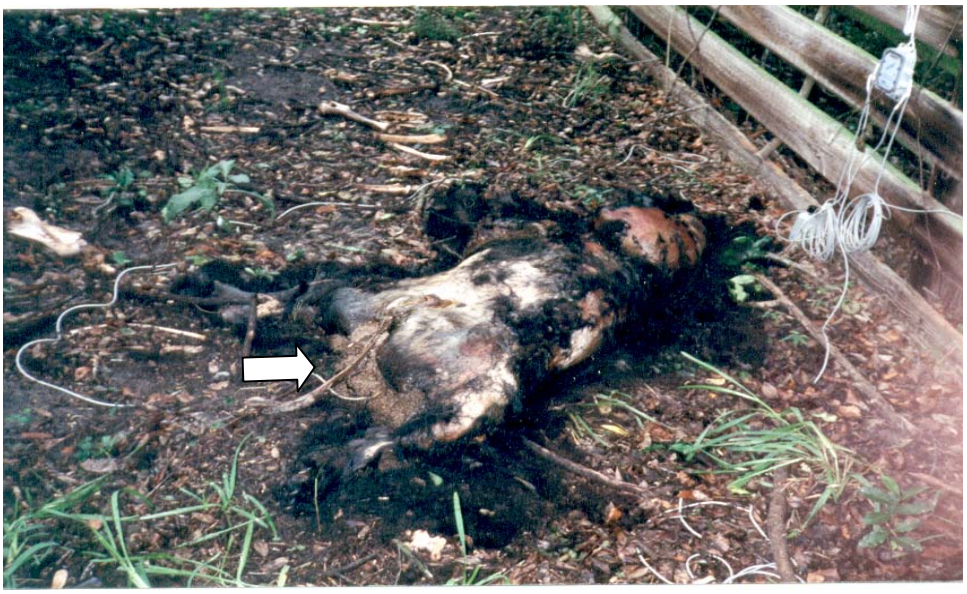

Figure 2-30. Day 3, the early stages of decomposition have begun and maggot masses are present at the orifices on Bear 1, June 2002.

Figure 2-31. Day 4, maggot masses of *C. rufifacies* have formed around the extremities and head region of Bear 1, June 2002.

Figure 2-32. Day 5, the larval masses have increased in size and are more observable on Bear 1, June 2002.

Figure 2-33. Day 6, the skin of Bear 1, June 2002, is becoming weathered while the larvae consume the tissue underneath.

Figure 2-34. Day 8, the bear mass of Bear 1, June 2002, has become depleted by the feeding of the larvae and the skin is being pulled close around the bones.

Figure 2-35. Day 9, the skin has tightened and the bones are becoming exposed on Bear 1, June 2002.

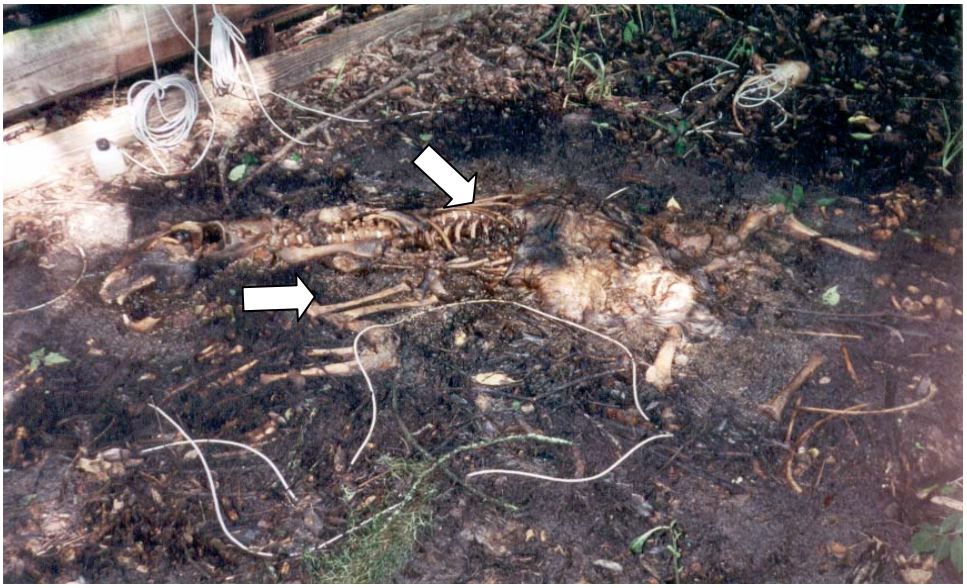

Figure 2-36. Day 11, the majority of Bear 1, June 2002, has been eaten and the bones are exposed.

Bear 2, August 2002

Figure 2-37. Bear 2, August 2002, is a large 195 lb female, this picture taken Day 1 shows her in the fresh stage.

Figure 2-38. Day 1, Bear 2, August 2002 is bloating and shows signs of trauma on her back.

Figure 2-39. Day 4, large maggot masses have begun to consume the head, neck, chest and extremities of Bear 2, August 2002.

Figure 2-40. Day 6, the mass of Bear 2, August 2002 is deteriorating with the ferocious appetite of the larvae.

Figure 2-41. Day 9, most of the tissue mass of Bear 2, August 2002 has been consumed and the larvae have begun to migrate down the fence line where they will pupate at.

Figure 2-42. Day 11, Bear 2, August 2002 bones from the extremities are becoming visible and fly activity has slowed.

Figure 2-43. Day 12, larval activity has ended while the beetles continue to utilize the hair and skin of Bear 2, August 2002.

Bear 3, November 2002

Figure 2-44. Day 1, initial photo of a male cub (Bear 3) about 38 lbs hit by a car on November 1, 2002, in Ocala, FL.

Figure 2-45. Day 1, close up of the wound present above the right shoulder blade of fore limb of Bear 3, November 2002.

Figure 2-46. Day 1, photo showing the fly activity that has begun to occur within 2 hours after Bear 3, November 2002 arrived at the study site.

Figure 2-47. Day 4, the hair has begun to slough off as the maggot masses form at the orifices and around the perimeter of Bear 3, November 2002.

Figure 2-48. Day 5, larval masses have consumed several areas of Bear 3, November 2002 such as the abdomen, chest, head and extremities.

Figure 2-49. Day 6, *C. rufifacies* is the dominant species forming the maggot mass on Bear 3, November 2002.

Figure 2-50. Day 6, Bear 3, November 2002 mass has been consumed by the larvae, which leave very little amounts of flesh behind.

CHAPTER 3
MAGGOT MASS OBSERVATIONS

The maggot mass temperatures were found to be increasingly higher than the ambient temperature for all three of the bears after the first 24 hours. At the beginning of decomposition, when eggs and 1st instar larvae were present, the temperature of the maggot mass, not yet fully formed, was less than the ambient temperature. The highest ranges of temperature were recorded when there were 3rd instar larvae present and the highest peak occurred at the transition stage of 2nd instars into 3rd instar larvae.

Due to the inconclusive photographs and technical difficulties from the IR camera, the photos were unable to be used in the results. The relative humidity was not determined due to the water bottle boiling at the study site and altering the recorded temperatures. In order to compare the four different temperatures: wet bulb, air, maggot mass, and underground beneath the bear, the extreme temperatures recorded by the wet bulb were removed before charting.

Bear 1, June 2002

After 24 hours, the maggot mass temperatures surpassed the ambient, wet bulb and underground temperatures. The mean maggot mass temperature was 31.17°C, the minimum was 23.63°C and the maximum was 45.89°C (Table 3-1). A one-way ANOVA and Duncan's test and found the data to be significant with a P value of <0001.

The increasing maggot mass temperature can be observed in the following graphs that depict the temperatures recorded. Figure 3-1 shows all the temperatures and their correlation with each other during decomposition. Figure 3-2 shows the daily means of

the temperatures analyzed with a Duncan's test graphed together. Table 3-2 shows the daily means for all temperatures and their significance from a Duncan's test. Figure 3-3 represents the mean growth rate of the species *Chrysomya rufifacies* Macquart compared with the mean maggot mass temperatures. The peak in maggot mass temperature at 72 hours to 45.89°C represents the growth of 2nd instars into 3rd instar larvae.

Table 3-1. Descriptive statistics of temperatures recorded for Bear 1, June 2002 throughout decomposition.

Temperature Data Recorded from Bear 1, June 2002

	Wet Bulb	*Underground*	*Maggot Mass*	*Air*
Mean temperature[a]	23.58D	29.81B	31.17A	25.02C
Standard Error	0.044	0.07	0.128	0.053
Minimum Temperature	17.14	24.01	23.63	19.04
Maximum Temperature	35.7	36.13	45.89	33.17
Confidence level	0.085	0.138	0.252	0.103

[a]Means in the same row followed by the same letter are not significantly different (P=0.05; Duncan's multiple range test [SAS Institute 2003])

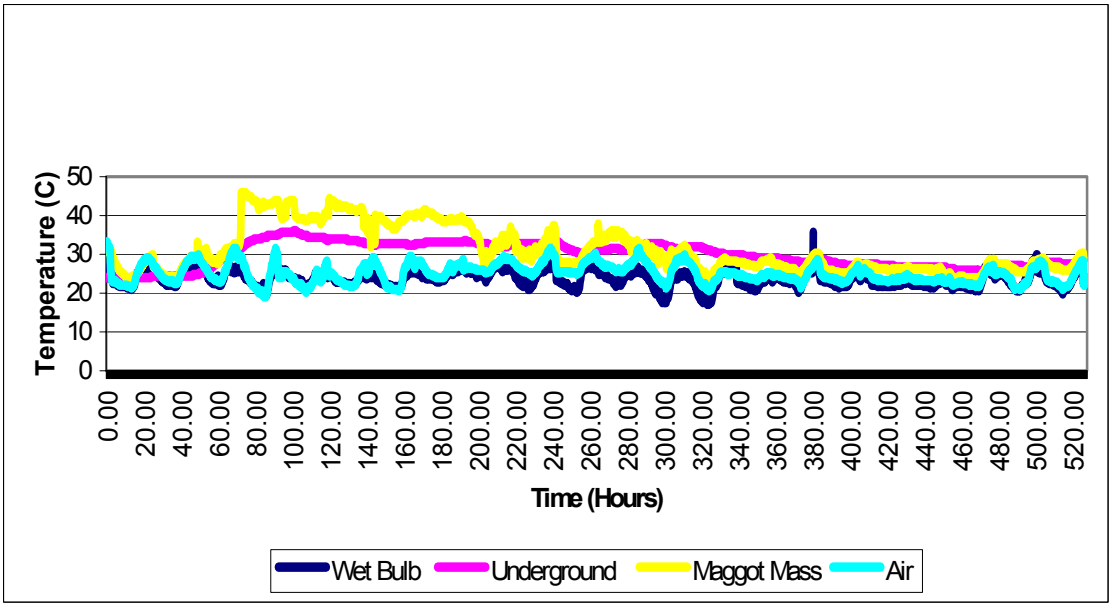

Figure 3-1. Temperature readings recorded on 15-minute intervals during decomposition of Bear 1, June 2002.

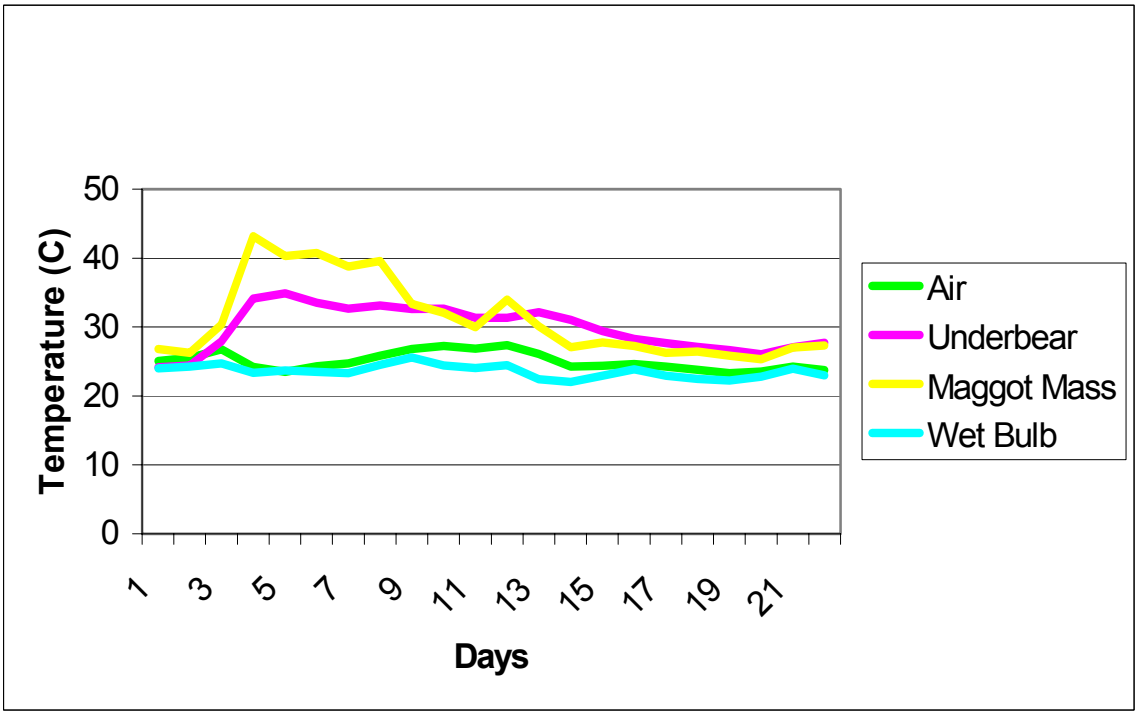

Figure 3-2. Daily means for temperature from Duncan's test for Bear 1, June 2002.

Table 3-2. Significance of daily means for Bear 1, June 2002 from Duncan's test.

Duncans On Daily Means for Bear 1, June 2002

Day	Air	Underbear	Maggot Mass	Wet Bulb
1	25.0806B	24.1385C	26.7919A	23.9886B
2	25.5204B	24.4244C	26.2476A	24.244C
3	26.7514C	27.9286B	30.3676A	24.7303D
4	24.1923C	34.136B	43.1999A	23.3692D
5	23.5077C	34.8842A	40.3094B	23.6985C
6	24.2897C	33.496B	40.767A	23.5223D
7	24.7214C	32.6725B	38.7343A	23.3125D
8	25.8386C	33.1145B	39.5651A	24.5308D
9	26.8169C	32.6195B	33.3911A	25.5808D
10	27.2749C	32.6506A	32.0373B	24.4232D
11	26.8514C	31.3087A	29.9598B	24.0611D
12	27.3469C	31.3332B	33.978A	24.4634D
13	26.0746C	32.1607A	30.0875B	22.4356D
14	24.2494C	31.0507A	27.0573B	22.0399D
15	24.3839C	29.425A	27.7814B	22.9457D
16	24.6278C	28.2985A	27.2628B	23.8699D
17	24.2527C	27.649A	26.2445B	22.9652D
18	23.82854C	27.1026A	26.44615B	22.48813D
19	23.31875C	26.665A	25.83417B	22.22094D
20	23.5582C	26.0516A	25.3146B	22.7827D
21	24.2539B	27.0682A	27.0053A	23.9799B
22	23.7669B	27.7088A	27.2951A	23.0029C

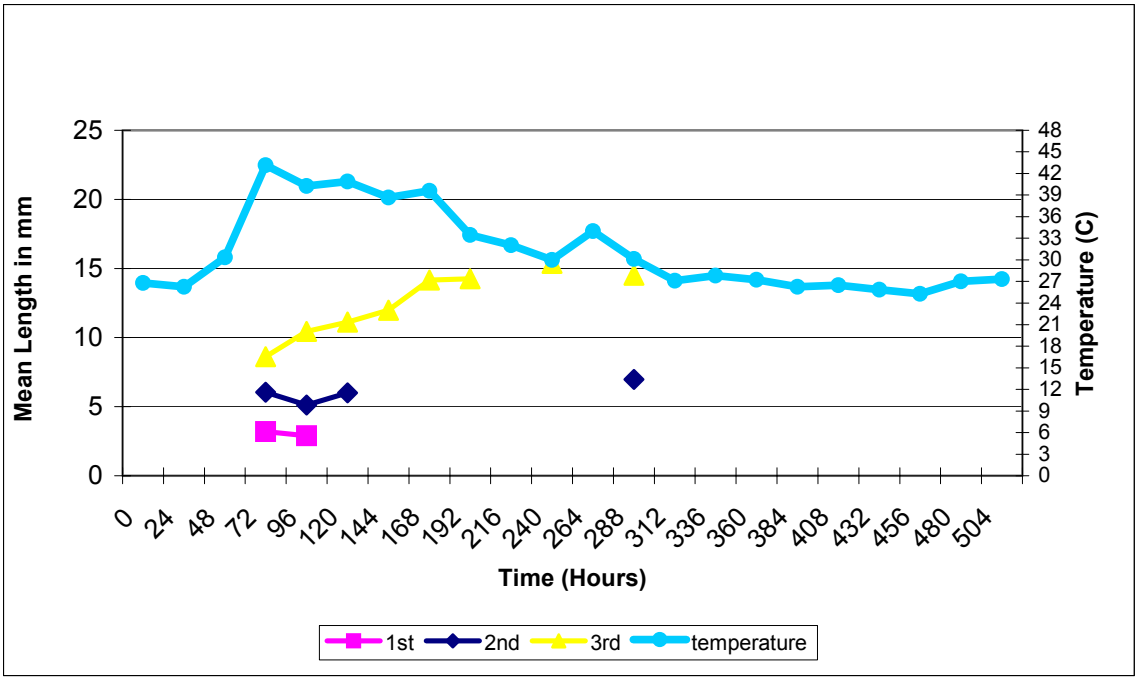

Figure 3-3. Mean growth rate of Chrysomya rufifacies over time compared to mean maggot mass temperature for Bear 1, June 2002.

Bear 2, August 2002

The maggot mass temperature within the first 24 hours was very similar to the other temperatures recorded. Shortly thereafter, the maggot mass temperature increased greatly as the larval activity increased, as did the size of the mass. Figure 3-4 shows the relationship of the temperatures collected during the time the bear decomposed. Figure 3-6 shows the daily means of the temperatures analyzed with a Duncan's test graphed together. Table 3-4 shows the daily means for all temperatures and their significance from a Duncan's test. Figure 3-6, shows the increased temperature produced in the maggot mass as the larvae molted from 2nd to 3rd instars. The mean maggot mass temperature for the experiment on Bear 2 was 33.89°C, the minimum temperature was 22.48°C, and the maximum-recorded temperature was 54.13°C (Table 3-3). The one-way ANOVA and Duncan's test found the data to be significant with a P value of <.0001.

Table 3-3. Descriptive statistics of temperatures recorded for Bear 2, August 2002 throughout decomposition.

Temperature Data Recorded for Bear 2, August 2002				
	Wet Bulb	*Maggot Mass*	*Underground*	*Air*
Mean Temperature[a]	24.97B	33.89A	32.56A	25.24C
Standard error	0.037	0.091	0.06	0.039
Minimum temperature	20.19	22.48	23.24	20.95
Maximum temperature	37.44	54.13	39.67	35.27
Confidence level	0.073	0.178	0.117	0.076

[a]Means in the same row followed by the same letter are not significantly different (P=0.05; Duncan's multiple range test [SAS Institute 2003])

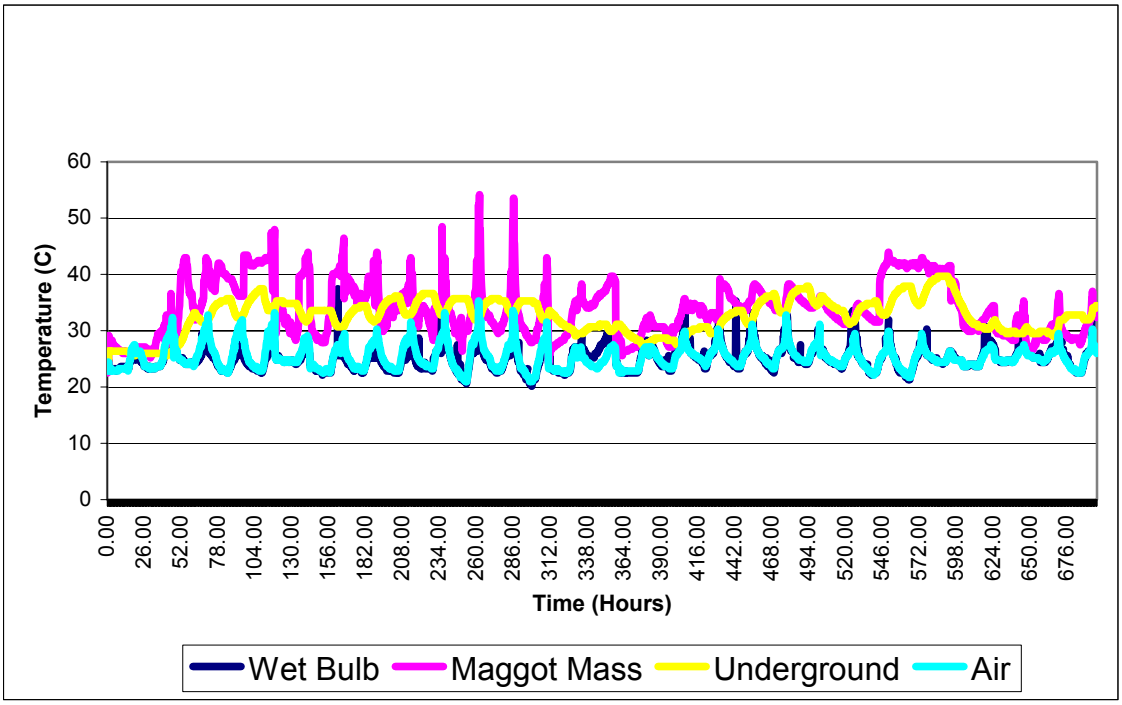

Figure 3-4. Temperature readings recorded on 15-minute intervals during decomposition of Bear 2, August 2002.

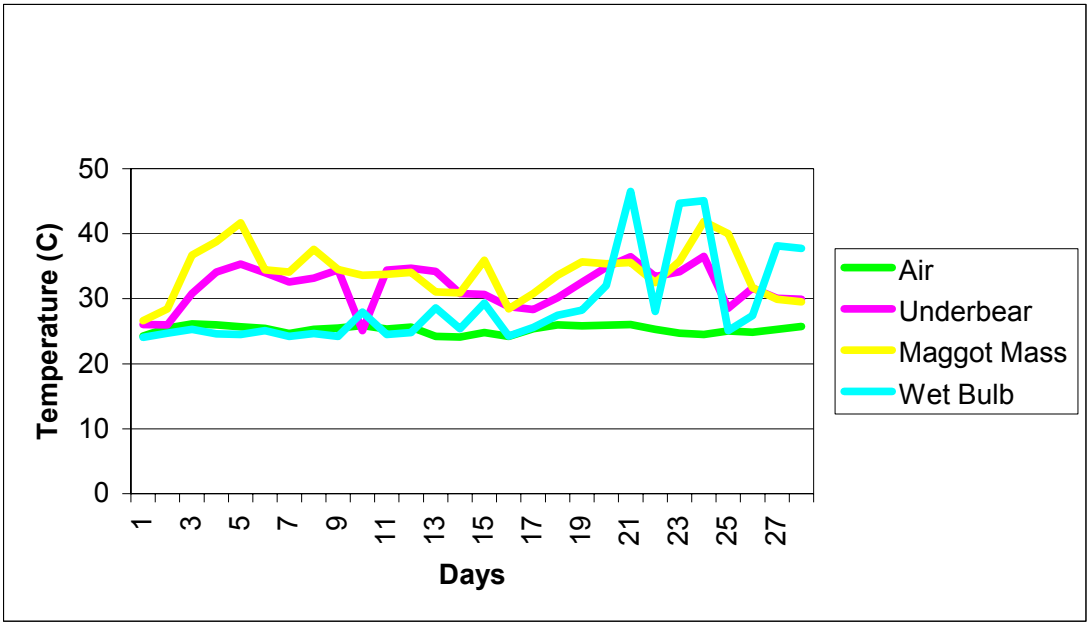

Figure 3-5. Daily means for temperature from Duncan's test for Bear 2, August 2002.

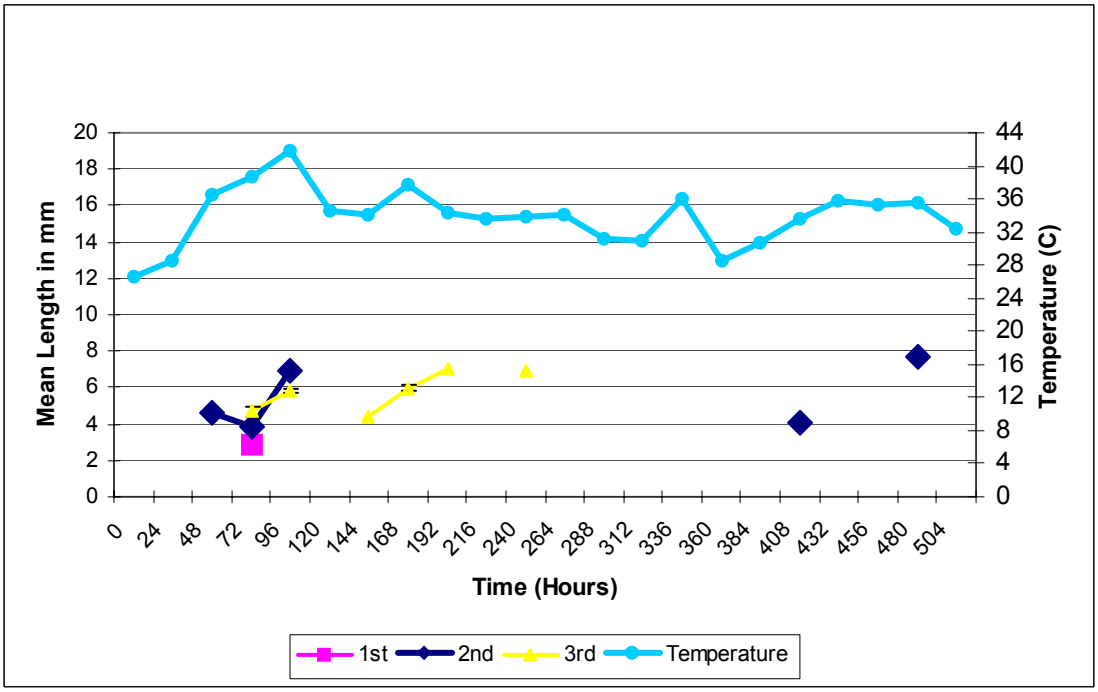

Figure 3-6. Mean growth rate of *Chrysomya rufifacies* over time compared to mean maggot mass temperature for Bear 2, August 2002.

Table 3-4. Significance of daily means for Bear 2, August 2002 from Duncan's test.

Duncans On Daily Means for Bear 2, August 2002

Day	Air	Underbear	Maggot Mass	Wet Bulb
1	24.2731C	26.0511B	26.6206A	24.066C
2	25.5047B	25.9906B	28.4656A	24.715C
3	26.1398C	30.7927B	36.7181A	25.2866D
4	25.9667C	34.1235B	38.7817A	24.618D
5	25.6825C	35.3234B	41.6851A	24.5005D
6	25.4554B	33.9924A	34.4442A	25.1002B
7	24.6336C	32.5811B	34.1073A	24.2113C
8	25.3024C	33.1466B	37.5952A	24.6695C
9	25.4973B	34.4431A	34.5021A	24.2269C
10	25.893B	25.104A	33.63A	27.97B
11	25.3215B	34.4034A	33.7581A	24.5217B
12	25.6556B	34.709A	34.0343A	24.8175C
13	24.199C	34.18A	31.069B	28.611B
14	24.1027B	30.8139A	30.9231A	25.3932B
15	24.79C	30.658B	35.903A	29.3398B
16	24.2294B	28.7881A	28.4537A	24.2568B
17	25.3719C	28.3404B	30.7935A	25.6121C
18	26.001D	30.1684B	33.6088A	27.4676C
19	25.814D	32.536B	35.684A	28.24C
20	25.959B	34.858A	35.39A	32.05A
21	26.058C	36.447B	35.56B	46.509A
22	25.304C	33.403A	32.476A	28.066B
23	24.716C	34.133B	35.756B	44.672A
24	24.485C	36.529B	41.897AB	45.079A
25	25.0295C	28.5188B	40.012A	25.1149C
26	24.8703C	31.6621A	31.6929A	27.3933B
27	25.31B	30.055B	29.917B	38.139A
28	25.718B	29.899B	29.528B	37.726A

Bear 3, November 2002

The cooler temperatures of November did not inhibit the thermal energy production by the developing larvae. After the first 24 hours, the maggot mass temperatures were higher than the ambient. The mean maggot mass temperature was calculated to be 26.48°C; the minimum was 13.70°C and the maximum was 43.91°C. Temperature data are shown in Table 3-5. The one-way ANOVA and Duncan's test showed significance in the data with a P value of <.0001.

The high temperatures of the maggot mass and the steady increase of the underground soil temperature are shown in Figure 3-7. Figure 3-8 shows the daily means of the temperatures analyzed with a Duncan's test graphed together. Table 3-6 shows the daily means for all temperatures and their significance from a Duncan's test. Figure 3-9 is the relationship of the mean growth for *C. rufifacies* with time and compared to the mean maggot mass temperature.

Table 3-5. Descriptive statistics of temperatures recorded for Bear 3, November 2002 throughout decomposition.

Temperature Data Recorded For Bear 3, November 2002

	Air	*Maggot Mass*	*Underground*	*Wet Bulb*
Mean temperature[a]	17.93C	26.48B	34.09A	17.19D
Standard error	0.212	0.223	0.221	0.125
Minimum temperature	9.03	13.7	18.66	7.83
Maximum temperature	37.88	43.91	44.4	25.56
Confidence level	0.417	0.438	0.434	0.246

[a]Means in the same row followed by the same letter are not significantly different (P=0.05; Duncan's multiple range test [SAS Institute 2003])

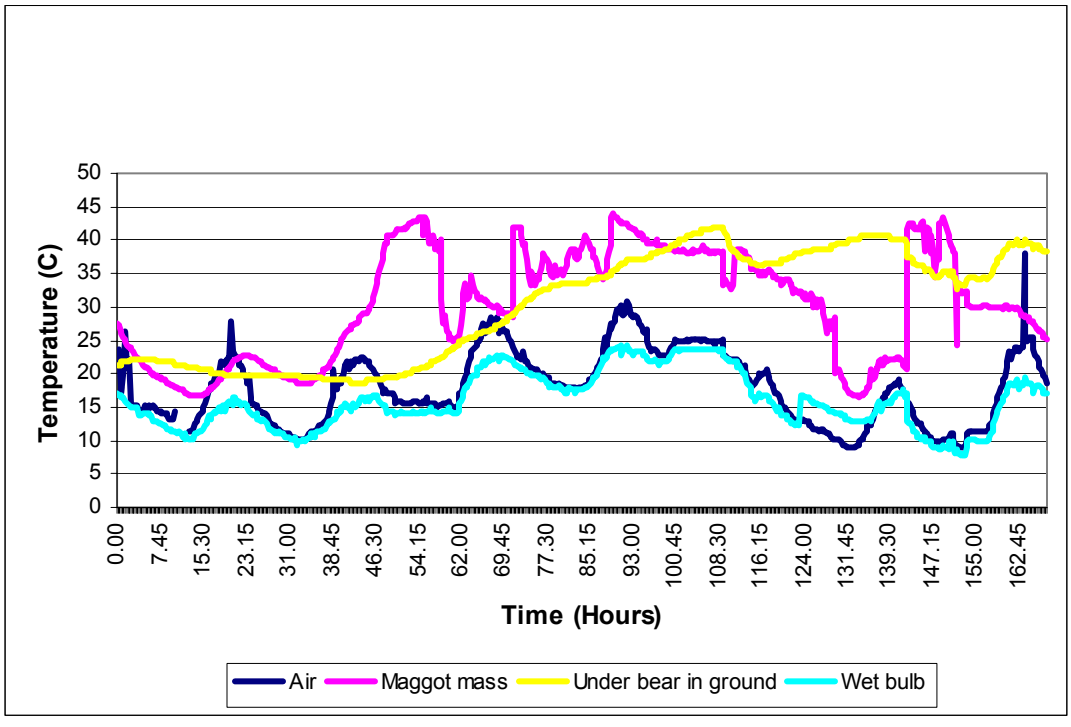

Figure 3-7. Temperature readings recorded on 15-minute intervals during decomposition of Bear 3, November 2002.

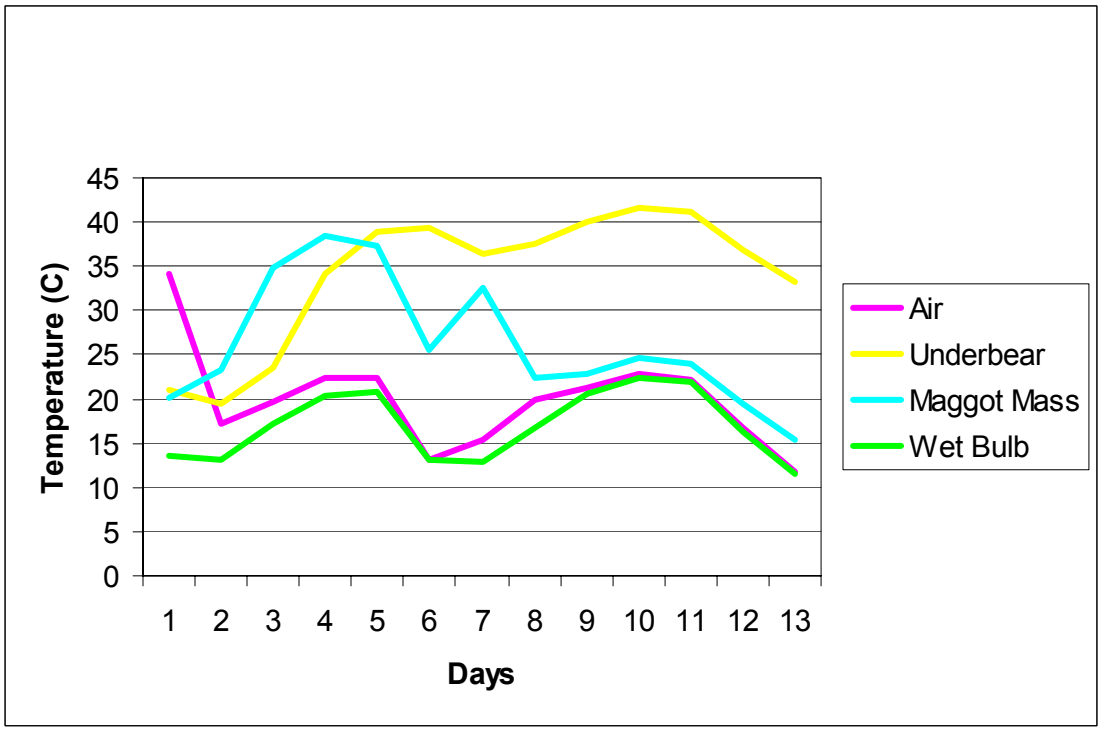

Figure 3-8. Daily means for temperature from Duncan's test for Bear 3, November 2002.

Table 3-6. Significance of daily means for Bear 3, November 2002 from Duncan's test.

Duncans On Daily Means for Bear 3, November 2002

Day	Air	Underbear	Maggot Mass	Wet Bulb
1	34.114A	21.028B	20.169B	13.555C
2	17.286B	19.337B	23.397A	13.004C
3	19.6399C	23.5848B	34.9302A	17.1308D
4	22.4036C	34.0753B	38.4028A	20.4081D
5	22.3549C	38.899A	37.2429B	20.9029D
6	13.0654D	39.2501A	25.5395B	13.0654C
7	15.3749C	36.3875A	32.5645B	12.833D
8	19.941C	37.55A	22.44B	16.748D
9	21.3121C	40.1286A	22.823B	20.6413D
10	22.9493C	41.578A	24.6341B	22.3459D
11	22.2334C	41.1297A	23.9821B	21.8266C
12	16.7182C	36.9007A	19.515B	16.3894C
13	11.7707C	33.25A	15.3585B	11.6052C

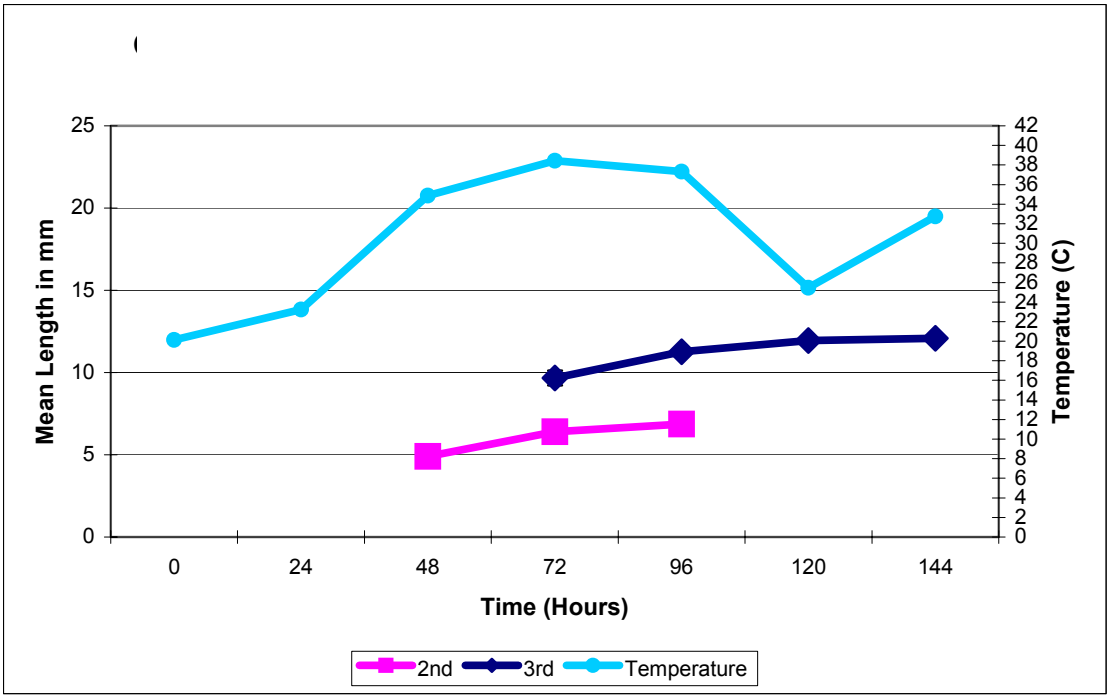

Figure 3-9. Mean growth rate of *Chrysomya rufifacies* over time compared to mean maggot mass temperature for Bear 3, November 2002.

The maggot mass first developed in or around the mouth of all three bears. Although superficial wounds were present from the car accident, the flies preferred to oviposit in the orifices and on the side of the face that was laying on the ground. The eggs and early instar larvae were found under the arms in the crevices of the skin, hidden from the weather and predators. Some went unnoticed in a few of the locations until the maggot mass started to form and move about the carcass. The maggot mass produced its elevated temperatures as it moved around the carcass and grew larger with the increasing size and number of the larvae. The majority of the maggot masses were formed between the bear and the ground around the perimeter of the carcass. Often when most of the skin of the carcass is dry, conditions are favorable for oviposition in parts of the carcass that come in contact with the soil (Deonier 1940); this could be the case here due to the heat and humidity of Florida. Figures 3-10 to 3-18 show the maggot mass heat production

versus the underground temperature and the movement of the masses for Bear 1, June 2002. Figures 3-19 to 3-28 show the maggot mass heat versus the underground temperature for Bear 2, August 2002. Figures 3-29 to 3-34 show the maggot mass heat production versus the underground temperature and the masses movement about the bear for Bear 3, November 2002.

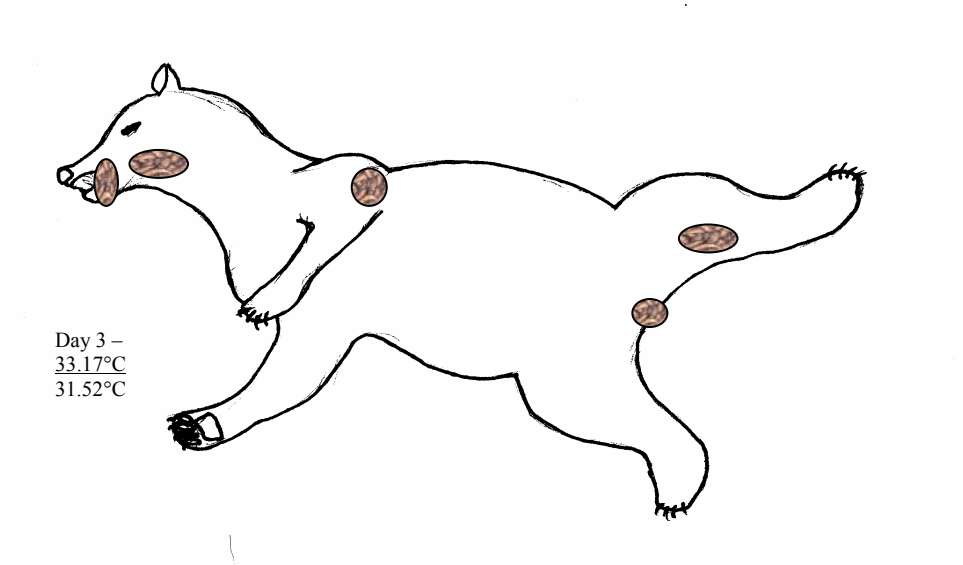

Figure 3-10. Day 3, maggot mass positions that have formed within the first 72 hours for Bear 1, June 2002, with comparison of the maggot mass temperature to the soil under the bear temperature.

Figure 3-11. Day 4, the movement of the maggot masses for Bear 1, June 2002, with comparison of the maggot mass temperature to the soil under the bear temperature.

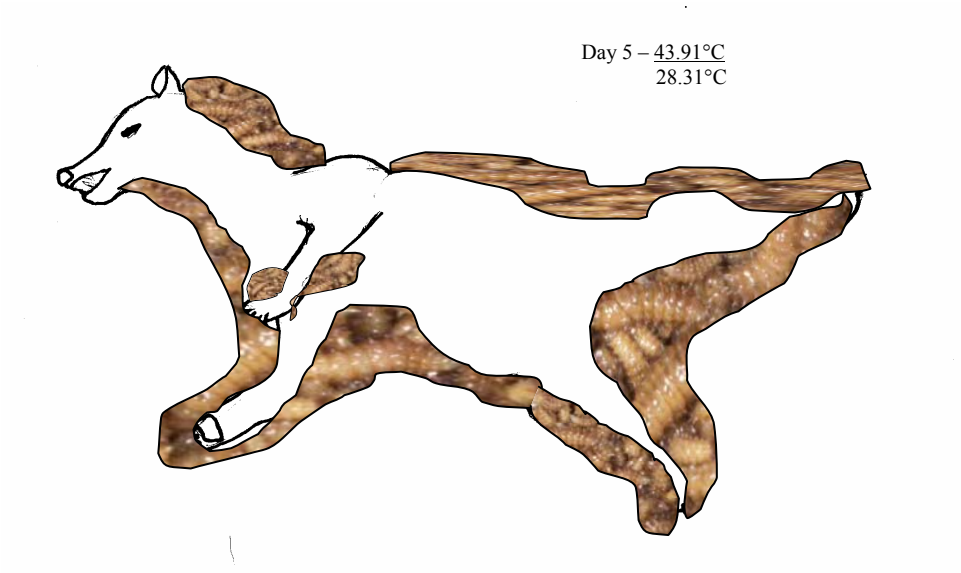

Figure 3-12. Day 5, the maggot masses are present in the same locations as those of Day 4 for Bear 1, June 2002, the temperature of the maggot mass compared to the soil temperature under bear is shown.

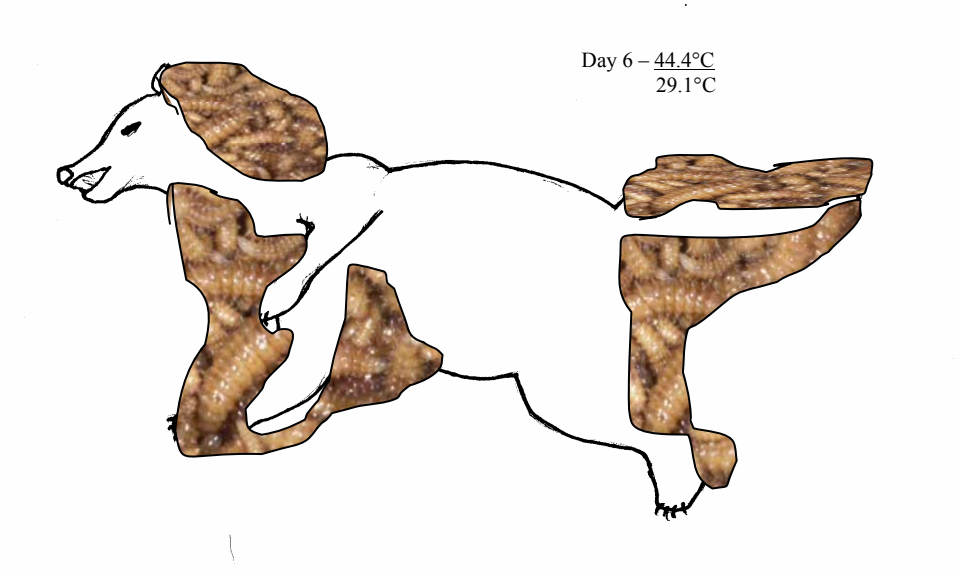

Figure 3-13. Drawing shows the variation in locations upon which the larvae prefer to grow at after Day 6 on Bear 1, June 2002, it also compares the maggot mass temperature with the soil temperature under the bear.

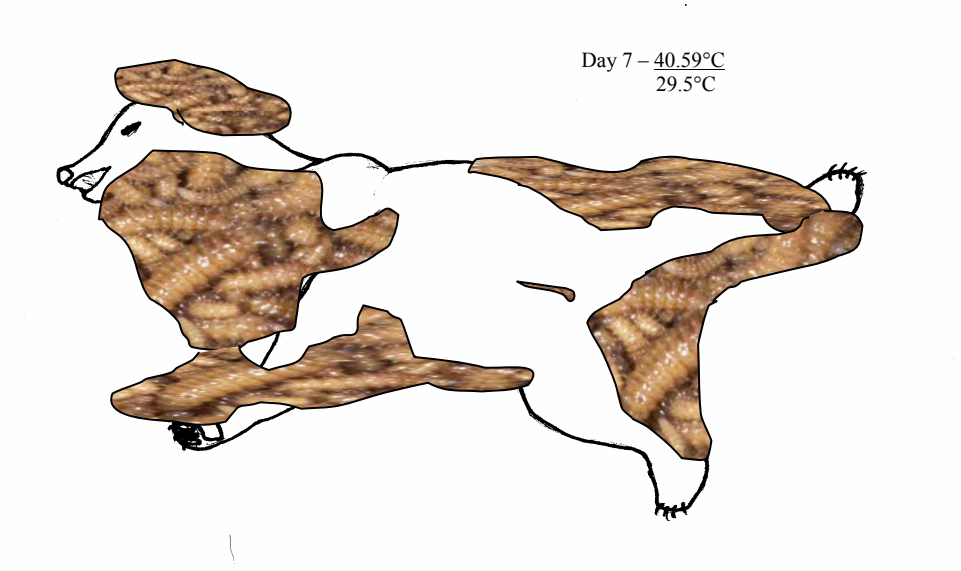

Figure 3-14. Maggot mass movement fluctuates in size as the temperature difference increases from the ambient soil temperature on Bear 1, June 2002.

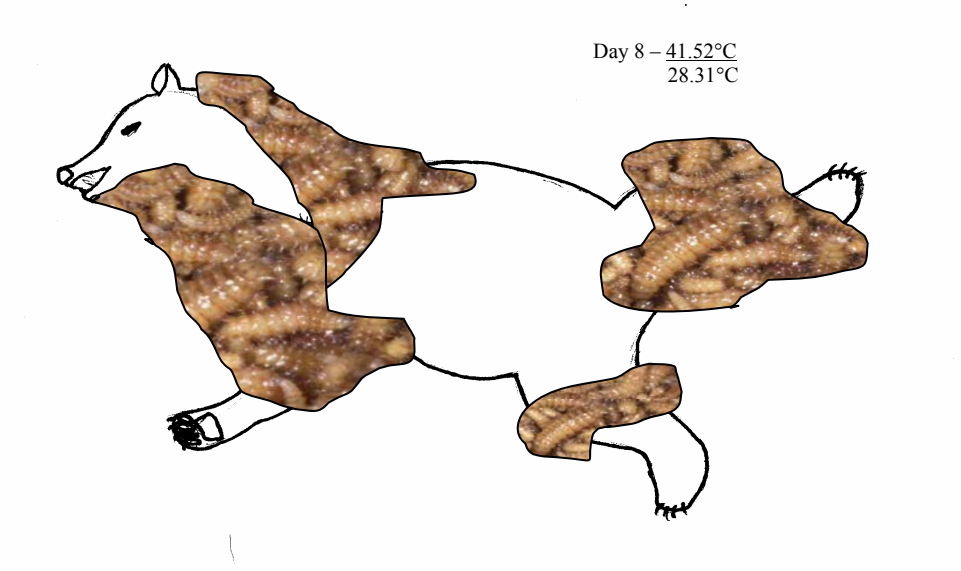

Figure 3-15. This drawing shows how the larvae come closer together as they feed and grow together in a mass on Bear 1, June 2002 and compares the maggot mass temperature with the soil temperature.

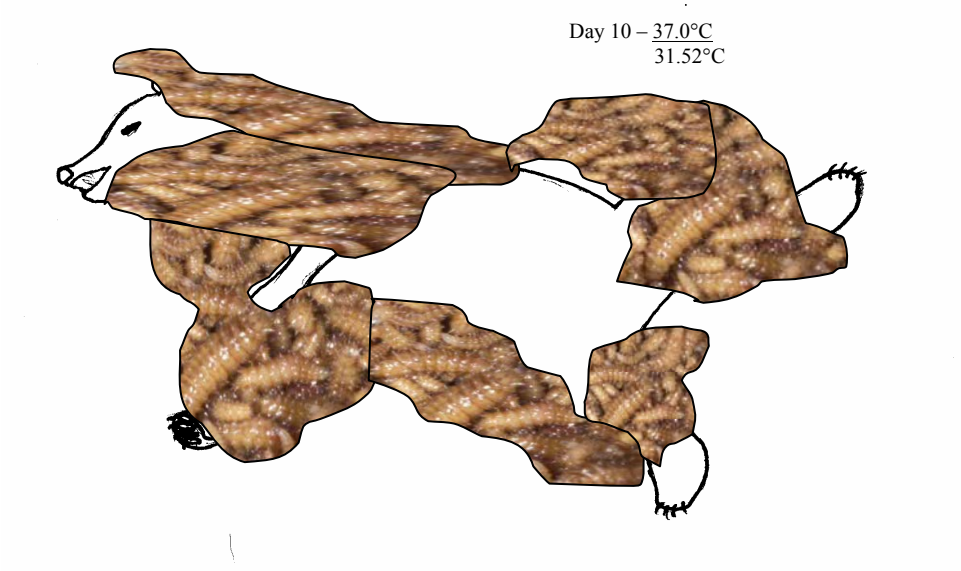

Figure 3-16. As the larvae slowly reach the post-feeding stage on Bear 1, June 2002, they begin to spread out on the surfaces of the bear and surrounding areas, a comparison of the maggot mass temperature to the soil under the bear temperature is shown.

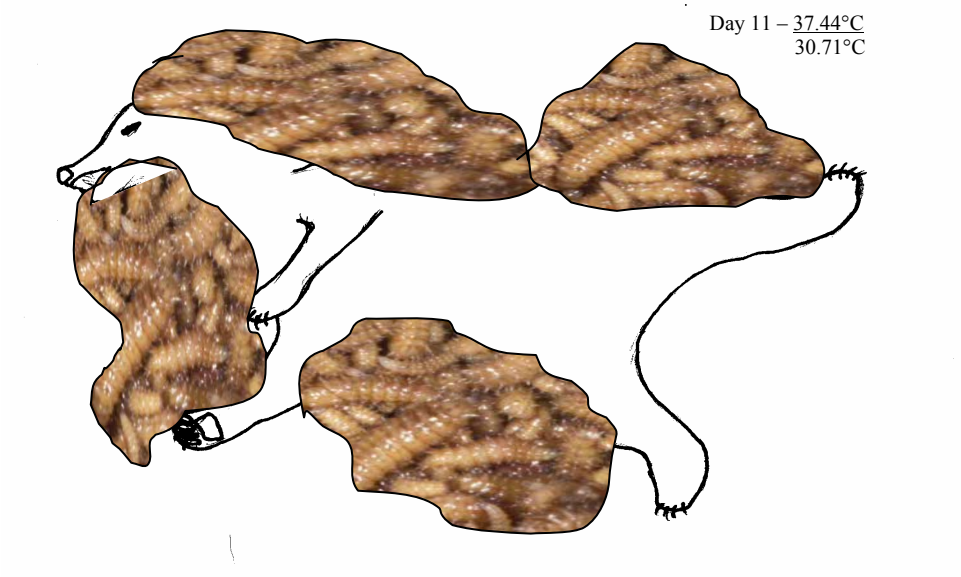

Figure 3-17. Day 11, the maggot masses activity is starting to slow and remain in a constant location until ready to migrate away from Bear 1, June 2002, the maggot mass temperature is shown in relation to the soil temperature.

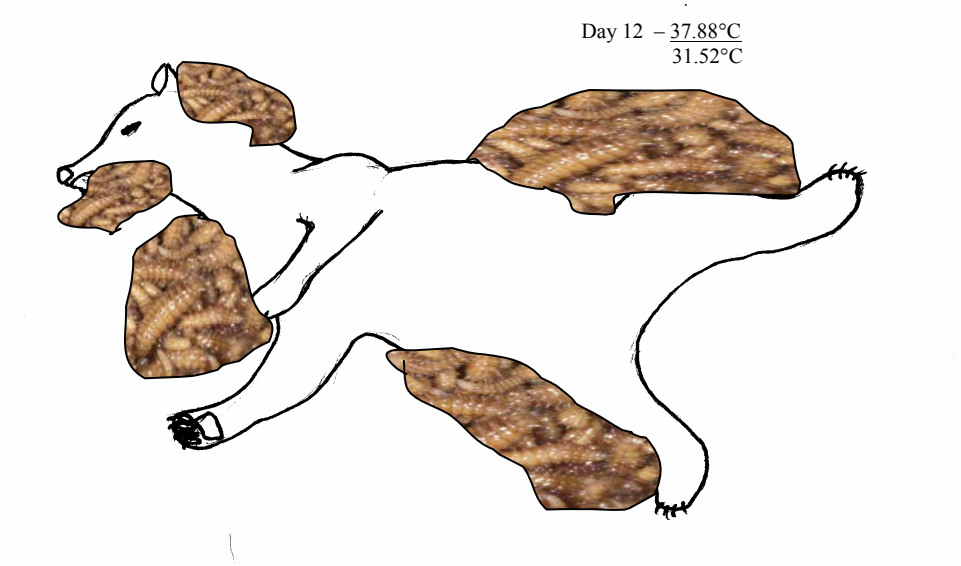

Figure 3-18. The final day of the maggot masses on Bear 1, June 2002, before the post-feeding larvae migrate away from the carcass to pupate, the soil temperature is still less than the maggot mass.

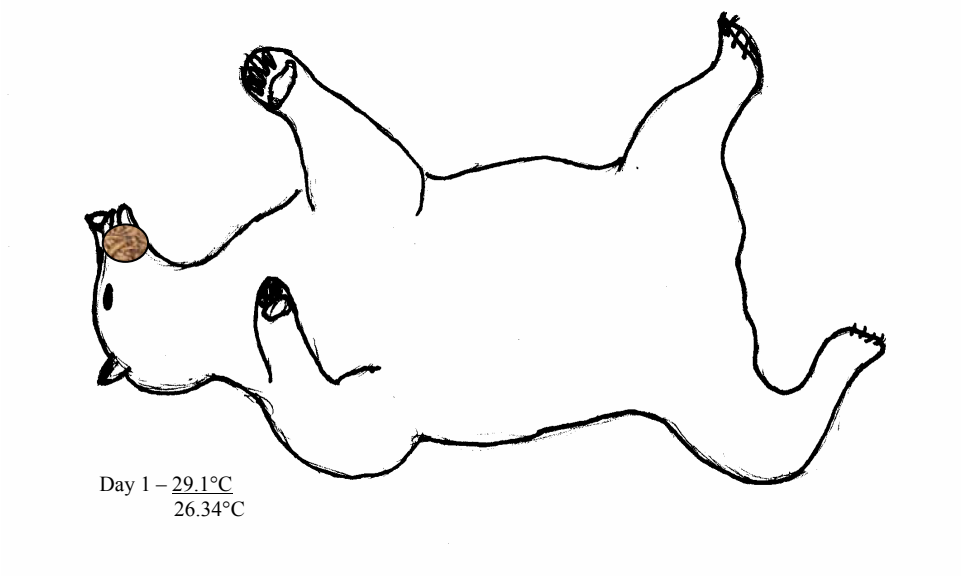

Figure 3-19. Drawing from Day 1 showing the first maggot mass to form on Bear 2, August 2002, the temperature of the maggot mass is compared to the soil temperature underneath the bear.

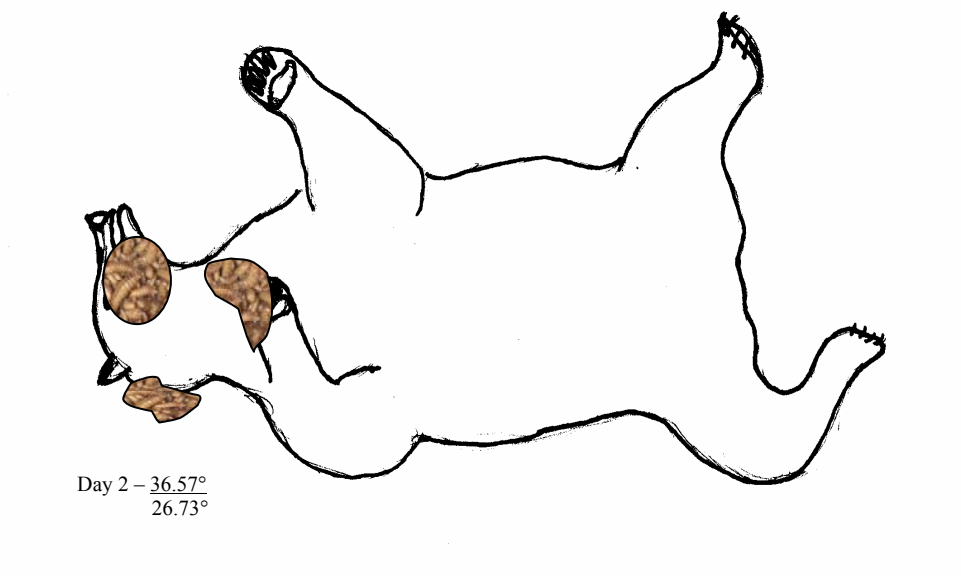

Figure 3-20. The original maggot mass is increasing in size while other areas of the carcass are beginning to form masses on Bear 2, August 2002. A comparison is done between the maggot mass temperature and the soil.

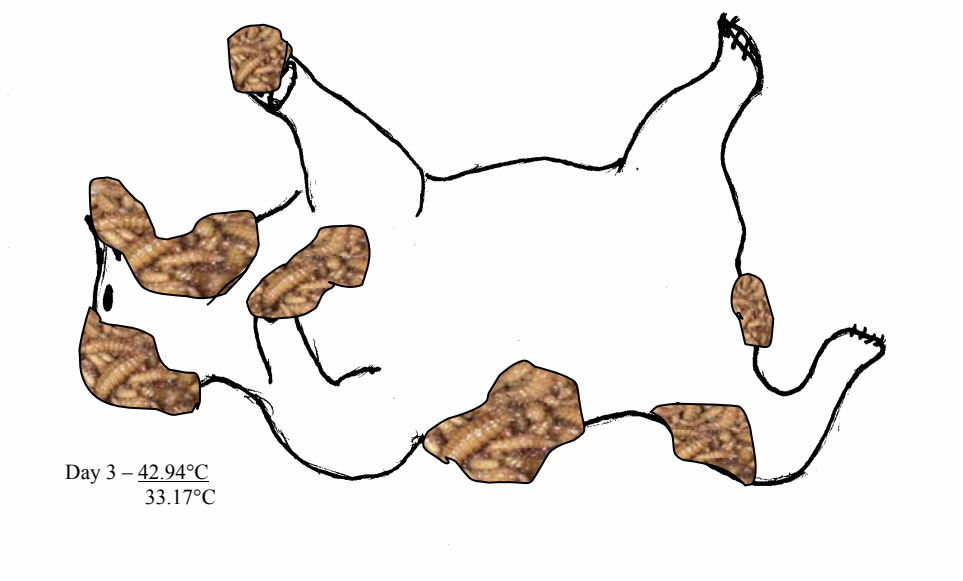

Figure 3-21. Day 3, all of the orifices of Bear 2, August 2002, have maggot masses along with areas of the carcass that are touching the ground. The maggot mass temperature is compared to the soil temperature under the bear.

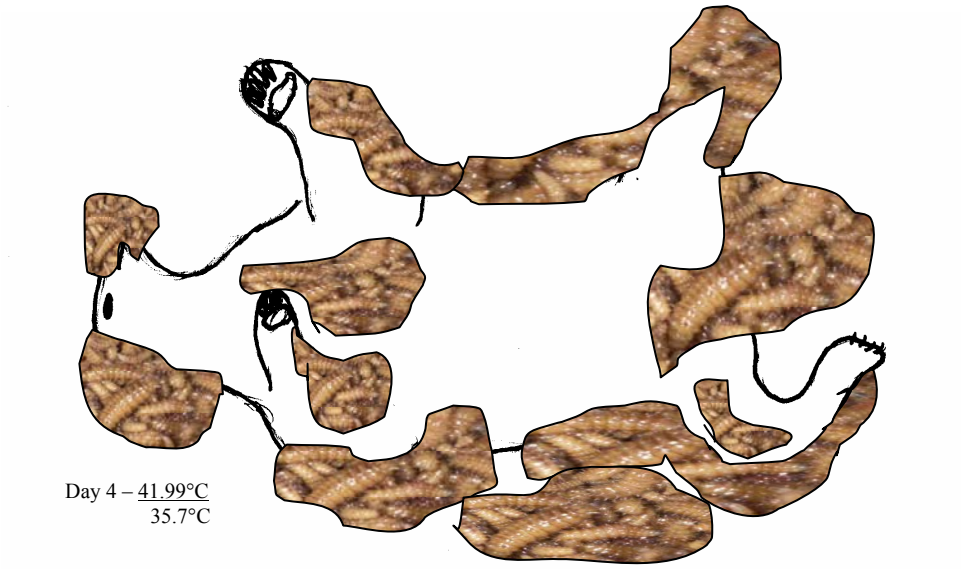

Figure 3-22. The larvae have increased in size as well have the masses that they have formed on Bear 2, August 2002, the maggot mass temperature is compared to the soil temperature under the bear.

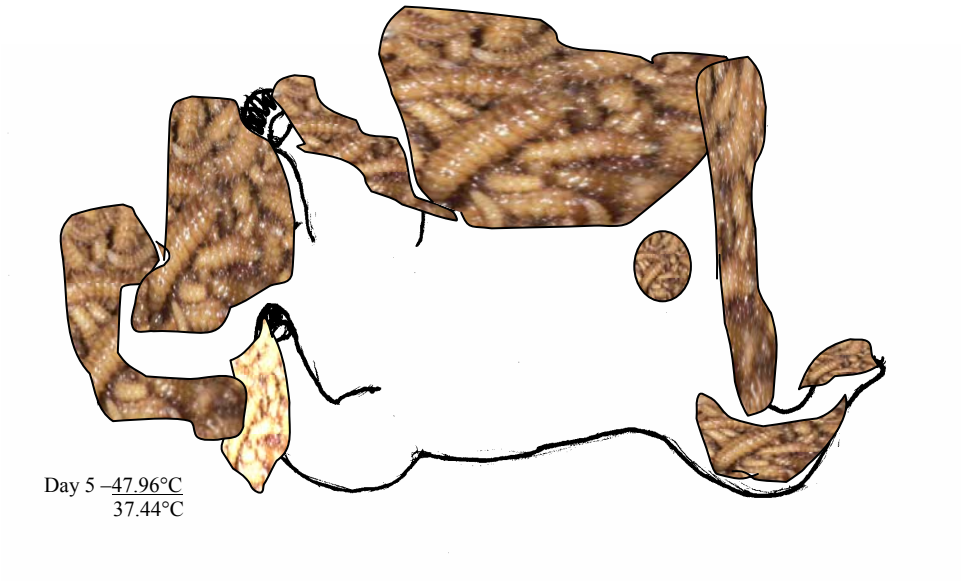

Figure 3-23. Day 5, the larval masses are found mostly on one side of Bear 2, August 2002 feeding on the tissue of the extremities, head and abdominal regions, the temperature produced by these masses are compared to that of the soil.

Figure 3-24. The drawing shows the main areas of interest to the developing larvae on Bear 2, August 2002 with a comparison of the maggot mass temperature to the soil temperature.

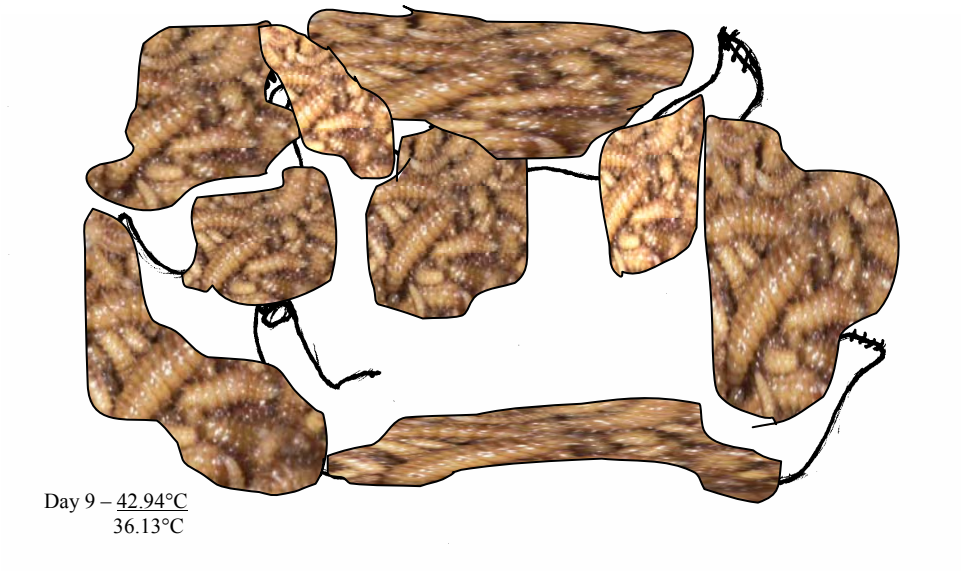

Figure 3-25. The developing larvae, which are close to migrating in order to pupate, have consumed the majority of Bear 2, August 2002 tissue but the maggot mass temperature is still higher than the soil.

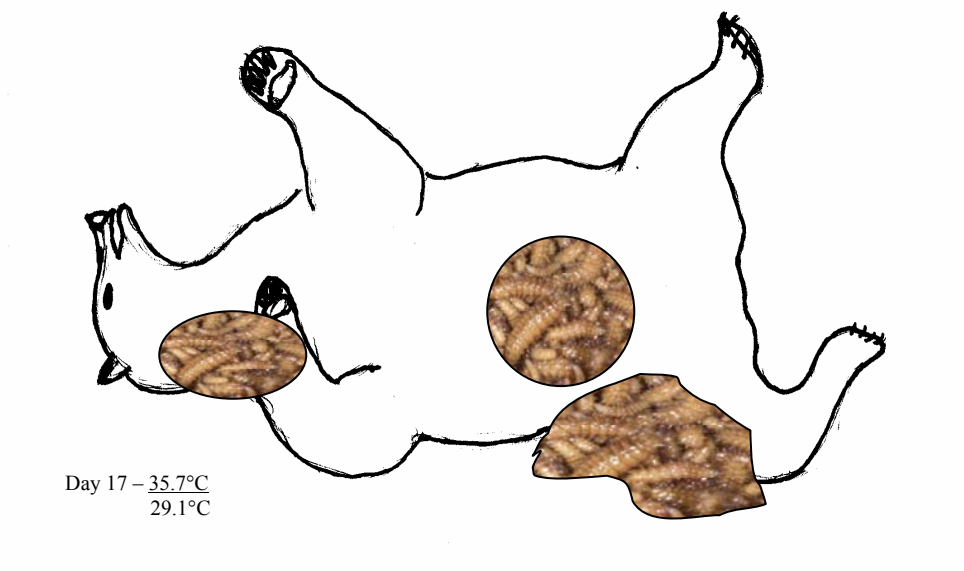

Figure 3-26. Day 17, a new wave of blow fly larvae has begun to develop on Bear 2, August 2002 and the maggot mass temperature is being compared to the soil temperature under the bear.

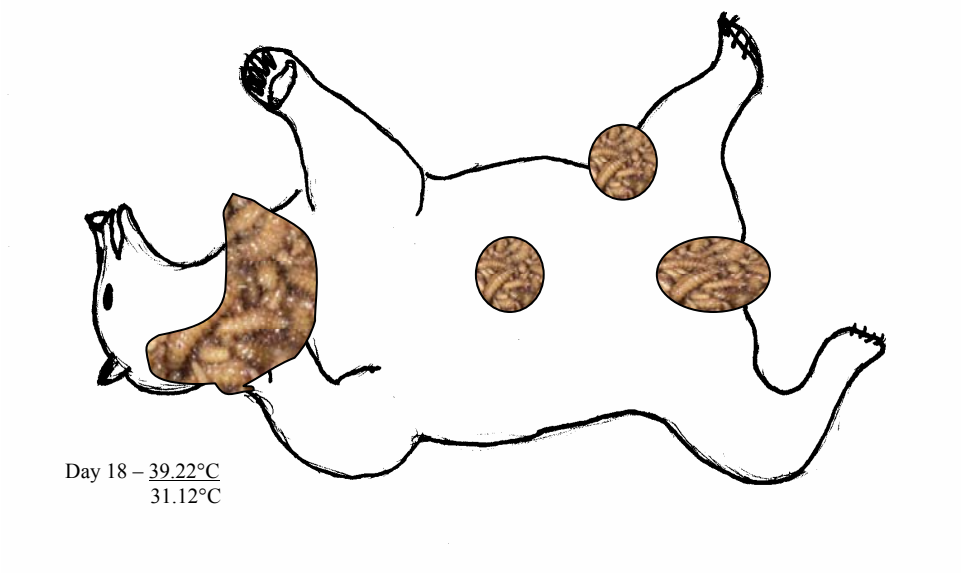

Figure 3-27. The larvae of the new maggot masses are developing rapidly on Bear 2, August 2002 but the numbers are much lower than those from the first wave of blow fly, the maggot mass temperature is still higher than that of the soil.

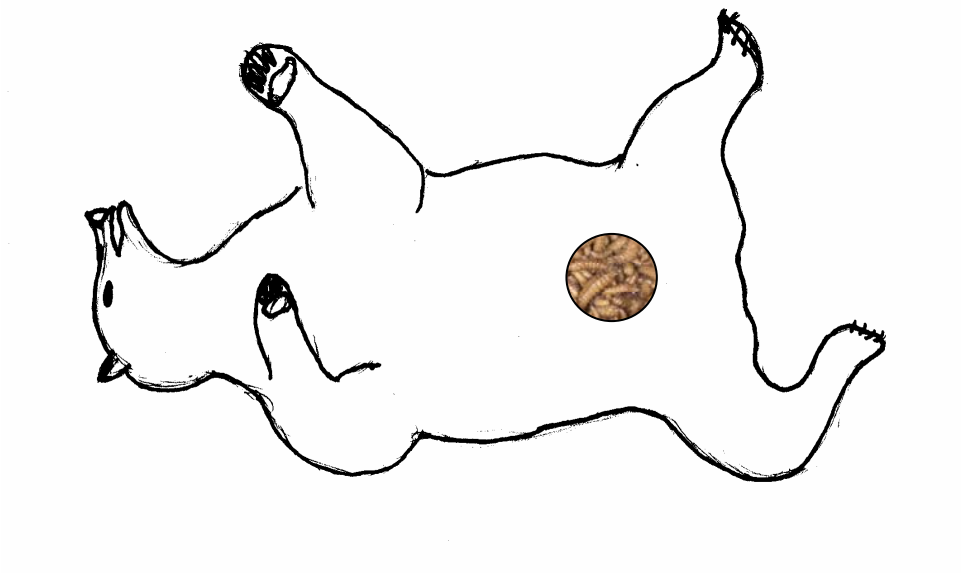

Figure 3-28. Day 20, one small maggot mass still remains on Bear 2, August 2002 even in the late stage of decay, its temperature is not much more than that of the soil.

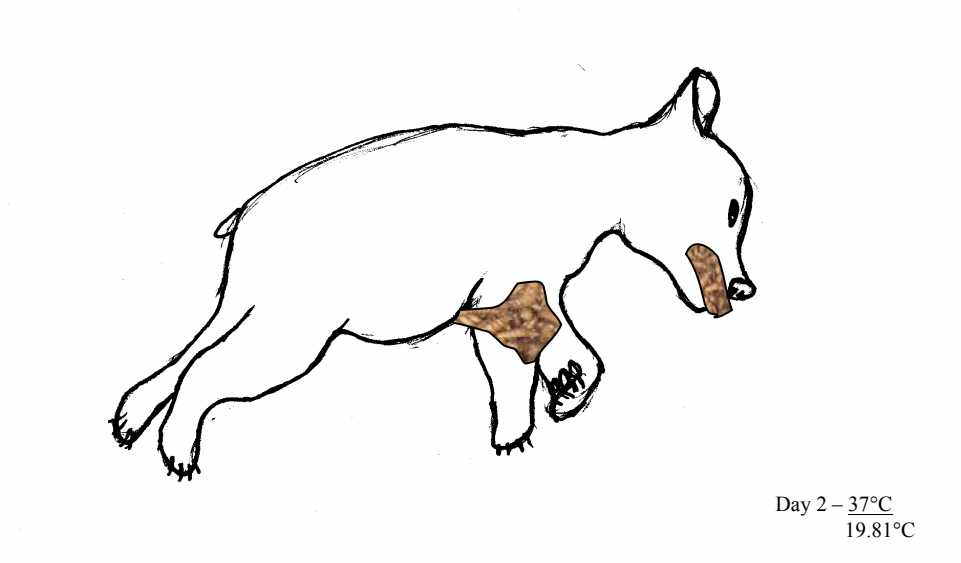

Figure 3-29. Day 2, early signs of maggot mass formation taking place at the mouth and the chest for Bear 3, November 2002, the temperature of the maggot mass is compared to that of the soil temperature under the bear.

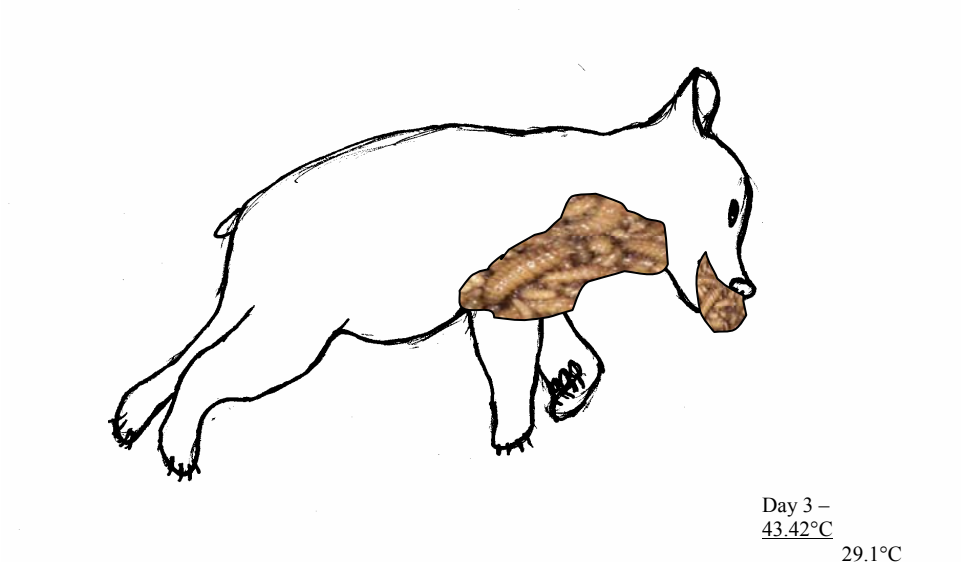

Figure 3-30. The larvae in the chest mass on Bear 3, November 2002 have begun to increase in numbers and size, so has the difference between the maggot mass and soil temperatures.

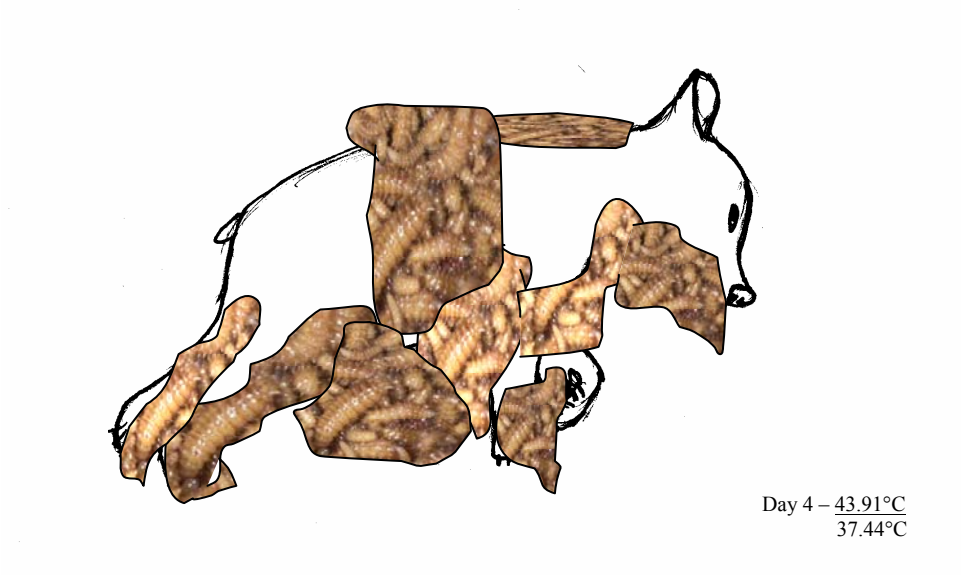

Figure 3-31. By day 4, the larval masses of Bear 3, November 2002 have moved throughout the body and the numbers have increased greatly, the maggot mass temperature is still significantly higher than that of the soil.

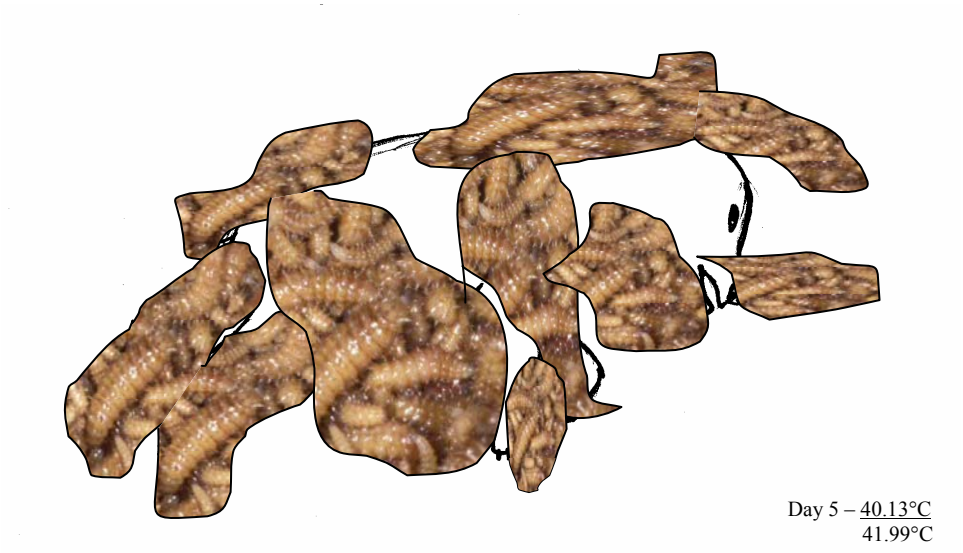

Figure 3-32. Although there are larger maggot masses present on Bear 3, November 2002, the soil temperature underneath the bear is slightly hotter on day 5.

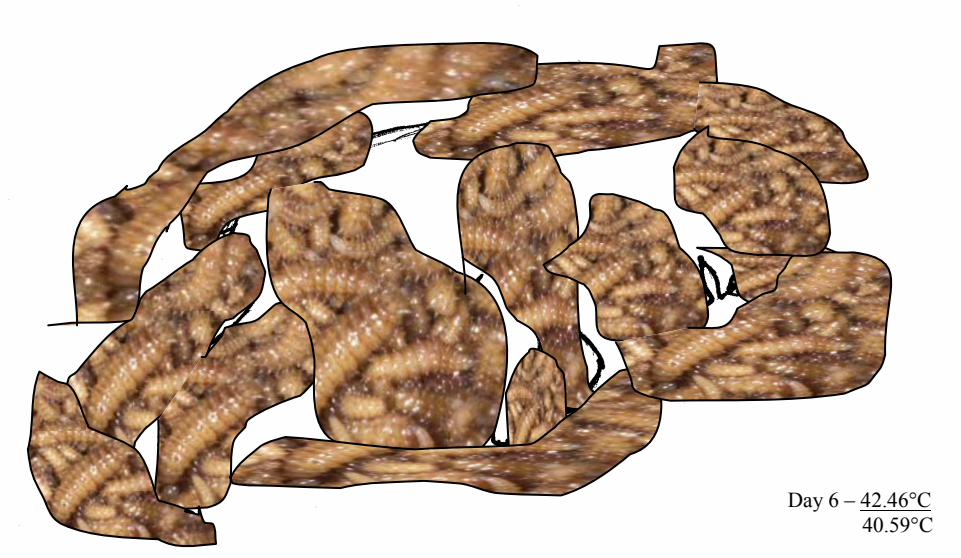

Figure 3-33. On day 6, the maggot mass temperatures on Bear 3, November 2002 was higher than that of the soil. The larval masses have also increased in numbers and size.

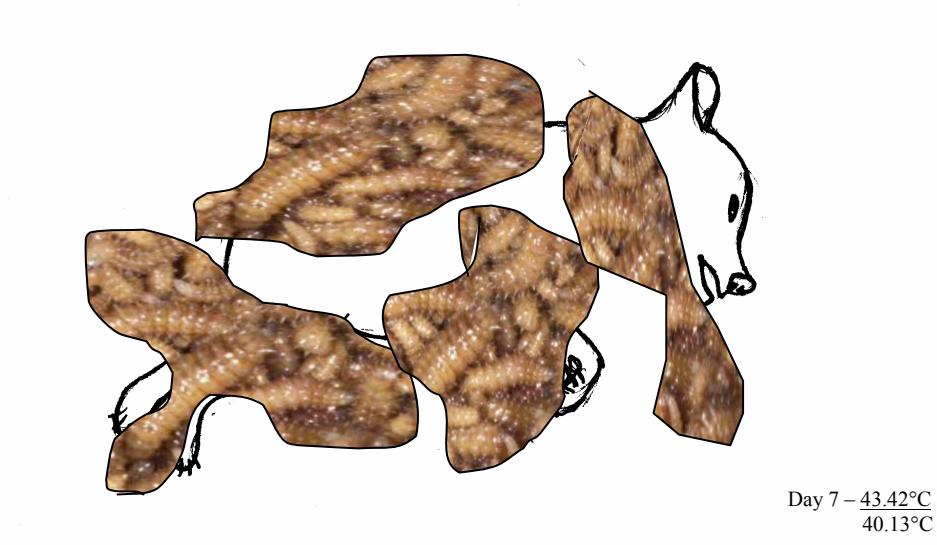

Figure 3-34. The larval masses have become a little bit smaller and the larvae are reaching migration on Bear 3, November 2002 but the heat they generate is still higher than that of the soil.

CHAPTER 4
SUMMARY

Discussion

Species Interaction

As mentioned before, the most abundant blow fly species found in North Central Florida is the Hairy Maggot Blow Fly, *Chrysomya rufifacies*. The Hairy Maggot Blow Fly is one of the earliest to arrive to a carcass but the larvae grow at a little slower rate in the beginning. This gives the other larvae present a chance to begin their life cycle and prosper before the *C. rufifacies* begin to increase in size. During the late 2nd instar, the *C. rufifacies* larvae were found on opposite sides of the carcass from the other larval fly species present (Goodbrod and Goff 1990). Thus C. rufifacies larvae will consume one side of the carcass while the other side is infested with other larval species. As the *C. rufifacies* larvae grow and molt into 3rd instars, they will slowly move around the carcass to the side with the other larval species and consume them along with the carcass. Other forensic entomologists have observed this phenomenon in the southern locations of the U.S. [Goff (personal communication) and Butler (personal communication)]. It has also been reported that the *C. rufifacies* larvae need live flesh in order to progress into 3rd instars (Butler, personal communication; Goodbrod and Goff 1990; Baumgartner 1993).

The first larval developers at the carcasses were either *C. macellaria* or *C. megacephala*. The larvae of these species have similar characteristics and grow quickly into large maggot masses. When these species were late 2nd and early 3rd instars, the *C. rufifacies* larvae were 1st and 2nd instars. For the first 24 hours the maggot masses present

were composed of these species but shortly after that the *C. rufifacies* would overpower them. They were either forced away from their food source (the carcass) or consumed by the *C. rufifacies*. The same observation has been made in laboratory settings (Wells and Greenberg 1992) when *C. macellaria* and *C. rufifacies* were reared together. But it was not certain at that time if the same would occur in the field.

There were considerable differences in the size of the maggot masses formed by the two species. The *C. rufifacies* larval mass were very large and covered most of the carcass' surface area, while the other maggot masses were relatively small and made up small clusters on the surface. The increased maggot mass size for *C. rufifacies* is a characteristic that enables them to be the dominant species when present (Goodbrod and Goff 1990).

Thermal Energy of the Maggot Mass

The thermal energy of the maggot mass, or the energy being produced by the massing larvae, was shown to be higher than the ambient temperature throughout larval development during the early stages of decomposition. The largest temperature increase occurred at approximately 48 hours when the *C. rufifacies* were observed molting from 2^{nd} to 3^{rd} instars. The first 24 hours of larval growth can be contributed more to the ambient temperature than the maggot mass, which had not formed completely. This has been recorded by Goff (2000) who observed the heat generated by the maggot mass as influencing the rate of development but the heat is not generated immediately. A temperature probe was inserted into the mouth of the bear upon arrival because it is one of the first orifices where eggs are laid. But during the first 24 hours the small 1^{st} instars do not produce intense thermal energy on their own like the larger larvae, therefore preventing the early maggot mass from surpassing the ambient temperature. Deonier

(1940) found that the heat came at first from the sun, but as larval development progressed, the maggot mass temperature increased and remained at least 5°C higher than the ambient regardless of daily weather fluctuations. This phenomenon was also observed in the data recorded for the bears in this experiment and at times the heat was over 20°C higher than ambient. The increased peak of temperature in the maggot mass is seen with the appearance of the 3rd instar larvae. This was also observed by Cianci and Sheldon (1990). For Bear 1 there was a 17°C increase from the 2nd instar larvae to the 3rd instars. Bear 2 showed a 17°C increase in temperature with the onset of 3rd instar larvae. The increased peak for Bear 3 resulted in a 22°C difference from the 2nd instars to full 3rd instar larvae. It is reported to take several days for a maggot mass to develop (Goff 2000). It was observed during this experiment that massing began after 24 hours and the largest increase of temperature was recorded around 48 hours.

The data presented in Tables 3-2, 3-4, and 3-6, show the daily mean variations that occur between the four temperatures (air, wet bulb, underground soil and maggot mass) as the bear carcass decomposes. This represents the significance that can occur between temperatures during decomposition and how they can fluctuate from day to day. The Duncan's test run on the data to show significance verifies that the maggot mass is higher than the ambient air temperature throughout decomposition. The data also shows the decrease and increase of the maggot mass on a daily basis in regards to the other three temperatures. The changing temperatures can be seen in Figures 3-2, 3-5, and 3-8 for the bear carcasses

In Figures 3-3, 3-6, and 3-9, the larval growth of *C. rufifacies* is compared to the average maggot mass temperature over time. A peak is observed at approximately 48

hours. This peak represents the changes in instar from 2nd to 3rd. This phenomenon has been reported previously and shown in Greenberg (1991). The increased temperature was recorded as the mean larval growth increased between 24 and 72 hours.

Forensic entomologists utilize the ambient air temperature when determining the post mortem interval (PMI). This is accomplished by contacting the closet weather station to get daily temperature and humidity readings for the time in question (Goff 2000). The entomologist will also take readings from the crime scene site at the time of collection and for the next few days to average the mean (Byrd and Castner 2001a; Goff 2000; Catts 1990; Goff 1993; Anderson 2001). This is of course an effective way to get a mean growth cycle for the larval species in question, but it does not incorporate the thermal energy produced by the developing larvae. The data shown here give evidence that the larvae prefer to choose a specific mean temperature at which they like to grow, seen in Byrd and Butler (1996; 1997; 1998). The maggot mass can fluctuate from 45°C to nearly 20°C. The larvae in the mass will move about between the varying temperatures to find the optimum location to develop. Cianci and Sheldon (1990) report that the formation of an endothermic environment can alleviate the stress on individual maggots and allow each maggot in the mass to function at its maximum efficiency. Using just the ambient air temperature gives the assumption that the larvae grow based only on the ambient mean without considering the effects the maggot mass has on the larvae.

Goff (2000, pg. 62) also recognized the movement of the larvae in the mass and expressed a clear insight of what events were taking place:

> "The temperature of the maggot mass does not necessarily reflect the actual temperatures at which the maggots are developing. The temperature of the mass is

> recorded at the middle of the mass, and temperatures are lower on the outer portions of the mass and in other parts of the corpse. Since maggots cannot regulate their own temperatures, at ambient temperatures above 50°C they are in danger of thermal death, and thus they seem to circulate throughout the mass, moving to the inside to feed and, as their temperatures become dangerously high, moving back to the outside of the mass to cool down and digest. After a period of cooling, they reenter the mass and repeat the cycle. In the process, they spend a good deal of their time at temperatures lower than the temperature at the center of the maggot mass."

The maggot mass mean thermal energy should be considered when estimating the PMI based on the data shown here. The maggot mass temperature is consistently higher than that of the ambient. Deonier (1940) found that the high temperatures in the carcasses he studied were due partially to heat absorbed from the sun but principally from the heat generated by blow fly larvae, which were developing in the carcasses.

The effect of the maggot mass are explained by Catts (1990, pg. 127) all of which were observed in my experiment:

> "Ambient heat does play a dominant role during egg and early larval development, but after that its effect decreases rapidly. Maggot activity generates its own heat that can prevent cooling and slowed development when air temperatures drop. The early maggot mass will develop at a rate somewhat in synchrony with fluctuations in ambient temperatures. However, in the late 2nd and 3rd instars, heat generated by the massed maggots can far exceed ambient heat and in effect produces a stable optimal heat level for accelerated larval development. The warmth produced by the maggot-mass serves also to warm the substrate underlying the remains so that subcorpse temperatures also may exceed that of the air. As the maggots from the mass scatter during postfeeding dispersal, the ground and corpse warming also dissipates."

This statement clearly explains the function and activity of the maggot mass in nature. The underground soil temperatures recorded for all three bears was elevated from the norm and at times was observed to be 12°C – 18°C warmer than the ambient temperature. This is believed to occur due to the larval massing. But, the underground soil temperature for Bear 3 reached its highest temperature of 41.99°C when the larvae

were in the late 3rd instar or early migration stage and the temperature held constant around 41°C for the next few days. This event could have been due to the screening placed between the bear and the soil to prevent insect overflow from the other bears. The screen might have heated the soil further even after larval development had ended.

Larval development cannot be solely based on ambient temperature. Although the accumulated heat from the sun warms the surface of a carcass, this is still not sufficient to spawn extensive larval growth (Deonier 1940). Shaded carcasses were reported to lack higher temperatures until larval development occurred (Deonier 1940). The carcasses for this experiment were located in a semi-wooded shaded area. So therefore without the larval development the carcass temperature would have been lower than that of the ambient. In the event no adverse effect occurred from the developing larvae, once the body had gone through the three stages of mortis: rigor, livor and algor, the body would essentially cool to a base temperature similar to the ambient. The idea of a corpse being uninhabited by larvae leads to the speculation that if the PMI determination is based on the ambient temperature, it could be under estimated. The corpse will appear as if it has been in the environment a shorter amount of time than it actually was due to lack of the increased heat for the larvae, which in turn increases the rate of decomposition.

The maggot mass temperature was found to be several degrees higher than the ambient throughout the time that the larvae were growing from 2nd instars and through to the late 3rd instar stage. The maggot mass temperature for Bear 1, June, 2002, was recorded 23°C above the ambient temperature of 20°C during 3rd instar larval growth. The greatest difference recorded during decomposition of Bear 2, August 2002, was

when the maggot mass temperature was 22°C over the ambient temperature of 32°C. For Bear 3, November 2002, the largest variation between maggot mass and the ambient temperature of 9°C occurred at about 145 hours when the maggot mass was 33°C higher. Goff (2000) also experienced a 22°C maggot mass temperature above the ambient in Hawaii. Deonier (1940) observed temperatures 70 degrees (Fahrenheit) above ambient in certain parts of carcasses and more than 50 degrees above the ambient in larval masses.

It appears that the thermal maggot mass has more influence when the ambient air temperature is lower due to weather and season. For Bear 1 and 2 the difference was much less due to the high temperatures being recorded as the ambient. The summer months and early fall months have high daily temperatures in Florida and the late fall months begin to show signs of winter coming with decreased temperature. It can be said that when determining the PMI in colder regions of the U.S. or at colder times of the year, the maggot mass thermal energy should be the main heat contributor. This is because the low ambient temperatures would not be high enough to sustain the increased development of the larvae present. Mann et al. (1990) report that the maggots within the body cavities such as the head, chest, abdomen, and vagina will continue to feed and develop even in freezing weather because they produce their own heat due to their large numbers. In the warmer months and regions of the U.S., the ambient air temperature will play more of a role even though maggot mass thermal heat development is decreased.

Conclusion

Temperature is a main contributor when estimating the time of death. An accurate growth rate of Dipteran larvae cannot be determined without knowing the temperature of the median where the flies are growing. When an individual approaches a crime scene

where the PMI will be needed, the appropriate temperatures should be taken. Many are unaware of the correct procedure and some important temperatures will not be collected (Smith 1986), thereby making the closest weather station's data extremely important to a case (Goff 2000). If a maggot mass is still present when a corpse is discovered, several temperatures should be taken throughout to get a relative mean. As seen in this experiment, the maggot mass temperature can have a great effect on the development of the larvae based on season and weather.

Maggot mass temperature does not stay constant in the field and thus the use of laboratory tests can give altered predictions. The results from my experiment correspond with several growth curves developed by Byrd and Butler (1996, 1997, 1998) and Byrd and Allen (2001), but the actual field data are very unpredictable. In a laboratory setting, larvae of *Phormia regina* (Meigen) were unable to sustain life through the adult stage at temperatures above 35°C, but a larval mass can reach temperatures well above this. It can be said that when the larvae have control of the thermal temperature they are growing in, they are more likely to survive in extensive heat. Even so, it is apparent that extensive heat is more important at varying times of development. The molting of 2nd to 3rd instars produces increased thermal energy, which continues during the 3rd instar feeding frenzy. However, during post-feeding, the maggot mass temperature slowly starts to decline. One must keep in mind that a maggot mass is a dynamic process with maggots continually moving in and out of the higher temperature areas.

Species composition of the maggot mass is thought to have dissimilar effects on the results. In North Central Florida the dominant species *Chrysomya rufifacies* made up all of the large maggot masses studied on the carcasses. Therefore, the data presented here

applies only to that species. Other species might have different effects when massing together on carrion and they might not be able to produce as much heat. This is something that needs to be researched in other locations. In conducting this experiment the temperature readings for the first 24 hours were taken from a species other than *C. rufifacies,* which gave very low readings compared to the rest of the data. It can be assumed that the first instars did not produce extensive heat. It can also be stated that the larval species present within the first 24 hours are unable to produce extensive heat.

In conclusion, the maggot mass plays a significant role in controlling the developmental time of Dipteran larvae. The thermal energy that the growing larvae produce in the mass should be taken into consideration when determining the post mortem interval. There are substantial data recorded in this experiment to show the importance of the maggot mass and help to understand how the larvae are able to live under such extreme conditions.

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BIOGRAPHICAL SKETCH

Sonja Lise Peters was born and raised in Lehigh Acres, located in southwest Florida. She graduated second in her class from Lehigh Senior. High School in 1997 and headed to college. Aspiring to be a pediatrician, Sonja was soon introduced to the world of six legged creatures at Bethany College. Her infatuation with insects grew during her second year, when she learned about forensic uses of arthropods. Sonja graduated with a Bachelor of Science degree in biology in 2001; and started at the University of Florida Entomology and Nematology department in the fall. She never looked back to medicine after finding her place in forensic entomology.