Research Article

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Seasonal abundance and host plants of coconut stick insect (*Graeffea crouanii* Le Guillou) in coconut plantations of Fiji islands

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Abstract

Field survey conducted in major coconut growing regions in the three Fiji islands *viz.,* Viti Levu, Vanua Levu, and Taveuni, revealed the presence of only one pest species of stick insect, *Graeffea crouanii*. Temperature had a significant effect on the level of infestation in the farms surveyed, while the effect of rainfall and humidity on the infestation was insignificant. Severe infestation was observed in isolated pockets, and the pest distribution was discontinuous in the surveyed areas. On a damage scale index, the insect infestation on coconut palms ranged from 0 to 4 grades. The peak increase of *G. crouanii* populations was from November to April in wet season at each of the three hotspots: Namaumada (Viti Levu), Dawara (Vanua Levu), and Salialevu (Taveuni). The occurrence of *G. crouanii* at varying damage levels in the present study may be attributed to the presence of sparse coconut palms in isolated coconut plantations. The field survey identified many alternate host plants of *G. crouanii* in the two plant families *viz.,* Arecaceae and Pandanaceae. The information on the seasonal abundance and infestation levels of *G. crouanii* and its alternate host plants are discussed in formulating location-specific pest management strategies.

Keywords: Alternate host, *Cocos nucifera* L., Fiji, management, phytophagous, stick insect pest

Introduction

The coconut palms contribute immensely to the health of the environment, food security, and livelihood of many people in the Pacific Islands Countries and Territories. It is not only an important local food crop but is perhaps even more important for the tourism industry (Luigi, 2005). At present, approximately 65,000 ha of land in Fiji is under coconut cultivation (Anon, 2013). Copra remains the most traded coconut commodity in Fiji with small scale virgin coconut oil production rapidly gaining popularity amongst rural women communities. About 120,000 rural dwellers (13% of the total population) entirely or partially rely on coconut as a source of livelihood. The coconut sector's contribution to Fiji's total export earnings is at an annual average of 0.23 per cent from 2011 to 2015 as reported in Fiji Agriculture Research Services, and Fiji Bureau of Statistics reports (Anon, 2017).

Unfortunately, copra production has continued to decline for the past five decades dropping from 41,000 tonnes in 1950s to less than 7,000 tonnes in 2012 (Anon, 2013). One of the primary reasons is that the coconut plantations in the South Pacific are invaded by a number of insect pests and diseases, and few of them even killing the coconut palms, thus impacting the livelihood of the coconut growers. Rhinoceros beetle or black beetle, *Oryctes rhinoceros* (L.) (Bedford, 1980), and the coconut

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stick insect, *G. crouanii* are the insect pests of significant economic concern causing major threats to the coconut industry and stakeholders in Fiji. Among the two insect pests, very little is known about the coconut stick insect and its impact on the coconut industry. Farmers have the least control over them, and hence they are the significant biotic constraints causing low production of coconut.

Stick insects have been recorded as significant phytophagous pests of agricultural crops, including coconut palms since the early 1800s in the Pacific Islands (Howard *et al*., 2001; Baker, 2015). Coconut stick insect of the genus *Graeffea* have for long been known to defoliate coconut palms in many islands of the South Pacific and have been the most widespread economically important pest of coconut (Swaine, 1971). They cause severe defoliation, crop loss, and even death of trees. Thus the economic losses caused by the coconut stick insect are significant. To undertake the management practices at the country level, the knowledge on its distribution, seasonal abundance and biology are fundamental.

Earlier field studies undertaken by Deesh *et al*. (2013) indicated the wide distribution of coconut stick insect and its pest status in Fiji. These studies are in conformity with the studies by Paine (1968) and Swaine (1969) who mainly concentrated their research in coconut growing areas of Vanua Levu and Taveuni and reported outbreaks in Fiji from few acres to well over 500 acres in 1958, 1961, 1965 and 1968 and in 1971 it killed over 200 palms. Therefore, the present field surveys were undertaken in three major coconut growing islands of Fiji (Viti Levu, Vanua Levu, and Taveuni), to document the pest status of *G. crouanii*, its seasonal abundance, damage levels, and alternate host plants.

Materials and methods

The field survey on coconut stick insect, *G. crouanii* (Le Guillou), was coordinated from the Ministry of Agriculture, through its Crop Research Division headquarters based at Koronivia Research Station, Nausori, Fiji. The Plant Protection Section, Entomology Unit, directly coordinated the field survey activities in the three major coconut growing areas of the Fiji group of islands, namely Viti Levu, Vanua Levu, and Taveuni.

Description of the study area

Field surveys were conducted to determine the distribution, level of occurrence, and infestation by *G. crouanii* on coconut palms. The geographical locations for the survey were confined to the wet zones of the major coconut plantation since the preliminary studies between 2009-2012 on *G. crouanii* showed that it was localized mostly in wet areas as compared to the dry zone (Deesh *et al*., 2013). The wet zones in Viti Levu, Vanua Levu and Taveuni were surveyed to determine the level of infestations of *G. crouanii*. The weather data was obtained from the Fiji meteorological services for the study areas on mean temperature, rainfall, and relative humidity for 2012. The geo-positional coordinates of the surveyed area lay between 17.4057(S), 178.2454(E), and 18.1641(S), 177.4559(E) for Viti Levu; 16.8595(S), 178.8621(E), and 16.6284(S), 179.8677(E) for Vanua Levu; and 16.8115(S), 179.8650(E), and 16.9925(S), 180.4717(E) for Taveuni.

Weather data collection and analysis

The weather data collected from the Fiji Meteorological Services, Fiji was used for analysis using the MINITAB statistical software (Allen and Kellie, 2010) fo a logistic regression, as it provides insights on the effect of different weather parameters on the level of pest infestation. The logistic regression model for the expected number of infestation in a particular location is given by:

$$E(y) = \frac{n}{1 + e^{-[\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3]}}$$

where, n = number of experimental farms trialled in the location, y = number of infested farm, x_1 = temperature, x_2= rainfall, x_3 = relative humidity and i (i = 1,2,3) are the regression coefficients.

Field survey technique

The detailed map showing coconut growing areas of the study site was obtained from the Land Resource Planning Division, Ministry of Agriculture, Fiji. These maps were used as a guide for undertaking scientific survey's on infestation levels of *G. crouanii*. Fixed point survey was conducted during the 2012 season, and survey area or the number of samples depended on area

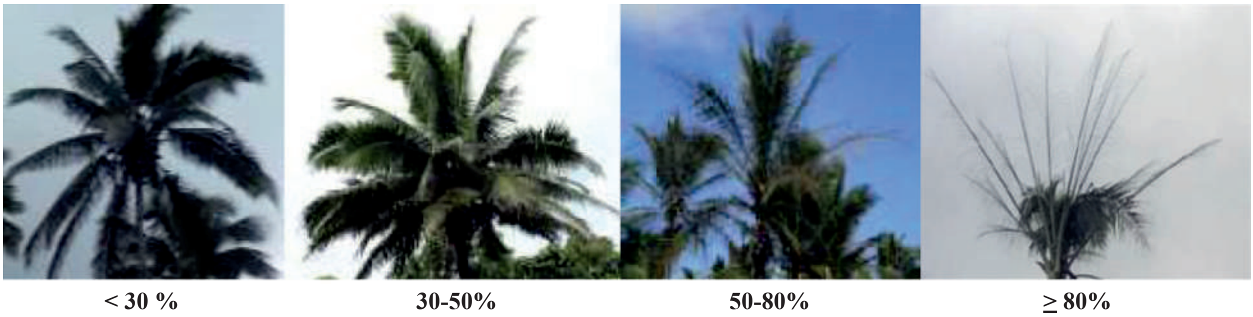

Fig. 1. The damage scale index used for survey of *G. crouanii* in three islands of Fiji

accessible or presence of coconut plantations in the wet zone of each of the three islands selected. At every 10 km intervals from start point, the *G. crouanii* incidence was recorded in the scale of 0 to 4. Assessment of palm foliage of all ages was recorded using the damage scale index and the visual rating system (Fig. 1) on coconut, according to Deesh *et al*. (2013).

0 - No damage

1 - Scatter pest damage (<30%)

2 - Light infestation on palm leaves (30-50%)

3 - Medium infestation on the palm leaves (50-80%)

4 - Heavy infestation on palm leaves with petioles only (≥ 80%)

Data representation using Geographical Information System

At each of the study area, the Global Positioning System coordinates were recorded in the coconut plantation with most stable reading. The Geographical Information System tool was used to plot the coordinates of the study area on the map with the infestation levels recorded at each of the survey site using the QGIS software. A base map was created using the composite of multiple downloaded Google earth images that was geo-referenced (Chang *et al*., 2009). Layers of information, such as locations of survey and pest infestation levels, were overlaid on the base-map to provide a virtual map of study sites and to determine the variation in pest infestation from site to site within the island surveyed. This technique on data representation was acquired during International Training on Basics of Remote Sensing and GIS (its application in agriculture) at the Mahalanobis National Crop Forecast Centre, Pusa Campus, New Delhi, India. Some techniques were also learnt during the workshop facilitated by an expert from the Unitec Institute of Technology, New Zealand that was held at Institute of Applied Science, Suva, Fiji.

After survey and mapping of the pest infestation at each of the surveyed islands, three heavily infested sites (named as hotspots), one per island was selected for detailed field data collection and exploratory survey was undertaken using the following guidelines:

i. For general information purposes, GPS coordinates, elevation (masl), approximate height and weight of plants, number of senile and fruit bearing coconut trees were recorded.

ii. The habitat was described after observing and recording if the site was near the forest areas, intercrop with root crops, near/ intercrop with vegetable plantation, mangrove or coastal areas, pandanas/other palms, grass land area, near or in sugarcane plantation or with non-crops (houses *etc.*)

iii. The damage level on leaf was observed by examining top (new) leaves, tip of leaves and the basal part of the leaves.

iv. The type of weeds near the site was recorded in terms of weed density and diversity.

v. The presence of other insects on each palm and on the ground under each palm was observed and recorded as well.

vi. Finally, the pest diversity was noted through observation of the eggs, nymphs and adults.

Seasonal pest infestation

At each of the hotspots, fifteen coconut palms were randomly selected for observations on pest infestation at two months interval during 2012-2013. The incidence of pest infestation was recorded in the scale of 0 to 4 (Deesh *et al.*, 2013). The pest infestation data gathered from this study over different seasons (dry and wet) were analyzed using the Mann-Whitney U test in the IBM Statistical Package for the Social Science (SPSS) statistical software (Allen and Kellie, 2010).

Level on infestation

The extent of infestation at different levels of the palm crown (upper and lower canopy), and palm fronds (tip and basal area of individual leaflets), was recorded using the assessment key prepared for this study. At each hotspot, the same fifteen coconut palms randomly selected earlier were used for observations on the extent of infestation at bi-monthly intervals during 2012-2013. Data was subjected to Mann-Whitney U test in the IBM SPSS statistical software (Allen and Kellie, 2010).

Alternate host plants herbarium samples

The samples of commercial crops and the ornamental plants that were identified as alternate host plants of *G. crouanii* were collected, preserved and deposited at the South Pacific Regional Herbarium, Suva Fiji as reference material and they were allocated with accession numbers and passport data.

Results and discussion

Stick insect species diversity and pest status

During the field surveys in the three major coconut growing Fiji islands (Viti Levu, Vanua Levu, and Taveuni), only one pest species of the stick insect was encountered, *Graeffea crouanii*.

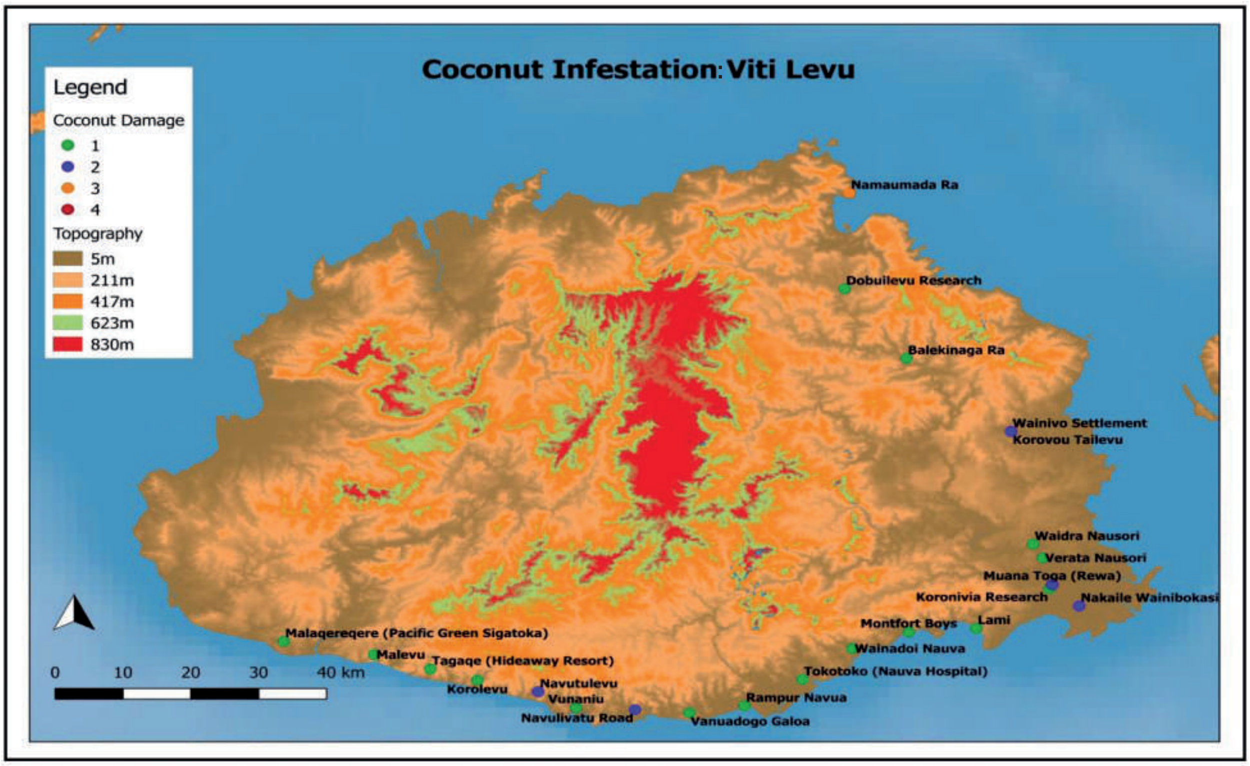

Fig. 2. Distribution and infestation of *G. crouanii* at survey sites in Viti Levu island, Fiji islands

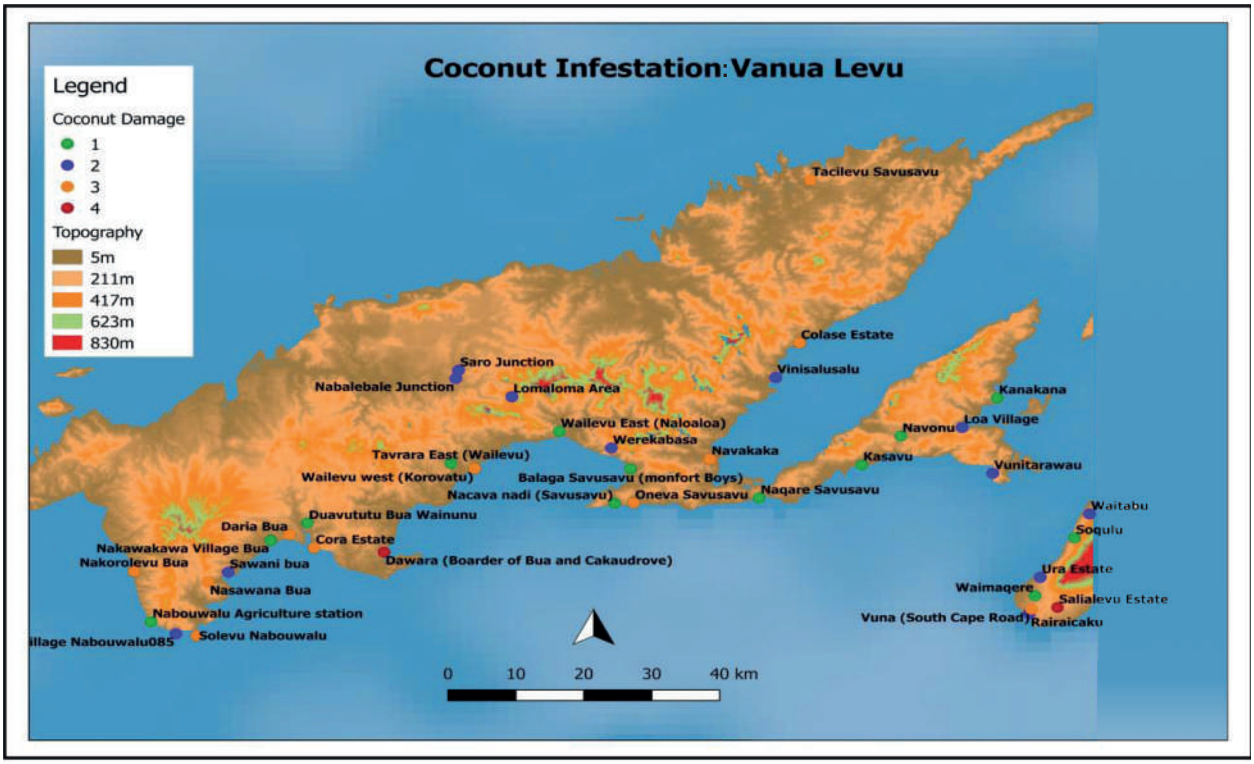

Fig. 3. Distribution and infestation of *G. crouanii* at survey sites in Vanua Levu and Taveuni islands, Fiji islands

The species determination was further confirmed using molecular analysis by the Unitec Institute of Technology, New Zealand. The first record of this phasmida was described by Swaine (1969), who considered it as sporadic, but a serious pest in Fiji causing large-scale defoliation, crop loss, and death of coconut trees. In addition, similar reports of the damage by both nymphs and adults have been reported (Swaine, 1971; Singh, 1981; Rapp, 1995). Reports of *G. crouanii* affecting nut yields in Vanua Levu and Taveuni had been reported as early as 1950's (Paine, 1968; Swaine, 1969). In addition, extensive damage to the coconut plantations by *G. crouanii* along with the rhinoceros beetle, *Oryctes rhinoceros* has been reported by Bedford (1978).

Stick insect distribution and seasonal infestations in relation to weather parameters

The distribution and infestation of *G. crouanii* varied in the coconut farms at different locations in the three islands surveyed during 2012 (Fig. 2 and 3). The infestation levels ranged in the scale of 1 to 4, with the highest number of coconut palms registering less than 30 per cent infestation (Table 1). These variations can be attributed to favourable conditions existing in places where pest infestations were high.

Table 1. Infestation levels of *G. crouanii* in coconut palms in different locations of Vanua Levu, Viti Levu, and Taveuni in Fiji islands

Island	Scale	No. of sites
Vanua Levu	1	12
	2	8
	3	10
	4	1
Viti Levu	1	16
	2	6
	3	1
	4	0
Taveuni	1	6
	2	4
	3	2
	4	1

Scale: 0 - No damage, 1-Scatter appearance of coconut stick insect (<30%), 2-Light infestation on the plant (30-50%), 3-Medium Infestation on the plant (50-80%), 4-Heavy infestation in total plant (≤ 80%)

Table 2. Infestation of *G. crouanii* on coconut palms in hotspots at Vanua Levu, Viti Levu and Taveuni, surveyed during 2012-2013

Month/Year	0 to 4 Scale*		
	Vanua Levu (Dawara)	Viti Levu (Namaumada)	Taveuni (Salialevu)
November 2012	3.79	3.36	3.64
January 2013	3.73	3.33	3.53
March 2013	3.67	3.27	3.33
May 2013	3.53	3.33	3.47
July 2013	3.40	3.93	3.27
September 2013	3.07	3.73	3.87

*Mean of 15 plants

The infestation of *G. crouanii* was monitored on coconut palms at two months intervals from November 2012 until September 2013, in one hot spot each identified in Vanua Levu, Viti Levu and Tavenui (Table 2). In Vanua Levu at Dawara, decreasing trends in *G. crouanii* infestations were observed, but for Viti Levu at Namaumada and Taveuni at Salialevu slight increase was observed in the month of May which further declined till September. However, overall higher pest infestation was recorded between November 2012 and January 2013 that coincided with the wet season; while low infestation was registered from March 2013 to September 2013 coinciding with the dry season. Similar infestation levels of *G. crouanii* were earlier reported from surveys in many South Pacific islands (Dharmaraju, 1978, 1979a, b and 1980a, b, c). The outcome of survey conducted during 1978 in Tokelau Island revealed that pest was prevalent on fairly large scale in some villages and in all the other islets. This survey also revealed, for the first time, that Pandanus plants in all villages and islets were damaged by *G. crouanii* with quite severe damage in some islets (Dharmaraju, 1978). Earlier survey conducted in Niue Island, revealed the infestation of *G. crouanii*, in coconut growing areas throughout the island for the first time (Dharmaraju, 1980b). Similarly, the preliminary survey of insect pest revealed that in several of the places in Tuvalu where pest was located for first time, the damage was found to be quite severe with number of affected fronds by the pest per palm ranged from 40-70 per cent (Dharmaraju, 1980a).

The level of infestations in relation to the direction of the wind revealed that higher infestations of *G. crouanii* were observed in the leeward side, compared to the windward side, in all the three islands surveyed. The leeward side is the side protected by the elevation of the island from the prevailing wind, and is typically the drier side of an island. Thus, the presence of over grown weeds beneath the palms in the leeward side of the study area might have reduced the temperature and induced dampness which could have favoured the egg survival and the early development of *G. crouanii* nymphs. Increased protection to eggs and early development of nymphs has also been suggested by the earlier researchers (Crooker, 1979; Lever, 1969).

Increasing temperature affects egg survival. The statistical analysis of results show that only coefficient β_1= -2.24326 is significant (*p* value = 0.042), indicating that temperature has a significant effect on level of infestation. The results also showed that the odds ratio for temperature is 0.11, which indicated that for every one degree increase in temperature it reduced odds of infestation by 0.11. The possible reason for this observation is that the eggs and nymphal stages of the pest could not thrive leading to decreased population. In contrast, the effects of rainfall and humidity on the infestation were not statistically significant. In plantations with low ground cover, stick insect eggs on the ground probably get desiccated by the sun. This assumption was supported by Crooker (1979) and Lever (1969) and they reported high pest densities in plantations with dense ground cover in Tonga. Singh (1981) reported that plantations with low ground cover were free from stick insect infestation in Fiji. Singh (1977; 1979; 1981) found 12-44 per cent increase in desiccated eggs in plantations with low ground cover, when compared to areas under poor weed management. However, the odd ratios of rainfall and humidity, every one centimetre increase of rainfall and one per cent increase of humidity reduced infestation by 0.94 and 0.42, respectively, but it was not statistically significant. The eggs of *G. crouanii* are normally laid at the base of palms (Rapp, 1995). It has been suggested earlier that the moist conditions prevailing at the base of the palms aid

Table 3. Statistical analysis of the infestation levels of *G. crouanii* in two different seasons, Fiji islands

Infestation	Mean	Std. deviation	95% Confidence interval for mean		Mann-Whitney U Test	p value
			Lower bound	Upper bound		
Dry Season	3.1778	0.53065	3.0874	3.2681	U = 6259.5	< 0.001
Wet Season	3.5259	0.50119	3.4406	3.6112		

in the protection of the eggs and thus favour early development of nymphs (Lever, 1969; Crooker, 1979). A study by Hosang and Alouw (2010) found that Eco73 friendly traps used to control indigenous insect, *Sexava* sp. causing serious damage to coconut palms/plantations in some province of Indonesia captured reasonable number of nymphs and adults that successfully developed at palm base. This was evident from the fact of lower pest incidence in the dry regions of the coconut growing area within Fiji as reported by Deesh *et al*. (2013). Hence, moisture was proved to be vital for early development of the pest leading to subsequent higher level of infestation. Nakata (1961) reported the higher susceptibility of adult and nymph stages to adverse environmental conditions than the egg stage. However, O'Connor *et al.* (1954) concluded non-significant effects of atmospheric and soil humidity on the development and hatching of the eggs based on the laboratory studies. While studying the nymphal emergence under different temperatures (20 ^{0}C, 30 ^{0}C and 40 ^{0}C) reported that eggs survived only at 20 ^{0}C (Rapp, 1995).

The *G. crouanii* infestation levels varied between the dry and wet seasons. Mann-Whitney U test indicated that the infestation levels in the wet season were significantly higher than those in the dry season [U = 6259.50, z = -5.148 (corrected for ties) and p < 0.001] (Table 3). This may be due to fact that the wet season provides favourable conditions for the *G. crouanii* development. To the best of our knowledge, no published reports have been made earlier on the seasonal variations on the infestations by *G. crouanii*.

Table 4. Infestation of *G. crouanii* on different parts of the coconut palm crown, Fiji islands

Coconut palm part infested	Vanua Levu (Dawara) ($\bar{x}$ ± S.D.)	Viti Levu (Namaumada) ($\bar{x}$ ± S.D.)	Taveuni (Salialevu) ($\bar{x}$ ± S.D.)
Upper canopy	1.4 ± 0.5	1.0 ± 0.0	1.0 ± 0.0
Lower canopy	2.4 ± 0.5	1.5 ± 0.5	2.1 ± 0.7
Tip of leaves	2.3 ± 0.5	1.5 ± 0.5	1.7 ± 0.6
Basal part of peaves	1.6 ± 0.8	1.0 ± 0.0	1.3 ± 0.5

S.D. = Standard deviation

Fig. 4. Extent of damage by *G. crouanii* is more on the older leaves (lower area of the crown) and less on the newly formed leaves (upper area of the crown), Fiji islands

Fig. 5. Extent of damage by *G. crouanii* is more on the tip area of leaflet, and less on the middle and basal areas of the leaflet, Fiji islands

Stick insect infestations and the influence of plant phenology and plant canopy

The extent of infestation of *G. crouanii* was also assessed at different levels of the coconut palm leaves (Table 4). More damage was exhibited on the older leaves (lower part of palm crown), as compared to the newly opened leaves (upper part

Table 5. Infestation of *G. crouanii* on upper canopy and lower canopy of the coconut palm crown, Fiji islands

Coconut palm part infested	Mean ($\bar{x}$)	Standard deviation (S.D.)	95% confidence interval for mean		Mann-Whitney test	p value
			Lower bound	Upper bound		
Upper canopy	1.1333	0.34378	1.0301	1.2366	U = 300.000	< 0.001
Lower canopy	2.0000	0.67420	1.7974	2.2026		

Table 6. Infestation of *G. crouanii* on different parts of the coconut palm leaves, Fiji islands

Coconut palm part infested	Mean ($\bar{x}$)	Standard deviation (S.D.)	95% confidence interval for mean		Mann-Whitney test	p value
			Lower bound	Upper bound		
Tip of leaves	1.8444	0.63802	1.6528	2.0361	U = 535.500	< 0.001
Basal part of leaves	1.2889	0.58861	1.1121	1.4657		

of palm crown) (Fig. 4). The extent of damage on single leaflet, around the tip of leaves was more compared to the middle and basal area of the leaflet (Fig. 5). Mann -Whitney *U* test indicated that the infestation levels in lower canopy were significantly higher than those in upper canopy (Table 5), and also the infestation levels in leaflet tip area were significantly higher than those in basal area of fronds (Table 6). This may be due to the prolonged exposure of the older fronds to *G. crouanii* than the younger fronds. As the younger fronds become old, they may also be infested at higher levels. This suggests that *G. crouanii* has no preference over the younger and older fronds, and pest population may be the determining factor for the varied levels of infestations. This is in conformity with earlier studies conducted by Rapp (1995) who reported the infestation by both nymphs and adults on the leaflets of young and middle-aged fronds. The feeding by adult and nymphs on the leaves of coconut leaving only the midrib, complete defoliation of the whole crown which could lead to death of the palms were also reported by Swaine (1969, 1971). Bedford (1978) also reported about the damage by both nymphs and adults affecting the growth and yield mainly through the reduction in the photosynthetic area owing to severe leaf cuts by the stick insect. Dharmaraju (1980a) estimated the damage of coconut fronds to the level from 40 to 70 per cent of the coconut fronds by *G. crouanii* based on the observation made in Tuvalu, where the reduction was estimated up to 15 per cent.

Host plants of *G. crouanii*

The field surveys identified a total of more than 15 alternate host plants of *G. crouanii* in the coconut fields of the three islands in Fiji. They were agricultural crops, commercial crops, ornamental plants, and weed species. Dalo (*Colocasia esculenta*), cassava (*Manihot esculenta*), banana (*Musa sapientum*), *Panadanus tectorius,* voivoi (*Panadanus caricosus*), *Pritchardia pacifica, Dypsis lutescens* and *Tychosperma macarthurii*. Alternate host plants such as cocoa (*Theobroma cacao*), and kava (*Piper methysticum*) were common to Vanua Levu and Taveuni, while *Merremia peltata* was common to Vanua Levu and Viti Levu. *Sabal palmetto, Licuala grandis, Pandanus veitchii, Agave* sp., *Cycas revolute, Cycas revolute* and reed (*Miscanthus japonicas)* were found to be serving as alternate host plants only in Viti Levu.*G. crouanii* damage on two species of *Pandanus* was observed in Taveuni and Vanua Levu. Hence, while adopting management strategies of *G. crouanii*, the presence of *Pandanus* plants in the vicinity of coconut plantations should also be considered.

In the present study, severe infestation of *G. rouanii* was observed in isolated pockets. Also the *G. crouanii* distribution was discontinuous in the surveyed areas. This could be attributed to either the presence of sparse coconut palms in isolated coconut plantations; influence of biotic and abiotic factors prevailed during the study period, and/or neglected conditions of coconut plantations making early detection of *G. crouanii* difficult.

Conclusion

Field surveys in the coconut growing areas of Fiji revealed that there is only one pest species of coconut stick insect, *G. crouanii*. However, it had varying levels of infestations to the coconut palms. The population of *G. crouanii* was found to be higher during the wet seasons as compared during dry seasons. The hotspots of *G. crouanii* in Fiji identified are Dawara in Vanua Levu, Namaumada in Viti Levu, and Salialevu in Taveuni. Apart from the main plant host coconut, the field surveys revealed a wide range of alternate host plants comprising agricultural crops, commercial crops, ornamental plants, and weed species. The alternate host plants were utilized by *G. crouanii*for either feeding or hiding, and these alternate host plants may have strong influence on the survival and proliferation of *G. crouanii*. Thus alternate host plants such as voivoi (*Pandanus caricosus*), Fiji fan palm (*Pritchardia pacifica*) and cabbage palmetto (*Sabal palmetto*), should be avoided near the coconut plantations, and should be regularly monitored for the presence of *G. crouanii*. This is important for the development of ecologically sustainable management system for *G. crouanii*. In future in-depth field research on *G. crouanii* is needed so as to have a clear understanding of the crop loss relationships and the coconut plant compensation ability to leaf damage in the changing climate, and on enhancing naturally-occurring biological control effectiveness.

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