Omar A. Shalaby,[1,2] *M.S.; Lucila M. L. deCarvalho,*[1,3] *and M. Lee Goff,*[1] *Ph.D.*

Comparison of Patterns of Decomposition in a Hanging Carcass and a Carcass in Contact with Soil in a Xerophytic Habitat on the Island of Oahu, Hawaii

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ABSTRACT: Decomposition studies were conducted to determine differences in rates and patterns of decomposition of carcasses hanging and exposed on the surface of the soil. These studies were conducted between 17 October and 17 December 1997 inside of Diamond Head Crater on the island of Oahu, Hawaii. The animal model was the domestic pig, *Sus scrofa.* The rate of biomass removal from the hanging carcass was significantly slower than that observed for the control carcass during the bloat and decay stages of decomposition. Internal temperatures for the control carcass were elevated above the ambient air temperatures during the earlier stages of decomposition (bloated and decay), while those recorded for the hanging carcass approximated the ambient air temperatures. There was a greater diversity of arthropod species recorded and numbers of individuals observed were higher for the control carcass. A significant site of arthropod activity was observed on the surface of the soil immediately under the hanging carcass and this became the primary site of arthropod activity as decomposition progressed.

KEYWORDS: forensic science, forensic entomology, Hawaii, decomposition, hanging, entomology, succession, postmortem interval

A basic assumption in the application of entomological techniques to the estimation of postmortem intervals is that the invasion of a body by insects and other arthropods will occur soon after death (1). It has been well documented that, once this invasion has occurred, the rates and patterns of arthropod mediated decomposition can be influenced by a variety of factors, including temperature, humidity, and rainfall (2–4). In a series of studies conducted at the Forensic Entomology Laboratory, University of Hawaii at Manoa, Gunatilake and Goff (5) and Goff et al. (6–11) demonstrated that the presence of drugs and/or toxins in a decomposing body may serve to alter the rate of insect invasion of a body and subsequent development of immatures. Additionally, factors such as burning or wrapping of the body may serve to either delay or accelerate the invasion of a body by insects and other arthropods (1,4). One situation which, to date, has not been adequately documented is the possible change in rates and patterns of decomposition and arthropod activity in cases where the body is hanging. In the present study, these differences are documented for carcasses in a xerophytic habitat on the island of Oahu, Hawaii.

[1] Visiting scholars and Professor of Entomology, respectively, Department of Entomology, University of Hawaii at Manoa, Honolulu, HI 96822.
[2] Current address: Zoology Department, Alexandria University, Alexandria, Arab Republic of Egypt.
[3] Current address: Department of Parsitology, Institute of Biology, Universidade Estadual de Campinas, Campinas/SP-Brazil.
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Study Site

The study was conducted inside of Diamond Head Crater on the southern coast of the island of Oahu, Hawaii. Diamond Head Crater is a dormant volcano, approximately 232 m high and 1.3 km in diameter. The interior of the cone is an arid habitat with xerophytic vegetation, predominantly grasses and stands of haole koa, *Leucaena chiliensis.* Annual rainfall is approximately 102 cm and is delivered primarily during winter storms, with minimal rainfall from tradewind showers. The study site is within the compound of the Hawaii National Guard and has been used in several earlier studies of decomposition (4,12,13). As noted in these earlier studies, sanitation in the area is excellent and populations of synanthropic Diptera associated with decomposition are low. There are populations of birds, mongoose, and feral cats within the crater which serve to maintain a population of carrion-frequenting arthropods.

Materials and Methods

Carcasses of two adult domestic pigs, *Sus scrofa,* weighing 9.2 and 10.7 kg, were obtained dead from the Department of Animal Sciences, University of Hawaii at Manoa. The 9.2 kg carcass was suspended by the neck from a tree limb (*L. chiliensis*) using a nylon rope. The lowest portions of the carcass (hind legs) were approximately 0.75 m from the ground. The 10.7 kg carcass served as the control and was placed approximately 20 m away from the hanged carcass on a 2.54 cm^2 welded wire mesh weight platform. The control carcass was protected by a 0.6 × 1.0 × 0.5 m exclosure cage of 2.54 cm^2 welded wire mesh to exclude vertebrate scavengers. Telethermometer probes were inserted into the mouth, abdomen, and anus of each carcass to record internal temperatures. Ambient temperatures and relative humidity were recorded using a hygrothermograph and a maximum/minimum thermometer. Rainfall was measured using a rain gage placed at the site.

The study was conducted from 17 October to 17 December 1997. Carcasses were visited twice a day for the first 14 days of the study and then once a day for the remainder of the study. At each visit, ambient temperature, relative humidity, and internal carcass

temperatures were recorded. Observations were made of the physical condition of each carcass and visible arthropod activity. At each visit, photographs were taken of each carcass to record physical changes. After observing arthropod activity, representative specimens were collected from each carcass using insect nets and by hand. Specimens were taken to the Forensic Entomology Laboratory, University of Hawaii at Manoa, for identification and preservation. Beginning on Day 8, soil samples 10 cm in diameter and 3 cm deep were removed from under each carcass and processed in Berlese/Tulgren funnels for 48 h to extract soil arthropods. Previous studies have demonstrated that this sampling does not significantly alter the decomposition processes (4). For this study, emphasis is placed on major indicator species, rather than attempting a complete inventory of arthropod taxa present, and results of the soil sampling will be presented in a later report.

Results

As shown in Table 1, a total of 37 arthropod species were collected and identified during this study. These represented 24 families of insects in 8 orders. As in previous studies, the Diptera were the predominant group during the earlier stages of decomposition, being replaced by Coleoptera as decomposition progresses. The total number of taxa recovered during this study was lower than the 133 taxa identified by Early and Goff (12) for the same general area, but the emphasis during this study was on dominant taxa rather than a complete inventory of species. The physical stages of decomposition observed during this study corresponded well to those previously established by Early and Goff (12) and redefined by Goff (1): fresh, bloated, decay, post-decay, and skeletal.

TABLE 1—*Classified list of arthropods collected from hanging and control carcasses inside Diamond Head Crater.*

Order	Family	Genus and Species
Amphipoda		
Araneae	Salticidae	
	Filistatidae	
Coleoptera	Cleridae	*Necrobia rufipes* (DeGeer)
	Dermestidae	*Dermestes ater* DeGeer
		Dermestes frischi Kugelann
		Dermestes maculatus DeGeer
	Histeridae	*Saprinus lugens* Erichson
	Nitidulidae	
	Ptilidae	
	Staphylinidae	*Philonthus longicornis* Stephens
Collembola	Entomobryidae	
Dermaptera	Labiduridae	*Euborellia annulipes* (Lucas)
		Labidura riparia (Pallas)?
Dictyoptera	Blattidae	*Pycnoscelus surinamensis* (L.)
Diptera	Calliphoridae	*Chrysomya megacephala* (Fabricius)
		Chrysomya rufifacies (Macquart)
	Chironomidae	
	Drosophilidae	*Scaptomyza* sp.
	Milichidae	
	Muscidae	*Musca domestica* L.
		Musca sorbens Wiedemann
		Ophyra chalcogaster (Wiedemann)
		Ophyra leucostoma Wiedemann
	Phoridae	*Diplonevra peregrina* (Wiedemann)
	Otitidae	*Physiphora aenea* (Fabricius)
	Sarcophagidae	*Boettcherisca peregrina* (R-D)
		Parasarcophaga africa (Wiedemann)
		Parasarcophaga ruficornis Fabricius
	Stratiomyidae	
	Syrphidae	*Allograpta cubana* Curran
Hempitera	Anthocoridae	
Homoptera	Aphididae	
Hymenoptera	Chalcidae	*Brachymeria fonscolombei* (Dufour)
	Formicidae	*Paratrechina longicornis* (Latreille)
		Solenopsis geminata (Fabricius)

As shown in Table 2, the insect activity was basically the same for hanging and control carcasses during the fresh stage. The only difference was in the species of ants, with *Paratrechina longicornis* invading the hanging carcass and *Solenopsis geminata* invading the control carcass. At this site, *S. geminata* was not observed in trees, while *P. longicornis* was commonly found on trees and moved down the rope onto the hanging carcass. In earlier studies involving carcasses placed on the ground, *P. longicornis* was not observed on carcasses (4,12,13).

Beginning with the bloated stage, the hanging carcass began to lag behind the control carcass in the rate at which biomass was removed and stages of decomposition were prolonged (Table 2, Fig. 1). The bloated stage lasted until Day 4 in the control carcass, but until Day 5 for the hanging carcass. As shown in Fig. 2, internal abdominal carcass temperatures in the control carcass began to rise significantly above ambient temperature during the bloated stage, peaking at 41.6°C on Day 7. This elevation continued until Day 13, after which time temperatures approximated ambient. By contrast, internal abdominal temperatures for the hanging carcass appeared to be more closely similar to ambient air temperatures throughout the study, with a peak of 34.3°C on Day 11. The temperature peak for the control carcass was 10.7°C above ambient, while the peak for the hanging carcass was only 2.7°C above ambient. While the arthropods present on both carcasses were similar in diversity and species represented (Table 2), there was a marked difference in numbers of individuals with the control carcass more heavily exploited by Diptera larvae. While observed oviposition by the two predominant species of Calliphoridae, *Chrysomya megacephala* and *Chrysomya rufifacies*, was similar for both carcasses, there was a marked difference in survivability between carcasses once the eggs hatched. Larvae feeding on the control carcass formed dense maggot feeding masses, as detailed by Early and Goff (12) and Goff (1), and were able to move between the carcass and the substrate easily. By contrast, larvae falling from the hanging carcass were restricted to the substrate for the remainder of their development, dependent on materials falling from the carcass as a food source. This resulted in a smaller population on the hanging carcass and a maggot feeding mass was not formed on the carcass. A feeding mass was observed on the soil immediately beneath the hanging carcass.

The decay stage began on Day 4 for the control carcass and lasted for approximately 9.5 days, while for the hanging carcass it began on Day 5 and lasted for approximately 11.5 days (Table 2). This difference in duration was due, at least in part to the smaller populations of Diptera larvae on the hanging carcass, combined with the lower temperatures of the hanging carcass. During this stage, the hanging carcass stretched toward the ground, and Diptera larvae were primarily observed on the head and few on the lower portions of the body. This was in marked contrast to the large maggot masses observed on the control carcass. As noted above, maximum internal temperatures for both carcasses were recorded during the decay stage. For the hanging carcass, during the decay stage, the primary site for larval Diptera activity was in the area immediately under the carcass. In this site, with a limited food source, *C. rufifacies* was observed actively preying on larvae of *C. megacephala*. Larvae of two species of Sarcophagidae, *Parasarcophaga ruficornis* and *Parasarcophaga africa*, were also observed under

TABLE 2—*Stages of decomposition and dominant arthropod taxa observed on hanging carcass and control carcass inside Diamond Head Crater, Oahu, Hawaii.*

	Hanging Carcass		Control Carcass	
Stage	Duration	Taxa	Duration	Taxa
Fresh	Days 1–2	**Diptera** Calliphoridae *C. megacephala* AD* *C. rufifacies* AD Sarcophagidae *P. africa* AD **Hymenoptera** Formicidae *P. longicornis* AD	Days 1–2	**Diptera** Calliphoridae *C. megacephala* AD *C. rufifacies* AD Sarcophagidae *P. africa* AD **Hymenoptera** Formicidae *S. geminata* AD
Bloated	Days 2–5	**Diptera** Calliphoridae *C. megacephala* L, AD *C. rufifacies* L, AD Sarcophagidae *P. africa* AD *P. ruficornis* AD Muscidae *M. domestica* AD *M. sorbens* AD *O. chalcogaster* AD *O. leucostoma* AD **Coleoptera** Dermestidae *D. frischi* AD *D. maculatus* AD Cleridae *N. rufipes* AD Staphylinidae *P. longicornis* AD **Hymenoptera** Formicidae *P. longicornis* AD Chalcididae *B. fonscolombei* AD **Araneae** Filistatidae	Days 2–4	**Diptera** Calliphoridae *C. megacephala* L, AD *C. rufifacies* L, AD Sarcophagidae *P. africa* AD *P. ruficornis* AD Muscidae *M. domestica* AD *M. sorbens* AD *O. chalcogaster* AD **Coleoptera** Dermestidae *D. ater* AD *D. frischi* AD *D. maculatus* AD Histeridae *S. lugens* AD Staphylinidae *P. longicornis* AD **Hymenoptera** Formicidae *S. geminata* AD Chalcididae *B. fonscolombei* AD **Dictyoptera** Blattidae *P. surinamensis* AD
Decay	Days 5–16	**Diptera** Calliphoridae *C. megacephala* L, AD *C. rufifacies* L, P, AD Sarcophagidae *P. africa* L, AD *P. ruficornis* AD *B. peregrina* AD **Muscidae** *M. domestica* AD *M. sorbens* AD *O. chalcogaster* AD *O. leucostoma* AD **Coleoptera** Dermestidae *D. frischi* L, AD *D. maculatus* L, AD Histeridae *S. lugens* AD Staphylinidae *P. longicornis* AD Cleridae *N. rufipes* AD	Days 4–13	**Diptera** Calliphoridae *C. megacephala* L, P, T, AD *C. rufifacies* L, P, T, AD Sarcophagidae *P. africa* L, AD *P. ruficornis* AD **Muscidae** *M. domestica* AD *M. sorbens* AD *O. chalcogaster* AD *O. leucostoma* AD **Coleoptera** Dermestidae *D. ater* AD *D. frischi* L, AD *D. maculatus* L, AD Histeridae *S. lugens* AD Staphylinidae *P. longicornis* AD Cleridae *N. rufipes* AD

TABLE 2—*Continued.*

		Hymenoptera Formicidae *P. longicornis* AD *S. geminata* AD Chalcididae *B. fonscolombei* AD **Araneae** Salticidae Filistatidae		**Hymenoptera** Formicidae *S. geminata* AD Chalcididae *B. fonscolombei* AD **Dermaptera** Labiduridae *Labidura riparia* AD **Hemiptera** Anthocoridae **Dictyoptera** Blattidae *P. surinamensis* AD **Araneae** Salticidae
Post-Decay	Days 16–40	**Diptera** Calliphoridae *C. megacephala* P, AD *C. rufifacies* P, T, AD Sarcophagidae *P. ruficornis* L, P *P. africa* L, P Muscidae *M. domestica* AD *O. chalcogaster* AD *O. leucostoma* AD **Coleoptera** Dermestidae *D. frischi* L, AD *D. maculatus* L, AD Cleridae *N. rufipes* AD Staphylinidae *Philonthus longicornis* AD **Hymenoptera** Formicidae *P. longicornis* AD *S. geminata* AD Chalcididae *B. fonscolombei* AD **Isopoda** **Araneae** **Salticidae**	Days 13–35	**Diptera** Calliphoridae *C. megacephala* P, AD *C. rufifacies* P, T, AD Sarcophagidae *P. ruficornis* P, AD *P. africa* P, AD Muscidae *M. domestica* AD *M. sorbens* AD *O. chalcogaster* AD **Coleoptera** Dermestidae *D. ater* AD *D. frischi* L, AD *D. maculatus* L, AD Histeridae *Saprinus lugens* AD Cleridae *N. rufipes* AD Staphylinidae *P. longicornis* AD **Hymenoptera** Formicidae *S. geminata* AD **Dermaptera** Labiduridae *E. annulipes* AD *L. riparia* AD **Dictyoptera** Blattidae *P. surinamensis* N **Isopoda** **Araneae** Salticidae
Skeletal	Days 40+	**Diptera** Calliphoridae *C. megacephala* P, T *C. rufifacies* P, T Sarcophagidae *P. africa* P, AD *P. ruficornis* P, AD **Coleoptera** Dermestidae *D. frischi* L, AD *D. maculatus* L, AD Cleridae *N. rufipes* AD **Hymenoptera** Formicidae *P. longicornis* AD *S. geminata* AD	Days 35+	**Diptera** Calliphoridae *C. megacephala* P, T *C. rufifacies* P, T Sarcophagidae *P. ruficornis* P, T **Coleoptera** Dermestidae *D. frischi* L, AD *D. maculatus* L, AD Staphylinidae *P. longicornis* AD **Hymenoptera** Formicidae *S. geminata* AD **Dermaptera** Labiduridae *L. riparia* AD **Dictyoptera** Blattidae *P. surinamensis* N

* L = larvae; P = pupa; N = nymph; T = teneral adult; AD = adult.

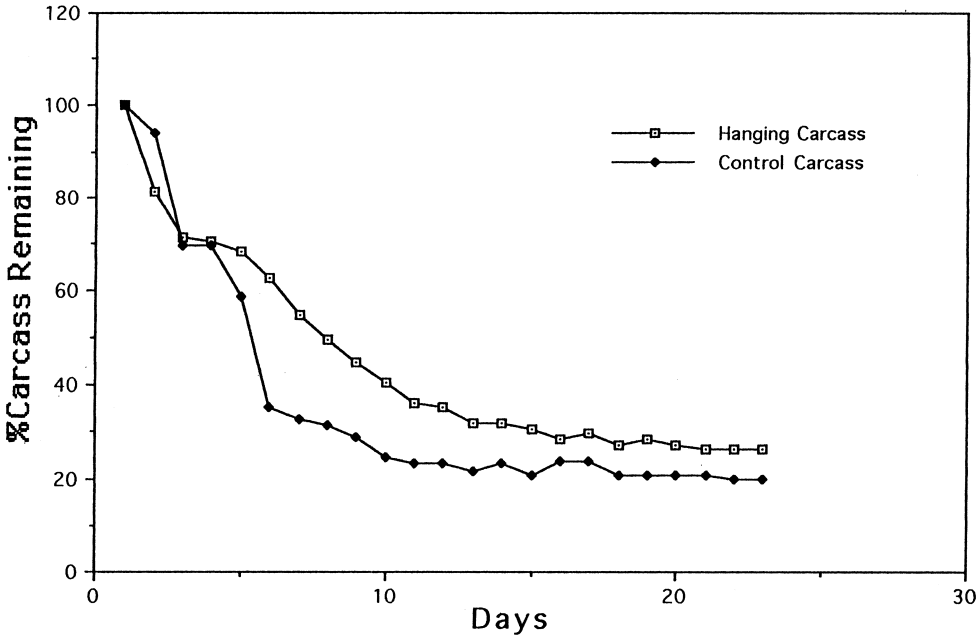

FIG. 1—*Rate of biomass removal indicated as percent of carcass remaining.*

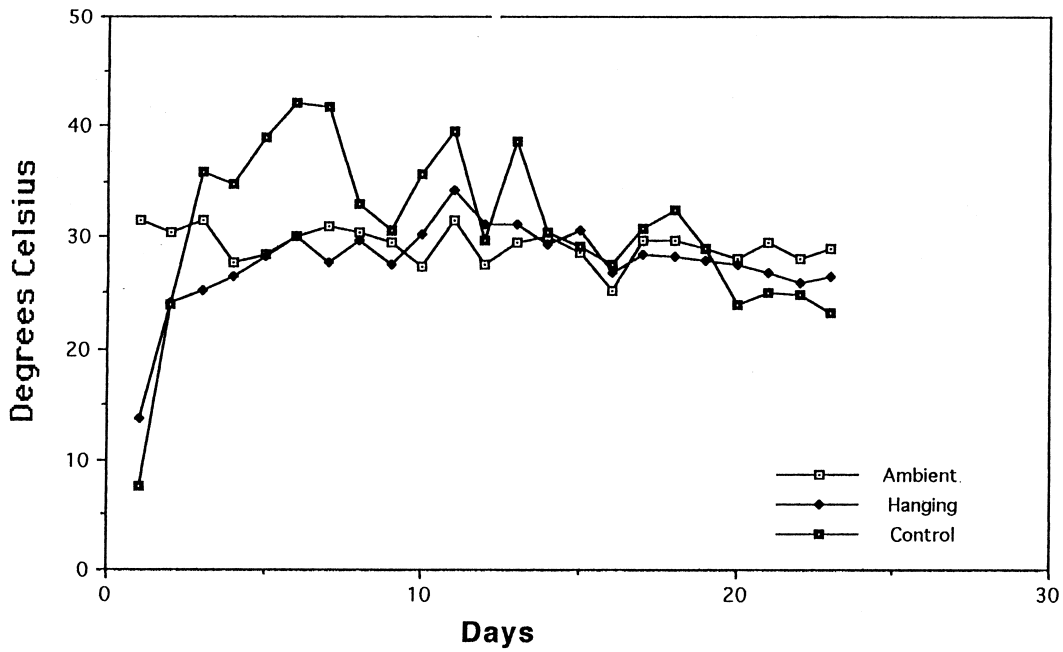

FIG. 2—*Internal temperatures of carcass and ambient air temperature.*

the hanging carcass. Predictably, puparia of *C. rufifacies* were found on the hanging carcass and under the carcass, but puparia of *C. megacephala* were not seen. These same species of Calliphoridae and Sarcophagidae were present on the control carcass, with activities of the Sarcophagidae larvae concentrated in areas under the carcass. While adult Dermestidae were observed on carcasses during the bloated stage, larvae were not observed until the decay stage. A total of three species of dermestids were present on the control carcass: *Dermestes maculatus, Dermestes ater,* and *Dermestes frischi,* while only *D. maculatus* and *D. frischi* were present on the hanging carcass during the decay stage. Adults of the clerid beetle, *Necrobia rufipes,* were present on the hanging carcass during the bloat and decay stages, but not on the control carcass.

The post-decay stage was considered to begin on Day 13 for the control carcass and lasted until Day 35. The hanging carcass was slower in reaching this stage, beginning on Day 16 and lasting un-

til Day 40 (Table 2). For the control carcass, this stage was marked by the mass departure of Diptera larvae in preparation for pupariation. The hanging carcass began to fall apart during this stage and the parts provided food for the few remaining Diptera larvae in the area immediately under the carcass. Sarcophagidae puparia were observed at both carcasses during this stage. As the stage progressed, Dermestidae adults and larvae became the predominant arthropod taxa at both carcasses. During the post-decay stage, *S. geminata* began to be observed on the hanging carcass and this continued into the skeletal stage. Prior to the post-decay stage, *S. geminata* had restricted its activities to the control carcass. By contrast, *P. longicornis* was not seen on the control carcass. The total diversity of arthropod taxa observed was greater for the control carcass than for the hanging carcass (Table 2).

The skeletal stage, characterized by the presence of only dried skeletal materials, was considered to begin on Day 35 for the control carcass and 5 days later on Day 40 for the hanging carcass. There is no definite end point to this stage (1) and it is characterized by the gradual departure of carrion-associated taxa and the return of the normal soil fauna to the area.

Discussion

Results of this study demonstrate significant differences in the rates of decomposition between a hanging carcass and a carcass in contact with the soil. The hanging carcass showed a delayed progression through the physical stages of decomposition, beginning with the bloated stage. This lag, a period of 5 days by the beginning of the skeletal stage, can be partially attributed to the greater influence of ambient air temperatures, reduced numbers of Diptera larvae exploiting the carcass, and inability of ground-dwelling arthropods to access the carcass. The hanging carcass was exposed to the cooling effects of the surrounding air on all sides and internal temperatures more closely approximated the ambient air temperatures. The control carcass was less subject to cooling effects of the air and temperatures were elevated above ambient air temperature through the end of the decay stage.

The internal temperatures recorded in each carcass were also directly related to the level of colonization of the carcass by Diptera larvae. Initial colonization of both carcasses occurred shortly after exposure and at the same time. There did not appear to be any difference in attractiveness between carcasses. Initial oviposition for both was in the natural body openings associated with the head. Once eggs hatched, a difference was observed between the carcasses. Feeding masses began to be formed and the larvae cycled through these masses regulating their temperatures for optimum feeding activities as noted for *Sarcophaga africa (=haemorrhoidalis)* by Byrd and Butler (14). While the larvae on the control carcass were able to regain the carcass if they fell from the maggot mass, those on the hanging carcass fell to the ground and were unable to regain the carcass. This prevented the formation of large, heat-generating maggot masses on the hanging carcass and resulted in slower biomass removal and lower internal temperatures (Figs. 1 and 2). By contrast, the maggot masses formed on the control carcass resulted in higher internal temperatures and a rate of biomass removal more consistent with results seen in earlier studies (4,12,13) conducted at the same site.

Goff and Lord (15) presented some preliminary observations at the Annual Meetings of the American Academy of Forensic Sciences on differences in species diversity between decomposing bodies which were hanging and those in contact with the soil. As shown in Table 3, based on analyses of cases from the island of Oahu, Hawaii, the number of arthropod taxa invading a hanging body is far less than what is encountered in a body decomposing in contact with the soil, regardless of habitat. This is consistent with observations made in studies conducted in Virginia (unpublished observations, MLG). While many taxa may be absent from the hanging body, these taxa are often present in the area immediately beneath the hanging body. This area, the "drip zone," is provided with nutrient materials falling from the decomposing carcass and serves as a very significant, secondary site of activity. Diptera larvae develop in this site and with them come their complexes of predators and parasites. As decomposition progresses, a succession also occurs in this site although not as distinct as what may be observed on a carcass in contact with the soil. Unfortunately, this site is frequently overlooked in sampling by non-entomologists processing a scene and significant data are lost to the entomologist. As the drip zone becomes established relatively early in the decomposition process, taxa present

TABLE 3—*Arthropod orders recovered from corpses found hanging and on the ground in different habitat types on the island of Oahu, Hawaii.*

	Habitat Type			
Days PMI	Hanging	Xerophytic	Mesophytic	Rain Forest
7–8	Diptera (3)* Coleoptera (3)	Diptera (7) Coleoptera (4) Hymenoptera (1) Isopoda (1) Salticidae (1)	Diptera (8) Coleoptera (4) Hymenoptera (2) Diplura (1) Acari†	Diptera (12) Coleoptera (5) Hymenoptera (1) Hemiptera (1) Isopoda (1)
11	Diptera (3) Coleoptera (2)	Diptera (5) Coleoptera (5) Hymenoptera (1) Collembola (2)	Diptera (5) Coleoptera (4) Hymenoptera (1) Isopoda (1)	Diptera (9) Coleoptera (2) Dermaptera (2) Acari†
19–20	Diptera (2) Coleoptera (3)	Diptera (6) Coleoptera (5) Hymenoptera (2) Isopoda (2) Acari†	Diptera (10) Coleoptera (6) Hymenoptera (1) Dermaptera (1) Isopoda (1) Acari†	Diptera (5) Coleoptera (3) Hymenoptera (1) Dermaptera (2) Hemiptera (1) Acari†

* Numbers in parentheses indicate numbers of species involved.
† Indicates multiple orders and taxa.

there may more accurately reflect the total period of insect activity than those collected from the hanging remains.

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Additional information and reprint requests:
M. Lee Goff, Gh.D.
Department of Entomology
3050 Maile Way
University of Hawaii at Manoa
Honolulu, HI 96822