Fixed Precision Sampling Plans for White Apple Leafhopper (Homoptera: Cicadellidae) on Apple

ELIZABETH H. BEERS AND VINCENT P. JONES

Tree Fruit Research and Extension Center, Washington State University, 1100 N. Western Avenue, Wenatchee, WA 98801

J. Econ. Entomol. 97(5): 1752–1755 (2004)

ABSTRACT Constant precision sampling plans for the white apple leafhopper, *Typhlocyba pomaria* McAtee, were developed so that it could be used as an indicator species for system stability as new integrated pest management programs without broad-spectrum pesticides are developed. Taylor's power law was used to model the relationship between the mean and the variance, and Green's constant precision sequential sample equation was used to develop sampling plans. Bootstrap simulations of the sampling plans showed greater precision (D = 0.25) than the desired precision (D_o = 0.3), particularly at low mean population densities. We found that by adjusting the D_o value in Green's equation to 0.4, we were able to reduce the average sample number by 25% and provided an average D = 0.31. The sampling plan described allows *T. pomaria* to be used as reasonable indicator species of agroecosystem stability in Washington apple orchards.

KEY WORDS *Typhlocyba pomaria*, indicator species, sampling plans

THE WHITE APPLE LEAFHOPPER, *Typhlocyba pomaria* McAtee (Homoptera: Cicadellidae), is a nuisance pest commonly found in Washington apple orchards. Its feeding causes stippling of the leaves and its excrement causes "tar spots" on the apple fruit when population levels are high. However, Beers et al. (1995) found that feeding damage had no effect on fruit size, color, quality, return bloom, or fruit set. Likewise, Welker et al. (1995) found that only soluble solids were related to leafhopper feeding, and all other indices (fruit size, weight, starch, color, or firmness) were unaffected. In Washington, the primary problem associated with white apple leafhopper occurs at harvest, when the adults can become so numerous and active that they fly into the eyes, ears, nose, or mouth of pickers (Beers 1991). Pickers may refuse work in orchards where high populations are present, which can result in increased costs and delayed harvest. If harvest is delayed too long, growers may loose substantial parts of the crop, particularly if overnight lows drop below freezing.

In Washington State, apple integrated pest management (IPM) is in a state of flux as the acreage under mating disruption for codling moth increases and as the changes in pesticide use patterns required to meet the Food Quality Protection Act are implemented. The effect of these changes on nontarget insects becomes a key factor in understanding and designing a stable IPM program (Beers et al. 1998). Ecologically, the white apple leafhopper is an excellent indicator species of ecosystem stability because its high reproductive rate allows the population density to increase dramatically if its egg parasitoid *Anagrus epos* Girault (Hymenoptera: Mymaridae) or other generalist predators are disrupted by pesticide applications. However, for white apple leafhopper to be useful as an indicator species, it is important that methods are available that, when used, give both rapid and accurate estimates of the population density. The purpose of this study is to develop sampling plans for white apple leafhopper that meet these criteria.

Materials and Methods

Orchard Sampling. Forty-three data sets were used in the development and validation of the sampling program. Each data set consisted of an orchard sampled once during the summers of 1988 or 1989. Orchards were located in Chelan (41 orchards), Douglas (one orchard), and Grant counties (one orchard). Orchards were sampled by randomly selecting 20 trees within a block and then randomly selecting 20 leaves per tree between 1 and 2 m from the ground. Nymphs were counted in the field (Beers et al. 1994), whereas adults were generally not counted because of their tendency to immediately fly when disturbed.

Analysis. Twenty of the data sets were randomly selected and used to model the relationship between variance and the mean using Taylor's power law ($s^2 = \alpha m^\beta$) (Taylor 1961). A log-log transform was used to linearize the equation ($\log s^2 = \log \alpha + \beta \log$ mean), and linear regression was used to estimate α and β. Taylor indicates that $\beta < 1$ means the population is uniformly distributed between the sample units, $\beta =$

1 is randomly distributed, and $\beta > 1$ is clumped. After parameter estimation, values for α and β were used in Green's constant precision sequential sample equation (Green 1970) to generate stop lines. The equation is as follows:

$$T_n = \exp\left[\frac{\log(D_o^2/\alpha)}{(\beta - 2)} + \frac{\beta - 1}{\beta - 2}\log n\right]$$

where T_n is the summation of the individual tree mean number of leafhoppers per leaf on samples 1 through n, D_o is the desired precision in terms of SEM/m ratio (expressed as a proportion), and α and β are the Taylor coefficients. The desired precision was set at 0.30. Once the stop line is exceeded, the orchard-wide mean number of leafhoppers per leaf is estimated as follows:

$$\textit{orchard-wide mean} = \frac{T_n}{\textit{no. of trees sampled}}$$

The remaining 23 data sets were used to validate the sequential sample program by using bootstrap simulations (Efron and Tibshirani 1986). Because Green's formula (Green 1970) produces sample size estimates that are based on an average variance to mean ratio (predicted by Taylor's power law), and because it can produce noninteger values for the required number of sampling units, simulations must be used to determine the actual precision obtained and to minimize sample size requirements. The simulations were performed by selecting a data set and randomly selecting a sample of 20 trees from the data set with replacement. The program would then select a tree and compare the number of leafhoppers present to the stop lines from Green's formula (Green 1970). When the threshold was exceeded or all 20 trees in the data set had been sampled, the number of trees required to reach a decision, the calculated orchard mean, the number of times no decision was reached (i.e., the stop line was not exceeded within the 20 tree sample), and the precision achieved were calculated and stored. The procedure was repeated 1000 times for each data set and then the bootstrap means and SEMS for n (i.e., the average sample number or ASN), orchard mean, and the precision were calculated. The procedure was repeated for the remaining data sets. Comparison of the bootstrap mean and the actual orchard mean were made using linear regression (SAS Institute 2002), and the desired and actual precision and the predicted and bootstrap n were performed using graphical methods and simple summary statistics to assess sampling plan performance. All bootstrap simulations were performed using macros written for Minitab (Minitab 1995). The same types of simulations are reported in detail by Naranjo and Hutchison (1997).

If departures from the desired precision are found in the orchards where the terminal decisions were not caused by limited sample size (Hutchison et al. 1988), the D_o value in Green's equation (Green 1970) needs to be adjusted to achieve the desired 0.30 level and bootstrap simulations were rerun to determine the precision achieved.

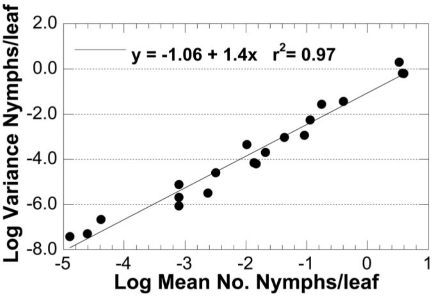

Fig. 1. Taylor's power law regression plotted for the white apple leafhopper data set.

Results and Discussion

Taylor's power law provided a good fit ($R^2 = 0.97$) to the relationship between variance and the mean (Fig. 1). The β value (1.40) was significantly >1 (t = 22.5, df = 19, $P < 0.001$) and indicated the population was clumped between trees. The α value (−1.06) was significantly different from 0 (t = 6. 8, df = 19, $P <$ 0.001), indicating that regression through the origin was not appropriate.

Green's formula suggested that mean orchard wide average of ≈0.07 leafhopper per leaf was required to exceed the stop line when 20 trees were sampled. Bootstrap simulation demonstrated that the average sample number was slightly higher than that predicted by Green's formula, but this is to be expected because Green's stop line formula can produce noninteger values, whereas, in reality, sampling can only terminate after an entire tree is counted (Fig. 2). The precision obtained showed departures from the desired 0.30 (Fig. 3), particularly at very low means where the termination decision was caused by the maximum number of trees sampled (20). However, the precision was also higher (i.e., lower numerically) than desired when the stop lines caused termination; in these cases, the average level of precision was 0.254. This means that our predictions had higher precision than desired and, consequently, more samples were taken than necessary. To offset this, the D_o in Green's equation was adjusted to 0.35 and 0.40 to minimize the ASN and to reach the desired precision of 0.3 precision level. When D_o was set to 0.35, the average precision

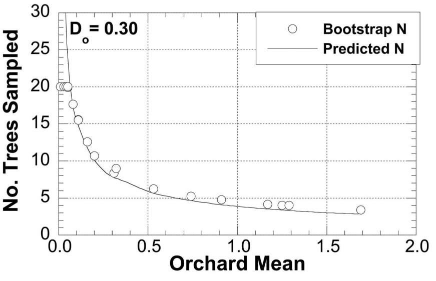

Fig. 2. Number of trees sampled at different orchard means compared with that predicted by Green's formula when $D_0 = 0.30$.

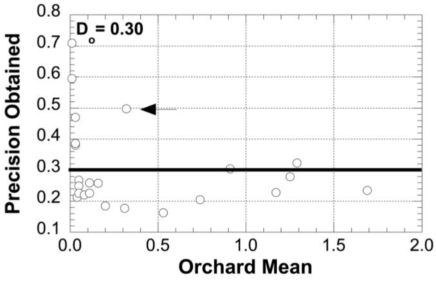

Fig. 3. Precision obtained at different orchard means by using bootstrap simulations when D_0 in Green's formula was 0.30. The desired precision is given by the heavy line at 0.30. Arrow indicates an orchard with higher intertree variation than predicted by Taylor's power law.

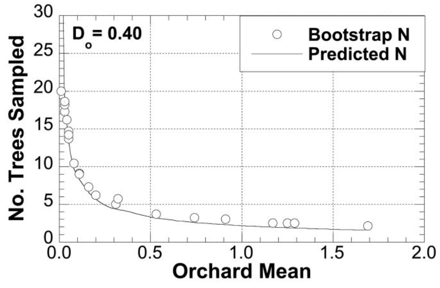

Fig. 5. Number of trees sampled at different orchard means compared with that predicted by Green's formula when D_0 = 0.40.

obtained was 0.28 and at D_o = 0.40 bootstrap simulations showed the obtained value was 0.31, very close to our desired value (Fig. 4). The change in D_o in Green's equation from 0.30 to 0.40 resulted in fewer leafhoppers being required to exceed the stop lines, and the average sample number decreased by 25% while still providing the required precision (Fig. 5). The lower stop line also resulted in more of the samples with low means having sampling terminated by the stop lines; overall, the number of times no terminal decision was reached declined 65%. Therefore, the sampling programs were constructed using D_o = 0.4 in Green's equation

In examining the precision versus orchard mean, one orchard in the validation data set consistently had a lower precision (higher numerically) than expected using Green's equation (Fig. 4, arrow), even though the terminal decision was always the result of exceeding the stop line. In examining the raw data, this orchard had a several very high tree means with several that were very low, resulting in a much higher variance than would be predicted for the orchard-wide mean using a power law regression. This would cause the sampling program to terminate sampling before variation had been adequately characterized; thus, the precision was higher numerically than what was desired. Although the precision was higher numerically, the bootstrap means and the average sample number were not significantly different from predicted (Figs. 5 and 6).

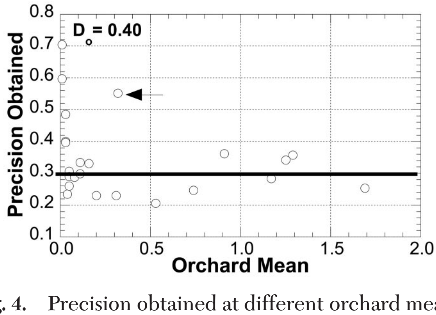

Fig. 4. Precision obtained at different orchard means by using bootstrap simulations when D_0 in Green's formula was 0.40. The desired precision is given by the heavy line at 0.30. Arrow indicates an orchard with higher intertree variation than predicted by Taylor's power law (same orchard as in Fig. 3).

The bootstrap means were very similar to the orchard mean when all 20 trees were sampled (Fig. 6). The intercept of the equation (−0.01) was not significantly different from 0 ($t = -0.07$, df = 22, $P = 0.94$), but the slope of the line (1.08) was significantly >1 ($t = 4.63$, df = 22, $P < 0.001$). Again, this difference is probably associated with Green's equation giving noninteger values, whereas only whole trees could be sampled. Regardless, the difference (8% higher) is relatively small at the densities observed in these orchards.

Indicator species in agricultural systems will become more important as pest management practices shift toward use of selective tactics such as mating disruption. In Washington apple orchards, the elimination of broad-spectrum pesticides has resulted in the reappearance of pests that have not been reported in decades (Beers et al. 1998). This means that control tactics for secondary pests and the "new" pests must be targeted in a manner that prevents the delicate balance of the system from being disrupted. Although a single indicator species is unlikely to be a reasonable predictor of system stability, we feel that several different indicator species with different phonologies and from different taxonomic groups with a taxonomically diverse assemblage of natural enemies will provide a good assessment of system stability. Because of their different phonologies, in Washington apple or-

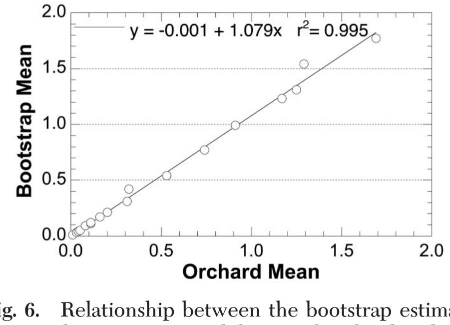

Fig. 6. Relationship between the bootstrap estimate of the mean when D_0 = 0.40 and the actual orchard-wide mean obtained from sampling all trees in an orchard.

chards, the white apple leafhopper sampling plan described above along with those for spider mites (Acari: Tetranychidae) (Jones 1990, 1994; Beers et al. 1994) and *Phyllonorycter* leafminers (Lepidoptera: Gracillariidae) (Jones 1991, Beers et al. 1994) should provide a reasonable first assessment of agroecosystem stability at different times throughout the season.

Acknowledgments

We acknowledge the help of Randy Talley, Mary Ann Drake, Gord Taylor, Mike Doerr, Lilani Wood, and Shane Ramey in the collection of these data. The project was funded, in part, by a grant from the Washington Tree Fruit Research Commission.

References Cited

Beers, E. H. 1991. Control strategies for leafminers and leafhoppers revisited, pp. 157–167. *In* K. Williams, E. H. Beers, and G. G. Grove [eds.], New directions in tree fruit pest management. Good Fruit Grower, Yakima, WA.

Beers, E. H., L. A. Hull, and V. P. Jones. 1994. Sampling pest and beneficial arthropods of apple, pp. 383–416. *In* L. A. Pedigo and G. D. Buntin [eds.], Handbook of sampling methods for arthropods in agriculture. CRC, Boca Raton, FL.

Beers, E. H., E. A. Elsner, and S. R. Drake. 1995. White apple leafhopper (Homoptera: Cicadellidae) effect on fruit size, quality, and return bloom of apple. J. Econ. Entomol. 88: 973–978.

Beers, E. H., P. D. Himmel, J. D. Dunley, J. F. Brunner, A. L. Knight, B. Higbee, R. Hilton, P. Van Buskirk, and S. C. Welter. 1998. Secondary pest abundance in different management systems. Proc. Wash. St. Hort. Assoc. 94: 121–127.

Efron, B., and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Stat. Sci. 1: 54–77.

Green, R. H. 1970. On fixed precision level sequential sampling. Res. Popul. Ecol. 12: 249–251.

Hutchison, W. D., D.B.H. Hogg, M. A. Poswal, R. C. Berberet, and G. W. Cuperus. 1988. Implications of the stochastic nature of Kuno's and Green's fixed-precision stop lines: sampling plans for the pea aphid (Homoptera: Aphididae) in alfalfa as an example. J. Econ. Entomol. 81: 749–758.

Jones, V. P. 1990. Developing sampling plans for spider mites: those that don't remember the past may have to repeat it. J. Econ. Entomol. 83: 1656–1664.

Jones, V. P. 1991. Binomial sampling plans for tentiform leafminer (Lepidoptera: Gracillariidae) on apple in Utah. J. Econ. Entomol. 84: 484–488.

Jones, V. P. 1994. Sequential estimation and classification procedures for binomial counts, pp. 175–205. *In* L. Pedigo and G. D. Buntin [eds.], Handbook of sampling methods for arthropod pests in agricultuure. CRC, Boca Raton, FL.

Minitab. 1995. Minitab reference manual, release 10Xtra. Minitab Inc., State College, PA.

Naranjo, S. E., and W. D. Hutchison. 1997. Validation of arthropod sampling plans using a resampling approach: software and analysis. Am. Entomol. 43: 48–57.

SAS Institute. 2002. JMP statistics and graphics guide. Version 5. SAS Institute, Cary, NC.

Taylor, L. R. 1961. Aggregation, variance and the mean. Nature (Lond.) 189: 732–735.

Welker, R. M., R. P. Marini, and D. G. Pfeiffer. 1995. Influence of first-generation white apple leafhopper (Homoptera: Cicadellidae) and leaf-to-fruit ratio on apple fruit size and quality. J. Econ. Entomol. 88: 959–964.

Received 29 February 2004; accepted 20 May 2004.