Attraction of Nontarget Species to Fruit Fly (Diptera: Tephritidae) Male Lures and Decaying Fruit Flies in Traps in Hawaii

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ABSTRACT Synthetic male lures are commonly used to monitor and mass trap pestiferous fruit flies (Diptera: Tephritidae: Dacinae). However, there has been much dispute as to the nontarget impacts of such lures on beneficial and native insects. To evaluate nontarget attraction effects, traps baited with Cue-Lure and methyl eugenol were maintained and emptied weekly in a range of native and non-native forest and commercial orchard and backyard sites on Hawaii and Maui Islands. Lure trap captures were compared against those from unbaited control traps and traps artificially baited with decaying fruit flies to mimic the effect of accumulation of dead trapped target flies in male lure traps. Cue-Lure did not attract nontargets, and methyl eugenol attracted low but significant numbers of five species of flower-associated insects (honey bees, syrphid flies, nitidulid beetles, and endemic crambid moths) and two endemic Hawaiian species of sciarids (Diptera) and mirids (Hemiptera). Saprophagous nontargets, mostly Diptera, were abundant and diverse in traps baited with decaying flies and in male lure traps where accumulation of dead flies occurred but not in male lure traps with few or no fruit fly captures. Most of the previously published records of attraction to methyl eugenol are shown to actually be secondary attraction to decaying fruit flies. Endemic nontargets were collected in native and adjacent forest, but almost exclusively invasive species were attracted to traps placed in non-native habitats. Attraction of flower-associated species may be minimized if methyl eugenol traps are placed in trees after flowering season in orchards.

KEY WORDS *Bactrocera*, Cue-Lure, methyl eugenol

The genus *Bactrocera* (Tephritidae) has >440 described species in the Old World tropics, including severe pests of virtually all fruit and fleshy vegetables. Although no reliable estimates of global economic losses caused by *Bactrocera* species exist, economic impacts are likely very high, as suggested by the estimated USD 200 million losses annually attributable to *B. dorsalis* (Hendel) and *B. zonata* (Saunders) in Pakistan alone (Stonehouse et al. 1998). Fortunately, effective fruit fly control methods are available, based on adult female attraction to protein bait and specific male attraction to kairomone lures. The males of most *Bactrocera* species are attracted to either of two kairomone male lures: Cue-Lure [4-(*p*-acetoxyphenyl)-2-butanone] and methyl eugenol (4-allyl-l, 2-dimethoxybenzene-carboxylate) (Metcalf 1990). Of the 54 pest species in the Asia-Pacific region, 26 respond to Cue-Lure and 16 are attracted to and ingest methyl eugenol (Drew 1989, White and Elson-Harris 1992, Clarke et al. 2005). In Hawaii, for example, the invasive melon fly [*B. cucurbitae* (Coquillett)] and oriental fruit fly [*B. dorsalis* (Hendel)] respond to Cue-Lure and methyl eugenol, respectively. Methyl eugenol occurs naturally in plants, detected in essential oils from >200 species in 32 families (Tan 2000). Although a synthetic molecule, Cue-Lure is quickly hydrolyzed into raspberry ketone that also occurs naturally in various plants (Metcalf 1990).

Male lures, combined with insecticides, have been used for >50 yr in traps for population monitoring and quarantine surveillance and in various formulations for the eradication of invasive *Bactrocera* pests (Steiner et al. 1970, Cunningham and Suda 1985, Allwood et al. 2002), and for fruit fly suppression in fruit orchards and cucurbit crops (Cunningham and Suda 1986). Improved lure application technologies are becoming widely available to growers (Leonhardt et al. 1994; Vargas et al. 2005, 2008; Hiramoto et al. 2006). Whether used on their own in traps, or combined with a pesticide of natural origin such as spinosad (Vargas et al. 2003), male lures are environmentally acceptable and may even be used by organic growers.

The increasing use of male lures for fruit fly control and eradication has, however, raised concern of possible nontarget impacts on insect species that might be attracted to lures. The earliest records of this happen-

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ing were the consistent captures of green lacewings (Neuroptera: Chrysopidae) in methyl eugenol traps on Hawaii Island (Suda and Cunningham 1970), in the Philippines (Umeya and Hirao 1975), and more recently in Taiwan (Pai et al. 2004). To address the concern, several studies in Hawaii attempted to determine which nontarget species are attracted to lures, based on a comparison of lure trap catches with unbaited traps (Conant 1978, 1979b, c; Asquith and Kido 1994; Kido and Asquith 1995, Kido et al. 1996; Asquith and Burny 1998; Uchida et al. 2006). Results from these earlier studies are summarized in Table 1.

Conant (1978, 1979a, b, c, 1980) compared catches of insects in methyl eugenol traps to fermenting mushroom (a potent drosophilid attractant), traps solely baited with dead *B. dorsalis,* and unbaited control traps in Lanai Island (Hawaii) forests. Mushroom traps, dead flies, and methyl eugenol traps with accumulation of dead trapped *B. dorsalis* attracted a diversity of scavenger flies and beetles. One native drosophilid was consistently drawn to the methyl eugenol traps, including traps with brass screens at entrance holes to prevent *B. dorsalis* from entering, suggesting a true methyl eugenol attraction.

Large numbers of *B. dorsalis* (206–321 per trap per day) and 16 species of nontarget flies and beetles (Table 1) were collected in methyl eugenol bucket traps along streams and rivers in altitudinal transects on Kauai Island from native forest (1,035 m) down to agricultural areas at sea level (Kido and Asquith 1995, Kido et al. 1996). All nontarget species trapped were aliens except for two endemic Drosophilidae. In a survey of native forest areas in the Kokee State Park of Kauai (1,200 m) (Asquith and Kido 1994, Asquith and Burny 1998), methyl eugenol traps again collected substantial numbers of *B. dorsalis* (20–60 per trap per day), 13 species of mostly endemic nontargets (Table 1), and small numbers of honey bees. They speculated that methyl eugenol may emulate plant kairomone cues that help phytophagous nontargets and their natural enemies to locate food, oviposition sites or their prey. In an independent study in native forests of Kauai, Uchida et al. (2006) collected more individuals of five drosophilids and one muscid in methyl eugenol traps than unbaited controls but warned that the effects of lure and decaying flies might be confounded.

Thus, although it is possible that nontarget impacts from methyl eugenol and Cue-Lure traps may be negligible, or restricted to native forest areas, past research results are equivocal because of confounding effects of different lures, traps, locations, and the accumulation of dead insects. Twelve species of endemic Hawaiian *Drosophila* have recently been added to the U.S. endangered species list (U.S. Fish and Wildlife Service 2007), making any possible nontarget attraction of such species unacceptable. Before methyl eugenol and Cue-Lure traps can be widely used for *Bactrocera* monitoring and suppression, strong and clear evidence must be collected to show the level and spatial characteristics of the impacts these traps may have on nontarget insect populations. Because Hawaii was the location of most of the aforementioned trials, it is an ideal place to conduct a robust assessment of the nontarget impacts that methyl eugenol and Cue-Lure may exert. The objectives of our study are to conclusively and robustly distinguish nontarget species actually attracted to male lures from those attracted to decaying insects found in traps across a range of environments, including intact native forest, mixed native/invasive forest, invasive forest, agricultural, and residential areas. The results of this project will carefully address a longstanding question related to the environmental safety of methyl eugenol trapping and greatly improve the specificity and application parameters for using Cue-Lure and methyl eugenol lures in fruit fly control, not only in Hawaii, but anywhere this genus causes significant agricultural damage.

Materials and Methods

We selected a total of 81 trapping sites, in five distinct geographic locations on Hawaii and Maui Islands (Figs. 1–4). Our goal was to distribute the sites across agricultural lands, invasive forest, and mixed and native forest ecotypes to assess the impact of plant community composition and distance from such plant communities on nontarget insects collected in male lure traps and traps baited only with dead insects. We used sites on the islands of Maui and Hawaii because they are the two largest islands and have some of the most extensive agricultural areas adjacent to invasive and native forest habitats, therefore providing an ideal transition from different land uses across elevation gradients.

Hawaii Island Sites. Nine sites were along a 20-km transect along the Stainback Highway, from the Panaewa Rainforest Zoo near Hilo (138 m above sea level) to an elevation of 1,045 m above sea level. This transect included, in declining elevation, native wet montane ohia-dominated (*Metrosideros polymorpha* Gaudich.) forest (four sites), invasive strawberry guava (*Psidium cattleianum* Sabine) dominated forest (three sites), and a citrus and a mixed fruit orchard (Fig. 1). Fifteen sites were set up following the Saddle Road, along a 35-km transect, from the junction of Kaumana and Saddle Roads (439 m) to Puu Huluhulu (2,012 m; Fig. 1). Habitats included invasive strawberry guava forest (one site), montane wet herbland bogs over recent lava flows (native) (three sites), wet montane ohia forest (native) (two sites), and native wet (six sites) and dry (three sites) ohia-dominated kipuka forests (islands of intact forest isolated by more recent lava flows). Six collecting points were established in the North Kohala Forest Reserve, along the upper Hamakua Ditch Trail in wet forest, from the far end of the flume (1,019 m) to the entrance of the Forest Reserve (906 m; Fig. 2). All sites were in mixed native wet montane ohia forest, except the entrance site, which was in the strawberry guava belt adjacent to native forest. Approximately 4 km southwest, we maintained another set of five trapping sites in the agricultural community of Waimea (744–872 m), including two

Table 1. List of nontarget insects recorded in the literature as attracted in largest numbers to traps baited with methyl eugenol and a toxicant (malathion or naled) compared with control traps without methyl eugenol

	Status[a]	No. per ME trap per day	Reference[b]	Actual attraction
Coleoptera: Anobiidae				
Mirosternus carinatus Sharp	E	0.008	AK94	Methyl eugenol ?
Mirosternus oculatus Perkins	E		AK94	
Xyletobius lineatus Sharp	E		AK94	
Coleoptera: Cucujidae				
Cryptolestes pusillus (Schoenherr)	I	0.024	Ki96	Dead flies (probably)
Coleoptera: Nitidulidae				
Carpophilus dimidiatus (Fabricius)	I	0.072–0.127	Ki96	Dead flies
Coleoptera: Staphylinidae				
Philonthus longicornis Stephens	I	0.116–0.142	Ki96	Dead flies
Diptera: Calliphoridae				
Pollenia rudis (Fabricius)	I	0.014–0.270	Ki96	Dead flies
Diptera: Chloropidae				
Semaranga dorsocentralis Becker	I	0.834	Ki96	Dead flies
Diptera: Drosophilidae				
Drosophila immigrans Sturtevant	I	3.219–10.930	Ki96	Dead flies
Drosophila suzukii (Matsumara)	I			Dead flies
Drosophila suzukii (Matsumara)	I	9.70–17.56	Uc06	
Drosophila basimacula Hardy	E	0.128	AK94	Dead flies
Drosophila crucigera Grimshaw	E	0.016–0.043	Ki96	Dead flies
Drosophila kokeensis Hardy	E	0.009	AK94	Dead flies
Drosophila perissopoda Hardy	E	3.17–5.99	Uc06	Dead flies
	E	0.012	Ki96	
	E	0.139	AK94	
Drosophila villosipedis Hardy	E	0.015	AK94	Dead flies
Drosophila sp.	E	0.33	Uc06	Dead flies
Scaptomyza n.sp. nr *silvicola*	E	0.038–0.281	Co	Methyl eugenol ?
Scaptomyza rostrata Hardy	E	0.119	AK94	Dead flies
Scaptomyza uliginosa Hardy	E	0.035	AK94	Dead flies
Scaptomyza varipicta Hardy	E	0.26–0.44	Uc06	Dead flies
	E	0.153	AK94	
Scaptomyza sp.	E	1.72	Uc06	Dead flies
Diptera: Milichiidae				
Desmometopa tarsalis Loew	I	1.991–4.599	Ki96	Dead flies
Diptera: Muscidae				
Atherigona orientalis Schiner	I	0.01–0.38	Uc06	Dead flies
	I	0.150–0.213	Ki96	
Lispocephala hirtifemur Malloch	E	0.008	AK94	Dead flies (probably)
Lispocephala kauaiensis (Grimshaw)	E		AK94	Dead flies (probably)
Diptera: Neriidae				
Telostylinus lineolatus (Wiedemann)	I	0.384–0.543	Ki96	Dead flies
Diptera: Otitidae				
Euxesta annonae (Fabricius)	I	0.322–1.370	Ki96	Dead flies
Diptera: Phoridae				
Diplonevra peregrina (Wiedemann)	I	1.272–2.145	Ki96	Dead flies
Megaselia sp.	?			Dead flies
Megaselia sp.	?	0.019	AK94	Dead flies
Diptera: Sarcophagidae				
Sarcophaga peregrina (Robineau-Desvoidy)	I	0.012–0.191	Ki96	Dead flies
Hemiptera: Miridae				
Orthotylus n. sp.	E	0.009	AK94	Methyl eugenol
Sarona hiiaka Asquith	E	0.004	AK94, As94	Methyl eugenol
Sarona mokihana Asquith				Methyl eugenol
Hymenoptera: Apidae				
Apis mellifera Linnaeus	I	0.054	AB98	Methyl eugenol
Hymenoptera: Proctotrupidae				
Brachyserphus hawaiiensis (Ashmead)	E	0.003	AK94	Dead flies (probably)

All records from surveys on Kauai, except *Scaptomyza* n.sp. nr *silvicola* from Lanai. Actual attraction is the corrected conclusion, based on results from this study.

[a] E, endemic; I, Introduced.

[b] References: AB98, Asquith and Burny 1998; AK94, Asquith and Kido 1994; As94, Asquith 1994; Co, Conant 1978, 1979b, c; Ki96, Kido et al. 1996; Uc06, Uchida et al. 2006.

sites in backyards with a diversity of fruit trees, one site in a citrus orchard, one site in a large feral stand of common guava (*Psidium guajava* L.), and the last site at the foot of the North Kohala Forest Range, in a forest dominated by invasive *Fraxinus uhdei* (Wenzig) Lingelsh. (Fig. 2).

Maui Island Sites. In the agricultural community of Kula, we maintained 14 sets of traps in nine sites (517–1,138 m elevation), within persimmon (*Diospyros kaki* L. fil.) orchards (six sites), coffee plantations (two sets in maintained plots and two sets in abandoned plots), two sets in non-native forest adjacent to

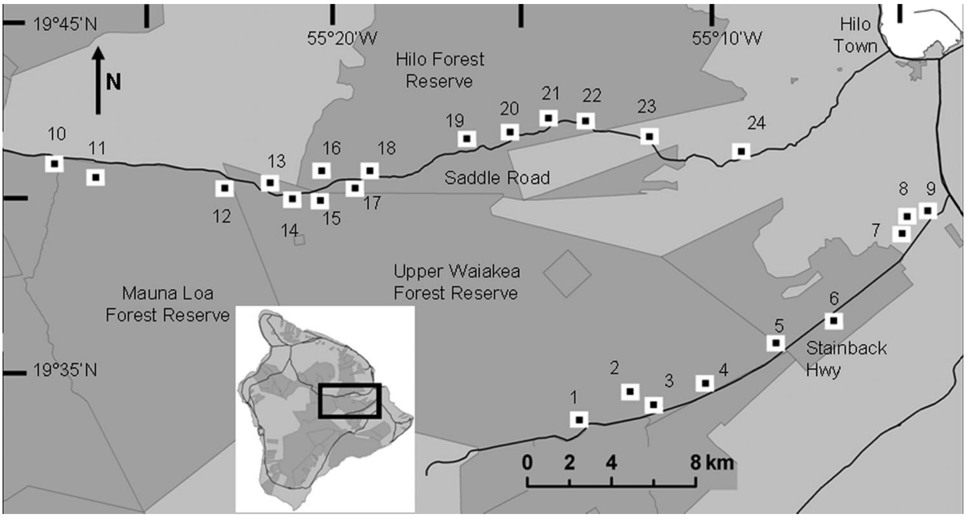

Fig. 1. Trapping sites on Hawaii Island along Stainback Highway and Saddle Road. Habitats (and corresponding sites) include wet ohia-dominated forest (1–4, 20, 21), wet kipuka forest (13–18), dry kipuka forest (10–12), open bogs over recent lava flows (19, 22, 23), strawberry guava–dominated forest (5, 9, 24), non-native forest (6), mixed fruit orchard (7), and citrus orchard (8).

persimmon orchards, and two sets in citrus and mixed fruit orchards (Fig. 3). In addition, we established 37 trapping sites on the northern slope of Haleakala Mountain, with one site every 150 m, along two linear intersecting transects (Fig. 4). The first transect runs 2 km along the Maile Trail, in the Waikamoi Forest Preserve, from the Flume road in the Makawao Forest Reserve (1,294 m; mixed native/invasive forest) into the Waikamoi Nature Conservancy Reserve (intact mesic forest dominated by ohia and koa (*Acacia koa* A. Gray) up to near Ukulele Camp at 1,583 m. The second (4 km) transect runs along the Flume Road, from the entrance of Makawao Forest Reserve (1,284 m), first along non-native plantation forest dominated by *Pinus* sp., *Eucalyptus* sp., or *Fraxinus uhdei*, and then into mixed native mesic forest, continuing into the Koolau Forest Reserve (wet native ohia-koa forest) to the junction of the Pipeline Road (1,285 m), and for 1 km

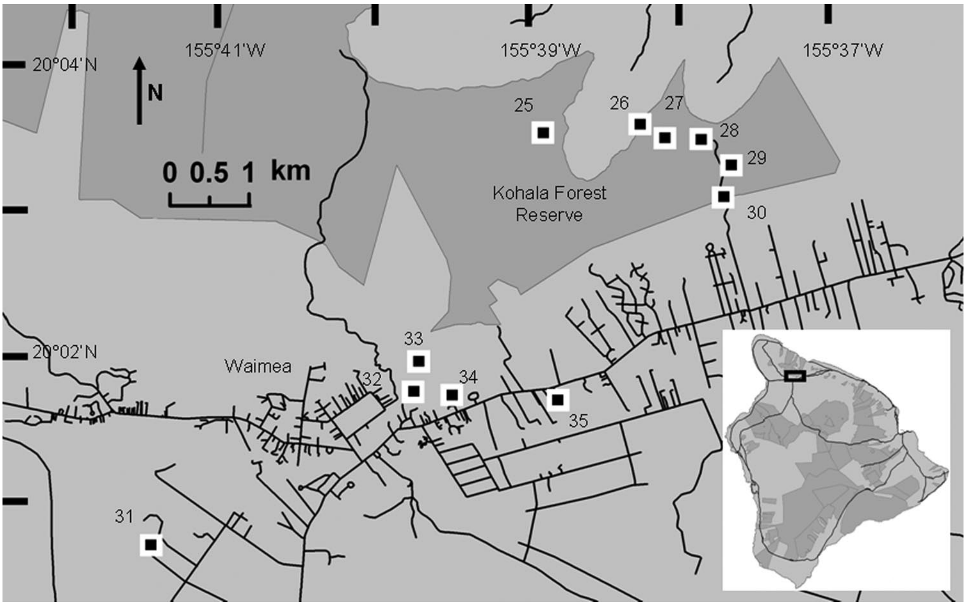

Fig. 2. Trapping sites on Hawaii Island in Kohala Forest Reserve and Waimea agricultural area. Habitats (and corresponding sites) include wet ohia-dominated forest (25–29), strawberry guava forest adjacent to native forest (30), feral guava stand (32), non-native forest dominated by *F. uhdei* (33), citrus orchard (31), and mixed backyard orchard (34, 35).

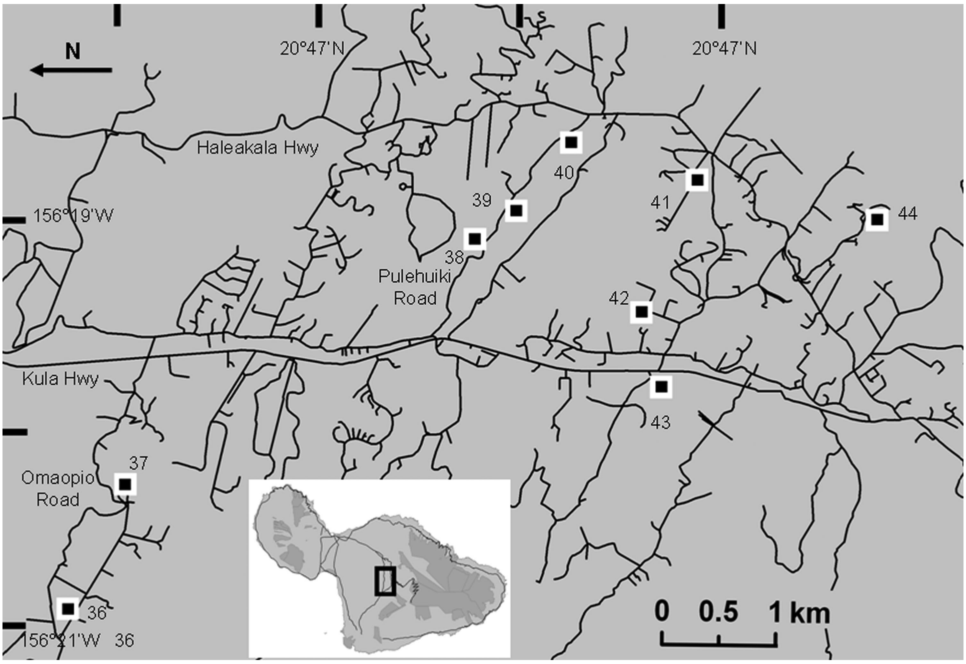

Fig. 3. Trapping sites in Kula agricultural area on Maui Island. Habitats (and corresponding sites) include persimmon orchards (38–41, 43, 44), coffee orchards (36, 42–44), non-native forest adjacent to orchards (40, 44), mixed fruit orchard (37), and citrus orchard (37).

along the Pipeline Road forest down to 1,184 m elevation (mixed native/invasive wet forest).

Trap Design. Bucket traps were made of white 1.3-liter plastic drinking cups (21 cm tall by 11 cm lid diameter; Berry Plastics, Evansville, IN), with two lateral 23-mm-diameter holes on opposite sides, 50 mm below the top, to allow insect entry. The trap top was covered with a tightly fitting plastic lid, with a hole

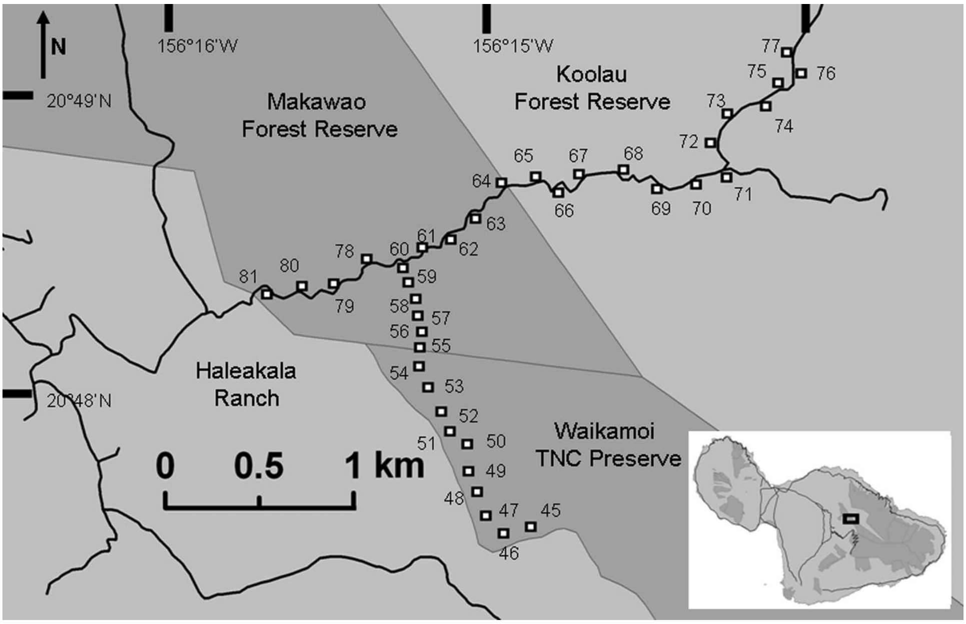

Fig. 4. Trapping sites in forest reserves on Maui Island. Habitats (and corresponding sites) include native mesic ohia-koa forest as pure native forest (45–55) or mixed with invasive trees (55–60), wet native ohia-koa forest (61–77), and non-native forest dominated by *Pinus*, *F. uhdei*, or *Eucalyptus* (78–81).

drilled in its center, through which a 30-cm-long, 15-gauge aluminum tie wire was inserted, and bent into a hook below the lid. A 30-cm white plastic food plate was placed on top of each trap to prevent trap flooding by frequent rain. Each trap was allocated one of four possible lure treatments. For the two male lure treatments, lure plugs with 2 g Cue-Lure or 10 g methyl eugenol active ingredient (Scentry Biologicals, Billings, MT) were placed inside a plastic basket (AgriSense, Palo Alto, CA) (Hiramoto et al. 2006), and suspended from the trap's inner ceiling, on the tie wire hook. The third treatment consisted of dead fruit flies (*B. dorsalis*) obtained from the USDA–ARS Manoa mass rearing facility (Honolulu, HI) to emulate the effect of accumulation of trapped, decaying fruit flies. Fifty milliliters of dry dead flies (1,142 ± 58 [SEM] flies, $n = 10$) were placed in pouches made of gauze, and pouches were briefly dipped in water and placed inside a closed plastic bag for 3 d before their use for trapping, allowing flies to decay, thus replicating a decaying trap catch. One pouch was placed at the bottom of each dead flies trap in the liquid preservative. The last treatment was an unbaited control trap. One half of a 25 by 90-mm strip containing 10% dichlorvos (2,2–dichlorovynil dimethyl phosphate; Vaportape II; Hercon Environmental, Emingsville, PA) was attached to the inner hook of all the traps, providing rapid kill of captured arthropods before they could escape from the trap. Additionally, 200 ml of a 20% solution of propylene glycol such as Sierra antifreeze was used in all traps to retard decay of captured arthropods and facilitate identification of liquid-preserved specimens.

Trapping Procedure. At each site, traps were hung in trees 1.5–2 m above the ground and at least 10 m apart to avoid interference among traps. Trap contents were cleared weekly. Traps on Hawaii Island were maintained from June to August 2005 for 10 wk on Stainback, 9 wk on Saddle and in Waimea, and 8 wk in Kohala. Male lure traps and the lure-free control were maintained and serviced continuously through the season. Traps artificially augmented with decaying flies as bait were maintained continuously at Waimea sites and for 1 wk straight every other week, in Stainback (five collections starting at week 1) and Kohala and Saddle (three collections starting at week 3), to avoid collecting too many native insects. Traps in Kula (Maui) were set on May 2006, near the end of the persimmon flowering season, to coincide with the start of fruit maturation and consequent fruit fly activity, and left until the end of harvest season in late November. The traps were serviced weekly for 13 wk (until late August), and subsequently monthly for the last 3 mo, because the main investigator had moved back to Honolulu to sort samples. Traps baited with decaying flies were maintained continuously in Kula and removed after 13 wk. Traps with decaying flies were not used along the Maui forest transects, because data collected on Hawaii Island in 2005 were judged sufficient to characterize the taxonomic range of nontargets attracted to dead flies in native forest. Instead, we used mushroom bait traps (Carson and Heed 1983) and yellow pan traps, which both collected a broad diversity of endemic Drosophilidae similar to those attracted to decaying flies. In this case, we wanted to establish the presence of potential nontargets in the trapping area. Thus, if potential nontarget insects were present, but not attracted to the methyl eugenol and Cue-Lure traps, we could show their presence without lure attraction. Traps in the Maui forest transects were maintained for 12 wk (June–August 2006). After 6 wk, all trap sites were shifted downslope by 75 m along the transects to maximize habitat coverage for potential nontarget insects.

Positions of traps at all sites on both islands were rerandomized every 3 wk to minimize effect of trap position on catches. Pouches of decaying flies were replaced weekly, whereas lure plugs and pesticide strips were used for the whole trapping duration on Hawaii and Maui forests and replaced once after 13 wk in Kula. Lure plugs are known to remain effective over the entire exposure period (Hiramoto et al. 2006). In addition to the bucket traps, Multi-Lure traps charged with the three-component BioLure food attractant (Heath et al. 1997) were maintained intermittently or continuously at all trapping sites for nontarget effect studies that will be published separately (L.L., unpublished data), but are referred to in the discussion, and to confirm that the apparent lack of attraction to male lures is not caused by the absence of nontarget species at trapping sites.

Sample Processing. All fruit flies and nontarget species trapped during this study were sorted by morphology, counted, sexed, and identified to species level whenever feasible. Numbers of individuals in very large samples of conspecifics were estimated by using 2-ml subsamples for invasive Drosophilidae (contained an average of 631 ± 133 flies, $n = 38$) and 5-ml subsamples for Oriental fruit fly (107 ± 14 flies, $n = 58$). Reference collections of voucher specimens have been deposited at the University of Hawaii Insect Museum (Manoa) and the Bernice P. Bishop Museum, both in Honolulu (HI).

Data Analysis. All insect counts were converted to number of flies per trap per day and analyzed using SAS 9.1 (SAS Institute 2004). ANOVAs were performed on catch data for all species (or genera) represented by at least 50 individuals. For each species, we used only data from sites where at least one specimen of the species was collected to avoid including data from sites where the nontarget species is rare or absent. Analyses were also done on total numbers of specimens of all species in each family to evaluate the less specific effect of decaying fruit flies on catches of insect families as a whole. Because of the non-normal distribution of the data and the large number of zero trap catch values, mixed model analysis of variance (ANOVA) with the minimum variance unbiased quadratic estimation (PROC MIXED MIVQUE0; SAS Institute, 2004) was used, with lure type treated as a fixed factor and site as a random factor. Catches from different collecting dates were treated as repeated measures. Trap catches varied but did not decrease with time from lure or insect depletion. Least square means

Table 2. Nontarget insects significantly attracted to methyl eugenol fruit fly male lure

Species	Status[a]	No. sites		Mean ± SEM no. captured per trap per day[b]			
		Hawaii	Maui	Cue-Lure	Methyl eugenol	Decaying flies	Control
Sciaridae: *Bradysia setigera* (Hardy) (Fem)	E	18	44	0.022 ± 0.004b	0.253 ± 0.032a	0.004 ± 0.002b	0.019 ± 0.006b
Syrphidae: *Allograpta obliqua* (Say)	I	18	27	0.009 ± 0.002b	0.041 ± 0.006a	0.0b	0.002 ± 0.001b
Apidae: *Apis mellifera* L.	I	19	39	0.008 ± 0.002b	0.092 ± 0.010a	0.006 ± 0.002b	0.007 ± 0.002b
Nitidulidae: *Carpophilus marginellus* Motsch.	I	2	19	0.001 ± 0.001b	0.032 ± 0.005a	0.052 ± 0.022a	<0.001b
C. marginellus (Kula)	I	0	9	<0.001b	0.045 ± 0.009a	0.056 ± 0.023a	0.0b
C. marginellus (Maui forest)	I	0	10	0.002 ± 0.002b	0.017 ± 0.005a	No data	0.001 ± 0.001b
Miridae: *Orthotylus coprosmae* Polhemus	E	0	20	0.018 ± 0.004b	0.048 ± 0.009a	No data	0.012 ± 0.003b
Crambidae: *Mestolobes minuscula* (Butler)	E	0	10	<0.001b	0.146 ± 0.043a	0.002 ± 0.002b	0.001 ± 0.001b
Crambidae: *Orthomecyna* ? *exigua* (Butler)	E	0	12	<0.001b	0.061 ± 0.009a	0.015 ± 0.004b	0.012 ± 0.004b

All counts include females and males, unless otherwise specified.

[a] E, endemic; I, introduced.

[b] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). $P < 0.0001$ for all analyses, unless otherwise indicated. *B. setigera:* $F = 37.33$; df = 3,2305; *A. obliqua:* $F = 29.46$; df = 3,1656; *A. mellifera:* $F = 51.26$; df = 3,2288; *C. marginellus:* $F = 12.62$; df = 3,925; *C. marginellus* (Kula): $F = 7.04$; df = 3,512; *C. marginellus* (Maui forest): $F = 7.55$; df = 2,345; $P = 0.0006$; *O. coprosmae:* $F = 9.80$; df = 2,705; *M. minuscula:* $F = 10.73$; df = 3,576; *O. ? exigua:* $F = 26.57$; df = 3,696.

estimates for each lure treatment were compared using Tukey's honest significant difference test. To address the confounding issue of flies accumulating in traps and possibly influencing nontarget species captures, an analysis of covariance (ANCOVA) was used (crossing number of target fruit flies caught with lure in the ANOVA). A significant interaction for the ANCOVA term indicated a confounding effect of increased target fly captures. Furthermore, for nontargets with apparent attraction to methyl eugenol in the analysis results, the ANOVA were repeated, excluding data from the methyl eugenol samples with at least 1,000 trapped *B. dorsalis,* and methyl eugenol effect became nonsignificant for species attracted to dead *B. dorsalis* rather than to methyl eugenol.

Results and Discussion

Nontarget arthropods collected during the study belong to 17 orders, 93 families, and 197 genera. Most specimens (96.9%) were identified to species and a further 2.3% to genus only. A total of 401 nontarget species, including 187 endemic and 183 invasive species, were identified as known species (286), clearly recognizable morphospecies (100), or undescribed species (15). Catches were dominated by Diptera (94.9% of the specimens, 248 species), followed by Lepidoptera (1.5%), Hymenoptera (1.4%), and Coleoptera (1.3%). The majority of trapped nontarget species belonged to four families of Diptera: Ceratopogonidae (34.4% of total, with 4 recognized species but dominated by 1 native species), Drosophilidae (29.1%, 116 species, including 94 native species), Phoridae (11.6%, 12 species), and Milichiidae (10.7%, 1 species). Results from ANOVA of data are reported in Tables 2–7 for all species or families for which a significant ($P < 0.05$) attraction was detected to male lures (Table 2) or decaying flies (Tables 3–7).

Cue-Lure Effect. Cue-Lure did not significantly attract any nontarget insects, and melon flies were not numerous enough in traps (maximum was 5.8 per trap per day at one orchard site) for Cue-Lure traps to secondarily attract scavengers. Uchida et al. (2003) reported nontarget captures in Cue-Lure traps and assumed them to be drawn to dead flies, because 92.5% of their specimens were saprophagous species.

Methyl Eugenol Attraction. Seven nontarget species from five orders were significantly ($P < 0.05$) attracted to methyl eugenol-baited traps, regardless of the presence or number of *B. dorsalis* (Table 2). All but the Sciaridae and the Miridae are closely associated with flowers, as pollen or nectar feeders. Catches of honey bees (0.09 per trap per day) and the syrphid *Allograpta obliqua* (0.04 per trap per day) were very low and comparable to honey bee catches previously reported by Asquith and Burny (1998) (0.054 per trap per day). In 1 yr of methyl eugenol trapping in South America, Vayssières et al. (2007) collected only 12 bees, including 1 honey bee and 5 euglossine bees, known to respond to methyl eugenol (Williams and Whitten 1983). Asquith and Burny (1998) failed to detect methyl eugenol in flower extracts of the three native trees most visited by honey bees during their survey. They speculated that methyl eugenol may either mimic other compounds present in flower blossoms attractive to bees or methyl eugenol or its related compounds in flowers may mimic terpenoid pheromones produced by the bees themselves. The latter hypothesis would not adequately explain the attraction of the taxonomically unrelated but flower-associated syrphids, moths, and beetles shown in this study and lacewings in previous literature (Suda and Cunningham 1970, Umeya and Hirao 1975, Pai et al. 2004).

Two endemic species of Crambidae (Lepidoptera) were significantly attracted to methyl eugenol in Kula orchards and especially on flowering coffee trees: *Mestolobes minuscula* is a frequent visitor of flowers, common at lower altitudes, and *Orthomecyna exigua* visits flowers of forest trees and is sometimes found in the open country below the forest belt (Perkins 1913). During this study we observed, and showed at two Kula sites, that these moths were captured in methyl eugenol traps mainly when support trees are bearing flowers.

Table 3. Attraction of Drosophilidae to decaying flies in traps

Species	Status[a]	No. sites		Mean ± SEM no. captured per trap per day[b]			
		Hawaii	Maui	Cue-Lure	Methyl eugenol	Decaying flies	Control
Drosophila spp. (endemic) (55 spp.)	E	27	38	0.057 ± 0.007b	0.053 ± 0.008b	2.477 ± 0.437a	0.049 ± 0.005b
D. (*Antopocerus*) spp (Fem)	E	18	0	0.023 ± 0.020b	0.033 ± 0.029b	1.991 ± 0.385a	0.011 ± 0.004b
D. bipolita Hardy Hardy (Fem)	E	11	5	0.016 ± 0.005b	0.001 ± 0.001b	0.309 ± 0.076a	0.024 ± 0.008b
D. (modified tarsus group) spp. (Fem)	E	18	0	0.009 ± 0.004b	0.026 ± 0.009b	1.957 ± 0.380a	0.011 ± 0.004b
D. multiciliata Hardy and Kaneshiro	E	6	0	0.003 ± 0.003b	0.0b	0.424 ± 0.106a	0.0b
D. neutralis Hardy (Mal)	E	10	0	0.005 ± 0.003b	0.0b	0.346 ± 0.106a	0.0b
D. ochracea Grimshaw	E	8	0	0.002 ± 0.002b	0.030 ± 0.001b	0.156 ± 0.054a	0.0b
D. percnosoma Hardy (Mal)	E	13	0	0.003 ± 0.002b	0.001 ± 0.001b	0.362 ± 0.081a	0.0b
D. tanythrix (Hardy) (Mal)	E	18	0	0.0b	0.024 ± 0.007b	0.586 ± 0.125a	0.002 ± 0.001b
Drosophila spp. (introduced) (15 spp.)	I	35	36	0.195 ± 0.081b	1.587 ± 0.472b	11.759 ± 2.246a	0.077 ± 0.013b
D. busckii Coquillett	I	10	12	0.003 ± 0.001b	0.003 ± 0.002b	0.055 ± 0.012a	<0.001b
D. hydei Sturtevant	I	2	7	0.001 ± 0.001b	0.0b	0.083 ± 0.025a	0.0b
D. immigrans Sturtevant	I	22	5	0.0c	0.055 ± 0.011b	0.111 ± 0.026a	<0.001c
D. sulfurigaster bilimbata Bezzi	I	16	1	0.015 ± 0.006b	1.927 ± 0.559b	7.969 ± 4.510a	0.007 ± 0.003b
D. suzukii (Matsumura)	I	35	19	0.030 ± 0.008b	1.418 ± 0.502b	9.173 ± 1.280a	0.019 ± 0.004b
Scaptomyza spp. (endemic) (39 spp.)	E	31	45	0.174 ± 0.013b	0.051 ± 0.006c	0.774 ± 0.144a	0.219 ± 0.018b
S. cryptoloba Hardy	E	19	0	0.086 ± 0.015b	0.065 ± 0.011b	0.556 ± 0.168a	0.094 ± 0.015b
S. exigua (Grimshaw)	E	10	0	0.008 ± 0.004b	0.024 ± 0.011b	1.921 ± 0.350a	0.141 ± 0.043b
S. inaequalis (Grimshaw)	E	7	0	0.148 ± 0.042b	0.036 ± 0.016b	1.773 ± 0.781a	0.082 ± 0.016b
S. undulata (Grimshaw)	E	8	0	0.0b	0.0b	0.572 ± 0.234a	0.0b

All counts include females and males, unless otherwise specified.

[a] E, endemic; I, introduced.

[b] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). $P < 0.0001$ for all analyses. *Drosophila* spp. (endemic): $F = 143.90$; df = 3,2279; *D.* (*Antopocerus*) spp.: $F = 63.94$; df = 3,535; *D. bipolita:* $F = 44.19$; df = 3,527; *D.* (modified tarsus): $F = 69.35$; df = 3,531; *D. multiciliata:* $F = 45.30$; df = 3,181; *D. neutralis:* $F = 26.93$; df = 3,287; *D. ochracea:* $F = 13.81$; df = 3,274; *D. percnosoma:* $F = 50.76$; df = 3,381; *D. tanythrix:* $F = 55.66$; df = 3,531; *Drosophila* spp. (introduced): $F = 49.36$; df = 3,2686; *D. busckii:* $F = 24.76$; df = 3,988; *D. hydei:* $F = 14.67$; df = 3,474; *D. immigrans:* $F = 21.38$; df = 3,973; *D. sulfurigaster bilimbata:* $F = 4.92$; df = 3,579; *D. suzukii:* $F = 57.93$; df = 3,2074; *Scaptomyza* spp. (endemic): $F = 61.24$; df = 3,2750; *S. cryptoloba:* $F = 18.20$; df = 3,570; *S. exigua:* $F = 75.64$; df = 3,293; *S. inaequalis:* $F = 13.99$; df = 3,206; *S. undulata:* $F = 17.17$; df = 3,241.

The introduced sap beetle *Carpophilus marginellus* (Nitidulidae) was attracted to decaying fruit flies but apparently also to methyl eugenol. The ANCOVA reported in Table 8 did not show a significant interaction between lure effect and numbers of *B. dorsalis* caught in methyl eugenol traps for this species in Kula. Additionally, catches were higher in methyl eugenol traps than Cue-Lure and control traps in Maui forests, where *B. dorsalis* was not trapped (Table 2). Although the larvae of *C. marginellus* feed in decaying fruit, both female and male adults are common flower visitors (Tsukada et al. 2008).

The reported captures of large numbers of green lacewings in methyl eugenol traps in Hawaii [*Mallada basalis* (Walker): 1.6 per trap per day] (Suda and Cunningham 1970), the Philippines [*Cunctochrysa* probably *albolineata* (Killington): 2.7 per trap per day] (Umeya and Hirao 1975), and Taiwan [*Ankylopteryx exquisite* (Nakahara): up to 52.9 per trap per day] (Pai et al. 2004) cannot be overlooked, even

Table 4. Attraction of Phoridae to decaying flies in traps

Species	Status[a]	No. sites		Mean ± SEM no. captured per trap per day[b]			
		Hawaii	Maui	Cue-Lure	Methyl eugenol	Decaying flies	Control
Phoridae ALL (11 species)	I-E	35	15	0.011 ± 0.002b	0.670 ± 0.224b	6.438 ± 0.764a	0.010 ± 0.002b
Chonocephalus spp.	E ?	6	2	0.003 ± 0.003b	0.082 ± 0.024a	0.063 ± 0.021a	0.0b
Diplonevra peregrina (Wiedemann)	I	21	9	0.0b	0.030 ± 0.012b	0.173 ± 0.052a	0.0b
Megaselia scalaris (Loew)	I	12	13	0.011 ± 0.003b	1.075 ± 0.386a	0.440 ± 0.078ab	0.007 ± 0.002b
Megaselia furcatilis Beyer	E	3	14	0.005 ± 0.002b	0.005 ± 0.002b	2.970 ± 0.692a	0.005 ± 0.002b
Megaselia sp1 (Fem)	?	0	15	0.003 ± 0.001b	0.004 ± 0.002b	0.364 ± 0.049a	<0.001b
Megaselia sp2 (Fem)	?	31	6	0.001 ± 0.001b	0.008 ± 0.003b	5.724 ± 0.989a	0.005 ± 0.002b
Megaselia sp3 (Fem)	?	16	0	0.0b	0.001 ± 0.001b	0.628 ± 0.135a	0.0b
Megaselia sp5 (Fem)	E	11	0	0.0b	0.003 ± 0.002b	0.584 ± 0.169a	0.0b
Puliciphora borinquenensis Wheeler	I	8	6	0.0b	0.038 ± 0.016b	0.744 ± 0.208a	0.0b

All counts include females and males, unless otherwise specified.

[a] E, endemic; I, introduced.

[b] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). $P < 0.0001$ for all analyses, unless otherwise indicated. Phoridae: $F = 91.07$; df = 3,1930; *Chonocephalus* spp: $F = 7.90$; df = 3,310; *D. peregrina:* $F = 15.00$; df = 3,1166; *M. scalaris:* $F = 6.21$; df = 3,1140; $P = 0.0003$; *M. furcatilis:* $F = 23.22$; df = 3,907; *M.* sp1: $F = 72.51$; df = 3,840; *M.* sp2: $F = 62.41$; df = 3,1306; *M.* sp3: $F = 49.93$; df = 3,490; *M.* sp5: $F = 36.45$; df = 3,326; *P. borinquenensis:* $F = 18.48$; df = 3,614.

Table 5. Attraction of various Diptera to decaying flies

Species	Status[a]	No. sites		Mean ± SEM no. captured per trap per day[b]			
		Hawaii	Maui	Cue-Lure	Methyl eugenol	Decaying flies	Control
Cecidomyiidae: *Contarinia* sp.	I	10	26	0.013 ± 0.003b	0.004 ± 0.001b	0.468 ± 0.153a	0.011 ± 0.002b
Chloropidae ALL (10 species)	I	13	12	0.009 ± 0.003b	0.019 ± 0.006b	0.916 ± 0.279a	0.005 ± 0.002b
Chloropidae: *Cadrema pallida* (Loew)	I	3	0	0.0b	0.0b	2.136 ± 1.130a	0.0b
Chloropidae: *Conioscinella formosa* (Becker)	I	1	5	0.004 ± 0.002b	0.002 ± 0.002b	0.155 ± 0.068a	<0.001b
Chloropidae: *Gampsocera hardyi* Kanmiya	I	7	2	0.006 ± 0.004b	0.036 ± 0.015b	0.361 ± 0.141a	0.0b
Chloropidae: *Gaurax bicoloripes* (Malloch)	I	3	0	0.005 ± 0.005b	0.020 ± 0.012b	0.652 ± 0.392a	0.011 ± 0.007b
Chloropidae: *Siphunculina striolata* (Wiedemann)	I	4	0	0.0b	0.021 ± 0.010b	4.949 ± 1.794a	0.004 ± 0.004b
Lonchaeidae: *Silba* sp.	I	9	1	0.0b	0.011 ± 0.009b	0.269 ± 0.076a	0.0b
Milichiidae: *Desmometopa tarsalis* Loew	I	2	12	0.011 ± 0.006b	2.383 ± 0.980a	0.211 ± 0.116b	0.0b
Neriidae: *Telostylinus lineolatus* (Wiedemann)	I	8	0	0.0b	0.108 ± 0.026a	0.067 ± 0.027ab	0.002 ± 0.002b
Otitidae: *Euxesta annonae* (Fabricius)	I	6	7	0.0b	0.001 ± 0.001b	0.643 ± 0.240a	0.0b
Psychodidae: *Psychoda* spp (Fem)	?	31	37	0.013 ± 0.003b	0.020 ± 0.003b	0.177 ± 0.057a	0.012 ± 0.002b
Sphaeroceridae: *Poecilosomella punctipennis* (Wied.)	I	24	0	0.005 ± 0.002b	0.002 ± 0.001b	0.677 ± 0.166a	0.036 ± 0.015b
Tephritidae: *Ceratitis capitata* (Wiedemann)	I	0	8	<0.001b	0.002 ± 0.002b	0.485 ± 0.158a	0.0b
Tephritidae: unknown species	?	0	6	0.003 ± 0.002b	0.004 ± 0.002b	0.104 ± 0.036a	0.023 ± 0.022b

All are scavengers on decaying plant material, except for the Cecidomyiidae and Tephritidae, which attack live plants. All counts include females and males, unless otherwise specified.

[a] E, endemic; I, introduced.

[b] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). $P < 0.0001$ for all analyses, unless otherwise indicated. *Contarinia* sp.: $F = 18.03$; df = 3,1539; Chloropidae: $F = 14.37$; df = 3,1115; *C. pallida:* $F = 8.30$; df = 3,96; *C. formosa:* $F = 6.47$; df = 3,302; $P = 0.0003$; *G. hardyi:* $F = 9.10$; df = 3,327; *G. bicoloripes:* $F = 6.15$; df = 3,96; $P = 0.0007$; *S. striolata:* $F = 15.38$; df = 3,135; *Silba* sp.: $F = 17.38$; df = 3,341; *D. tarsalis:* $F = 5.14$; df = 3,762; $P = 0.0016$; *T. lineolatus:* $F = 11.15$; df = 3,264; *E. annonae:* $F = 9.72$; df = 3,586; *Psychoda* spp.: $F = 29.02$; df = 3,2416; *P. punctipennis:* $F = 33.82$; df = 3,740; *C. capitata:* $F = 11.74$; df = 3,452; Tephritidae unknown: $F = 5.60$; df = 3,344; $P = 0.0009$.

though no attraction could subsequently be shown in Hawaii, and only four specimens of *M. basalis* were collected during our study. Adult chrysopids, depending on species, are either predominantly carnivorous or palyno-glycophagous, feeding on flower pollen, nectar, and honeydew released by Hemiptera (Principi and Canard 1984). Adults of *M. basalis* and *C. albolineata* are palyno-glycophagous (Canard 2005, Chang and Hsieh 2005), suggesting an attraction to methyl eugenol as emulation of floral compounds. The methyl eugenol–related natural flower fragrance compound eugenol is indeed highly attractive to the lacewing *Glenochrysa* sp. (up to 4.8 per trap per day) when used in traps in Malaysian rainforest (Sajap et al. 1997). Further study is required in sites where chrysopids and syrphids are most common and contribute to the natural control of aphids to evaluate the risks of large-scale methyl eugenol applications. Only three specimens of the endemic Hawaiian *Anomalochrysa* lacewings randomly entered traps in our study. In the

Table 6. Attraction of calyptrate Diptera to decaying flies

Species	Status[a]	No. sites		Mean ± SEM no. captured per trap per day[b]			
		Hawaii	Maui	Cue-Lure	Methyl eugenol	Decaying flies	Control
Calliphoridae: *Dyscritomyia grimshawi* James	E	12	0	0.0b	0.0b	0.372 ± 0.086a	0.0b
Calliphoridae: *D. hawaiiensis* Grimshaw	E	12	0	0.0b	0.0b	0.170 ± 0.036a	0.0b
Calliphoridae: *D. lucilioides* (Grimshaw) and/or *D. obscura* (Grimshaw)	E	20	0	0.003 ± 0.002b	0.001 ± 0.001b	2.658 ± 0.399a	0.001 ± 0.001b
Calliphoridae (introduced) ALL (10 species)	I	11	5	0.004 ± 0.002b	0.004 ± 0.002b	0.104 ± 0.035a	0.003 ± 0.002b
Calliphoridae: *Pollenia rudis* (Fabricius)	I	4	2	0.005 ± 0.003b	0.005 ± 0.003b	0.489 ± 0.233a	0.005 ± 0.003b
Muscidae: *Atherigona orientalis* Schiner	I	13	13	0.002 ± 0.001b	0.018 ± 0.004b	2.137 ± 0.562a	<0.001b
Muscidae: *Hydrotaea houghi* Malloch	I	11	2	0.0b	0.0b	0.223 ± 0.107a	0.0b
Muscidae: *Muscina levida* (Harris)	I	8	0	0.006 ± 0.004b	0.283 ± 0.156b	1.152 ± 0.334a	0.0b
Sarcophagidae ALL (9 species)	I	19	12	0.002 ± 0.001b	0.002 ± 0.001b	0.213 ± 0.048a	0.003 ± 0.002b
Sarcophagidae: *Helicobia morionella* (Aldrich)	I	4	11	0.0b	0.0b	0.120 ± 0.038a	0.003 ± 0.003b
Sarcophagidae: *Sarcophaga albiceps* Meigen	I	10	0	0.0b	0.003 ± 0.002b	0.239 ± 0.138a	0.0b
Tachinidae (3 species)	I	2	5	0.003 ± 0.002b	0.0b	0.247 ± 0.137a	0.002 ± 0.002b

All counts include females and males.

[a] E, endemic; I, introduced.

[b] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). $P < 0.0001$ for all analyses, unless otherwise indicated. *D. grimshawi:* $F = 45.21$; df = 3,345; *D. hawaiiensis:* $F = 50.37$; df = 3,360; *D. lucilioides-obscura:* $F = 110.28$; df = 3,593; Calliphoridae (introduced): $F = 14.32$; df = 3,588; *P. rudis:* $F = 22.61$; df = 3,188; *A. orientalis:* $F = 19.54$; df = 3,1172; *H. houghi:* $F = 7.07$; df = 3,457; $P = 0.0001$; *M. levida:* $F = 10.80$; df = 3,243; Sarcophagidae ALL: $F = 28.46$; df = 3,1292; *H. morionella:* $F = 12.54$; df = 3,752; *S. albiceps:* $F = 5.57$; df = 3,313; $P = 0.001$; Tachinidae: $F = 6.70$; df = 3,313; $P = 0.0002$.

Table 7. Attraction of Coleoptera and Hymenoptera to decaying fruit flies

Species	Status[a]	No. sites		Mean ± SEM no. captured per trap per day[b]			
		Hawaii	Maui	Cue-Lure	Methyl eugenol	Decaying flies	Control
Braconidae: *Aphaereta pallipes* (Say)	I	14	5	0.0b	0.0b	0.096 ± 0.016a	0.0b
Encyrtidae: *Tachinaephagus zealandicus* Ashmead	I	13	14	0.0b	0.0b	0.561 ± 0.061a	<0.001b
Formicidae: *Linepithema humile* (Mayr)	I	2	3	0.009 ± 0.007b	0.002 ± 0.002b	0.199 ± 0.076a	0.003 ± 0.002b
Corylophidae: *Corylophodes suturalis* (Sharp)	I	18	32	0.016 ± 0.005b	0.003 ± 0.001b	0.486 ± 0.068a	0.023 ± 0.004b
Nitidulidae spp (endemic) ALL (14 species)	E	12	19	0.010 ± 0.003b	0.009 ± 0.002b	0.065 ± 0.019a	0.011 ± 0.003b
Nitidulidae: *Prosopeus inauratus* (Sharp)	E	10	0	0.013 ± 0.005b	0.015 ± 0.006b	0.106 ± 0.036a	0.014 ± 0.006b
Staphylinidae: *Atheta* spp	?	25	11	0.0b	0.002 ± 0.001b	0.168 ± 0.022a	0.001 ± 0.001b

All counts include females and males.

[a] E, endemic; I, introduced.

[b] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). $P < 0.0001$ for all analyses. *A. pallipes:* $F = 66.25$; df = 3,728; *T. zealandicus:* $F = 115.53$; df = 3,1222; *L. humile:* $F = 10.18$; df = 3,236; *C. suturalis:* $F = 108.74$; df = 3,2015; Nitidulidae spp. (endemic): $F = 19.72$; df = 3,1089; *P. inauratus:* $F = 10.49$; df = 3,280; *Atheta* spp: $F = 96.34$; df = 3,1374.

absence of native aphids, their larvae are suspected to feed primarily on endemic barklice (Psocoptera) (Zimmerman 1957). If adults are also carnivorous, they are unlikely to be impacted by methyl eugenol.

The attraction we found to methyl eugenol of the endemic *Orthotylus coprosmae* (Hemiptera: Miridae) in Maui forest areas supports similar findings for three other mirid species by Asquith and Kido (1994). Among these past records is *Sarona mokihana,* which feeds on *Melicope anisata* (Mann) T.G. Hartley and B.C. Stone (Rutaceae), known to contain methyl eugenol (Scheuer and Hudgins 1964). It is unknown whether the endemic *Coprosma foliosa* A. Gray and *C. pubens* A. Gray (Rubiaceae), the food plants of *O. coprosmae* (Polhemus 2002), contain methyl eugenol. A similar food-related plant kairomone relationship may also explain past captures of three species of endemic Anobiidae in methyl eugenol traps on Kauai (Asquith and Kido 1994). We are unable to confirm methyl eugenol attraction for Anobiidae, because only 14 individuals were caught in our traps, the majority (12) at the Maui mesic forest sites.

Although the above nontarget records are likely related to stimuli associated with food location by the insects, methyl eugenol may emulate a pheromone for the endemic fly *B. setigera* (Hardy) (Sciaridae) because, despite the trapping of conspecific males and of seven other sciarid species that randomly entered all the bucket traps regardless of lure, only females of *B. setigera* were specifically drawn to methyl eugenol. *B. setigera* was the nontarget species most commonly and consistently attracted to methyl eugenol in our study, primarily in forest environments. Adult biology and larval breeding habits of this endemic species are unknown, but Steffan (1974) suggested that most Hawaiian sciarids, including the endemics, appear to be phytosaprophagous, mycetophagous, or both.

Attraction to Decaying Flies. At least 56 species in 21 families of Diptera, Hymenoptera, and Coleoptera were significantly ($P < 0.05$) attracted to traps artificially baited solely with decaying fruit flies (no male lures; Tables 3–7). Kido et al. (1996) listed attraction of 16 nontarget species to methyl eugenol, but cautioned that only 7 of these species, associated with

Table 8. Further analysis of cases of apparent nontarget attraction to methyl eugenol reported in Tables 3–7, caused by accumulation of dead *B. dorsalis* (OFF) in traps

Species	r	Lure effect			Lure × OFF			ANOVA for ME including all ME samples		ANOVA for ME when omitting samples with over 1,000 *B. dorsalis*	
		F	df	P	F	df	P	N[a]	Mean ± SEM	N[a]	Mean ± SEM
Drosophilidae: *D. immigrans*	0.125	20.96	3,969	<0.0001	19.51	4,969	<0.0001	272	0.055 ± 0.011b	214	0.012 ± 0.007b
Drosophilidae: *D. suzukii*	0.446[b]	65.31	3,2070	<0.0001	40.34	4,2070	<0.0001	586	1.418 ± 0.502b	527	0.067 ± 0.033b
Milichiidae: *D. tarsalis*	−0.053	5.62	3,759	0.0008	0.52	3,759	0.6703	204	2.383 ± 0.980a	183	2.542 ± 1.087a
Neriidae: *T. lineolatus*	0.384[b]	3.24	3,262	0.0227	32.27	2,262	<0.0001	78	0.108 ± 0.026a	29	0.010 ± 0.010b
Phoridae: *Chonocephalus spp*	0.36[b]	4.33	3,306	0.0053	17.46	4,306	<0.0001	86	0.082 ± 0.024a	39	0.0b
Phoridae: *D. peregrina*	0.386[b]	16.93	3,1103	<0.0001	11.83	3,1103	<0.0001	325	0.030 ± 0.012b	293	0.001 ± 0.001b
Phoridae: *M. scalaris*	0.389[b]	0.95	3,1136	0.4142	61.84	4,1136	<0.0001	307	1.075 ± 0.386a	248	0.005 ± 0.002b
Muscidae: *A. orientalis*	0.236[b]	10.52	3,1168	<0.0001	349.2	4,1168	<0.0001	315	0.018 ± 0.004b	256	0.003 ± 0.001b
Nitidulidae: *C. marginellus*	−0.008	12.26	3,923	<0.0001	0.47	2,923	0.6280	275	0.032 ± 0.005a	264	0.032 ± 0.005a

For each species, we report the Pearson product-moment correlation coefficient (r) between nontarget and OFF catches in methyl eugenol traps (r, and its associated P value), results from ANCOVA between nontarget catches in lure traps and no. of OFF catches (lure × OFF), and the same ANOVAs as reported for methyl eugenol on Tables 3–7, but excluding samples with >1,000 OFF.

[a] n = number of methyl eugenol samples used in analysis.

[b] $P < 0.05$ for r.

plants or their metabolites, in the families Drosophilidae, Neriidae, Chloropidae, and Cucujidae, might actually be attracted to methyl eugenol. The remaining species, associated with carrion, were more likely secondarily attracted to dead fruit flies (Kido et al. 1996). Our results show that even the plant scavengers are attracted to dead flies in the traps. Of the 36 species purportedly attracted to methyl eugenol listed in Table 1, 8 species are shown here to be attracted solely to dead flies, and an additional 13 species belong to four families with species overwhelmingly drawn to dead flies rather than methyl eugenol (Drosophilidae, Chloropidae, Sarcophagidae, and Staphylinidae). The possible attraction to dead flies had previously been suggested by several authors (Conant 1978, 1979a, 1980; Loope and Medeiros 1992; Kido et al. 1996; Uchida et al. 2003, 2006). In fact, the well-known fruit fly attraction to volatiles from bacterial decomposition of protein was exploited to develop the synthetic BioLure (Heath et al. 1997), a potent attractant for *Ceratitis* and *Anastrepha* fruit flies, but also for nontargets, especially Diptera (Thomas 2003). Similar volatiles from decaying fruit flies in male lure traps likely attracted nontargets in this study. The confounding effect of *B. dorsalis* in methyl eugenol traps is profound, because *B. dorsalis* catches in methyl eugenol traps were high (20–321 per trap per day) in the Kauai studies. In our study, native forest sites on Hawaii Island had very few *B. dorsalis* (2.4 per methyl eugenol trap per day), and only one specimen was collected during 4 mo of trapping in the Maui forest transect. No nontargets, other than the flower insects, mirid, and sciarid cited above, were collected in methyl eugenol traps in these habitats, apart from insects randomly entering traps.

Endemic and introduced Drosophilidae dominated nontarget catches in this study, in numbers of specimens and species diversity, but most if not all are drawn to dead flies rather than methyl eugenol. Previously, six endemic and two introduced *Drosophila* and five endemic *Scaptomyza* were reportedly drawn to methyl eugenol (Conant 1978, Asquith and Kido 1994, Kido et al. 1996, Uchida et al. 2006) (Table 1). Based on these findings, with seven endemic and five introduced *Drosophila* and four endemic *Scaptomyza* in sufficient numbers to show attraction to dead flies in traps rather than methyl eugenol (Table 3), it is likely that most previous drosophilid records were inaccurately interpreted, except possibly for *Scaptomyza* n.sp. nr *silvicola* (Conant 1978). We also confirmed with BioLure, mushroom-baited traps, and pan traps, the presence of drosophilid populations in trap areas, to make sure that negative male lure attraction results were the product of nonattraction rather than absence of these species. Of the 306 described species of Drosophilidae known or expected to occur in the surveyed areas, nearly one half (143) were collected, including 123 endemic species (L.L., unpublished data). On Hawaii Island, 53 of all the 79 drosophilid species collected in all traps were also present in the traps baited with decaying flies. Despite the presence of a broad diversity of endemic drosophilids at the trapping sites, none were attracted to methyl eugenol. Plant species used as larval breeding substrate by the Drosophilidae are known for 71 of the 123 endemic species collected during this study (Magnacca et al. 2008) and include over 41 plant species in 30 genera and 24 families. The absence of methyl eugenol in the fragrant leaves of *Cheirodendron trigynum* (Gaud.) Heller (Araliaceae), the most common larval host species for endemic Hawaiian Drosophilidae (22% of endemic species with known hosts in Hawaii), was shown by Kircher (1969) and more recently confirmed using solid phase microextraction (SPME) analysis (Pawliszyn 1997) performed at the USDA–ARS lab (Hilo, HI), which showed a dominance of monoterpenes and sesquiterpenes but no trace of methyl eugenol in fresh or fallen (yellow or brown) leaves. Nevertheless, it is possible that one or several species of drosophilids may actually be drawn to methyl eugenol, as suspected for one *Scaptomyza* (Conant 1979b). Possible candidates may be among species that breed in host plants known to contain methyl eugenol, such as *Melicope anisata* (Scheuer and Hudgins 1964) and *Platydesma spathulata* (Gray) B. C. Stone (Rutaceae) (S. L. Montgomery, personal communication), or 1 of the 27 species known to use flowers as larval breeding substrate (Magnacca et al. 2008).

Wherever native or introduced Phoridae (Diptera) occur, they are invariably attracted in large numbers to dead flies, as evidenced by the capture of nine species in numbers sufficient to be included in the analysis (Table 4). Although parasitoid Phoridae species are known from elsewhere, the introduced and most, if not all, of the endemic species in Hawaii are thought to be scavengers (Hardy 1964).

Aside from Drosophilidae, a diversity of other flies breeding on decaying plant material (Chloropidae, Lonchaeidae, Neriidae, and Otitidae), manure (Sphaeroceridae), and organic matter in aquatic environments (Psychodidae) are readily drawn to dead flies rather than to methyl eugenol (Table 5). Except for a few species of Psychodidae, the Hawaiian fauna represented by these families is entirely composed of introduced species. The recorded attraction of Mediterranean fruit flies (*Ceratitis capitata*) and another undetermined tephritid species to decaying flies in Kula is not surprising, because *C. capitata* responds to the volatiles from bacterial decomposition used in the attractant BioLure (Heath et al. 1997) and was reported as attracted to decaying tephritids by Keiser et al. (1976).

Data on the introduced fly *Desmometopa tarsalis* (Milichiidae), whose larvae are saprophagous or coprophagous (Hardy and Delfinado 1980), are hard to interpret because of the conflation with *B. dorsalis* catches, and its attraction to flies rather than methyl eugenol can only be indirectly argued. It was previously collected in methyl eugenol traps that had also captured large numbers of *B. dorsalis* (Conant 1978, Kido et al. 1996, Uchida et al. 2007) and in traps artificially baited with dead flies, without methyl eugenol (Conant 1978). In our trapping, *D. tarsalis* was restricted to Kula, where it did not appear in large numbers until September 2006, after the dead fly-baited traps had been removed and when the number of *B. dorsalis* began to increase in methyl eugenol traps. Because traps were serviced monthly rather than weekly during that period, large numbers of *B. dorsalis* accumulated inside traps. The very low numbers of *D. tarsalis* in methyl eugenol and dead fly traps from May to August and their increase by September may have been a seasonal phenomenon, coincident with but independent from the increase in *B. dorsalis* catches. Kido et al. (1996) reported a sudden increase in *D. tarsalis* catches in November 1991, with a peak of 82.3 per trap per day in December, followed by a rapid decline and very low levels until the end of their survey, despite a subsequent increase in *B. dorsalis* captures. Although melon flies in our Kula Cue-Lure traps (<2 per trap per day) were never sufficient to attract saprophagous nontargets, Uchida et al. (2003) reported the capture of 1,936 *Desmometopa inaurata* (3.1 per trap per day), representing the main bulk (81.7%) of their nontarget catches in dry Cue-Lure traps serviced every 2–4 wk in Kula, Maui, from late November 2001 to late January 2002, when melon fly trap catches averaged 9.9 per trap per day (Mau et al. 2007). Seasonally focused surveys, examining the attraction stimulants and phenology of *D. tarsalis,* would be needed to understand exactly when and why this nontarget species is being trapped periodically regardless of type of lure used in the traps.

Calyptrate Diptera (Calliphoridae, Sarcophagidae, Muscidae), mostly associated with manure or decaying animal and plant matter, were strongly attracted to decaying flies (Table 6). Although the majority are introduced species, the attraction in native forest of endemic *Dyscritomyia* (Calliphoridae), ovoviviparous species that bear one larva at a time to maturity (Pollock 1974), in numbers (2.48 per trap per day) as high as all combined endemic *Drosophila* (2.66 per trap per day) may be a concern if traps are used in native forest.

Moderate numbers of beetles were captured in dead fly traps (Table 7). Despite the diversity of native (14 species) and introduced (8 species) sap beetles (Nitidulidae) collected in our survey, many of which are associated with flowers, attraction to methyl eugenol could be shown only for *Carpophilus marginellus.* Conant (1980) collected large numbers of the introduced *Carpophilus humeralis* and *C. hemipterus*, both very common scavengers on decaying flowers and fallen fruit in orchards (Ewing 2005), in methyl eugenol traps with accumulation of dead *B. dorsalis.* The published methyl eugenol attraction of *C. dimidiatus* (Kido et al. 1996) likely also resulted from dead flies in traps. One endemic species (*Prosopeus inauratus*), trapped in sufficient numbers to be analyzed separately from others, came only to decaying flies, even though most species of this large endemic genus are associated with fresh and decaying flowers (Ewing 2007). Other beetles, mostly in dead fly traps, include the minute fungal spore-feeding Corylophidae and the predatory Staphylinidae (*Atheta* spp). We suspect that the staphylinid *Philonthus longicornis,* a predator common in manure previously reported as attracted to methyl eugenol (Kido et al. 1996), actually came to dead flies.

Very few predators or parasitoids were attracted to dead flies except for several Hymenoptera species well known to parasitize housefly and other calyptrate flies: *Tachinaephagus zealandicus* (Encyrtidae), *Aphaereta pallipes* (Braconidae), and *Pachycrepoideus vindemiae* (Pteromalidae) (Table 7). A few species of introduced Tachinidae were also attracted to the dead flies (Table 6) and also drawn to BioLure (Thomas 2003; L.L., unpublished data). The endemic predatory flies *Lispocephala* (Muscidae) (two species) and parasitoid *Brachyserphus hawaiiensis* were reported to be methyl eugenol–attracted by Asquith and Kido (1994). In the Maui forest transects, only five specimens of *Lispocephala* and no *B. hawaiiensis* entered the male lure traps, despite their common occurrence at most trapping sites, as shown by their presence in fermented mushroom traps (0.21 per trap per day for *B. hawaiiensis*) and yellow bowl pan traps (0.39 per site per day of 14 species for *Lispocephala*). Thus we conclude that neither genus is significantly attracted to methyl eugenol.

The most abundant nontarget species overall in traps was the biting midge *Forcipomyia hardyi* (Diptera: Ceratopogonidae), a species native but abundant throughout Hawaii, at elevations up to 1,200 m (Wirth and Howarth 1982). It was the most common endemic species in the insect survey of crop fields on Kauai (Asquith and Messing 1993) and was caught in large numbers in methyl eugenol traps on Oahu Island (Howarth and Howarth 2000). The majority (95%) of the specimens collected in our study were from nine non-native forest and orchard sites on Hawaii Island, and they were particularly abundant in strawberry guava forest, with a record high of 720 per trap per day in one sample. Because they were consistently captured in significantly lower numbers in methyl eugenol traps (0.178 ± 0.0354 per trap per day) than Cue-Lure traps (4.063 ± 1.015), unbaited control traps (3.406 ± 0.710), or dead flies (2.802 ± 1.240; $F = 5.74$; df = 3,2848; $P = 0.0007$), we suggest that they probably randomly enter traps and that methyl eugenol may have a repelling effect on these midges.

A number of nontargets might appear to be attracted to methyl eugenol (Tables 1–7) from the effect of accumulated dead trapped oriental fruit flies, including a number of species erroneously reported to be attracted to methyl eugenol in the earlier literature. Kido et al. (1996) had reported a positive correlation between captures of *B. dorsalis* and most species of nontargets collected during their study. To show this confounding effect, Table 8 displays, for all ambiguous cases and for species previously recorded as attracted to methyl eugenol (Table 1), the correlation between nontarget and *B. dorsalis* catches in methyl eugenol traps in our study. The results of the ANOVAs in Tables 1–7 are also presented in Table 8, including an interaction term between lure effect and *B. dorsalis* catches (ANCOVA with *B. dorsalis* catches by male lure traps). Further, the ANOVAs were repeated, ex-

Table 9. Comparison of nontarget catches in methyl eugenol and control traps on flower-bearing coffee trees and adjacent non–flower-bearing persimmon orchards at two sites in Kula (Maui)

Species	Site	Mean ± SEM no. captured per trap per day[a]			
		ME coffee	Control coffee	ME persimmon	Control persimmon
Apis mellifera	Harada	0.608 ± 0.117b	0.062 ± 0.031a	0.150 ± 0.064a	0.0a
	Buetler	0.182 ± 0.040b	0.002 ± 0.002a	0.026 ± 0.015a	0.0a
Mestolobes minuscula	Harada	0.039 ± 0.021a	0.011 ± 0.009a	0.0a	0.0a
	Buetler	1.121 ± 0.318b	0.0a	0.038 ± 0.018a	0.0a
Flower insects[b]	Harada	0.743 ± 0.131b	0.073 ± 0.031a	0.195 ± 0.064a	0.002 ± 0.002a
	Buetler	1.412 ± 0.340b	0.069 ± 0.038a	0.085 ± 0.029a	0.0a

[a] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). df = 3,60 for all analyses. $P < 0.0001$ for all analyses, unless otherwise indicated. *A. mellifera* (Harada): $F = 16.08$; *A. mellifera* (Buetler): $F = 16.74$; *M. minuscula* (Harada): $F = 2.56$; $P = 0.0634$; *M. minuscula* (Buetler): $F = 12.14$; flower insects (Harada): $F = 20.45$; flower insects (Buetler): $F = 15.79$.

[b] Pooled data for *A. mellifera, A. obliqua, C. marginellus, M. minuscula,* and *Orthomecyna* ? *exigua.*

cluding data from all the methyl eugenol samples that contained 1,000 or more *B. dorsalis.* In all cases, except for *Carpophilus marginellus* (Coleoptera: Nitidulidae) and possibly *Desmometopa tarsalis* (Diptera: Milichiidae), lure attraction was confounded with attraction to dead flies, as shown by the high correlation coefficient and the significant ANCOVA interaction term. Omitting samples with >1,000 *B. dorsalis* resulted in no difference between methyl eugenol and control trap catches of nontarget species being shown.

Minimizing the Nontarget Impact. Fruit fly male lures, when used over large areas for fruit fly control or eradication, may potentially affect populations of nontarget insects directly by attraction to methyl eugenol of flower-associated insects, including pollinators and aphid predators, plant feeding Miridae, and Sciaridae, or indirectly by secondary attraction of large numbers of saprophagous species to the accumulation of dead trapped flies. Unwanted nontarget effects on beneficial and endemic species can be minimized if a few suggested basic precautionary measures are followed.

The relatively small numbers of flower insects in methyl eugenol traps (0.03–0.15 per trap per day) suggests that attraction is likely to occur over short distance and can probably be minimized if one avoids applying methyl eugenol to trees during the flowering stage. This is supported by comparing methyl eugenol trap captures in Kula, at two sites with sets of traps in coffee and persimmon orchards <50 m apart, with the highest methyl eugenol catches of flower-visiting insects (Fig. 3, sites 43 and 44). Because traps were set at the end of the persimmon flowering season and coffee was bearing flowers more or less continuously during the study, these may be regarded as two replicates of a comparison of trap catches between flower-bearing trees and trees without flowers. Although the dataset is limited, numbers of *Apis mellifera* (both sites) and *Mestolobes minuscula* (one site) captured in methyl eugenol traps were much lower in persimmon than coffee (Table 9). The relationship holds true when total numbers of the five flower-visiting insect species are analyzed collectively (Table 9). The relationship between orchard phenology and nontarget catches deserves further attention to develop more specific recommendations for the safe use of methyl eugenol as a tool for orchard-wide male fruit fly annihilation.

Because most native insect species are rather uncommon in highly modified habitats in Hawaii, the risk of attracting large numbers of endemic saprophagous nontargets to decaying flies is probably very low in the non-native and agricultural habitats where male lures are primarily used. This is confirmed in a preliminary comparison of catches of Drosophilidae in traps baited with decaying flies in relatively undisturbed native forest, two ecotone forest sites adjacent (<100 m away) to native forest and non-native forest and agricultural areas (Table 10). One ecotone site was dominated by strawberry guava (*Psidium cattleianum*) (Fig. 2, site 30) and the other by tropical ash (*F. uhdei*) (site 33). Endemic drosophilids were trapped in native forests and the two ecotone habitats, but very few endemic species were captured in small numbers in

Table 10. Comparison of nontarget catches in traps baited with decaying fruit flies in native forest, ecotone forest habitats adjacent to native forest, and non-native forest and orchards

	No. sites			Mean ± SEM no. captured per trap per day[a]		
	Native	Ecotone	Non-native	Native	Ecotone	Non-native
Drosophila spp. (endemic)	20	2	4	5.175 ± 0.853a	1.556 ± 0.549a	0.063 ± 0.017b
Drosophila spp. (introduced)	23	2	24	6.774 ± 1.208b	41.060 ± 15.381a	12.027 ± 2.963b
Scaptomyza spp. (endemic)	22	2	12	2.149 ± 0.383b	0.297 ± 0.086a	0.089 ± 0.034a

[a] Values in each row followed by the same letter are not significantly different at the 0.05 level, Tukey's test, PROC MIXED mivque0 (SAS Institute 2004). *Drosophila* spp. (endemic): $F = 12.18$; df = 2,117; $P < 0.0001$; *Drosophila* spp. (introduced): $F = 3.60$; df = 2,315; $P = 0.0283$; *Scaptomyza* spp. (endemic): $F = 23.68$; df = 2,197, $P < 0.0001$.

non-native forest and orchard-backyard sites on Hawaii and Maui. Endemic *Dyscritomyia* blowflies (Calliphoridae) were commonly collected on Hawaii island in the native (2.71 ± 0.44 per trap per day) and ecotone (3.05 ± 0.69 per trap per day) forests, but only one specimen was collected in one orchard. Adults are attracted to and feed on a wide assortment of decaying animal matter and, in the absence of large volumes of carrion in Hawaiian forests, evolved ovoviviparity (Hardy 1981). Thus, gravid females can probably forage over long distances, actively seeking a small volume of decaying matter (Hardy 1981) to deposit a single, nearly mature larva. *Dyscritomyia* may potentially be the most directly impacted by the use of methyl eugenol traps in and at the periphery of native forest, unless the accumulation of dead insects in traps is eliminated.

If traps baited with methyl eugenol are used for monitoring purposes in orchards, they should be set at a safe distance from native forest to avoid drawing large numbers of endemic insects to the dead flies that accumulate in traps. In studies of attraction to food bait for 14 common Nearctic *Drosophila* species, some of which are present in Hawaii (*D. immigrans, D. hydei, D. busckii, D. melanogaster*, and *D. simulans*), McInnis (1978) found that the attractive radial distance of marked and recaptured flies to banana bait was at most 60 m/d for wild males and females in forest and open conditions. Within the measured maximum lifespan of 7 d in the field, their maximal dispersal distance was estimated to be ≈300 m at most (D. McInnis, personal communication). If these species are treated as surrogates for native Hawaiian drosophilids, using traps at least 300 m from native forest could minimize unwanted nontarget effects if large numbers of target flies are likely to accumulate inside traps. Respecting this safe distance is particularly important if trapping is done in proximity of the critical habitats designated for the 12 endemic drosophilids included on the endangered species list (U.S. Fish and Wildlife Service 2007).

In conclusion, the majority of nontarget species cited in the previous literature as attracted to methyl eugenol are scavengers of plant and animal material actually attracted to dead fruit flies in traps. Nevertheless, a small number of taxonomically unrelated native species (Sciaridae, Miridae, and perhaps Anobiidae) and a few flower-seeking insects are truly attracted to methyl eugenol. We agree with previous authors (Asquith and Kido 1994, Kido et al. 1996, Asquith and Burny 1998, Uchida et al. 2006) that the negative impact of the use of male lures on nontarget populations, at least in agricultural systems, should be minimal. We support the recommendation from Uchida et al. (2007) to use lures in devices with open bottoms to prevent the accumulation of dead flies, or the use of mineral oil rather than ethylene or propylene glycol as preservative if monitoring traps must be used in endemic habitats. We further recommend that methyl eugenol bait stations for male annihilation be applied to support trees in orchards after the flowering season has ended.

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References Cited

Allwood, A. J., E. T. Vueti, L. Leblanc, and R. Bull. 2002. Eradication of introduced *Bactrocera* species (Diptera: Tephritidae) in Nauru using male annihilation and protein bait application techniques, pp. 19–25. *In* C. R. Veitch and M. N. Clout (eds.), Turning the tide: the eradication of invasive species. Occasional Papers of the IUCN Species Survival Commission. No. 27. IUCN, Gland, Switzerland and Cambridge, UK.

Asquith, A. 1994. Revision of the endemic Hawaiian genus *Sarona* Kirkaldy (Heteroptera: Miridae: Orthotylinae). Bishop Museum Occasional Papers 40. Bishop Museum Press, Honolulu, HI.

Asquith, A., and R. H. Messing. 1993. Contemporary Hawaiian insect fauna of a lowland agricultural area on Kaua'i: implications for local and island-wide fruit fly eradication programs. Pac. Sci. 47: 1–16.

Asquith, A., and M. Kido. 1994. Native Hawaiian insects attracted to the semiochemical methyl eugenol, used for male annihilation of the Oriental fruit fly (Diptera: Tephritidae). Environ. Entomol. 23: 1397–1408.

Asquith, A., and D. Burny. 1998. Honeybees attracted to the semiochemical methyl eugenol, used for male annihilation of the Oriental fruit fly (Diptera: Tephritidae). Proc. Hawaiian Entomol. Soc. 33: 57–66.

Canard, M. 2005. Seasonal adaptations of green lacewings (Neuroptera: Chrysopidae). Eur. J. Entomol. 102: 317–324.

Carson, H. L., and W. B. Heed. 1983. Methods of collecting *Drosophila*, pp. 2–31. *In* M. Ashburner, H. L. Carson, and J. N. Thompson (eds.), The genetics and biology of *Drosophila*. Academic, London, United Kingdom.

Chang, C. P., and F. K. Hsieh. 2005. Effects of different foods on the longevity and fecundity of *Mallada basalis* (Walker) adults (Neuroptera: Chrysopidae). Formosan Entomol. 25: 59–66.

Clarke, A. R., K. F. Armstrong, A. E. Carmichael, J. R. Milne, S. Raghu, G. K. Roderick, and D. K. Yeates. 2005. Invasive phytophagous pests arising through a recent tropical evolutionary radiation: the *Bactrocera dorsalis* complex of fruit flies. Annu. Rev. Entomol. 50: 293–319.

Conant, P. 1978. A test of the attraction of non-target flying insects to a poison fruit fly lure composed of methyl eugenol and malathion. Technical report for USDA–ARS.

Conant, P. 1979a. A survey of ground dwelling insects that could be affected by a poison fruit fly lure composed of a mixture of malathion and methyl eugenol. Technical report for USDA–ARS.

Conant, P. 1979b. Distribution of non-target insects attracted to a poison fruit fly lure composed of methyl eugenol and malathion on Lanaihale, Lanai. Technical report for USDA–ARS.

Conant, P. 1979c. Non-target insects attracted to the separated components of a poison fruit fly lure composed of a mixture of methyl eugenol and malathion. Technical report for USDA–ARS.

Conant, P. 1980. A survey of flying insects on the island of Lanai that could be attracted by a malathion-methyl eugenol fruit fly lure. Technical report for USDA–ARS.

Cunningham, R. T., and D. Y. Suda. 1985. Male annihilation of Oriental fruit fly, *Dacus dorsalis* Hendel (Diptera: Tephritidae): a new thickener and extender for methyl eugenol formulations. J. Econ. Entomol. 78: 503–504.

Cunningham, R. T., and D. Y. Suda. 1986. Male annihilation through mass-trapping of male flies with methyl eugenol to reduce infestation of Oriental fruit fly (Diptera: Tephritidae) larvae in papaya. J. Econ. Entomol. 79: 1580–1582.

Drew, R.A.I. 1989. The tropical fruit flies (Diptera: Tephritidae: Dacinae) of the Australasian and Oceanian regions. Memoir Queensl. Mus. No. 26. Queensland Museum, Brisbane, Australia.

Ewing, C. P. 2005. Key to adventive sap beetles (Coleoptera: Nitidulidae) in Hawaii, with notes on records and habits. Coleopterist Bull. 59: 167–183.

Ewing, C. P. 2007. Phylogenetic analysis of the genera of endemic Hawaiian sap beetles (Coleoptera: Nitidulidae) based on morphology with redescription and key to the genera of endemic Hawaiian Nitidulidae. Zootaxa 1427: 1–36.

Hardy, D. E. 1964. Insects of Hawaii. Volume 11. Diptera: Brachycera, Family Dolichopodidae. Cyclorrhapha, series Aschiza. Families Lonchopteridae, Phoridae, Pipunculidae, and Syrphidae. University of Hawaii Press, Honolulu, HI.

Hardy, D. E. 1981. Insects of Hawaii. Volume 14. Diptera: Cyclorrhapha IV, series Schizophora, section Calyptratae. University of Hawaii Press, Honolulu, HI.

Hardy, D. E., and M. D. Delfinado. 1980. Insects of Hawaii. Volume 13. Diptera: Cyclorrhapha III, series Schizophora, section Acalypterae, exclusive of family Drosophilidae. University of Hawaii Press, Honolulu, HI.

Heath, R. R., N. D. Epsky, B. D. Dueben, J. Rizo, and F. Jeronimo. 1997. Adding methyl-substituted ammonia derivatives to a food-based synthetic attractant on capture of the Mediterranean and Mexican fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 90: 1584–1589.

Hiramoto, M. K., L. Arita-Tsutsumi, and E. Jang. 2006. Test of effectiveness of newly formulated plastic matrix with methyl eugenol for monitoring *Bactrocera dorsalis* (Hendel) populations. Proc. Hawaiian Entomol. Soc. 38: 103–110.

Howarth, V.M.C., and F. G. Howarth. 2000. Attractiveness of methyl eugenol-baited traps to Oriental fruit fly (Diptera: Tephritidae): effect of dosage, placement and color. Proc. Hawaiian Entomol. Soc. 34: 187–198.

Keiser, I., M. Jacobson, S. Nakagawa, D. H. Miyashita, and E. J. Harris. 1976. Mediterranean fruit fly: attraction of females to acetic acid and acetic anhydride, to two chemical intermediates in the manufacture of Cue-Lure, and to decaying Hawaiian tephritids. J. Econ. Entomol. 69: 517–520.

Kido, M. H., and A. Asquith. 1995. Attraction of Hawaiian aquatic insects to pest tephritid parakairomone lures. Environ. Entomol. 24: 810–816.

Kido, M. H., A. Asquith, and R. I. Vargas. 1996. Nontarget insect attraction to methyl eugenol traps used in male annihilation of the Oriental fruit fly (Diptera: Tephritidae) in riparian Hawaiian stream habitat. Environ. Entomol. 25: 1279–1289.

Kircher, H. W. 1969. Sterols in the leaves of the *Cheirodendron gaudichaudii* tree and their relationship to Hawaiian *Drosophila* ecology. J. Insect Physiol. 15: 1167–1173.

Leonhardt, B. A., R. T. Cunningham, D. L. Chambers, J. W. Avery, and E. M. Harte. 1994. Controlled-release panel traps for the Mediterranean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 87: 1217–1223.

Loope, L. L., and A. C. Medeiros. 1992. Potential effects of alien fruit fly eradication on natural areas of Hawaii: an exploratory investigation in Haleakala National Park. Elepaio 52: 71–75.

Magnacca, K. N., D. Foote, and P. M. O'Grady. 2008. A review of the endemic Hawaiian Drosophilidae and their host plants. Zootaxa 1728: 1–58.

Mau, R.F.L., E. B. Jang, and R. I. Vargas. 2007. The Hawaii area-wide fruit fly pest management programme: influence of partnerships and a good education programme, pp. 671–683. *In* M.J.B. Vreysen, A.S. Robinson, and J. Hendrichs (eds.), Area-wide control of insect pests from research to field implementation. Springer, Dordrecht, The Netherlands.

McInnis, D. O. 1978. Ecological genetics of *Drosophila:* field dispersal of wild flies and directional selection for dispersal rate in laboratory flies using methods of mark, release, and recapture. PhD dissertation, North Carolina State University, Raleigh, NC.

Metcalf, R. L. 1990. Chemical ecology of the Dacinae fruit flies (Diptera Tephritidae). Ann. Entomol. Soc. Am. 83: 1017–1030.

Pai, K. F., C. J. Chen, J. T. Yang, and C. C. Chen. 2004. Green lacewing *Ankylopteryx exquisite* attracted to methyl eugenol. Plant Protect. Bull. 46: 93–97.

Pawliszyn, J. 1997. Solid phase microextraction: theory and practice. Wiley, New York.

Perkins, R.C.L. 1913. Fauna Hawaiiensis. Volume 1, Part 6. Introductory essay on the fauna. Cambridge University Press, United Kingdom.

Polhemus, D. A. 2002. An Initial review of *Orthotylus* in the Hawaiian Islands, with descriptions of twenty-one new species (Heteroptera: Miridae). J.N.Y. Entomol. Soc. 110: 270–340.

Pollock, J. N. 1974. Comparative notes on adaptations for viviparity shown by *Dyscritomyia* (Calliphoridae, Diptera) of Hawaii, and *Glossina* (Glossinidae, Diptera). Proc. Hawaiian Entomol. Soc. 21: 447–455.

Principi, M. M., and M. Canard. 1984. Feeding habits, pp. 76–92. *In* M. Canard (ed.), Biology of Chrysopidae. Dr W. Junk Publishers, The Hague, The Netherlands.

Sajap, A. S., K. Maeto, K. Fukuyama, F.B.H. Ahmah, and Y. A. Wahab. 1997. Chrysopidae attraction to floral fragrance chemicals and its vertical distribution in a Malaysian lowland tropical forest. Malays. Appl. Biol. 26: 75–80.

SAS Institute. 2004. SAS/STAT 9.1 user's guide. SAS Institute, Cary, NC.

Scheuer, P. J., and W. R. Hudgins. 1964. Major constituents of the essential oil of *Pelea christophersenii* St. John & Hume. Essential Oil Res. 55: 723–724.

Steffan, W. A. 1974. Laboratory studies and ecological notes on Hawaiian Sciaridae (Diptera). Pac. Insects 16: 41–50.

Steiner, L. F., W. G. Hart, E. J. Harris, R. T. Cunningham, K. Ohinata, and D. C. Kamakahi. 1970. Eradication of the Oriental fruit fly from the Mariana Islands by the methods of male annihilation and sterile insect release. J. Econ. Entomol. 63: 131–135.

Stonehouse, J. M., J. D. Mumford, and G. Mustafa. 1998. Economic loss to tephritid flies (Diptera: Tephritidae) in Pakistan. Crop Protect. 17: 159–164.

Suda, D. Y., and R. T. Cunningham. 1970. *Chrysopa basalis* captured in plastic traps containing methyl eugenol. J. Econ. Entomol. 63: 1706.

Tan, K. H. 2000. Behaviour and chemical ecology of *Bactrocera* flies, pp. 647–656. *In* K. H. Tan (ed.), Area-wide control of fruit flies and other pests. Penerbit University, Penang, Malaysia.

Thomas, D. B. 2003. Nontarget insects captured in fruit fly (Diptera: Tephritidae) surveillance traps. J. Econ. Entomol. 96: 1732–1737.

Tsukada, M., D. Tanaka, and H. Higuchi. 2008. Thermal requirement for development of *Carpophilus marginellus* (Coleoptera: Nitidulidae), a potential pollinator of cherimoya and atemoya trees (Magnoliales: Annonaceae). Appl. Entomol. Zool. 43: 281–285.

Uchida, G. K., D. O. McInnis, R. I. Vargas, B. R. Kumashiro, L. M. Klungness, and E. Jang. 2003. Nontarget arthropods captured in Cue-Lure-baited bucket traps at area-wide pest management implementation sites at Kamuela and Kula, Hawaiian Islands. Proc. Hawaiian Entomol. Soc. 36: 135–143.

Uchida, G. K., B. E. Mackey, R. I. Vargas, J. W. Beardsley, D. E. Hardy, M. L. Goff, and J. D. Stark. 2006. Response of nontarget insects to methyl eugenol, Cue-Lure, trimedlure, and protein bait bucket traps on Kauai island, Hawaii, USA. Proc. Hawaiian Entomol. Soc. 38: 61–72.

Uchida, G. K., B. E. Mackey, D. O. McInnis, and R. I. Vargas. 2007. Attraction of *Bactrocera dorsalis* (Diptera: Tephritidae) and nontarget insects to methyl eugenol bucket traps with different preservative fluids on Oahu island, Hawaiian Islands. J. Econ. Entomol. 100: 723–729.

Umeya, K., and J. Hirao. 1975. Attraction of the jackfruit fly, *Dacus umbrosus* F. (Diptera: Tephritidae) and lacewing, *Chrysopa* sp. (Neuroptera: Chrysopidae) by lure traps baited with methyl eugenol and Cue-Lure in the Philippines. Appl. Entomol. Zool. 10: 60–62.

U.S. Fish and Wildlife Service. 2007. Endangered and threatened wildlife and plants: revised proposed designation of critical habitats for 12 species of picture-wing flies from the Hawaiian Islands: proposed rule. Fed. Reg. 72: 67427–67522.

Vargas, R. I., N. W. Miller, and J. D. Stark. 2003. Field trials of spinosad as a replacement for naled, DVVP, and malathion in methyl eugenol and Cue-Lure bucket traps to attract and kill male Oriental fruit flies and melon flies (Diptera: Tephritidae) in Hawaii. J. Econ. Entomol. 96: 1780–1785.

Vargas, R. I., J. Stark, B. E. Mackey, and R. Bull. 2005. Weathering trials of amulet™ C-L and amulet™ M-E attract and kill stations with male melon flies and Oriental fruit flies (Diptera: Tephritidae) in Hawaii. J. Econ. Entomol. 98: 1551–1559.

Vargas, R. I., J. D. Stark, M. Hertein, A. Mafra Neto, R. Coler, and J. Pinero. 2008. Evaluation of SPLAT with spinosad and methyl eugenol or Cue-Lure for "attract-and-kill" of Oriental and melon fruit flies (Diptera: Tephritidae) in Hawaii. J. Econ. Entomol. 101: 759–768.

Vayssières, J. F., J. P. Cayol, and X. Perrier. 2007. Impact of methyl eugenol and malathion bait stations on non-target insect populations in French Guiana during an eradication program for *Bactrocera carambolae.* Entomol. Exp. Appl. 125: 55–62.

White, I. M., and M. M. Elson-Harris. 1992. Fruit flies of economic significance: their identification and bionomics. CAB International, Wallingford, United Kingdom.

Williams, N. H., and W. M. Whitten. 1983. Orchid floral fragrances and male euglossine bees: methods and advances in the last sesquidecade. Biol. Bull. 163: 355–395.

Wirth, W. W., and F. G. Howarth. 1982. The "*Forcipomyia ingrami*" complex in Hawaii (Diptera: Ceratopogonidae). Proc. Hawaiian Entomol. Soc. 24: 127–151.

Zimmerman, E. C. 1957. Insects of Hawaii. Volume 6. Ephemeroptera-Neuroptera-Trichoptera. University of Hawaii Press, Honolulu, HI.

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