Predictive Model for Strawberry Bud Weevil (Coleoptera: Curculionidae) Adults in Strawberry Fields

N. J. BOSTANIAN,[1] M. BINNS,[2] J. KOVACH,[3] G. RACETTE,[1] AND G. MAILLOUX[4]

Environ. Entomol. 28(3): 398–406 (1999)

ABSTRACT Three different sampling methods (sweep net, D-Vac, tapping into a carton container) were evaluated for *Anthonomus signatus* Say in strawberry fields. The results suggest that sampling with a sweep net reflects population numbers best. A predictive model for adult abundance was developed to describe and predict population build-up. The strawberry fields used in the study were in their 2nd yr of production. Overwintering adults generally begin to appear in a strawberry field ≈300 cumulatitive degree-days (DD) calculated from 1 April at temperatures above 0°C. These weevils attain maximum abundance anywhere from 500 to 670 DD. Within that interval, a treatment with cypermethrin or chlorpyriphos was effective against this pest. The summer generation attained maximum abundance anywhere from 1,250 to 1,650 DD. A treatment with chlorpyriphos at 1,679 DD reduced the summer generation of weevils and decreased clipped buds in the field the following year.

KEY WORDS *Anthonomus signatus*, predictive model, adult abundance, management

THE STRAWBERRY BUD weevil, *Anthonomus signatus* Say, is 1 of 2 key insect pests of strawberries in Northeastern North America. The other is the tarnished plant bug, *Lygus lineolaris* (Palisot du Beauvois). Overwintering weevils have been reported on strawberries from mid-May to the end of June with maximum abundance toward the end of May in Quebec (Rivard et al. 1979). In New York, these events occur ≈2 wk earlier (Kovach et al. 1993).

Decreases in yield can be dramatic depending on cultivar. Losses in Quebec range from 10 to 70% (Paradis 1979). In New York, strawberry yield reductions range from 50 to 100% (Schaefers 1978). Early maturing cultivars are more susceptible to injury than late maturing cultivars (Dorval 1938). The biology of this insect was described by Mailloux and Bostanian (1993). They confirmed earlier observations that the insect had 4 distinct nonoverlapping stages of development (egg, larva, pupa, adult) (Clarke and Howitt 1975). Furthermore, Mailloux and Bostanian (1993) showed that a 1:1 sex ratio was prevalent throughout spring and summer. The maximum abundance of each developmental stage was determined in relation to cumulative degree-days (DD). Currrently, monitoring is carried out very early in the spring by counting the number of cut buds per flower cluster per linear meter and comparing this with a tentative action threshold of 2 clipped buds per meter (Kovach et al. 1993), although some recent work suggests that this threshold is too low (Pritts et al. 1999). However, as weevil populations increase from zero to threatening numbers within a very short period (Mailloux and Bostanian 1993), management action based on damage alone risks being very late. Because there is no generally accepted sampling technique and the timing of control measures is difficult, many growers make a prophylactic treatment at the onset of buds, to be followed by a 2nd prophylactic treatment just before bloom.

This study was used to evaluate 3 different sampling techniques to estimate the abundance of this insect. Abundance data were collected to develop a predictive model (based on degree-days) to estimate when adult beetles would first be seen and when peak abundance could be expected to occur. Management control based on the results was then validated using data collected in Quebec and New York during 1994.

Materials and Methods

Model Development. Field observations were made twice a week from early May to the end of August in 1976 and 1987–1991 in strawberry fields not treated with insecticides. The fields were in their 2nd yr of production and their sizes ranged from 0.5 to 0.75 ha. They were situated at L'Assomption, Frelighsburg, Lavaltrie (near Montreal), St. Louis de Terrebonne, and St. Augustin (near Quebec city). They represent the major strawberry-growing regions of Quebec.

Eighteen sets of data on strawberries (15 on 'Redcoat' and 3 on 'Bounty') were collected over a period of 15 yr from the above mentioned locations (Table 1). Counts were made by walking a W-shaped pattern across the field and collecting samples. The following

[1] Horticulture Research and Development Centre, Agriculture and Agri-Food Canada, Saint-Jean-sur-Richelieu, QC, Canada J3B 3E6.
[2] Eastern Cereal & Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa, ON, Canada K2C 1Y2.
[3] New York State Agriculture Experiment Station, Cornell University, Geneva, NY 14456–0462.
[4] Institut de Recherches et de Développement, en Agro-Environnement, Saint-Hyacinthe, QC, Canada J2S 480.

Table 1. Methods, cultivar, and year used to collect data in Quebec, Canada

Series	Method	Location	Year	Cultivar	No. of sample units
N_1	Sweep net	l'Assomption	1985	Redcoat	42
N_2	Sweep net	l'Assomption	1986	Redcoat	22
N_3	Sweep net	l'Assomption	1987	Redcoat	20
C_1	Container tapping	St-Augustin	1983	Redcoat	24
C_2	Container tapping	St-Augustin	1983	Bounty	24
C_3	Container tapping	Lavaltrie	1984	Redcoat	24
C_4	Container tapping	St-Louis de Terrebonne	1985	Redcoat	24
C_5	Container tapping	Frelighsburg	1986	Redcoat	19
C_6	Container tapping	Frelighsburg	1987	Redcoat	21
C_7	Container tapping	Frelighsburg	1988	Redcoat	24
C_8	Container tapping	Frelighsburg	1989	Redcoat	32
C_9	Container tapping	Frelighsburg	1990	Redcoat	25
C_{10}	Container tapping	Frelighsburg	1991	Redcoat	38
D_1	D-Vac	l'Assomption	1981	Redcoat	34
D_2	D-Vac	l'Assomption	1981	Bounty	33
D_3	D-Vac	l'Assomption	1982	Redcoat	41
D_4	D-Vac	l'Assomption	1982	Bounty	41
D_5	D-Vac	Frelighsburg	1976	Redcoat	32

3 sampling techniques were used: (1) 200 suctions with a D-Vac insect aspirator (D-Vac, Riverside, CA). (2) Two hundred sweeps with a 71 cm long heavy duty muslin insect net. That was D-shaped and had a 38 cm diameter. (3) Tapping 100 flower clusters twice each over a carton container (500 ml capacity and 10 cm diameter); the number of weevils present was recorded and the weevils were allowed to escape.

No samples were recorded from the edges of the fields, and all sampling was done between 10.00 and 13.00 hours on sunny days. In 2 of the sets, replicate sets of 100 container tappings were taken to assess

Fig. 1. Data from the 3 sampling techniques (C, container tapping; N, sweep net; D, D-Vac).

Table 2. Fitted parameters of the abundance model

Series	M_1	μ_1	γ_1	θ_1 ($\times 10^3$)	M_2	μ_2	γ_2	θ_2 ($\times 10^3$)
N_1	69.2	429	28.1	5.67	73.7	1197	218	5.53
N_2	65.5	428	58.9	6.31	257	1467	407	96.9
N_3	37.1	451	58.1	4.49	73.7	1185	661	7.62
AllN	49.8	43.3	40.9	5.07	56.2	1230	213	6.50
C_1	127	483	6.83	12.6	484	1374	405	9.04
C_2	13.7	485	36.8	11.0	53.5	1306	871	9.79
C_3	134	670	27.0	33.4	252	1456	152	58.8
C_4	90.3	581	66.1	8.20	606	1500	560	84.3
C_5	25.1	533	97.1	6.23	137	1467	219	75.2
C_6	13.3	450	45.8	4.41	202	1206	119	21.0
C_7	20.8	484	498	3.33	93.3	1492	47556	11.9
C_8	35.9	484	110	3.24	61.6	1566	811	5.74
C_9	25.7	416	6.01	4.45	68.6	1415	7374	8.56
C_{10}	176	578	9.73	14.1	121	1480	118	30.8
D_1	63.7	392	30306	2.04	1226	1364	234	32.0
D_2	127	392	48634	1.43	187	1361	3130	7.77
D_3	96.3	355	13.2	6.79	80.7	1300	3594	6.99
D_4	24.4	279	7390	3.76	14.5	1262	4913	2.73
D_5	24.3	526	164	3.98	2881	1395	434	234

sampling variability. Table 1 summarizes the location, year, cultivar, and number of samples per plot. A *sample* refers to 200 suctions (D-Vac), 200 sweeps (net sampling), or 100 tappings (tapping into carton containers).

Ambient air temperature data were obtained from Environment Canada weather stations located <8 km away from each strawberry field. Cumulative degree-days above 0°C from 1 April to the end of August were calculated using the Baskerville and Emin (1969) method.

Various preliminary attempts were made to relate the seasonal abundance data to temperature and precipitation, but temperature was clearly the factor influencing development. The relationship between sample counts and degree-days was initially estimated by smoothing the data (Gaussian kernal method) using Mathcad (Mathsoft 1995) separately for each sample method (container, net, D-Vac). The results indicated so much variability within each method (Fig. 1) that fitting an overall model was deemed inappropriate except possibly for net sampling. Therefore, the model was fitted to each series of data separately and also to all net samples together.

Numerous abundance models have been suggested for variability of agricultural pest populations throughout the season based on thermal summation units (Niemczyk et al. 1992, Cockfield et al. 1994). We chose to adapt models intended for estimating life histories (Kempton 1979, summarized in Manly 1990). The adaptation was to reduce the model from predicting all life stages to predicting only the adult stage. The derivation of the model for $N(t)$, the total number of adults found at time t, follows. Because the data were totals of a large number of suctions, sweeps, or tappings, a Poisson distribution for $N(t)$ was assumed. The goodness-of-fit of the model was assessed by the residual deviance (McCullagh and Nelder 1989). The deviance is comparable to the residual error sum of squares in linear regression, but is dimensionless; if everything fits well, the mean deviance (comparable

Fig. 2. Fitted curves for 3 net tapping series: N_1, N_2, and N_3. Square brackets in N_1 and N_2 indicate 1st and 3rd quartiles of the distribution of spring emergence from cages (Mailloux and Bostanian 1993).

Table 3. Estimates in cumulative degree days (DD) for the 1st adult emergence in spring and maximum abundance of summer generation

Series	DD for 1 emergence	DD at spring peak	DD at summer peak
N1	274	508	1282
N2	325	487	1471
N3	346	530	1244
Mean	315	508	1332
Standard error	37	22	122
All sweep net data	307	511	1311
C1	158	484	1438
C2	385	537	1356
C3	422	672	1463
C4	434	645	1509
C5	441	601	1475
C6	360	535	1238
C7	502	587	1508
C8	404	566	1639
C9	229	486	1488
C10	237	663	1523
Mean	357	578	1464
Standard error	111	68	107
D1	338	460	1388
D2	338	463	1403
D3	171	426	1341
D4	224	296	1393
D5	453	599	1393
Mean	305	449	1384
Standard error	110	108	24

Table 5. Deviance goodness-of-fit values for the overall model, and within-date error deviance values where data were available

Series	Overall			Within date		
	Residual deviance[a]	df	Mean deviance[b]	Residual deviance	df	Mean deviance
N_1	73*	34	2.2			
N_2	23	14	1.7			
N_3	18	12	1.5			
C_1	106*	16	6.7			
C_2	15	16	0.9			
C_3	33*	16	2.1			
C_4	75*	16	4.7			
C_5	20*	11	1.8			
C_6	19	13	1.5			
C_7	32*	16	2.0	40*	6	6.7
C_8	110*	24	4.6			
C_9	51*	17	3.0			
C_{10}	148*	30	4.9	21	14	1.5
D_1	159*	26	6.1			
D_2	166*	25	6.6			
D_3	163*	33	4.9			
D_4	218*	33	6.6			
D_5	77*	24	3.2			

*, Significant ($P < 0.05$) departure from Poisson.
[a] To be tested as chi square (deviance is dimensionless).
[b] Residual deviance divided by degrees of freedom.

to the error mean square) should be equal to 1, and the deviance can be tested as χ^2. For the 2 datasets where extra data had been collected (Table 1: C_7, C_{10}), a within-date residual deviance was also calculated for comparison. Genstat (1996) was used for all these calculations.

Data for spring emergence of adults from cages reported in Mailloux & Bostanian (1993) were collected during the same time and at the same location as 4 of the datasets. The data from the emergence cages were compared with the fitted model (based on sample data) around the time of spring emergence to check for consistency.

Derivation of the Abundance Model. The basic life-stage model suggested by Kempton (1979) takes the following form: the probability that an individual is in stage *j* at time *t* (i.e., is at that stage, in the field and able to be sampled) can be written as the product of the following: (1) the probability that at time *t* it has matured to but not passed stage *j*, and (2) the probability that it has not died in the meantime. Because we are interested only in the adults, "stage *j*" is the emerging adult, so we rewrite (1) above as follows: (1a) the probability that it has emerged by time *t*.

Two mathematical formulations of this have been mentioned in the literature. In one, the possibility of dying is deemed to begin when the "experiment begins," which here would be 1 April when degree-days = 0 (Manly 1990, p. 60). In the other, the possibility of dying is deemed to begin when the "individual emerges," which would be after 1 April (Manly 1990, p. 52). Although, in several instances including the version used here, there is no formal difference between the representations, we chose the 2nd as being more appropriate for the weevil data. Thus, an appropriate model has an emergence distribution, defined by the probability density $f(x)$:

Probability that an individual emerges at time x, along with a survival distribution, defined by the probability density $w(t - x)$,

Probability that an individual survives from time x to time $t = w(t - x)$.

Thus, the probability of emerging at time x and then surviving for a further time $(t\text{-}x)$ can be written as $f(x)$

Table 4. Control of the strawberry bud weevil on strawberry, 1994

	Spring treatment						Summer treatment	
	Frelighsburg				Geneva		Geneva	
	No. of berries	Injured,[a] %	No. of berries	Injured,[b] %	No. of berries	Injured,[c] %	No. of berries	Injured,[d] %
Treated	627	0.5	538	2.2	695	0.9	695	1.6
Control	691	9.1	545	13.2	695	5.6	695	5.6

[a] 10 d after treatment (Ripcord 400 EC applied on 3 July 1994 [549 DD] at 188 ml/ha).
[b] 26 d after treatment (Ripcord 400 EC applied on 3 July 1994 [549 DD] at 188 ml/ha).
[c] 17 d after treatment (Lorsban 4 E applied on 27 May 1994 [566 DD] at 2,336 ml/ha).
[d] 1 yr after treatment (Lorsban 4 E applied on 22 July 1993 [1679 DD] at 2,356 ml/ha).

Fig. 3. Fitted curves for 6 container tapping series, C_1–C_6. Square brackets in C_5 and C_6 indicate 1st and 3rd quartiles of the distribution of spring emergence from cages (Mailloux and Bostanian 1993).

$\times\ w\ (t - x)$. When this formula is integrated over values of x less than or equal to t, the probability of having emerged and still being alive at time t can therefore be written as

$$p(t) = \int_0^t f(x)\, w(t - x)\, dx.$$

This formulation was used for both spring and summer generations. Emergence for the 1st generation refers to emergence from winter diapause, and for the summer generation it refers to emergence from the pupa. Of course, the parameters of the probability density functions are different for spring and for summer.

Several distributions have been proposed for $f(x)$ (e.g., gamma, Gaussian, inverse Gaussian). For the bud weevil, the Gaussian distribution was rejected because it is symmetric. Both gamma and inverse Gaussian were tried, but $f(x)$ represented by the gamma distribution was found to fit the data better. Like Manly (1990, p. 50) we used $w(t) = \exp(-\theta t)$. Thus, the formula for $p(t)$ is

$$p(t) = \int_0^t g(\mu, \gamma, x) \exp(-\theta[t - x])\, dx, \qquad [1]$$

where $g(\mu, \theta, x)$ is the gamma probability distribution function with mean μ and exponent γ:

$$g(\mu,\gamma,x) = \frac{\left(\frac{\gamma}{\mu}\right)^{\gamma} x^{\gamma-1}\, e^{-\frac{\gamma x}{\mu}}}{\Gamma(\gamma)}.$$

The expression for $p(t)$ in equation 1 can be reparameterized so that the formula for emergence and mortality are mathematically separate.

$$p(t) = \int_0^t \frac{\left(\frac{\gamma}{\mu}\right)^{\gamma} x^{\gamma-1}\, e^{-\frac{\gamma x}{\mu}}}{\Gamma(\gamma)}\, e^{-\theta(t-x)}\, dx, \qquad [2]$$

$$= \left(\frac{\gamma}{\gamma - \mu\theta}\right)^{\gamma} e^{-\theta t} \int_0^t g(m, \gamma, x)\, dx,$$

where

$$m = \frac{\gamma\mu}{\gamma - \mu\theta}.$$

However, for much of the bud weevil data, this formula (equation 2) cannot be used numerically because the emergence probability factor [the integral of $g(m,\gamma, x)$] is often very small, whereas the other

Fig. 4. Fitted curves for 4 container tapping series, C_7–C_{10}.

factor is very large, causing unacceptable round-off errors. Therefore, the complete integral of equation 1 had to be approximated by numerical quadrature. Using a 3-point Simpson rule (Abramowitz and Stegun 1972) for each interval between sampling times gave poor precision, especially at the beginning of the season, so the season was divided into 50 intervals, the function estimated by 3-point Simpson rules in each, and interpolated at the sample times.

Based on the above formulation, 1st- ($i = 1$) and 2nd- ($i = 2$) generation adults were modeled using the same basic formulae, but with different parameters:

$$p(t, \mu_i, \gamma_i, \theta_i) = \int_0^t g(\mu_i, \gamma_i, x) \exp(-\theta_i[t - x])\, dx \quad [3]$$

and the complete model for $N(t)$, the total number found at time t, is a weighted sum of these.

$$N(t) = M_1 p(t, \mu_1, \gamma_1, \theta_1) + M_2\, p(t, \mu_2, \gamma_2, \theta_2) \quad [4]$$

The parameters to be fitted are as follows: μ_i = mean of the emergence distribution in generation i, γ_i = exponent parameter of the emergence distribution for

Fig. 5. Fitted curves for 5 D-Vac series: D_1–D_5.

generation i, θ_i = mortality parameter for generation i, M_i = constants, 1 for each generation.

Model Validation. The individual fitted models were used to estimate key pest management indicators of abundance: time (degree-days) of appearance of 1 adult in spring, time of peak spring abundance, and time of peak summer abundance. In 1994, 2 of these indicators (peak spring and summer abundance) were evaluated in Frelighsburg, Quebec, and Geneva, NY. A 3-yr-old (2nd yr of production) cultivar 'Glooscap' strawberry plot was used in Quebec and a similar but slightly larger plot containing 'Earliglow', 'Allstar', and 'Honeoye' was used in New York. At each location, the plots were divided such that one half was treated according to the model, and the other half was left untreated as a control. At both locations, the control plots received no insecticide treatments for this or any other pest. For the treated plots at Frelighsburg, cypermethrin (Ripcord 400 EC[emulsifiable concentrate] [American Cyanamid, Wayne, NJ]) was applied to 0.05 ha at 188 ml/ha when 549 DD had been accumulated and berry clusters were examined twice. The 1st observation was 10 d after treatment and the 2nd was at harvest. At Geneva, chlorpyriphos (Lorsban 4 E [emulsifiable] [Dow-Elanco, Indianapolis, IN]) was applied to 0.09 ha at 2,336 ml/ha, when 566 DD (27 May) had been accumulated. One hundred berry clusters from each plot were examined for clipped berries at 4 different times (31 May, 2 June, 7 June, and 13 June). Moreover, a summer treatment, at 1,679 DD on 22 July 1993, was also carried out in New York against the summer adults before they entered into reproductive diapause and disappeared on or into the soil. The following year, berries from this treated field were compared with berries from an adjacent control plot.

Results

The fitted parameters of the abundance model are shown in Table 2. The fitted curves are presented in Figs. 2–5. The lower and upper quartiles of the distribution of spring emergence in cages (Mailloux and Bostanian 1993) are plotted in the figures for N_1, N_2, C_5, and C_6.

	Lower quartile, DD	Median, DD	Upper quartile, DD
N_1	286	320	419
N_2	367	375	390
C_5	411	454	581
C_6	375	398	509

Estimated times for finding the 1st spring adult and for spring and summer peaks are shown in Table 3. The

expected time in spring for finding the 1st emerging adult (using any one of the 3 sampling techniques) was found to be between 300 and 350 DD, although with anything but sweep net the variability was high. Expected time for spring peak ranged from around 450 DD (D-Vac), 510 DD (sweep net) to 580 DD (container tapping), with high variability except with sweep net. Expected time for the summer peak ranged from around 1,310 DD (sweep net), 1,380 DD (D-Vac) to 1,460 DD (container tapping), with high variability except for D-Vac.

Results from the 2 field evaluations are presented in Table 4. With a spring treatment in Geneva, 0.9% of the buds were clipped in the treated plot, 17 d after treatment, compared with 5.6% in the untreated control plot. At Frelighsburg, the percentages of clipped berries were 0.5% in the treated plot and 9.1% in the untreated control plot 10 d after treatment. At harvest time these percentages increased to 2.2 and 13.2%, respectively. In the summer treated plot (1,679 DD), 1.3% of the berries were clipped, the following year in Geneva, whereas, in the control plot the percentage of clipped berries was 5.6%.

Discussion

Fitting the Model. Sample estimates of population sizes varied considerably among the series of data. Maximum values for 100 container tappings ranged from <10 (C_2) to >60 (C_4) among spring generation data, and from <10 (C_5) to around 200 (C_1) among summer generation data. In some datasets the peak spring generation densities were much larger than the summer ones (e.g., N_2), in some they were similar (e.g., C_4, C_8), and in others the peak summer densities were much larger (e.g., C_1, C_2). It is not surprising therefore that the fitted parameter values varied greatly from one dataset to another.

The 2nd-generation data seemed to fit the model better than the 1st-generation data (Figs. 2–5). In the spring, the distribution is likely to be more patchy than in the summer because of adults emerging not only from the strawberry field but also from surrounding fields and brush. There was much variability in the data: samples taken only a few degree-days apart from each other occasionally provided greatly differing estimates of abundance, which could not be accounted for by any reasonable model (for example, D_2 between 500 and 900 DD, and C_5 around 1,500 DD). This variabilty is reflected in the goodness-of-fit tests for the models (Table 5). The D-Vac data appear to be especially variable. The sweep net data fitted better than the container tapping data, but the larger number of net sweeps (200) than container tappings (100) may account for that. In 2 of the datasets where container tapping was used, it was possible to estimate "within date" variability (Table 5). Comparison with the Poisson model indicated large heterogeneous variabilty among samples. Heterogeneity beyond that expected from a Poisson distribution may have contributed to the variability of data points around the curves as, for example in C_4, C_7–C_{10}.

In most sampling situations, the mean count from a sample consisting of 100 sampling units would have relatively small variance, and would be a good predictor of actual abundance. The fact that there was heterogeneity above the Poisson level implies that the variability among individual counts was extremely large. In general, variability was least for net sampling, higher for container sampling, and very high for D-Vac sampling (Table 5). It is possible that D-Vac sampling, holding the apparatus just above the plant canopy, is harder to perform consistently. For this reason, we paid less attention to the D-Vac results.

Future work on estimating density of *Anthonomus* sp. would need to consider these and other complications. For example, *A. pomorum* displayed predominantly nocturnal behavior patterns in both laboratory and field studies (Duan et al. 1996). Therefore, for such species, the numbers of individuals that can be sampled on the plants during the day may not represent a constant proportion of the true population, thus increasing sample variability.

Pest Management. For the cultivars examined here, harvest takes place approximately between 950 and 1,500 DD (Mailloux and Bostanian 1991), so the bud weevil affects harvest only through its 1st generation. Figs. 2–5 and Table 3 show that the spring generation attains maximum abundance anywhere from 500 to 670 DD above 0°C.

The results in Table 4 suggest that control measures based on degree-days can be effective in maintaining weevil populations at low numbers and thus reduce berry loss. A summer treatment after harvest is an interesting concept and the results shown here look promising but further research needs to be done. If such a pest management program becomes viable, it means that no pesticides would be needed against this pest before the berries are picked, and several insecticides that cannot be used currently because of residue considerations could then be used without much concern, because these would be applied a year before harvest.

A pesticide intervention may not always be necessary, especially in the 1st yr of harvest. However, for the 2nd yr of harvest, the results of this study indicate that the optimal time of chemical treatment to control the strawberry bud weevil is between 500 and 670 DD above 0°C calculated from 1 April. The beetles may be sampled either by sweeping or tapping into carton box of 500-ml capacity. The percentage of clipped buds after treatment carried out in that interval of time would be commercially acceptable to growers. Unfortunately, a relationship between weevil numbers and clipped buds (harvest loss) does not exist. Such a relationship is a prerequisite for establishing an action threshold based on pest abundance and a sampling program.

Acknowledgments

Agriculture and Agri-Food Canada Contribution No. is 335/99.04.21R at The Horticulture Research and Development Center, St. Jean-sur-Richelieu, QC, Canada.

References Cited

Abramowitz, M., and I. A. Stegun. 1972. Handbook of mathematical functions. U.S. Department of Commerce, National Bureau of Standards, Washington, DC.

Baskerville, G. L., and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperature. Ecology 50: 514–517.

Cockfield, S. D., S. M. Fitzpatrick, K. V. Giles, and D. L. Mahr. 1994. Hatch of blackheaded fireworm (Lepidoptera: Tortricidae) eggs and prediction with temperature-driven models. Environ. Entomol. 23: 101–107.

Clarke, R. G., and A. J. Howitt. 1975. Development of the strawberry weevil under laboratory and field conditions. Ann. Entomol. Soc. Am. 68: 715–718.

Dorval, P. 1938. Les ennemis du fraisier. Rev. Oka 12: 1–10.

Duan, J. J., D. C. Weber, B. Hirs, and S. Dorn. 1996. Spring behavioral patterns of the apple blossom weevil. Entomol. Exp. Appl. 79: 9–17.

Genstat. 1996. Genstat for Windows. NAG, Oxford, UK.

Kempton, R. A. 1979. Statistical analysis of frequency data obtained from sampling an insect population grouped by stages, pp. 401–418. *In* J. K. Ord, G. P. Patil, and C. Taillie [eds.], Statistical distributions in scientific work. International Cooperative, Burtonsville, MD.

Kovach, J., W. Wilcox, A. Agnello, and M. Pritts. 1993. Strawberry IPM scouting procedures: a guide to sampling for common pests in New York State. IPM No. 203b. Cornell Cooperative Extension, Cornell University, Ithaca, NY.

Mailloux, G., and N. J. Bostanian. 1991. The phenological development of strawberry plants and its relation to tarnished plant bug seasonal abundance. Adv. Strawberry Prod. 10: 30–36.

1993. Development of the strawberry bud weevil (Coleoptera: Curculionidae) in strawberry fields. Ann. Entomol. Soc. Am. 86: 384–393.

Manly, B.F.J. 1990. Stage Structured populations, sampling, analysis and simulation. Chapman & Hall, London.

Mathsoft. 1995. Mathcad PLUS 6.0. Mathsoft, Cambridge, MA.

McCullagh, P., and J. A. Nelder. 1989. Generalized linear models, 2nd ed. Chapman & Hall, London.

Niemczyk, H. D., R.A.J. Taylor, M. P. Tolley, and K. T. Power. 1992. Physiological time-driven model for predicting frst generation of the hairy chinch bug (Hemiptera: Lygaeidae) on turfgrass in Ohio. J. Econ. Entomol. 85: 821–829.

Paradis, R. O. 1979. Essais d'insecticides contre l'anthonome du fraisier, *Anthonomus signatus* Say, présent conjointement avec la punaise terne, *Lygus lineolaris* (P. de B.) dans des fraisières. Phytoprotection 60: 31–40.

Pritts, M., M. J. Kelly, and G. English-Loeb. 1999. Strawberry cultivars compensate for simulated bud weevil (*Anthonomus signatus* Say) damage in matted row plantings. Hort. Sci. 34: 109–111.

Rivard, I., G. Mailloux, R. O. Paradis, and G. Boivin. 1979. Apparition des adultes de l'anthonome du fraisier, *Anthonomus signatus* Say, en fraisiéres et framboisiéres au Québec. Phytoprotection 60: 41–46.

Schaefers, G. A. 1978. Efficacy of Lorsban brand insecticides for the reduction of strawberry "bud" weevil, *Anthonomus signatus* Say, damage in stawberries. Down Earth 35: 1–3.

Received for publication 8 April 1998; accepted 9 February 1999.