Field Suppression of the Invasive Ant *Wasmannia auropunctata* (Hymenoptera: Formicidae) in a Tropical Fruit Orchard in Hawaii

EVANN SOUZA,[1,2] PETER A. FOLLETT,[2,3] DON K. PRICE,[1] and ELIZABETH A. STACY[1]

J. Econ. Entomol. 101(4): 1068–1074 (2008)

ABSTRACT The little fire ant, *Wasmannia auropunctata* (Roger) (Hymenoptera: Formicidae), is an invasive ant that forms supercolonies when it successfully invades new areas. *W. auropunctata* was first reported in Hawaii in 1999, and it has since invaded a variety of agricultural sites, including nurseries, orchards, and pastures. Amdro (hydramethylnon; in bait stations), Esteem (pyriproxyfen; broadcast bait), and Conserve (spinosad; ground spray) were tested for their efficacy against *W. auropunctata* in a rambutan, *Nephelium lappaceum* L. and mangosteen, *Garcinia mangostana* L., orchard by making treatments every 2 wk for 16 wk. Relative estimates of ant numbers in plots was determined by transect sampling using peanut butter-baited sticks. Significant treatment effects were observed on weeks 13–17, with reductions in ant counts occurring in the Amdro and Esteem treatments. During this period, the reduction in ant numbers from pretreatment counts averaged 47.1 and 92.5% in the Amdro and Esteem plots, respectively, whereas ant numbers in the untreated control plots increased by 185.9% compared with pretreatment counts. Conserve did not cause a reduction in ant counts as applied in our experiment. No plots for any of the treatments achieved 100% reduction. Pseudococcidae were counted on branch terminals at 4-wk intervals. The two predominant species, *Nipaecoccus nipae* (Maskell) and *Nipaecoccus viridis* (Newstead) were significantly lower in the Amdro and Esteem treatments on week 16 compared with controls. Many *W. auropunctata* were found nesting in protected sites in the orchard trees, which may have compromised the ground-based control methods. Absolute density estimates from shallow core samples taken from the orchard floor indicated the *W. auropunctata* supercolony exceeded 244 million ants and 22.7 kg wet weight per ha.

KEY WORDS little fire ant, invasive species, unicolonial, ant management, ant baits

Hawaii has no native ants, but >40 species of alien ants have been accidentally introduced (Krushelnycky et al. 2005). The little fire ant, *Wasmannia auropunctata* (Roger) (Hymenoptera: Formicidae), is an invasive ant originating from Central and South America that has spread throughout tropical and subtropical areas of the world, particularly in the Pacific (Fabres and Brown 1978, Wetterer and Porter 2003, Krushelnycky et al. 2005). *W. auropunctata* was first reported in Hawaii in 1999 near Pahoa on the island of Hawaii at three sites covering an area of 12 ha, and it has now spread to a variety of agricultural sites such as nurseries, orchards, and pastures, covering a total of >100 ha (P. Conant, personal communication).

W. auropunctata workers are very small (1.5 mm in length), pale orange, and slow moving, making the ant difficult to detect at low levels. *W. auropunctata* forms supercolonies when it invades a new area (Le Breton et al. 2004), and once it is well established on more than a few hectares it is difficult to eradicate (Wetterer and Porter 2003). *W. auropunctata* has a powerful sting that poses problems for domestic animals, wildlife, agricultural workers, and others who come into contact with infested plants (Wetterer and Porter 2003). Like many sugar-loving ants, *W. auropunctata* will tend hemipterans such as mealybugs and soft scales for their honeydew (Holldobler and Wilson 1990), which causes plant stress and can lead to increased prevalence of these pests on fruit (Smith 1942).

Amdro (hydramethylnon) granular ant bait is the primary pesticide used for control (Wetterer and Porter 2003, Causton et al. 2005). Broadcast application of Amdro was used successfully to eradicate *W. auropunctata* populations on Santa Fe Island and Marchena Island in the Galapagos (Abedrabbo 1994, Causton et al. 2005). In Hawaii, the original labeled use for Amdro in fruit- or nut-bearing orchards was in bait stations deployed at ≈15.2-m (50-ft) intervals (every other tree). A supplemental label was published afterward allowing for closer spacing of Amdro bait stations in orchards. *W. auropunctata* has a short foraging distance (Lubin 1984); therefore, the bait station approach may leave much of the ant population unaffected (e.g., in drive rows and along borders) and ready to reinvade trees when Amdro efficacy diminishes.

[1] Tropical Conservation Biology and Environmental Science program, University of Hawaii at Hilo, 200 W. Kawili St., Hilo, HI 96720.
[2] USDA–ARS, U.S. Pacific Basin Agricultural Research Center, 64 Nowelo St., Hilo, HI 96720.
[3] Corresponding author, e-mail: peter.follett@ars.usda.gov.

Although *W. auropunctata* is slow to disperse by natural means (Walsh et al. 2004), many agricultural and natural areas in Hawaii will be invaded in the near future through the movement of nursery stock, landscape and ornamental plants, farm equipment, and harvested fruit, as well as through natural dispersal (Le Breton et al. 2003). Information on the best control methods for *W. auropunctata* is critical as this ant continues its spread into new areas. We conducted field studies to determine the efficacy of currently available ant control products against *W. auropunctata,* and the effect of ant control on associated Hemiptera in trees. Estimates of ant population densities and biomass also were made.

Materials and Methods

The experiments in this study were conducted at Honualani Orchard, Papaikou, HI (elevation 362 m, coordinates 19° 47.31′ N and 155° 07.61′ W) from May to December 2006. The 6.0-ha (15-acre) orchard contained blocks of rambutan *Nephelium lappaceum* L. (Nephelium: Sapindaceae) and mangosteen *Garcinia mangostana* L. (Garcinia: Clusiaceae) trees planted in an 8.5- by 9.1-m (28- by 30-foot) grid. Trees were 15 yr old and ≈4–5 m in height.

Insecticide Treatments. *W. auropunctata* is distributed throughout Honualani Orchard, and the boundary of the supercolony extends well beyond the perimeter of the orchard. The experiment used a randomized block design with four treatments replicated four times; replicates were divided between two orchard blocks, one with only rambutan trees, and one with only mangosteen trees. Each orchard block was ≈1.2 ha (3 acres) and separated by windrows of eucalyptus trees (*Eucalyptus robusta* Smith) and fishtail palms (*Caryota mitis* Lour.). (The fishtail palms originated from a *W. auropunctata*-infested nursery, and are the probable origin of the *W. auropunctata* at this site.) Each treatment within a block was applied to a 4 by 4 grid of trees, and all data were taken from the four trees in the center. Plot size and the number of replicates were designed to use the entire orchard area.

Specific ant insecticide treatments tested during this study were Amdro (BASF Co., Triangle Park, NC) in Perimeter Patrol System Bait Stations (B&G Equipment, Jackson, GA) placed at one station per tree, Esteem (Valent Co., Walnut Creek, CA) bait broadcast application, Conserve SC (Dow AgroSciences, Indianapolis, IN) spray application, and an untreated control. Each of the formicides has a different formulation, active ingredient, and mode of action. Amdro granules (hydramethylnon) contain a slow-acting metabolic inhibitor dissolved in oil. Workers carry the oil back to the colony where it is shared with other workers, the brood, and queens, eventually killing the entire colony. Taniguchi et al. (2003) reported that Amdro in bait stations maintained effectiveness for 12 wk against big-headed ant, *Pheidole megacephala* (F.). Esteem Ant Bait (pyriproxyfen) is a juvenile hormone analog registered for broadcast application. Esteem interferes with growth and development of immature stages, and it causes reduced reproduction or sterility in queens (Ishaaya and Horowitz 1992, Vail et al. 1996). The colony declines as worker ants age and die and are not replaced; therefore, colony destruction can take 1–3 mo. *W. auropunctata* feeds on Amdro and Esteem granules, but it does not carry them back to the nest (P.A.F., unpublished data). Conserve SC (spinosad) is applied as a spray and is intended for use against mounding fire ants such as *Solenopsis invicta* Buren (Oi and Oi 2006). Conserve is a contact insecticide that causes excitation of the insect nervous system.

Delivery rates applied were Amdro at 10 g per bait station at 25′ × 25′ distance apart for a total of 1.52 lb/acre; Esteem at the maximum label rate of 2 lb/acre; and Conserve SC applied at a concentration of 1 fl oz/gallon of water applied using a Fimco 25-gallon lawn and garden sprayer (Fimco Industries, North Sioux City SD) with a 2.1 GPM pump at 30 psi and a two-nozzle (Teejet Spraying Systems Company Nozzle 110° XRTJET 11606VS) insecticide boom sprayer. Treatments were applied at 2-wk intervals for 16 wk from June to October 2006. The biweekly treatment schedule was deemed necessary due to the warm, high rainfall conditions typical of east Hawaii.

W. auropunctata densities were estimated weekly in each treatment plot by using transect and tree sampling. A preliminary experiment indicated that *W. auropunctata* is active and foraging 24 h per day and that activity is reduced during rainy periods, as was reported by Clark et al. (1982). Therefore, all sampling was done during mid-morning (8:00 a.m.–11:00 a.m.) under sunny to partly cloudy conditions. Transect sampling used peanut butter (Peter Pan Creamy Peanut Butter, ConAgra Foods, Irvine CA) baited jumbo craft sticks (Forster Inc., Wilton, ME) placed at 2-m intervals along a transect between two trees across the drive row (six points total) in each plot. The baited sticks were retrieved and ants counted 30 min after placement. Tree sampling involved wrapping a piece of 5.08-cm (2 in.)-wide packaging tape (3M Masking tape, Skilcraft, Cincinnati, OH) around the trunk of each of the four trees at the center of each plot at knee height to detect ant trails moving up and down the tree. The two sampling methods were used to estimate the activity of ants within and between rows and the presence or absence of ants in trees. After the 16-wk period of ant control treatments, plots were monitored for another 9 wk (weeks 17–25) to examine ant population recovery.

Hemipterans (mealybugs and scale insects) were sampled in the tree canopy every 4 wk by randomly selecting one branch terminal (0.5 m in length) from two trees in each plot and inspecting for insects. The number and species of Hemiptera were recorded for each terminal.

Ant Population Size Estimate. Seventy-five shallow-core thatch and soil samples were collected randomly from three different habitat types. Twenty-five samples were taken from the untreated orchard, 25 samples were taken from a grass pasture adjacent to the experimental orchard, and 25 samples were taken from within the orchard windbreaks. Each sampling area was chosen randomly from a map of the field area, and then the specific sampling sites were determined haphazardly by throwing a rock within that area. The sample was collected with a 16-cm-diameter plastic sample cup (shallow core sample area 201 cm^2) by excavating under the cup with a trowel to a depth of 2 cm. *W. auropunctata* is typically found near the soil surface, and it does not build mounds (Clark et al. 1982; P.A.F., unpublished data). Samples were placed in the freezer for 24 h, allowed to thaw for another 24 h, and then dried in a dehumidifier for 24 h before examination. Worker ants, eggs, larvae, and queens were separated and counted on a white sheet of paper. Average numbers were used to extrapolate the number of ants per acre for each habitat type.

Recently collected live ants were chilled in a freezer (−2°C) and weighed in groups of 20 individuals to estimate wet weight. Ants were then dried for 48 h at 50°C and weighed in groups of 100 individuals to estimate dry weight.

Statistical Analysis. Data were the average number of ants counted on six peanut butter-baited sticks along a transect for each plot on each sampling date. To make comparisons between treatments in the field control experiment, data were transformed and subjected to analysis of variance (ANOVA). The analysis of ant count data were partitioned into the effects of sampling date, ant control treatment, and the date × treatment interaction. Ant counts for each treatment were corrected for differences in pretreatment densities by dividing post- and pretreatment counts [i.e., mean number of ants at time (x) / mean number of ants at time 0]. After examination of residual plots, the data were transformed by [log (ant count time (x)/ant count time 0) × 1.198] by using the Box–Cox procedure to normalize the distribution and stabilize error variance (SAS Institute 2002). Hemiptera counts were log $(x + 1)$ transformed to normalize the data and stabilize error variance after examination of residual plots. The analysis of hemipteran count data were partitioned into the effects of sampling date, ant control treatment, and the date × treatment interaction. Orchard type (rambutan or mangosteeen) was used as a blocking factor in all analyses. Means separations in all experiments were done using the Tukey's honestly significant difference (HSD) test at $P \leq 0.05$. Descriptive statistics were calculated for ant density and biomass estimates.

Results

Insecticide Treatments. Pretreatment ant counts were variable, but ANOVA showed there were no significant differences among treatments ($F = 0.34$, df = 3, $P = 0.80$) (Fig. 1A); however, ant densities were considerably lower in the Amdro plots than the other plots, which made it difficult to evaluate the efficacy of this treatment compared with the other treatments (see later discussion). ANOVA on the change in ant densities [time (x)/time 0] during weeks 1–16 when the ant controls were applied was significant for the effects of sampling date ($F = 2.6$, df = 13, $P = 0.003$), ant control treatment ($F = 7.2$, df = 3, $P = 0.0001$), and the sampling date × ant control treatment interaction ($F = 2.0$, df = 39, $P = 0.002$). There was also a significant block effect for orchard type ($F = 37.8$, df = 1, $P = 0.0001$). Due to the significant interaction effect, means separations analysis focused on weekly treatment comparisons by using blocking as a factor.

Means separations on ant control treatment effects were significant for weeks 13–17 (Fig. 1A and B), with reductions in ant counts occurring in the Amdro and Esteem treatments. On each of the sampling dates during this period, the Esteem treatment was significantly different than the control and Conserve treatment but not the Amdro treatment; the Conserve treatment was not significantly different from the control or the Amdro treatment, and the Amdro treatment was not significantly different than any of the other treatments ($P < 0.05$; Tukey's HSD test).

Mean pretreatment ant counts were 11.8, 22.9, 27.2, and 31.7 for the Amdro, Esteem, Conserve, and untreated control plots, respectively. Because ANOVA was done on the relative increase or decrease in ant counts [time (x) / time 0] and ant counts initially were lower in the Amdro, Esteem and Conserve treatments (particularly the Amdro treatment) compared with the untreated control (Fig. 1A), the effectiveness of the formicide treatments in terms of statistical significance may have been partially obscured. For example, between weeks 13 and 17, the reduction in ant numbers from pretreatment counts averaged 47.1 and 92.5% in the Amdro and Esteem plots, respectively, whereas ant numbers in the untreated control plots increased by 185.9% compared with pretreatment counts (Fig. 1B). The increase in ant counts in the untreated control plots reflected the favorable conditions for population growth during the summer. Ant counts during weeks 13 to 17 in the untreated control plots were ≈10 times higher than in the Amdro plots; yet, the relative change from pretreatment counts plots were not significant. The numbers of ants in the Esteem and Amdro plots were similar during this period, but the Esteem treatment was significantly different from the control because its pretreatment counts were twice that of the Amdro treatment; therefore, the relative change was greater. Conserve did not cause a reduction in ant counts as applied in our experiment. No plots for any of the treatments achieved a 100% reduction. Variable ant counts and low replication also reduced the power of the experiment to detect significant differences among treatments. Nevertheless, the low numbers of ants in the Amdro and Esteem treatments on weeks 13–17 while ant numbers were increasing in the untreated controls underscores the potential for these ant baits to suppress little fire ant in the field.

The ant control treatments applied to the ground did not eliminate ants in the trees. Tape sampling of tree trunks showed the presence of ant trails on 100%

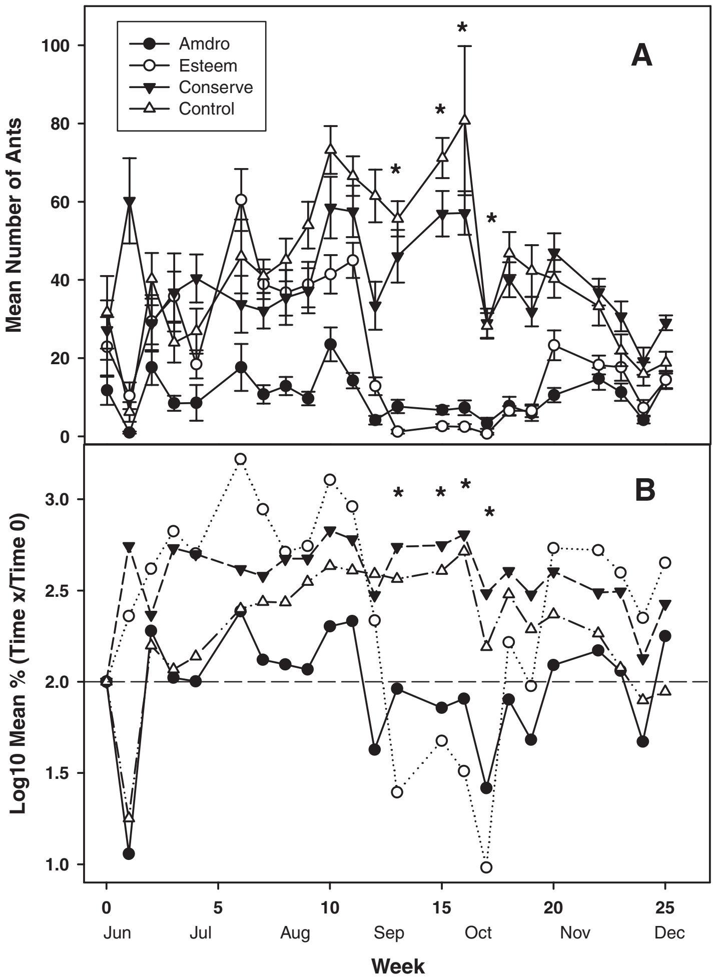

Fig. 1. (A) Mean ant counts ± SEM from transect sampling during weeks 0–25. Ant control treatments were applied every 2 wk for 16 wk; no ant control treatments were applied from weeks 17–25. An asterisk (*) denotes a significant ant control treatment effect. (B) Mean percentage of increase or decrease in ant counts on each sampling date (time x) relative to pretreatment counts (time 0). Data were $\log_{10}$ transformed; 2.0 on the y-axis is 100% or no change, 1.0 is 10% of pretreatment ant counts (90% reduction), and 3.0 is a 10-fold increase over pretreatment counts. On all weeks showing significant treatment effects (weeks 13–17), the reduction in ants relative to pretreatment counts was significantly greater in the Esteem plots than in the Conserve and control plots, but not significantly different from the Amdro plots ($P < 0.05$; Tukey's HSD test) (see Results).

of trees used in the experiment on all sampling dates (data not shown).

Ant numbers in the Amdro and Esteem plots recovered after the ant control treatments were stopped after week 16 (Fig. 1A). At week 25, ant counts were similar and not significantly different for any of the treatments ($F = 0.25$, df = 3, $P = 0.86$), indicating that the effects of the ant control treatments had completely dissipated (Fig. 1A and B).

Hemiptera Sampling. Four Hemiptera species were found during sampling of branch terminals: one diaspidid scale, *Ceroplastes rubens* (Maskell), and three pseudococcids, *Nipaecoccus nipae* (Maskell), *Nipaecoccus viridis* (Newstead), and *Planococcus citri* (Risso). *N. nipae* was the most prevalent species (80.8%), followed by *N. viridis* (13.7%). *C. rubens* and *P. citri* were uncommon in all plots on all dates (mean number of individuals <2.5), so they were dropped from further analysis. *C. rubens*, like all armored scales, does not secrete honeydew; therefore, it should not have been affected by the ant treatments. ANOVA on log-transformed pseudococcid counts (*N. nipae* and *N. viridis*, only) during the ant control experiment was significant for the effect of week ($F = 2.3$, df = 1, $P = 0.05$), and ant control treatment ($F = 4.5$, df = 3, $P = 0.005$), but not for the week × treatment interaction ($F = 1.8$, df = 3, $P = 0.14$). The block effect for orchard type (rambutan or mangosteen) was highly significant ($F = 33.6$, df = 1, $P < 0.001$) as mealybug densities were generally higher in the rambutan than the mangosteen blocks. Means separations analysis focused on monthly treatment comparisons using blocking as a

Table 1. Mean number of Pseudococcidae sampled (± SEM) from branch terminals

Treatment	Wk				
	0	4	8	12	16
Amdro	29.3 (14.3)a	16.4 (6.3)a	9.6 (4.9)a	8.6 (3.8)b	15.4 (2.0)ab
Esteem	31.6 (9.9)a	2757 (10.2)a	14.7 (1.6)a	9.0 (2.9)ab	9.8 (4.0)b
Conserve	15.0 (3.2)a	30.4 (9.1)a	9.4 (2.7)a	5.5 (2.2)ab	22.5 (8.3)ab
Control	37.9 (19.5)a	25.4 (14.3)a	15.8 (9.5)a	16.5 (7.2)a	37.4 (6.0)a

Means within a column followed by the same letter are not significantly different ($P > 0.05$; Tukey's HSD test). Data were log transformed before analysis. Pseudococcidae included *N. nipae* and *N. viridis.*

factor. The Amdro treatment was significantly different from the control treatment on week 12, and the Esteem treatment was significantly different from the control treatment on week 16 ($P < 0.05$; Tukey's HSD test) (Table 1). Ant counts were significantly reduced in the Esteem plots at week 16 (Fig. 1B), suggesting ant control may have reduced the number of mealybugs on branch terminals (presumably due to increased predation or parasitism). Although presence/absence sampling of tree trunks showed that ants were present on all tree trunks throughout the experiment, the actual number of ants foraging in the trees and tending mealybugs may have been reduced in the ant control treatments.

Population Size and Biomass Estimates. *W. auropunctata* densities varied among the three habitats sampled (Table 2). Ant densities were higher, and there were higher percentages of samples with evidence of active reproduction (i.e., eggs, larvae, and queens), in the orchard and windbreak habitats than the pasture habitat. The upper range counts for each habitat showed significantly larger aggregations of ants in the orchard and windbreak than in the pasture, although low range counts were similar across habitats. The orchard habitat had the highest mean number of ants at 491.1 per 201-cm^2 soil core sample, or an estimated 24,443 ants per m^2 (244.3 million/ha). The wet weight of a *W. auropunctata* worker was estimated as 0.093 mg, and the dry weight as 0.032 mg. *W. auropunctata* worker biomass in the orchard therefore was estimated as 2.3 g wet weight/m^2 and 0.78 g dry weight/m^2.

Discussion

Esteem was the most effective treatment in this experiment, but a reduction in ant counts in the Esteem plots did not occur until week 12. A delay in substantial colony mortality is typical for insect growth regulators, as the bait acts on the immatures stages and queens, and worker numbers decrease only by attrition without replacement. However, none of the pesticide treatments applied in this study achieved 100% reduction of ants in any of the plots. In all treatments, ant populations recovered to pretreatment levels within 9 wk of cessation of ant control treatments. These results may reflect the sheer size and distribution of the ant population. *W. auropunctata* had achieved high densities at Honualani Orchards (estimated 24,443 ants per m^2) and in the surrounding area when the experiment was conducted. The population density estimate in the orchard was almost certainly an underestimate. High numbers of ants were found foraging and nesting in trees, particularly on moss-covered trunks, and trees were not sampled as part of the ant population density estimate. Given the prevalence of nesting sites on the tree trunks, and the large surface area of the tree canopy, actual ant densities may have been >two-fold greater than the estimates from ground sampling.

The population density estimates for *W. auropunctata* of >20,000 individuals per m^2 is considerably higher than densities estimated for many other genera of mounding ants, probably due to *W. auropunctata*'s small size (reviewed in Macom and Porter 1996); however, the estimate for *W. auropunctata* biomass of 0.78 g dry weight/m^2 was similar to estimates for other ant genera. For example, polygyne red imported fire ant colonies in Florida had an average density of 4,100 individuals per m^2 and a mean biomass of 1.30 g dry weight/m^2 (Macom and Porter 1996).

It is not clear from our experiment whether the ground-based ant control affected ants in the tree canopy. It is also not known whether recovery of ant

Table 2. Ant population density and biomass estimates from ground sampling

Habitat type	Mean no. ants (± SEM)	Count extremes[a]	% samples with evidence of reproduction[b]	Estimated no. ants per ha ($\times 10^6$) or m^2 ($\times 10^2$)	Wet wt per ha (kg)[c]
Orchard	491.1 (±194.8)	11–4794	32	244	22.7
Windbreak	474 (±92.3)	22–1821	48	236	21.9
Pasture	186.6 (±33.4)	12–564	24	93	8.6

$N = 25$ for each habitat type; the area of each sampling unit was 201 cm^2.
[a] Highest and lowest numbers of ants sampled.
[b] Samples containing eggs, larvae, and adult females.
[c] Average wet weight of workers was 0.093 mg.

populations on the ground after the ant control treatments were terminated at week 16 was due to population growth from within the plots, reinvasion by ants residing in the tree canopies, or reinvasion from boundary areas. Future studies will focus on the foraging habits of *W. auropunctata,* particularly in the tree canopy. Pasture and grassland habitats seem to support lower ant population densities than orchards and windbreaks, perhaps due to limited arboreal nesting sites and food resources.

No information is available on the effect of Amdro bait station spacing and density against *W. auropunctata,* or on the possibility for applying bait in trees. Currently, broadcast application of Esteem is permitted, but broadcast application of Amdro is not. One of the disadvantages of Amdro is that it decomposes quickly (Vander Meer et al. 1982), and it cannot be applied during or soon after rainfall, which is problematic in east Hawaii where rainfall averages >300 cm/yr. Persistent sprayable ant baits or ant baits formulated in waterproof pastes would be ideal for use in orchards with arboreal ants.

Spinosad, the active ingredient in Conserve, is known to be toxic to various ants (e.g., Oi and Oi 2006), but it showed limited effectiveness in our experiment. This was probably due to orchard management factors rather than poor efficacy. The grass in the orchard was often 10–15 cm in height, which likely reduced penetration of the spray to the thatch and soil where ants reside. Conserve sprays aimed at the tree canopy against exposed foraging ants may be a useful tactic to supplement baits for population suppression.

Eradication of introduced *W. auropunctata* was achieved from 3- and 20-ha areas on Santa Fe Island and Marchena Island (Causton et al. 2005), respectively, in the Galapagos using broadcast applications of Amdro. Several factors may explain the greater success in controlling *W. auropunctata* in these islands compared with the current study. Marchena Island and Santa Fe Island are arid and principally covered with dry eroded soil with areas of dry forest (Causton et al. 2005); also, the species of trees did not provide good nesting sites for the ants. Therefore, the treated habitats in the Galapagos probably supported less dense populations of *W. auropunctata* than the wet site in Hawaii where our study was conducted. However, Amdro applications on Marchena Island were made to areas described as having dense vegetation. On Marchena Island, Amdro was applied three times at 3-mo intervals and broadcast at more than two times the labeled rate due to the dense vegetation (Causton et al. 2005). In the current study, Amdro was applied in widely spaced bait stations, and the experimental design left many areas untreated including control plots and windbreaks within the orchard, and pasture and macadamia trees in the surrounding habitat, which may have allowed constant immigration into treated plots, despite the limited dispersal of *W. auropunctata.* Also, Amdro and the other ant control treatments were applied for only 4 mo in our study, albeit more frequently than in the Galapagos studies, and they may have had greater success in eliminating ants if the treatments were continued for a longer time.

W. auropunctata invasion can change the diversity of ants and other fauna (Lubin 1984, Clark et al. 1982, Le Breton et al. 2003). No other ant species beside *W. auropunctata* was observed at Honualani Orchard during our study. Ants commonly found in tropical fruit orchards in east Hawaii and in the areas surrounding the infested area used in this study are the bigheaded ant, *Pheidole megacephala* (F.); *Technomyrmex albipes* (Smith), and *Anoplolepis gracilepis* (Jerdon) (P.A.F., unpublished data). *W. auropunctata* is apparently displacing these ants.

The premium price afforded by exporting fruit and vegetable crops from Hawaii has resulted in a rapid expansion in acreage, and the number of small farmers exporting fruits and vegetables is growing rapidly. Many of these crops are harvested by hand. *W. auropunctata* is small, cryptic, and has a painful sting. In some cases, agricultural workers refuse to harvest from *W. auropunctata*-infested trees or orchards, which is a critical issue for farms that rely on hand harvesting. *W. auropunctata* is also of quarantine concern, because the presence of ants on exported fruits and vegetables from Hawaii can cause rejection and return shipment to Hawaii (Costa et al. 2005, Follett and Taniguchi 2007). Packinghouses may refuse shipments from infested orchards. Rejection of a single export shipment due to ants can be devastating financially to the small farmer.

Future studies should focus on the foraging behavior of *W. auropunctata* supercolonies in orchards and other agricultural environments so that bait stations or other baiting strategies can be deployed most effectively. Granule size may be an important factor in bait effectiveness (Hooper-Bui et al. 2002). *W. auropunctata* feeds on Amdro and Esteem bait granules without removing the granules to carry them back to their nests. Smaller granule size might result in transport to nests leading to greater efficacy. Other formicides such as fipronil are highly effective against ants in general (e.g., Klotz et al. 2007), but they are not currently registered for agricultural uses in Hawaii.

Acknowledgments

This research was submitted by E.S. in partial fulfillment of a master's degree in the Tropical Conservation Biology and Environmental Science program at the University of Hawaii at Hilo. We are grateful for technical, logistical, and product support provided by Bob Lower and Mary Golden (USDA–ARS, Hilo, HI), Colleen Schrandt (Honualani Orchards), Patrick Conant (Hawaii Department of Agriculture), Charles Ensey, Thomas Thompson, and Kenneth Grace (University of Hawaii at Manoa), Valent, and Dow AgroSciences. Douglass Miller (USDA–ARS–SEL, Beltsville, MD) identified the Hemiptera. Michael Rust (University of California, Riverside) provided a helpful review of an early draft of the paper. This research was funded partly by grants from Bill Feldner (BF Tile Inc.), the Hawaii Tropical Fruit Growers Association, and the Hawaii Farm Bureau Federation.

References Cited

Abedrabbo, S. 1994. Control of little fire ant *Wasmannia auropunctata,* on Santa Fe Island in the Galapagos Islands, pp. 219–227. *In* D. F. Williams [ed.], Exotic ants: biology, impact, and control of introduced species. Westview Press, Boulder, CO.

Causton, C. E., C. R. Sevilla, and S. D Porter. 2005. Eradication of the little fire ant, *Wasmannia auropunctata* (Hymenoptera: Formicidae), from Marchena Island, Galapagos: on the edge of success? Fla. Entomol. 88: 159–168.

Clark, D. B., C. Guayasamin, O. Pazmina, C. Donosu, and Y. P. de Villacis. 1982. The tramp ant *Wasmannia auropunctata:* autecology and effects on ant diversity and distribution on Santa Cruz Island, Galapagos. Biotropica 14: 196–207.

Costa, H. S., L. Greenberg, J. Klotz, and M. K. Rust. 2005. Response of Argentine ants and red imported fire ants to permethrin-impregnated plastic strips: foraging rates, colonization of potted soil, and differential mortality. J. Econ. Entomol. 98: 2089–2094.

Fabres, G., and W. L. Brown. 1978. The recent introduction of the pest ant *Wasmannia auropunctata* into New Caledonia. J. Austral. Entomol. Soc. 17: 139–142.

Follett, P. A., and G. Taniguchi. 2007. Effect of irradiation on the longevity and reproduction of *Pheidole megacephala* (Hymenoptera: Formicidae) queens. Proc. Hawaiian Entomol. Soc. 39: 43–47.

Holldobler, B., and E. O. Wilson. 1990. The ants. Belknap Press, Cambridge, MA.

Hooper-Bui, L. M., A. G. Appel, and M. K. Rust. 2002. Preference of food particle size among several urban ant species. J. Econ. Entomol. 95: 1222–1228.

Ishaaya, I., and A. R. Horowitz. 1992. Novel phenoxy juvenile hormone analog (pyriproxyfen) suppresses embryogenesis and adult emergence of the sweetpotato whitefly (Homoptera: Aleyrodidae). J. Econ. Entomol. 85: 2113–2117.

Klotz, J. H., M. K. Rust, L. Greenberg, H. C. Field, and K. Kupfer. 2007. The evaluation of several urban pest management strategies to control Argentine ants (Hymenoptera: Formicidae). Sociobiology 50: 391–398.

Krushelnycky, P. D., L. L. Loope, and N. J. Reimer. 2005. The ecology, policy, and management of ants in Hawaii. Proc. Hawaiian Entomol. Soc. 37: 1–25.

Le Breton, J., J.H.C. Delabie, J. Chazeau, and H. Jourdan. 2003. Immediate impacts of invasion by *Wasmannia auropunctata* (Hymenoptera: Formicidae) on native litter ant fauna in a New Caledonian rainforest. Austral. Ecol. 28: 204–209.

Le Breton, J., J.H.C. Delabie, J. Chazeau, A. Dejean, and H. Jourdan. 2004. Experimental evidence of large-scale unicoloniality in the tramp ant *Wasmannia auropunctata* (*Roger*). J. Insect. Behav. 17: 263–271.

Lubin, Y. D. 1984. Changes in the native fauna of the Galapagos Islands following invasion by the little red fire ant, *Wasmannia auropunctata.* Biol. J. Linn. Soc. 21: 229–242.

Macom, T. E., and S. D. Porter. 1996. Comparison of polygyne and monogyne red imported fire ant (Hymenoptera: Formicidae) population densities. Ann. Entomol. Soc. Am. 89: 535–543.

Oi, D. H., and F. M. Oi. 2006. Speed of efficacy and delayed toxicity characteristics of fast-acting fire ant (Hymenopera: Formicidae) baits. J. Econ. Entomol. 99: 1739–1748.

SAS Institute. 2002. JMP user's guide. SAS Institute, Cary, NC.

Smith, M. R. 1942. The relationship of ants and other organisms to certain scale insects on coffee in Puerto Rico. J. Agric. Univ. Puerto Rico 26: 21–27.

Taniguchi, G. Y., A. K. Ota, M. K. Kawate, K. G. Rohrbach, and G. K. Uchida. 2003. Preliminary field tests on the suitability of Amdro® and Distance® in ant bait containers for control of the big-headed ant, *Pheidole megacephala* (Hymenoptera: Formicidae). Proc. Hawaiian Entomol. Soc. 36: 129–133.

Vail, K. M., D. F. Williams, and D. H. Oi. 1996. Perimeter treatments with two bait formulations of pyriproxyfen for control of pharaoh ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89: 1501–1507.

Vander Meer, R. K., D. F. Williams, and C. S. Lofgren. 1982. Degradation of the toxicant AC 217,300 in Amdro imported fire ant bait under field conditions. J. Agric. Food Chem. 30: 1045–1048.

Walsh, P. D., P. Henschel, K. A. Abernethy, C.E.G. Tutin, P. Telfer, and S. A. Lahm. 2004. Logging speeds little red fire ant invasion of Africa. Biotropica 36: 637–641.

Wetterer, J. K., and S. D. Porter. 2003. The little fire ant, *Wasmannia auropunctata:* distribution, impact and control. Sociobiology 44: 1–41.

Received 16 July 2007; accepted 5 March 2008.