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Evaluation of the Quality of Four Commercially Available Natural Enemies

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The post-shipment quality of four species of natural enemies, *Encarsia formosa* Gahan (Hymenoptera: Eulophidae), *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae), *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), and *Hippodamia convergens* Guérin (Coleoptera: Coccinellidae), was evaluated from shipments from 10 companies ordered over 2.5 years at three locations. Evaluations included the numbers received, emergence rates, sex ratio, survivorship, species identity, reproduction, and parasitism. In general, natural enemies arrived on time in protective shipping containers. There were considerable differences in the numbers received, depending on the company supplying the natural enemy and time of year. There were also differences among companies for survivorship and emergence rates of some natural enemies. Chrysopids other than *C. carnea* were shipped and cannibalism by larvae reduced the numbers received. Approximately 20% of coccinellids were found to be parasitized. Using average characteristics of *H. convergens* shipments, an estimated 75–508 reproductively active females would be received from an order of 1000 beetles. If confirmed by further study, information such as this could provide customers an "industry standard" for the expected number of natural enemies in a given reproductive or other physiological state. © 1998 Academic Press

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INTRODUCTION

In the United States, augmentative biological control is being practiced in an estimated 10% of greenhouses, 8% of nurseries, and 19% of cultivated fruit and nut acreage (Anon., 1995). In Europe, augmentative biological control is used on 40–60,000 ha of orchard, vineyard, and vegetable crops (Bigler 1991). The majority of natural enemy species used in augmentative programs is produced commercially. There are over 130 commercial suppliers of biological control agents in North America, selling some 100 species of arthropod natural enemies of insect pests in the United States (Hunter, 1994). Both the number of species sold and companies involved have increased significantly in the past 15 years (Cranshaw *et al.*, 1996).

The number and timing of releases of natural enemies depend upon a number of factors, including the effectiveness of the natural enemies in reducing pest population growth, the economics of crop production, and abiotic conditions (Debach and Rosen, 1991). Releases made with poor quality natural enemies or made with fewer natural enemies than needed can lead to control failures and contribute to the unpredictability of augmentative biological control (Hoy *et al.*, 1991). Because of potential growth of augmentative biological control programs (Parella *et al.*, 1992), the increased number of firms selling natural enemies (Cranshaw *et al.*, 1996), and recent regulatory concerns (Anon., 1995), a number of issues relating to the "quality" of commercially available natural enemies have been raised (Hoy *et al.*, 1991; van Lenteren, 1991; Van Driesche and Bellows, 1996).

Bigler (1991) identified three components of quality control in insect mass production. "Production control" involves monitoring the overall procedures of the rearing process, such as equipment maintenance and environmental conditions. "Process control" involves monitoring the quality of the unfinished product, such as egg hatch, larval and pupal weight, and percentage pupation. "Product control" involves monitoring the quality

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of the final product, such as quantity, sex ratio, size, fecundity, and other biological and behavioral characteristics. Although several papers have been written on the methods used to assess quality of commercially produced natural enemies by producers (see papers in Bigler, 1991; King and Leppla, 1984) there have been very few studies assessing the quality of natural enemies as received by customers (e.g., Losey and Calvin, 1995; Hoddle and Van Driesche, 1996).

Product control is of the utmost importance to users of natural enemies. Natural enemies of inferior quality may not control the target pest and economic damage to the crop may result. Such failures may cause users to become disenchanted with augmentative biological control and to communicate this dissatisfaction to other potential users.

We present results from an assessment of selected aspects of the quality of four species of commercially available natural enemies, two parasitoids and two predators. The four species were chosen because they are available from a number of companies (Hunter, 1994) and have been widely suggested for use in augmentative biological control (Van Driesche and Bellows, 1996; Anon., 1996). *Encarsia formosa* Gahan (Hymenoptera: Eulophidae) is used for control of greenhouse whitefly, *Trialeuroides vaporariorum* (Westwood), primarily in greenhouses. *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae), an egg parasitoid, is used for control of eggs of several lepidopteran pests in vegetable crops. *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) and *Hippodamia convergens* Guérin (Coleoptera: Coccinellidae) are sold for control of aphids and other pests in crops and home gardens. The objective of our study was to assess the post-shipment quality of these commercially available natural enemies.

MATERIALS AND METHODS

Natural enemies were ordered from 10 companies located in six U.S. States. The number of natural enemies ordered was the advertised minimum number for each species and company. For *C. carnea*, 1000, 4000, or 5000 eggs were ordered. For *H. convergens,* 1500, 2250 (1/4 pt.), 4500, 16250, or 18000 adults were ordered. For *E. formosa,* 500 or 1000 were ordered. For *T. pretiosum*, 40,000, 50,000, 100,000, or 250,000 were ordered. Parasitoids were supplied as pupae within parasitized hosts; *T. vaporariorum* were hosts for *E. formosa,* and *Sitotroga cerealella* (Olivier) eggs were hosts for *T. pretiosum*.

Each natural enemy was ordered from four companies (identified by number), five times at each of three locations/time periods (e.g., 20 orders per natural enemy were placed from each location). Orders were placed at "Purdue" (Tippecanoe Co., IN) from November to December, 1991, "Iowa State" (Story Co., IA) from January to May, 1993, and "Wisconsin" (Dane Co., WI) from May to October, 1994. Natural enemies were ordered by paid cooperators who lived within 15 km of each location (e.g., Purdue, Iowa State, Wisconsin). Cooperators were told not to disclose that they were ordering natural enemies for evaluation. Natural enemies were delivered to their home, postal box, or place of business.

Each order was requested to be shipped using 2-day guaranteed delivery. Upon delivery, cooperators contacted their respective institution for transport to the institution for subsequent evaluation. Orders were picked up within 24 h of delivery; most on the same day as the delivery to cooperators. Cooperators were instructed to follow package instructions on storing shipments (e.g., "store in a cool/dry place") and not to open the package containing the order. At each institution, the condition of the shipping container was evaluated and the requested vs arrival date noted. Packages were then opened inside sleeve cages and the evaluation begun. Voucher specimens were kept from each company. Adult specimens of natural enemies were sent to appropriate taxonomic experts for identification. Laboratory conditions where evaluations were made at each location were ca. 50–70% RH, 22–26°C, and 16:8 L:D photoperiod.

The number of natural enemies received was estimated by taking five samples per shipment (see sampling methods, below). To determine if a sample size of $N = 5$ provided acceptable levels of variation, the standard error/mean (SEM/$\overline{X}$) ratio of the number of natural enemy per sample processed at Purdue was computed and compared to a target SEM/$\overline{X}$ of 0.10–0.25. (A SEM/$\overline{X}$ of 0.25 allows a doubling or halving of the population being sampled to be detected. See Southwood, 1978.)

For all natural enemies, an observed:expected (O:E) ratio was computed from the estimated number of natural enemies received (O) versus the number of natural enemies ordered (E). Two-way ANOVA (company and location) was used to analyze the O:E ratios for each natural enemy. At Iowa State, additional measurements of survivorship (with and without supplemental nutrition), sex ratio (proportion female), and reproduction of all natural enemies and the rate of parasitism of *H. convergens* were made. One-way ANOVA was used to analyze company differences in natural enemy survivorship, reproduction, sex ratio, and rates of parasitism of *H. convergens*. Survivorship of natural enemies with and without supplemental nutrition was tested using paired *t* tests. Statistical tests were done using STATSWORK statistical software (STATSWORK, 1985). Sex ratios and all percentage estimates were arcsin transformed before analysis. For all estimates, only those companies from which a minimum of three shipments had been properly received and processed were analyzed. All statistical tests were conducted at the $\alpha = 0.05$ level of significance.

Encarsia formosa. *Encarsia formosa* were shipped as pupae inside hosts glued to cardboard cards. The estimated number of parasitized hosts in a shipment was calculated as the average number of parasitized hosts per card times the number of cards shipped. The estimated number parasitized pupae per card was calculated from counts of parasitized pupae on five randomly selected cards per shipment. Pupae on cards were counted under 15× magnification.

At Iowa State, emergence of *E. formosa* was estimated by counting the number of parasitoids that emerged in 10–14 days for 1–2 randomly selected cards in 1–4 shipments/company. (In one order, parasitoids had begun emerging during shipment. In this instance, all cards were held for parasitoid emergence.) To estimate survivorship, cohorts of adults emerging during a 24-h period were held in 20 mm × 150 mm glass vials plugged with cotton. Survivorship was estimated for adults provided with and without honey. Honey was either supplied as a 1:1 honey:water solution applied to vial's cotton plug or streaked inside the vial. Adults were held for 48 h at which time the number alive or dead was recorded. Sex ratios were not estimated for *E. formosa*, as visual inspection revealed that all adults had light-colored abdomens, and thus were, as expected, females.

Trichogramma pretiosum. *Sitotroga cerealella* eggs containing *T. pretiosum* pupae were shipped on perforated cardboard cards. The estimated number of *T. pretiosum* per shipment was calculated as the number of cards shipped multiplied by the estimated number of parasitized eggs per card. The number of eggs per card was estimated as the average number of parasitized eggs per square centimeter multiplied by the area (cm^2) per card. The number of parasitized eggs per square centimeter was calculated from five 0.5-cm-diameter (0.196 cm^2) samples randomly taken from one randomly selected card. The number of parasitized eggs per sample was counted under 15× magnification.

At Iowa State, 48-h survival of emerged parasitoids was determined for adults held with and without honey. To estimate survivorship, cohorts of adults that had emerged during a 24-h period were held in 20 mm × 150 mm glass vials plugged with cotton. Honey was either supplied as a 1:1 honey:water solution applied to the cotton plug or streaked inside the vial; the other vial did not contain honey.

Sex ratios were estimated at both Purdue and Iowa State using antennal characteristics, for ca. 5–20 adults per shipment. Data from both sites were combined for analysis, giving between 29–125 individuals sexed per company. Differences among companies were tested using one-way ANOVA.

Hippodamia convergens. Beetles were shipped as adults within cylindrical cardboard cartons or cloth bags containing straw-like packing material. Upon opening the carton, the contents were emptied into a clear plastic bag and the shipping material removed. The plastic bag was then gently shaken to mix the beetles and then placed in a refrigerator for 10–20 min. Upon removal from refrigeration, the shipment was weighed and five samples were taken using a ca. 30-ml plastic cup. The weight (g) and number of beetles per sample were recorded. The total number of beetles per shipment was estimated as the number of beetles per sample multiplied by the total weight/sample weight relationship.

At Iowa State, the percentage of beetles that were alive upon arrival, their 48-h survivorship (with and without water), the incidence of parasitism by *Dinocampus coccinellae* Schrank (Hymenoptera: Braconidae), beetle sex ratio, and reproduction were determined for each shipment. The percentage alive upon arrival was calculated from the number of live and dead beetles in the five samples used to estimate total number (above). The 48-h survivorship was estimated for two randomly selected samples by placing live beetles in mesh-covered cardboard cartons. One sample was provided water in cotton-stopped glass vials. Sex ratio and parasitism were estimated by dissection of 20 adults for each shipment. The number of eggs laid was estimated for 20 pairs per shipment held in cardboard cartons 14 days and provided *ad libitum* pea aphids, *Acrythosiphon pisum* Harris, Wheast, and water.

Chrysoperla carnea. Lacewings were shipped inside several types of small vials or cups, usually containing rice hulls. Although lacewings were ordered as eggs, a substantial number of shipments arrived with both eggs and larvae that had eclosed during shipment. The number of eggs and larvae per shipment was estimated from the total weight/sample weight relationship of each shipment. The total weight (g) of eggs and larvae and packing material in each shipment was recorded. Five samples of a known weight were taken from each shipment. The number of eggs and larvae, both dead and alive, in each sample was then counted. The total number of eggs and larvae per shipment was estimated as the number of eggs and larvae per sample multiplied by the total weight/sample weight relationship.

At Iowa State the impact of cannibalism, 48-h survivorship of larvae, specific identification, and sex ratio of adults were estimated. The impact of cannibalism was estimated by regressing the percentage of eggs and larvae alive against the percentage larvae in shipments. The 48-h survivorship was estimated for 20 newly eclosed *C. carnea* larvae from two of five randomly selected samples per shipment held individually with and without *S. cerealella* eggs. Specific identification and sex ratio was obtained for adults reared from 10 larvae, provided *ad lib. S. cerealella* eggs.

RESULTS

In most shipments, the natural enemies were appropriately packed for shipment, including foam insulation and/or blue ice packets. In general, natural enemies were received in good condition and within the time frame indicated by the company. There was one example in which the contents were apparently destroyed in shipment; the supplier re-shipped after being contacted about the problem. In one instance, a company would not provide *H. convergens* for two consecutive orders at Wisconsin, claiming that they no longer had the product. Coincidentally, the percentage adults alive had declined in previous orders from this company. There were several times in which other lacewing species were sent to cooperators although they specifically asked for *C. carnea*. Also, there were several orders in which lacewing larvae were substituted for eggs.

Sampling precision. Examination of SEM/$\overline{X}$ ratios for the estimated number of natural enemies for 60 Purdue shipments indicated that five samples per shipment were adequate for study. Of the 60 estimates, 59 were below 0.25 and 48 were below 0.10. Only *C. carnea* had a single SEM/$\overline{X}$ ratio >0.25. Relative frequencies of SEM/$\overline{X}$ ratios <0.10 were 14/15, 14/16, 15/17, and 5/12 for *E. formosa*, *T. pretiosum*, *H. convergens*, and *C. carnea*, shipments, respectively.

Encarsia formosa. Thirty-eight shipments were included in the analysis, 12–14 shipments from each of three companies (3, 6, 12). Most often, few adults were noted in shipments upon arrival. Mean O/E ratios for the three sites ranged from 0.8 to 2.8 (Table 1). Two-way ANOVA indicated significant location (F = 4.842, $df = 2, 29$; $P = 0.0153$) and company (F = 7.883, $df = 2, 29$; $P = 0.0018$) differences in O/E ratios. There was a significant interaction between locations and companies (F = 14.135, $df = 4, 29$; $P = 0.0001$). An average of 41.3% (SEM = 10.1) of the *E. formosa* emerged (Table 2). There was a significant difference in percentage emergence among companies (F = 17.278, $df = 2, 4$,

TABLE 1

Observed:Expected (O:E) Ratios of Orders of Four Natural Enemies Shipped by Various Companies to Three Locations

Species	Location	O:E ratios (SE, *N*)			
		Company Number			
		3	6	12	
Encarasia formosa	Purdue	2.77 (0.34, 4)	0.84 (0.17, 4)	2.56 (0.20, 3)	
	Iowa State	1.60 (0.24, 3)	1.82 (0.09, 5)	1.54 (0.13, 4)	
	Wisconsin	1.51 (0.23, 5)	1.71 (0.07, 5)	1.72 (0.07, 5)	
		Company Number			
		4	7	11	
Trichogramma pretiosum	Purdue	0.88 (0.04, 5)	1.24 (0.28, 6)	2.44 (0.34, 5)	
	Iowa State	0.63 (0.07, 4)	0.94 (0.10, 5)	0.91 (0.16, 3)	
	Wisconsin	0.96 (0.09, 5)	1.19 (0.10, 5)	0.92 (0.14, 5)	
		Company Number			
		2	5	8	9
Hippodamia convergens	Purdue	0.88 (0.05, 3)	1.32 (0.48, 4)	0.89 (0.04, 4)	1.11 (0.20, 5)
	Iowa State	1.12 (0.06, 4)	1.09 (0.11, 5)	1.13 (0.04, 5)	1.27 (0.07, 4)
	Wisconsin	0.76 (0.02, 5)	0.62 (0.12, 5)	0.88 (0.03, 5)	0.89 (0.05, 5)
		Company Number			
		4	7	8	
Chrysoperla carnea	Purdue	2.20 (0.89, 4)	0.65 (0.50, 3)	0.53 (0.23, 4)	
	Iowa State	1.21 (0.10, 5)	0.85 (0.12, 5)	0.72 (0.14, 5)	
	Wisconsin	1.03 (0.22, 5)	0.42 (0.08, 5)	0.53 (0.23, 3)	

Note. N, the number of shipments evaluated. An O:E ratio >1.0 means that more natural enemies were received ("Observed") than were ordered ("Expected"). See text for details.

TABLE 2

Life History Characteristics (SE, *N*) Used to Assess Post-shipment Quality of Four Commercially Available Natural Enemies, Evaluated at the Iowa State Location

Species	Company no.	Percentage alive[a]	Life history characteristic: 48 h survival, w/ nutrient	48 h survival, w/o nutrient	Sex ratio[b]	Percentage ovipositing[c]
Encarsia formosa	3	51.2 (—, 1)[d]	93.7 (3.2, 5)[e]	98.7 (1.3, 5)		
	6	75.3 (10.4, 2)	89.7 (2.7, 3)	83.4 (6.9, 3)		
	12	21.9 (9.5, 4)	95.0 (5.0, 4)	84.6 (8.6, 4)		
Trichogramma pretiosum	4		54.3 (17.6, 4)[e]	21.3 (8.8, 4)	48.3 (12.0, 3)	
	7		71.3 (5.2, 5)	68.4 (2.7, 5)	46.4 (3.6, 10)	
	11		86.2 (11.0, 3)	36.0 (6.7, 3)	56.6 (13.1, 6)	
Hippodamia convergens	2	79.1 (14.2, 3)	81.8 (16.0, 3)[f]	74.9 (22.8, 3)	58.3 (1.7, 3)	80.0 (5.0, 3)
	5	81.1 (5.9, 5)	91.4 (5.9, 5)	90.6 (7.1, 5)	63.0 (4.1, 5)	79.0 (5.1, 5)
	8	80.1 (6.8, 5)	96.0 (2.7, 5)	93.6 (2.2, 5)	68.0 (7.5, 5)	67.0 (4.4, 5)
	9	50.5 (8.8, 4)	93.4 (1.6, 4)	85.0 (1.2, 4)	65.0 (2.0, 4)	72.5 (3.2, 4)
Chrysoperla carnea	4	78.8 (8.4, 5)	35.0 (11.7, 5)[g]	0.7 (0.7, 5)	55.0 (—, 20)	
	7	80.1 (1.9, 5)	83.0 (2.0, 5)	21.3 (9.6, 5)	37.5 (—, 40)	
	8	61.3 (11.7, 5)	35.0 (16.1, 5)	0.0 (0.0, 5)	61.5 (—, 13)	

Note. Columns left blank indicate that life history characteristic was not evaluated for the particular species. See text for details.

[a] Percentage emergence for *E. formosa*.

[b] Percentage female. For *H. convergens*, *N* represents the number of shipments evaluated per company. Twenty adults were examined per shipment. For *C. carnea*, *N* is the combined number of adults reared from 10 larvae from all shipments. No SE could be calculated from these data. For *T. pretiosum*, *N* represents the number of shipments examined per company. Data combined for Purdue and Iowa State locations. Approximately 6–20 adults were examined per shipment. All *E. formosa* adults examined were female. See text for details.

[c] Percentage females ovipositing over 14-day period.

[d] All cards used to estimate percentage alive for the one shipment evaluated for company 3. No SE could be calculated from these data.

[e] Nutrient = 50% honey-water solution.

[f] Nutrient = water.

[g] Nutrient = *S. cerealella* eggs.

$P = 0.011$; Table 2), but no differences in the percentage alive after 48 h were detected (F = 1.654, $df = 2, 9$, $P = 0.245$; Table 2). Providing honey to the parasitoids did not significantly affect their 48-h survivorship ($t = 0.862$, $df = 11$, $P = 0.407$; Table 2).

Trichogramma pretiosum. Forty-three shipments were included in the analysis, 13–16 shipments from each of three companies (4, 7, 11). Few adult *T. pretiosum* were noted in shipments upon arrival. Mean O/E ratios for the three sites ranged from 0.63 (Iowa State) to 2.44 for Purdue (Table 1). Two-way ANOVA indicated significant location (F = 11.367, $df = 2, 35$, $P = 0.0002$) and company (F = 6.995, $df = 2, 35$, $P = 0.0028$) differences in O/E ratios. There was a significant interaction between locations and companies (F = 6.651, $df = 4, 35$; $P = 0.0004$). There was a significant difference among companies in the percentage alive after 48 h (F = 6.873, $df = 3$, $P = 0.006$). Adults provided honey-water showed higher survivorship than adults without honey-water ($t = 4.228$, $df = 14$, $P = 0.001$; Table 2). Sex ratios were near 50% females, and no significant difference in sex ratios was found among companies (F = 0.68, $df = 2, 16$, $P = 0.521$; Table 2).

Hippodamia convergens. Fifty-four shipments were included in the analysis, 12–14 shipments from each of four companies (2, 5, 8, 9). Mean O/E ratios ranged from 0.62 in Wisconsin to 1.32 at Purdue (Table 1). Two-way ANOVA indicated significant location (F = 6.338, $df = 2, 41$, $P = 0.004$), but no company (F = 0.651, $df = 3, 41$, $P = 0.587$) effects on O:E ratios. There was no significant interaction between locations and companies (F = 1.07, $df = 6, 41$; $P = 0.398$). The average percentage live *H. convergens* in shipments ranged from 50.5 (SEM = 8.8) to 81.1% (SEM = 5.9; Table 2). There was no significant company difference in the percentage alive in shipments (F = 2.670, $df = 3, 13$, $P = 0.091$) or in the 48-h survivorship of *H. convergens* without water (F = 0.573, $df = 3, 13$, $P = 0.643$; Table 2). There were significant differences in the 48-h survivorship of *H. convergens* with and without water ($t = 3.163$, $df = 16$, $P = 0.006$).

The percentage of unparasitized adults varied from 78 (SEM = 2.0, Company 5) to 91.3% (SEM = 5.5, Company 9). Eighty percent of females from Company 2 (SEM = 7.6) and Company 8 (SEM = 4.5) were free of parasitoids. There was no significant difference in the percentage *H. convergens* free of parasitoids (F = 2.286, $df = 3, 13$, $P = 0.127$). The percentage females varied from 58.3 (SEM = 1.7, Company 2) to 68% (SEM = 7.5, Company 8). The percentage females ovipositing varied from 67.0 (SEM = 4.4, Company 8) to 80.0% (SEM = 5.0, Company 8). Neither the percentage females (F = 0.579, *df* = 3, 13, *P* = 0.639; Table 2) nor the percentage females ovipositing (F = 1.906, *df* = 3, 13, *P* = 0.179; Table 2) showed significant differences among companies.

Chrysoperla carnea. Thirty-nine shipments were included in the analysis, 12–14 shipments from each of three companies (4, 7, 8). Two lacewings were reared to adulthood from Company 8, whereas five lacewings were reared each from Companies 4 and 7, respectively. All lacewings reared to adulthood and identified were *C. rufilabris* (Burmeister) not *C. carnea.* Mean O/E ratios for lacewings ranged from a low of 0.42 in Wisconsin to a high of 2.2 at Purdue (Table 1). Two-way ANOVA indicated significant company (F = 6.935, *df* = 2, 30, *P* = 0.0033), but not location (F = 1.343, *df* = 2, 30, *P* = 0.276), differences in O/E ratios. There were no significant interactions between locations and companies (F = 1.261, *df* = 4, 30, *P* = 0.307). The average percentage larvae in shipments ranged from 0.1 (SEM = 0.1, Company 7) to 52.6% (SEM = 16.7, Company 8). Company 4 had an average of 16.7% larvae in shipments (SEM = 11.4). As the percentage of larvae in the shipments increased, the percentage eggs and larvae alive decreased (F = 31.382, *df* = 1, 9, *P* = 0.001, $r^2 = 0.78$; Fig. 1). There were significant differences among companies in the 48-h survivorship of lacewings without *S. cerealella* eggs (F = 5.934, *df* = 2, 10, *P* = 0.020; Table 2). Larvae provided *Sitotroga* eggs lived longer than those without eggs ($t = 7.542$, *df* = 12, *P* = 0.001 Table 2). Sex ratios varied between 37.5 and 61.5% females (Table 2).

DISCUSSION

The timeliness of orders and the good condition in which they were received suggested that *where* the orders were placed from did not affect the subsequent condition of the natural enemies. Thus, "location effects" on natural enemy quality reflect *when* in the calendar year the order was placed, and not the locale to which it was shipped. However, examining orders simultaneously placed from locations further distant from each other (than the present three locations) may indicate otherwise, and should be included in future research efforts.

The five samples taken per shipment were adequate to give a SEM within 0.10–0.25 of the mean for almost all shipments. Because the desired level of precision will depend on the objectives of a sampling program (Southwood, 1978), we cannot conclude that as a general finding, five samples would be sufficient for all evaluations of natural enemy post-shipment quality. A higher level of precision (e.g., $SEM/\overline{X}<0.10$) would require more samples. Estimating the necessary number of samples can be done using a variety of formulae (see Southwood, 1978; Elliott, 1979; O'Neil *et al.*, 1989), and this should be examined in future studies. It is less clear how many orders or companies should be evaluated in future quality control studies. Five orders per company for the four companies evaluated per species was logistically difficult for 1–2 full-time workers to process. As a result of these difficulties, data from several companies were dropped from analyses. While the remaining data did allow for statistical analysis, we caution future workers to carefully consider the logistics of ordering and processing large numbers of shipments.

We feel it is critical that evaluation of the quality of commercially available natural enemies be done periodically and that comparisons be made over time. For example, our findings of significant location effects, for all species but *C. carnea,* may reflect changes in production procedures, or in the intrinsic properties of the natural enemies over time, that influence the numbers received by the consumer. Significant company effects for all species but *H. convergens* suggest that customers will receive different numbers of natural enemies (for the same-sized order), depending on the company from which they order. Because we detected significant interactions between companies and locations for *E. formosa* and *T. pretiosum,* further research may be needed to delineate the relative importance of when and from whom an order is placed. Regardless, our data suggest that from whom and when an order is placed affects the numbers of natural enemies received, and further research should be done to help define these differences for the consumer.

We suggest that future assessments continue to use the "blind ordering" system of the current study. While blind ordering does complicate logistics, it helps preserve the independence of the evaluation. We should note that several cooperators told us that they were asked by company representatives if they were participating in "some sort of study." Although we cannot exclude the possibility that our orders were given "special treatment" by companies, a blind ordering system would seem to lessen this possibility. Finally, we suggest that future published results name the companies involved to allow comparisons among companies and evaluation of company performance over time.

The O/E values for *C. carnea* shipments were highly variable (Table 1). Evaluating the numbers of lacewings was confounded by the packing media in which they are shipped, the presence of newly hatched larvae, and associated cannibalism (Fig. 1). The relatively high $SEM/\overline{X}$ ratios for the five samples per shipment reflect these sampling difficulties and suggest that more samples should be taken in future evaluations. For the customer, the cannibalistic nature of the lacewing larvae suggests that if lacewing eggs are ordered, they

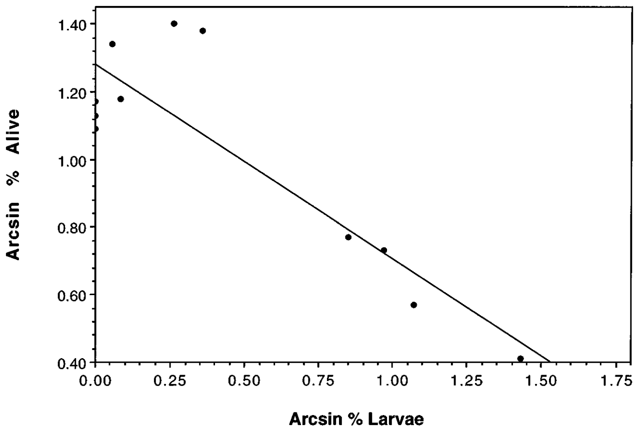

FIG. 1. Average percentage lacewing eggs and larvae alive as a function of the average percentage larvae in shipments. Line represents the regression equation: $Y = -0.58 + 1.28X$ (see text). Data presented have been arcsin transformed.

should be either released into the environment immediately or cooled to prevent eclosion. Also, because the 48-h survival of lacewing larvae without prey was low (Table 2), rapid release would seem necessary to provide larvae an opportunity to feed. Alternatively, to reduce cannibalism of chrysopids and increase their survivorship, it may be necessary to include supplementary "food" in orders.

Finally, although we have a small sample size ($n = 12$ from three companies), every lacewing reared to adulthood was *C. rufilabris* instead of *C. carnea*. It is doubtful that a customer would either take the time to rear lacewings or have the taxonomic expertise to distinguish species. Because different lacewing species preferentially attack different prey (Tauber and Tauber, 1975; Agnew *et al.*, 1991), it is critical that the customer receive the proper species. Further investigation on the prevalence of the correct species being shipped would seem warranted.

The O:E ratios for *E. formosa* were mostly >1.0 (Table 1), and thus consumers would, in general, receive more *E. formosa* than they ordered. However, their emergence rates varied between 0.21–0.75, and as a result the numbers of *E. formosa* adults available to control pests would, in general, be below the numbers the customer ordered (and presumably needed). Therefore, when ordering *E. formosa*, customers should adjust their orders to accommodate the decline in the number of parasitoids due to relatively low emergence rates. Also, while no data were taken on *T. pretiosum* emergence, their O:E ratios were usually below 1.0 with 48-h survivorship ranging from a low of 21.3% without supplemental nutrition to a high of 86.2% with supplemental nutrition (Table 2). Customers should take these findings into consideration when ordering *T. pretiosum* (see also Losey and Calvin, 1995).

Our study was not an attempt to define the effectiveness of commercially available natural enemies. Such studies require evaluation of the impact on pest populations and the economics of control (e.g., see Hoddle and Van Driesche, 1996). In addition, how the natural enemies are to be used will also determine the elements of evaluation. While we did not directly evaluate the natural enemies from these perspectives, the data do provide some insight, as we can use the values of estimated characteristics (O/E ratio, percentage alive, etc.) to estimate a range in expected numbers for a particular natural enemy. For example, using the ranges of data for *H. convergens* in Tables 1 and 2, a hypothetical shipment of 1000 *H. convergens* ordered would give the customer between 75–508 reproductively active, non-parasitized females after 48 h. As other studies add to our results, estimates of product quality that include O:E ratios, emergence, survival, etc., can help define an "industry standard" for the expected number of natural enemies in a particular state (e.g., reproductively active females). Such standards would do much to improve the information available to customers and give them an objective basis to judge the quality of specific shipments of natural enemies or the performance of companies selling natural enemies.

Ultimately the responsibility for the quality control of commercially available natural enemies depends on the producers and distributors of these products. The role of regulatory agencies or extension services should be one of periodic evaluation with the goal to improve and maintain the quality of commercially available natural enemies. These evaluations should be periodic, blind to the companies involved, and be regularly published in scientific and trade journals. Working relations between producers, evaluators, and customers would benefit all. Defining realistic expectations for the quality of commercially available natural enemies will serve to expand their use in augmentative biological control and IPM programs.

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