Distribution of Egg and Larval Populations of Cranberry Fruitworm (Lepidoptera: Pyralidae) and Cherry Fruitworm (Lepidoptera: Tortricidae) in Highbush Blueberries

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ABSTRACT The spatial distribution of immature stages of the cranberry fruitworm, *Acrobasis vacinii* Riley, and cherry fruitworm, *Grapholitha packardii* Zeller was studied in Michigan blueberry farms. Single blueberry plants or individual clusters of fruit were compared as sampling units. Distributions of eggs and larvae at each sampling date were described by fitting data to either Poisson (random) or negative binomial (aggregated) distributions, and by calculating parameters of Taylor's power law. Additionally, two methods were used to calculate optimal sample sizes for use in future pest sampling. In one approach, Taylor's power law parameters were used to compute optimal sample sizes needed to estimate populations at two fixed-precision levels, 10 or 20%. In another method, the minimum number of samples required to collect at least one insect in 95% of samples was calculated. Results based on Taylor's power law parameters suggest that prohibitively large sample sizes would be required for even 20% precision, whereas the other method required substantially fewer samples and may thus be of more practical value in a pest monitoring program. All insect populations varied between aggregated and random distributions over the season, but *A. vaccinii* eggs and larvae were more often aggregated than *G. packardii.* Analysis of within-field distribution of fruitworm populations showed that *A. vaccinii* eggs were significantly more abundant in blueberries closer to woods when populations were at their peak. The distribution of eggs suggests that adjacent wooded habitats, which often contain wild hosts of this insect, may provide a source for individuals that colonize commercial fields.

KEY WORDS blueberry, *Vaccinium*, *Grapholita*, *Acrobasis*, cranberry fruitworm, cherry fruitworm

MICHIGAN IS THE major producer of highbush blueberries in the United States, with an annual production of ≈65 million pounds of fruit, comprising 40% of the 1999 crop (Anonymous 2000). Blueberries in Michigan and other regions of North America suffer frequent infestation by a complex of berry-boring insects, of which larvae of the cranberry fruitworm, *Acrobasis vacinii* Riley, and the cherry fruitworm, *Grapholitha packardii* Zeller, are the dominant species. Larvae of *A. vaccinii* infest fruit of a range of berry bearing plants, including cranberries, blueberries, beach plums, huckleberries, and dangle-berries throughout eastern North America, and westward to Wisconsin and Texas (Beckwith 1941, Neunzig 1986). In blueberries, larvae develop within the berries of a single cluster, and later in the season leave webbing and frass on the cluster (Hutchinson 1954). This damage and evidence of activity makes them the most economically important insect pest during the early part of the growing season in Michigan blueberries.

Grapholitha packardii is relatively less of a pest because it feeds on one or two berries and does not web fruit together. This species has been recorded on apple, cherry, hawthorn, and blueberry (Chapman and Lienk 1971). It is present at most commercial blueberry farms, and can be the dominant fruitworm at some sites (R.I., unpublished data). In Michigan, both species are univoltine, and larvae of *A. vaccinii* overwinter as diapausing hibernaculae under a light layer of soil and leaf litter, while *G. packardii* pupates on the plant. Adults of both species emerge from early May to mid-July, and are active nocturnally. Both species deposit single eggs in the calyx cup of unripe berries (Hutchinson 1954, Tomlinson 1970).

Tolerance among blueberry buyers for insect contamination is extremely low. If more than one cranberry fruitworm larva is detected in a sample of four pints of fruit from a single pallet on a shipment of blueberries, the entire pallet is rejected (D. Trinka, Michigan Blueberry Growers Association, personal communication). In response to the low threshold and financial risk of detecting fruitworm contamination, management is currently based on prophylactic insecticide applications in response to captures of adult moths in pheromone traps. A sampling scheme for eggs or larvae and a decision-making protocol could

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reduce insecticide treatments for fruitworms by minimizing applications to fields where they are not necessary.

Obtaining information on the abundance and spatial distribution of an insect pest is an essential step in the development of sampling protocols that will drive pest management decision-making (Binns et al. 2000). Fruitworm populations in Michigan blueberries are variable between years, between and within farms, and in the timing of their damage. Consequently, a reliable sampling scheme would provide decision-makers with a method of deciding when, and where, intervention is required, and thus avoid unnecessary insecticide applications at sites where fruitworm populations are low enough not to warrant the expense. Although pheromone lures are commercially available for monitoring males of cranberry fruitworm (McDonough et al. 1994) and cherry fruitworm (Roelofs et al. 1969), they are used to alert growers to the start of adult emergence rather than to predict population size. However, the timing of the first chemical control is often made at petal fall when the calyx cup oviposition site becomes accessible to female fruitworms, rather than if these insects are detected. The egg or early larval stages of development offer other stages to sample that may provide a more reliable measure of infestation potential, once adult populations have been detected with pheromone traps.

Whole plant or individual berry clusters are obvious potential sampling units that could be employed in blueberry fields. Visually surveying entire mature blueberry plants (a likely approach in such a high value crop, where destructive sampling would not be permitted by most growers) is inherently more time-consuming and labor-intensive than examining single fruit clusters. Therefore, the latter sampling unit may be more attractive to commercial pest managers in terms of incorporation into a decision-making component of fruitworm management.

Determining the spatial distribution of a pests' life stages allows the calculation of optimal sample sizes required to estimate population abundance at given levels of precision, defined as a fixed proportion of the mean (Southwood 1987, Pitcairn et al. 1994, Lindblade et al. 2000). This is an important first step in the development of a sequential sampling scheme. An alternative approach is to calculate the minimum number of samples needed to observe at least one insect in a fixed proportion of the samples collected. In other words, this approach could be used to estimate the number of samples needed to achieve a 95% probability of obtaining at least one pest individual (Wilson and Room 1983, Pitcairn et al. 1994). This latter method provides a basis for a binomial pest sampling scheme, in which the presence of pest individuals (and not the absolute number) is the variable of interest. In this study, we examined the utility of both of these approaches to sample size calculation in the blueberry crop system.

Another issue of importance in sampling lepidopteran pests of herbaceous fruit crops is that they are often more abundant at the border of commercial crops, because of the movement of adults and larvae from surrounding habitats (Rabb 1985). Most high-bush blueberry production in the United States occurs in low-lying habitats that consist of cleared woods or riparian areas. As a result, blueberry fields have wooded edges that often contain wild blueberries and other hosts for the fruitworm species in question. These plants may serve as a source of pest individuals colonizing commercial crops. For this reason, the development of an effective sampling scheme will require an understanding of the distribution of pest infestation relative to adjacent wooded habitat. There are currently no published data on the spatial distribution of *A. vaccinii* or *G. packardii* in blueberry or other types of agroecosystems.

The study reported here had the following four objectives: (1) to describe the distribution of eggs and larvae of *A. vaccinii* and *G. packardii* using blueberry plants and individual berry clusters as the sampling units; (2) determine optimal sample sizes needed to estimate absolute pest egg and larval abundance using either sampling unit; (3) determine the number of samples of either unit needed to ensure a 95% probability of obtaining at least one pest individual, and (4) to determine whether fruitworm population distribution is influenced by location relative to adjacent wooded habitats.

Materials and Methods

Population Sampling. Two blueberry fields at each of six blueberry farms in Van Buren and Allegan counties in Michigan were surveyed for this study. Fields contained either Bluecrop or Elliott cultivars, both of which are relatively late-maturing varieties. To achieve a range of fruitworm population densities throughout the sites, we chose to use three farms that were conventionally managed (with broad-spectrum insecticides) and three that were minimally managed (with no insecticide use or only *Bacillus thuringiensis*). Sampling of eggs and larvae began in mid-May 2000, when these insects typically begin oviposition, and was repeated weekly for eight weeks, until the end of July, when sites at the commercial farms were harvested. Analyses for each week are reported separately. To sample for eggs and larvae, six plants were sampled in each of 10 rows, to provide a 60-plant sample per field. Plants were sampled from every other row, and every other plant was sampled within a row, to provide a total sample area of 20 rows $\times$ 12 plants ($\approx$60 by 24 m). Each sampling area was located within a blueberry field adjacent to a wooded border, with the first plants sampled at the edges of the field nearest the woods.

Fruitworms were sampled from a randomly selected cluster in the top half of each plant described above, and from the whole plant. In whole-plant surveys, an observer visually scanned multiple clusters on each plant for one minute, and all fruitworm eggs or larval damage was recorded. Trained observers were able to find the eggs within the restricted sample area, but since the eggs are small and laid individually, hand

lenses (16× magnification) were used to confirm their species identity. Cranberry fruitworm eggs are unevenly ovoid, white when newly laid, turning more orange when mature. In contrast, eggs of cherry fruitworm are much flatter, spherical, mostly clear, and have a shiny exterior. Eggs of both species are laid primarily in the calyx cup, with a small percentage of *G. packardii* eggs laid on the outer edge of the rim of the calyx cup (R.I., unpublished data), providing a specific site for sampling eggs within blueberry clusters. Larval presence was identified by locating entry holes early in the season, and by the presence of webbing and/or frass on clusters later in the season. In single-cluster surveys, a cluster was visually scanned in the same manner and left on the plant. Three observers were deployed for each weekly survey. To record flight activity of adult moths, commercially available pheromone traps (Great Lakes integrated pest management [IPM], Vestaburg, MI) were baited with either cranberry fruitworm or cherry fruitworm pheromone, and were placed along the perimeter and on the inside edge of each grid sampled for eggs and larvae. The number of moths trapped was counted weekly, and the lures were changed monthly.

Statistical Analysis. Insect populations are frequently aggregated in their spatial distribution, producing clumped distribution patterns that are often described well by the negative binomial distribution (Southwood 1987). However, at low densities, counts of individuals can appear more random, and a Poisson distribution may provide a better fit (Taylor et al. 1978). Both fruitworm species in this study lay solitary eggs and the visual apparency of these species often increases dramatically as the season progresses as egg abundance and subsequent larval damage increase. Therefore, both the negative binomial and Poisson distributions were fitted to the data obtained on each sampling date. Chi-square goodness-of-fit tests were used to compare the observed distribution of the number of insects per sampling unit to the expected frequencies under either the negative binomial or Poisson distributions (Bailey 1995, Southwood 1987).

Spatial distribution patterns of egg and larval fruitworm populations were examined by fitting data from each sampling date to Taylor's power law (Taylor 1961). This is based on the observation that in aggregated populations, the variance among samples increases as a function of density. Taylor (1961) demonstrated this relationship between the variance (s^2) and the mean (m), using the power function:

$$s^2 = am^b.$$

The parameters a and b were obtained by a regression of the $\log_{10}$ of the variance against the $\log_{10}$ of the mean. The intercept of the resulting regression equation is the $\log_{10}$ of a, while the slope is b. Parameter estimates were calculated and reported for weekly counts of fruitworm eggs from the first four weeks of sampling, and for weekly counts of fruitworm larvae from the last four weeks of the total eight-week sampling period. The parameter b provides information on the nature of population distribution. Values of $b > 1$ indicate clumped (aggregated) populations, $b = 1$ indicates random distribution, and $b < 1$ indicates uniform distribution. A t-test was used to determine if b was significantly different from 1.

Taylor's power law was also used to determine the number of each type of sampling unit needed to produce a fixed level of precision, in situations where distributions are either Poisson, normal, or negative binomial (Wilson and Room 1983, Pitcairn et al. 1994). In this approach, optimal sample size is calculated as follows:

$$n = (Z_{\alpha/2}/D)^2 \cdot am^{(b-2)},$$

where n is the optimal sample size, $Z_{\alpha/2}$ is the upper $\alpha/2$ of the standard normal distribution, α is a set level of confidence required for the sample size, and D is a fixed proportion of the absolute mean of the population involved. It is also known as the allowable error, or fixed-precision level, with which the mean is measured (Lindblade et al. 2000). We used a 95% confidence interval, so that $\alpha = 0.05$ and $Z_{\alpha/2} = 1.96$ when $n > 30$. We calculated sample sizes based on two values of D; 10 and 20%.

In addition to this approach, sample sizes needed to obtain a 95% probability of obtaining at least one insect per sample can also be calculated based on

$$[P_{(0)}]^n = 0.95 - 1,$$

where $P_{(0)}$ is the probability of observing zero insects per sample and n is the sample size (Pitcairn et al. 1994). From this expression one can derive n as

$$n = \log_e(1 - 0.95)/\log_e(P_{(0)}),$$

We estimated $P_{(0)}$ after Pitcairn et al. (1994). If a population fits a Poisson distribution, then

$$P_{(0)} = e^{-m},$$

where m is the observed population mean. If a negative binomial population is assumed, $P_{(0)}$ can be calculated based on Taylor's power law, using derivations by Wilson and Room (1983) and Pitcairn et al. (1994). Here,

$$P_{(0)} = (1 + (am^b - m)/m)^{-m^2/(am^b - m)}$$

where a and b are Taylor's power law parameters. The use of each computation approach (outlined above) was based on results of the chi-square tests of distribution fits to the data. If a dual fit of both Poisson and negative binomial distributions was indicated, the formula based on an assumption of a negative binomial distribution was used, because sample sizes required for this type of distribution are always higher than those needed for populations in a Poisson distribution (Hayek and Buzas 1997). Therefore, this approach provided a conservative estimate of sample size.

The effect of plant location within fields, as a fixed treatment, was tested with repeated-measures analysis of variance (ANOVA) (using PROC MIXED, SAS Institute 1996). Before analysis, data were $\log_{10}$ transformed to correct for departures from normality. Akaike's Information Criterion was used to select the covariance structure with the best fit to the repeated-

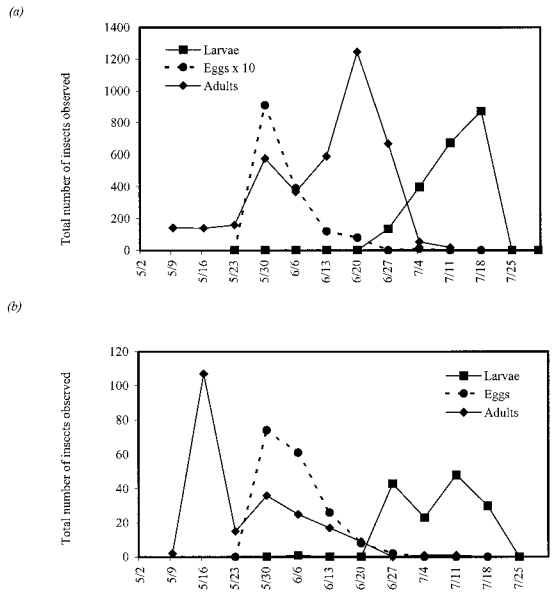

Fig. 1. Phenology of adults, eggs, and larvae of (a) *A. vaccinii* and (b) *G. packardii* in Michigan highbush blueberry fields during 2000. Results of egg and larval populations are from whole-plant surveys.

measures data (Little et al. 1997). Analyses were performed on the first four weeks' data for egg abundance, and the data for the last 4 wk for larval abundance.

Results

Both fruitworm species were detected at all twelve blueberry fields sampled, and abundance varied across these sites. The phenology of *A. vaccinii* (Fig. 1a) was similar to that of *G. packardii* (Fig. 1b); first flight, first egg, and first significant larval damage of the two species all occurred within a week. In all sites, *G. packardii* populations were far less abundant than those of *A. vaccinii* (Fig. 1; Table 1). For both fruitworm species, there was a four week period during which eggs were detected (23 May–20 June), and larval populations were most abundant between 27 June and 18 July. This indicates that there were distinct and similar periods during the population development of these two fruitworm species when eggs and larvae are present for sampling.

Sampling from either the whole plants or single clusters showed similar fluctuations in mean egg and larval populations over the sampling dates (Table 1). Chi-square tests indicated that the negative binomial distribution provided a good fit to the egg and larval count data, regardless of sampling unit used. However, data from single-cluster samples of *G. packardii* eggs and larvae were also described well by the Poisson distribution (Table 1). This duality of fit to Poisson and negative binomial distributions was also observed for *A. vaccinii* egg counts from the whole-plant samples on some dates (Table 1).

Application of Taylor's power law to data from whole-plant samples yielded $b > 1$ on most dates for both fruitworm species (Table 2), indicating a clumped (negative binomial) distribution. These results were thus in general agreement with those of the chi-square tests. Data from single-cluster samples, however, produced b coefficients that were often significantly less than one, suggesting a uniform distribution where random distribution had been indicated by the chi-square tests. However, in the case of *A.*

Table 1. Goodness-of-fit parameters for either the Poisson or negative binomial distributions, derived from counting *A. vaccinii* and *G. packardii* eggs and larvae, from either whole-plant or single-cluster samples

		Whole-plant samples				Single-cluster samples			
Date	Life stage	Mean no. per plant	s^{2a}	χ (p)^b	χ (nb)^c	Mean no./cluster	s^{2a}	χ (p)^b	χ (nb)^c
				A. vaccinii					
30 May	Eggs	0.13	0.191	31.42	0.533*	0.11	0.129	3.84	0.7*
6 June	Eggs	0.05	0.052	1.00*	0*	0.09	0.118	6.11	0.8*
13 June	Eggs	0.02	0.017	0.11*	0*	0.03	0.02	0.04*	0.01*
20 June	Eggs	0.01	0.031	5360.2	3.92*	0.02	0.02	0.02*	0.0*
27 June	Larvae	0.23	0.38	39.98	0.525*	0.14	0.142	0.07*	0.06*
4 July	Larvae	0.69	7.14	257.38	12.86*	0.26	0.3	2.49	1.69*
11 July	Larvae	0.97	4.96	735.97	15.08*	0.35	0.448	8.7	3.88*
18 July	Larvae	1.25	13.99	1311.45	11.78*	0.22	0.272	7.61	3.22*
				G. packardii					
30 May	Eggs	0.09	0.1	5.62	0.85*	0.08	0.084	0.34*	0.07*
6 June	Eggs	0.09	0.1	5.66	0.85*	0.16	0.151	0.13*	0.02*
13 June	Eggs	0.04	0.042	5.4	0.23*	0.05	0.065	5.67	0.36*
20 June	Eggs	0.01	0.017	16.89	0.24*	0.02	0.02	0.02*	0.01*
27 June	Larvae	0.07	0.1	23.45	0.35*	0.05	0.048	0.13*	0.0*
4 July	Larvae	0.04	0.05	6.01	0.27*	0.03	0.03	0.05*	0.0*
11 July	Larvae	0.07	0.128	55.72	0.17*	0.03	0.025	0.04*	0.0*
18 July	Larvae	0.04	0.056	114.6	1.08*	0.02	0.017	0.017*	0.0*

Values followed by an asterisk show a significant fit to the distribution ($P < 0.05$).
[a] Variance.
[b] Chi-square value for the Poisson distribution.
[c] Chi-square value for negative binomial distribution.

Table 2. Taylor's law parameters and optimal sample sizes for whole-plant and single-cluster samples of *A. vaccinii* and *G. packardii* eggs and larvae

Insect stage	Date	r^2	df	a^a	b^a	SE (b)	n1[b]	n2[c]	n3[d]
				Whole plant samples					
A. vaccinii									
Eggs	30 May	0.94	7	1.01	1.30*	0.113	78,337	19,584	16
Eggs	6 June	0.96	10	1.01	1.09	0.070	1,673,615	418,404	47
Eggs	13 June	1.00	10	1.00	0.97*	0.005	88,405,253	22,101,313	176
Eggs	20 June	0.92	10	1.00	1.97*	0.166	2,466,647	616,662	53
Larvae	27 June	0.97	10	1.01	121*	0.064	21,560	5,390	11
Larvae	4 July	0.99	10	1.15	2.42*	0.069	775	194	4
Larvae	11 July	0.98	10	1.00	1.33*	0.061	385	96	3
Larvae	18 July	0.99	10	1.07	1.88*	0.053	252	63	3
G. packardii									
Eggs	30 May	0.97	7	1.01	0.99	0.063	458,451	114,613	32
Eggs	6 June	0.98	10	1.01	1.20*	0.057	364,395	91,099	27
Eggs	13 June	0.98	10	1.00	1.12*	0.054	4,794,922	1,198,730	66
Eggs	20 June	0.99	10	1.00	1.26*	0.040	52,797,062	13,199,265	135
Larvae	27 June	0.91	10	1.00	1.12*	0.108	599,255	149,814	33
Larvae	4 July	0.99	10	1.00	1.06*	0.029	3,913,497	978,374	63
Larvae	11 July	1.00	10	1.01	1.45*	0.024	385,070	96,267	26
Larvae	18 July	0.95	10	1.00	1.11*	0.073	3,655,976	913,994	60
				Single cluster samples					
A. vaccinii									
Eggs	30 May	0.93	7	1.00	1.30*	0.117	149,524	37,381	20
Eggs	6 June	1.00	10	1.00	0.95*	0.005	431,134	107,783	30
Eggs	13 June	1.00	10	1.00	1.00	0.000	14,231,425	3,557,856	100
Eggs	20 June	1.00	10	1.00	0.98	0.000	51,929,191	12,982,298	150
Larvae	27 June	1.00	10	1.00	0.85*	0.020	188,456	47,114	21
Larvae	4 July	0.88	10	1.00	1.08	0.117	19,638	4,909	11
Larvae	11 July	0.95	10	1.01	0.84*	0.060	10,648	2,662	9
Larvae	18 July	0.99	10	1.00	1.16*	0.035	28,336	7,084	12
G. packardii									
Eggs	30 May	1.00	7	1.00	0.94*	0.005	873,689	218,422	37
Eggs	6 June	1.00	10	1.00	0.96*	0.005	100,969	25,242	19
Eggs	13 June	1.00	10	1.00	0.98*	0.004	3,263,193	815,798	60
Eggs	20 June	1.00	10	1.00	0.97	0.000	53,999,701	13,499,925	150
Larvae	27 June	1.00	10	1.00	0.98*	0.002	3,263,118	815,779	60
Larvae	4 July	1.00	10	1.00	0.98*	0.003	15,262,158	3,815,540	100
Larvae	11 July	1.00	10	1.00	1.00	0.000	14,228,148	3,557,037	100
Larvae	18 July	1.00	10	1.00	1.00	0.000	48,020,000	12,005,000	150

Values of b that are significantly different from 1 are followed by * ($P < 0.05$).
[a] a and b are calculated parameters of Taylor's power law where $s^2 = am^b$.
[b] Sample size needed for 10% fixed precision.
[c] Sample size needed for 20% fixed precision.
[d] Sample size needed for 95% probability of obtaining at least 1 insect per sample.

vaccinii eggs, even single-cluster samples showed b values >1 for the first sampling date, a result consistent with all other analyses.

When data were analyzed using Taylor's power law to determine the optimal sample sizes, very large values of n were calculated (Table 2). For example, even when insect eggs were comparatively abundant, as was the case for *A. vaccinii* on 30 May, over 19,000 whole-plant samples and over 37,000 cluster samples would be needed to obtain 20% fixed-precision in sampling, and sample sizes needed for 10% precision are often orders of magnitude greater (Table 2). The large number of samples required for even 20% precision of the absolute population means is a result of the very low population density for eggs and larvae of these species (see mean values in Table 1).

Analyses to determine the number of samples needed to observe at least one insect in 95 out of 100 samples showed that the required sample size was considerably lower than that calculated for obtaining estimates of the population mean. Using whole-plant samples, only 16 samples were needed to achieve a 95% probability of observing one *A. vaccinii* egg in every sample, and even with the single-cluster sampling method, only 20 samples were needed (Table 2). Sample size requirements for single-cluster sampling units were higher but were never >200 for any life stage of either fruitworm species. Sample sizes needed for 95% probability of obtaining eggs in every sample never exceeded 50 for either species, for either sampling unit (Table 2).

Repeated-measures analysis of the effect of plant location within fields on fruitworm abundance yielded different results for each species. Analysis of whole plant samples showed that the abundance of *A. vaccinii* eggs varied with plant location within the fields ($F = 2.33$; df = 5, 684; $P = 0.041$). *A. vaccinii* eggs were most abundant adjacent to the wooded borders, with abundance decreasing with distance from the edge (Fig. 2a). However, this was not the case for *A. vaccinii*

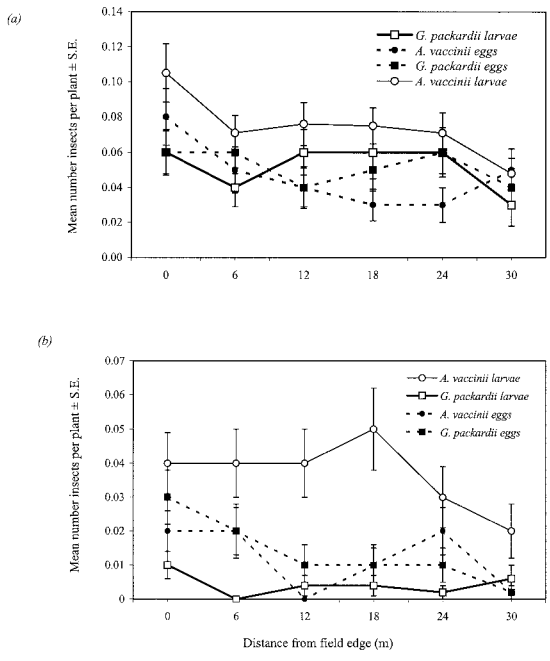

Fig. 2. Fruitworm abundance on blueberry plants, relative to wooded field edges, as estimated by (a) whole-plant sample units, and (b) single-cluster sample units. Note that values are summed over rows and fields sampled, and means for *A. vaccinii* larvae observed in the whole-plant sample units are shown divided by 10 to allow depiction on one graph.

larvae ($F = 2.17$; df = 5, 684; $P = 0.056$), or *G. packardii* eggs ($F = 0.58$; df = 5, 684; $P = 0.714$) or larvae ($F = 0.7$; df = 5, 684; $P = 0.622$), and their abundance was not significantly greater nearest the woods (Fig. 2a). When single-cluster samples were analyzed, similar effects of proximity to wooded borders were observed, and only the density of *A. vaccinii* eggs was significantly influenced by plant location ($F = 2.38$; df = 5, 678; $P = 0.038$). Although plots of mean values from single-cluster data (Fig. 2b) suggest increases in larval populations inside fields, these changes were not significant when ANOVA was used to incorporate repeated-measures effects.

Sampling date was a significant factor in the ANOVA model for all dependent variables ($P < 0.001$), regardless of sampling unit used, except for *G. packardii* larvae, which were relatively scarce in the samples ($F = 2.33$; df = 3, 1,143; $P = 0.073$ for whole-plant samples; $F = 1.16$; df = 3, 1,163; $P = 0.325$ for single-cluster samples). No significant interaction between sampling date and plant location was detected for any of the data analyzed, from either the whole-plant or single-cluster samples.

Discussion

This study demonstrates that the eggs and larvae of *A. vaccinii* and *G. packardii* have a generally aggregated distribution in highbush blueberries. Dual fits of the data to both the Poisson distribution and the negative binomial distribution were likely due to the very low populations of insects observed on these dates, particularly with the single-cluster samples. This overlap of Poisson and negative binomial distributions for very low population densities is not unusual, and has been noted previously (Taylor et al. 1978, Taylor 1984). The low densities may also account for the indication of uniform distribution that Taylor's power law parameters gave, which occurred more often with the single-cluster samples. This suggests that whole-plant samples, in which multiple clusters are sampled, are more reliable as a method for detecting population distributions of these insect species when densities are low. The Poisson distribution did not fit the data on populations of *A. vaccinii* eggs recorded from either sampling unit in the first week of surveys, indicating that this life stage of *A. vaccinii*, in particular, is strongly aggregated early in the season.

Estimates of sample sizes required to achieve sample values within even 20% of the population mean (i.e., 20% fixed-precision), indicated that thousands of either sampling unit would have to be examined, particularly for the egg stage of both fruitworm species. Such large sample sizes are clearly impractical for routine pest monitoring. In contrast, the number of samples needed to ensure a 95% probability of obtaining at least one insect in every sample was considerably lower for at least the first two weeks of egg populations of both pest species, regardless of sampling unit used. Calculations indicate that the number of samples needed in the first two weeks of the fruitworm season would not exceed 50, regardless of the sample unit involved (Table 2). Detection of eggs early in the growing season is likely to be crucial for a sampling scheme, in that it can be used to direct pest control before any fruit are infested. Thus, an approach based on the probability of detection produces a far more manageable number of samples for practical use in a sampling scheme for fruitworm management.

This study also revealed variation in fruitworm abundance with distance from the wooded field edges. *A. vaccinii* eggs were more abundant on plants nearest the wooded edges, a pattern not seen for *G. packardii* eggs, or larvae of either species. The significant effect of sampling date on most of the insect populations surveyed was not unexpected, since egg populations of both fruitworm species declined steadily over the sampling dates included in the analysis, while larval populations steadily increased. Only larvae of *G. packardii* did not show this trend, and remained at similar, low levels across the season (see Table one for means).

The difference in egg abundance of these species may be due to the presence of wild host plants more suitable for *A. vaccinii* than for *G. packardii* in wooded edges. Host plants for *A. vaccinii* that are not known to host *G. packardii* include cranberries, beach plums (*Prunus maritima*) and dangle-berries (*Gaylussacia frondosa*) (Beckwith 1941). These wild hosts would provide sources of adults that could recolonize fields as the season progresses. However, wild hosts were not sampled for either species, and the source of im-

migrating adult moths remains unknown. The greater abundance of *A. vaccinii* eggs at the borders was not seen in the larval stage, and this change may have been caused by border insecticide treatments to some of the sampled fields. Larvae are unlikely to move far from the position of eclosion, and behavioral observations have shown that most neonate *A. vaccinii* bore into the berry on which the egg was laid (R.I., unpublished data).

This study provides the foundation for the development of sequential sampling plans for use in an IPM program targeting fruitworm pests of blueberry. Future work will aim to construct such plans based on the sample sizes calculated for 95% probabilities of obtaining an insect in each sample, i.e., using a binomial approach which incorporates the proportion of infested samples observed (Jones 1994, Naranjo et al. 1996). Our future work will also focus on predicting phenology of these pests using degree-day models, and understanding the relationship between larval infestation at harvest with egg and adult populations. Development of a sampling plan for fruitworms will contribute to a comprehensive and proactive IPM program for highbush blueberries to reduce reliance on synthetic insecticides.

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