Survey of Predators and Sampling Method Comparison in Sweet Corn

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ABSTRACT Natural predation is an important component of integrated pest management that is often overlooked because it is difficult to quantify and perceived to be unreliable. To begin incorporating natural predation into sweet corn, *Zea mays* L., pest management, a predator survey was conducted and then three sampling methods were compared for their ability to accurately monitor the most abundant predators. A predator survey on sweet corn foliage in New York between 1999 and 2001 identified 13 species. *Orius insidiosus* (Say), *Coleomegilla maculata* (De Geer), and *Harmonia axyridis* (Pallas) were the most numerous predators in all years. To determine the best method for sampling adult and immature stages of these predators, comparisons were made among nondestructive field counts, destructive counts, and yellow sticky cards. Field counts were correlated with destructive counts for all populations, but field counts of small insects were biased. Sticky cards underrepresented immature populations. Yellow sticky cards were more attractive to *C. maculata* adults than *H. axyridis* adults, especially before pollen shed, making coccinellid population estimates based on sticky cards unreliable. Field counts were the most precise method for monitoring adult and immature stages of the three major predators. Future research on predicting predation of pests in sweet corn should be based on field counts of predators because these counts are accurate, have no associated supply costs, and can be made quickly.

KEY WORDS *Coleomegilla maculata*, *Harmonia axyridis*, *Orius insidiosus*, sampling methods

ALTHOUGH GENERALIST PREDATORS have been recognized for their potential to control *Ostrinia nubilalis* (Hübner) (Crawford and Spencer 1922, Conrad 1959), *Helicoverpa zea* (Boddie) (Caron and Bradley 1978, Reid 1991), and *Rhopalosiphum maidis* (Fitch) (Coderre and Tourneur 1988, Asin and Pons 1997) in field corn and sweet corn, *Zea mays* L., the benefits of these natural enemies have not been incorporated into sweet corn pest management models (CCE 2002). The use of broad-spectrum insecticides has typically killed natural enemies along with pests (Duffie et al. 1998, Tillman and Mulrooney 2000), limiting the potential to incorporate biological control into pest management. However, as broad-spectrum insecticides are replaced by new products that target specific pests while leaving the natural enemy complex largely intact (Pilcher et al. 1997, Musser and Shelton 2003a), predators will be available to provide some pest control. With a clearer understanding of predator population dynamics and their contributions to pest control, the impact of predators can be included in the decision-making process, further increasing the integration of biological control into commercial agriculture.

Predator populations are present at different times of the year and grow in response to numerous abiotic and biotic factors (Ewert and Chiang 1966, Kawai 1976, Coll and Bottrell 1991, Cottrell and Yeargan 1999, Nault and Kennedy 2000), making it difficult to predict their size without sampling. With sample data of sufficient accuracy and the results of studies that show the effectiveness of known predator populations in corn (Andow and Risch 1985, Andow 1990, Reid 1991, Musser 2003), the degree of pest control expected from predators may be estimated, allowing the benefits of biological control to be used by growers when making pest management decisions.

Sampling for making decisions is one of the building blocks of integrated pest management (IPM); however, there has been little work on sampling to predict biological control (Nyrop and Vanderwerf 1994). Like pest sampling, assessing natural enemy abundance requires developing sampling techniques and programs (Pedigo 1994). The requirements of a sampling program are that it be reasonably accurate, reliable, and practically feasible (Buntin 1994).

Based on previous survey work in the northeastern United States (Whitman 1975, Andow and Risch 1985, Coll and Bottrell 1992, Hoffmann et al. 1997), the primary predators in sweet corn were expected to be coccinellids, especially *Coleomegilla maculata* (De Geer), and the anthocorid *Orius insidiosus* (Say). Another coccinellid, *Harmonia axyridis* (Pallas), has entered the area since these surveys (Coderre et al. 1995, Wheeler and Stoops 1996) and has been found in sweet corn fields (Musser 2003). The first step in using

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the present predator guild is to identify the species and estimate their abundance at critical crop stages.

There are several reports on estimating populations of coccinellids in sweet corn by using sticky cards (Ewert and Chiang 1966, Hoffmann et al. 1997, Bruck and Lewis 1998, Colunga-Garcia and Gage 1998), a modified leaf blower (Beerwinkle et al. 1999), and visual field counts (Foott 1973, Nault and Kennedy 2000, Wold et al. 2001). In grain sorghum, a crop with a plant structure similar to corn, Michels and Behle (1992) found that visual counting had less bias than drop cloths, sweep nets, or pit traps for coccinellid adults. The only described sampling method for *O. insidiosus* found in corn is visual field counts (Dicke and Jarvis 1962, Isenhour and Yeargan 1981, Elkassabany et al. 1996).

Advantages of nondestructive field counts are that they require no supplies and can be used for any insect that is large and exposed enough to be seen. This method also allows recording of additional information such as insect location on the plant (e.g., height on plant; whether on leaf, stem, or other plant part). Field counts can be done for a specified time in dense canopy crops (Elliott et al. 1991) or on a specified number of plants in crops such as corn (Powell et al. 1996). Although field counts are commonly used in research and to monitor pests commercially, major weaknesses in this method are bias among observers (Morris 1960, Powell et al. 1996), bias due to changes in behavior between hungry and satiated insects (Frazer and Raworth 1985), and bias due to differences in insect behavior at different times of day (Frazer and Raworth 1985).

Sticky cards have the advantage of being continually present, so time of sampling is less of a factor. Results are also less affected by the visual acuity of field personnel because a single trained individual can record captures on the cards. Sticky cards are also relatively rapid and inexpensive to use. Yellow sticky cards have been shown to be as good or better than other colored cards for most natural enemies (Udayagiri et al. 1997). Although *C. maculata* adult counts are not affected by changing the height at which yellow sticky cards are placed (Bruck and Lewis 1998), the impact of sticky card height on *H. axyridis* or *O. insidiosus* counts is unknown. A disadvantage of sticky cards is that some species may be more attracted to them than others, resulting in bias when making comparisons among species (Hutchins 1994). Another limitation of sticky cards is that they are passive, requiring insects to move onto the card. As a result, only the more mobile and alate insect stages can be effectively monitored by sticky cards.

Destructive laboratory counts of samples collected in the field can be used to make absolute population estimates (Southwood 1978). Although this method is labor-intensive, it is sometimes needed for smaller, more cryptic insects. It is often used to calibrate relative sampling methods or to check for bias.

The objectives of the work reported herein were to describe the insect predator guild in New York sweet corn and to compare three sampling methods for their usefulness in monitoring these predators. The three methods were 1) in situ counting of predators by using a sample unit of 10 consecutive sweet corn plants, 2) destructive examination in the laboratory of a sample unit consisting of two adjacent sweet corn plants, and 3) deployment of yellow sticky cards for 48 h (a sample unit is three cards). Other sampling methods (e.g., Berlese funnels, light traps, vacuum samplers, water traps) that have been used to estimate predator populations (Powell et al. 1996) were not considered because they require specialized equipment not likely to be available for routine commercial use.

Materials and Methods

Data were collected for two purposes: 1) to describe the abundance of predators in New York sweet corn; and 2) to compare accuracy and reliability of field counts, destructive counts, and sticky cards for monitoring the most abundant predators. In 1999, data were collected solely for the first purpose by using destructive counts (see description below). In 2000 and 2001, both objectives were pursued by taking counts using all three methods in several trials. The sampling locations and protocol for each sampling method are described below.

Sampling Locations. In 1999, destructive counts were taken from nine commercial processing sweet corn fields (minimum 5 ha) planted between 30 April and 20 May in Ontario and Yates counties, New York. One sample unit per field (25 plants) was collected when the sweet corn was 65 cm in height and again during pollen shed from a site ≈6 m from the field edge. In 2000, one sticky card, field count, and destructive count sample unit per plot were taken weekly from each replicate of 13 varieties in a sweet corn variety trial planted 30 May. Sampling began 12 July when plants were ≈30 cm in height and continued until harvest in late August, resulting in 93 samples by each sampling method. In 2000 and 2001, one sample unit by each of the three methods was taken weekly from before tassel emergence until harvest in planting date studies with planting dates from early May until early July. The planting date studies generated 20 and 22 samples by each method in 2000 and 2001, respectively. Also in 2000 and 2001, one field count and destructive count sample unit per plot were taken 3 d after each insecticide application in trials testing selective insecticides. Sticky cards were not used in the insecticide trials. The insecticide trials produced 72 and 64 samples by each method in 2000 and 2001, respectively. Variety, planting date and insecticide trials in 2000 and 2001 had three or four replicates so each sample consisted of three or four sample units. These trials were planted at the Cornell University Fruit and Vegetable Research Farm in Geneva, NY, and had plot sizes ranging from 28 to 233 m^2.

Field Counts. The sample unit consisted of 10 consecutive plants selected from the interior rows of a sweet corn plot. Consecutive plants were examined rather than plants some random distance apart to minimize collection time and to minimize the frequency

of decisions on whether to count an insect observed moving between the plant being examined and an adjacent plant. Coccinellids, *O. insidiosus*, and other predators were identified and counted by trained staff. The counts from all 10 plants were pooled.

Sticky Cards. The sample unit consisted of three yellow sticky cards (7.6 by 14 cm and sticky on one side only) (Pherecon AM sticky traps, Trécé, Salinas, CA). Cards were placed on plants in the interior rows of a sweet corn plot and secured with wire ties to the corn stalk midway between the ground and the top of the plant, with the sticky side facing away from the plant. Each card was placed in a different row. During the corn reproductive stage, the cards were placed at ear height, because this is the region of the plant where biological control is most critical. The cards were retrieved after 48 h and covered with clear plastic wrap. Insects were later identified and counted using a dissecting microscope, and the counts from the three cards at a single site were pooled. Sticky cards were retrieved the same day as field counts were made.

Destructive Counts. The sample unit consisted of two consecutive plants (25 plants in 1999) chosen randomly from the interior rows of a sweet corn plot. Plants were cut on each sampling date at the soil surface and quickly placed in a large plastic bag, taking care not to dislodge the insects from the plant. Although a few actively flying insects could escape, the primary predators tended to stay in place or occasionally drop into the plastic bag during sampling. The plants were frozen to kill the insects and then plants and bags were examined in the laboratory to identify and count all the insects. The insects counted on the two plants were pooled. Destructive samples were cut the same day as the field counts were made and the sticky cards were retrieved.

Data Analysis. Our comparison of sampling methods consisted of an examination of bias and precision for adult and immature stages of the three most abundant predators.

Bias is any systematic deviation of a sample estimate from the true parameter (Binns et al. 2000). Although bias, if consistent and known, can be accounted for when sampling, variable bias, or a lack of reliability in the sample method, is problematic. Although bias is usually impossible to measure in practice because the population parameter to be estimated is not known, bias can be approximated and studied. We did so in two ways. First, we compared mean densities estimated over all grouping variables (time and treatments) for the three sampling methods, by using the destructive count estimates as the true population parameter. Densities were expressed on a per plant or per sticky card basis. Second, we estimated correlation coefficients among means obtained using the three sampling methods. A high correlation between counts from the different sampling methods would indicate a consistent bias or no bias and hence, a reliable estimate. Correlations were calculated using PROC CORR (SAS Institute 1999) for adults and immature stages of each of the major predator populations.

Precision of the sampling methods were compared by variance of estimates obtained using common sample sizes. Because variance is usually a function of the mean, the relationship between variance and mean was modeled using Taylor's Power Law (Taylor 1984). Because each sample only consisted of three or four sample units, estimated mean and variance were imprecise, which in turn would lead to an imprecise variance-mean model. To develop a more precise model, four samples, each with similar means, were grouped before regressing the log of variance on the log of mean using PROC REG (SAS Institute 1999). The parameters generated were then used to calculate the variance over the range of sample means encountered. Precision was compared using coefficients of variation [$CV = (V/n)^{0.5}/m$ where V is sample variance, n is number of sample units, and m is sample mean] for each method (Binns et al. 2000) with densities expressed on a per plant basis and $n = 10$. This combined sample variance and mean so that the pre-

Table 1. Mean populations ± SEM of predacious stages of insects from destructive count samples of sweet corn plants, Geneva, NY

Year Crop maturity	1999 Vegetative to silk/plant	2000 Vegetative to milk/plant	2001 Whorl to milk/plant
Predator			
Coleoptera: Coccinellidae			
C. maculata	0.073 ± 0.017	0.545 ± 0.067	0.840 ± 0.127
H. axyridis	0.026 ± 0.012	0.202 ± 0.030	0.623 ± 0.168
Coccinella septempunctata	0.005 ± 0.003	0.000 ± 0.000	0.019 ± 0.009
Propylea quatuordecimpunctata	0.000 ± 0.000	0.001 ± 0.001	0.005 ± 0.005
Hippodamia spp.	0.000 ± 0.000	0.001 ± 0.001	0.038 ± 0.013
Hemiptera: Anthocoridae:			
O. insidiosus	0.814 ± 0.197	2.091 ± 0.179	4.146 ± 0.489
Nabidae	0.033 ± 0.009	0.007 ± 0.003	0.038 ± 0.013
Reduviidae	0.016 ± 0.006	0.009 ± 0.004	0.024 ± 0.010
Diptera: Syrphidae[a]	0.000 ± 0.000	0.003 ± 0.002	0.028 ± 0.011
Cecidomyiidae[a]	0.005 ± 0.003	0.018 ± 0.005	0.033 ± 0.014
Neuroptera: Chrysopidae[a]	0.021 ± 0.007	0.007 ± 0.003	0.075 ± 0.018
Hymenoptera: Formicidae	0.007 ± 0.004	0.003 ± 0.002	0.024 ± 0.010
Araneida	0.035 ± 0.009	0.009 ± 0.004	0.009 ± 0.007

[a] Larva only

Table 2. Mean populations ± SEM of *C. maculata*, *H. axyridis*, and *O. insidiosus* in sweet corn from three sampling methods with bias shown as a percentage of the destructive count (n = 135), Geneva, NY, 2000–2001

Insect	Destructive count/plant	Field count		Sticky cards	
		/plant	% of destructive count	/card	% of destructive count
C. maculata adults	0.092 ± 0.011	0.066 ± 0.006	72	0.240 ± 0.029	261
C. maculata larvae	0.484 ± 0.055	0.193 ± 0.021	40	0.016 ± 0.005	3
H. axyridis adults	0.026 ± 0.006	0.023 ± 0.004	88	0.018 ± 0.005	69
H. axyridis larvae	0.217 ± 0.034	0.084 ± 0.014	39	0.001 ± 0.001	0
O. insidiosus adults	1.490 ± 0.132	0.274 ± 0.020	18	1.078 ± 0.096	72
O. insidiosus nymphs	1.012 ± 0.105	0.082 ± 0.011	8	0.034 ± 0.007	3

cision of the sampling methods could be directly compared.

Results

In New York sweet corn fields, predators from Araneida plus eight families in five insect orders were identified (Table 1). The most abundant predators were the coccinellids *C. maculata* and *H. axyridis,* and the anthocorid *O. insidiosus.* All other groups had mean populations <0.1 per plant in all years. The abundance of *H. axyridis* found in this survey confirms that this exotic predator is now common in sweet corn in the northeastern United States as previously reported for corn in other regions of the country (Colunga-Garcia and Gage 1998, Cottrell and Yeargan 1998).

The adult and larva or nymph stage populations of *C. maculata, H. axyridis,* and *O. insidiosus* were analyzed for each sampling method. No other predator populations were abundant enough to allow a comparison of sampling methods. Using the mean determined from destructive counts as an estimate of the true mean, bias for field counts and sticky cards were estimated (Table 2). Estimated densities of coccinellid larvae and *O. insidiosus* nymphs by using sticky cards were <5% of destructive count estimates. However, adults of all three species were readily captured on sticky cards. Field counts were biased against small insects with *O. insidiosus* nymphs underestimated to the greatest extent, followed by *O. insidiosus* adults and coccinellid larvae.

Field and destructive counts were significantly correlated for all populations, but the correlations were not as high for *C. maculata* adults and *H. axyridis* adults as for the other populations (Table 3). These weaker correlations are likely a result of the inability to accurately measure populations that were typically lower than 0.1 per plant by using six to eight plants, as done in the destructive count method. Sticky card estimates were correlated to both of the other methods for *C. maculata* larvae, *H. axyridis* adults, and *O. insidiosus* adults. Although *C. maculata* adults were captured on sticky cards at a high rate, the correlation between sticky card capture and destructive counts was not significant, indicating that the bias was not consistent between these sampling methods. The population estimates for *C. maculata* adults over crop maturity (Fig. 1) show that *C. maculata* adults were highly attracted to sticky cards early in the season when they were immigrating into the crop before pollen was available. However, adults present during the milk stage, which were primarily newly emerged adults, were never found on the sticky cards, even though they were about as abundant as at other times when they were captured on the sticky cards. *H. axyridis,* the other major coccinellid in corn, behaved very differently, because the adults were not as attracted to yellow sticky cards as were *C. maculata* adults (Fig. 1; Table 2). However, although the sticky card counts were lower for *H. axyridis* adults, they were significantly correlated to estimates obtained by field and destructive counts (Table 3). Because these two coccinellids reacted very differently to yellow sticky cards, population monitoring with yellow sticky cards alone will not accurately estimate the relative populations of these two species.

The parameters estimated using Taylor's power law for each of the methods (Table 4) were used to plot coefficients of variation in relation to relative density for each population (Fig. 2). Relative density was expressed as a proportion of the maximum density

Table 3. Pearson correlation coefficients between sampling methods (field counts, destructive counts, and sticky cards) for predator populations in sweet corn, Geneva, NY 2000–2001

Insects	Field × destructive n = 271		Sticky × destructive n = 135		Field × sticky n = 135	
	r	P	r	P	r	P
C. maculata adults	0.3144	<0.0001	0.0803	0.3549	0.3876	<0.0001
C. maculata larvae	0.6970	<0.0001	0.3075	0.0003	0.2688	0.0016
H. axyridis adults	0.2618	<0.0001	0.5552	<0.0001	0.3440	<0.0001
H. axyridis larvae	0.8184	<0.0001	0.0368	0.6721	0.0760	0.3807
O. insidiosus adults	0.7426	<0.0001	0.4153	<0.0001	0.3562	<0.0001
O. insidiosus nymphs	0.6170	<0.0001	0.0674	0.4371	0.0075	0.9314

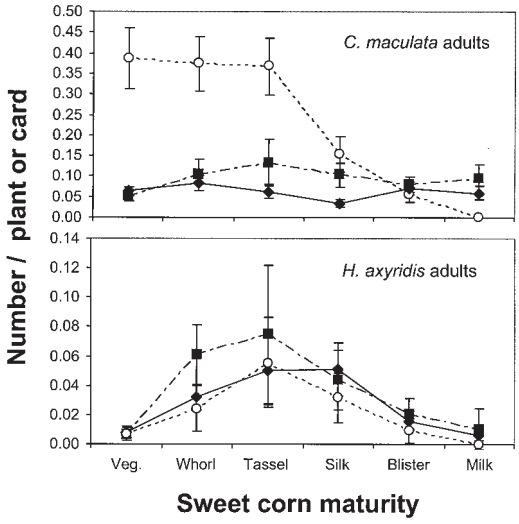

Fig. 1. *C. maculata* and *H. axyridis* adult populations ± SEM over corn maturity as estimated by field counts (◆), destructive counts (■), and sticky cards (○), Geneva, NY, 1999–2001.

recorded and allowed comparisons of precision to be made among sampling methods with systematic differences in density estimates. For all predators, field counts provided the most precise estimates as evidenced by their consistently lower coefficients of variation. This is likely a function of the greater number of plants included in each sample unit (10 plants). Coefficients of variation could not be calculated for *H. axyridis* adult destructive counts, *C. maculata* larva sticky cards, and *H. axyridis* larva sticky cards because the range of means recorded was not large enough to estimate the variance-mean model.

Because adults of all these species are easier to find than the smaller, more cryptic immature stages, it would be useful if monitoring adults alone could be used to predict overall populations. This would be most valuable for monitoring methods such as sticky cards that primarily capture adults. The correlations for adult populations by each sampling method with immature populations as estimated by destructive counts (Table 5) show that adult populations by all three methods provided variable predictive value for immature populations. Prediction was most consistent over methods for *O. insidiosus*, a population with nymphs greatly underrepresented by sticky cards and field counts. Because both adult and nymph *O. insidiosus* populations tended to increase throughout the growing season (Fig. 3), it seems that adult *O. insidiosus* populations could possibly be used to predict nymph populations. However, correlations were not very high (Table 5), so nymph population predictions based on adult populations would not be very precise. For coccinellids, estimation of larval populations from adult populations is not possible. With the exception of the correlation between field counts of *H. axyridis* adults and destructive counts of *H. axyridis* larvae, the correlations between coccinellid adult and larval populations were always <0.25, and in some cases negatively correlated, making any prediction about larval populations from adult populations unreliable.

Discussion

Determining the best sampling method for sweet corn predators is not only a function of finding one that is precise and reliable but also of finding a method that can be done quickly and inexpensively on a routine basis. Sticky cards require little time by trained personnel but necessitate two trips to the field to place and retrieve the cards. The time required to place, retrieve, and evaluate sticky cards was 10–15 min per three-card sample unit (40 min per sample), and placement and retrieval could be done by untrained personnel. In this study, the cards were in the field for 2 d, and there was a reasonable correlation with other sampling methods for some adult populations. When sticky cards were in the field for a week, as would be more practical in a typical weekly monitoring system, Hoffmann et al. (1999) found no significant correlations between field counts and sticky cards for any coccinellid populations. Therefore, the shorter time in the field may be critical for predicting predator populations from sticky cards. Advantages that sticky cards have over field and destructive counts are that the time of the day when placed or retrieved is not important when in the field for at least 24 h, and sticky

Table 4. Parameters and fit of variance-mean model generated from Taylor's power law (variance = a mean^b) for each predator by each sampling method.

Predator	Field counts				Sticky cards				Destructive counts			
	a	b	r^2	Maximum density/ plant	a	b	r^2	Maximum density/ plant	a	b	r^2	Maximum density/ plant
C. maculata adult	0.144	1.192	0.860	0.30	0.370	1.143	0.910	1.61	0.862	1.449	0.910	0.54
C. maculata larva	0.245	1.384	0.932	1.07	na	na	na	na	0.597	1.253	0.893	2.63
H. axyridis adult	0.197	1.263	0.932	0.28	0.821	1.563	0.996	0.30	na	na	na	na
H. axyridis larva	0.518	1.560	0.965	0.83	na	na	na	na	1.229	1.659	0.971	2.08
O. insidiosus adult	0.160	1.238	0.879	0.99	0.433	1.227	0.916	3.56	0.521	1.150	0.883	7.75
O. insidiosus nymph	0.197	1.273	0.894	0.42	0.916	1.606	0.999	0.44	0.600	1.145	0.802	4.87

na, not applicable as data could not be fit to Taylor's power law.

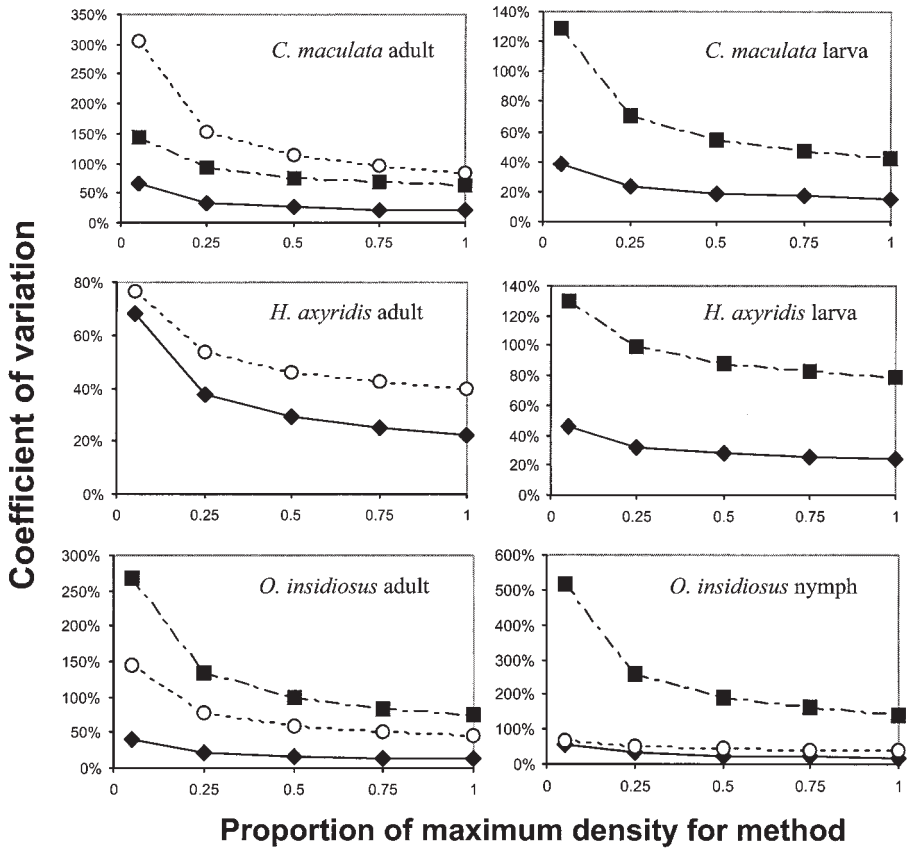

Fig. 2. Comparison of coefficients of variation per plant among sampling methods over the range of densities encountered from the major predator populations in sweet corn, Geneva, NY, 1999–2001. $n = 10$ for all methods. Field counts (♦), destructive counts (■), and sticky cards (○).

cards are the only method tested able to monitor nocturnal insects. However, the major predators in New York sweet corn are not nocturnal, so this is no advantage in sweet corn. The major weaknesses of sticky cards, evident from these data, are that sticky cards are unable to effectively monitor immature insect populations, and they have an inconsistent bias for *C. maculata* adults over crop maturity.

Destructive counts provide an unbiased assessment of most predator populations. This unbiased assessment is especially important for monitoring *O. insidiosus* nymphs, which tend to hide in the sweet corn ears and silks. Destructive counts necessitated only one trip to the field but required a large freezer and many hours for counting because it took 20–30 min to count a two-plant sample unit of corn at silk or later maturity (75 min per sample). Due to the time required to do destructive counts, fewer plants were sampled, resulting in less precise population estimates.

Field counts required only one trip to the field, had no supply costs, and took only 5–10 min to count the insects in a 10-plant sample unit (25 min per sample). Field counts gave the most precise population estimates and had a consistent bias for each predator over time and crop maturity. Differences of population estimates between observers and between different

Table 5. Pearson correlation coefficients between adult predator populations by each monitoring method and immature populations of the same species by destructive counts in sweet corn, Geneva, NY 2000–2001

Predator	Field counts (adults) $n = 271$		Sticky cards (adults) $n = 135$		Destructive counts (adults) $n = 271$	
	r	P	r	P	r	P
C. maculata larvae	−0.0346	0.5702	−0.2269	0.0081	0.2343	<0.0001
H. axyridis larvae	0.3953	<0.0001	0.1773	0.0397	0.1768	0.0035
O. insidiosus nymphs	0.3349	<0.0001	0.4625	<0.0001	0.3309	<0.0001

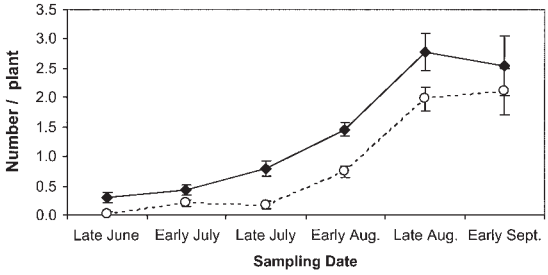

Fig. 3. *O. insidiosus* adult (◆) and nymph (○) populations ± SEM over time as estimated by destructive counts, Geneva, NY, 1999–2001.

times of the day were not tested in this study because we think these differences within the field count sampling method would be smaller than the differences between sampling methods.

The precision of destructive counts and sticky cards would likely be increased if the number of plants or cards sampled were increased. Based on the variance-mean models, the number of samples required for sticky cards and destructive counts to produce a coefficient of variation of 0.5 at half of the maximum recorded density was determined (Table 6). Although sticky cards required sampling of the fewest plants for this level of precision for *H. axyridis* adults and *O. insidiosus* nymphs, field counts required the least amount of time to reach this level of precision for all the predator populations. The time required to sample predators by destructive counts and sticky cards make the large number of plant samples needed for these methods impractical.

When sampling pest populations to make management decisions, it is seldom necessary to know the precise size of the population. It is often sufficient to classify the population as above or below some damage or economic threshold, based on the damage done by the pest. This generally requires less sampling than when estimating population size, which reduces the time and cost associated with sampling (Binns et al. 2000). The concept of an economic threshold was not designed for predators, and yet it is still possible that classification could be used in predator sampling to predict the amount of biological control on a pest. Predator/prey ratios have been proposed as a way to classify biological control impact (Nyrop and Vanderwerf 1994). However, for generalist predators where predation rates on a single pest are a function of other prey availability (Musser and Shelton 2003b), predator/prey ratios need to include all prey types (e.g., aphids, pollen). Perhaps a more feasible classification system for predicting biological control from generalist predators would be to classify the predator population as being large or small and estimate or classify the abundance of the primary prey types. This system could minimize the sampling effort while still providing some predictability of biological control.

Based on overall bias, destructive counts would be the best sampling method choice. However, based on correlations to other methods, the precision for each population monitored, and the time required, field counts seem to be the best sampling method for the primary sweet corn predators encountered in New York. The best sample size for population estimation was not addressed, because it will likely vary with the intended use of the information. Where predation rates can be estimated by knowing whether there are many or few predators present, population classification may be useful and would normally require a smaller sample size than when population means must be estimated. Future research on sampling methods for predators in sweet corn should use field counts to explore the benefits and costs of population estimation versus population classification as related to sample size requirements and pest predation predictability. The impact of the difference in population estimates between observers (Morris 1960, Powell et al. 1996) and between different times of day (Frazer and Raworth 1985) should also be measured to get a more complete estimate of variability before field counts of predators can be confidently used in pest management decisions.

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Table 6. Number of plants, samples and time required to obtain CV = 0.5 for a mean of half of the maximum density recorded for each sampling method based on the variance-mean model

Predator	Plants (samples) required			Time Required (min)		
	Field counts	Sticky cards	Destructive counts	Field counts (25 min/sample)	Sticky cards (40 min/sample)	Destructive Counts (75 min/sample)
C. maculata adult	81 (2.7)	468 (52)	138 (23)	68	2,080	1,725
C. maculata larva	42 (1.4)		72 (12)	35		900
H. axyridis adult	102 (3.4)	77 (8.5)		85	340	
H. axyridis larva	93 (3.1)		186 (31)	78		2,325
O. insidiosus adult	33 (1.1)	126 (14)	240 (40)	28	560	3,000
O. insidiosus nymph	75 (2.5)	64 (7.1)	888 (148)	63	284	11,100

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