

# Relationship Between Community Structure and Southern Green Stink Bug (Heteroptera: Pentatomidae) Damage in Macadamia Nuts

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**ABSTRACT** The effect of host weed phenology, abundance, and diversity and natural enemies on the population dynamics of the southern green stink bug, *Nezara viridula* (L.), in Hawaiian macadamia orchards was investigated. We found that the highest kernel damage occurred immediately following abrupt reductions in the flowering and fruiting stages of host weeds. Areas with the greatest diversity of host weeds showed higher damage, presumably because of higher *N. viridula* population levels. Predation rates on sentinel egg masses were highest over the two seasons in areas where the bigheaded ant, *Pheidole megacephala* (F.), comprised a large portion of the ant fauna. In one of the orchards, *P. megacephala* and the longlegged ant, *Anoplolepis longipes* (Jerdon), occurred in a spatial mosaic where the boundaries shifted back and forth over time. Sentinel egg masses placed in these two adjacent areas showed predation rates were highest in the areas dominated by *P. megacephala*, and intermediate in the interface zone and lowest where only *A. longipes* were found. The importance of weed phenology and natural enemy induced mortality is discussed.

**KEY WORDS** *Nezara viridula*, *Pheidole megacephala*, *Anoplolepis longipes*, biological control, community structure

THE SOUTHERN GREEN stink bug, *Nezara viridula* (L.), is probably the most important pentatomid pest of agriculture on a worldwide basis (Todd 1989) and is one of the most serious pests of macadamia nuts in Hawaii (Jones and Caprio 1992). Feeding by southern green stink bug can cause macadamia nut abortion before nuts reach 20 mm diameter, and feeding results in pits that decrease nut quality (Mitchell et al. 1965; Jones and Caprio 1994). In addition to the direct damage, southern green stink bug may also mechanically inoculate the kernel with fungi during the feeding process. Direct and indirect damage caused by southern green stink bug is responsible for approximately \$1 million farm gate value and approximately \$5 million wholesale value (Jones et al. 1992, HASS 1998).

Much of the worldwide problem with *N. viridula* can be traced to the need to understand its ecology and regulating mechanisms not only on the agricultural host, but also on its alternate host plants (Schumann and Todd 1982; Panizzi and Meneguim 1989; Todd 1989; Velasco and Walter 1992, 1993; Panizzi and Alves 1993; Panizzi 1997). Studies show that on most host plants, *N. viridula* feed primarily on seeds, pods, and fruits and that population growth is greatest when these structures are present (Schumann and Todd 1982, Todd 1989, Panizzi and Alves 1993, Panizzi 1997). In addition, *N. viridula* moves between host plants depending on weed phenology and time of year

(Velasco and Walter 1992, 1993; Panizzi 1997). Macadamia nuts are an extreme example of this because by themselves they cannot support survival or population growth of *N. viridula* (Shearer and Jones 1996). Thus, weeds within the orchards and at the orchard borders are necessary for population growth (Shearer and Jones 1998), and to understand *N. viridula* population dynamics and damage potential, weed phenology must be taken into account.

The second major component necessary to understand *N. viridula* population dynamics in macadamia nuts is the role of natural enemies in population regulation. Studies on the management of *N. viridula* on macadamia nuts in Hawaii have shown that the primary cause of egg mortality is predators, primarily ants, in the orchard (Jones 1995). Although previous information suggested that the egg parasitoid *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae) was extraordinarily effective (Davis 1964, 1967, Caltagirone 1981), Jones (1995) found that at least in the orchards investigated, parasitization levels were unimportant in population dynamics of *N. viridula*. Jones' (1995) results were similar to those observed by Nishida (1966) in Hawaii, and by Clarke and his co-workers in Australia (Clarke 1990 1992, Clarke and Walter 1990 1993). A more thorough understanding of the role and importance of the different ant species present in macadamia nuts are thus critical to understand the population dynamics of *N. viridula* in macadamia nuts.

These studies were initiated to determine the importance of ant species composition, weed species

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composition and phenology, and competition between ant species on stinkbug damage in Hawaiian macadamia nut orchards.

### Materials and Methods

**Study Sites.** Four  $\approx 0.5$ -ha plots were chosen on the island of Hawaii, two were near the Hilo area (Ama'u'ulu and Kea'au) where annual rainfall is  $\approx 300$  cm/yr, and the other two were chosen in drier conditions. The Honomalino orchard receives  $\approx 46$  cm/yr and the Pahala orchard is intermediate with  $\approx 170$  cm rainfall/yr. The Honomalino and Pahala orchard plots were part of  $\approx 2,000$ -ha orchards, and the Ama'u'ulu and Kea'au plots were part of orchards  $\approx 20$  and  $60$  ha in size. Plots at the Ama'u'ulu, Kea'au, and Pahala sites were chosen adjacent to borders of the orchard. The Honomalino site was situated within a large contiguous orchard block.

At monthly intervals from December 1994 to June 1996, we determined southern green stink bug damage, performed surveys for ant species present in the orchard, and determined ant foraging rates. Every other month throughout the study, we determined weed species composition and phenological stage of the weeds.

**Stink Bug Assessment.** Each month, from December 1994 to January 1996, adult and immature stages of *N. viridula* were sampled using eight 2-min timed visual surveys of weeds within the orchard. At the same time, weed species examined, as well as the phenological stage of the weeds (flowering, fruiting, vegetative, senescing, or a mixture) were recorded. When stinkbugs were found, the stage and sex of adults were determined.

Stink bug damage was assessed at each site at monthly intervals by collecting 10 recently fallen nuts randomly selected from the ground under 10 randomly selected trees in each orchard. These age nuts were chosen because stinkbug attacks the nuts during the first week after nut drop (Jones and Caprio 1994). Before analysis, data were checked for normality and homogeneity of variance. A two-way analysis of variance (ANOVA) with time and location as the factors was used to determine if there were significant differences between locations and over time (SAS Institute 2000). We used three preplanned single degree of freedom orthogonal contrasts to determine the effects of location: (1) the wet sites (Ama'u'ulu and Kea'au) versus the drier sites (Honomalino and Pahala), (2) Ama'u'ulu versus Kea'au, and (3) Honomalino versus Pahala.

**Weed Species Abundance.** In addition to the weed species composition determined through our visual surveys for *N. viridula* at each orchard, weed species and percentage cover for each species were determined every other month using 10 randomly placed 1-m<sup>2</sup> quadrants. We tabulated the various weeds found in the survey, but concentrated the analysis on those weeds known to be stinkbug host plants. At the Honomalino site, because the plot was within a large homogenous orchard block, we did not take the border samples.

Weed phenology was coded to facilitate analysis. Weeds that were senescing or in a vegetative stage were coded as 0, flowering plants with no seeds or fruit as 1, and those with fruits or seeds as 2. This coding system allowed us to construct a potential stinkbug growth index by multiplying the weed phenology code by the proportion cover of the weed and then averaging the index across all host weeds (i.e., the index was the average phenology weighted by proportion cover). The coding is based on the fact that senescing or vegetative hosts have little effect on stinkbug growth rates, whereas fruits and seeds are generally required for stinkbug population growth (Schumann and Todd 1982, Todd 1989, Panizzi and Alves 1993, Panizzi 1997).

**Ant Species Composition and Predation Rates.** We used two methods of determining ant species composition in the trees each month. For the first method, we collected 30 sticktight nuts from each orchard and placed each nut separately into a 29.6-ml plastic cup with a sealed plastic lid (Bioserve, Frenchtown, NJ). The nuts were frozen after returning to the laboratory and examined individually for ant species present and stage composition. However, because of the difficulty in separating and counting ant eggs, they were recorded only as being present or absent. The second method used clear packing tape (260 cm long by 10 cm wide, 3M, St. Paul, MN), which was briefly applied lengthwise around the tree trunk. We sampled 10 randomly chosen trees per orchard each month in this fashion. The tape was then applied to a clear acetate sheet to form a permanent record of species composition.

Predation rate on stinkbug egg masses was determined at monthly intervals by placing 15 frozen sentinel egg masses in the weeds at the edge and within each orchard and collecting them 1 wk later. Before placing them in the orchard, we counted the number of eggs present and the number destroyed in the colony (*N. viridula* feed on the eggs if left too long in the colony). After collecting the egg masses, we scored each egg mass for the number of eggs eaten and number parasitized by *T. basalis* or other parasitoids. Data were summarized as the percentage of eggs placed in the field destroyed, the percentage of the egg masses placed in the field found by natural enemies, and percentage of the egg masses eaten if they were found. Before analysis, data were checked for normality and homogeneity of variance. A two-way ANOVA with time and location as the factors was used to test for differences in predation rate between locations and over time. If significant differences were found, Tukey's honestly significant difference (HSD) test was used to determine where they occurred (Zar 1996). In addition, because monthly variation could obscure seasonal trends, we used a 4253H data smoother (Minitab 1995) to examine seasonal trends in egg destruction.

**Effect of Ant Species on Stink Bug Egg Predation.** At the Honomalino orchard, we found a site where the bigheaded ant, *Pheidole megacephala* (L.), and the long-legged ant, *Anoplolepis longipes* (Jerdon), occurred in a spatial mosaic. The mosaic consisted of two

Table 1. Host plants where stink bugs were collected from in the 2-min surveys summarized over all plots and all dates

Plant	Common name	No. plants found on	No. eggs found	No. <i>N. viridula</i> found	% total no. <i>N. viridula</i> found
<i>Abutilon grandifolium</i> Sweet	Hairy abutilon	1	111	0	0.00
<i>Amaranthus spinosus</i> L.	Spiny amaranth	18	103	25	56.8
<i>Bidens pilosa</i> L.	Spanish needle	6	0	6	13.6
<i>Crotalaria incana</i> L.	Fuzzy rattlepod	2	0	4	9.1
<i>Malvastrum coromandelianum</i> Garcke	False mallow	2	0	2	4.5
<i>Momordica charantia</i> L.	Balsam pear	2	0	2	4.5
<i>Boerhavia coccinea</i> Miller	—	1	0	1	2.3
<i>Desmodium intortum</i> Urban	Tick trefoil	1	0	1	2.3
<i>Macroptilium lathyroides</i> Urban	Cow pea	1	0	1	2.3
<i>Pueraria phaseoloides</i> Bentham	Tropical kudzu	1	0	1	2.3
<i>Ricinus communis</i> L.	Castor bean	1	0	1	2.3

relatively large territories composed almost exclusively of one species, and a relatively sharply delineated interface zone where the species present changed within one tree (either across the drive row [10 m] or between trees within a row [8 m]). To determine the effect of ant species on *N. viridula* egg predation, we placed 10 egg masses in each territory one row away from the interface. After the second week, we also placed 10 egg masses on the weeds in the interface zone between the two different areas. Egg masses were left in the orchard for one week and replaced for six consecutive weeks from 23 February to 11 April 1995. Egg masses were then returned to the laboratory and evaluated for predation rates. Log-linear analysis was used to determine differences in predation rate between ant territories.

## Results

**Stink Bug Assessment.** The timed surveys found only 44 *N. viridula* over all sites and all sampling periods. Except for three occasions, all bugs were found on plants that were either flowering or fruiting. We recovered four adult females and no adult males. By stage, the second through fifth instars accounted for 12, 8, 14, and 6 of the total individuals captured. The majority of the individuals (25) were found on spiny amaranth (*Amaranthus spinosus* L.), six were found on Spanish needle (*Bidens pilosa* L.), and four were found on fuzzy rattlepod (*Crotalaria incana* L.). No other plant species had >2 individuals (Table 1).

Kernel damage in the three wetter orchards (Ama'u'ulu, Kea'au, Pahala) was similar with two to three peaks of damage in each location (Fig. 1). We found one to two peaks occurred in the spring and one in the fall in all three plots. The driest orchard (Honomalino) had a prolonged damage period in the spring, but only minor damage occurred in the summer and fall.

ANOVA showed no overall differences in damage caused by either location ( $F = 2.13$ ;  $df = 3, 38$ ;  $P = 0.11$ ) or date ( $F = 1.76$ ;  $df = 13, 38$ ;  $P = 0.08$ ). The preplanned contrasts showed that overall, the dry areas (Honomalino and Pahala) had significantly more damage than the wetter areas (Ama'u'ulu and Kea'au) ( $T = 2.48$ ,  $df = 1$ ,  $P = 0.02$ ). However, there were no

significant differences for comparisons within the wet areas (Ama'u'ulu versus Kea'au) ( $T = 0.08$ ,  $df = 1$ ,  $P = 0.94$ ) or within the dry areas (Honomalino versus Pahala) ( $T = 0.44$ ,  $df = 1$ ,  $P = 0.66$ ).

When the kernel damage is compared with the weed phenology index, the dry site (Honomalino) had a mean phenology index that was relatively flat and showed a large amount of flowers; fruit and seeds were present throughout the entire study period. During this period, the kernel damage remained below 4% (Fig. 1). At the Pahala site (170 cm/yr rainfall) in September and October, the weeds became senescent or vegetative and the kernel damage increased markedly (Fig. 1). The two wetter sites (Kea'au and Ama'u'ulu) had a low flowering index throughout most of the year, but kernel damage still cycled so that it increased following reductions in flowering and fruiting and declined as flowering and fruiting increased (Fig. 1). At all sites, there was an increase in the fall that coincided with a mowing operation required for harvest from the ground.

**Weed Species Abundance.** The different orchards showed markedly different species composition and diversity. A total of 91 weed species were collected over all four sites, 34 at Ama'u'ulu, 49 at Kea'au, 25 at Honomalino, and 52 at Pahala. However, when only stinkbug hosts were considered, Ama'u'ulu had three hosts, Kea'au had seven, Honomalino had 10, and Pahala had 16 host plants (Table 2). The diversity of the host plants was also markedly different between the sites. Examination of the relative abundance of hosts at the different sites shows that *Desmodium* spp. comprised >84% of the total hosts at Ama'u'ulu and Kea'au. However, at Honomalino, *Amaranthus* spp. (*A. spinosus* and *Amaranthus* sp.), *Bidens pilosa*, *Desmodium* spp., and *Malvastrum coromandelianum* all had a relative abundance between 15 and 33%. The Pahala site was intermediate with *Amaranthus* spp., *Glycine wightii*, and *Macroptilium lathyroides* having a relative abundance of 52.3, 21.0, and 9%, respectively. The greater diversity at the two dry sites (which had higher levels of stinkbug damage) helped provide hosts of the correct phenological stage for stinkbug development for a longer period (Fig. 1).

**Ant Species Composition and Predation Rates.** Our sticky tape samples show that there were marked

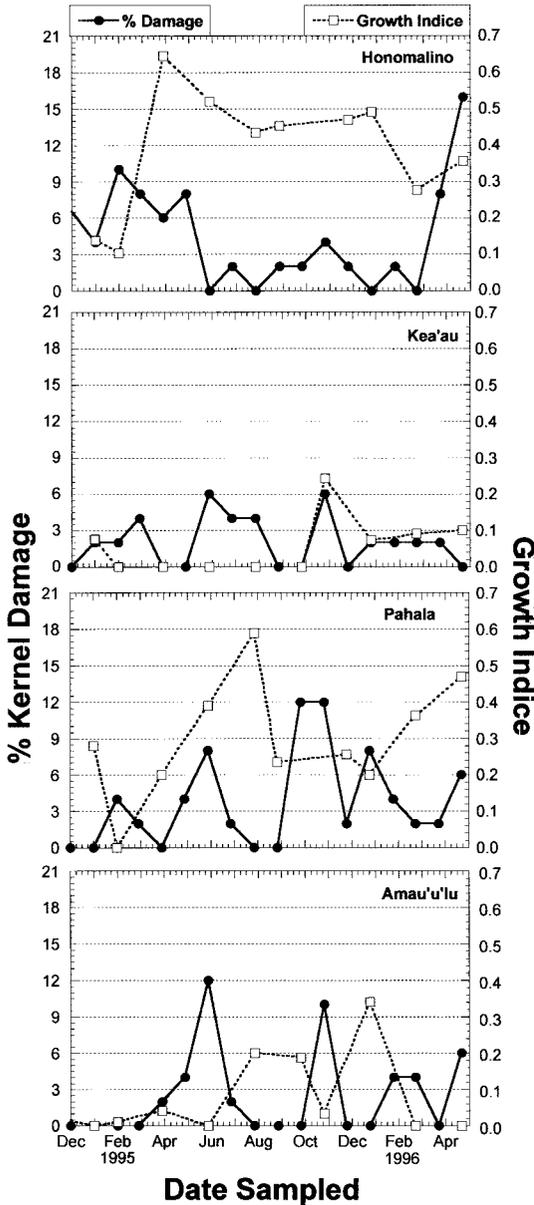


Fig. 1. Comparison of percentage kernel damage and the weed growth index used to determine weed suitability for stinkbug population growth potential.

differences in the number and abundance of ant species within the orchards (Table 3). All told, 15 ant species were found using sticky tape at the four sites. However, generally no more than three species were required to account for >90% of the total number of ants collected. Honomalino was the extreme case, where 96.6% of the ants collected were *P. megacephala*.

The samplings of sticktight nuts revealed only eight species, but several of these were either not advanced in the colony process, or were foraging in high numbers in the sticktights (Table 4). For example, *Car-*

*diocondyla wroughtoni* (Forel), *Monomorium floricola* (Jerdon), and *Technomyrmex albipes* (Fr. Smith) all appeared to have reasonable amounts of immature stages present in the sticktights (Table 5). The remaining species were rarely collected as anything other than adults or soldiers.

Predation by ants on the frozen sentinel egg masses varied considerably between sites. ANOVA detected no significant differences by date ( $F = 0.86$ ;  $df = 12, 36$ ;  $P = 0.59$ ), but significant differences were found between locations ( $F = 5.44$ ;  $df = 3, 36$ ;  $P = 0.003$ ). Honomalino was the driest site and had significantly greater overall egg predation (88%) than all the other sites, except for Kea'au (60%) according to Tukey's HSD. The other two sites were similar with overall averages of 53 (Ama'u'ulu), and 54% (Pahala) predation.

Seasonal trends of the predation rate were somewhat obscured by variation between months (Fig. 2A). To overcome this problem, we used a resistant data smoother to show seasonal patterns in predation (Fig. 2B). At the Honomalino site, where *P. megacephala* (bigheaded ant) was the dominant species caught in our trunk surveys, predation declined in the warm summer months and increased during the cooler months. The Kea'au and Ama'u'ulu sites show a seasonal predation pattern nearly inverted from the Honomalino site. The ant species present at Ama'u'ulu were mostly *C. wroughtoni* (56%) and *A. longipes* (32.7%), while at Kea'au the mixture was 24.9% big-headed ant, 20.7% *C. wroughtoni*, and 39.6% *T. albipes*. The seasonal predation rate observed at the Pahala site showed an intermediate pattern between the other sites, but was most similar to the Honomalino site. The sticky tape trunk surveys at Pahala revealed the ant species composition was 42% bigheaded ant and 51.2% *Plagiolepis alluaudi* (Forel).

*Trissolcus basalis* was collected at the Pahala site in eight of the 19 samples and once at the Honomalino site. The overall percentage of parasitization was 2.8% at Pahala site and 0.1% at the Honomalino site. Parasites were first recovered during January–September 1995, but not during the fall. During 1996, they were recovered only in the month of February. Peak parasite collections in 1995 occurred in April and May, with a second peak in August.

**Effect of Ant Species on Stink Bug Egg Predation.** Predation on egg masses placed in long-legged ant territories was significantly less than egg masses placed in the big-headed ant territories each week (Fig. 3). Maximum long-legged ant predation never exceeded 20% of the eggs placed in the field, whereas predation in the bigheaded ant areas never decreased below 50%. Eggs placed in the weeds at the interface between the two territories showed similar predation rates to those placed in the *P. megacephala* areas.

**Discussion**

Our data clearly shows that *N. viridula* damage in macadamia nut orchards is closely tied to the host weed diversity and phenology. The two wetter sites (Kea'au and Ama'u'ulu) had little damage and the

**Table 2.** Host plants for *N. viridula* and their percentage cover and relative abundance at four locations from December 1994–January 1996

Location	Species	No. surveys where found	% cover	Relative abundance
Ama'u'ulu	<i>Desmodium intortum</i> Urban	11	14.1	19.4
	<i>Desmodium triflorum</i> de Candolle	25	24.7	77.0
	<i>Richardia brasiliensis</i> Gomez	6	4.8	3.6
Kea'au	<i>Coix lacryma-jobi</i> L.	2	5.5	0.4
	<i>Desmodium intortum</i> L.	2	10.0	0.7
	<i>Desmodium triflorum</i> de Candolle	45	50.6	84.7
	<i>Glycine wightii</i> Verdcourt	6	10.2	2.3
	<i>Lablab purpureus</i> Sweet	17	17.0	10.7
	<i>Richardia brasiliensis</i> Gomez	5	4.4	0.8
	<i>Saccharum</i> sp.	1	10.0	0.4
Honomalino	<i>Abutilon grandifolium</i> Sweet	2	1.0	0.1
	<i>Amaranthus</i> sp.	2	35.0	2.2
	<i>Amaranthus spinosus</i> L.	13	44.9	18.0
	<i>Bidens pilosa</i> L.	37	20.0	22.9
	<i>Boerhavia coccinea</i> Miller	1	1.0	0.0
	<i>Desmodium intortum</i> L.	20	25.3	15.6
	<i>Desmodium tortuosum</i> de Candolle	2	13.5	0.8
	<i>Glycine wightii</i> Verdcourt	5	38.0	5.9
	<i>Macroptilium lathyroides</i> Urban	2	26.0	1.6
	<i>Malvastrum coromandelianum</i> Garcke	45	23.7	32.9
	<i>Abutilon grandifolium</i> Sweet	3	7.3	0.5
Pahala	<i>Amaranthus</i> sp.	10	20.2	4.9
	<i>Amaranthus spinosus</i> L.	55	29.7	40.0
	<i>Amaranthus viridis</i> L.	15	20.1	7.4
	<i>Bidens pilosa</i> L.	15	16.1	5.9
	<i>Chamaecrista nictitans</i> L.	1	5.0	0.1
	<i>Cleome gynandra</i> L.	14	9.8	3.4
	<i>Desmodium intortum</i> L.	3	2.7	0.2
	<i>Desmodium tortuosum</i> de Candolle	1	2.0	0.0
	<i>Glycine wightii</i> Verdcourt	21	40.8	21.0
	<i>Lycopersicon esculentum</i> Miller	5	17.2	2.1
	<i>Macroptilium lathyroides</i> Urban	24	15.4	9.0
	<i>Malvastrum coromandelianum</i> Garcke	14	7.1	2.4
	<i>Richardia brasiliensis</i> Gomez	1	1.0	0.0
	<i>Senna occidentalis</i> Link	3	12.0	0.9
	<i>Sonchus oleraceus</i> L.	18	4.7	2.1

time of damage was generally immediately after weeds stopped either flowering or fruiting. During the periods when weeds were flowering or fruiting, stinkbug damage was minimal, and presumably, they were feeding mostly on the weeds. In the drier areas, the greater weed diversity and the resulting longer period where

a mixture of flowering and fruiting occurred resulted in longer periods that were suitable for population growth of stinkbug. These more diverse areas had lower damage most of the time, however, even a small change in the abundance of suitable stages of host weeds resulted in a rather large change in macadamia

**Table 3.** Ant species collected using the sticky tape sampling method on macadamia tree trunks from December 1994 to May 1996 (180 trees sampled per location)

Location	% all ants collected at			
	Ama'u'ulu	Kea'au	Honomalino	Pahala
<i>Anoplolepis longipes</i>	32.7	0.0	0.0	0.0
<i>Pheidole megacephala</i>	0.5	24.9	96.6	42.0
<i>Cardiocondyla wroughtoni</i>	56.4	20.7	2.5	2.0
<i>Technomyrmex albigipes</i>	7.1	39.6	0.0	0.0
<i>Tetramorium bicarinatum</i> (Nylander)	1.4	1.8	0.0	0.4
<i>Monomorium floricola</i>	0.9	7.1	0.0	0.0
<i>Paratrechina vaga</i> (Forel)	0.0	1.2	0.0	0.0
<i>Plagiolepis alluaudi</i> Emery	0.0	0.6	0.0	51.2
<i>Strumigenys godeffroyi</i> Mayr	0.5	0.0	0.2	3.6
<i>Cardiocondyla emeryi</i> Forel	0.0	0.6	0.7	0.4
<i>Tetramorium tonganum</i> Mayer	0.5	0.0	0.0	0.0
<i>Strumigenys rogeri</i> Emery	0.0	0.6	0.0	0.0
<i>Cardiocondyla nuda</i> (Mayr)	0.0	1.2	0.0	0.0
<i>Tetramorium simillimum</i> (Fr. Smith)	0.0	0.0	0.0	0.4
<i>Solenopsis papuana</i> Emery	0.0	1.8	0.0	0.0
Total	100.0	100.0	100.0	100.0

Table 4. Number of times different ant species were collected in sticktight nuts over the period of November 1994–May 1996

Ant species	No. times collected			
	Ama'u'ulu	Kea'au	Honomalino	Pahala
<i>Anoplolepis longipes</i>	1	0	0	0
<i>Cardiocondyla wroughtoni</i>	70	20	1	0
<i>Monomorium floricola</i>	4	9	0	0
<i>Pheidole megacephala</i>	0	0	28	7
<i>Plagiolepis alluaudi</i>	0	0	0	16
<i>Technomyrmex</i> sp.	0	1	0	0
<i>Technomyrmex albipes</i>	95	75	0	0
<i>Tetramorium bicarinatum</i>	0	3	0	0

nut kernel damage, probably because of the higher stinkbug population levels present in the weeds.

The role of ants in population dynamics of *N. viridula* is less clear than the role of plant phenology and diversity. Species composition between locations varied markedly and the interactions (if any) between the different ant species could have either positive or negative effects on the biological control of *N. viridula*. In addition, ants are generalist predators that switch food sources used depending on the needs of the colony, food availability, and food suitability. For *A. longipes* and *P. megacephala*, we clearly saw that *A. longipes* spent a large amount of time and effort collecting honeydew from homopterans [black citrus aphid, *Toxoptera aurantii* (Boyer de Fonscolombe) (Homoptera: Aphididae), and the immature stages of the Van Duzee treehopper, *Vanduzeeia segmentata* (Fowler) (Homoptera: Membracidae)] and showed

little interest in feeding on *N. viridula* (V.P.J., unpublished data). However, our behavioral observations were not performed year around and predation by *A. longipes* may have been more common during periods with low honeydew availability. This is particularly interesting because in the areas where *P. megacephala* and *A. longipes* occurred in a spatial mosaic, *A. longipes* was found in extremely high numbers and foraging over a broad area. If the abundance of the honeydew producing homopterans was reduced abruptly and temporarily (such as by the application of an insecticidal soap), *A. longipes* may quickly shift from primarily farming homoptera to feeding on other arthropods until honeydew production increases to normal levels. Thus, a relatively innocuous way to encourage biological control at critical times in macadamia nut production may be possible.

Our data suggest that several strategies should be considered for managing southern green stink bug in macadamia orchards. First, planting borders of an attractive weed to prevent injury to the crop (Mitchell 1972) is a poor tactic because as soon as the border weeds start to decline, the bugs can move into the orchard and begin causing kernel damage. This is particularly the case because of the low efficiency of *T. basalis* at the levels common in macadamia orchards (Jones 1995). A better alternative would be to encourage nonhost grasses throughout the orchard and eliminate stinkbug host weeds (particularly those that flower around harvest period). Another strategy would be to mow frequently enough to shift the orchard floor vegetation to grasses. Frequent mowing

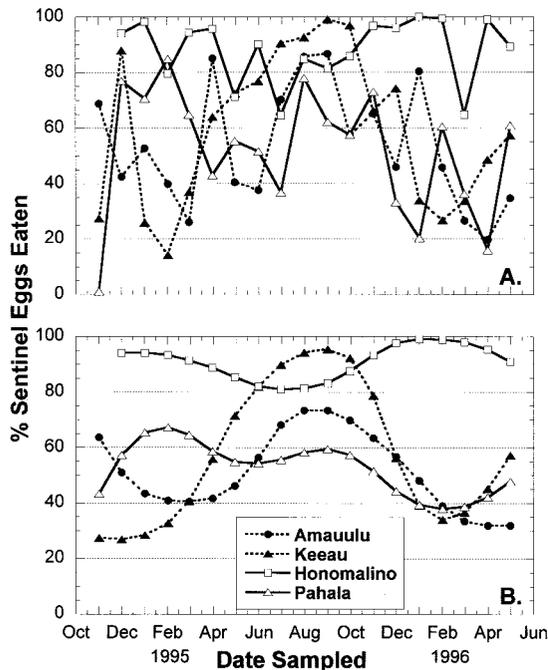


Fig. 2. Percentage of sentinel egg masses eaten at the four different sites over the study period. (A) Raw data. (B) Data after applying a 4253H data smoother to show seasonal trends.

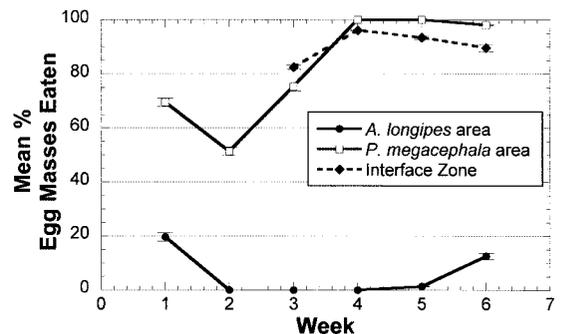


Fig. 3. Percentage of sentinel egg masses eaten in the areas where *A. longipes* and *P. megacephala* occurred in a spatial mosaic.

**Table 5.** Stage distribution of different ant species calculated over the period of November 1994–May 1996 and all 4 sites from sticktight nut samples

Species	Total Number	% Adults	% Pupae	% Larvae
<i>Anoplolepis longipes</i>	6	100	0	0
<i>Cardiocondyla wroughtoni</i>	12,731	46.8	25.9	27.2
<i>Monomorium floricola</i>	4,826	71.9	16.4	11.8
<i>Pheidole megacephala</i>	808	99.5	0.0	0.5
<i>Plagiolepis alluaudi</i>	6,717	95.6	0.4	4.0
<i>Technomyrmex</i> sp.	15	100	0	0
<i>Technomyrmex albigipes</i>	30,318	63.4	21.8	14.8
<i>Technomyrmex bicarinatum</i>	153	98.0	1.3	0.7

tends to reduce the incidence of broadleaved weeds with an upright growth habit, such as spiny amaranth, Spanish needle and fuzzy rattlepod, three common host species found in our study. This frequent mowing regime would also reduce flowering and fruiting of these species and would reduce the sudden decline of food for *N. viridula* within the orchard floor, causing less movement to macadamia nuts. Alternatively, preventing the weed hosts from setting flowers or fruits may be possible, but would require a more intensive weed management program than most growers could support. Finally, weed management tactics performed by many growers for harvest may need to be modified. Many growers allow weed growth throughout much of the summer and immediately before harvest, they mow the drive rows and herbicide the tree rows so that pickers can see the nuts on the ground. If this is performed when *N. viridula* population levels are high, the loss of suitable stages of the weed host will cause the stinkbugs to move into the orchard and increasing nut damage.

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### References Cited

- Caltagirone, L. E. 1981. Landmark examples in classical biological control. *Annu. Rev. Entomol.* 26: 213–232.
- Clarke, A. R. 1990. The control of *Nezara viridula* L. with introduced egg parasitoids in Australia. A review of a "Landmark" example of classical biological control. *Aust. J. Agric. Res.* 41: 1127–46.
- Clarke, A. R. 1992. Investigations into the biological control of *Nezara viridula* (L.) by the egg parasitoid *Trissolcus basalis* (Wollaston) in Eastern Australia. Ph.D. dissertation, University of Queensland, Brisbane.
- Clarke, A. R., and G. H. Walter. 1990. *Trissolcus basalis* as a biological control agent of *Nezara viridula* in south east Queensland. *Proc. 6th Aust. Soybean Res. Workshop*: 71–73.
- Clarke, A. R., and G. H. Walter. 1993. Biological control of green vegetable bug (*Nezara viridula* (L.)) in eastern Australia: Current status and perspectives, pp. 223–225. In S. A. Corey, D. J. Dall, and W. M. Milne [eds.], *Pest control and sustainable agriculture*. Division of Entomology, CSIRO, Canberra, NSW.
- Davis, C. J. 1964. The introduction, propagation, liberation and establishment of parasites to control *Nezara viridula* variety *smaragdula* (Fabricius) in Hawaii (Heteroptera: Pentatomidae). *Proc. Hawaii. Entomol. Soc.* 18: 369–375.
- Davis, C. J. 1967. Progress in the biological control of the southern green stinkbug, *Nezara viridula* variety *smaragdula* (Fabricius) in Hawaii (Heteroptera: Pentatomidae). *Mushi* 39: 9–16.
- (HASS) Hawaii Agricultural Statistics Service. 1998. Hawaii macadamia nuts final season estimates. Hawaii Department of Agriculture, Honolulu, HI.
- Jones, V. P. 1995. Reassessment of the role of predators and *Trissolcus basalis* in biological control of southern green stinkbug (Hemiptera: Pentatomidae) in Hawaii. *Biol. Control* 5: 566–572.
- Jones, V. P., and L. C. Caprio. 1992. Damage estimates and population trends of insects attacking seven macadamia cultivars in Hawaii. *J. Econ. Entomol.* 85: 1884–1890.
- Jones, V. P., and L. C. Caprio. 1994. Southern green stinkbug (Hemiptera: Pentatomidae) feeding on Hawaiian macadamia nuts: the relative importance of damage occurring in the canopy and on the ground. *J. Econ. Entomol.* 87: 431–435.
- Jones, V. P., K. Delate, and C.H.M. Tome. 1992. Macadamia IPM: where did all this damage come from? *Proc. Hawaii. Macadamia Nut Assoc.* 32: 48–56.
- Minitab. 1995. Minitab reference manual, Release 10Xtra. Minitab, State College, PA.
- Mitchell, W. C. 1972. Biological control of macadamia insect pests in Hawaii. *Hawaii. Macadamia Prod. Assoc.* 12: 37–44.
- Mitchell, W. C., R. M. Warner, and E. T. Fukunaga. 1965. Southern green stinkbug, *Nezara viridula* (L.), injury to macadamia nut. *Proc. Hawaii. Entomol. Soc.* 19: 103–109.
- Nishida, T. 1966. Behavior and mortality of the southern stinkbug *Nezara viridula* in Hawaii. *Res. Popul. Ecol.* 8: 78–88.
- Panizzi, A. R. 1997. Wild hosts of pentatomids: Ecological significance and role in their pest status on crops. *Annu. Rev. Entomol.* 42: 99–122.
- Panizzi, A. R., and A. M. Meneguim. 1989. Performance of nymphal and adult *Nezara viridula* on selected alternate host plants. *Entomol. Exp. Appl.* 50: 215–223.
- Panizzi, A. R., and R.M.L. Alves. 1993. Performance of nymphs and adults of the southern green stinkbug (Heteroptera: Pentatomidae) exposed to soybean pods at different phenological stages of development. *J. Econ. Entomol.* 86: 1088–1093.
- SAS. 2000. JMP statistics and graphics guide, version 4. SAS Institute, Cary, NC.
- Schumann, F. W., and J. W. Todd. 1982. Population dynamics of the southern green stink bug (Heteroptera: Pentatomidae) in relation to soybean phenology. *J. Econ. Entomol.* 75: 748–753.
- Shearer, P. W., and V. P. Jones. 1996. Suitability of macadamia nut as a host plant of *Nezara viridula* (L.) (Hemiptera: Pentatomidae). *J. Econ. Entomol.* 89: 996–1003.
- Shearer, P. W., and V. P. Jones. 1998. Suitability of selected weeds and ground covers as host plants of *Nezara viridula* (L.) (Hemiptera: Pentatomidae). *Proc. Hawaii. Entomol. Soc.* 33: 75–82.

- Todd, J. W. 1989. Ecology and behavior of *Nezara viridula*. *Annu. Rev. Entomol.* 34: 273–292.
- Velasco, L.R.L., and G. H. Walter. 1992. Availability of different host plant species and changing abundance of the polyphagous bug *Nezara viridula* (Hemiptera: Pentatomidae). *Environ. Entomol.* 21: 751–759.
- Velasco, L.R.L., and G. H. Walter. 1993. Potential of host-switching in *Nezara viridula* (Hemiptera: Pentatomidae) to enhance survival and reproduction. *Environ. Entomol.* 22: 326–333.
- Zar, J. H. 1996. *Biostatistical analysis*. Prentice-Hall, Upper Saddle River, NJ.

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