Patterns of Oviposition and Parasitism of Eggs of *Kallitaxila granulata* (Homoptera: Tropiduchidae), a Newly Invasive Planthopper in Hawaii

Pingjun Yang[1], **Andrei Alyokhin**[2,3], and **Russell Messing**
Department of Plant and Environmental Protection Sciences, 3050 Maile Way, University of Hawaii at Manoa, Honolulu, HI 96822; [1]Present address: Hawaii State Department of Health, 4398-B Pua Loke St., Lihue, HI 96766; [2]Present address: Department of Biological Sciences, University of Maine, 5722 Deering Hall, Orono, ME 04469. [3]Corresponding author.

Abstract. *Kallitaxila granulata* (Stål) (Homoptera: Tropiduchidae), a recent invasive species in Hawaii, is a potential pest of agricultural and forest ecosystems. We present information on the planthopper's oviposition behavior, its egg distribution patterns, and the occurrence of egg parasitoids in Hawaii. There were no differences in the percentage of leaves containing *K. granulata* oviposition scars or in the number of eggs per scar among four host plants (guava, hapuu, uluhe and kukui) at three sites. However, there were substantial differences in patterns of egg distribution among the host plants. The planthopper preferred to lay eggs into the veins and to oviposit clutches of eggs in clusters on guava plants, while it tended to lay eggs singly into the veins on hapuu. On kukui, eggs were deposited equally in or off the veins, and were mostly deposited singly. On all three host plants, eggs conformed to a negative binomial distribution. Two species of parasitoids were reared from *K. granulata* eggs: *Chaetomyma*r sp. near *bagicha* (a common parasitoid of the twospotted leafhopper, *Sophonia rufofascia),* and *Telenomus* sp. (Hymenoptera: Scelionidae). Total parasitism differed among host plants and sites with a range of 0 to 18.5%.

Introduction

Kallitaxila granulata (Stål) (Homoptera: Tropidicadae), a polyphagous planthopper previously known only from the Philippine islands of Luzon and Mindanao and the Christmas Islands in the Indian Ocean, was recently found to have been accidentally introduced into Hawaii (Asche 2000). It was first discovered on *Wedelia* plants on Oahu in 1995, and has since spread to Kauai and the island of Hawaii. The other islands of Hawaii have yet to be surveyed.

The planthopper is considered a potentially serious pest in both agricultural and native ecosystems. The following plants have been documented as hosts by Asche (2000) or by our own surveys: guava (*Psidium guajava* L.), grapefruit (*Citrus paradisi* Macfarlane), hapuu (*Cibotium chamissoi* Kaulfuss), uluhe (*Dicranopteris linearis* Underwood), ohia-lihua (*Metrosideros polymorpha* Gaudichaud), ti (*Cordyline fruicosa* (L.) A. Chevalier), kukui (*Aleurites moluccana* (L.) Willdenow), India coralbean (*Erythrina variegata* L.), and plumeria (*Plumeria acuminata* Aiton). Of these plants, guava, grapefruit, and plumeria are agriculturally important; ti and kukui are culturally significant for native Hawaiians; and hapuu, uluhe, and ohia-lehua are important native plants which not only protect soils from erosion but also are important elements of endemic Hawaiian ecosystems (Jones et al. 2000, Kepler 1984).

In our surveys, we found that *K. granulata* coexists on some plants with two important exotic pest leafhoppers, *Sophonia rufofascia* Kuoh and Kuoh and *Empoasca stevensi* Young. We also found that at least one species of egg parasitoid attacking *K. granulata* also attacks *S. rufofascia.*

K. granulata is the first Tropiduchidae to become established in Hawaii. Its wide host range, feeding and oviposition effects on host plants, and relations with other Homoptera via shared natural enemies suggest it may play a complex role in island ecosystems. However, no information has been published to date on its natural history in Hawaii or elsewhere. Here, as a preliminary study on *K. granulata*, we report on oviposition behavior of the planthopper, including the influence of four species of host plants on its oviposition patterns and on the occurrence of egg parasitoids.

Materials and Methods

Leaf infestation. Four host plants were chosen for the first study: guava, hapuu, uluhe, and kukui. During late February to early March 2000, leaves or fronds of each of the plants were randomly collected from Maunawilli Trail on the island of Oahu or from Wailua and Kilauea (Guava Kai Orchard) on the island of Kauai. Exact numbers of sampled leaves are shown in Table 1. In the laboratory, foliage was carefully examined under a dissecting microscope for presence and location of planthopper egg scars on each leaf.

To determine the effects of plant species and collection location on the oviposition of the planthoppers, the percentage of leaves with oviposition scars and the mean number of scars per leaf were calculated. Percentages were arcsine transformed and means were square root transformed to stabilize the variances (Zar 1999). Because of their ecological similarity, the two collection sites on Kauai were considered as one location. Two-factor ANOVA was used to examine the effects of host plant and location (island) on the percentage of leaves containing egg scars and the average number of egg scars per leaf (Analytical Software 1996).

Egg location and density. Three species of host plants (guava, hapuu, and kukui) were selected for the second study; the number of scarred leaves for each was 40, 53, and 8, respectively. The position of each egg scar was defined as being either directly on the leaf vein or off the vein, and egg scars were further categorized as being deposited either singly or in a cluster (> 1). All leaves with egg scars were thus placed in one of four categories: single egg/on-vein; single egg/off-vein; clustered eggs/on-vein; or clustered eggs/off-vein. Percentages were calculated for the leaves within each category and analyzed using the chi-square test (Analytical Software 1996).

To determine spatial distribution patterns of the planthopper egg scars, the frequency of the numbers (including 0) of eggs on each leaf of guava, hapuu, and kukui was recorded. The chi-square goodness-of-fit test using the method of moments (Elliott 1983) was utilized to examine the data for their agreement with the negative binomial distribution. Two additional techniques for testing egg spatial distribution patterns were also employed: Lloyd's mean crowding, $\boldsymbol{m^*}$ (Lloyd 1967), and the Morisita Index, $\boldsymbol{I}$ (Iwao 1968). We consider these methods complementary to the chi-square goodness-of-fit test.

Egg parasitization. In the third study, we examined parasitization of planthopper eggs deposited into guava, hapuu, uluhe, and kukui leaves or fronds. Similar to the first study, plant material was collected at random between late February and early March 2000 from Maunawilli Trail on the island of Oahu or from Wailua and Kilauea (Guava Kai Orchard) on the island of Kauai. Exact numbers of sampled leaves are shown in Table 3. The foliage was carefully examined under a dissecting microscope in the laboratory for presence of planthopper egg scars on each leaf. To recover egg parasitoids of *K. granulata*, leaves of each plant species with planthopper egg scars were held at room temperature and ambient light in plastic Ziploc® bags (8x16 cm; DowBrands, Indianapolis, IN) for parasitoid emergence. Samples were checked daily; emerged parasitoids were removed and placed in 70% ethanol. After 3 weeks, leaves were dissected under magnification to recover any immature

Table 1. The influence of four species of host plants and two collection locations on the percentage of oviposition-scarred leaves and the mean numbers of eggs per leaf laid by the planthopper *Kallitaxila granulata.*

Location	Host collected	Number of leaves	Leaves with ovip. scars (%)	Mean no. scars per leaf (± SE)
Maunawili Trail (Oahu)	Guava	146	4.79	2.4 ± 0.43
Wailua (Kauai)	Guava	114	1.75	1.0 ± 0
Maunawili Trail	Uluhe	205	3.41	1.4 ± 0.20
Wailua	Uluhe	49	6.12	1.0 ± 0
Maunawili Trail	Hapuu	237	9.28	1.8 ± 0.26
Maunawili Trail	Kukui	82	10.98	2.3 ± 0.47

ANOVA:

Percentage of leaves with oviposition scars:				*Mean number of scars per leaf:*			
Source	df	F	P	Source	df	F	P
Host	3,1	1.78	0.492	Host	3,1	2.40	0.435
Site	1,1	0.08	0.825	Site	1,1	8.91	0.206

or mature but unsuccessfully emerged parasitoids. Other homopteran egg scars, such as those from *Sophonia rufofascia*, were distinguished from *K. granulata* egg scars and destroyed.

Insect identification. Identity of the planthopper eggs was confirmed by association of eggs with newly hatched nymphs and adults, which were examined and identified by B. Kumashiro of the Hawaii Dept. of Agriculture. All parasitoids emerging from our leaf samples were compared with specimens previously identified by Dr. J. Huber (Agriculture and Agri-Food Canada, Ottawa). Specimens of unknown species were shipped to Drs. S. Triapitsyn (Dept. of Entomology, University of California at Riverside) and L. Masner (Agriculture and Agri-Food Canada, Ottawa) for further identification. Voucher specimens of leafhoppers and parasitoids are stored in the Canadian National Collection of Insects and in the Entomology Museum of the University of Hawaii at Manoa.

Results and Discussion

Leaf infestation. There were no significant differences in percentage of oviposition-scarred leaves nor mean number of scars per leaf among the four host plants and three collection sites (ANOVA, $P > 0.2$) (Table 1). Thus, there is no strong or readily apparent preference of *K. granulata* for any one of these four host plants or three sites. However, our results are limited to only four host plants, and a wider range of host sampling would likely reveal preferences affecting egg abundance. During our surveys we found that there were always large numbers of nymphs and adults on the leaves of several unidentified legume species. In contrast, we found very few planthoppers on ti and plumeria.

Egg location and density. Although leaf morphology is different for the three host plants examined, the pattern of *K. granulata* egg location on the leaves was similar. The planthoppers inserted eggs both into the veins (midrib and cross veins) and off the veins. They laid eggs singly or in clusters along the veins, or on the edge or at almost any location on the leaf surface. They inserted eggs all the way into the vein, or else between the upper and lower epidermis of the lamina. Some egg scars were located on the upper side of the leaves, but most were situated on the underside.

There was a highly significant difference in percentages of leaves with egg scars in each of the four categories among the three species of host plants (d.f. = 6, $c^2 = 72.88$, P <0.0001) (Fig. 1). Clearly, the planthopper prefers to lay eggs into the veins and to oviposit eggs in clusters on guava plants, while it tends to lay eggs singly into the veins on hapuu. On kukui, eggs were deposited equally in and off the veins, and were mostly deposited singly. However, since we were able to find only eight kukui leaves containing planthopper oviposition scars (possibly because this plant species is not a preferred oviposition host for *K. granulata*), a larger sample size might be required before we can make more definite conclusions.

Based on the chi-square goodness-of-fit test, the spatial pattern of *K. granulata* eggs on all three species of host plants followed the negative binomial distribution. Furthermore, the value of both Morisita's index, as well as Lloyd's mean-crowding index, was substantially larger than 1 (Table 2). Therefore, we can conclude that *K. granulata* oviposition on all three hosts showed a distinctive clumped distribution.

Relatively little attention has been paid to oviposition behavior compared with feeding behavior in phytophagous insects (Schoonhoven 1968). However, oviposition behavior is an important species characteristic. Recently, oviposition studies on *S. rufofascia* in Hawaii provided basic information to help understand its biology and to evaluate its damage (Culliney 1998; Yang et al. 2000). If *K. granulata* becomes a serious pest in Hawaii, this knowledge of its oviposition behavior may help in devising monitoring, research, or control strategies.

Egg parasitization. At least two species of parasitoids were reared from *K.granulata* eggs during our survey (Table 3). One of them was *Chaetomyma*r sp. near *bagicha* (Hymenoptera: Mymaridae), an exotic species that is also one of the most abundant parasitoids of *S. rufofascia*. The other parasitoid(s) were *Telenomus* sp. (Hymenoptera: Scelionidae). *Chaetomyma*r sp. near *bagicha* and at least one *Telenomus* species were also confirmed by dissection of the planthopper eggs.

Total parasitization varied among host plant species and among sample sites, with a range of 0–18.5%. The highest parasitization was on guava, followed by hapuu, both from Maunawili Trail, Oahu (Table 3). Parasitization of *K. granulata* on uluhe from Wailua, Kauai was fairly low and similar to that from Maunawili (Table 3). No parasitoids were found on kukui, perhaps because of the small number of planthopper eggs recovered in this survey.

Ch. sp. near *bagicha* was previously considered to have arrived in Hawaii together with *S. rufofascia* (Johnson et al., *in press*). Now, however, with the discovery of *K. granulata* as a host, the question of the origin of this parasitoid in Hawaii remains open. The low population densities of *S. rufofascia* in its area of origin made it difficult to collect. Two exploratory trips to Southern China in the 1990s by entomologists from Hawaii as well as collections by Chinese entomologists failed to recover any *S. rufofascia*, and *Ch.* sp. near *bagicha* was not recovered from any of the other three *Sophonia* species collected during the surveys in China (T. Culliney, R. Zhang, personal communications). Therefore, the likelihood that *Ch.* sp. near *bagicha* came to Hawaii together with the twospotted leafhopper appears low, and it may be more likely that it arrived together with the planthopper *K. granulata* from Southeast Asia.

The variable oviposition patterns observed for *K. granulata* may be the result of historical selection pressures by egg parasitoids, or possibly by its homopterous competitors stemming from the limited suitable sites for oviposition. This situation has been noted with other

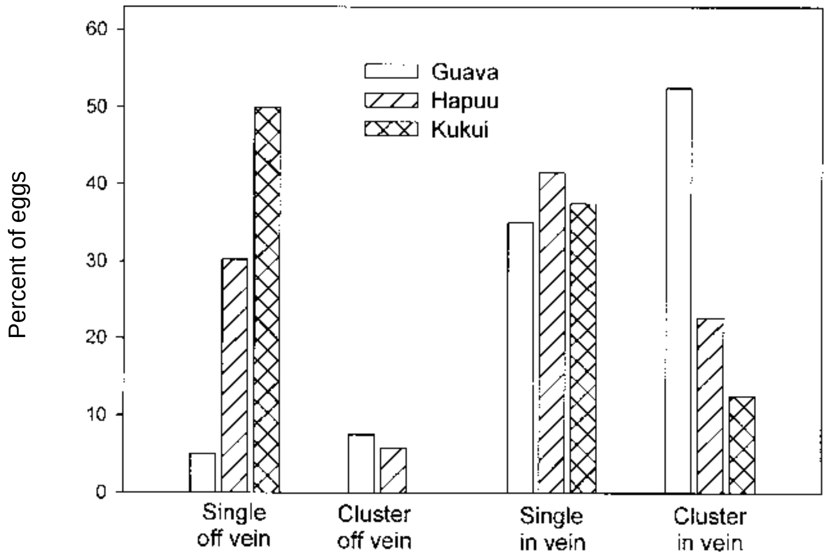

Figure 1. Proportion of oviposition scars located in the veins and off the veins, deposited singly or in clusters, for leaves from each of three host plants.

Table 2. ***K. granulata*** **egg scar distribution patterns on three species of host plants**

Host	Mean no. scars per leaf (± SE)	Chi-square	*P*	df	K	Lloyd's index	Morisita index
kukui	1.0 ± 0.42	2.17	0.14	1	0.08	2.09	12.91
hapuu	4.42 ± 1.26	6.57	0.09	3	0.05	2.43	20.14
guava	1.74 ± 0.52	5.74	0.22	4	0.05	4.75	21.51

species of Homoptera (Thompson 1978). Future studies should focus on the relations of *K. granulata* with other auchenorrhynchous Homoptera, especially the twospotted leafhopper, and examine rates of parasitization of *K. granulata* eggs on its favored host plants.

Acknowledgements

We thank B. Kumashiro (Hawaii Dept. of Agriculture) for the confirmation of the planthopper's identity. We are also grateful to J. Huber, L. Masner (Agriculture and Agri-Food Canada), and S. Triapitsyn (University of California at Riverside) for taxonomic assistance with the parasitoids. This work was supported in part by USDA-CSREES Special Grant No. 96-34135, Tropical and Subtropical Agriculture Research. This is Publication

Table 3. Parasitism of *K. granulata on* different plant species within the survey areas.

Site	Plant	No. leaves collected	Planthopper*			Parasitoids			Total no. of scars	Parasitism (%)
			nymphs	eggs	emerged	*Ch.* sp. near *bagicha*	*Telenomus* sp.	holes**		
Maunawili Trail (Oahu)	Guava	672	41	68	112	2	14	34	271	18.5
Maunawili Trail	Hapuu	1985	41	19	99	2	8	22	191	16.8
Maunawili Trail	Kukui	177	4	14	0	0	0	0	18	0
Wailua (Kauai)	Uluhe	243	0	10	18	0	2	0	30	6.7
Maunawili Trail	Uluhe	588	15	20	1	0	3	0	39	7.7

* Nymphs: emerged during rearing period; eggs: unhatched eggs; emerged: planthoppers emerged in the field before leaves were collected.
** Parasitoids emerged in the field before samples were collected.

No. 4545 of the University of Hawaii, College of Tropical Agriculture and Human Resources Journal Series.

Literature Cited

Analytical Software. 1996. Statistix for windows: user's manual. Analytical Software, Tallahassee, FL.

Asche, M. 2000**.** New state records of immigrant planthoppers in Hawaii (Homoptera: Fulgoroidea). Proc. Hawaiian Entomol. Soc. 34: 205–207.

Culliney, T. W. 1998**.** Site of oviposition and description of eggs of *Sophonia rufofascia* (Homoptera: Cicadellidae: Nirvaninae), a polyphagous pest in Hawaii. Proc. Hawaiian Entomol. Soc. 33:67–73.

Elliott, J. M. 1983**.** Some methods for the statistical analysis of samples of benthic invertebrates. Titus Wilson & Son, Kendal, UK.

Iwao, S. 1968**.** A new regression method for analysing the aggregation pattern of animal populations. Res. Pop. Ecol. 10: 1–20.

Johnson, M. T., P. Yang, J. T. Huber and **V. P. Jones.** 2000**.** Egg parasitoids of *Sophonia rufofascia* (Homoptera: Cicadellidae) in Hawaii Volcanoes National Park. Biol. Control. (in press).

Jones, V. P, P. Anderson-Wong, P. A. Follett, P. Yang, D. M. Westcot, J. S. Hu and **D. E. Ullman.** 2000**.** Feeding damage of the introduced leafhopper, *Sophonia rufofascia* (Homoptera: Cicadellidae) to plants in forests and watersheds of the Hawaiian Islands. Environ. Entomol. 29: 171–180.

Kepler, A. K. 1984. Hawaiian heritage plants. Oriental Publication Company, Honolulu, HI.

Lloyd, M. 1967**.** Mean crowding. J. Anim. Ecol. 36: 1–30.

Schoonhoven, L. M. 1968**.** Chemosensory bases of host plant selection. Annu. Rev. Entomol. 13: 115–135.

Thompson, P. 1978**.** The oviposition sites of five leafhopper species (Homop.: Auchenorrhyncha) *Holcus mollis* and *H. lanatus*. Ecological Entomology 3: 231–240.

Yang, P., P. A. Follett, V. P. Jones and **D. Foote.** 2000**.** Oviposition behavior and egg parasitoids of *Sophonia rufofascia* (Homoptera: Cicadellidae) in Hawaii Volcanoes National Park. Proc. Hawaiian Entomol. Soc. 34: 135–139.

Zar, J. H. 1999**.** Biostatistical Analysis, 4th Edition. Prentice Hall, Upper Saddle River, New Jersey.