Australian Government

Australian Centre for International Agricultural Research

Final report

SRA

Mastotermes darwiniensis in the Lae area of PNG: an assessment of current and potential status of the incursion, and options for management

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1. Executive Summary

The giant termite (*Mastotermes darwiniensis*) was first discovered in Lae in 1959 and from 1961 to 1973 attempts at eradication were made in two infested areas. The last small infested area at the nursing quarters at Lae hospital was treated in 1973 with the removal of all food sources including staff houses, treatment of colonies with arsenic dust and ripping the soil and incorporating heptachlor granules.

The current infestation appears to have started in the early 1990s in the nursing quarters close to the 1973 eradication attempt. It has since spread to adjoining areas including the main hospital area at the base of the escarpment and the adjoining Lae Botanical Gardens and the Forest Research Institute (FRI) building, where it was discovered in late 2001.

Since 2000 it has been present in the Okari Campus about 2 km north of FRI, and was discovered in the adjoining Police Barracks in 2004.

Dispersal flights appear to be uncommon despite winged reproductives (alates) forming in the colonies. Dispersal is instead occurring through budding off at the edges of colonies through the workers (pseudergates) forming secondary reproductives (neotenics). This appears to be limited by the high water table and the existence of large drains which often have standing water or waterlogged soil.

Dispersal also occurs through movement of infested firewood and constructional timber and this is probably how it jumped from the hospital/FRI area to the Okari Campus/Police Barracks area. The ability of workers to moult to become secondary reproductives facilitates this process.

The current infested area is estimated to approximately 0.6 km^2 at the hospital/FRI area and 0.8 km^2 at the Okari Campus/Police Barracks area, a total of 1.4 km^2 . This is seven times larger than the area at which the previous (1960-70s) eradication attempts were carried out (0.2 km^2). An eradication attempt on the current infestation is therefore likely to be a long-term and expensive operation, but this is offset by the very large amount of potential damage to crops and infrastructure if the termite establishes in drier areas of PNG.

In addition fipronil, the current control measure in use in tree crops in northern Australia and a chemical not available in the earlier campaign, is a very effective termiticide which is carried by the termites through the colonies to a distance of up to 50 m. This would have the effect of controlling undetected infestations close to existing ones, which would have been missed with the chemicals in use during the 1960-70 campaign.

The termite is very destructive to a wide range of horticultural crops and could disperse more rapidly once it has spread from the unfavourable high rainfall area of Lae to drier areas in the Markham Valley and elsewhere in PNG. As the size of the current infested areas gets larger the dispersal to more favourable areas becomes increasingly likely. The current infested areas are already approximately seven times larger than in the earlier out break in the 1960s-70s.
The National Agricultural Quarantine Authority (NAQIA) is keen to attempt to eradicate the insect and intends to declare it a notificable pest. This proposal is supported by FRI, Provincial DPI, Department of Health and NARI. FRI has agreed to host an eradication attempt overseen by a steering committee from the above agencies and with possible involvement from NT DPIFM. All the agencies supported

an official approach to a funding agency, probably AusAID, to set up an eradication team which would operate for a number of years.

In view of the still limited distribution of the termite in PNG, the potential for large scale damage to horticulture, forestry and infrastructure should it move to more favourable areas, the availability of more efficient termiticides and the commitment of the PNG authorities, it is recommended that funding is sought for a programme to at least contain the termite and substantially reduce the population in Lae town, and preferably to eradicate it completely.

2. Introduction

The giant termite, *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae), is the most destructive species of termite in tropical Australia. In the Northern Territory this species potentially accounts for several million dollars in annual production losses within horticultural tree crops and is also responsible for losses in vegetable and agricultural crops. *Mastotermes* can cause major damage to buildings, wooden structures, electrical cables and a variety of other materials.

The giant termite was inadvertently introduced to Lae during or shortly after World War II. In the 1960s to 1970s eradication was attempted in the two infested areas. Persistent organochlorine insecticides were used as barriers in the soil to kill the termites on contact and, while this method gave good control and containment, the fact that the toxicants were not transferred by the termites through the colonies, meant that not all individuals were killed and eradication was not achieved.

These treatments ceased in the 1970s and during the past few years the termite has reappeared and has spread from the confines of the infrastructure at the main hospital site and established in the nearby Lae Botanic Gardens, where trees of a range of species have been destroyed. The pest has recently rapidly extended its range to adjoining residential areas, government buildings and other infrastructure and there is now a major infestation in the Forest Research Institute building.

3. Objectives

The aim of this contract was to define the extent of the existing and potential problem posed by the *Mastotermes* incursion in PNG, and to recommend responses.

The specific objectives are to:

- Define much more precisely the current extent and nature of the incursion

- Develop a prognosis of likely rate of spread and of the potential impacts, if no management strategies are adopted

- Propose longer term management options.

The containment or management of the PNG *Mastotermes* incursion was not to be a part of this study as such a program would not qualify as an ACIAR project. However it is hoped that this study provides guidance and incentive for the implementation of a containment/management strategy by an appropriate authority.

4. Survey personnel and collaboration

Survey Personnel

The survey was carried out by two staff members from the Northern Territory Department of Primary Industry, Fisheries and Mines (DPIFM), Dr Brian M. Thistleton (Principal Economic Entomologist) and Michael Neal (Senior Technician – Termites), and by staff from the PNG Forest Research Institute (FRI), lead by Dr Mex Peki (Principal Scientific Officer, National Forest Management Programme) and John Dobunaba (Senior Scientific Officer - Entomology).

Visits to Lae

Three visits were made to Lae by the Australian staff:

- 5-15 December (BMT & MN)
- 12 – 25 February 2006 (BMT & MN)
- 7 -13 May 2006 (BMT only)

Liaison with other agencies

During the course of the survey there was liaison between the main survey team comprising officers from NT DPIFM and PNG FRI, and the following government agencies:

- PNG National Agricultural Research Institute (NARI)
- PNG National Agricultural Quarantine and Inspection Authority
- Morobe Province Department of Agriculture and Lands (DAL
- Morobe Province Department of Health (DOH).

In particular, NARI and DAL were kept fully informed of the survey because of the large potential for damage to food crops should the termite spread from the confines of Lae. The DOH was also kept informed as the hospital in Lae is being heavily damaged by the termites.

During the courses of the survey the following meetings were held with collaborators and stakeholders:

- A planning meeting was held in Lae in December 2005, attended by staff from FRI, NARI, NAQIA and DPIFM.
- A seminar was given to NARI staff in December 2005 in which details of the termite in Northern Australia and the preliminary results of the surveys in Lae were presented. A long host list, which included a lot of forestry and food trees, was presented to emphasise to NARI staff that this termite is not only a pest of timber in service.
- The DPIFM team also met with the Director of NARI in December, February and May to brief him on the progress of the project. NARI assisted with providing soil and weather maps from their GIS system and files from the period of the original infestation and eradication attempt.
- Meeting were also held in December, February and May with Mr Roy Masamdu, Chief Plant Protection Officer, NAQIA.
- The first day of the May trip was spent in Port Moresby. A visit was made to the ACIAR office to brief Dr Jacqui Wright, Country Manager PNG and Solomon Islands. Mr Roy Masamdu, Chief Plant Protection Officer, NAQIA, was also present at this meeting.
- A final meeting was held in Lae on May 11, attended by representatives from NAQIA, FRI, and the DAL to discuss the results of the survey and consider options for further work.

- The DOH, Morobe Province, is very concerned about the damage by *Mastotermes* as the Lae Hospital is in one of the infested areas and has been badly damaged by the pest. A visit was therefore made in May to the Director at the hospital to brief him on the results of the survey.

5. Methods

Collection of information on the history in PNG

There were various sources of literature detailing the history of the infestation and the attempts at control. Many of these were used during the survey and are listed in the references. Of particular importance were a series of files (DASF 1959-1973) containing reports from the entomologists dealing with the infestation in the 1960s and 70s. These gave maps of the areas that were infested and locations of trap posts and trenches and also included details of the control measures used.

Also of importance was a report of a survey carried out by FRI staff in 2002 which was used as a baseline for the survey in that area (Manum-Amarea and Asok 2002).

A visit was also made to the Papua New Guinea National Reference Collection at Kila Kila, Port Moresby, in May to look at specimens and data collected during the first discovery of the insect in 1961 and to check information in the files.

Survey

The termites bore up through the centre of the trees and into the limbs. Since this species does not produce mounds, its damage often goes undetected until the tree is ring barked or the weakened limbs start to fall in storms. The survey techniques involved inspection of trees for dead, hollow branches which often fold or break, *Mastotermes* ring-barking on the trunks of trees, termite mudding on trunks and limbs and for death of the trees.

It had initially been intended to also drill into the trunks using an auger attachment on a chainsaw to locate galleries and activity, which can be detected by the mudding up of the holes by the termites. The latter method of drilling the trees is a very accurate method of determining if *Mastotermes* are present, and has been used extensively in NT.

However it was found that for the purposes of the survey in each infested area there were enough visual symptoms evident, including the presence of termite killed trees and infested buildings, for presence/absence to be determined without drilling the larger trees. Nevertheless the drilling technique was demonstrated to the staff at FRI, as it will be necessary to use this for eradication.

Local knowledge

At each site local residents were shown photographs of the termites and asked if they had seen them. When damage is severe the termites are very evident and their size immediately distinguishes them from local forms. Residents were also asked if they had seen flights of termites, especially alates attracted to lights, but the response to this was negative in all cases.

Publicity

In December 2005 the Post Courier and the National newspapers both included items on the survey and local radio broadcast an announcement for six days asking people to report to FRI any unusual large termites in their houses or gardens. Following this FRI made another press release in January which resulted in one report being received which was checked by FRI staff and found to be negative.

A poster was produced to increase awareness of the termite in the Lae area and to request further reports of suspected infestations. The poster was designed by FRI and DPIFM Entomology Section in two versions, one in English and one in Papua New Guinea Pidgin (see Figures 1 and 2).

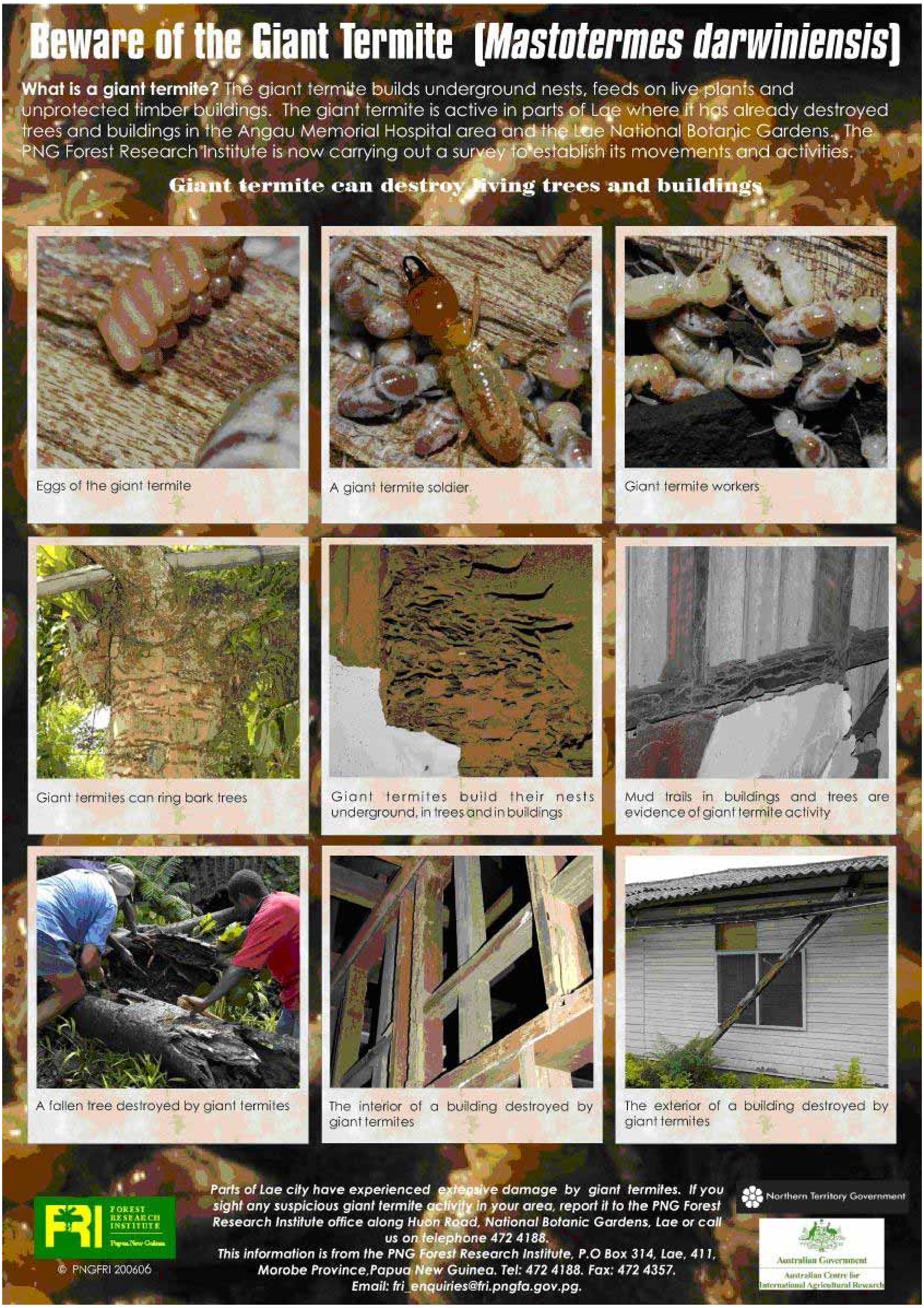
Beware of the Giant Termite (Mastotermes darwiniensis)
What is a giant termite? The giant termite builds underground nests, feeds on live plants and unprotected timber buildings. The giant termite is active in parts of Lae where it has already destroyed trees and buildings in the Angau Memorial Hospital area and the Lae National Botanic Gardens. The PNG Forest Research Institute is now carrying out a survey to establish its movements and activities.
Giant termite can destroy living trees and buildings
Eggs of the giant termite
A giant termite soldier
Giant termite workers
Giant termites can ring bark trees
Giant termites build their nests underground, in trees and in buildings
Mud trails in buildings and trees are evidence of giant termite activity
A fallen tree destroyed by giant termites
The interior of a building destroyed by giant termites
The exterior of a building destroyed by giant termites
Parts of Lae city have experienced extensive damage by giant termites. If you sight any suspicious giant termite activity in your area, report it to the PNG Forest Research Institute office along Huon Road, National Botanic Gardens, Lae or call us on telephone 472 4188.
This information is from the PNG Forest Research Institute, P.O Box 314, Lae, 411, Morobe Province, Papua New Guinea. Tel: 472 4188. Fax: 472 4357.
Email: fri_enquiries@fri.pngfa.gov.pg.
FRI Forest Research Institute Papua New Guinea
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Figure 1.

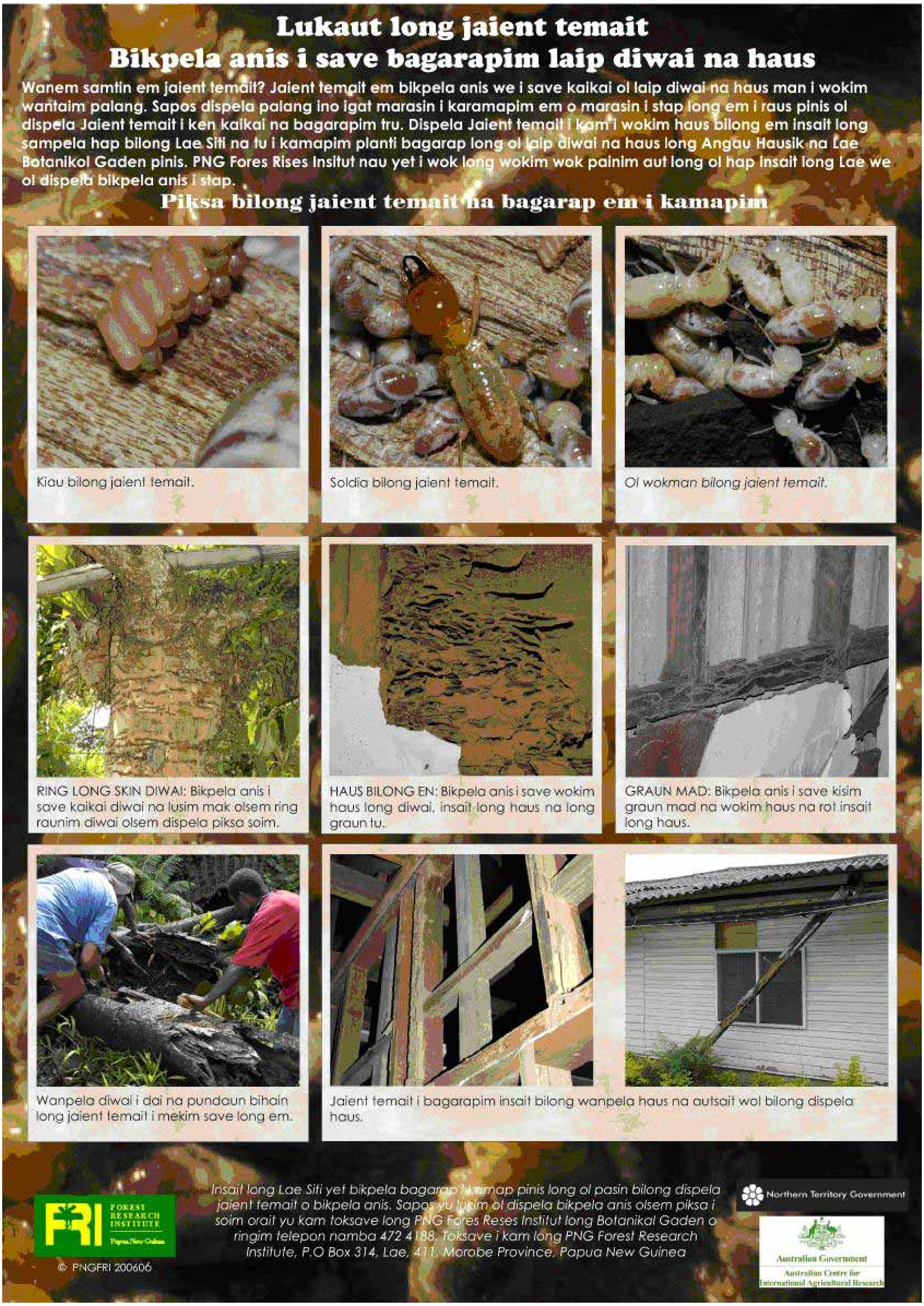
Lukaut long jaient temait
Bikpela anis i save bagarapim laip diwai na haus
Wanem samtin em jaient temait? Jaient temait em bikpela anis we i save kaikai ol laip diwai na haus man i wokim wantaim palang. Sapos dispela palang ino igat marasin i karamapim em o marasin i stap long em i raus pinis ol dispela Jaient temait i ken kaikai na bagarapim tru. Dispela Jaient temait i kam i wokim haus bilong em insait long sampela hap bilong Lae Siti na tu i kamapim planti bagarap long ol laip diwai na haus long Angau Hausik na Lae Botanikol Gaden pinis. PNG Fores Rises Insitut nau yet i wok long wokim wok painim aut long ol hap insait long Lae we ol dispela bikpela anis i stap.
Piksa bilong jaient temait na bagarap em i kamapim
Kiau bilong jaient temait.
Soldia bilong jaient temait.
Ol wokman bilong jaient temait.
RING LONG SKIN DIWAI: Bikpela anis i save kaikai diwai na lusim mak olsem ring raunim diwai olsem dispela piksa soim.
HAUS BILONG EN: Bikpela anis i save wokim haus long diwai, insait long haus na long graun tu.
GRAUN MAD: Bikpela anis i save kisim graun mad na wokim haus na rot insait long haus.
Wanpela diwai i dai na pundaun bihain long jaient temait i mekim save long em.
Jaient temait i bagarapim insait bilong wanpela haus na autsait wol bilong dispela haus.
Insait long Lae Siti yet bikpela bagarap i kamap pinis long ol pasin bilong dispela jaient temait o bikpela anis. Sapos yu lukim ol dispela bikpela anis olsem piksa i soim orait yu kam toksave long PNG Fores Reses Institut long Botanikal Gaden o ringim telepon namba 472 4188. Toksave i kam long PNG Forest Research Institute, P.O Box 314, Lae, 411, Morobe Province, Papua New Guinea
FOREST RESEARCH INSTITUTE
Papua New Guinea
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Figure 2.

Constraints to surveying

Law and order is a serious problem in PNG with frequent hold-ups from armed gangs. Two such events occurred on the current survey. In November in Lae an attempt was made to steal the car the team was using using a knife as a weapon, but this was avoided once the thieves recognised one of the team members. A second more serious event happened in Finschhafen where the team was held up at gunpoint and a computer, cameras and cash stolen.

Many of the criminals live in the settlement areas, and we were advised by the FRI team members that it was too dangerous to survey in these areas. This will be a major constraint if an eradication attempt is made.

6. History of the outbreak

First detection and early eradication attempts

Mastotermes darwiniensis was first discovered in Lae in 1959 and detected a second time in July 1961 when survey work was commenced. The species was declared a notifiable pest within the Plant and Disease Control Ordinance.

It was soon determined that there were two main areas of infestation, one around the hospital and one near the wharf (Milfordhaven) which included several sites. The areas were of approximately 30 and 20 acres respectively (Gay 1967).

An eradication campaign was started which included treating colonies with arsenic dust, ripping the ground in infested areas and treating with dieldrin or aldrin and later, in the 1970s, with heptachlor, planting of pine posts in the soil to detect infestations and light trapping to detect flights.

The next information in the files available to the team was in 1965. In January of that year it was established that the termite was still present at the hospital site. The trap posts had no termite activity but the termite was found in two trees. It was thought that these were remnants from the treatments done in 1962, but then in August eleven more sites were discovered, followed by five more in September, and it was realised that the infestations were much more extensive. In 1965 it was also rediscovered at Scott's area near the wharf, the first detection there since 1962.

As before, at both sites, the infestation was treated with arsenic dust into the colonies and the ripping of soil to a depth of twelve inches and incorporation of aldrin dust. Monitoring continued at Scotts until 1972, but no new infestations were found after the treatments applied in 1966.

From 1966 to 1968 new infestations continued to be found at the hospital, mainly in trees rather than in the post traps. In 1968 approximately 1000 feet of trenching was dug along the boundary of the hospital with the town and this was treated with dieldrin. This was extended in 1972 after further infestations were found.

Many of the new colonies had been found in trees, not in the trap posts and in 1973 T.V.Bourke (in DASF 1959-1973) stated that the "trap posting technique is of very limited value indeed in discovering colonies". In fact in 1969 it was thought that the infestation was eradicated as no records were being found in the trap posts, but later many colonies were found in trees in the hospital area.

All the colonies at the hospital site were in one small area containing staff housing, and by 1972 this was the only area still infested. A strategy was designed to take out all food sources, treat the soil with insecticides, and trench to prevent spread of colonies. A decision was therefore taken to move all the occupants of these houses to new accommodation and to demolish and burn the houses, to treat all remaining colonies, and to rip the soil and treat with hepatachor granules. This treatment commenced in June 1973.

Origin of the first outbreak

During surveys in the 1960's it was found that there were numerous small infestations in the two areas, plus one very large colony in a log dump consisting of Australian hardwoods (*Eucalyptus corymbosa, E. paniculata* and *E.sideroxylon*) imported into Lae towards the end of World War II (Gay 1967). It was concluded that this log dump was the focal point from which the infestation had originated.

Gay (1967) suggested that this timber had been shipped to Darwin where it had become infested with *Mastotermes* before being taken to PNG while the Papua New Guinea Chief Entomologist (T.V. Bourke) in 1973 in a departmental memo considered that the logs had been imported from north Queensland. Both are possible sources of infestation and there appears to be agreement that the infestation started during the activities of WWII. Thus it was a number of years from the initial introduction to the termite becoming abundant enough to be noticed and the first detection made.

History of the current outbreak

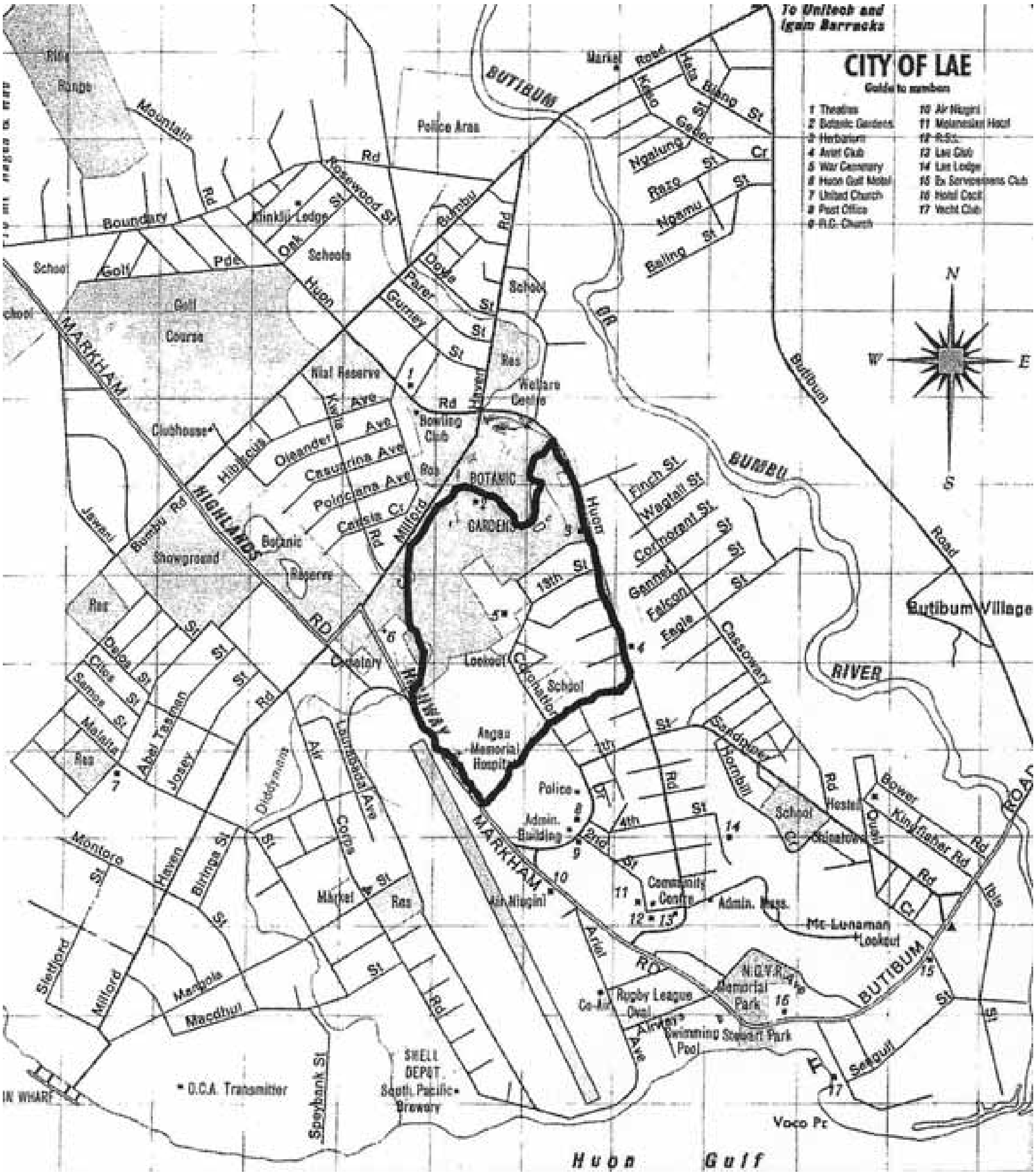
Manum-Amarea and Asok (2002) indicate that the Angau Memorial Hospital was first attacked by termites in the early 1990s. They indicate elsewhere in their report that the Nursing College on the hill “has been under attack for many years”. This is the area where the 1973 eradication attempt was made, and where the boundary trenches were dug so it is probable that the termites were not completely eradicated at that time.

The termites then moved into the buildings around the War Cemetery and the nearby SDA Church (Figure3) and later the Botanical Gardens. By 2000 klinki pines along Memorial Drive were infested and were felled (Manum-Amarea and Asok, 2002).

Figure 3. The SDA church which was damaged when a large tree killed by termites fell.

The termites were first discovered in the Forest Research Institute Building in November 2001 (Dobunaba, *pers. comm.*) and following this a survey was carried out by Jim Manum-Amarea and Frank Asok (2002). The area shown to be infested by this survey is shown in Map 1.

Map 1: Appendix D, reproduced from Manun-Amarea and Asok (2002), showing the area infested at that time.



7. Results of the Survey

Maps 2, 3 and 4 show the extent of the infestation determined by the current survey. There were two infested areas, the hospital, Forest Research Institute and Botanical Gardens where it had first been detected, and the new area around the Police Barracks.

Area 1 – Hospital, Forest Research Institute and Botanical Gardens

Hospital

As noted in the history, the termite was first discovered on the site of the old hospital (close to the present site) in 1961. There were several phases of control measures involving treatment of colonies with arsenic dust, ripping and treatment of soil with aldrin, dieldrin and heptachlor, digging of trenches around the area and treating these with dieldrin, monitoring with trap posts and finally removing all food sources including the demolishing of staff houses in 1973.

In the current phase of infestation, damage seems to have started in the nursing college above the main hospital and this is the area where the 1973 eradication attempt was made, and where the boundary trenches were dug. According to Manum-Amarea and Asok (2002) there are indications that this area was attacked in the early 1990s.

The team visited the hospital where damage (Figures 4 and 5) was worse than we have seen in Australia, with many of the old wards being so extensively damaged that they have been condemned. New wards under construction were already being damaged even before they were finished. The difference of course was that in Australia there are treatments required by the building codes, while in Lae little effective treatment is being done. Flick have been treating the hospital, but the products they have used (Lorsban and arsenic dust) have not been too effective. We mentioned that Termidor is now registered for use on buildings in Australia and talked to them about current control options.

Figure 4. Damage in the hospital.

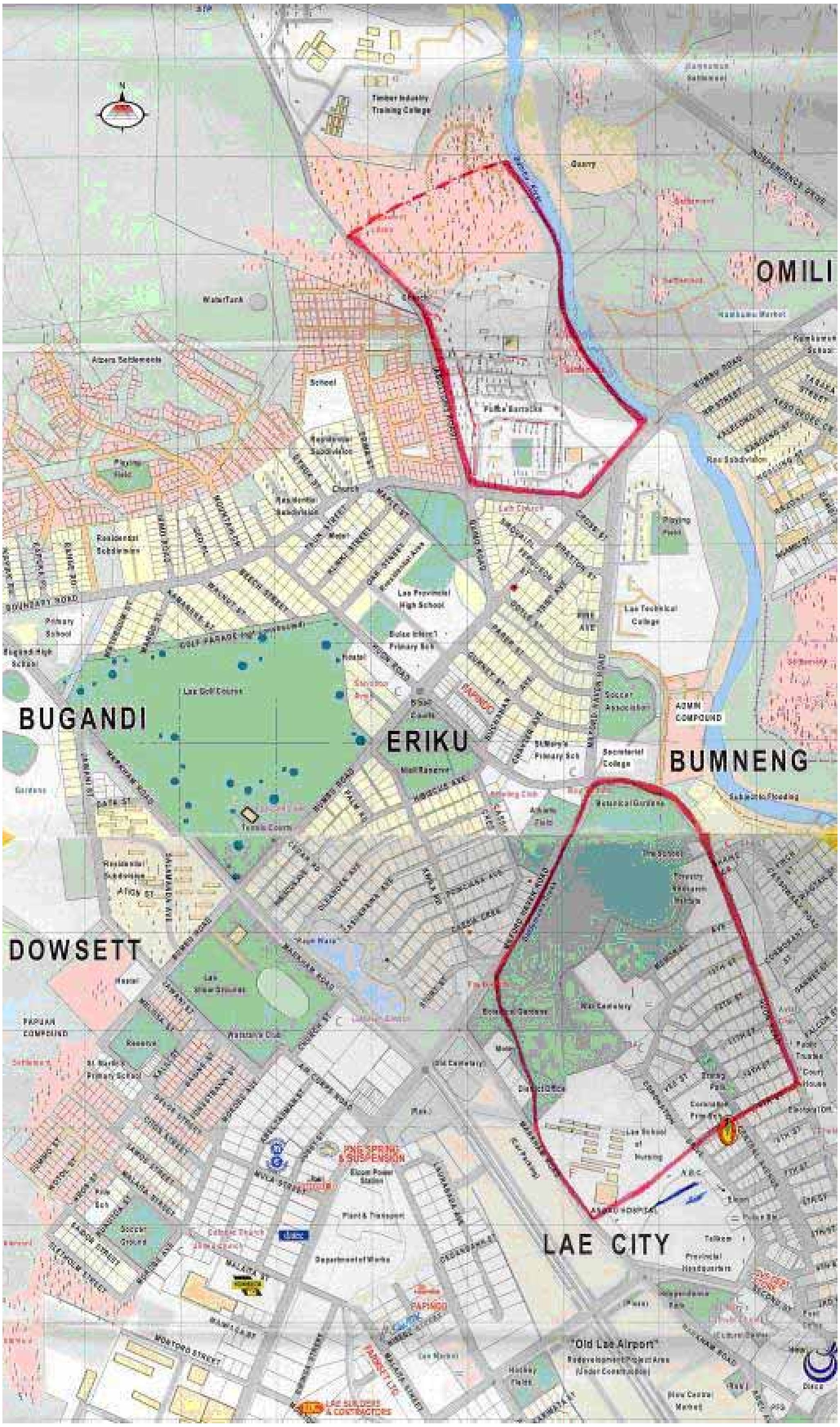

Figure 5. A ward at the hospital which had been destroyed by termites.

Forest Research Institute and Botanical Gardens

The termite was first seen at the FRI buildings in November 2001. This is when they became obvious but John Dobunaba (*pers. comm.*) thinks that they were probably there before this. In January 2002 a trench was dug along one side of the building to stop the termite gaining access to the building. This trench was 30 cm wide and 50 cm deep but was not treated with insecticide. In any event the termites were already inside the building and there was evidence that they were breeding there. In 2002 to 2003 numerous collections were made from inside the building some of which had secondary reproductives (neotenics).

John Dobunaba considers that the termites are now not as prevalent in the building as they used to be. Earlier huge numbers had been present, and substantial damage had been done to internal fitting and walls. The reduction in numbers was either due to sprays of chloroform which were made after the termite collections were made or to the removal of benches and other wooden fittings. Whatever the reason, a survey throughout the building during one of our visits showed that while the termites were still present, their numbers were quite low.

Map 2: The areas established as infested during the present survey.



Map 3: Area 1: Forest Research Institute to Hospital

Map 4: Area 2: Police Barracks and Okari Campus.

Most of the Botanic Gardens had already been shown to be infested during the survey by Jim Manun-Amarea, and Frank Asok.Frank (2002, see Map 1). The current survey extended this boundary slightly so that the northern boundary now extends to the junction between Huon and Milfordhaven Roads. Damage to trees in the gardens is shown in Figures 6 to 9.

Figure 6. A Terminalia killed by Mastotermes.

Figure 7. A *Terminalia* killed by *Mastotermes.*

Figure 8. A *Terminalia* killed by *Mastotermes.*

Figure 9.A *Ficus* killed by *Mastotermes.*

Southern Boundary

In the 2002 survey Manum-Amarea and Asok (2002) had marked the southern boundary as the drain which runs between 9th and 10th Streets separating the Lae International School and the shopping centre. This drain was examined during the visits and was often found to contain standing water (Figure 10).

Figure 10. One of the deep drains which are thought to be limiting spread of the termites.

During the current survey houses were visited in 7th, 8th, 9th, 10th, 11th and 12th streets. Termite activity was only found in 11th and 12th streets, verifying Manum-Amarea and Asok's findings. In 11th street most of the houses and trees were examined and no evidence of the termites were found, until in the last house to be examined they were discovered in the flooring of an outside wooden shelter (Haus Win). This was used to demonstrate to the survey team the necessity of thorough searching of all houses on the boundaries of the infestation.

Eastern Boundary

The eastern boundary is Huon Road. Buildings (houses, court house, Aviat Club, Provincial Government Offices, Anglican Church) and trees along the eastern side of this road were checked for symptoms and termites, but none were found.

Manum-Amarea and Asok (2002) considered that the compacted road surface had prevented the termites from moving to the areas to the east of the road. However it is more likely that the large deep drain along the western side of the road had a large impact on preventing spread.

Northern and north-west boundaries

Surveys were carried out along Milfordhaven Road and in the suburbs to the northwest comprising Oleander Avenue, Casuarina Avenue, Poinciana Avenue, Cassia Crescent and Kwila Road. The roads in the triangle bounded by Bumbu Road, Milfordhaven Road and Huon Road were also examined.

Western Boundary

The western side of the area is bounded by a large open area, which used to be the old airstrip. There are few trees in this area which could act as hosts for the termites. There are also some long, deep drains running parallel to the old airstrip which would have restricted movement by the termites. Nevertheless trees in Laurabada Avenue to the west of the old airstrip were examined but no evidence of termites was found.

Area 2 – Police Barracks and Okari Campus

Staff at FRI had previously been notified of suspected damage by *Mastotermes darwiniensis* at the Police Barracks. A visit by the team during December 2005 confirmed this, and the Police Barracks became a second area for detailed surveys. This area is almost 2 km from the Botanic gardens and FRI. The termite does not appear occur between the two areas, so it seems likely that it was taken in firewood or timber from the Botanic Gardens or hospital.

Police Barracks

Surveys were carried out within the Police Barracks boundaries in February 2006. We were shown a concrete slab in the centre of the barracks which was all that remained of the first building to be damaged there. According to the Officer-in-Charge (Ben Anton) the termites had been present for two years. The survey showed that the termite was present in other buildings (Figure 11) and had caused the loss of many trees including large mangoes (Figure 12), coconuts (Figures 13 and 14) and Acacias. The infestation stretched to the northern boundary of the barracks, where it joined the Okari Campus, which became the next area to survey.

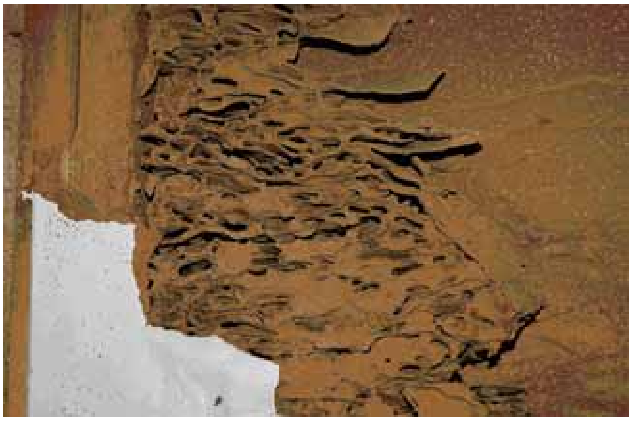


Figure 11. Damage at the Police Barracks.


Figure 12. A mango ring-barked and killed by *Mastotermes*

Figure 13. A coconut killed by *Mastotermes.*

Figure 14. A coconut killed by *Mastotermes.*

Okari Campus

This area used to be a school, at the time of the survey it was a sports centre, and it was soon to be taken over by the Assembly of God Church. The team found the termites in buildings and trees (*Acacia, Erythrina, Frangipani*, Mango, *Bauhinia* and Coconut). The infestation extended to the northern boundary which adjoined a settlement area.

The Property Manager (Nelson Toro) informed us that it was first discovered in Christmas 2000 in an administration building which was already very badly damaged at that time. This infestation therefore started before the one in the Police Barracks.

Timber Industry Training College

This is north of the settlement area. A damaged stand of *Pinus carabaea* was inspected, but the termites involved were shown to be *Coptotermes* sp. The sawmill area and associated wood and trash piles were extensively surveyed but no evidence of infestation was found.

Settlement area

It is therefore surmised that the northern boundary of this infestation is within the settlement area between the Okari campus and the Timber Industry Training College. However, on the advice of FRI collaborators, it was considered too dangerous to survey within the settlement area (see the section on constraints to surveying). A house on Abbatoirs Road, which runs up the western side of this area, was known to have been infested. This house was midway between the northern boundary of the Okari Campus and the southern boundary of the Timber Industry Training College and a provisional (dotted) line was drawn on the map from here across the eastern boundary (see Maps 2 and 4). The aerial photograph (Map 4) shows that the settlement area is highly populated.

East and West Boundaries

The Bumbu River to the east of this area forms a natural barrier to dispersion. To the west is another settlement area which it was not possible to survey.

Southern Boundary

To the south of the Police Barracks the area of the Lutheran Church and the area bounded by Bumbu Road, Milfordhaven Road and Doyle Street were examined. Activity was found in one Royal Palm on Bumbu Road, close to Doyle Street, but no other evidence of infestation was found.

Other areas in Lae

Visits were made to other locations in Lae from where reports of *Mastotermes darwiniensis* damage had been received, but all were determined to be due to native species of termites. In addition various trees at varying distances from the known infested areas were examined but all were negative.

These included:

- Busu Bridge (Bumagong) some way to the north of the Police Barracks, where workers from FRI live and where timber from FRI had been taken.
- A Lutheran Mission to the north of Lae, where a PCO had reported *Mastotermes* damage, but which turned out to be a local species.
- Assembly of God and Salvation Army Churches at Eriku, which we were told had similar damage to that at the Police Barracks, but which turned out to be damage by *Coptotermes* and *Cryptotermes*.
- Trees along the main road out of Lae from the town to just past Bubia Agricultural Research Station, 15 km from Lae..

Evidence from Pest Control Operators

All four Pest Control Operators (PCO) businesses in Lae were visited. All confirmed that most of the requests for control of *Mastotermes* originated from the two areas which we had already mapped. They did mention one or two suspected infestations outside of this area but most of these were inspected and were shown to be due to native termites (see above).

Previously infested areas

In 1960s there were several other areas towards the wharf which had been infested. These had been treated at that time and the termites eradicated. Nevertheless, when the locations of these became known through the files made available from NARI, they were checked in July 2006 but no evidence of termites could be found.

The sites included the corner of Milfordhaven/Mataram street, the Trukai Rice Factory and Papindo flats. Mataram Street is now an industrial area with many new buildings and very few trees. *Acacia* sp., *Dysoxylum* sp. and *Dracontomelum* sp. were examined but there was no sign of infestation by *M. darwiniensis.* Nor had there been any reports from this area since the 1960's.

Bulolo

A recent report by a PCO of termite damage to a house in Bulolo was of concern, since this is in the mountains about 60 km south of from Lae and is the site of large forestry plantations. The PCO who gave us this report also reported infestations in other areas which turned out to be negative. However FRI staff surveyed the area and could find no evidence of *Mastotermes* there.

Finschhafen

There had been several reports of *Mastotermes* at a primary school building and at the hospital in Finschhafen, over 100 km east of Lae. These were of concern as one of the reports came from a member of staff at the Angau Hospital in Lae, who was very familiar with the damage there.

A visit was made in February 2006. Photographs of the termites were shown to people in the area but, while they were familiar with damage by native species, none had seen any large termites like *Mastotermes*.

Two areas were examined at Finschhafen:

Gagidu School and surrounds

Classrooms had been badly damaged by *Coptotermes* and *Cryptotermes*. Damaged trees and stumps, including rain trees, poinciana and mangoes had been damaged by local termites including *Nasutitermes* sp.

Finschhafen Hospital

The hospital had been badly damaged by termites and a Pest Control Operator from Lae had been called in to examine the damage although, apart from one doctor's house, no control had been carried out. Damage was examined in a store room, several wards and the nurses school and quarters. In all cases the damage was by *Cryptotermes* sp. In addition trees in the hospital grounds were examined. No evidence of *Mastotermes* was found.

Conclusion to survey

The survey identified two areas of infestation:

- the Hospital, Forest Research Institute, Botanical Gardens and adjoining residential area, which is one of the areas where the earlier infestation (1960s-70s) was centred and which now covers an area of about 0.6 km2
- the Police Barracks and Okari Campus, 2 km from the first site, where the termite has been present since 2000 and where the present infestation covers approximately 0.8 km2

There was no evidence of the termite in any other localities in Lae, and the reports of damage in Finschhafen and Bulolo were found to be due to other termites.

8. Biology

While the main part of the contract was to determine the current extent of the infestation, some information on the biology of the termites was collected. This is presented below as it will have some bearing on strategies for managing or eradicating the species.

Colony size

Mastotermes darwiniensis colonies in undisturbed bush in Australia are relatively small and most hollow trees have been caused by *Coptotermes* rather than by *Mastotermes,* which generally accounts for less than five percent of the damage. However in areas disturbed by human settlement colonies can often be very large, containing over a million individuals and covering several hectares (Andersen et al. 2005, Watson and Gay, 1991).

In the Northern Territory fluorescent dyes added to aggregation drums have been carried over 180 metres by the termites (Thistleton and Neal, unpublished data). Using an analysis of population and colony genetic structure using molecular techniques, Goodisman and Crozier (2002) demonstrated a range of colony size from as little as just a few metres to over 100 m. In one case a colony in a pine forest occupied an estimated area of over 1.5 ha with the most widely separated sample trees being 320 m apart.

It is not known how large the colonies are in Lae, and detailed mapping with dyes or analysis of DNA would be required to ascertain this. Certainly in areas where the soil is waterlogged for much of the year, such as in the low areas of the Lae Botanic Gardens, colonies may cover a smaller area than in Australia, but the very large trees there could be able to support quite large colonies spreading vertically through the tree rather than horizontally.

Host plants

Table 1 gives a list of hosts recorded in Australia and PNG. During the survey many other potential hosts were examined for termite attack. Most of these were negative probably because they were in areas not yet infested, rather than being unsuitable as hosts, and the list is likely to expand as the termites disperse further.

Table 1. Hosts recorded for *Mastotermes darwiniensis* in Australia and PNG.

Host	Scientific Name	Australia	PNG
Buildings and man-made items			
Constructional timber		Yes	Yes
Gyprock		Yes	Yes
Insulation		Yes	Yes
Power cables		Yes	Yes
Rubber tyres		Yes	
Food plants			
Cashew	*Anacardium occidentale*	Yes	
Breadfruit	*Artocarpus altilis*	Yes	
Jackfruit	*Artocarpus heterophyllus*	Yes	
Pawpaw	*Asimina* sp.	Yes	

Host	Scientific Name	Australia	PNG
Carambola	*Averrhoa carambola*	Yes	
Water melon	*Citrullus lanatus*	Yes	
Citrus	*Citrus* sp.	Yes	Yes
Durian	*Durio zibethinus*	Yes	
Gingers	*Etlingera* spp.	Yes	
Sweet potato	*Ipomoea batatas*	Yes	
Mango	*Mangifera indica*	Yes	Yes
Cassava	*Manihot esculenta*	Yes	
Rambutan	*Nephelium lappaceum*	Yes	
Passion Fruit	*Passiflora edulis*	Yes	
Dragon Fruit	*Pitaya* sp.	Yes	
Guava	*Psidium guajava*	Yes	Yes
Sugarcane	*Saccharum* sp.	Yes	
Cocoa	*Theobroma cacao*	Yes	
Grapevines	*Vitis* sp.	Yes	
Forest trees and ornamentals			
Acacia	*Acacia mangium*	Yes	
Acacia	*Acacia* sp.		Yes
	Agathis sp.		Yes
Rain Tree	*Albizia*		Yes
Albizzia	*Albizzia* sp.	Yes	
Klinki Pine	*Araucaria hunsteinii*		Yes
	Astonia sp.		Yes
	Balsa sp.		Yes
Bamboo (clumping)	*Bambusa* spp. and *Dendrocalamus* spp.	Yes	
	Bauhinia sp.		Yes
	Brownea ariza		Yes
Kapok	*Ceiba pentandra*		
Cannon ball tree	*Courupita peruviana*		Yes
Cycad	*Cycas ruphii*		Yes
Cycads	*Cycas* spp.	Yes	
Royal Poinciana	*Delonix regia*		Yes
	Dracontomelon lenticulatum		Yes
	Dracontomelum sp. (exotic species)		Yes
	Elaeocarpus sphaericus		Yes
	Enterolobium sp.		Yes
Erythrina	*Erythrina* sp.		Yes
	Eucalyptus spp.	Yes	
	Ficus sterrocarpa		Yes
Silver oak	*Grevillea*	Yes	
Hibiscus	*Hibiscus* spp.		Yes
Kwila	*Instia baijuga*		Yes
	Mangifera minor		Yes
	Octomeles sumatrana		Yes

Host	Scientific Name	Australia	PNG
Pandanus	*Pandanus* spp.	Yes	
Pine	*Pinus caribaea*	Yes	
Frangipani	*Plumeria* sp.		Yes
	Pometia pinnata		Yes
Rose wood	*Pterocarpus indicus*		Yes
	Sterculia		Yes
Mahogany	*Swietenia* sp.	Yes	
	Syzygium sp.		Yes
	Tabebua sp.		Yes
Teak	*Tectona grandis*	Yes	
Terminalia	*Terminalia archipelagi*		Yes
Terminalia	*Terminalia brassi*		Yes
Terminalia	*Terminalia complanata*		Yes
Terminalia	*Terminalia sepicana*		Yes
Terminalia	*Terminalia whitmorei*		Yes
	Xantophyllum papuana		Yes
Palms			
Carpentaria palm	*Acuminata*	Yes	
Alexandra Palm	*Archontophoenix alexandrae*	yes	
Betel Nut Palm	*Areca catechu*	Yes	
Queen Palm	*Arecastrum romanzoffianum*	Yes	
Wine Palm or Jelly Palm	*Butia capitata*	Yes	
Clustered Fish Tail	*Caryota mitis*	Yes	
Single Stem Fish Tail Palm	*Caryota urens*	Yes	
Single Stem Golden Cane	*Chrysalidocarpus lucubensis*	Yes	
Clumping Golden Cane	*Chrysalidocarpus lutescens*	Yes	
Coconut	*Cocos nucifera*	Yes	Yes
Malay Dwarf Coconut	*Copernicia macroglossa*	Yes	
Sealing Wax Palm	*Cyrtostachys renda*	Yes	
African oil Palm	*Elaeis guineensis*	Yes	
Bottle Palm	*Hyophorbe lagenicaulis*	Yes	
Spindle Palm	*Hyophorbe verschaffeltii*	Yes	
Red Latan Palm	*Latania lontaroides*	Yes	
Fan Palm	*Licuala grandis*	Yes	
Fan Palm	*Licuala ramsayi*	Yes	
Chinese Fan Palm	*Livistona chinensis*	Yes	
Fan Palm	*Livistonia benthamii*	Yes	
Triangle Palm	*Neodypsis decaryi*	Yes	
Black Palm	*Nornmanbya normanbyi*	Yes	
Dwarf Date Palm	*Phoenix roebelenii*	Yes	
Fiji Fan Palm	*Pritchardia pacifica*	Yes	
Macathur Palm	*Ptychosperma macathurii*	Yes	
South American Royal Palm	*Roystonia oleracea*	Yes	
Cuban Royal Palm	*Roystonia regia*	Yes	Yes

Host	Scientific Name	Australia	PNG
Fox Tail Palm	*Wodyetia bifurcata*	Yes	
Foxtail palm	*Wodyetia bifurcata*	Yes	

Aggregation drums and dye studies

In the Northern Territory a method of aggregating *Mastotermes darwiniensis* into drums has been developed. A number holes are punched into the base of a 20 or 200 L drum, which is placed on a site with *Mastotermes* activity, usually a tree stump sawn off at ground level. The drum is filled with suitable timber, moistened and covered to keep in moisture and exclude light. Over a period of a few weeks the termites move into the drum and large aggregations can be obtained. This is a useful method to ensure that any chemical treatments are applied to a large number of termites, but it has also become a useful for research tool for studying the biology of the termite. As an indication of the success of this method a 200 L drum established for 5-6 weeks in Northern Territory will yield 5-7 kg of termites.

In Darwin fluorescent dyes have been used to map the extent of colonies. The dyes are applied to the surface of termites collected from an aggregation drum and the termites returned to the drum. The termites groom each other to clean the dye and share food and faeces (the latter to transfer important gut micro-organisms which aid cellulose digestion) and in this way the dye is transmitted through the colony

A series of 20 L aggregation drums was set up in the Botanic Gardens (Figure 15). After they became established, two colours of fluorescent dye were added to two different drums. Six days later samples were taken from all drums to ascertain how far the termites had spread the dyes. The samples (termite faecal smears on microscope slides) were brought back to Darwin for processing and termites were shown to have moved between the drums as they do in northern Australia. This is a technique that could be developed further if more detailed information on colony size is required as part of an eradication campaign.

Figure 15. Michael Neal demonstrating the set up of an aggregation drum to John Dobunaba and Tom.

DNA and morphological studies

Collections of termites were made into absolute alcohol for DNA studies. Dr Theodore Evans (CSIRO Termite Group) has been carrying out DNA studies of *Mastotermes* across northern Australia, and should be able to determine from these specimens where the original Lae infestation originated. These samples are at present in Darwin pending arrangements with Theo Evans analyse them.

Samples were also taken into 70% alcohol for morphological examination. All samples were brought back to Darwin and were covered by a Permit to Export Non-protected Insects from the PNG Office of Environment and Conservation.

9. Prognosis of likely rate of spread and of the potential impacts, if no management strategies are adopted

Present area of infestation

The original infestations had been in relatively small areas at the wharf and in the hospital grounds. Treatment of these colonies with a view to eradication was started as soon as they were discovered in 1961 and by 1973 it was thought that the species had been eradicated.

The current outbreak was first discovered in the early 1990s close to where the last treatments had been made in the 1973. It was not treated and has now spread to other parts of the hospital, to the botanical gardens and to the FRI building, and has been discovered in a new area at the Police Barracks.

The infested area is now far larger than that which was being dealt with in the 1960s and 70s and is estimated to be of the order of 1.4 square kilometres. This is seven times larger than the two areas which were infested in the 1960s, which were recorded by Gay (1967) as being 20 and 30 acres, a total of 50 acres or 0.2 square kilometres. With the large colonies now present the rate of spread would be expected to increase dramatically over the next few years.

Rate of spread

As detailed above, it is thought that the termites came into Lae towards the end of World War II (c1944), but they were only discovered in 1961, approximately 17 years later. At that time a large colony was found in a log dump near the wharf and a number of smaller colonies in two distinct areas. The initial build up must have been very slow at this time to a state where the termites had moved from the log dump and were causing enough damage to be easily visible.

Through the succeeding twelve years surveys and control measures were undertaken and by 1973 it was considered that the termite had been eradicated, or at least confined to a very small area. The termite was again recorded as causing damage in the early 1990's, again a period of some approximately fifteen years. It seems therefore that in Lae the build-up is very slow, most likely due to unfavourable conditions there (see below).

Now that numbers have increased recent rates of spread appear to be faster. The infestation at the Police Barracks and Okari Campus can be taken as an example of the current rate of spread. It was first found in the Okari Campus in 2000 in one building. Now, in mid 2006, it is present throughout the Campus, the adjoining Police Barracks to the south and the settlement area to the north. Thus, without adequate treatment, the area of infestation has increased from a small nucleus in 2000 (or perhaps slightly earlier) to an area of about 0.8 square kilometres by mid-2006.

There is now a danger that it will move into the residential areas to the south of the Police Barracks, to the settlement area to the west and then into further residential areas, and through the settlement to the north to the adjoining Timber Industry Training College.

Means of spread

There are two main methods that *Mastotermes darwiniensis* increases the size of its colonies in natural situations, flights by winged primary reproductives and the production of secondary reproductives and budding off at the edges of existing colonies. Added to this is now the human assisted spread with the movement of timber and firewood.

Flights

In northern Australia colonies of *Mastotermes darwiniensis* produce numerous nymphs during the year which develop into winged primary reproductives. Flights occur during the first rains of the wet season any when from October to December. However the establishment of new colonies from these flights appears to be a rare occurrence and no records are known from the wild of dealate primary reproductives (kings and queens) being found in colonies.

This may be partly explained by the fact that most of the suitable habitats already have colonies of either *M. darwiniensis* or competing species, and may not be the case in new uncolonised areas in PNG.

However it appears that dispersal through flights is not occurring to a great extent in PNG. If flights had taken place and if colonies had established then the current survey would have been expected to have located many small pockets of infestation. This was not the case.

There are also no observations of flights occurring, even though alates are being formed. During the first detection in 1962 nymphs and alates were discovered in the colonies and there are specimens of alates in the National Insect Collection in Konedobu, and Gay (1967) refers to alates being present in samples sent to CSIRO for identification. There is also a record on file of a large number of nature alates in a colony found in March 1962. These were obviously destroyed, but it is likely that other colonies in the area also had alates at the same stage of development. However a series of light traps which were run for five months from February to June 2005 in the infested areas did not trap any alates.

M. darwiniensis alates are large and easily distinguished from other termites. They fly at night and are attracted to lights, leading to large numbers being found under the lights of buildings in the morning following a flight. However the team could find no-one in Lae who had observed any of these termites at lights over the last few years when the populations have been expanding. Even one of the collaborators in this survey, John Dobunaba, a professional entomologist who is well aware of flights of other species of termites, has not seen any flights of *M. darwiniensis* or build up at lights at FRI despite the fact that populations are high in the FRI building and adjacent botanic gardens.

This lack of flights is not due to the failure to produce alates as shown by the early records, and the discovery of a developing nymph in the current survey. However in Northern Australia the flights are triggered and synchronised by the first rains. It is possible that in Lae, where rainfall occurs throughout the year, there is no trigger of going from a completely dry period to the first rains of a wet period to trigger the flights.

Budding off from main colony

M. darwiniensis is a primitive species of termites in which the workers are not sterile and are more correctly termed pseudergates. Each of these pseuderagtes has the ability to moult into a secondary reproductive (neotenic). These neotenics are commonly found in colonies in northern Australia and there are often several found in each nest.

In the Northern Territory of Australia a series of termite killed mango trees were dug up. It had been shown by dye studies that the termites in these trees were part of a large colony stretching for at least 180 m. However under each of the trees excavated there was a carton nest with many immature termites and several neotenics (Thistleton and Neal, unpublished data). These two observations indicate that colonies can be very large, but within the colonies there are numerous breeding sites each with their own reproductives.

The large size of colonies (up to 180 m shown with dye studies and 1.5 ha by DNA analysis Goodisman and Crozier, 2002) and their increase in size at the boundaries, show that the main method of spread is by the production of neotenics and the budding off from existing colonies underground.

This fits with the two current areas of infestation in PNG, where the infested areas have increased in size from an initial small areas of infestation, and this increase can be expected to continue if left unchecked.

Transport in construction timber and firewood

In addition to the natural spread, colonies can be moved in infested construction timber or firewood. The ability for all the pseudergates (workers) to moult into neotenics (secondary reproductives) means that new colonies can potentially form even when no reproductive is transported in the timber. In PNG where firewood is used for cooking purposes and is in short supply, any waste wood is collected and taken away. If this is infested, and is stored before being burnt, there is a high risk that a new colony will form. In addition there are cases where timber has been taken from FRI to use elsewhere for constructional purposes and undoubtedly this has also occurred with timber in the hospital where damaged buildings have been demolished.

This is probably the means that the second area of infestation, the Okari Campus/Police Barracks site became established. In fact it could be that the spread through this site could have occurred in a similar way. The termite was first found in 2000 in an administration building in the Okari Campus. In 2004 it was found in a building near the centre of the Police Barracks site, not on the common border with the Okari Campus.

This transport in timber is a large risk factor, and it is only a matter of time before some infested material is taken from Lae to more favourable habitats in the Markham Valley. This risk will increase as the populations of termites increase and the potential sources of infested material become more common.

Limiting factors

Even though the area infested by *Mastotermes darwiniensis* is increasing, it has been in Lae for almost sixty years, and its distribution is still limited. The earlier use of organochlorine and arsenic chemicals to control the termite is undoubtedly one reason. Other natural limiting factors, principally high rainfall and waterlogged soils are probably responsible for limiting its current spread.

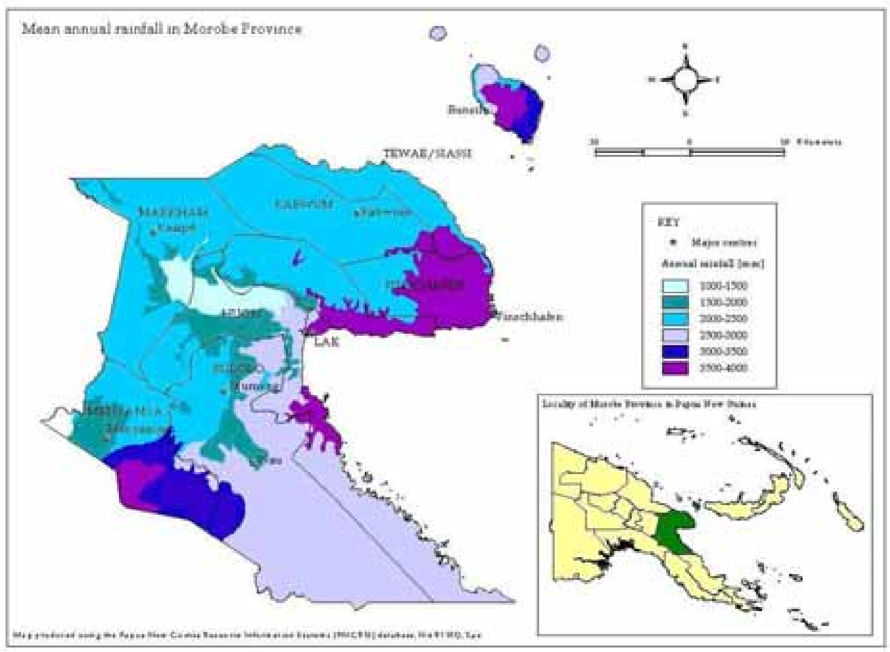
Rainfall

Mastotermes is common across the low rainfall areas of northern Australia but is absent from high rainfall coastal rainforest localities Queensland (Hill, 1942, Hadlington and Gerozisis 1985, Hadlington 2001). Its establishment in Lae is therefore unusual and Mercer (1989) discusses this in relation to the rainfall of Lae (4597 mm per year, spread throughout the year) to that in Darwin (1537 mm most occurring in a wet season).

Mastotermes normally needs contact with the ground for its nesting sites, but Mercer (1989) hypothesises that the termite could have adapted to live in the moist Lae soils, by having nesting sites in above ground structures. However Hadlington (2001) states that this also occurs in Australia and where there is an assured water supply to the colony the species can form nests between floors of multi-storeyed buildings. Neotenics were present in samples taken from the FRI building showing that nesting was occurring in the building.

Map 5 shows that only a small part of Morobe Province is as wet as Lae, and certainly the agricultural areas of the Markham Valley are much drier. These would be more similar to areas of Australia where the species is common and would be more suitable for colonisation by the termite once it moves from Lae.

Map 5: Annual rainfall in Morobe Province.

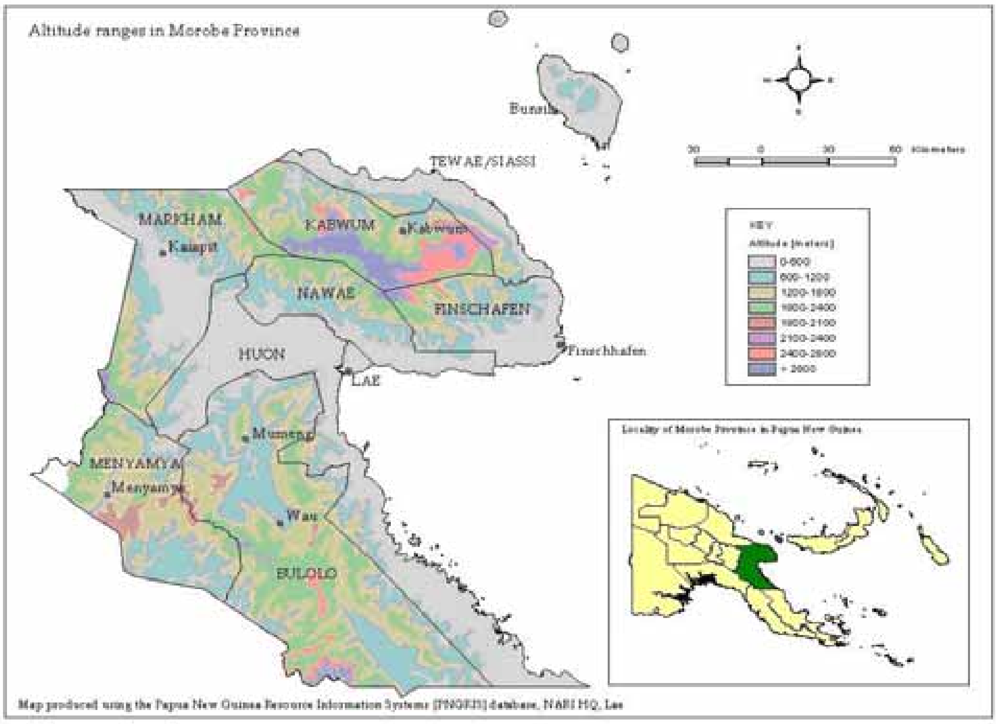


Temperature and altitude

In Australia *M. darwiniensis* is common in the north. It is found as far south as Ti Tree, but does not occur in Alice Springs. Ti Tree temperatures range from a mean daily maximum of 37.8°C in January to a mean daily minimum of 4.5°C in July with a lowest minimum temperature of -2.0°C and with an average of 5.7 days per annum less than 0 °C.

In Australia termites are encountered less frequently in the higher altitude area of Australia, this being related to temperature (Hadlington 2001). However PNG is close to the equator and temperatures at reasonable altitudes would still be suitable for termite colonisation. The highland valleys of Papua New Guinea at 1,500 metres rarely experience frosts and both the minimum and maximum temperatures would be less extreme than at Ti Tree. In the eastern highlands daytime temperatures of 26 ^{o}C falling to 12-15 ^{o}C at night are normal. There is therefore a high likelihood that *Mastotermes* could survive in these valleys. Bulolo, at an altitude of 700 metres has a climate between that of Lae and the highlands valleys and would also be a suitable habitat for *Mastotermes.*

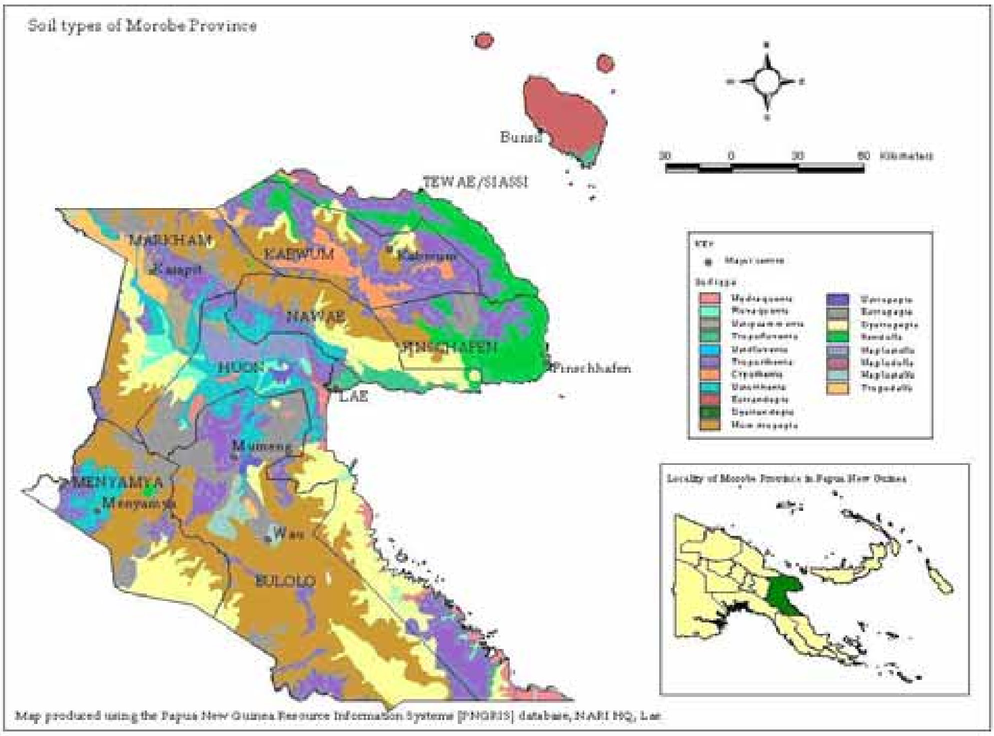
Map 6: Altitude in Morobe Province.



Soil types

In Australia the termite occurs in a range of soils and this not thought to be a limiting factor. In Northern Territory soil types in which the termites are found are lateritic podsolic soils, yellow podsolic soils, lateritic red earths, acid swamp soils and grey soils of heavy texture. They are absent from the grey soils of flood plains but this seems to be related more to wet season flooding than to the soil type. They are also absent from tropical rainforest soils, but this is also probably due to high rainfall and soil moisture.

Map 7: Soil types in Morobe Province.



Soil moisture

Soil moisture is a major constraint to movement of the termites. The water table in Lae is high and would restrict the depth to which the termites can move. This would obviously vary with elevation and would be different around FRI and the nursing school which are on the top of an escarpment and therefore relatively well drained, as opposed to the bulk of the botanic gardens and the hospital are which are at the base of this escarpment.

The southern and eastern boundaries of the infestation at the hospital/FRI areas are bounded by deep drains which often have standing water. Even when there is no water, the soil beneath is likely to be very wet, thus limiting movement. Indeed one of the survey team from FRI considered that the infestation had spread during a recent drought period when the soil moisture had decreased.

Potential damage to crops

The host plant list in section 8.2 shows the large number of economic species of food plants and forest trees which are likely to be affected.

Mangoes, coconuts and many large forest trees (rain trees, *Terminalia* etc., see Figures 6-9 and Figure 16) have already been killed in Lae. If the termite gets to the much drier and more favourable areas of the Markham Valley, cocoa, forestry plantations, coconuts, mangoes will all be at risk. There is also the danger to food plants such as cassava, which in Australia is a favoured host and has been used as a trap crop for the species. In addition village houses, which are mainly constructed of timber, are at high risk.

The termite is likely to survive at Bulolo (700 metres) where large forestry plantations would be at risk. While coffee (robusta in the lowlands and arabica in the highlands) and tea have not yet been shown to be hosts, the wide range of other plants attacked makes it highly likely that these will also be attacked. Coffee, in particular, is a major crop in PNG and while there are large commercial plantations, most coffee is produced in village plots where termite control would be difficult.

Figure 16. A rain tree ring-barked and killed by *Mastotermes*

Potential damage to infrastructure

In Lae the termite will almost certainly spread to new residential areas causing extensive damage to infrastructure. Where present, this is the most destructive termite to infrastructure in Australia, and in PNG, where present control and preventative measures are limited and inadequate, the situation is far worse, as shown by the degree of damage at the hospital and FRI buildings.

10. Management options

There are two main options for long term management of the giant termite in Papua New Guinea. The first is to accept that it is now an established pest and that control measures will be needed from now on to protect buildings and crops from this pest. If this option is taken the pest will continue its slow spread and will eventually be causing more extensive damage to a range of crops as detailed in the previous section. While control of the termite would be possible for large scale plantations it will be an additional production cost. But villagers would probably not be able to afford to protect their houses or their crops (e.g. village coconuts, mangoes and other fruit trees, small scale cocoa, coffee plots etc.).

The second option, and the one favoured by the authors of this report, is to set up a project to at least contain and reduce the current infestation and thereby slow its spread or, ideally, eradicate it completely. While the infestation still covers a relatively small area and in view of the recent availability of good termiticides, it is therefore recommended that an attempt at eradication is undertaken. Authorities in PNG (see details of the final meeting below) are also in favour of this approach.

The control measures covered in the next section would be the same for each of the two management options. The difference in the two would be that for ongoing management it would be left to the growers or the owners of buildings to implement the measures and not all would be able to afford to do this, whereas for containment and eradication it would be a government implemented project aimed at more extensive surveying and treatments in an attempt to find and remove all colonies.

Current control measures

In Australia recent control measures in horticulture and forestry have involved aggregating *M. darwiniensis* into drums and treating with mirex (Mirant®) which was carried by the termites through the colony. However this is a persistent organochlorine chemical which is being phased out worldwide through the international Persistent Organic Pollutants treaty.

Mirant® has now been replaced in Northern Territory with the use of fipronil (Termidor® and Regent®), a much less persistent chemical with good termiticidal properties.

Fipronil

A good termiticide should be toxic to termites, non-repellent so that the termites will pick it up on their bodies and will feed on material impregnated with the toxin, slow acting to allow transfer by colony members and transferable through the colony through food sharing, protodeal feeding[1] and grooming.

Fipronil meets all of these requirements. There are three available formulations: Termidor Residual Termiticide® (100 g/L fipronil), Termidor Dust® (5 g/KG fipronil) and Regent 200 SC (200 g/L fipronil).

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[1] Social feeding on liquid excrement containing intestinal flagellates and bacteria resulting in the transfer of symbionts.

Control in trees

Twenty-three trials have been carried out in Northern Territory using this chemical under aggregation drums, soil injected or drenched round the base of infested trees and injected into termite produced cavities within trees. The chemical not only kills termites in the infested trees, but is carried through the colony. Activity has been shown to cease in trees up to 50 metres from treated sites. Outside of this area where the termites are killed, there is normally a zone where the termites exhibit sub-lethal effects and become sick and covered with soil mites, which they would normally clean from each other.

The agricultural supplier Farmset imported some Termidor® for the project and a demonstration was given to collaborators at FRI on how to drill trees to establish that *Mastotermes* were active, and how to apply the termiticide to trees and aggregation drums. FRI staff are already treating trees in the Lae Botanic Gardens where the institute is located.

Control in Buildings

In Australia there are a number of chemicals used for control of termites in buildings and there are building codes governing their use. The persistent organochlorines have been phased out but current active ingredients include chlorpyrifos, bifenthrin and fipronil. Control measures include:

- Insecticide applications before laying slabs
- Under slab irrigation
- Perimeter treatments
- Insecticides such as chlorpyrifos, bifenthrin and fipronil
- Treatment of trees with Termidor can control *Mastotermes* in adjacent buildings
- Regular inspections by pest control officers
- Stainless steel mesh barriers
- Control water and ventilate sub-floor areas
- Removal of trees or other termite food close the house

Possibilities of eradication

The present infestation is estimated to be approximately 1.4 sq km, whereas the earlier one was estimated to be a seventh of this. The first eradication attempt spanned a period of ten years, with episodes of control activities when new outbreaks were located.

In addition the initial infestations were in areas where survey and control were easy to carry out. This is true for some of the areas currently infested, but the presence of the termite in the botanical gardens, where there are numerous large forest trees, and in settlement areas where there are law and order problems will make surveying and control more difficult. The current eradication is therefore likely to involve more effort than the earlier attempts
However previous treatments had used chemicals that are not readily transferred through the colony. The current chemical for *Mastotermes* control, fipronil, is very effective and is transferred through the colonies up to distances of 50 m, so that if infested sites are missed control is likely to be achieved through treatments to nearby sites.

The use of this chemical and the formation of a full time team to survey and apply the chemical over the next few years would reduce the population substantially to a state where it can be contained in small areas, and possibly even eradicated completely.

Meeting to discuss results and plan for the future

A meeting was held in May 2006 attended by representatives from NAQIA, FRI, Provincial DPI and DPIFM. Health and NARI were not represented but they were briefed on the decisions made. Outcomes of this meeting were:

Proposal to eradicate

Roy Masamdu, Chief Plant Protection Officer, NAQIA, proposed that an attempt should be made at eradicating the pest, which is in line with the recommendations of the authors of this report. He would undertake to gazette the pest as a notifiable pest under the appropriate legislation[2]. All agencies represented at the meeting agreed with this course of action. An approach would be made by PNG Government to an appropriate funding agency (e.g. AusAID) to finance the eradication.

Eradication team

The following proposals were made by participants at this meeting:
A team should be set comprising a scientist/manager (preferably an entomologist), two technical officers and five labourers
The team should be formed for three years in the first instance
The team would be based at FRI, but its activities would be governed by a committee of representatives from FRI/NAQIA/NARI. Provincial DPI, Health, possibly UNITECH, and possibly NTDPIFM
It is suggested that some of the labourers should come from the settlement area between the Okari Campus and Timber College to facilitate safe access to this area).
Australian collaborators could assist with training, advice on panning and implementation and reviews of progress.

[2] The species was declared a notifiable pest within the Plant and Disease Control Ordinance in 1962 and it is not known if this was ever revoked.

Activities

The activities of this team would be to:

- Survey all trees with the current areas of infestation and treat those that are infested. Where infested trees are small and numbers of termites in the tree are low, aggregation drums should be established and treated once highly active (four to six weeks). In high risk areas where it is not possible to determine early infestations in large trees, these should be treated as a precaution
- Survey the current borders of infestation and possibly treat trees in a buffer zone outside of these borders to kill off early and not yet detectable infestations.
- Continue surveys at regular intervals to check that activity has ceased in treated trees, and to locate new ones.
- Continue with public awareness campaigns using radio, posters (some already developed) and other media to:
- Educate the public and encourage them to report any new occurrences of this pest.
- To dissuade the public from moving firewood and building materials from high risk areas. If NAQIA declare the termite as a notificable pest then it will become an offence to move timber and firewood from infested areas.
- Follow-up on any new records found through the above publicity and set up new eradication sites and buffer zones.

Control and eradication in infrastructure

For buildings it will be necessary to involve Pest Control Operators. In many cases the householders will wish to organise control of the termites themselves and will no doubt employ PCOs to do this. The team will obviously assist by surveying and treating trees in the gardens of these houses.

The problem areas will be institutional housing and buildings at the Police Barracks, FRI and the Hospital. While the authorities managing these would wish to carry out control measures, funds are a problem and current measures are either non-existent or at least insufficient to give adequate control.

Funding requirements:

Funding would be required for:

- the salaries and wages of team members:
    - Scientist/manager The salary level used is for an Papuan New Guinea entomologist with five or more years of experience.
    - Two technical officers, grade 10
    - Five labourers
- transport (a 4x4 double cab)
- office equipment (the office will be provided by FRI) including:
    - computer with email access
    - telephone and fax facilities
    - office supplies
    - publicity material
- field equipment
    - chainsaws with auger attachments (3 or 4)
    - application equipment (spray tanks with soil injection wands)

- surveying equipment including GPS units.
- Supplies of chemical (fipronil)
- Protective clothing

- visits of staff from Australia to train, assist and review progress if required.

Indicative budget

The budget below covers a three year period and is based on the costs of an entomologist, technical officers and labourers at PNG rates of pay. This is the cost for the eradication. Extra funding could be sourced from another agency for a research component.

	PNG Kina per unit per year	Number	PNG Kina per year	AUD per year	AUD per three years
Salaries and wages					
Entomologist	26,000	1	26,000	10,650	31,950
Technical Officers	18,000	2	30,000	12,289	36,866
Labourers	2,600	5	13,000	5,325	15,975
				subtotal	**84,791**
Vehicle					
Vehicle purchase	130,000	1	130,000	53,250	53,250
Running costs	15,000		15,000	6,144	18,433
				subtotal	**71,683**
Computer and office supplies					
Computer, printer and software	10,000	1	10,000	4,096	4,096
Digital Camera	2,500	1	2,500	1,024	1,024
Office supplies			3,000	1,229	1,229
Publicity material			2,500	1,024	3,072
Telephone			7,200	2,949	8,848
Field supplies:					
Chainsaws and augers	2,000	3	6,000	2,458	2,458
Termidor			15,000	6,144	18,433
Soil injection equipment	2,000	2	4,000	1,638	1,638
Knapsack sprayers	1,000	5	5,000	2,048	2,048
GPS	1,500	1	1,500	614	614
Protective clothing			2,000	819	2,458
				subtotal	**39,159**
Visit by overseas expert to train, assist with surveys and review progress					
Airfares and accomodation		1		5,400	27,000
Personnel costs		10 days		3,000	15,000
				subtotal	**42,000**
				Total	**237,633**

Research

In addition to the eradication campaign, the team could also be involved with a research component, possibly with funding from a different agency (e.g. ACIAR). Possible objectives of this research component could include:

- Studies on the biology of the insect and comparison with known biology in Australia, e.g.
    - Colony size (is this the same as in Australia or is it limited by soil moisture in PNG?). Use aggregation drums and dye methods, or DNA analysis (much experience with DNA studies on *Mastotermes* colonies is already available in Australia) .
    - Implications of colony size and movement for chemical control (is fipronil being carried as far as it is in Australia?)
    - Time of year that alates are formed and abundance of these. Light trapping at high risk periods to detect flights.
    - Longevity of the chemical in the soil – the NARI chemist could be involved with this work.
    - Studies on limiting factors to dispersal – soil moisture, soil types etc.
    - Recording of host plants. In addition to the extensive list already presented there are many other potential hosts. Many of these are in areas which are not yet infested, so their potential as hosts has not yet been determined.

11. Recommendation

In view of the still limited distribution of the termite in PNG, the potential for large scale damage to horticulture, forestry and infrastructure should it move to more favourable areas, the availability of more efficient termiticides and the commitment of the PNG authorities, it is recommended that funding is sought for a programme to at least contain the termite and substantially reduce the population in Lae town, and preferably to eradicate it completely.

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