YELLOW CRAZY ANTS AND FRUIT FLY SURVEYS IN TUVALU

25th October to 4th November 2014







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Executive Summary

Survey of alien invasive species (AIS) ants, particularly, the Yellow Crazy Ant (YCA), and their impacts on native biota were undertaken in Tuvalu towards the end of October 2014 for a period of one week and was co-funded by the Secretariat of the Pacific Community (SPC), through its Biosecurity and Trade Services (BATS) section of the Land Resources Division (LRD), and Tuvalu government. The survey was carried out on Fongafale islet (Funafuti atoll), Niulakita Island, and five islets in the Nukulaelae atoll. An entomologist from SPC and two Quarantine staff from Department of Agriculture of Tuvalu participated in the survey.

The survey was carried out in fulfilment of a request by the Tuvaluan government to SPC, if all possible, to eradicate or at least reduce the populations of YCA which was reported to have adversely affected and reduced both land and coconut crab populations in some islands in Tuvalu. The main complaint came from the community of Nukulaelae atoll, through its Local Island Council (LIC) or

Taupule, on YCA which has already invaded five of their eighteen islets with unprecedented overwhelmed high population densities.

Key findings in the survey showed a total of 18 ant species altogether were found present on the different localities surveyed. The distributions of the different ants according to the islands and regions were documented. Some ant species were found to be more common among others while others were only present in certain localities thus posing quarantine threats to those areas of pest freedom.

Yellow crazy ant was confirmed to be present in Fongafale Islet (Funafuti atoll), only some parts of Niulakita Island and some islets of Nukulaelae atoll. Three of the islets in the Nukulaelae atoll were confirmed to be infested with YCA. Anecdotal reports from the locals suggested two other islets in the Nukulaelae atoll that were not visited due to time constraint also had YCA infestations.

Population intensity for all the ant species varied from among the different localities and, perhaps, depended on how long the ants had been there, food source availability and the level of disturbance that these ant colonies received from human and other animal activities at the respective localities.

The impact of YCA was quite evident in the results of the survey with the apparent extinction or suppression of other species of ants. Furthermore, there were evidence of dead land crabs and earthworms on the islands during the survey that consolidated the urgency to eradicate or manage YCA on these islands. According to the locals of Tuvalu there were only small remnants of coconut crabs existed on islands owing largely to the adverse impact of YCA.

Asia and Mulitealua islets in the Nukulaelae atoll that were about 30m and 500m away, respectively, from Motala islet (which was infested with YCA in high population density for years) were surprisingly free from YCA infestation. The above mentioned incidence disproved the general belief that purports that alate queen ants can disperse naturally to new locations after nuptial mating flight with male ants. Natural dispersal of YCA can only be possible through budding process where new queens are making new nests close to existing colonies and form super-colonies. The spread of YCA from island to island and even within island at long distances away depend very much on human and other mediated activities, especially when transferring soil, plant materials, equipment and others with complete colonies of YCA.

Key recommendations for Tuvalu government, especially the communities affected by key AIS ants, particularly, YCA encompass strengthening of biosecurity through quarantine awareness, regular ant inspections and monitoring surveillance, and border security enforcement to contain and avoid their further spread. Localities that are already infested with invasive ants may try eradication or management interventions.

Key Terms and Acronyms

Glossary

Contain/containment: Keeping an invasive species within a defined area.

Control: Reducing the population of an invasive species.

Eradication: Intentional extirpation of geographically discrete populations of a species, irrespective of whether other discrete populations still remain within the landscape.

Impact(s): A routinely used term in invasion ecology and management that refers to the negative effects of an invasive species on resident native organisms (biodiversity), agriculture, economy, health or lifestyle.

Incursion: A single arrival event of an invasive species in a new environment.

Infestation: A single discrete area where the invasive species is localised. An incursion consists of one or more infestations.

Alien invasive species ants: Ant species that become destructive to the environment or human interests in one or more ecological or environmental contexts. Not all invasive ants have major negative effects, and for many species the effects are density-dependent (i.e. effects only occur or are perceived by humans as negative when a threshold of abundance is reached).

Alien invasive species: Introduced species that become destructive to the environment or human interests; can also include some native species that proliferate and become destructive following environmental changes caused by human activities.

Management: Reducing or eliminating the impacts of established invasive species, by eradication, containment, exclusion, or population reduction by physical, chemical or biological control.

Monitoring:	A continuous close follow-up on a programme to detect changes and keep track of progress, for example in the distribution of invasive species, the success of management projects etc.
Mutualistic:	A co-existence of two or more species, for example an ant species and hemipteran species, that benefit each other, and often at the expense of others
Suppression control:	Management actions that aim to reduce populations of a species, thereby reducing impacts, or preventing further dispersal
Treatment:	Application of control measures at a single point in time

Acronyms

AIS:	Alien Invasive Species
BATS:	Biosecurity and Trade Services
Bt:	*Bacillus thuringiensis*
GPS	Global Position System
IUCN/SSC:	International Union for Conservation of Nature)/Species Survival Commission
ISSG:	Invasive Species Specialist Group
LFA:	Little Fire Ant
LIC:	Local Island Council
LRD:	Land Resources Division
PII:	Pacific Invasive Initiative
SPC:	Secretariat of the Pacific Community
SPREP:	Secretariat of the Pacific Environment Programme
TTM:	Taiwanese Technical Mission
YCA:	Yellow crazy ant

1.0 **Introduction**

Yellow crazy ant (YCA), *Anoplolepis gracilipes* Smith, is a tramp ant; with all workers morphologically same in appearance, relatively large body approximately 5mm long, yellow to orange in colour with long legs, large eyes and extremely long antennal scape. It is considered by the International Union for Conservation of Nature)/Species Survival Commission (IUCN/SSC) Invasive Species Specialist Group (ISSG) to be among the 100 worst Alien Invasive Species (AIS) (Csurhes and Hankamer, 2012). Being an invasive ants, YCA can substantially devastate and alter an entire ecosystem if eradication or management interventions are not given early enough (Sakai *et al*. 2001 and Wetterer and Porter 2003). In the Pacific Islands context, particularly in small atoll islands, the impact of invasive ants on ecosystems has an even greater implication due to the vulnerability of limited biodiversity. The devastation on the environment in localities where invasive ants have established is evidently threatening and catastrophic. A very good example was seen on Christmas Island in the Indian Ocean, where the presence of YCA has been blamed for the unprecedented declining of thousands and, even millions, of land red crabs (O'Dowd et al. 2003). Another classical negative impact of invasive ant was reported in Solomon Islands, where the Little Fire Ant (LFA), *Wasmania uropuntata,* has apparently causing blindness to many domesticated animals, especially dogs (Fasi 2009).

The impact of invasive ants in connection to economic and agricultural costs can be substantial, particularly when considering the cost of trying to contain and manage, or even eradicate both new incursions and established populations. An example of such economic impact can be seen in Australian when the government have been spending more than AUD 275 millions in its effort to try and contain and eradicate the Red Imported Fire Ant (RIFA) in Southeast Queensland (Keith and Spring 2013). Even with such astronomical spending, the battle to contain RIFA is still raging and has taken to a new landmark twist when it was recently discovered in Sydney in December 2014 (Dye 2014).

Ants have symbiotic mutual relationship with hemipterans (mealybugs, scales and aphids) and are known to be capable of farming hemipterans in exchange for sugary honey-dews and therefore protecting them from natural enemies (Csurhes and Hankamer 2012). Hemipterans are plant pests that are known to inflict direct damage to plants through sucking of plant saps in exchange for toxin injections to host plants causing metabolic dysfunction and low yields, and even death to plants (Hill et al. 2002; Styrsky and Eubanks 2007). Some, hemipterans, especially aphids, are also indirect havoc to plants as vectors of important plant diseases, such as mycoplasma and viruses (Persley *et al*. 2010). Also, another indirect impact of invasive ants to agriculture and environment can be seen in the proliferation of sooty-moulds on surfaces of leaves and branches of plants that hamper photosynthetic process to take place on plants thus adversely affecting plant health. In this case, ants can be blamed for coming into contact with honey-dews as they feed on them and farm the hemipterans and in so doing spread traces of them on plant leaves and branches which fungi love to grow on to form the black sooty mould (Nelson 2008).

On the contrary, invasive ants may also contribute positively to agriculture in that they are regarded as natural enemies of other pests of crops like cocoa, and coconut coffee (Csurhes and Hankamer 2012). In most cases, or if not all, these invasive ants are generally known for their adverse impacts and may not have been intentionally introduced as biological agents, but once they are well established in the localities, then they can also have impact to control pests. For example, the big headed ant, *Pheidole megacephala*, and YCA were found to have reduced pest damage level on coconut at places where these ants were present in Papua New Guinea (McGregor and Moxon 1985; GISD 2009)

The origin of YCA is still uncertain but some people believed that it must have come from South-East Asia (Drescher *et al*. 2007). Yellow crazy ant is not the only ant that is called crazy. There is also another ant that is also acting similarly crazy and is called the Black crazy ant (*Parachitina longicornis*). These species are named “crazy ants” because of their erratic walking style and frantic movements, especially when disturbed (Fact Sheets of State of Queensland 2013).

A colony of YCA usually has eggs, larvae pupae, queen (queens), workers and males. Eggs of YCA usually hatch in 18 - 20 days at 20 - 23^{o}C (Fluker and Beardsley 1970). In the tropical warmer region, the timing of development may be faster. Worker larvae and pupae develop in 16 - 20 days and 20 days, respectively. Workers can live approximately 6 months.

Newly emerged adult males and queens have wings, which some people believed to aid them to fly some distance away from original colonies to establish new nests (Abbott *et al*. 2005). However, ants can also disperse naturally by nest budding where the queens and workers, after mating, relocate to new nest in the vicinity of their original colonies (Clark *et al*. 1982). It is very fundamental to note that for new queen nests to survive, they have to be initially assisted by workers from existing nearby colony or colonies.

Only the queen is the fertile female in a colony and is capable of laying 700 eggs annually in her life time of several years (Fluker and Beardsley 1970). The workers are sterile females and therefore are not usually capable of reproducing off-springs. The job of the workers is to take good care of the queen, the larvae, pupae and making sure all the rest of nest affairs are in order. The workers are the, farmers, scavengers and foragers that bring in food for the queens and juveniles inside the nests. The function of the males in the colony is to mate with the queens and then die thereafter.

After the mating flight, the queen lands at a distance closer enough to an existing colony for workers to tend and take care of herself and her initial off-springs. Super-colonies can expand between 37m to 402m per year (Holway et al. 2002). Therefore, the main and perhaps, the only possible way that YCA can colonize new localities further away from original ant nests is through human-mediated dispersal activities (Csurhes and Hankamer 2012). Between countries, YCA are readily dispersed as contaminants in a range of cargo. They can be spread in soil and produces in the agricultural and horticultural industry; on contaminated military equipment, mining and commercial road transport equipment; and in sea and air freight on timbers, goods, packaging material and pallets. (GISD 2009).

Unlike other ants which can invade and thrive in only either disturbed or undisturbed area, YCA is known to be capable of existing in both environment, even in native forest habitats and attaining high rich densities (Haines and Haines 1978).

1.1 **Objectives of the survey**

The purposes of the survey trip in Tuvalu during specified period were as follows:

- To investigate and assess the occurrences and population distributions and intensities of ant species in the southernmost atolls and a coral reef islands of Tuvalu. These atolls Funafuti and Nukulaelae, while the coral reef island was Niulakita Island
- To assess the risk of new ant species arrivals and the biosecurity tasks needed on island or islets that already had AIS ants, with particular interest on YCA and together with community awareness and preparedness for responding rapidly to new incursions;
- To assess the social, environment and economic impacts of YCA in Funafuti and Nukulaelae atolls and Niulakita Island;
- To assess management options for YCA on the islands;
- To assess the current management and monitoring systems on threatened and sensitive biota such as coconut crabs, land crabs, earthworms, turtles, seabirds and others;
- To assess the technical information and support that department staffs of Tuvalu from Agriculture Quarantine and Extension and Environment require containing, managing and if possible eradicating YCA in the future in Tuvalu.

2.0 Materials and methods in the surveys

2.1 General description of Tuvalu as the survey sites

Formerly known as the Ellice Islands, Tuvalu is an independent island nation in the middle of the Pacific Ocean (between latitude of 7° 6' 34.326"7 and longitude of 177° 38' 57.5874") and comprised of four isolated coral reef islands and five coral atolls. The total area of Tuvalu is 26 km^{-2}. The country has two distinct seasons; a wet season from November to April and a dry season from May to October, with average annual rainfall between 1,920 – 2,400mm. The maximum temperature is between 31–32°C and the minimum temperature between 25–26°C all year round. Air temperatures are strongly tied to the ocean temperatures surrounding the islands and atolls of the country.

The vegetation of the islands is typical of small Pacific atolls and coral reef islands that comprises of varying areas of indigenous trees, low in diversity, but dominated by coconut palms and pandanus.

The survey of AIS ants in Tuvalu was conducted on Fongafale Islet (Funafuti atoll) (28th October 2014), Niulakita Island (30th October 2014) and five islets in the Nukulaelae atoll (31st October 2014). Five sites were surveyed at these localities to determine the presence of different ant species and their population distributions and densities.

Figure 1.0 Map of Tuvalu (Source: World Atlas.com)

2.2 Fongafale site and activities

Fongafale Islet is the largest and longest of all the 33 islets of Funafuti atoll. It is also the main inhabited islet in the Funafuti atoll, which is the capital of Tuvalu. This islet is the main gate way to Tuvalu as a nation which has the main seaport and only airport. The airfield was constructed during World War II and is now the Funafuti International Airport, which serves both as the airstrip for the flights, mainly from Fiji (twice a week schedule), as well as providing a place for sporting and other recreational activities.

Five selected sites that were surveyed on Fongafale Islet included quarantine high risk areas, farming areas, and localities where food sources were deemed to be abundant for ants' population to thrive best. These five sites included the rubbish dump, main wharf, Airport terminal building (including Filamona Guest-house), Taiwanese Technical Mission (TTM) farm and a piggery sty compound. Each of the sites had eight sub-sites which were about 5m apart and where two traps were place 2m apart; one trap had a protein-based bait which comprised of a combination of a cubic centimetre of a piece of sausage and a cubic centimetre of peanut butter, while the other trap was a sugar-based and comprised of one part of sugar dissolved in one part of water.

Plastic DRAM specimen tubes of clear styrene, non-wadded with lids were used as traps (53mm x 35mm or 44.36ml approx.) (Figure 2 b) and c)). The baits were put inside a specimen tubes which were then placed on the ground, directly side-ways with lids removed. A truck was used to install and about two hours later collect the traps at the sites. At collection time, the collector would quickly lifted the trap off the ground with one hand and another hand swiftly closing and screwing back the lid on before the ants inside the tube could escape. Ants inside the closed tubes were then taken to the quarantine laboratory and killed by freezing for more than three hours before they were sorted, labeled and put in specimen bottles and ready for shipment to SPC laboratory in Suva (Fiji) for determination of their species identities and population counts.

Figure 2.0 a) Matio Lonalona (Senior Quarantine Officer) installing an ant at Funafuti Airport; b) Protein-based bait; and b) Sugar-based bait with ants.

2.3 Niulakita site and activities

Niulakita Island is an isolated and the southernmost reef island of Tuvalu. The isle has an oval outline, with the longer axis running east-west (about 1 km long). This island features highest point of Tuvalu (4.6 metres (15 ft) above sea level).

A similar set up as in Fongafale Islet was carried out in Niulakita Island. The same type of trap and baits were used there as well. Again, five sites with eight sub-sites (each sub-site with each of the bait-types) were installed in the morning of Thursday 30th October 2014 and collected two hours later in the afternoon. Installation and collection of the traps were done by walking. The trap sites included the main landing area, the village compound, piggery sty area, a picnic area and a coconut plantation. Again, the same procedure as executed in Funafuti was followed through during the retrieving of traps and collection time of ants. The ants in the traps were taken to the ship (MV Kavaga II) where they were killed before being sorted, transferred into specimen tubes, labeled and ready to be taken to Fiji for determination of ant species identities and population counts.

2.4 Nukulaelae site and activities

Nukulaelae is the southmost atoll of Tuvalu, with the form of an oval and consists of at least 18 islets. The inhabited islet is Fangau, which is 1.5 kilometres long and 50 to 200 meters wide.

The survey in Nukulaelae atoll was conducted in the similar way as on Fongafale (Funafuti) and Niulakita, except that this time each sub-site was represented by an islet than a locality within an island/islet. The five islets surveyed included Fangau (the main inhabited islet of Nukulaelae atoll), Motala, Asia, Mulitealua and Tumiloto. Eight sets of trap of the two bait-types were installed on each of islets on Friday the 31st of October 2014 and were collected about 2 hours later. A motor bike was used to install and collect traps on Fangau Island, while similar installations and collections of traps on the other islands were made possible with the use of an outboard motor engine boat. Again, the ants collected in the traps were taken to the ship where they were put into a freezer to die before being sorted, transferred into specimen tubes, labeled and ready to be taken to Fiji for determination of their species identities and population counts.

2.5 **Other sites and activities**

Other activities that were also carried out on these atolls and islands/islets included fruit fly trap surveillance to update fruit fly records, investigation on the cause of defoliated and death of trees, *Cordia subcordata* (known as Kanava in Tuvalu) on Funafala islet in the Funafuti atoll, and brief visitations to two conservation islets (Tefala and Fuagea) of the Funafuti atoll where seabirds used as roosting and breeding habitat.

3.0 **Results of the survey**

The results of the ant survey that was carried out on Fongafale (Funafuti) and Nukulaelae atolls and Niulakita has revealed some fundamental information, particularly about the different species of ants that were present and distributed on the islands. The results, to a certain extent, also showed how the presence or absence of certain species of ants had affected the very existence and populations of other ant species. The results also portrayed the responsive preference in terms of the numbers for the different species towards the two types of ant baits used.

By and large, the focus of the survey was to collate information YCA distributions and impacts on the islands/islets that would be used to make recommendations for their management and even eradication. On that note, most of the results that had been extracted from the survey and presented here have been biased towards YCA issues than other ant species. Nevertheless, this does not mean to say that other ant species are less important either. According to the results, there are some ants of AIS status that have been found to exist, on the surveyed localities worth mentioning and that people should also be aware and weary of and take all all necessary quarantine and management measures against.

3.1 Ants species and distributions

A total of 18 ant species were recorded from Fongapale (Funafuti), Niulakita and Nukulaelae (Table 2.0). All the ant species recorded in Niulakita were also the same ant species that were found to be present in Nukulaelae. However, Nukulaelae had a record of a species identified as *Pheidole flavens* that was not recorded in both Niulakita and Fongafale (Table 1.0). The list of ant species from Fongafale had the record of five species that were not found in both Nukulaelae and Niulakita (Table 3.0).

Table 1.0 Lists of the total number of ant species from Fongafale (Funafuti), Niulakita and Nukulaelae

Fongafale (Funafuti) (14)	**Niulakita (12)**	**Nukulaelae (13)**
• *Anoplolepis gracilipes*	• *Anoplolepis gracilipes*	• *Anoplolepis gracilipes*
• *Brachymyrmex* sp.	• *Nylanderia bourbonica*	• *Nylanderia bourbonica*
• *Monomorium destructor*	• *Nylanderia vaga*	• *Nylanderia vaga*
• *Monomorium ebeninum*	• *Odontomachus simillimus*	• *Odontomachus simillimus*
• *Nylanderia bourbonica*	• *Paratrechina longicornis*	• *Paratrechina longicornis*
• *Nylanderia vaga*	• *Pheidole fervens*	• *Pheidole fervens*
• *Paratrechina longicornis*	• *Pheidole megacephala*	• *Pheidole flavens*
• *Pheidole fervens*	• *Pheidole rugosula*	• *Pheidole megacephala*
• *Pheidole megacephala*	• *Pheidole* sp.	• *Pheidole rugosula*
• *Pheidole* sp.	• *Tapinoma melanocephalum*	• *Pheidole* sp.
• *Solenopsis germinata*	• *Tetramorium bicarinatum*	• *Tapinoma melanocephalum*
• *Tetramorium bicarinatum*	• *Tetramorium simillimum*	• *Tetramorium bicarinatum*
• *Tetramorium caldarium*		• *Tetramorium simillimum*
• *Tetramorium simillimum*		

Table 2.0 A combined list of 18 ant species recorded in Fongafale (Funafuti), Niulakita and Nukulaelae

Ant species	Ant species
1) *Anoplolepis gracilipes*	10) *Pheidole flavens*
2) *Brachymyrmex* sp.	11) *Pheidole megacephala*
3) *Monomorium destructor*	12) *Pheidole rugosula*
4) *Monomorium ebeninum*	13) *Pheidole* sp.
5) *Nylanderia bourbonica*	14) *Solenopsis germinate*
6) *Nylanderia vaga*	15) *Tapinoma melanocephalum*
7) *Odontomachus simillimus*	16) *Tetramorium bicarinatum*
8) *Paratrechina longicornis*	17) *Tetramorium caldarium*
9) *Pheidole fervens*	18) *Tetramorium simillimum*

The tendency of some ant species with natural ability to compete aggressively for food, water and space that enabled them to suppressing or displacing their other ant species and wildlife was quite evident among the different ant species. The sentiment was evident when comparing the proportion of the number of individual ants of each ant species at the five selected islets in the Nukulaelae atoll (Figure 5.0). Furthermore, apparently the vulnerability of many ant species to be manipulatively deprived and displaced or even wiped out as a result of YCA invasion was indeed the case.

The incident on Motala Islet in the Nukulaelae atoll was a classical demonstration of how YCA have displaced other ant species that were there before its invasion on the islet. The five islets surveyed in the Nukulaelae atoll were Fangau, Motala, Asia, Mulitealua and Tumiloto. It was evident from the trapping results that Motala Islet had only YCA and no other ant species which its close neighbouring islets had. Nobody really knew the exact time that YCA had gone into the Nukulaelae atoll, let alone Motala Islet but people believed that it was quite a recent invasion as far back as a decade ago. On that same note, if was also not known when other ant species had first gone to these islets. Two hypothetical introduction scenarios of these ants could have been possible. Firstly, was the assumption that, all or if not some, of the ant species recorded in the neighbouring islands used to be on Motala Islet as well before the incursion of YCA but were since then out-competed and displaced. The second assumption was that the YCA was on Motala Islet before other ant species and therefore made it difficult for these ants to establish on the islet. Having said that, it was, however, not fully known if these other ant species were totally wiped out altogether or still existing but at very low population on the islands. The possibility of these ant species presence still but could not make it to the traps due to interference by YCA could not be ruled out. A survey in Tokelau had recorded very low number of six species of other ant species co-existing with YCA (Sarty et al. 2007). However, from observation (eye witness), it was quite clear that the whole Motala Islet was fully colonized by YCA and in dense super-colonies. There seemed to be no sign of other ant species existing on the island. Furthermore, there was nothing of this magnitude of population of YCA in Motala Islet that was witnessed elsewhere in Nukulaelae atoll and other regions of Tuvalu that were visited during the survey trip. A huge number of YCA fresh nests with a lot of eggs were observed embedding and sandwiched between litters of dead leaves and other parts of of trees, coconuts and pandanus throughout the island (Figure 3). The ants were incredibly active and swarming in high numbers and in all directions when disturbed during the installations and collections of traps around the island.

Figure 3.0 A nest of YCA with eggs and worker ants.

Two closest neighbouring islets of Motala islets, namely Asia and Mulitealua (see Figure 4.0), both did not record the presence of YCA but interestingly enough did have records of other ant species (Figure 5.0). Motala Islet was about 7 hectares and was located between Asia Islet (about 30m to the northeast) and Mulitealua Islet (about 500m to the southwest). In a situation where islets are very close to each other with more or less similar ecosystem, it is highly likely to see almost the same biota existing alongside each other unless impacted by some external forces. Ant species records in the two neighbouring islets, Asia and Mulitealua, showed the co-existence of four common species (*Nylandreria vaga, Pheidole fervens, P. megacephala* and *Tapinoma melanocephalam*), apart from two species (*Tetramorium simillimum* and *Paratrechina longicornis*) that were only present at Mulitealua islet.

Motala Islet with an explosive magnitude population of YCA was only a close distance from the neighbouring islands which the queens during their nuptial flights could have flown over to initiate new colonies apparently did not happen. An important finding which was true here was that fact that YCA was unable to naturally spread to the nearby islands. They could only encroach to new territories through budding method where new queens form new nests but very close to existing super colonies, presumably reachable to workers from existing colonies. It can only be assumed here that the main reason why new queens could not establish colonies in the neighbouring islets even if they could successfully get across during their nuptial flights after mating with the males was probably due to the absence of workers to assist the queens to nurture and initiate new colonies at these isolated new localities.

Fangau Islet, which was the main inhabited islet and part of Tumiloto islet, which was well-known for picnic and retreat area also recorded YCA's presence in the Nukulaelae atoll. Although the whole of Fangua Islet was infested with YCA, however, the population there was not as heavily dense as on Motala Islet. A similar case was observed in the inhabited island of Fongafale Islet (Funafuti) where the population was also not as dense as on Motala Islet. Perhaps, disturbances by human activities in these inhabited islands could be among myriads of factors to consider as reasons why populations of YCA seemed not to build up that much in those localities.

The duration of survey on Niulakita Island and Nukulaelae atoll was very much dependent on the MV Kavanga II schedule and due to limited time constraint, the visitation on other islets in the Nukulaelae atoll as we planned could not be done. As a result of the curtailed plan, it was not possible to confirm if YCA had made its presence on other islands as well. However, some reliable information gathered from the locals suggested that YCA had also established on a couple of other small islets in the atoll that were not visited during the survey trip.

Figure 4.0 Map showing the three very close islets: Muliteatua, Motala and Asia. The GPS spots were trap sites. The closest distance between Motala and Asia was about 30m.

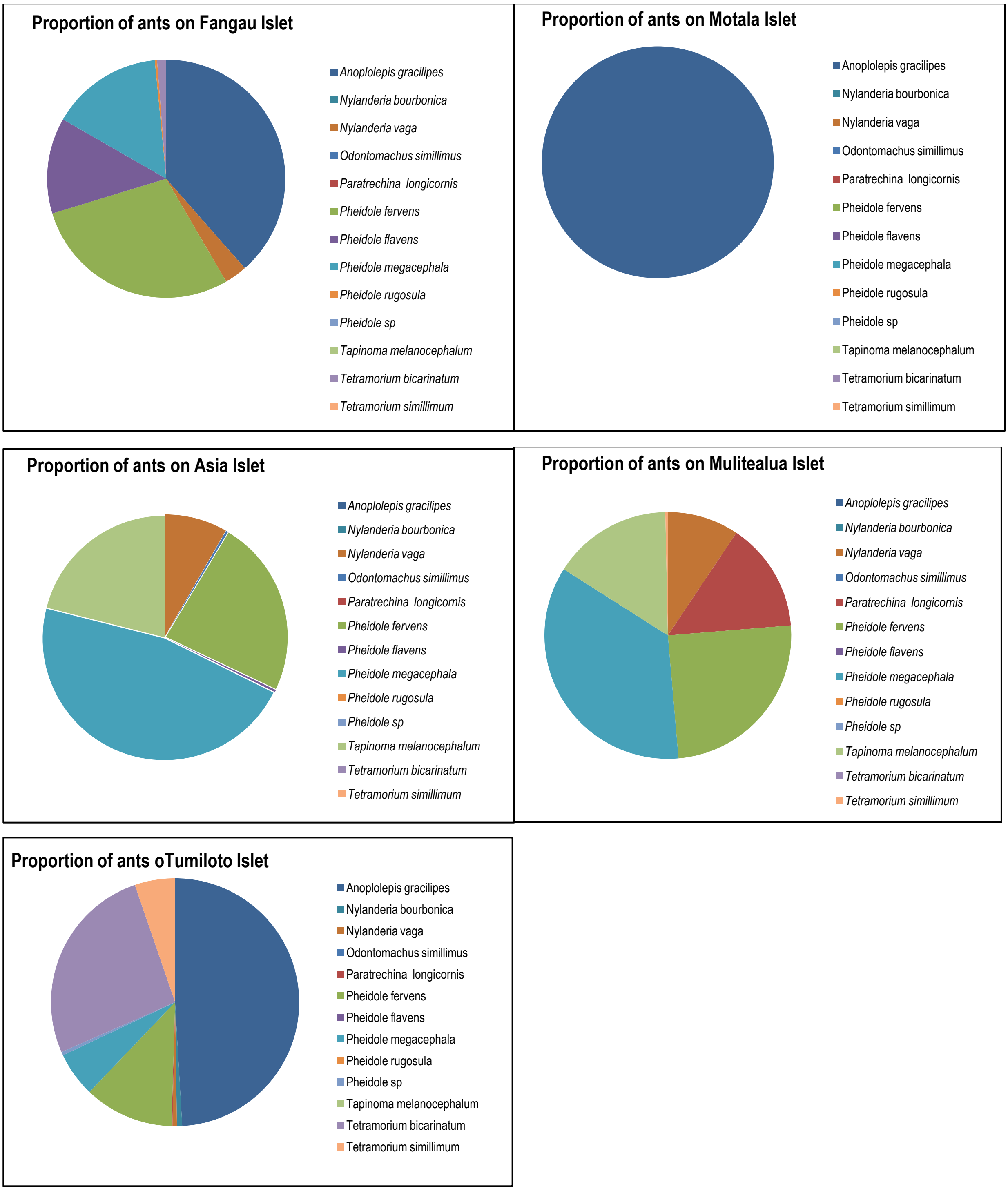

Figure 5.0 The Pie graph of the proportion of the different ants on five islets (Fangau, Motala, Asia, Mulitealua and Tumiloto) in the Nukulaelae atoll. A total of 13 ant species was recorded on the islets that were surveyed. Ant species that do not appear in the Pie graph were not recorded as present on the respective localities.

Table 3.0 A list of ant species that were recorded in Fongafale (Funafuti) but absent in both Nukulaelae and Niulakita.

- *Brachymyrmex* sp.
- *Monomorium destructor*
- *Monomorium ebeninum*
- *Tetramorium caldarium*
- *Solenopsis geminate*

3.2 Ant bait preferences and ant species distributions

Ant bait preferences and distributions of ant species on the islands were investigated during the survey with some fascinating revelations.

Preference for the two bait types (Protein-based and Sugar-based) were investigated on all the ant species that were found present in Fongafale (Funafuti), Niulakita and Nukulaelae had shown mixed responses (Figure 6.0). Most species responded positively to both bait types but at different levels as indicated by the mean number of ants caught per trap. It also occurred that a few ant species only responded positively to one bait-type but not the other. Moreover, it was interesting to note that even different species with the same genus, (for example, *Pheidole*) had differences in bait-type preferences.

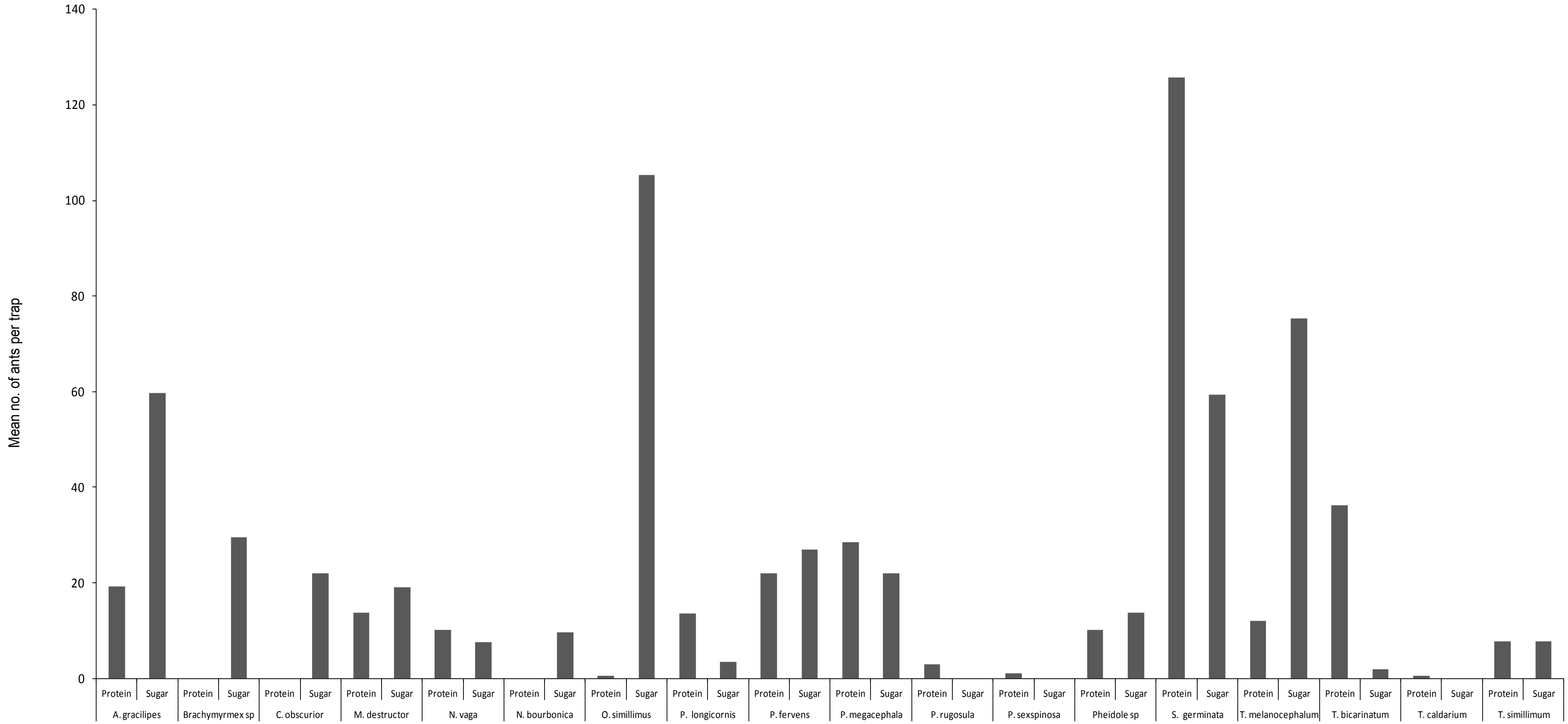

Figure 6.0 The mean number of worker ants of the different ant species in Fongafale (Funafuti), Niulakita and Nukulaelae trapped in the different bait types (either Protein-based or Sugar-based).

The data result on the number of ants that got into the traps after about two hours revealed an overall mean number of ants at the different sub-sites (8 sites) of the five sites in Fongafale (Funafuti), Niulakita and Nukulaelae with no significant difference ($F_{2,\ 237}$ = 1.01; P = 0.37), although there was an overall slightly increase in the number of ants caught in Nukulaelae (Figure 7.0). The difference was attributed by the population density at Motala Islet.

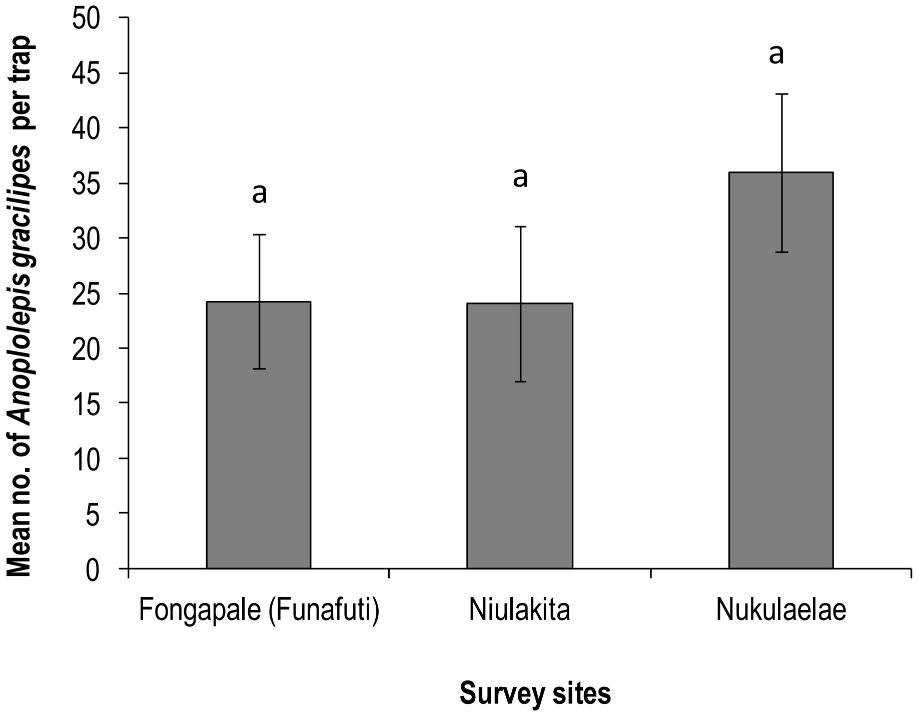

Figure 7.0 The mean number of *A. gracilipes* per trap for Fongafale (Funafuti), Niulakita and Nukulaelae. No differences in alphabetical letters for error bars depict the fact that there was no significant difference between mean numbers of *A. gracilipes* per trap in the three survey sites.

The results of the survey showed a significant good turnout of YCA attracted to sugar-based bait than protein based bait. Yellow crazy ants responded positively to both protein-based and sugar-based baits. The analysis of data collected from all the regional sites (Funafuti, Niulakita and Nukulaelae) showed YCA's significant preference for sugar-based bait than protein-based bait (Fongafale (Funafuti), $F_{1,\ 78}$ = 10.45; P = 0.002; Niulakita, $F_{1,\ 78}$ = 4.30; P = 0.04; Nukulaelae, $F_{1,\ 78}$ = 7.55; P = 0.007) (Figure 8.0).

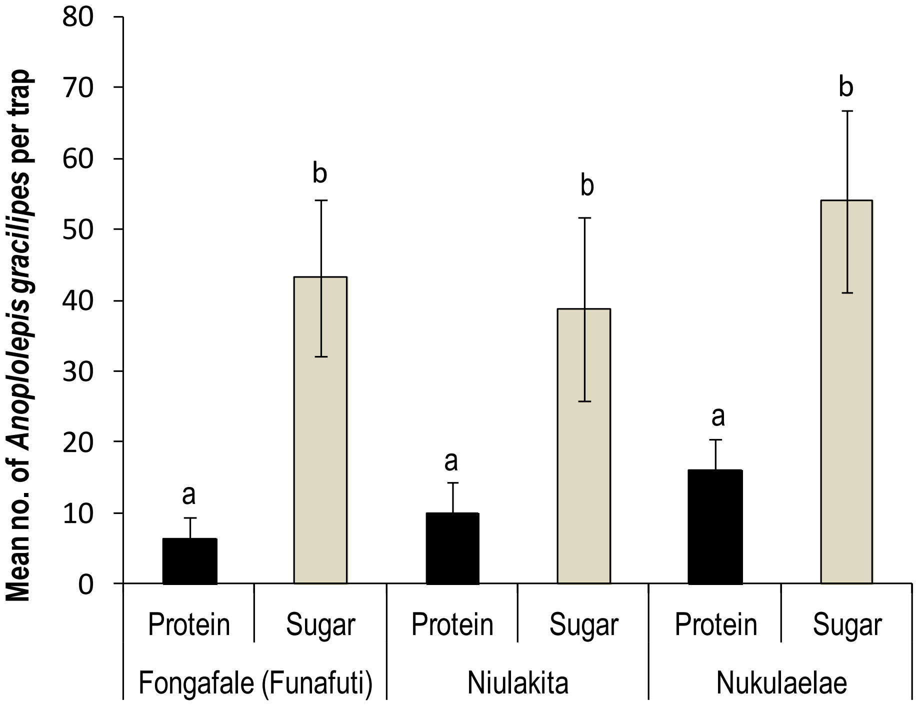

Figure 8.0 The mean number of *A. gracilipes* caught in a trap at different sites where protein-based and sugar-based baits were placed together side-by-side (2m apart). The differences in alphabetical letters for the error bars indicate significant differences between the bait types.

The distribution and density of YCA at the different sub-sites (A, B. C, C, D and E) in each of the regional sites (Fongafale (Funafuti), Niulakita and Nukulaelae) was shown in Figure 9, 10 and 11.

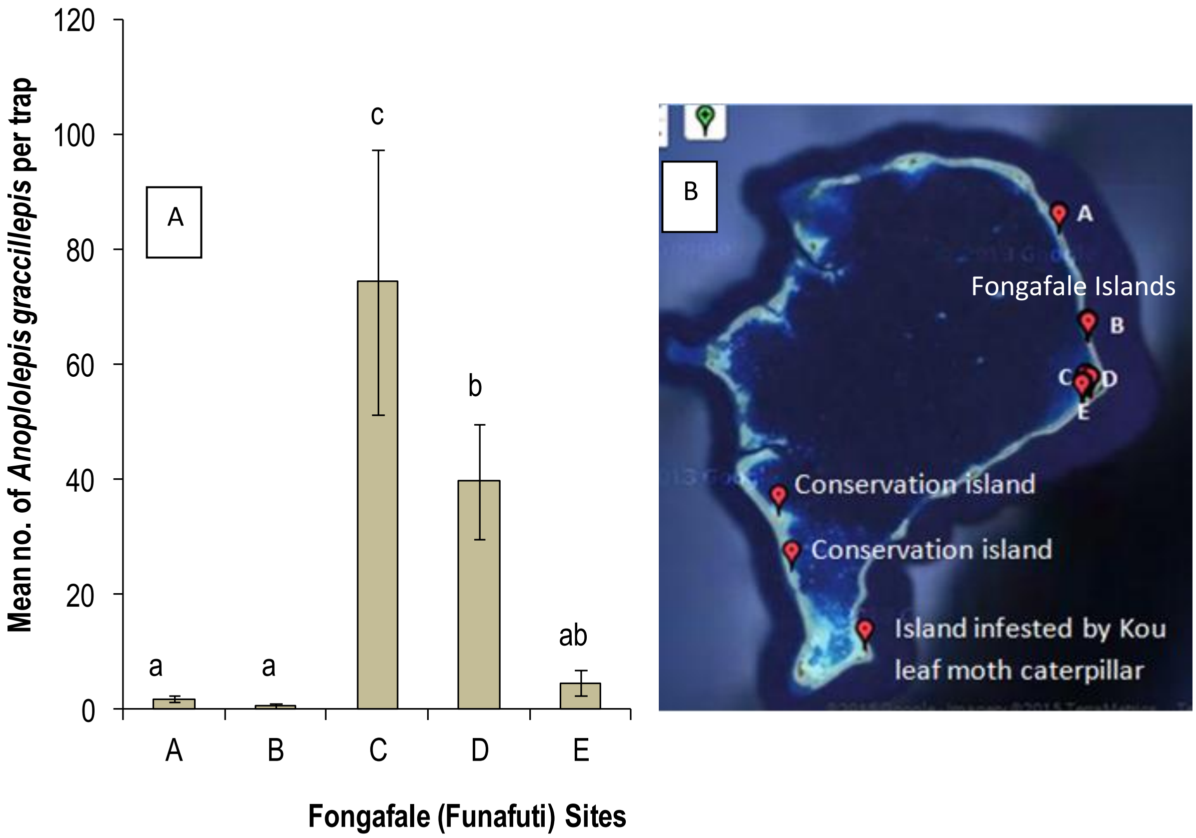

Figure 9.0 A) The mean number of *A. gracilipes* caught inside each trap (protein-based and sugar-based traps combined in the analysis) at each sub-sites (A, B, C, D, D and E as depicted in the map B) on the right). A = Damp site, B = Wharf compound, C = Airport and Hotel compounds, D = Taiwanese Technical Mission farm compound, and E = Piggery sty compound. The differences in the alphabetical letters in the standard error bar indicate significant differences between sub-sites.

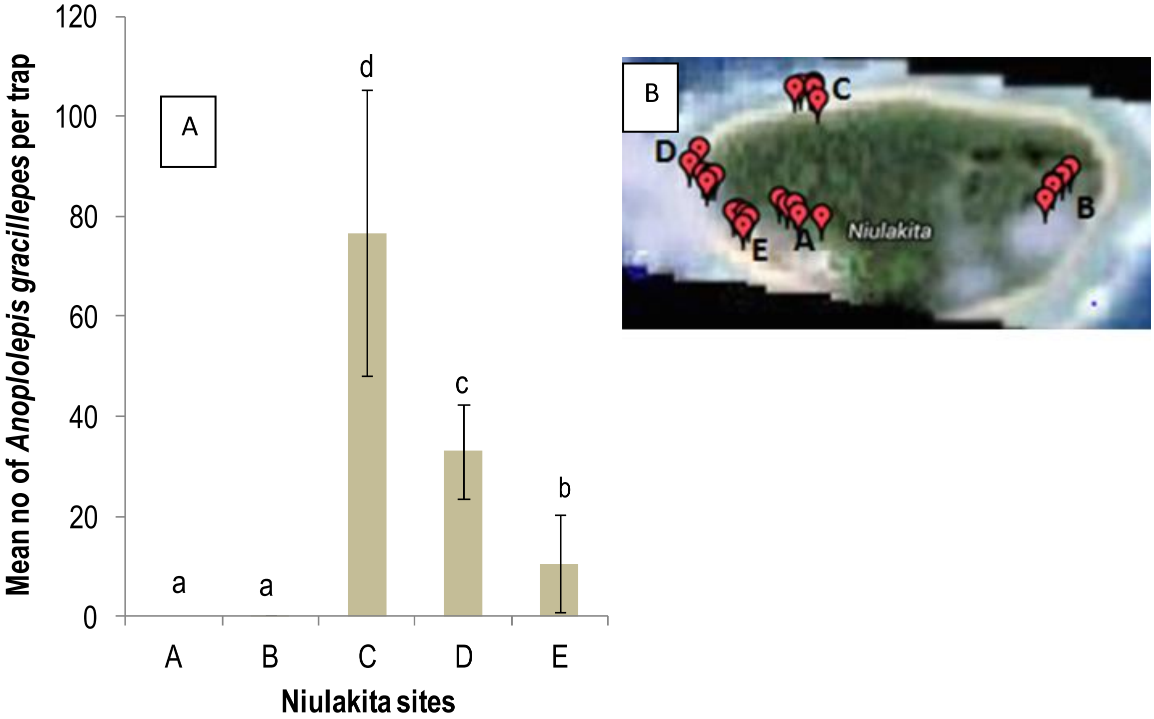

Figure 10.0 A) The mean number of *A. gracilipes* caught inside each trap (protein-based and sugar-based traps combined in the analysis) at each sub-sites (A, B, C, D, D and E as depicted in the map B) on the right). A = Village compound, B = Coconut plantation, C = Picnic compound, D = Piggery sty compound, and E = Main landing compound. The differences in the alphabetical letters in the standard error bar indicate significant differences between sub-sites.

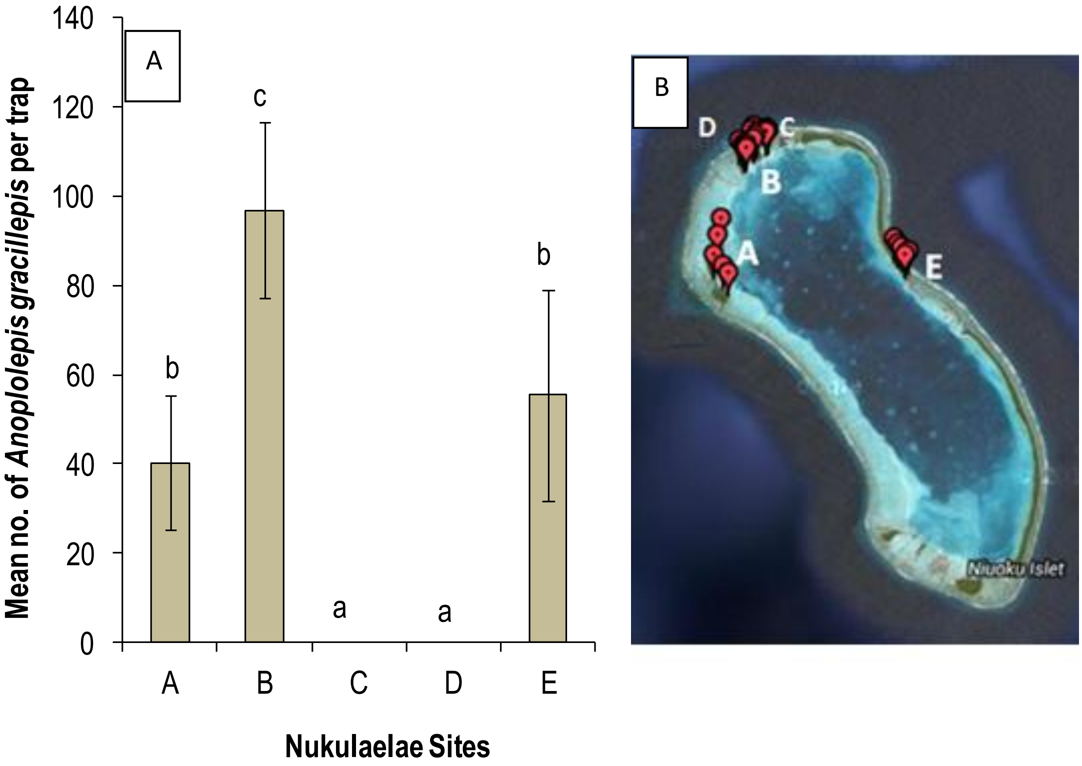

Figure 11.0 A) The mean number of *A. gracilipes* caught inside each trap (protein-based and sugar-based traps combined in the analysis) at each sub-sites (A, B, C, D, D and E as depicted in the map B) on the right). A = Fangua Islet, B = Motala Islet, C = Asia Islet, D = Mulitealua Islet, and E =Tumiloto Islet. The differences in the alphabetical letters for the standard error bar indicate significant differences between sub-sites.

The ubiquitous presence of mutualistic honey-dew producing hemipterans was observed to be high and immensely supporting high population of YCA and other ant species on the islands.

Figure 12.0. Mutualistic honey-dew producers (aphids and mealy bugs) on vegetation of the islands

Apart from information obtained from the above results during the survey, other information about ants in general, particularly YCA, was obtained through meetings, (both official and unofficial conversations) with the government officials, local community individuals and the Local Island Council (LIC) members or Taupule.

3.3 Other activities (result and recommendation)

The results obtained from fruit fly trap showed that Fongafale (Funafuti) had the lighter form of *Bactrocera passiflorae,* while Niulakita had *Bactrocera xanthodes* results. No fruit flies got in the traps in the Nukulailai atoll. These fruit fly species have been recorded in these localities before and were not new records.

The investigation on the cause of massive defoliation and death of trees, *Cordia subcordata* (locally known as Kanava in Tuvalu) on the island of Funafala in the Funafuti atoll confirmed to be the leaf worm (*Ethmia nigroapicella*). The moth is in the Family Tortricidae, subfamily Olthreutinae. About 10 big trees were affected on the island. The worms grazed on the leaves, usually starting from the top of the plant crown and making headway down. Worst infestations ultimately resulted in the whole plant without any leaves and plants eventually dried up and died. This moth was reported to have caused similar damage and death of the same tree species in Nanumea in 2011.

The infestation on Funafala Islands was the first recorded case in the Funafuti atoll. How and when it came to the island was unknown. However, the locals of the island thought that it came in about two years ago. The infestation was not occurring on Fongalore Island (main inhibited island) which was quite a surprise. Application of a biological insecticide known as Bt (*Bacillus thuringiensis*), which is non-toxic to humans, domestic animals, and the great majority of other fauna was recommended to the Biosecurity Officers to control the culprit pest.

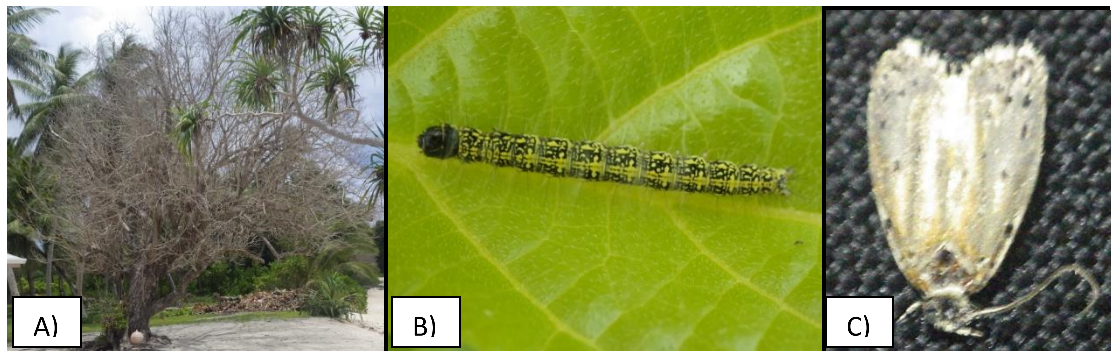

Figure 12 A) a complete defoliated Kanava tree on Funafala Islet; B) caterpillar that caused defoliation of Kanava trees; C) moth of the caterpillar that caused defoliation of Kanava trees

A brief visitation to two conservation islands (Tefala and Fuagea) of Funafuti atoll confirmed that there were no YCA on these islands as yet. Sea bird nests and chicks were all over on the ground and on top of trees on both these islands. Coconut crabs and land crabs were also found on the islands. Turtles used to come and breed on these islands.

4.0 Discussion and recommendations

Tuvalu like other atoll island nations in the Pacific has high biodiversity, cultural and economic values that support its community. The threats and impacts of AIS such as YCA to these small fragile island ecosystems have becoming a real matter of concern. As most of AIS cannot naturally get to these remote scattered islands unless mediated by human activities, Tuvalu has been spared from many other worst IAS. However, with the increase in population and improvement of shipping services that has enabled frequent movement of people between countries and islands, the likely new invasions of AIS will increasingly a looming threat to this nation.

The survey was unable to quantify the impacts of YCA or other ant species for that matter. However, the dead of crabs and earthworms that were attended and eaten by YCA as observed during the survey has been indicatives of continuous threats to their existence on these islets. While it is important to protect crabs which the locals regarded as food, it is also important protection of earthworms which are responsible for the breakdown of compost materials required for soil nutrient improvement in generally very poor soil conditions in the atoll islets.

4.1 Biosecurity Strengthening

The paramount importance of quarantine awareness and appropriately execution border security and inspection cannot be over-emphasized enough as the vital means of avoidance and containing pests from spreading to free infestation areas. It is crucial to remind the general public of the importance of recognising AIS entry pathways and comply with quarantine practices and procedures to keep away unnecessary spreading of pests, especially when transporting items between the islands and between islands in order to curb the spread of key invasive ants, especially YCA within Tuvalu. Although scattered islands can slow down the spread of AIS, including ants, it has disadvantaged Tuvalu when considering the operational costs and logistic difficulties of maintaining border security and execution of pest eradication and management campaigns.

The facts that YCA was unable to spread naturally even at about 30m distance as observed between Motala Islet and Asia Islet in the Nukulaelae atoll underpins the recommendation to concentrate more on creating effective quarantine awareness and avoiding human activities that promote the spread of YCA between and within islets and atolls. Most islets in the two atolls visited were uninhabited but were frequently visited by the local communities for recreational and survival activities such as picnics, fishing and collection of coconuts, edible vegetable ferns, coconut and land crabs and fire woods. All the invasive species ants, including YCA have gone to these islands by people taking their colonies with materials in which they breed. Apparently a number of uninhabited islets, including some that were visited during the survey trip are now threatened by YCA. The onus is now on the Tuvaluan government, through its Biosecurity Department to make sure that these islets are kept free from YCA infestation.

Tuvalu through its local Biosecurity Department has carried out quarantine inspections of incoming international vessels both at the Airport and Seaports. Biosecurity Department for Tuvalu has a total three officers that are based in the capital Funafuti. With this limited number of staff with the expectation upon them to carry out the desired level of effective quarantine inspections, pest monitoring and surveillance would be just too much and quite unfair to the incumbents. Recruitment of additional staff to assist the current workforce and or assigning additional responsibility to Agriculture Extension to take up quarantine activities on-site in other atolls and islands may be assist alleviating some of the burdens faced by quarantine staff in Tuvalu.

4.2 Eradication and management of YCA recommendations

Depending on funds and the availability of resources and the size of the infestations the management of YCA for Tuvalu can be implemented on either eradication or suppression control levels. Eradication entails the intentional extirpation of geographically discrete populations of YCA, irrespective of whether other discrete populations still remain within the landscape. Suppression control is basically the management actions that aim to reduce populations of YCA, thereby reducing impacts, or preventing further dispersal. Although there are non-chemical controls that do exist, for example, the use of natural enemies such as pathogens and other insects, the fact that they are ineffective to achieve quick and effective desired outcomes, they are not recommended here. Instead, the application of chemical which are reasonably safe for human beings and most wildlife in a fragile ecosystem in the atoll and island is to be pursued.

Controlling of mutualistic hemipterans may be a way to indirectly suppress the population of ants. The use of white oil insecticides can be an effective method of controlling hemipterans which may also reduce food source for ants. White oil insecticides work by blocking hemipterans breathing pores, thus eventually cause suffocation and dead to the pests.

The distribution of YCA and other ant species in Tuvalu nationwide is unknown. However, the results of this survey had shown that Fongafale (Funafuti atoll), Fangua and Motala in the Nukulaelae atoll were all completely covered by YCA. The exact area coverage of infestation in each of the inhabited islets (Fongafale and Fangua) is not given here but are both quite large areas. The distributions of YCA in both these inhabited localities were wide spreading faster due to the myriads of human activities taking place on these islets. However, the densities of YCA populations on the inhabited islands were observed to be not as high as on undisturbed islands or parts of them. The disturbance factor in inhabited islands was probably the main reason of the decline in population densities in inhabited than undisturbed localities. A third of Niulakita Island and about 5 hectares of Tumiloto (Nukulaelae towards the southernmost tip were also infested with YCA. Eradication of YCA and other invasive ant species on all of these islands may be possible but will mean committing a hefty amount of funds for insecticides, technical personals and other resources. However, it's entirely the decision that Tuvalu government can pursue further with align partners and funding institutions in future.

The original request for assistance from Tuvalu government which prompted SPC to participate in this particular survey was, in fact, coming from the community of Nukulaelae atoll. The request was to find possible ways of eradicating and/or managing YCA on some of the infested islands there. After having talked with the Taupule, it was clear that YCA infestation on Motala Islet was really their main concern for such interventions. The survey results had clearly shown that the island was really hard hit by YCA and with no records of other ants getting to the traps (Figures 5.0 and 9.0).

The approach and recommendation that this report advocate here is to first implement a pilot eradication and/or management programme on Motala Islet and learn lessons from there before rolling out similar interventions onto other islets and islands or atolls in Tuvalu.

Eradication and management of ants, particularly, YCA have been proven successful in a few places in Australia before with the use of safe insecticides. An insecticide that may be effect is Antoff® ant bait with Fipronil at a concentration of 0.01g/kg in a proprietary attractant matrix. This is the same bait that has been recommended to be used in Tokelau and Kiritimati (Kiribati) for the eradication and management of YCA under a New Zealand (NZ) Ministry of Foreign Affairs and Trade (MFAT) project known as *Building resilience to biosecurity threats from invasive ants throughout the Pacific.* Funding for the project has been approved in mid-2014 with involvement of Victoria University of Wellington, SPC, Secretariat of Pacific Regional Environmental Programme (SPREP), Pacific Invasive Initiatives (PII), Tokelau, Kiribati as partners. This insecticide is classified as moderate toxic but has the ability to wipe out ant colonies. It is a slow release killing active ingredient that does not kill foraging worker ants instantly when they come into contact with the bait, thus giving them enough time to take and accumulate poison particles inside the nests that become toxic to the queens and new generations in the nests.

Application rate per ha. for Antoff® ant bait is 10 kilograms (kg) and so for Motala Islet which is about 7 ha. will require 70 kg for one application. The bait is recommended to be applied twice in an eradication campaign period and so the total of 140 kg will be required. The product package is 12.5 kg per pail and so a total of 12 pails will be required. It is advisable to purchase 6 pails of 12.5 kg of Antoff® to be used in the first year and the then purchase the other 6 batch in the second year. The bait is a granulated insecticide that can easily be dispersed manually by hand with proper protective gears on but alternatively spreaders (a proper tool for dispersing the product) can also be used.

Protective gears such as overalls, safety boots, respirators, hats, and hand gloves are very important safety items for every person that handle and apply Antoff® ant bait. These safety gears must be purchased and worn in the application of the bait in the field.

Secure storage facilities are required to ensure the ant bait, protective gears and equipment are safely contained so as to avoid hazard risks happening on the islands and so it is recommended to designate a responsible person on the Nukulaelae atoll to take care of these items once they arrived at the scene and appropriately dispatch them when and if required.

Antoff® bait can be sourced from Animal Control Technologies Pty Ltd Australia and air-freighted to Funafuti (Tuvalu). The spreaders can be sourced from either Australia or New Zealand and also air-freighted to directly to Tuvalu, while all safety gears can be sourced from Fiji. All the materials and equipment can be gathered and stored safely in Funafuti before shipped together by sea to Nukulaelae atoll.

Below in Appendix I is the information about the pesticide (Antoff® ant bait) description and hazard which have been compiled for the NZ MFAT funded project - Building resilience to biosecurity threats from invasive ants throughout the Pacific which are also relevant for Tuvalu government which may also in pursuit for similar eradication/management of YCA project .

In trying to fulfil the request from Tuvalu government, SPC should be a collaborator and leading partner in the implementation of the eradication/management project on Motala Islet if funding is available. An estimated budget to carry out eradication programme at Motala Islet is presented in Appendix II. Fund for the implementation may include ant bait, spreaders, safety gears, fuel for outboard motor (OBM), boat fares and per diems from Funafuti for two Tuvalu Biosecurity staff (Funafuti based) for quarterly visits to the island for a period of two years. At least two technical staff from SPC (Suva-based) should be involved in the eradication/management programme and pay quarterly visits in the first year and every six months in the second year of operation. Both air and sea fares and per diems for SPC staff should therefore be accounted for in the budget.

It is important to designate at least a government officer on-site in Nukulaelae atoll for the YCA eradication/management project day-to-day operations for a period of two years. Preferably an officer should be someone that has been employed by the government, for example, an Extension Officer. Also, it would be good to have assistant officer in case the officer may need to temporarily leave the atoll within the project period.

Required fund for YCA eradication will encompass the costs of ant bait, spreaders, safety gears, fuel for outboard motor (OBM), boat fares and per diems from Funafuti for two Tuvalu Biosecurity staff (Funafuti based) for quarterly visits to the island for a period of two years. At least two technical staff from SPC (Suva-based) may be involved in the eradication/management implementation and make quarterly visits in the first year and every six months in the second year. Both air and sea fares and per diems for SPC staff will need to be accounted for as in the project budget.

It is important to designate at least a government officer on-site in Nukulaelae atoll for the YCA eradication/management project day-to-day operations for a period of two years. Preferably an officer should be someone that has been employed by the government, for example, an Extension Officer. Also, it would be good to have assistant officer in case the officer may need to temporarily leave the atoll within the project period.

It is strongly recommended that SPC and Tuvalu government to consult and invite other institutions within the region and abroad (for example, Victoria University of Wellington, SPRED and PII) to review the results and recommendations of this report create partnership that may provide funding and technical back stop to YCA management in Tuvalu.

5.0 **Conclusions**

The survey on the islands and atolls has captured some vital information about the ant species that have been present on the southern atolls and islands of Tuvalu, particularly in the Nukulaelae atoll where the local community through its Taupule had raised complaints on YCA infestation. The duration of the survey to capture all possible anticipated details on ant species and other animal species, their distributions and impacts was restricted by the tight schedule that the cargo boat had. However, all in all it, the results have confirmed that

YCA has been present in some islands and not the others which demanded the need the strengthening of biosecurity between the islands. The approach recommended here for eradication/management is to commence with a pilot programme on Motala Islet for the first two year period before trying to embark on the same programme on other localities. The recommendations here may be hindered by lack of funds. However, the need to protect the biota system on the fragile ecosystem on these islands, especially coconut crabs, land crabs, earthworms that are very much connected to the livelihood of the people on these affected islands cannot be overlooked and allowed to go into extinction by invasive ants such as the YCA. Building partnership with other organization and seeking funding to rescue these islands from native animal species into extinction is paramount important and which this report favours to advocate.

Acknowledgments

The survey on ants carried out in the respective localities in Tuvalu in October 2014 and which has resulted in this report would not have occurred without the invaluable contributions of all the people and organizations that have involved. First and foremost, we are indebted to Secretariat of the Pacific Community (SPC), through the Land Resource Division (LRD), and its Biosecurity and Trade Services (BATS) and Tuvalu Government, which provided co-funding for this work. Special thanks to Mr. Josua Wainiqolo (Co-ordinator of BATS) and Ms. Radilaite Nawalowalo (Programme Assistant) and SPC Finance staff for organizing air travel arrangement and per diems for SPC Entomologist, and also the same level of appreciations goes Mr. Itaia Lausaveve (Director of Agriculture), Mr. Sam Panapa (Senior Biosecurity Officer) and Mr. Matio Lonalona (Biosecurity Officer) for all of their support in making internal travel and other logistic arrangements at different localities during the survey a great success. Also, thanks to Mr. George (Tuvalu Foreign Affairs Office) and Ms. Tilia Tima (Biodiversity Officer-from Department of Environment) for supplying invaluable information and fruitful discussions. To the communities and Taupules of Funafuti, Niulakita and Nukulaelae, thanks so much for your gesture of friendly hospitality. Immense thanks to Mr. Navneel Prasad for assistance on data analysis. Lastly but not the least, a big thank you to Mr. Feroz Khan and Dr. Disna Gunawardana for their assistance in determining the morphological identities of the ant species that were collected from the different localities in the survey.

References

Abbott, K., Harris, R. and Lester, P. 2005. Invasive ant risk assessment: *Anoplolepis gracilipes*. Landcare Research contract report for Biosecurity New Zealand, Ministry of Agriculture and Forestry, Wellington, New Zealand

Clark, D. B., Guayasamin, C., Pazmino, O., Donoso, C. and Paez de Villacis, Y. 1982. The Tramp ant *Wasmannia auropunctata*: Autecology and effects on ant diversity and distribution on Santa Cruz Island, Galapagos. *Bio-tropical*. 14: 196-201

Csurhes, S. and Hankamer, C. 2012. Pest: Yellow Crazy Ant (*Anoplolepis gracilipes*). *Animal Risk Assessment Report*. Queensland Department of Employment, Economic Development and Innovation. Australia

Drescher, J., Blüthgen, N. and Feldhaar, H. 2007. 'Population structure and intra-specific aggression in the invasive ant species *Anoplolepis gracilipes* in Malaysian Borneo'. *Molecular Ecology* 16: 1453–1465.

Dye, J. 2014. "Red fire ant outbreak in Sydney could cost economy billions". *Sydney Morning Herald*. Australia.

Fact Sheets of State of Queensland. 2013. Yellow Crazy Ant (*Anoplolepis gracilipes*). The State of Queensland Department of Agriculture, Fisheries and Forestry. Australia

Fasi, J. 2007. Quantifying the dominance of Little Fire ant (Wasmannia auropunctata) and its effects on crops in Solomon Islands. *Master Thesis*. University of the South Pacific, Suva, Fiji

Fluker, S.S. & J.W. Beardsley. 1970. Sympatric associations of three ants: *Iridomyrmex humilis*, *Pheidole megacephala,* and *Anoplolepis gracilipes*. Hawaii. *Annals of Entomological Society of America*: 63:1290-1296.

GISD 2009. '*Anoplolepis gracilipes'*. *Global Invasive Species Database*, IUCN SSC ISSG, compiled by O'Dowd, D, viewed 18 August 2010, <www.issg.org/database/species/ecology.asp?si=110>.

Hill M, Holm. K., Vel. T. and Shah N. J., Matyot P, 2003) Impact of the introduced yellow crazy ant, *Anoplolepis gracilipes* on Bird Island, Seychelles. *Biodiversity Conserv*ation: 12:1969–1984

Hill, J. H., Alleman, R., Hogg D. B. and Grau, C. R. 2001. First report of transmission of Soybean mosaic virus and Alfalfa mosaic virus by *Aphis glycines* in the New World. *Plant Disease*: 85: 56

Keith, J. and Spring, D. 2013. Agent-based bayesian approach to monitoring the progress of invasive species eradication programs. *Proceedings of the National Academy of Sciences. doi*: 10.1073/pnas.1216146110.

McGregor, A. J and Moxon, J. E. 1985, 'Potential for biological control of tent building species of ants associated with *Phytophthora palmivora* pot rot of cocoa in Papua New Guinea'. *Annals of Applied Botany* 107: 271–277.

Nelson, S. 2008. "Sooty Mold" In: Plant disease by Cooperative Extension Service, college of tropical Agriculture and human resources, University of Hawaii. PD: 52.

O'Dowd, D.J., Green, P. T. and Lake, P. S. 2003, 'Invasional "meltdown" on an oceanic island'. *Ecology Letters* 6: 812–817.

Persley, D., Cooke, T., House, S. 2010. Diseases of Vegetable Crops in Australia, CSIRO, Australia

Sakai, A., Allendorf, F.W., Holt, J.S., Lodge, D.M., Molofsky, J.,With, K.A., Baughman, S., Cabin, R.J., Cohen, J. E., Ellstrand, N. C., McCauley, D. E., O'Neil, P., Parker, I. M., Thompson, J. N. and Weller, S. G. 2001. The population biology of invasive species. *Annual Reviews of Ecology and Systematics*, 32, 305–332.

Styrsky, J. D. and Eubanks, M. D. 2007. Ecological consequences of interactions between ants and honeydew-producing insects. *Proceedings of the Royal Society Botany Biological Sciences*, 274, 151–164.

Wetterer, J. K., and Porter, S. D. 2003. The Little Fire Ant, *Wasmannia auropunctata*: distribution, impact and control. *Sociobiology* 41: 1-41.

Appendix I

Compiled by Dr. Monica Gruber (2014) but tailored for Tuvalu eradication/management of YCA.

Antoff® ant bait

The active ingredient in Antoff® ant bait, fipronil is a moderately hazardous pesticide, and classified as a WHO Class II chemical, with a number of environmental risks. The technical information available on which the following assessment is based relates to Fipronil in its pure form. The concentration of the chemical in the bait is 0.01 g/kg (10 mg/kg). According to information provided by the Australian supplier, the low concentration of fipronil in Antoff® and the low application rate make this product non-hazardous by Australian work safe standards and is not classified as a dangerous good according to the Australian Dangerous Goods Code (2007).

Chronic effects on humans

The RfD (Reference Dose or estimated amount of fipronil ingested per day for the rest if their life without any appreciable risk of adverse health effects) is 0.019 mg/kg of body weight. For a 50 kg human this is equivalent to 0.95 mg per day. Given that the fipronil concentration in Antoff® bait is 10mg/kg, a 50 kg human would need to ingest nearly 100g of bait per day for life to generate possible chronic effects. Clearly doses are lower and risks are higher for small children (who are also more likely to pick up baits from the ground and eat them). For a 15kg child, the RfD would be less than 30g of bait. However, reference materials note that no data is available on what chronic effects might be, and it appears none have been reported – even among pest management contractors. In addition there are no recommended or regulatory occupational exposure limits for Fipronil in the US. Fipronil is reported as a possible carcinogen in chronic doses, however it has not been shown to cause mutations in mutagenicity screening tests designed to screen chemicals for carcinogenicity. Ingestion rates of 2.5 mg/kg per day in rats (i.e. equivalent to ~80g of Antoff® bait for a 15 kg child per day for life) have been associated with delayed sexual development and growth. Chronic effects would occur only with continual exposure over time and acute effects (due to the nature of pesticide use in the context of this Activity) are a higher risk.

Acute effects on humans

Technical grade (undiluted) fipronil is considered moderately toxic by ingestion with an oral LD50 of 97 mg/kg in rats and 95 mg/ kg in mice. Although no data is available for human LD50, based on the rat and mouse data a 50 kg adult would need to ingest ~10kg of Antoff® bait in a single dose, and a 15 kg child would need to ingest ~3 kg of bait to cause death in a single exposure.

Signs of acute toxicity reported for humans after ingestion of fipronil include sweating, nausea, vomiting, headache, abdominal pain, dizziness, agitation, weakness, and seizures. These signs are reported as being generally reversible and resolve without treatment.

Fipronil is considered of low to moderate in toxicity via inhalation. The proposed output does not involve spraying, but the Fipronil Technical fact sheet reports low to moderate in toxicity by inhalation with the 4-hour LC50 ranging from 0.390 to 0.682 mg/L in rats. The fact sheet also relates the case of a 50-year-old man who complained of headache, nausea, vertigo, and weakness after spraying his field with a fipronil product for five hours. Inhalation or dermal contact were identified as probable causes of exposure in this case. Symptoms were reported to have developed after two hours and resolved spontaneously.

Fipronil metabolism in soil

The half-life of fipronil is 122-128 days in aerobic soils. Under aerobic conditions, naturally occurring soil organisms break down fipronil to form fipronil-sulfone. Fipronil can also be hydrolyzed to form fipronil-amide.

Fipronil degrades on soil surfaces by ultraviolet radiation (i.e. sunlight) to form fipronil-desulfinyl, and has a measured half-life of 34 days in loamy soil. However, soil particles may prevent light from penetrating any significant depth of soil under field conditions and thereby increase residence time for buried particles (i.e. bait returned by worker ants to the nest). In studies to determine the fate of fipronil in soil, researchers found "no evidence of volatility" of fipronil or fipronil metabolites. Fipronil has low mobility in soil and is not expected to leach into groundwater. After soil treatment, fipronil usually does not travel further than the upper six inches of soil, and significant lateral movement is not expected.

Fipronil metabolism in water

Fipronil degrades rapidly in water when exposed to UV light to form fipronil-desulfinyl. Under these conditions, fipronil has a half-life of 4 to 12 hours. Fipronil is stable to hydrolysis at pH 5 and pH 7. However, it degrades in alkaline conditions in direct proportion to increasing pH values. Fipronil-amide is the primary residue formed from hydrolysis.

One study on fipronil accumulation in sediments indicated that fipronil degradation products accumulate in riverbed sediment while the parent compound does not.

Fipronil-desulfinyl photodegrades more quickly in water than soil, and in aerated and static water half-lives of 120 (± 18) hours and 149 (± 39) hours, respectively have been recorded.

Ecotoxicity

As Tokelau and Kiritimati are home to no freshwater fish or invertebrates, this discussion relates only to marine life. When applied to water, fipronil varies in its toxicity and potential to bio-accumulate in aquatic invertebrates, depending on the species. The proposed Activity will not apply Antoff® to water, not use sprays, and a number of measures will be taken to avoid run-off (See Impacts and mitigation measures).

Fipronil is highly toxic to marine fish. The 96-hour LC50 is 0.083 mg/L for bluegill sunfish, and 0.130 mg/L for sheepshead minnows. The primary metabolites in fish are fipronil-sulfone and fipronil-sulfide. Fipronil-sulfone is 3.3 times more toxic to bluegill sunfish than the parent compound fipronil. Laboratory tests have shown fipronil accumulation in fish with a bioconcentration factor of 321 for whole fish, 164 for edible tissue, and 575 for nonedible tissue. However in these tests treated fish eliminated fipronil completely 14 days after being transferred to clean water. Thus, in large volumes of water, such as the lagoon or ocean, together with the low concentration of Fipronil in the ant bait, and the application method more likely to result in the toxin remaining on land, the likelihood of bioaccumulation in fish is minimal.

Fipronil is highly toxic to marine invertebrates. In daphnids (planktonic crustaceans), the NOEL for fipronil was measured at 9.8 µg/L, and the LOEL 20.0 µg/L. In this study the fipronil-sulfone and fipronil-desulfinyl metabolites were 1.9 times more toxic to than the parent compound. In one study, male copepods (benthic and planktonic crustaceans) raised in a 0.63 µg/L fipronil solution had a 75-89% decrease in reproductive success. Fipronil has been found to be highly toxic to oysters with an EC50 of 0.77 mg/L, and very highly toxic to shrimp with a 96-hour LC50 of 140 ng/L. Again, in the context of the proposed Activity, the large volumes of water, together with the low concentration of Fipronil in the ant bait, and the application method more likely to result in the toxin remaining on land, the likelihood of effects on marine invertebrates are minimal.

Fipronil is also toxic to terrestrial invertebrates, and has been found to kill 38.8-94.5% of beneficial predators. When used for locust control, fipronil killed >90% of the resident non-target insects Carabidae, Tenebrionidae, (both beetles) Scelionidae, and Sphecidae (both wasps) populations in 2 days, with poor recolonization. Fipronil treated soil is non-toxic to worms, including earthworms. These examples all relate to spray application, which is not the deployment method used in the proposed Activity. Fipronil is also highly toxic to bees, which is an important consideration in cropping environments and when the pesticide is deployed by spray. Bees are not scavengers, and as the bait matrix base is fishmeal, bees are unlikely to be attracted to it. However, Tuvalu (Nukulaelae atoll) have no bee significant populations that will be impacted by the application of the bait.

No information appears to have been published on the effects of fipronil on vertebrates other than fish and mammals. Given the phylogenetic position of birds and reptiles is between fish and mammals, it is possible non-target effects might occur in these groups, particularly ground foragers that might be attracted to the bait matrix.

Pesticide resistance

The supplier information for insecticide resistance of advises the product is a Group 2C insecticide. It is possible that some biotypes or genotypes of insect species are resistant to Antoff® and other Group 2C insecticides, due to naturally occurring genetic variability in any population. The resistant individuals can eventually dominate the insect population these insecticides are used repeatedly, which would decrease the effectiveness of the pesticide. Pesticide resistant individuals are impossible to detect prior to exposure. Resistance has not been reported in any yellow crazy ant populations. Excessive use of pesticides is linked to pesticide resistance, and the proposed Activity minimises the exposure to pesticide.

Details of operational processes

Effective ant management requires that the ant queen(s) must be killed to kill the colony (colonies of yellow crazy ants can have hundreds or thousands of queens). Ant baits containing pesticides must be attractive to workers, so that the workers return the bait to the nest for the queen to feed on, but the bait must be not so toxic that it kills the workers before the bait is returned to the nest. Ants are attracted to protein and sugar however some combinations are more attractive to specific ant species than others. Antoff® bait has been used extensively for yellow crazy ants in Australia and its effectiveness and non-target environmental effects are well known.

Yellow crazy ant colonies are made up of long-lived queens (~3-5 years), short lived workers (~3 months), and short lived males that die immediately after mating. Queens produce new workers year-round, and produce new queens and males during certain environmental conditions. Typically production of queens and males coincides with the onset of the wet season (when there are distinct wet and dry seasons). While the new queens are in pupal stage they do not eat, and while treatment at this stage will kill adult queens, the pupal queens will be unaffected and thus the colony will not be killed.

Thus effective treatment must take into account the biology of the ant, and its relationship with environmental conditions, as well as an appropriate pesticide concentration and bait matrix for the target species.

For this reason treatment is undertaken during the dry season. The second reason for undertaking treatment in the dry season is to minimise the risk of non-target effects through run-off into the marine environment.

The number of treatments (within a season and throughout the management programme) depends on the objective of the operation. Typically eradication involves application over a number of years, and as the populations of invasive species are lower with progressive years, the amount of residual pesticide is likely to increase as population size declines. The objective of the proposed Activity is to reduce the abundance of the yellow crazy ants to levels below which environmental effects are likely to be severe, and below which people perceive the ant to be a serious social problem. Thus, we propose only two control treatments in successive years, followed by three years of monitoring.

Safe storage, handling and operations

Manufacturer's precautions for safe handling

The proposed Activity will follow the manufacturer's guidelines for safe handing, which are as follows: "To avoid risks for people and environment the instructions for use on the product label are to be followed. Avoid all contact with the product and wear protective clothing and gloves."

Manufacturer's conditions for safe storage

The proposed Activity will follow the manufacturer's guidelines for safe storage, which are as follows: "Store in the closed, original container in a dry, cool, well-ventilated area out of direct sunlight. Store in a locked room or place, away from children, animals, food, feedstuffs, seed and fertilisers and ignition sources. Fipronil is stable in normal temperatures for one year."

Disposal

All Antoff® ant bait not used will be shipped back to New Zealand for disposal according to New Zealand Environment Act requirements.

Appendix II

Estimated budget for YCA eradication on Motala Islet

Qty	Description	Supplier	Per item (AUD)	Total cost (AUD)
12 pails	Antoff® ant bait, rate =10kg/ha., Area = 7ha., Time of application = twice. 12.5kg/pail	Animal Control Technologies Pty Ltd Australia	325.00	3,900.00
4	Overalls	Supplier from Fiji	5.00	20.00
6 pairs	Hand gloves	Supplier from Fiji	5.00	30.00
6 pairs	Safety boots	Supplier from Fiji	200.00	1,200.00
4	Scott Spreaders	Supplier from Fiji	30.00	120.00
6	Hats	Supplier from Fiji	5.00	30.00
10	Disposable respirators	Supplier from Fiji	23.00	230.00
6 pairs	Eye glasses	Supplier from Fiji	10.00	60.00
2	Knapsack sprayers	Supplier from Fiji	25.00	50.00
10 bottles	Insecticides (white oil insecticide) 500ml/bottle	Supplier from Fiji	10.00	100.00
2	Tuvalu Biosecurity Staff sea-fares (8 trips)	Tuvalu Shipping Co.	1000.00	4,000.00
2	Tuvalu Biosecurity Staff per diems (8 trips x 1 wk)	Tuvalu Govt	2,800.00	5,600.00
2	SPC Staff airfares (4 trips)	Fiji Airways	4,528.00	9,056..00
2	SPC Staff sea-fares (4 trips)	Tuvalu Shipping Co.	1000.00	2,000.00
2	SPC Staff per diems (4 trips x 1wk)	SPC	2,500.00	5,000.00
1	44 gallon Unleaded Petrol and mix	Funafuti Fuel Depot	400..00	400.00
4	Storage containers	Supplier from Fiji	10.00	50.00
	Freight charges	DHL	500.00	500.00
	Miscellanies		1,000.00	1,000.00
				AUD $33,56.00