QUANTIFYING THE DOMINANCE OF LITTLE FIRE ANT (*Wasmannia auropunctata*) AND ITS EFFECT ON CROPS IN THE SOLOMON ISLANDS

by

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DECLARATION

Statement by Author

I, John Fasi, declare that this thesis is my own work and that, to the best of my knowledge it contains no materials previously published, or substantially overlapping with material submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

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Statement by Supervisor

The research in this thesis was performed under my supervision and to the best of my knowledge is the sole work of Mr. John Fasi.

Signature .... Date ……………………………

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Designation …………………………………………………………………….............

DEDICATION

In loving memory of my parents, George Fasiqworoa and Ruth Katarofa.

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ABSTRACT

Introduced most probably intentionally, as a biological control against nutfall bugs (*Amblypelta* sp) in coconut and cocoa, the Little Fire Ant (*Wasmannia auropunctata*) has for more than 30 years continued to spread and colonise a number of different environments in the Solomon Islands. To date, no studies have investigated the ecological impact of these ants. The impact of Little Fire Ants was measured on (1) the overall ant fauna within subsistence gardens, (2) the prevalence of additional insect pests in subsistence gardens, and (3) the significant pest *Tarophagus* sp. of one crop - taro and its natural predator *Cyrtohinus fulvus.* Ant fauna was surveyed on two study areas in garden sites of four common subsistence crops: potato, cassava, taro and yam; a total of 36 gardens per study area with three trials per garden, using baiting and hand collecting. The existence of insect pests that form a relationship with *W. auropunctata* was measured in the same gardens by standardised visual searches, plus some identification and collecting from randomly selected crop within the gardens. The impact of *W. auropunctata* on the significant taro pest *Tarophagus* sp. and its natural predator *Cyrtohinus fulvus* was measured in 56 taro gardens with half of the gardens infested with Little Fire Ants. Twenty five taro plants were randomly selected in each taro garden and sampled using standardized visual identification. Sites with *W. auropunctata* had significantly lower mean abundance of other ant species than gardens free of *W. auropunctata*. A number of hemipteran insects (most of them pests) were also observed to have developed relationships with *W. auropunctata*. Although there was no significant difference in the mean population density of *C. fulvus* per taro plant between taro plants infested and free of *W. auropunctata*, significantly more *Tarophagus* were found on taro plants in the presence of *W. auropunctata* than in the absence of *W. auropunctata*. Three conclusions are drawn here, (1) the presence of *W. auropunctata* leads to a reduction in the ant fauna at a site, and is likely to lead to ecological damage to other invertebrates and vertebrates, (2) the presence of *W. auropunctata* in the subsistence crops may have lead to the development of harmful relationships between hemipteran pests and *W. auropunctata*, and (3) the presence and dominance of *W. auropunctata* on subsistence crops may provide an environment that

allows insect pests to thrive. Little Fire Ants therefore pose an economic as well as an ecological risk in subsistence gardens in the Solomon Islands.

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CHAPTER 1
GENERAL INTRODUCTION

1.1 Ecological and Agricultural Impact of Invasive Ants

1.1.1 Overview of the Study

The impact of invasive ants can be devastating and can substantially alter an entire ecosystem (Sakai *et al*. 2001; Christian, 2001; Wetterer and Porter, 2003; O'Dowd *et al*. 2003). In the Pacific Islands, the impact of invasive ants on ecosystems has an even bigger implication due to the vulnerability of many of the islands to any environmental disturbance such as the devastating effect of invading ants (Vitousek, 1988; Williamson, 1996; Holway *et al*. 2002; Wetterer and Vargo, 2003; Lester and Tavite, 2004). Significant interest is also linked to the economic and agricultural cost associated with invasive ant species. For example, in the United States alone, US Department of Agriculture (2007) reported millions of dollars lost because of crop loss due to the infestation of the invasive ant *Solenopsis invicta*. The ant species is reported to be inflicting damage to fifty – seven cultivated plant species (Adams, 1986) and it is of concern that Pacific Islands may not have the capacity to deal with the compounded effect of such invasive ant species.

A lot of interest on invasive ants in the Pacific relates to the impact of ants on the smaller islands; particularly the islands in Polynesia and Micronesia which have limited native and endemic ants (Ward and Wetterer, 2006). Invasive ant species capable of eliminating other ant species would be a disaster for the native ants of these islands. The Melanesian Islands on the other hand may have a more diverse number of endemic species (Ward and Wetterer, 2006). According to Ward (2007), recent interest and study on ant species in the bigger Melanesian Islands was on a particular invasive ant species, the Little Fire Ant *Wasmannia auropunctata* in New Caledonia and Vanuatu (Jourdan 1997; Jourdan *et al*. 2002; 2006; Le Breton *et al.* 2005). There is also a report of the destructive nature of *W. auropunctata* to plants, animals and humans on Bougainville, in Papua New Guinea (Tseraha, 2009). However, despite such a scenario existing within the Melanesian Islands, very little is known about the invasion of *W. auropunctata*, or any other invasive ants, in the Solomon Islands.

1.1.2 Invasive ants in the Solomon Islands

Solomon Islands with a land area of 27,556 km^2 (Island Directory, 1998), is second only in land area to Papua New Guinea in the Pacific Islands. The Solomon Islands may hold vast ant species richness compared with other Pacific Islands given its location in relation to the pattern of the distribution of ants; from Southeast Asia, Australia and Papua New Guinea (Wilson, 1961) and the pattern of decline in the ant species richness as one moves away from the West to the East in the Pacific (Ward and Wetterer, 2006). Known documented studies of ants in the Solomon Islands were published by Mann (1919) and Wheeler (1935) however, our knowledge of the true number of the native and endemic ants of the Solomon Islands is still limited. Furthermore, the occurrence and likely increase of invasive ants in the Solomon Islands is of concern given that they are capable of eliminating native and endemic ant species and there is still a lot to discover about ant species richness and endemism.

Currently, 20 invasive ants are recorded in the Solomon Islands (Ward and Wetterer, 2006). Of all the current invasive ants recorded in Solomon Islands, *W. auropunctata* and *Anoplolepis gracilipes* are probably the invasive ant species most reported to be inflicting damage to humans, plants and also to certain other vertebrates and invertebrates (Wetterer, 1997; Bapo, 2009). Other than anecdotal and media reports, little else is known about *W. auropunctata* in the Solomon Islands other than the reporting of its presence (Fabres and Brown, 1978; Ikin, 1984) although there are numerous undocumented reports of gradual blindness in domesticated dogs, cats and birds from the stinging effect of *W. auropunctata* (pers. obs.). Studies undertaken in the Solomon Islands in the 1950s to identify ants that could be used against a pest responsible for early ripening of coconut (Brown, 1959) did not report *W. auropunctata*.

W. auropunctata is a tiny and almost invisible ant but with distinct notable features, one of which is its painful sting (Smith, 1965). It is among a group of invasive ants known to have spread across the globe from their native range in the South American region (Fabres and Brown 1978; Wetterer and Porter 2003, Krushelnycky *et al.* 2005) and are known to cause havoc in their introduced range in some Pacific Islands and the African region (William, 1994). *W. auropunctata* has been increasing in concern and in more recent years, it has emerged as a major global exotic pest (Wetterer and Porter, 2003). In disturbed areas, such as agricultural and forestry land in the regions outside its native range, the impact of *W. auropunctata* on native ant communities and other invertebrates can be very devastating (Hölldobler and Wilson, 1994).

Given its ecological and economical impacts in other areas of the globe, the introduction of *W. auropunctata* to the Solomon Islands and other Pacific Islands is a cause for concern for these fragile island ecosystems. Recognised as a potential threat to biodiversity, many studies have highlighted the impact of the invasion of *W. auropunctata* to an ecosystem. Of particular interest is its negative impact on invertebrates and vertebrates (Clark *et al*. 1982; Ulloa- Chacón and Cherix, 1990; Torres and Snelling 1997). The potential threat by *W. auropunctata* poses to the biodiversity of the Pacific Islands and especially in Solomon Islands is however, understudied. Based on other studies undertaken in both the native and introduced range of *W. auropunctata* (Levings and Franks, 1982; Clark *et al*. 1982; Tennant, 1994; Jourdan, 2002; Le Breton *et al*. 2005) it is possible that the survival of many native and endemic invertebrates and vertebrates could be threatened as a result of its introduction to Solomon Islands and other Pacific Islands.

Another important area that has not received as much attention is the effect of *W. auropunctata* on agriculture. Plants in general play an important role in the relationship between ants and insects (hemipterans) and although the mutualistic aspects of ant – hemipteran interactions are well studied (Buckley, 1987; Delabie, 2001) the consequences of such interactions, particularly on the host plant has received little attention (Styrsky and Eubanks, 2007). It is therefore important and relevant to look at such relationships in the light of their effect on host plants/crops that are important to humans. For example, crops such as potato, tomato, taro, yam or other edible plant species. This is because any direct or indirect negative effect of such relationships on plants or crops such as these may have wide agricultural, social and economical implications. Its impact on agriculture may be under estimated but it is considered by some to be devastating (Spencer, 1941; Delabie *et al.* 1994; de Souza *et al.* 1998).

1.1.3 Effect of W. auropunctata on helpful crop insects

The presence of *W. auropunctata* on crops may also lead to the ineffectiveness of some of the known natural predators and parasitoids. Known for its mutualistic relationship with some of the hemipterans (many are pests) the presence of *W. auropunctata* on crops could make biological control a less effective means to control some of the known crop pests. This is by protecting the pests from being preyed upon by their natural predators. The presence of natural predators and parasitoids in plants is important as they help control the level of pest population by feeding on either the nymphs or eggs of the pests (Simmons and Abd-Rabou, 2007).

A well-known example of the use of a natural predator to control populations of pests was the introduction of a natural predator *Cyrtohinus fulvus* to control a taro pest, a planthopper *Tarophagus* sp. in some of the Pacific Islands (Hagen *et al.* 1999). *C. fulvus* was proved effective in controlling *Tarophagus* sp. in taro plants in Fiji, Ponape and Samoa (Waterhouse and Norris, 1987). The genus *Cyrtohinus* has three species (Hagen et al. 1999). *C. fulvus* is a species common in the Pacific Islands (Matsumoto and Nishida, 1966). It is possible that the presence of *W. auropunctata* on taro plants in some Pacific Islands will lead to high densities of *Tarophagus* sp. This is possible given that *Tarophagus* sp. is a honeydew-producing insect (a source of food for *W. auropunctata*) and *therefore W. auropunctata* would protect *Tarophagus* sp. from its natural predator *C. fulvus*.

1.1.4 Subsistence Gardens

Studying subsistence gardens can offer a good understanding of ant species (native and invasive) colonisation and re-colonisation within local habitats in Solomon Islands. Since subsistence gardening in the rural areas initially involves disturbances of the flora and the soil (per. obs.), it effectively removes almost all ants within the area where the garden is prepared (Castaño-Meneses and Palacios-Vargas, 2004). One of the recognised arguments about the vulnerability of Pacific Island ecosystems to invasion of exotic ants is the lack of native ants that may offer resistance to the invading exotic ant species (Cole *et al.* 1992; Le Breton *et al*. 2005). Subsistence gardens during their succession stage (when crops are starting to grow) may lack the native ants that could offer resistance to invading exotic ants, and therefore the crops are more susceptible to invasion. Hobbs and Huenneke (1992) noted that when a habitat is disturbed, it often allows itself to become more invasible. Ward (2007) further argued that vulnerability of a community to the invasive ant species could either be due to disturbance of an area before or upon arrival of an invasive species or communities with low species richness and vacant niches. Subsistence gardens appear to meet these criteria, therefore, making them more invasible.

The ant community that eventually establishes itself in a garden site may come from two possible sources. The most probable source is from the immediate surroundings. The second source is from planting materials physically taken to the garden sites. This is the major route used by invasive ants such as *W. auropunctata* (Wetterer, 2007). However, subsistence garden sites, as agriculturally disturbed environments, are where invasive ant species such as *W. auropunctata* flourish (Armbrecht and Ulloa-Chacon, 2003; Rowles and Silverman, 2009). Perhaps due to the abundance of high-carbohydrate resources either from the subsistence crops or other honeydew-producing insects present, subsistence gardens provide a beneficial environment for invasive ants. Subsistence gardens could therefore be good models for communities that are highly vulnerable to biological invasions (Lodge, 1993).

1.2 Definitions

The four terms, which are used interchangeably in this thesis to describe *W. auropunctata*, are invasive, exotic, alien and tramp ant species. An invasive species is defined as a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Invasive Species Advisory Committee, 2006). Within this thesis, the definition of invasive ant species is specifically defined as a species, which is found in a new region, which it is not native to, and impacts negatively on native ant species and other organisms already existing in the community. The term exotic ant species is defined here as species that is not native to a region it is found but has been transported to that region mostly by human action (Ward, 2007). Exotic ant species can be either invasive or not invasive. An alien species is a species introduced outside its native range but an alien species can become invasive if its establishment modifies and causes harm to the recipient environment. A tramp ant species is defined as an ant species that is transported to new region primarily through human – mediated means (Harris *et al*. undated). *W. auropunctata* is a good example of a tramp ant species, because it relies greatly on human-mediated dispersal and close association with humans (Passera, 1994).

1.3 Solomon Island Situation: The case of *Wasmannia auropunctata*

Although published records of the negative impact of invasive ant species such as *W. auropunctata* are common, some sectors in the Solomon Islands appear to think otherwise. For example, the agriculture department in the Solomon Islands appears to advocate the positive significance of *W. auropunctata* to certain commercial crops especially, coconut and cocoa (Solomon Islands Agriculture Dept, 2008). Since *W. auropunctata* is reported anecdotally to be numerous in the Solomon Islands, it is essential to look at how much *W. auropunctata* has impacted on the resident vertebrates and invertebrates, subsistence and commercial crops, and daily lives of villagers, particularly the farmers. As *W. auropunctata* has now been established in the Solomon Islands for over 30 years, (Wetterer, 1997; Ikin, 1984) and has perhaps colonized almost all disturbed environments, it is timely and worthwhile to begin the documentation of its impact. This is also vitally important because it will offer an alternative view to the one held by some sectors of the Solomon Islands community.

1.4 Aims and Objective of the Study

This study aims to do the following on selected areas in the Solomon Islands. Firstly, it aims to determine the relative density of *W. auropunctata* in respect to other ants in gardens containing four different subsistence crops. This will show the impact of *W. auropunctata* on other ants. Secondly, the study aims to observe and record other insects found on the four different subsistence crops/plants, which have an obvious or observable relationship with *W. auropunctata*. Some of these insects may be serious crop pests on their own. It is important to determine if *W. auropunctata* has developed a relationship with such pests because this will relate directly to the overall impact of *W. auropunctata.* Thirdly, this study aims to determine if *W. auropunctata* has any effect on crop productivity and crop/plant fitness. To achieve this, the study examined the indirect effect of *W. auropunctata* on a specific crop within one of the four subsistence crops. This involved determining whether the relationship between *W. auropunctata* and one of the known crop pests (*Tarophagus* sp. – an hemipteran responsible for damage in taro leaves and stem) might lead to that pest being protected from its natural predators (*Cytorhinus fulvus* – a predatory hemipteran that preys on *Tarophagus* sp.). This means that the presence of *W. auropunctata* might indirectly create an environment favourable to the overall increase of crop/plant pest species. This part of the study will indicate as to whether the presence or absence of *W. auropunctata* may significantly affect the population density of pest species (*Tarophagus* sp.) and its natural enemy (*C. fulvus*).

The major objectives of the study therefore are;

1. To quantify the impact of *W. auropunctata* (Little Fire Ants) on the native ant fauna in subsistence gardens
2. To determine the presence and type of crop damaging insects that have developed relationships with *W. auropunctata*

3. To determine if the relationship between *W. auropunctata* and the crop pest species *Tarophagus* sp. has an effect on the abundance of the crop pest species *Tarophagus* sp. and its natural predator *Cyrtohinus fulvus.*

1.5 Significance of the Study

This study will provide the following;

1 A clear indication of the relative dominance of *W. auropunctata* in different subsistence crops and gardens in the Solomon Islands. Although anecdotal reports of the presence of *W. auropunctata* do exist, it has not been documented in any quantifiable form or manner. By undertaking this research on *W. auropunctata,* the relative presence can be measured and thus give an indication of its density per given area. This information is important to ecologists and farmers in making predictions about invasions of *W. auropunctata* into new garden sites or disturbed forest.

2 A documented measure of the invasiveness and aggressiveness of *W. auropunctata.* The study will look at the overall ant fauna in the sites (with and without *W. auropunctata*) and thus make a comparative analysis as to whether *W. auropunctata* has played any significant role in the reduction of other ant species. Although such knowledge is common it has not been documented anywhere in the Solomon Islands. This is important because if the study shows a strong dominance of *W. auropunctata,* it would not only be ecologically significant; it has strong implications for commercial agriculture and subsistence farming.

3 A measure of how many additional crop pests may have developed a mutualistic relationship with *W. auropunctata.* Such findings would enable further studies to determine if such relationships could have affected the growth of crops thereby influencing and affecting crop productivity.

4 A well recorded document based on rigorous scientific data that offers another view on *W. auropunctata* to one held by agriculture authorities in the Solomon Islands. This study will be the first of its kind to highlight the negative aspect of *W. auropunctata* in the Solomon Islands. This is important as information about

the adverse effect of *W. auropunctata* urgently needs to become available and hopefully it would give responsible authorities a firm basis to make decisions and implement plans. Such information will have direct practical application in terms of biosecurity, trade and pest management in the Solomon Islands and the Pacific region.

5 A document that will highlight knowledge gaps and help to prioritise further work in other areas relating to biodiversity, ecology and practical pest control and management.

1. 6 Outline of this Thesis

This thesis is organized into six chapters. The first chapter has presented an overview of the study with the aims and objectives of the study. Chapter 2 reviews and critically examines the background literature on *W. auropunctata*. Chapter 3 details the methodology used in this study. It also provides maps of the Solomon Islands and Makira Island, where the research was conducted and clearly shows the location of the actual sites in Makira Island where the field work took place. Chapter 3 also provides details of the statistical tests used in the study while Chapter 4 details the results of the study. Chapter 5 discusses the results in the light of previous work and knowledge, highlights significant findings while Chapter 6 states the final conclusions drawn from the study and outlines priority areas and recommendations for future work.

CHAPTER 2
BACKGROUND

2.1 Introduction

This section is intended to critically examine literature on *Wasmannia auropunctata* as an invasive ant, its biology, how it spreads and establishes in new environments, its ecological impact on island ecosystems and the impact it may have on subsistence crops and farming. *W. auropunctata* has received a lot of attention in many studies especially in regions that *W. auropunctata* is not native to. This is because of the adverse effect it brings about on the environments where it is established. It is known to have impacted negatively on different populations of vertebrates, invertebrates and plants as well as on humans (Williams, 1994; Spencer, 1941; Delabie *et al.* 1994). Despite the wealth of literature available, there are still gaps in our knowledge particularly in respect to the negative impact *W. auropunctata* poses on the fragile environments of the Pacific Islands. This is surprising because it has been present in the region for over thirty years in some islands such as the Solomon Islands and New Caledonia (Le Breton *et al*. 2003). However, it is generally considered that invasive ants can take up to twenty years before an obvious impact on wildlife (native ant fauna, vertebrates and invertebrates) is notable (Mount, 1981).

2.2 The Ant Genera

All ants belong to the Phylum Anthropoda, Class Insecta and Order Hymenoptera. They are also members of the social insects, a group that includes sawflies, wasps and bees (Borror and White, 1970). Ants (family Formicidae) are very diverse, according to Shattuck (1999) there are sixteen subfamilies, three hundred genera and about fifteen thousand species and subspecies and hundreds of ant species yet to be described. Agosti and Johnson (2005) reported roughly the same magnitude of species richness with 12,039 species of Formicidae recorded to date.

Ants are among the most ecologically successful groups of animals (Wilson, 1992). They are a ubiquitous component of terrestrial invertebrate faunas on islands and continents (Häolldobler and Wilson, 1990), and are fundamental to the function of any terrestrial ecosystem. Highly successful colonisers of islands and continents (McGlynn, 1999b), ants contribute to a diversity of activities significant to the ecological balance of terrestrial ecosystems. These functions include acting as detrivores, herbivores, granivores, seed dispersers and scavengers (Holway *et al*. 2002). Ant activities extend to the formation of associations with other insects and plants (Huxley and Cutler, 1991) and they also serve as agents for soil turnover and nutrient re-distribution (MacMahon *et al*. 2000). Together ants as family are known to turn more soil than earthworms (Lyford, 1963). It is estimated that about 35% of all herbaceous plants are dispersed by ants (Alonso and Agosti, 2000). Ants are therefore a significant indicator group for diversity and ecosystem function (Holway *et al*. 2002; Andersen *et al*. 2004). They have a highly structured social organisation and therefore, ant colonies can do tasks that individual ants cannot perform (Dorigo and Stutzle, 2004). Changes to the ant fauna can affect the faunal and floral structure of an ecosystem and can disrupt and transform an entire biological community (Jones *et al.* 1994; Abensperg-Traun and Steven, 1997; Folgarait, 1998; Eastwood and Fraser, 1999).

There are however, certain species of ants referred to as invasive ants. This includes ants such as the Little Fire Ant *W. auropunctata*, red imported fire ant *Solenopsis invicta*, the Argentine ant *Linepithema humile,* the big-headed ant *Pheidole megacephala* and the long-legged ant *Anoplolepis gracilipes*, formerly *Anoplolepis longipes* called the crazy ant (Porter and Savignano, 1990; Suarez *et al.* 1998; Hoffman *et al.* 1999; Feare, 1999). Invasive ants are among the major group of alien and exotic ant species and can become significant pests to humans in any environment (Holway *et al*. 2002). Invasive ants are usually non-native to a habitat and are some of the world's worst invaders when introduced to a new habitat (Lowe *et al*. 2000; CSIRO, 2003). Such introduced species have become recognized as a significant threat to the diversity of native ecosystems worldwide (Enserink, 1999).

2.3 *Wasmannia auropunctata* as an Invasive Ant

Invasive ants such as *W. auropunctata* are among the most widespread and damaging of all introduced species (Tsutsui and Suarez, 2003). Referred to as invasive, exotic or alien ants, invasive ants are distinct unit of the ant community because many invasive ants share a suite of characteristics that facilitate their introduction, establishment, and subsequent range expansion (Passera, 1994; Tsutsui and Suarez, 2003). These traits include aggressiveness and being adaptable to disturbed environments (Helms and Vinson, 2002). Many invasive ants are confined to disturbed environments such as agricultural altered areas, logged areas or other human altered environments such as housing and recreational estates (Holway *et al*. 2002). As noted by Gabriel *et al.* (2001), disturbance appears to increase the species richness and abundance of introduced species at a location. Another feature common to all invasive ants is unicoloniality; an extraordinary social organization in some ant species whereby individuals mix freely among physically separated nests (Giraud *et al*. 2002). It is one feature that characterises their success; which reduces intraspecific aggression while increasing interspecific competitive ability (Errard *et al*. 2005).

Globally about 150 species of ants have been introduced into new environments (McGlynn, 1999b). Among the worst destructive invaders are the red imported fire ant *Solenopsis invicta*, Argentine ant *Linepithema humile*, Big headed ant *Pheidole megacephala*, Yellow crazy ant *Anoplolepis gracilipse* and *W. auropunctata* (Wetterer and Porter, 2003). According to Holway *et al.* (2002) *W. auropunctata* is among the six of the most widespread, abundant, and damaging invasive ants in the world. This rating is supported by the Invasive Species Specialist Group of the World Conservation Union (IUCN) who consider *W. auropunctata* as one of the 100 worst invaders of all invasive organisms in the world (Lowe *et al*. 2002).

An invasion by non-native ants can be an ecologically destructive phenomenon and they can become highly abundant in their introduced range and often out-number native ants (Holway *et al*. 2002). It is thought that environmental resistance to an invasion from introduced species may depend on the richness and abundance of native species, however, it has also been found that abiotic factors may play a significant role in the likelihood of the establishment of invasive ants (Gabriel *et al.* 2001). For example, *W.*

auropunctata tends to be found in warmer environments rather than colder environments (Ward, 2007).

2.4 Identifying *Wasmannia auropunctata*

As a member of the family Formicidae and the sub-family Myrmicinae (Borrow and White, 1970; Le Breton et al. 2003) *W. auropunctata* is characterised by a two segmented abdominal waist (petiole and post petiole), a distinct long propodeal spine with a presence of an antenna scrobe that extends close to the posterior of the head, ten antennal segments and two segmented club (Fig. 2.1) (Sarnat, 2008). *W. auropunctata* is very small (Fig. 2.2 & 2.3), less than 2 mm in length and barely visible in the field. The workers are yellow or light brown to golden brown in coloration (Fig. 2.3). The queen (Fig. 2.2) however is much larger; about 4.5 mm in length with darker coloration, which can be identified easily when among lighter workers in a nest (Wetterer and Porter, 2003).

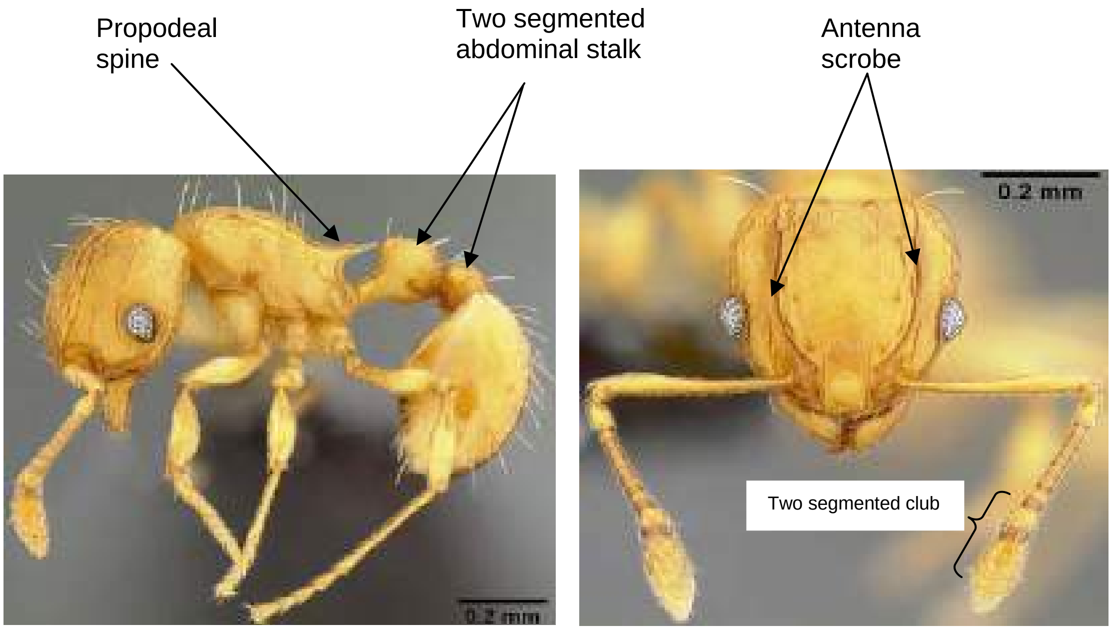


Fig. 2.1 Profile view and frontal view of *Wasmannia auropunctata* (adapted from: Sarnat, 2008)

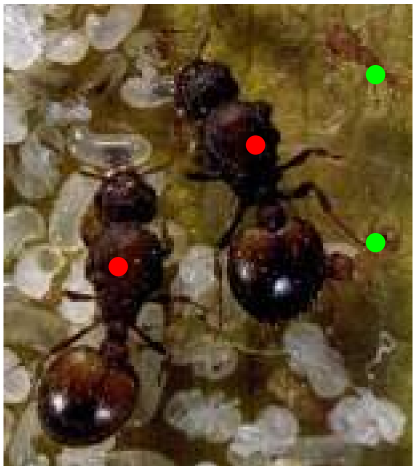


Fig. 2.2 Two queens (●) of *W. auropunctata* with workers (●) (Adapted from: Queller, 2005)

Fig. 2.3 A nest of *W. auropunctata* from Makira Island, Solomon Islands. (Adapted from: Sarnat, 2008)

2.5 Biology of *Wasmannia auropunctata*

2.5.1 A Colony of W. auropunctata

Apart from its physical characteristics, *W. auropunctata* like many invasive ant exhibits the significant biological characteristic; polygyny and monogyny, i.e., either single or multiple queens in a nest (Passera, 1994; McGlynn, 1999; Le Breton *et al*. 2003). A nest of *W. auropunctata* may therefore contain several queens, a large population of workers, pupae, larvae and eggs (Longino and Fernández, 2007b), or it may just have a nest of a single queen with workers. The queen may live up to one year (Passera, 1994). *W. auropunctata* is also polydomous, which means that it may have a super colony with many nests (Errard *et al*. 2005; Le Breton *et al*. 2005; de Souza *et al*. 2008) which leads to low intra-specific aggression within colonies (Le Breton *et al*. 2004; 2005).The workers however, are monomorphic, which means they display no physical differentiation (Holway *et al*. 2002). Being opportunists for food and fast nest relocation after perturbation (where a colony may relocate it self if it is disturbed) are also some of its characteristics (Le Breton *et al*. 2003). *W. auropunctata* may make its nest on the ground or in trees (Clark *et al*. 1982) and where it is abundant, *W. auropunctata* is estimated to have a population range of 1000 – 5000 workers per square meter (Clark *et al*. 1982) although it is reported to be very high in other places. For example, de Souza *et al*. (2008) surveyed *W. auropunctata* on different habitats in Hawaii, and estimated the population be above 20,000 per m^2.

W. auropunctata delivers venom, which has an additional stinging effect and creates a very strong burning sensation (Romanski, 2001). The toxicological characteristic of *W. auropunctata's* sting has been discovered to contain an alkylpyrazine compound in the mandibular glands of the workers (Howard *et al*. 1982). It is suggested that workers might apply the mandibular gland product as an irritating secretion, enhancing the defensive properties of the venom (Romanski, 2001). Schmidt (1986) argued that *W. auropunctata* and other fire ants make extensive use of their powerful venom in offensive and defensive behavior. These biological characteristics therefore, enhance the survival and the spread of *W. auropunctata* (McGlynn, 1999a) by substantially increasing its competitive ability.

2.5.2 Feeding

W. auropunctata feeds on almost all available food sources. Its choice of food may include other invertebrates, plant parts or seeds (Clark *et al*. 1982; Romanski, 2001), nectar produced by plants (Schemske, 1980; Smiley, 1986) and on sugary honeydew excreted by different insects such as aphids, mealybugs, scale insects and whiteflies (Delabie *et al*. 1994; Naumann, 1994). Wherever food is found, *W. auropunctata* will congregate in large numbers to feed and to carry the food away to the waiting queen and brood (Clark *et al*. 1994; Armbrecht and Ulloa-Chaon, 2003). The utilisation of carbohydrates from sap-sucking insects has been also suggested as a significant source of nutrition of *W. auropunctata* and many other invasive ants. For example, Helms and Vinson (2003) noted that the hemiptera *Antonina graminis* is estimated to supply about half of the daily energy requirements for *S. invicta* at one study site.

W. auropunctata is also noted to effectively scavenge and prey on other ants and small insects as a means of feeding (Clark *et al*. 1982). Often when it is in competition with other ants for food, *W. auropunctata* will walk off with the food thus depriving its competitors (Brandao and Paiva, 1994). Cooperation among workers in retrieving food is a means of sharing the workload and a very effective way to increase survival rates for *W. auropunctata*. In their native range, *W. auropunctata* will tend to defend food sources closest to its nest rather than defending its territory (Torres, 1982). This behaviour is typical of most exotic unicolonial ants and hence they can out - compete native ants when in competition for resources (Human and Gordon, 1999).

2.5.3 Reproduction

W. auropunctata shows an extraordinary reproduction system, where both males and females (queens) are produced clonally (Foucaud *et al*. 2007). Foucaud *et al*. (2007) have shown that males within a colony are genetically identical, indicating that females are produced only by females and males only by males. It is possible that males are produced clonally by eliminating the maternal half of the genome in the diploid egg, which resulted in the male offspring having nuclear genomes of their father (Foucaud *et al*. 2007). It is therefore possible that male and female *W. auropunctata* ants are two separate genetic lineages whose only sexually produced diploid progeny are the sterile (female) workers (Fournier, 2005).

Newly emerged males and queens have wings, which may result in them flying some distance to establish new nests. However, they can also disperse naturally by nest budding where the queens and workers relocate to new nest (Clark *et al*. 1982).Workers alone are sterile and cannot form new nests without a queen, therefore, for a new colony of *W. auropunctata* to be established, the workers and the queen need to be transported together to the new location (Harris *et al*. 2005). Since colonies have more than one queen, the reproductive rate of *W. auropunctata* can be very high.

2.6 Distribution and the spread of *W. auropunctata*

W. auropunctata is native to the South American region and the Caribbean (Fig. 2.4) (Mikheyev and Mueller, 2007; Longino and Fernández, 2007a). Other than these two regions, the presence of *W. auropunctata* in any location is most probably by introduction.

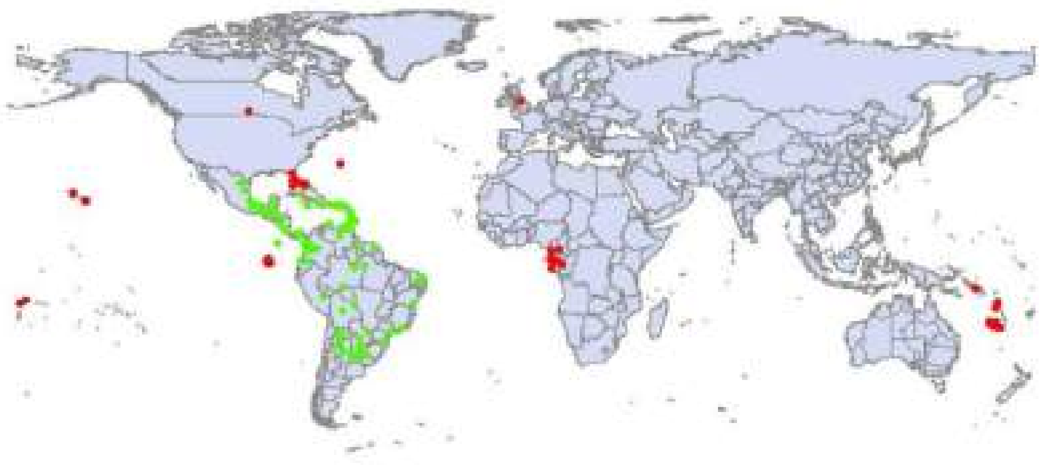


Fig. 2.4 Known world distribution of *W. auropunctata*. Green areas represent regions where *W. auropunctata* is native and red areas represent regions where *W. auropunctata* is introduced. (Adapted from: Harris *et al*. 2005)

There have been two documented significant means of introduction or dispersal mechanisms seen at a local or between regions level. Firstly through human mediated means and secondly by budding (Clark et al. 1982; Passera. 1994). By far, human – aided dispersal is the most significant means for the spread and dispersal of *W. auropunctata*. (Holldobler and Wilson, 1990; Passera, 1994). *W. auropunctata* is known to associate closely with humans and to nest in plant nursery stock or other such products traded locally or globally, hence, their potential to spread great distances via human use is very high (Holway *et al*. 2002). Products from nurseries, fruit tree orchards, and ornamental plants are all potential habitat for *W. auropunctata*. Since *W. auropunctata* has an affinity for nesting in soil at the bases of trees or parts of plants; they can easily be spread between plant nurseries. When plants infested with *W. auropunctata*, are sold or taken to another area or part of the world, *W. auropunctata* is spread along with these products (Romanski, 2001) especially when quarantine measures are not in place or are inadequate. Thus, growing trade between countries along with the surge in movement of people and cargo throughout the Pacific region is seen to have increased the spread and abundance of many tramp ant species such as *W. auropunctata* (Abbott *et al*. 2006). The ant's ability to hitchhike via a wide range of international trade pathways is increasing because of the increasing levels of international trade through the region (Orapa, 2007). Given their invasiveness it is inevitable that *W. auropunctata* and several other invasive ant species will eventually colonise the entire region if no effective quarantine measures are in place (Orapa, 2007). Some examples of *W. auropunctata's* movement between islands as mediated by humans is seen in the case where it was introduced to Vanuatu from Solomon Islands in 1998 through movements of timber products (Wantok Environmental Centre, 2004), and in New Zealand in 1997, where workers ant of *W. auropunctata* were intercepted from an air passenger from Solomon Islands (Harris *et al*. 2005).

2.6.1 Spread of W. auropunctata encouraged

Despite their invasive nature there are cases in some parts of the world where the spread of *W. auropunctata* is encouraged and therefore purposefully introduced by humans. For example, *W. auropunctata* is used as a biological control against cocoa pests (particularly Miridae, a hemipteran insect) it was intentionally transported between cocoa plantations in Cameroon (Bruneau de Mire, 1969). This is also the case in the Solomon Island and is well discussed in section 2.6.5.

2.6.2 Factors Aiding W. auropunctata establishment

Climatic conditions are important factors in determining the distribution of most invertebrates including invasive ant species (Kaspari *et al.* 2000). By looking at the regions *W. auropunctata* is native to (Fig. 2.4) it is possible to deduce climatic parameters (conditions) that favour their establishment and survival. Knowing these parameters (see Table 2.1); and assuming they are prerequisites for the establishment and survival of *W. auropunctata*, it is possible to determine other parts of the world where *W. auropunctata* would probably survive if introduced. Temperature alone for example is a single climatic parameter that influences greatly the distribution and establishment of *W. auropunctata*. Cerda *et al*. (1998) stressed that the foraging activity of certain ant species is influenced very much by temperature. In the work by Holway *et al.* (2002) for example, *W. auropunctata* were found to be more abundant on baits when the ground temperature was at 30ºC and above compared abundance during periods of much lower temperature. Bestelmeyer (2000) also confirmed this when collecting ants in Argentina using baits, that the ant family Myrmicinae (which include *W. auropunctata*) were most active when the ground temperature was above 30ºC. Harris *et al*. (2005) argued that should colonies of *W. auropunctata* arrive in New Zealand; climate would be the most determining factor as to their establishment and survival. And that lower temperature would most probably limit the chance of the ant's survival.

The climatic conditions of a country are therefore very influential in the survival of an introduced ant species. Harris and Barker (2007), described climate matching as a good means of assessing risk of invasive ants invading a new environment. For example, in the case of *W. auropunctata*, by looking at the climatic conditions of where it is native, it is possible to predict countries at high risk of its invasion. It is evident that *W. auropunctata* is well suited to climatic condition of relatively high temperature (Wetterer and Porter, 2003) thus the Pacific Islands are ideal places for the establishment and propagation of *W. auropunctata*. For example, with a day time temperature range of 24ºC to 31ºC along with a minimal fluctuation in temperature (South Pacific Travel Guide, 2008) the Pacific Islands are very well placed for the survival, increase and the spread of *W. auropunctata.*

Table 2.1 Comparison of known climate parameters necessary for native and introduced range of *W. auropunctata.* (Source: Harris *et al*. 2005).

Parameter	n	Mean	Minimum	Maximum
Mean Annual Temperature (ºC)				
Native Range	102	23.3	13.7	27.4
Introduced Range	73.0	23.0	2.7	27.0
Minimum Temperature (ºC)				
Native Range	102.	16.3	- 0.1	24.4
Introduced Range	73.0	15.1	- 21.5	23.5
Mean Annual Precipitation (mm)				
Native Range	102.0	1704.0	384.0	4835.0
Introduced Range	73.0	1559.0	384.0	4835.0

2.6.3 Establishment W. auropunctata in the Pacific Islands

Although climatic conditions play a significant role in the invasion and establishment of *W. auropunctata* in an introduced range, its interactions with its new environment are also significant if it is to survive. These include the interaction of *W. auropunctata* with both the flora and fauna, which may offer resistance to invasion of exotic ants such as *W. auropunctata*. These resistant interactions are barriers invasive ant species such as *W. auropunctata* must overcome to remain established in a new location. Le Breton *et al*. (2005) argued that island communities offer weak resistances to biological invasions due to the unbalanced distribution of their fauna and flora. In particular, interactions between exotic ants such as *W. auropunctata* with the native ants of the introduced range are significant to its survival and establishment. It is thought that where there are several non-native ant species and possibly low richness of native ant fauna in a community, it can lead to less competitiveness and the dominance of one invasive ant over the remaining ant fauna (Solomon and Mikheyev, 2005). This often results in niche opportunity for the invading ants (Shea and Chesson, 2002). However, it is suggested by that given the success of *W. auropunctata* and a few other invasive ant species in colonization of diverse sites globally, it is unlikely that *W. auropunctata* will encounter problems with establishing itself even within a habitat that is abundant and diverse with native ants in any of the Pacific Islands (Harris *et al*. 2005)**.** Furthermore, workers of *W. auropunctata* are known to be highly aggressive to other ant species and in some locations where they have invaded, they have been able to exclude all other ant species completely (Clark *et al*. 1982; Jourdan, 1997). With the favourable climatic conditions, and usually low level of ant richness to offer resistance, and the aggressiveness of *W. auropunctata* over native and even other exotic ants, it is considered that *W. auropunctata* would find all Pacific Islands a very favourable environment for its establishment and survival.

2.6.4 Islands in the Pacific region already infested by W. auropunctata

There are confirmed reports of six Pacific Islands; Hawaii, Tahiti, New Caledonia, Tuvalu, Solomon Islands and Vanuatu being where *W. auropunctata* is currently introduced to (Wetterer, 1997; Jourdan, 1997; Jourdan *et al*. 2006). Fabres and Brown

(1978), noted the earliest records of *W. auropunctata* in the Pacific to be in New Caledonia, from around 1972. Since its introduction, *W. auropunctata* has established itself as the dominant ant species in New Caledonia and has spread to other islands (Jourdan, 1997). Found in Tahiti in 2004, *W. auropunctata* has spread throughout Tahiti in the last ten years and is now found mostly in habitats modified by humans (Jourdan *et al*. 2006). Although six countries in the Pacific have been officially declared to have *W. auropunctata*, the actual number may be under estimated. For example, recent reports have indicated its presence in Papua New Guinea (Fito, 2007).

It is known that *W. auropunctata* found in the Pacific are of two different clades possibly from different origin (Mikheyev and Mueller 2007). *W. auropunctata* found in New Caledonia, belong to a clade different from that found in the Solomon Islands and other Pacific Islands. The clade found in Solomon Islands and other Pacific islands is closely related to ants of the Caribbean clade (Mikheyev and Mueller, 2007). There is also a possibility of multiple introduction which means that there could be more than one source of origin for *W. auropunctata* distribution to some of the sites in the Pacific (Ross and Fletcher, 1985).

2.6.5 Introduction of W. auropunctata in the Solomon Islands

The introduction of *W. auropunctata* into the Solomon Islands is believed to have taken place about 1974, possibly with the arrival of coconut nurseries (Fabres and Brown, 1978; Ikin, 1984; Wetterer, 2006). Although *W. auropunctata* is currently very common in coconut and cocoa plantations in the Solomon Islands (pers. obs.), studies conducted in the Solomon Islands in the 1950s (to identify ants that could be used against a pest responsible for early ripening of coconut) Brown, (1959) did not report *W. auropunctata*. Instead, four very common ant species, of which two were introduced, are documented; the big-headed ant *Pheidole megacephala* and the yellow crazy ant *Anoplolepis gracilipes* were the dominant ants found in coconut plantations (Brown, 1959). This was also confirmed by Greenslade (1971) and Brian, (1983). In addition both Mann (1919) and Wheeler (1935) while in the Solomon Islands made no records of *W. auropunctata.*

Considered as a potential biological control against the nutfall bug (*Amblypelta cocophaga* and *Amblypelta gallegonis)* which causes early ripening in coconut and cocoa fruit, *W. auropunctata* may have been purposely introduced to the Solomon Islands (Wetterer, 2006). One reason for believing that the introduction of *W. auropunctata* in Solomon Islands may have been made purposely comes from a report from the Ministry of Agriculture in the Solomon Islands which shows the following statement; **"….** in more recent years, a fire ant, *W. auropunctata* has become established throughout Solomon Islands. This ant is capable of protecting palms against *Amblypelta*....." (Solomon Islands Agriculture Dept, 2008). Secondly, in the fight against *Amblypelta* in coconuts in the 1950s, several introduced ants which include *A. gracilipse, P. megacephlala, Oecophylla smaragdina* and *Iridomyrmex myrmecodiae* were trialed to determine which ant would be the more effective ant to be used as a biological control against *Amblypelta* (Brown, 1959). This resulted in the ant species *A. gracilipse* and *O. smaragdina* being used against *Amblypelta* although they were less effective than expected. It is therefore possible that there was a search for a more effective biological control agent for *Amblypelta* control and possibly information as to the effectiveness of *W. auropunctata* against *Amblypelta* sp in other parts of the world saw the arrival of *W. auropunctata* in the Solomon Islands. Even if the introduction of *W. auropunctata* was unintentional, its establishment and spread in Solomon Islands was undoubtedly encouraged by the Agricultural Authorities (pers. obs.).

The probability of *W. auropunctata* establishing itself in all islands in the Solomon Islands is very high given the following reasons. Since the arrival of coconut nurseries from pantropical countries where *W. auropunctata* is thought to have originated, the coconut species, that is believed to have arrived in the Solomon Islands with *W. auropunctata* is distributed in every island in the Solomon Islands (British Solomon Island Protectorate, 1974). Secondly, within and between islands, the movement of garden crops and planting materials is very common as the rural populace exchanging of crops and planting materials is the cultural norm (pers. obs.). When there is a preference species of crop, the demand for planting materials of this crop means that it will be taken from one village to another or shipped from one island to another routinely (pers. obs.). Thirdly, it is possible that the introduction and spread of *W. auropunctata* in the Solomon Islands is enhanced by the logging industry. Carrying out logging operations on pristine forests becomes a means for *W. auropunctata* incursions inland to previously undisturbed and unifested areas. Between islands, movement of logging machinery is also an agent for the spread of *W. auropunctata*. Since logging is a major industry in the Solomon Islands (Kofana, 2008) and has occurred in almost every island that has sizeable and marketable trees, one can directly correlate logging with the spread of *W. auropunctata.* An example of this in other parts of the world include equatorial Africa where commercial logging has increased the incursion of *W. auropunctata* into the continent's interior by sixty times, what it would have been with out such disturbance (Walsh *et al*. 2004).

Finally but more importantly is the lack of any measures by the relevant authorities in the Solomon Islands to contain further spread of *W. auropunctata* within and between Islands. This has allowed laxity among farmers and loggers to transport their produce or equipment from one area to another without any regard to whether such produce or equipment is infested with *W. auropunctata* or any other invasive species. For example, simple measures such as cleaning logging equipment and the application of insecticide before transportation to another island may significantly reduce the risk of spread. Farmers also need to ensure that before any produce or plant materials are moved from one area to another that they are free of invasive ants. Such measures are carried out routinely in Vanuatu where there is a temporary ban on all agricultural products from *W. auropunctata*-infested islands (Rapp, 1999). Without such measures, the likelihood of incursion of *W. auropunctata* into every part of the Solomon Islands is a reality. However, with its current range of coverage in the Solomon Islands, it may be beyond the means of any eradication plan although it may still be possible to contain them (Thompson, 2007).

2.6.6 Ants of Solomon Islands

A total of 179 ant species of which 121 are endemic, 38 are native and 20 are exotic was recorded for the Solomon Islands (Ward and Wetterer, 2006). Previously, Wheeler

(1935) reported 170 ant species. Wetterer (1997) records of exotic ant species in the Solomon Islands include the invasive species *Pheidole megacephala*, *Solenopsis geminata*, *Anoplolepsis gracilipes* (yellow crazy ant) and *W. auropunctata*. Most of the records of ants in the Solomon Islands are from Mann (1919) who collected ants in the Solomon Islands in 1916. Many of the native ants reported by Mann (1919) may have now been significantly disturbed, reduced or even have become extinct as a result of the introduction of *W. auropunctata*. Hence, there is a need to update current ant records in the Solomon Islands and compare them with the previous list by Mann. This will give an indication of the invasiveness of *W. auropunctata* and their likely effect on the native ant fauna in the Solomon Islands.

2.7 Impacts on Island Ecosystems

Island ecosystems are generally very vulnerable to changes induced by introduced species such as *W. auropunctata* (Orapa, 2007). The vulnerability of island ecosystems may result from the low number of native species such as ants that could resist any invasion (Holway *et al*. 2002). Invasions by exotic species are more likely to produce major ecological impact on islands than on continents (Vitousek, 1988; Williamson, 1996). Islands are known to have lower diversity of species and functional roles in native arthropod and vertebrate communities than continents (Cole *et al.* 1992; Vanderwoude *et al*. 2000; Dejean *et al*. 2000). Holway *et al*. (2002) made reference to the possible negative impacts invasive ants such as *W. auropunctata* would have on native invertebrates in the Pacific Islands.

2.7.1 Impact on Invertebrates and Vertebrates

Invasive species in general are second only to habitat loss as agents leading to extinction or decline of vertebrate or invertebrate species (Vitousek *et al*. 1996; Enserink, 1999; Pimentel *et al*. 2000). *W. auropunctata* as an invasive species is an extremely competitive tramp ant with generalist habitat and food requirements (Romanski, 2001). Incidents of the negative impact of *W. auropunctata* on vertebrates and invertebrates in its introduced range have been well documented in many countries, but in the Pacific, they have never been properly reported or documented. *W.*

auropunctata generally decrease arthropod diversity, can out-compete and prey on native ants, and are predators of vertebrates, such as birds and lizards (Romanski, 2001). The effect of *W. auropunctata* on vertebrates is particularly notable. It has affected nesting activities and the survival of young birds and reptiles (Causton *et al*. 2005). Jourdan *et al*. (2001) reported a decrease in the abundance of native lizards on sclerophyll forest in New Caledonia when *W. auropunctata* was introduced and a negative association between *W. auropunctata* presence and the abundance of an arboreal lizard species, *Bavayia cyclura*. In the Solomon Islands, reports of dog, bird and cat blindness caused by the sting of *W. auropunctata* are a common occurrences in many villages (pers. obs.). Of most visible effect on vertebrates is cornea trauma reported on dogs from *W. auropunctata* sting (Fig. 2.6). Gradual blindness in dogs (*Canis domesticus*) is reported in Solomon Island villages and dogs rarely live more than five years after being stung (Wetterer, 1997). Theron (2007) observed in his work on *W. auropunctata* on Tahiti that the eye area of vertebrates studied is where *W. auropunctata* inflict most injuries. Data for non-domestic vertebrates is scarcer, and it is more difficult to directly attribute mortality to invasive ant species (Holway *et al*. 2002). However, the impact of *W. auropunctata* on domestic animals provides an indication of potential effect on wild animals.

Fig. 2.5 A case of cornea trauma on a village dog caused by *W. auropunctata* as reported, Bauro in Makira (Solomon Islands). (pers. photo)

Perhaps a better documented negative impact of *W. auropunctata* is its effect on both native and other introduced ants. *W. auropunctata* is very successful in displacing native ants. For example, since its establishment in New Caledonia, *W. auropunctata* has been responsible for a significant reduction in the native ant diversity (Le Breton *et al.* 2003). Similarly, a large number of ant extinctions in Puerto Rico including a species of *Paratrechina* and a species of *Tapinoma* was as a result of the introduction of *W. auropunctata* (Torres and Snelling, 1997). Also in the Galapagos Islands, *W. auropunctata* has greatly impacted on and is responsible for the reduction of native and some introduced ants (Clark *et al*. 1982; Wetterer and Porter, 2003). The competitive performance of *W. auropunctata* and its ability to exploit disturbed sites may help to explain why they are able to displace other ants (Armbrecht and Ulloa-Chacon, 2003; Grangier *et al.* 2007). It is proposed that the abundance of *W. auropunctata* can be used as an indicator of low diversity of other ants (Armbrecht and Ulloa-Chacon, 2003).

2.7.2 Impact on Ecological Processes

Other adverse effect of invasive species such as the red imported fire ants *Solenopsis invicta* and *W. auropunctata* is the likelihood that they will impact on the ecosystem by changing or eliminating ecological processes such as seed dispersal (Zettler *et al.* 2001; Allen *et al*. 2006; Gorb and Gorb, 2003). By impacting on vertebrates and invertebrates, invasive species such as *W. auropunctata*, that are alien to a new habitat, may (by direct or indirect means) change an ecosystems ecological process, structure and function (Allen *et al*. 2006). Invasive species such as *S. invicta* and *W. auropunctata* provide an ecological context that favours other invasive species (Billick, 2001). About 35% of all herbaceous plants are dispersed mostly by native ants (Alonso and Agosti, 2000) and therefore, any disturbance to the population of native ants will have an impact on plant dispersal. A consequence of a likely decrease in native ants would be the alteration of the ecosystem (Holway *et al*. 2002). As predators, scavengers, herbivores, grainivores, and prey for many other vertebrates and invertebrates, the presence and dominance of native ants is significant for the balance of the ecosystem (Holway *et al*. 2003).

2.8 Effect on Agricultural Crop yield

Invasive ant species have received considerable attention globally and regionally, with increasing evidence of economic and agricultural impacts (Williams 1994; Christian 2001; Holway *et al*. 2002; Lard *et al*. 2002). The interactions between invasive ants and plants are inevitable phenomena and have potentially greater negative implications for agriculture (Lach, 2003). According to Buckley (1987), ant – hemipterans interactions are very common in agricultural settings as well as in more natural habitats. Typical features of invasive ants such as their higher abundance, aggressive nature and attraction to high carbohydrate food resources may lead to significant impact on plants (Lach, 2003).

Despite numerous published works on invasive ants, there are still knowledge gaps that exist. Firstly, only a few invasive ants have received much attention. These include the red imported fire ants, *Solenopsis invicta*, the Argentine ant, *Linepithema humile* and the yellow crazy ant, *Anoplolepis gracilipse* (Haskins and Haskins, 1988; Porter and Savignano, 1990; Human and Gordon, 1997; Heterick, 1997; Hoffman *et al.* 1999; Feare, 1999; Holway, 1998; Holway *et al*. 2002). Secondly, the bulk of what is known about invasive ants is related to their ecological impact and therefore, little information is available on the direct impact of invasive ants on crop productivity. However, information available on the impact of invasive ants on crops is particularly related to their association with hemipterans (true bugs) many of which are common crop insect pests. It is well known that these insects generally display enhanced survival rates in the presence of tending ants most of which are invasive (Eastwood, 2004). For example, honeydew-producing scale insects (which are also pest) were greatly increased in the presence of *A. gracilipes* (Abbott and Green 2007).

Although in many instances invasive ants are not directly involved in crop productivity loss, invasive ants have played a significant role in the problem. For example, invasive ants have been known to aid crop damaging hemipteran insects to carry out their activity unimpeded. Invasive ant species tend to develop a close association with hemipterans, which produce honeydew. Lester *et al*. (2003) noted that an association between ants and pest hemipterans in horticultural crops is established when ants were observed to collect honeydew directly from the hemipteran species. Ants in turn may protect such insects from their natural predators. This often results in high density of pest hemipteran populations that could in turn result in crop loss (Gonzalez-Hernandez *et al*. 1999). Although much is known about the ant – hemipterans interactions, the consequence of such an interaction in terms of host plant/crop fitness has received little attention (Styrsky and Eubanks, 2007). Perhaps with the exception of the well-studied invasive ant species *S. invicta*, impacts on agriculture are not well covered. *S. invicta* is reported to be a major agricultural pest in the southern United States (Stimac and Alves, 1994), reducing crop yield significantly on certain crops it infests (Lofgren and Adams 1981).

In the case of *W. auropunctata,* Le Breton *et al*. (2002) noted it to be a well-known pest of agricultural areas and natural ecosystems in New Caledonia. Association between *W. auropunctata* and crop damaging hemipterans was also noted in areas where *W. auropunctata* was in abundance (Fowler *et al*. 1990; Naumann, 1994). Honeydew producing hemipterans, which are themselves pests, are known to inflict damage to their host by sucking sap and encouraging sooty mould and at the same time their populations are being enhanced by *W. auropunctata (*Delabie *et al*. 1994; Wetterer and Porter, 2003). The association between *W. auropunctata* and hemipterans may also increase the occurrence of plant diseases including viral and fungal infections on crops (Fabres and Brown, 1978). However, the actual affect of *W. auropunctata* on subsistence crops is yet to be fully understood. It is likely however, that crops that produces large quantity of sugary sap are more likely to attract both honeydew – producing hemipterans and *W. auropunctata*. Honeydew producing hemipterans would then have the benefit of being protected from their natural predators by *W. auropunctata.* This would give these hemipterans the “freedom” to cause increased damage to plants. Therefore, it is possible to correlate the abundance of *W. auropunctata* and honeydew – producing hemipterans (such as aphids, mealy bugs and scale insects) to the likelihood of damage inflicted or likely to be inflicted on associated crops. Exploitative or mutually beneficial associations that occur between these insects and *W. auropunctata* may be an important, previously unrecognized factor promoting the success of some of the major hemipteran pest thereby playing a major role in crop loss (Helms and Vinson, 2003). Other than inferring damage to crops from such relationships, little else is known about the real impact on crop productivity of the presence and infestation of *W. auropunctata.*

2.8.1 Effect of W. auropunctata on subsistence gardening and crops in Solomon Islands

Little work has been published on the direct effect *W. auropunctata* has on subsistence crop production in Pacific countries. However, there are some published reports on the effect of *W. auropunctata* on farmers and how *W. auropunctata* may have affected their normal farming activities (Wetterer *et al*. 1999). With only a few references available on the indirect effect of *W. auropunctata* on agricultural crops (Le Breton *et al*. 2002; Lester *et al*. 2003), there are still many basic questions that need to be answered from a scientific perspective. For example, are crop yields really reduced in the gardens infested with *W. auropunctata*? Is it possible to quantify the destructive effect of *W. auropunctata* on subsistence gardening in rural areas in the Solomon Islands and other Pacific Islands where it is present? Does *W. auropunctata* invade major subsistence crops planted in rural areas?

A lot has been published on the abundance, survival and distribution of the natural enemies of ant tended hemipterans (Cushman and Whitham, 1989; Del-Claro and Oliveira 2000; Kaplan and Eubanks, 2002). It is important to place such studies in context with problems *W. auropunctata* pose to rural subsistence farming. For example, a number of pests that develop a mutualistic relationship with *W. auropunctata* have natural enemies that would normally keep the population of such pests to a level less destructive to crops. It is possible that *W. auropunctata* could be responsible for the reduction or elimination of some of these natural predators. If that is true, then *W. auropunctata* could be directly responsible for the population explosion of pests in subsistence crops and therefore indirectly responsible for extensive crop loss. Such questions are important if we are to determine the full extent of the negative impact of

W. auropunctata to the rural community in the Solomon Islands and other similar Pacific Island subsistence farming communities.

Often referred to as a disturbance specialist (Le Breton *et al*. 2003), there is a strong social aspect to the impact of *W. auropunctata* to farmers. For example, *W. auropunctata* has the ability to sting very badly, which often results in reluctance for subsistence farmers to work on areas in which the ant is heavily infested (Wetterer *et al*. 1999; Le Breton *et al*. 2003). Often this issue is ignored and its impact is under estimated by agricultural authorities. These issues are real and without doubt affect the performance of farmers but are some how over looked. For example, in the case of coffee plantations in Tahiti, farmers were unable to work and harvest coffee due to the constant attacking and painful sting of Little Fire Ant *W. auropunctata* (Biosecurity, NZ. 2007). Such scenario may also occur in the Solomon Islands as well.

2.9 Effect on Crop Export Commodity in the region

Quantification of the direct and indirect impacts of *W. auropunctata* on fresh produce commodity lines and crop export potential from the Pacific islands is also a major task in need of completion, especially with countries that are known to have been infested with invasive ants and more particularly the infestation of *W. auropunctata*. Many Pacific countries have agriculture driven economies, which rely on export of primary raw products. For example, between 2001 – 2003, an estimated 9626 tonnes of sea freight originated from *W. auropunctata* infested countries in the Pacific and of these, 8% are fresh crop produce and much of this produce originated from New Caledonia and the Solomon Islands; two of the most *W. auropunctata* infested countries in the Pacific (Harris *et al*. 2005).

However, stringent surveillance policy to ensure crop exports are free of invasive ant species such as *W. auropunctata* and Red Imported Fire Ants (RIFA), to meet major importers demand, could prove a very expensive exercise for Pacific Islands (Orapa, 2007). And without doubt it will result in certain importing countries refusing agricultural produce from Pacific Islands that are known to have *W. auropunctata*.

This therefore requires fast development of effective surveillance strategy and techniques for *W. auropunctata*. For example, what likely areas should be targeted, what management strategy should the Pacific Islands adopt, and can each Pacific Island develop national capacities to deal with new incursions itself; may be an effective strategy is to contain *W. auropunctata* and other invasive ants (Orapa, 2007). Developing and implementing such strategies may also be a very expensive on going exercise for Pacific Island

CHAPTER 3

MATERIAL and METHODS

3.1 Study Area: Makira Island (San Cristobal)

This research project was conducted in the Solomon Islands on the island of Makira (formerly referred to as San Cristobal) (Fig. 3.1) in the Solomon Islands. The Solomon Islands is located within 12°S of the equator and more than 1500 km from the nearest continent (Island Directory, 1998). There are six major islands within the archipelago with approximately 900 smaller volcanic islands and coral atolls (Fig. 3.1). Major islands are characterized by steep mountain ranges with dense tropical forest.

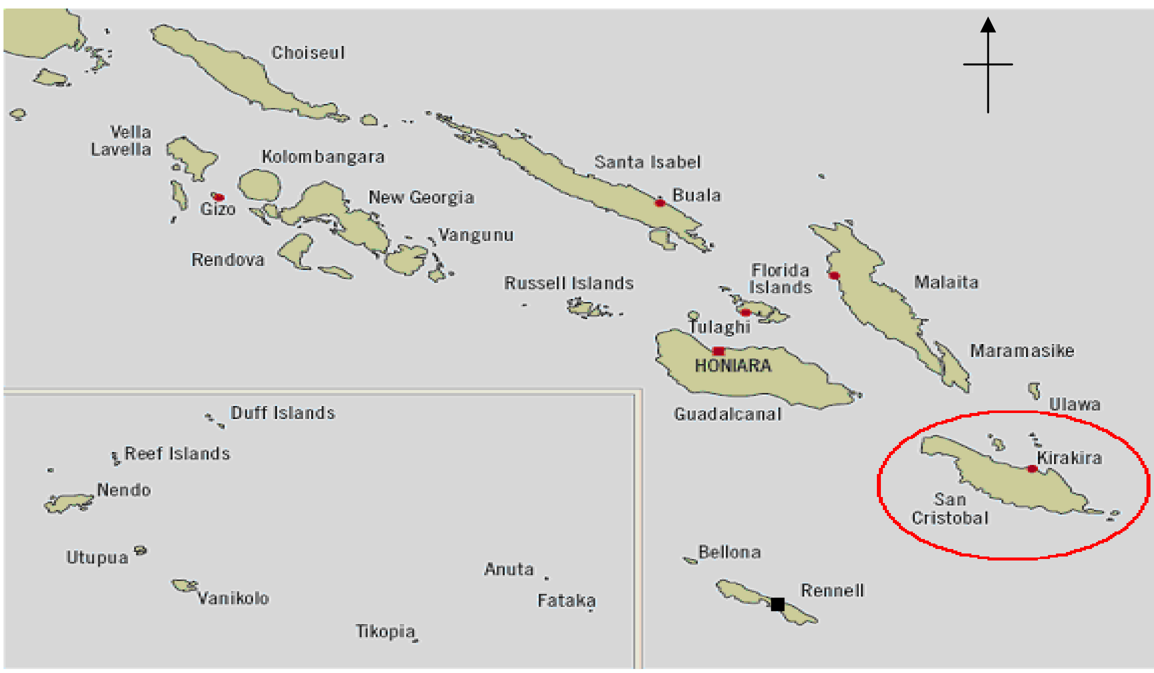


Fig. 3.1 Map of Solomon Islands showing Makira (San Cristobal) in red circle. (Adapted from: Bourke *et al.* 2006)

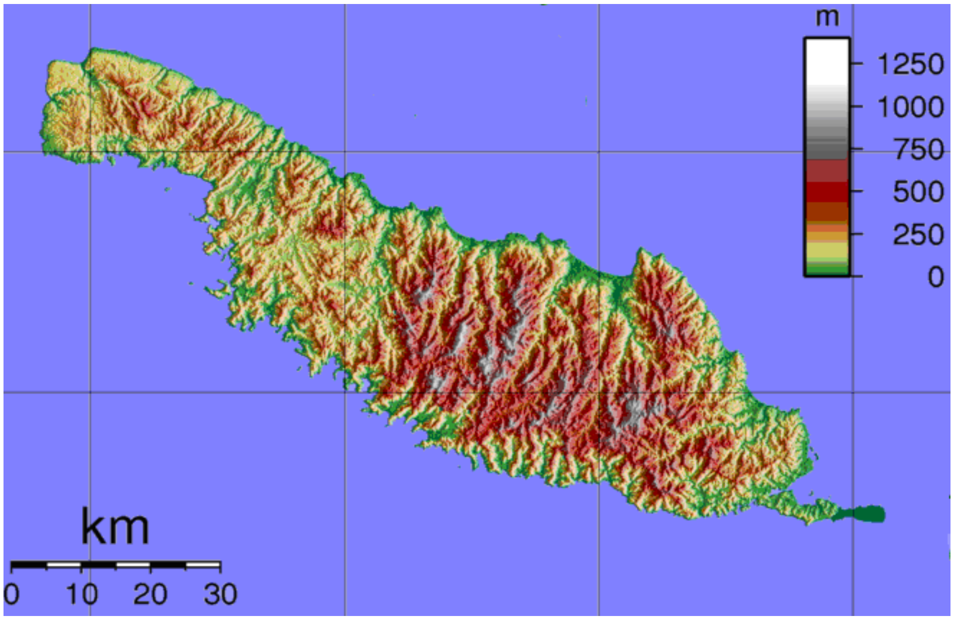


Fig. 3.2 Topography of Makira Island. (Source: Sadalmelik, 2007)

The island of Makira is located at 10.60º S 161.85º E (Island Directory) and is about 200 km southeast of Honiara, the capital of Solomon Islands (Fig. 3.1). Makira is 140 km long and between 12 and 40 km wide with a land area of 3,100 sq km and the highest point above sea level at 1,250 meters (Fig. 3.2) (Allen *et al*. 2006). Makira is rated the fourth of the Solomon Islands archipelago (Patterson *et al*. 1998; Calder, 2006). Makira Island has a tropical climate characterized by high humidity and uniform hot temperatures, which are occasionally tempered by sea breezes. There are no true changes of season although there are seasons of greater or lesser rainfall with the greater falls between December and March where the northeast equatorial winds bring hot weather and heavy rainfalls and the lesser falls between April and November when the islands are cooled by dryer southeast trade winds (Solomon Islands Meteorological Service, 2008). The annual mean rainfall is within the range of 3000 to 5000 mm with the average temperature of 23 – 32 ºC and the humidity is about 80% (Solomon Islands Meteorological Service, 2008).

In addition to the above rainfall pattern, there is generally a higher occurrence of rainfall from May to October and November to April in the southeast and west of the island respectively, whereas the central region of the island where the study was conducted experiences rainfall almost all year around (Allen *et al*. 2006). The environmental conditions and the topography of Makira are generally typical of the major islands in the Solomon Islands, with plains towards the coastal area and steeply dissected mountainous interiors rising to over 1,000 m (Fig. 3.2). Agricultural activity occurs on the more favorable topography found primarily along the coast where climate is hot and wet with lowland rainforest (Chase *et al*. 1986).

3.1.1 Reason for choosing the Study Area

Published and unpublished works (Fabres and Brown, 1978; Ikin, 1984; Wetterer, 2006) together with anecdotal reports indicate the spread of *W. auropunctata* in the Solomon Islands to be severe and the species may well have covered all the islands. Bauro, the study area on Makira Island represents an environment with conditions common across the Solomon Islands. The climatic conditions, the topography and gardening practices are typical of all the islands. It is therefore expected that the results obtained from this study on the Bauro area in Makira Island would represent a typical picture of the overall situation in other parts of the Solomon Islands.

3.1.2 Sampling Areas

The fieldwork took place in the Bauro district in central Makira (Fig. 3.3). It was carried out on two distinct areas, firstly in the Bauro lowland, marked with small dark circles (Fig. 3.3) and secondly in the Bauro highland marked with dark square (Fig. 3.3). Lowland as indicated on Fig. 3.3 is located towards the coast and highland area is located in the interior. In an ideal situation, the two sampling areas would be chosen within the Bauro lowland to ensure all physical factors are the same and eliminate all confounding variables. However, no garden sites within the Bauro lowland was free of *W. auropunctata*. Therefore, Bauro highland sites were the only available choice as they had garden sites still free of *W. auropunctata*. Although the two areas may be different in physical conditions, this will be accounted for in the interpretation of the results. The fieldwork took place from January to February 2008 and again from April to May 2008.

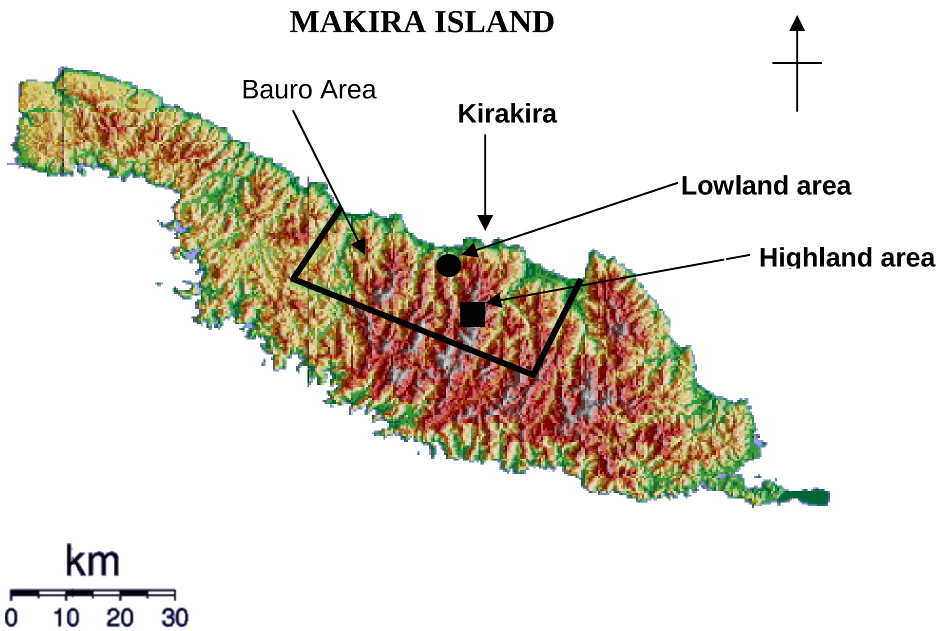


Fig. 3.3 Map of the Island of Makira (San Cristobal) indicating the 2 areas on Bauro (in rectangle) where the study was conducted. The two areas are marked dark circle on the Bauro lowland and dark square on the Bauro highland.

3.1.2.1 Bauro lowland: Study Area 1.

The first field area is in the Bauro lowland (Fig. 3.3). This area is characterised by lowland secondary forest with coastal plains. The topography of the sampling area ranges from about 50 to about 200m above sea level. The area is typical of lowland areas in Solomon Islands in that it has undergone substantial human related environmental disturbance such as human habitation, subsistence farming, coconut and cocoa plantation and reforestation. The locations of the sampling sites on Bauro lowland are shown in Fig. 3.4.

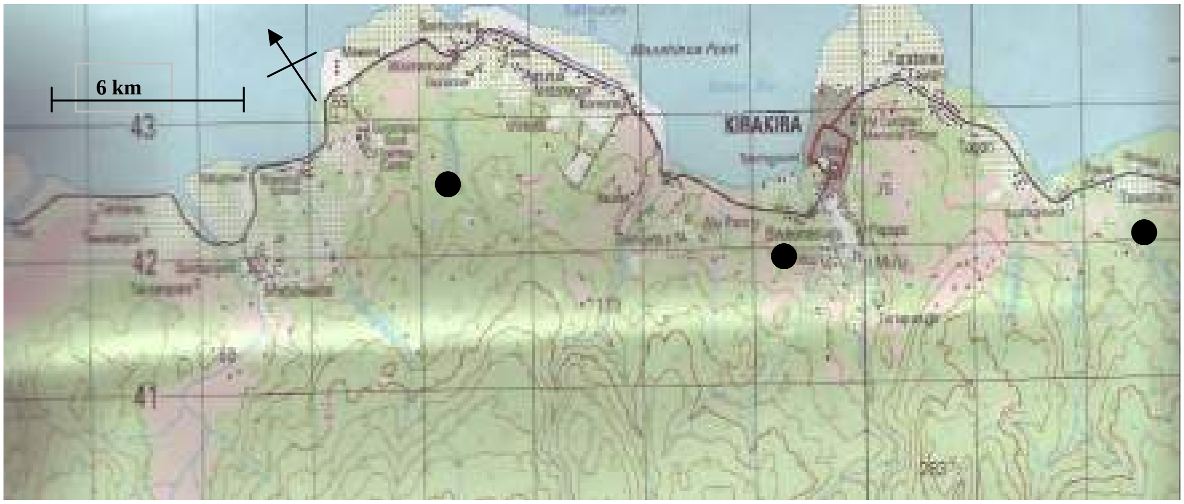


Fig. 3.4 A map of Bauro Lowland with sampling sites indicated by three dark circles. (Adapted from: Ministry of Lands and Housing, Solomon Islands Gov't - Map of Makira).

3.1.2.2 Bauro Highlands: Study Area 2

The second Study area is in the Bauro highlands (Fig. 3.3) which is approximately 14 km from the coast and is only accessible through bush tracks. The area is characterised by dense mountainous forest with an elevation of over 900 m in some places. The elevation in this area ranges from about 300 to close to 800m above sea level. Except for subsistence farming, there is no evidence of any commercial plantations such as cocoa or coconut in Maraone (Fig. 3.5) or any nearby villages. Farming activities in the area are typically traditional in nature and therefore pose no risks to the surrounding environments in terms of threats to the biodiversity. The Bauro Highland Conservation Area set up by the locals with the help of Conservation International (Fig. 3.6) is about 1 km from where highland sampling took place for this study. Seven sampling sites near Maraone and Maniate villages are marked with dark squares (Fig. 3.6). Sampling was also conducted on one other location at Nara village not shown on the map. The subsistence gardens of Bauro highland sites are thought to be one of the few areas still free of *W. auropunctata*, although *W. auropunctata* was observed in the village itself.

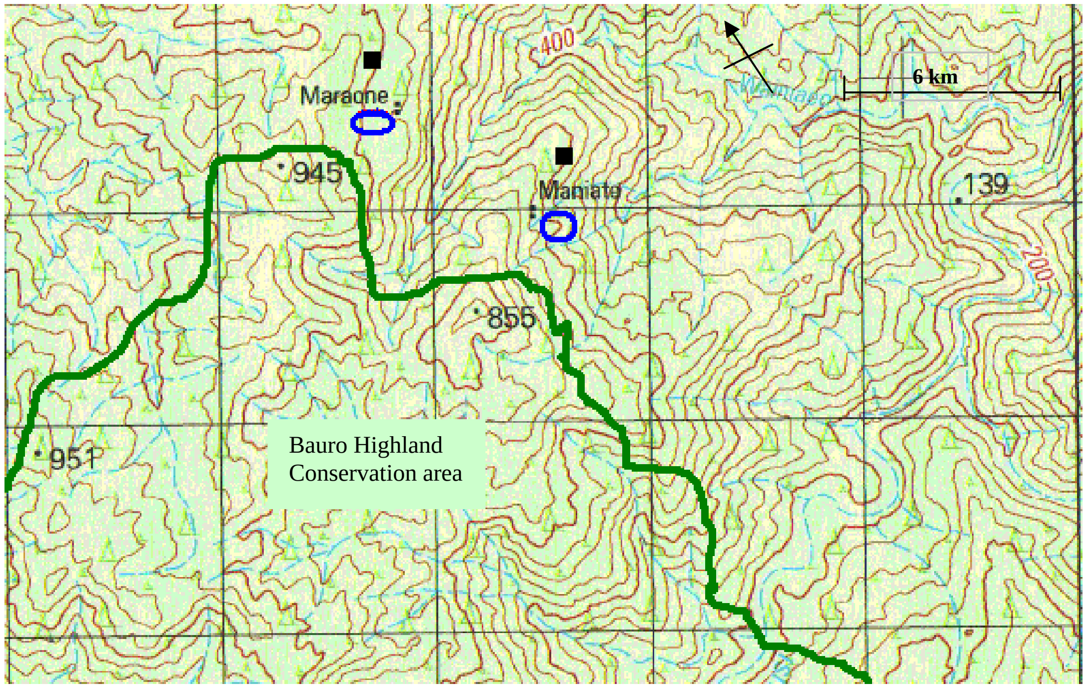


Fig. 3.5 A map of Bauro Highland area showing two sampling sites indicated by dark squares in on the map. (Adapted from: Ministry of Lands and Housing, Solomon Islands Gov't – Maps of Makira)

3.2 Subsistence Gardens

Sampling was carried on selected subsistence gardening sites to determine ant presence and dominance. Within gardens, four subsistence crops were sampled for the presence of ants and *W. auropunctata* tended pests. The subsistence crops examined were sweet potato, cassava, taro and yam. These crops were chosen because they are the most common subsistence crops in Solomon Islands and are commonly grown crops in every garden site (Ale *et al*. 2005). The gardens sites were chosen within each study area after consultation with villagers. Typically, in many gardens the crops overlap slightly as there is no physical boundary to demarcate one garden crop from another (Fig. 3.6). For example, a garden of taro would edge with a potato garden such that potato vines would grow into the taro garden or a taro patch directly next to a yam garden with no physical boundary between them (Fig. 3.6). Overall, a family or community farmed area may be big; however, there are several smaller plots of different subsistence crops within the larger area. The size of the plots of each subsistence crops also vary considerably from 80 m^2 to 116m^2 on lowland area and 159 m^2 to 322 m^2 on the high land sites. The measured sizes of gardens surveyed are summerised in the Table 3.1 & 3.2

Fig. 3.6 Potato garden over laps with yam garden with taro plants in between. No physical boundary between different subsistence crops.

Bauro lowland

Table 3.1 Average sizes of plots of subsistence crops sampled for ants and ants tended insects in lowland area. Nine gardens of each subsistence crop (3 in each of the 3 sites) were sampled.

Subsistence crops	No. of garden/plots	Average area (m^2)/garden
Potato	9	111
Cassava	9	80.3
Taro	9	102
Yam	9	116.3

Bauro highland

Table 3.2 Average size of plots of subsistence crops sampled for ants and ants tended insects in highland area. Nine gardens of each subsistence crop (3 in each of the 3 sites) were sampled.

Subsistence crops	No. of garden/plots	Average area (m^2)/garden
Potato	9	253.67
Cassava	9	159.33
Taro	9	322.66
Yam	9	256

It was noted that generally, garden sizes on Bauro highland area were larger than those farmed in the Bauro lowland area (Table 3.2). Therefore, to allow near same dimensions among all the gardens surveyed, garden sites to be sampled were standardised to approximately $80m^2$ (8m x 10m).

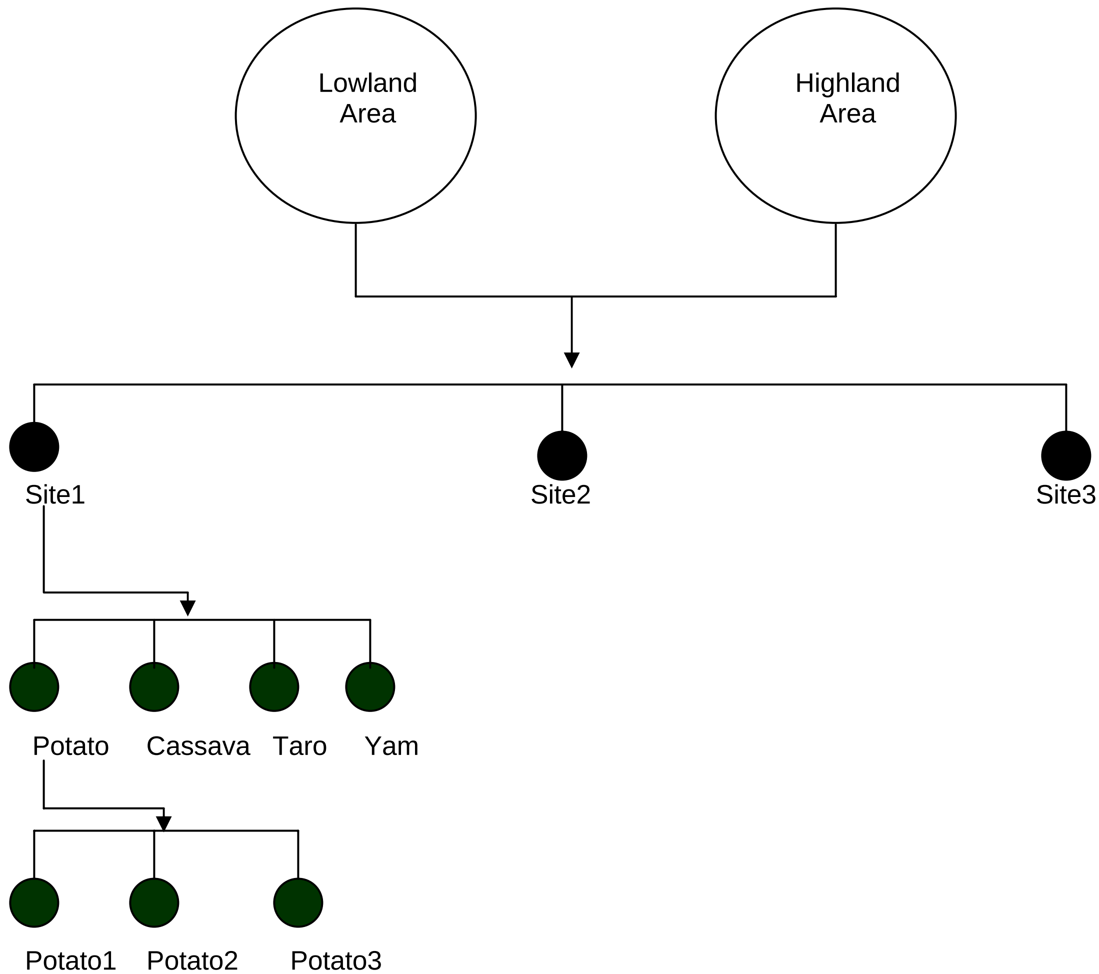


Fig. 3.7 Schematic diagram of the sampling design for the 2 areas (lowland & highland). Within each study area there is 3 sampling sites (Site1, 2 & 3,), 4 subsistence crops (Potato, Cassava, Taro and Yam) and three subsistence gardens for each subsistence crops selected (Potato1, 2 & 3). Each garden was sampled for ants and also used in the determination of the presence of *W. auropunctata* tended crop damaging hemipterans and other insects.

3.3 Sampling of the ant fauna

Sampling for the ant fauna was conducted twice in each garden site; during January to February and then again during April to May 2008. Each crop sampled was separated by about 100 m.

In taxonomic studies, nests which contain all castes (workers, including majors and minors, and if present, queens and males) are desirable to allow the determination of variation within species (Shattuck and Barnett, 2001). However, this being an ecological study, the important factor was collecting identifiable samples of as many of the different species present as possible. The survey method was therefore selected to determine how many different ant species were present in the study area and to estimate their relative abundances. Therefore, to collect as wide a range of species as possible, two different collection methods were used; timed hand collecting and sampling using baits as attractants.

3.3.1 Bait Based Method

For the bait-based method, a total of 30 baited 60 ml vials were placed along six parallel transects lines, running along the width of each garden sampled. The transect lines were set at 1.5m apart. Each baited vial was also placed 1.5m apart along the transect lines. Following Harris *et al*. (2002), baited vials consisted of (1) protein (tuna) and (2) peanut butter. The vials were left for 30 minutes before collecting.

3.3.2 Timed Hand Collecting Method

Timed hand collecting was used on all four crops (potato, cassava, taro and yam) and involved collecting ants on the soil, ground litter and on plants. This is a well-established ant collection technique (Room, 1975; Ward and Harris, 2002; Shattuck and Barnett. 2001) but in this study, it was modified by changes in timing and size of gardens surveyed. This method is an excellent way of directly collecting ants that would not be attracted to baits or those that might be chased away by more dominant ants during baiting. It also allowed collection of both arboreal and ground ants. The method involves dividing each garden of 8m x 10m into four quarters (Fig. 3.8). Each quarter is approximately $20m^2$. Approximately 15 minutes is spent in each quarter collecting ants from the soil, dead leaves, litter, stem and leaves of the crops. Collecting is undertaken using forceps or direct hand picking and a small manually operated aspirator. Collected ants were stored in a vial of 95% ethanol before identification at the University of the South Pacific.

3.3.3 Analysis of Data

Samples of ants collected in each of the four subsistence crop plots by the two collecting methods were firstly presented as total ant richness (total number of ant species) found in both areas. The abundance of individual ants (irrespective of species) were then averaged for the three trials and presented as the total number of ants collected for each subsistence crop. This showed a total abundance for every ant species collected in both surveyed areas. The results were then presented as comparative graphs to show the mean abundance of “other” ant species in the presence and absence of *W. auropunctata*. An Independent Sample t test was then carried out using SPSS version 16 software to determine the significance of the impact of *W. auropunctata* on the native ant fauna.

3.4 The presence of *W. auropunctata* tended crop damaging hemipterans and other insects on the subsistence crops

Following Jourdan *et al*. (2001) and Lester *et al*. (2003), determination of the presence or absence of *W. auropunctata* tended hemipterans (aphids, mealy bug, scale insects or whiteflies) and other insects (most of them being crop damaging insects) was conducted by standardised visual searching, identification and collecting. This activity was undertaken in the same subsistence crops referred to in section 3.3.1. Using the same quarters referred to in section 3.3.1, the crop plots were randomly surveyed for the presence of crop damaging insects tended by *W. auropunctata*. Samples of *W. auropunctata*-tended insects found in the gardens were collected and stored in 95% ethanol for identification. According to Lester *et al*. (2003), a relationship between an ant species and hemipterans was considered to be established if the ants were observed to be collecting the exudates from the hemipterans or seen to be congregating around the insects. Confirmations of such relationships were therefore undertaken by direct observations.

3.4.1 Analysis of Data

The results of this survey (section 3.4) were presented in a comparative table with insects collected in each of the subsistence crops presented under the crops they were found on. Insects were identified to their genus (species if possible) and common names given using Key reference (Borror and White, 1970; French, 2006) and by cross reference to hemipterans reference collections held at the Biology Division, University of the South Pacific and Koronivia Agriculture Research Station, Fiji. Pest status was determined using these same references. The *W. auropunctata* tended insects were then sorted and divided as either crop pests or not. Finally, all the insects collected were classified as either having a mutualistic relationship with *W. auropunctata* or not, using field notes taken during direct observation.

3.5 Specific Impact of *W. auropunctata* on the Abundance of *Tarophagus* sp. (a well recognised Taro pest) and its natural predator *Cyrtohinus fulvus* on Taro plants

Determination of the possible impact of *W. auropunctata* on subsistence crops was conducted the correlating the dominance of *W. auropunctata* to populations of *C. fulvus* and *Tarophagus* sp. on taro plants. This was undertaken to determine whether *W. auropunctata* interferes with the natural predation of *Tarophagus* sp. on taro plants and therefore, is responsible for the increase in *Tarophagus* sp. on taro plants. The *Tarophagus* sp. and *C. fulvus* survey involved standardised visual identification and recording of *C. fulvus* and *Tarophagus* sp on individual taro plants in taro plots on lowland area (taro plants infested with *W auropunctata*) and highland area (taro plants free of *W. auropunctata*).

Within study areas, taro gardens were grouped into four different locations (Fig. 3.8). Each location is separated by over 2 km. Within each location, taro plots (gardens) were separated by about 100m. A total of 56 taro gardens were selected, half of it being on Bauro lowland and the other half on Bauro highland (Fig. 3.8). Within each selected taro plot, twenty five (25) taro plants were randomly selected and standardised visual identification and recording for *Tarophagus* sp and its natural enemy, *C. fulvus* was conducted (Fig. 3.8).

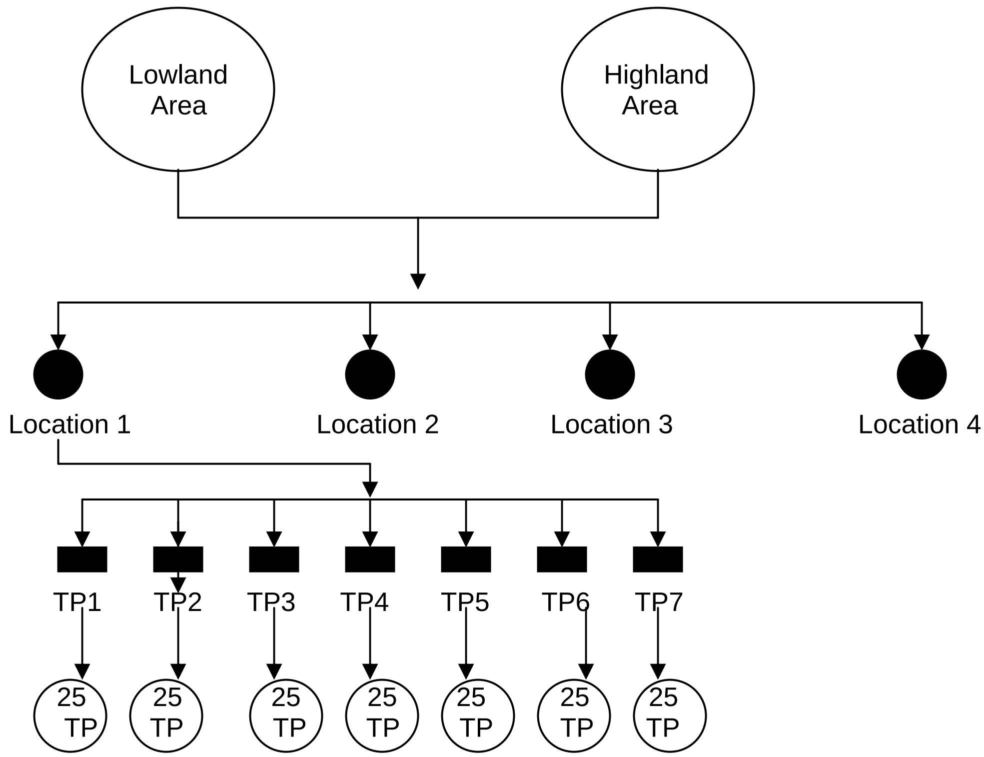


Fig. 3.8 Schematic diagram of the sampling design for taro plants sampled to examine the impact of *W. auropunctata* on *Tarophagus* sp. (a well known taro pest) and its natural predator *Cyrtohinus fulvus*. This schematic diagram represents 2 areas, each with 4 locations (Location 1, 2, 3 & 4). Each location has 7 taro gardens making a total of 28 taro gardens on each of the study location. Twenty five (25) taro plants (TP) from each of the 7 taro gardens was then randomly selected.

3.5.1 Analysis of results

The average density and mean abundance of the pest species *Tarophagus* sp. and predator *C. fulvus* per taro plant in the taro plots were compared by use of a comparative graph. An Independent Sample T test using SPSS version 16 software was then carried out to determine the significance of the difference.

CHAPTER 4

RESULTS

4.1 Ant Species Richness

A total of 13 different ant species were found in both lowland and highland areas (Table 4.1). Highland sites however, showed 12 ant species compared to only 5 species in the lowland sites where *Wasmannia auropunctata* was present. There were four ant species found in both areas. *W. auropunctata* was found only in lowland sites. Except for *W. auropunctata, Paratrechina vaga* and *Anoplolepis gracilipes*, which are exotic and invasive ant species, all other ants are native to Makira Island.

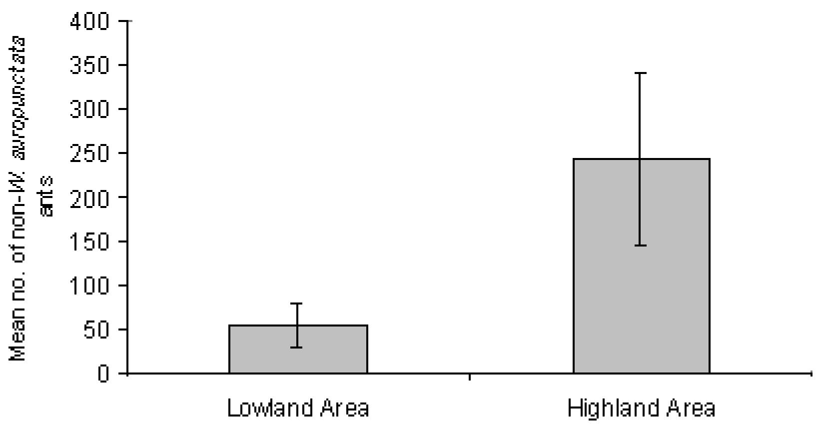
Table 4.1 Ant species composition found in both study areas. Lowland Sites are infested with *W. auropunctata* and Highland Sites are free of *W. auropunctata*. Plus (+) indicates that ant species was found, minus (-) indicates ant species was not found during the sampling period and * indicates that the species is found in both areas. Sampling methods were equal in both areas.

Ants Species	Lowland Sites	Highland Sites
Wasmannia auropunctata	+	-
Paratrechina stigmatica *	+	+
Paratrechina vaga *	+	+
Paratrechina consuta	-	+
Paratrechina oceanica *	+	+
Pheidole oceanica	-	+
Pheidole sp. 2	-	+
Polyrachis sp.1	-	+
Rhytidoponera sp.1	-	+
Odontomachus sp.1	-	+
Camponotus sp.1	-	+
Anoplolepis gracilipes	-	+
Oecophylla smaragdina *	+	+
Total	5	12

4.2 Impact of *W. auropunctata* on the abundance of other ants (the native, exotic and invasive ant species)

A significant difference was observed ($t_{(22)} = -2.21$, $p = 0.04$) between the overall abundance of non – *W. auropunctata* ants on lowland sites and highland sites (Figure. 4.1). Correspondingly, comparing the mean abundance of a single species of ants found in both sites, a marked difference was observed (Figure. 4.2). Except for *Paratrechina oceanica* and *O. smaragdina*, the mean abundance of individual ant species was significantly different in both areas (Figure. 4.2). The mean abundance of these individual ant species is significantly higher in highland sites than in lowland sites. On the other hand, *P. consuta*, *Pheidole oceanica*, *Pheidole* sp. 2, *Polyrachis* sp.1, *Anoplolepis gracilipes*, *Camponotus* sp.1, *Rhytidoponera* sp.1, and *Odontomachus* sp.1 were present on highland sites but were not found in lowland sites during the sampling conducted for the current study (Figure 4.2).

The overall mean abundance of *W. auropunctata* in lowland sites was however, exceptionally high compared to that of other ants (Table 4.2) and the probability of collecting a *W. auropunctata* in any of the sampled gardens in lowland sites is 97% (Table 4.2).



(Infested with *W. auropunctata*) (Free of *W. auropunctata*)

Fig. 4.1 The mean abundance of non-*W. auropunctata* ants found during the sampling period at both lowland and highland sites.

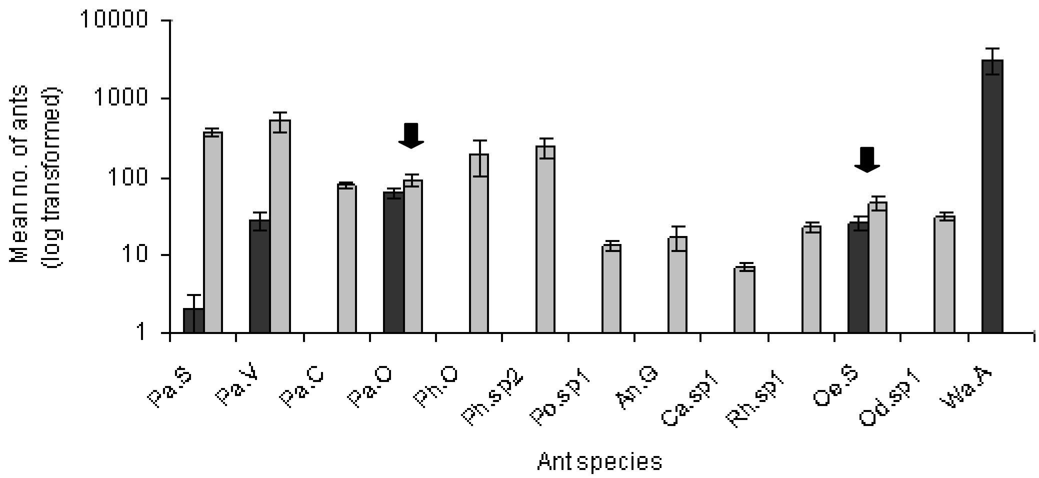


Fig. 4.2 A comparison between the mean numbers of different ant species collected in the two sampling areas. ■ Ants collected on lowland sites. □ Ants collected highland sites. *Pa.S - Paratrechina stigmatica, Pa.V - Paratrechina vaga, Pa.C - Paratrechina consuta, Pa.O - Paratrechina oceanica, Ph.O - Pheidole oceanica, Ph.sp2 - Pheidole* sp. 2, *Po. Sp1 - Polyrachis* sp.1, *An.G - Anoplolepis gracilipse, Ca.sp1 - Camponotus* sp.1, *Rh.sp1 - Rhytidoponera* sp.1, *Oe.S - Oecophylla smaragdina, Od.sp1 - Odontomachus* sp.1, *Wa.A - Wasmannia auropunctata*, ⬇ = comparison without a significant difference between lowland and highland sites.

Table 4.2 The mean abundance of *W. auropunctata* found compared to all other ants combined in each of the four subsistence crop gardens sampled in lowland sites. The probability of collecting *W. auropunctata* in each of the subsistence, garden types is also indicated.

Subsistence Crops	***Mean No. of W. auropunctata***	**Mean No. of other ants**	**Probability of collecting a *W. auropunctata***
Potato (P)	2475 ±836	44 ±2	0.98 (98%)
Cassava (C)	6467 ±153	25 ±7	0.99 (99%)
Taro (T)	1958 ±371	80 ±5	0.96 (96%)
Yam (Y)	1719 ±481	55 ±4	0.96 (96%)
Mean	3095±1117	51± 11	0.97 (97%)

4. 3 Relationship between *W. auropunctata* and crop damaging hemipterans and other insects.

Twenty different insect species were found on all four subsistence crops studied (Table 4.3). The insects found on each crop were different with potato having the highest number of different insect types present (Table 4.3 & 4.4). The majority of insects found overall belong to the insect order Hemiptera. Of the twenty insect species found, eight were observed to have a positive relationship with *W. auropunctata*. A positive relationship means that *W. auropunctata* was observed collecting sugar exudates or congregated in large numbers around the insects. All eight of these insects are recognised crop pests (Table 4.4). Six insects *(Bemisia* sp., *Planococcus citri*, *Planococcus dioscoreae,* 2 species of *Aleurodicus* sp., *Tarophagus* sp.) are hemipterans and two (*Spodoptera* sp. and *Hippotion* sp.) are lepidopterans in the larval stage. A *Bemisia* sp. was found in potato gardens; Planococcus *citri, Aleurodicus* sp. and *Spodoptera* sp. were found in cassava gardens; *Tarophagus* sp., *Planococcus citri*, *Spodoptera* sp. and *Hippotion* sp were found in Taro gardens and *Planococcus citri*, *Planococcus dioscoreae*, *Aleurodicus* sp were found in Yam gardens. Other insects showing no relationship with *W. auropunctata* were also recognised serious crop pests, for example, the sweet potato weevil *(Cyclas formicarius)* and two species of unidentified grasshopper (Table 4.4). Ten different species of "*W. auropunctata* un-tended" insects were recorded in potato crops in the study site compared to only two in each of the other three crops (Table 4.5). In contrast, only one *W. auropunctata* tended insect species was observed in potato crops compared to three in cassava crops, four in taro crops and three in yam crops.

Table 4.3 Common insects found in different subsistence crops at lowland garden sites. P = Potato, C = Cassava, T = Taro, Y = Yam

Insect Species	Order	Common Name	Crop where insect found
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
Atractomorpha sp	Orthoptera	Grasshopper	P, Y
Valanga sp	Orthoptera	Grasshopper	P, Y
Sanninoidea sp	Lepidoptera	Tree borer	C
Spodoptera litura	Lepidoptera	Cluster worm	C, T
Hippotion celerio	Lepidoptera	Taro hornworm	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
Cyrtohinus fulvus	Heteroptera	Leafhopper	T
Planococcus dioscoreae	Hemiptera	Mealybug	Y

Table 4.4 Insects observed in the 4 subsistence crop gardens surveyed in lowland sites. (+) = Relationship observed with *W. auropunctata*, (–) = Relationship with *W. auropunctata* not observed, (√) = Insect known to cause damage to crops, (X) = Insect not documented to cause damage to crops.

Crops/Insect species	Order	Common name	Crop Pest: Status of insect	Observed relationship with *W. auropunctata*
Potato				
Cyclas formicarius	Coleoptera	Sweet potato weevil	√	-
Hippodamia sp	Coleoptera	Ladybird	X	-
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	X	-
Jalysus wickhami	Hemiptera	Stilt bug	X	-
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	X	-
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	√	-

Table 4.5 Total number of insect species observed to be tended and un-tended by *W. auropunctata* in each of the subsistence crops surveyed in lowland area.

Subsistence crops	Observed no. of different insect sp. tended by *W. auropunctata*	Observed no. of different insects sp. un-tended by *W.*
auropunctata		
Potato	1	10
Cassava	3	2
Taro	4	2
Yam	3	2

4.4 Effect of *W. auropunctata* on *Tarophagus* sp and *Cyrtohinus fulvus* (natural predator of *Tarophagus* sp.)

The introduction of *W. auropunctata* to taro plants did not significantly affect the population of *Cyrtohinus fulvus* (predator) in taro plants but has significantly influenced the population abundance of the taro pest *Tarophagus* sp. There was no significant difference in the mean density of *C. fulvus* per taro plant in the taro gardens in both sites (lowland sites – taro gardens infested with *W. auropunctata* and highland sites – taro gardens free of *W. auropunctata*), ($t_{(54)}$ = -1.61, p = 0.11) (Fig. 4.3). However, taro plants in highland sites show a slightly higher mean density of *C. fulvus* (Fig. 4.3). In contrast, the mean abundance of *Tarophagus* sp per taro plant (same taro plants surveyed for *C. fulvus*) in the two areas was significantly different ($t_{(54)} = 7.1$, $p < 0.05$). In the presence of *W. auropunctata*, more *Tarophagus* sp were observed in taro plants compared with when *W. auropunctata* was absent.

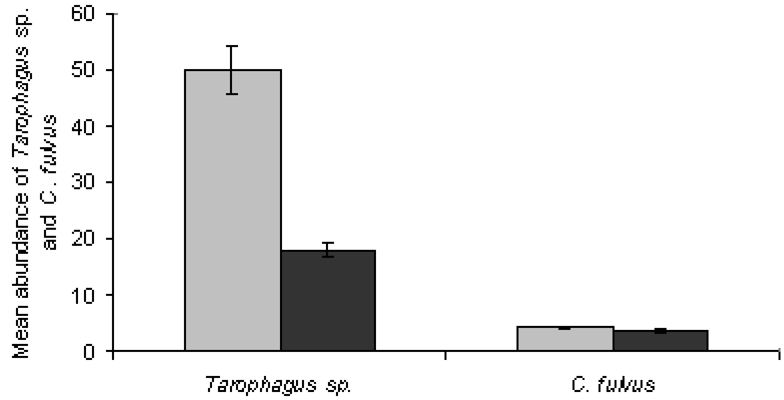


Fig. 4.3 The mean abundance of *Tarophagus* sp. and *C. fulvus* per taro plant sampled. ■ = Taro plants free of *W. auropunctata*, ■ = Taro plants infested with *W. auropunctata*

CHAPTER 5

DISCUSSION

5.1 Impact of *Wasmannia auropunctata* on native ant fauna in subsistence gardens

5.1.1 Effect on Species richness and Abundance

The results highlighted the negative relationship between the richness and abundance of non-*W. auropunctata* ant species in the presence of *W. auropunctata* in subsistence gardens. Twelve species of ants were found in garden areas free of *W. auropunctata* compared with four species of ants found in garden areas infested with *W. auropunctata*. Therefore it is obvious that the species richness and the abundance of the non-*W. auropunctata* ant species, is reduced significantly in the *W. auropunctata* invaded areas. This finding is consistent with previous studies conducted in other *W. auropunctata* invaded areas, including parts of New Caledonia, Vanuatu and the Galapagos Islands (Clark *et al*. 1982; Lubin, 1984; Jourdan *et al*. 2002).

Although the two study areas in this current study are different in altitude, it has been shown that altitude does not significantly affect ant species richness (although the ant species richness tends to be higher in the lower to mid-altitude areas and to decrease at higher altitudes) (Kusnezov 1957; Araújo and Fernandes, 2003; Yek *et al*. 2009). In Fiji for example, ant species richness peaks at about 300m elevation and decreases at higher altitudes (E. Economo, pers. comm.). Given such a scenario, it would be expected that ant species richness in the lowland garden sites in the current study would be higher than ant species richness on the Bauro highland. This was however, not the case and therefore, the difference in ant richness in the two areas is clearly influenced by the presence and absence of *W. auropunctata.*

Despite the unavoidable necessity for an unbalanced sampling design, it seems evident from the current study that *W. auropunctata* has impacted negatively on the native ant fauna of Bauro lowland area on Makira Island. Although not directly addressed in the current study, the mechanisms *W. auropunctata* uses to displace other ants in the garden sites, its ability to monopolize baits of tuna and peanut butter while eliminating other ant species, was observed. *W. auropunctata* appears not to coexist well with other ant species (Way and Bolton 1997). Being very competitive with effective recruitment ability resulting in a large population density (Clark *et al.* 1982; Jourdan, 1997) *W. auropunctata* obviously played a major role in disrupting and eliminating other ants in the garden sites. Based on the current study, it is also possible that *W. auropunctata* may be directly preying on other ant species as well. Competitive ability as well as the notorious dominating nature of *W. auropunctata* over other ant species in monopolising food resources as well as territory was also observed in the rainforest of New Caledonia and Galapagos Island (Clark *et al*. 1982; Jordan, 1997; Le Breton *et al.* 2003; 2005). This is in contrast to what is observed in its native range where *W. auropunctata* was observed to share food resources with different ant species that share the same dietary needs (Levings and Frank, 1984; Tennant, 1994).

Further evidence that *W. auropunctata* is impacting negatively on Bauro lowland area is drawn from the finding that only four “non-*W. auropunctata*” ant species were found in the lowland area in this study compared with 52 ant species found by Mann (1919) along the lowland coastal area of Makira. The finding of the current project represents 7% of the ant species found by Mann (1919) compared with 23% for the highland area. Although both areas show comparatively low species counts compared to Mann’s (1919) record, agricultural activities (as opposed to in the undisturbed areas) may have accounted for the displacement of some native ant species. For example, it has been documented that many arboreal and ground dwelling ants may be displaced when trees are slashed and burnt and when soil is prepared during garden preparation (Castaño-Meneses and Palacios-Vargas, 2004). However, given that gardening practices in both areas (lowland and highland) went through a similar preparation processes (pers. obs.) gardening practice cannot be used to argue for a difference in species richness.

The findings from the current study also support the concept of negative interspecific interactions among ant species as a means of maintaining the exclusive territories of the dominant ant species as discussed by Morrison (1996). In the current study, the lowland subsistence garden sites appeared to be the primary territories of *W. auropunctata*, probably owing to the large supply of carbohydrates supplied from the crop pests in these gardens. In the presence of few dominant ant species, Morrison (1996) showed that the overall ant richness decreases on baits and rich food resources. This is also the trend seen in the current study. With its superior predatory nature and its ability to rapidly recruit in large numbers (Le Breton *et al.* 2005), *W. auropunctata* often displays a negative interspecific interaction in many ant communities.

Bauro lowland represents a cross section of agriculturally altered coastal habitats that are typical of the islands in the Solomon Islands. Many of the agricultural activities occur along coastal areas where people live and there is more flat arable land (Bourke *et al*. 2006; Evan, 2006). Drawing from the results obtained from Bauro lowland areas, that ant species richness and abundance in agriculturally disturbed environments in the Solomon Islands may be significantly reduced as a result of the introduction of *W. auropunctata.* Such assumption is supported by similar studies done in other countries (Clark *et al*. 1982; Perfecto and Vandermeer, 1996; Ness and Bronstein, 2004; Wetterer, 2007).

5.1.2 Spread of Wasmannia auropunctata in the Solomon Islands

Based on the current study together with anecdotal reports and published work, the spread of *W. auropunctata* in the Solomon Islands can be mapped (Fig. 5.1).This study has documented presence and abundance in garden crops on Bauro lowland area on Makira Islands. *W. auropunctata* is also present in high abundance in Choiseul, Russell Islands, Guadalcanal, Santa Cruz (pers. obs.). Wetterer (1997) also confirms the presence of *W. auropunctata* on Guadalcanal, Savo and Santa Cruz. Many other islands in the Solomon Islands such as the Shortlands, Gizo, New Georgia, Malaita and Rennell are also reported to have been invaded by *W. auropunctata* (rural farmers, pers. comm.). It is therefore highly probable that no islands in the Solomon Islands are spared from the intrusion of *W. auropunctata.*

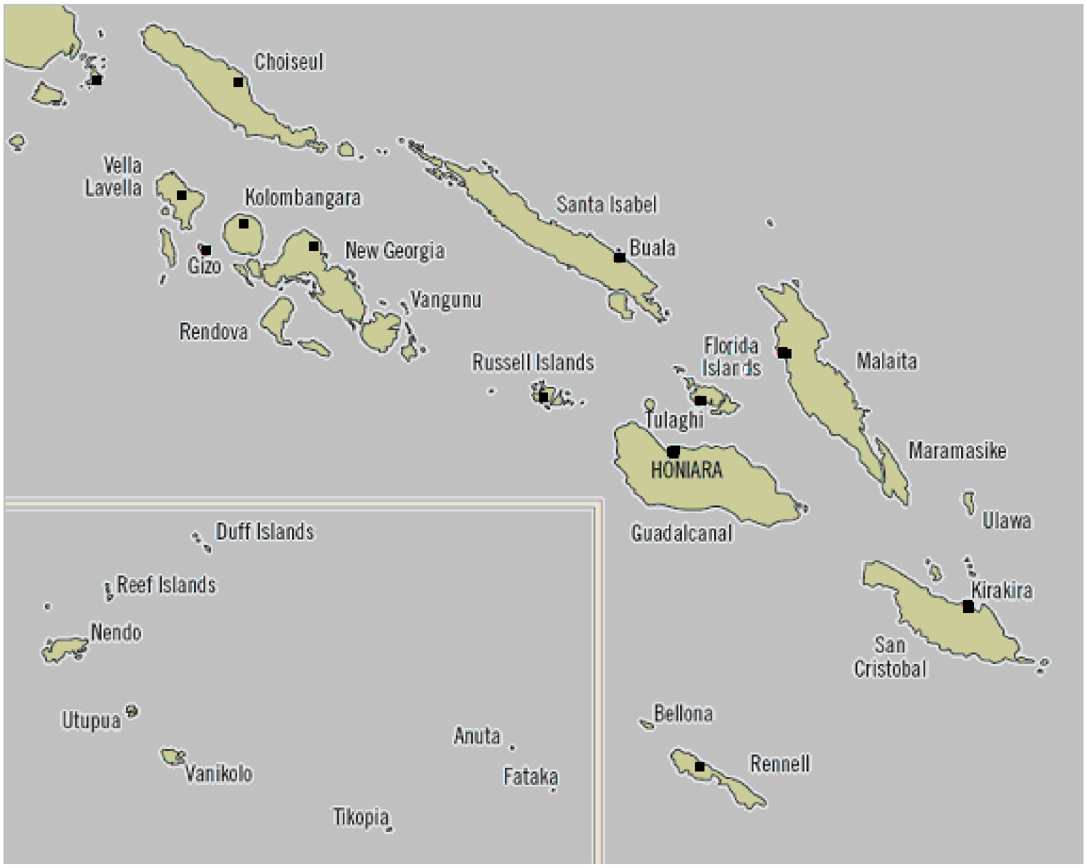


Fig. 5.1 Islands in the Solomon Islands where *W. auropunctata* is present is indicated by the dark square (Agriculture Dept. pers. comm.)

5.1.3 Ant record on Makira Island

It should be remembered that the overall number of ant species found during the current project is confined to selected gardens containing four subsistence crops; potato, cassava, taro and yam and therefore, does not reflect the total number of ant species in Bauro, on Makira Island. It is highly likely that ant species richness may be higher than that recorded if this survey were to be extended to other crops and to natural environments. Mann (1919) recorded 52 species of ants on Makira Island (Table 5.1) which is 36% of the 170 ant species recorded in the same publication for the whole of the Solomon Islands. Mann's (1919) record of ants of Makira Island and the Solomon Islands probably represents ant species diversity in environments with little to no disturbance that were also *W. auropunctata* free. To date, there are no updated estimates of the native ant fauna in Makira Island or the Solomon Islands. It is also worth noting that the list of exotic ants; some of which are invasive may have increased in the last decade since the introduction of *W. auropunctata* into the Solomon Islands in 1972. For example, Ward and Wetterer (2006) reported twenty exotic ants in the Solomon Islands (Table 5.2). Except for *A. gracilipes* and *Paratrechina vaga*, the other 18 ants in Ward and Wetterer (2006) list of exotic ants were not recorded in the work by Mann (1919).

Table 5.1 Archival record of ants of Makira Islands (San Cristobal) in Solomon Islands. (Source: Mann, 1919). Collections and reporting of these ants were conducted before the introduction of *W. auropunctata*. Most of the collections were carried out by Mann (1919) and were most probably conducted on the lowland area of Makira Island.

Amblyopone celata Mann	*Pristomyrmex obesus* Mann
Myopopone castanea Smith	*Lordomyrma epinotalis* Mann
Rhytidoponera araneoides Le Guillou	*Tetramorium mayri* Mann
Pachycondyla sheldoni Mann	*Tetramorium tonganum* Mayr
Pachycondyla stigma Fabricius	*Tetramorium carinatum* Smith
Cryptopone testacea Emery	*Tetramorium aspersum* Smith
Hypoponera gleadowi Forel	*Strumigenys autaeus fuscior* Mann
Hypoponera papuana Emery	*Eurhopalothrix procera* Emery
Hypoponera pruinosa Emery	*Philidris myrmecodiae* Emery
Anochetus cato Forel	*Technomyrmex albipes* Smith
Anochetus graeffei Mayr	*Anoplolepis gracilipes* Smith
Odontomachus haematodus Linnaeus	*Acropyga moluccana papuana* Mann
Pheidole isis Mann	*Acropyga rhizomyrma lauta* Mann
Pheidole nindi Mann	*Oecophylla smaragdina* Emery
Pheidole oceanica Mayr	*Opisthopsis manni* Wheeler
Pheidole philemon Forel	*Camponotus novaehollandiae* Mayr
Pheidole umbonata Mayr	*Camponotus loa* Mann
Pheidole sexspinosa Mayr	*Camponotus elysii* Mann
Cardiocondyla nivalis Mann	*Polyrhachis osae* Mann
Crematogaster foxi Mann	*Polyrhachis dahlii* Forel
Vollenhovia pedestris Smith	*Polyrhachis annae* Mann
Vollenhovia subtilis Emery	*Polyrhachis similis* Viehmeyer
Monomorium australicum Forel	*Paratrechina minutula* Forel
Solenopsis papuana Emery	*Paratrechina obscura bismarckensis*
Carebara viehmeyeri Mann	*Euprenolepis stigmatica* Mann
Myrmecina modesta Mann	*Strumigenys godeffroyi* Mayr

Table 5.2 List of Exotic ants in the Solomon Islands. Many of these ants are recently introduced to the Solomon Islands. (Source: Ward and Wetterer, 2006).

Anoplolepis gracilipes (Smith)	*Pyramica membranifera* (Emery)
Solenopsis geminata (Fabricius)	*Hypoponera gleadowi* (Forel)
Strumigenys emmae (Emery)	*Hypoponera punctatissima* (Roger)
Strumigenys rogeri	*Monomorium floricola* (Jerdon)
Tapinoma melanocephalum (Fabr.)	*Pachycondyla stigma* (Fabr.)
Monomorium pharaonis (L.)	*Paratrechina bourbonica*
Tetramorium bicarinatum (Nyl.)	*Paratrechina longicornis* (Latr)
Tetramorium lanuginosum (Mayr)	*Paratrechina vaga* (Nylander)
Tetramorium simillimum (Smith)	*Pheidole megacephala* (Fabricius)
Wasmannia auropunctata (Roger)	*Tetramorium grassii* (Emery)

5.1.4 Ecological Risks

The impact of *W. auropunctata* as an invasive ant species also has ecological risks. Its presence and dominance is a threat to the overall biodiversity (Clark *et al*. 1982; Le Breton *et al*. 2003; Wetterer and Porter, 2003). For example, *W. auropunctata* is believed to have caused a decrease in reptile populations in New Caledonia and in the Galapagos archipelago, where it eats tortoise hatchlings and attacks the eyes and cloacae of the adult tortoises (Holway *et al*. 2002; Lubin, 1984). A case of a decrease in local arthropod diversity is also reported in the Solomon Islands (including the areas where this study is conducted) as a result of the introduction of *W. auropunctata* (Romanski, 2001). Local communities of Bauro (Makira Island) report incidents of domesticated birds, cats and dogs being blinded by the venom from the sting of *W. auropunctata* which often leads to their death. Although data for non-domestic vertebrates and invertebrates are absent and, it is therefore difficult to directly attribute mortality to invasive ant species, the impact of *W. auropunctata* on domestic animals provides an indication of the potential effect of these ants on wild animals. It is very likely that the high abundance of *W. auropunctata* within the areas surveyed has inflicted ecological damage to a many native invertebrates and vertebrates, unnoticed. For example, *W. auropunctata* could be preying on numerous native insects and may be significantly responsible for a decline in a number of small invertebrates and vertebrates. This likely biodiversity loss has widespread implications for ecosystem function and sustainable development.

5.1.5 Summary

W. auropunctata is the dominant ant species in the four subsistence crops sampled in Bauro lowland area. Based on the evidence from the current study, it is probably the dominant ant species in different subsistence crops and in gardens on different islands in the Solomon Islands as well. Its dominance has a negative effect on the overall ant species present as *W. auropunctata* has been shown to reduce different ant species on the subsistence crops where it is present. Based on the evidence from its negative effect on other ant species, it is highly likely that it can inflict similar loss to other invertebrates and also possibly vertebrates present within the same habitat.

5.2 Relationship between *W. auropunctata* and crop damaging hemipterans and other insects.

The ability of ant species to exploit food resources through mutual relationships with honeydew producing insects is a common ecological interaction (Way, 1963; Buckley, 1987; Delabie, 2001). Such relationships though common and natural, may sometimes be negative to the host plants. In this study, six hemipterans were observed to have developed mutual relationships with *W. auropunctata* on four subsistence crops in lowland garden sites. According to Styrsky and Eubanks (2007) such relationships are an example of food-for-protection mutualism and are common between ant (Formicidae) and honeydew-producing insects in the hemipteran suborders Sternorrhyncha (particularly the aphids, whiteflies, scales and mealy bugs) and Auchenorrhyncha (particularly the leafhoppers). The hemipterans observed in the current study to have developed relationships with *W. auropunctata* are all common crops pest (French, 2006) and fall under the two suborders of hemipteran described by Styrsky and Eubanks (2007).

The presence of *W. auropunctata* – hemipteran relationships on the subsistence crops surveyed in this study is quite wide spread and expected according to Way and Khoo (1992) and Rowles and Silverman (2009) who stated that agriculture crops are where ant-hemipteran interaction is very common and where invasive ant species flourish. In the four crops surveyed in the lowland area, such relationships (ant-hemipteran interaction) are more noticeable on the young potato plants, cassava plants and the young leaves of taro and yam plants.

If the concept of food for protection mutualism between ants (Formicidae) and hemipterans (Styrsky and Eubanks, 2007) holds in the subsistence crops in this current study, there is a high probability the hemipteran pests are being protected from their natural enemies and therefore increasing in density. Often mutual relationships between members of the Formicidae and hemipterans involves protection, stimulating feeding rates and fecundity in favour of the hemipteran (Beattie, 1985; Delabie, 2001). This results in the tending ant increasing the negative effects of honeydew-producing hemipterans on plants, including stunted growth and the introduction of plant pathogens, which can decrease plant fitness and productivity (Way, 1963; Buckley, 1987). Protection by tending ants can also lead to large hemipteran population outbreaks in agricultural gardens, resulting in a significantly reduced crop yield (Banks and Macaulay, 1967; Delabie, 2001; Lester *et al*. 2003). Although it was not directly determined in the current study the extent and influence of the relationships between *W. auropunctata* and hemipterans to the productivity and yield of the four crops surveyed, can be assumed to be negative.

Non – hemipteran insects were also noted in the current study to have formed relationship with *W. auropunctata*. For example, two unidentified caterpillar species of Lepidoptera collected in taro and cassava crops were observed to have several individuals of *W. auropunctata* swarm around them as they were feeding. The caterpillars may have secreted exudates that attract *W. auropunctata* as this has previously been seen by Marshall (1999). Although Freitas and Oliveira (1992) highlighted the predatory habits of some ant species on caterpillar, the major predator of the two species of caterpillar found in taro and cassava according to Hinckley, (1964) and Vargo *et al*. (1993) are two species of wasp *Apanteles* sp. and *Trichogramma* sp. No studies could be found that currently confirm predation of caterpillar by *W. auropunctata* or other ant species, therefore, the food for protection relationship with *W. auropunctata* may also extend to non-hemipterans in the subsistence crops surveyed.

Current knowledge on ant-insect relationships focus primarily on hemipteran insects (Lester *et al*, 2003; Styrsky and Eubanks, 2007). This could be due to the known ability of such insects to excrete sugar exudates and the fact that they are crop pest themselves. The ability of other insect species to inflict crop loss as a result of any formed relationship with *W. auropunctata* or other invasive ant species is poorly studied.

It was observed in the current study that *W. auropunctata* tends to congregate in large numbers on the leaves of taro, yam and potato having been grazed or mined by grasshoppers *(Atractomorpha* sp. and *Valanga* sp.). It is possible that these herbivores would have tapped into the phloem of the leaves therefore exposed the sugary sap of the plant, which attracted *W. auropunctata* to their activities.

Being both ground and arboreal dwelling, *W. auropunctata* has a three dimensional foraging habit, where it tends to forage for food on leaf litter on the garden floor and also at higher levels on parts of the crop (Jourdan, 1997). 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 found by the observations taken in the current study.

It was observed in the current study that in the presence of *W. auropunctata* the overall abundance of "non-*W. auropunctata*" tended insects are relatively low. Several studies have shown that the species richness of non-honeydew herbivores including non-predatory and predatory insects was significantly reduced in the presence of ant-aphid relationships (Fowler and MacGarvin, 1985; Mahdi and Whittaker 1993). Kaplan and

Eubanks (2005) also observed a similar pattern in that the relationship between the invasive ant *Solenopsis invicta* and aphids deterred hemipterans spending time on cotton plants. It is possible that a similar situation exists on the crops in the lowland area in the current study. Perhaps in the gardens where *W. auropunctata* tended a number of different hemipteran species, the protective ability of *W. auropunctata* towards those hemipterans affects the presence of predatory insects and the overall herbivores on the crops as well.

Suppression of herbivores by natural enemies is theoretically simple when biological control involves three trophic levels, for example, the herbivorous pest, the natural predator and the host plant (Styrsky and Eubanks, 2007). However, the addition of an invasive ant species such as *W. auropunctata*, as in the case of this study, often has a broad agricultural and ecological effect (Snyder and Evans, 2006; Abbott *et al*. 2007; Grover *et al.* 2007; Lach, 2008). Often invasive ant species such as *W. auropunctata* can alter the behaviour of some predators of crop pests. This was observed in the *S. invicta* – aphid mutualism in cotton plants where the introduction of the invasive ant affected adversely both herbivore and predator taxa on the cotton plants (Kaplan and Eubanks, 2005). Subsistence gardening and agricultural activities like those investigated in the current study have been known to create environments that aid inclusion of invasive ants into the system (Rowles and Silverman, 2009).

5.2.1 Summary

This study has shown eight insect pests, which include six hemipterans and two caterpillars of butterflies that have mutualistic relationship with *W. auropunctata* on the four subsistence crops surveyed. There is sufficient evidence to show that such mutualistic relationships, between invasive ant species such as *W. auropunctata* and honeydew producing hemipterans, can result in outbreaks of hemipterans, which cause yield loss to crop/plants (Beattie, 1985; Delabie, 2001; Holway *et al*. 2002). Such relationships have both ecological as well as economical consequences (Styrsky and Eubanks, 2006). Accurate determination of insect pests that have mutualistic relationship with *W. auropunctata* in the subsistence garden crops is important because it might provide us a with better understanding of (1) pests out breaks and (2) causes of high density of certain insect pests on subsistence crops not properly understood before. Studies into other invasive ant species having mutualistic relationships with crop damaging hemipterans are common (Buckley, 1987; Holway, 2002; Cooper, 2005; Renault *et al.* 2005) and it is on many of the subsistence crops in the Bauro area. It is therefore possible to make predictions of the relationship *W. auropunctata* might have with other pests; particularly those in the aphids, mealy bug and scale insects categories not recorded in the current study.

5.3 Effect of *W. auropunctata* on *Tarophagus* sp. (Taro pest) and *Cyrtohinus fulvus* (natural predator of *Tarophagus* sp.) on Taro (*Colocasia esculenta*) Plants

5.3.1 Population abundance of Tarophagus sp. and *Cytorhinus fulvus per taro plant*

Cytorhinus fulvus is a mirid bug that is almost exclusively found on the taro plant *Colocasia esculenta* and other taro species (Matthews, 2003). This relationship exists because *C. fulvus* is attracted to *Tarophagus* sp., a taro pest that is almost exclusively found on taro plants (Waterhouse and Norris, 1987). *C. fulvus* feeds on the eggs of *Tarophagus* sp. and thereby acts as a natural control mechanism for the pest (Fig. 5.2). On taro plants that are infested with *W. auropunctata*, the *Tarophagus* sp. (taro pest) was observed to have a mutualistic relationship with *W. auropunctata*.

Based on similar studies (Eubanks, 2001; Moreira and Del-Claro, 2005; Altfeld and Stiling, 2006) it was predicted that the populations of *Tarophagus* sp. in the current study would be significantly higher on *W. auropunctata* infested taro plants compared with taro plants free of *W. auropunctata*. This hypothesis proved to be true as population numbers of *Tarophagus* sp. increased with *W. auropunctata* presence. However, contrary to many studies that described the hemipteran-tending ants to be responsible for a reduction of the survival and abundance of specific natural enemies of hemipterans (Tedders *et al*. 1990; Stechmean *et al*. 1996; Kaplan and Eubank, 2002; Renault *et al*. 2005), the current study did not show the same results for *C. fulvus.* Instead, *W. auropunctata* as the ant tending *Tarophagus* sp. on taro plants did not appear to have affected the survival and abundance of *C. fulvus*, the specific natural enemy/predator of *Tarophagus* sp. This is demonstrated by the similarity in the mean abundance of *C. fulvus* per taro plant on taro plants infested and free of *W. auropunctata*.

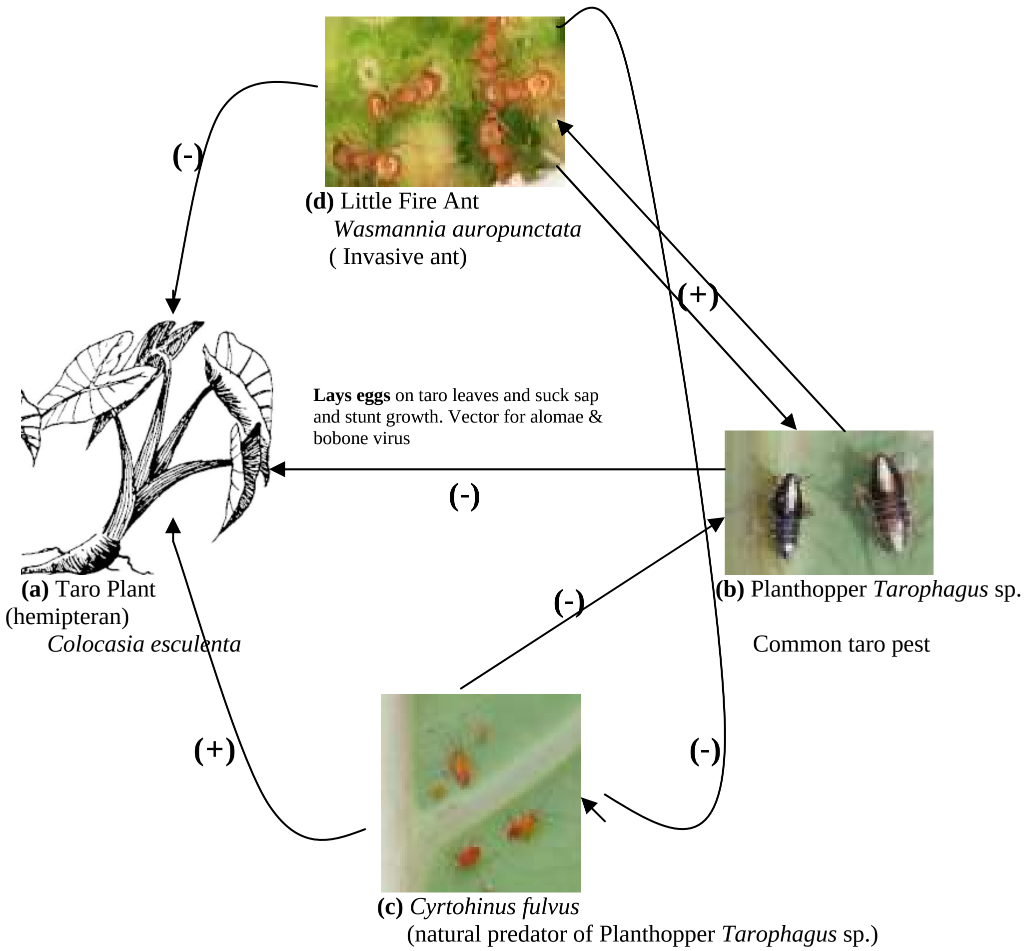


Fig. 5.2 Flow diagram of the relationship between **(a)** taro plant *Colocasia esculenta*, **(b)** Planthopper *Tarophagus* sp; a hemipteran which is a common insect pest found exclusively on taro plants, **(c)** *Cyrtohinus fulvus*; a natural predator of the *Tarophagus* sp. is used as a biological control against *Tarophagus* sp. on taro plants, and **(d)** *Wasmannia auropunctata*, an invasive ant dominant on taro plants in Solomon Islands and which has a mutualistic relationship with *Tarophagus* sp. and responsible for increase and possible outbreak of *Tarophagus* sp on taro plants. (+) = positive relationship; both benefit (plant and insect or both insect), (-) = negative relationship; taro plant or insect is affected.

Although the presence of *W. auropunctata* on taro plants may not have affected the population of the natural predator (*C. fulvus*), *W. auropunctata* appeared to be directly responsible for the increase of *Tarophagus* sp. on taro plants. This may involve *W.*

auropunctata protecting *Tarophagus* sp. from its predator *C. fulvus* and by stimulating *Tarophagus* sp. feeding rate, fecundity and dispersal (Bristow 1983; Buckley, 1987; Delabie, 2001; Billick and Tonkel, 2003). Consequently, *W. auropunctata* may exacerbate the negative effects of honeydew-producing hemipterans such as *Tarophagus* sp. on taro plants, including stunted growth, reduced leaf area and the introduction of plant pathogens, all of which can decrease taro plant productivity (Beattie, 1985; Delabie, 2001).

Del-Claro and Oliveira (2000) showed that the presence of tending ants can have a positive impact on the hemipteran productiveness. *Tarophagus* sp. may have benefited in this way from the presence and the attendance of *W. auropunctata*. It is possible that *W. auropunctata* is providing some form of disturbance to the normal activity of *C. fulvus* such that it prevents *C. fulvus* preying on the eggs of *Tarophagus* sp. This may amount to some form of protection of *Tarophagus* sp against its natural predator (*C. fulvus)*. Therefore, the presence and abundance of *W. auropunctata* on taro plants may be sufficient to provide an environment conducive to an increase and possible outbreak of *Tarophagus* sp.

5.3.2 Summary

The presence and abundance of *W. auropunctata* on taro plants can significantly contribute to the increased population density of the taro pest *Tarophagus* sp. A mutualistic relationship developed between *W. auropunctata* and the planthopper *Tarophagus* sp, or any other crop pests, has a tendency to favour the pests. The presence and abundance of *W. auropunctata* may therefore provide an opportunity for an increase in the number of pests in many subsistence crops. Such an association is often at the detriment of the host plant and this is one of the risks subsistence farmers will have to bear as *W. auropunctata* continues to increase its presence and dominance in subsistence gardens, farms and agricultural sites in the Solomon Islands. Pest management on subsistence crops in the Solomon Islands must be directed towards understanding the role *W. auropunctata* plays on pest outbreaks.

5.4 Implications for Agriculture and Subsistence Farming

Wasmannia auropunctata is the dominant ant species in agriculture and subsistence crop farms in the Bauro lowland area on the island of Makira and most probably in many island lowland areas in the Solomon Islands. This being the case, there is a high probability that *W. auropunctata* has direct and indirect impact on crop loss and the susceptibility of crop plants to diseases and an overall reduction of plant fitness. These are some of the vitally important underlying issues that will need further attention. The current project clearly shows *W. auropunctata* is abundant (mean range from 3095±1117) in gardens for each of the four subsistence crops surveyed. They account for 97% of ants collected in the *W. auropunctata* invaded garden sites and this result is undoubtedly also reflected for other non-surveyed crops as well. For example, Vanderwoude and Masamdu, (2007) noted that *W. auropunctata* is very abundant in PNG on banana plants. This is also confirmed by Clark *et al*. (1982) in other parts of the tropics where *W. auropunctata* has been introduced. The dominance of *W. auropunctata* in other subsistence crops not surveyed in this project is also supported by verbal correspondence from locals in the Bauro area.

There have been studies of invasive ants linked to crop loss (due to direct or indirect effects) as a result of their presence and abundance in a number of crops worldwide. For example, the estimated crop loss due to the effect of *S. invicta* (red imported fire ants) in Texas, USA alone is calculated to be in the range of sixty million dollars a year (Lard *et al*. 2002). Although, there is little published work on the direct and indirect effect of *W. auropunctata* on economic losses associated with lowered crop productivity, a much information is available about the effect of invasive ants on crops in general (Buckley, 1987; Fowler *et al*. 1990; Way and Khoo, 1992; Michaud and Browning, 1999; Addison and Sammy, 2000; Helms, 2002; Coppler *et al*. 2007). For example, the invasive ant *L. humile* is linked to variety of crop losses due to its association with hemipteran pests (Addison and Sammy, 2000), and studies of associations between *S. invicta* and aphids showed that *S. invicta* tends aphids extensively (Helms, 2002; Coppler *et al*. 2007). As the dominant ant species in subsistence crops in Bauro lowland areas, it is highly likely that *W. auropunctata* inflicts crop damage through either direct and indirect means or both.

In the current study, an obvious but little known route to crop damage as a result of the "*W. auropunctata* – hemipteran" mutual relationship is the spread of alomae and bobone virus which can cause wilting and stunted growth in taro plants (Matthews, 2003). The abundance of *Tarophagus* sp. on taro plants is a serious concern for farmers (Fullaway, 1940; Matsumoto and Nishida, 1966; Waterhouse and Norris, 1987; Matthews, 2003). Although different species of the hemipteran *Tarophagus* are common in the Pacific, their effect on taro plants may be increased by the relationship with *W. auropunctata*. It has however been suggested that under natural conditions, hemipterans as *Tarophagus* sp. do not reach high densities and therefore their presence is not generally destructive (Rico-Gray and Thien, 1989).

The current study proposes that taro farming in Bauro lowland areas (that are infested with *W. auropunctata*) are more prone to an increase of hemipterans such as *Tarophagus* sp. and consequently the crops probably have an increased susceptibility to viral and fungal disease. Although there is no published work on the impact of the relationship between *W. auropunctata* and *Tarophagus* sp. on the productivity and fitness of taro plants, there is evidence from the current study on Bauro to correlate the abundance of *Tarophagus* sp. to the presence and dominance of *W. auropunctata* on taro plants. The ability of *W. auropunctata* to protect *Tarophagus* sp. against C. *fulvus* can only lead to an increase of *Tarophagus* sp in taro plots and hence the relationship between *W. auropunctata* and *Tarophagus* sp. is a problem for farmers.

Several studies have highlighted the importance of *C. fulvus* as a biological control agent against *Tarophagus* sp. on taro plants (Fullaway, 1940; Pemerton, 1954; Waterhouse and Norris, 1987; Esguerra, 1997). Following an outbreak of *Tarophagus* sp. on taro in Hawaii in the 1930s, *C. fulvus* was introduced to taro farms, which brought *Tarophagus* sp. under control (see Fig.5.3) (Fullaway, 1940). This was also the case in Guam in 1947 when *C. fulvus* was introduced for the same reason (Pemerton, 1954) and on Yap and Kosrae (Esguerra, 1997).

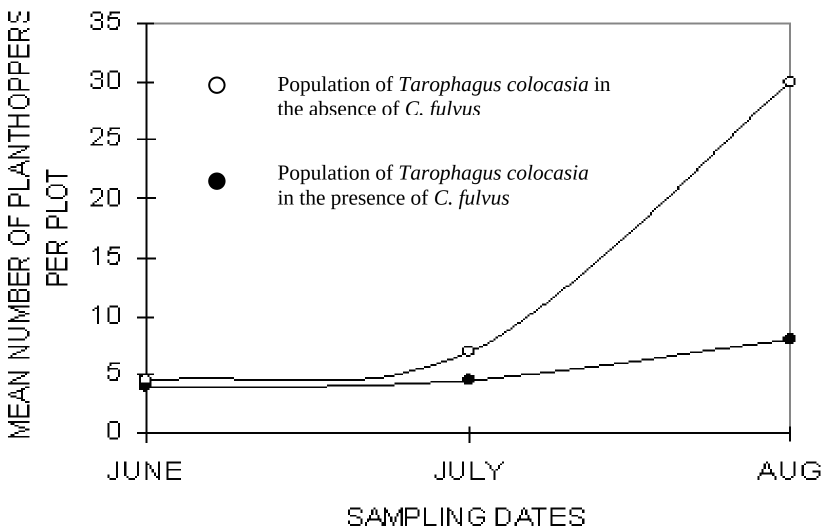


Fig. 5.3 Graph showing the **e**ffect of *C. fulvus* on population of *Tarophagus colocasia* in Hawaii. (Adapted from: Matsumoto and Nishida, 1966).

Recent verbal reports from the Solomon Islands in 2008 (H. Tsastia, pers. comm.) have identified a serious problem of *Tarophagus* sp on taro plants on Rennell Island, a small outlying island on the southern most part of Solomon Islands, (see Fig. 3.1, marked in dark square). The taro plants under attack from *Tarophagus* sp. are also heavily infested with *W. auropunctata* (H. Tsastia, pers. comm.). Work is currently underway to determine the distribution of *C. fulvus* (Agriculture Department, pers. comm.). *C. fulvus* is an important biological control agent for *Tarophagus* sp. and some think it should be introduced to countries in the Pacific where *Tarophagus* sp a problem (Waterhouse and Norris, 1987). Although *C. fulvus* was effective in controlling *Tarophagus* sp. on taro plants in other Pacific countries, it may not work effectively on the *W. auropunctata* infested taro gardens in the Bauro lowlands. *W. auropunctata* interferes with *C. fulvus* control of *Tarophagus* sp. reducing the effectiveness of *C. fulvus* as a predator and consequently increasing the population of *Tarophagus* sp. Such a relationship is supported by Cushman and Beattie (1991), Moreira and Del-Claro (2005) and Helms (2002), for ant tended hemipterans.

According to Bauro farmers *W. auropunctata* is the major cause of disturbance to farming activities of the farming communities of Bauro area. Some farmlands in Bauro areas are untouched due to the abundance of *W. auropunctata*. There are also reports of a shift in farming practices (Bauro farmers. pers. comm.). Bauro farmers have developed new gardening times and methods to avoid the nuisance of *W. auropunctata*. For example, gardening is often conducted on rainy days, which is a shift from previous "normal" gardening practices. Experience has shown farmers that *W. auropunctata* is less active during rainy days. Cole *et al*. (1992) support this in their findings that ants do not forage during rain days.

Proving quantitatively how much a farmer is losing in terms of crop production because of disturbance by *W. auropunctata* could be a difficult task. However, going by anecdotal reports from rural village farmers on Bauro areas, Makira Island in the Solomon Islands it is possible to see the difference in farming crop productivity (Bauro farmers. pers. comm.). If the effect of *W. auropunctata* on the work output of a rural farmer can be quantified, it would show how much damage *W. auropunctata* might have caused to the livelihood of a rural Solomon Islander. Quantitatively linking the disturbance *W. auropunctata* causes to the direct or indirect impact on crops is an area very much understudied.

5.4.1 Summary

The findings in this study concur with anecdotal reports that fewer farmers in the Bauro lowlands are involved in taro farming. This is evident during the field survey for *Tarophagus* sp. and *C. fulvus* as a very large area had to be covered just to sample 28 taro gardens of gardens size 25 taro plants and above. This contrasts with the Bauro highlands area where a number of taro gardens are within short walking distances from each other. The reasons for the reluctance of farmers to be involved in taro farming were primarily focused towards the prevalence of diseases, wilting and stunted growth as a result of pests. Apart from taro beetles as a major pest of taro (Theunis and Aloali'i, 1999; Adams, undated) it is strongly suggested that *Tarophagus* sp. (with its relationship with *W. auropunctata*) is the new and previously under-recognised threat to successful taro farming in the Bauro lowland area on Makira Island and other *W. auropunctata* infested taro farms in the Solomon Islands.

CHAPTER 6

CONCLUSION and RECOMMENDATIONS

6.1 Major Findings of this study

This research has highlighted that *W. auropunctata* impacts negatively on the native ant fauna found in subsistence gardens in the Solomon Islands. By becoming the dominant ant species in disturbed lowland gardens, *W. auropunctata* has effectively eliminated many of the native ants known to be present in lowland garden areas. *W. auropunctata* is also the dominant invasive ant species in subsistence garden crops in the lowland area. Compared with the native and introduced ants found, *W. auropunctata* has shown an astonishing dominance and abundance. In the subsistence gardens where it was present, *W. auropunctata* made up 97% of the total number of ants found. This is attributed to *W. auropuncatata's* ability to eliminate most other ants by their aggressive nature and therefore being able to deprive them of food resources.

Gardening activities offer considerable opportunities for the introduction of *W. auropunctata* to new sites. This is because *W. auropunctata* as an invasive "tramp" ant is spread through human mediated activities and local gardening practices. These local practices involve regular movement of planting materials from one area to another. Whenever planting materials from a *W. auropunctata* infested garden site are transported to a new garden site free of *W. auropunctata*, an opportunity for the spread of *W. auropunctata* is created. Therefore, as community gardening continues to move inland and into previously undisturbed forests, so follows the spread of *W. auropunctata*. Although the studied garden sites in the Bauro highland area are still currently free of *W. auropunctata*, it should be noted that within the villages and gardens closest to the villages in the highland area, *W. auropunctata* is present and it is quite possible that gardens that did not have *W. auropunctata* during the time when this study was conducted, could have been by now invaded.

The dominance of *W. auropunctata* on subsistence crops also has negative consequences for the social aspect of farming, crop production and economics as well as native ant fauna. For example, *W. auropunctata* has established relationships with a number of hemipterans that result in lower crop health. Fifty percent of these hemipterans are well documented crop pests. Such important relationships have been seen in the current study and previous studies (Jourdan 1997; Jourdan *et al*. 2002; 2006; Le Breton *et al.* 2005) to assist the hemipteran pests to increase their damaging activity. However, based on the observations made in the current study (on a number of hemipterans tended by *W. auropunctata* in the four subsistence crops surveyed) *W. auropunctata* may also have developed similar negative relationships with many more crop damaging invertebrates not previously observed. The current study also determined that the presence and dominance of *W. auropunctata* on taro plants interfered with the natural predator *C. fulvus* ability to prey on the Taro pest *Tarophagus* sp. and hence provided an opportunity for *Tarophagus* sp. to increase its population numbers resulting in unhealthy taro plants. This being the case, it is strongly suggested that for any other crop pests (particularly those that may provide sugar exudates) *W. auropunctata* may also protect the pest against its natural predators thereby allowing these pests to substantially increase their numbers. This in turn could make biological control a less successful means of controlling pests within crops.

Furthermore, the cost of the infestation of *W. auropunctata* to the Solomon Islands or any Pacific Islands may go beyond the impact on invertebrates and vertebrates, crops and farmers. It has greater substantial implications for the national economy as there are both visible and hidden costs associated with the presence of *W. auropunctata* in the Solomon Islands or other Pacific Islands and therefore, it is important that such issues are brought to the surface and given close attention by the agriculture departments and governments.

In summary, the presence of *W. auropunctata* in subsistence garden environments in the Bauro lowlands area leads to a reduction in overall ant fauna. Secondly, *W. auropunctata* appears to have developed a mutualistic relationship with a number of hemipterans present on the subsistence crops and many of these insects are the common crop pests. Thirdly, the presence and dominance of *W. auropunctata* on subsistence crops provides an environment for insect pests to thrive. Therefore, *W. auropunctata* or

Little Fire Ants, as they are better known, pose an economic as well as an ecological risk to subsistence farming in Solomon Islands.

6.2 Recommendations and Future Work

This study had two parts; the ecological biodiversity aspect and the agricultural crop issues both as a consequence of the impact of the dominance of *W. auropunctata* in the environment. As the study progressed, it became apparent that there were a number of questions this study could not adequately answer and that there were also vitally important issues that were outside the scope of the study. In particular, it is important to investigate further the real state of the ecological and agricultural impacts of *W. auropunctata* in the Solomon Islands.

On the ecological side, several areas require further work. This includes the following;

i. Ascertain and quantify the exact status of the distribution and abundance and of *W. auropunctata* in the Solomon Islands. This would involve extending the current survey into other environments and other islands. For example, a larger survey should be conducted across a cross-section of environments, including garden sites, non – garden sites, shrubs, low land forests, swamp environments and mountain forests. Such surveys would encompass both disturbed and undisturbed environments. This would provide accurate information as to the spread and the extent of the Little Fire Ant intrusion to add weight to anecdotal reports. Such information is vital because it would provide a sound basis for any proposed containment or eradication measures.

ii. Quantify the ecological impact of *W. auropunctata* in the Solomon Islands. This would involve investigating the extent of *W. auropunctata* impact on other invertebrates and vertebrates in both disturbed and undisturbed areas. Much is known about the adverse effect of *W. auropunctata* on domesticated cats, birds and dogs by means of anecdotal reports. However, it is important to substantiate such claims via scientific methods that produce well-documented written papers.

iii. Prevent the spread of *W. auropunctata* into designated Conservation areas. A number of areas in the Solomon Islands have recently been declared conservation areas or reserve forests through community initiatives with support from overseas environmental groups. This is needed for the conservation of the unique biota that many of the local communities can benefit from in monetary terms. For the sake of the conservation of biodiversity, individuals or groups owning such conservation areas must be educated on the invasiveness of *W. auropunctata*, and how it can be responsible for severe reductions of biodiversity. It is important to implement measures to stop the intrusion of *W. auropunctata* into such reserve areas. One method is to ensure that all gardening or agricultural activities should be ceased 1 km from the edge of the reserve forests. This would create a buffer zone that should exclude logging activities as well. Secondly, no plants or planting materials should be taken into the reserve forests from any gardening sites.

On the agricultural side, it is important to investigate the following;

i. Further work is needed on the effect of *W. auropunctata* on natural predators of insect pests that have established mutual relationships with *W. auropunctata*. It is important to determine the true impact of *W. auropunctata* on these natural predators so as to provide a sound basis for further remedial action. In order to do this, it will be important to carry out experimental work on *W. auropunctata* and its natural predators on all crops utilized by farmers. This will involve exclusion type experiments, where *W. auropunctata* is excluded from crops and the behaviour and abundance of predators as well as the pests tended by *W. auropunctata* can be observed and compared when *W. auropunctata* is present. This could be a full factorial design experiment as such approach will provide meaningful and worthwhile outcomes.

ii. Quantifying the effect of *W. auropunctata* on crop production and community economics. It would be meaningful to determine the effect of *W. auropunctata* on crop productivity by comparing the dry weight of the crops infested and free of *W. auropunctata*. Using the same design as set up for (i), it would be possible to determine the dry weight of crops infested with *W. auropunctata* and the same for crops where *W. auropunctata* is excluded. This should be conducted for a number of different crops. Such information would be very useful to substantiate and help quantify the negative economic impact of *W. auropunctata* on subsistence farming and agriculture.

Finally but equally important is the need to look at the impact of *W. auropunctata* on the life of ordinary Solomon Island farmers and their family. This could be undertaken by doing a qualitative analysis that looks at how *W. auropunctata* may have impacted on the overall life style of a farmer and his family. For example, does the stinging ability of *W. auropunctata* reduce the time farmers spend in their gardens or doing farming? Does it also reduce the work output or size of garden farmers establish and tend? Also how can we quantify the social impact of *W. auropunctata* on life style of a farmer into economic terms? For example, is it possible to equate reduced time spent farming with income return in the long term? These are important questions that need answers. Although reports of invasive ant occurrence in the Solomon Islands and the Pacific are well known, virtually no research has been undertaken to fully understand the social and economic losses involved.

By carrying out some of the recommendations stated above as new projects, it will provide relevant authorities such as; Agriculture Departments in the Solomon Islands, the Secretariat of the Pacific Community (SPC), environmental groups and other stake holders with strong baseline information that will allow them to collaboratively implement meaningful planning and remedial work in terms of biosecurity for the region. This in combination with the results of the current study, the additional results of these recommended new projects will also provide concrete information about the real threats and risks of *W. auropunctata* to human livelihood in the Solomon Islands.

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Appendices

Appendix 1.

List of ants and abbreviations

Genus and species name	**Symbol of Ant species**
Pheidole oceanica	Ph.M1
Pheidole sp.2	Ph.M2
Polyrachis sp.1	Po
Paratrechina stigmatica	Pa.M1
Paratrechina vaga	Pa.M2
Paratrechina consuta	Pa.M3
Paratrechina oceanica	Pa.M4
Rhytidoponera sp.1	Ry
Oecophylla smaragdina	Oe
Odontomachus sp.1	Od
Anoplolepis gracilipes	An
Camponotus sp.1	Ca
Wasmannia auropunctata	W.a

Appendix 2.

Summary of raw data

Mean number of ants collected by two methods on the 4 subsistence crops on Bauro lowland area. THC – Timed Hand Collecting method

Four Subsistence crops									
Ant species	**Potato**		**Cassava**		**Taro**		**Yam**		**Total**
	Baiting	**THC**	**Baiting**	**THC**	**Baiting**	**THC**	**Baiting**	**THC**	
Pa.M1	2	5	0	0	0	0	0	0	7
Pa.M2	19	2	5	9	36	12	15	10	108
Pa.M3	0	0	0	0	0	0	0	0	0
Pa.M4	10	6	8	3	18	14	17	13	89
Ph.M1	0	0	0	0	0	0	0	0	0
Ph.M2	0	0	0	0	0	0	0	0	0
Po	0	0	0	0	0	0	0	0	0
An	0	0	0	0	0	0	0	0	0
Ca	0	0	0	0	0	0	0	0	0
Ry	0	0	0	0	0	0	0	0	0
Oe	0	0	0	0	0	0	0	14	14
Od	0	0	0	0	0	0	0	0	0
W.a	2430	45	6442	25	1878	80	1650	69	12619

Mean number of ants collected by two methods on the 4 subsistence crops on Bauro highland area.

Four Subsistence crops									
Ants specie	**Potato**		**Cassava**		**Taro**		**Yam**		**Total**
	Baiting	**THC**	**Baiting**	**THC**	**Baiting**	**THC**	**Baiting**	**THC**	
Pa.M1	25	16	73	23	182	36	0	15	370
Pa.M2	353	11	42	14	670	23	77	2	1192
Pa.M3	30	14	2	1	3	1	21	7	79
Pa.M4	39	8	37	8	0	0	0	0	92
Ph.M1	5	2	2	0	3	1	353	28	394
Ph.M2	238	19	17	5	0	0	201	2	482
Po	0	8	0	15	0	13	1	17	54
An	0		0	0	0	9	9	16	34
Ca	0	2	0	2	0	2	0	1	7
Ry	4	15	0	13	0	6	2	3	43
Oe	0	4	15	24	0	8	7	31	89
Od	3	20	3	22	0	23	1	14	86
W.a	0	0	0	0	0	0	0	0	0

Appendix 3.

Statistical tests (T-Test)

Group Statistics

	Two Sites sampled	N	Mean	Std. Deviation	Std. Error Mean
Native Ants	Site 1	11	6.1818	13.34030	4.02225
	Site 2	12	213.2500	309.37154	89.30787

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Native Ants	Equal variances assumed	4.052	.057	-2.214	21	.038	-207.06818	93.54288	-401.60126	-12.53511
	Equal variances not assumed			-2.316	11.045	.041	-207.06818	89.39840	-403.73580	-10.40057

T-Test

Group Statistics

	Sample	N	Mean	Std. Deviation	Std. Error Mean
Tarophagus sp	1.00	28	49.9964	22.94981	4.33711
	2.00	28	17.9643	6.84031	1.29270
C. fulvus	1.00	28	3.5079	1.87005	.35341
	2.00	28	4.2025	1.31991	.24944

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Tarophagus sp	Equal variances assumed	33.625	.000	7.078	54	.000	32.03214	4.52565	22.95875	41.10553
	Equal variances not assumed			7.078	31.760	.000	32.03214	4.52565	22.81095	41.25334
C. fulvus	Equal variances assumed	3.300	.075	-1.606	54	.114	-.69464	.43257	-1.56189	.17261
	Equal variances not assumed			-1.606	48.553	.115	-.69464	.43257	-1.56413	.17484