TECHNICAL NOTE

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Observations of Differential Decomposition on Sun Exposed v. Shaded Pig Carrion in Coastal Washington State

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ABSTRACT: The decomposition of two pig carcasses in close proximity to each other, one exposed and the other shaded, in a continuous woodland were observed and different rates of decay were recorded. The exposed pig decomposed much faster than the shaded pig, reaching a stable minimal weight two weeks before the shaded carcass. Bloat size, body weight, occurrence of blow fly larvae, and ambient air temperatures are compared. Maggot development appeared to be a major factor in the overall rate of decomposition and was affected primarily by different temperature patterns at the two sites.

KEYWORDS: forensic science, decomposition, postmortem interval entomology

Forensic entomology aids the legal/medical investigator in estimating the time elapsed since death (postmortem interval or PMI), or exposure to insect invasion, and can help determine if a corpse has been moved from one geographical area to another [*1–3*]. This however is predicated on the assumption that insects were not prevented from accessing the corpse soon after death or exposure [*4*]. Insects have also been used as toxicological indicators for the detection of controlled drugs present in tissues of the corpse (reviewed in Ref [*4*]).

Blow flies (Diptera: Calliphoridae) are the initial and major consumers of carrion and, hence, the most important entomological indicator in evaluating human decomposition [*5–7*]. Subsequent to the initial wave of blowflies, community structure of associated insects becomes important in PMI analysis. Determining the rate of larval development, and working backwards to estimate when blow fly eggs were laid (which may not necessarily correlate with time/date of death), forms the basis of estimating postmortem intervals. In addition to ambient air temperature affecting larval development [*8–11*], a number of other factors pertaining to temperature are also important. They include,

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maggot mass self-generating heat, and the rate of heat dissipation from the corpse and its maggot masses to the environment [*12,13*].

When attempting to model human decomposition, the use of pigs is desirable because they more closely resemble humans in degree of body hair and torso size than do other animals [*14*]. During the summer of 1986 a study in carrion decomposition was conducted in the southern Puget Sound area of western Washington State. The decomposition of two freshly killed, unburied, white pigs was observed at a shaded and exposed site in a woodland near Olympia, Washington. Ambient air temperatures, maggot mass temperatures, weight loss, bloat, and abundance and character of insect fauna were recorded at both sites and compared.

Materials and Methods

Two study sites, one shaded and the other unshaded, were chosen approximately 300 m apart in the woods of The Evergreen State College campus near Olympia, Washington. The exposed, or unshaded, site was in a clearing with direct sunlight from about 12 noon to approximately 7:00 pm (late June). The surrounding vegetation consisted of Douglas fir (*Pseudotsuga menziesii*), Red Alder (*Alnus rubra*), and Broad-leaf Maple (*Acer macrophyllum*) with bracken (*Pteridium aquilinum*), salal (*Gaultheria shallon*), and crab grass (*Digitaria spp.*) as ground cover. A small area within this clearing that was relatively free of salal was chosen and the bracken cleared away in order to establish a work compound.

The second site was located in a heavily shaded area of the forest where the upper story canopy of Douglas fir provided approximately 80% cover. The predominant understory vegetation surrounding the site consisted of bracken, salal, and sword fern (*Polystichum munitum*). Here an understory clearing was chosen and a study compound established to minimize disturbance to the area.

At both sites, a fenced compound approximately 2 m^2 by 1.5 m high was established using steel fence posts and 2.5 cm mesh poultry wire pulled down several centimeters around the bottom and secured to prevent disturbance from large scavengers. A small gate in the fence allowed access to the compound interior. A standard, white-louvered, field weather station was positioned at each site that housed a drum-type hygrothermograph that provided daily, 1.5 m above ground, ambient air temperature and humidity data. Maximum and minimum ambient air temperatures for the duration of this study were also attained from the National Weather Service station located six aerial miles away at the Olympia, WA, municipal airport. The Olympia maximum and minimum temperatures were correlated (Pearson correlation coefficient) against the maximum and minimum temperatures from the shaded and exposed sites to determine how well the official, regional, weather station data fit that of the study sites.

Two white pigs (*Sus scrofa*) were killed on June 27, 1986, by firing a .22 caliber bullet to the base of the brain. The 22.7 kg pig was killed at the shaded site and the 20.3 kg pig at the exposed site. Immediately following death of each pig, a knife cut approximately two cm deep and 10 cm long was made on the exposed surface of the neck to provide an incised bleeding wound to determine what effect, if any, this had on fly ovipositional site preference. Each pig was then placed on its side (wound up) in a wooden-framed chicken wire casket (2.5 cm mesh) which had a hinged lid to aid in observations and collection of insects. Caskets allowed insects to move freely to and from the carcass while preventing birds and other animals from interfering with the decomposition process. Caskets allowed the pig carcasses to be in direct contact with the ground and were placed inside the fenced compound.

Daily observations were made at both sites simultaneously. Insects associating with the carcasses were noted and samples collected using aerial insect nets, aspirators and pit-fall traps while trying to minimize disturbance to the decay process. Maggots were collected from the mouth, knife wound, anus and other major masses, as they developed, to see if one group of flies preferred one site over another in the early stages of decay. Once maggots began to amass on the carcasses, samples were collected from each of these early masses (that is, head, knife wound, and anus) and preserved for subsequent identifications. In addition, daily maggot mass temperatures were recorded from each pig during the period of active decay. Later, the separate masses intermixed as the abdominal and thoracic cavities were invaded.

Adult insects were pinned, dried, and labeled. Immature and very small specimens were first "fixed" in KAAD solution (95% ethanol 85 ml, Kerosene 10 mL, Glacial acetic acid 20 mL, Dioxane 10 mL) in the field and then transferred to 75% ethanol, 3% glycerin as soon as possible. Identification of first and second instar calliphorid larvae is not possible, based on morphology, below the level of family. Thus, in the early stages of decay while the larval masses remained separate and isolated, we recorded the location and abundance of first and second instar maggots as pertaining to one of the three major masses (that is, the mouth, knife wound, or anus). Once larvae developed to the third instar, they were classified into three principle subdivisions of the Calliphoridae (the subfamily, Calliphorinae, and the two tribes, Phormiini and Luciliini [*15*]). Individual third instar larvae were often seen moving about on the carcass and did not seem to remain localized to a single larval mass, as did the younger instars. Thus they were simply categorized as either being present on the carcass or wandering away in search of pupariation sites.

Insect activity was observed for periods of one to three hours per day (10:00 am to 1:00 pm). Weights of the carcasses (minus the 1.8 kg of the casket) were measured by suspending the wire casket from an overhead scale. Caskets were returned to their original position with as little disturbance as possible. Bloat measurements were taken at the greatest girth just behind the ribs using a plastic measuring tape left permanently under each pig within the casket.

Results

Daily maximum and minimum air temperatures for both the shaded site and the exposed site are presented in Fig. 1. Typically the temperatures were higher at the exposed site during the day but often fell below those of the shaded site during the night and just before dawn. In general, temperatures at the shaded site fluctuated less than those at the exposed site. Temperatures between the two sites showed the least fluctuation during times of cloud cover and rain as evidenced by the minimum temperatures recorded from 8–12 July. During this time of overcast skies and light rain, both sites experienced nearly identical minimum temperatures. The maximum temperatures recorded at both sites during these same four days also showed less variation: the exposed site remaining a nearly constant 2°C warmer.

Maximum and minimum ambient air temperatures from the National Weather Service station, located six aerial miles away at the Olympia airport, were correlated against the maximum and minimum temperatures from the two study sites (Table 1). In general, the maximum temperatures from the Olympia station and the two study sites were more highly correlated than were correlations using the Olympia minimums and either the minimums or the mean of the maximum and minimum from the study sites. The Olympia maximum when correlated with the shaded and exposed site maximums over the entire study period was 0.959 and 0.963, respectively while the Olympia minimum versus the shaded and exposed minimum was 0.720 and 0.858, respectively. When the same correlations were looked at in five day periods for the duration of the study the same general pattern held. That is, the maximum temperatures between the Olympia weather station

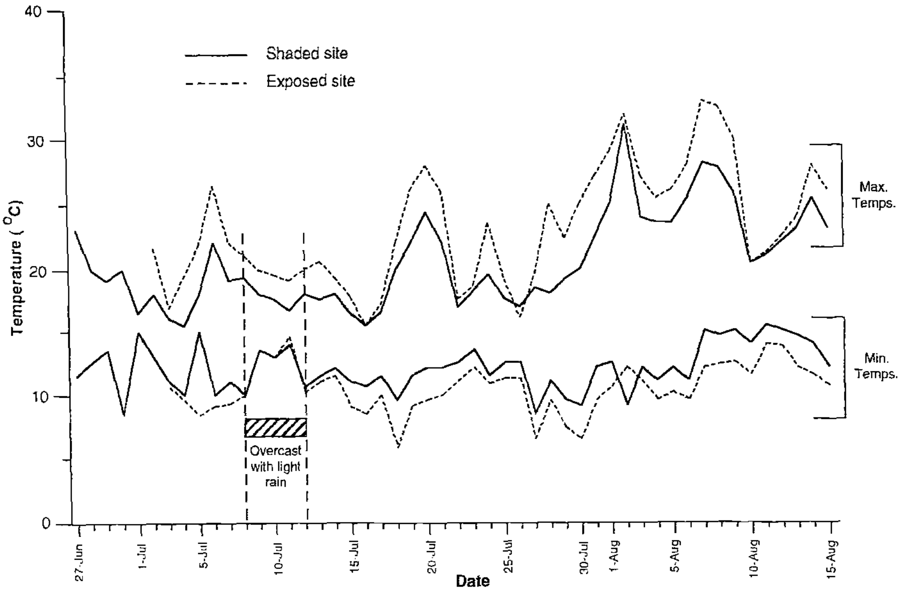

FIG. 1—*Daily maximum and minimum ambient air temperatures recorded at both shaded and exposed sites; Olympia, WA, 27 June–15 Aug. 1986.*

and the two study sites were more highly correlated than were the same minimum temperature correlations. Of the ten five-day periods, the correlation between Olympia maximum and shaded site maximum fell below 0.9 only twice, as did the correlation between Olympia maximum and exposed site maximum. On the other hand, correlations between Olympia minimum and shaded site minimum and exposed site minimum were below 0.9 during eight of the same ten five-day periods.

Maggot mass temperatures were not consistently recorded above the daily ambient air maximum until around 3 July, six days after death. Until this time, the masses were apparently not large enough to maintain a stable temperature and fluctuated more with the ambient air temperatures during the day (data not shown). For the 11 days of maximum maggot activity at the exposed pig (3 July to 13 July), the amount by which the maggot mass temperature was above the ambient air temperature averaged 16.7°C [range: 12° to 22°C; SD (σ_{n-1}): 3.4°C] (Table 2). For the same eleven days at the shaded carcass, the maggot mass temperature averaged only 9.6°C above the ambient air temperature [range: 4° to 15°C; SD (σ_{n-1}): 3.7°C]. When averaged over the 26 days of maximum maggot activity at the shaded pig, the amount by which the maggot mass temperature exceeded the ambient air temperature was 11.4°C [range: 4° to 16°C; SD (σ_{n-1}): 3.3°C].

The carcasses at both locales attracted blowflies within 20 min after death and oviposition was observed two to three hours later on both pigs around the mouth and within the naris. Ovipositioning was observed at the shaded pig, albeit reduced, even during periods of light rain and drizzle (8 to 12 July, Fig. 1) while very little was observed at the exposed pig during this time (Fig. 4). This difference in ovipositioning behavior is primarily the result of the exposed carrion being nearly consumed by 12 July (Fig. 3). Both adult *Lucilia illustris* (Meigen) and *Calliphora vomitora* (Linnaeus) were attracted to the fresh pigs. However, more *L. illustris* were observed at the exposed pig whereas more *C. vomitora* were observed at the shaded site. Adult *Phormia regina* (Meigen) were observed more frequently at the exposed location than at the shaded site. These obser-

TABLE 1—*Correlation coefficients of maximum and minimum ambient air temperatures between Olympia, WA, National Weather Service station and a shaded and exposed study site six aerial miles away. Correlations done over entire study period (27 June to 15 August) and in five day increments.*

	Olympia National Weather Service station at Olympia municipal airport, Olympia, WA.											
	Overall correlation 27/6–15/8		Five day incremental correlations									
			27/6–1/7		2/7–6/7		7/7–11/7		12/7–16/7		17/7–21/7	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Shaded max	0.959		0.987		0.986		0.723		0.877		0.969	
Exposed max	0.963		—		0.984		0.717		0.908		0.982	
Shaded min		0.720		0.896		−0.033		0.629		0.235		0.966
Exposed min		0.858		—		0.413		0.729		0.612		0.926
	Five day incremental correlations (continued)											
	22/7—26/7		27/7–31/7		1/8–5/8		6/8–10/8		11/8–15/8			
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min		
Shaded max	0.907		0.961		0.931		0.992		0.901			
Exposed max	0.998		0.616		0.996		1.000		0.931			
Shaded min		0.333		0.724		−0.606		0.843		0.943		
Exposed min		0.136		0.682		0.790		0.798		0.993		

TABLE 2—*Shaded and exposed site maximum temperatures with maggot mass temperatures during the period of maximum maggot activity. Amount that temperature of maggot masses were above site maximum air temperature is shown as "mass above site."*

	Shaded temperatures (°C)			Exposed temperatures (°C)		
Date	Site max.	Maggot mass	Mass temp. Above site temp.	Site max.	Maggot mass	Mass temp. Above site temp.
3-Jul	16	20	4	17	30	13
4-Jul	16	21	5	19	32	13
5-Jul	18	24	6	22	36	14
6-Jul	22	28	6	27	39	12
7-Jul	19	31	12	22	42	20
8-Jul	19	31	12	21	36	15
9-Jul	18	30	12	20	39	19
10-Jul	18	30	12	20	38	18
11-Jul	17	28	11	19	39	20
12-Jul	18	33	15	20	42	22
13-Jul	18	29	11	21	39	18
14-Jul	18	32	14			
15-Jul	17	31	14			
16-Jul	16	28	12			
17-Jul	17	30	13			
18-Jul	20	32	12			
19-Jul	22	34	12			
20-Jul	24	35	11			
21-Jul	22	35	13			
22-Jul	17	33	16			
23-Jul	18	29	11			
24-Jul	20	35	15			
25-Jul	18	34	16			
26-Jul	17	31	14			
27-Jul	19	26	7			
28-Jul	18	29	11			

vations of adult fly activity are also reflected in Fig. 4, which shows the relative abundance of larvae from each of these groups on the carcasses.

Differences in "bloat," as indicated by girth measurements, between the two pigs during the early stages of decomposition were great (Fig. 2). The shaded pig slowly increased in bloat from an initial girth of 77 cm to a maximum of 80.3 cm 15 days after death. Thereafter, the bloat of the shaded pig steadily decreased for an additional 13 days whereupon a minimum measurement of 67.2 cm was recorded on 24 July.

Bloat measurements for the exposed pig showed a greater rate of increase than the shaded pig during the initial stages of decomposition (Fig. 2). The initial girth of 71.5 cm, at time of death, rapidly increased to a maximum of 80.1 cm just nine days later. Thereafter, the bloat decreased rapidly until 13 days postmortem when the rib cage became exposed, and measurements were discontinued. Thus, the exposed carcass had swelled to its maximum girth five days before the shaded carcass reached its maximum. One day before the shaded carcass reached its maximum bloat, the exposed carcass had completely deflated due to the action of maggots entering the abdominal cavity.

Differences in the rate of decomposition, as determined by weight loss, was also substantial between the two carcasses. Weight loss of the exposed carcass was much more rapid than that of the shaded carcass, particularly between 5 to 14 July (Fig. 3). By 14 July the exposed pig had been reduced to a stable 17% of its original body weight while, the shaded pig retained approximately 71% of its original body weight. This rapid loss

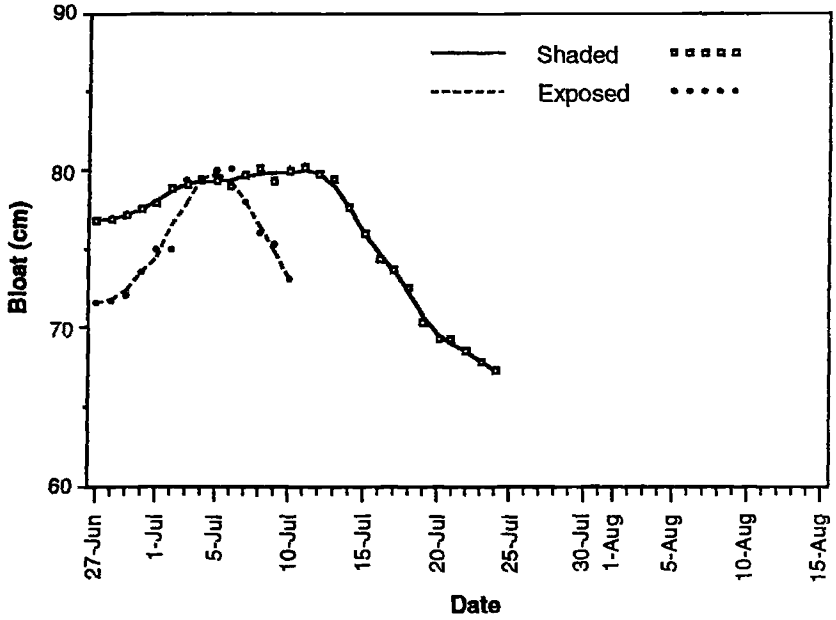

FIG. 2—*Daily maximum girth measurements, as measured just posterior to the rib cage, for both the shaded and exposed pig; Olympia, WA, 27 June–15 Aug. 1986. Lines through data points smoothed by using a floating three point mean.*

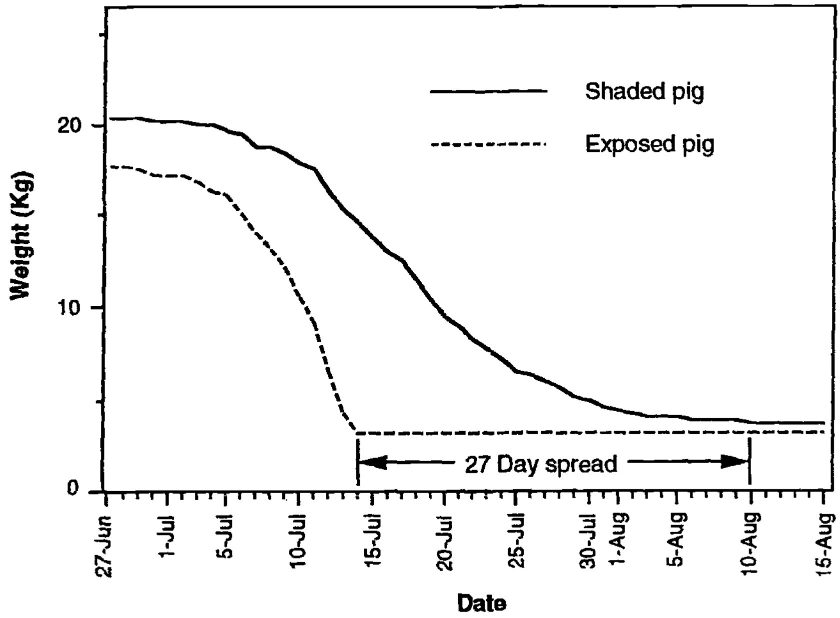

FIG. 3—*Daily weights of both the shaded and exposed pigs; Olympia, WA, 27 June–15 Aug. 1986.*

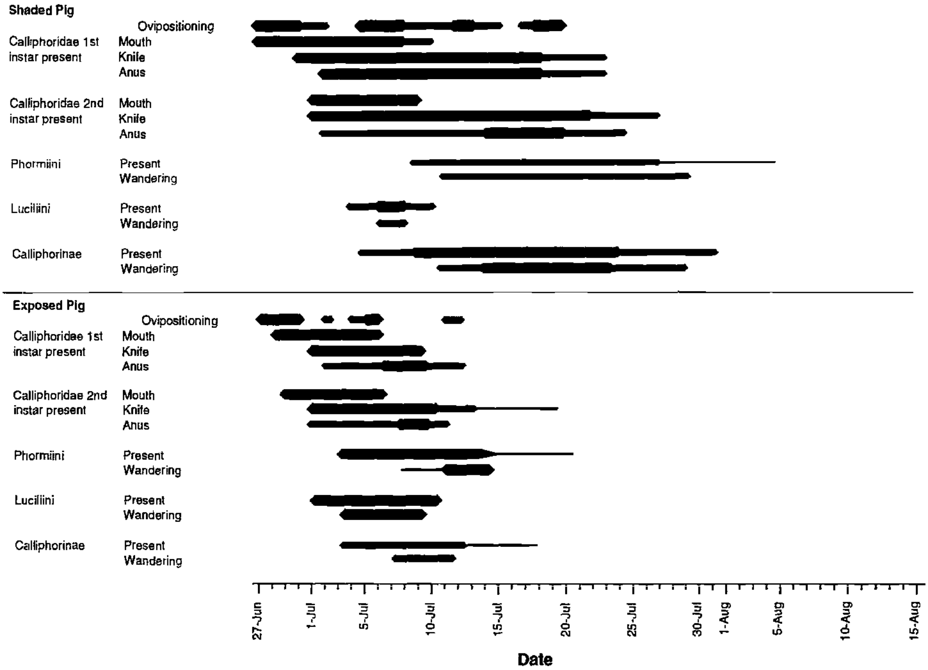

FIG. 4—*Temporal occurrence and relative abundance of calliphorid fly larvae at both the shaded and exposed pigs. Location and abundance of first and second instar larvae were cataloged to one of the three early maggot masses at either the mouth, knife wound, or anus. Third instar larvae could be identified to tribe and were recorded as either present, within the main larval mass, or as wandering away from the carcass. Thick lines indicate more maggots present relative to thin lines.*

in weight of the exposed pig was principally the result of two large masses of mature maggots migrating away from the carcass suggesting some degree of synchronous development. The first mass was observed leaving via the head region on 11 July. Also at this time, liquids frothing from both the rectal and rib cage regions were staining the ground and had discolored an area slightly greater than that of the carcass itself. The draining of bodily liquids was partly facilitated by a gentle downward slope of the ground away from the rectal area. The second large mass of maggots left the exposed pig on 12 July from the rectal area traversing over the stained area of ground. Similar, large and rapid, migrations of maggots away from the shaded pig were not observed. Instead, there was a much more gradual and sustained migration of maggots. It is important to note that some of the observed differences in weight loss between the shaded and exposed carcasses were likely due to the differential effects of dehydration on the two carcasses.

Figure 4 indicates the occurrence and relative abundance of each of the major groups of calliphorid larvae collected and identified from the pigs at both sites throughout the study period. Although blow fly ovipositioning was observed to commence at essentially the same time for both pigs, this activity showed different temporal patterns and was continued for a longer period of time on the shaded carcass. The extended ovipositional period on the shaded carcass is presumed to be due to the prolonged availability of suitable carrion.

The total distribution of first and second instar calliphorid larvae among the mouth, knife wound, and anus on both the shaded and exposed carcasses is shown in Fig. 4. In general, the distribution of first and second instar larvae at the sites was similar between the two pigs despite the fact that the exposed pig was consumed much faster than the shaded pig. At both sites, first instar larvae were observed first in the mouth and nostrils followed by the knife wound and anus respectively, which probably reflects ovipositional site preferences by adult blow flies [7]. With the exception of the exposed pig's mouth, second instar larvae appeared at approximately the same time at all three sites on both pigs. All three groups of calliphorid larvae were present a shorter time at the exposed pig than at the shaded pig. The Calliphorinae larvae were more common at the shaded site and the Phormiini and Luciliini were more common at the exposed site.

In addition to the calliphorid flies, many other groups of insects were collected and identified from the carcasses (Table 3). Members from eleven families of Diptera, eight

TABLE 3—*Species list of all insects collected from both the shaded and exposed pigs; Olympia, WA, 27 June–15 August 1986. Days at which insects were first observed are given as days from time of death, for example, 27 June equals day 1, and 15 August equals day 50.*

	Day first observed	
	Shaded pig	Exposed pig
Diptera:		
Rhagionidae:		
Rhagio sp.		Day 16
Symphoromyia sp.	Day 22	Day 13
Phoridae:		
Anevrina sp.	Day 9	
Spiniphora sp.	Day 6	
Sepsidae: sp.	Day 16	Day 6
Piophilidae:		
Parapiophila sp.	Day 6	Day 6
Mycetaulus sp.	Day 15	Day 18
Sphaeroceridae:		
Leptocera sp.	Day 6	Day 21
Ephydridae: sp.	Day 36	
Chloropidae: sp.	Day 6	Day 6
Heleomyzidae:		
Neoleria inscripta (Meigen)	Day 32	
N. lutea (Loew)	Day 3	Day 5
Muscidae:		
Fannia sp.	Day 3	Day 6
Hydrotaea sp.	Day 2	Day 3
Calliphoridae:		
Phormia regina (Meigen)	Day 4	Day 1
Lucilia illustris (Meigen)	Day 1	Day 1
Eucalliphora lilaea (Walker)	Day 1	Day 1
Calliphora vomitor (L.)	Day 1	Day 1
Melanodexia grandis Shannon		Day 16
Sarcophagidae: spp.	Day 1	Day 1
Coleoptera:		
Carabidae:		
Cychrus tuberculatus Harr.	Day 5	
Pterostichus sp.		Day 27
Zacotus matthewsi LeC.		Day 16
Staphylinidae:		
Tachinus sp.	Day 5	Day 14
Staphylinus maxillosus L.	Day 4	Day 9
Ontholetus cingulatus Grav.	Day 2	Day 6
Philonthus sp.	Day 7	Day 11
Silphidae:		
Thanatophilus lapponica (Herbst).	Day 16	Day 10
Nicrophorus vespilloides Herbst.	Day 5	Day 11
N. investigator Zett.	Day 16	

TABLE 3—*Continued.*

	Day first observed	
	Shaded pig	Exposed pig
Cleridae:		
Necrobia violacea (L.)		Day 18
Nitidulidae:		
Omosita discoidae Fabr.		Day 19
Histeridae:		
Saprinus impressus Lec.		Day 10
S. lugens Er.		Day 11
Margarinotus stercorarius Hoffm.	Day 10	
M. depurator Say	Day 5	
Dermestidae:		
Dermestes frischi Kug.		Day 23
D. undulatus Brahm		Day 24
Scarabaeidae:		
Aphodius fimetarius L.		Day 23
Hymenoptera:		
Diapriidae: sp.	Day 18	Day 15
Braconidae: sp.	Day 16	
Formicidae:		
Lasius sp.	Day 6	
Formica sp.		Day 7
Camponotus vicinus Mayr.		Day 23
C. modoc Wheeler		Day 16
Vespidae:		Day 24
Vespula vulgaris (L.)	Day 10	
Dolichovespula arenaria (Fabr.)	Day 16	Day 6
D. maculata (L.)		Day 33

families of Coleoptera, and four families of Hymenoptera were collected from both carcasses during the duration of this study. The dates at which these first appeared on the respective carcasses is also noted. The calliphorids were, by far, the most conspicuous and dominant consumers of this carrion and arrived earliest.

Discussion

The decomposition rate of both pig carcasses was affected primarily by feeding of the calliphorid larvae and their relative rate of development, which in turn was related to ambient air temperatures. Though the study sites were only 300 m apart, different ambient air temperature patterns were observed (Fig. 1). Daily temperatures generally were higher at the exposed site than at the shaded site thus accelerating decomposition of the exposed pig relative to shaded pig (Figs. 2 and 3). Evening lows were generally cooler at the exposed site than at the shaded site. It appears that the differences in maximum temperatures between the two sites affected the rate of decomposition more than the minimum temperatures at night during which maggot activity probably slowed at both sites, more or less equally. It should be noted that some of the difference in decomposition rates between the two pigs may be attributed to differential dehydration at the two sites and the fact that the exposed pig was slightly smaller.

Maggot mass temperatures were, in part, a function of their size. That is, the maggot mass temperatures of both pigs began to rise as more maggots began feeding and developing even as ambient air temperatures remained fairly cool (for example, 3 to 4 July, Fig. 1 and Table 2). Although maggot mass temperatures were recorded at both sites consistently above ambient air temperature starting 3 July, the difference was much greater at the exposed site (Table 2). It appears that the effect of increased temperature and/or direct sun on a corpse acts as a catalyst in stimulating maggot growth and activity which is reflected in higher maggot mass temperatures and faster decay of carrion.

Marchenko [*12*] showed that such factors as maggot mass self-heating and dissipation of heat to the environment are important in determining rates of larval development. Thus, the size of the maggot masses and the degree to which the corpse is either exposed to, or insulated from, the environment (for example, shaded vs. exposed) thereby affecting the amount of heat absorbed and dissipated, has a significant effect upon the rate of larval development and the decomposition of a corpse. These variables, in turn, have a direct bearing on the calculation of postmortem intervals based on weather data collected some distance from the site; as does correlating the size and abundance of maggots collected from the corpse to those of laboratory-reared larvae under fixed temperature regimes.

Microclimatic differences can vary between two closely spaced sites, as we have shown (Fig. 1), and also between a study or crime scene and an official weather service recording station some distance away (Table 1). For example, during 8 to 12 July when light rain was present at both sites, the Olympia National Weather service station six miles away recorded rain on only two of those days: 0.51 and 0.07 inches on 10 and 11 July respectively. Reconstructing past climatic patterns at a given local is difficult and requires careful comparison of recorded site data to those of an official, or reliable, source some distance away. We found reasonably good temperature correlations ($r > .95$) were obtained when site maximums and official weather station maximums were used (Table 1).

A consequence of attempting to observe the natural decay process at the expense of collecting a more comprehensive species list results in Table 1 not including all incidental insect species associated with this carrion. It does, however, list the most important carrion frequenting fly species in addition to many carrion frequenting insects of this geographical locale. Of the 49 species of insects collected from the two sites, 11 were collected from only the shaded site while 16 were collected only from the exposed site. Aside from estimating postmortem intervals, knowing what species of insects associate with carrion during various seasons in a particular area can be useful for determining if a body has been moved or not, the evaluation of ante mortem trauma, and as possible toxicological indicators. Thus, the compilation of species lists for carrion-inhabiting insects from various geographical regions becomes important.

We conclude that ambient air temperatures are extremely important in influencing carrion decomposition primarily through the activities of calliphorid larvae. Air temperatures can vary significantly between areas as little as 300 m apart and tend to show more extreme maximum and minimum temperatures at exposed locations than do areas that are more shaded. These differences in temperature patterns can have a profound effect upon the decomposition rate of a corpse.

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