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Arthropod Succession Patterns onto Burnt Carrion in Two Contrasting Habitats in the Hawaiian Islands

REFERENCE: Avila FW, Goff ML. Arthropod succession patterns onto burnt carrion in two contrasting habitats in the Hawaiian Islands. J Forensic Sci 1998;43(3):581–586.

ABSTRACT: Decomposition studies were conducted using carcasses of domestic pigs, *Sus scrofa* L., one burned and the other unburned (the control) to determine effects of burning on arthropod succession patterns. The burnt carcass corresponded to a CGS level #2 burn victim. The studies were conducted in two contrasting habitats, both on the island of Oahu. The first was conducted in a xerophytic habitat from 1 Sept. 1995 through 1 Oct. 1995 while the second was conducted in a rainforest habitat from 29 April 1996 to 28 May 1996. No marked differences were noted in arthropod fauna present or the duration of the stages of decomposition between the carcasses at either site. The major oviposition by flies of the family Calliphoridae occurred one day earlier on the burnt carcass than the control carcass at Diamond Head and four days earlier at Lyon Arboretum. This resulted in all successional waves onto the burnt carcass occurring one day earlier at Diamond Head and four days earlier at Lyon Arboretum. These differences could alter a postmortem interval estimate based on arthropod succession patterns by up to 24 hours and 4 days, respectively.

KEYWORDS: forensic science, forensic pathology, entomology, Diptera, oviposition, arthropod succession, postmortem interval, decomposition

Decomposing remains provide a temporary microhabitat offering a progressively changing food source to a wide variety of organisms ranging from bacteria and fungi to vertebrate scavengers (1). Arthropods constitute a major portion of this fauna, with the insects as the predominant group, both in terms of diversity of taxa and numbers of individuals present. The initial invasion of the remains starts the biological clock that is interpreted to give a postmortem interval estimate. Forensically significant conclusions often are drawn by determining the point in the colonization process by local arthropod fauna represented by collections taken from the corpse (2). A basic assumption in this process is that arthropod invasion will occur soon after death (3). This may not always be the case, as there are factors influencing invasion of the remains which must be considered.

Adverse climatic factors, such as cloud cover, temperature, and rainfall, may inhibit or completely stop adult fly activity (1). Drugs and toxins in decomposing tissues have also been shown to affect the oviposition by adult flies and the subsequent development of fly larvae. Goff and co-workers (4) investigated the effects of cocaine on the rate of development of the sarcophagid *Boettcherisca peregrina.* In this study, lethal dosages of cocaine in decomposing tissues were found to significantly increase the rate of development of the larvae feeding on the tissues. Similar studies were conducted with heroin (5), which showed similar effects during larval stages. Concealing the remains can also delay invasion by flies for varying periods. Goff (6) discussed an experimental determination of the period of delay for remains wrapped in blankets. Although many studies have been conducted on factors influencing invasion of remains, there are no published studies dealing with alteration of arthropod succession patterns by the burning of a corpse. The present study compares the rates of decomposition and patterns of arthropod succession between two carcasses, one burned, the other unburned. The extent of burn injury was classified according to the Crow and Glassman Scale (CGS) (7). While the results of this study are preliminary and additional studies are indicated, some significant differences were observed and are detailed here.

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Received 9 June 1997; and in revised form 20 Oct. 1997; accepted 27 Oct. 1997.

Study Site

The first field study was conducted inside of Diamond Head Crater on the southern coast of the island of Oahu, Hawaii from 1 to 30 Sept. 1995. Diamond Head, a dormant volcano, is approximately 232 m high at the rim and 1.3 km in diameter. The interior is a semi-arid tropical habitat with xerophytic vegetation consisting primarily of grasses and dense strands of haole koa, *Leucaena chilensis.* Annual rainfall is 102 cm and delivered primarily from winter storms; negligible rainfall due to tradewind showers occurs during other times of the year. Sanitation around the few buildings of the Hawaii National Guard and Federal Aviation Administration is excellent, and synanthropic flies associated with decomposing animal carrion are not present in large numbers. There are, however, enough feral cats, mongooses, and birds to maintain a population of carrion frequenting arthropods inside the crater.

The second study took place inside of Harold L. Lyon Arboretum, situated at the head of Manoa Valley. This study was conducted from 28 May 1996 to 28 June 1996. The arboretum receives about 318 cm of rain annually from winter storms and year-round trade winds. The arboretum is located at the interface of two vegetation zones: closed guava forest and closed ohia lehua rainforest. The closed guava forest is characterized by guava, *Psidium guajava* L., kukui, *Aluerites moluccana* Willd., and false staghorn fern, *Dicranopteris linearis* (Birm.). The closed ohia lehua rainforest is characterized by ohia lehua, *Metrosideros collina* (Forst.), Cooke pine, *Araucaria collumnaris* (Forst.), and hapu'u, *Cibotium splendeus* (Gaud.). A portion of the arboretum has been extensively landscaped and is open to the public. The decomposition study was conducted in an area which had not been disturbed. Vegetation at the site consisted of both introduced and endemic plant species. A visitors' center, workers' cottages, and a caretaker's home are located at the base of the arboretum. Sanitation around the arboretum is good and the number of synanthropic flies is low. Feral pigs, cats, dogs, rats, and birds maintain a population of carrion associated arthropods in the area.

Materials and Methods

The carcasses of the domestic pigs, *Sus scrofa* L., were used at both study sites. These animals were obtained dead from the Department of Animal Science, University of Hawaii College of Tropical Agriculture and Human Resources. At Diamond Head, two pigs weighing 24.5 kg and 26.8 kg were used. At Lyon Arboretum, two pigs weighing 15.5 kg and 15.6 kg were used. These pigs were killed 36 h before the initiation of the study and placed immediately into a freezer. For each study, the carcasses were removed from the freezer 12 h prior to placement in the field and held in the laboratory in sealed, double plastic bags to allow for thawing with no exposure to arthropod activity. The carcasses were then transported to the study sites in these sealed plastic bags to prevent onset of arthropod activity. At Diamond Head, the 26.8 kg carcass was doused with 3.8 L (1 gal) of gasoline to give a CGS level #2 burn. At Lyon Arboretum, the 15.5 kg carcass was doused with 1.9 L (0.50 gal) gasoline to produce a CGS level #2 burn. The carcasses were then ignited and allowed to burn while the other carcasses were left untouched. At each site both carcasses were placed on welded wire mesh weigh platforms of a 2.54 cm^2 mesh on the ground. This size mesh in previous studies (8,9) has been shown to allow for adequate contact between the carcass and ground for normal invasion of soil-dwelling arthropods. Exclosure cages of the same material were placed over the carcasses to prevent disturbance by vertebrate scavengers. Sites for the carcasses were 10 m apart. For both studies, carcasses were checked twice a day for the first 10 days of the study, then once a day for the remainder of the study. At each visit, carcass weights were taken with a handheld scale to determine the rate of biomass removal. Internal temperatures were recorded with a digital thermometer using penetration probes inserted into the anus and abdomen. Daily ambient temperatures were obtained from a maximum-minimum thermometer set up near the carcasses, and rainfall was measured with a rain gauge set up near the site. A hygrothermograph was also present at the site to record ambient temperatures and relative humidity.

During each observation, arthropod activity was observed first, and then representative specimens were collected using insect nets and by hand. Specimens collected were taken to the laboratory for identification and preservation. To determine the soil fauna, soil samples were taken from beneath each carcass starting from day 12. From day 12 to 16, soil samples 10 cm in diameter and 3 to 5 cm deep were removed from beneath the carcass. From day 17 to 30, soil samples were collected every other day. Results of earlier studies indicated that this level of sampling would not impact the normal pattern of arthropod succession (9). Soil samples were processed in a Berlese-Tullgren funnel for 24 h to extract arthropods and other soil-dwelling invertebrates. Carcasses were photographed during each visit to record physical changes during the decomposition process.

Results

The burnt carcasses at both sites corresponded to a CGS level #2 burn victims (7). This defines a body that may be recognizable but most often exhibits a varying degree of charring. The bodies of the carcasses were intact with the head, back, and legs receiving the most charring. The burnt carcass at Lyon Arboretum received more charring than did the carcass at Diamond Head. The burning also resulted in cracks in the skin of the carcasses on those areas most charred.

Based on previous studies (8–10), four stages of decomposition were recognized: fresh, bloated, decay, and postdecay. The remains stage was not reached at either site during this study. A total of 66 arthropod taxa were recovered from the carcasses at both sites during this study (Table 1). Duration of the stages and the predominant taxa are given in Tables 2 and 3.

At Diamond Head the arthropod fauna present was basically the same for both burnt and control carcasses. Adult Calliphoridae were the first insects to arrive, within minutes of exposure of the carcasses. While some oviposition occurred immediately on both carcasses, major oviposition by adult Calliphoridae was observed one day earlier on the burnt carcass (day 2) and, consequently, the presence of first instar larvae was observed one day earlier. Two species of Calliphoridae were the predominant maggots observed: *Chrysomya megacephala* and *Chrysomya rufifacies.* Both of these species were present until the later stages of decay, when *C. rufifacies* became the predominant species. The final observation of *C. rufifacies* maggots occurred on day 9 on the burnt carcass and day 10 on the control carcass. The beetles in the families Dermestidae, Histeridae, and Staphylinidae were first observed associated with the carcass between days 3 and 6. Adult Histeridae and Staphylinidae were predatory on maggots of both *Chrysomya* species. The Dermestidae are primarily associated with the postdecay stage, where they feed on dried skin, muscle, and cartilage tissues. Dermestidae larvae first appeared on day 9 for the burnt carcass and day 10 for the control carcass.

At Lyon Arboretum, as at Diamond Head, the arthropod fauna observed was also basically the same for both the burnt and control carcasses. Adult Calliphoridae were the first insects to arrive at both carcasses. On the burnt carcass, flies were observed lighting on the nonburning parts of the carcass even while other portions were still in flames. The burnt carcass attracted much more fly activity than did the control. While there was oviposition on both carcasses, significant oviposition by adult Calliphoridae was observed on day 1 for the burnt carcass. Significant oviposition on the control carcass was not noted until day 2. First instar maggots were noted on the burnt carcass on day 2. No first instar larvae were readily detected on the control carcass until day 5. The same two species of calliphorid flies were the predominant maggots observed: *C. megacephala* and *C. rufifacies.* Both of these species were present until late in the decay stage when *C. rufifacies* became the dominant species. The final observations of *C. rufifacies* occurred on day 9 on the burnt carcass and day 15 on the control carcass. Staphylinid beetles, mainly *Creophilus maxillosus* and *Thyreocephalus albertisi*, were first observed associated with carcass during the bloated and decay stages of both, where the adults were preying on the Diptera larvae (Table 2). Dermaptera were associated with the carcasses near the ends of the decay stage and throughout the remainder of the study.

Decay curves were plotted for both study sites (Figs. 1 and 2) by plotting time (days) against percentage of the carcass remaining by weight. At the Diamond Head site, the curves were very similar, and no marked differences between the carcasses occurred during the stages of decomposition. In contrast, at Lyon Arboretum, the curves are noticeably different. Major removal of the biomass by

TABLE 1—*Anthropods collected from pig carcasses inside Diamond Head Crater and Lyon Arboretum.*

Order	Family	Genus and Species
Acari	Acaridae	
	Anoetidae	
	Ascidae	
	Camerobiidae	
	Digamasellidae	
	Ereynetidae	
	Eviphididae	
	Macrochelidae	
	Parasitidae	
	Pygmephoridae	
	Tarsonemoidea	
	Terpenacaridae	
	Uropodidae	
Amphipoda		
Araneae	Salticidae	
Coleoptera	Cleridae	*Necrobia ruficolis* (Fabricus)
		Necrobia rufipes (DeGeer)
	Dermestidae	*Dermestes ater* De Geer
		Dermestes frischi Kugelann
		Dermestes maculatus De Geer
	Histeridae	*Saprinus fimbriatus* LeConte
		Saprinus lugens Erichson
	Nitidulidae	
	Ptilidae	
	Scolytidae	
	Staphylinidae	*Anotylus vinsoni* (Cameron)
		Creophilus maxillosus L.
		Philonthus discoideus (Gravenhorst)
		Thyreocephalus albertisi Fauvel
Collembola	Entomobryidae	
Dermaptera	Chelisochidae	
	Labiduridae	*Eurobellia annulipes* (Lucas)
	Labiidae	
Dictyoptera	Blattidae	*Pycnoscelus surinamensis* (Linnaeus)
Diptera	Calliphoridae	*Chrysomya megacephala* (Fabricus)
		Chrysomya rufifacies (Macquart)
		Phaenicia cuprina (Weidemann)
		Phaenicia sericata (Meigen)
	Chloropidae	
	Chronomidae	
	Syrphidae	
	Ceratopogonidae	
	Drosophilidae	
	Empedidae	
	Milichidae	
	Muscidae	*Athergonia orientalis* Schiner
		Musca domestica Linnaeus
		Ophyra aenescens (Weidemann)
		O. chalcogaster (Weidemann)
	Otitidae	
	Phoridae	
	Piophilidae	
	Psychodidae	
	Sarcophagidae	*Boetcherisca peregrina* (Robineau-Desvoidy)
	Sciaridae	
	Sphaeroceridae	
	Stratiomyidae	
Hemiptera	Anthocoridae	*Xylocoris discalis* (Van Duzee)
	Nabidae	
Homoptera	Aphididae	
Hymenoptera	Encyrtidae	*Tachinaephagus zealandicus* Ashmead
	Brachonidae	
	Ichneumonidae	
	Formicidae	*Anoploepis longipes*
		Irdomyrmex humilis
		Solenopsis geminata Fabricus
Isopoda	Oniscidae	
Psocoptera		

necrophagous Diptera maggots occurred by day 4 for the burnt carcass and day 7 for the control carcass.

Temperature curves for the two carcasses compared with the ambient maximum and minimum temperatures are presented in Figs. 3 and 4. During the fresh stage, internal temperatures of the carcasses at both sites were responsive to changes in the ambient temperature. During the bloated and decay stages, there was no influence of ambient temperatures on the internal temperatures of the carcasses. At Diamond Head, internal carcass temperature peaked at 45.2°C on day 5 for the burnt carcass and 42.8°C on day 7 for the control carcass. At Lyon Arboretum, internal carcass temperatures peaked at 38.7°C on day 4 for the burnt carcass and at 49.7°C on day 9 for the control carcass. With the onset of the postdecay stage, internal carcass temperatures declined but remained well above the ambient for both the burnt and control carcasses at Diamond Head while internal carcass temperatures decreased and approximated the ambient temperatures at Lyon Arboretum.

Discussion

Calliphorid flies were immediately attracted to the burnt corpse and significant oviposition was evident on day 2 at both study sites. This appears to contradict the results of other research that suggested burning and charring of the flesh retarded its immediate attraction to adult blowflies (3). The present study confirms that oviposition does occur on a burned corpse. As the arthropod faunas present were similar for both the burnt and control carcasses at both sites, we conclude that burning the carcass did not influence or significantly delay the presence of any carrion community species at Diamond Head Crater.

The total number of arthropod taxa observed during these studies were comparable to previous studies conducted at Diamond Head Crater at Lyon Arboretum. Tullis and Goff (8) reported 46 taxa for 95 days of observation at Lyon Arboretum while Early and Goff (9) reported 43 taxa for their study lasting 76 days at Diamond Head Crater. Since the duration of the present studies was only 30 days at Lyon Arboretum and 31 days at Diamond Head, those arthropods associated with the later parts of the postdecay and remains stage were not found during these studies. The intense ant activity reported in earlier studies conducted at the Diamond Head site (9) was not encountered during this study. At Diamond Head, a number of muscid species had been reported in earlier studies associated with the decay stage but were not found during this study. *Fannia pusio, Musca sorbens*, and *Ophyra* spp. occur in low numbers relative to the *Chrysomya* spp., and our nonvigorous sampling of adult flies probably accounts for their apparent absence in this study, as their larvae frequently are prey for the more numerous *C. rufifacies* larvae on the carrion. However, the small number of adult *Phaenicia sericata* (Diptera: Calliphoridae), observed during the earlier stages of decay at Diamond Head, had not been observed in previous studies.

Although the animal models for some earlier studies conducted at Diamond Head (9) were smaller than those in the present study, work by Hewadikaram and Goff (10) has demonstrated that this would not alter the durations of the stages of decomposition under conditions in the Hawaiian Islands. The durations of the stages of decomposition for the carcasses at both sites in this study were consistent with previous studies using *Sus scrofa* as an animal model (8,10). Although both carcasses showed similar durations for the stages of decomposition, the bloated stage of decomposition

TABLE 2—*Duration of stages of decomposition and dominant arthropod taxa for pig carcasses inside Diamond Head Crater.*

	Burnt Carcass		Control Carcass	
Stage	Duration	Dominant Taxa and Developmental Stage	Duration	Dominant Taxa and Developmental Stage
Fresh	days 1–2	Diptera Calliphoridae *C. megacephala* AD *C rufifacies* AD Hymenoptera Formicidae *S. geminata* AD	days 1–2	Diptera Calliphoridae *C. megacephala* AD *C rufifacies* AD Hymenoptera Formicidae *S. geminata* AD
Bloated	days 3–4	Coleoptera Dermestidae *D. frischi* AD Diptera Calliphoridae *C. megacephala* AD, Lv *C rufifacies* AD, Lv Muscidae *A. orientalis* AD *M. domestica* AD Hymenoptera Formicidae *S. geminata* AD	days 3–5	Coleoptera Dermestidae *D. frischi* AD *D. maculatus* AD Histeridae *S. lugens* AD Diptera Calliphoridae *C. megacephala* AD, Lv *C. rufifacies* AD, Lv Muscidae *M. domestica* AD
Decay	days 5–9	Coleoptera Dermestidae *D. ater* AD *D frischi* AD *D maculatus* AD Histeridae *S. fimbriatus* AD *S. lugens* AD	days 6–10	Coleoptera Dermestidae *D. ater* AD *D frischi* AD *D. maculatus* AD Histeridae *S lugens* AD
Postdecay	days 10–30	Coleoptera Cleridae *N. rufipes* AD Dermestidae *D. ater* AD, Lv *D. frischi* AD, Lv *D. maculatus* AD, Lv Histeridae *S. fimbriatus* AD *S. lugens* AD Staphylinidae *P. discoideus* AD Hemiptera Anthocoridae *X. discalis* AD, NY Hymenoptera Encyrtidae *T. zealandicus* AD	days 11–30	Coleoptera Cleridae *N. rufipes* AD Dermestidae *D. ater* AD, Lv *D. frischi* AD, Lv *D. maculatus* AD, Lv Histeridae *S. fimbriatus* AD *S. lugens* AD Hemiptera Anthocoridae *X discalis* AD, Lv Hymenoptera Encyrtidae *T. zealandicus* AD

for the control carcasses at both sites was one day longer at Diamond Head and three days longer at Lyon Arboretum than observed for the burnt carcasses. The shorter bloat stage of the burnt carcasses may have resulted from the release of metabolic gases produced by bacteria through cracks in the burnt flesh. The carcass weight loss pattern, especially during the decay stage, where biomass removal is most rapid, suggests that biomass removal by necrophagous species occurred at a similar rate for carcasses at both sites.

Although succession patterns and rates of decomposition were similar for both the burnt and control carcasses at both sites, significant oviposition by flies in the family Calliphoridae onto the burnt carcasses was observed one day earlier than the control at Diamond Head and Lyon Arboretum. At Lyon Arboretum, some oviposition was noted on the forehead of the control carcass on day 3. However, the egg mass was much smaller than masses observed on the burnt carcass on day 2. The burnt carcass had huge egg masses in the mouth as well as the front leg and abdomen. The major of oviposition onto the control carcass was observed on day 4 at Lyon Arboretum. Olfactory attractants are believed to induce oviposition (11) by flies and it is likely that the body fluids seeping from cracks in the burnt flesh served to attract blowflies to the burnt carcass. Once oviposition began, it is likely the carcass became even more attractive to ovipositing flies. Studies by Esser (12) showed that more ovipositing *C. megacephala* were attracted to pieces of fish that were ''spiked'' with fly eggs, resulting in more eggs being deposited. The cracks in the skin of the burnt carcass also seemed to serve as alternative oviposition sites for the blowflies, as we noted oviposition on various areas of the body in addition to the usual natural body openings.

Oviposition by necrophagous flies starts a biological clock that is ultimately interpreted to give a postmortem interval estimate. Arthropods arrive at a decomposing corpse in a predictable succession, consisting of a series of blending waves. The establishment

TABLE 3—*Duration of stages of decomposition and dominant arthropod taxa for pig carcasses inside Lyon Arboretum.*

	Burnt Carcass		Control Carcass	
Stage	Duration	Dominant Taxa and Developmental Stage	Duration	Dominant Taxa and Developmental Stage
Fresh	day 1	Diptera Calliphoridae *C. megacephala* AD *C. rufifacies* AD	days 1–2	Diptera Calliphoridae *C. megacephala* AD *C. rufifacies* AD
Bloated	day 2	Diptera Calliphoridae *C megacephala* AD *C. rufifacies* AD		Diptera Calliphoridae *C. megacephala* AD *C. rufifacies* AD
Decay	days 3–8	Coleoptera Staphylinidae *C. maxillosus* AD *T. albertisi* AD Diptera Calliphoridae *C. megacephala* AD, Lv *C. rufifacies* AD, Lv Muscidae O. aenescens AD O. chalcogaster AD	days 5–13	Coleoptera Staphylinidae *C. maxillosus* AD *T. albertisi* AD Diptera Calliphoridae *C. megacephala* AD, Lv *C. rufifacies* AD, Lv Muscidae *O. aenescens* AD *O. chalcogaster* AD
Postdecay	days 9–30	Coleoptera Cleridae *N ruficolis* AD Dermaptera Chelisochidae AD Labiduridae AD Labiidae AD Diptera Muscidae *O. aenescens* AD *O. chalcogaster* AD	days 14–30	Coleoptera Cleridae *N. ruficolis* AD Dermaptera Chelisochidae AD Labiduridae AD Labiidae AD Diptera Muscidae *O. aenescens* AD *O. chalcogaster* AD

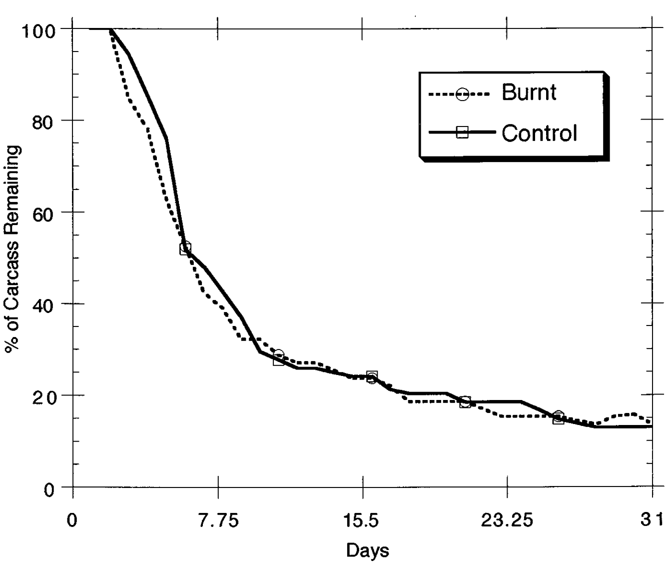

FIG. 1—*Rates of biomass removal over time from burnt and control carcasses inside Diamond Head Crater expressed as percent weight remaining.*

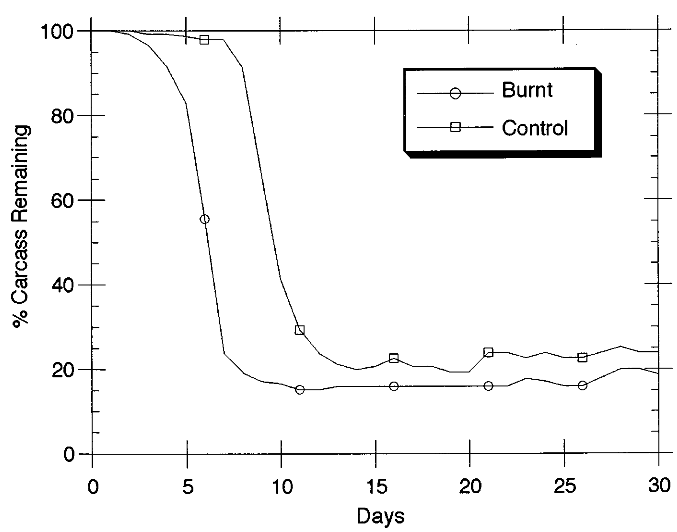

FIG. 2—*Rates of biomass removal over time from burnt and control carcasses inside Lyon Arboretum expressed as percent weight remaining.*

of later arrivals onto a carcass is dependent upon the modifying actions of early colonists (13). Because oviposition marks the start of arthropod succession onto a carcass, a delay in initial oviposition may serve to delay the appearance of each successive taxon although this effect will diminish shortly after invasion of the initial waves of arthropods. This accounts for the later appearance of successive groups of arthropods onto the control carcasses compared to the burnt carcasses. Most notable were the appearance and migration of Calliphoridae maggots at both sites and the appearance of Dermestidae larvae at Diamond Head. Because oviposition on the burnt carcasses occurred earlier than control carcasses at both sites, successional waves occurred earlier on the burnt carcasses than the control carcasses.

Results of this study indicate that, although the arthropod fauna

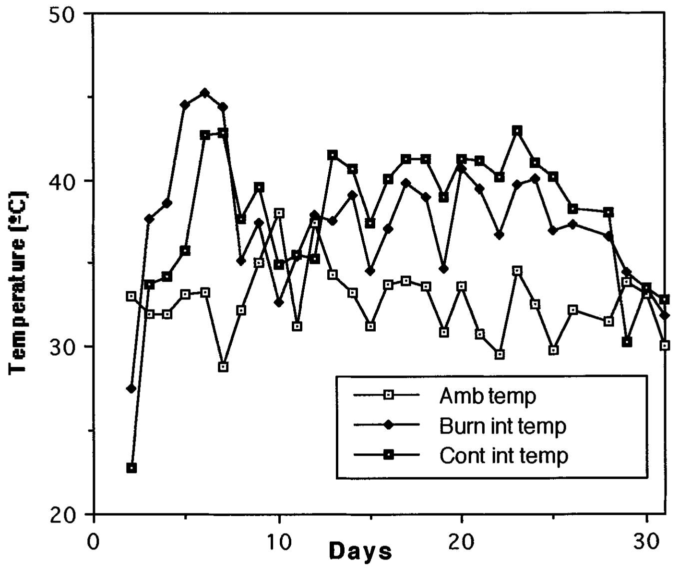

FIG. 3—*Daily ambient maximum/minimum and internal carcass temperatures at Diamond Head site.*

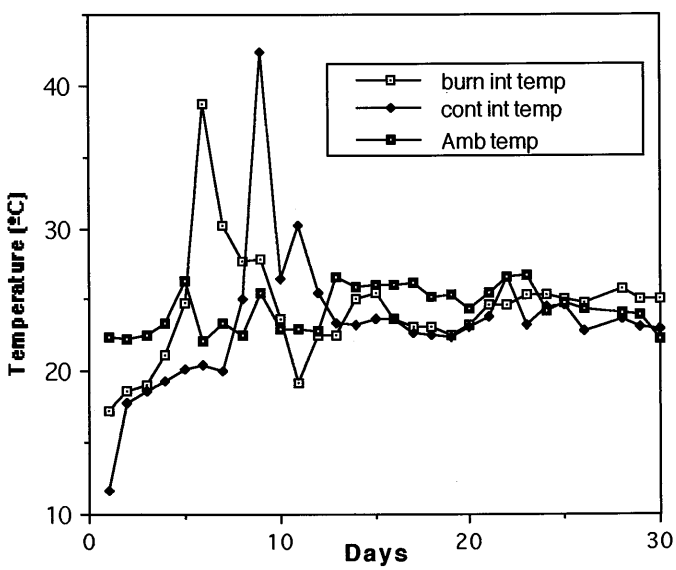

FIG. 4—*Daily ambient maximum/minimum and internal carcass temperatures at Lyon Arboretum site.*

and the stages of decomposition are similar for both the burnt and control carcasses, there appears to be a difference in timing of early stages of arthropod succession related to the burning of the corpse. This difference may have an important implication for the estimation of a postmortem interval by entomological techniques in cases involving the burning of a corpse. If a postmortem interval estimate were based on arthropod succession patterns for unburned carcasses, the estimate would be greater than the actual time frame because of the successional waves arriving one day earlier due to earlier oviposition. Further investigations on the effects of a burnt carcass on arthropod succession patterns are needed as different degrees of burning may have different outcomes for the arthropod population. Until baseline data are available, care must be taken in interpretations of arthropod succession in cases where the burning of the corpse is evident.

Acknowledgments

Thanks are extended to Dennis A. Lapointe, Elizabeth Richards, and Michael Richardson for their assistance during the field portions of this research. Access to the Diamond Head site was through the courtesy of the Hawaii Air National Guard. Support for this research was provided by a grant from the Howard Hughes Medical Institute through the Undergraduate Biological Sciences Education Program. This is Journal Series No. 4307 of the Hawaii Institute of Tropical Agriculture and Human Resources.

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