Estimating the Relative Abundance of Adult Citrus Root Weevils (Coleoptera: Curculionidae) with Modified Tedders Traps

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ABSTRACT Taylor's power law ($s^2 = a\,\bar{x}^{\,b}$) was fitted to the means and variances of numbers of adult *Diaprepes abbreviatus* L. and *Pachnaeus litus* (Germar) caught monthly in modified Tedders traps (citrus Tedders traps). Data for *D. abbreviatus* were obtained in six Florida citrus groves, two located on the central ridge and the others in the central and southern flatwoods. Parameters for *P. litus* ($a = 2.15$, $b = 1.17$) using data pooled from two sites were consistent with parameters derived from the individual sites. Parameters derived from pooled data for *D. abbreviatus* were $a = 2.69$, $b = 1.33$; however, there was significant variability of the parameter b among sites. For specified levels of precision (confidence interval half-length:mean ratio), from 0–30% fewer traps were needed to estimate numbers of *P. litus* compared with *D. abbreviatus* at densities encountered in these groves. Plot size from 0.06 to >12 ha affected the numbers of traps needed to obtain monthly mean estimates of adult weevils per trap with a given level of precision. In general, sample precision was equal in large and small plots when population density in large plots was double that in small plots. At a given population density, ≈70% more traps were required in large compared with small plots to achieve a similar level of precision. Changes in trapped weevil abundance larger than 2.5-fold were detected as significantly different with the sampling plans used in these studies. Seasonality in the numbers of each species was evident at all sites ($P = 0.05$) because monthly means varied by 30- to 60-fold. In a separate study, the numbers of weevils recovered monthly from citrus Tedders traps were approximately congruent ($r = 0.78$, $n = 33$, $P = 0.01$) with numbers recovered from cone-shaped ground traps that only recover adult weevils as they emerge from soil. Annual maxima for both types of traps occurred at the same times during 33 mo, but each year weevil emergence from soil (as measured by cone traps) remained high for 1–2 mo after weevil recovery from citrus Tedders traps declined. Polynomial regression on monthly recovery from citrus Tedders traps explained 66% of the variation in monthly emergence of weevils from soil. Results of this study support the use of citrus Tedders traps in integrated pest management programs to detect the onset of emergence from soil by weevil cohorts, and to measure relative differences in weevil population density due to experimental treatments.

KEY WORDS *Diaprepes abbreviatus*, *Pachnaeus litus*, insect traps, population monitoring, sample size, sampling, Taylor's power law

THE LARVAE OF several polyphagous species of Curculionidae feed on the roots of citrus trees in Florida and elsewhere in the Caribbean region. *Diaprepes abbreviatus* L. is the most economically important species, causing severe decline of trees, particularly in groves with conditions that are conducive to phytoparasitic oomycetous fungi in the genus *Phytophthora* (Graham and Menge 1999). Approximately 13,000 of the 340,000 ha of citrus in Florida were thought to be infested by *D. abbreviatus* in 1997 (LaPointe et al. 1999). *D. abbreviatus* commonly occur in groves concomitantly with *Pachnaeus litus* (Germar), a weevil species somewhat less damaging to citrus (McCoy 1999).

Diaprepes abbreviatus was first detected in central Florida in 1964 (Woodruff 1964) and subsequently spread into all of the citrus growing regions of the state to become a major threat to the industry (McCoy and Simpson 1994). The profitability of current recommendations to manage the insect with chemical and biological insecticides and cultural practices has not been reported, but appears to be modest (Duncan et al. 1999). Achieving better control of *D. abbreviatus* requires information about the population biology and ecology of the insect, and methods to measure the effects of management tactics. Published sampling methods to estimate the abundance of weevil larvae in soil are labor intensive and destructive to trees (Duncan and McCoy 1996, Duncan et al. 1996). Of the several traps tested for monitoring aboveground population densities of adult weevils, the Tedders trap, modified for use in citrus, has been found to be one of the most efficient and is now commonly used to study curculionids including this pest (Adair 1994, Tedders

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Table 1. Characteristics of six experimental sites used to derive parameters of Taylor's power law for *Diaprepes abbreviatus* and *Pachnaeus litus* in Florida citrus groves and to study the relationship between numbers of *D. abbreviatus* caught in Tedders pyramid traps and emergence of adult *D. abbreviatus* from the soil

Site	Location	Soil type Bed style Irrigation	Tree age (yr)	Tree spacing (m)	Plot size (ha)	Site size (ha)	Plot configuration (no. rows × no. trees)	Rootstock/scion
C1	Bartow	Astatula sand Non-bedded Microsprinkler	8	4.5 × 8.7	0.46	8.2	8 × 30	Carrizo citrange/Hamlin and Valencia
C2	Ft. Pierce	Pineda sand Double bed microsprinkler	12	3.0 × 7.6	0.09	12.6	4 × 20	Swingle citrumelo/mixed variety
C3	Lakeland	Astatula sand Non-bedded microsprinkler	15	3.8 × 6.0	na	5.3	4 × 30	Swingle citrumelo/Hamlin
S1	Ft. DeNaud	Pinea sand Single bed Drip	12	3.8 × 7.6	0.07	1.6	1 × 24	Mixed/Hamlin
S2	Ft. Danaid	Pinea sand Single bed Drip	10	3.0 × 6.7	0.06	3.7	3 × 29	Swingle citrumelo/Hamlin
S3	Ft. Danaid	Tuscawilla fine sand Single bed Microjet	8	3.8 × 7.6	0.07	4.2	3 × 24	Swingle citrumelo/Fallglo and Sunburst

C = central and S = southern regions of Florida's citrus industry.

and Wood 1994, Stansly et al. 1997, Prokopy and Wright 1998, Mizell et al. 1999).

Despite their widespread use for research and monitoring of weevil pests of citrus, there are no reports of sample size requirements to estimate abundance of *D. abbreviatus* or *P. litus* with modified Tedders traps. Therefore, the purpose of our study was to determine the precision with which Tedders traps, modified for use in citrus, measure *D. abbreviatus* and *P. litus* over a range of population densities and in research plots ranging in size from small (<0.5 ha) to large (1.6–12.6 ha) in several areas of Florida with different edaphic and climatic conditions. We also investigated the relationship between numbers of adults caught in modified Tedders traps and in ground traps that catch only adults emerging from soil.

Materials and Methods

Study Sites and Trap Design. Taylor's power law (Taylor 1961) was fitted to data from experimental plots in four commercial groves infested by *D. abbreviatus* and in two groves (C1 and C2) infested with both *D. abbreviatus* and *P. litus* (Table 1). The experiments at five of the sites were designed to measure the effects of various cultural, chemical and biological tactics to manage the weevils. Modified Tedders traps (hereafter designated citrus Tedders traps) were used to estimate relative differences in weevil population densities among the treatments. Cone shaped ground traps that catch only weevils emerging from soil were used at the remaining site (C3) to explore the relationship between numbers of weevils caught in citrus Tedders traps and numbers of adult weevils emerging from the soil. Sites C1 and C3 were on the Florida central ridge, which is characterized by deep sandy soils. The remaining sites were in "flatwoods" areas of the central and southern parts of the citrus industry. Flatwoods soils are variable in texture and lie above shallow water tables that require trees to be planted on beds of soil to facilitate water drainage.

The citrus Tedders traps are modifications of the trap described by Tedders and Wood (1994). The collector consists of the portion of a cotton boll weevil trap (Great Lakes IPM, Vestaburgh, MI) used by Tedders and Wood (1994). The trap is mounted on a pyramid-shaped base 61 cm high and formed from two roughly triangular shaped pieces of black masonite or corrugated polyethylene (PBE Graphics, West Palm Beach, FL) that are slotted to half of their lengths in different directions in the middles to fit together and form a pyramid. The four flanges of the base are anchored to the soil with wire pins (Wireco, Winter Haven, FL).

The cone-shaped screen ground traps were constructed of standard galvanized hardware cloth (0.3-cm mesh size) shaped to form a base with a 91.4 cm diameter. A 1.0-cm hole was formed at the tip of each trap to allow crawling adults access to a detachable cotton boll weevil trap top (as used on the Tedders trap) attached to the tip of the ground cone trap.

The placement of traps varied in the different experiments. At site C1, three citrus Tedders traps were placed randomly in each of the four center rows of each plot (12 traps per plot, 144 traps total). Traps were placed in-line with the rows of trees, beneath the canopy ≈30 cm from the trunk. Numbers of weevils caught in the traps were monitored weekly from two February 1998 until 30 December 1999. At site C2, a single citrus Tedders trap was placed beneath the canopies of 20 randomly selected trees in the two center rows of each plot. Traps were monitored biweekly for 9 mo during March–December 1999. At site C3, a citrus Tedders trap was placed beneath 20 randomly selected trees in each of six plots. Traps were positioned midway between the trunk and canopy

Table 2. Estimated parameters for Taylor's power law derived from six experiments in citrus groves located in different regions of Florida

Site and (sample unit size)	Traps/unit	Traps/ha	TPL parameter					r^2	P	Range of mean weevils trap^{-1} month^{-1}
			a	SE(A)	b	SE(b)	n^a			
			Diaprepes abbreviatus							
C1 (8.2 ha)	144	17.6	1.62	0.031	1.13	0.013	23	0.94	0.001	0.035–1.01
C2 (14.6 ha)	360	24.7	1.87	0.052	1.11	0.011	7	0.99	0.001	0.003–0.25
C3 (5.3 ha)	84	15.8	2.61	0.023	1.32	0.008	31	0.97	0.001	0.024–2.15
S1 (1.6 ha)	192	120.0	3.06	0.040	1.37	0.023	25	0.86	0.001	0.068–1.81
S2 (3.7 ha)	160	43.2	1.99	0.026	1.24	0.015	16	0.97	0.001	0.038–0.75
S3 (4.2 ha)	160	38.1	2.61	0.015	1.58	0.026	18	0.92	0.001	0.344–4.06
C1 (0.46 ha)	12	26.1	1.40	0.004	1.16	0.002	165	0.90	0.001	0.083–1.81
C2 (0.09 ha)	20	222.2	1.57	0.015	1.16	0.007	50	0.93	0.001	0.050–1.05
S1 (0.07 ha)	8	114.3	1.55	0.002	1.25	0.002	330	0.86	0.001	0.125–8.63
S2 (0.06 ha)	8	133.3	1.29	0.003	1.12	0.002	215	0.85	0.001	0.125–3.63
S3 (0.07 ha)	8	114.3	1.53	0.002	1.38	0.002	368	0.83	0.001	0.125–15.62
			Pachnaeus litus							
C1 (8.2 ha)	144	17.6	2.06	0.03	1.16	0.009	16	0.98	0.001	0.007–0.91
C2 (14.6 ha)	360	24.7	2.54	0.05	1.20	0.019	9	0.98	0.001	0.011–1.84
C1 (0.46 ha)	12	26.1	1.43	0.001	1.17	0.004	107	0.91	0.001	0.083–4.00
C2 (0.09 ha)	20	222.2	1.71	0.002	1.21	0.003	115	0.97	0.001	0.050–4.20

C = central regions, S = southern region of the citrus industry in Florida. SE(A) = standard error of the intercept ($\log_e a$).

[a] n may vary from the potential number of observations because counts of 0.0 cannot be transformed to logarithms when fitting the model.

drip line while cone-shaped traps were placed under an adjacent tree with the edge of the trap almost touching the tree trunk. The C3 plots were the only ones that did not receive experimental treatments. However, carbaryl sprays specifically applied for adult weevil control were performed on 17 April 1995, 10 June 1995, 28 August 1995, 13 May 1996, and 15 August 1996. Commercially available entomopathogenic nematodes were applied to soil on 19 May 1995 and three May 1996 for control of weevil larvae. Plots at sites S1-S3 consisted of 1–3 rows of 24–29 trees. Citrus Tedders traps were placed beneath the canopies of eight randomly chosen trees in the center row of each plot. Traps were monitored weekly between April 1996–June 1998 at site S1, February 1998–December 1999 at site S2, and August 1998–December 1999 at site S3.

Analyses of Sampling Precision. We used the ratio of the confidence interval half-length ($\alpha = 0.05$) to the sample mean as a measure of sampling precision. Numbers of *D. abbreviatus* and *P. litus* recovered each month from citrus Tedders traps or cone traps were computed for each experimental site and Taylor's power law ($s^2 = a\,\bar{x}^b$; Taylor 1961) was fitted to the $\log_e$-transformed monthly means and variances for all traps within a site or within each experimental plot (Elliot 1977). The Taylor's power law parameter estimates were then used in the formula

$$0.5\ CI/\bar{x} = \sqrt{z^2_{\alpha/2} a \bar{x}^{b-2}/n}\,, \qquad [1]$$

where CI = confidence interval, z = the standard normal variate (1.96, $P = 0.05$), n = number of traps and a and b are the parameters of Taylor's power law, to estimate the influence of geographic location and plot size on the precision of population size estimates (Elliot 1977, Duncan et al. 1994). The same formula rearranged as

$$n = (z^2_{\alpha/2} a \bar{x}^{b-2})/(0.5\ \mathrm{CI}/\bar{x})^2 \qquad [2]$$

was used to predict the minimum numbers of traps needed to estimate population size with a given precision.

To evaluate the precision with which changes in the average numbers of trapped insects were detected, t-tests were computed for differences ($P \leq 0.05$) between all possible pairs of monthly means for *D. abbreviatus* abundance during 1998 at site C1. The probabilities of a type I error were compared with the proportional magnitude of the mean differences.

Results

The mean-variance relationships for *D. abbreviatus* as measured by Taylor's power law (slopes and intercepts of log-transformed variances regressed against log-transformed means) did not differ significantly for data from the small plots at each site (Table 2). However, estimates of the parameter b for each entire site were more variable, and b for sites C2 (1.108 ± 0.029; $b \pm$ SD) and S3 (1.583 ± 0.113) differed significantly ($P = 0.001$). There were no significant correlations between the size of sample area and the parameters a or b. However, the range of numbers of weevils/trap/mo at each site was correlated ($n = 6$, $r = 0.97$, $P = 0.001$) with b.

The variation in parameters between sites did not result in appreciably different estimates of sampling precision, except for those of site C3 which indicate greater precision than at the other sites for estimated population densities <0.32 weevils trap^{-1} month^{-1} (Fig. 1A). We pooled the data from all sites, either including or excluding those from site S3, and found that the resulting precision estimates from Taylor's power law and equation 1 did not differ much across

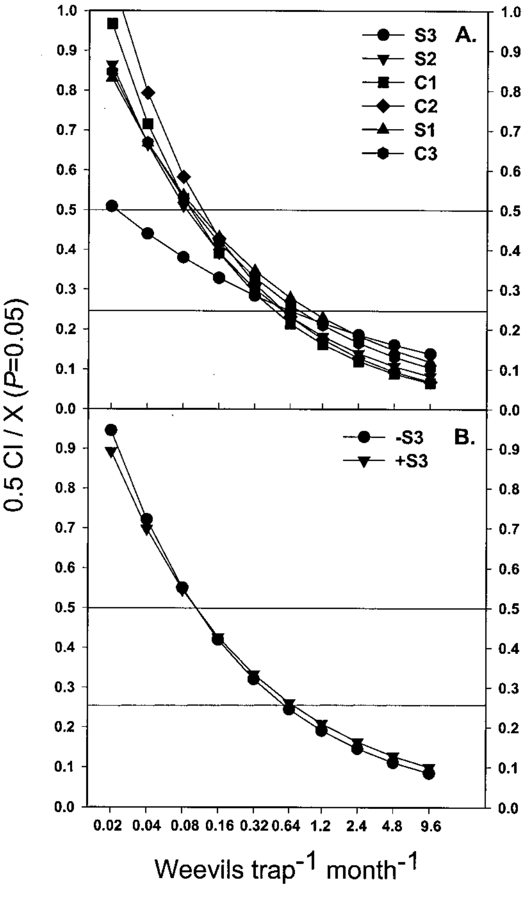

Fig. 1. Predictions of the precision with which 200 Tedders traps will measure the mean density of *Diaprepes abbreviatus* using Taylor's power law and the equation $0.5\ CI/\bar{x} = \sqrt{z_{\alpha/2}^{2}\, a\bar{x}^{b-2}/n}$: (A) predictions using Taylor's power law parameters derived from each of six different citrus groves in the central (C1–C3) and southern (S1–S3) citrus-growing regions of Florida; (B) predictions using parameters derived from data pooled from all six groves, or from five groves and excluding data from site S3.

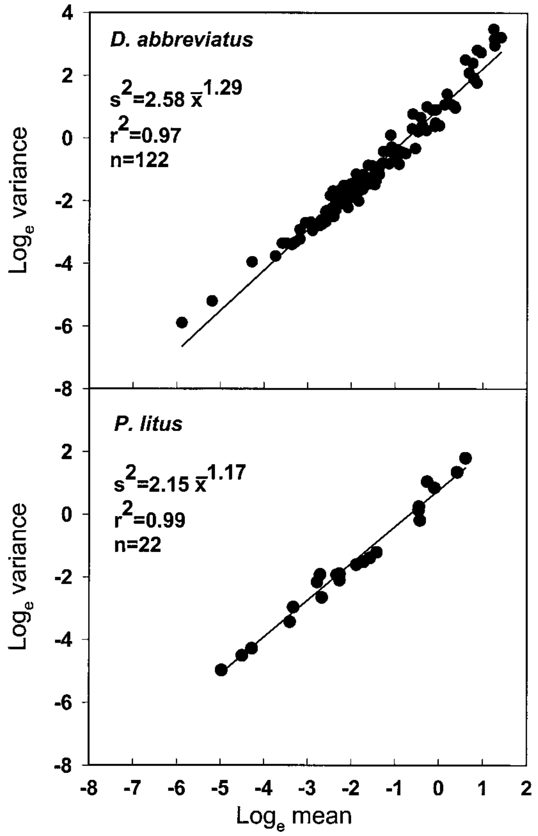

Fig. 2. Relationships between variances and means (weevils/trap/mo) of the numbers of (A) *Diaprepes abbreviatus* from six citrus groves, and (B) *Pachnaeus litus* from two citrus groves.

the range of mean population densities encountered in our studies (Fig. 1B). Therefore, we chose to use Taylor's power law parameters fitted to the data pooled from all sites as the best estimators of the variance-mean relationships for *D. abbreviatus* in Florida citrus groves (Fig. 2A). However, several points at the lowest mean densities exerted a disproportionately large effect on the regression. These points represented cases in which only one to two weevils were captured during a month, constraining the variance estimate to be larger than might occur at the same mean density, but with a greater number of traps. We chose to recognize this discontinuity in the linear relationship by omitting data based on counts of a single weevil. The resulting regression provided estimates of the parameters *a* and *b* equal to 2.69 and 1.33, respectively (n = 119, r^2 = 0.96). Parameters for *D. abbreviatus* from small plots pooled across the six sites (omitting data for counts of a single weevil) were a = 1.56, b = 1.32 (n = 872; r^2 = 0.84; data not shown). Both Taylor's power law parameters for *P. litus* were smaller than those for *D. abbreviatus,* and geographic location did not affect the relationship (Table 2; Fig. 2B).

The sampling precision for *D. abbreviatus* was higher for the small experimental plots than for the entire sites. In general, precision in plots and sites was equal when population densities in sites were double those in plots (Fig. 3A). Assuming the use of 200 traps/unit, sampling precision exceeded 0.5 at population densities >0.04 and > 0.08 weevils/trap/mo in small and large plots, respectively. Weevil densities >0.32 and >0.64/trap/mo in small and large plots, respectively, resulted in sampling precision of at least 0.25. At a given population density, ≈70% more traps were required in large sites compared with small plots, for an equivalent level of precision (data not shown). In large plots, sample sizes ≥ 100 Tedders traps were estimated to provide sampling precision <0.50 at *D. abbreviatus* abundance >0.32 weevils per trap per month, and <0.25 at weevil abundance >2.4 per trap per month (Fig. 3B).

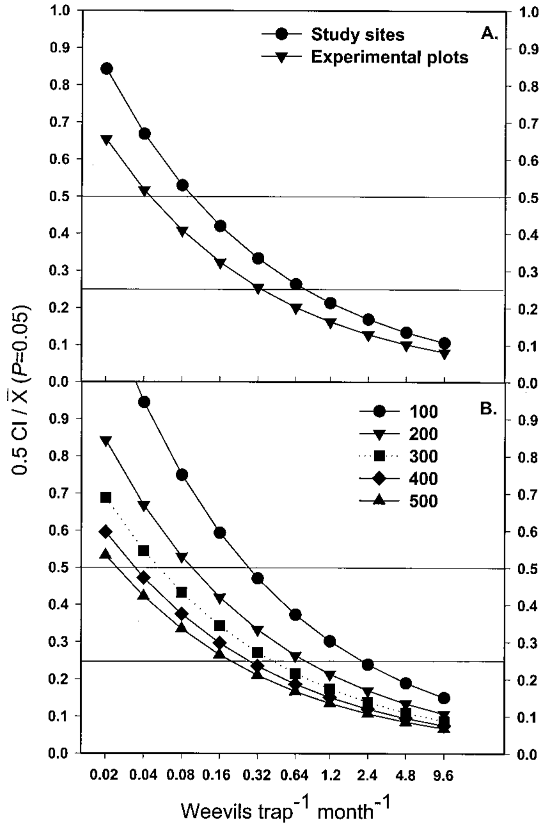

Fig. 3. Predictions of the precision with which Tedders traps will measure the mean density of *Diaprepes abbreviatus* using Taylor's power law in the equation $0.5\ CI/\bar{x} = \sqrt{z^2_{\alpha/2}\ a\bar{x}^{b-2}/n}$ for (A) plots of different size (0.06–0.46 ha versus 1.6–12.6 ha) using 200 traps and (B) large plots using different numbers of traps. Parameters for small plots were $a = 1.56$, $b = 1.32$, and for large plots $a = 2.69$, $b = 1.33$.

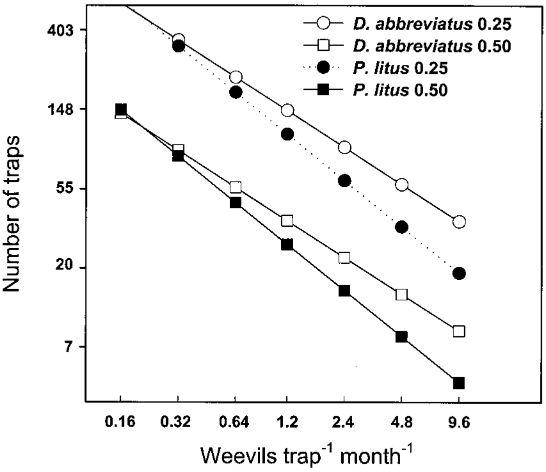

Fig. 4. Optimum numbers of Tedders traps to achieve different levels of precision (given in legend) at different levels of abundance of *Diaprepes abbreviatus* and *Pachnaeus litus* according to the equation $n = (z_{\alpha/2}{}^2\ a\ x^{-b-2})/(0.5\ CI/\bar{x})^2$, where $a = 2.69$ and $b = 1.33$ for *D. abbreviatus* and $a = 2.15$ and $b = 1.17$ for *P. litus*.

At a population density of 1.2 weevils per trap per month, 20% fewer traps on average were needed to estimate numbers of *P. litus* compared with *D. abbreviatus* in the large sample site plots (Fig. 4). Sampling requirements for the two weevils converged at lower densities and diverged at higher densities.

Numbers of citrus Tedders traps used at the various sites (84–360) were adequate to reveal seasonality in the abundance of both weevil species (Figs. 5 and 6). The abundance of weevils in untreated control plots was often greater than that in plots that received experimental treatments, but the patterns of seasonal abundance were similar for both types of plot (data not shown). The maximum monthly averages for *D. abbreviatus* at the southern sites occurred in April each year between 1996 and 1999 (Fig. 5). In the central region, highest numbers of *D. abbreviatus* and *P. litus* were recorded in May 1998–1999 at the C1 site, but at the C2 site the greatest number of both species were caught in April 1999 (Fig. 6). Compared with springtime months, significantly lower numbers of either species were trapped after midsummer at any location. Differences in mean monthly weevil abundance could be identified by *t*-tests; the probability of a type I error did not exceed 0.05 when the proportional difference in mean weevil abundance exceeded 2.5 (Fig. 7).

At site C3, the numbers of *D. abbreviatus* caught in citrus Tedders traps were correlated ($r = 0.78$, $n = 33$, $P < 0.01$) with the emergence of adult weevils from soil (Fig. 8A). Sixty-six percent of the monthly variation in adult emergence from soil (as measured by cone traps) was explained by second order polynomial regression against numbers of adults recovered from Tedders traps (Fig. 8B). Both types of traps produced similar patterns of adult emergence from soil during the initial phase of emergence each spring during 1995–1997. However, weevils were caught at proportionally higher rates in cone traps compared with

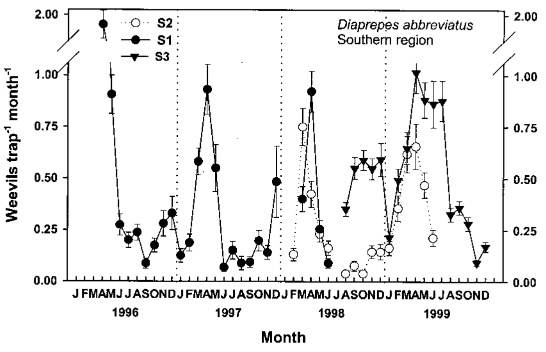

Fig. 5. Mean and standard error of numbers of *Diaprepes abbreviatus* trapped monthly in three citrus groves in the southern region of the Florida citrus industry. Numbers of weevils trapped at the S3 site were divided by 4.0 to facilitate comparison of sites.

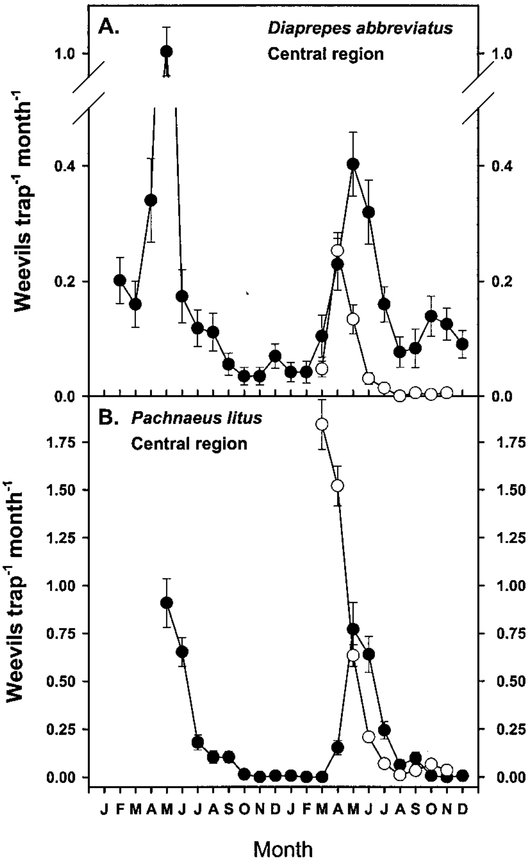

Fig. 6. Mean and standard error of numbers of (A) *Diaprepes abbreviatus* and (B) *Pachnaeus litus*, trapped monthly at sites C1 (filled circles) and C2 (open circles) in the central region of the Florida citrus industry.

Tedders traps throughout the early summer months. On average, Tedders traps caught 4.2 times as many weevils as did cone traps. The efficiency of cone traps was comparable to that of Tedders traps (Fig. 9).

Discussion

Unbaited citrus Tedders traps can be effective devices for estimating the relative abundance of adult root weevils in units of citrus at a given point in time. The use of 144 or more traps revealed recurring annual patterns of abundance of the adult stage of two weevil species in each of the study sites in which they occurred. The natural pattern of seasonality was not confounded by pesticide use at the experimental sites because identical patterns occurred in untreated control plots. Moreover, the patterns for *D. abbreviatus* derived from Tedders traps were similar to those of adults emerging from the soil. Even at low population abundance, (<0.05 weevils per trap per month), less than a three-fold change per month was consistently found to be significant. Collecting data from 144 traps in an area of 8.2 ha required less than 2 h in the field each week.

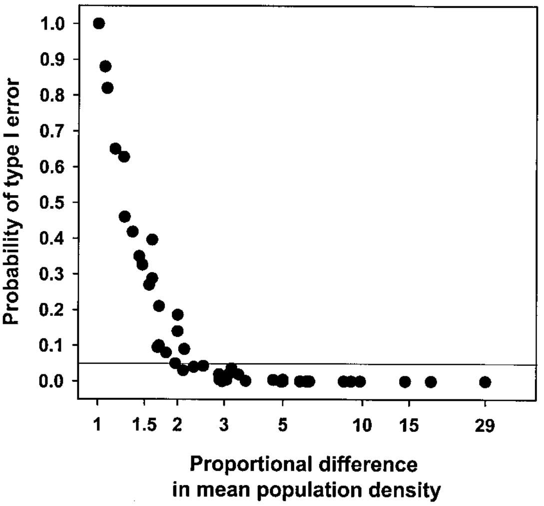

Fig. 7. Proportional change in the abundance of *Diaprepes abbreviatus* caught by Tedders traps each month and the probability of a type I error if the densities are designated as different. *t*-tests were used to estimate probabilities of difference between each pair of monthly means measured during 23 mo at site C1.

Whether there is a consistent relationship over time between numbers of weevils caught in citrus Tedders traps and weevil abundance in a grove is unknown. A significant positive correlation between weevils recovered in citrus Tedders traps and from beat sampling of trees during 65 wk provided evidence that the traps reveal the relative population density of adult *D. abbreviatus* in a grove (H. Nigg, personal communication). Nevertheless, *D. abbreviatus* is a polyphagous insect (Simpson et al. 1996) and, therefore, it is possible that the temporal and spatial patterns of abundance of the insect in citrus groves is regulated not only by its population dynamics on citrus, but by periodic movement to and from other habitats. In this study, the onset of emergence from soil by adult weevils in the spring coincided with increased recovery of weevils in citrus Tedders traps in each of 3 yr. Sherman and Mizell (1995) were able to detect emergence of *P. opalus* in a Florida peach orchard using original Tedders traps. However, in our study, weevils continued to be caught at high levels in cone traps for 1–2 mo after weevils caught by Tedders traps declined significantly. Insecticides that were used to manage *D. abbreviatus* at site C3 were usually applied at peak weevil emergence and may explain the more rapid decline in weevils trapped in Tedders traps than in cone traps following the spring emergence period. Additional research on this question is needed because density dependent biological control of adult weevils, seasonal migration of weevils to and from citrus, or behavioral changes related to physiological development might also influence patterns of abundance derived from Tedder traps.

The spatial patterns of *D. abbreviatus* and *P. litus* appear to be less aggregated than those of many in-

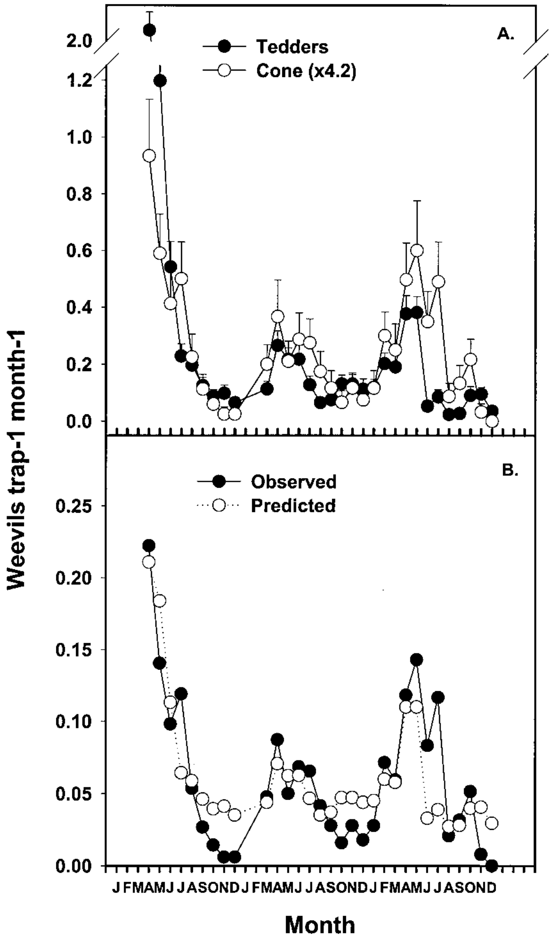

Fig. 8. Numbers of *Diaprepes abbreviatus* caught monthly in Tedders traps and in cone traps at site C3 (A) and predicted weevil emergence based on polynomial (second order) regression of numbers of weevils caught in Tedders traps on those caught in cone traps (B). Numbers of weevils caught in cone traps were multiplied by 4.2 to facilitate comparison with data from Tedders traps.

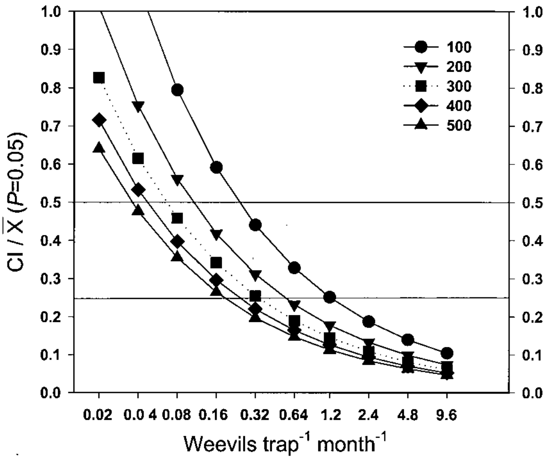

Fig. 9. Relationship between numbers of cone traps and sampling precision for *Diaprepes abbreviatus* predicted from the equation 0.5 $CI/\bar{x} = \sqrt{z^2_{\alpha/2}\, a\bar{x}^{b-2}/n}$, where $a = 1.13$ and $b = 1.40$. Parameter estimates were derived from data at the Lakeland site.

sects, as shown by estimates of the Taylor's power law parameter *b* that were closer to 1.0 than to 2.0 (Elliot 1977). The relatively small ranges in the numbers of weevils caught by individual traps at our sites provides intuitive evidence that the adult insects were not highly aggregated. Of greater concern for the purpose of determining general sampling requirements for these weevils is that the largest and smallest estimates of *b* in this study varied significantly. Although the parameter *b* has been suggested to be characteristic for a given species (Southwood 1966), Taylor et al. (1998) note that there is "ample evidence" that the spatial pattern of a species can vary with region, crop, crop phenology, location on the plant, or due to pest management. Variability in the parameter *a* is frequently greater than that of *b*, is affected by sampling protocol, and has a proportionately greater effect on sampling requirements (Taylor et al. 1998). Our analysis of pooled data for *D. abbreviatus*, in which counts of a single insect/trap/month were omitted, is consistent with the observations of Taylor et al. (1998) because sampling requirements in plots of different size were influenced by differences in *a*, while *b* remained constant. Indeed, the variation in *b* between experimental sites (all data included) may be an artifact of sample size and differences in population densities between sites, because *b* was positively correlated with the ranges of population densities. Sites with smaller ranges contained the greatest number of observations in which only one or a few insects were trapped per observation period. If insects are not highly aggregated, the greatest likelihood is that the variance for a given mean density will decrease with increased sample size. For example, when a single insect is trapped in a month the variance will equal the mean. However, if two insects were trapped using twice as many samples, the same mean density would exceed the variance unless both were caught in the same trap. Thus, at low population density the variance estimate may be inflated, thereby reducing the estimate of *b*.

These results support the use of citrus Tedders traps in weevil integrated pest management programs. All of the current tactics to manage weevil adults and eggs in the tree canopy or larvae in the soil have relatively short residual activity requiring accurate timing for maximum benefit (Knapp 2000). Insecticides for use against adult weevils are disruptive to natural biological control in citrus groves (McCoy 1999). Growers attempt to use these materials as infrequently as possible by applying them at peak adult abundance in the spring to reduce ovipositioning which reaches a maximum rate about 20 d after emergence of adults from soil (Beavers et al. 1982). Application of insecticides to the soil surface to kill neonate larvae dropping from the tree canopy and treatment of soil with entomopathogenic nematodes to manage larvae in soil also require accurate timing with respect to the insect life-cycle. However, numerous Tedders traps are required to accurately monitor weevil activity in a grove. For example, from equation 1, a grove containing 40 citrus Tedders traps is likely to provide a precision of 0.5 for a peak springtime number of *D. abbreviatus* per trap per month = 1.0. Assuming that the abundance of adult weevils trapped increased ≥10-fold during the spring, then (from equation 1) use of 40 traps is likely to provide significant evidence of a difference between 0.1 and 1.0 weevils per trap per month, indicating that a major period of emergence from soil is occurring. Peak weevil numbers at several sites, however, were well below 1.0 per trap per month and greater numbers of traps would be needed to achieve the necessary precision. Therefore, regular reporting of results obtained from greater numbers of traps at several sites in each of several different geographic/climatic regions may provide a more accurate and cost-effective means for timing management tactics (Stansly et al. 1997).

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