# Comparison of Sampling Methods for Determining Relative Densities of *Homalodisca vitripennis* (Hemiptera: Cicadellidae) on Citrus

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**ABSTRACT** Four sampling methods that included A-Vac, D-Vac, pole-bucket, and beat-net devices were evaluated for estimating relative densities of glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae) nymphs and adults on citrus (*Citrus* spp.) trees. All four methods produced similar temporal and spatial distribution profiles, although significant differences in quantities of *H. vitripennis* adults and nymphs caught by each device were observed. The four sampling methods also showed a consistent male bias in adult populations across a range of densities, suggesting that previously reported male-biased sex ratios in *H. vitripennis* adult populations are real and not a product of sampling bias. A strong relationship ($R^2 = 0.95$) between the monitoring methods we evaluated and yellow sticky trap catches of female *H. vitripennis* adults suggest that yellow sticky trap catches may provide a good relative index of infestation levels in citrus trees. Based on quantitative analyses examining precision and cost, the pole bucket was the most efficient method for sampling nymphs, and it was as efficient as the beat-net method for sampling adults and both stages combined. In addition to these analyses, consideration of other sampling characteristics such as added flexibility in sampling and higher sensitivity in detecting infestations within individual trees helped to fortify the conclusion that the pole bucket was the best overall sampling method of those tested.

**KEY WORDS** glassy-winged sharpshooter, orange trees, pest management, sex ratio, yellow sticky trap

Knowledge-based crop protection begins with an understanding of how different densities of a pest impact the growth and development of a crop. The concepts of economic injury level and economic threshold were developed decades ago to relate pest densities to damage levels in crops and to provide a rational basis for initiating protective action to avoid further damage (Stern et al. 1959; Poston et al. 1983; Pedigo et al. 1986). The key to incorporating these concepts into pest management is being able to appraise relative densities of target populations on crops so that timely counteractive measures can be imposed when economic thresholds have been attained. Moreover, evaluations of experimental treatments in applied field research often rely upon dependable and repeatable estimates of pest density. Development of sound sampling methodology is essential for the appraisal of pest densities and the informed implementation of control measures. Optimal sampling methods and plans should detect all key stages of interest, be representative and repeatable, rapid, simple to use and sampler-independent, and provide density estimates with acceptable levels of confidence (Cochran 1977).

For the glassy-winged sharpshooter, *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae), invasion of California, little information was available concerning what densities were important from a crop protection standpoint or what field sampling methods would most effectively evaluate relative densities. These questions were raised as government-coordinated control actions were being implemented to halt further crop damage due to the spread of *Xylella fastidiosa* Wells et al., causal bacterium of Pierce's disease of grapevines, and other *X. fastidiosa*-induced diseases, such as oleander leaf scorch (Purcell and Saunders 1999), all vectored by *H. vitripennis* and other leafhopper vectors. Progressive dieback of vineyards in the Temecula wine district of southern California coupled with the first recovery of *H. vitripennis* in the San Joaquin Valley in 1999 precipitated intensive pest control efforts to halt expanding populations of *H. vitripennis.* The entire 345,000+ ha of wine, table, and raisin grapes in California was suddenly perceived to be at risk to *H. vitripennis* despite general knowledge of its establishment years before in southern California (Sorensen and Gill 1996, Blua et al. 1999). The first regional control program was initiated in Temecula in spring 2000 along with a flourish of new research projects to develop pest management guidelines for *H. vitripennis* and improve understanding of its role in Pierce's disease.

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Prior research on control strategies or sampling methods for *H. vitripennis* in California or elsewhere had been limited at the time that concerted action against *H. vitripennis* was initiated. Apart from the use of sticky traps to ascertain distributions and seasonal occurrences of sharpshooters (Ball 1979, Timmer et al. 1982), development of sampling tools and methodologies had been largely ignored. As a sharpshooter native to the southeastern United States and Mexico (Sorensen and Gill 1996), *H. vitripennis* was known as a vector of *X. fastidiosa*-caused diseases such as phony peach disease, alfalfa stunt, and Pierce's disease (Turner and Pollard 1959, Ball 1979, Adlerz 1980); yet, there were few reports from its home range to suggest that control actions against *H. vitripennis* had ever been taken. Consequently, specific pest management guidelines were not available once the commitment was made statewide to combat *H. vitripennis* California. This meant that new sampling tools and control methods needed to be developed to provide effective monitoring and management and prevent further spread of *H. vitripennis* populations.

As a strictly xylophagous insect (Andersen et al. 1992), *H. vitripennis* feeds on herbaceous annuals, woody shrubs, and trees. At least 264 plant genera have been identified as feeding hosts for *H. vitripennis* (http://pi.cdfa.ca.gov/pqm/manual/454.htm#gwhostlist) by the California Department of Food and Agriculture. Differences in plant architecture and location of feeding sites on or within various plant species could require adoption of multiple sampling tools according to study or survey objectives. Many of these plants represent only occasional hosts, but *H. vitripennis* populations have nevertheless been conspicuous on many different landscape and agricultural plants over the past 10 yr in California. Although *H. vitripennis* adults are capable of wide dissemination and can be found feeding on many different plant species, especially during summer, they nevertheless have been recognized to concentrate in certain plant settings. In particular, heavy populations of *H. vitripennis* in various locations within California have been associated with large citrus acreages. In the Temecula region in southern California, wine grape vineyards intermixed with various citrus orchards proved to be a disastrous combination as intolerable proportions of grapevines became infected by *X. fastidiosa* and eventually succumbed to Pierce's disease (Perring et al. 2001).

Our principal goal in this study was to evaluate the effectiveness of various sampling devices that could be used routinely as a component of standard sampling methodology for *H. vitripennis* on citrus. In addition, we were seeking to expand general knowledge of *H. vitripennis* field ecology through systematic sampling of natural populations over time.

## Materials and Methods

**Field Site.** Sampling studies were carried out at the 204-ha farm belonging to the University of California Agricultural Operations in Riverside, CA, from fall 2001 through fall 2002. Large tracts of diverse citrus species and varieties contributed to a robust population of *H. vitripennis* that nonetheless tended to be patchily distributed among different plantings. By sampling under conditions of high and low *H. vitripennis* densities on both young and old citrus trees, relative sensitivities of the different sampling devices could be tested as well as their performance across a range of tree sizes. Two different sections (sites 1 and 2) of a 5.2-ha Valencia orange grove (variety Frost Valencia grafted on Troyer citrange) were used for carrying out studies that compared various sampling devices. Each section consisted of 20 rows with six trees per row that allowed the interior four trees in each row to be randomly assigned for sampling by each of four devices.

**Sampling Devices.** The four devices compared in this study included the fuel-powered A-Vac (a conventional leaf-blower with a vacuum attachment, Fuji Robin model 30935, Shizuoka, Japan) and D-Vac (Rincon-Vitova Insectaries, Ventura, CA) suction devices and the hand-operated beat-net and pole-bucket dislodgement devices. The suction devices were each powered by a gasoline motor mounted on a backpack frame complete with a throttle lever that controlled engine speed and ultimately suction force. Attached to each motor was a 1.8-m flexible extension tube with a terminal plastic collar that allowed a fine-mesh nylon organdy bag to be inverted and held in place by an elastic band when suction was applied. Sampling with each device involved thrusting the end of the suction tube into the canopy of a citrus tree to help dislodge and suck *H. vitripennis* nymphs and adults into the inverted nylon bags. The major difference between the two suction devices is that the D-Vac is more massive and has a 0.5-m-diameter collecting tube compared with the lighter and trimmer A-Vac with a 0.1-m-diameter suction tube.

The beat-net consisted of a standard conical net with 0.5-m-diameter opening attached to a 1-m-long wooden handle. In practice, the opening of the beat-net was placed below foliage while using a 3-m stick in the other hand to beat the foliage to dislodge *H. vitripennis.* The pole bucket sampler represented a novel device consisting of a 19-liter rigid plastic bucket firmly attached to a 3.7-m extension pole. The bottom of the bucket was cut away and a large plastic funnel riveted to the outside walls of the bucket. Dislodged adults and nymphs were ultimately collected in a plactic jar fastened to the bottom of the funnel. The basic design was adapted from the beat bucket device used to sample arthropods in cotton (Knutson et al. 2000) and similar to the funnel collection method used to sample arthropods from deciduous fruit trees (Bostanian and Herne 1980). However, the firm attachment of a lightweight, rigid pole to the bucket sampler provided extended reach and permitted access to both lower and upper sections of the trees.

**Sampling.** Insect sampling with all four devices began in fall 2001 and resumed in spring 2002 through early fall following the low densities of *H. vitripennis* adults during the winter (Castle et al. 2005). Two teams of two people each carried out the sampling by

first proceeding through rows 1–20 with the two hand-operated devices on separate randomly selected trees before repeating the pattern on different trees within the same 20 rows by using the fuel-powered devices. Sampling was conducted during mid-morning with ≈50 min per site required to complete sample collections with all four devices. Each device was used under similar temperature and light conditions on any particular sampling date, although temperatures varied from spring through fall. However, the range of conditions through the seasons was the same for all four devices.

In total, 25 samples of 20 trees each were collected from four different orchards over 15 sampling dates. All samples were collected at ≈1–2 m above the ground with the exception of those collected by the pole-bucket that enabled sampling from 1 to 6 m above ground. Sample units for the suction devices consisted of thrusting the end of the suction tube five times into five separate areas around each tree. A sample unit for the beat net consisted of beating the foliage five times above the net at five separate areas around the tree. Similarly, for the pole bucket a sample unit consisted of five thrusts into the foliage at five areas around a tree. Sample unit contents were emptied into labeled zip-lock bags and returned to the laboratory where they were stored in a freezer until processing. Upon removal, the contents of each bag were transferred to labeled 20-dram plastic vials containing 70% alcohol. All nymphs in each bag were identified to instar, and adult sex was determined.

The time required in the field to collect individual sample units with each device was recorded with stopwatches on 50 occasions for each sampling method. Once back in the laboratory, the time necessary to process and record a sample was measured ≈250 times for each device. From these data, a regression model was developed that estimated processing time as a function of *H. vitripennis* density.

**Yellow Sticky Traps.** Ten yellow sticky traps (20 by 30.5 cm) were placed randomly throughout the sampling area on six dates to evaluate adult numbers caught on sticky traps relative to adult densities in tree canopies as determined by one or more sampling devices. The yellow sticky traps were mounted at a height of 1.5 m on a wooden stake in clearings between orange trees and exposed for 4 d before collecting adult males and females for counting.

**Statistics.** Basic descriptive statistics were used to summarize the count data obtained from samples collected with each device. A repeated measures analysis of variance (ANOVA) on log-transformed ($\log_e n + 1$) data were used to evaluate whether adult or nymphal catches varied significantly according to sampling device ($\alpha = 0.05$). Post hoc comparison of means was completed using orthogonal contrasts. Linear regression was used to compare sex ratio proportions in the adult *H. vitripennis* population by regressing numbers of females caught against males + females for all four devices. Slopes of regression lines were tested for sameness by using ANOVA.

**Table 1. Summary data for *H. vitripennis* adults and nymphs in citrus at 25 spatiotemporal sites in 2002**

| Stage | Method | Positive sample units | Max count | Mean count | Total count |
|---|---|---|---|---|---|
| Adults | A-Vac | 278 | 19 | 2.6 | 1,260 |
| | Beat-Net | 336 | 61 | 6.9 | 3,372 |
| | Bucket | 323 | 44 | 5.7 | 2,804 |
| | D-Vac | 342 | 101 | 9.6 | 4,712 |
| Nymphs | A-Vac | 110 | 18 | 0.7 | 334 |
| | Beat-Net | 141 | 52 | 1.6 | 796 |
| | Bucket | 157 | 51 | 1.9 | 937 |
| | D-Vac | 124 | 43 | 1.8 | 869 |

Based on a total of 490 sample units for each method with positive sample units indicating those sample units with ≥ 1 individual.

A cost-efficiency analysis was conducted to compare the four sampling methods. First, Taylor's power law $S^2 = am^b$ (Taylor 1961) was used to model the relationship between the mean ($m$) and variance ($S^2$) of samples from each sampling method, where $a$ and $b$ are parameters fit by regressing $\ln(S^2)$ on $\ln(m)$. Following the formula of Cochran (1977) for sample size ($n = [S/mD]^2$), where $S$ is the standard deviation and $D$ is precision (measured as the standard error to mean ratio), and substituting $am^b$ for $S^2$, we then estimated the density-dependent number of samples required to achieve a fixed precision by $n = am^{b-2}/D^2$. The cost of sampling at a particular density was then estimated as the product of $n$ and the per-unit cost of sampling. The value of $D$ was set to 0.25 for all analyses. To directly compare performance among sampling methods, density was scaled relative to the beat-net method by $m_i/M_b$, where $m_i$ was the mean density of all samples using the A-Vac, D-Vac, or bucket methods, and $M_b$ was the mean density from the beat net method ($n$ = 20–25).

## Results

Out of a total of 490 samples units collected for each device, the number with at least one adult was similar for the pole-bucket, D-Vac, and beat-net at 323, 342, and 336, respectively (Table 1). The A-Vac was considerably less sensitive at only 278 positive samples. The D-Vac collected the most adults throughout the study period of all four methods, but with 48% of its total catch occurring on just three sampling dates during fall 2001. For nymphs, the pole-bucket proved considerably more sensitive than all other methods in both detection (positive samples) and total number of nymphs collected (Table 1). Although the total number of nymphs collected by the pole-bucket (937) exceeded the other three methods, the mean count per sample was highest for the D-Vac due to the fewer number of samples that were positive with at least one nymph.

The profiles of *H. vitripennis* nymph and adult densities at sites 1 and 2 were similar among the four sampling methods (Fig. 1). From the first sampling date on 19 April through mid-June, very few if any adults were detected by any sampling method.

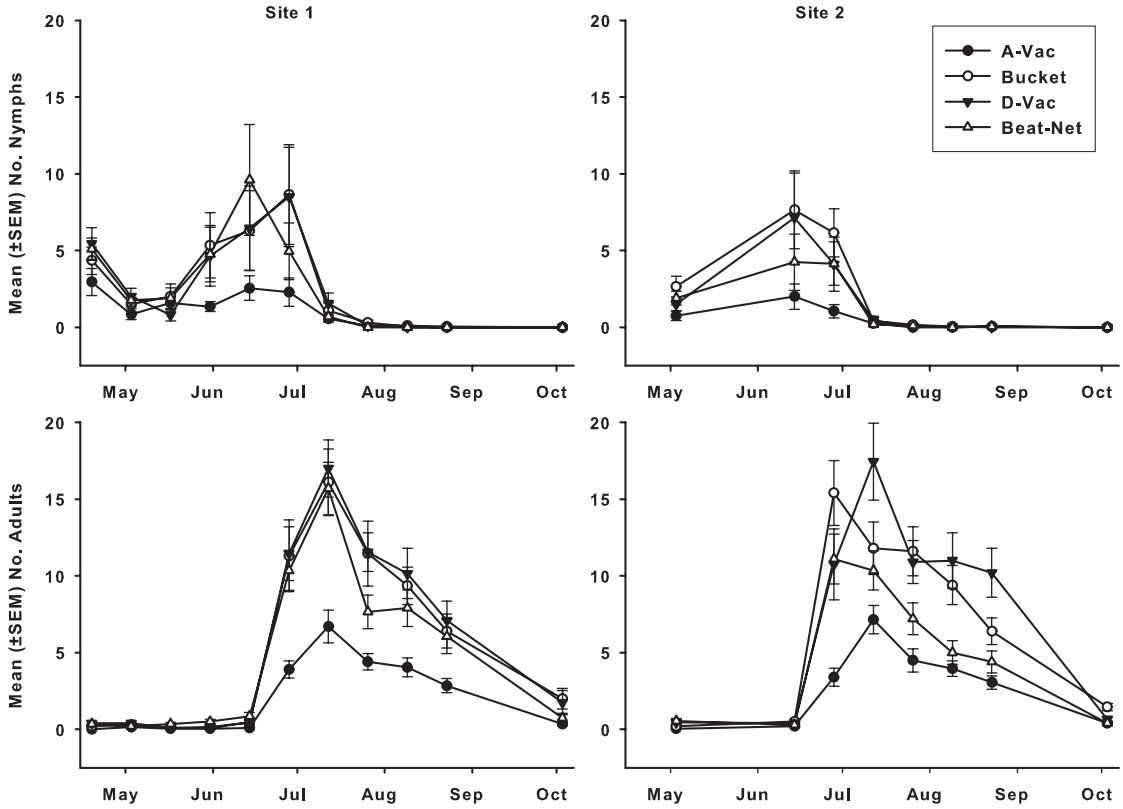


**Fig. 1.** Comparison of four sampling devices used in two different sections (sites 1 and 2) of a Valencia orange orchard to collect *H. vitripennis* nymphs (top) and adults (bottom).

Nymphs were more prevalent during this period, but catches were quite variable due perhaps to cool morning temperatures in May that seemed to reduce densities in the peripheral canopies of citrus trees. The new generation of adults began to emerge in late June as recorded by all four devices on 28 June. Peak numbers of adults were collected by all four methods on 12 July in field G and by the D-Vac and A-Vac methods in field F. Thereafter, adult numbers gradually declined to relatively low densities by 3 October (Fig. 1). There were highly significant differences among the four methods in quantities of *H. vitripennis* adults collected through the season at site 1 ($F = 17.8$; df = 3, 76; $P < 0.0001$) and site 2 ($F = 19.9$, df = 3, 76; $P < 0.0001$) during 2002. Post hoc contrasts among treatment means revealed that only the A-Vac differed significantly ($P < 0.0001$) from the other three methods in quantities of *H. vitripennis* adults caught at site 1. The same was true at site 2 with the A-Vac catching significantly fewer *H. vitripennis* adults ($P < 0.0001$) than the other three methods. However, the beat-net also caught significantly fewer *H. vitripennis* adults than either the D-Vac ($P = 0.0002$) or the pole-bucket ($P = 0.0028$), whereas the D-Vac and pole-bucket did not differ significantly in quantities collected from each other ($P = 0.3735$).

In addition to producing similar temporal profiles, albeit of varying magnitude, there was also congruence among all four devices in revealing spatial structure in nymphal distributions within the Valencia orange orchard. Over a period of four consecutive sampling dates beginning 31 May, much higher densities of nymphs were caught in the first six rows of the 20 row sections than in the remaining 14 rows (Fig. 2). The pole-bucket was the most sensitive method in revealing the presence of nymphs in a particular location within the sampling area. For example, on 14 June, nymphs were caught in each of the 20 rows by the pole bucket compared with 14, 15, or 17 rows for the A-Vac, D-Vac, or beat-net, respectively. Similarly, on 28 June, the pole-bucket caught nymphs in a total of 18 rows compared with 8, 12, or 15 rows for the A-Vac, D-Vac, or beat-net methods, respectively (Fig. 2). By 12 July, relatively few nymphs remained as most of the nymphal population had already emerged as adults. Dispersion of the adults among all 20 rows of the sampling area was much greater for young adults due to their excellent mobility and heightened flight activity soon after emergence.

All four sampling methods determined a male biased sex ratio in the adult *H. vitripennis* population. Higher proportions of males were observed consistently through the sampling study and across the full range of adult densities in orange tree canopies (Fig. 3). The A-Vac caught the lowest pro-

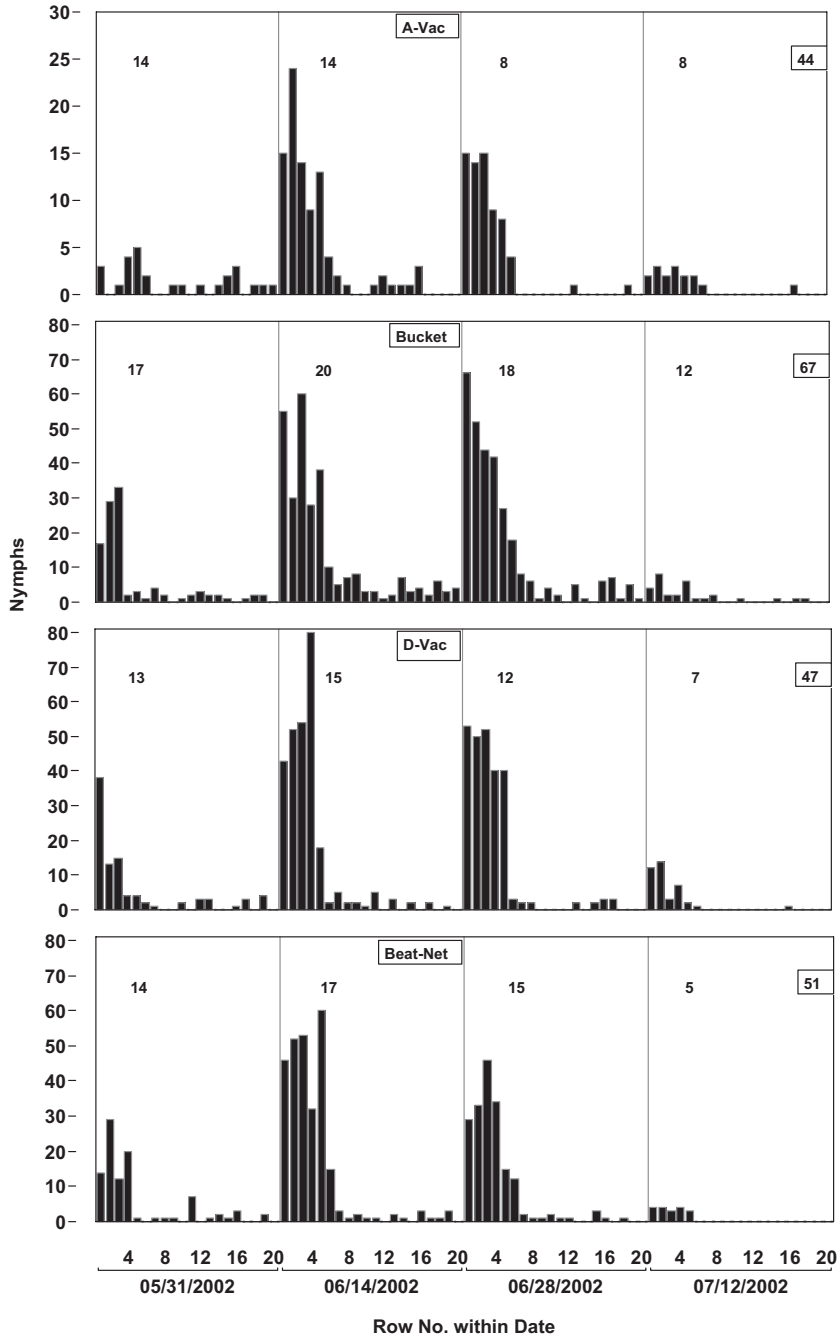


**Fig. 2.** Spatial distribution of *H. vitripennis* nymphs within the study area according to row number and relative sensitivity of each sampling method on four sampling dates in 2002. The number appearing in each panel represents the number of rows in which at least one *H. vitripennis* nymph was present. The total number of rows (maximum possible 80) for all four sampling dates for each device is presented in the box contained within the 12 July 2002 panel.

portion of females and the D-Vac the highest, but slopes were not significantly different among any of the four devices ($F = 0.84$, df = 3, 1,271; $P = 0.47$) and were especially similar among the D-Vac, pole-bucket, and beat-net methods. The relationship between yellow sticky card catches and population densities in tree canopies proved to be a strong one when only female adults were counted (Fig. 4). Greater variability was observed with catches of adult males on the yellow sticky traps that also strongly influenced the profile of total adults (Fig. 4). The coefficient of determination ($R^2$) for fe-

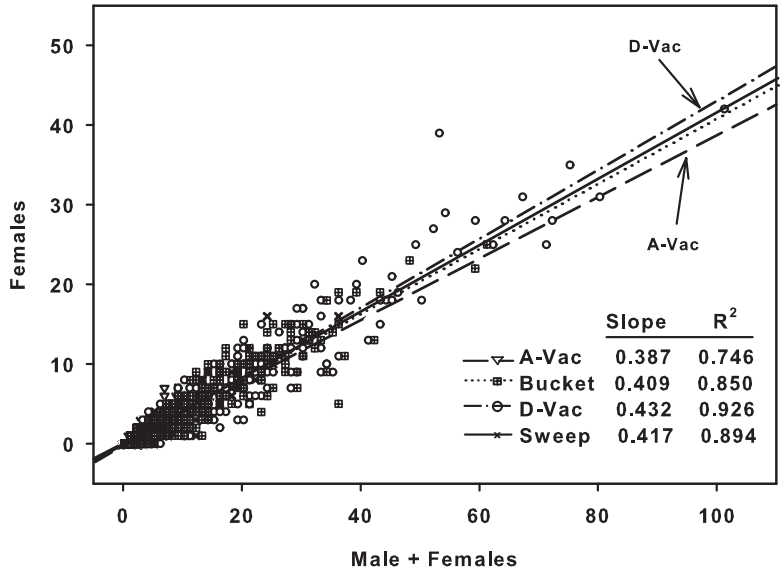


**Fig. 3.** Simple regressions and point scatters of the number of adult females on number of adult males + females as measured by each sampling method. The slopes and $R^2$ values generated in the regression analyses are presented for each method.

males ranged from 0.937 to 0.981 in the regressions of yellow trap catches on device catches for the D-Vac, pole-bucket, and beat-net in comparison with males, which ranged from 0.663 to 0.771 (Fig. 4).

Although all sampling methods showed similar patterns of population change over time, the A-Vac and D-Vac samplers required considerably more effort and preparation to use. The time required to collect each sample unit in the field averaged 1.0, 0.8, 1.1, and 0.9 min by using the A-Vac, bucket, D-Vac and beat-net, respectively. Laboratory processing times were generally highest for the D-Vac due to the excessive leaf litter that accompanied each sample (Table 2). Comparative analyses of the four methods using Taylor's power law parameters (Table 3) showed that sample sizes required to estimate density with a fixed precision of 0.25 declined with increasing density for nymphs, adults, and both stages combined (Fig. 5). For nymphs, fewer samples were generally needed when using the bucket and beat net methods over the broadest range of densities (Fig. 5A). Accounting for the time needed to collect and process a sample unit, the bucket method allowed the estimation of density with the lowest overall cost. For adults, more samples would be required using the A-Vac compared with the other methods (Fig. 5B). The lowest sampling cost over the broadest range of densities was achieved using either the bucket or the beat-net methods. For both stages combined, the A-Vac required the largest sample size and once again, both the bucket and beat-net methods proved the most efficient in terms of precision and cost (Fig. 5C).

## Discussion

The four different foliage sampling methods produced general agreement in terms of temporal and spatial profiles of *H. vitripennis* nymphs and adults in orange trees as well as revealing a male bias in adult sex ratios. However, the pole-bucket was superior to the others by measure of its greater sensitivity at detecting smaller infestations in trees. Because of the reach advantage of the pole-bucket, the sampling unit may have been different than for the other three devices. Its greater extension into thicker foliage of the upper canopy enabled the pole bucket to detect smaller infestations of nymphs in contrast to the other three devices that were limited by a sampler's reach. Because of the potential for variation in the vertical distributions of *H. vitripennis* nymphs and adults, comparison of the pole-bucket to the other three devices should be considered as a comparison of devices rather than identical sample units.

Leaves and small branches dislodged by the thrusting of the pole bucket into a canopy tended to remain in the bucket and funnel portion of the pole-bucket sampler, whereas the dislodged *H. vitripennis* continued through the funned into the collecting jar. The debris collected in the bucket was easily emptied by tipping the bucket in preparation for the next sample. In contrast, samples collected by the two vacuum devices and the beat-net generated larger quantities of leaf litter that eventually had to be sorted in the laboratory to collect the *H. vitripennis* nymphs and adults. The A-vac and D-vac devices also proved to be burdensome for moving across rows of citrus trees and for the extreme noise and combustion pollution produced. Quantitative analyses based on sampling dis-

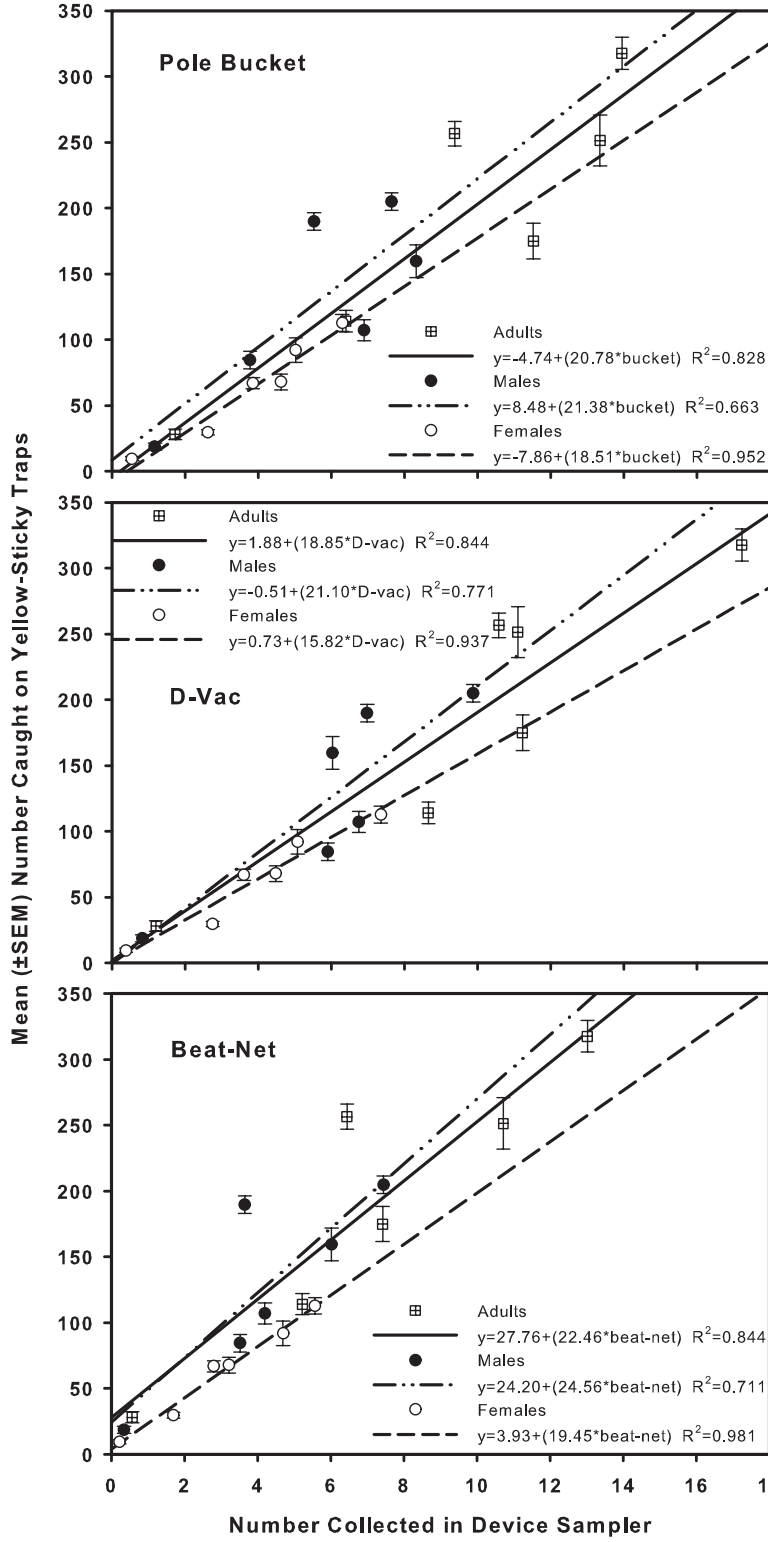


**Fig. 4.** Relationship of citrus canopy densities of adult *H. vitripennis* determined by the pole-bucket, D-Vac, and beat-net sampling devices (Y1 axis) to yellow sticky trap catches (Y2 axis) for females, males, and adults on six sampling dates.

**Table 2. Sampling cost (time) of for four methods of estimating *H. vitripennis* adult and nymphal densities**

| Method | Field cost (min) | Laboratory processing cost[a] (min) | | | |
|---|---|---|---|---|---|
| | | Equation | *F* | $r^2$ | *n* |
| A-Vac | | | | | |
| Nymphs | | 0.87 + 0.36m | 103.1 | 0.29 | 254 |
| Adults | | 1.12 + 0.16m | 97.2 | 0.28 | 254 |
| Total | 1.0 | 1.79 + 0.13m | 87.3 | 0.26 | 254 |
| Bucket | | | | | |
| Nymphs | | 1.09 + 0.15m | 78.0 | 0.24 | 246 |
| Adults | | 1.15 + 0.13m | 232.9 | 0.49 | 246 |
| Total | 0.8 | 2.32 + 0.08m | 88.8 | 0.26 | 246 |
| D-Vac | | | | | |
| Nymphs | | 1.04 + 0.24m | 137.9 | 0.35 | 258 |
| Adults | | 1.73 + 0.11m | 331.0 | 0.56 | 258 |
| Total | 1.1 | 2.89 + 0.10m | 130.3 | 0.33 | 258 |
| Beat net | | | | | |
| Nymphs | | 1.06 + 0.23m | 148.8 | 0.38 | 245 |
| Adults | 0.9 | 1.30 + 0.15m | 280.3 | 0.54 | 245 |
| Total | | 2.49 + 0.11m | 112.5 | 0.32 | 245 |

[a] Equation represents the regression of time on density (m) of insects in the sample unit.

tributions and sampling costs showed the bucket method was most cost-efficient for sampling nymphs over a broad range of potential densities, whereas the bucket and beat-net methods were roughly equal in efficiency for sampling adults and a combination of nymphs and adults. Based on other sampling characteristics and the added flexibility in sample collection, the bucket sampler was the best overall sampling device of those tested.

The pattern of nymphs in the spring emerging as adults beginning in late June (Castle et al. 2005) was again observed in the current study. Furthermore, once the last of the spring generation of nymphs had developed through to the adult stage, there were no further collections of nymphs made through August and into October. This same general result produced by the four sampling devices confirms previous observations that a second generation of eggs laid during summer rarely materializes into nymphs and adults, probably due mainly to very high parasitism rates (Phillips 1998, Triapitsyn et al. 1998, Hoddle 2004). The male-biased adult sex ratio reported previously (Castle et al. 2005) also was confirmed by the use of four different sampling devices that essentially showed the same pattern.

**Table 3. Sampling statistics and Taylor's power law parameters (Taylor 1961) of four techniques for estimating density of *H. vitripennis* in citrus**

| Method | Mean density (range) | Taylor power law parameter[a] | | | |
|---|---|---|---|---|---|
| | | *a* | *b* | $r^2$ | *n* |
| A-Vac | | | | | |
| Nymphs | 0.1–2.9 | 3.12 | 1.43 | 0.96 | 16 |
| Adults | 0.1–7.8 | 1.42 | 1.16 | 0.98 | 24 |
| Total | 0.1–7.8 | 1.80 | 1.21 | 0.86 | 25 |
| Bucket | | | | | |
| Nymphs | 0.1–8.7 | 3.61 | 1.58 | 0.96 | 17 |
| Adults | 0.1–16.1 | 1.97 | 1.28 | 0.97 | 25 |
| Total | 0.1–21.6 | 2.05 | 1.42 | 0.87 | 25 |
| D-Vac | | | | | |
| Nymphs | 0.1–8.5 | 4.51 | 1.59 | 0.96 | 15 |
| Adults | 0.1–53.5 | 1.86 | 1.36 | 0.96 | 24 |
| Total | 0.5–53.5 | 2.89 | 1.32 | 0.83 | 25 |
| Beat net | | | | | |
| Nymphs | 0.1–9.6 | 3.27 | 1.57 | 0.93 | 14 |
| Adults | 0.1–28.9 | 1.49 | 1.34 | 0.98 | 25 |
| Total | 0.1–28.9 | 2.04 | 1.36 | 0.88 | 25 |

[a] Taylor power law $S^2 = am^b$, where $S^2$ is sample variance, $m$ is sample mean density, and $a$ and $b$ are parameters fitted by regressing $\ln(S^2)$ on $\ln(m)$.

The spatial distribution of nymphs within the study area was interesting in that a distinctive edge effect was apparent during spring when nymphs were present. One side of the rectangular study area (row 1) fell on the edge of the university farm that was bordered by an urbanized section of the city of Riverside, CA. The other three sides were bordered by more citrus orchard of which the study area was a contiguous part. The clumping of nymphs on the urban edge of the orchard indicates that oviposition took place in the rows of citrus bordering this edge. It may be possible that the adult female parents of the nymphs used the border rows of citrus to oviposit and feed, but that they also depended on other dietary sources outside of the study area within the citrus orchard. The strong flying ability of *H. vitripennis* adults may permit wide ranging foraging for alternative dietary sources while retaining citrus orchards as a base host for oviposition and feeding. An earlier study (Bi et al. 2005) in a different area of the same study orchard showed the shifting of adult *H. vitripennis* between lemons and Valencia oranges that corresponded with fluctuations in amino acid concentrations within the two citrus species. The clumping of nymphs in rows bordering the urban landscape occurred possibly because of the concentration of parental females that required a more diverse diet than could be provided alone by Valencia oranges during the critical period of oogenesis.

The robust relationship between pole-bucket samples and yellow sticky card catches of adult females suggests that yellow sticky cards may indeed provide a reliable indication of *H. vitripennis* infestation levels within a citrus orchard. A previous study also found significant relationships between yellow sticky card catches and numbers of adult *H. vitripennis* obtained by beat-net catches and timed counts on tree foliage (Blua and Redak 2003). It is unknown why a stronger relationship was observed for females than for males, but perhaps attractiveness to yellow varies to some degree between the sexes. Alternatively, greater flight activity may be responsible for males being trapped more frequently than females, although no indication of differences between sexes was apparent in a study of *H. vitripennis* flight dispersal (Blackmer et al. 2004).

The pole-bucket proved ideal for sampling the mature Valencia orange trees contained within the study area. The rigid-sided bucket easily withstood the thrusting forces from impacting the dense canopies of the orange trees to dislodge *H. vitripennis* nymphs and adults into the collecting jar of the bucket. The extension pole connecting to the bucket sampler provided good reach to the upper canopy of sample trees

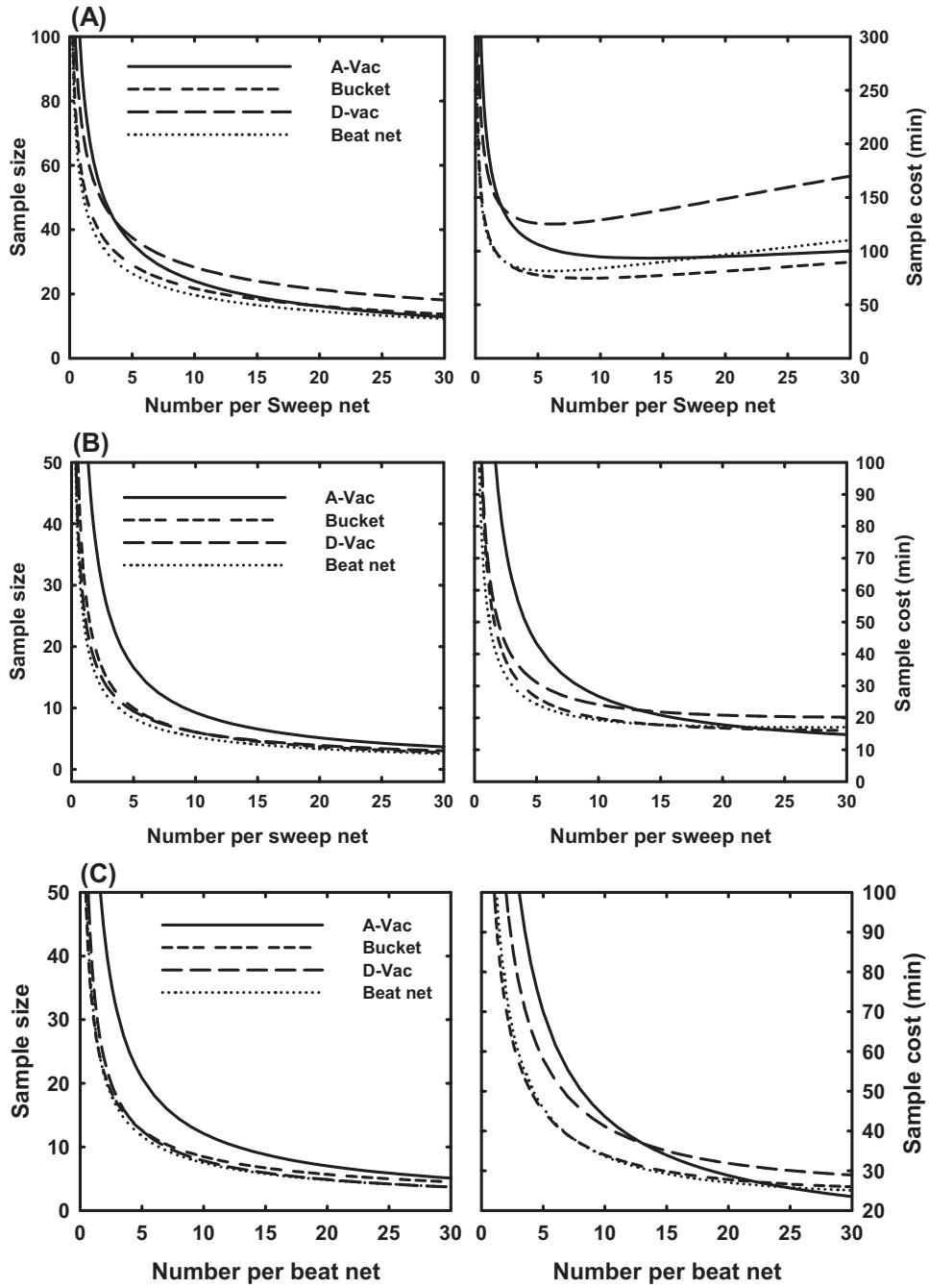


**Fig. 5.** Density-dependent sample sizes and sampling costs for four sampling methods for *H. vitripennis* (A) nymphs, (B) adults, and (C) nymphs and adults combined in citrus based on a desired precision of 0.25.

and enabled more sensitive detection of low densities of *H. vitripennis* compared with the other three devices. Although the pole-bucket has been used on many other shrubs and trees for collecting *H. vitripennis*, it seems to work best in dense, rigid vegetation where impaction causes dislodgement of *H. vitripennis* nymphs and adults into the collecting bucket with a relative minimum of leaf litter.

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