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ORIGINAL CONTRIBUTION

Increases in crop pests caused by Wasmannia auropunctata in Solomon Islands subsistence gardens

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Abstract

The impacts of Wasmannia auropunctata (the little fire ant) on the native biota and subsistence agriculture in the Solomon Islands are poorly understood. This species was originally introduced as a biological control against nut-fall bugs (Amblypelta sp.) around 30 years ago and in the intervening time has spread throughout the Solomon Islands, aided movement of produce and planting material. It is now itself a major pest of coconut, cocoa and subsistence agriculture. In this study, we show the negative effects of this invasive ant on subsistence agriculture in the Solomon Islands. We do this by (i) assessing the presence of insect pests that develop a mutual relationship with W. auropunctata on four common subsistence crops; and (ii) measuring the impact of a significant pest (Tarophagus sp.) and its natural predator the bug Cyrtohinus fulvus, in the presence and absence of W. auropunctata on taro crops. The existence of insect pests that form a mutual relationship with W. auropunctata was measured in a total of 36 gardens of the four subsistence crops. This was conducted through standardized visual searches, plus identification and collecting from randomly selected plants within the gardens. A number of additional insect pests causing major problems to subsistence crops have also developed mutual relationships with W. auropunctata. Infested taro gardens have more Tarophagus sp. compared with taro plants that are free of the little fire ant. The presence and abundance of Wasmannia therefore has the potential to inflict considerable crop loss in rural subsistence gardens in the Solomon Islands.

Introduction

Wasmannia auropunctata (Roger 1863) (the little fire ant) is an invasive species alien to the Pacific region (Holway et al. 2002) and is listed among the hundred worst invaders globally (Lowe et al. 2000). Most previous studies of this species have focused on its biology and ecological impacts. For example, *W. auropunctata* decrease arthropod diversity and are general predators of vertebrates such as birds and lizards (Allen et al. 1995; Jourdan et al. 2001). They can out-compete prey on native ants (Clark et al. 1982) as well as affect nesting and survival of young birds and reptiles. *W. auropunctata* cause blinding of dogs and cats (Wetterer 1997; Wetterer and Porter 2003; Causton et al. 2005; Theron 2005) and decrease the abundance of native lizards in sclerophyll forests of New Caledonia (Jourdan et al. 2001). This invasive ant also infests homes and causes disturbance to the inhabitants. The practice of treating inside the residential structures with dichloro-diphenyl-trichloroethane (DDT) to control mosquitoes (Sadasivaiah et al. 2007) also appears to control *W. auropunctata* from invading some homes (personal observations).

In the Solomon Islands, the little fire ant has been responsible for the gradual blindness of domesticated dogs, cats and birds (Fasi et al. 2009). Cornea trauma inflicted on many village dogs by *W. auropunctata* is common, and dogs rarely live more than 5 years after being stung (Wetterer 1997). Data for non-domestic vertebrates, however, are scarce, and it is more difficult to directly attribute mortality to invasive ant species (Holway et al. 2002).

There are few previous studies describing the impacts of *W. auropunctata* on agriculture or crops. Introduced into Solomon Islands around 1974 (Ikin 1984), the little fire ant was widely accepted as a biological control against nut-fall bug (*Amblypelta* sp) in coconut and cocoa (Wetterer 2006). Since that time, it has spread across the Solomon Islands, carried by human movement and transport of commodities.

In the rural areas in the Solomon Islands, the little fire ant is associated with stings and discomfort, and subsistence farmers are often reluctant to work in infested gardens. These 'social' impacts are rarely included in assessments of damage by agricultural agencies (Fasi et al. 2009). Compounding these 'social' impacts, many common crop pests thrive in the presence of invasive ants, especially hemiptera in which ants actively tend for their carbohydrate-rich excretions (Eastwood 2004). For example, honeydew-producing scale insects are greatly increased in the presence of another invasive ant, *Anoplolepis gracilipes* (Abbott and Green 2007). In the case of the little fire ant, Le Breton et al. (2002) noted it was a well-known pest of agricultural areas and natural ecosystems in New Caledonia. The association between the *W. auropunctata* and crop-damaging hemipterans was also noted in areas where they were in abundance by Wetterer and Porter (2003).

The actual effect of *W. auropunctata* on subsistence crops, however, is yet to be fully understood. The common understanding is that crops that produce large quantities of sugary sap are more likely to attract both honeydew-producing hemipterans and the little fire ant. Hemipterans would have the benefit of being protected from their natural predators by these ants and thus result in increased damage to plants. Mutually beneficial associations such as these may be an important, previously unquantified factor promoting the success of some of the major hemipteran pests and thereby playing a major role in crop loss (Helms and Vinson 2003). Often, the impacts of these mutualistic relationships are anecdotal, and little is known about the real impacts on crop productivity this may cause.

In this study, we measured the effects of this mutualism on crop productivity for common subsistence garden crops in the rural areas in the Solomon Islands. We did this by (i) surveying crop pests that may develop mutual relationship with *W. auropunctata*; and (ii) assessing the role of *W. auropuntata* on the population density of *Tarophagus* sp, an important pest of taro and its natural predator.

Colocasia esculenta (Taro) is an important subsistence crop in the Solomon Islands. It provides edible corms and leaves. The corm is especially important because it can be stored for later consumption, unlike many other crops that must be consumed quickly after harvest. Additionally, it has a high cultural value, often featuring in ceremonial gift-giving ceremonies. Productivity of this crop is affected by two important crop-specific pests: *Papuana woodlarkiana* Montrouzier (the Taro Beetle) and *Tarophagus* sp. (the Taro Planthopper). *Tarophagus* sp. damages the edible leaves, reduces plant vigour and is implicated in the spread of pathogens and viruses such as alomae and bobone. These viruses cause wilting and stunted growth in affected plants (Matthews 2003).

Material and Methods

Study area: Makira Island (San Cristobal)

This study was conducted in the district of Bauro on the island of Makira (formerly referred to as San Cristobal) in the Solomon Islands. The islands are located within 12°S of the equator and more than 1500 km from the nearest continent (Government of Solomon Islands, 2009). There are six major islands within the archipelago (fig. 1) with approximately 900 smaller volcanic islands and coral atolls. Major islands are characterized by steep mountain ranges with dense tropical forest. The island of Makira is located at 10.60°S 161.85°E. It is 140 km long and between 12 and 40 km wide with a land area of 3100 sq km and the highest point above sea level at 1250 m (Allen et al. 2006). Makira is the fourth largest island of the Solomon Islands archipelago (Petterson et al. 1998) and has a wet tropical climate characterized by high humidity and uniform hot temperatures, which are occasionally tempered by sea breezes. We conducted the study from January to February and from April to May 2008.

Four study sites were selected: two in villages infested with *W. auropunctata* and two in villages that were uninfested. Each village was separated by more than 2 km, ensuring independent sampling locations (fig. 1). The infested villages were located closer to the coastline and were at a lower elevation than the uninfested villages (approximately 50 m. a.s.l. vs. approximately 400 m. a.s.l.).

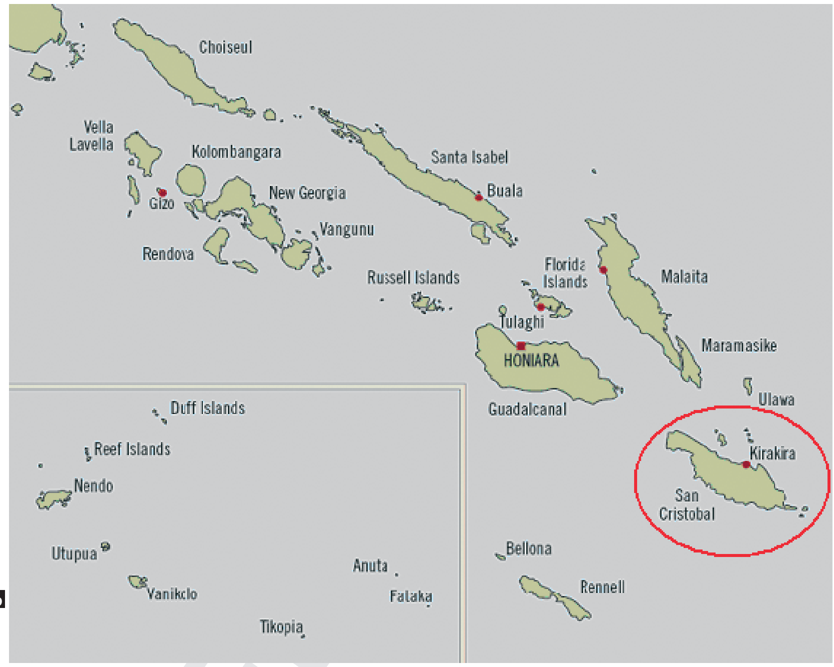

Fig. 1 Map of Solomon Islands showing Makira (San Cristobal) in red circle. (Adapted from: Bourke et al. 2006).

Surveying crop pests that develop mutual relationship with *Wasmannia auropunctata*

Four common subsistence crops, cassava (*Manihot esculenta*), sweet potato (*Ipomea batatas*), taro (*Colocasia esculenta*) and yam (*Dioscorea* spp.), were surveyed for crop pests and associations with *W. auropunctata*. Within study areas, taro gardens were grouped into four different locations. Each location was separated by over 2 km. Within each location, taro plots (gardens) were separated by about 100 m. A total of 56 taro gardens were selected: half infested with LFA and the other half free of LFA. Within each taro plot, 25 taro plants were randomly selected, and standardized visual identification and recording for *Tarophagus* sp and its natural enemy *C. fulvus* was conducted. The size of gardens varied considerably from 80 m^2 to 322 m^2. To allow for equal or similar dimensions among all the gardens surveyed, the actual sampling area within each garden was standardized to approximately 80 m^2 (8 × 10 m). Following Jourdan et al. (2001) and Lester et al. (2003), we determined the presence or absence of hemipterans (aphids, mealy bug, scale insects or whiteflies) tended by *W. auropunctata*, as well as other insects (most of them being crop pests). This was conducted by systematic visual searching for 30-min duration at each location, identification and collection. A relationship between an ant species and hemipterans was defined as established if the ants were observed collecting the exudates from the hemipterans or seen to be congregating around them (Lester et al. 2003).

The results of this survey were tabulated against the crops they were associated with. Insects were identified to genus (species if possible) and common names assigned using nomenclature provided by Borror and White (1970) and French (2006), as well as by cross reference to insect collections held at the Biology Division, University of the South Pacific. Pest status was determined using information provided by Borror and White (1970). The insects that were tended by *W. auropunctata* were categorized according to their status as crop pests. Finally, all the insect species were classified as either having a known mutualistic relationship with *W. auropunctata*, or not, using field notes taken during direct observation.

Assessing a significant pest of *Colocasia esculenta* and its natural predator

Measuring the possible impact of *W. auropunctata* on subsistence crops was conducted by correlating the abundance of *W. auropunctata* with those of *Tarophagus* sp (a pest of taro) and *Cyrtohinus fulvus* (a natural predator of *Tarophagus* sp.) on taro plants. This was undertaken to determine whether *W. auropunctata* changed the relationship or abundance of *Tarophagus* sp and *C. fulvus*, thereby changing rates of phytophagy on the crop.

At each village, seven taro gardens were selected, each approximately 100 m apart from the others. These gardens constituted plots. Twenty-five taro plants of approximately equal size were randomly selected within each garden for measuring insect abundance. On each plant the number of *W. auropunctata*, *Tarophagus* sp. and *C. fulvus* was counted. An independent sample *t*-test using SPSS version 16 was conducted to determine whether any significant differences between abundances existed.

Results

Relationships between the little fire ant and other insects

Twenty different insect species were found on the four subsistence crops studied (table 1). The insect assemblages on each crop were different. Eleven crop pests were recorded on potato, six on yam and five on cassava and taro (table 1). The majority of insect species found overall were from the order Hemiptera. Of the twenty insect species found, eight were had a putative mutualism with *W. auropunctata* (table 2). All eight of these insects are recognized crop pests. Six insects *(Bemisia* sp., *Planococcus citri, Planococcus dioscoreae,* 2 species of *Aleurodicus* sp. and *Tarophagus* sp.) are hemipterans, and two (*Spodoptera* sp. and *Hippotion* sp.) are lepidopterans in the larval stage. A *Bemisia* sp. was also found on potato gardens; Planococcus *citri, Aleurodicus* sp. and *Spodoptera* sp. were found on cassava; *Tarophagus* sp., *Planococcus citri*, *Spodoptera* sp. and *Hippotion* sp were found on taro; and *Planococcus citri*, *Planococcus dioscoreae* and *Aleurodicus* sp were found on yam. Other serious crop pests did not exhibit ant mutualism including the sweet potato weevil *(Cyclas formicarius)* and two species of unidentified grasshopper (table 2). In total, ten different insect species found on potato did not appear to be tended by ants. This compares with only two in each of the other three crops (table 1). In contrast, only one ant-tended insect species was observed in potato crops compared with three in cassava crops, four in taro crops and three in yam crops (table 2).

Table 1 Common insects found in different subsistence crops at lowland garden sites

Insect species	Order	Common name	Crop
Atractomorpha sp	Orthoptera	Grasshopper	P, Y
Valanga sp	Orthoptera	Grasshopper	P, Y
Cyrtohinus fulvus	Heteroptera	Leafhopper	T
Riptortus sp	Hemiptera	Pod-sucking bug	P
Podisus maculiventris	Hemiptera	Spine soldier bug	P
Jalysus wickhami	Hemiptera	Stilt bug	P, Y
Bemisia sp	Hemiptera	Whitefly	P
Planococcus citri	Hemiptera	Mealybug	C, T, Y
Aleurodicus sp	Hemiptera	Whitefly	C, Y
Leptoglossus phyllopus	Hemiptera	Leaf-footed bug	C
Tarophagus sp	Hemiptera	Planthopper	T
Planococcus dioscoreae	Hemiptera	Mealybug	Y
Cyclas formicarius	Coleoptera	Sweet potato weevil	P
Hippodamia sp	Coleoptera	Ladybird	P
Henosepilachna sp	Coleoptera	Ladybird	P
Otiorhynchus sp	Coleoptera	Snout beetle	P
Aspidomorpha sp	Coleoptera	Tortoise beetle	P
Sanninoidea sp	Lepidoptera	Tree borer	C
Spodoptera litura	Lepidoptera	Cluster worm	C, T
Hippotion celerio	Lepidoptera	Taro hornworm	T

P, potato; C, cassava; T, taro; Y, yam.

Effect of *Wasmannia auropunctata* on abundance of *Tarophagus* sp and *Cyrtohinus fulvus*

We selected one plant pest (*Tarophagus* sp.) and its natural predator *Cyrtohinus fulvus* for closer study. A mean of 50.0 (SE ± 4) *Tarophagus* sp. adults were recorded per taro plant in *W. auropounctata*-infested gardens. This was compared with only 18.0 ± 1 adults in uninfested gardens ($t_{(54)} = 7.1$, $P < 0.05$). In contrast, the mean number of *C. fulvus* per plant was similar in infested gardens (3.5 ± 0.4 per plant compared with 4.2 ± 0.3 in uninfested gardens) (fig. 2). This difference was not statistically different ($t_{(54)} = -1.61$, $P = 0.11$).

Discussion

Relationship between *Wasmannia auropunctata* and other insects

In this study, six hemipteran species exhibited mutual relationships with *W. auropunctata* on four subsistence crops. According to Styrsky and Eubanks (2007), such relationships are an example of food-for-protection mutualism and are common between ants (Formicidae) and honeydew-producing insects in the hemipteran suborders Sternorrhyncha (particularly the aphids, whiteflies, scales and mealy bugs) and Auchenorrhyncha (particularly the leafhoppers). The six ant-tended hemipteran species in this study are all common crop pests (French 2006) and are from the two hemipteran suborders listed above.

This mutualistic behaviour is common and widespread in agricultural production systems (Way and Khoo 1992). The presence of a large number of host plants allows an abundance of crop pest species to

Table 2 Insects observed in the lowland gardens

Crops/Insect species	Order	Common name	Pest Status	Observed relationship
Potato				
Cyclas formicarius	Coleoptera	Sweet potato weevil	+	–
Hippodamia sp	Coleoptera	Ladybird	–	–
Henosepilachna sp	Coleoptera	Ladybird	+	–
Otiorhynchus sp	Coleoptera	Snout beetle	+	–
Aspidomorpha sp	Coleoptera	Tortoise beetle	+	–
Riptortus sp	Hemiptera	Pod-sucking bug	+	–
Podisus maculiventris	Hemiptera	Spine soldier bug	–	–
Jalysus wickhami	Hemiptera	Stilt bug	–	–
Bemisia sp	Hemiptera	Whitefly	+	+
Atractomorpha sp	Orthoptera	Grasshopper	+	–
Valanga sp	Orthoptera	Grasshopper	+	–
Cassava				
Planococcus citri	Hemiptera	Mealybug	+	+
Aleurodicus sp	Hemiptera	Whitefly	+	+
Leptoglossus phyllopus	Hemiptera	Leaf-footed bug	+	–
Sanninoidea sp	Lepidoptera	Tree borer	+	–
Spodoptera litura	Lepidoptera	Cluster worm	+	+
Taro				
Tarophagus sp	Hemiptera	Planthopper	+	+
Planococcus citri	Hemiptera	Mealybug	+	+
Cyrtohinus fulvus	Hemiptera	Leafhopper	–	–
Valanga sp	Orthoptera	Grasshopper	+	–
Spodoptera litura	Lepidoptera	Cluster worm	+	+
Hippotion celerio	Lepidoptera	Taro hornworm	+	+
Yam				
Planococcus citri	Hemiptera	Mealybug	+	+
Planococcus dioscoreae	Hemiptera	Mealybug	+	+
Jalysus wickhami	Hemiptera	Stilt bug	+	–
Aleurodicus sp	Hemiptera	Whitefly	+	+
Atractomorpha sp	Orthoptera	Grasshopper	+	–

(+), relationship observed with *Wasmannia auropunctata*; (–), relationship not observed with *W. auropunctata*; (+), insect known to cause damage to crops; (–), insect not documented to cause damage to crops.

flourish, and the proximity to human structures provides a vector for the movement of invasive ants into cropping systems (Rowles and Silverman 2009). In the four crops surveyed at the lowland sites, crop damage appeared most severe on young potato plants, cassava plants and the young leaves of taro and yam plants.

Some non-hemipteran insects were also tended by *W. auropunctata*. For example, two unidentified Lepidoptera caterpillar species collected from taro and cassava plants were seen with several *W. auropunctata* swarming around them as they were feeding. Myrmecophily is common in lepidoptera (Holldobler and Wilson 1990). The caterpillars may secrete exudates that attract *W. auropunctata* (Marshall 1999), and at times, in return, the ants protect the caterpillars from natural enemies such as wasps (Devries 1991). The major predators of the two species of caterpillar found in taro and cassava according to Hinckley (1964) and

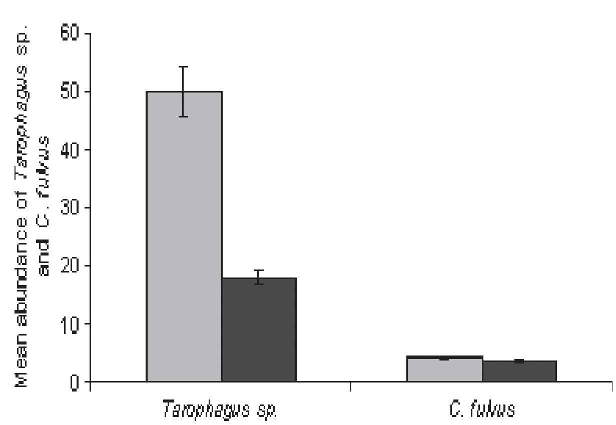

Fig. 2 Mean abundance of Tarophagus sp. and C. fulvus per taro plant sampled. ■ = uninfested taro plants, ■ = infested taro plants.

LOW RESOLUTION FIG

Vargo et al. (1993) are two species of wasp *Apanteles* sp. and *Trichogramma* sp. Protection of lepidopteran larvae from such wasps has been previously observed by Devries (1991). In other cases, ants may predate on the larvae rather than protect them (Freitas and Oliveira 1992). While current knowledge on ant–insect relationships focuses primarily on hemipteran insects (Lester et al. 2003; Styrsky and Eubanks 2007), similar relationships with lepidopteran species may also exist, with associated losses in crop productivity. Although it appears the behaviour we observed in this case was mutualistic, further study is needed to confirm this.

Wasmannia auropunctata also congregated in large numbers on the leaves of taro, yam and potato being grazed by grasshoppers *(Atractomorpha* sp. and *Valanga* sp.). It is possible that these phytophagous insects damaged the leaf through feeding activity, thus exposing the sugary sap of the plant. This may have attracted *W. auropunctata* to these leaves and allowed them easier access to the same resources. This behaviour is neither mutualistic nor predatory, but simply convenient for the ants that would consume the same sources of carbohydrates as the herbivores.

Being both ground and arboreal dwelling, *W. auropunctata* has a three-dimensional foraging strategy and forage for food on leaf litter on the garden floor and also at higher levels on parts of the crop (Jourdan 1997; Vanderwoude et al. 2010). It is very likely that within a crop, *W. auropunctata* may be tending honeydew-producing hemipteran pests at all levels including the stem, leaves, flowers and roots. Hence, the level of insect load being tended by *W. auropunctata* could be much higher than was estimated by the observations taken in this study.

There is sufficient evidence to show that mutualistic relationships between *W. auropunctata* and honeydew-producing hemipterans can result in greatly increased densities of these crop pests. This will clearly lead to increased yield losses for crop plants such as those observed in other studies (Delabie 2001; Holway et al. 2002). Accurate determination of insect pests that have mutualistic relationships with *W. auropunctata* in subsistence garden crops is important because it provides a better understanding of (i) pest outbreak dynamics; and (ii) causes of high densities of certain insect pests on subsistence crops. Studies of mutualism dynamics of other invasive ant species are reported more frequently
8 (Buckley 1987; Holway et al. 2002; Renault et al. 2005), and some of these ant species are also common in many food gardens in the Bauro area. Additional studies of the relationships between *W. auropunctata* and other plant pests, particularly for aphids, mealy bug and scale insects, may reveal similar relationships affecting crop health.

Effect of *Wasmannia auropunctata* on abundance of *Tarophagus* sp and *Cyrtohinus fulvus*

Cyrtohinus fulvus is a mirid bug that is found almost exclusively on taro plants (*Colocasia esculenta*) and other taro species (Matthews 2003). This relationship exists because *C. fulvus* feeds on the eggs of *Tarophagus* sp., a pest that is almost exclusively found on taro plants (Waterhouse and Norris 1987). On infested taro plants, the *Tarophagus* sp. and their eggs appeared to be protected from *C. fulvus* by *W. auropunctata;* however, we did not directly observe specific interactions between these two species. This protection disrupts the normal predator–prey relationship and led to the increase in pest densities we observed.

Based on similar studies (Eubanks 2001; Moreira and Del-Claro 2005), we predicted that the abundance of *Tarophagus* sp. in this study would be significantly higher on taro plants infested with *W. auropunctata*. This hypothesis proved to be correct as population densities of *Tarophagus* sp. were substantially greater where *W. auropunctata* were present. Contrary to other studies that attribute reduction in survival and abundance of hemipteran predators to ant-hemipteran mutualisms (Tedders et al. 1990; Stechmann et al. 1996; Kaplan and Eubanks 2002; 9, 10
Renault et al. 2005), this study did not show the same results for *C. fulvus.* Predator abundance, as determined by counts of *C. fulvus,* was not lower in infested gardens (3.5 vs. 4.3 mean individuals per plant), despite three times greater prey availability. Population estimates were unchanged, but the proportion of *C. fulvus* to *Tarophagus* sp was substantially lower when *W. auropunctata* were tending *Tarophagus*. The primary food source for *C. fulvus* is *Tarophagus* eggs, and it could be expected there would be more eggs with a higher *Tarophagus* population. Therefore, an imbalance between predator and prey availability existed.

Although the question of whether *W. auropunctata* alters *C. fulvus* abundance remains unanswered, they appeared to be directly responsible for a substantial increase in *Tarophagus* sp. on taro plants. This may be due to *W. auropunctata* protecting *Tarophagus* sp. from its predator (*C. fulvus*) or by stimulating *Tarophagus* sp. feeding rate, fecundity and dispersal as found in other ant mutualisms (Bristow 1983; Buckley 1987; Delabie 2001; Billick and Tonkel 2003). Consequently, *W. auropunctata* may exacerbate the negative effects of honeydew-producing hemipterans on taro plants, which include stunted growth, reduced leaf area and the introduction of plant pathogens, all of which can decrease taro plant productivity (Beattie 1985; Delabie 2001).

Tarophagus sp. benefit from the presence and attendance of *W. auropunctata*. Del-Claro and Oliveira (2000) also demonstrated increased hemipteran productivity in the presence of tending ants. The mechanism leading to increased abundance is not clear and may be one or a combination of interference, predation or aggressive defence that prevents *C. fulvus* predation, thus allowing an increase in *Tarophagus* sp density and resulting crop damage. Regardless of the exact mechanism(s) involved, the presence and abundance of *W. auropunctata* on taro plants appears to increase *Tarophagus* abundance.

Decreases in crop productivity directly impact subsistence farmers whose primary purpose for cropping is to supply food to the family or the community on a day-to-day basis. Taro is a particularly important staple in the Solomon Islands, as it is often the most readily available and abundant source of complex carbohydrates. Additionally, it is one of the few crops that can be stored and consumed at a later time. Refrigeration and other forms of food preservation are usually not available so most other food items have to be grown and harvested on a daily basis. A substantial increase in the abundance of the primary crop pest of taro may therefore limit the sustainable production of this important crop.

As *W. auropunctata* spread further through the Pacific region, crop losses in subsistence gardens will become more common and is expected to be one of the major impacts on island communities. Once established, many communities will be unable to manage this pest because access to appropriate treatment methods is not readily available. The best strategy should be based on prevention and include rigorous biosecurity measures, early detection surveillance, good awareness and outreach programs.

Conclusion

This study documents common invertebrates found on four subsistence crops in the rural areas in the Solomon Islands that harbour little fire ants. It identifies a number of insects (many of which are pest species) that form mutualistic relationships with *W. auropunctata* and highlights the association of *W. auropunctata* with a common pest *Tarophagus* sp. in the important subsistence crop *C. esculenta*. This relationship results in an increased population density of *Tarophagus* sp., and this relationship appears to reduce the effectiveness of its natural predators against the pest which in turn reduces crop fitness and yield.

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