Melon Aphid (Homoptera: Aphididae) Control by Inundative Convergent Lady Beetle (Coleoptera: Coccinellidae) Release on Chrysanthemum

STEVE H. DREISTADT[1] AND MARY LOUISE FLINT[1,2]

ABSTRACT Convergent lady beetles, *Hippodamia convergens* Guérin-Méneville, collected from aggregations in California were released for control of melon aphids, *Aphis gossypii* Glover, infesting potted chrysanthemum, *Dendranthema grandiflora* (Tzvelev) 'Hurricane,' outdoors. Most beetles dispersed from plants within 1–3 d after a single release during May 1993 and July and September 1993 and 1994. Most dispersing beetles left the study area, although some moved within release plots to adjoining plants or dispersed to nearby plots within ≈40 m. Aggregation-collected beetles that were allowed to drink and fly in a screen tent for 7–10 d before release and insectary-reared beetles dispersed more slowly than aggregation-collected beetles that were stored at 4–10°C until the day of release. Although beetles dispersed within days, releases significantly reduced aphid densities during all trials. A single release of 34–42 adult *H. convergens* per pot provided 25–84% aphid control, calculated according to the Abbott method. Each beetle consumed ≈25–170 melon aphids per day. There was a density-dependent functional response in predation; beetles consumed more aphids when released on plants with higher aphid densities. Release of commercially available convergent lady beetles can provide augmentative control of relatively high aphid densities on small potted plants.

KEY WORDS *Hippodamia convergens, Aphis gossypii, Dendranthema grandiflora*, inundative control

THE CONVERGENT LADY beetle, *Hippodamia convergens* Guérin-Méneville, is widely released for aphid control. Large aggregations in the Sierra Nevada allow convergent lady beetles to be readily collected and packaged for sale in nurseries, garden supply catalogs, and other outlets across the United States. No data are available, but our commercial supplier reportedly sells ≈20,000 liters (≈5,000 gal) of convergent lady beetles each year and estimates that these sales are ≈10% of the California market. Because 1 gal contains 70,000–80,000 beetles, several billion convergent lady beetles are apparently collected and sold each year.

The University of California has historically recommended against releasing aggregation-collected convergent lady beetles because releases were believed ineffective (Moore and Koehler 1981, Hagen 1982). The recommendation against releases was based mostly on observations that *H. convergens* collected from aggregations dispersed soon after being released. Davidson (1919, 1924) released marked beetles in barley, *Hordeum vulgare* L., and wheat, *Triticum* sp., and found that only ≈10% of beetles remained after 1 wk. Eddy (1939)

reported that most *H. convergens* quickly dispersed after release in sugar cane, *Saccharum officinarum* L. Packard and Campbell (1926) found that a few of the *H. convergens* released in alfalfa, *Medicago sativa* L., remained after 12 d and that the postrelease density of pea aphids, *Acyrthosiphon pisum* (Harris), apparently declined. Cooke (1963) credited *H. convergens* release for some aphid reduction in alfalfa, but like Fenton and Dahms (1951) and Hatch and Tanasse (1948), Cooke concluded that releases would not be economical in comparison with insecticides. Starks et al. (1975) found that 72% of *H. convergens* dispersed immediately after release in sorghum, *Sorghum vulgare* Persoon, in Kansas; although dispersal was slowed by providing a shelter of wet burlap, releases did not significantly reduce aphid densities.

Except for Starks et al. (1975), none of these authors provide any data on aphid densities and none report using nonrelease control plots in their experimental designs. Most early researchers were investigating inoculative control, and because most beetles soon dispersed without reproducing, these workers concluded that releases would be ineffective. At least some workers did not consider it possible that the beetles they released could provide inundative control. For example, Packard and

[1] IPM Education and Publications, Statewide IPM Project, University of California, Davis, CA 95616–8620.

[2] Department of Entomology, University of California, Davis, CA 95616.

Campbell (1926) observed a decrease in pea aphids but did not credit this to the release because "it was too soon after liberation for progeny of the introduced beetles to have become effective." Recent research focused on dispersal and effects of temperature, wind, and nutrition on dispersal of *H. convergens* (Hagen 1962, Rankin and Rankin 1980, Davis and Kirkland 1982).

Despite long-standing opinions that *H. convergens* releases are ineffective, apparently only Raupp et al. (1994) and Flint et al. (1995) have conducted replicated, controlled experiments on aphid density changes from release of *H. convergens*. Raupp et al. (1994) released 10 *H. convergens* per plant on potted firethorn, *Pyracantha lelandii*, infested with spirea aphid, *Aphis spiraecola* Patch, and a woolly aphid (*Eriosoma* sp.) in the greenhouse. Release controlled only spirea aphids and only if plants were caged. An uncaged field release of 1,500 beetles by Raupp et al. (1994) apparently reduced *Capitophorus elaeagni* (del Guerico) aphids on an *Elaeagnus pungens* Thunberg hedge.

Flint et al. (1995) reported significant reductions in numbers of melon aphid, *Aphis gossypii* Glover, on chrysanthemum, *Dendranthema grandiflora* Tzvelev, and rose aphid, *Macrosiphum rosae* (L.), on rose, *Rosa* sp., when beetles were released outdoors on uncaged, potted plants. Here we report on our investigation of whether dispersal of aggregation-collected *H. convergens* was reduced by flying and feeding beetles before releasing them. We compared dispersal of insectary-reared beetles with dispersal of beetles from aggregations and determined whether inundative release of convergent lady beetles controls aphids on potted plants outdoors.

Materials and Methods

We released marked adult convergent lady beetles outdoors on potted chrysanthemums infested with melon aphids. We conducted 5 trials; each trial of an experiment was conducted once during May, July, and September 1993 and July and September 1994. Except for the insectary-reared beetles discussed below, beetles were from Unique Insect Control, Citrus Heights, CA. This commercial supplier reports that beetles were from aggregations at an altitude of ≈600 m in Placer County, California, and that beetles were collected ≤2 wk before each trial in July and September. Beetles released in May reportedly were collected in late February 1993 and stored at 4–10°C.

Treatment Effects on Beetle Dispersal. We preconditioned (treated) beetles before release and conducted mark–release–recapture studies to compare dispersal tendencies among treatments. All 5 trials included the following 2 treatments conducted with aggregation-collected lady beetles: (1) beetles were allowed to fly for 1 wk (during 1993) or 10 d (1994) in a screen-wall tent (3 by 3

by 2 m) outdoors, sprayed daily with diluted honey, and marked before release (flown); or (2) beetles were removed from cold storage (4–10°C) ≈8 h before release, confined with honey and water, marked before release, and sprayed with soda pop immediately after release (stored). Soda pop was applied because beetle distributors commonly recommend application of this or other sweet liquids to reduce beetle dispersal. Third treatments were added to the trials during May 1993 and September 1994, as described below.

The May 1993 trial included a 3rd treatment of beetles produced in the insectary (reared) to determine whether rearing beetles influenced dispersal in comparison with aggregation-collected beetles. Reared *H. convergens* adults were the 1st-generation offspring from adults collected in alfalfa in Davis (Yolo County) in April. Field-collected adults and their progeny were held in petri dishes at 20°C and continuous light. They were provided honey, water, and ad lib an assortment of field-collected aphids, mostly *Aphis fabae* Scopoli, *Aphis gossypii*, and green peach aphid, *Myzus persicae* (Sulzer). After eclosion, adults were held and fed the same diet as larvae for 1–2 wk before release.

The 3rd treatment during September 1994 was designed to assess whether marking influenced beetle dispersal. Aggregation-collected beetles were released but not marked before release (unmarked). They were otherwise handled the same as stored beetles.

To distinguish flown from stored beetles, we marked beetles before release by spraying 1 treatment with white Ace Instant Drying Interior/Exterior Lacquer (Ace Hardware, Oak Brook, IL). Dark (black or blue) Ace Instant Drying Interior/Exterior Lacquer was applied to beetles in the 2nd treatment. We also used aluminum Zynolyte Spray Lacquer (Zynolyte, Carson, CA) during May, when a 3rd treatment marking was needed.

To apply lacquer, we confined beetles from each treatment in a separate cardboard box (30 by 22 by 5 cm) with window screen on 1 side, and sprayed lacquer into the box through the screen onto beetles for ≈2 s. We aired the box for ≈30 s to dry the lacquer and disperse solvent, shook beetles down onto the bottom of the box, allowed beetles to right themselves so that their elytra were exposed, and resprayed them. We repeated this spray–and–shake procedure ≈4 times until most beetles appeared to be marked.

To assure ourselves of the effectiveness of marking, we retained and inspected beetles from treatments before release during July 1994 and September 1993 and 1994. We collected 5–8 samples, of 17 (during 1993) or 40 (1994) beetles each, from every treatment during each trial and examined beetles for marking using a dissecting binocular microscope. Except for the unmarked treatment during September 1994, 96.4% (SD = 4.6) of the beetles recovered were marked. We do not report unmarked beetles recovered in the numbers pre-
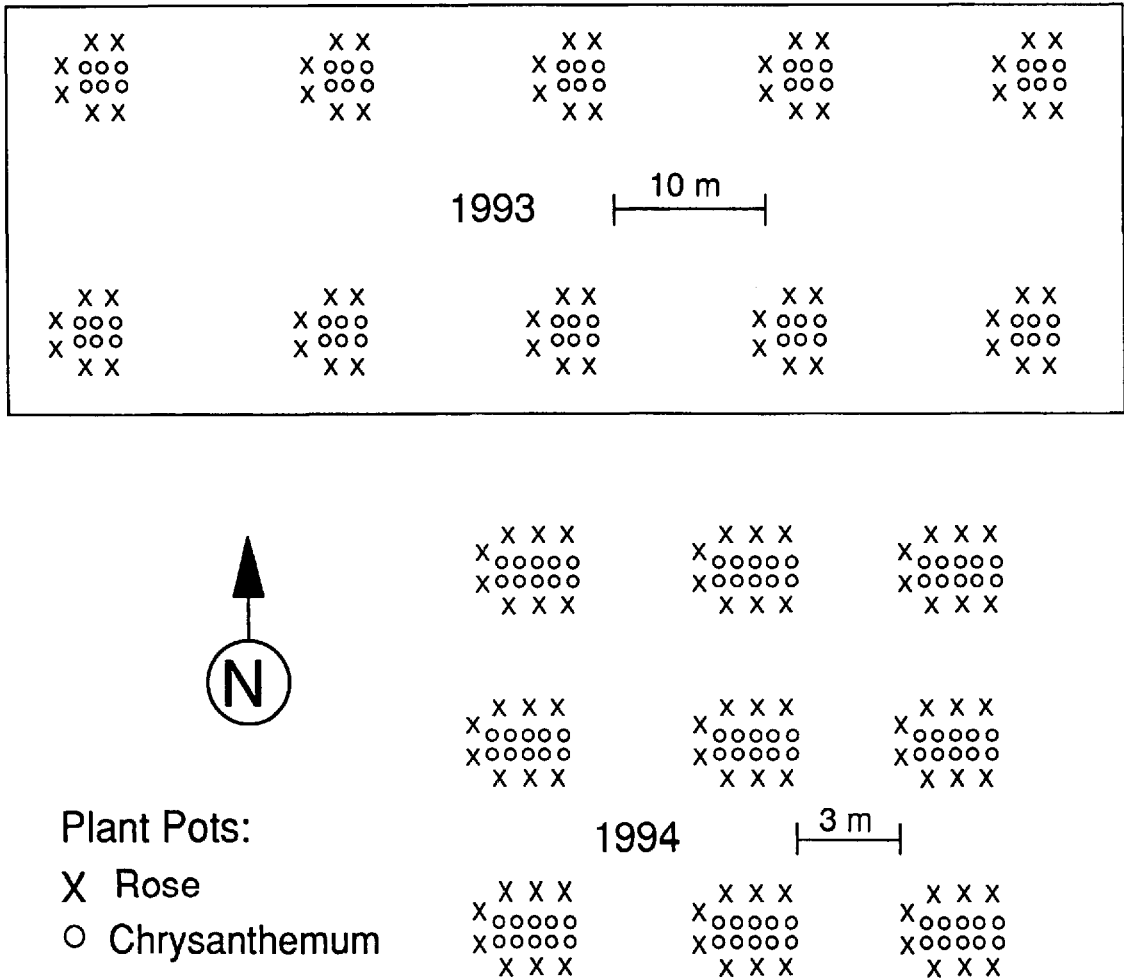
Fig. 1. Convergent lady beetle experimental design. Release and control plots were a randomized block: 2 × 5 plots during 1993 (above within rectangle) and 3 × 3 plots during 1994 (below), except as described in *Materials and Methods*. Each 4-liter pot (o) contained 4 chrysanthemum plants, with 6 (during 1993) or 10 (1994) pots per plot. Each plot was sheltered on 3 sides by 6 (1993) or 8 (1994) aphid-free, 1-m-tall rose, *Rosa* sp. 'Tropicana,' plants in 20-liter pots (x). Beetle dispersal out of plots was evaluated by collecting all beetles from 1 or 2 previously unsampled pots in each release plot at intervals of 12, 24, 36, 48, and 69 h after release. Beetle movement within plots was evaluated at each interval by resampling and removing beetles from all previously sampled pots.

sented here, except during September 1994, when all unmarked beetles we recovered were presumed to be from the unmarked treatment beetles we released.

Beetle Releases. We conducted all experiments outdoors at the University of California Davis Arboretum nursery in a gravel-surfaced area (130 by 80 m). The area was free of plants except for those in our study. Each 4-liter pot contained 4 chrysanthemum plants. We used 6 (1993) or 10 (1994) chrysanthemum pots (24 or 40 plants) in each plot, surrounded on 3 sides by potted roses. Roses were aphid-free and were used to shade the chrysanthemums, which had been produced in a whitewashed greenhouse. Chrysanthemum pots did not touch; within plots there was a gap (3–8 cm) between the canopy of each pot. Distance from plot edge to the

nearest other plots was 10 m (during 1993) or 3 m (1994) (Fig. 1).

We counted the number of beetles to be released into each pot by aspirating them into a vial, selecting only apparently healthy (active) beetles that appeared marked. We released beetles by knocking them from vials onto potting media at the base of the plants. We released the stored beetles, sprayed them with ≈10 ml of soda pop per pot, then released the other treatment beetles in that same pot (during 1993) before moving to release beetles in the next pot. Foliage and media were wet from watering plants immediately before release.

We released 34–42 beetles per pot (see $h = 0$ in *Results* for exact numbers) once at dusk on 18 May, 20 July, and 28 September 1993, and on 26

July and 27 September 1994. During 1993, we released equal numbers of flown and stored *H. convergens* in each pot. During May, when we also released reared beetles, 1/3 of the beetles released in each pot were of each treatment. During 1994, each release plot received only beetles from 1 treatment, either all flown or all stored beetles during July, or all flown, stored, or unmarked beetles during September. Release plots were replicated 6 times during 1993 and 3 times for each treatment during 1994 as illustrated in Fig. 1. Nonrelease (control) plots were replicated 4 (1993) or 3 (1994) times, except that the May 1993 trial included only 1 plot of control pots. A randomized block of 2 × 5 plots was used during 1993, 3 × 3 during July 1994, and 3 × 4 during September 1994; the former 2 designs are illustrated in Fig. 1. Before release, we controlled ants around all plants by deploying Grants Kills Ants (0.03% arsenic) (Grant Laboratories, San Leandro, CA) ant stakes.

Beetle Dispersal. At 12, 24, 36, 48, and 69 h after release, we evaluated dispersal by aspirating all beetles from 1 (during 1993) or 2 (1994) previously unsampled pots in each plot. Two exceptions were as follows: (1) during September 1993, we collected beetles from 2 previously unsampled pots per plot at 69 h, and (2) during July 1993, we collected beetles at 12, 24, and 48 h and beetles were collected from 4 previously unsampled pots per plot at 48 h.

Nondispersing beetles (none) were those recovered on previously unsampled pots and marked the same color as the beetles released in that plot. We measured dispersal within plots at these same intervals by resampling and removing beetles from all previously sampled pots; for example, at 36 h after release during 1994, we removed all beetles from 2 previously unsampled pots in each plot and removed beetles that had moved onto pots sampled 12 and 24 h earlier. To measure dispersal among plots we recorded whether the beetles we recovered were marked with the same color as the beetles released into that plot.

Aphid Control. We grew chrysanthemums in the greenhouse under a photoperiod of 16:8 (L:D) h at 20–30°C. We planted 4 cuttings in each 4-liter pot, grew them for 8–10 wk, then moved plants outdoors to the study area the day of release. We inoculated plants with *A. gossypii* 4–5 wk after potting and excluded other insects by screening, yellow sticky traps, or removal of infested leaves.

At ≤36 h before release (t_0), we sampled aphids on 3 or 4 pots per plot during 1993 and on 4 or 6 pots per plot during 1994. We resampled 2 pots per plot at 36 h after release during 1994 and resampled 2–4 pots per plot ≈72 h after release during 1993 and 1994. The release plants sampled for aphids at 36 h were those from which we had just removed beetles for the dispersal assessment described previously. Release pots resampled 72 h after release were those from which beetles were 1st removed at 48 and 69 h after release, except

that during September 1994, aphids were not sampled on pots from which beetles were first removed at 48 h.

We counted all aphids on 1 leaf per plant (4 leaves per pot). Each sample leaf was from about halfway up the main stem from the soil line, because middle-canopy leaves consistently provide an average measure of aphid density per plant (Vehrs et al. 1992). During July 1994, we counted aphids on each 1/2 (on either side of the midvein) of 1 middle canopy leaf on 32 plants and used a paired *t*-test to determine whether there was significant difference ($t = 0.19$, $P = 0.85$) in aphid density between halves of the same leaf. For the remaining plants during July and all plants during September 1994, we counted aphids on only 1/2 of 1 leaf per plant, and multiplied this value by 2 to obtain whole-leaf estimates.

In May 1993, we randomly allocated pots to release or nonrelease plots. During July and September of both years, before release we sampled aphids on ≈2 times the number of pots needed. We averaged the aphid density on the 4 plants per pot, rank-ordered pots according to aphid density, discarded pots with the highest and lowest aphid densities, and allocated pots so that the average prerelease aphid density was not significantly different among plots. We randomized pot location within plots and randomly assigned plots to controls or releases.

We counted the number of leaves and measured the height of 1 plant per pot. We multiplied the number of leaves per plant by 4 plants per pot to estimate leaves per pot (*LPP*). We estimated daily aphid consumption per beetle (*AB*):

$$AB = \frac{[AR_{t_0} - AR_{tn}) - (AC_{t_0} - AC_{tn})] \times LPP}{(B_{t_0} + B_{tn})/2}$$

where *AR* and *AC* are aphids per leaf on release and control plants, respectively, and *B* is beetles per pot at release time (t_0) or 36 or 72 h after release (tn). We included ($AC_{t_0} - ACtn$) in the formula to adjust estimates of aphid consumption. This adjustment was necessary because even in the absence of lady beetles, aphids declined during 4 of 5 trials, probably because of hot, dry conditions in the field or because some other aphid predators colonized plants after they were moved outdoors, or both.

To determine whether there was a density-dependent functional response in predation, we used least squares linear regression analyses (PROC REG, SAS Institute 1988) to examine the relationship between aphid density at the time of release (AR_{t_0}) (the independent variable) and daily aphid consumption per beetle (*AB*). During 1993, we determined *AB* for all treatments combined during each of 3 trials (May, July, and September), because all treatments were released into the same plots. Treatments were released in different plots during 1994, so we were able to calculate *AB* sep-

arately for each treatment during both 1994 trials (July and September). The result is 8 observations for the regression at 72 h. There were 5 observations for the regression at 36 h, because aphids were not sampled at that interval during 1993.

Percentage control (C) was calculated for each treatment according to the Abbott (1925) method:

$$C = [(N - R)/N] \times 100$$

where N is the percentage of aphids alive (postrelease density divided by prerelease density, multiplied by 100) on nonrelease plants and R is the percentage of aphids alive on release plants at 36 or 72 h after release.

Statistical Analyses. For each treatment, we compared mean aphid densities before and after releases and mean numbers of beetles recovered at all postrelease times combined. Beetles in nonrelease plots were excluded from the data and analyses. Less than 1% of beetles recovered during each trial were collected in nonrelease plots. Unless stated otherwise, we used t-tests for 2-way comparisons and analysis of variance (PROC ANOVA, SAS Institute 1988) for multiple comparisons. Because the beetle dispersal "out" category equals the sum of all other categories subtracted from the total number of beetles released, all means were not independent, and multiple t-tests instead of ANOVA were used to compare beetle dispersal.

Results

Beetle Dispersal. Most adult *H. convergens* released on groups of aphid-infested potted plants (Fig. 1) dispersed within 1–3 d (Figs. 2 and 3). In 2 of 5 trials (Figs. 2C and 3A), allowing these aggregation-collected beetles to drink and fly (flown) in a screen tent for 7–10 d before release, delayed dispersal from plots in comparison with beetles that were stored at 4–10°C (stored) until the day of release. About 20% (SE = 7) and 36% (SE = 13) more flown beetles were recovered in comparison with stored beetles during September 1993 (Fig. 2C) (t = 2.28, n = 36, P = 0.029) and July 1994 (Fig. 3A) (t = 2.60, n = 90, P = 0.011), respectively, when samples from all postrelease times (12–69 h) were combined. During July 1993, significantly more stored than flown beetles were recovered during all sample times pooled (Fig. 2B) (t = 3.03, n = 36, P < 0.005).

Insectary-reared beetles dispersed from plots more slowly than did aggregation-collected beetles (Fig. 2A). About 19% (SE = 10) and 41% (SE = 9) more reared beetles were recovered in comparison with flown (t = 2.09, n = 30, P = 0.046) or stored (t = 3.89, n = 30, P = 0.0005) beetles, respectively, when all postrelease samples were pooled during May 1993 (Fig. 2A).

Because treatments were marked with a different color and released into separate plots during 1994, we were able to determine that most of the
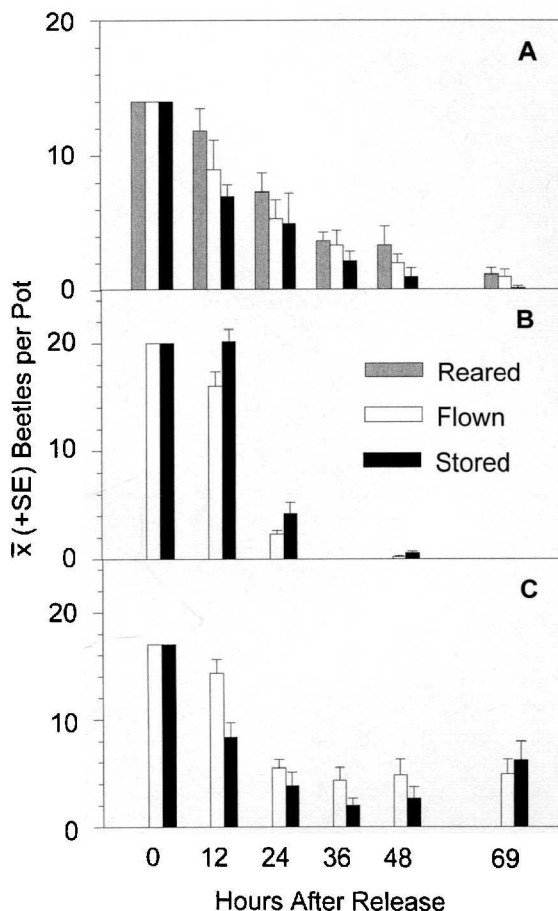

Fig. 2. Mean + SEM number of adult lady beetles recovered after a single release on chrysanthemums infested with melon aphids, for trials conducted in May (A), July (B), and September (C) 1993. Beetles were insectary-reared (reared), collected from aggregations and cold-stored until the day of release (stored), or collected from aggregations and conditioned (flown).

beetles we recovered were in the same plots where they were released. Because we also resampled plants from which we had previously removed all beetles, we found that when beetles did disperse, they usually left our study site (Fig. 4, "out" category) rather than moving to nearby plants. Most of the beetles that we did recover were on plants in the pots where they were released (Fig. 4, dispersal category "none"). Fifteen percent or less of the beetles dispersed to other plants in their release plot (Fig. 4, "within" category). Five percent or less of beetles were recovered in nearby plots (Fig. 4, "other" category). Flown beetles were more likely to disperse locally in comparison with stored beetles; about twice as many flown beetles were recovered on other plants ("within" category) in the release plot or in nearby plots ("other" category) (Fig. 4) in comparison with stored beetles.

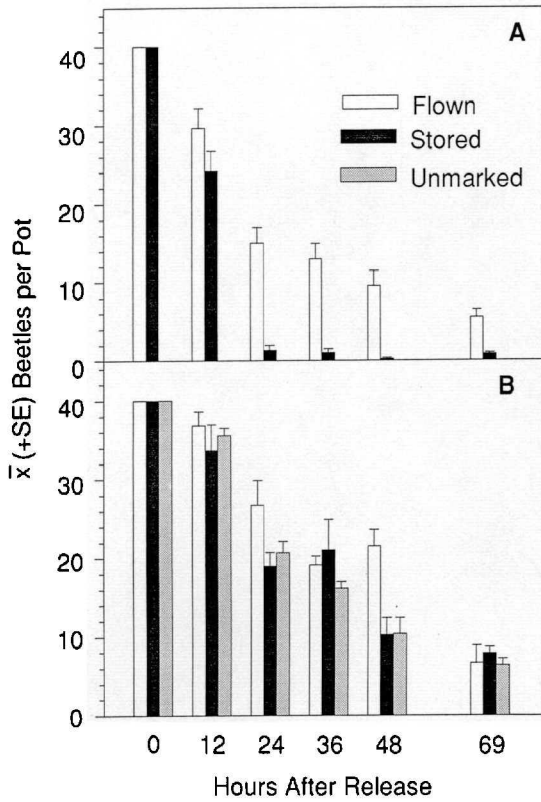Marking beetles with lacquer to distinguish treatments had no apparent effect on aphid con-

Fig. 3. Mean + SEM number of adult convergent lady beetles recovered after a single release on chrysanthemums infested with melon aphids, for trials conducted in July (A) and September (B) 1994. Beetles were collected from aggregations and were cold-stored until the day of release (stored), cold-stored until release and not lacquered (unmarked), or conditioned (flown).

Fig. 4. Mean + SEM dispersal (percentage of released beetles recovered) for flown and stored convergent lady beetles for all sample times pooled over 3 d during July (A) or September (B) 1994. In total, 2,400 beetles were released in July and 2,400 beetles (1,200 each flown and stored) were released during September. Nondispersing beetles (none) were recovered in pots where they were released. Beetles that left the study area (out) were not recovered. Some beetles moved from the pot where they were released but remained within their release plot (within). The remaining beetles were recovered after dispersing from release plants to other plots (other) in our study area. Within each month, means that do not share a common letter are significantly different ($P < 0.05$, t-tests).

sumption (see below) or dispersal. During September 1994, we released cold-stored *H. convergens* that were both marked (stored) and not marked (unmarked) and there were no obvious differences in average recovery at individual sample times (Fig. 3B) or when all samples were pooled ($t = 0.68$, $n = 120$, $P = 0.50$). No natural populations of convergent lady beetles were observed on surrounding vegetation in September, and presumably all unmarked beetles we recovered were those we released.

Aphid Control. Despite relatively rapid dispersal from plots, release of convergent lady beetles significantly reduced melon aphid densities on potted chrysanthemums during all trials (Figs. 5 and 6). Within 3 d after a single release of 34–42 beetles per pot, *H. convergens* provided 25–84% control as calculated according to the Abbott (1925) method. Up to 54% control occurred 1.5 d after release (Table 1).

Each adult *H. convergens* consumed ≈25–170 melon aphids per day (Fig. 7), as estimated by dividing the average reduction in aphids by the average number of beetles present. Samples collect-
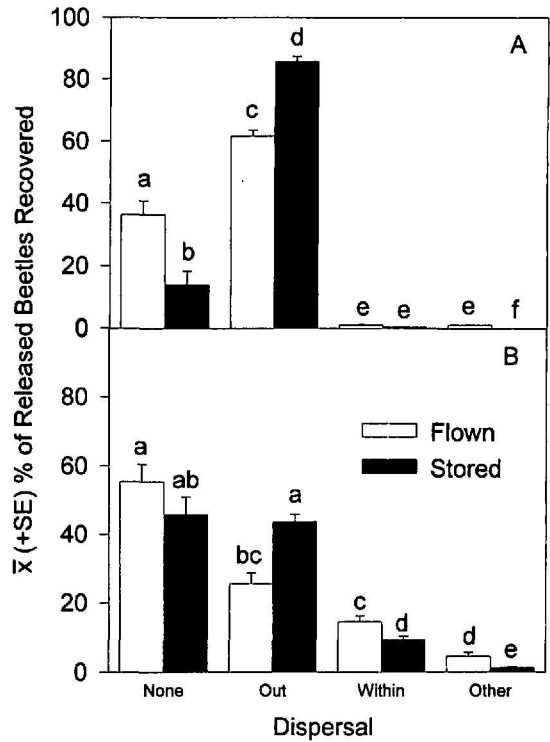
ed 3 d after release reveal a strong positive association between aphid density per leaf at the time of release and daily aphid consumption per beetle (*AB*); *AB* was higher on plants with a higher initial aphid density (Fig. 7). Feeding rate and initial aphid density were not significantly correlated at 1.5 d ($r^2 = 0.65$; $F = 5.6$; $df = 1, 3$; $P = 0.1$); aphids were sampled at this interval only during 1994 and sample size was small.

The extent of predation by flown beetles in comparison with stored beetles could not be determined during 1993 because equal numbers of beetles from all treatments were released on each pot. However, flown and stored beetles were released into separate plots during 1994 and both treatments significantly reduced aphid densities in comparison with plots without beetles (Fig. 6). There were no apparent differences in daily aphid consumption per beetle among treatments (flown,
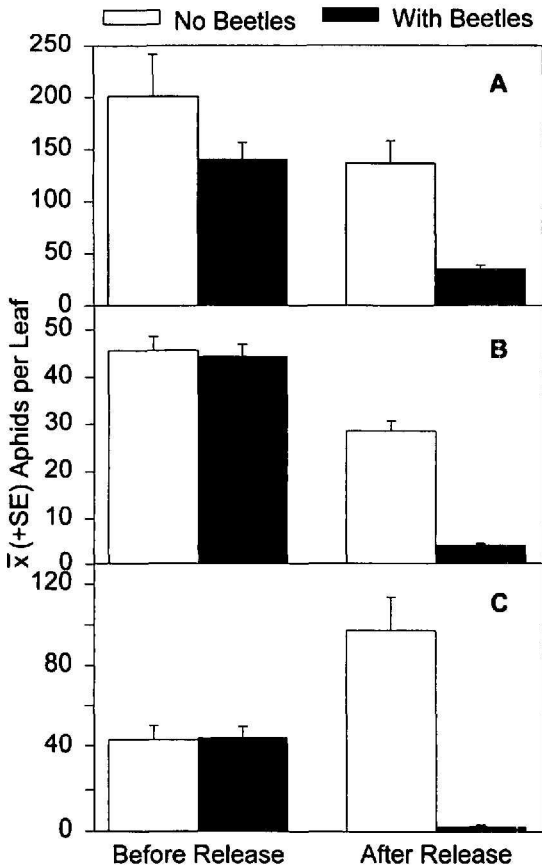
Fig. 5. Mean + SEM melon aphids per leaf before and 3 d after release outdoors of 34–42 adult lady beetles per pot, each pot containing 4 chrysanthemum plants, for trials conducted in May (A), July (B), and September (C) 1993. Aphid means in each trial were not significantly different ($P > 0.01$) before release. (A) $t = 1.39$; $n = 12$, 72. (B) $t = 0.31$, $n = 48$, 72. (C) $t = 0.08$, $n = 64$, 96. Means were significantly different ($P < 0.0001$) after release: (A) $t = 4.68$; $n = 20$, 72. (B) $t = 11.86$; $n = 48$, 72. (C) $t = 5.74$; $n = 64$, 96. Mean ± SEM leaves per plant (L) and plant height (H) in centimeters for all treatments pooled were (A) L = 15.4 (0.4), H = 28.7 (0.6). (B) L = 15.8 (0.4), H = 30.1 (0.8). (C) L = 17.1 (0.6), H = 29.7 (1.1).

Fig. 6. Mean + SEM melon aphids per leaf before and 1.5 and 3 d after release outdoors of 40 flown, stored, or unmarked adult convergent lady beetles per pot, each pot containing 4 chrysanthemum plants, for trials conducted in July (A) and September (B) 1994. Aphid means in each trial were not significantly different ($P > 0.05$) before release. (A) $F = 0.0$; df = 2, 213. (B) $F = 0.02$; df = 3, 187. There were significant differences ($P < 0.0001$) in aphid densities after release of convergent lady beetles. ANOVA statistics are (A) 1.5 d: $F = 19.5$; df = 2, 69; 3 d: $F = 41.2$; df = 2, 141. (B) 1.5 d: $F = 14.6$; df = 3, 92; 3 d: $F = 75.4$; df = 3, 116. Mean ± SEM leaves per plant (L) and plant height (H) in centimeters for all treatments pooled were (A) L = 11.1 (0.4), H = 17.6 (0.3). (B) L = 17.8 (0.4), H = 25.2 (0.4).

stored, unmarked) (Fig. 6B). However, at 1.5 d after release during July 1994, flown beetles provided more control in comparison with stored beetles (Fig. 6A) because flown beetles dispersed less quickly (Fig. 3A) so that more individuals were present to feed.

Discussion

We found that preconditioning aggregation-collected *H. convergens* or releasing reared beetles in some instances delayed dispersal in comparison with cold-stored beetles from aggregations. Our findings differ from those of Starks et al. (1975), who found no differences in dispersal after release
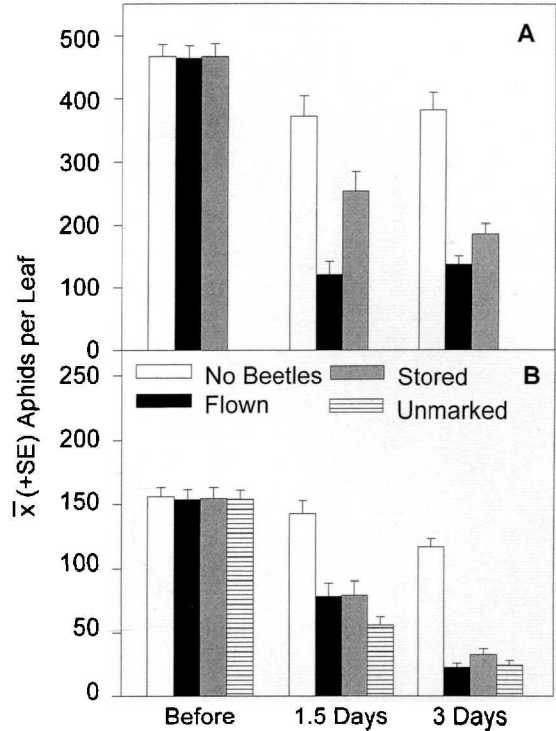
Table 1. Melon aphid control provided 1.5 and 3 d after a single release of 34–42 convergent lady beetles per chrysanthemum pot

Month	Year	Treatment[b]	Mean ± SE % control[a]	
			1.5 d	3 d
May	1993	All	NS	34.5 (20.1)
July	1993	All	NS	78.4 (4.3)
Sept.	1993	All	NS	84.4 (5.9)
July	1994	Flown	54.4 (11.1)	52.0 (6.4)
Sept.	1994	Flown	28.9 (14.7)	68.6 (6.3)
July	1994	Stored	6.7 (16.0)	24.9 (12.9)
Sept.	1994	Stored	35.3 (11.6)	63.6 (5.8)
Sept.	1994	Unmarked	53.9 (7.0)	69.7 (6.9)

NS, not sampled.

[a] Calculated according to the Abbott (1925) method.

[b] All, all treatments (flown, stored, and reared) were released on the same plants during 1993, so aphid consumption cannot be separated by treatment, and results from all treatments are combined.
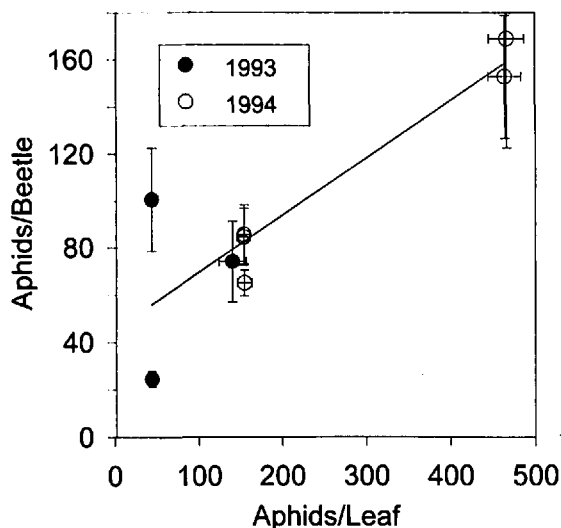
Fig. 7. Daily aphid consumption per adult convergent lady beetle (*AB*, aphids per beetle, mean ± SEM) versus initial density of melon aphids per leaf (*AL*, aphids per leaf, mean ± SEM) on potted chrysanthemums. The equation for the line is $AB = 42.7$ (SEM $= 12.3$) $+ 0.25$ (SEM $= 0.05$) AL ($r^2 = 0.82$; $F = 27.2$; df $= 1, 6$; $P = 0.002$).

in sorghum of nondiapausing, native *H. convergens* in comparison with dispersal of aggregation-collected beetles. Although preconditioning in our study slowed dispersal, treatments appear to have little practical benefit given that release of both treated and untreated beetles controlled aphids. *H. convergens* produces few or no eggs unless fed aphids, so rearing is expensive. Preconditioning in a flight tent requires watering beetles and recollecting them before release. Some beetles die during preconditioning, reducing the number available at the time of release. Because *H. convergens* is relatively inexpensive when purchased in bulk, ($\approx$\$40 buys 70,000–80,000 beetles), it is less expensive to release greater numbers of stored beetles, or to introduce them more often to compensate for their more rapid dispersal in comparison with preconditioning or rearing beetles.

Although Starks et al. (1975) found no differences in dispersal among treatments, native beetles provided better aphid control than aggregation-collected beetles. When Starks et al. (1975) released 2 beetles per plant in the greenhouse on caged sorghum infested with 100–400 greenbugs, *Schizaphis graminum* (Rondani), per plant, they observed $\approx$95 and 67% aphid reduction, respectively, 5 d after release of native and aggregation-collected beetles. These differences were apparently because beetles from aggregations often rested at the top of cages without feeding on aphids.

Hippodamia convergens in our study consumed $\approx$25–170 melon aphids per day, increasing consumption as aphid density increased (Fig. 7). This

density-dependent, functional response in predation by *H. convergens* has been demonstrated in a model by Gutierrez et al. (1981) and has been reported for other aphid-feeding lady beetles, including *Coccinella septempunctata* L. and *Harmonia axyridis* (Pallas) (Hukusima and Ohwaki 1972, Hodek 1973).

Hippodamia convergens consumed a mean of 91 (SEM $= 9.4$) aphids per day, which agrees with Hodek's (1973) conclusion that the daily feeding rate of adult aphidophagous Coccinellidae usually amounts to $\approx$100 aphids. Clausen (1916) reared *H. convergens* in the laboratory on hop aphids, *Phorodon humuli* (Schrank), which at maturity are about the same size (1–2 mm body length) as melon aphids (Palmer 1952). Clausen found that adult *H. convergens* over their life time consumed $\approx$66 (SEM $= 4.9$; range, 17–203) hop aphids each day. Clausen used nearly full-grown aphids, whereas ours were of varying age and included smaller aphids, which may account for the 1/3 lower number of aphids eaten in Clausen's (1916) study in comparison with our data. Hagen and Sluss (1966) studied *H. convergens* consumption of another small species, the spotted alfalfa aphid, *Therioaphis maculata* (Buckton). Preovipositional adult beetles consumed 112 (SEM $= 2.1$) spotted alfalfa aphids per day, and each beetle ate an average of 91 aphids per day over their lifetime.

Differences in aphid control or dispersal among treatments might be more dramatic with different prerelease treatment of beetles. Ignoffo et al. (1977) found that clipping the wings of *H. convergens* and other entomophages before release reduced dispersal and increased predation. Beetles in our study were active during their 7–10 d outdoors in a screen tent before release (the flown treatment); beetles moved with daily changes in shade and when disturbed during watering. However, beetles spent little time actually flying in the tent. The main difference between our treatments was that flown beetles were exposed to ambient light, wind, temperature, and humidity for 7–10 d before release in comparison with stored beetles, which were kept at 4–10°C and constant dark until the day of release.

With the exception of 1 lady beetle egg cluster in May 1993 (when reared beetles were released), no reproduction by *H. convergens* was observed. Given rapid dispersal and lack of reproduction, any control from a single release would likely be temporary. Releases are useful for inundative control but apparently are not effective for inoculative biological control.

Further research is needed to investigate the relationships among aphid density, beetle release rates and frequency, dispersal, and control. Our study plants harbored relatively high aphid densities (Figs. 5 and 6) and dispersal and control might differ at the lower aphid densities more characteristic of a commercial nursery. Hagen (1974) reports that the tendency of *H. convergens* to feed,

aggregate, and disperse varies with seasonal differences in physiological condition of the beetles. Host plant, aphid species, release environment, and environmental conditions also may affect aphid control from beetle release.

We are not aware of any studies indicating that convergent lady beetle releases are effective in controlling aphids on a large scale. Our preliminary research on landscape roses indicates that release of relatively large numbers of beetles or multiple releases may be needed to obtain control on larger plants. Little is known about overwintering *H. convergens,* and the potential ecological effects of large-scale harvesting of aggregating lady beetles have not been investigated. Even if releases of aggregation-collected convergent lady beetles could control aphids on a large scale, potential ecological or nontarget effects might make large-scale releases undesirable.

There are quarantine considerations regarding the shipment of field-collected insects. Aggregating beetles may harbor microorganisms and bulk collections may be contaminated with other invertebrates. The parasite *Dinocampus* (=*Perilitus*) *coccinellae* (Shrank) (Hymenoptera: Braconidae) emerged from a few of the commercial *H. convergens* we received. We did not dissect hosts to check parasitism and did not hold beetles and feed them aphids to induce *D. coccinellae* emergence, so we do not know the extent of their parasitization by *D. coccinellae,* which attacks >40 coccinellid species (Obrycki 1989). Ruzicka and Hagen (1985) found that ≥10% of the *H. convergens* collected from aggregations in California are parasitized by *D. coccinellae,* and parasitized beetles have less of a tendency to disperse in comparison with unparasitized *H. convergens.*

Augmentative release of commercially available convergent lady beetles can provide inundative control of relatively high aphid densities on small potted plants in a limited area. Convergent lady beetles are organically acceptable, readily available, hardy, easily handled, and store well. Pesticide exposure hazards and worker reentry restrictions after pesticide application may make lady beetle releases an attractive option for aphid control in nurseries and greenhouses. However, lady beetle releases must be integrated with other management practices, and pesticide applications for other pests may need to be modified for releases to be effective.

Acknowledgments

References Cited

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265–267.

Clausen, C. P. 1916. Life-history and feeding records of a series of California Coccinellidae. Univ. Calif. Pub. Entomol. 1(6): 251–299.

Cooke, W. C. 1963. Ecology of the pea aphid in the blue mountain area of eastern Oregon and Washington. U.S. Dep. Agric. Tech. Bull. 1287.

Davidson, W. M. 1919. The convergent ladybird beetle (*Hippodamia convergens* Guerin) and the barley-corn aphis (*Aphis maidis* Fitch). Mon. Bull. Calif. State Comm. Hortic. 8: 23–26.

1924. Observations and experiments on the dispersion of the convergent lady-beetle (*Hippodamia convergens* Guérin-Méneville) in California. Trans. Am. Entomol. Soc. 50: 163–175.

Davis, J. R., and R. L. Kirkland. 1982. Physiological and environmental factors related to the dispersal flight of the convergent lady beetle, *Hippodamia convergens* (Guérin-Méneville). J. Kans. Entomol. Soc. 55: 187–196.

Eddy, C. O. 1939. An attempt to colonize *Hippodamia convergens.* Proc. Int. Soc. Sugar Cane Technol. 6: 385–386 (abstracted in Rev. Appl. Entomol. 28: 245 [1940]).

Fenton, F. A., and R. G. Dahms. 1951. Attempts at controlling the greenbug by the importation and release of lady beetles in Oklahoma. Proc. Okla. Acad. Sci. 32: 49–51.

Flint, M. L., S. H. Dreistadt, J. Rentner, and M. P. Parrella. 1995. Lady beetle release controls aphids on potted plants. Calif. Agric. 49(2): 5–8.

Gutierrez, A. P., J. U. Baumgaertner, and K. S. Hagen. 1981. A conceptual model for growth, development, and reproduction in the ladybird beetle, *Hippodamia convergens* (Coleoptera: Coccinellidae). Can. Entomol. 113: 21–33.

Hagen, K. S. 1962. Biology and ecology of predaceous Coccinellidae. Annu. Rev. Entomol. 7: 289–326.

1974. The significance of predaceous Coccinellidae in biological and integrated control of insects. Entomophaga 7: 25–44.

1982. Notes on the convergent lady beetle. Univ. Calif. Div. Agric. Nat. Resour. Leafl. 2502.

Hagen, K. S., and R. R. Sluss. 1966. Quantity of aphids required for reproduction by *Hippodamia* spp. in the laboratory, pp. 47–59. *In* I. Hodek [ed.], Ecology of aphidophagous insects. Junk, The Hague.

Hatch, M. H., and C. Tanasse. 1948. The liberation of *Hippodamia convergens* in the Yakima Valley of Washington, 1943 to 1946. J. Econ. Entomol. 41: 993.

Hodek, I. 1973. Biology of Coccinellidae. Junk, The Hague.

Hukusima, S., and T. Ohwaki. 1972. Further notes on feeding biology of *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae). Res. Bull. Fac. Agric. Gifu Univ. 33: 75–82.

Ignoffo, C. M., C. Garcia, W. A. Dickerson, G. T. Schmidt, and K. D. Biever. 1977. Imprisonment of entomophages to increase effectiveness: evaluation of a concept. J. Econ. Entomol. 70: 292–294.

Moore, W. S., and C. S. Koehler. 1981. Aphids in the home garden and landscape. Univ. Calif. Div. Agric. Nat. Resour. Leafl. 21032.

Obrycki, J. J. 1989. Parasitization of native and exotic coccinellids by *Dinocampus coccinellae* (Schrank) (Hymenoptera: Braconidae). J. Kans. Entomol. Soc. 62: 211–218.

Packard, C. M., and R. E. Campbell. 1926. The pea aphid as an alfalfa pest in California. J. Econ. Entomol. 19: 752–761.

Palmer, M. A. 1952. Aphids of the Rocky Mountain region. Thomas Say Foundation 5. Entomological Society of America, Lanham, MD.

Rankin, M. A., and S. Rankin. 1980. Some factors affecting presumed migratory flight activity of the convergent lady beetle, *Hippodamia convergens*, (Coccinellidae: Coleoptera). Biol. Bull. 158: 356–369.

Raupp, M. J., M. R. Hardin, S. M. Braxton, and B. B. Bull. 1994. Augmentative releases for aphid control on landscape plants. J. Arboric. 20: 241–249.

Ruzicka, Z., and K. S. Hagen. 1985. Impact of parasitism on migratory flight performance in females of *Hippodamia convergens* (Coleoptera). Acta Entomol. Bohemoslov. 82: 401–406.

SAS Institute. 1988. SAS/STAT user's guide, release 6.03. SAS Institute, Cary, NC.

Starks, K. J., E. A. Wood, R. L. Burton, and H. W. Somsen. 1975. Behavior of convergent lady beetles in relation to greenbug control in sorghum. U.S. Dep. Agric. Agric. Res. Serv. S-53.

Vehrs, S.L.C., G. P. Walker, and M. P. Parrella. 1992. Comparison of population growth rate and within-plant distribution between *Aphis gossypii* and *Myzus persicae* (Homoptera: Aphididae) reared on potted chrysanthemums. J. Econ. Entomol. 85: 799–807.