Sampling Plan for *Dicyphus hesperus* (Heteroptera: Miridae) on Greenhouse Tomatoes

JUAN ANTONIO SANCHEZ SANCHEZ, ROBERT R. MCGREGOR,[1] AND DAVID R. GILLESPIE[2]

Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, P.O. Box 1000, Agassiz, BC, Canada V0M 1A0

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ABSTRACT *Dicyphus hesperus* Knight has good potential as a biological control agent for greenhouse pests in greenhouse tomato crops. The spatial distribution of *D. hesperus* was studied and a sampling plan was developed to monitor this species in greenhouse-grown tomatoes. Adults and nymphs are distributed in a more aggregated pattern among plants than within plants. The strong, significant relationship between the mean population density and the proportion of occupied sample units (leaves or plants) makes it possible to use a binomial or presence-absence sampling approach. Presence-absence sampling is an efficient method for crop management purposes because less time is needed to process the samples compared with a method where all insects are counted. At high densities, considering a sample unit to be occupied only when there are more than a determined number of individuals reduces considerably the optimum sample size required.

KEY WORDS *Dicyphus hesperus*, spatial distribution, binomial sampling

Dicyphus hesperus KNIGHT is an omnivorous predator that is under development as a biological control agent for arthropod pests of greenhouse-grown tomatoes in British Columbia, Canada (McGregor et al. 1999, 2000; Gillespie and McGregor 2000). Adults and nymphs may also feed on and cause damage to tomato fruits under certain conditions (McGregor et al. 2000). Consequently, populations of *D. hesperus* on the crop need to be monitored more closely than other biological control agents, and a simple and accurate approach to sampling is required.

Nymphs of *D. hesperus* readily complete their growth and development on either the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae), or twospotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae) (McGregor et al. 1999), two of the primary pests of greenhouse tomatoes in British Columbia. In addition to feeding on these prey species, *D. hesperus* nymphs and adults also feed on plant material (Gillespie and McGregor 2000, McGregor et al. 2000). Plant feeding in *D. hesperus* apparently functions to acquire the water necessary for extra-oral digestion of prey (Gillespie and McGregor 2000). In the absence of tomato leaves or other sources of water, *D. hesperus* cannot feed on prey or complete nymphal development (Gillespie and McGregor 2000).

Damage to tomato fruits has been reported for a number of other omnivorous mirid species like *Macrolophus caliginosus* Wagner, *Dicyphus tamaninii* Wagner, and *Cyrtopeltis (Engytatus) modestus* (Distant) (Tanada and Holdaway 1954, Alomar and Albajes 1996, Malausa and Trottin-Caudal 1996, Sampson and Jacobson 1999). Because of its role in pest management and its potential to damage tomato fruits, it is particularly important that an adequate sampling method be available for *D. hesperus* to monitor populations after releases. For example, *D. tamaninii* typically damages tomato fruits when predator populations are high and whitefly populations are low (Alomar and Albajes 1996). Chemical controls may be applied against this predator when these conditions exist and the probability of damage to the crop is high (Alomar and Albajes 1996).

The choice of an appropriate sample unit is one of the first problems in designing a sampling plan. The selection of the sample unit will affect estimates of the population size. Broadbent (1948 in Southwood 1978) observed that the choice of the plant or the leaf as the sample unit for determining the population density affected estimates of the population levels of *Myzus persicae* (Sulzer) in potato crops. Shipp et al. (1992) compared the absolute population size of *Orius* spp., obtained by counting all individuals on whole pepper plants, with results from both leaf and flower samples and concluded that the flower samples were better related with the absolute counts.

Once the sample unit has been established, several sampling methods can be adopted. Counting the total number of individuals present in a sample unit is a commonly used technique in research, although this may be expensive and impractical for pest manage-

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[1] Department of Biology, Douglas College, P.O. Box 2503, New Westminster, BC, Canada V3L 5B2.

[2] E-mail: Gillespied@em.agr.ca.

ment monitoring. Binomial, or presence-absence sampling techniques, that are based on the relationship between population density and spatial distribution represent a good alternative. Sampling methods have been developed for a number of pests and predatory arthropods based on presence-absence schemes (Nachman 1984, Raworth 1986, Raworth and Merkens 1987, Nyrop et al. 1989, Binns and Bostanian 1990, Frazer and McGregor 1990, Sanchez et al. 1997).

The knowledge of the spatial distribution provides information about the biology of the organisms and can be used to develop binomial or presence-absence sampling methods. A negative binomial relationship is a theoretical function that is commonly used to describe aggregated distributions in insect populations (Bliss and Fisher 1953). The Poisson distribution is more appropriately used to describe populations that are randomly distributed (Southwood 1978, Garcia-Mari et al. 1994, Sanchez et al. 1997). Presence-absence sampling methods are highly practical for pest management purposes because of the substantial reduction in the time required to process samples compared with complete count samplings. Besides the theoretical distribution functions, an empirical model based on experimental data can also be used to describe the relationship between the density and the proportion of occupied sample units (Kono and Sugino 1958, Gerrard and Chiang 1970, Nachman 1984). At high densities the binomial method does not accurately estimate population size. When this occurs, the binomial method can be modified by increasing the threshold at which the sample unit is considered to be occupied (e.g., tally threshold, $T > 2$). This alternative makes binomial sampling practical at higher densities and may also improve the accuracy of the method (Gerrard and Chiang 1970, Binns and Bostanian 1990).

In this study we analyzed 2 yr of data from *D. hesperus* releases in tomato greenhouses. Our objective was to study its spatial distribution and to develop a sampling method that could be used by researchers, pest managers, and greenhouse growers to determine the population density of *D. hesperus* in greenhouse tomato crops.

Materials and Methods

Crop History. Samples were taken during the 1999 and 2000 growing seasons from tomatoes (*Lycopersicon esculentum* Mill.) grown in greenhouses at the Pacific Agriculture and Agri-Food Research Center in Agassiz (British Columbia). In the first year the greenhouse compartment was 12 by 6.4 m, with a trellis wire height of 2.9 m. In the second year, four compartments were used, each 12 by 3.2 m, with a trellis wire height of 2.9 m. No supplemental lighting was used, and the temperature was maintained at 22°C day and 18°C night, with a relative humidity setpoint of 70%. In the first growing season, ≈6-wk-old tomato seedlings ('Trust') were placed on rockwool slabs in the greenhouse on 17 January 1999. The seedlings were arranged in three double rows of 40 plants each, and two peripheral single, guard rows of 20 plants each. The rows were parallel to the long axis of the greenhouse. Whiteflies were introduced in two batches of 500 adults each, once on 19 February 1999 and again on 25 February 1999. They were dispersed evenly through the crop. *Dicyphus hesperus* adults were introduced on 15 March 1999 (400), 19 April (400), 26 April (400), and 3 May (1000) and were also dispersed evenly. Sulfur dust was applied to the floor to control powdery mildew, and Safer's insecticide soap (Safer's Ltd., Scarborough, Ont.) was applied at label rates to the top 10 leaves on 17 May to control excessive numbers of whitefly adults. In the second growing season seedlings ('Rhapsody') were transplanted on 18 January, arranged in one central double row of 40 plants and two peripheral single guard rows of 20 plant in each compartment. Whiteflies were introduced at 100 adults/compartment on 3 February 2000 and *D. hesperus* at 100 adults/compartment 20 d later. Both whitefly and *D. hesperus* were introduced evenly through the crop.

Sampling and Data Collection. In 1999, 18 plants per week were sampled by selecting six plants randomly from each double row each week. Plants were not sampled again until all plants had been sampled. After all plants had been sampled, we rerandomized the plant numbers and continued selecting samples as above. In 2000, 21 plants were sampled from each of the four compartments using the same routine previously described. Plant and leaf samples were collected in each of 27 wk during the 1999 growing season and in each of 20 wk during the 2000 growing season.

Two types of samples were taken from each sample plant. First, all of the *D. hesperus* adults and nymphs on each sampled plant were counted visually in situ (hereafter called "plant samples"). Second, a single leaf was randomly selected, and cut and bagged individually from each of the upper, middle and bottom of the plant on the first year (hereafter called "leaf samples"). In the second year a single leaf was randomly selected from the middle level and was cut and bagged. These leaves were carried to the laboratory where all of the *D. hesperus* nymphs and adults were counted.

Data Analysis. *Selection of the Sample Unit.* In our analysis we assumed that plant samples were a good estimation of the absolute population size. Although these plant samples are subject to sample error, the population of tomato plants is composed of individuals with similar characteristics and theoretically equal probabilities of being colonized. On the leaves, *D. hesperus* may be unevenly distributed depending on the location within the plant. Therefore, the estimation of the population density might be different, depending on the location of the leaf sample.

The average number of *D. hesperus* per week was compared among the leaves from the three plant sections (bottom, middle and upper), through the 1999 growing season, with a two-factor analysis of variance (ANOVA) test. The relationship of the average number of insects between plant samples and leaf samples was established by regression analysis, to determine in which sections the leaf density was most strongly correlated with the plant density. The data were previously transformed by ln $(x + 1)$. Linear regression was done using Systat (Wilkinson et al. 1992). Differences among means were established with the Tukey test.

Spatial Distribution. Taylor's power law ($s^2 = a \cdot m^b$) establishes a relationship between the variance (s^2) and the mean density (m) that is considered to be constant and characteristic for each species (Taylor 1961). This distribution is considered to be random when $b = 1$, regular when $b < 1$ and aggregated when $b > 1$ (Taylor et al. 1978). We calculated parameters a and b by regression analysis of the log–transformed expression.

The spatial distribution of *D. hesperus* was further evaluated by fitting the experimental data to the Poisson and negative binomial distributions. The Poisson distribution describes random patterns, in which, for any given mean density (m), the probability (P) of finding a number (x) of individuals in a sample unit is given by the expression $[P_x = e^{-m}\ (m^x/x!)]$.

The negative binomial distribution function is used to describe aggregation patterns (Bliss and Fisher 1953). The proportion of sample units with x individuals is calculated by the equation $[(P_x = [\Gamma\ (k + x)/x!\ \Gamma(k)] \cdot [m/(m + k)]^x \cdot [k/(m + k)]^k$, where $\Gamma(x)$ is the gamma function, m is the mean population density and k the binomial parameter. The parameter k was calculated by equation $k = m^2/(am^b - m)$. In this expression, Taylor's power law substitutes for the variance (Wilson and Room 1983).

The fit of the experimental data to the negative binomial and Poisson distributions was tested by chi-square with a probability level $P < 0.05$ (Southwood 1978). The chi-square test was only applied when there were at least 3 df. The Poisson distribution was tested in all cases. The fit to the negative binomial was tested only when b was significantly >1 (t-test, $P <$ 0.05).

Sampling Method. The sample size (n) for the complete count sampling, was given in terms of the relative precision of the mean density (m) or coefficient of variation $[CV_m = (S/\sqrt{n})/m]$ by the expression $(n = am^{b-2}/CV_m^2)$ (Karandinos 1976). Knowledge of the relationship between the mean population density and the spatial distribution makes it possible to estimate the mean density from the proportion of unoccupied leaves. Although the relationship described by the Poisson and negative binomial may be used for sampling purposes, for convenience, an empirical model $[m = e^{a'}\ (\text{-}\ln P_T)^{b'}]$ was adopted to establish the relationship between the mean population density (m) and the proportion of nonoccupied leaves (P_T) (Kono and Sugino 1958; Gerrard and Chiang 1970; Nachman 1984). The function's parameters (a' and b') were calculated by regression analysis by transforming the previous equation by natural logarithm $[\ln(m) = a' + b' \ln(\text{-}\ln P_T)]$. Different tally thresholds (T) were assayed, in which a sample unit was considered to be occupied when it held more than T individuals.

The sample size (n) for the binomial or presence-absence method was calculated in terms of relative precision (CV) with the equation $n = P\ (1 - P)\ (df/dp)^2/m^2CV^2$ given by Binns et al. (2000). In this equation, $P(1 - P)$ is the variance of the binomial sampling, df/dp is the first derivative of the equation $m = e^{a'}\ (-\ln P_T)^{b'}$, and m the mean density.

An approximation to the sampling cost of plant sampling versus middle leaf sampling was calculated for the binomial sampling method. Total sampling cost was summarized by the sum of the time spent moving to a new sample unit plus the time spent exploring the sample unit. The relative cost of the time spent moving to a new sample unit can be expressed as the relation between the plant sample size (N_p) and the leaf sample size (n_l). For binomial sampling, an approximation of the exploring cost of plant as sample units versus leaf as sample unit was given by the expression ($n_p\ N\ P_T/n_l$). The sample size (n_p) was calculated with the equation of the binomial sampling size in relation to the mean plant density, which in turn, was estimated from the experimental relationship established by regression analysis between plant density and middle leaf density. For simplification, all leaves of the plant were implied to have the same characteristics as the middle leaf. The average number of leaves in plants (N) is usually constant, because leaves are pruned from the plants as they grow. In our crops the mean number of leaves per plant was 22.6 ± 2.2. Therefore the cost of sampling plants was assumed to be the product of the number of leaves explore in each plant plus the required sample size (n_p). The term ($N\ P_T$) represents the number of leaves that have to be counted in a plant before finding an occupied leaf and consequently stop sampling the plant and move to the next plant.

Results and Discussion

Selection of the Sample Unit. Comparison of the mean densities of the total numbers of *D. hesperus* through the entire 1999 growing season denoted a significant decrease in the number of individuals from the leaves of the top of the plant to that of the bottom (two-factor ANOVA: plant section, $F = 242$; df = 2, 1,272; $P < 0.001$; week sample, $F = 42.5$; df = 24, 1,272; $P < 0.001$). However, there was a greater difference between upper and middle or bottom leaves, than between middle and bottom leaves.

A significant relationship was found among the plant samples and the samples from the leaves on each third of the plant for adults, nymphs and the total (adults+nymphs) (Table 1). The regression coefficient (r^2) of plant counts versus leaf counts from the middle or bottom section of the plants were higher than the r^2 for plant counts versus leaf counts from the upper section in almost all the cases. In the upper and middle leaves, the quadratic component of the independent variable was significant ($P < 0.05$) (Table 1). This might arise from an increase in the colonization rate of the upper leaves of the plant as *D. hesperus* density per plant increases, or because of the difficulty of sampling the whole plant as the number of individuals increases.

Table 1. Regression parameters for *D. hesperus* nymphs and adults for plant samples versus leaf samples from different plant sections

	Parameter	Plant samples vs leaf samples		
		Upper leaves	Middle leaves	Bottom leaves
Nymphs	N	26	106	25
	a	1.10 ± 0.23	0.22 ± 0.06	0.69 ± 0.17
	b	6.67 ± 1.82	2.88 ± 0.26	1.13 ± 0.13
	c	−5.28 ± 2.14	−0.77 ± 0.16	NS
	r^2	0.403	0.802	0.752
Adults	N	26	106	25
	a	NS	0.39 ± 0.06	0.76 ± 0.21
	b	5.66 ± 0.87	6.39 ± 0.90	2.57 ± 0.39
	c	−8.15 ± 2.53	−3.10 ± 1.12	NS
	r^2	0.632	0.620	0.642
Nymphs + adults	N	26	106	25
	a	1.46 ± 0.24	0.40 ± 0.07	1.02 ± 0.16
	b	6.44 ± 1.58	2.90 ± 0.31	1.24 ± 0.11
	c	−3.73 ± 1.53	−0.61 ± 0.17	NS
	r^2	0.538	0.777	0.838

N is the number of pair of data used in the regression; *a*, *b*, and *c* are parameters of the function $Y = a + bX + cX^2$; r^2 is the regression coefficient; n.s indicates that no significant relationship was detected ($P > 0.05$).

Based on the above results, we recommend sampling *D. hesperus* on leaves from the middle or bottom section of the plant because the density on these leaves is higher than on the upper leaves and is better correlated with the density of the insects on the whole plant. The selection of position of the leaf to be sampled may also depend on whether another species with a particular spatial distribution is to be sampled at the same time.

Spatial Distribution of *Dicyphus hesperus*. On leaves, the aggregation index (*b*) for the nymphs was significantly greater than one on the bottom ($t = 2.160$, df = 22, $P < 0.05$), middle ($t = 7.221$, df = 79, $P < 0.05$), and upper leaves ($t = 1.831$, df = 15, $P < 0.05$) (Table 2). For adults, the aggregation index on the leaves was not significantly different from one on the upper ($t = 0.482$, df = 13, $P = 0.319$) and bottom leaves ($t = 0.004$, df = 17, $P = 0.498$), but was significantly greater than one in the middle leaves ($t = 5.167$, df = 45, $P < 0.001$) (Table 2). When nymphs and adults were considered together, the aggregation index in leaves was significantly greater than one on the middle ($t = 7.140$, df = 79, $P < 0.001$) and bottom leaves ($t = 2.236$, df = 22, $P = 0.018$) but not significantly different from one in the upper leaves ($t = 1.641$, df = 19, $P = 0.059$) (Table 2). On plants, the aggregation index was significantly greater than one for nymphs ($t = 9.41$, df = 110, $P < 0.001$), adults ($t = 11.491$, df = 114, $P < 0.001$), and the nymphs+adults among plants ($t = 11.183$, df = 118, $P < 0.001$), (Table 2).

The samples were also tested for the negative binomial where the aggregation index was significantly different from one and there were enough degrees of freedom (i.e., df > 3). In most of the leaf samples from the upper section, the degrees of freedom were not sufficient to test the theoretical function because of the low number of individuals. The distribution of nymphs on leaf samples from the middle section fitted the negative binomial in 20 out of the 23 samples tested, and the Poisson distribution in 17 out of 35 samples. For the leaf samples from the bottom section all 17 samples fitted the negative binomial and 15 out of 19 samples fitted the Poisson distribution. The distribution of adults in leaf samples was tested only against the Poisson distribution, due to a lack of the degrees of freedom to test the negative binomial. In 24 of the 27 samples from the middle and bottom leaves, the distribution of adults fitted the Poisson distribution.

The distribution of adults in the plant samples fitted the negative binomial in 74 out of 82 and the Poisson distribution in 45 out of 96 cases. The distribution of the nymphs in plant samples fitted the negative binomial in 87 out of 99 samples and the Poisson distribution in 39 out of 89 cases.

These results suggest that the negative binomial relationship describes the distribution of nymphs and adults of *D. hesperus* among plants and the distribution of nymphs on the leaves better than the Poisson distribution (Fig. 1). The Poisson distribution describes the distribution of the adults on the leaves from the middle and bottom plant sections. Therefore, the spatial distribution of *D. hesperus* on leaf samples within the plant may be considered aggregated for nymphs and close to random for adults. The distribution of both nymphs and adults among plant may be described as aggregated.

Several generalist predators in the Order Hemiptera, with a similar biology, have been characterized as having a random distribution pattern. These include *Nabis* spp. and *Geocoris* spp. in soybean (Waddill et al. 1974), *Orius laevigatus* (Fieber) in strawberries flowers (Garcia-Mari et al. 1994), and *Orius albidipennis* (Reuter) and *O. laevigatus* in pepper flowers (Sanchez et al. 1997).

Table 2. Taylor's distribution index for nymphs and adults of *D. hesperus* on tomato leaves (upper, middle, and bottom) and tomato plant

	Nymphs				Adults				Nymphs + Adults			
	N	In a	b	r^2	N	In a	b	r^2	N	In a	b	r^2
Upper	17	0.46 ± 0.21	1.20 ± 0.11	0.884	15	−0.10 ± 0.08	0.99 ± 0.03	0.990	21	0.25 ± 0.15	1.12 ± 0.08	0.918
Middle	73	0.55 ± 0.05	1.21 ± 0.03	0.960	47	0.36 ± 0.06	1.13 ± 0.03	0.976	81	0.54 ± 0.05	1.20 ± 0.03	0.959
Bottom	24	0.50 ± 0.07	1.09 ± 0.04	0.966	23	−0.03 ± 0.08	1.00 ± 0.05	0.938	24	0.48 ± 0.08	1.12 ± 0.05	0.952
Plant	112	0.73 ± 0.05	1.34 ± 0.04	0.927	116	0.53 ± 0.04	1.27 ± 0.02	0.963	120	0.55 ± 0.05	1.32 ± 0.03	0.946

Values are given ±SE.

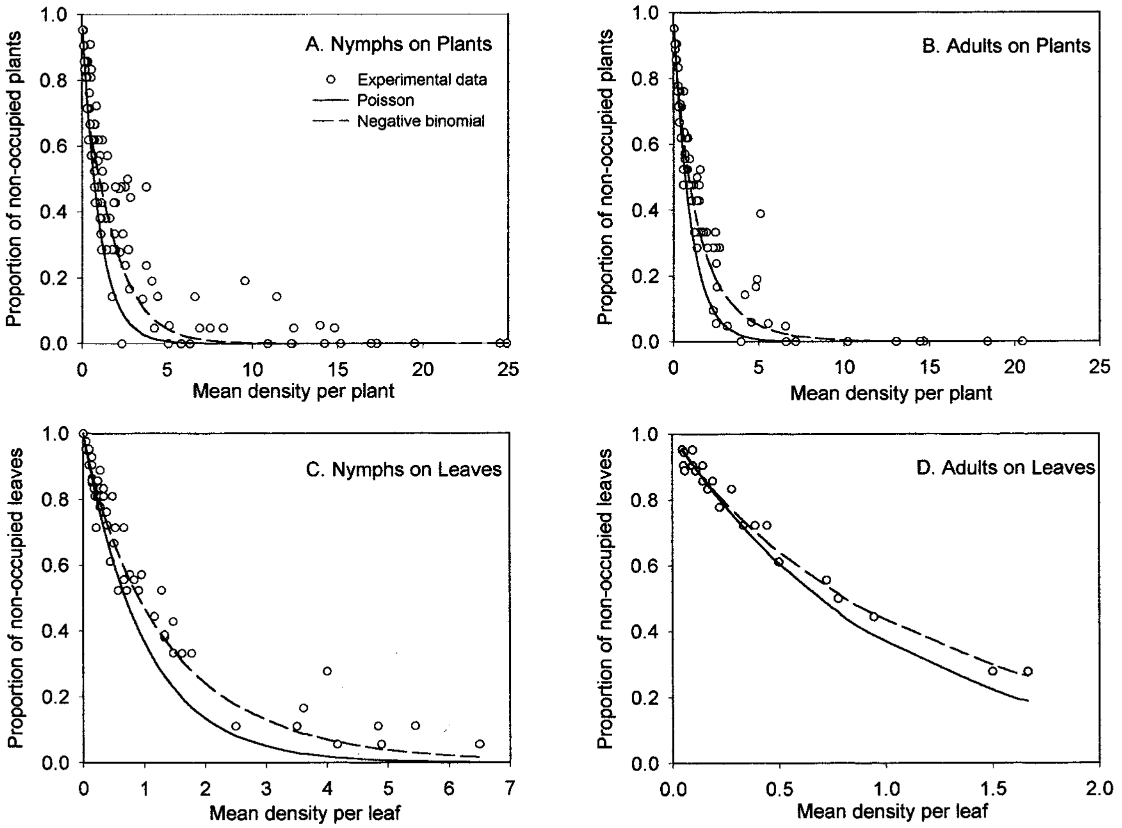

Fig. 1. Spatial distribution of nymphs and adults *Dicyphus hesperus* on leaves from the middle plant section and on the whole tomato plants. Lines show the theoretical values for Poisson and negative binomial distributions. (A) Nymphs on the whole plant. (B) Adults on the whole plant. (C) Nymphs on a single leaf sampled from the middle section of the plant. (D) Adults on a single leaf sampled from the middle section of the plant.

It is difficult to determine all of the factors that influence a species' spatial distribution and their relative contribution. However, prey searching behavior is likely one of the primary factors involved. An aggregated distribution among plants might be partly explained by the predator selecting plants where prey is available. Thus, the *D. hesperus* distribution could be influenced by the distribution of the prey. In this study the prey was mostly *T. vaporariorum*, which has a strongly aggregated distribution (J.A.S. and D.R.G., unpublished data). The aggregated pattern of the *D. hesperus* nymphs in the middle and bottom leaves may result from a higher concentration of individuals on the leaves where the nymphs and pupae of *T. vaporariorum* are more abundant. Random searching for prey by adults of *D. hesperus* on leaves might explain this kind of distribution. However, this could be also a consequence of the low density at which they were usually found on the leaf samples.

Sampling Methods. The sample size for methods where all insects present on the sample unit are counted (complete count sampling) is always lower than that for binomial sampling (Fig. 2). The optimum sample size for complete count sampling is similar for both leaf and plant samples. Fig. 2 shows sample size variation in relation to mean density for nymphs and adults counted together on the whole plant (A) and on the middle leaves (B) for a coefficient variation = 0.25.

A highly significant relationship was found between the mean density (m) and the proportion of nonoccupied leaves (P_T) with the empirical model at several tally thresholds (Table 3 and Fig. 3). The relationships described by this empirical model can be used to estimate the mean density (m) based on the proportion of nonoccupied leaves (P_T) on plants or leaves. Regression parameters for middle and bottom leaves at $T = 0$ and $T = 1$, and for plants from $T = 0$ to $T = 3$ are given in Table 3.

Binomial sampling requires a larger sample size than the complete count sampling. However, it may reduce the time required to process samples because checking whether a sample unit is occupied or not takes less time than counting the actual number of insects present. The cost of binomial sampling of plants increases in relation to the cost of binomial sampling of leaves as the population increases. Exploring the entire plant is more expensive than exploring the leaves, in both of the cases assayed: a tally threshold $T = 0$ for leaf sampling and a tally threshold either $T = 0$ or $T =$

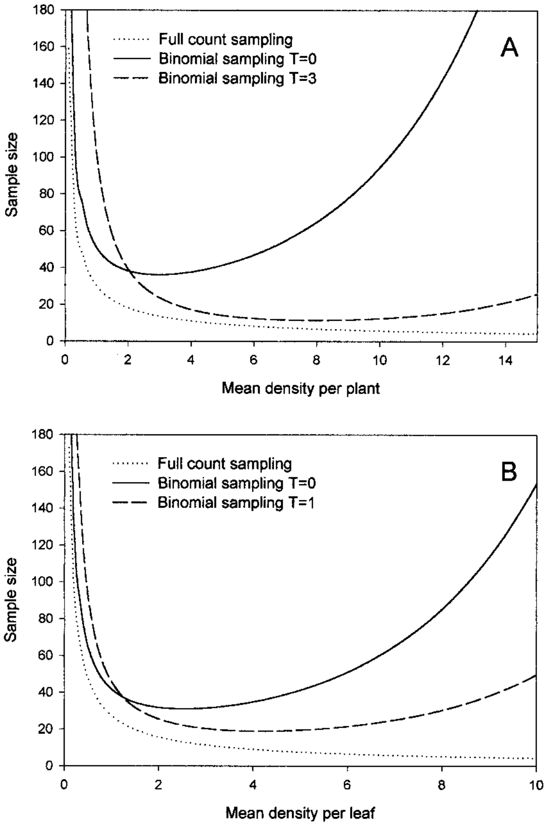

Fig. 2. Optimum sample size for full count and binomial sampling methods. (A) Whole plant samples for *D.hesperus* (nymphs+adults) in tomato. (B) Single leaf samples from the middle section of the plant for *D. hesperus* (nymphs+adults) in tomato.

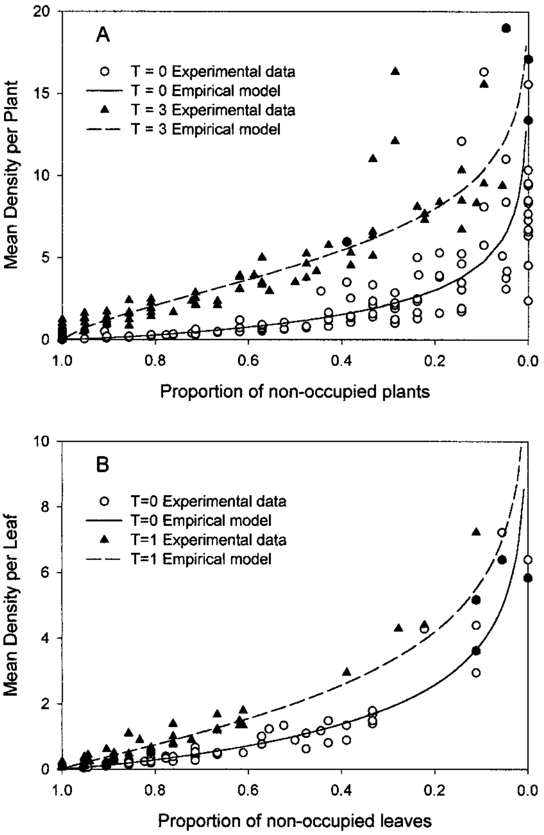

Fig. 3. Mean density of *Dicyphus hesperus* (nymphs+adults) versus the proportion of nonoccupied samples. (A) Data for whole-plant samples at tally thresholds $T = 0$ and $T = 3$. (B) Data for single-leaf samples from the middle section of the plant at tally thresholds $T = 0$ and $T = 1$. Lines show the predictions made with the empirical model.

3 for plant sampling (Fig. 4). The cost of moving to a new sampling unit is higher for leaf sampling than for plant sampling when middle leaf density is above 0.9 individuals/leaf for a plant tally threshold $T = 0$ and above 2 for a plant tally threshold $T = 3$ (Fig. 4).

Binomial sampling is generally less reliable when the proportion of occupied leaves is under 20% or above 80%. When the proportion of occupied sample units (leaves or plants) is under 20% we recommend the use of a complete count sampling because at low densities this approach is more reliable and requires a lower sample size (Fig. 2). When the proportion of occupied sample unit is above 80%, a tally threshold $T > 0$ must be used to avoid the saturation of the sample units that takes place at high densities (Fig. 3). Recording nymphs and adults separately can also help to avoid the saturation problem in binomial sampling.

Table 3. Regression parameters of the empirical model for nymphs and adults for tomato plants and leaves from the middle and bottom plant sections.

	T	Nymphs				Adults				Nymphs + Adults			
		N	a'	b'	r^2	N	a'	b'	r^2	N	a'	b'	r^2
Plant	0	97	0.62 ± 0.05	1.19 ± 0.04	0.889	104	0.38 ± 0.04	1.15 ± 0.03	0.951	95	0.53 ± 0.05	1.21 ± 0.05	0.863
	1	88	1.22 ± 0.05	0.90 ± 0.03	0.912	75	1.07 ± 0.05	0.84 ± 0.03	0.928	95	1.19 ± 0.04	0.86 ± 0.03	0.918
	2	77	1.57 ± 0.05	0.78 ± 0.03	0.911	54	1.45 ± 0.07	0.73 ± 0.04	0.881	79	1.55 ± 0.04	0.76 ± 0.03	0.913
	3	72	1.81 ± 0.05	0.78 ± 0.03	0.922	41	1.63 ± 0.07	0.59 ± 0.04	0.860	70	1.75 ± 0.04	0.68 ± 0.03	0.886
Middle leaves	0	73	0.41 ± 0.03	1.11 ± 0.03	0.958	47	0.13 ± 0.09	1.04 ± 0.04	0.95	79	0.41 ± 0.05	1.12 ± 0.03	0.956
	1	47	1.01 ± 0.04	0.85 ± 0.04	0.929	23	0.07 ± 0.15	0.91 ± 0.07	0.887	51	1.02 ± 0.08	0.87 ± 0.04	0.911
Bottom leaves	0	19	0.47 ± 0.08	1.03 ± 0.05	0.956	23	−0.03 ± 0.04	0.98 ± 0.03	0.980	18	0.52 ± 0.08	1.08 ± 0.07	0.940
	1	18	0.88 ± 0.06	0.90 ± 0.04	0.962	17	0.73 ± 0.09	0.61 ± 0.05	0.915	19	1.00 ± 0.06	0.86 ± 0.04	0.964

T is the tally threshold, a′ and b′ are parameters of the model, N is the number of samples and r^2 is the regression coefficient.

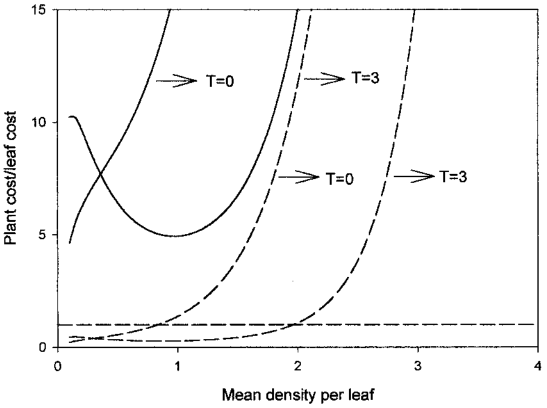

Fig. 4. Relative cost of a binomial sampling in plants versus a binomial sampling in middle leaves, in relation to the mean population density of *D. hesperus* (nymphs+adults) in the middle leaves. Relative cost of the displacement time (dashed) and relative counting cost (solid) for tally threshold $T = 0$ and $T = 3$ in plants, and $T = 0$ in leaves. Above the dotted straight line plant sampling is more time consuming than in leaf sampling.

Predatory mirids are currently used for biological control of insect pests in a variety of crop systems worldwide (Alomar and Albajes 1996, Malausa and Trottin-Caudal 1996, McGregor et al. 1999). Some species, like *M. caliginosus*, are inundatively released for biological control of pests of greenhouse crops (Malausa and Trottin-Caudal 1996). Other species, spontaneously colonize the crops when insecticide spraying is reduced (Alomar and Albajes 1996). In either case, an accurate determination of predator population densities is essential for the development of successful integrated pest management programs using predatory mirids. In this study a sampling design is reported for *D. hesperus* releases on tomatoes grown in greenhouses in British Columbia. The structure of the sampling plan presented here may also be used to develop sampling methods for related species and other crops.

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