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Carrion-associated arthropods in rural and urban environments

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ABSTRACT

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Preferences of arthropods are important in forensic entomology, as the species collected can help determine the postmortem interval or if remains have been moved. This study looked at arthropods that are attracted to pig carcasses in rural and urban habitats in Northwest Indiana. The species and number of carrion-associated arthropods that are found at a carcass vary with habitat type, month, and stage of decomposition. *Lucilia sericata* (Diptera: Calliphoridae) is a synanthropic species that was found in higher numbers in urban locations for both adults and larvae. Though *L. sericata* had higher numbers in urban habitats, caution must be exercised when using the information in a criminal case, as adults and larvae were still collected in rural habitats, and thus presence of *L. sericata* does not conclusively show that remains were previously located in an urban habitat. No other Diptera or Coleoptera species showed a preference for habitat type. Isopoda were found in higher numbers in urban habitats. Calliphoridae species, except for *L. sericata*, had differences in numbers between the months studied (June - October). Most adult taxa and all larval taxa showed differences in numbers between decomposition stages. Succession tables for all arthropods and non-arthropods collected were created to show when taxa that were found at the carcasses. Crickets (Orthoptera: Gryllidae) were observed feeding on the carcass, and holes left in the carcasses by dipteran larvae. The cricket feeding modified the appearance of the holes, which could be confused for antemortem or perimortem wounds in a criminal investigation.

1. INTRODUCTION

1.1 Forensic Entomology

Forensics relates to a court of law and has come to mean using the scientific method to solve crimes. Forensic entomology is the application of entomology to legal issues (Catts and Goff, 1992). Forensic entomology has been broken into three basic types; urban, stored product and medico-legal. Urban forensic entomology involves arthropods as pests in dwellings, gardens and the misuse of pesticides (Catts and Goff, 1992). Stored product forensic entomology is legal proceedings involving arthropod contamination or infestation of consumer goods (Catts and Goff, 1992). Medico-legal forensic entomology can be used in the event of felonies, trafficking, violent crimes, physical abuse and neglect (Catts and Goff, 1992; Smith, 1986) as well as in cases of animal poaching (Anderson, 1999). Medico-legal forensic entomology uses insect development, insect distribution, insect behavior and ecology to aid in legal proceedings (Carvalho et al., 2004). The succession patterns and development rates of necrophilous and necrophagous fauna can be used to estimate the post mortem interval (PMI) (De Jong and Hoback, 2006). Necrophilous fauna is associated with carcasses and may feed on arthropods associated with carrion or on the carcass and associated arthropods, while necrophagous fauna specifically feeds on carcass. The PMI determined using entomological data is often more statistically reliable than autopsy results and police reports (Gruner et al., 2007; Kashyap and Pillay, 1989; Catts and Haskell, 1990; Anderson, 2001a).

Diptera and Coleoptera are the two main insect groups present on carrion. Blow flies (Diptera: Calliphoridae) have been shown to arrive at pig remains within 30 seconds of placement outside (Gruner et al., 2007) and will generally oviposit on bodies within the first few hours following death (Catts and Goff, 1992; Catts, 1992).

Depending on the species involved, Coleoptera may come to feed on the carcass, to feed on the arthropods feeding on the carcass or to feed on both the carcass and associated arthropods (Catts and Goff, 1992).

1.2 Diptera

Blow flies are the dominant arthropod group associated with carcasses and are considered the most important forensically (Reed, 1958). Most species are necrophages, though some are ectoparasites, endoparasites, predators or coprophages; while some species fulfill different roles depending on the situation (Denno and Cothran, 1976). Calliphoridae flies are generally the first to arrive at a carcass and are the most numerous insect feeding on the carcass (Denno and Cothran, 1976). Calliphorids oviposit large numbers of eggs on the carcass, generally in moist areas (Denno and Cothran, 1976). The egg and larval stages develop rapidly, with most of the pre-adult lifespan being as a postfeeding larva or pupa (Greenberg, 1991).

Haskell (1989) collected 10 species of blow flies on pig carrion in Northwest Indiana. The species were *Phormia regina* (Meigen), *Lucilia coeruleiviridis* Macquart, *Lucilia illustris* (Meigen), *Lucilia sericata* (Meigen), *Calliphora livida* Hall, *Calliphora vicina* Robineau-Desvoidy, *Calliphora vomitoria* (Linnaeus), *Cynomya cadaverina* Robineau-Desvoidy, *Cochliomyia macellaria* (Fabricius), and *Cochliomyia terraenovae* Macquart (Haskell, 1989). The species and number of blow flies found will vary with habitat, season, and geography (Brundage et al., 2011; Hwang and Turner, 2005). However, habitat associations can differ between geographic regions (Hwang and Turner, 2005).

Dipteran larvae feeding on the carcass can bioacculmulate drugs, poisons and heavy metals and can thus assist in toxicological analysis even after the tissues from the carcass are too decomposed to be tested (Wolff et al., 2001).One can also use known arthropod distributions to place a suspect or victim at the scene of a crime

(De Jong and Hoback, 2006) and to determine cause and method of death (Catts and Goff, 1992).

Greenberg (1985) relates some cases that used forensic entomological evidence. In a case from Waukegan, Illinois, larvae of *C. vicina* were found on a girls corpse in an abandoned building. Using accumulated degree hours, it was estimated that the eggs had been laid on the body during the day on the 29th or 30th of May, 1984. The girl had been last seen alive with a man in his 20s at noon on the 29th near the building where her body was found.

In Manitoba, Canada, Anderson (2001b) was involved in the investigation of the murder of a teenaged girl. At the scene empty pupal cases of *P. regina* were found. Using accumulated degree days, the minimum postmortem interval was found to be 30 days and the man accused of the murder was convicted (Anderson, 2001b).

In a case from Maryland, the remains of a young woman were found with masses of Diptera larvae on the chest, neck, and hands. Initially the woman was thought to have died of a drug overdose, but after an entomologist checked the photographs of the body they noted that the pattern of larval feeding indicated trauma at those sites. The body was exhumed and evidence of stab wounds was found at the larval feeding sites. The cause of death was changed to homicide (Lord, 1990).

1.2.1 Calliphoridae

Calliphora vicina

Calliphora vicina is a blue bottle fly with a black thorax and a slightly metallic blue abdomen (Hall, 1948). The posterior portion of the head is black, and the anterior portion is orange to red-orange with black hairs (Hall, 1948). The distribution of this species is Holarctic (Hall, 1948). This fly can be found in many habitat types including urban areas in cooler seasons, and females are attracted to carrion and refuse (Hall, 1948). Though Hanski (1977) found that *C. vicina* prefers forested areas. Greenberg (1991) considers *C. vicina* to be psychrophilic, preferring cooler temperatures. Due

to the lower temperature preferences of *C. vicina* it is often found during spring, fall, and winter, with lower numbers being found in summer (Arnaldos et al., 2005). This species has a lower developmental threshold than many other Calliphorids, with some individuals showing activity as low as 2.5°C, but are generally active at 4°C (Arnaldos et al., 2005; Deonier, 1940). Greenberg (1991) found that *C. vicina* would most often move away from the feeding source to pupariate.

Calliphora vomitoria

Calliphora vomitoria is a blue bottle fly with a black head that has reddish orange hairs on the posteroventral area (Hall, 1948). The distribution is Holarctic and *C. vomitoria* is not commonly found in North America (Hall, 1948). This fly has been found to prefer sheltered and shady habitats (MacLeod and Donnelly, 1956) and Smith (1986) found it to prefer rural areas. Larvae of *C. vomitoria* have been found to feed in tanks of blood at slaughter houses (Green, 1951). Green (1951) found that *Calliphora spp.* would lay eggs in slaughter houses during the night. Female *C. vomitoria* have been shown to oviposit late into autumn (Green, 1951). Diapause generally occurs around 2.5 cm under the soil or other substrate, and adults start to emerge beginning in March (Green, 1951).

Chrysomya rufifacies

Chrysomya rufifacies (Macquart) is originally from Australasia and the Pacific but was introduced to Latin America in 1978, and became established in the United States in 1980 (Baumgartner and Greenberg, 1984; Wells and Greenberg, 1992). Larvae of *C. rufifacies* feed on the carcass as well as facultatively prey on other dipteran larvae (Wells and Greenberg, 1992; Fuller, 1934). Females are monogenic and produce offspring of only one sex (Wells and Greenberg, 1992; Ullerich, 1976). First instar *C. rufifacies* are necrophagous, not predaceous, while second and third instars are shown to be predators as well as necrophagous (Watson and Carlton, 2005;

Greenberg, 1971). Larvae were found to be able to tolerate higher temperatures and larval densities than other species (Catts and Goff, 1992). Larvae of *C. rufifacies* have been found to pupariate close to the feeding substance (Greenberg, 1991) and may be vulnerable to parasitism by the hymenopteran *Nasonia vitripennis* (Walker) because the puparia are often not hidden in the substrate (Norris, 1965). Vogt (1988) found a lower temperature threshold of 13C, under which no adult *C. rufifacies* were caught in traps. Adults of *C. rufifacies* can travel 3.2 km per day (Baumgartner and Greenberg, 1984).

Cochliomyia macellaria

Cochliomyia macellaria is native to the Americas (Faria et al., 1999). The head of the adult is orange with pale orange to yellowish hair on the bucca (Hall, 1948). The thorax is bluish-green with three black longitudinal stripes on the dorsum (Hall, 1948). Adults have been found to be active at temperatures over 10°C (Deonier, 1940). Females generally oviposit on carrion, but occasionally will oviposit on live animals (Hall, 1948). Deonier (1940) found that *C. macellaria* was most commonly found on large carcasses, such as those of livestock. Deonier (1940) found the peak population of *C. macellaria* to be during August in the Midwestern United States. Larvae of *C. rufifacies* have been shown to reduce the populations of *C. macellaria* due to competition and predation (Wells and Greenberg, 1992).

Lucilia coeruleiviridis

Lucilia coeruleiviridis is a blue-green fly that has a Nearctic distribution (Hall, 1948). This fly is common in woods and fields, but are generally not abundant near houses unless there is decomposing meat to attract them (Hall, 1948). Specimens of *L. coeruleiviridis* are commonly collected at pig carcasses (Weidner et al., 2014).

Lucilia illustris

Lucilia illustris is a green bottle fly that has a Holarctic distribution (Hall, 1948). This fly has been found to occur in both open and shady habitats by MacLeod and Donnelly (1956). Greenberg (1991) stated that *L. illustris* is found in open woodland and meadows. In the Midwestern United States, *L. illustris* larvae often compete on carcasses with larvae of L. sericata (Hall, 1948). Wardle (1930) found that 24% of the fly population in Minnesota during July, August, and September, was *L. illustris*.

Lucilia sericata

Lucilia sericata are a metallic green bottle fly frequently collected in forensic investigations (Lord, 1990). Blow flies such as *L. sericata*, have three instars followed by pupariation and then eclosion into the adult. The prepupal stage begins in the third instar and involves the end of larval feeding and the wandering from the food source, to the start of the puparium formation (Kamal, 1958). Ullyett (1950) found that *L. sericata* seek a protected area to pupariate, often digging into substrate; this behavior protects the puparia from parasitism. For *L. sericata*, diapause occurs as a third instar after feeding has ceased (Tachibana and Numata, 2004). In North America, this species can be found throughout the United States and Southern Canada (Ash and Greenburg, 1975). Larvae of *L. sericata* are necrophagous, but polyphagous in urban environments (Povolny and Rozsypal, 1968). The larvae feed on carrion and can cause myiasis in humans and other animals (Denno and Cothran, 1976). Mariluis et al. (1994), found larvae of *L. sericata* feeding on a live cat from the area around Buenos Aires, Argentina. In England, *L. sericata* is less prevalent in number on animal carcasses, except in near urban areas (Smith and Wall, 1997b; Isiche et al., 1992). This species is often associated with animal dung (De Jong, 1994), and human dung (Schoof et al., 1954). Siverly and Schoof (1955) found that *L. sericata* was able to reproduce in garbage. Female *L. sericata* will oviposit on vegetable matter and larvae have been found to successfully complete their life cycle on it (Green, 1951).

Greenberg (1971) states that *L. sericata* has adapted to developing on kitchen waste, even waste material that primarily consists of carbohydrates. This species is an early colonizer of carrion (Denno and Cothran, 1976). Larvae are negatively phototrophic as second and third instars, and are less so at the start of their first instar (Green, 1951).

This species is considered eusynathropic and exophilous, meaning that it prefers to live around humans but not in their dwellings (Ash and Greenburg, 1975). Higher numbers of *L. sericata* have been found in open pasture than in woodlands in England (Smith and Wall, 1997b). Isiche et al. (1992) found that *L. sericata* is heliophilous and came to carrion that was exposed to the sun in near-urban areas. Savage and Schoof (1955) found *L. sericata* to prefer cooler weather, being most common in spring and early summer. Adult *L. sericata* have been found to be active at temperatures of 10°C and over (Deonier, 1940). Yurkiewicz (1968) found that *L. sericata* flew for shorter periods of time and more erratically at temperatures of 15°C and lower. Quarterman et al. (1954) found that in urban areas that *L. sericata* traveled up to 5.6 km, with some moving 2 km in 7 hours. Higher relative humidities of 80 to 100% allow for longest survival in adult *L. sericata*, compared to lower relative humidities (Evans, 1935).

Adults are anautogenous and do not eclose with enough protein to begin egg production and must obtain protein through food before producing eggs (Wall et al., 2002). Flies in the genus *Lucilia* become active and orient upwind toward putrefactive, sulfur-rich volatiles and ammonia-rich compounds; these compounds along with moisture will elicit oviposition (Ashworth and Wall, 1994). While olfaction is important for long range detection, at shorter distances, vision is also important (Amendt et al., 2008). Kamal (1958) found that *L. sericata* would oviposit in natural cavities and moist areas on the underside of the oviposition material, usually depositing all of their eggs in one area. Females will lay approximately 200 eggs per oviposition session (Cruickshank and Wall, 2002) and as many as 1,400 eggs during the fly's lifetime (Davies, 2006). Female *L. sericata* were found to not oviposit at night by Zurawski et

al. (2009). Their study suggested that *L. sericata* is inactive in complete darkness. Amendt et al. (2008) also found no nocturnal oviposition for *L. sericata* in the field in Germany. A decrease in temperature due to sunset might also prevent females from ovipositing, as oviposition is unlikely for Calliphorids under 12°C (Amendt et al., 2008). High temperatures, light, disturbance, and an attractive carcass might provide enough stimulation for flies to oviposit during the night in some situations (Amendt et al., 2008). 62 degree days (Base 11°C) are required to mature an initial batch of eggs for *L. sericata*, while an additional 28 degree days are needed for subsequent batches (Pitts and Wall, 2004; Wall et al., 1991). Higher humidities promoted growth of ovaries in the females (Evans, 1935).

Phormia regina

The black blow fly, *P. regina*, is metallic blue-green to black with the anterior spiracle covered with orange setae (Hall, 1948). The distribution of *P. regina* is Holarctic and Australian (Hall, 1948). This fly has been found in urban, open woodland, and meadow habitats (Greenberg, 1991). Deonier (1940) found that adults become active around 10°C and *P. regina* is considered a cold weather blow fly. Adults are most abundant during spring and fall (Hall, 1948). This species was found to be common on large carcasses, such as those of livestock (Deonier, 1940). Though, Paine (1912) found *P. regina* larvae feeding in garbage, as did Walton (1914). Pupariation of *P. regina* has been found to occur close to their feeding source (Greenberg, 1991). Diapause occurs as an adult (Hall, 1948).

1.2.2 Sarcophagidae

Flesh flies (Diptera: Sarcophagidae) are ovoviviparous and thus larviposit first instar larvae instead of laying eggs on the carcass (Denno and Cothran, 1976). This allows their larvae to feed on the corpse immediately. Sarcophagidae larviposit fewer young on a carcass than a Calliphoridae will lay, but the lack of an egg stage for the

Sarcophagidae larvae along with more rapid maturity allows Sarcophagidae larvae to feed and develop on the carcass before the Calliphorid larvae entirely consume it (Denno and Cothran, 1976). In temperate areas, Calliphorids most often come to the carcass first, followed by Sarcophagids, though in tropical and subtropical areas the opposite may be true (Goff and Catts, 1990). Voss et al. (2011) found that Sarcophagids generally larviposited late in the bloat stage and in the early part of active decomposition, while Calliphorids would oviposit in the fresh and bloat stages. Sarcophagids may prefer smaller carcasses, Denno and Cothran (1975) found that, of the flies reared from rat carcasses, 64% were Sarcophagidae and the rest were Calliphoridae. From rabbit carcasses 2.8% were Sarcophagidae and the rest were Calliphoridae. Adult Sarcophagids are larger, have lower fecundity, and longer time to first reproduction than Calliphorids (Denno and Cothran, 1976).

1.3 Coleoptera

Most forensic entomology research has been concentrated on necrophilous Diptera and less research has been done on necrophilous Coleoptera (Midgley et al., 2010). Coleoptera are an integral part of postmortem biology and can accelerate decomposition (Midgley et al., 2010). Most Coleoptera are attracted to the carcass by volatile organic compounds emitted by the carcass and the arthropods present on the carcass (Matuszewski and Szafaowicz, 2013). The immature stages of Coleoptera are generally longer in development than the immature stages of Diptera; therefore Coleoptera can be useful in later stages of decomposition (Midgley et al., 2010). More species and individuals of Coleoptera become present during advanced stages of decomposition (Almeida and Mise, 2009). Developmental landmarks, such as instar, are more precise than using size in determining minimum postmortem interval (Midgley et al., 2010). If size must be used to estimate minimum postmortem interval, ethanol, causing the least change in size for coleopteran larvae, should be used for preservation (Midgley et al., 2010). Two common necrophilous families of Coleoptera are Silphidae and

Staphylinidae. Body size of necrophagous beetles has been found to be decreased towards the center of urban areas (Ulrich et al., 2007).

1.3.1 Cleridae

The Red Legged Ham beetle, *Necrobia rufipes* (De Geer), a beetle in the family Cleridae, is a metallic blue or green beetle with reddish brown legs (Kulshrestha and Satpathy, 2001). Adults and larvae feed on carrion and have been found to feed on larvae of Piophilidae and Dermestidae (Kulshrestha and Satpathy, 2001; Reed, 1958). This species may be forensically importance in cases with dry remains either due to climactic conditions or decomposition stage (Kulshrestha and Satpathy, 2001).

1.3.2 Dermestidae

Most adult Dermestidae (Order: Coleoptera) are small, from 0.5 to 1 cm long, and oval with minute scales on the elytra (Charabidze et al., 2014; Kulshrestha and Satpathy, 2001). The larvae of dermestid beetles are covered in long setae (Charabidze et al., 2014). Both larvae and adults feed on dry materials such as skin, hair, dry flesh, feathers, bone, and insect exoskeletons, though some can be facultative predators (Menezes et al., 2006; Schroeder et al., 2002; Reed, 1958). Their feeding can accelerate skeletonization in dry situations (Schroeder et al., 2002). The adult beetles generally arrive later in decomposition and are most common as adults and larvae in the dry remains stage (Goff, 2009). Larvae and adults have strong mouthparts that can make impressions even in bone (Schroeder et al., 2002). Larvae and adults seem to prefer feeding on the extremities of the remains (Charabidze et al., 2014). In a study by Charabidze et al. (2014) Dermestids were found in 7.5% of their forensic cases. Dermestids can be forensically important in indoor cases where large numbers may be present on the carcass (Charabidze et al., 2014).

1.3.3 Histeridae

Histeridae are predators of Diptera larvae and other Coleoptera (Reed, 1958). Known as Hister or clown beetles, they have been found to arrive early in decomposition (Goff and Catts, 1990; Payne and Crossley, 1966).

1.3.4 Silphidae

Silphidae is a family of carrion beetles. Reed (1958) stated that the larvae feed on the carcass, while the adults feed on the carcass and Diptera larvae. Payne (1965) found that the Silphidae arrived in early decomposition and stayed, feeding and reproducing, until the dry stage.

1.3.5 Staphylinidae

The family Staphylinidae has the most species in the order Coleoptera and the Kingdom Animalia (Aballay et al., 2014; Grebennikov and Newton, 2009). Many species of Staphylinidae are predators and will feed on Diptera larvae and adults (Reed, 1958). The hairy rove beetle, *Creophilus maxillosus*, is a widely-distributed species in the family Staphylinidae, typically found at carrion (Asenjo, 2007). It may be forensically important due to its feeding on Calliphoridae larvae, which could modify the number of larvae present or by feeding on larvae that have been on the carcass for the longest period of time, biasing the postmortem interval determined from the larvae found on the carcass. The range for *C. maxillosus* is Europe, Asia, North America, Central America and South America, and some Pacific and Atlantic islands (Asenjo, 2007; Herman, 2001). It prefers open disturbed habitats (Asenjo, 2007). *Creophilus maxillosus* feeds on carrion-feeding larvae (Kramer, 1955) and dipteran eggs (Personal observation, S. Gross). With a body length of nearly 2 cm, *C. maxillosus* is one of the largest North American staphylinids (Jefson et al., 1983).

1.4 Other Arthropods of Forensic Interest

1.4.1 Crustacea

Isopoda

Terrestrial Isopoda are crustaceans in the suborder Oniscidea (Schmalfuss, 2003). Commonly referred to as woodlice, these arthropods are important decomposers of plant material (Zimmer, 2002). Terrestrial isopods require moisture for oxygen uptake, with low humidities reducing oxygen uptake and eventually causing death (Carefoot, 1993). Water can be taken up through the legs of the isopod through capillary action and some species are able to absorb water vapor at high humidities (Carefoot, 1993).

1.5 Research Carcasses

Pig (*Sus scrofa*) carcasses are used as models for human bodies (De Jong and Hoback, 2006) because of their similarity to humans in hair coverage, skin composition, and diet (Anderson and VanLaerhoven, 1996). No significant differences have been found between the insect community and decomposition between human and pig carcasses (Haskell, 1989). In the presence of insects, the weight loss of the body, which directly relates to soft tissue decomposition, is sigmoidal (Adlam and Simmons, 2007; Payne, 1965). Kuusela and Hanski (1983) found that the size and type of carcass did not affect the community structure of the insects involved. Similar insect composition and succession has been found for large and small carcasses, though the decomposition rate is different (Hewadikaram and Goff, 1991). Larger carcasses were found to decompose at a faster rate due to the higher numbers of Diptera larvae on the carcass (Hewadikaram and Goff, 1991).

1.6 Habitat Preference

Bodies are often relocated postmortem (Hans, 2010; Smith 1986; Anderson, 1995; Anderson and VanLaerhoven, 1996; Haskell et al., 1997) and if an insect that is found exclusively in rural or urban environments is found on a body that is not in that environment, it can indicate that a body has been moved from one environment to another (Grassberger and Frank, 2004; Catts and Haskell, 1990; Erzinclioglu, 1989).

Studies have been conducted in urban and rural environments on the insect species that are associated with carrion, though not all studies directly compared rural sites to urban sites and often statistical replicates were not used. Brundage et al. (2011) found flies to be more abundant in rural areas than urban areas, though some species are synanthropic and thus are associated with humans. The species *C. vicina* has been found to be synanthropic, while *C. vomitoria* has been found to prefer rural habitats (Hwang and Turner, 2005; Nuorteva, 1963; Smith, 1986). *Calliphora vomitoria* was found to prefer rural habitats in Central California but has also been found in high numbers in urban habitats in Austria (Brundage et al., 2011; Grassberger and Frank, 2004). *Lucilia illustris* has shown a wide range of habitats in different studies (Hwang and Turner, 2005; Nuorteva, 1963, 1966; Davies; 1999). In central London, *C. vicina*, and *L. illustris* characterized urban habitats while *C. vomitoria* characterized rural woodlands (Hwang and Turner, 2005). In England, higher numbers of *L. illustris* were found in woodlands (Smith and Wall, 1997b). In British Columbia, *C. vomitoria* was found only in urban areas (Anderson, 1995). *Phormia regina* and *C. terraenovae* were found in both urban and rural areas of British Columbia (Anderson, 1995). In Central California *P. regina* was found to prefer rural areas to urban areas (Brundage et al., 2011). *Cochliomyia macellaria* was found to be attracted to pig carcasses in urban areas in Brazil (Carvalho et al., 2004).

Lucilia sericata has been found in rural areas in England and New Zealand, and in urban areas in southern England and Finland (Hwang and Turner, 2005; Smith and Wall, 1997b; Davies, 1999; Dymock and Forgie, 1993; Nuorteva, 1963, 1966; Isiche et

al., 1992). In rural areas where *L. sericata* is commonly found, they are associated with sheep strike. Though, Cragg (1955) found no difference in the response of *L. sericata* to sheep wool from adults bred on sheep or adults from urban areas. In Central California *L. sericata* was found to prefer urban areas, but was still found in rural areas in spring and summer (Brundage et al., 2011). Figueroa-Roa and Linhares (2002) found that *L. sericata* strongly preferred urban areas, though it did not routinely enter houses. *Lucilia sericata* was found in urban areas in central London (Hwang and Turner, 2005), as well as in heavily urban areas of Chicago, Illinois (Baumgartner, 1988). *Lucilia sericata* was the most common fly found in a study by Williams (1954) in New York City, New York. In Bogotá, Colombia, *L. sericata* was found to have a high degree of synanthropy (Beltran et al. 2012). The highest percentage of insects arriving to pig carcasses in an urban area of Medellin, Colombia was *L. sericata* (Perez et al., 2005). Centeno et al. (2004) found *L. sericata* was the characteristic species for urban areas. In British Columbia *L. sericata* was found only in urban areas (Anderson, 1995). In Australia *L. sericata* is found primarily in urban areas (Wall and Shearer, 1997). *Lucilia sericata* was found to be the fly most often found in urban areas from March to November (Schoof and Savage, 1955). In the Czech Republic, Fischer (2000) found that *L. sericata* was the dominant species in heavily populated areas. Világiová and Petko (1994) found that *L. sericata* and *Protophormia terraenovae* (Robineau-Desvoidy) were the dominant species in public dining rooms in Košice city, Slovakia.

Savage and Schoof (1955) also found *L. sericata* to be the predominant species in garbage dumps. *Lucilia sericata* has been found to be attracted to carcasses and garbage (Ash and Greenberg, 1975). Schoof et al. (1954) found garbage to be the main source of flies in urban areas, and from samples taken *L. sericata* was found to be one of the most commonly found species. Blow fly larvae were more commonly found in garbage in cans, than in garbage strewn on the ground (Schoof et al., 1954). Meat scraps, though less common than garbage as a whole, also produced *L. sericata* larvae in urban areas (Schoof et al., 1954).

Centeno et al. (2004) looked at the degree of diversity of Calliphoridae in Argentina. They examined a natural site, an urban site, and a rural site. Their bait was a piece of decomposing pig lung, and flies were collected with a sweep net. They found the natural area to be the most diverse, with no significant difference between the diversity in the urban and rural areas. *Lucilia sericata* was found to be characteristic of urban areas (Centeno et al., 2004).

Hwang and Turner (2005) used bottle traps baited with pig liver to collect flies from around central London. These traps were attached 1.5 m above the ground at six locations, three of the locations were urban, one was suburban, another was rural and the last was semi-natural. Diversity was highest in the rural sites and lowest in the urban sites. Urban and suburban sites had the highest number of *L. sericata* and *L. illustris* (Hwang and Turner, 2005).

Hans (2010) conducted a study using pig carcasses in Northeast Ohio with sites in an urban and rural environment, and tested the movement of carcasses from the urban location to the rural location. Two carcasses were used at the urban location, two carcasses were at the rural location and two carcasses were located in the urban location for 24 hours and then moved to the rural location. There was no statistical difference in insects found between the treatments.

Brundage et al. (2011) looked at the species of Calliphoridae found in Central California in rural, urban, and riparian areas. They used fly traps baited with beef liver and placed four traps in each habitat. The traps were hung from trees and were approximately 2 m off the ground. Most flies were caught in rural traps, and the lowest number of flies were caught in the urban traps. They found that *C. vomitoria* preferred rural habitats and *L. sericata* preferred urban habitats, though it was still present in rural areas in spring and summer. The preference of *L. sericata* for urban areas is attributed to their ability to complete their life cycle using either refuse or carrion (Brundage et al., 2011).

1.7 Urban Environments

The National Resource Inventory (NRI) defines urban areas as commercial, industrial, infrastructural, institutional, and residential land (Alig et al., 2004). Urban areas typically have more precipitation, lower wind speeds, less solar radiation, and lower relative humidity than rural areas (Hwang and Turner, 2009; Chandler, 1976; Horbert et al., 1982; Mayes, 1997). Urban areas are generally considered to have higher ambient temperatures than rural areas; this phenomenon is called the urban heat island (Kim, 1992). The cause of higher urban temperatures is considered to be the heating of surfaces such as; asphalt, bare soil, buildings, and the short grass of lawns (Kim, 1992). When these surfaces are higher in temperature than the air it leads to sensible heat flux, and the air will warm and increase the temperature in the urban area (Kim, 1992). Moisture slows the rise in temperature and water absorbs solar radiation well, while dry surfaces reflect more sunlight (Kim, 1992).

However, Peterson (2003) found that urban areas were no warmer than rural when adjustments for bias from differences in latitude, time of day the measurement was taken, elevation, instrument used, and microscale site characteristics were made. When average temperatures were found to be warmer, most of the warming was from higher minimum temperatures and that urban areas were found to be cooler than rural areas during the warmest parts of the day (Karl et al., 1988; Peterson, 2003). Local surroundings and microclimates can affect the temperatures in urban and rural areas, and can cause a site to be 1°C to 2°C warmer or cooler than another site in a neighboring area (Peterson, 2003).

1.8 Insect Attraction

Diptera use chemicals in their environment, primarily through olfaction, to locate food and oviposition sites (LeBlanc and Logan, 2010). After following a chemical odor plume toward the source of the volatiles, Diptera will use gustatory, physical, and visual, cues to determine the exact location of the carcass and ideal oviposition

sites (LeBlanc and Logan, 2010). The olfactory organs are located primarily on the antennae and are known as sensilla (LeBlanc and Logan, 2010). Each sensillum has sensory neurons which detect volatile compounds, these compounds are also known as semiochemicals (LeBlanc and Logan, 2010; Shields and Hildebrand, 2001). These compounds can be detected as one compound alone, or a mixture of compounds (LeBlanc and Logan, 2010).

Higher numbers of *L. sericata* adults are caught with increasing carrion odor concentration from decomposing liver (Wall and Warnes, 1994). Blow flies in the genus *Lucilia* are attracted to bacterial decomposition products such as putrefactive sulfur-rich volatiles (Ashworth and Wall, 1994). Ethyl mercaptan has been shown to attract *L. sericata* to sheep (Cragg, 1950). *Lucilia sericata* has been shown to oviposit in the presence of ammonium carbonate (Cragg, 1955).

1.9 Decomposition

Decomposition is a continuous process but it is generally divided into five different stages; fresh, bloat, active decomposition, advanced decomposition, and dry remains (Haskell and Williams, 2008). Immediately after death adenosine triphosphate (ATP) is converted to adenosine diphosphate (ADP) and the cellular pH lowers, which causes the muscles to stiffen in rigor (Goff, 2010). When rigor begins and ends depends on temperature and the metabolic state of the body at death (Goff, 2010). Cooler temperatures cause rigor to occur sooner and last longer than in warmer temperatures (Goff, 2010). Higher metabolic states cause rigor to occur sooner than at lower metabolic states (Goff, 2010).

1.9.1 Fresh Stage

The fresh stage begins at death and continues until bloat is visible (Anderson and VanLaerhoven, 1996). After death; lack of oxygen, increased levels of carbon dioxide, decreasing pH, and accumulating wastes cause cells to begin to die (Vass,

2001). Autolysis begins; in which enzymes from the cells dissolve the cells from the inside until the cells rupture, which releases nutrient rich fluids (Vass, 2001). These nutrient rich fluids allow putrefaction to begin, where microorganisms in the body cause destruction of the soft tissues of the body (Vass, 2001). At this time complex protein and carbohydrate molecules in the carcass start to breakdown into simpler compounds (LeBlanc and Logan, 2010; Early and Goff, 1986).

1.9.2 Bloat Stage

Bloat stage is characterized by gas accumulating that is produced by anaerobic bacteria in the carcass feeding on the tissues of the carcass, causing bloating of the abdomen (Goff, 2009; Anderson and VanLaerhoven, 1996; Early and Goff, 1986). The gasses consist of ammonia, carbon dioxide, hydrogen, hydrogen sulfide, methane, and sulfur dioxide (Vass, 2001). The pressure caused by the increase in gasses causes fluids to seep from opening on the carcass causing a release of compounds, such as ammonia (Goff, 2009). The fluids will also cause the substrate under the body to become more alkaline (Goff, 2009). Butyric and propionic acid are also produced by the anaerobic fermentation (Vass, 2001). During this stage large numbers of Calliphoridae adults are generally attracted to the carcass (Goff, 2010). The metabolic activity of the anaerobic bacteria and dipteran larvae will start to cause a temperature increase in the carcass (Goff, 2009).

1.9.3 Active Decomposition Stage

Bloat ends and the active decomposition stage begins when the carcass has deflated due to dipteran larvae feeding or bacterial putrefaction which allows the gasses contained in the abdomen to escape (Goff, 2009; Anderson and VanLaerhoven, 1996). Most of the flesh and skin is still present in the active decomposition stage. Carcasses at this stage have a strong odor of decomposition and large masses of dipteran larvae (Goff, 2010). Bacterial decomposition yields volatile fatty acids, phenolic com-

pounds, glycerols, and compounds such as indole, skatole, cadaverine, and putrescine (Vass, 2001). When the skin of the carcass is broken after bloat ends, more air moves into the body cavity and aerobic decomposition is facilitated (Reed, 1958). Bacterial decomposition produces ammonia, hydrogen sulphide, and sulphur compounds (Eisemann and Rice, 1987; Gill, 1982). These compounds have been found to attract adult Diptera to the carcass to oviposit (Ashworth and Wall, 1994). Diptera larvae secrete ammonia and enzymes to dissolve soft tissue and muscle fibers so that the tissue and muscle can be consumed (Hans, 2010; Oldroyd, 1965; Braack, 1987).

1.9.4 Advanced Decomposition Stage

n the advanced decomposition stage much of the flesh has been removed from the carcass (Anderson and VanLaerhoven, 1996). Most of the Calliphoridae and Sarcophagidae larvae will have completed development and left the carcass (Goff, 2010). Coleoptera are generally more important in this stage than Diptera, and Dermestidae adults and larvae may become the dominant fauna (Goff, 2010). Though in wetter habitats Coleoptera may not become predominant and instead some of the Diptera that prefer moist habitats, such as the family Psychodidae, may colonize the carcass (Goff, 2010).

1.9.5 Dry Remains Stage

The dry remains stage has very little tissue left on the carcass and primarily bones and cartilage are left (Anderson and VanLaerhoven, 1996). Most of the arthropods associated with decomposition have left by this stage, though soil arthropods such as Collembola and mites can still be numerous and the populations of these might be different from the surrounding fauna for months or years after the carcass has decomposed due to the decomposition fluids left by the remains (Goff, 2010).

1.10 Factors Affecting Decomposition

Not all carcasses will go through all of the stages described above, factors such as temperature, insect access, burial, depth of burial, geographic region, non-insect animal disturbance, trauma to the body, climate type, humidity, rainfall, size of the body, body type and weight, embalming, clothing, and the surface the body is on, can all affect the decomposition of the body (Hans, 2010; Mann et al., 1990). Carcasses in cooler temperatures will not necessarily go through the bloat stage due to the inhibition of bacterial feeding (Reed, 1958). If the carcass does bloat in cooler temperatures the bloating and deflation of the body may be more gradual than it is in warmer temperatures (Reed, 1958). Mummification can happen to carcasses in habitats with very low humidity, in either low or high temperatures, such as deserts or the Arctic (Vass, 2001). Carcasses that go through mummification may not go through all of the common stages of decomposition and may skip bloat and active decomposition depending on the habitat, and go through modified versions of the advanced decomposition and dry remains stages with most of the skin left intact and most of the tissue desiccated (Vass, 2001). Mummification requires a particular set of conditions, and if the carcass becomes moist later it can again become susceptible to insects.

1.11 Succession

As a carcass is an ephemeral resource that is used by a wide variety of organisms, insects that use it as a larval resource generally only complete one generation on a particular carcass (Wells and Greenberg, 1992). Insects are attracted to carcasses in a qualitatively predictable sequence, but the insects found are quantitatively variable based on the conditions affecting the carcass such as biogeoclimatic zone, habitat, and season (Payne, 1965; Early and Goff, 1986; Tullis and Goff, 1987; Catts and Goff, 1992; Richards and Goff, 1997). An understanding of the arthropod community can be gained by using developmental data from as many species as possible that

have been collected from the carcass, which will allow for a more precise postmortem interval (Midgley et al., 2010).

As certain insects prefer certain decomposition stages, different families or types of insects will arrive and leave at certain points in decomposition (Putman, 1978). The particular genus or species that are found vary with location (Tabor et al., 2004). Preference is partially due to the changes that insect feeding and microbes cause a carcass to go through, as certain insects will come to the carcass to feed or parasitize on other insects that have already arrived on the carcass. Volatiles produced by decomposition or insects on the carcass may attract or repel other insects, causing them to be absent or present during different decomposition stages or the carcass volatiles may indicate that the carcass is not suitable for the insect at that time (LeBlanc and Logan, 2010).

In temperate North America; flies such as Calliphoridae and Sarcophagidae are generally the first to arrive, afterward parasites and predators of the dipteran larvae arrive (Goff and Catts, 1990). Reed (1958) found that the most common insects in the fresh stage were Calliphoridae and Muscidae, followed in the bloat stage by Silphidae, Histeridae, Staphylinidae, Lepidoptera, Sarcophagidae, and Hymenoptera. Some of these families are predators and parasites of the Diptera larvae, such as beetles in the families Histeridae, Silphidae, and Staphylinidae (Tabor et al., 2004). Reed (1958) found that Nitidulidae and Phoridae were common in the decomposition stages covered by active decomposition and advanced decomposition, though Reed did not divide this decomposition period into two stages. Some families of Diptera such as Piophilidae and Stratiomyidae come to carcasses during advanced decomposition (Voss et al., 2011). During the later stages of decomposition as the carcass starts to dry out, arthropods that feed on the skin and hair, such as Cleridae and Dermestidae, arrive (Reed, 1958). Things such as region, habitat, weather, season, vegetation structure, type and density, ability of insects to access the carcass, and soil type can possibly affect the timing and number of insects arriving at the carcass and must be

taken into account (Prado e Castro et al., 2011; Anderson, 2010, Mann et al., 1990, MacLeod and Donnelly, 1962).

1.12 Sampling

The populations of flies sampled can be regarded as the proportion of the population that is interested and able to come to the bait stimulus (MacLeod, 1956). There has been found to be no difference in the number of taxa found on carcasses that are sampled repeatedly or ones that are sampled only once (De Jong and Hoback, 2006). Similarly, no differences in decomposition stages have been found between carcasses that have been sampled and ones that were left undisturbed (Eberhardt and Elliot, 2008). Adlam and Simmons (2007) found that the maggot mass temperature peak was earlier for undisturbed carcasses, but longer and not as high for disturbed carcasses, but that both disturbed and undisturbed carcasses had a similar amount of heat added from the maggot masses. The time to each decomposition stage was also found to be statistically similar in disturbed and undisturbed carcasses (Adlam and Simmons, 2007).

2. METHODS

Deceased fetal pigs weighing approximately 2 kg each were obtained from the Purdue University swine unit in West Lafayette, Indiana and Northwind Pork in Rensselaer, Indiana and frozen prior to use. The experiment was set up in a randomized complete block design with four replications and two treatments. The treatments were the habitat types of rural or urban. The experiment was conducted monthly starting on the 1st of each month from June until October. Each month two pig carcasses were placed at each location, for a total of 16 pigs used each month. A total of 160 pigs were used throughout the study. The trials took place in 2011 and 2012. Before the start of each trial the pigs were thawed for 24 hours in a room without fly access. Carcasses were checked for evidence of eggs and larvae before being put at the research sites.

Freezing was found not to significantly impact decomposition of muscle tissue or soil chemistry by Stokes et al. (2009). Though, Micozzi (1986) found primarily aerobic decomposition in carcasses that had been previously frozen and anaerobic decomposition in freshly killed animals. In a study by Bugajski et al. (2011), no significant differences were found in the time of appearance of *C. maxillosus*, adult Diptera, eggs, larvae, or the initiation and conclusion of maggot migration between fresh and previously frozen pig carcasses.

Each month after all carcasses had reached dry decomposition, leaving only bones and cartilage, the remains were removed from the site. Dead plant material and other associated remnants were also removed from the site. The next month new pig carcasses would be placed away from the exactly placement of the previous pig which could be noted due to the lack of plant cover. This was done to maintain similar substrate under the carcasses.

2.1 Sites

The four rural sites were in the vicinity of West Lafayette, Indiana. Rural sites had low populations, farmland, and were not located closely near more than one residential building, and residential buildings could not be closer than 50 m. The four urban sites were in Lafayette, Indiana. Urban locations were defined as having residential buildings, businesses or commercial areas, lawns, proximity to trash bins or dumpsters, consistent human activity, and streets closely situated together. A list of the GPS locations and elevations for sites can be found in Table 2.1. All carcasses were placed on their right side on mowed grass so that surfaces would be similar among all sites.

Rural site number one was located at N 40°25.68', W 086°56.960', and 211 m above sea level (Figure 2.1). The carcasses were placed approximately 1.5 m from a stand of bushes and trees that were approximately 14 m tall, and approximately 5 m from a small one-story storage building of approximately 8 m. The area where the carcasses were placed was sunny from midmorning to evening from June to August and until afternoon in September and October (Table 2.2 and Figure 2.10). Plants around the carcass consisted primarily of grasses and clover (*Trifolium spp.*). The grass here was mowed consistently so that was not taller than the pig carcass and the soil was often dry and packed down. The area adjacent was used for beekeeping and honey bee research and has many bee hives approximately 60 m away from the carcasses.

Rural site number two was located at N 40°25.95', W 086°56.976', and 214 m above sea level (Figure 2.2). Carcasses were placed next approximately 1 m from a stand of bushes and trees that were approximately 6 m in height. Plants at the site consisted primarily of grasses, clover (*Trifolium spp.*), and milkweed (*Asclepias spp.*). This area was not mowed as often as other sites and thus often had slightly longer grass than the other sites. When not mown the grass would become taller than the pig carcasses. The carcasses were in the sun from late morning to evening from June

to August and until afternoon in September and October (Table 2.2 and Figure 2.11). Approximately 15 m away from the carcasses was a paved roadway.

Rural site number three was located at N 40°28.176', W 086°59.817', and 224 m above sea level (Figure 2.3. Carcasses were placed approximately 1.5 m from a stand of bushes and trees that were approximately 14 m tall, 6 m from a one-story storage shed approximately 8 m in height, and approximately 8 m from a larger one-story storage building approximately 10 m tall. Plants around the carcasses consisted primarily of grasses, clover (*Trifolium spp.*), and poison ivy (*Toxicodendron radicans*). The area was mown to a level that did not exceed the heigh of the pig carcass. The area was sunny from midmorning until late afternoon or evening (Table 2.2 and Figure 2.12). The area was used as a research farm and is planted with corn and soybeans, with the closest field being approximately 24 m away.

Rural site number four was located at N 40°28.566', W 087°00.094', and 219 m above sea level (Figure 2.4. Carcasses were placed approximately 3 m away from an approximately 18 m tall two-story barn used for the storage of old farming equipment. Plants around the carcasses were primarily grasses and clover (*Trifolium spp.*). The plants were at the height of the pig carcass or lower. The area where the carcasses were placed was sunny from morning until evening (Table 2.2 and Figure 2.13). This site is used as a research farm and was planted with corn and soybeans, with the closest field being approximately 24 m away.

Urban site number one was located at N 40°24.242', W 086°53.684', and 196 m above sea level (Figure 2.5. This site is located in the backyard of an approximately 8 m one-story single family home. Carcasses were placed next to a row of lilac bushes (*Syringa spp.*) and a forsythia bush (*Forsythia spp.*) and around the carcass the plants were primarily grasses and clover (*Trifolium spp.*). The grass was mown to a level that did not exceed the height of the pig carcass. The carcasses were placed approximately 3 m from the gravel driveway and 5 m from a compost pile. On garbage collection days there was a closed garbage bin approximately 4.6 m away from the carcasses in a paved alleyway. The area where carcasses were placed was sunny from

early morning until the afternoon, except in July when it was sunny until evening (Table 2.2 and Figure 2.14). Other houses were situated approximately 6 m from the site and along the alleyway.

Urban site number two was located at N 40°25.372', W 086°52.219', and 214 m above sea level (Figure 2.6. This site was located on a grassy area approximately 15 m from a church parking lot and approximately 1.5 m from the parking area for buses behind a school. The carcasses were placed 1.5 m from a small stand of bushes and trees approximately 10 m in height. The plants around the carcass were primarily grasses, clover (*Trifolium spp.*) and mosses. The grasses did not exceed the height of the pig carcass. A playground for the church was located on the other side of a fence, approximately 2 m from the carcasses. The area the carcasses were placed was partially shaded due to tree cover throughout most of the day (Table 2.2 and Figure 2.15). The area immediately around this site is primarily paved parking lot, though houses are in the area adjacent to the church and school. This site is the furthest of the urban sites, with the nearest house being located approximately 100 m away.

Urban site number three was located at N 40°25.115', W 086°51.748', and 209 m above sea level (Figure 2.7. This site is located in the backyard of an approximately 8 m tall one-story single family home with other houses approximately 30 m adjacent. Carcasses were approximately 1.5 m from an exterior wall of the garage. A small garden plot with tomatoes (*Solanum lycopersicum*), onions (*Allium cepa*), and garlic (*Allium sativum*) plants was located approximately 0.5 m from the nearest carcass. The majority of plants around the carcasses were grasses and clover (*Trifolium spp.*). Plants did not exceed the height of the pig carcass. The carcasses were placed in a location that was sunny from midmorning until evening (Table 2.2 and Figure 2.16). An unpaved alleyway was located approximately 5 m from the carcasses; the alley is adjacent to the lawns of other residences. The closest restaurant and dumpsters, which receive trash from restaurants and businesses is approximately 0.4 km away from this site.

Urban site number four was located at N 40°24.736', W 086°51.932', and 211 m above sea level (Figure 2.9. This site was located in the backyard of an approximately 8 m tall one-story single family home. Four houses were within 45 m of the carcasses. Carcasses were located approximately 1 m from an exterior wall of the garage. Plants around the carcasses were primarily grasses, plantain (*Plantago spp.*) and clover (*Trifolium spp.*). The plants did not exceed the height of the pig carcass. A paved alleyway was located approximately 5 m from the carcasses. A closed garbage bin was located approximately 5 m from the carcasses. The carcasses were placed in an area that was sunny from early morning until midafternoon (Table 2.2 and Figure 2.17). Approximately 2.5 m away from the closest carcass was a compost bin. The closest restaurant, as well as dumpsters for restaurants and businesses is approximately 0.7 km from this site. There is a small zoo and park approximately 0.6 km from this location which would have waste from a variety of animals, including a number of waterfowl that live at a pond near the facilities.

Table 2.1.
The latitude, longitude, and elevation of each of the research sites. Information was taken from a Garmin GPS device.

Site	Latitude: North	Longitude: West	Elevation in Meters
Urban Site One	40°24.242’	086°53.684’	211
Urban Site Two	40°25.372’	086°52.219’	214
Urban Site Three	40°25.115’	086°51.748’	224
Urban Site Four	40°24.736’	086°51.932’	219
Rural Site One	40°25.68’	086°56.960’	196
Rural Site Two	40°25.95’	086°56.976’	214
Rural Site Three	40°28.176’	086°59.817’	209
Rural Site Four	40°28.566’	087°00.094’	211

Table 2.2.
Approximate hours of sun at each site for each month of sampling. All times are Eastern Standard Time.

Site	June	July	August	Sepember	October
Rural Site 1	9:00am - 7:00pm; 10 Hours	8:00am - 7:00pm; 11 Hours	8:00am - 7:00pm; 11 Hours	8:30am - 3:00pm; 6.5 Hours	9:00am - 2:00pm; 5 Hours
Rural Site 2	11:00am - 7:00pm; 8 Hours	10:30am - 7:00pm; 8.5 Hours	10:00am - 7:00pm; 9 Hours	10:00am - 3:00pm; 5 Hours	11:00am - 3:00pm; 4 Hours
Rural Site 3	9:00am - 7:00pm; 10 Hours	9:00am - 7:00pm; 10 Hours	9:00am - 7:00pm; 10 Hours	10:00am - 6:00pm; 8 Hours	10:30am - 5:30pm; 7 Hours
Rural Site 4	7:00am - 7:00pm; 12 Hours	7:30am - 7:00pm; 11.5 Hours	8:00am - 6:30pm; 10.5 Hours	9:00am - 6:00pm; 9 Hours	9:00am - 5:00pm; 8 Hours
Urban Site 1	6:00am - 4:00pm; 10 Hours	6:30am - 7:00pm; 12.5 Hours	6:00am - 3:00pm; 9 Hours	7:00am - 3:00pm; 8 Hours	8:00am - 3:00pm; 7 Hours
Urban Site 2	5:00am - 6am; 11:00am - 1:00pm; 3 Hours	5:00am - 6:00am; 12:00pm - 1:00pm; 2 Hours	Shaded	11:30am - 2:00pm; 2.5 Hours	8:00am - 5:30pm; 9.5 Hours
Urban Site 3	9:00am - 7:00pm; 10 Hours	9:00am - 6:30pm; 9.5 Hours	10:00am - 6:30pm; 8.5 Hours	10:00am - 5:30pm; 7.5 Hours	10:30am - 5:30pm; 7 Hours
Urban Site 4	6:00am - 4:00pm; 10 Hours	6:30am - 4:00pm; 9.5 Hours	7:00am - 4:00pm; 9 Hours	6:30am - 3:00pm; 8.5 Hours	7:30am - 2:30pm; 7 Hours

Pig carcasses were each contained in a separate bottomless wire mesh cage to prevent feeding and disturbance by vertebrate scavengers, but allowing unrestricted insect access to the carcass. The cages were made of wire fencing material with 2.5 cm by 5.1 cm spacing or 5.1 cm by 10.2 cm spacing. Carcasses were placed 1.5 m from each other. Carcasses were monitored, sampled and photographed daily for the first week. After the first week the carcasses were sampled and photographed every other day until complete decomposition occurred.

2.2 Sampling

Ambient temperature, ground surface temperature, carcass surface temperature, ground/body interface temperature, internal temperature while possible, maggot mass temperature, if a maggot mass was present, and the temperature 10 cm under the ground were taken with an H-B partial immersion liquid-in-glass thermometer with an accuracy of $\pm 1°C$) each time the carcasses were sampled. When taking ambient temperature the thermometer was held and the bulb was shaded from direct sunlight, but other sources of heat such as reflective heat from the ground was not blocked. Amount of precipitation was measured with semicircular rain gauges at each site, the rain gauges were 20 cm off the ground, 11 cm along the straight edge and 6 cm wide. Weather conditions at the time of sampling were noted. Decomposition stage was noted for each carcass on each sampling date. Decomposition stages used in this study were; fresh, bloat, active decomposition, advanced decomposition, and dry remains. Carcasses were sampled between 12:00 pm and 4:00 pm.

Presence of Diptera eggs and larvae were noted, as well as the instar of the larvae; first instar, second instar, or third instar, maggot migration activity, and approximate number of adult flies. Presence of adult and larval Coleoptera was noted as well as presence of other arthropods. Numbers of *C. maxillosus* were counted but not collected to preserve the population and determine when they arrive and leave the carcass. Other Coleoptera were collected and identified as needed to confirm identi-

fication. Other taxa occurring at the carcass were noted, and collected as needed to confirm identification.

Adult flies were collected at the carcass with a sweep net and preserved in 70% EtOH. Flies that were not caught in the sweep net were disturbed and flew away from the carcass, though adults would begin returning to the carcass within seconds or minutes of disturbance by the sweep net. Carcasses were visually searched for adult and larval beetles, which were collected with forceps or by hand and preserved in 70% EtOH. Dipteran larvae were collected by scooping with a spoon and killed in KAA (composed of 95% Ethanol (77%), Acetic Acid (15%) and Kerosene (8%)) and then transferred to 70% EtOH for preservation. After the insects found on the surface of the carcass were noted and collected, the carcass was moved to search the underside for other arthropods. Moving of the carcass would disturb some of the arthropods found causing them to move away from the carcass. Though, as Eberhardt and Elliot (2008) found, it does not appear that disturbance causes the arthropods to leave the carcass and not return. Beetles were identified using keys from Arnett et al., 2002). Third instar dipterans were identified using keys from Dodge (1966) and Wells et al. (1999). As only third instar Calliphoridae can be identified visually to species, all larval counts represent numbers of third instars. Adults were pinned and labeled before identification using keys by Dodge (1966), and Whitworth (2006).

2.3 Analysis

Statistical analysis on the number of arthropods collected was conducted using analysis of variance (ANOVA). Habitat type was the treatment variable, the block variable was Site, and the arthropod species as dependent variables. ANOVA was completed on arthropods that were found more than 100 times, as arthropods with lower numbers would not be able to show a reliable statistical analysis.

Fig. 2.1. Rural site number one. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.2. Rural site number two. White rectangle marks the approximate placement of pig carcasses.

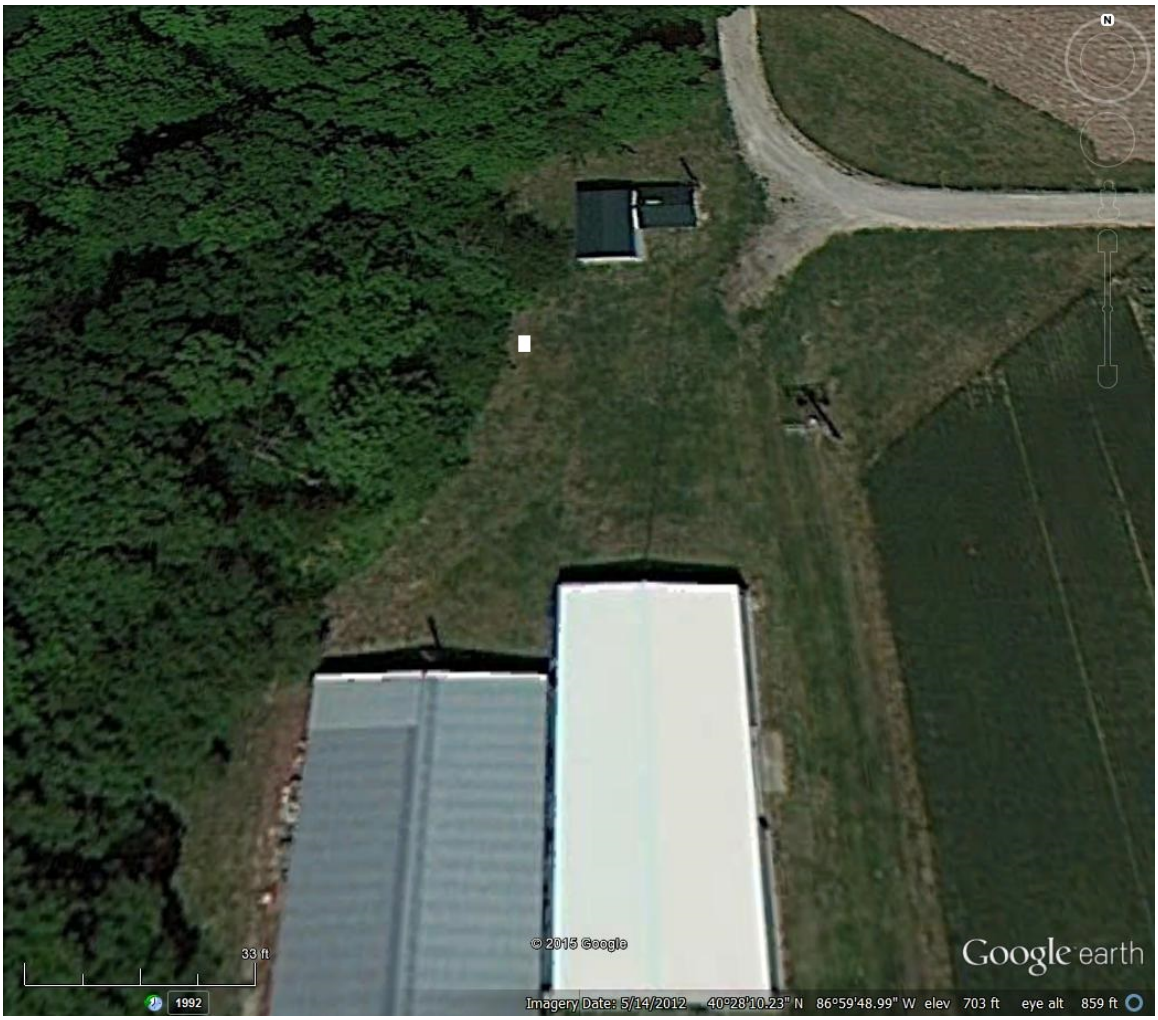

Fig. 2.3. Rural site number three. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.4. Rural site number four. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.5. Urban site number one. White rectangle marks the approximate placement of pig carcasses.

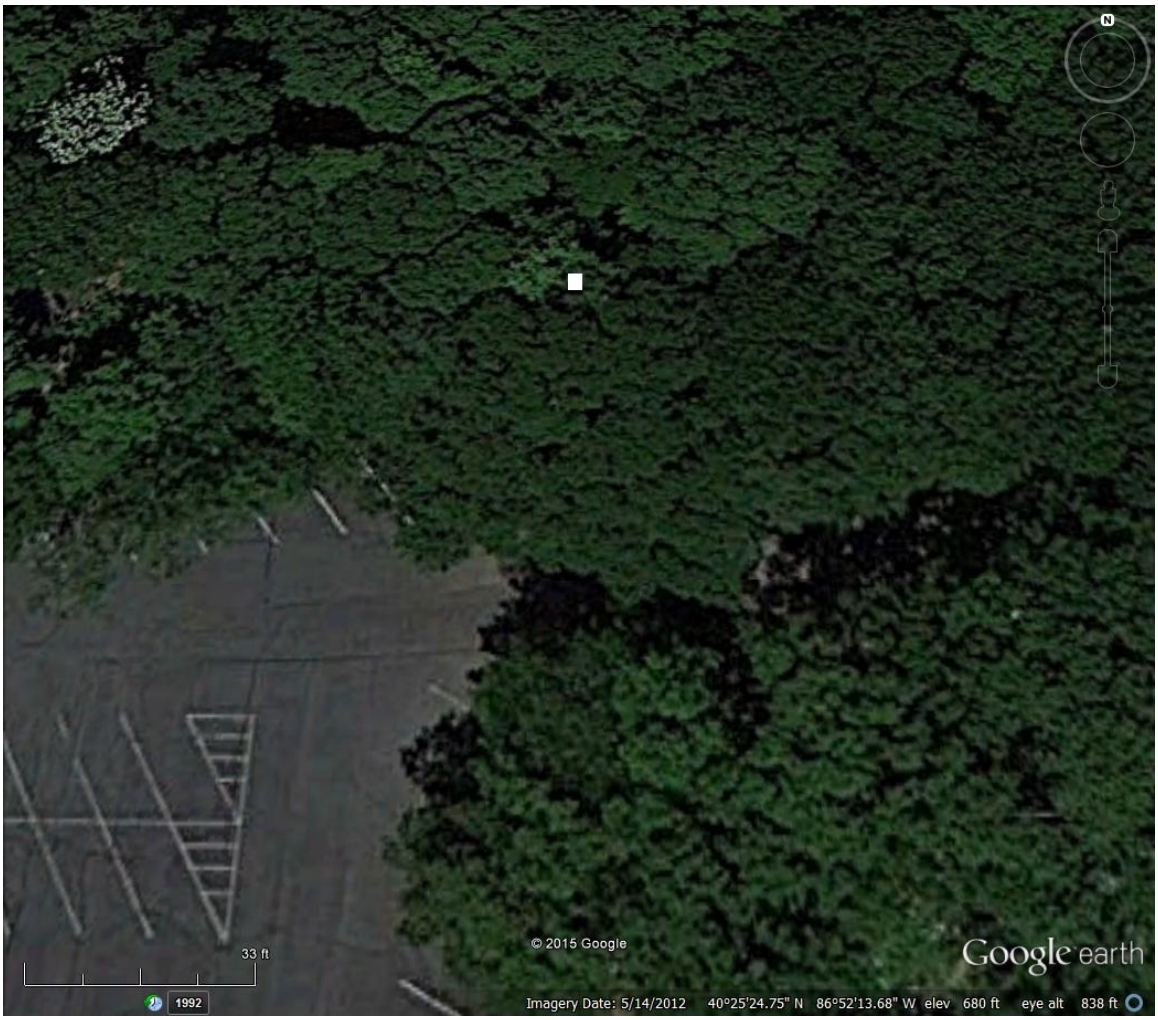

Fig. 2.6. Urban site number two. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.7. Urban site number three. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.8. Urban site number four. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.9. Urban site number four. White rectangle marks the approximate placement of pig carcasses.

Fig. 2.10. Hemispherical photograph of rural site number one. North is at the top of the picture.

Fig. 2.11. Hemispherical photograph of rural site number two. North is at the top of the picture.

Fig. 2.12. Hemispherical photograph of rural site number three. North is at the top of the picture.

Fig. 2.13. Hemispherical photograph of rural site number four. North is at the top of the picture.

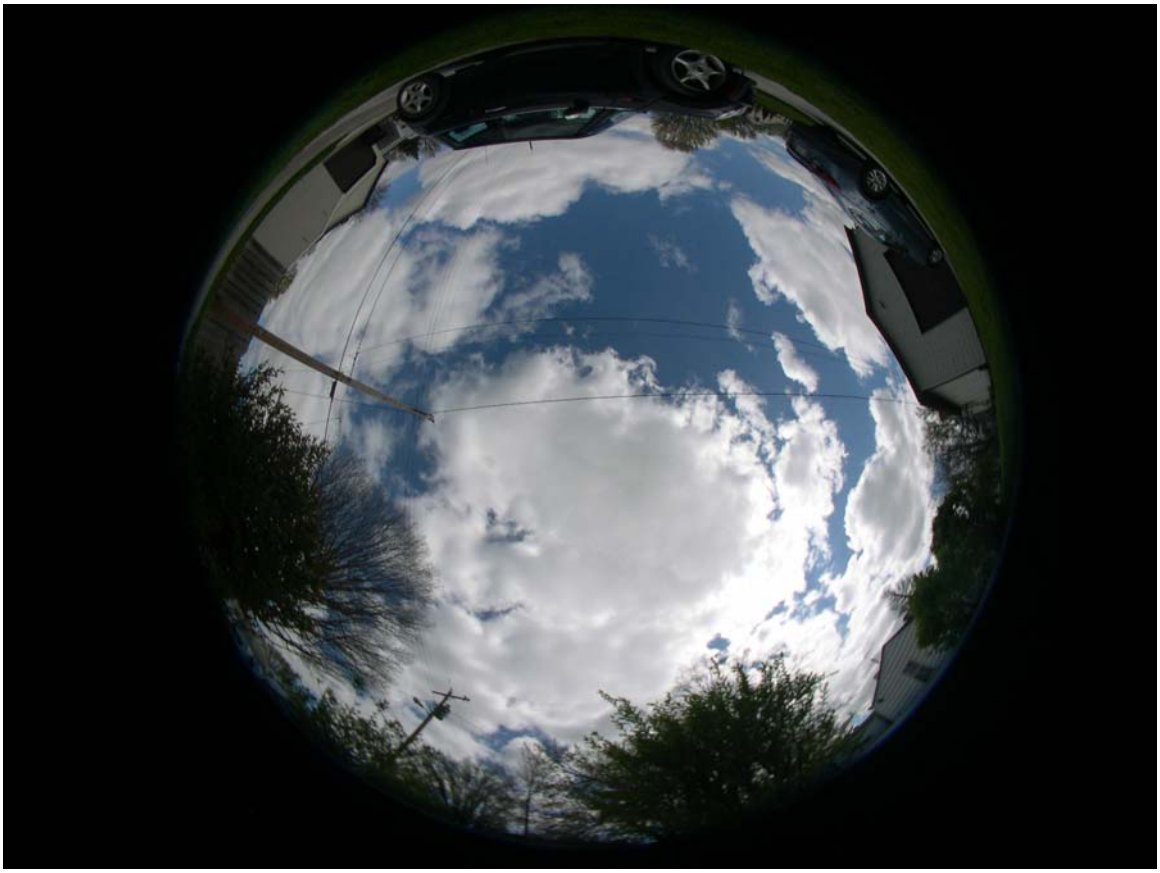

Fig. 2.14. Hemispherical photograph of urban site number one. North is at the top of the picture.

Fig. 2.15. Hemispherical photograph of urban site number two. North is at the top of the picture.

Fig. 2.16. Hemispherical photograph of urban site number three. North is at the top of the picture.

Fig. 2.17. Hemispherical photograph of urban site number four. North is at the top of the picture.

3. RESULTS AND DISCUSSION

3.1 Numbers of Specimens Collected

3.1.1 Adults

Some taxa of arthropods that were found on the carcasses were collected more than 100 times throughout the study. For adult Diptera (Table 3.1), the highest number found overall was for *L. sericata*, with 1,061 specimens found. For *C. rufifacies* adults there were 95 specimens collected. Adults of *C. macellaria* were collected 398 times. For *L. coeruleiviridis* there were 535 adult specimens collected. Adult *L. illustris* specimens were collected 475 times. Adults of *P. regina* were collected 490 times. For Sarcophagidae adults there were 113 specimens collected. For Coleoptera, Histeridae beetles were collected 262 times. Isopoda specimens were found 457 times overall.

3.1.2 Larvae

Though *L. sericata* had the highest number of adults collected, they did not have the highest number of larvae collected. For larval *L. sericata*, 1,781 specimens were collected, while for *L. coeruleiviridis* 2,150 larvae were collected (Table 3.2). It is possible that lower numbers of *L. sericata* larvae is due to competition between the larvae on the carcass, as *L. sericata* has sometimes been regarded as a poorer competitor (Smith and Wall, 1997a; Fischer et al., 1998). Smith and Wall (1997a) found that *L. sericata* had higher mortality and smaller adult size when in mixed cultures with *C. vicina*. Though most of the difference in larval numbers for *L. sericata* was the result of low numbers collected in the rural environment, competition may make a difference in the number of larvae of certain species found on carcasses.

For other Diptera species, the number of larvae collected overall was: 275 for *C. macellaria*, 258 for *C. rufifacies*, 190 for *L. illustris*, 795 for *P. regina*, and 199 for Sarcophagidae.

Chrysomya rufifacies was not collected in 2011, but was collected in 2012. As *C. rufifacies* is a primarily tropical fly (Baumgartner, 1993), it is likely that the high temperatures during 2012 allowed it to move into Indiana. This species has been moving northward since its arrival in the United States in 1980 ((Baumgartner and Greenberg, 1984).

3.2 Rural and Urban Habitats

3.2.1 Diptera

Analysis of variance (ANOVA) was conducted on taxa that had more than 100 specimens collected during the study to determine differences in population densities on carcasses in rural versus urban sites. Adult *L. sericata* showed a strong preferences for urban locations (P <0.0001), with 35 flies found at rural sites and 1,026 at urban sites (Table 3.1). For *L. sericata* larvae, the results were similar with 497 larvae sampled from rural locations and 1,284 larvae from urban locations (P <0.0001) (Table 3.2). Only a small number of *L. sericata* adults were collected, compared to the number of *L. sericata* larvae that were collected, which would partially be due to the number of eggs a single female *L. sericata* can oviposit at one time, which can be around 200 eggs (Cruickshank and Wall, 2002). Therefore it would only take a few individuals being able to find a carcass and oviposit for large numbers of larvae to be found if the larvae are not outcompeted or fed upon.

Urban areas will contain household waste which often has a high organic component that may allow for proliferation of species that can complete their larval development in waste material. Odors produced by household waste will attract adults of *Lucilia* (Goulson et al., 1999). In Brown et al. (1970), *L. sericata* was found to be able to complete development in household refuse and Goulson et al. (1999)

confirmed the ability of *Lucilia spp.* to develop in household waste. *Lucilia sericata* was found to be the most numerous species found in garbage in containers in urban areas (Schoof et al., 1954). Though *Lucilia* generally feed on animal matter as larvae (Goulson et al., 1999; Colyer and Hammond, 1968), animal matter may be present in the household waste in urban areas. *Lucilia sericata* has also been found to complete development in pig food that was made up entirely of vegetable matter (Green, 1951). Compost piles and bins would also provide material that could allow for larval development (Goulson et al., 1999). The ability of *L. sericata* to complete its development in household waste is possibly why this species is able to exploit and have a preference for urban areas. It is unlikely that dung provides an important breeding substrate (Cragg, 1955), which may explain why population densities were lower in rural areas where household waste is minimized but dung may be in abundance.

Though *L. sericata* is reported to prefer open areas (Cragg, 1955), the urban sites were generally less open than the rural sites in this study, so it is unlikely that *L. sericata* preferred the urban habitats due to openness of the conditions surrounding the sites and it is likely another factor was affecting their preference. Unfortunately it is difficult to estimate how many naturally occurring carcasses may be located in rural or urban areas, and thus the species present from those carcasses is hard to assess (Cragg, 1955). Higher numbers of naturally occurring carcasses that Diptera larvae can complete their life cycles in would affect the populations found in those areas. An ability to exploit larger numbers of carcasses in either the rural or urban habitat would also benefit those species.

It is possible that urban areas would have more carcasses that would remain for longer periods of time, as rural areas may have more scavengers to find and feed on the carcasses in those areas. In a study by Ward et al. (2006), carcasses of birds were found to persist in urban environments longer than in urban environments, with carcasses decomposing or being scavenged after an average of 1.6 days in the rural environment and 2.1 days in the urban environment. Though they found similar species composition of scavengers for rural and urban areas, they attended carcasses

at a higher rate in the rural areas (Ward et al., 2006). Urban areas may also have more road kill, which may be present for enough time for insects to complete their life cycle on, depending on the methods of removal of road kill in that particular location and the numbers of scavengers present.

For adult *C. rufifacies* there was no statistically significant preference for habitat type ($P = 0.1118$), and larval *C. rufifacies* also had no statistically significant preference for urban or rural locations ($P = 0.4599$) (Tables 3.1 and 3.2). *Cochliomyia macellaria* adults ($P = 0.5864$) and larvae ($P = 0.5381$) had no statistically significant preference for rural or urban sites. *Lucilia coeruleiviridis* had no statistically significant preference for either rural or urban locations for adults ($P = 0.2935$) or larvae ($P = 0.5786$). For *L. illustris* adults ($P = 0.6465$) and larvae ($P = 0.5179$), there were no statistically significant differences between rural and urban locations. Adults ($P = 0.3407$) and larvae ($P = 0.7668$) of *P. regina* also showed no statistically significant preference for rural versus urban locations. Sarcophagidae adults ($P = 0.1215$) and larvae ($P = 0.0736$) were not found in statistically different numbers in either habitat.

3.2.2 Coleoptera

Adult Histeridae numbers showed no statistical differences between rural and urban habitats ($P = 0.7458$) (Table 3.1). Table 3.4 shows the number of adult and larval beetles that were collected in the rural and urban habitats. For Silphidae adults there were 61 *Necrophila americana* (Linnaeus), with 56 specimens being found in rural locations and 5 in urban locations. The majority of specimens, 49, from rural locations were found at rural site number two. A possible reason for this might be the structural diversity of the plants around this site, which may have given *N. americana* more locations to hide.

3.2.3 Hemiptera

Table 3.5 shows the number of other insects that were collected in rural and urban habitats. There were not enough specimens of Hemiptera collected to statistically analyze. Payne et al. (1968) found 12 species of Hemiptera present at pig carcasses, in the families; Cydnidae, Coreidae, Lygaeidae, Tingidae, Reduviidae, and Miridae, but did not find any of the families Anthocoridae, Pentatomidae or Nabidae as was seen in this study. Specimens of Pentatomidae were observed feeding on the carcass in this study, so it is possible that these specimens may use the opportunity to gain nutrients from the fluids on or near the carcass; or, in the case of specimens of Anthocoridae or Nabidae, to predate on arthropods feeding on the carcass. Anthocoridae in the genus *Orius* would land on and bite the investigator during sampling, particularly in the autumn months. *Orius* specimens are also known to feed on prey much larger than themselves. Other specimens may be found on the carcass incidentally, while moving about in their environment.

3.2.4 Hymenoptera

There were not enough specimens of Hymenoptera collected to statistically analyze. Ants were found at the carcasses, but specific numbers of ants found were not recorded. On one occasion an ant was seen scaring away adult flies from the pig carcass by waving their front legs in the direction of the flies. Ants were also seen to be feeding on fluids from the carcasses and Diptera larvae and eggs. *Vespula* were seen to feed on Diptera adults and larvae, and to feed on the carcass itself, occasionally removing large portions of flesh. On one occasion, a specimen of *Vespula* was observed removing a ball of Diptera eggs from the carcass. *Vespula* were also observed to pick up ants from the carcass, remove them, and appeared to drop them away from the carcass. Five specimens of *Apis mellifera* Linnaeus (Hymenoptera: Apidae) were found on the carcasses, putting their proboscis on the carcass and appearing to feed on fluids.

Herrera (1990) recorded bumble bees (Hymenoptera: Apidae: Apinae), specifically *Bombus terrestris* (Linnaeus) feeding on the fluid available on goat carrion. Bumble bees have also been noted to feed at feces and urine, and it is suspected that they are using these products to get nitrogenous substances (Herrera, 1990). Bees usually acquire nitrogen from pollen (Herrera, 1990). A number of beetles in the family Silphidae appear to be Mllerian mimics of bumble bees and Herrera (1990) hypothesized that this habit of bumble bees feeding on carrion would aid in the evolution of this mimicry. While no bumble bees were found in this study, both honey bees (*A. mellifera*) and carpenter bees in the genus *Xylocopa* (Hymenoptera: Apidae: Xylocopinae) were found at the carcass feeding on fluids. It is presumed that these bees would act similarly to bumble bees, using the carcass to obtain nitrogenous substances.

3.2.5 Lepidoptera

Lepidoptera were found on the pig carcasses, but were too few to be statistically analyzed. Most Lepidoptera specimens were found in the rural habitats. Several members of the skipper family, Hesperiidae, were seen including; the least skipper, *Ancyloxypha numitor* (Fabricius), the silver spotted skipper, *Epargyreus clarus* (Cramer), and the Zabulon skipper, *Poanes zabulon* (Boisduval and Leconte). One member of the family Lycaenidae was seen; the Eastern Tailed-Blue, *Cupido comyntas* (Godart). Other butterflies found were in the family Nymphalidae; the common buckeye, *Junonia coenia* Hübner, the monarch butterfly, *Danaus plexippus* (Linnaeus), the great spangled fritillary, *Speyeria cybele* (Fabricius), the Pearl Crescent, *Phyciodes tharos* (Drury), and the Silvery Checkerspot, *Chlosyne nycteis* (Doubleday).

Puddling is the behavior of lepidopterans where they attend mud puddles, moist ground, tears and perspiration, excrement, and carcasses to obtain moisture and nutrients (Beck et al., 1999). Downes (1973) collected specimens of *P. tharos* feeding from a frog carcass and found that specimens of *D. plexippus* would feed on sweat

moistened skin, or skin that had been treated with sodium chloride. Most puddling and carcass attending lepidopterans are male (Beck et al., 1999). Fluids from carcasses contain nutrients and protein that male lepidopterans may use to aid in reproduction, as male lepidopteran often pass a spermatophore to females when mating, which can increase reproductive success (Beck et al., 1999). This spermatophore may contain nutrients, such as sodium, calcium phosphate, or amino acids (Beck et al., 1999). Beck et al. (1999) found that Lepidoptera in the families; Hesperiidae, Lycaenidae, and Nymphalidae, such as those found in this study, preferred resources containing protein, which may explain their attraction to the carcass instead of moist ground. Lycaenidae are likely attracted to olfactory cues emitted by decomposing matter, and in their study the presence of decoy butterflies did not attract individuals in the families; Hesperiidae, Lycaenidae, and Nymphalidae, to the bait indicating that members of these families did not use the presence of other lepidopterans to determine where to puddle (Beck et al., 1999).

3.2.6 Orthoptera

Too few Orthoptera were found to be analyzed statistically. Most of the grasshoppers (Orthoptera: Acrididae), 8, were found in the rural habitats, with only 1 found in the urban habitats. Grasshoppers appeared to feed on the carcass or moisture from the carcass, but no feeding damage was evident.

Most of the crickets in the genus *Gryllus* (Orthoptera: Gryllidae), 36, were found in the urban habitats with only 1 found in the rural. As crickets prefer areas where the level of moisture is high, it is possible that more crickets were found in the urban habitats for that reason. Crickets were observed feeding on carcasses, leaving wounds in the flesh and enlarging feeding holes made by larval Diptera. It is also likely that if crickets feed at these dipteran feeding holes, they would also cause modification to antemortem and perimortem wounds on the body. This behavior is important because this damage can be confused for antemortem or perimortem wounds, cause

incorrect assumptions to be made about the case, or cause problems in identifying what weapons or tools made the initial wound.

Insects can cause difficulties in postmortem evaluation by removing parts of the carcass, organs, removing hair and eyelashes, or by modifying wounds on the remains (Byard et al., 2002). Cockroaches (Denic et al., 1997) and ants (Byard, 2005) have been shown to feed on the corpse following death, causing wounds that can look like antemortem or perimortem wounds. Damage by ants has been thought to be antemortem or perimortem; trauma to the body, abrasions, and lesions caused by a fall or assault (Byard, 2005; Byard et al., 2002).

3.2.7 Non-Insect Arthropods and Others

Among non-insect arthropods, only Isopoda had enough specimens found to statistically analyze with 457. The number of specimens of Isopoda were found to have a statistical difference between habitat types ($P = 0.0001$), with more Isopods being found in urban habitats. Twelve specimens were found in the rural locations and 445 in the urban locations (Table 3.1). While Isopods are generally considered to feed on plant matter, Isopods were observed to put their mouthparts on and appear to feed on the carcass in this study, though it is unknown if the majority of specimens found were feeding on the carcass. It is also possible that the Isopods will use the carcass as a source of moisture and as habitat. The numbers of all non-insect specimens found in rural and urban habitats are listed in Table 3.6.

3.3 Within Treatment Differences

3.3.1 Rural

In the rural environments, the Histeridae adults and number of individuals of Isopoda had differences between sites (Table 3.7). Larger numbers of Histeridae were collected at sites one and two, which were located close together while sites three and

Table 3.1.
Total number of adults of each taxon collected in urban and rural environments.

Taxa	Urban Numbers	Rural Numbers	*P*	F
C. macellaria Adults	213	185	0.5864	0.30
C. rufifacies Adults	79	16	0.1118	2.53
L. coeruleiviridis Adults	243	292	0.2935	1.10
L. illustris Adults	225	250	0.6465	0.21
L. sericata Adults	1026	35	0.0000	109.15
P. regina Adults	221	269	0.3407	0.91
Sarcophagidae Adults	46	67	0.1215	2.40
Histeridae Adults	127	135	0.7458	0.11
Isopoda	445	12	0.0001	15.51

Table 3.2.
Total number of larvae of each taxon collected in urban and rural environments.

Taxa	Urban Numbers	Rural Numbers	*P*	F
C. macellaria Larvae	123	152	0.5381	0.38
C. rufifacies Larvae	106	152	0.4599	0.55
L. coeruleiviridis Larvae	1123	1027	0.5786	0.31
L. illustris Larvae	106	84	0.5179	0.42
L. sericata Larvae	1284	497	0.0000	35.14
P. regina Larvae	414	381	0.7668	0.09
Sarcophagidae Larvae	71	128	0.0736	3.21

Table 3.3.
Number of Diptera adults and larvae collected in urban and rural habitats.

Family	Genus	Species	Urban Adults	Urban Larvae	Rural Adults	Rural Larvae
Calliphoridae						
	Calliphora					
		Calliphora vicina	4	1	1	2
		Calliphora vomitoria	4	8	4	9
	Chrysomya					
		Chrysomya rufifacies	79	106	16	152
	Cochliomyia					
		Cochliomyia macellaria	213	123	185	152
	Lucilia					
		Lucilia coeruleiviridis	243	1123	292	1027
		Lucilia illustris	225	106	250	84
		Lucilia sericata	1026	1284	35	497
	Phormia					
		Phormia regina	221	414	269	381
Drosophilidae						
	Drosophila		2	0	0	0
Fanniidae						
	Fannia		1	27	0	44
Muscidae			33	0	42	0
Sarcophagidae			46	71	67	128
Uliitidae			0	0	2	0

Table 3.4.
Number of Coleoptera adults and larvae collected in urban and rural habitats.

Order	Family	Genus	Species	Urban Adults	Urban Larvae	Rural Adults	Rural Larvae
Coleoptera							
	Carabidae						
			Unidentified species	2	0	0	3
		Cicindela		0	0	1	0
	Cleridae						
		Necrobia					
			Necrobia rufipes	1	0	1	0
	Dermestidae			44	5	15	4
	Histeridae			127	-	135	-
	Nitidulidae			6	-	15	-
	Scarabaeidae						
		Onthophagus		7	0	10	0
			Onthophagus hecate				
		Cotinis					
			Cotinis nitida	2	-	0	-
	Silphidae			-	1	-	2
		Necrophila					
			Necrophila americana	5	0	56	0
		Nicrophorus		0	0	1	0
		Oiceoptoma					
			Oiceoptoma inaequale	0		9	
			Oiceoptoma noveboracense	5		8	
	Staphylinidae						
			Unidentified species	153	0	95	0
			Creophilus maxillosus	34	0	43	0

Table 3.5.
Number of other insects collected in urban and rural habitats.

Order	Family	Genus	Species	Urban Adults	Rural Adults
Dermaptera					
	Forficulidae				
		Forficula	*Forficula auricularia*	1	0
Hemiptera					
	Anthocoridae				
		Orius		5	1
	Nabidae			1	0
	Pentatomidae			3	11
Hymenoptera					
	Apidae				
		Apis	*Apis mellifera*	0	5
		Xylocopa		2	0
	Halictidae			0	1
	Vespidae				
		Dolichovespula	*Dolichovespula maculata*	0	2
		Polistes		1	
		Vespula		37	34
Lepidoptera					
	Hesperiidae				
		Ancyloxypha	*Ancyloxypha numitor*	0	2
		Epargyreus	*Epargyreus clarus*	0	12
		Poanes	*Poanes zabulon*	0	1
	Lycaenidae				
		Cupido	*Cupido comyntas*	0	8
	Nymphalidae				
		Chlosyne	*Chlosyne nycteis*	0	3
		Danaus	*Danaus plexippus*	1	1
		Junonia	*Junonia coenia*	1	18
		Phyciodes	*Phyciodes tharos*	0	5
		Speyeria	*Speyeria cybele*	0	7
Orthoptera					
	Acrididae			1	8
	Gryllidae				
		Gryllus		36	1

Table 3.6.
Non-insects collected in urban and rural habitats.

Taxa	Common Name	Urban	Rural
Araneae	Spider	1	4
Chilopoda	Centipede	0	1
Diplopoda	Millipede	25	9
Gastropoda	Slug	23	17
Isopoda	Woodlouse	445	12
Oligochaeta	Earthworm	2	0
Opiliones	Harvestman	0	1

four were approximately 7 km away, though in close proximity to each other. Rural sites one and two are also near a larger patch of wooded area, while sites three and four are in an area of primarily agricultural land. These differences in habitats could lead to differences in the number of Histeridae found at those locations.

For Isopoda, though overall numbers at the rural locations were low, there were slightly more Isopods found at rural sites two and three, with 8 and 3 specimens respectively, and no specimens collected at site one. The slightly longer grasses at rural site two may have provided more habitat and more moisture, which would allow for a higher population of Isopods at that site. At rural site three the proximity of the trees and bushes may have maintained a population of Isopods that occasionally located the carcasses. Consistent low mowing and drier soil at rural site one may be the reason that no Isopods were found at that location, site four was also very dry and further from stands of trees that may maintain moisture and provide habitat for Isopods and one specimen was found there.

In the rural environments *L. sericata* larvae and Sarcophagidae larvae numbers were different between sites (Table 3.9). For *L. sericata* larvae, lower numbers were collected at rural site three. Though *L. sericata* adults had slightly lower numbers at rural site three, it was not the lowest numbers found at any rural site. It is possible that site was not as conducive to *L. sericata* larvae due to characteristics of the site that werent measured, greater competition from other larval species, greater predation, frequent disturbance by vertebrate scavengers, pesticides that may have been applied to the area or residual from storage, or that *L. sericata* larvae were on an area of the carcass that was not sampled as heavily.

Sarcophagidae larvae had lower numbers at rural site two, and Sarcophagidae adults also showed lower numbers at that site than the other rural sites. Lower numbers of adult Sarcophagids would have a significant impact on numbers of larvae as their reproductive strategy is to larviposit a few, more developed larvae on any one carcass. The highest numbers of adult and larval Sarcophagidae were collected at rural site four.

3.3.2 Urban

In the urban environments, adults of *L. coeruleiviridis*, *L. sericata*, and Sarcophagidae had differences between sites (Table 3.8). Higher populations of adult *L. coeruleiviridis* were collected at urban sites one and two, with the highest population being found at site two. As *L. coeruleiviridis* has been said to prefer woods and fields (Hall, 1948), and urban site two is more shaded with trees than the other sites. Though, urban site one is not more wooded than the other sites.

For *L. sericata*, urban site two had the lowest population of adults which may be due to the slight distance from residences, which may have reduced the amount of waste material in that area. More garbage in adjacent areas may have been more attractive to the adult *L. sericata* near that site.

Adult Sarcophagidae had a higher population at urban site two, and the lowest number was collected at urban site four. Higher numbers of Calliphoridae were found at urban site four, so it is possible that competition deterred the Sarcophagidae adults that site. The more shaded nature of urban site two may have been more attractive to the Sarcophagidae adults, while site four was sunny for most of the day (Table 2.2).

Individuals of Isopoda also showed a difference between urban sites (Table 3.8). Urban site two had a very high population of Isopoda, followed by site three, site one, and the lowest population being found at site four. Of the urban sites site two was the shadiest and has the closest forested area, which is likely attractive to Isopods due to their need for moisture. Urban site four was the least vegetated and sunniest site, which is not ideal for Isopod populations.

Site four had lower numbers of *C. macellaria* and *C. rufifacies* larvae when compared with the other urban sites (Table 3.10). This site had a high number of *L. sericata* larvae, which may have led to competition between the *C. macellaria* and *C. rufifacies* larvae and *L. sericata*, or the other species causing a reduction in number. It is possible that the larvae of *C. macellaria* and *C. rufifacies* were more negatively

phototrophic, and that the amount of sun on the carcasses caused them to migrate to the interior of the carcass where they were harder to sample.

Table 3.7.
Mean number of adults found per carcass at each site for each sampling date in the rural environments.

Taxa	Site 1	Site 2	Site 3	Site 4
C. macellaria Adults	0.3077	0.3000	0.4538	0.3615
C. rufifacies Adults	0.0462	0.0000	0.0462	0.0308
L. coeruleiviridis Adults	0.7769	0.7769	0.3769	0.3154
L. illustris Adults	0.6462	0.5692	0.3385	0.3692
L. sericata Adults	0.0923	0.0308	0.0692	0.0769
P. regina Adults	0.5462	0.4385	0.4077	0.6769
Sarcophagidae	0.1231	0.0846	0.1462	0.1615
Histeridae Adults	0.4615	0.2846	0.1615	0.1308
Isopoda	0.0000	0.0615	0.0231	0.0077

3.4 Seasonal Dynamics

To determine if there were differences in the arthropod numbers found throughout the study by month, an ANOVA test was conducted. For adults, *C. macellaria* was statistically different between months (P <0.0001) with August having statistically more adults collected than any other month (Table 3.11) which agrees with the finding of Deonier (1940) of August being the peak population for *C. macellaria* in the Midwest. For *L. sericata* adults there was no statistical difference between any of the sampling months (P = 0.4496). *Lucilia coeruleiviridis* adults were statistically different (P <0.0001) among the months over the sampling season, with statistically

Table 3.8.
Mean number of adults found per carcass at each site for each sampling date in the urban environments.

Taxa	Site 1	Site 2	Site 3	Site 4
C. macellaria Adults	0.5379	0.2500	0.3333	0.4924
C. rufifacies Adults	0.2197	0.0000	0.2879	0.0909
L. coeruleiviridis Adults	0.4015	0.9545	0.2652	0.2197
L. illustris Adults	0.6136	0.6212	0.2727	0.1970
L. sericata Adults	1.6061	0.9242	2.1136	3.1288
P. regina Adults	0.3182	0.4848	0.4545	0.4167
Sarcophagidae Adults	0.0758	0.1818	0.0606	0.0303
Histeridae Adults	0.3561	0.1136	0.3258	0.1667
Isopoda	0.0455	3.0833	0.2273	0.0152

Table 3.9.
Mean number of dipteran larvae found per carcass at each site for each sampling date in the rural environments.

Taxa	Site 1	Site 2	Site 3	Site 4
C. macellaria Larvae	0.3615	0.0385	0.2077	0.5615
C. rufifacies Larvae	0.3462	0.0000	0.4000	0.4231
L. sericata Larvae	1.2308	0.9077	0.3231	1.3615
L. coeruleiviridis Larvae	2.3462	1.5462	1.5923	2.4154
L. illustris Larvae	0.2615	0.1308	0.0308	0.2231
P. regina Larvae	0.9538	0.5846	0.4308	0.9615
Sarcophagidae Larvae	0.1692	0.0077	0.1846	0.6231

Table 3.10.
Mean number of dipteran larvae found per carcass at each site for each sampling date in the urban environments.

Taxa	Site 1	Site 2	Site 3	Site 4
C. macellaria Larvae	0.3485	0.2879	0.2348	0.0606
C. rufifacies Larvae	0.3561	0.1439	0.2197	0.0833
L. sericata Larvae	2.2121	2.3485	2.3485	2.8182
L. coeruleiviridis Larvae	2.5530	2.3788	2.1364	1.4394
L. illustris Larvae	0.3030	0.1742	0.1667	0.1591
P. regina Larvae	0.7348	0.5833	0.8258	0.9924
Sarcophagidae Larvae	0.1894	0.0682	0.1439	0.1364

more found during both June and October than the other months. For adult *L. illustris* there were statistical differences between months (P <0.0001), with June and July having higher numbers found than during the other months. *Phormia regina* showed a statistical difference ($P = 0.0131$) with June having lower numbers of adults collected than in August.

In 2011, *P. regina* had higher numbers than *L. illustris*, while *L. illustris* had higher numbers than *P. regina* in 2012. In most cases high numbers of *L. illustris* were found at the same time as low numbers of *P. regina*, which may indicate similar niche usage, competition or different weather and temperature requirements. Though, Greenberg (1991) found that *L. illustris* was found in open woodlands and meadows, not urban areas, and that *P. regina* could be found in each of these habitats. In this study *L. illustris* and *P. regina* were both found in rural and urban habitats, and neither species showed a statistically significant preference for either habitat. For Sarcophagidae adults there was a statistical difference (P <0.0001), with June, July, and August having statistically more flies collected than in October.

Histeridae showed a statistical difference (P <0.0001) with the highest number of beetles being found in August and the lowest number being found in October.

Isopoda also showed a statistical difference (P <0.0001), with Isopoda being found statistically more often in June.

3.5 Seasonal Dynamics by Treatment

Table 3.12 shows the number of specimens collected in each month for both years combined, to show how many of each type of arthropod were collected in the rural and urban habitats. For *C. macellaria* the larger numbers of adults were collected in the urban habitats early in the season but the differences were not statistically significant (June: $P = 0.1007$; July: $P = 0.7972$; August: $P = 0.2324$). Though, in September ($P = 0.8201$) and October ($P = 0.4644$) larger numbers were collected in the rural habitats the results were not statistically significant. This might indicate

Table 3.11.
Numbers of adult Diptera, Histeridae, and Isopoda collected each month with 2011 and 2012 combined. Numbers collected were measured with Tukey HSD All-Pairwise Comparisons Test, $\alpha = 0.05$. Taxa with the same letter were not statistically different from each other.

Taxa	June	July	August	September	October
C. macellaria	10 C	44 BC	176 A	118 B	50 C
L. coeruleiviridis	151 A	67 B	34 B	42 B	241 A
L. illustris	202 A	175 A	52 B	38 B	8 B
L. sericata	217 A	173 A	219 A	168 A	284 A
P. regina	40 B	116 AB	134 A	89 AB	111 AB
Sarcophagidae	34 A	24 AB	38 A	10 BC	7 C
Histeridae	66 AB	43 ABC	89 A	51 BC	13 C
Isopoda	283 A	44 B	99 B	15 B	16 B

differing preferences in the fall, or a movement of flies from one habitat to the other, though the differences in populations were not extreme. In August *L. coeruleiviridis* had larger numbers in urban habitats ($P = 0.0066$), though higher numbers were collected in rural habitats in October ($P = 0.0622$) the results were not statistically significant. Numbers in June ($P = 0.7130$), July ($P = 0.7416$), September ($P = 0.1666$), were not statistically significant. Numbers of *L. coeruleiviridis* were highest at the beginning and end of the season. For all months, populations of *L. illustris* were similar in rural and urban habitats (June: $P = 0.8268$; July: $P = 0.3673$; August: $P = 0.1761$; September: $P = 0.4458$; and October $P = 0.4818$). It doesnt appear that *L. illustris* has a seasonal preference for habitat in this area. For *L. sericata*, numbers of adult flies were significantly higher in urban habitats during all months; June ($P <0.0001$), July ($P <0.0001$), August ($P <0.0001$), September ($P = 0.0005$), and October ($P <0.0001$) which indicates that their preference for urban habitats is not dependent on season. There was no difference in numbers of *P. regina* found during June ($P = 1.0000$), July ($P = 0.4911$), September ($P = 0.3608$) or October ($P = 0.5173$). In August, *P. regina* showed higher adult numbers in rural habitats ($P = 0.0195$). This may indicate different habitat preferences during the season, or a movement of flies from one habitat to another during August. Though Sarcophagidae adult populations were low throughout the study, (June: $P = 0.1905$; August: $P = 1.0000$; September: $P = 1.0000$; October: $P = 0.4330$), though in July there were larger numbers collected in rural habitats ($P = 0.0120$) which may indicate a preference for rural habitats or larger numbers of Sarcophagidae being produced in the rural habitat.

For Histeridae, higher numbers were collected in rural habitats in June ($P = 0.0068$) and July ($P = 0.0064$). However, higher numbers were collected in urban habitats from August ($P = 0.0589$) and September ($P = 0.0064$), which might indicate a different preference early and later in the season. Very low numbers were collected in October ($P = 0.5594$), which is likely late in the season for the beetles which would cause lower populations to be active.

Isopoda showed higher numbers in urban habitats during all months with June ($P = 0.0002$) and September ($P = 0.0488$) being statistically significant and no statistical significance in July ($P = 0.3185$), August ($P = 0.1113$), and October ($P = 0.0557$). Differences in preference might be expected due to weather changes, with increased moisture being preferred by the Isopods, but no difference was seen in this study.

Table 3.12.
Numbers of adult Diptera, Histeridae, and Isopoda found during each month of sampling in each habitat by month combined for 2011 and 2012.

	June		July		August		September		October	
Taxa	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
C. macellaria	2	8	20	24	71	105	62	56	30	20
L. coeruleiviridis	71	80	36	31	4	30	29	13	152	89
L. illustris	97	105	108	67	17	35	23	15	5	3
L. sericata	6	211	12	161	3	216	1	167	13	271
P. regina	20	20	68	48	100	34	35	54	46	65
Sarcophagidae	22	12	19	5	19	19	5	5	2	5
Histeridae	56	10	37	6	27	62	10	41	5	8
Isopoda	5	278	2	42	0	99	2	13	3	13

3.6 Differences between Decomposition Stages

An ANOVA test was conducted to determine if there were any statistically significant differences between the numbers of arthropods that were found in each decomposition stage to determine if taxa were more likely to be found in certain decomposition stages. Only taxa with over 100 specimens collected were analyzed.

3.6.1 Adults

Most adult taxa showed a statistically significant difference: *C. macellaria* ($P < 0.0001$); *L. coeruleiviridis* ($P < 0.0001$); *L. illustris* ($P < 0.0001$); *L. sericata* (P

<0.0001); *P. regina* (P <0.0001); and Sarcophagidae (P <0.0001). While *C. rufifacies* did not show a statistically significant difference at $P = 0.0692$. For Histeridae ($P = 0.0001$) and Isopoda ($P = 0.0018$) there were also statistically significant differences between decomposition stages. Table 3.13 shows the mean number of Diptera adults, Histeridae beetles and Isopods that were found in each decomposition stage.

Some taxa were most commonly found in the fresh stage including; *L. coeruleiviridis* and Isopoda. Adults of *L. coeruleiviridis* were found to be early arrivers in this study, which would be helpful in determining the postmortem interval in an investigation. These flies likely arrived quickly after carcasses were placed to oviposit and allow their larvae to feed on the carcass before other species arrived. It is unknown why numbers of Isopoda were higher during the fresh stage of decomposition; the Isopods could be taking advantage of the carcass as a food or moisture source.

For the bloat stage, numbers of adult *L. sericata* and Sarcophagidae adults were higher. Though more adult *L. sericata* arrived during the bloat stage than the fresh stage, numbers of *L. sericata* were still high during the fresh stage and active decomposition stage. While the higher numbers in the bloat stage may show an increased attraction during that stage, the carcass was still highly attractive to adult *L. sericata* in the fresh and active decomposition stages as well. As Sarcophagidae adults larviposit, instead of oviposit skipping the time needed for an egg to eclose, Sarcophagids can arrive later in decomposition without losing their advantage of less time in development before they can begin feeding.

During the active decomposition stage, numbers of *L. illustris* and *P. regina* were high indicating that this stage may be particularly attractive to these species. The numbers of *L. illustris* and *P. regina* that were collected during each decomposition stage was similar, which may indicate that these species have similar preferences for decomposition stage and similar niche usage.

Though not statistically significant, Adult *C. rufifacies* had larger numbers in the advanced stage of decomposition, which is consistent with the larvae being able to facultatively predate on other Diptera larvae, so it is less important to feed on the

carcass before other species, and it may even be beneficial to wait until other species are already feeding on a carcass. The numbers of Histeridae were also highest during the advanced stage, which is consistent with their feeding on Diptera larvae, as large numbers of larvae would be present during the advanced decomposition stage, as well as during the active decomposition stage which had the next largest amount of Histeridae beetles.

Numbers of adult Diptera were consistently lower in the dry remains stage, which is likely due to the lack of decomposing matter left on which to oviposit or feed upon. Adult flies that would oviposit when insufficient amounts of flesh are left will be unlikely to have their offspring complete their life cycle and survive. There was some variation on the decomposition stage that had the largest population for particular fly species, which could indicate a preference for decomposition stage or the particular volatiles expressed at that stage.

3.6.2 Larvae

For larvae all taxa showed a statistically significant difference: *C. rufifacies* (P <0.0001), *C. macellaria* ($P = 0.0032$), *L. coeruleiviridis* (P <0.0001), *L. illustris* (P <0.0001), *L. sericata* (P <0.0001), *P. regina* (P <0.0001), and Sarcophagidae (P <0.0001). Table 3.14 shows the mean number of Diptera larvae that were found in each decomposition stage.

Low numbers of Diptera larvae were collected during the fresh stage, as most adult flies have just begin to oviposit during this stage and most of the time will be spent in the egg stage and early larval instars. As only third instar Calliphoridae are able to be visually identified to species, Table 15 only shows numbers of third instar Calliphoridae. Sarcophagidae are visually identifiable to family without reaching the third instar.

For *C. macellaria* the highest number of third instars was collected during the active decomposition stage. Most species had their highest larval numbers during the

advanced decomposition stage, including: *C. rufifacies*, *L. coeruleiviridis*, *L. illustris*, *L. sericata*, *P. regina*, and Sarcophagidae. The active and advanced decomposition stages would have the largest number of larvae as during these stages as the adult flies have had time to discover and oviposit on the carcass, and the larvae have had time to develop through their egg stage and begin feeding on the carcass, before the carcass has been reduced to bone and other inedible portions.

During the dry remains stage low numbers of dipteran larvae were collected for a few species, including: *C. rufifacies*, *L. coeruleiviridis*, *L. illustris*, and *L. sericata*. As there is little flesh left on the carcass at this time, most of the larvae should be migrating from the carcass to begin pupation or will risk running out of food before completing their development.

Table 3.13.
Mean number of Adult Diptera, Histeridae and Isopoda found per carcass for each sampling date for each of the decomposition stages. Means were measured with Tukey HSD All-Pairwise Comparisons Test, $\alpha = 0.05$. Species means with the same letter were not statistically different from each other.

Taxa	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
C. macellaria Adults	0.0862 CD	0.6803 AB	1.0667 A	0.5528 BC	0.0000 D
C. rufifacies Adults	0.0000 A	0.0544 A	0.0727 A	0.3769 A	0.0000 A
L. coeruleiviridis Adults	2.0776 A	0.9932 B	0.6242 B	0.0503 C	0.0000 C
L. illustris Adults	0.3276 BC	0.7007 AB	1.2424 A	0.5327 BC	0.0000 C
L. sericata Adults	1.0259 BC	2.9932 A	2.1333 AB	0.4774 C	0.0360 C
P. regina Adults	0.1552 C	0.7891 AB	1.3636 A	0.5075 BC	0.0000 C
Sarcophagidae Adults	0.1638 AB	0.3129 A	0.1939 A	0.0553 B	0.0000 B
Histeridae	0.0000 C	0.2585 BC	0.4242 AB	0.6030 A	0.3063 ABC
Isopoda	2.0948 A	0.6054 AB	0.4424 B	0.1709 B	0.1532 B

Table 3.14.
Mean number of Diptera larvae found per carcass for each sampling date for each of the decomposition stages. Means were measured with Tukey HSD All-Pairwise Comparisons Test, $\alpha = 0.05$. Species means with the same letter were not statistically different from each other.

Taxa	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
C. macellaria Larvae	0.0000 B	0.3265 AB	0.6364 A	0.6080 A	0.0000 B
C. rufifacies Larvae	0.0000 B	0.0000 B	0.1273 B	1.1457 A	0.0811 B
L. coeruleiviridis Larvae	0.1379 B	0.4694 B	4.7455 A	5.9146 A	0.3243 B
L. illustris Larvae	0.0000 B	0.0000 B	0.4667 A	0.5578 A	0.0180 B
L. sericata Larvae	0.0345 C	0.2109 C	3.4606 B	5.2111 A	0.0090 C
P. regina Larvae	0.0000 B	0.5170 B	1.6242 A	2.1156 A	0.0000 B
Sarcophagidae Larvae	0.0000 B	0.0000 B	0.4909 A	0.5829 A	0.0000 B

3.7 Decomposition Stages

3.7.1 Fresh Decomposition Stage

During the fresh stage of decomposition, which begins at death and continues until bloat is visible (Anderson and VanLaerhoven, 1996), Calliphoridae adults were present including: *C. vicina* with 2 specimens, *C. vomitoria* with 3 specimens, *C. macellaria* with 10 specimens, *L. coeruleiviridis* with 241 specimens, *L. illustris* with 38 specimens, *L. sericata* with 119 specimens, and *P. regina* with 18 specimens (Table 3.15). No specimens of adult *C. rufifacies* were collected during the fresh stage.

For larvae during the fresh stage of decomposition, there were individuals of Caliphoridae including; 16 *L. coeruleiviridis* and 4 *L. sericata* (Table 3.16). No larval specimens of *C. vicina*, *C. vomitoria*, *C. rufifacies*, *C. macellaria*, *L. illustris*, *P. regina* were found during the fresh decomposition stage. As only third instar Calliphorids can be sight identified to species, most specimens would not have had time to develop to the third instar during the fresh stage.

For Sarcophagidae 19 adults were found in this stage, though no Sarcophagidae larvae were collected (Table 3.16). This is consistent with the findings of Voss et al. (2011), who found that Sarcophagidae generally don't larviposit during the fresh stage.

There were no beetles in the family Histeridae found on the carcasses during the fresh stage (Table 3.15). As the Histeridae are predators of dipteran larvae, the low numbers of dipteran larvae present during the fresh stage would be one reason for Histeridae not to be present during the fresh stage of decomposition.

3.7.2 Bloat Stage

During the bloat stage of the carcass, which characterized by gas accumulating that causes bloating of the abdomen (Early and Goff, 1986), adult Calliphoridae were present: 1 *C. vicina*, 8 *C. rufifacies*, 100 *C. macellaria*, 146 *L. coeruleiviridis*, 103 *L.*

illustris, 440 *L. sericata*, and 116 *P. regina* (Table 3.15). No adult specimens of *C. vomitoria* were collected during the bloat stage, which may be due to low numbers present in the environment.

Larvae of Calliphoridae were also collected during the bloat stage including: 48 *C. macellaria*, 69 *L. coeruleiviridis*, 31 *L. sericata*, and 76 *P. regina* (Table 3.16). The greater numbers of third instars show that the Diptera larvae have had time to develop since the fresh stage.

For Sarcophagidae 46 adults were collected (Table 3.15). No Sarcophagidae larvae were collected in the bloat stage, while Voss et al. (2011) found that Sarcophagidae generally begin to larviposit late in the bloat stage. It is possible that Sarcophagidae had begun to larviposit during the bloat stage in this study, but that the larvae were not found or were on areas of the carcass that are difficult to sample. Due to the low number of Sarcophagidae larvae that would be expected on any particular carcass, it is possible that they were not collected in the samples taken.

Histeridae beetles were found 38 times on carcasses in bloat (Table 3.15). As Histeridae feed on dipteran larvae, Histerids would come to the carcasses during the bloat stage when Diptera larvae were present in larger numbers than during the fresh stage.

3.7.3 Active Decomposition Stage

In the active decomposition stage, which begins when the carcass has deflated after the gases contained in the abdomen escape (Goff, 2009; Anderson and VanLaerhoven, 1996), the number of Calliphoridae adults collected was: 2 *C. vicina*, 3 *C. vomitoria*, 12 *C. rufifacies*, 176 *C. macellaria*, 103 *L. coeruleiviridis*, 205 *L. illustris*, 352 *L. sericata*, and 225 *P. regina* (Table 3.15). For Calliphoridae larvae found in the active stage there were: 2 *C. vicina*, 1 *C. vomitoria*, 21 *C. rufifacies*, 105 *C. macellaria*, 783 *L. coeruleiviridis*, 77 *L. illustris*, 571 *L. sericata*, and 268 *P. regina* (Table 3.16).

For Sarcophagidae there were 32 adults found during the active decomposition stage (Table 3.15). There were 81 Sarcophagidae larvae collected during the active stage (Table 3.16). The presence of Sarcophagidae larvae is consistent with Voss et al. (2011), that Sarcophagidae adults begin larvipositing late in the bloat stage and early active decomposition.

Seventy specimens of Histeridae were collected during active decomposition (Table 3.15). The increased number of Histeridae is consistent with the increased availability of Diptera larvae as prey.

3.7.4 Advanced Decomposition Stage

In the advanced decomposition stage, after much of the flesh has been removed from the carcass by larval feeding (Anderson and VanLaerhoven, 1996), the numbers of Calliphoridae adults found was: 75 *C. rufifacies*, 110 *C. macellaria*, 10 *L. coeruleiviridis*, 106 *L. illustris*, 95 *L. sericata*, and 101 *P. regina* (Table 3.15). Calliphoridae larvae were collecting during the advanced decomposition stage including: 1 *C. vicina*, 16 *C. vomitoria*, 121 *C. macellaria*, 228 *C. rufifacies*, 1,177 *L. coeruleiviridis*, 111 *L. illustris*, 1,037 *L. sericata*, and 421 *P. regina* (Table 3.16).

For Sarcophagidae adults 11 specimens were collected in the advanced stage (Table 3.15). For Sarcophagidae larvae there were 116 found during the advanced decomposition stage (Table 3.16).

There were 120 Histeridae adults collected during the advanced decomposition stage (Table 3.15), which is the most Histeridae found in any decomposition stage which is consistent with the greater number of Diptera larvae as prey. One sexton beetle in the genus *Nicrophorus* was seen during the advanced stage. *Nicrophorus* generally use small carcasses, such as birds and mice; therefore the carcasses used in this study were likely too big for these beetles to use for reproduction.

3.7.5 Dry Remains Stage

In the dry stage, where very little tissue is left on the carcass (Anderson and VanLaerhoven, 1996), 4 specimens of *L. sericata* adults were collected (Table 3.15). For Calliphoridae larvae there were 9 *C. rufifacies*, 36 *L. coeruleiviridis*, 2 *L. illustris*, and 1 *L. sericata* collected during the dry stage (Table 3.16).

Thirty four specimens on Histeridae were collected during the dry stage (Table 3.15). This is the lowest number of Histeridae found in any stage except the fresh stage, which is consistent with the reduced number of larvae available in the dry remains stage. As the larvae migrate in preparation for pupariation, there would be less prey available for the Histeridae.

Fewer Isopods were seen in the dry remains stage than any other stage, the most were found in fresh decomposition and progressively fewer were collected in each following stage (Table 3.18). It is possible that this indicates that the Isopods prefer fresher carcasses. If the Isopoda were using the carcass as a source of moisture, it would seem that there would be increasing numbers through the active decomposition stage where moisture is seeping from the carcass, and then see a drop in numbers as the carcass dries out in advanced decomposition and the dry remains stage. If the Isopods were only using the carcass as a habitat, a reduction in numbers would not necessarily be expected throughout the decomposition stages.

Small numbers of unidentified early instar dipteran larvae were found in the hooves during the dry remains stage; after all other larvae had left the carcass as was also seen by Martinez et al. (2007). It may be that these larvae were seeking any carcass material that was left, or sheltering in areas that still contained moisture. Table 3.17 includes insects other than Diptera and Coleoptera that were collected during each decomposition stage.

Table 3.15.
Number of Diptera and Coleoptera adults from all study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Diptera								
	Calliphoridae							
		Calliphora						
			Calliphora vicina	2	1	2	0	0
			Calliphora vomitoria	3	0	3	0	0
		Chrysomya						
			Chrysomya rufifacies	0	8	12	75	0
		Cochliomyia						
			Cochliomyia macellaria	10	100	176	110	0
		Lucilia						
			Lucilia coeruleiviridis	241	146	103	10	0
			Lucilia illustris	38	103	205	106	0
			Lucilia sericata	119	440	352	95	4
		Phormia						
			Phormia regina	18	116	225	101	0
	Drosophilidae							
		Drosophila		1	1	0	0	0
	Fanniidae							
		Fannia		0	0	1	0	0
	Muscidae			6	18	38	11	0
	Sarcophagidae			19	46	32	11	0
	Ulitidae			0	2	0	0	0
Coleoptera								
	Carabidae							
			Unidentified species	1	1	0	0	0
		Cicindela		0	1	0	0	0
	Cleridae							
		Necrobia						
			Necrobia rufipes	0	0	1	1	0
	Dermestidae			3	0	10	15	31
	Histeridae			0	38	70	120	34
	Nitidulidae			0	6	10	5	1
	Scarabaeidae							
		Onthophagus						
			Onthophagus hecate	4	2	5	6	0
		Cotinis						
			Cotinis nitida	0	0	0	2	0
	Silphidae							
		Necrophila						
			Necrophila americana	8	19	18	14	2
		Nicrophorus		0	0	0	1	0
		Oiceoptoma						
			Oiceoptoma inaequale	0	8	1	0	0
			Oiceoptoma noveboracense	0	3	7	3	0
	Staphylinidae							
			Unidentified species	14	15	40	122	57
			Creophilus maxillosus	0	1	13	54	9

Table 3.16.
Number of larvae from all study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Diptera								
	Calliphoridae							
		Calliphora						
			Calliphora vicina	0	0	2	1	0
			Calliphora vomitoria	0	0	1	16	0
		Chrysomya						
			Chrysomya rufifacies	0	0	21	228	9
		Cochliomyia						
			Cochliomyia macellaria	0	48	105	121	0
		Lucilia						
			Lucilia coeruleiviridis	16	69	783	1177	36
			Lucilia illustris	0	0	77	111	2
			Lucilia sericata	4	31	571	1037	1
		Phormia						
			Phormia regina	0	76	268	421	0
	Fanniidae							
		Fannia		0	0	1	15	53
	Sarcophagidae			0	0	81	116	0
Coleoptera								
	Carabidae			2	0	1	0	0
	Dermestidae			0	2	1	1	5
	Silphidae			0	0	2	0	1

Table 3.17.
Number of other insect adults from all study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Dermaptera								
	Forficulidae							
		Forficula						
			Forficula auricularia	0	1	0	0	0
Hemiptera								
	Anthocoridae							
		Orius		1	3	2	0	0
	Nabidae			0	0	1	0	0
	Pentatomidae			0	0	5	4	5
Hymenoptera								
	Apidae							
		Apis						
			Apis mellifera	0	2	1	2	0
		Xylocopa		0	1	1	0	0
	Halictidae			0	0	0	1	0
	Vespidae							
		Dolichovespula						
			Dolichovespula maculata	0	1	1	0	0
		Polistes		0	0	0	1	0
		Vespula		32	14	16	6	2
Lepidoptera								
	Hesperiidae							
		Ancyloxypha	*Ancyloxypha numitor*	0	0	1	1	0
		Epargyreus	*Epargyreus clarus*	0	1	4	6	1
		Phyciodes	*Phyciodes tharos*	0	0	1	2	1
	Lycaenidae							
		Cupido	*Cupido comyntas*	0	0	5	3	0
	Nymphalidae							
		Chlosyne	*Chlosyne nycteis*	0	0	2	0	1
		Danaus	*Danaus plexippus*	0	0	2	0	0
		Junonia	*Junonia coenia*	0	6	5	8	0
		Poanes	*Poanes zabulon*	0	1	0	0	0
		Speyeria	*Speyeria cybele*	0	1	1	5	0
Orthoptera								
	Acrididae			0	1	2	6	0
	Gryllidae							
		Gryllus		12	9	14	1	1

Table 3.18.
Number of non-insects from all study sites during the five decomposition stages.

Taxa	Common Name	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Araneae	Spider	1	0	3	1	0
Chilopoda	Centipede	1	0	0	0	0
Diplopoda	Millipede	18	3	13	0	0
Gastropoda	Slug	32	2	4	1	1
Isopoda	Woodlouse	243	89	73	34	17
Oligochaeta	Earthworm	0	1	1	0	0
Opiliones	Harvestman	0	0	1	0	0

3.8 Decomposition Stages and Habitat

No larvae of Calliphora species were collected during the active decomposition stage in the urban habitats, though these species were found during that stage in the rural habitats (Table 3.21 and 3.22). During the advanced stage *C. vicina* larvae were present in urban habitats but not rural habitats. In both rural and urban habitats, *C. rufifacies* larvae were found during the active decomposition stage and all stages that followed. Larvae of *C. macellaria* were found during and after the bloat stage in the rural habitats and during and after the active stage in the urban habitats. In urban habitats, *L. coeruleiviridis* larvae were seen in all decomposition stages. In the rural habitats, *L. coeruleiviridis* larvae were seen during the bloat stages and all subsequent stages. Larvae of *L. illustris* were collected beginning in the active decomposition stage in both rural and urban environments and were found into the dry stage. For *L. sericata*, larvae were collected beginning during the bloat stage until the dry stage in the rural habitats and from the fresh stage to the advanced decomposition stage in the urban habitats. In both the rural and urban habitats *P. regina* was collected from the bloat stage until the advanced decomposition stage.

Fannia larvae were collected earlier in decomposition at the rural habitats, starting in active decomposition and going until dry decomposition while in urban habitats the larvae were collected in advanced and dry decomposition (Table 3.21 and 3.22).

Carabidae larvae were collected in fresh and active decomposition in the rural habitats and not collected in the urban habitats (Table 3.21 and 3.22). In rural habitats Dermestidae larvae were found in the bloat and dry stages of decomposition, while in the urban habitats the larvae were found from the bloat stage to the dry stage. Silphidae larvae were collected in the active decomposition stage in both the rural and urban habitats, and additionally in the dry stage in the rural habitats.

Table 3.19 through 3.26 show the particular taxa found in each habitat type for each decomposition stage. Though most of these taxa were not found in numbers that were able to be statistically analyzed with confidence, the tables are presented to show

presence of arthropods that may be useful in future studies or in investigations, as successional data can be used when postmortem intervals cannot be calculated due to lack of dipteran larvae to determine degree days from.

Table 3.19.
Number of Diptera and Coleoptera adults from rural study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Diptera								
	Calliphoridae							
		Calliphora						
			Calliphora vicina	0	1	0	0	0
			Calliphora vomitoria	1	0	1	0	0
		Chrysomya						
			Chrysomya rufifacies	0	7	2	7	0
		Cochliomyia						
			Cochliomyia macellaria	8	48	71	56	0
		Lucilia						
			Lucilia coeruleiviridis	140	86	41	3	0
			Lucilia illustris	18	69	96	44	0
			Lucilia sericata	9	12	7	3	0
		Phormia						
			Phormia regina	4	63	127	60	0
	Drosophilidae							
		Drosophila		0	0	0	0	0
	Fanniidae							
		Fannia		0	0	0	0	0
	Muscidae			5	9	21	6	0
	Sarcophagidae			9	26	21	7	0
	Ulitidae			0	2	0	0	0
Coleoptera								
	Carabidae							
			Unidentified species	0	0	0	0	0
		Cicindela		0	1	0	0	0
	Cleridae							
		Necrobia						
			Necrobia rufipes	0	0	0	1	0
	Dermestidae			0	0	1	3	11
	Histeridae			0	27	32	61	15
	Nitidulidae			0	4	7	3	1
	Scarabaeidae							
		Cotinis						
			Cotinis nitida	0	0	0	0	0
		Onthophagus						
			Onthophagus hecate	4	2	1	3	0
	Silphidae							
		Necrophila						
			Necrophila americana	8	19	18	9	2
		Nicrophorus		0	0	0	1	0
		Oiceoptoma						
			Oiceoptoma inaequale	0	8	1	0	0
			Oiceoptoma noveboracense	0	2	4	2	0
	Staphylinidae							
			Unidentified species	5	6	9	31	44
			Creophilus maxillosus	0	0	4	31	8

Table 3.20.
Number of Diptera and Coleoptera adults from urban study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Diptera								
	Calliphoridae							
		Calliphora						
			Calliphora vicina	2	0	2	0	0
			Calliphora vomitoria	2	0	2	0	0
		Chrysomya						
			Chrysomya rufifacies	0	1	10	68	0
		Cochliomyia						
			Cochliomyia macellaria	2	52	105	54	0
		Lucilia						
			Lucilia coeruleiviridis	101	60	62	7	0
			Lucilia illustris	20	34	109	62	0
			Lucilia sericata	110	428	345	92	4
		Phormia						
			Phormia regina	14	53	98	41	0
	Drosophilidae							
		Drosophila		1	1	0	0	0
	Fanniidae							
		Fannia		0	0	1	0	0
	Muscidae			1	9	17	5	0
	Sarcophagidae			10	20	11	4	0
	Ulitidae			0	0	0	0	0
Coleoptera								
	Carabidae							
			Unidentified species	1	1	0	0	0
		Cicindela		0	0	0	0	0
	Cleridae							
		Necrobia						
			Necrobia rufipes	0	0	1	0	0
	Dermestidae			3	0	9	12	20
	Histeridae			0	11	38	59	19
	Nitidulidae			0	2	2	2	0
	Scarabaeidae							
		Onthophagus						
			Onthophagus hecate	0	0	4	3	0
		Cotinis						
			Cotinis nitida	0	0	0	2	0
	Silphidae							
		Necrophila						
			Necrophila americana	0	0	0	5	0
		Nicrophorus						
		Oiceoptoma						
			Oiceoptoma inaequale	0	0	0	0	0
			Oiceoptoma noveboracense	0	1	3	1	0
	Staphylinidae							
			Unidentified species	9	9	31	91	13
			Creophilus maxillosus	0	1	9	23	1

Table 3.21.
Number of larvae from rural study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Diptera								
	Calliphoridae							
		Calliphora						
			Calliphora vicina	0	0	2	0	0
			Calliphora vomitoria	0	0	1	8	0
		Chrysomya						
			Chrysomya rufifacies	0	0	3	145	4
		Cochliomyia						
			Cochliomyia macellaria	0	48	33	70	0
		Lucilia						
			Lucilia coeruleiviridis	0	51	358	577	20
			Lucilia illustris	0	0	39	44	1
			Lucilia sericata	0	11	134	347	1
		Phormia						
			Phormia regina	0	46	125	206	0
	Fanniidae							
		Fannia		0	0	1	9	34
	Sarcophagidae			0	0	53	75	0
Coleoptera								
	Carabidae			2	0	1	0	0
	Dermestidae			0	1	0	0	3
	Silphidae			0	0	1	0	1

Table 3.22.
Number of larvae from urban study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Diptera								
	Calliphoridae							
		Calliphora						
			Calliphora vicina	0	0	0	1	0
			Calliphora vomitoria	0	0	0	8	0
		Chrysomya						
			Chrysomya rufifacies	0	0	18	83	5
		Cochliomyia						
			Cochliomyia macellaria	0	0	72	51	0
		Lucilia						
			Lucilia coeruleiviridis	16	18	425	600	16
			Lucilia illustris	0	0	38	67	1
			Lucilia sericata	4	20	437	690	0
		Phormia						
			Phormia regina	0	30	143	215	0
	Fanniidae							
		Fannia		0	0	0	6	19
	Sarcophagidae			0	0	28	41	0
Coleoptera								
	Carabidae			0	0	0	0	0
	Dermestidae			0	1	1	1	2
	Silphidae			0	0	1	0	0

Table 3.23.
Number of other insects from rural study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Dermaptera								
	Forficulidae							
		Forficula	*Forficula auricularia*	0	0	0	0	0
Hemiptera								
	Anthocoridae							
		Orius		0	0	1	0	0
	Nabidae			0	0	0	0	0
	Pentatomidae			0	0	4	3	4
Hymenoptera								
	Apidae							
		Apis	*Apis mellifera*	0	2	1	2	0
		Xylocopa		0	0	0	0	0
	Halictidae			0	0	0	1	0
	Vespidae							
		Dolichovespula						
			Dolichovespula maculata	0	1	1	0	0
		Polistes		0	0	0	0	0
		Vespula		24	2	4	3	0
Lepidoptera								
	Hesperiidae							
		Ancyloxypha	*Ancyloxypha numitor*	0	0	1	1	0
		Epargyreus	*Epargyreus clarus*	0	1	4	6	1
		Poanes	*Poanes zabulon*	0	1	0	0	0
	Lycaenidae							
		Cupido	*Cupido comyntas*	0	0	5	3	0
	Nymphalidae							
		Chlosyne	*Chlosyne nycteis*	0	0	2	0	1
		Danaus	*Danaus plexippus*	0	0	1	0	0
		Junonia	*Junonia coenia*	0	5	5	8	0
		Phyciodes	*Phyciodes tharos*	0	0	1	2	1
		Speyeria	*Speyeria cybele*	0	1	1	5	0
Orthoptera								
	Acrididae			0	1	1	6	0
	Gryllidae							
		Gryllus		1	0	0	0	0

Table 3.24.
Number of other insects from urban study sites during the five decomposition stages.

Order	Family	Genus	Species	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Dermaptera								
	Forficulidae							
		Forficula						
			Forficula auricularia	0	1	0	0	0
Hemiptera								
	Anthocoridae							
		Orius		1	3	1	0	0
	Nabidae			0	0	1	0	0
	Pentatomidae			0	0	1	1	1
Hymenoptera								
	Apidae							
		Apis						
			Apis mellifera	0	0	0	0	0
		Xylocopa		0	1	1	0	0
	Halictidae							
	Vespidae							
		Dolichovespula						
			Dolichovespula maculata	0	0	0	0	0
		Polistes		0	0	0	1	0
		Vespula		8	12	12	3	2
Lepidoptera								
	Hesperiidae							
		Ancyloxypha	*Ancyloxypha numitor*	0	0	0	0	0
		Epargyreus	*Epargyreus clarus*	0	0	0	0	0
		Phyciodes	*Phyciodes tharos*	0	0	0	0	0
	Lycaenidae							
		Cupido	*Cupido comyntas*	0	0	0	0	0
	Nymphalidae							
		Chlosyne	*Chlosyne nycteis*	0	0	0	0	0
		Danaus	*Danaus plexippus*	0	0	1	0	0
		Junonia	*Junonia coenia*	0	1	0	0	0
		Poanes	*Poanes zabulon*	0	0	0	0	0
		Speyeria	*Speyeria cybele*	0	0	0	0	0
Orthoptera								
	Acrididae			0	0	1	0	0
	Gryllidae							
		Gryllus		11	9	14	1	1

Table 3.25.
Number of non-insects from rural study sites during the five decomposition stages.

Taxa	Common Name	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Araneae	Spider	1	0	3	0	0
Chilopoda	Centipede	1	0	0	0	0
Diplopoda	Millipede	3	2	4	0	0
Gastropoda	Slug	17	0	0	0	0
Isopoda	Woodlouse	2	4	2	1	2
Oligochaeta	Earthworm	0	0	0	0	0
Opiliones	Harvestman	0	0	1	0	0

Table 3.26.
Number of non-insects from urban study sites during the five decomposition stages.

Taxa	Family	Fresh Stage	Bloat Stage	Active Stage	Advanced Stage	Dry Remains Stage
Araneae	Spider	0	0	0	1	0
Chilopoda	Centipede	0	0	0	0	0
Diplopoda	Millipede	15	1	9	0	0
Gastropoda	Slug	15	2	4	1	1
Isopoda	Woodlouse	241	85	71	33	15
Oligochaeta	Earthworm	0	1	1	0	0
Opiliones	Harvestman	0	0	0	0	0

3.9 Temperatures

Temperature data were analyzed with ANOVA and showed a statistical difference between sites for all measurements of temperature. Ambient temperature was higher in rural environments ($P = 0.0018$) with a mean of 30.7°C for rural environments and 28.9°C for urban environments. The temperature for the body surface ($P < 0.0001$) had a mean of 32.6°C for rural habitats and 29.1°C for urban habitats. In rural environments the ground surface temperature ($P < 0.0001$) had a mean of 30.0°C and the urban environments had a mean of 27.2°C. The mean temperature of the ground body interface ($P < 0.0001$), taken directly under the carcass, had a mean of 30.8°C in the rural environments and a mean of 27.8°C in the urban environments. The mean of the internal temperature for the pig carcasses ($P < 0.0001$) was 33.0°C in the rural environments and 28.8°C in the urban environments. The rural environments had a mean temperature of 26.3°C for 10 cm under the ground surface while urban environments had a mean temperature of 24.5°C ($P = 0.0003$). Measurement of temperature 10 cm under the ground was lower than all other temperature variables taken. The maggot mass temperature ($P = 0.0002$) had a mean of 37.1°C in the rural habitats and a mean of 32.8°C in the urban habitats. It is possible that the rural areas had statistically higher temperatures due to fewer trees and structures around to shade the carcasses during periods of the day. Means of temperatures sampled at the sites were compared with Tukey HSD All-Pairwise Comparisons Test, $\alpha = 0.05$. (Table 3.27)

When delta temperatures were taken from the difference in temperatures from ambient temperatures taken at the scene and temperatures at the weather station at the Purdue University Airport in West Lafayette, Indiana, there was a statistically significant difference between rural and urban temperatures for both years combined ($P < 0.0001$). There was also a significant difference between the delta temperature between the weather station and the ambient temperature in rural and urban sites in 2011 ($P < 0.0001$) and 2012 ($P < 0.0001$). For 2011 and 2012 combined the rural

Table 3.27.
Mean temperature for each temperature variable. Measured with Tukey HSD All-Pairwise Comparisons Test, $\alpha = 0.05$. Means followed by the same letter were not statistically different from each other.

Temperature Variable	Mean	Homogeneous Groups
Maggot Mass	34.738	A
Internal	30.961	B
Body Surface	30.849	B
Ambient	29.788	BC
Under the Body	29.267	C
Ground	28.574	C
Ten cm under the Ground	25.353	D

sites had a mean of 5°C and the urban sites had a mean of 3°C for 2011 and 2012 combined. For 2011 the mean delta temperature for rural sites was 4°C and for urban sites it was 2°C. The mean delta temperatures for 2012 was 5°C for rural sites and 3°C for urban sites. Due to the error for the thermometers and the way in which the ambient temperatures were measured, which only excluded direct radiation from the sun, this difference is unlikely to be a real difference in temperature and would likely have little effect on the arthropods.

The delta temperature between the ambient temperature and the ground surface temperature showed no statistical difference ($P = 0.6265$), with a mean of 2°C for both rural and urban sites (Table 3.28). For the delta temperature of the ambient temperature and the temperature 10 cm under the ground was not statistically significant ($P = 0.5600$) with a mean of 5°C for both rural and urban sites. The delta temperature for the ambient temperature and the ground-body interface was statistically significant ($P = 0.0109$) with a mean of 3°C for rural habitats and 4°C for urban habitats. This was due to slightly cooler mean ground-body interface temperatures in the urban habitats. For the delta temperature of the body surface and the ambient temperature there was a statistical difference ($P = 0.0081$) with rural sites having a mean of 4°C and urban sites having a mean of 3°C. The delta temperature for the ambient temperature and the maggot mass temperature was statistically significant ($P = 0.0351$) with a mean of 5°C for the rural habitats and 4°C for the urban habitats. For the delta temperature of the ambient and internal temperature there was no statistical difference ($P = 0.0744$) with a mean temperature of 4°C for both rural and urban sites.

Carcasses in the rural areas were checked earlier in the day, closer to midday than urban areas due to how the locations had to be situated. Though, urban sites were never checked after sundown. Weather data checked from the weather station at Purdue University Airport, West Lafayette, Indiana generally showed an increase in temperature until sundown. The urban areas tended to have more lush green plants than the rural habitats. The rural areas had ground that felt drier than the ground

in the urban areas. It is likely that the urban areas would retain more moisture than the rural areas due to increased tree cover and shade from buildings. Agricultural fields in the Midwest are also often tile drained to remove excess moisture from the soil subsurface (Fausey et al., 1995).

Joy et al. (2006) found that maggot mass temperatures were statistically higher than ambient temperature, but only after there were larvae on the carcass that had reached the third instar. In this study, maggot mass temperatures were not measured until at least some of the larvae had reached the third instar. In this study the mean maggot mass temperature was higher than ambient temperature, as well as all other temperature variables.

Delta temperatures were looked at for each month for 2011 and 2012 (Table **??**). For monthly temperatures, June showed no statistical difference between 2011 and 2012 in the rural habitats ($P = 0.3498$) in delta temperatures for the ambient temperatures taken at each site and the weather station at the Purdue University Airport in West Lafayette, Indiana. For June for urban habitats there was a statistical difference between 2011 and 2012 ($P = 0.0001$) for the delta temperatures. For delta temperatures during July in the rural sites during 2011 and 2012 there was a statistical difference ($P = 0.0013$) and for urban sites there was a statistical difference between years ($P = 0.0007$). There was no statistical difference in the delta temperatures during August for the rural sites ($P = 0.4141$) or the urban sites ($P = 0.1544$) between years. For September the delta temperatures in the rural sites had no statistical difference ($P = 0.2180$) but urban sites showed a statistical difference ($P = 0.0003$). The delta temperatures for October were statistically different between 2011 and 2012 at the rural sites ($P = 0.0461$). There was no statistical difference between the delta temperature for October for the urban sites in 2011 and 2012. Table 29 shows delta temperatures of ambient temperatures taken at each site for 2011 and 2012 with temperatures taken at the weather station at the Purdue University Airport in West Lafayette, Indiana. This shows that for Diptera and other measured arthropods in this study, their preference for rural or urban habitats is not dependent

on temperature of the sites, but is likely due to other variables. For *L. sericata* this may be things such as the presence of trash and other materials that the larvae may feed on.

Despite the fact that 2011 and 2012 were climatically different, all Diptera adults were present in both years, except for *C. rufifacies* were was only collected in 2012. As the other dipteran taxa are not primarily tropical like *C. rufifacies* it is unlikely that small differences would make a much of a differences in their habits, so long as the temperature is above their minimum for activity. Small temperature differences would be important in measure growth rates of larval dipterans, but is less important for adult activity. For most Calliphoridae their minimum temperature for activity is 6°C or 10°C, depending on their preference for warm or cool seasons. The minimum temperature for *C. rufifacies* activity has been shown to be 13°C (Vogt, 1988). This species were also not normally present in central Indiana at the time of this study and thus had to migrate up from more southern locations.

Table 3.28.
Mean delta temperature for each temperature variable compared to ambient temperature for each site.

Sites	Ground Surface	10 cm Under the Ground	Ground-Body Interface	Body Surface	Maggot Mass	Internal
Rural Site 1	2.0	4.6	3.0	3.6	6.1	3.6
Rural Site 2	2.6	6.7	3.6	4.5	5.4	4.0
Rural Site 3	2.4	3.7	3.0	3.6	4.9	5.0
Rural Site 4	2.2	4.6	2.4	3.6	4.6	4.6
Urban Site 1	2.8	6.3	4.6	4.2	5.3	4.3
Urban Site 2	2.2	4.4	3.3	2.1	2.4	3.2
Urban Site 3	1.9	3.2	3.5	2.2	4.5	2.8
Urban Site 4	2.3	4.5	3.7	3.1	4.4	4.0

3.10 Precipitation

Precipitation amount was not statically different ($P = 0.0613$) for rural or urban environments. The mean amount for rural environments was 0.5 cm and the mean amount of urban environments was 0.4 cm. Though the standard deviation for the precipitation reading is 0.44 cm, therefore evaluation of the precipitation between

Table 3.29.
Mean delta temperature of each site during each sampling month for 2011 and 2012 for ambient temperature compared to temperatures taken at the weather station at the Purdue University Airport in West Lafayette, Indiana.

	June		July		August		September		October	
Site	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Rural Site 1	5.8	5.0	3.9	7.7	4.1	7.0	3.4	5.5	4.5	7.5
Rural Site 2	5.2	4.6	3.9	6.3	5.6	8.3	3.9	4.0	3.6	4.2
Rural Site 3	4.9	4.2	1.9	5.9	6.2	5.7	4.4	3.2	2.8	5.4
Rural Site 4	6.3	5.2	4.5	6.3	7.4	7.0	3.4	4.3	3.0	2.5
Urban Site 1	1.9	4.1	1.6	3.8	5.5	6.1	1.8	4.2	2.3	3.2
Urban Site 2	1.3	3.0	0.0	2.9	2.0	2.3	1.5	3.1	2.6	2.9
Urban Site 3	1.1	1.7	1.0	2.2	1.2	2.1	1.5	2.8	2.4	1.8
Urban Site 4	1.6	4.1	1.5	3.5	3.3	4.9	2.2	4.1	2.8	2.3

the environments is not useful. Though Huff and Changnon (1973) found higher precipitation in large urban cities, they did not find higher precipitation in smaller urban areas like Indianapolis, Indiana. They found that aerosols and thermal outputs from heavily industrialized areas can lead to increased precipitation during a storm (Huff and Changnon, 1973).

3.11 Increasing Urbanization

Between 1982 and 1997 there was a 34% increase in urban land in the United States, partially due to an increasing population (Alig et al., 2004). This increasing urbanization may cause increases in populations of species that are synathropic and prefer urban areas. Though, if species that prefer rural areas are able to utilize urban areas more, the species composition found in urban areas may change. Though urbanization is increasing, there is still a majority of the United States that is not urbanized and is rural, forested, reclaimed or undisturbed habitat. In 1997 in the contiguous United States, 5.2% of the total land area was urbanized (Alig et al., 2004).

4. CONCLUSIONS

Knowing preferences and behaviors of the insects associated with carcasses and human remains is imperative for entomology to be of use in criminal investigations. Crickets were seen to modify dipteran feeding holes and feed on the flesh of the carcass, causing damage that could be confused with antemortem or perimortem wounds. Confusing this feeding damage for antemortem or perimortem wounds could lead an investigation in the wrong direction as to what occurred, which would waste valuable time and effort or even lead to an incorrect conclusion or verdict in a crime. Therefore, information regarding postmortem feeding damage from arthropods and other animals is extremely important.

Preferences of arthropods for different habitat types can add valuable information to a forensic case. In this study, *L. sericata* was found to prefer urban habitats with both adults and larvae being collected statistically more often at the urban habitats. It is possible this preference is due to the ability of *L. sericata* to complete development in household waste, as well as animal carcasses. Though preferences for *L. sericata* were statistically significant and ecologically important, it is harder to assign forensic importance to this finding. It is possible this information could be useful in criminal investigations, if a large number of larvae on the remains are found to be *L. sericata* it could indicate that the remains had been in an urban location that allowed *L. sericata* access. Though, presence of *L. sericata* is not going to definitively show, in the geographic area of this study, that the remains had been located in an urban area. Presence of *L. sericata* will not exclude the possibility that death may have occurred in a rural environment. So remains found in a rural location with *L. sericata* would not necessarily indicate that the remains were moved from an urban location.

Because the life stages that will be moved when the remains are transported from one location to another are the eggs and larvae, preferences of the adult flies from the original location where the remains were located is important for trying to determine location. Therefore, adults collected on remains will primarily be from the habitat where the remains are located, but eggs and larvae may have been transported away from the original location. The difficulty is that *L. sericata* larvae were still found on the carcasses even in rural habitats. A small number of adults, or even one adult female, can produce a large number of larvae on the remains as a female can oviposit hundreds of eggs during one oviposition time. Therefore, caution must be used if *L. sericata* is going to be used as an indicator of movement of the remains. This is why it is particularly important to sample all life stages in a study, when trying to determine species preference in a particular habitat.

To gain addition information and see if *L. sericata* is located in the habitat the remains were found, it may be useful to sample the habitat where the remains were found using sticky traps to help determine the species of flies that are found at that location, in addition to sweep netting from around the remains at the scene.

Isopods were also found to have a preference for urban areas, though Isopods are not generally used in forensic cases and if they were to be used more research would have to be conducted to determine their preferences over time and in other geographical areas, to determine if their preference is associated with urban areas or particular microhabitat conditions. As the urban areas appeared to have moister soil and lusher plant cover, likely due to greater shade from trees and buildings and lack of tile drainage, it is possible Isopods' preference is just for habitats that are wetter. As Isopods are crustaceans that need to remain moist for proper breathing through their gills, it is possible that more specimens were just located in the urban habitats due to the moisture content.

For insects and other arthropods, behavior and habitat preferences may be different in different geographical areas, and information from the geographical area where an investigation occurs is important to make sure that the conclusions of the forensic

entomologist are applicable in that region. For example, in sheep producing regions such as in New Zealand and Britain, *L. sericata* is primarily found in rural areas and is associated with sheep strike. Were remains to be found in a rural area in the sheep producing regions of New Zealand or Britain, with specimens of *L. sericata*, it would not indicate that the remains had been originally in an urban area and moved to the rural location. However, in other areas such as central Indiana, remains that were found in a rural habitat, but from which the majority of specimens were of *L. sericata*, could indicate movement of the remains from an urban location to the location where the remains were found. Though, care has to be taken in assuming the remains were moved, even if the majority of larvae collected from the remains are *L. sericata*.

Chrysomya rufifacies is a species that has been only found occasionally in Indiana. In this study it was found only in 2012, not in 2011. This species may become more important in forensic investigations in this region as it moves northward. That *C. rufifacies* is facultatively predaceous is especially important in forensic investigations, as *C. rufifacies* could feed on the larvae that have arrived on remains earlier, closer to the time of death, causing the postmortem interval to be incorrectly estimated.

Most adult taxa showed a statistical different in numbers collected during different months. Adult *L. sericata* was the only taxa with high enough populations to analyze that showed no statistical difference between months. Adult *C. macellaria* had a peak population in August. For *L. coeruleiviridis* numbers peaked in June and October, which may indicate a preference for earlier and late in the season, though sampling would need to be conducted in earlier months of the year. June and July had the highest numbers of *L. illustris*, with a steep drop in number starting in August, which showed that the fly was less likely to be collected late in the season. While *P. regina* numbers were higher than the number of *L. illustis* in 2011, the numbers appeared to switch in 2012, showing higher numbers of *L. illustis* than *P. regina*. This may indicate that these two species utilize a similar niche, complete with each other, or have different weather and temperature requirements that shifted between

years. More information would need to be collected to determine what may be behind this.

Most adult Diptera, as well as the Histeridae and Isopoda, showed a difference in the numbers collected during different decomposition stages. Adult *L. coeruleiviridis* were most often found in the fresh stage, and was the most commonly collected Diptera in the fresh stage. This information could be helpful in an investigation for determining postmortem interval as *L. coeruleiviridis* would be some of the earliest flies arriving at the body. Adult *L. sericata* were collected most often in the bloat stage, which may indicate that this stage is the most attractive to this species, though they were still collected in high numbers in the active and fresh decomposition stages.

Most taxa had their highest larval numbers in the advanced stage, and the active decomposition stage had the next highest numbers. This is consistent with the adult flies having to find the carcass, oviposit, and for the larvae to have time to hatch and reach the third instar, and most larvae should have completed feeding and moved off the carcass to pupariate by the dry remains stage.

Consistent with their feeding on dipteran larvae, Histeridae were collected in increasing numbers from the bloat to the advanced decomposition stage, in which there were the most third instar dipterans. Isopods were also collected in higher numbers in the fresh stage, with lower numbers collected in each subsequent stage which may be due to how they are using the carcass as a resource, either for food, moisture, or habitat.

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