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Insect Succession on Buried Carrion in Two Biogeoclimatic Zones of British Columbia

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ABSTRACT: We established a database of insect succession on buried carrion in two biogeoclimatic zones of British Columbia over a 16-month period beginning June 1995. Pig (*Sus scrofa* L.) carcasses were buried shortly after death in the Coastal Western Hemlock and Sub-boreal Spruce biogeoclimatic zones of British Columbia. Buried pigs exhibited a distinct pattern of succession from that which occurred on above-ground carrion. The species composition and time of colonization for particular species differed between the two zones. Therefore ideally, a database of insect succession on buried carrion should be established for each major biogeoclimatic zone. We did not observe maggot masses on any of the buried carcasses; therefore, the presence of maggot masses may indicate a delayed burial. Soil temperature was a better indicator of internal buried carcass temperature ($r^2 = 0.92$, $p < 0.0001$) than was ambient air temperature ($r^2 = 0.60$, $p < 0.0001$); thus soil temperature should be used to determine developmental rates of insects for determination of the postmortem interval by a forensic entomologist.

KEYWORDS: forensic science, forensic pathology, pig, British Columbia, forensic entomology, grave fauna, burial

Forensic or medicolegal entomology is the study of insects associated with a dead body, primarily to determine elapsed time since death. The elapsed time since death can be used to confirm or refute a suspect's alibi and to aid in the identification of unknown victims by focusing an investigation into the correct time frame. This information can be vital in a homicide investigation (1).

There are two methods of determining elapsed time since death using insect evidence (2). The first uses maggot age and developmental rates. Since blowflies usually arrive and begin laying eggs within minutes after death (3), an analysis of the oldest insects present will give a minimum postmortem interval. The second method uses the succession of insects on a decomposing corpse. Decomposing bodies constitute a rapidly changing habitat. After death, carrion undergo rapid physical, chemical and biological changes during the decomposition process. At each stage of decomposition, carrion is attractive to different species of insects. These insects colonize the remains in a predictable sequence, so that an analysis of the arthropods on a human homicide victim, weeks or months after death, can lead to an accurate estimate of elapsed time since death. This method requires an accurate database of insect succession.

The succession of insect species on carrion varies according to temperature, habitat and geographic location (3–14). This variation occurs on both above-ground and buried carcasses (15,16), but the location of the remains influences the time required for insects to locate a carcass, the sequence of colonization and the rate of decomposition (15–17). This variation makes extrapolation of insect succession databases between habitats and geographic locations extremely difficult. However, it is hypothesized that once insects locate buried remains, they will feed and develop normally, and will colonize in a predictable sequence.

No experimental research into insect succession on buried corpses has been done in Canada. This research was designed to mimic the homicide scenario wherein a body is disposed of by shallow burial. Our specific objective was to establish a database of insect succession on buried carrion in both the Coastal Western Hemlock (CWH) and Sub-boreal Spruce (SBS) biogeoclimatic zones (characteristic of the Vancouver and Cariboo Regions, respectively) of British Columbia for use in homicide investigations.

Methods and Materials

Experimental areas were located in the CWH zone within the Vancouver Forest Region and the SBS zone within the Cariboo Forest Region. Most of the research was concentrated in the CWH zone since most buried corpses are found there (1). Buried carcasses were studied in the SBS zone in conjunction with extensive exposed carcass experiments conducted at the same time (4). Both areas were chosen on the basis of representative soil type and vegetation.

Two weeks before carcass placement, 250-mL glass jar pitfall traps containing soapy water were placed at each planned carcass site and at three control sites (no carcass), at least 15 m from the carcass sites. After burial, the pitfall traps were placed in the soil above the carcasses to trap a sample of the insects attracted to or leaving the remains. The control pitfall traps remained at their original sites.

At each site graves were dug with a shovel on the same day, deep enough to allow the upper surface of a carcass to lie approximately 30 cm below the forest floor. All graves were at least 15 m away from the next grave or above-ground carcass, so that olfactory orientation of insects to each carcass was minimally influenced.

Twenty-three kg (50 lb) pigs (*Sus scrofa* L.) were used as surrogate human models, as these are considered to be excellent models for human decomposition (18). A 15 cm pin gunshot to the head

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was used to kill all the pigs. To allow insertion of temperature probes, the carcasses were shot a second time, in the side of the thorax, using a .22 caliber rimfire bullet. This produced a small entrance wound just wide enough to allow insertion of the probe, but did not produce an exit wound. Pigs were transported from the slaughter yard to the burial site by an enclosed pickup truck after death. Because clothing influences insect succession (19) and most homicide victims are clothed or have cloth associated with the body, each carcass was identically clothed with underwear, a T-shirt, blouse, shorts and socks. A freshly killed pig was placed in each grave within hours of death and the grave was filled to ground level with loosely packed soil. The top of each grave was disguised with branches, leaves and rocks. Above-ground carcasses were protected from large scavenger attack by wire mesh (4 in. $\times$ 2 in. [10 $\times$ 5 cm], 12.5 gage) staked to the ground over the entire carcass. Buried carcasses were protected by wire mesh staked down over the grave.

On 10 June 1995, 12 pigs were buried within 8 h after death. Three of these pigs were exhumed at each of 2 and 6 weeks, and 3 and 16 months after death. Three control carcasses were left above ground and were examined at 2 weeks after death after which they were consumed by a large scavenger and could not be sampled again.

On 17 June 1995, 15 pigs were buried within 5 h after death. Three of these pigs were exhumed at each of 2 and 6 weeks and 3, 11 and 16 months after death. Three control pigs were left above ground and were examined at the same time as the exhumed pigs.

Internal carcass temperature was taken from one above-ground carcass and one buried carcass (the last to be exhumed) within each biogeoclimatic zone. Ambient air and soil temperature (from soil adjacent to the buried carcass) was recorded in both zones. Temperatures were recorded using two types of dataloggers. Double channel dataloggers (SmartReader 1®, Young Environmental Systems, Richmond, B.C.) measured the temperature every 30 min. Single-channel dataloggers (Hobo®, Hoskins Scientific, Vancouver, B.C.) measured the temperature every 90 min. Failure of all but one Hobo® and several SmartReaders® precluded recording of additional internal carcass, ambient air or soil temperatures. Ambient air temperature data in the CWH zone were lost due to these failures; thus ambient air temperature data were taken from an Environment Canada weather station, 2 km south of the research site.

Biomass loss was measured by placing an exhumed carcass on a mesh platform and weighing it using a 70 kg (150 lb) scale on a pulley system. Above-ground carcasses were not weighed, because the disturbance could have affected the succession pattern since the carcasses were not on mesh platforms.

At each sampling date, insects in each pitfall trap were separated from the soapy water by the use of a small tea strainer and placed in 70% ethanol in a sterile 100 mL vial. Fresh soapy water was then placed in each pitfall trap. Insect species that were collected in equal abundance from control and carcass sites were excluded because these were considered to be endemic species that are not associated with carrion.

The buried carcasses were exhumed carefully, in the manner of crime scene investigations, with the grave divided into a 1 $\times$ 1 m grid, with four 50 cm^2 quadrants, laid out before the excavation. Collection of insects began with careful removal of surface plants. They and the exposed ground were sampled for insects. Next, soil was removed systematically, one quadrant at a time moving from the outermost to the innermost area (20). Soil was sorted by hand and inspected for insects, samples of which were collected. When the entire corpse was exposed, the carcass was lifted out of the grave and the soil in the bottom of the grave was examined. The entire exhumed carcass, as well as all areas of the clothing, including pockets, were examined. The carcass was then placed in a plastic bag and later disposed of.

Above-ground control carcasses were sampled in a similar manner on each exhumation day, but on a lesser scale because above-ground succession can be determined from the established database (4).

We used Microsoft Excel (21) to calculate the linear regression equations predicting internal carcass temperature from ambient air temperature and soil temperature and predicting soil temperature from ambient air temperature. The temperature data for the first three days after death were omitted to eliminate the effect of *algor mortis.*

Results

Temperature

Differences were observed between the ambient air and grave soil temperatures and between the internal carcass temperatures of buried and above-ground pigs. These trends held true for carcasses in both study sites. In both zones, buried carcasses did not show the same internal temperature spike experienced by above-ground carcasses (Fig. 1). During the winter months in the SBS zone, internal buried carcass temperature did not fluctuate with ambient air temperature (Fig. 2). However, during the winter months in the CWH zone, the internal buried carcass temperature (estimated by grave temperature[3] because the datalogger failed) did fluctuate significantly ($r^2 = 0.73$, $p < 0.0001$) with the ambient air temperature recorded at the Environment Canada weather station (Fig. 2).

There was less fluctuation in soil than in ambient air temperature overall, as illustrated by data collected in the SBS zone (Fig. 3). After *algor mortis* was complete, there was little difference between grave temperature and internal carcass temperature. In both zones, diurnal fluctuations were much greater in the ambient air temperature than in the internal buried carcass temperature, as illustrated by data collected in the CWH zone (Fig. 4).

Weather station ambient air temperature was not a good predictor of the internal temperature of above-ground carcasses in the CWH zone, although it was a good predictor of the internal temperature of above-ground carcasses in the SBS zone before the action of the maggot masses increased the internal temperature (Table 1). Soil temperature was an excellent predictor of internal buried carcass temperature in the SBS zone (Table 1). Mean and minimum ambient air temperatures were also acceptable predictors ($r^2 > 0.5$) of internal buried carcass temperature in the SBS zone, but only in the spring, summer and fall months (Table 1). In contrast, ambient air temperature taken from the weather station 2 km away was not a good predictor ($r^2 < 0.5$) of internal buried carcass temperature in the CWH zone, likely due to small sample size, although it was an acceptable predictor of grave temperature (Table 1).

Decomposition

The rate of decomposition of buried carcasses was considerably slower than for the above-ground carcasses. Although decomposition is continuous, Payne et al. (1968) recognized five stages of

[3] The use of grave temperature is justified by the strong relationship between internal carcass and grave temperatures recorded for 262 days from the SBS zone ($r^2 = 0.92$, $p < 0.0001$).

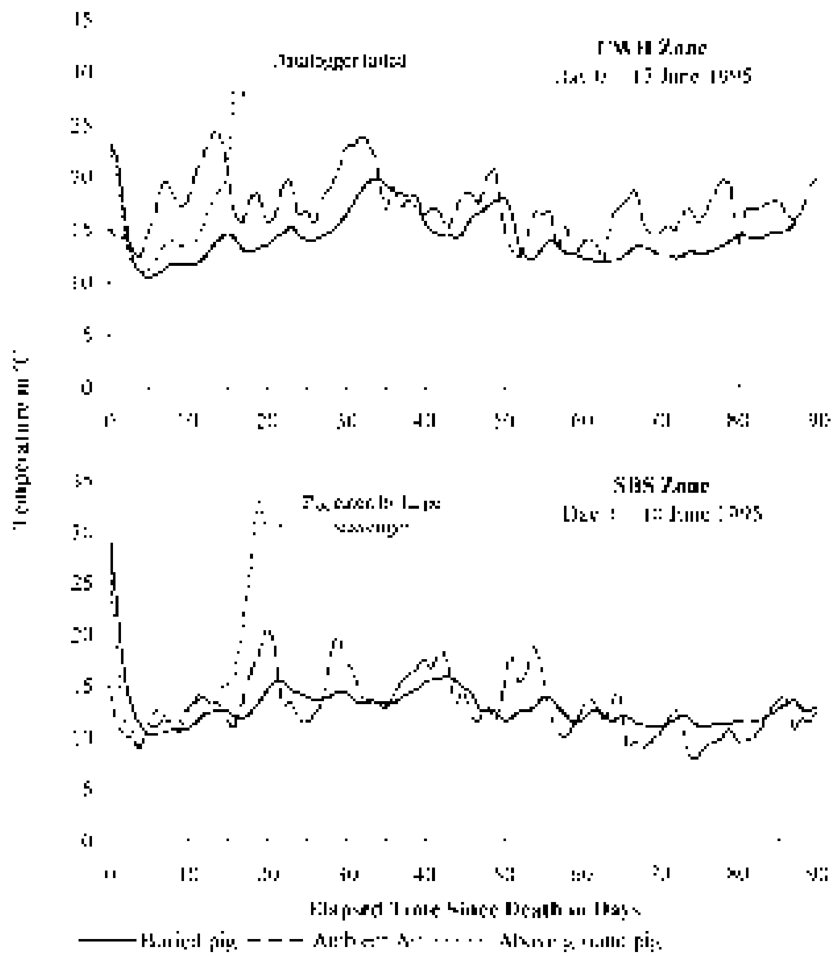

FIG. 1—*Mean daily internal temperature of above-ground and buried pig carcasses measured every 90 min in the Coastal Western Hemlock (CWH) and in the Sub-boreal Spruce (SBS) biogeoclimatic zones of British Columbia. Ambient air temperature in the CWH zone was recorded twice daily from the Malcolm-Knapp Research Forest weather station, 2 km from the research site. Ambient air temperature in the SBS zone was measured every 90 min at the research site.*

physical decomposition, which we have adapted to characterize the buried carcasses.

The fresh stage began at death and continued until bloating of the carcasses was visible. This stage was not observed after the initial placement of the carcasses since both above-ground carcasses and buried carcasses had passed beyond this stage by 2 weeks after death (Table 2).

By 2 weeks after death above-ground carcasses had passed the bloat stage (Table 2), characterized by the accumulation of gases within the body as anaerobic bacteria within the gut begin to digest the carcass. This was evidenced by the deflated nature of the carcasses. However, buried bodies decompose at a much slower rate, allowing characterization on the basis of disarticulation. By 2 weeks after death, buried carcasses had entered a primary bloat stage (Table 2), characterized by both the bloated appearance and the lack of disarticulation. By 6 weeks after death, buried carcasses were in a secondary bloat stage (Table 2), still bloated, but with the limbs disarticulated.

The active decay stage was characterized by the deflation of the carcass and disarticulation of the head. Flesh and skin were still present. By 2 weeks after death, the above-ground carcasses were in this stage (Table 2), with large maggot masses rapidly consuming flesh. The buried carcasses were in this stage by 3 months after death (Table 2). No maggot masses were present. The abdomen was collapsing with the head and legs disarticulated. The carcasses were very wet with a strong odor once they were removed from the grave.

At the advanced decay stage, most of the flesh had been removed, but skin, bone, fat and cartilage remained on above-ground carcasses, which had reached this stage by 6 weeks after death in the CWH zone (Table 2). The above-ground carcasses in the SBS zone had been eaten by a large scavenger by this time. By 11 months after death, the buried carcasses in the CWH zone had reached the equivalent of this stage (Table 2). Some flesh remained, although some of it had turned to adipocere tissue, formed by the conversion of soft tissue to hydrolyzed fat in the presence of cool moist soil or water (22) and the abdomen had collapsed. The carcasses were still fairly wet. At 16 months after death, the buried carcasses in the CWH zone were still in this stage (Table 2), with the remaining flesh turned to adipocere tissue and the ribcage collapsed, giving the carcasses a flattened appearance. Buried carcasses in the SBS zone had reached the advanced decay stage by the time the experiment was terminated at 16 months after death (Table 2). They resembled the buried carcasses exhumed in the CWH zone at 11 months after death.

By 11 months after death, the above-ground carcasses had

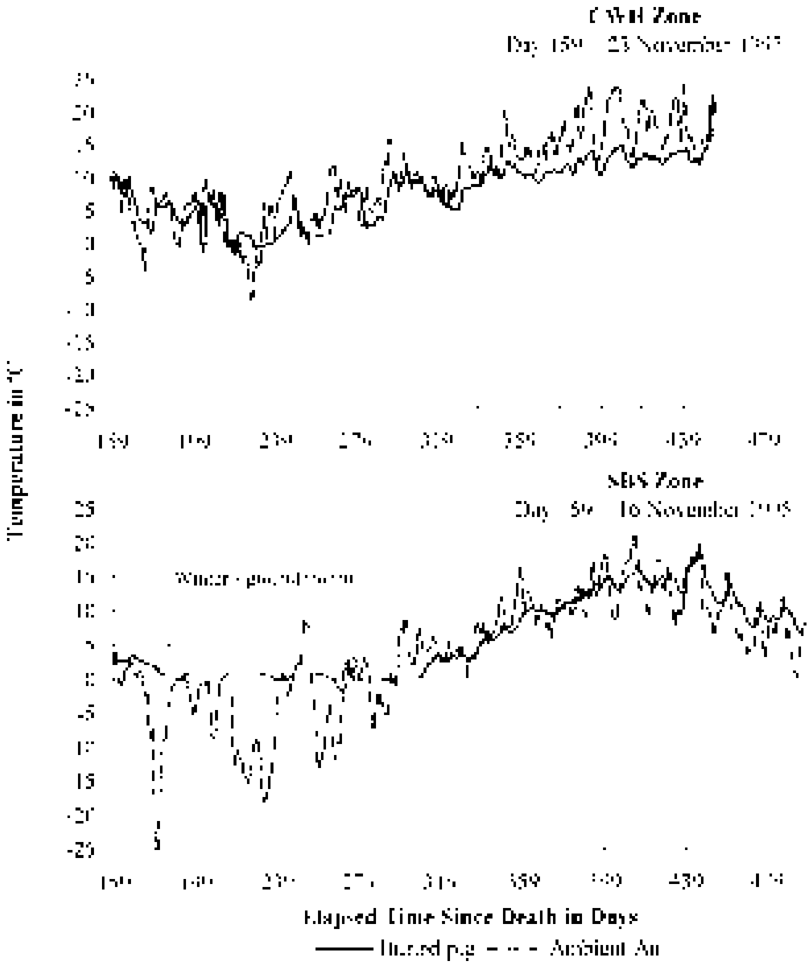

FIG. 2—*Mean daily internal buried pig carcass temperature in the Coastal Western Hemlock (CWH) and Sub-boreal Spruce (SBS) biogeoclimatic zones of British Columbia (estimated by grave temperature in the CWH zone) measured every 90 min from November 1995 (159 days since death) to October 1996. Ambient air temperature in the CWH zone was recorded twice daily from the Malcolm-Knapp Research Forest weather station, 2 km away from the research site. Ambient air temperature in the SBS zone was measured every 90 min at the research site.*

entered the final dry remains stage with only bone, cartilage and some skin remaining (Table 2). Bits of clothing and bones were the only remaining evidence of these carcasses.

Biomass Loss

Biomass loss in buried carcasses was slightly faster in the CWH zone than in the SBS zone (Fig. 5). However, buried carcasses in both zones lost biomass much more slowly than above-ground carcasses in the shade in the spring of 1994 in the CWH zone (19). The slower rate of decomposition and decreased rate of biomass loss prolongs insect succession on buried carcasses.

Insect Succession

The following successional data are based on insects collected both through exhumation and pitfall trapping. At 2 weeks after death, the buried carcasses in both zones were in the primary bloat stage (Table 2). We collected adults of several species of blowfly (Diptera: Calliphoridae) from pitfall traps in both zones, but only *Calliphora vomitoria* (L.) and *Lucilia illustris* (Meigen) larvae in the SBS zone on buried carcasses (Table 3). Adults of the dipteran families Muscidae, Sphaeroceridae, Phoridae and Sarcophagidae were collected from pitfall traps above buried carcasses in both zones. Adults and pupae of *Fannia cannicularis* (L.) (Diptera: Fanniidae) were collected in the SBS zone on buried carcasses and in pitfall traps, but only adults were collected in the CWH zone at this time. We collected adult Coleoptera in the families Staphylinidae, Silphidae and Leiodidae on buried carcasses and in pitfall traps in both zones. Larval Staphylinidae and Histeridae (Coleoptera) were collected in the SBS zone on buried carcasses. *Nasonia vitripennis* (Walker) (Hymenoptera: Pteromalidae) and *Camponotus herculeanus* (L.) (Hymenoptera: Formicidae) adults were collected on buried carcasses and in pitfall traps in both zones.

The buried carcasses were in the secondary bloat stage by 6 weeks after death (Table 2). We collected pupae of *Eucalliphora latifrons* (Hough) (Diptera: Calliphoridae) and *Ophyra leucostoma* (Wied.) (Diptera: Muscidae) from the buried carcasses in the SBS zone (Table 3). Pupae of *Hydrotaea* sp. and *Morellia* sp. (Diptera: Muscidae) as well as larvae, pupae and adults of *F. cannicularis* were collected from buried carcasses in both zones. *Dohrniphora* sp. (Diptera: Phoridae) larvae were collected from buried carcasses in the CWH zone. We collected adults of these species in pitfall traps above the buried carcasses at the same time.

The buried carcasses did not reach the active decay stage until 3 months after death, but the above-ground carcasses had reached this stage by 2 weeks after death (Table 2). *Phormia regina*

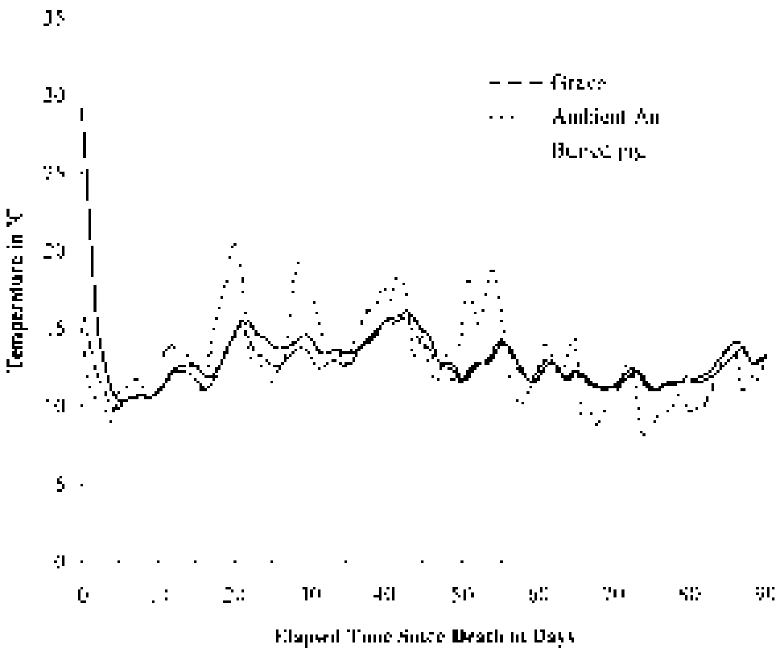

FIG. 3—*Mean daily ambient air temperature, ambient grave temperature and internal buried pig carcass temperature measured every 90 min for the first 90 days after death in the Subboreal Spruce (SBS) biogeoclimatic zone of British Columbia. Day 0 = 10 June 1995.*

(Meigen) and *Protophormia terraenovae* (Robineau-Desvoidy) (Diptera: Calliphoridae) immatures (Table 3) were found in large masses on the above-ground carcasses in both zones. *L. illustris* larvae and pupae were collected only from above-ground carcasses in the CWH zone, although adult *L. illustris* were collected from pitfall traps above buried pigs in the CWH zone and beside above-ground carcasses in the SBS zone. We collected adult *Hydrotaea* sp., *Leptocera* sp. (Diptera: Sphaeroceridae), *Dohrniphora* sp. and *F. cannicularis* in pitfall traps beside above-ground pigs in the SBS zone. Staphylinidae and Silphidae were collected from above-ground carcasses and pitfall traps in both zones. We collected adult *Catops basilaris* Say (Coleoptera: Leiodidae) and larval Staphylinidae from pitfall traps and above-ground carcasses in the CWH zone.

Leptocera sp., whose pupal cases closely resemble those of the Piophilidae (Diptera), were collected as pupae on buried carcasses in both zones at 3 months after death, during the active decay stage (Table 3). Heleomyzidae (Diptera) larvae were collected from buried carcasses in the SBS zone. We did not observe maggot masses on any of the buried carcasses in either zone.

Buried carcasses in the CWH zone had entered advanced decay by 11 months after death and were still in this stage at 16 months after death (Table 2). Buried carcasses in the SBS zone were also in this stage when we exhumed them at 16 months after death (Table 2). We collected very few insects on buried carrion at this time. However, larval Histeridae were collected from buried carcasses at this point (Table 3).

Above-ground carcasses in the CWH zone had entered the advanced decay stage by 6 weeks after death (Table 2). Adult *Leptocera* sp., *Sphaeridium bipustulatum* (F.) (Coleoptera: Hydrophiloidae) and *Ctenicera comes* (Brown) (Coleoptera: Elateridae) were collected from the above-ground carcasses and pitfall traps, as well as adult and immature *F. cannicularis* and *Stearibia nigriceps* (Meigen) (Diptera: Piophilidae). We also collected larval *Necrophilus* sp. (Coleoptera: Argyrtidae) from above-ground carcasses. Since the above-ground carcasses in the SBS zone were eaten by a large scavenger, no further data were available.

By 3 months after death, above-ground carcasses in the CWH zone had entered the dry/remains stage (Table 2). Larval and adult *Leptocera* sp. were collected on the above-ground carcasses (Table 3). This was the first time that we collected larvae of this species on above-ground carcasses. Throughout the study, we observed the ant *Camponotus herculeamus* and silphids (Coleoptera) *Nicrophorus defodiens* Mannerheim and *Nicrophorus investigator* Zetterstedt feeding on carcasses.

Discussion

During the analysis of insect evidence from a crime scene, the temperature of the body prior to discovery must be predicted in order to determine the minimum postmortem interval using maggot developmental rates. This is usually done by comparing temperature data taken at the scene with data from the nearest weather station during the same time period. If there is a good correlation between the two, then the weather station data can be used to predict what the temperature at the scene was prior to discovery of the body. This technique assumes that there is a good correlation between the ambient temperature at the scene and the internal temperature of the body. In our study, there was a poor correlation between the weather station ambient air temperature and the internal temperature of above-ground carcasses in the CWH zone (Table 1), probably due to maggot mass activity raising the internal carcass temperature and micrometeorological differences between the weather station and the research sites. Support for this cause is found in the excellent correlation between ambient air and internal above-ground carcass temperature in the SBS zone (Table 1) before maggot mass activity raised the internal carcass temperature and when the two temperatures were recorded within 1 m of each other. Since there were no maggot masses on any of the buried bodies, it is not surprising that ambient air temperature was well correlated

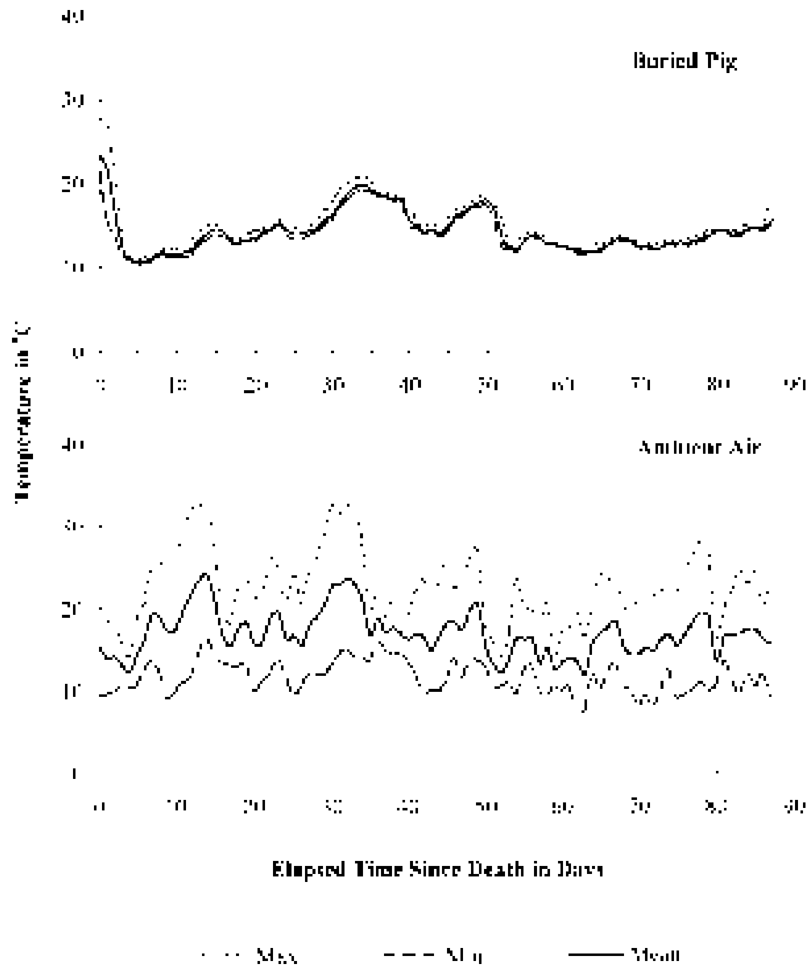

FIG. 4—*Maximum and minimum ambient air temperatures recorded twice daily from the Malcolm-Knapp Research Forest weather station and maximum and minimum internal buried pig carcass temperatures measured every 90 min for the first 90 days after death in the Coastal Western Hemlock (CWH) biogeoclimatic zone, British Columbia. Day 0 = 17 June 1995.*

(Table 1) with internal buried carcass temperature, at least during the spring, summer and fall in the SBS zone. During the winter in the SBS zone, ambient air temperature continued to fluctuate, but internal temperature of the buried carcass in the frozen ground did not, resulting in no correlation (Table 1).

Because soil temperature was the best predictor of internal buried carcass temperature (Table 1), it would be best to establish soil temperatures at scenes of buried victims. Soil temperature has been used in at least one case, to determine blowfly development rates (23).

The rapid development of insects on the above-ground carcasses during the early stages of decay (Table 3) was undoubtedly influenced by action of maggot masses which can increase the internal temperature of a carcass up to 40°C, although this fluctuates considerably during a 24 h period (3). Because soil acts as a temperature sink, there was much less fluctuation in temperature within the soil than in ambient air temperature (Fig. 3) as also observed in other studies, especially as depth within the soil increases (16,24–26). The resulting consistently cooler temperatures than in above-ground carcasses would have retarded the development of carrion-inhabiting insects. Any differential effects of low (CWH) and freezing (SBS) temperatures during the winter were not evident in this study, despite a slight difference in the rate of decomposition due to the winter soil conditions in the SBS zone.

The slower decomposition of buried than above-ground carcasses (Table 2) has also been observed in other studies (13,17,27). The rate of decomposition of buried carcasses in both biogeoclimatic zones was much slower than in previous burial studies conducted in South Carolina (17).

Numerous species of Diptera were predictably the most common inhabitants of buried carcasses in this study. The collection of immature *Fannia cannicularis* on buried carcasses in both biogeoclimatic zones (Table 3) is consistent with the occurrence of this species in the soil (28), as well as on carrion in later stages of succession (3). Its early role in the succession on buried carrion is possibly due to the moisture associated with buried carcasses, since this species prefers a moist habitat (15).

The sequence in the SBS zone of *Calliphora vomitoria* larvae and pupae during primary bloat (2 weeks after death), then *Hydrotaea* sp., *Morellia* sp. and *Ophyra leucostoma* pupae during secondary bloat (6 weeks after death), follows a successional pattern similar to that found in another study (31), where a succession of insects on buried carrion began with *C. vomitoria* and *Muscina stabulans* (Fall.) soon after death, followed by *Ophyra anthrax. O. leucostoma* were also collected from dog cadavers buried in coffins at 2 months after death in Washington, DC (29). In British Columbia, immature *Hydrotaea* sp. were collected from 5 days to 10 months after death on buried human bodies (1). Muscids have

TABLE 1—*Linear regression analysis of temperature data collected during decomposition of pig carcasses in the Coastal Western Hemlock (CWH) and Sub-boreal Spruce (SBS) biogeoclimatic zones of British Columbia, June 1995 to October 1996.*

Dependent Temperature Variable	Biogeoclimatic Zone and Days Since Death	Independent Temperature Variable	N	Slope	y Intercept	r^2	*P*
Internal, buried carcass	SBS, days 3–94, 327–499 (spring, summer, fall)	Maximum daily soil	262	1.13	−1.33	0.9	<0.0001
		Minimum daily soil	262	1.13	−0.4	0.92	<0.0001
		Mean daily soil	262	1.14	−0.86	0.92	<0.0001
		Maximum daily air	262	0.34	5.94	0.36	<0.0001
		Minimum daily air	262	0.62	7.2	0.53	<0.0001
		Mean daily air	262	0.59	4.9	0.6	<0.0001
	SBS, days 159–326 (winter)	Maximum daily soil	167	0.68	0.45	0.64	<0.0001
		Minimum daily soil	167	0.83	0.38	0.8	<0.0001
		Mean daily soil	167	0.78	0.39	0.77	<0.0001
		Maximum daily air	167	0.023	0.97	0.02	0.08
		Minimum daily air	167	0.024	0.9	0.02	0.04
		Mean daily air	167	0.024	0.93	0.02	0.05
	CWH, days 3–88 (summer, fall)	Maximum weather station	85	0.16	11.23	0.09	0.0055
		Minimum weather station	85	0.66	6.12	0.37	<0.0001
		Mean weather station	85	0.35	8.25	0.19	<0.0001
Soil	CWH, days 120–461 (fall, winter, spring, summer)	Maximum weather station	341	0.47	2.01	0.64	<0.0001
		Minimum weather station	341	0.63	3.94	0.71	<0.0001
		Mean weather station	341	0.58	2.29	0.73	<0.0001
Internal, above-ground carcass	SBS, days 3–22 (summer)	Maximum daily air	19	0.42	9.84	0.79	<0.0001
		Minimum daily air	19	0.29	4.83	0.37	0.001
		Mean daily air	19	0.4	6.4	0.83	<0.0001
	CWH, days 3–18 (summer)	Maximum weather station	15	0.26	11.46	0.059	0.38
		Minimum weather station	15	0.94	1.8	0.37	0.016
		Mean weather station	15	0.47	6.74	0.14	0.16

TABLE 2—*Decompositional stages of pig carcasses buried and left above ground in the Coastal Western Hemlock (CWH) and Sub-boreal Spruce (SBS) biogeoclimatic zones of British Columbia.*

		Time Taken to Reach Each Stage of Decomposition (in days)					
Zone	Treatment	Fresh	Primary Bloat	Secondary Bloat	Active Decay	Advanced Decay	Dry/ Remains
CWH	burial	0	<14	<45	<90	<335	+490
	above ground	0	stage not observed		<14	<45	<90
SBS	burial	0	<14	<45	<90	<490	+490
	above ground	0	stage not observed		<14	n/a	n/a

previously been collected from buried carrion, but their time of colonization was not known (27,30). Our collection of *Neobelleria cooleyi* (Diptera: Sarcophagidae) adults in pitfall traps above buried carcasses in the primary bloat stage, in the SBS zone 2 weeks after death agrees with the finding of this species on buried human bodies 20 days after death in the Prince George Forest Region (1).

In the only experimental study that used buried human cadavers, Calliphoridae and Sarcophagidae were collected from the cadavers but were identified only to the family level (16). Other studies have been done on human bodies exhumed from actual homicide cases, or from anthropological studies (23,27,29–34). The study using buried human cadavers (16) utilized six cadavers each buried at a different time of year. Unfortunately this work suffered from many problems, including no replication; two cadavers with missing brains and internal organs that would have eliminated bloat-causing gut fauna; burial at different times after death; some bodies clothed and others not clothed, which can influence insect succession (19); burial at different depths and only 1.5 m apart, too close for insects to distinguish them as separate; proximity of many other bodies; and repeated exhumation and re-burial.

Our collection of adult *Leptocera* sp. and *Dohrniphora* sp. in pitfall traps above bloated buried carcasses in both zones and the recovery of larval *Dohrniphora* sp. from buried carcasses during secondary bloat in the CWH zone and pupae of *Leptocera* sp. from buried carcasses during the active stage in both zones (Table 3) agrees with the results of another study (17) which collected adult *Leptocera* sp. and *Dohrniphora incisuralis* (Loew) during the bloat stage and larvae of these two species at the onset of the active stage in North Carolina. One study (29) stated that Phoridae colonized buried dog carrion at 2 months after death, but another (31) did not find *Phora aterrima* on buried carrion until a year after death. Two other studies (27,30) noted the presence of Phoridae on buried bodies, but did not indicate a time of colonization. The occurrence of larval Heleomyzidae on buried carcasses in the SBS zone during the active decay stage, at 3 months after death (Table 3), is in agreement with previous (27) documentation of heleomyzids on buried carrion.

During heterotrophic succession, entomophagous insects tend to increase as the succession continues (13,35). The most common predators in the soil are beetles in the families Carabidae and Staphylinidae (24,26). Although the great majority of insects collected in this study were saprophagous, generalist predatory carabid, histerid and staphylinid beetles, as well as ants and wasps, were well represented on both above-ground and buried carcasses in both zones,

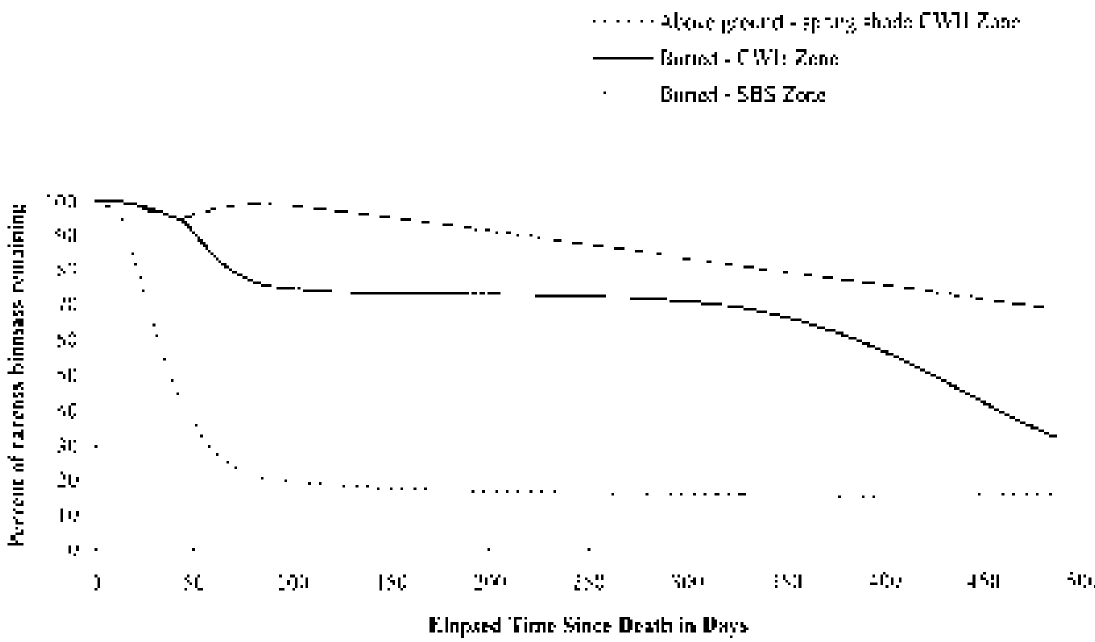

FIG. 5—*Percent weight loss during decomposition, in above-ground and buried pig carcasses in the Coastal Western Hemlock (CWH) and Sub-boreal Spruce (SBS) biogeoclimatic zones of British Columbia Data from above-ground carcasses taken from Dillon and Anderson (19).*

probably feeding on dipteran eggs and larvae. We also collected elaterid beetles but this family has both carnivorous and saprophytic members (24,26). Predaceous dipteran larvae, *Ophyra leucostoma* and *Hydrotaea* sp. were collected on buried carcasses, the former in the SBS zone and the latter in both zones. *Nasonia vitripennis* and *Atractodes* sp., both parasitoids of immature dipterans, were attracted to both above-ground and buried carcasses.

Staphylinidae beetles are commonly found on buried carrion (16,27,30). In the Vancouver, Cariboo and Prince Rupert Forest Regions of British Columbia, various species of Staphylinidae were collected from buried human bodies from 5 days to 5 months after death (1). They were the predominant beetles collected on buried carrion in both zones throughout the 16-month period (Table 3). We found adult *Philonthus* sp. at primary bloat, much earlier than observed in another study (31), which stated that *Philonthus ebeninus* did not arrive on buried bodies until 2 years after death in France. In North Carolina, Staphylinidae were not present on buried pigs until the active stage (17), also later than in our study. Other prominent beetles were the silphids *Nicrophorus defodiens* and *Nicrophorus investigator* (Table 3). We initially collected them from buried carcasses during the primary bloat stage, in both zones. These results contradict a previous report that silphids could not locate carrion buried under 4 cm of sand (36).

The carpenter ant *Camponotus herculeanus* was the most common hymenopteran we collected. It occurred during the primary bloat stage on buried carcasses in both biogeoclimatic zones (Table 3). In North Carolina, other ant species were collected during the fresh and bloat stages from a pig carcass in a simulated coffin (17). Perpetrators rarely bury homicide victims in coffins and this scenario would influence the ability of insects to reach the carcass.

The occurrence of certain species of insects on buried carcasses at predictable times in the succession suggests that these species can be used as indicators of the elapsed time since death of a buried homicide victim.

The family Muscidae contains some potential indicator species that could be used to calculate the elapsed time since death. At 6 weeks after death, pupal *Hydrotaea* sp. and *Morellia* sp. were collected from buried carcasses in both zones, and pupal *Ophyra leucostoma* were collected from buried carcasses in the SBS zone (Table 3). If the developmental rates for these three muscids were known at particular temperatures, the time taken for immatures to reach the pupal stage could be calculated, thus giving a minimum postmortem interval.

Fanniid flies are usually considered to colonize cadavers late in the succession of insect species. However, pupal *Fannia cannicularis* were collected from buried carcasses at 2 weeks after death in the SBS zone and larval and pupal *F. cannicularis* were collected from buried carcasses at 6 weeks after death in the CWH zone, possibly due to the wet condition of the buried carcasses which is preferred by members of this family. Therefore, when using this species to predict a minimum postmortem interval, it is important to note its early arrival on buried carrion, as well as the difference in arrival times between the two zones.

Larvae of *Dohrniphora* sp. were collected on buried carcasses in the CWH zone at 6 weeks after death. The presence of immatures of this species gives a minimum postmortem interval of >2 weeks after death and <6 weeks after death for the CWH zone.

Pupae of *Leptocera* sp. were collected on buried carcasses in both zones at 3 months after death. The presence of immatures of this species gives a minimum postmortem interval of >6 weeks after death and <3 months after death. Pupal cases of *Leptocera* sp. were collected on buried carcasses in the CWH zone at 11 months after death. The presence of pupal cases of this species gives a minimum postmortem interval of >3 months and <11 months after death for the CWH zone.

Since most of the coleopteran species collected on the buried carcasses are general predators, they cannot be used to determine a postmortem interval.

Recommendations

1. When using the succession of insect species to determine the elapsed time since death of a buried homicide victim, it is

TABLE 3—*Succession of insect species collected through exhumation (Ex) and pitfall traps (Pt) on buried and above-ground pig carcasses in the Coastal Western Hemlock (CWH) and Subboreal Spruce (SBS) biogeoclimatic zones of British Columbia.*

Decomposition Stage	Order and Family	Genus and species	CWH Zone Buried Ex	CWH Zone Buried Pt	CWH Zone Above-ground Ex	CWH Zone Above-ground Pt	SBS Zone Buried Ex	SBS Zone Buried Pt	SBS Zone Above-ground Ex	SBS Zone Above-ground Pt
Primary bloat	Diptera: Calliphoridae	*Lucilia illustris* (Meigen)			—	—	[illegible]		—	—
		Phormia regina (Meigen)		A						
		Protophormia terraenovae (Robineau-Desvoidy)			—	—		A	—	—
		Calliphora vomitoria (L.)		A			[illegible]			
		Cynomyopsis cadaverina Robineau-Desvoidy		A	—	—		A	—	—
		Calliphora terraenovae Macquart						A		
		unknown sp.			—	—	I			
	Muscidae	*Hydrotaea* sp.		A				A	—	—
		Ophyra leucostoma (Wied.)			—	—		A	—	—
		unknown sp.					I			
		unknown sp.			—	—	I		—	—
	Sphaeroceridae	*Leptocera* sp.		A	—	—		A	—	
	Fanniidae	*Fannia canicularis* (L.)		A			I	A		
	Phoridae	*Megaselia* sp.		A	—	—		A	—	—
	Sarcophagidae	*Sarcophaga* sp.		A	—	—				
		[illegible] (Meigen)						A	—	—
	Piophilidae	unknown sp.	[illegible]		—	—	[illegible]		—	—
	Coleoptera: Staphylinidae	*Philonthus* [illegible] (Gmelin)	A				A			
		Philonthus [illegible] Horn	A				A		—	—
		Tachinus [illegible] Erichson	A		—	—	A		—	—
		Philonthus [illegible] Nordmann					A			
		Staphylinidae			—	—	[illegible]		—	
	Silphidae	*Nicrophorus defodiens* (Mannerheim)		[illegible]	—	—		A		
		Nicrophorus investigator Zetterstedt		A				A	—	—
		Nicrophorus sp.					I			
	Leiodidae	*Catops basilaris* Say		A	—	—	A			
		Catops sp.					I		—	—
	Histeridae	[illegible]	I		—	—			—	—
	[illegible]	unknown sp.			—		I			
	Hymenoptera: [illegible]	[illegible] (Müller)	A					A	—	—
	Formicidae	*Camponotus* [illegible]		A	—	—		A	—	
		unknown sp.						A		
Secondary bloat	Diptera: Calliphoridae	*Lucilia illustris* (Meigen)		A			[illegible]	A	—	—
		Phormia regina (Meigen)			—	—		A	—	
		Protophormia terraenovae (Robineau-Desvoidy)						A		
		Calliphora vomitoria (L.)			—	—	[illegible]	A	—	
		[illegible]			—	—	[illegible]			
		unknown sp.					[illegible]			
	Muscidae	*Hydrotaea* sp.	[illegible]	A		—	[illegible]	A	—	—
		Ophyra leucostoma (Wied.)		[illegible]	—	—	[illegible]		—	
		[illegible] sp.	[illegible]				[illegible]			
		unknown sp.	[illegible]		—		[illegible]		—	—
		unknown sp.	[illegible]		—	—	[illegible]		—	

TABLE 3—*Continued*

Decomposition Stage	Order and Family	Genus and Species	CWH Zone Buried P1	CWH Zone Buried P2	CWH Zone Exposed P1	CWH Zone Exposed P2	SBS Zone Buried P1	SBS Zone Buried P2	SBS Zone Exposed P1	SBS Zone Exposed P2
Secondary Stage	Diptera Sphaeroceridae	*Leptocera* sp.	A	A	-	-		A	-	
	Fanniidae	*Fannia canicularis* (L.)	L, P	A	-		L, P	A		
	Phoridae	*Conicera* sp.	L	A	-	-		A		
	Piophilidae	*Stearibia nigriceps* (Meigen)			-	-		A	-	-
	Scathophagidae	*Scathophaga* sp.						A		-
		[illegible] (Parker)			-	-		A		
	Rhagionidae	unknown sp.			-	-			-	-
	Coleoptera Staphylinidae	*Philonthus cruentatus* (Gmel.)		A				A		-
		Philonthus [illegible] Horn		A	-	-	A		-	
		Tachinus [illegible] Erichson			-	-	A		-	-
		Philonthus furvus (Nordm.)					A			-
	Staphylinidae	*Staphylinus* (larvae)	L				L		-	-
	Silphidae	*Nicrophorus defodiens* (Mann.)		A	-	-		A		
		Nicrophorus investigator Zetterstedt		A	-	-	A		-	-
		Nicrophorus sp.	L		-	-	L		-	
	Leiodidae	*Catops basilaris* Say	A	A		-	A		-	-
		Catops sp.	L							-
	Histeridae	*Hister* [illegible] Say			-	-		A	-	
		unknown sp.				-	L		-	-
	Carabidae	[illegible] Casey					A			
	Histeridae	[illegible]	L		-	-	L		-	-
	Hymenoptera Pteromalidae	*Nasonia vitripennis* (Walker)		A				A	-	-
	Vespidae	*Dolichovespula maculata* (L.)						A		
		unknown sp.			-	-		A	-	-
	Formicidae	*Camponotus herculeanus* (L.)	A					A	-	-
		unknown sp.			-	-		A		
Active Decay	Diptera Calliphoridae	*Lucilia illustris* (Meigen)		A	L, P					A
		Phormia regina (Meigen)			L, P	A			L, P	A
		Protophormia terraenovae (Robineau-Desvoidy)			P				L	A
		Calliphora vomitoria (L.)					P			
		unknown sp.					L			
	Muscidae	*Hydrotaea* sp.					L, P			A
		Ophyra leucostoma (Wied.)					L, P			
		Muscina sp.					P			
		unknown sp.					L			
	Sarcophagidae	unknown sp.					L		L	
	Sphaeroceridae	*Leptocera* sp.	P				P			A
	Fanniidae	*Fannia canicularis* (L.)	L, P				L, P	A		A
	Phoridae	*Conicera* sp.		A						A
	Heleomyzidae	unknown sp.					L			
	Coleoptera Staphylinidae	*Philonthus furvus* (Nordm.)		A	A					A
		Tachinus [illegible] Erichson	A				A			A
		Aleochara [illegible] (Gravenhorst)				A				A
		Creophilus maxillosus (L.)			A				A	
		Philonthus cruentatus (Gmel.)		A						A
		Philonthus [illegible] Horn							A	
		Staphylinus (larvae)	L		L					
	Silphidae	*Nicrophorus defodiens* (Mann.)		A	A					A
		Nicrophorus investigator Zetterstedt		A						

TABLE 3—*Continued*

Decomposition Stage	Order and Family	Genus and species	CWH Zone				SBS Zone			
			[illegible]		[illegible]		[illegible]		[illegible]	
			Ex	Pt	Ex	Pt	Ex	Pt	Ex	Pt
Active Decay	Coleoptera: Silphidae	*Thanatophilus lapponicus* (Herbst)								A
	Leiodidae	*Catops basilaris* Say	A	A		A	A			A
		Catops sp.	L				L			
	Carabidae	*Carabus* sp.								
	Histeridae	[illegible]	L				L			
	Hymenoptera: Vespidae	*Dolichovespula maculata* (L.)								A
		unknown sp.								A
	Formicidae	*Camponotus herculeanus* (L.)								A
		unknown sp.	A	A						
	[illegible]	[illegible] sp.								A
Advanced decay	Diptera: Calliphoridae	[illegible] (Meigen)				A				-
		[illegible] (Meigen)				A			-	-
	Muscidae	*Ophyra leucostoma* (Wied.)	A							
		Hydrotaea sp.				A			-	-
		unknown sp.			L				-	-
		unknown sp.			L					
	Sphaeroceridae	*Leptocera* sp.	PC, A			A			-	-
	Fanniidae	*Fannia canicularis* (L.)	P	P	P	A				-
	Phoridae	[illegible] sp.				A			-	-
	Piophilidae	*Stearibia nigriceps* (Meigen)				L, A				
	[illegible]	unknown sp.	L						-	-
	Coleoptera: Staphylinidae	[illegible]		A	A				-	-
		[illegible]	A		L		A		-	-
		[illegible]	A		A					
		Staphylinidae (order)			L				-	-
	Silphidae	*Nicrophorus defodiens* (Mann.)		A					-	-
	Leiodidae	*Catops basilaris* Say	A	A	A					
		Catops sp.	L		L				-	-
	Hydrophilidae	*Sphaeridium* [illegible]			A					
	Histeridae	unknown sp.	L						-	-
	Elateridae	[illegible] (Brown)			A				-	
		[illegible] (order)	L		L					
	Agyrtidae	[illegible] sp.				L			-	-
	Hymenoptera: Pteromalidae	*Nasonia vitripennis* (Walker)				A			-	
	Formicidae	*Camponotus herculeanus* (L.)				A				-
		unknown sp.				A			-	-
Dry Remains	Diptera: Muscidae	*Hydrotaea* sp.	-	-		A	-	-	-	
		unknown sp.			L					
	Sphaeroceridae	*Leptocera* sp.	-	-	L	A	-	-	-	-
	Fanniidae	*Fannia canicularis* (L.)	-	-	L	P	-	-	-	
	Piophilidae	unknown sp.								
	Coleoptera: Staphylinidae	[illegible]	-		A		-	-	-	-
		Staphylinidae (order)	-	-			-	-	-	
	Silphidae	*Nicrophorus defodiens* (Mann.)				A				
		Nicrophorus investigator Zetterstedt				A	-	-	-	
	Histeridae	unknown sp.								-

Note: A = adults, P = pupae, PC = pupal cases, L = larvae, E = eggs, - = no collection possible.

important to have a database of insect succession for that particular ecosystem. Therefore; ideally, a successional database for each major biogeoclimatic zone should be established.
2. Since dipteran species other than those from the family Calliphoridae could be used as indicator species, more studies on the developmental rates of these species would allow the estimation of a more precise postmortem interval.
3. When using the developmental rates of early successional dipteran species to determine the elapsed time since death of a buried homicide victim, a datalogger should be placed in the soil for comparison with the nearest weather station. If the weather station records soil temperature, this should be used instead of ambient air temperature.
4. Although depth of burial was not examined in this study, it probably affects the succession of insect species on the carcasses. Therefore, more research should be done to determine how the depth of burial influences insect succession.

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