

Decomposition and insect succession on cadavers inside a vehicle environment

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Abstract This study presents differences in rate of decomposition and insect succession between exposed carcasses on the soil surface and those enclosed within a vehicle following carbon monoxide (CO) poisoning. Nine 45-kg pigs were used as models for human decomposition. Six animals were sacrificed by CO gas, half of which were placed within the driver's side of separate enclosed vehicles and half were placed under scavenger-proof cages on the soil surface. A further three animals were sacrificed by captive headbolt and placed under scavenger proof cages on the soil surface. The pattern of insect succession and rate of decomposition were similar between surface carcasses within trials regardless of the mode of death. Progression through the physical stages of decomposition was 3–4 days faster in the enclosed vehicle due to higher temperatures there compared to external ambient temperatures. Patterns of insect succession also differed between the vehicle and surface treatments. Carcass attendance by representatives of the Calliphoridae was delayed within the vehicle environment by 16–18 h, while oviposition was not observed until 24–28 h following death. In contrast, attendance by Calliphoridae at surface carcasses occurred within 1 h of death, and oviposition occurred within 6–8 h of death. Typical patterns of insect succession on the carcasses were also altered. Carcass attendance by representatives of the Coleoptera occurred during the bloat stage of

decomposition at surface carcasses but was delayed until the onset of wet decomposition (as defined by carcass deflation and breakage of the skin) within the vehicle environment. This study provides baseline data outlining the decomposition patterns of a carcass enclosed within a vehicle following CO poisoning in Western Australia. Understanding how variations in decomposition situations impact on the rate of decomposition and patterns of insect succession is essential to obtaining an accurate estimate of minimum post-mortem interval (PMI).

Keywords Carbon monoxide poisoning · Decomposition · Forensic entomology · Insect · Suicide · Vehicle

Introduction

Decomposing remains provide a temporary, changing habitat which can support a large microorganism and arthropod community [1]. Invasion of a body by insects and other arthropods occurs soon after death and generally follows a predictable sequence [2, 3]. While geographically specific, the pattern of arthropod succession on a cadaver has been well documented by forensic researchers globally [4–7]. Where the pattern of arthropod succession on a cadaver is known, analysis of the arthropod fauna can be used to estimate the post-mortem interval (PMI). This aspect of the science, forensic entomology, is regularly used by police services in forensic investigations worldwide in cases where the time of death is unknown [8].

When using arthropods to estimate PMI, it is important to consider the factors which may affect the rates and patterns of insect invasion on the body. The influence of environmental conditions, including temperature, humidity

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and rainfall, has been previously investigated [9]. Circumstances surrounding the death scenario may also affect the initial time of appearance of insects on a body [10]. Drugs and toxins present in decomposing tissue have been shown to affect oviposition of adult flies and the rate of development of fly larvae [11, 12]. The burning and hanging of carcasses have also been studied to determine their effect on decomposition and, subsequently, arthropod succession [1, 3]. Wrapping a body in several layers of blankets can also cause a delay of up to several days in blowfly invasion of a corpse by reducing access to the body [9, 10].

One scenario which has not previously been well documented is the decomposition of a cadaver in a closed vehicle environment where fly access is restricted. A study in Louisiana attempted to estimate the time delay preceding blow fly strike on a body placed inside a vehicle trunk compartment [10]. Although preliminary results suggested a delay of 3 days, conclusive results have not yet been published. Furthermore, decomposition in a trunk compartment is not comparable to decomposition within the vehicle interior, yet investigators are often faced with such cases in relation to suspected suicides. Intentional inhalation of carbon monoxide (CO) gas from the exhaust of a vehicle accounts for a large number of suicidal deaths within Australia each year [13, 14]. In most instances, the victim is found within the vehicle with a hose leading from the exhaust pipe through the back window to the interior of the sealed vehicle [13, 15].

Carbon monoxide is a colourless, odourless gas which is highly poisonous and can be fatal in large concentrations. Death by CO poisoning is commonly the result of deliberate exposure to the gas within a confined space, such as a vehicle [16–18]. Death occurs as a result of oxygen deprivation at a cellular level whereby the binding of CO to blood haemoglobin in place of oxygen reduces the oxygen-carrying capacity of the blood [17, 19, 20]. Even low concentrations of inhaled CO (1500 ppm) over a prolonged period can result in a lethal concentration of carboxyhaemoglobin in the blood [19, 20]. Death can occur in less than 20 min from initial exposure [17, 21, 22].

Many suicides conducted in vehicles occur in isolated areas, and the vehicle is parked in wooded areas for the purposes of concealment [21]. Such sites can be heavily shaded, with only minimal exposure to the sun. Detection of the vehicle may take weeks or months, during which time decomposition of the body will commence. Within such a situation, aspects of insect succession on decomposing remains may be altered as a result of the initial high concentration of CO present within the vehicle and the ability of each species to gain access to the vehicle interior.

The objective of this study was to determine the pattern of entomological succession on a decomposing carcass

placed inside a closed vehicle environment following its sacrifice by CO poisoning. The results are compared to decomposition and insect succession within an open, surface environment. The significance of the research is directly related to the requirement by police, coronial and justice systems for an accurate estimation of PMI, particularly in regards to suicide investigations.

Materials and method

The decomposition trials were conducted in a wildlife reserve situated 23 km south of Perth, Western Australia (32°10'S, 115°50'E). The study area consisted of 253 ha of coastal bushland on Bassendean sands with a Mediterranean climate and average yearly rainfall of approximately 900 mm [23, 24]. The surrounding vegetation was low, open woodland, and each site was in a wooded, partially shaded area.

The study utilised non-human corpses to mimic fly succession in a simulated suicide environment. Ethical restrictions in Australia prevent the use of human bodies in decomposition trials, and current debate among experts suggests that decomposing pigs (*Sus scrofa*) are the next most reliable model [9, 10]. Nine 45-kg pigs were used as models for human decomposition. Three animals were used per trial, and each trial was replicated three times. Within trials, two animals were euthanised in a chamber containing 99% pure CO, and the third was sacrificed by captive headbolt, as commonly utilised in abattoirs throughout Australia. The headbolt wound was immediately closed using a silicon sealant so that the wound did not present a focus for insect activity. Following death, the pigs were immediately clothed in cotton shirts and shorts.

Within 10 min death, one of the dressed, CO-sacrificed pigs was placed in the front seat on the driver's side of an enclosed vehicle. Prior to this, all vents to the vehicle were sealed. Following placement of the pig carcass within the vehicle, exhaust fumes were pumped into the interior for approximately 8 h. Exhaust fumes were produced by means of an additional vehicle with the engine idling on a full tank of unleaded petrol. The duration was based on preliminary tests of the running vehicle used and the resulting time taken for it to eventually stall when the engine was idling (unpublished data, IR Dadour). The doors and vents to the vehicle remained sealed for 5 days following death to allow for the undisturbed succession of arthropod fauna. The date of death was designated as Day 0, and on Day 5 the doors were opened for sampling and the vents unblocked. The vehicles obtained for use in this study were all sedans with a similar interior layout (Ford Fairlane, Holden Gemini and Nissan Bluebird).

The decomposition process and insect activity were recorded using an infrared video camera (Sanyo VC9212B/WCCD) bolted to the inside roof of the vehicle. This was connected to a time lapse VCR (Sanyo TLS-1600P) and programmed with a recording speed of two frames per second. Daily observations through the windows of the vehicle also provided additional information. The temperature inside the vehicle was measured and recorded using Tinytag Plus temperature data loggers (Hastings Data Loggers, Port Macquarie, NSW, Australia). An abdominal probe inserted into the abdomen of the pig post-mortem recorded changes in internal temperature of the cadaver via a connection to a Tinytag Plus data logger. All data loggers were programmed to record the minimum and maximum temperature at 30-min intervals. Unfortunately, upon retrieval of the data loggers at the completion of the study we discovered that two of them had been damaged during the study. Temperature data for the inside of the vehicle in trial 2 (autumn 2001) and the internal carcass temperature of the headbolt-sacrificed surface pig in trial 3 (autumn 2004) were lost.

The remaining two pigs, one sacrificed by CO and the other by captive headbolt, were placed directly on the soil surface approximately 10 m from the vehicle and each other, in a wooded, partially shaded site. Abdominal probes with accompanying Tinytag Plus data loggers were inserted post-mortem into the abdomen to record internal body temperatures. Each pig was surrounded by a metal cage covered with 2.5-cm mesh to protect it from large animal scavenging. The cage sides were extended 30 cm into the ground to prevent scavengers burrowing beneath the cage. Ambient temperature, humidity and soil temperatures outside of the vehicle were recorded using a Datalogger DT50 data logger (Hinc Instruments, Canning Vale, WA, Australia). The two surface carcasses acted as controls. Control animals allowed a comparison of decomposition and entomological succession in a closed vehicle environment with the same processes in an open outdoor environment during identical seasonal conditions. Two controls were used to determine whether differences in decomposition occurred based on the style of euthanasia.

Using identical methodology, this set-up was repeated three times using a total of nine animals in summer 2001, autumn 2001 and autumn 2004. Replicates were not run concurrently due to the logistics associated with obtaining a suitable vehicle for the decomposition of large animal carcasses.

Sampling occurred on a daily basis, with recordings made of the progression of decomposition, species composition and insect attendance at each carcass. For surface carcasses, sampling was conducted from Day zero. Initially, for vehicle carcasses, video recordings of the vehicle

interior and visual assessment through the transparent glass of the vehicle windows were used to identify the stage of decomposition, species composition and insect attendance at each carcass. Following the first 5 days, the door to the vehicle was opened for a 5-min period each day to allow for the collection of observed samples. Representative samples of taxa were collected from all carcasses to allow accurate identification. Previous studies have shown that sampling does not significantly alter the decomposition process [1]. Larval samples were reared through to maturity in the laboratory for ease of species identification. Emphasis was placed on the collection and identification of key indicator species for estimating PMI rather than a catalogue of all arthropod species present. Carcasses were monitored throughout decomposition until they had reached the skeletal stage.

Values are given as the mean \pm standard error; the significance level was 0.05. Analyses of variance (ANOVA) with Student-Newman-Keuls multiple-comparison test were calculated after Zar [25]. ANOVA was used to identify differences between species occurrence and diversity between trials.

Results

Decomposition progression

Five observable stages of decomposition were recognised for both surface-exposed and vehicle-enclosed carcasses: fresh, bloat, wet decomposition, dry decomposition and skeletal [26–28]. In this study, the rate of progression through these stages differed between the surface and vehicle carcasses, dependant on temperature and the decomposition environment. No differences were evident in the progression of decomposition between the surface carcasses within each trial, regardless of the mode of death (Table 1).

Fresh

This stage commences from the instant of death until the onset of bloat. In this study, the duration of this stage was the same for both surface and vehicle carcasses (Day 0–1). As expected, the temperature inside the vehicle was consistently higher than the outside ambient temperature. In all replicates, there was an initial gradual decline in internal body temperature as the carcasses began to equilibrate with the ambient temperature (*algor mortis*). However, this was less marked in the vehicle replicates than in the surface replicates due to the expected higher internal temperatures of the vehicle (Fig. 1). Discolouration of the skin (*livor mortis*) resulted from the gravitational settling of the blood

Table 1 Comparison of the progression of decomposition stages observed under three decomposition environments in three separate seasons: carcass enclosed in a vehicle simulating death by carbon monoxide (CO) poisoning, carcass exposed on the soil surface following CO poisoning and a carcass exposed on the soil surface following captive headbolt

	Stage of decomposition	Duration of decomposition stage (days since death)		
		Vehicle (CO)	Surface (CO)	Surface (headbolt)
Trial 1: Summer 2001	Fresh	1 (0–1)	1 (0–1)	1 (0–1)
	Bloat	3 (2–4)	4 (2–5)	4 (2–5)
	Wet decomposition	10 (5–14)	11 (6–16)	11 (6–16)
	Dry decomposition	19 (15–33)	20 (17–36)	20 (17–36)
	Skeletal	>Day 34	>Day 37	>Day 37
Trial 2: Autumn 2001	Fresh	1 (0–1)	1 (0–1)	1 (0–1)
	Bloat	3 (2–4)	7 (2–8)	7 (2–8)
	Wet decomposition	11 (5–15)	9 (9–17)	9 (9–17)
	Dry decomposition	21 (16–36)	23 (18–40)	23 (18–40)
	Skeletal	>Day 37	>Day 41	>Day 41
Trial 3: Autumn 2004	Fresh	1 (0–1)	1 (0–1)	1 (0–1)
	Bloat	3 (2–4)	4 (2–5)	4 (2–5)
	Wet decomposition	6 (5–10)	6 (6–11)	6 (6–11)
	Dry decomposition	16 (11–26)	19 (12–30)	19 (12–30)
	Skeletal	>Day 27	>Day 31	>Day 31

and was particularly evident in the lower legs of the carcass within the vehicle replicates.

Bloat

This stage is defined by the gradual inflation of the carcass resulting from the production of gases by anaerobic bacteria in the body and ends when the carcass eventually deflates. The duration of this stage differed between trials and between surface and vehicle carcasses within trials (Table 1). Bloat duration was consistent between vehicle carcasses in each trial (3 days). Surface carcasses remained in bloat for a longer period (4, 7 and 4 days, respectively) than vehicle carcasses. The differences in the duration of bloat in surface carcasses between trials are partially accounted for by average ambient temperature differences between trials (25.0 ± 0.61 , 17.0 ± 0.52 and $20.1 \pm 0.71^\circ\text{C}$, respectively).

Wet decomposition

This stage commences when the skin of the carcass has broken as a result of gas build-up and larval feeding. The remaining skin surface appears marbled due to putrefaction, and extensive fluid leakage is evident. No discernable patterns were evident in terms of the duration of wet decomposition between vehicle and surface carcasses. However, the duration of the wet decomposition stage was considerably shorter in trial 3 for both vehicle and surface carcasses than in trials 1 and 2 (Table 1). Differences in the

duration of wet decomposition between trials correspond closely to variations in the internal carcass temperatures throughout the wet decomposition stage (Fig. 1). For example, throughout this stage the internal carcass temperature of the vehicle pig in trial 3 ($41.5 \pm 2.74^\circ\text{C}$) was higher than that observed in trial 1 and 2 (35.7 ± 0.82 and $27.7 \pm 0.69^\circ\text{C}$, respectively).

The length of the wet decomposition stage observed in each trial was more closely related to the internal carcass temperature than ambient temperature (Table 1; Fig. 1). For example, throughout the wet decomposition stage, the internal temperatures of the surface carcasses were higher in trial 2 ($\text{Surface}_{(\text{CO})} = 28.7 \pm 0.45^\circ\text{C}$; $\text{Surface}_{(\text{Headbolt})} = 27.1 \pm 0.46^\circ\text{C}$) than in trial 1 ($\text{Surface}_{(\text{CO})} = 25.6 \pm 0.31^\circ\text{C}$; $\text{Surface}_{(\text{Headbolt})} = 24.4 \pm 0.91^\circ\text{C}$), and the duration of wet decomposition in trial 2 was shorter by 2 days despite the comparatively higher ambient temperature recorded throughout trial 1. Extensive larval aggregations of both beetles and flies were observed in association with this stage, potentially contributing to the observed carcass temperature differences (see faunal succession section).

Dry decomposition

This stage is characterised by a reduction in flesh and fluid and by an abundance of the dry constituents of the carcass, predominantly skin, cartilage and bone. Differences in the time taken to progress from dry decomposition to the skeletal stage were evident between vehicle and surface pigs and

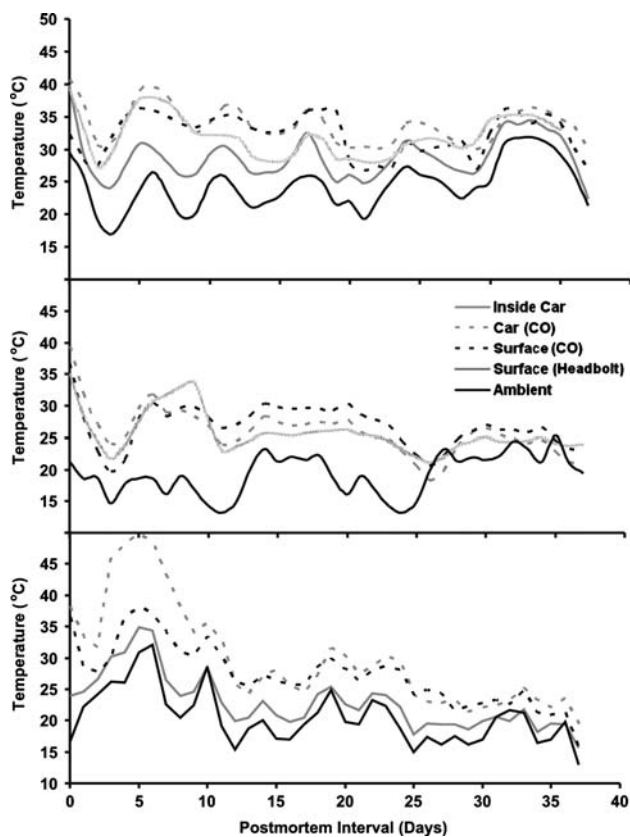


Fig. 1 Temperature recordings of ambient temperature, temperature inside the vehicle and internal temperatures of carcasses enclosed in a vehicle following death by carbon monoxide poisoning [*Car (CO)*]; exposed on the soil surface following CO poisoning [*Surface (CO)*] and exposed on the soil surface following sacrifice by captive headbolt [*Surface (Headbolt)*]. From top to bottom: trial 1 (summer 2001), trial 2 (autumn 2001) and trial 3 (autumn 2004), respectively

between the three trials. Within trials, the duration of dry decomposition was consistently shorter for the vehicle carcasses than for the surface carcasses (Table 1). A higher ambient temperature inside the vehicle was evident throughout the dry decomposition stage (Fig. 1). The duration of dry decomposition for surface carcasses was longest in trial 2 (23 days), while the progression through the dry decomposition stage in the surface carcasses of trial 1 and 3 were considerably faster (20 and 19 days, respectively).

Skeletal

This late stage is identifiable by the absence of soft tissue: only bones, cartilage and hair remain. Overall, vehicle carcasses reached the skeletal stage faster – by between 3 and 4 days – than their corresponding surface carcasses. Decomposition progressed more quickly in trial 3 for both vehicle and surface carcasses, particularly the wet decomposition stage where larval activity and abundance drives the rate of decomposition (Table 1).

Faunal succession

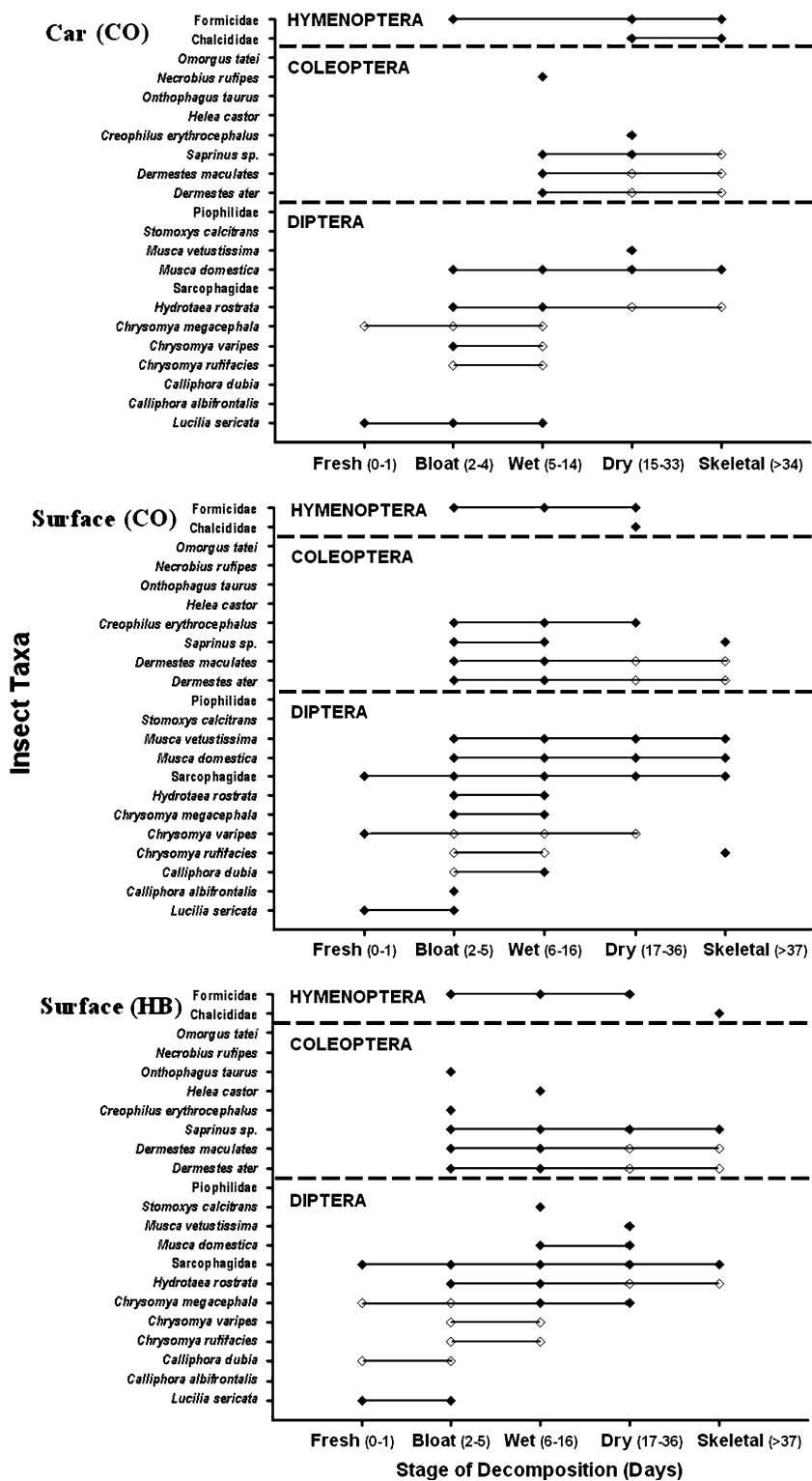
Of the predominant taxa observed in association with both surface and vehicle carcasses throughout the duration of the three trials, we identified a total of 22 arthropod taxa, representing 13 families and three orders (Table 2). Representatives of the order Diptera were the first colonisers of all nine carcasses, closely followed by representatives of the order Coleoptera as decomposition progressed. The pattern of insect succession was essentially the same between the surface carcasses, regardless of the mode of death, and the pattern of insect succession associated with the stages of decomposition was similar between trials. Differences in the timing of insect colonisation were evident between the vehicle and surface replicates within trials for all three trials (Figs. 2–4).

Based on video recordings of the vehicle interior, adult flies were observed inside the vehicle 16–18 h after death. This is in sharp contrast to the surface carcasses where flies were observed within the first hour after death. Video observations and collection of larvae from the carcasses indicated a distinct lag in the timing of oviposition between vehicle and surface carcasses. Eggs and first instar larvae of

Table 2 Taxa collected and identified from decomposition studies at Harry Waring Marsupial Reserve, south-west of Perth, Western Australia

Order	Family	Genus and species	
Diptera	Calliphoridae	<i>Lucilia sericata</i>	
		<i>Calliphora albifrontalis</i>	
		<i>Calliphora dubia</i>	
		<i>Chrysomya ruffifacies</i>	
		<i>Chrysomya varipes</i>	
		<i>Chrysomya megacephala</i>	
		Muscidae	<i>Hydrotaea rostrata</i>
			<i>Musca domestica</i>
			<i>Musca vetustissima</i>
		Sarcophagidae	Not identified beyond family
Piophilidae	Not identified beyond family		
Coleoptera	Dermestidae	<i>Dermestes ater</i>	
		<i>Dermestes maculatus</i>	
	Histeridae	<i>Saprinus</i> sp.	
	Staphylinidae	<i>Creophilus erythrocephalus</i>	
	Scarabaeidae	<i>Onthophagus taurus</i>	
	Cleridae	<i>Necrobius rufipes</i>	
	Trogidae	<i>Omorgus tatei</i>	
	Tenebrionidae	<i>Helea castor</i>	
	Hymenoptera	Chalcididae	Not identified beyond family
		Formicidae	<i>Iridomyrmex</i> sp.

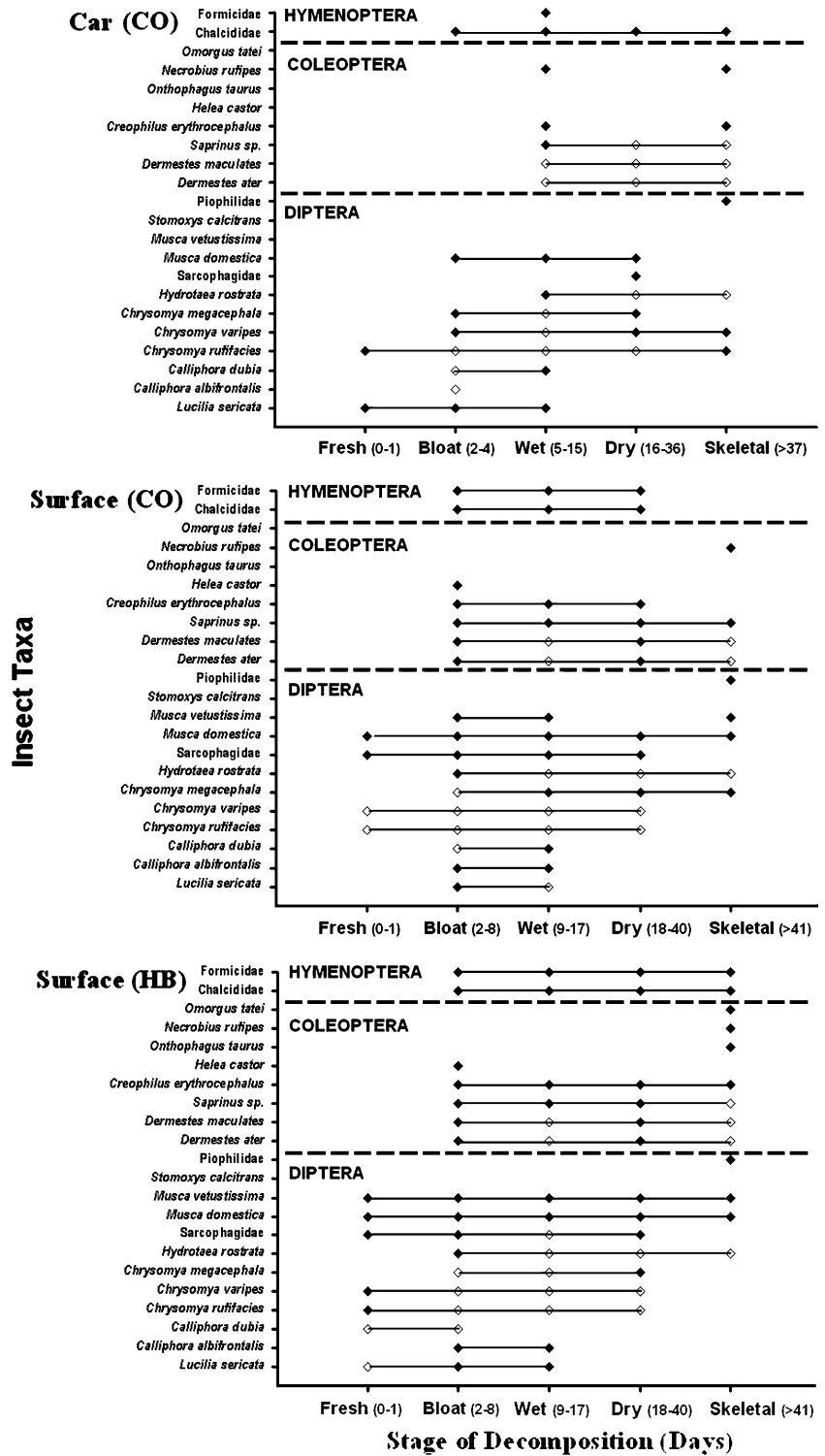
Fig. 2 Dominant insect taxa associated with the stages of decomposition of three pig carcasses sacrificed and placed at Harry Waring Marsupial Reserve, south-west of Perth, Western Australia in summer 2001. *CO* Pig sacrificed by CO poisoning, *HB* pig sacrificed by lethal headbolt, *Car* pig placed in an enclosed vehicle, *Surface* pig placed on the soil surface. *Filled diamonds* indicate the presence of adults, *open diamonds* indicate the presence of larvae with or without adults



the blowfly species, *Chrysomya megacephala* and *Calliphora dubia* (laviposition), were observed on the surface carcasses as early as the afternoon of Day 0 while second instar larvae were evident on Day 1. In comparison, eggs were not observed on the vehicle carcasses until the late morning of Day 1.

During bloat, larvae of *Calliphora albifrontalis*, *C. dubia*, *Chrysomya varipes*, *C. rufifacies* and *C. megacephala* were observed on both vehicle and surface carcasses. Sarcophagids, the largest flies, were not observed on the vehicle carcasses during either the fresh or bloat stages of decomposition but were repeatedly evident at surface carcasses in

Fig. 3 Dominant insect taxa associated with the stages of decomposition of three pig carcasses sacrificed and placed at Harry Waring Marsupial Reserve, south-west of Perth, Western Australia in autumn 2001. *CO* Pig sacrificed by CO poisoning, *HB* pig sacrificed by lethal headbolt, *Car* pig placed in an enclosed vehicle, *Surface* pig placed on the soil surface. Filled diamonds indicate the presence of adults, open diamonds indicate the presence of larvae with or without adults

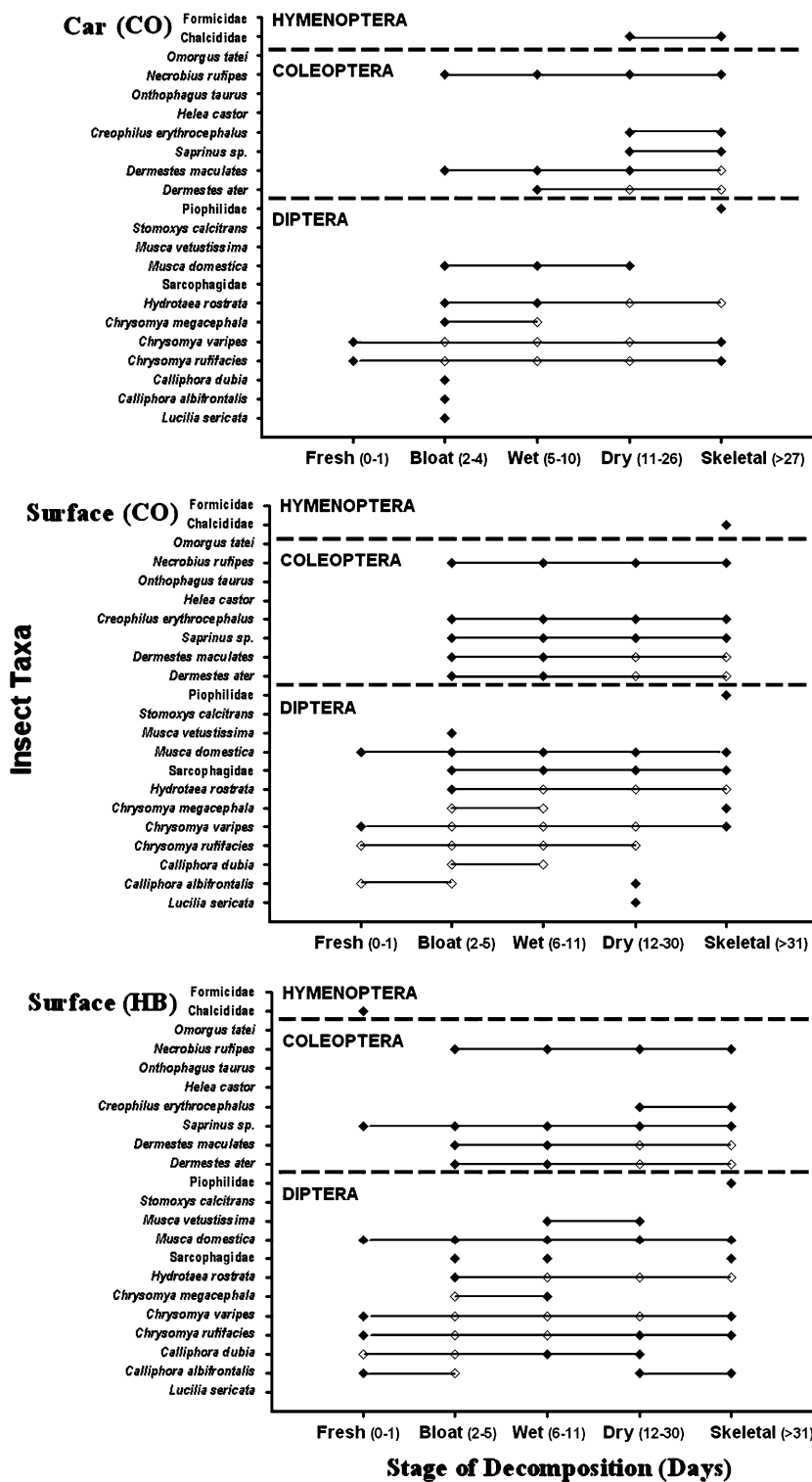


these early stages (Figs. 2–4). These early colonisers were eventually replaced by the fly species *Hydrotaea rostrata* in the latter stages of decomposition. The generation of heat by larval masses throughout both the bloat and wet decomposition stages was evident in internal carcass temperature measurements, where carcass temperatures were consistently

above ambient temperatures throughout these stages [10, 29]. As decomposition progressed, internal carcass temperatures gradually declined before equilibrating with ambient temperature (Fig. 1).

Fly emergence commenced during the wet decomposition stage in all carcasses and continued through to the

Fig. 4 Dominant insect taxa associated with the stages of decomposition of three pig carcasses sacrificed and placed at Harry Waring Marsupial Reserve, south-west of Perth, Western Australia in autumn 2004. *CO* Pig sacrificed by CO poisoning, *HB* pig sacrificed by lethal headbolt, *Car* pig placed in an enclosed vehicle, *Surface* pig placed on the soil surface. *Filled diamonds* indicate the presence of adults, *open diamonds* indicate the presence of larvae with or without adults



latter stages of the dry decomposition phase, with the exception of the black carrion fly *Hydrotaea rostrata*. Pupae of *H. rostrata* were still evident during the early skeletal stage.

Greater diversity was observed in association with the surface carcasses throughout the fresh and bloat stages of

decomposition. In contrast, the number of species observed on the vehicle carcasses lagged behind that found on the surface carcasses. Species diversity peaked on the vehicle carcasses during the wet decomposition stage, and then matched the species diversity of the surface carcasses during the latter stages of decomposition. This timing lag

was primarily represented by the Coleoptera (Figs. 2–4). Necrophagous and predatory beetles in the families Cleridae, Dermastidae, Histeridae and Staphylinidae commonly arrived on the surface carcasses during the bloat stage of decomposition but were not observed on the vehicle carcasses until the wet decomposition stage. One exception occurred in 2004 where two beetle species, *Necrobius rufipes* and *Dermestes maculatus*, were observed on the vehicle carcass on the final day of bloat.

Seasonally, the ongoing occurrence of species and overall species diversity observed in association with the carcasses in trial 1 were slightly lower than those of trials 2 and 3 ($F_{2,6} = 6.53$, $P < 0.05$). Trials 2 and 3 were conducted during the autumn while trial 1 was conducted in the summer. Average temperature differences between the three trial periods (trial 1 = $25.1 \pm 0.61^\circ\text{C}$; trial 2 = $21.0 \pm 0.71^\circ\text{C}$; trial 3 = $17.0 \pm 0.52^\circ\text{C}$) and seasonal variation in species abundance may be linked to the observed differences.

Discussion

Insect succession within Australia has been described in previous reports [30–32]. While some differences occurred as a result of zoogeographic and climatic differences between studies, the species pattern of insect succession and progression of decomposition observed for the surface carcasses of this study were similar to those noted in previous investigations [31, 33]. However, the results of this study indicate significant differences in the rate of decomposition and pattern of insect succession between a carcass enclosed in a vehicle following CO poisoning and a surface carcass in contact with the soil.

The overall progression of decomposition through the identified physical stages was 3–4 days faster within the vehicle environment than in a surface decomposition situation. The duration of both the bloat and dry decomposition stage was shorter within the vehicle compared to the surface situation. This can be partially attributed to the consistently higher temperatures experienced within the enclosed vehicle compared to the external ambient temperature outside the vehicle. At higher temperatures, microbial and insect activity increases, a factor relevant to both the bloat stage and the gradual removal of skin and tissue by beetle activity during the dry decomposition stage [34, 35]. However, no difference was observed in the duration of the wet decomposition stage between the vehicle and surface carcasses. Throughout this stage, larval activity is at a peak and, correspondingly, the internal carcass temperature was at its highest. This suggests that heat generation by larval aggregations was comparable between surface and vehicle carcasses regardless of

ambient temperature differences and that internal carcass temperature was a major contributing factor driving this stage.

A basic assumption in estimates of PMI is that the initial invasion of remains by arthropods occurs soon after death. Our findings for surface carcasses were consistent with earlier decomposition research where Calliphoridae activity was noted within the first hour of exposure at surface carcasses [3, 35]. However, this was not the case for the vehicle decomposition environment. Calliphorid flies were in evidence within the vehicle 16–18 h after death, and eggs were not observed until the late morning of Day 1 (24–28 h after death). The presence of flies and the occurrence of oviposition within the vehicle demonstrate that flies were able to gain access to the vehicle despite the closed windows and doors. Access was most likely achieved through the air vents of the vehicle, and the time spent obtaining access to the vehicle interior would likely have contributed to the observed delay in fly attendance and oviposition. While the presence of CO and its slow dissipation over time within the vehicle may well have compounded the observed delay, a similar study of decomposition within an enclosed vehicle following sacrifice by a headbolt (not CO) is consistent with these findings in relation to carcass attendance (unpublished data, IR Dadour). Further, death by CO poisoning did not alter the observed pattern of insect succession or rate of decomposition in surface carcasses. Surface decomposition following sacrifice by headbolt or CO poisoning was similar within trials.

The results of this study identify the need to incorporate a 24- to 28-h delay for oviposition by Calliphoridae when estimating PMI for situations in which the body is discovered within an enclosed vehicle. Attendance by adult beetles was also different between surface and vehicle carcasses with the attendance of representatives of the order Coleoptera delayed until the wet decomposition stage within a vehicle environment. In contrast, beetles were observed during the bloat stage of surface carcasses, although larvae were not observed until the wet stage of decomposition. A delay needs to be considered when estimating PMI based on larval age and patterns of insect succession for enclosed vehicle situations.

The accuracy of a PMI estimation depends on available knowledge of insect biology and behaviour in relation to the use of decomposing remains as a food resource. Knowledge pertaining to surface decomposition cannot reliably be applied to alternative situations often encountered in homicide/suicide cases. Previous studies have reported that the circumstances of decomposition, such as hanging and wrapping of the body, can impact on the pattern of insect succession and the progression of decomposition [3, 9]. Our findings with regard to death

within an enclosed vehicle have also highlighted the uniqueness of each situation. Understanding how such situations impact on decomposition and insect succession is necessary to obtain an accurate estimate of PMI. This study provides baseline data outlining the decomposition patterns of a carcass enclosed within a vehicle following CO poisoning for the accurate estimate of PMI in Western Australia. While the data presented here can be used to improve the accuracy of PMI estimates in vehicle-related death situations, further work is needed to accurately predict internal vehicle temperature when presented with the diversity of vehicle models and their respective thermal properties.

Educational message

1. The pattern of insect succession and rate of decomposition was similar between surface carcasses regardless of the mode of death (CO poisoning vs. captive headbolt).
2. Patterns of insect succession differed between vehicle and surface carcasses.
3. Decomposition was 3–4 days faster for carcasses within an enclosed vehicle compared to surface decomposition.
4. Carcass attendance by representatives of the Calliphoridae was delayed for vehicle carcasses by 16–18 h.
5. Fly oviposition occurred within 6–8 h following death for surface carcasses but was not observed until 24–28 h following death for vehicle carcasses.

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