Assessment of Yellow Crazy Ants (*Anoploleps gracilipes*) on Nuulua Island, Aleipata, Samoa with recommendations for population control

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Background

The Samoan islands of Nuutele and Nuulua form part of the Aleipata Marine Protected Area, in recognition of their contribution to biological diversity in Samoa. In a 1986 review of 226 islands in the South Pacific region, these islands together rated 30th in importance for biological diversity. The islands provide essential habitat for a range of sea birds, bats and land birds such as the rare friendly ground dove, sea turtles, shell fish and other marine life. Human access to Nuutele and especially Nuulua is difficult and this has, in part facilitated the preservation of this habitat to date.

In a recent field trip to Nuulua in 2003, the forest floor and vegetation appeared covered in fast moving ants which were later identified as Yellow Crazy Ants (*Anoplolepis gracilipes*), an invasive ant species with a pan-tropical distribution. These ants had previously not been observed on this island, and it was therefore presumed to have been a recent arrival.

This report outlines an investigation of this biological invasion and provides options for managing Yellow Crazy Ants on Nuulua.

Ecology of Tramp Ants

Ants are an extremely species-rich group of organisms. They occupy every continent on earth with the exception of Antarctica and in many ecosystems contribute to essential processes such as bioturbation, decomposition, pollination and seed dispersal. Many ant species are generalists and their population dynamics are regulated in their home ranges by complex and interacting biotic and abiotic factors. A small number of ant species have characteristics that provide them with the means to invade new habitats, often to the detriment of other organisms. Collectively, these species are termed tramp ants due to their reputation for stowing away and hitching rides with human commerce.

Many Pacific islands have a well documented history of invasion by successive waves of tramp ants including Coastal Brown Ants (*Pheidole megacephala*), Argentine Ants (*Linepithema humile*) Yellow Crazy Ant (*Anoplolepis gracilipes*) and more recently Little Fire Ant (*Wasmannia auropunctata*).

Sociality is a key factor that contributes to the success of tramp ants as invaders. However, all tramp ants share the following additional characteristics that set them apart from other species:

- Polygyny, or the tolerance of worker ants for more than a single queen within a colony;
- Unicoloniality or the formation of large inter-connected super-colonies;
- High interspecific aggression;
- reproduction by budding instead of nuptial flight;
- A tendency to form mutualistic associations with other organisms; and
- Dispersal via human commerce. (Passera 1994; Jourdan 1997)

Polygyny

Typically, an ant colony consists of a single reproductive female (the queen) attended by her daughters which are sterile female workers. From time to time, winged males and females with functional ovaries are produced and these normally depart the nest to mate and initiate new colonies (Holldobler and Wilson 1990). Worker ants will defend their territory from incursion by a nearby colony of the same species with the same degree of aggression as they would from incursion of their territory by a different species. This "kin recognition" is most probably pheromone (or odour) derived. However, not all ant species conform to this model of colony organization. An extreme example is the colony organization of the green-headed ant (*Rhytidoponera metallica*) where, most workers in a colony are mated egg-laying queens that are unrelated and live co-operatively but not as an organized colony (Chapuisat and Crozier 2001) However, such extremes are rare.

Polygynous or multiple queen colonies are another social form that occurs in a minority of ant species (Holldobler and Wilson 1990). The presence of more than one functional queen in a colony bestows it with competitive and survival advantages including increased production of workers and a lower risk of colony death as a consequence of queen mortality. The worker caste in these colonies are not all sisters as is the case for monogyne colonies because they are not daughters of a common queen. One invasive species, *Solenopsis invicta* (the Red Imported Fire Ant), possesses both social forms. In the case of this species, the polygyne form is widely regarded as the more virulent invasive form, which suggests polygyny as an advantageous trait for invasive ants.

Unicoloniality

Invasive ants often form interconnected super-colonies which may extend for many hectares. This unicoloniality is closely associated with the trait of polygyny and the lack of aggression exhibited by worker ants towards neighbouring colonies. Often, there is an exchange of individuals between nests (Passera 1994). In some cases, these super-colonies may extend over huge areas of many square kilometres and even entire states (McFarling 2002).

High interspecific aggression

While tolerant of neighbouring colonies of the same species, invasive ants behave very aggressively towards other ant species that are found within their foraging territory. As an example Argentine ants frequently attack newly mated queens of other ant species thus interfering with the establishment of new nests (Human and Gordon 1996)). However, the most substantial interactions occur at or near food resources. Argentine ants monopolise food sources, which they actively defend from other ant species (Holway and Case 2001). As a result they are generally able to acquire the majority of resources to the detriment of competitors.

Reproduction by budding

For many ant species, mating occurs in the air as part of a synchronized mating flight of winged males and virgin queens (alates). There are substantial risks associated with this activity and the colony founding process as the newly inseminated queens are exposed to predation, parasitism and attack from enemies in the search for a suitable habitat and their subsequent attempt at producing the first clutch of workers.

For invasive ant species, mating often occurs within the nest. Newly inseminated queens leave the natal nest on foot with a small group of attendant workers to form a new locus of the main nest. This process is called budding and carries with it a far lower risk of failure, because many of the causes of mortality whilst in flight and during colony establishment are eliminated. The queens are provided with the protection of the natal nest and there is a high likelihood that suitable nest sites will be found close to the original nest. Through this process, the invasion locus can expand and fuse to form a dense population and a continuous invasion front (Porter 1988) which is highly resistant to predatory forces.

Mutualistic associations

Invasive ants are often found at much greater densities than a “normal” ant community. This poses the obvious question of where such ant colonies get their nutrition. A recently observed characteristic of invasive ants is their tendency to form mutualistic associations with animals or plants. Coastal brown ants “farm” mealybugs in Hawaiian pineapple plantations in return for carbohydrates. In southern USA Red Imported Fire Ants tend mealybugs that live on grasses, while on Christmas Island, Yellow Crazy Ants form associations with tree canopy scale insects in return for carbohydrates.

Dispersal via human commerce

Dispersal of all tramp ant species is facilitated by human commerce. Colony fragments containing a fertile queen and enough workers to maintain a functional colony are carried with produce or cargo to new locations. This phenomenon is not new and has actually been going on for centuries. *Pheidole megacephala* was carried throughout the Pacific region including Australia by ships carrying produce. It is no surprise that this species established so readily. As few as ten workers attending a single inseminated queen are sufficient to start a new invasion of this species (Chang 1985). In the 1890s, entomologists in Brisbane had observed that areas in the settlement where *P. megacephala* had established were no longer good collection sites for other invertebrates.

Yellow Crazy Ants

Anoplolepis gracilipes (Smith) (Yellow Crazy Ant) is a slender ant with elongate legs and antennae approximately 4 mm in length. Their species name (*gracilipes*; long legs) is descriptive of their general appearance. When harvesting food items or when disturbed, their exited frenetic movements, give rise to their common name of Yellow Crazy Ants. In the field, they can be confused with Green Tree Ants (*Oecophylla smaragdina*), which are approximately the same size and general appearance but have a distinctive green gaster (abdomen), and species of *Leptomyrmex* which are also similar in appearance but carry their gaster folded over their thorax giving the appearance of a long legged spider. The Yellow Crazy Ant is readily identified in the field once an observer has familiarized her/himself with the appearance and behaviour of the species.

The Yellow Crazy Ant is a tramp ant with a worldwide tropical/sub-tropical distribution (Figure 1). Its original range is difficult to determine because it was transported across the globe as early as the nineteenth century and perhaps earlier. Eastern Africa or an Asian origin is most likely. It was inadvertently spread by commerce as well as deliberately introduced as a biological control agent in cocoa, coconut and coffee plantations through the nineteenth and twentieth centuries. It was already recorded from virtually the full range of its current known distribution before 1900: from India (1851), Southeast Asia (1854), Chile (1859), Polynesia (1867), Melanesia (1876), Mexico (1893), East Africa (1893), Australia (1894), and Indian Ocean islands (1895) (see Wetterer 2005). This distribution remained fairly static until recent times, and as Asia/Pacific trade has increased, the number of incursions at new locations has also increased.

General behaviour

The Yellow Crazy Ant is a generalist feeder, predating on small insects and other invertebrates. In common with other tramp species, Yellow Crazy Ants will also form symbiotic relationships with other insects. A well documented example of this exists at Christmas Island where they "farm" scale insects in the forest canopy in return for the sugary exudates produced by these insects. Prey size is no impediment to this species as they are known to attack and consume red land crabs *Brachyura gecarcinidae* which are substantially larger than themselves. In common with ants in the sub-family Formicidae, the Yellow Crazy Ant has no functional sting mechanism. They overpower their prey by spraying them with a toxin comprised mainly of formic acid.

In common with many other generalist feeders, Yellow Crazy Ants seek out sources of carbohydrates, lipids and proteins as food sources. Carbohydrates and lipids are used chiefly for energy while proteins are used for queen maintenance and brood-rearing.

Colony structure

Yellow Crazy Ants do not build structures or galleries but utilize sites suitable for their needs.

These may be crab burrows, under stones or logs, within heavy litter, or human-made sites such as drains, culverts, access points for underground services and mulched garden beds. The lack of distinctive nest locations makes detection more difficult than for mound-building species such as Red Imported Fire Ants (*Solenopsis invicta*) or those species with distinctive nest entrances.

This species is polygyne and also forms super-colonies or networks of closely connected colonies. Once established, they monopolise the entire site they occupy to the exclusion of other ant species by using all available nesting sites and dominating any food resources that may be present. There is no intraspecific aggression thus territory defence is shared amongst neighbouring colonies and the length of territorial boundaries is minimized.

A high proportion of females (about 15%) in a colony may be sexually reproductive queens. Colony dispersal is primarily by budding rather than nuptial flights. Dispersal over distances greater than a few metres is accomplished when part of a colony including at least one queen, is transported to a new location by other means. Invariably, such dispersal events are human mediated, and is the mechanism that results in incursions into countries where Yellow Crazy Ants previously did not exist.

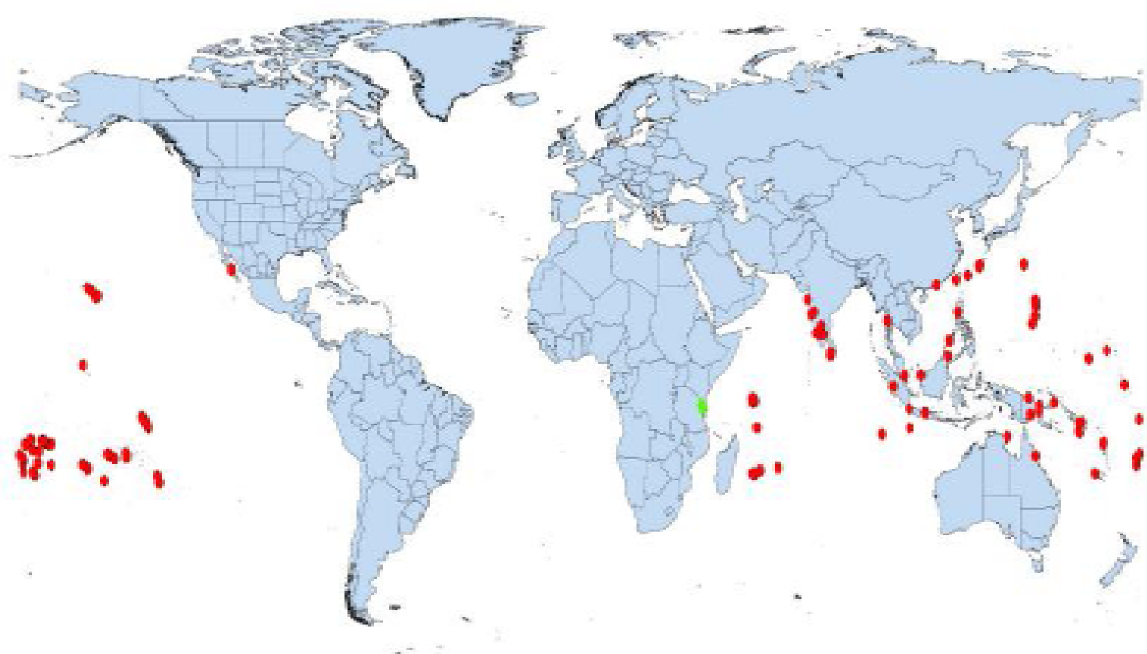


Figure 1. Worldwide known Yellow Crazy Ant distribution (putative natural distribution in green, putative introduced distribution in red) (from Harris et al. 2005).

Section 1. Field Assessment

A field assessment was conducted on Nuulua island between 26 and 29 July 2006 by CV, SS and FS. A day labourer from Aleipata also accompanied the team. During the visit, ant activity, density, distribution and interaction with crabs and scale insects were investigated.

Ant activity and density

Yellow Crazy Ants were observed on every part of Nuulua island above the spring tide mark. Activity was very high along the beach area on the eastern side of the island, extending inland over lower elevations. On 26 July, the team climbed to the ridge area which extended along the northern, western and southern boundaries of the island. Human access between this ridge area and the sea was not possible due to the steep topography. Ant activity was assessed along the ridge using tuna baits placed at approximately 100 metre intervals. Locations were recorded using a Garmin Etrex GPS where canopy conditions allowed (Table 1). The baits were inspected after approximately 60 minutes. Yellow Crazy Ants recruited to all tuna baits in very large numbers indicating their dominance of the above-ground ecosystem. Ant densities, while high, were not as high as those recorded in supercolonies on Christmas Island, another island location where this species has become established.

Table 1. Locations of tuna baits placed on 26 July (six locations unable to be recorded due to heavy canopy cover)

14^{o} 04’ 28.3”	171^{o} 24’ 33.4”
14^{o} 04’ 27.6”	171^{o} 24’ 36.9”
14^{o} 04’ 27.8”	171^{o} 24’ 36.7”
14^{o} 04’ 26.3”	171^{o} 24’ 36.1”
14^{o} 04’ 22.0”	171^{o} 24’ 38.0”
14^{o} 04’ 18.7”	171^{o} 24’ 40.5”

YCA distribution

Observations across the island on 26, 27 and 28 July confirmed that Yellow Crazy Ants were distributed over all parts of the island accessible by humans. The cliff area on the southern, western and northern coastlines could not be assessed. The ridge area on the south-east extremity of the island was occupied by Yellow Crazy Ants but ant densities appeared to be lower than other parts of the islands. This may have been due to a number of possible factors including a generally drier microclimate, distance from the original incursion or a lack of food or prey items.

Reproductive status

Wherever nests of Yellow Crazy ants were observed, these were excavated to determine the makeup of nest contents. The rocky substrate was used consistently by Yellow Crazy Ants in lieu of constructing nests and generally too deep to examine completely. Many nests were located at the bases of trees, decayed stumps or in depressions where litter had accumulated. It appeared that the reproductive queens were located in the lower portions of nests and these were generally inaccessible. Large amounts of worker brood were observed within each nest that was opened. Reproductive queens and alates were rarely observed indicating that these may be kept in deeper portions of the nest than was possible to excavate, or a general paucity of these life forms at the time of survey.

July is on average the month with least rainfall in Samoa. The dry season is also the time when resources are most limiting for ants and the time of lowest worker and alate production. While large quantities of worker brood were observed, few if any alates were visible during this survey. During the wet season, it can reasonably be expected to observe larger amounts of alate production as this is the season when maximum dispersal would be expected.

Interaction with land crabs

The coconut or robber crab (*Birgus latro*) is a large land crab with an Indo-Pacific distribution. It is a hermit hermit crab that belongs to the monospecific genus (*Birgo*) within the family Coenobitidae and is the largest of the land crabs. The flesh of the coconut crab is a sought after food amongst the people of Samoa and has great socio-cultural significance. Commercial exploitation of the coconut crab, via the tourist market, is becoming increasingly significant and this in combination to land clearing and predation by domestic animals has led to a decline in populations on many Indo-Pacific islands.

Mating occurs on land, and although a terrestrial animal, the females deposit their eggs into the ocean. Here the eggs hatch and after a 2-3 week pelagic phase, find a gastropod shell for protection and climb ashore. After approximately nine months, the juveniles assume a true adult shape and discard their protective shell. Sexual maturity is reached after five years and adults are thought to live for up to forty years.

On Christmas Island, an infestation of Yellow Crazy Ants has led to dramatic population declines of the island's endemic red land crab. Coconut crabs are also found on Christmas Island, and these too are predated by Yellow Crazy Ants. Anecdotal evidence from the Natural Resources Manager on Christmas Island suggests that Yellow Crazy Ants begin to cause noticeable coconut crab mortality once they attain supercolony status. During the island visit, the team observed many coconut crabs but did not record any predatory interactions between the species. However, it is very probable that Yellow Crazy Ants do predate on *B. latro* here especially given their needs for sources of protein for brood development and queen maintenance.

Interaction with scale insects

Almost all invasive ant species form mutualistic associations with insects that produce honeydew. On Christmas Island this association is with scale insects that live on leaves in the rainforest canopy. The ants farm these scale insects and protect them from predators. Their "reward" is the sugary exudates produced by the insects. This association between Yellow Crazy Ants and exotic scale insects has caused a collapse of the rainforest canopy and resulted in dramatic changes to the vegetative structure of the forest there.

No such associations were evident for Yellow Crazy Ants on Nuulua. Some phytogaphy was evident, but this appeared to be principally damage from weevils or other large insects. It is possible that the scale insects on Nuulua, if present, are not the exotic species recorded on Christmas Island. The much lower levels of human visitation and the absence of human occupation on Nuulua may have prevented the introduction of damaging scale insects to date.

Conclusions from field assessment

Yellow Crazy Ants are present in high numbers on all parts of Nuulua island. Population density has not as yet reached critical supercolony levels where impacts will become obvious and cause large-scale ecological change as recorded on Christmas Island. Currently, Yellow Crazy Ants probably predate on some land crabs, other invertebrates and carbohydrate sources from flowers, fruits and extra-floral nectarines. Some lipids are probably being obtained from the plentiful seeds of the Maali trees which are common on the island.

Section 2: Pre-operational Monitoring

Design and implementation of monitoring

One of the project objectives was to design and conduct some pre-operational monitoring. The purpose of this monitoring was to provide baseline information with which to record change as a result of Yellow Crazy Ant presence and/or any treatment programme established to control the ants.

There are several important considerations when designing an invertebrate monitoring programme for Nuulua island. First, human access is difficult, sometimes hazardous, and trips need to be of a short duration with sampling completed in a few days. Second, the invertebrate community of most island ecosystems is relatively simple, and finally, sampling should cover all habitats on the island.

Human access

Gaining access to the island is often difficult and dependent on the weather and availability of suitable boats and pilots. All supplies including water, camping equipment, food and scientific equipment must be ferried to the island in a small dinghy. Any monitoring program therefore must be simple, robust and be accomplished with a minimum of equipment and time.

The invertebrate community

Island ecosystems are often much simpler than those of larger locations. On Nuulua island the two most important vertebrate groups are the Yellow Crazy Ants themselves and the coconut crabs which are an iconic and important organism both to the ecosystem and those responsible for the island. A monitoring programme should focus on collecting the best possible information on these two organisms.

Habitat

A steep ridge of volcanic origin runs along the southern, western and northern perimeter of Nuulua Island. The eastern portion of the island is low lying and terminates in a beach along the eastern perimeter. Three distinct habitats are therefore present: areas of rocky cliffs >45^o incline (not sampled due to safety considerations), the high elevation areas on the ridge, and the lowland areas on the eastern side of the island.

The bulk of invertebrate biomass and diversity will be concentrated on the forest floor and the tree canopy. Both habitats are utilized by Yellow Crazy Ants and Coconut crabs. Sampling tree canopies can be difficult and time consuming. A popular method for sampling the canopy is to "fog" individual trees with a pyrethrin aerosol and catch dead or dying insects on sheets laid out beneath the tree. This method can be a highly productive means of sampling biological diversity present in the canopy. The amount of equipment needed to conduct canopy assessments of invertebrate biodiversity made this option undesirable for this aspect of the study, and sampling was restricted to the forest floor.

Possible monitoring methods

Ants and other arthropods

There are a number of efficient and effective methods of sampling ground-active arthropods. Undoubtedly, pitfall trapping is the most widely used method of sampling epigaeic arhtropods. This method uses a pit to trap unwary invertebrates that happen to be passing (Southwood 1978) at a scale appropriate to the target animal. Usually, a suitable container is buried so that the mouth of the container is flush with the soil surface. The pitfall is partially filled with a suitable preservative to prevent escape by captive insects. The main factors that influence the catch are population size, movement of individuals, and the size of pitfall used (Jansen & Metz 1979). An important feature of pitfall trapping is the capacity of this method to be repeated at a number of locations simultaneously in order to obtain comparative data.

While pitfall trapping is regarded as an efficient way of obtaining a representative sample of surface-active arthropods (Simmonds *et al.* 1994; Abensperg-Traun *et al.* 1996) the catch is not always proportional to absolute arthropod density (Topping & Sunderland 1992). Quantitative results from pitfall trapping are an "index of species' importance" (Greenslade & Greenslade 1971). Although pitfall trapping as a way of sampling invertebrate communities is now widely used and accepted, the data should be treated with caution (Southwood 1978) as other factors will also influence the size and composition of the catch.

Pitfall trapping is most likely to under-sample organisms that exhibit cryptic or hypogeal behaviour (Andersen & Reichel 1994), and these species are best surveyed through litter extraction techniques (Majer 1997). Extraction of ants from a large number of litter samples is achievable provided sufficient extraction equipment (Tullgren funnels, Winkler sacks) are available. However desirable litter extraction may be, supplementary assessments of this nature were considered unlikely to result in the detection of many additional species and the resource cost would be disproportionally high in comparison with the data resulting from pitfall trapping.

Coconut Crabs

Estimates of population density of Coconut Crabs could not reasonably be achieved through pitfall trapping as the pitfall traps would need to be very large and setting large pitfalls on Nuulua would be impractical. Researchers on Christmas Island conduct visual counts of Coconut Crabs in plots of predetermined size. This method will always under-estimate absolute population density as Coconut Crabs are cryptic, choosing to spend much of their time hidden in burrows, cracks and crevices. Provided that the same observers are used from sample to sample period (or observers with approximately equal skill), this method will provide an adequate index of population size and provide adequate between-plot and between-sample comparisons.

Another method of sampling Coconut crabs is to count recruitment to lures of coconut meat placed at intervals along a transect. The lures are observed through the night and visitation by crabs recorded. In contrast to visual searches, this method is likely to over-estimate population densities as the lures are likely to attract crabs from an area larger than that being surveyed. No relationship between absolute population densities and recruitment to lures could be found in the literature which means either method could be used, each allowing adequate between-plot and between-sample comparisons..

Sampling method selected for this study

Six 0.05 hectare circular plots were established, three on lowland areas and three on high elevation areas, resulting in a 1% survey of the island (6 x 0.05ha = 0.3ha). Plots were located in such a way that the entire island was adequately covered. Approximate locations of these plots are shown in Figure 2. Plot boundaries were located using a 12.6 metre length of 3mm nylon cord [(12.6^2)*(22/7)=500m^2]. One end of the cord is held by an operator who stands in the centre of the plot, while a second operator marks the plot boundaries with flagging tape. Plot establishment took no more than five minutes. Ground-active arthropods were sampled by means of pitfall trapping and coconut crabs population was estimated by visual counts in plots.

Pitfall trapping, using 60 ml medical specimen vials, was selected as the most practical sampling method for this survey. The vials were buried with the lip of the vial flush with the soil surface, primed with approximately 10ml ethanol. Five pitfall traps were set in a line, 2 metres apart, in an east-west direction with the centre pitfall trap located in the centre of the plot. These were opened for 24 hours (timing determined by time available on the island). Two searchers counted all empty shells, juvenile coconut crabs, adults, large adults and crab burrows within the plot. Search time was set at 30 minutes per plot.

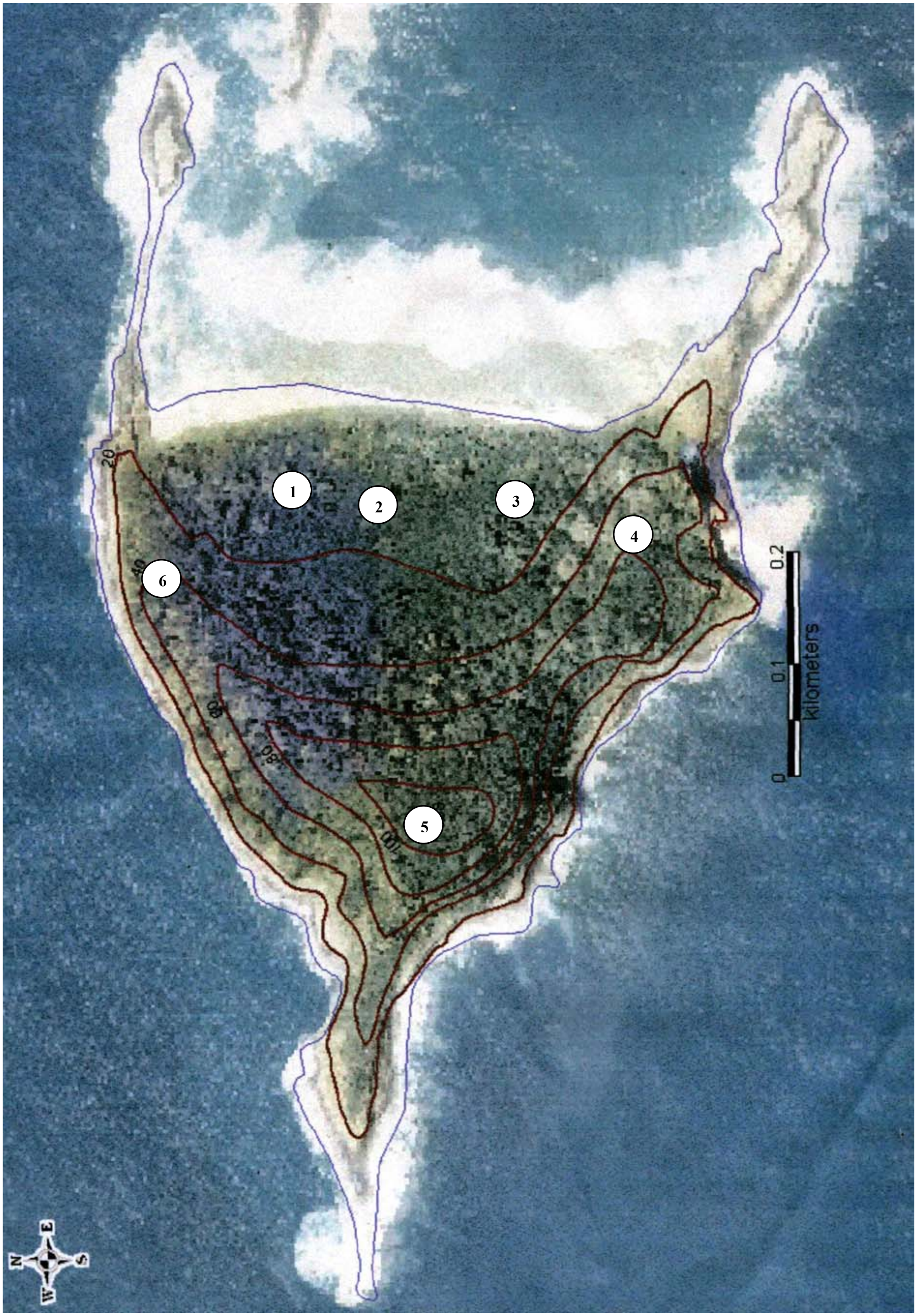
Results of July 2006 survey

Pitfall trap contents were transported back to the Flybusters/AntiAnts laboratory in Auckland where Yellow Crazy Ants, other ants, and other invertebrates were counted. Counts from each pitfall were combined to provide a total count of organisms captured in each plot. Other ants and invertebrates were not identified but the were sorted and counted. These samples were stored at the laboratory and will be identified when resources allow. Table 2 provides a summary of the results.

A total of 109 crabs were located, 21 in low elevation plots and 88 in high elevation plots. The data were skewed as the result of a very high count of small crabs in a single high-elevation plot. Empty snail shells which are utilized by juveniles were more abundant in low elevation plots while live juvenile crabs in shells were more abundant in high elevation plots (Figure 3) Yellow Crazy Ants were the most abundant captured in pitfall traps accounting for 39.2% of all individuals captured and 64.4% of ants. Mean abundance of Yellow Crazy Ants, other ants and other invertebrates was higher in low elevation plots than high elevation plots (Figure 4).

There was a non significant relationship between Yellow Crazy Ant abundance and the abundance of other invertebrates (n=6, r^2=0.3424) (see Figure 5) and a significant relationship between Yellow Crazy Ant abundance and the abundance of other ants (Figure 6) (n=6, r^2=0.8657). There was a weak, non-significant inverse relationship between the abundance of Yellow Crazy Ants and Coconut Crabs (n=6, r^2=0.0459) (Figure 7) suggesting that plots with high Yellow Crazy Ant abundance had proportionally lower abundance of Coconut Crabs.

Figure 2. Aerial image of Nuulua Island showing approximate locations of plots.



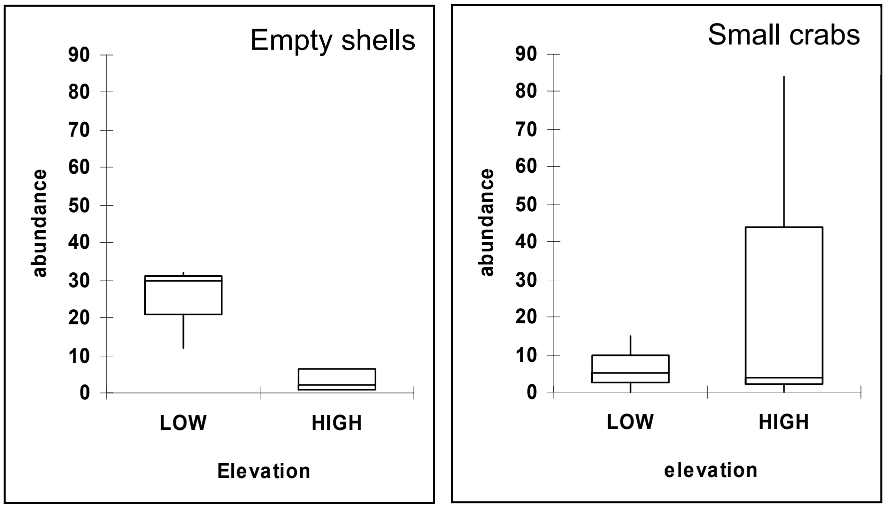


Figure 3. Box and whisker plots showing counts of empty shells and small crabs at high and low elevation plots.

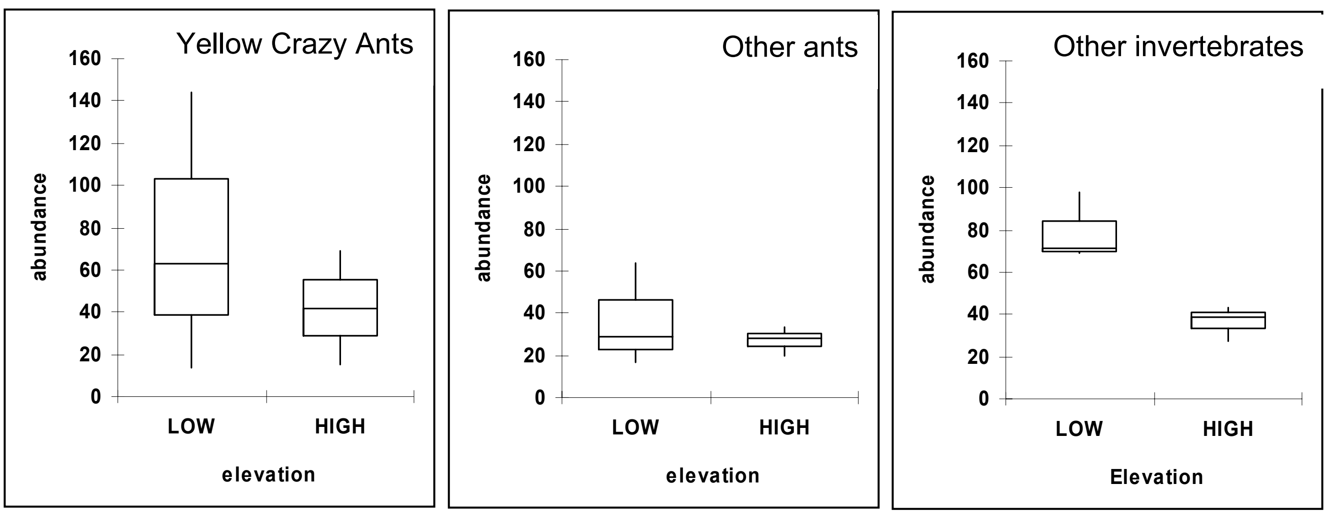


Figure 4. Box and whisker plots showing counts of Yellow Crazy Ants, other ants, and other invertebrates captured in pitfall traps high and low elevation plots.

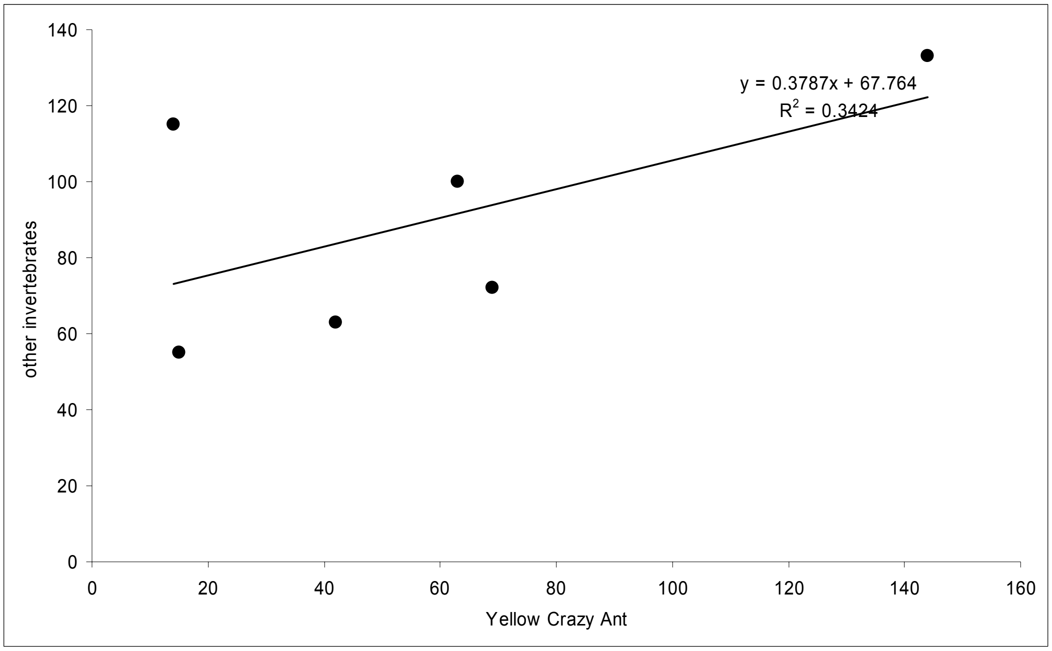


Figure 5. relationship between abundance of Yellow Crazy Ants and other invertebrates.

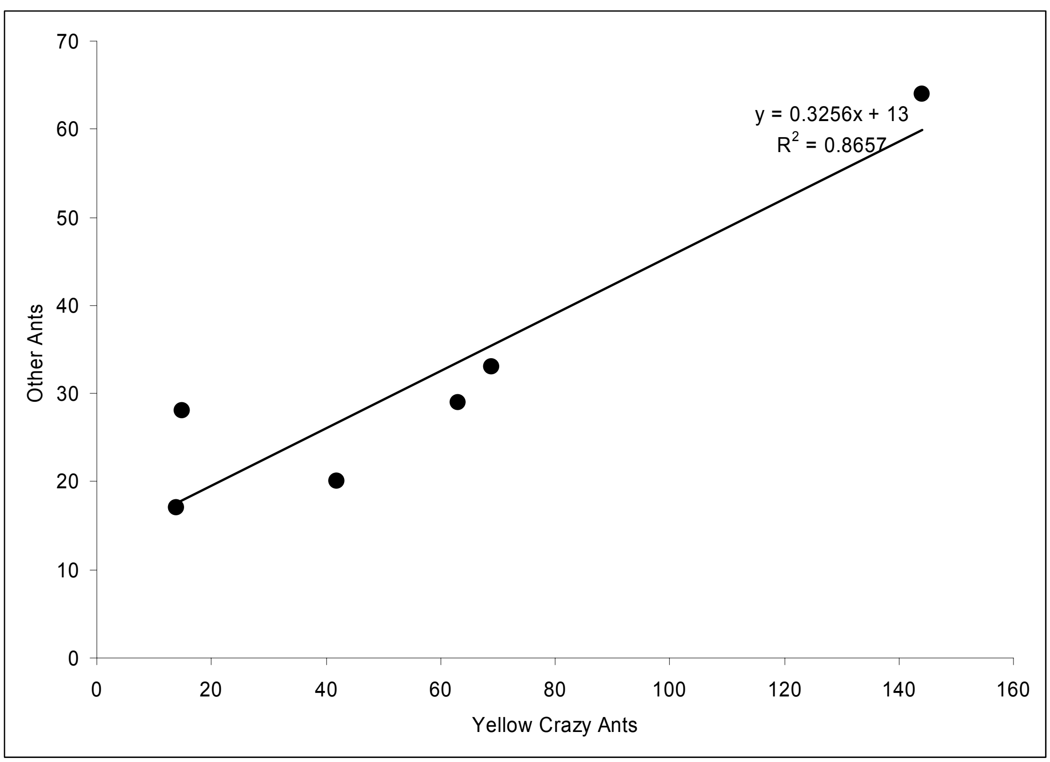


Figure 6. relationship between abundance of Yellow Crazy Ants and other ants.

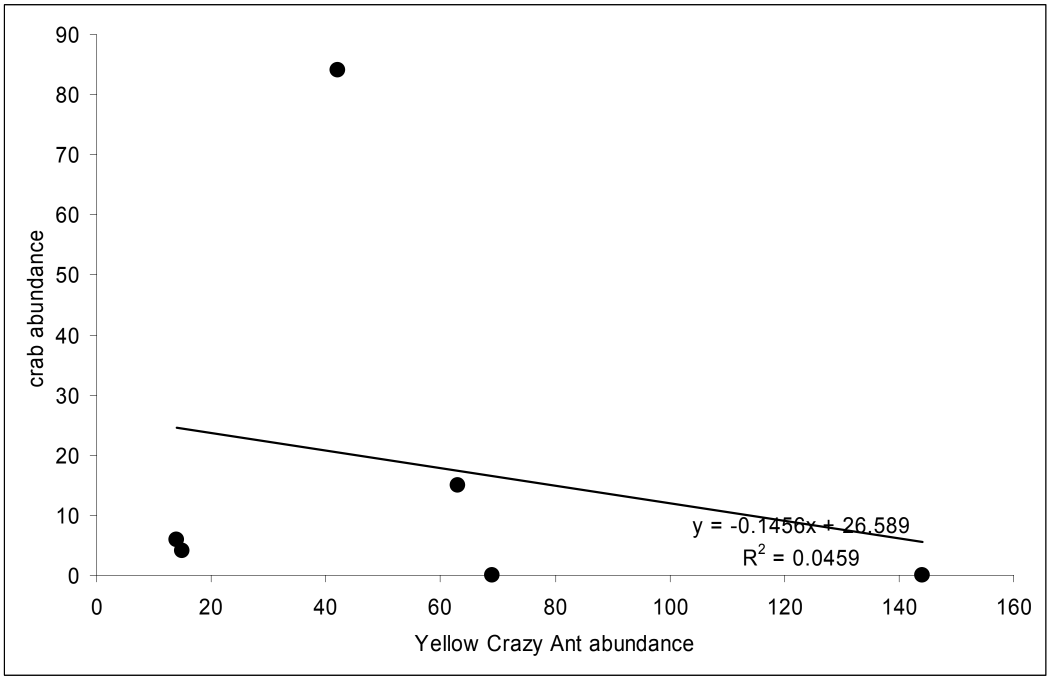


Figure 7. relationship between abundance of Yellow Crazy Ants and crab abundance

Table 2. Summary of results for plots 1-3 (low elevation) and 4-6 (high elevation) on Nuulua Island

	Location			crabs					ants	
Plot number	S	W	Empty shells	Small crabs	Medium crabs	Large crabs	Crab burrows	YCA	other ants	other invertebrates
1 (low)	14°4'14.9"	171°24'32.4"	30	0	0	0	0	144	64	69
2 (low)	14°4'18.4"	171°24'33.9"	32	15	0	0	0	63	29	71
3 (low)	14°4'21.7"	171°24'35.2"	12	5	0	1	12	14	17	98
		Mean	24.7	6.7	0	0.3	3	73.7	36.7	36.3
4 (high)	14°4'29.2"	171°24'35.8"	2	4	0	0	1	15	28	27
5 (high)	14°4'23.5"	171°24'42.8"	0	0	0	0	0	69	33	39
6 (high)	14°4'14.5"	171°24'34.9"	11	84	0	0	0	42	20	43
		Mean	4.3	29.3	0	0	0.3	42	27	36.3

Brief discussion of survey results

Greater abundance of Yellow Crazy Ants, other ant species and other invertebrates were recorded on low elevation sites suggesting that this habitat is more favourable generally for invertebrates. No apparent trend was observed for Coconut Crabs, but this may be due to the low number of sample points. The survey data also confirmed that the entire island is occupied by Yellow Crazy Ants and that they appear to favour habitats where other ant species were found. The weak inverse relationship between Yellow Crazy Ant abundance and Coconut Crabs may suggest that Yellow Crazy Ants are having an impact on crab numbers but this relationship is far from proven. Sampling a greater number of points and repeated sampling in time could confirm this trend or establish that no relationship exists.

Recommendations for further monitoring

The monitoring conducted on Nuulua in July 2006 helped establish a practical method for sampling and was used as an exercise to train MNRE staff. Further pre-treatment monitoring would greatly enhance the quality of data gathered so far. While it would be desirable to re-sample the original plots, it is not essential. The rapidity of establishing 0.05 hectare plots means that they can be set up in different locations without much extra effort. For future monitoring, it would be statistically desirable to add at least 2 additional plots (one each on high elevation and low elevation habitats) and to open pitfalls for a longer period of at least 48 hours.

Sampling tree canopies with a mister or thermal fogger could also be considered. Implementing a sampling strategy which includes canopy sampling will need careful planning, correct equipment and calm weather without winds. It is also desirable that the operation be conducted by a qualified experienced pest controller with all appropriate licenses.

Once an operational plan for control of the Yellow Crazy Ant population has been selected, pre and post-operational monitoring is strongly recommended. Pre-operational monitoring should be conducted on at least one occasion in the month prior to treatment and at least twice after treatment: once immediately post-treatment and at least once approximately 12 months later.

Collection of samples for DNA

Ant specimens were collected from a nest near each of the six monitoring plots (Table 2). These have been retained in ethanol for later DNA comparisons.

Section 3. Operational Plan and Recommendations

Objectives

One objective of this study is to develop an operational plan for population control of Yellow Crazy Ants on Nuulua Island. Any operational plan developed for the island must consider the following before a suitable strategy is selected:

1. controlling further spread of the organism
2. preventing new incursions, and
3. Costs and benefits of various control options

Controlling further spread

Based on this survey, Yellow Crazy Ants are well-established over the entire island. As a consequence, controlling spread within this island habitat will have little or no effect on population dynamics. However, based on observations of other incursions of invasive ants, the population density could increase dramatically if Yellow Crazy Ants are able to form a mutualistic association with scale insects. At present, no such association appears to exist and one possible reason for this could be the absence of a suitable symbiant. It is therefore very important to ensure such an organism is not introduced to Nuulua. In order prevent this, movements of plant materials onto Nuulua should be prevented. This should include any plants, leaves, baskets, fruit and vegetables or other host material capable of transporting scale insects. The consequence of an introduction of scale insects may well be catastrophic. These restrictions should also be implemented for movement of people and goods on neighbouring Nuutele Island.

Preventing new incursions

New incursions of Yellow Crazy Ants should also be prevented. Again, this requires that visitors to the island pay close attention to any products, goods or personal possessions they bring with them. Camping equipment such as tents and sleeping mats have a well-deserved reputation of being vectors for exotic pests including ants. The beautiful baskets made from palm fronds which are in common use throughout Samoa are also an ideal vehicle for movement of ants, and their use for transport of goods onto Nuulua and Nuutele should be avoided.

Costs and benefits of control options

The response to an incursion of a new organism should be selected after weighing the costs of options against the benefits achieved by implementing them and the probability of achieving the planned outcome. The option of doing nothing should also be considered. Eradicating an invading organism is always the most desirable option but often can be expensive and outcomes can rarely be guaranteed. Often, an option that limits the population (and therefore its impact) is the best alternative. Table 3 lists the estimated costs, benefits and impacts of management options.

Doing nothing: impacts of Yellow Crazy Ants

Nuulua Island enjoys considerable freedom from human interference, provides a safe habitat for birds, bats, sea turtles and other marine life. At least one of the bird species nests and feeds on the ground. Coconut crabs inhabit the island and enjoy relative freedom from predation by humans and domestic animals. There is ample evidence in the literature to make predictions about potential impacts of Yellow Crazy Ants on this ecosystem. Invasive ants will feed on any convenient source of protein, including turtle hatchlings, crabs, chicks, reptiles and other invertebrates. Yellow Crazy Ants therefore have the potential to disrupt the ecosystem in a number of ways. Turtle hatchlings and reptile eggs are often the target of predation by invasive ants. For example, in Florida, the main predator of loggerhead turtle hatchlings are Red Imported Fire Ants. Young chicks are often predated on by ant species, especially during the pipping stages. Many ecosystems invaded by exotic ants have severely depleted invertebrate communities. Animals and ecological processes that depend on the invertebrate community are therefore severely compromised.

The effects of Yellow Crazy Ants on red land crabs and coconut crabs on Christmas Island is well documented and the potential for this to occur on Nuulua and Nuutele is high. Once Yellow Crazy Ants reach super-colony status, crab mortality will begin to escalate. The crabs are killed or blinded by the toxin sprayed by the ants and eventually succumb to predation by the ants and other animals. Fortunately, the incursion of Yellow Crazy Ants on Nuulua appears relatively recent and to date, the organism has not been able to increase in size to supercolony status. As a result, the damage caused to date is reversible.

Impacts of treatment

At present, the only treatment with documented effectiveness is the application of Presto 001™ bait. This bait contains 0.001% fipronil as the active ingredient. Ant baits work by exploiting the social nature of ant colonies. Foraging ants represent a minority caste within an ant colony and are often the oldest and therefore most expendable caste. Their function is to search for food and return resources to the nest. Often this food is carried in the ant's crop and on returning to the nest, regurgitated to other workers on demand. This process is termed trophallaxis. A desirable food source laced with an effective active ingredient can thereby enter the colony with foragers and be rapidly distributed through the colony. The active ingredient must be sufficiently slow-acting in order that foraging workers can return to the nest without dying and still be effective after it is diluted through the colony. For Yellow Crazy Ants, Presto 001 appears to fill these criteria well.

Fipronil is also a contact insecticide and other invertebrates that come into physical contact with the bait or ingest it may also be affected. On Christmas Island, Coconut Crab mortality following baiting with Presto has been observed and documented. While it is difficult to determine the degree of mortality, unpublished reports by researchers on Christmas Island suggest it may be between 5.1 and 55%. However, these results may be biased by the transient nature of the crab population. Regardless, substantial mortality of Coconut Crabs was observed.

The use of food lures has been tested on Christmas Island as a way of reducing mortality caused by baiting. Stations containing commercial chicken feed is placed at strategic locations, 50 metres from the intended baiting area prior to baiting (coconut meat could easily be used as an alternative and may be more readily available). This has the effect of luring the crabs away from areas to be baited for long enough to avoid the effects of the baits. Results to date have been variable due to the mobile nature of Coconut Crabs.

An alternative bait product is currently being tested both at Tokelau and Christmas Island. This bait is similar to Presto but contains a different active ingredient, Indoxacarb. Testing against coconut crabs so far indicates it has little or no impact on this species. However, the efficacy of this bait against Yellow Crazy Ant is as yet unknown. Should this bait be effective against Yellow Crazy Ants, it should be used as an alternative to the currently available Presto 001.

Eradication

The eradication of an invasive pest or disease requires their complete elimination from the target area and also should include measures that prevent future incursions. For ants, this involves repeated systematic with suitable baits. A single application of baits will not achieve eradication. The Red Imported Fire Ant programme in Brisbane is based on 10-12 applications of bait over the entire treatment area. Even after this many treatments, some ants appear to still remain.

Nuulua is a small island of approximately 25 hectares. It is infrequently visited as access is difficult. These two factors are an advantage for any eradication attempt. However, the landscape of the island, and difficulty of access pose pragmatic problems for eradication. Approximately 50% of the island can be safely accessed on foot. The remainder is too steep and treacherous. Any attempt at eradication must therefore be accomplished by aerial means.

Baiting the entire island by helicopter is a surprisingly simple task, which could be accomplished in a single day including flying time from Apia airport. The costs are limited to the cost of the helicopter and the bait. However, for eradication to be achieved, this baiting would need to be repeated at least twice a year for 3 years, preferably 3-4 times per year. Even with this intensity of baiting, there is a statistical probability that eradication will not be effective. An eradication programme will also require the previously recommended movement controls to be strictly enforced.

Careful long-term monitoring to validate results is a necessary requirement of an eradication programme. A rule of thumb used for plant pests is that eradication has been achieved when a rigorous surveillance strategy does not detect the pest for two lifecycles of that pest (normally two years).

One possible undesirable impact of such a programme may be that substantial crab mortality could occur as a result of contact or ingestion of the baits. The reduction in abundance across the entire island may hinder recovery of the crab population. While some “collateral” damage should be expected, not treating may well result in similar reductions as a consequence of predation by the pest species.

Aggressive control

The term "aggressive control" is used for population control programmes that aim reduce the pest population to trace levels without the need for absolute eradication. An aggressive control programmes provides virtually all the benefits of eradication at a much lower cost. For Nuulua Island, and aggressive control programme would require application of bait to the entire island which can only be practically applied by aerial means. However, the frequency of application could be much less. A single application annually may be sufficient to provide almost total control. Movement controls as previously recommended would need to be implemented, however the need for strict enforcement is much lower.

Integrated Pest Management

Pest management in cropping situations is driven by an analysis of returns against costs, and employs a variety of strategies, which in concert provide the most economically beneficial outcomes. This approach is called "integrated pest management", and with some modification can also be used as a means of managing pest populations where the return on investment is not an economic one.

The basis of integrated pest management is an understanding of the impacts associated with various pest densities and keeping the population below the level (the thresh-hold level) where impacts are acceptable. Essential in this approach is an ability to predict when thresh-hold levels will be exceeded so that management actions can be taken before this happens. Integrated pest management heralds a shift away from prophylactic treatments to treating only when necessary.

Establishing a thresh-hold level for Yellow Crazy Ants on Nuulua would require an estimate of the level at which impacts became unacceptable. Given the conservation values of the Island, the acceptable level may well be very low. Present ant densities are undoubtedly causing some impacts, however, these are not at a magnitude where they are easily detected. Current ant levels have probably displaced other ant species and resulted in population declines of invertebrates which may be prey items for birds, lizards, and crabs. It is also possible that some pollination and seed dispersal processes have also been disrupted. General ant activity is probably disrupting bird nesting especially by ground-nesting species and some predation of Coconut Crabs may also be occurring.

In lieu of any other data, the current ant density should be viewed as the upper thresh-hold level, and this should be modified as other information becomes available. Thus, in keeping with IPM principles, some control action is warranted immediately. The easiest method of accomplishing this is by aerially baiting the entire island. The ant population should then be monitored at regular intervals (at least annually) until the population nears present levels. A repeat sample using the method outlined in this study would be appropriate for this purpose. Another aerial baiting should then be planned when the ant population recovers.

Alternative options to aerial baiting could also be considered. While parts of the island are clearly not safe for human access, more than half the area is accessible. The accessible portion of the island is also the likely location of greatest ant abundance. Ants will forage for some distance so the effects of a control programme will exceed the area actually baited. Baits can be applied by the use of small inexpensive spreading devices or even spread by hand. Furthermore, baiting need not be island-wide at one time but could be staged as resources allow.

An added benefit of this approach may be that Coconut crabs could have a better opportunity to recover between baiting as the crabs would rapidly repopulate treated areas from those areas that had not been treated. The rate of re-population by crabs should also be more rapid than the re-invasion of the same habitat by ants.

Brief discussion of options

While eradication of Yellow Crazy Ants from Nuulua Island is technically feasible, resources for such a program may not be available. Furthermore, it could be argued that such resources may be better allocated to projects with greater expectations of return. Likewise, doing nothing carries an unacceptably high risk of substantial and possibly irreversible impacts on the island ecosystem and some of the endangered species that live there. A program based on aggressive control with or without an IPM component is therefore recommended for this situation. Either option should provide sufficient reductions in Yellow Crazy Ant population density to provide a practical benefit to the biological diversity and conservation values of the island.

Whole-of-island treatment by means of helicopter mounted distribution is an attractive option. Helicopters equipped for vector control operations are generally suited to distributing Presto Ant Bait. A similar large scale operation over Christmas Island was very successful both in terms of control outcomes and ease/cost of treatment. The Red Imported Fire Ant programme in Brisbane has treated tens of thousands of hectares with helicopters. The method has proven the most economical means of treatment over urban areas particularly compared with the cost treatment by hand application. Areas with extremely steep topography were successfully treated for Red Imported Fire Ants in Napier New Zealand.

Some logistical difficulties would be associated with obtaining the services of an appropriately equipped helicopter at Aleipata. However, if these difficulties can be overcome, the act of treatment itself is relatively straight-forward. Only 3-6 hours treatment time would be needed to bait the entire island given relatively calm conditions. The risks associated with helicopter treatment are as follows:

1. Catastrophic failure. In the Brisbane Red Imported Fire Ant programme, two catastrophic helicopter failures have been recorded. On one occasion, the helicopter was totally destroyed and both the pilot and co-pilot were hospitalized for an extended period. On another occasion, a helicopter applying bait was forced to make a rapid descent and landing. No injuries were recorded on that occasion. A similar failure over or near Nuulua Island could occur although the risks are very low.

Table 3. summary of material costs		benefits and impacts of alternative treatment options	
Treatment option	Treatment costs	benefits	impacts
Do nothing	nil	Resources could be utilized on other projects deemed more important	Yellow Crazy Ants will reach supercolony density, resulting in biodiversity decline, reduced crab population, fewer birds especially ground nesters. Local species extinctions inevitable
IPM approach (hand baiting)	Per treatment, approx US$1,000 for bait and 40 person-days labour	IPM programme will keep ant population at levels that do not impact on conservation values. Resources can be scheduled more easily	Some ants will always remain. Ant population will need to be monitored regularly in order to know when to treat.
Aggressive control (aerial)	Annual cost of approx US$7,000-12,000 for helo and bait	Very large reductions in Yellow Crazy Ant population Opportunity for crab population to recover between treatments	Eradication unlikely but ant population will be kept to very low levels. Annual treatment still may impact on Coconut Crabs.
Eradication (aerial)	8 treatments of island = approx US$16,000 for bait, approx US$40,000-80,000 helo hire, plus project management costs. Also high costs of rigorous monitoring	Probability of eradication high, impact of ants reduced to almost zero even if eradication not successful	Coconut crab population at risk of serious mortality with a possibility of local extinction Other ant species and invertebrates may also be affected Wsill need large monitoring programme

2. Over-spray onto the ocean. The only available bait at present contains fipronil as the active ingredient. Fipronil is dangerous to aquatic life and there is a risk of non-target

impacts such as fish deaths should this occur. The dilution effect of a large body of water should ensure this does not occur and the effects, if any, would be very short lived. Applying bait over all of Nuulua Island will result in some over-spray over the ocean, so the possibility of some impact can not be ruled out. One option to mitigate this risk is to exclude treatment to the shore line area of the island. If eradication was not a target, this approach is entirely consistent with an aggressive containment approach

3. Non-target impacts (Coconut Crabs). Treatment of the entire island may result in mortality of a portion of the Coconut Crab population. Studies of Coconut Crab mortality on Christmas Island, strongly indicate that some impacts would be evident. The program would need to include a monitoring component that includes measuring impacts on Coconut Crabs.
4. non-target impacts (bird life). The presence of a helicopter over and near Nuulua Island may also alarm bird life. This would be especially undesirable when birds were nesting or rearing young. It is recommended that baiting be timed to co-incide with periods of least impact on bird life on the island.

Application of baits by hand with or without an Integrated Pest Management approach also presents logistical difficulties. A team of four operatives would need approximately ten days work time on the island in order to bait accessible areas. Boat access to the island is notoriously difficult and dependent on weather and the availability of a suitable pilot. However, hand treatment need not be completed in a single operation, and could be staged over a period of months. Additionally, such staging would reduce impacts of baiting on the Coconut Crab population. A similar risk of catastrophic failure exists for this option. On an earlier trip, the boat ferrying MNRE officers to the island capsized in rough seas. This resulted in a situation that carried a real and substantial risk of injury to the people involved.

Finally, the choice of baits needs to be considered. Currently, the only effective bait is Presto 001 which contains fipronil as the active ingredient. Coconut Crabs and other invertebrates are very susceptible to this active ingredient and some non-target impacts are to be expected. Regardless, these impacts are unlikely to be greater than the impacts on the same organisms should Yellow Crazy Ants not be controlled.

An alternative bait is being tested on the islands of Tokelau. Although the bait matrix is the same, the active ingredient is indoxacarb. Early testing of this bait against Coconut Crabs strongly suggests that they are not susceptible to this active. However, trials demonstrating efficacy against Yellow Crazy Ants are not currently complete. If trial results show that indoxacarb is an effective agent, a decision to use the alternative bait is recommended. However, if trial results do not become available soon, the Presto bait should be used without delay.