Seasonal and Spatial Distribution of Banana Aphid, *Pentalonia nigronervosa* (Hemiptera: Aphididae), in Banana Plantations on Oahu

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Abstract. *Banana bunchy top virus* (BBTV) severely affects the sustainability of Hawaii's banana crop industry. Although the virus rarely kills the plant, infection severely limits production of marketable fruit. The only known vector of BBTV is the banana aphid (*Pentalonia nigronervosa*, Hemiptera: Aphididae).

This study was conducted on three farms located in Kahuku, Waialua and Waianae on the island of Oahu, Hawaii. Within each farm, 16 plots were set up in a grid pattern for monthly sampling. Average numbers of aphids were compared with ANOVA for each farm by month. Taylor's Power Law was used to determine dispersion within plantations. There were no distinct patterns in seasonal distribution, but aphid numbers were negatively correlated with rainfall in some plantations. An aggregated dispersion pattern was evident in plantations with lesser cultural management inputs. We also observed a seasonal edge-effect (larger numbers of aphids closest to plantations' edges). Due to the vector status of banana aphid, an understanding of the seasonal and spatial distribution of banana aphids is an important component in developing efficient BBTV management strategies.

Key words: Banana aphid, dispersion, seasonality, banana, *Musa*

Introduction

Bananas (*Musa* spp.) are Hawaii's tenth most important agricultural crop, with a farm value of $10.6 million in 2001 (Hawaii Agricultural Statistic Service 2003). They are produced on all the inhabited islands of the Hawaiian archipelago, with the largest farms on the isles of Hawaii and Oahu. Banana production in Hawaii has been severely constrained by a viral disease, *Banana bunchy top virus* (BBTV). Commercial-scale production of bananas on Kauai has been nearly terminated as the result of BBTV, and production in all other areas is severely impacted by this disease. Management of BBTV is achieved through aggressive roguing of infected plants, and attempted vector management. Banana aphids (*Pentalonia nigronervosa*, Hemiptera: Aphididae) are the only known vectors of BBTV. The virus is not transmitted mechanically. The aphids acquire the virus from infected plants, and no transovarial infection occurs (Hu et al. 1996). BBTV is transmitted persistently (Hu et al. 1996), and alate aphids are presumably responsible for spread of the virus. Management of these aphids is difficult owing to their cryptic lifestyle, with large colonies developing under the sheaths of banana leaves or on underground plant parts (Waterhouse and Norris 1987). Foliar applications of diazinon and imidacloprid are currently used on a restricted basis for aphid management. Efforts are underway to develop alternative approaches to managing *P. nigronervosa* in Hawaii, including biological control options. Banana aphids appear to disperse slowly within plantations and it is possible that an effective means of reducing population build-up could contribute significantly to reducing the rate of spread of

BBTV within plantations, given the persistent nature of transmission. Biological control may offer viable options for reducing aphid colonies, and reducing the rate of disease spread. This approach has been applied in other systems (e.g. Puterka 1999), but there are currently no known effective predators or parasitoids that suppress *P. nigronervosa* in Hawaii. The data reported in this study were collected as part of an effort to identify indigenous insect pathogens in Hawaii that have potential as biological control agents.

Knowledge of the seasonal and spatial distribution of *P. nigronervosa* within banana plantations can be used to create or improve pest monitoring procedures and pesticide application programs, as well as to effectively plan augmentative releases of biological control agents. Basic data in Hawaii are lacking. This study was therefore undertaken to investigate the seasonal and spatial distribution of *P. nigronervosa* and to contribute to the development of a fixed precision sampling plan for *P. nigronervosa* within banana plantations in Hawaii.

Materials and Methods

Study sites: This study took place at three farms located in Kahuku, Waialua and Waianae. Kahuku is located near the northern tip of the island of Oahu, on the Windward (northeast) coast. Of the three study locations, it receives the most rainfall, an average of 1143 mm per year. The area in banana production is 1.6 ha. Waialua receives an intermediate amount of rainfall, averaging 858 mm per year. It is located just inland of Oahu's North Shore, and between the island's two mountain ranges, the Koolau and Waianae mountains. The plantation in Waialua is the largest, with over 20.2 ha in banana production. Waianae is located on the southwest shore of Oahu, in the rain shadow of the Waianae mountains. Its annual rainfall averages 508 mm (Hawaii Agricultural Statistics Service, 2002). The farm located in Waianae is the smallest at about 0.2 ha. The Waialua and Waianae farms use drip irrigation; the Kahuku farm does not use supplemental irrigation. Cultural practices were slightly different in each plantation. The Kahuku plantation was densely planted, with almost 100% canopy cover within rows. The rows at Waialua were thinned, and the canopy approximately 75% closed. At Waianae, the plantation was carefully sanitized regularly, the individual mats of banana were widely spaced, and canopy cover was approximately 50%.

Sampling: Within each farm, the study area was a 60mx60m section of a plantation. At the Kahuku and Waialua plantations, 16 plots were set up in a 4x4 grid pattern for sampling, approximately 20m apart. The Waianae farm, due to size constraints, was set up in a similar manner but only allowed for 11 plots. Banana aphids were typically found in large numbers only on the suckers, rather than on mature plant parts. Within each plot, banana aphids were counted monthly on each of 10 randomly selected suckers per plot to determine their spatial distribution within the plantations. Although the same plots were sampled monthly, different suckers were sampled each time. Previously sampled suckers were easily identified by damage caused to the leaf sheaths during previous sampling. Sampled suckers were 50–100 cm in height. Average numbers of aphids per sucker were plotted monthly for each farm for the period of August 2002–August 2003 to explore seasonal fluctuations in populations. Mean numbers of banana aphids were compared by analysis of variance for each farm by month and across all farms, with location and month as main factors (PROC ANOVA, SAS 1988). Means were compared using Tukey's test.

Dispersion of *P. nigronervosa* in the plantations was explored using Taylor's Power Law. The means and variances of aphid densities were calculated for each plot on each sampling date. Taylor's Power Law was used to describe the relationship between the logarithm of the variance (s^2) and the logarithm of the mean (Taylor, 1961):

$$\log_e s^2 = b \log_e \bar{x} + \log_e a$$

where *b* is the slope of the regression line. The slope of the regression provides a measure of dispersion with: $b < 1$ uniform (regular); $b > 1$ aggregated (contagious); and $b = 1$ random. Regression analyses were conducted using SAS PROC REG. Slopes were tested for significant differences from unity (1) using the SAS hypothesis TEST option. Analyses were conducted using SAS PROC REG (SAS Institute, 1988).

A possible edge-effect (with the hypothesis that aphid numbers would be highest at the edges of plantations) was explored by correlating (SAS PROC CORR) monthly and annual mean numbers of aphids per plot and proportion of suckers infested per plot with distance (0 m, 20 m, 40 m, 60 m) from the plantation edge for the Waialua and Kahuku plantations. Inadequate data were available to do this for the Waianae site due to the small number of plots that could be accommodated in the plantation.

Results

There were no distinct or consistent patterns in seasonal distribution. No significant overall pattern in seasonality was observed ($F_{13;25} = 1.01$, $P = 0.4630$). Peak numbers of banana aphids occurred at both the Waialua and Waianae farms in September 2002 (Fig 1). The monthly mean number of aphids at Waianae did demonstrate statistically significant variability ($F_{1;12} = 541.28$, $P = 0.035$) with significantly higher aphid numbers in September; there was no significant variability at the Waialua site ($F_{1;12} = 1.83$, $P = 0.5247$). No sharp rise in aphid density occurred at the Kahuku study site until October of the same year (Fig. 1). Correlations between mean monthly rainfall and mean aphid numbers in the study sites ranged from non-significant (Kahuku, r = 0.10) to weakly-significant (Waianae, r = –0.46, d.f. = 11, P = 0.10; Waialua, r = –0.55, d.f. = 11, P < 0.050). The peak aphid numbers at the Waianae and Waialua farms (Fig. 1) were preceded by low rainfall in August, which continued in September. However, the peak counts at Kahuku (Fig. 1) were preceded by moderate rainfall in October followed by a slightly drier November. The seasonal distribution of aphids showed the least fluctuation at the Kahuku farm (Fig. 1). For much of the study period average numbers of aphids per sucker hovered around 35–40. The Waialua farm had moderate variation, usually within the range of 15–25 aphids per sucker. The Waianae farm showed the most variation in average numbers of aphids per plant, ranging from a low of 15 to a high of nearly 70.

No significant difference in mean number of aphids per sucker was detected overall by locality (means for 13 months of data for each farm, $F_{2;25} = 1.61$, $P = 0.2198$; mean number aphids ± SEM: Waialua: 25.57 ± 2.19; Kahuku: 33.25 ± 2.30; Waianae: 31.21 ± 4.41).

Analysis of each farm using data from multiple sampling dates gave significant regressions for the relationship between the variance and the mean using Taylor's power law. Slopes were > 1, indicating aggregated dispersion of the aphids within the sampling sites, for the Waialua and Kahuku study sites, and not significantly different from 1 for the Waianae site, indicating a random dispersion pattern (Table 1).

Correlations between mean number of aphids per plot and distance from the edge are shown in Figure 2. Most correlations were not significant, and others only weakly significant (P < 0.10). Significant correlations (P < 0.050) were found in only three cases (Figure 2). There was a tendency for highest aphid numbers to be present within plots further from the edge of the plantations during most of the year (positive correlations), and for a slight edge effect (negative correlations) to occur during May–August (Figure 2). Weak positive correlations between the overall mean number of aphids per plot for the 12 months of sam-

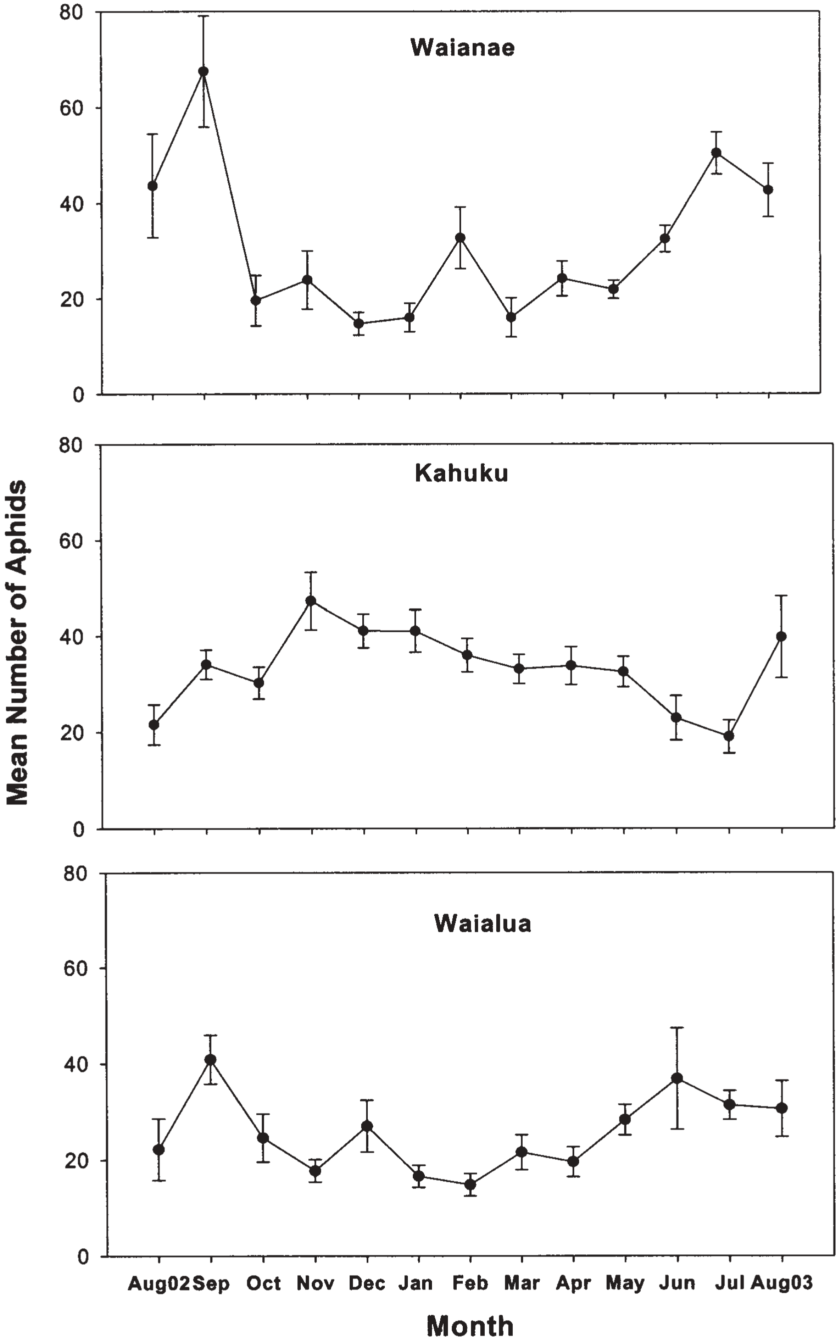

Figure 1. Seasonal distribution (mean ± SE) of banana aphids in three banana plantations on Oahu, Hawaii.

Table 1. Slopes for Taylor's Power Law (linear transformation) applied to banana aphids in banana plantations on Oahu.

Site	Slope *b*	SE	Test for Unity, *P*	Dispersion
Waianae	1.086	0.066	P = 0.1967	Random
Kahuku	1.670	0.045	P < 0.0001	Aggregated
Waialua	1.610	0.049	P < 0.0001	Aggregated

pling and distance from the edge of plantations were found (Kahuku, $r = 0.57$, $P < 0.050$; Waialua, $r = 0.41$, $P > 0.10$). Correlations between proportion of suckers infested and distance are shown in Figure 3. A pattern similar to that for number of aphids was found, with indications of an edge effect during the months June–August. There were no significant correlations between the 12 month mean proportion of suckers infested and distance from the plantation edge for either of the plantations.

Discussion

The lack of distinct seasonal fluctuations in banana aphid populations at low elevations on Oahu is not atypical for tropical areas, where aphids are anholocyclic, and often show minor fluctuations in numbers seasonally (Agarwala and Bhattacharya 1994). Fluctuations in aphid numbers on some crops in Hawaii appear to be the result of epizootic outbreaks rather than seasonality (MGW pers obs., Messing R.H. pers comm.). At first inspection, this seems to be reflected by the (weak) negative correlation of aphid numbers with increased rainfall, but we recorded extremely low levels of infection by entomopathogens (Young and Wright unpublished data). Our results are somewhat surprising considering aphid mortality in other systems. Rajan (1981) reported that heavy mortality of aphids occurred during the monsoon season (in India) due to the growth of the entomogenous fungi, *Verticillium intertextum*. It is possible that the sheaths of the leaves became inundated with water during high rainfall, and drowned many aphids. Samways (1979) showed that in the absence of significant predator populations, rainfall was the key mortality factor for a spectrum of small arthropods in Brazil. It is interesting to note that highest rainfall was correlated with lowest aphid numbers in the plantations with the least dense canopies (Waianae and Waialua), while the Kahuku plantation had a relatively consistent aphid population and the highest rainfall, but also the most dense canopy. A dense canopy may significantly reduce the amount of rainfall penetrating to the leaf whorls of banana suckers below. A replicated study of the effect of canopy management on banana aphid might provide more conclusive evidence on the effect of rain inundation of leaf sheaths, on banana aphid populations.

Our data indicate an infrequent edge-effect. Understanding the effect of edges on insect populations has been emphasized in prior studies of natural enemies of aphids (Brown and Lightner 1997), with the authors determining a minimum distance from the edge that one should sample to avoid biasing sampling data by selecting areas likely to support more insects. In the case of sampling an insect that is the vector of a viral pathogen, the inverse may be preferred. That is, sampling may be concentrated in the areas where aphids are most likely to be detected followed by samples taken elsewhere in the crop. The utility value of sampling will depend upon the economic injury level, which may be extremely low for banana aphid. This aspect requires greater attention.

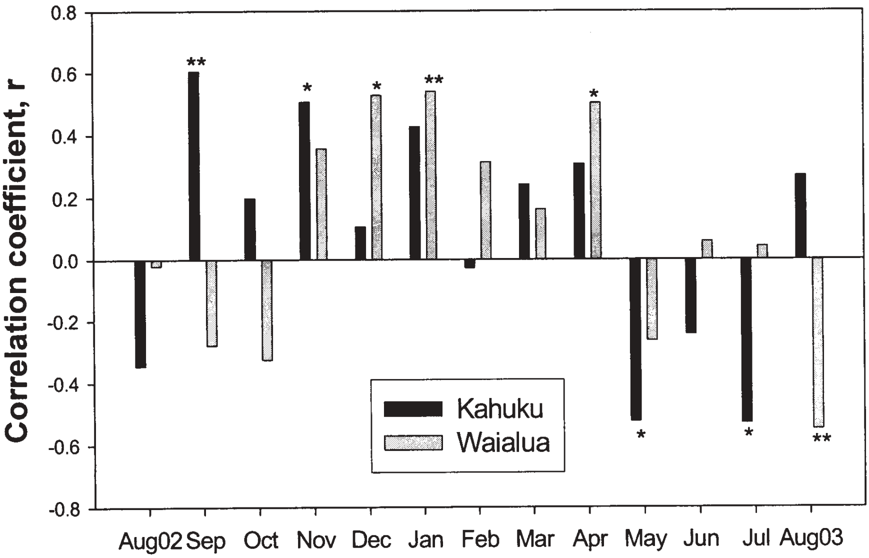

Figure 2. Correlations between mean banana aphid numbers per plot and distance from edges of banana plantations, for monthly aphid counts (* P < 0.10; ** P < 0.050). Negative correlation coefficients indicate an edge-effect.

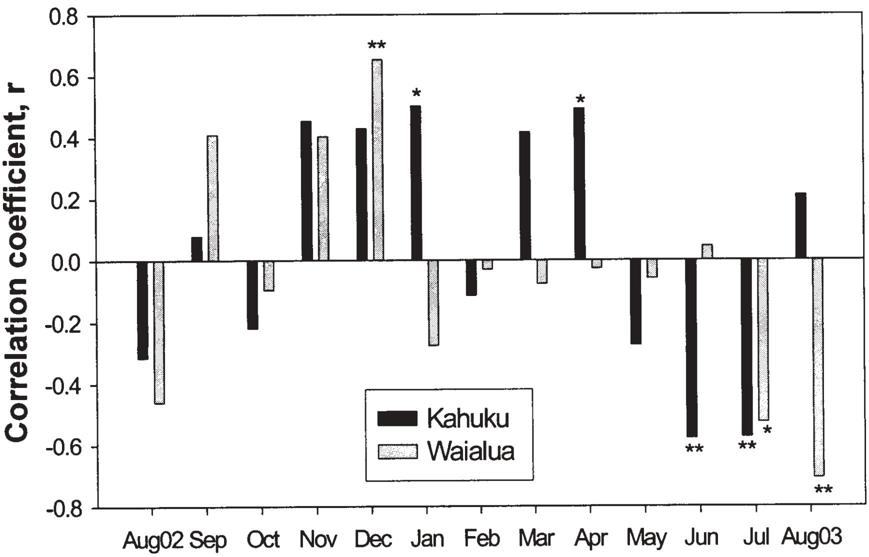

Figure 3. Correlations between proportion of banana suckers infested per plot with banana aphids and distance from plantation edges, for monthly aphid surveys (* P < 0.10; ** P < 0.050). Negative correlation coefficients indicate an edge-effect.

It is typical for a species to have a consistent dispersion pattern under specific conditions (e.g. Hummel et al. 2004, Nestel et al. 1995, Taylor 1961). The regression slopes for the Kahuku and Waialua samples were comparable (Table 1, both indicating aggregation). The random dispersion of aphids indicated by a TPL slope = 1 at the Waianae farm was unexpected, but is likely to be due the diligence of the farmer in managing his bananas. Sanitation on the Waianae farm was always rigorously carried out. Senescing leaves were not left lying about and any plant suspected to be virus-infected was removed and destroyed immediately. The banana root mats were also farther from each other on this farm; individual mats formed little islands within the farm as opposed to the more typical rows of plants at Waialua and Kahuku. This added distance may have limited aphid dispersion. It is also likely that the diligent sanitation and cultural control practices helped the farmer effectively prevent aphid populations from building up large aggregations. This is significant in that winged alates are indicated as the main culprits in the spread of BBTV, owing to their higher mobility (Waterhouse and Norris 1987), and these are only produced under crowded conditions. Therefore, suppression of the aphid population below the 'alate-production threshold' may limit spread of the disease.

The Waialua and Waianae farms were less rigorously sanitized. Within the rows, banana plants were crowded; individual mats were not discernable. Other plants such as mint (*Mentha* spp.) and ivy gourd (*Coccinia grandis*) were observed growing around the pseudostems, indicating that these farmers were not as conscientious regarding sanitation. Perhaps inattention to this aspect of banana farming allowed aphid populations to develop significant aggregations.

The data presented in this paper show that banana aphids are present in relatively consistent numbers in the banana plantations of Oahu. Populations tend to be aggregated under fairly typical farm management conditions. Factors that influence their distribution within plantations deserve further attention, and may result in improved cultural approaches to banana aphid management.

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