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Final report

Small research and development activity

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2 Executive summary

This SRA project documents existing knowledge and status of the galip weevil pest (GW), an emerging major pest on galip nut trees (*Canarium indicum*) in Papua New Guinea (PNG). In doing so, the project identifies PNG research capacity and future research needs to address its impact. Galip R&D plots were established ca. 10 years ago at the NARI fieldstation in Keravat (East New Britain) to support the development of the *Canarium* nut industry in PNG. GW was first recorded in the Keravat plots in 2015, and was found to cause extensive damage and tree death. A subsequent delimiting survey by NARI and NAQIA in late 2015 found the GW in multiple locations in the Gazelle Peninsula, with up to 90% infestation, in commercial locations and small farmer holdings. The SRA activities were implemented in the 2016/2017 financial year, and the key findings were as follows.

Key findings and outcomes

- The weevil was definitively identified as *Ectatorhinus magicus*, an ithyoporine curculionid, and we herein refer to it as the galip weevil (GW).
- GW was first described in 1860 and is endemic to PNG.
- GW was recorded as a minor pest of *Canarium indicum* in 2006.
- The life history of GW was investigated in ENB. GW is a wood-boring insect that forms larval tunnels, has four instars, pupal cells in larval tunnels, and has free-living adults.
- GW larval tunnels effectively ringbark young trees, commonly leading to mortality.
- In ENB GW is in an outbreak phase causing widespread tree mortality.
- GW impact has increased significantly in ENB in the year between the NARI/NAQIA 2015 surveys and the UNSW/AM/NARI survey (26 Nov–6 Dec 2016); within site damage is extensive, best observed in the Agmark plantation at Vunapau (ENB), where tree death is catastrophic, with 100% of trees dead or dying.
- Anecdotal evidence that GW damage was first observed in the Agmark plantation in 2012; this is the earliest record of the current GW outbreak.
- GW was found in ENB in the ‘elite’ galip varieties (Nissan variety mostly, interplanted with Buka variety) and the ‘local’ variety (wild populations) of *Canarium indicum*.
- GW breeding program at NARI Keravat campus has started but has been unsuccessful to date.
- Long term monitoring sites were established in the Keravat plots measuring tree response variables against GW presence; canopy cover and tree age were found to be significantly correlated with the presence of GW larval tunnels.
- The Madang survey (3-11 April 2017) resulted in the first formal discovery of GW in that province; 5% of galip trees (local varieties only) were infected and local farmers were aware of GW.
- GW was not found on Buka, Nissan or Duke of York islands in 2016/17 surveys.
- NARI staff at Keravat have been trained in GW identification, sampling design and data recording; Madang DPI staff have been trained in GW detection
- Communication about GW as a serious pest of galip was undertaken through radio, television, the mobile network, and distribution of a factsheet in PNG.
- A poster presentation of SRA activities was prepared for the PNG Plant Protection 2017.

Conclusions and recommendations for further work

The GW is in a classical outbreak phase and is an immediate threat to the development and long-term viability of the galip industry. Galip is also highly significant to Papua New Guineans as a food source and in traditional life, and the emergence of GW has broad social impacts. UNSW and NARI recommend ongoing research into the ecology, distribution, identity and genetics of GW, and its association with galip varieties and species, as well as the commencement of control trials.

3 Introduction

Background and Justification

Galip (*Canarium indicum*) is a native tree of the lowlands of Papua New Guinea, Solomon Islands and Vanuatu, which has been used traditionally as a food source, building material, medicinal plant and in cultural life (Jones 2012, Braidotti 2016). Over the past 20 years the nut has been in development as a commercial crop, with the support of ACIAR, and in collaboration with PNG's National Agricultural Research Institute (NARI) (Akus 1996, Nevenimo et al. 2008, Wallace et al. 2016). Nissan and Buka varieties of galip (referred to as elite varieties) were propagated and distributed in PNG, with plantations in the Gazelle Peninsula of East New Britain established.

In mid-2015 a few trees in the experimental galip blocks at NARI's Keravat fieldstation, in East New Britain, were under severe stress. NARI staff found GW to be the pest agent, causing significant mortality in the elite varieties of galip, which had been planted extensively in the Gazelle Peninsula, including the Keravat blocks.

In response to the detection of GW, NARI and the National Agricultural and Quarantine Inspection Agency (NAQIA) undertook a delimiting survey in East New Britain in late 2015. These agencies detected a broad scale outbreak of GW, from smallholdings (up to 100 galip trees) to large scale commercial plantings (ca. 6000 trees). The damage to galip trees was catastrophic, with up to 90% tree morbidity and mortality at multiple sites.

The issue of GW and its damage to galip plantations was brought to the attention of Prof. Cassis (UNSW) and Dr. Reid (Australian Museum) during their entomological capacity building workshop in East New Britain in November 2015 (DFAT funded). They inspected galip trees in blocks at the Keravat field station and confirmed catastrophic damage to the trees attributed to GW. During the workshop, Dr Sim Sar of NARI called a meeting of NARI Keravat staff (including Tio Nevenimo, Fidelis Hela, Godfrey Hannet and John Bokosou) to discuss the status of the GW. It was decided at this meeting that the UNSW/Australian Museum team would partner with NARI staff to carry out a scoping study of GW.

The University of New South Wales (UNSW) was engaged by ACIAR (SRA pilot project FST/2016/013) to undertake fact finding surveys in northern PNG, including island provinces, building on the NARI/NAQIA delimiting survey of 2015, as well as reviewing existing data. This project aligns with ACIAR project FST/2014/099, on the development of galip as a commercial crop and with ACIAR's AOP targets, including improved sustainability and resilience of production systems, and the diagnosis and development of strategies combating emerging pests and diseases.

4 Objectives

The aim of this project was to measure and describe the current status and history of weevil infestation of galip (*Canarium indicum*) trees in Papua New Guinea and identify further research and capacity needs.

Consolidation of existing knowledge, acquisition of new data on GW and compiling this information into a reference report was the main objective of the work.

The specific objectives were to:

I. Determine aspects of the biology of the GW.
II. Determine if the GW is a Papua New Guinea endemic species.
III. Determine type and extent of damage GW is causing to galip trees.
IV. Review the extent, gaps and accessibility of knowledge.
V. Review in-country GW related analytical capacity, and complimentary Australian support.
VI. Provide recommendations to ACIAR on threats of GW and follow-on research.

The activities proposed were:

I. Consolidation of existing information based on trip to Keravat, East New Britain and collaboration with NARI staff.
II. Determination of taxonomic identity of GW, which may have been misidentified. This will include the preparation of a scientific publication on the GW.
III. Study life history traits of GW, including larval, pupal and adult stages.
IV. Field trip to other PNG sites where Nissan cultivars have been planted (e.g., Madang sites).
V. Preparation of report to ACIAR on identity, life history traits and pest status of GW.

Proposed outcomes envisaged were:

- By understanding the identity, history, biology and distribution of the GW, PNG research partners and the fledgling galip industry will have greater capacity to develop methods to manage or eliminate the pest's impact.
- The project will enhance research capacity within NARI, as well as other PNG counterparts, through an enhanced entomological network brokered by UNSW between 2013-2016.
- The project report will provide entomological support for FST/2014/099, and identify priority follow on research activities for further ACIAR project work.
- The project will provide a baseline for ongoing studies on GW, including the development of an IPM program, and the implementation of control trials.
- Improved smallholder confidence in growing galip trees for agroforestry throughout East New Britain.

5 Methodology

In relation to the proposed activities, the following methodology was developed and implemented:

I. **Consolidation of existing information based on trip to Keravat, East New Britain and collaboration with NARI staff**

- A planning trip to NARI Keravat facility to establish the project team between UNSW and NARI, and the Australian Museum.
- Consolidation of existing data on GW, its association with galip wild varieties and cultivars in PNG, focusing on the Keravat blocks and other sites in the Gazelle Peninsula, where damage is extensive.
- Further survey of wild, domesticated and plantation populations in East New Britain to determine type and extent of damage, and distribution of GW locally.
- Establishment of survey plots at Keravat to monitor tree response to GW.
- Collection of GW samples for activities II. and III.

II. **Determination of taxonomic identity of GW**

- Assess the taxonomic identity of the GW.
- Assess if GW is a single species, if it was previously described or is a new species.
- Determine if GW is a native of Papua New Guinea.

III. **Study life history traits of GW, including larval, pupal and adult stages.**

- Describe the life stages of GW based on available specimens and new collections, focusing on the morphology of the larvae, pupae and adults.
- Prepare manuscripts for publication in the scientific literature on the taxonomy and pest outbreak of GW in ENB.
- Record other aspects of the GW activity including type and extent of damage.
- Undertake life history studies in caged experiments at NARI Keravat.
- Compare GW biology and pest attributes with other wood-boring weevils.

IV. **Field trip to other PNG sites where Nissan cultivars have been planted (e.g., Madang sites)**

- Fieldtrip to Madang to assess if the GW is found in this province.
- Survey of elite varieties translocated to the Madang province.
- Survey of galip on Buka, Nissan and Duke of York Islands for evidence of GW, by NARI staff.

VI. **Preparation of report to ACIAR on identity, life history traits and pest status of GW**

- Summary of findings of activities I-IV.
- Report on the threat of GW to the galip industry.
- Recommendations for future work.

6 Results and Discussion

This results and discussion section consolidates existing and new information on GW in PNG and its potential impact on the galip industry. The information given in this section are aligned against the objectives and activities of this SRA as follows.

6.1 Summary of existing information on Galip and GW outbreak

Prof. Cassis (UNSW) and Dr Chris Reid (Australian Museum) undertook the first trip to East New Britain from 26 November - 6 December 2016 to investigate damage of GW on galip (elite and local varieties). NARI staff at Keravat field station (Islands Regional Centre) and Dr Sim Sar (NARI Lae) facilitated the meetings with the Australian team, and assisted in the fieldwork in East New Britain.

Establishment meetings and information exchange at Keravat, November 2016

The Australian and PNG project team was formed at the NARI Keravat field station, and planning of the activities for the SRA and transfer of existing knowledge between the parties was carried out.

The planning meeting was held on November 28 at NARI Keravat field station, chaired by Dr Sim Sar. Those in attendance from NARI Keravat included Ofara Petilani (Head of Keravat Station), Tio Nevenimo, Fidelis Hela, Godfrey Hannet and John Bokosou.

The following information was provided by NARI at this meeting, and supporting documentation was tabled subsequent to the meeting:

- First specimens of GW were collected by Fidelis Hela on 15 July 2015 in block #405 at Keravat, establishing GW as the pest of elite galip trees in the experimental blocks.
- A GW delimiting survey was undertaken by NARI (Fidelis Hela, John Bokosou, Tio Nevenimo and Godfrey Hannet) and NAQIA (Amanda Mararuai, Anna Kawi) staff in East New Britain, from 12-17 October 2015. Dr Sim Sar tabled the delimiting survey report (Hela 2016).
- Background information on *Canarium indicum* varieties was provided by NARI staff. The seeds of two elite varieties, sourced from Nissan Island and Buka (Bougainville), were selected and developed at NARI because of high nut to shell ratios. These were distributed in East New Britain and other parts of Papua New Guinea. The distribution data for elite varieties by province were tabled by Dr Sim Sar.
- Background information on *Canarium indicum* plantings in NARI Keravat blocks was given, and included: (1) mostly elite varieties (mostly Nissan variety, but also intermixed with Buka variety); (2) mixed West New Britain and Local “Vimmy” block; (3) mixed block with varieties from multiple PNG locations (‘Tio’s block’). The Australian team sought more clarity about the varieties grown in the Keravat blocks. It was unclear if record keeping on varieties per block was complete.
- The ‘local’ (i.e. wild) variety of *Canarium indicum* was also attacked by GW but apparently less so than the elite varieties (the Australian team observed GW attack on the local variety but trees were larger and older, and it was not causing tree death).
- NARI Keravat staff member Godfrey Hannet (native to Nissan Island) reported inspections on Nissan Island and Buka in 2015/2016 and that GW was not found.
- Dr John Moxon of the Productive Partnerships in Agriculture Project (PPAP), Cocoa Board, inspected a large scale galip plantation on New Ireland in late 2016 and found no GW damage.
- NARI reported on preliminary assessment of tree spacing and shading with coconuts; differences were found and it was reported that low shade sites were less susceptible to GW attack.

- Fidelis Hela of NARI reported the following life history traits: (1) early instars feed around oviposition site; (2) later instars produce subcortical burrows; (3) several larvae can be found at one oviposition site, implying that either one female lays >1 egg per site, or other females lay at the same site. In addition, GW adults were reported to occur throughout the calendar year, found on the trunks of the trees.
- Fidelis Hela reported a small scale systemic insecticide trial undertaken using root application of Methamidophos (20 mL at lateral root per tree). Some recovery was observed post-application at ca. 4 months, but GW reinfestation did occur. Dr Sim Sar noted that Methamidophos is an organophosphate that is being phased out in most countries and an alternative will need to be sought.

At this meeting it was also discussed how to proceed with the project, including:

- How to sample the GW and assess the response variables of galip trees. A preliminary list of response variables was presented (e.g., tree health, %canopy cover, exudates, leaf wilt and loss, epicormic response) based on literature for other pestiferous wood-boring beetles, e.g. https://www.aphis.usda.gov/import_export/plants/manuals/emergency/downloads/nprg-wood_boring_bark_beetles.pdf).
- Field survey sites and the establishment of long term monitoring sites at NARI Keravat was discussed.
- Preparation of a fact sheet on GW to be distributed to stakeholders across PNG.

On 1 Dec 2016 Prof. Cassis and Dr Chris Reid held a meeting with Dr John Moxon of the Cocoa Board. The following key points were communicated and discussed:

- Confirmed that there are two ‘elite’ varieties, Nissan and Buka (‘Manchungan’).
- Elite plantations are a mixture of the two varieties.
- Galip was likely domesticated ca. 10,000 years ago (later discussion by CR with archaeologists Jim Specht and Robin Torrence at the Australian Museum, who gave an estimate of at least 30,000 years).
- Nissan variety has large nuts and has probably been highly selected for on its small and isolated island.
- the germplasm block at Keravat includes galip varieties grown from across PNG.
- The Vimmy plantation has about 6000 trees, which have been periodically planted over the past 20 years.
- Estimated that one in every ten trees in the wild is a *Canarium*.
- GW damage first reported in 2015.
- *Anoplolepis* (yellow crazy ants) and *Oecophylla* (green tree ants or weaver ants) are possible biocontrol agents.
- John Moxon was very concerned about GW attack and regarded it as catastrophic for the fledging industry; it was an urgent issue for him as he had to plant 350,000 galip trees by April 2017 as part of his PPAP project and was uncertain about what galip variety to grow.

Summary of NARI/NAQIA delimiting survey 2015

The purpose of the delimiting survey was to identify the limits and spread of GW, and the extent of damage. The survey was limited by road conditions.

Key points were:

(1) widespread occurrence of GW in central Gazelle, with 100% damage at Vunapau Plantation (Agmark);

(2) five of 11 Baining sites (inland Gazelle) had GW occurrence, with up to 90% damage;

(3) NCR Gazelle district had no GW damage;

(4) Kokopo – Upper Warangoi LLG had no GW damage;

(5) Kokopo – Bitapaka LLG had one of seven sites with low GW damage, and

(6) Rabaul district had one of 19 sites with GW occurrence, reporting 100% damage.

The NARI/NAQIA survey team established a qualitative damage index based on inspection of trunk and canopy; the index included leaf wilt and necrosis, loss of canopy cover, and damage to the trunk. The data recorded was qualitative in nature.

Galip industry development and tree varieties

Galip (*Canarium indicum*) has long been identified as a potential crop tree in the South Pacific for its edible nut, traditionally traded fresh in roadside or village markets (Wallace 2016). *Canarium indicum* is a cultivated species in PNG, but it is also known to be common in the wild (Akus 1996, John Moxon pers. comm.). It is currently grown and used on Bougainville, New Ireland, New Britain, Manus, the Milne Bay islands and the northeast coast of the PNG mainland (see Figure 1) (Akus 1996). Galip was also identified as an alternative lowland cash crop, in light of the significant pest problems that have beset cocoa and coconut, the traditional export cash crops in these lowland regions (Cornelius 2012).

Nut quality and processing issues were identified as requiring research and development to create a stable product for galip industry establishment and expansion (Akus 1996, Nevenimo 2008). Commercialisation and value adding opportunities were also identified as important for R&D (Nevenimo 2008, Carter and Smith 2016, Wallace 2016).

Early R&D work at Keravat (1991 survey) identified high yielding trees with large nuts in smallholdings on the Gazelle Peninsula, which were considered to be potentially more promising than those used at that time for seed stock distribution from the Keravat Islands Research Centre (IRC) (formerly LAES) (Akus 1996).

Elite galip

The seeds of two elite varieties, sourced from Nissan Island and Buka (Bougainville), were eventually selected and developed at NARI primarily because of high nut to shell ratios (Sim Sar, pers. comm.). Most plantations are wholly of the two elite varieties, the majority from Nissan Island ('Nissan') and the remainder from Buka (Bougainville), known as 'Manchungan'.

Seedling distribution and plantation establishment

Around 250,000 seedlings were distributed by NARI from Keravat to provinces including Manus, New Ireland, West New Britain, Morobe and Madang (Sim Sar, Fidelis Hela, pers. comm.). From current data on nursery stocktakes at Keravat IRC, it was estimated that 200,000-250,000 elite galip seedlings were distributed between 2008 and 2012 (see Appendix 9.5). Excluding 2011 (data not currently available), records show 96% of the stock were distributed on East New Britain and the majority of these seedlings were distributed locally on the Gazelle Peninsula, an estimated 97,000 and 89% of seedlings overall (Figure 1).

The only other sizable distributions accounted for were made to New Ireland (3330 trees), Lae (640 trees), and Manus (200 trees) in this period.

Two thirds of the seedlings were distributed to or purchased by smallholders or smallholder cooperatives and almost a third to plantations (Figure 2). The data include dates, names and localities of the recipients and the number of seedlings acquired. Over 200 smallholders were recorded receiving elite galip seedlings in East New Britain, including some large allocations to the Sukolkols, the mountains in the Open Bay area (Fidelis Hela, pers. comm.) and the North Baining Cooperative (20,000 each) in 2012. The main plantation holdings are with Agmark (at Vunapau), Cleanwara (or Cleanwater), Vimmy and Tokiala. Vudal University also has established blocks of elite galip. See Appendix 6 for the data in summary. At Keravat experimental blocks were established, comprising mostly the two elite varieties (>3000 trees), with the majority of trees 8 to 9 years old in 2016. Additional varieties were also planted, including a mixed block of the West New Britain variety of *Canarium indicum* and a local variety sourced from the Vimmy plantation; and a mixed block with varieties from multiple PNG locations (referred to as ‘Tio’s block’).

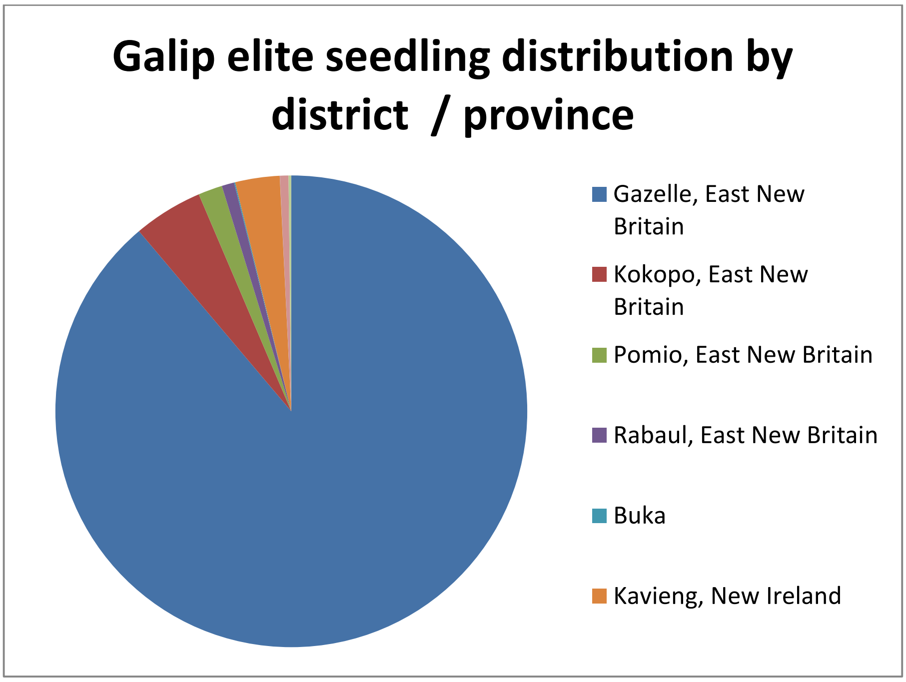

Figure 1. Distribution for galip elite seedlings by region.

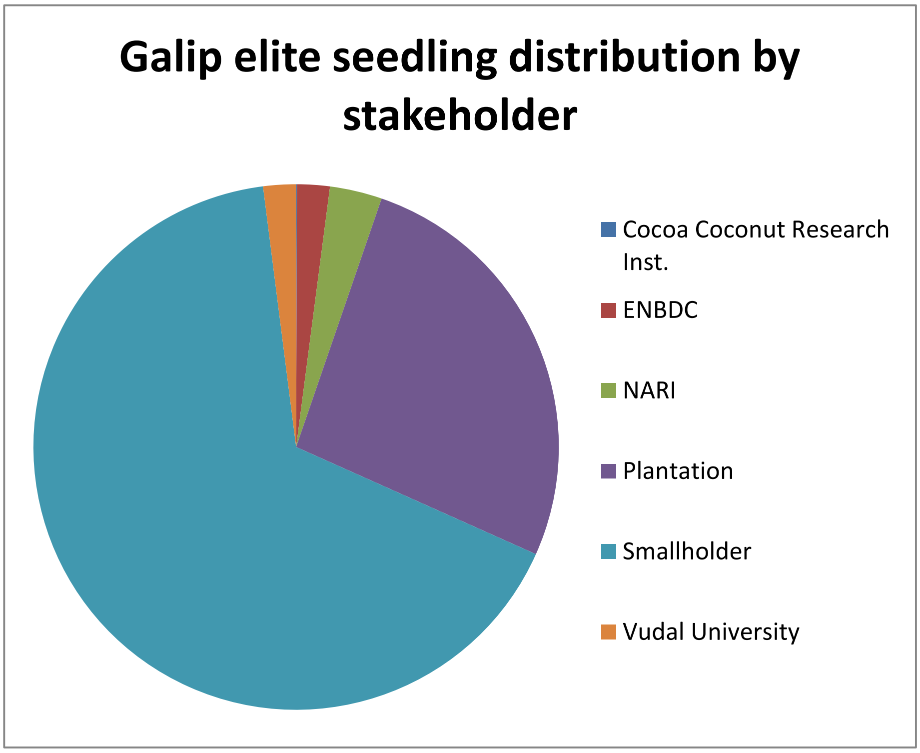

Figure 2. Distribution of galip elite seedlings by stakeholder. ENBDC = East New Britain Development Corporation

Canarium overview of species and varieties

In order to understand the biology and impact of GW (also see section 6.2 on host plants of GW), we provide the following overview of the diversity, taxonomy, history and use of galip and other *Canarium* species in PNG.

Canarium species are collectively referred to as galip in Tok Pisin (Thompson and Evans 2006). The taxonomy of *Canarium* as a whole has not been revised since the 1950's (Leenhouts 1956) and it is acknowledged that the genus requires a modern systematic treatment (Thomson and Evans 2006, Weeks 2009). Past taxonomic work has largely been based on dried herbarium specimens and the taxonomy of the cultivated taxa in particular is known to be inaccurate (Thomson and Evans 2006). Preliminary molecular work on a representative sample of species of the genus indicates that *Canarium* is not monophyletic and that the three ingroup lineages proposed are also not monophyletic (Weeks 2009). These preliminary results indicated two major evolutionary lines within the genus, both containing species with cultivated and edible fruits (Weeks 2009).

Canarium has a paleotropical distribution and comprises around 100 species (The Plant List 2013). Thirty of these species have edible fruit, with 12 species at least partly domesticated and the other 18 species harvested solely from the wild (Weeks 2009). Twenty species of *Canarium* are known from New Guinea with 9 endemic species (Leenhouts 1956). The varieties and local cultivars within *Canarium indicum* have not been documented in any detail but there are two formally recognised varieties, var. *indicum* and var. *platycerioideum*. The latter has larger leaves and fruit, is uncommon and found in West Papua (Thomson and Evans 2006, after Leenhouts 1956).

Aside from *Canarium indicum*, another three *Canarium* species with edible nuts have been domesticated in PNG; *Canarium decumanum, C. lamii* and *C. salomonense* (Bourke 2010, Kennedy and Clarke 2004, Yen 1996). *Canarium indicum* is the most important and widespread of these four domesticated species (Bourke 2010) and is grown in lowland rainforest and secondary forest, old garden areas and around villages and settlements (Thomson and Evans 2006). Stands of *C. indicum* in a forest are sometimes thought to indicate the presence of an abandoned village (Thomson and Evans 2006) and it is common for wild and domesticated varieties to be present at the same locality (Kennedy and Clarke 2004, after Yen). There is archaeological evidence that *Canarium* is the oldest domesticated plant in Melanesia, dating to at least 14,000 years (McClatchey et al. 2006).

In PNG *Canarium indicum* is grown widely on coastal and inland areas on the north of the mainland at altitudes below 500m and in the island regions (Yen 1996). It is most common in Madang, East Sepik, East and West New Britain, New Ireland, Bougainville, Manus, Sandaun, Morobe, Oro and Milne Bay provinces (Bourke 2010, Kennedy and Clarke 2004) (Figure 15). It is uncommon above 500m but will grow up to 930 m altitude (Bourke 2010). Yen (1996) mapped the distribution of cultivated *Canarium* species in Melanesia which was also summarised by Kennedy and Clarke (2004), with *C. decumanum* grown in Manus, *C. lamii* grown on the north coast of mainland PNG, and *C. salomonense* on the mid north coast of the mainland PNG and Bougainville.

Canarium australianum, *C. kaniense, C. schlechteri*, *C. sylvestre* and *C. vitiense* are non-domesticated species that are known to be wild harvested for nuts (Weeks 2009); however, *C. schlecteri* and *C. vitiense* are likely synonyms (The Plant List 2013).

There is overlap in the distribution of both domesticated and wild species. For example, in lowland forest in the Wanang area of Madang province, six species are recorded as co-occurring, including *Canarium indicum* and the other edible species *C. sylvestre*, *C. schlecteri* and *C. vitiense*; it is noted in herbarium records that the fruits are locally used as food (BRIT 2005-11).

It is unclear to what extent local people can distinguish varieties of *Canarium indicum* and other domesticated or wild species of *Canarium*, or if they collectively refer to them to as galip. On the other hand, the frequent co-occurrence of varieties of *Canarium* is not seen as accidental but consistent with Melanesian cropping systems (Kennedy and Clarke 2004, after Yen 1996). The ethnobotanical literature reports on different *Canarium* species that have been cultivated or wild collected (Weeks 2009, Bourke 2010), but the accuracy of these identifications is unknown (Kennedy and Clarke 2004) and there is generally no reference to herbarium vouchers. On Lauru island (Solomon Islands) *C. indicum* and *C. solomonsense* co-occur, both are utilised for their edible nuts, and villagers can distinguish them (McClatchey et al. 2006).

There are digitised herbarium records available for all *Canarium* species in PNG through the Global Biodiversity Information Facility (GBIF 2017) and PNGtrees (Conn et al. 2006+), as well as a more limited number of records on the Digital Flora of New Guinea from the Wanang area of Madang (BRIT 2005-11). These data are nonetheless patchy and there are no currently digitised herbarium records for *Canarium indicum* in commonly cultivated localities, such as on Nissan Island and Manum Island off the north coast of Madang. The distribution of *Canarium* spp. in agricultural landscapes was recorded into the Mapping of Agricultural System of Papua New Guinea (MASP) database (Bourke et al. 1998) in collaboration with NARI.

Factors associated with wood boring weevil attack

The uniform age class of the trees across ENB, as well as being largely of one variety (i.e., Nissan) suggests an even greater risk to the remaining GW elite plantings. In forestry entomology, tree size is known to be a factor in resistance and resilience from borer attack (Wylie 1982). The link between tree vigour and insect attack is well established in other insect-tree systems (Wylie and Speight 2012) although unknown in the galip-GW interaction. Although trees were reported as healthy before GW attack, the impact of other factors affecting tree health, and leading to a susceptibility of GW attack, requires further exploration.

Outbreaks of another endemic PNG weevil species *Vanapa oberthuri* at Bulolo-Wau in the 1960’s in hoop pine (*Araucaria cunninghamii*) plantations in PNG, presents a similar situation to the current GW outbreak. In this system wood boring larvae were found ringbarking and killing young trees, with those 5 to 15 years being most affected (Barrett 1967). The *Vanapa* weevil lays eggs on the stems of hoop pine and the larvae tunnel into the cambium and heartwood, with 7 to 12 year old trees were the most susceptible to attack (Wylie 1982, after Gray and Howcroft 1970) and silvicultural practices (i.e. pruning) made the trees more susceptible (Barrett 1967, Wylie 1982). Barrett’s (1967) life history study of the *Vanapa* weevil found that resin production in healthy trees made them more resistant to attack by drowning larval tunnels. Field control measures established at Bulolo were aimed at reducing the abundance of *Vanapa* adults in outbreak areas and preventing spread to new areas. These measures were initially thought to curtail *Vanapa* populations (Barrett 1967), but this was not supported by a later study (Gray and Barber 1974).

This attack on hoop pine by *Vanapa oberthuri* and a branchlet-mining scolytid, *Hylurdrectonus araucariae*, led to the cessation of planting of *Araucaria cunninghamii* in the Bululo-Wau district (Gray 1972, 1974, Wylie 1982). These two species are host specific to *A. cunninghamii* and do not attack *Araucaria hunsteinii*, which was subsequently planted in logged forest infill sites rather than plantation monocultures (Gray 1974). In a comparable outbreak, the pine bark weevil, *Aesiotes notabilis*, was found to be pestiferous in *Araucaria cunninghamii* plantations in North Queensland, and tree size was also a factor in determining susceptibility of attack, with younger trees more affected (Brimblecombe 1945, Wylie 1982). Controls included pruning of trees in the dry cool months when weevil activity was found to be reduced (Brimblecombe 1945), which greatly reduced weevil damage (Wylie 1982). This highlights the importance of understanding the host plant range and location of pestiferous insects. Findings and research techniques from these other wood-boring weevil studies in Australia and PNG serve as benchmarks for the control and management of GW in galip production.

Impacts on the developing Galip industry

The nut processing work supported by ACIAR and the UNDP has made significant progress and overcome issues with the nut cracking, drying, packaging and finding commercial pathways, which has now developed a relatively stable dry nut product. With these developments in the commercialisation chain, production could further be intensified. The large plantation holdings of both elite and local galip varieties in East New Britain were also planned to upscale the local industry in ENB (Wallace 2016).

The reliance on largely one variety and source of seed was identified as an issue and a risk for the industry. Genetic studies on galip nut varieties and further work on vegetative propagation were recommended (Cornelius 2012).

ACIAR (1996) reported no major pests of *Canarium indicum*. Subsequently, French (2006) reported GW as a minor pest. The recent NARI/NAQIA in 2015 survey and this SRA work found GW to be an emerging major pest and a threat to the sustainability of plantings of elite galip across the Gazelle Peninsula, and potentially in other provinces of PNG.

6.2 GW taxonomy, distribution, host plants and natural history

Identity

The Australian team, in consultation with Rolf Oberprieler (CSIRO Canberra) and Chris Lyal (Natural History Museum, London), established that GW is *Ectatorhinus magicus* (Figure 3), belonging to the subtribe Ithyporina, tribe Ithyporini, subfamily Molytinae, family Curculionidae (‘true weevils’).

There are 34 genera in the tribe Ithyporini and 28 genera in the subtribe Ithyporina, mostly African (Alonso-Zarazaga & Lyal 1999). The genus *Ectatorhinus* includes 13 species, found in Japan, Taiwan, China, Korea, Sri Lanka, India, the Malay Peninsula, Sumatra, Borneo and New Guinea (Lyal 2014). Greatest diversity of species is in Borneo (6). *Ectatorhinus magicus* was originally described in 1860 from New Guinea (Gerstaecker 1860) and in 1881 it was noted from Duke of York Island, near New Britain (Fairmaire 1881). Heller (1908) listed GW from Duke of York Island, New Britain and New Ireland. There are no additional published distribution records. *Ectatorhinus magicus* is the only described species of *Ectatorhinus* known from mainland New Guinea and eastern islands.

The adult of *Ectatorhinus* is distinguished from other Ithyporina by: procoxae approximate or contiguous (Figure 4) (Morimoto 1978); buccal cavity narrowly elongate V-shaped, submentum without peduncle, mentum elongate, mandibles not decussate (Figure 5), antennal club ovate and segmented (Figure 6) (Marshall 1930); or, antennal scrobes subcontiguus at base of rostrum (Figure 7). *Ectatorhinus magicus* shows all of these attributes of the genus and is correctly placed in *Ectatorhinus*.

Figure 3. Living adult male *Ectatorhinus magicus*, Keravat Field Station: photo Celia Symonds

Figure 4. Underside of *Ectatorhinus magicus* showing adjacent procoxae, a diagnostic character for *Ectatorhinus* (photo: Max Beatson)

Figure 5. Rostrum and antennae of *Ectatorhinus magicus* showing ovate multisegmented club, a diagnostic character for *Ectatorhinus* (Photo: Max Beatson)

Figure 6. Mouthparts of adult *Ectatorhinus magicus* showing characteristic features of subtribe Ithyporina. (photo: Mike Burleigh)

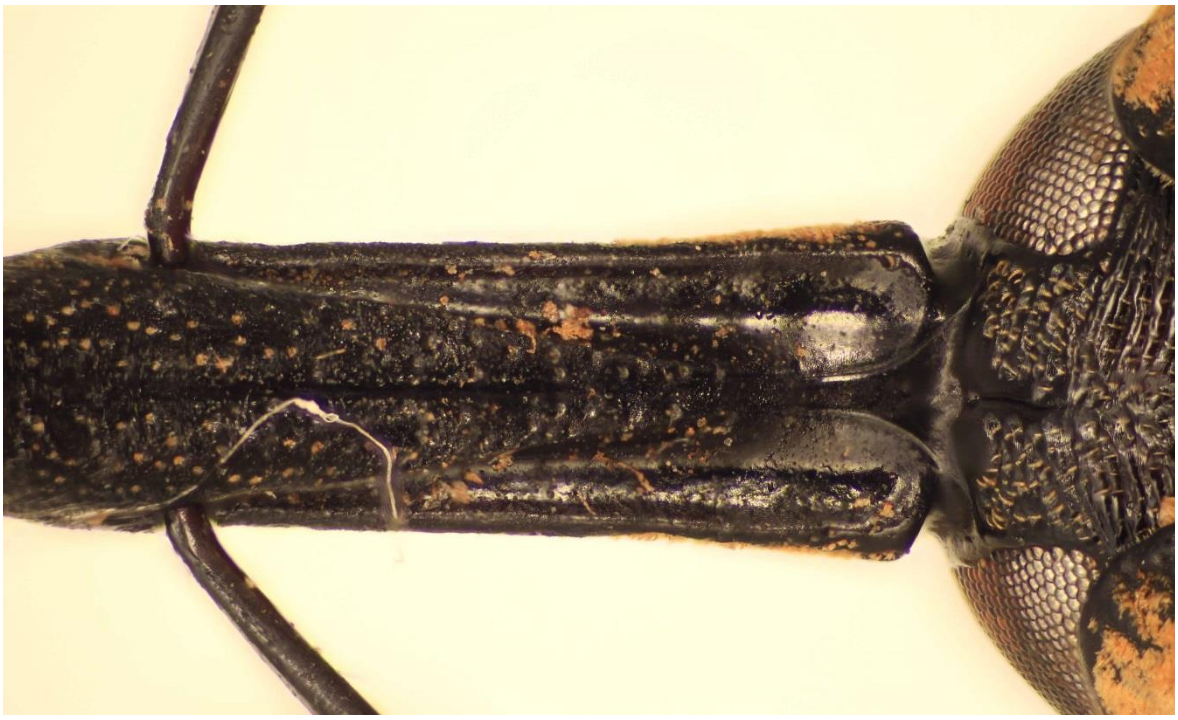

Figure 7. Convergence of scrobes at base of rostrum, characteristic of only two genera in Ithyporina, including *Ectatorhinus*. (photo: Mike Burleigh)

The larva and pupa of *Ectatorhinus* have not previously been described, nor are there descriptions of larvae or pupae of any other of the 34 genera of Ithyporini or of several other tribes of Molytinae (May 1994, Marvaldi & Morrone 1998, Lyal 2014). The larva of *Ectatorhinus magicus* is most similar to that of *Orthorhinus* (Molytinae, Orthorhinini), which like *Ectatorhinus* has a deeply embedded head capsule (Figures 8 and 9) and bores into living plant tissue. The larval epipharnyx has a unique combination of struts and setae (Figure 10). The mandibles and labiomaxillary complex are typical of Molytinae and are illustrated in Figures 11 and 12 respectively. The larval spiracle is characterised by a small side chamber (Figure 13).

Figure 8. Mature larva of *Ectatorhinus magicus* – note deeply embedded head capsule (photo: Max Beatson)

Figure 9. Larval head capsule *Ectatorhinus magicus* (photo: Max Beatson), similar to *Orthorhinus*, otherwise different from all other described Molytinae

Figure 10. Larval epipharynx of Ectatorhinus magicus, showing unique combination of struts and setae in Molytinae (photo: Max Beatson)

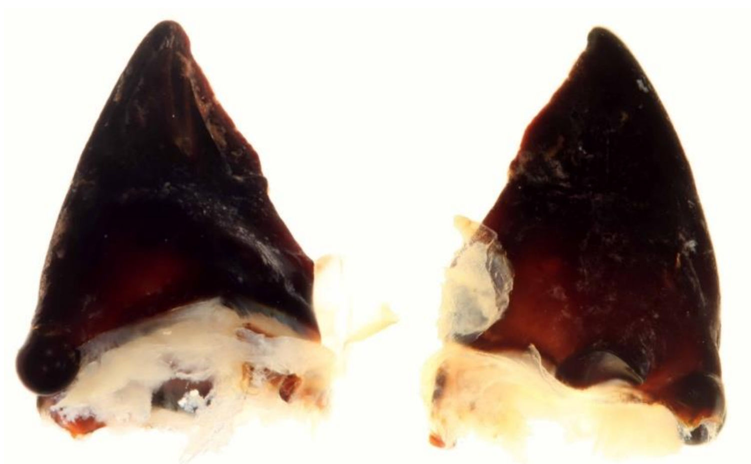

Figure 11. Larval mandibles of *Ectatorhinus magicus* (photo: Max Beatson)

Figure 12. Larval labiomaxillary complex of *Ectatorhinus magicus*, similar to other described Molytinae (photo: Max Beatson)

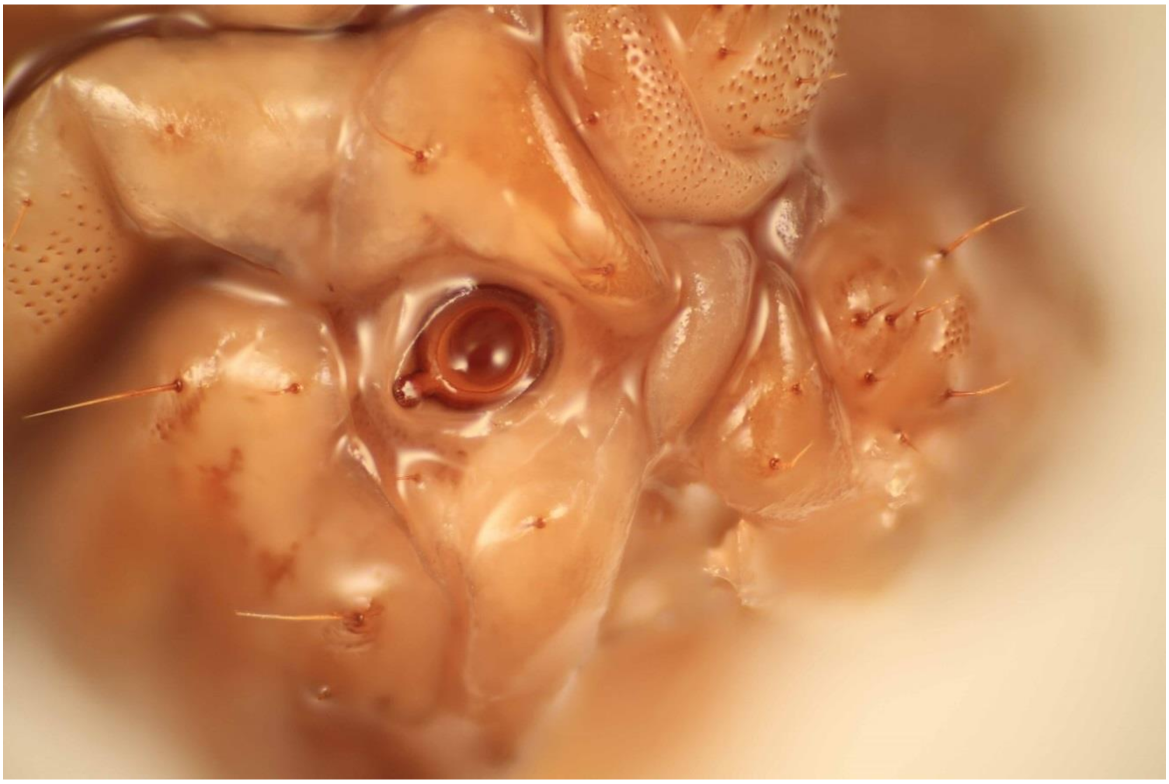

Figure 13. Larval thoracic spiracle of *Ectatorhinus magicus*, similar to *Orthorhinus* but with small side chamber (photo: Mike Burleigh)

The pupa of *Ectatorhinus magicus* is unique amongst described Molytinae because it lacks urogomphi at the apex of the abdomen. It also shows unique combinations of setae on the rostrum and pterothorax (Figure 14).

Figure 14. Pupa of *Ectatorhinus magicus* showing unique absence of urogomphi and setal patterns compared with other described Molytinae (photo: Max Beatson)

Historical distribution records

GW is rare in museum collections. The material Heller (1908) examined in Dresden from New Britain and New Ireland was destroyed in World War II. We checked the following collections by sending a photo of the adult and asking the curators to examine their material: Natural History Museum, London (NHML), Australian National Insect Collection, Canberra (ANIC) and Bishop Museum, Hawai'i (BPBM). We also examined the National Agricultural Insect Collection (NAIC) at Kilakila, Port Moresby and the Australian Museum collection, Sydney (AMS). There were no specimens in AMS and ANIC and only two in NHML. Most specimens are from ENB, particularly Keravat, collected from 1955 onwards. In NAIC there are specimens from Keravat and Kokoda, Oro Province. In BPBM there are specimens from New Ireland, Fly River, Sepik River and Feramin (Western Highlands), collected between 1956-1963. These records are all prior to any plantation activity and the development of galip as a crop. See Table 1 below for a summary of historical records for GW.

GW is evidently a native species and widespread in PNG and as a consequence it is potentially a pest of galip throughout the country, including the island provinces.

Locality recorded	Georeferenced	Source
New Guinea		Gerstaecker (1860)
Duke of York Island	-4.1666, 152.4622	Fairmaire (1881)
Neu Pommern (New Ireland)		Heller (1908) noted specimens in Dresden Museum collection
Neu Mecklenberg (New Britain)		Heller (1908) noted specimens in Dresden Museum collection
Gilingil Plantation, SW New Ireland	-4.46667, 152.6667	BPBM
Kiunga, Fly River	-6.11667, 141.2833	BPBM
Ambunti, Sepik River	-4.23333, 142.8167	BPBM
Feramin, nr Telefomin	-5.15, 141.5333	BPBM
"Kokoda Trail"	-8.87729, 147.7374	NAIC
Keravat	-4.35004, 152.0429	BPBM / NAIC / NHML

Table 1. Summary of historical records for GW (GW), *Ectatorhinus magicus*.

Current distribution records

GW has not been recorded from Bougainville. NARI staff undertook preliminary surveys of Buka and Nissan Island (source of elite varieties) post-October 2015 and found no evidence of GW attack in those places. John Moxon (PAPP) visited New Ireland in late 2016 and found no GW damage.

GW was found at a number of locations along the Madang coast by the Australian/PNG team in April/May 2017. The NARI delimiting survey and subsequent survey by the Australian/PNG team of galip plantations confirms the distribution of GW across the Gazelle Peninsula. See Table 2 below for a summary of current GW records, and Figure 15 for the mapped distribution.

Locality	Georeference	Source
East New Britain		
Birar		NARI/NAQIA delimiting survey
Burit	-4.43522, 152.93815	NARI/NAQIA delimiting survey
Kareeba	-4.36912, 152.039117	NARI/NAQIA delimiting survey
Keravat, NARI Islands Regional Centre (IRC)	-4.20133, 152.02088	NARI/NAQIA delimiting survey*
Mandres (2 sites)	-4.35624, 151.92267	NARI/NAQIA delimiting survey*
Menebonbon	-4.41353, 152.35709	NARI/NAQIA delimiting survey
Ramale	-4.46472, 152.145833	NARI/NAQIA delimiting survey
Tokiala		NARI/NAQIA delimiting survey
Vudal, University of Natural Resources and Environment (UNRE)	-4.34809, 151.99718	NARI/NAQIA delimiting survey*
Vunapalading (2 sites)	-4.37021, 151.98361	NARI/NAQIA delimiting survey*
Vunapau (also known as Vunarakan) (4 sites) (Agmark)	-4.32996, 152.02733	NARI/NAQIA delimiting survey*
Madang		
1 km inland from Megiar	-4.81607, 145.75693	UNSW/AM/NARI survey
Jahil	-5.23922, 145.72067	UNSW/AM/NARI survey
Jobdo	-5.26722, 145.51038	UNSW/AM/NARI survey
Karkum	-4.7558, 145.66496	UNSW/AM/NARI survey
Malsalu	-5.27936, 145.67009	UNSW/AM/NARI survey

Table 2. Summary of localities where GW (*Ectatorhinus magicus)* has been recorded in current survey work, following the 2015 outbreak. Note: asterisk indicates sites that were revisited under this project (Nov-Dec 2016) where GW was confirmed (*).

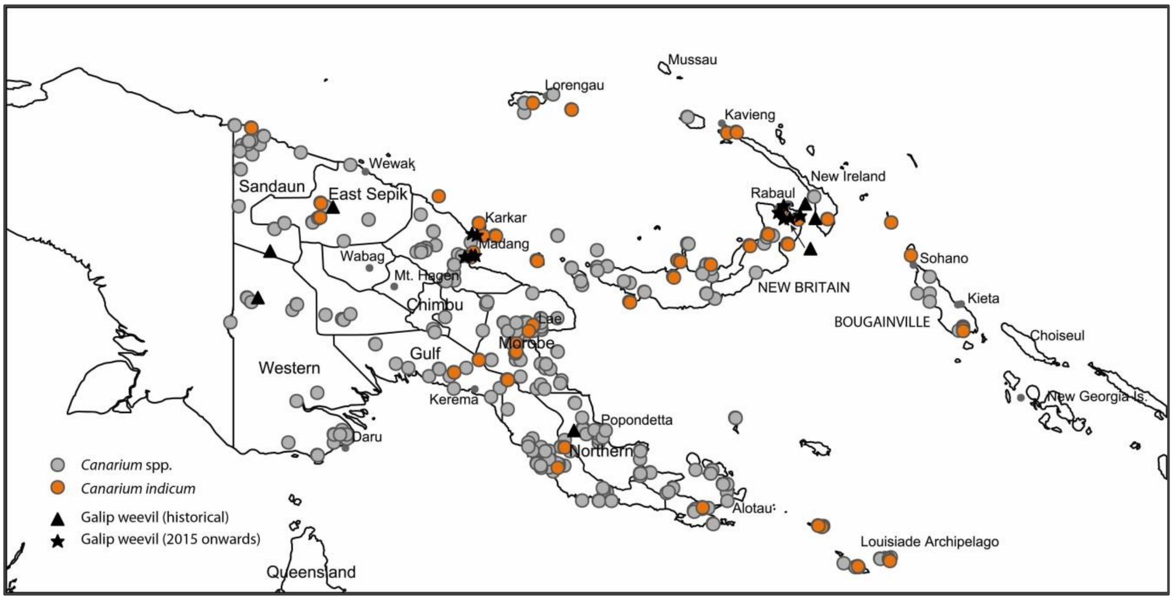

Figure 15. Galip and GW distribution in Papua New Guinea. Distribution records for *Canarium* species and *Canarium indicum* largely from GBIF with additional localities of known occurrence added (e.g. Nissan Island, Manum Island). GW occurrence records from museum specimens and literature (historical), and current survey work post-2015 with the GW outbreak. Map made using SimpleMappr (www.simplemappr.net).

Host plants

Canarium indicum is the only recorded host plant of GW. It belongs to the family Burseraceae, a small family of plants, that has a circumtropical distribution. The family comprises 18 genera and about 700 species (Weeks et al. 2005) and numerous species are used for housing, furniture, crafts, medicines, food and rituals (Grimes et al. 1994). In particular, the genus *Canarium* has several species that are noteworthy as edible nuts, in the Oriental region (e.g., *C. album* in China, and *C. ovatum* [or pili nut] in the Philippines) and Melanesia (*C. indicum*, galip).

The ACIAR (1996) report made no mention of pests of galip in PNG. French (2006) and Thomson & Evans (2006) listed GW as a minor pest of galip, noting that the larva bored into galip trunks, but without providing further information.

Discussion with NARI staff and John Moxon (PPAP) revealed that *Canarium indicum* is common in native forest (frequency described as “1 in every 10 trees”) in ENB and that other species of *Canarium* naturally occur in this region. GW appears to occur outside the natural range of *Canarium indicum*, for example at elevation of 1450m at Feramin (altitudinal limit of galip is 950m according to Bourke 2010) but there is a montane species of *Canarium* at this altitude which is used ceremonially by local people.

On this basis, it is likely that GW attacks more than one *Canarium* species, but we have no field evidence for alternative hosts, neither with other *Canarium* species, other Burseraceae taxa, or related plants. A few trees of two other species of *Canarium* (as identified by DPI field officers) were examined in Madang Province, without any evidence of GW attack.

The Indian species *Ectatorhinus adamsi*, a congener of GW, feeds on mango (*Mangifera*, Anacardiaceae) (Lyal 2014). Because of this record and the Anacardiaceae being the nearest relative of the Bursaraceae, we surveyed mango as a potential alternative host of GW in ENB and Madang, but found no evidence of damage. A species of the weevil genus *Mecocorynus*, the probable sister genus of *Ectatorhinus*, is an African pest of cashew (Anacardiaceae). We also examined cashew trees at Keravat but found no GW damage.

Varietal susceptibility of galip at Keravat was difficult to assess, because of limited information about the source of the seedlings. The 'elite' varieties, sourced from both Nissan and Buka islands, predominate at Keravat. The elite variety was extensively attacked in ENB. In ENB, plants that are self-seeded (supposedly dispersed by fruit bats, hornbills or cockatoos) are referred to as 'wild' galip. We did examine a few mature wild galip trees and found evidence of GW attack.

In Madang Province, the galip trees were mostly planted by local people, from imported or local seeds. Those galip with GW attack were 'local' varieties, seeded from Serang, Karkum area, the Rai Coast and Karkar Island. Transplanted elite galip seedlings were examined in Megiar village, in Madang Province, but these were small (<2m high) and did not harbour GW.

6.3 GW life history and biology

We evaluated the GW life history information acquired by NARI staff. We undertook, in collaboration with Fidelis Hela and support staff, field and lab investigations of GW during their ENB field trip in Nov/Dec 2016. We report the following findings from these investigations:

Rearing studies

Fidelis Hela (NARI) attempted to rear GW at the NARI Keravat field station, in a makeshift insectory (Figure 16), and in outdoor rearing cages with galip saplings (Figure 17).

Larvae (instars 2-4) were housed in takeaway food containers with a mix of sawdust and soil, wood and woodchips from galip trees. Adult GW were released in large numbers (ca. 20 live at one time) into a cage of cut galip trunks Four outdoor cages of living galip

saplings were inoculated with several male and female GW adults (ca. 10 each).

Figure 16. Insectary at NARI Keravat. Facility not climate controlled.

Figure 17. Outdoor rearing cages at NARI Keravat inoculated with GW. Top image: GW on elite galip leaves. Bottom image: cages around cut living elite galip saplings.

There is no evidence that *ex situ* rearing has been successful to date. The artificial diet was not used by instars 2-4 and larval mortality was due to a combination of starvation and microbial/fungal infection (Figure 18). In the caged galip neither adult feeding nor oviposition was observed, and larvae were not seen in the sapling trunks. Caged adults were dissected and there was no plant tissue in the gut nor fat bodies in the abdomen, indicating non-feeding.

Figure 18. Third larval instar in captivity.

Larvae

There are probably 4 larval instars, as in many other weevils. In ENB, 3 larval instars were collected (Figure 19), with the smallest too large to have emerged from an egg. In standing trees, GW larvae were captured in subcortical tunnels (Figure 20), and exit holes on *Canarium indicum* trees, ranging from 3-year old saplings to mature trees (10-180 cm DBH). Two trees were destructively sampled (Figures 21), and GW larval tunnels and empty pupal cells were exposed, demonstrating severe damage to tree vascular material, which likely results in leaf wilt, necrosis and abscission, and loss of photosynthetic capacity. Multiple larval attacks on an individual tree were commonly observed, likely resulting in ring-barking of standing trees. Larval attack was demonstrated by subcortical feeding tunnels that were encased by hardened tree exudate. Larval attack was mostly between ground level and 3m height and only rarely in branches.

Figure 19. Second GW instar extracted from base of galip tree.

Figure 20. Exit holes (left) and subcortical tunnels (right) of GW, showing resin response.

Figure 21. Felled *Canarium indicum* tree exhibiting exit hole (top) and remains of a standing trunk exhibiting damage to heartwood by GW larvae (bottom).

Adults

GW adults were captured on the trunks of standing *Canarium indicum* trees (Figure 22). In the field GW adults were found on tree trunks, or sheltering under vine leaves on trunks, usually below the first branch. Felled galip trees exhibited canopy petiole/branchlet grazing (Figures 23), leaving feeding scars typical for other weevil species (including *Pantorhytes* spp., cocoa weevils). The width of the petiole damage matched the width of GW adult mouthparts, which points towards GW feeding, and not *Pantorhytes* feeding, which has much broader mouthparts. However, no adult GW were found in the canopy and direct observations of adult feeding is required. NARI staff reported that males and females have been found in copula on tree trunks; this was not observed by the Australian team in the field, but was observed in adult specimens kept in the NARI Keravat insectory.

Figure 22. GW adults on trunk of *Canarium indicum*, at Keravat.

Figure 23. Canopy leaves from felled *Canarium indicum tree* (NARI Keravat) with petiole grazing (top), possible GW adult feeding; weevil feeding scars on dried branchlet (bottom).

In Madang, there was petiole grazing on small saplings of elite galip (<2m high) but this was associated with leaf damage and an abundant small brachyderine weevil not seen at any other site. The petiole grazing was small and erratic and most likely caused by the small brachyderine and not GW. (Figure 24)

Figure 24. Petiole grazing of *Canarium*, Madang Province, by a small grey weevil. Note the shorter grazing marks when compared to GW grazing marks on *Canarium* from ENB.

Lifecycle study

Adults, larvae and pupae were collected and all life stages except eggs and first instar larvae are in the possession of Dr Reid at the Australian Museum. With the exception of pupae, study material has been collected from both East New Britain and Madang.

We propose that GW undergoes the following development: egg-four larval instars-pupa-adult.

Gonad maturity probably requires feeding by the adults, probably petiole grazing in GW. Mating occurs on tree trunks (observed by NARI staff). Mated females are assumed to excavate a small oviposition tunnel on galip trunks with the rostrum and lay a single egg per site with their elongate ovipositor (yet to be observed). Attacks are mostly on the first 3 metres of the trunk, from ground level, but attack holes were observed higher than this, and on side branches or just below ground level at the base of the trunk.

Based on head capsule size it is estimated that there are four larval instars (first instar yet to be discovered). The first instar probably feeds on the remains of the egg at the oviposition site and also any pulp or frass left by the female, rapidly moult and not greatly enlarge the tunnel. The second instar (based on head capsule and body size) is found in subcortical tunnels, and is assumed to be feeding on cambium and plant vessels; the subcortical tunnels in any direction including horizontally and vertically, and are externally covered by solidified plant exudate. Some third and fourth instars attack the heartwood of the tree but others remain close to the bark surface or may even be exposed under frass and soil at the base of the tree. Larval development might be less than six months in duration (yet to be confirmed, requiring ex situ rearing).

In felled trees, excavated pupal cells were found deep in the trunk, lined with strips of wood (no pupae were found on the two UNSW/AM trips). Post-metamorphosis, adults exit via enlarged holes on the trunk surface.

Adults probably graze on petioles in the canopy. Adult longevity is unknown. Old exit holes may be secondarily attacked by GW.

Many wood-boring beetles in temperate regions of the world are known to develop slowly and can take over a year or more to develop. In contrast, because of constant climatic conditions in the tropics, we predict that GW development will be rapid and this is supported by increased rates of infestation in the Gazelle Peninsula over the past year. NARI's reporting of yearlong presence of GW adults suggests that this species is bi- or multivoltine and emergences are ongoing, with no peak population period.

Adult females were dissected and found to have four ovarioles and a spermatheca (sperm storage organ). However, all dissected females lacked any development of oocytes. It is not possible to assess the reproductive potential of the GW from these observations.

6.4 GW field survey reporting from East New Britain and Madang Provinces, Bougainville and Duke of York Island

Field surveys were undertaken in the provinces of East New Britain, Madang, Nissan Island, Buka (Bougainville), Nissan and Duke of York islands over the course of the project, as outlined in the Methodology. See Figure 25 for sites.

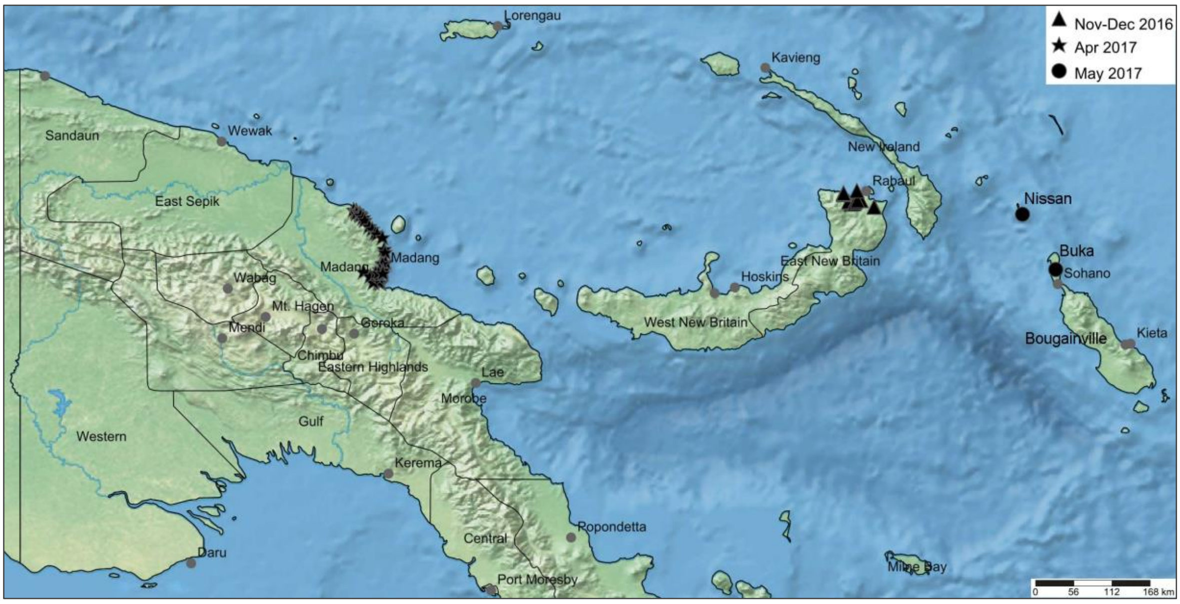

Figure 25. Sites surveyed for presence and damage assessment of GW during this SRA project, in East New Britain, Madang and Bougainville. Map made using SimpleMappr.

East New Britain 26 November – 6 December 2016

During the ENB trip for this project, Prof. Gerry Cassis (UNSW) and Dr Chris Reid (Australian Museum), with Fidelis Hela (NARI) conducted a field survey of sites on the Gazelle Peninsula.

The field survey revisited sites of the NARI /NAQIA delimiting survey (October 2015) and included small (ca. 100 trees) to large (ca. 6000) plantings of elite galip on small farmer holdings and plantation properties. The field survey also undertook a search for alternative hosts for GW.

The results were given in full in the SRA ENB trip report and are summarised herein. Field notes are given in Appendix 3.

Field survey of galip elite plantings and some local varieties planted nearby

Of the more than 30 localities visited by the delimiting survey team, 16 sites were revisited and surveyed over a four-day period (Table 3). GW adults and larvae were captured in the field on standing galip trees, with the larvae causing tree mortality. Although there was no evidence that GW had spread to new sites in this period, morbidity and mortality of elite galip trees within affected sites had increased between surveys. At affected sites between 80-100% of elite galip plantings were found to be dead or severely damaged by GW attack. Most galip trees surveyed were of a similar age to the Keravat trees - no more than 8-9 years old. Overall, GW damaged galip trees appeared to be progressing to death.

Site	**Galip variety**	**Planting type**	**GW present**	**Note**
Vunapau (also known as Vunarakan), Block #3 (Agmark)	Elite	Plantation	Yes	More or less all trees dead or dying. Extensive exit holes, canopy reduced and dead trees. Site manager first observed GW damage in 2012
Vunapalading 2	Elite	Smallholder	Yes	All trees severely damaged, with greatly reduced canopy.
Mandres 1	Elite	Smallholder	Yes	For six years galip were healthy; in 2015 80 galip trees died, remainder now dying. GW adult collected.
Mandres 2	Elite	Smallholder	Yes	80% of galip trees with GW attacked. Some trees were dead. Possible recovery of previously attacked trees.
Vunapalading 1	Elite	Plantation	Yes	Extensive damage on elite galip trees, much of galip dead or dying.
Vudal, UNRE	Elite / Local	Plantation	Yes	Extensive GW damage on elite varieties. Local variety at first thought to be free of GW attack with healthy looking trees (DBH range ca. 150-180, ca. 90% canopy cover, no sign of leaf wilt or necrosis. Further inspection revealed GW larva (probably 3rd instar) at base of trees with mix of larval frass and tree exudate in soil and larvae in exit holes up to 2.5 m.
Cleanwara, Site 1	Elite	Plantation	No	No evidence of GW damage.
Ramandu, Site 1	Elite	?	No	Elite galip intercropped with cocoa.
Ramandu, Site 2	Elite	?	No	Elite galip intercropped with cocoa.
Ramandu, Site 3	Elite	?	No	Elite galip intercropped with cocoa.
Vunapau (also known as Vunarakan), Block 1	Elite	Plantation	Yes	Most extensive elite variety plantings examined in the Gazelle Peninsula. About 100% severely damaged to dead trees.
Vunapau (also known as Vunarakan), Block 3, Site 1	Elite	Plantation	Yes	100% of elite galip severely damaged or dead.
Vunapau (also known as Vunarakan), Block 3, Site 2	Elite	Plantation	Yes	100% of elite galip severely damaged or dead.
Vimmy Plantation	Elite / Local	Plantation	No	Mix of galip varieties, mostly local variety examined. Galip trees very healthy with no GW damage found.
Keravat NARI, interface of blocks 308 and 309	Elite	Plantation	Yes	Block #308 was planted exclusively with elite galip variety. Trees were much smaller and exhibited extensive GW damage. The two blocks were separated by 5m and there was no evidence of colonisation of block #309 from #308.
Keravat NARI, interface of blocks 308 and 309	WNB/ Local	Plantation	No	Block #309 was uniformly planted with both a West Britain galip variety and the local ‘Vimmy’ variety; trees were very tall and healthy.

Table 3. Summary of site observations from East New Britain field survey, 28 November – 4 December 2016.

The only observed sign of tree recovery was at the Mandres 2 site, where a plantation of more previously attacked mature elite galip trees showed signs of recovery, including denser canopy, and less wilting and necrosis of leaves.

The epicentre of GW damage is in central Gazelle (Figure 26), including the Agmark plantation at Vunapau (Figure 27), Keravat, Mandres and Vunapalading. The Agmark plantation (where GW was first noticed in 2012, but not reported at that time) has the most extensive plantings of elite galip (ca. 10,000 trees) and the most extensive damage, with near 100% tree mortality, attributable to GW. At Mandres and Vunapalading up to 80% of trees are dead or dying from GW attack.

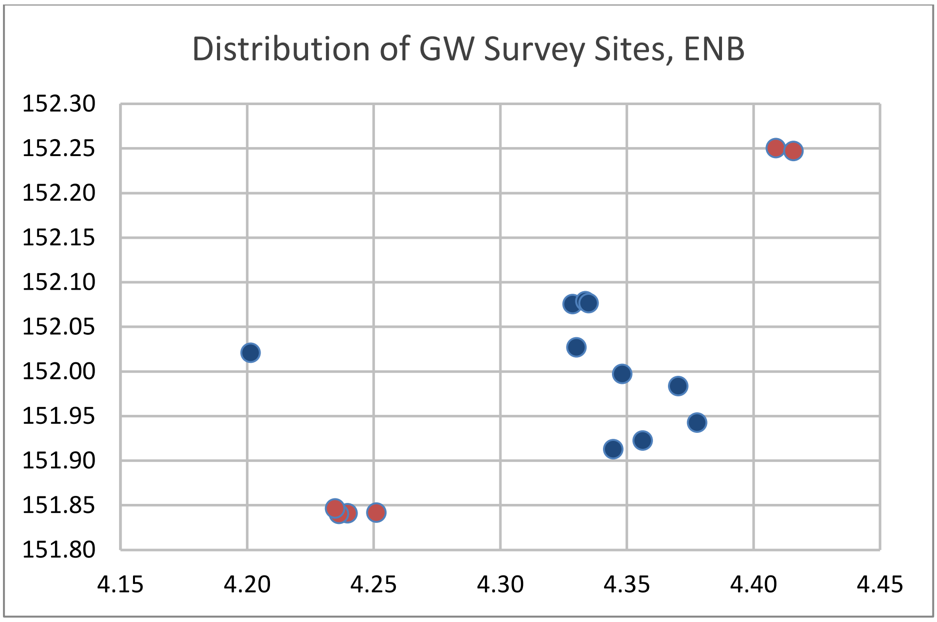

Figure 26. Distribution of East New Britain (ENB) survey sites by latitude (x-axis) and longitude (y-axis), with presence of GW (GW) found at sites in dark blue

Cleanwara and the Vimmy plantations also comprise extensive galip holdings, but were free of GW attack as of late 2016. In contrast to Cleanwara, which comprises largescale plantings of elite galip

In three localities, there are mixed plantings of local and the elite varieties. At the Vimmy plantation both local and elite varieties were healthy with no evidence of GW damage. At NARI Keravat, there is a mixed block of West New Britain and local 'Vimmy' variety of galip trees (#309), adjacent to an elite block (#308) (Figure 28). The #309 block showed no sign of GW damage, whereas #308 exhibited extensive GW damage.

At UNRE, Vudal, both elite and local galip varieties exhibited evidence of GW attack, with exudate and frass around the base of the trees and larval exit holes on the trunks. On a qualitative basis, it appeared that the 'local' varieties are a little more resistant to GW attack, although they appeared older with greater DBH.

Figure 27. Dead galip trees in the background at Vunapau, Block 1.

Figure 28. Interface of galip blocks #308 (left side of track, elite galip variety) and #309 (right side of track, West New Britain and local 'Vimmy' variety), NARI Keravat.

Current extent and nature of damage to galip plantations on East New Britain

We destructively sampled trees at Vunapau (Agmark), and found extensive GW larval tunnelling and empty pupal cells were exposed. Standing trees had severe damage to vascular material, loss of canopy cover and tree death (Figure 29).

Figure 29. Extensive GW damage to Vunapau (Agmark) plantation. Large exit hoes (top); extensive canopy loss (middle); dead tree (bottom).

Infected trees at sites in ENB exhibited the same attributes, with multiple exit holes and tree resin, as at Vunapalading 1 (Figure 30).

Figure 30. Extensive GW damage at Vunapalading 1, showing numerous exit holes with tree resin**.**

Late GW larval instars were also discovered at the base of trees in the soil, in a mix of larval frass and tree exudate. These larvae were also observed to partly emerging from tunnels at the base of the trunk and rapidly retreating when disturbed. It is unknown if GW causes root damage.

Further damage assessment from sampling of elite galip blocks at Keravat is summarised in section 6.5.

Host plant range

Canarium belongs to the family Burseraceae. This is a family of plants with few taxa in PNG and we have not as yet been able to determine if there are other potential alternative burseraceous plants in East New Britain. Other species of the GW genus *Ectatorhinus* occur on plants belonging to the Anacardiaceae, a family which is the sister-group to the Burseraceae. For example, *Ectatorhinus adamsi* is found on *Mangifera* (Anacardiaceae) in India (where it is known as the Mango twig boring weevil) and on *Juglans* in Japan. For this reason, we searched for possible GW attack on anacardiaceous plants.

NARI Keravat research manager Ofara Petilani provided the following anacardiaceous targets as possible alternative hosts: (1) *Mangifera* (mango); (2) *Semicarpus* sp. (3) *Anacardium* sp. (cashew nut); (4) *Dracontomelon dao* (native walnut); (5) *Buchanania* sp.; (6) *Campnosperma* sp.; and (7) *Spondias* sp.

We sampled mango and cashew nut trees on the Keravat fieldstation and found no evidence of GW attack. We were unable to locate the above-listed native anacardiaceous hosts in the wild.

Madang Province 4–9 April 2017

Prof. Gerry Cassis (UNSW) and Dr Chris Reid (Australian Museum), with Dr Sim Sar (NARI) conducted a five-day field survey in coastal habitats in Madang Province, in the vicinity of Madang town. Madang Province is a known galip growing district, including offshore islands, such as Karkar Island. Previous to this survey GW had not been recorded from Madang Province. The aim of the field trip was to establish if GW is present in Madang Province, the extent and type of damage if present, and to make a qualitative assessment of the galip varieties present. The team visited over 30 localities north, south and southwest of Madang town (see field note summary, Appendix 9.5, for field notes). Most villages on the coast around Madang had at least a few galip trees, including some very large established trees (Figure 31). Villagers in general proclaimed knowledge about the provenance of their galip trees, which appeared to follow local paths of migration. Before undertaking the Madang survey, we were informed that the main sources of galip in the coastal Madang region are Saidar, Karkar and Manum Islands (but compare with our survey notes, Fig 32). In contrast Long Island off the Rai Coast was settled by West New Britain Islanders, from which they brought galip (NARI, pers. comm.).

Figure 31. Established local variety galip trees in village settings, Madang Province.

Ten local varieties of galip were sampled, with the majority from West of Madang, south of Madang, Karkar Island (planted on the mainland), and the Megiar and Rai Coast local varieties. Additionally, elite variety galip sapling brought from Keravat seedlings were planted near Megiar village. See Figure 32 for a summary of galip varieties sampled.

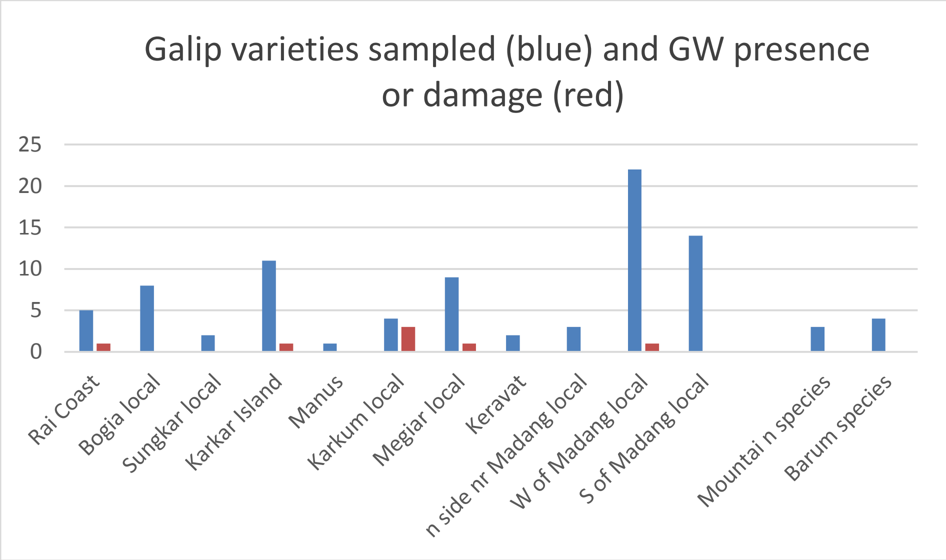

Figure 32. Number of trees of different varieties of galip surveyed and GW presence in Madang Province during the April 2017 field trip.

Villagers were sometimes familiar with GW when shown images or video clips. Local people confidently identified GW when shown live specimens on galip trees in villages (e.g. Karkum and Jobdo villages). Where villagers were not shown images or specimens they had no awareness of GW (e.g. Aiyab village). Twelve farmers reported GW weevil damage in response to notices at markets, in villages and radio broadcasts.

GW, or GW damage, was found at 5 localities on the north and south coasts, and west of Madang, as follows: Karkum (2 trees), nr Megiar (1 tree) and Jahil (1 tree) (north) and Jobdo (2 trees) and Malsalu (1 tree) (south) (Figure 33). Adult GW were collected at Jobdo and Malsalu villages.

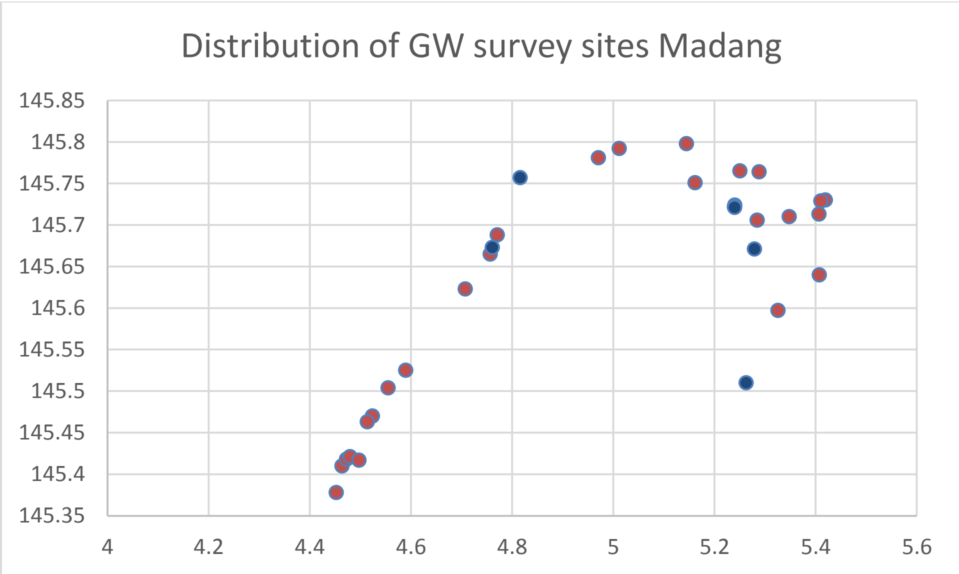

Figure 33. Distribution of Madang survey sites by latitude (x-axis) and longitude (y-axis), with presence of GW found at sites in dark blue.

The damage to trees by GW in the Madang region was minor and found most often in larger, more established trees (Figure 34). Larger trees (1.2–2.5 m DBH) were not found to be adversely affected by GW presence and appeared to be otherwise healthy (i.e., no canopy loss or necrosis). The one smaller tree (30 cm DBH) found with a large GW hole (at Jahil village, Figure 35) was showing signs of stress with epicormic growth on the bottom 1 m of the trunk, but no sign of morbidity, with healthy canopy cover (80% cover).

The damage was at a relatively small scale and easy to overlook in large trees with sap flows from wounds also inconspicuous.

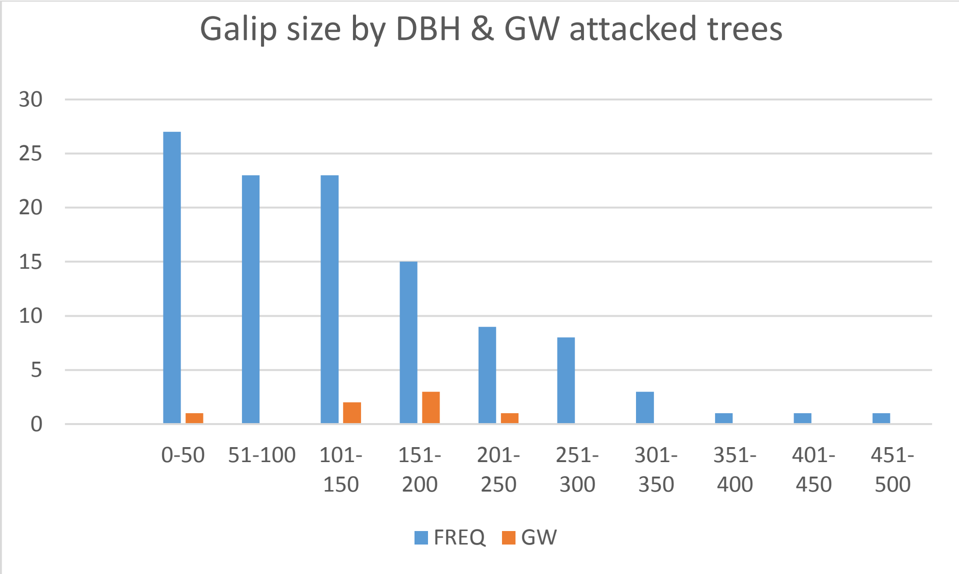

Figure 34. Frequency distribution of galip tree size (DBH) and GW attack, from Madang survey.

Figure 35. GW larval damage to young galip tree at Jahil village, Madang Province.

GW was found sheltering under *Piper* leaves when growing on the trunks of galip trees (Figure 36).

Figure 36. GW sheltering under *Piper* leaves (bottom) when growing on mature galip trees.

Elite galip saplings translocated from Keravat to the Megiar area were not found to be affected by GW, but were almost certainly to small to be susceptible (<2m high, <10cm DBH).

We commonly detected extensive machete and knife damage to galip trunks, which likely results in the release of plant volatiles that may attract GW. We also observed evidence of burning of rubbish, which can commonly result in fire damage to nearby galip trees. These trees often showed similar signs of stress to GW attack, such as canopy loss and epicormic shoots, but they also had large burn scars at the base of their trunks with extensive dead wood. It is unknown if such cultural practices result in trees being more susceptible to GW attack.

We also examined two other species of *Canarium* for GW damage: (1) a *Canarium* species referred to by locals as Mountain Galip, from the Adelbert Mountains (Madang Province) where it grows up to altitudes of 900m (Madang DPI staff, pers. comm.). This species was found at three localities; and (2) a *Canarium* species found at the edge of wild forest at Geutar village in the Barum area. The Mountain Galip species was also found in this village. Neither species showed signs of GW damage; also, neither was found at localities where GW was detected.

In summary, the Madang survey establishes the presence of GW in the Madang region for the first time, in local varieties of *Canarium indicum*. The survey also provides qualitative evidence that GW adversely affects smaller galip trees more so than larger trees, albeit the sample size was small.

Bougainville, Buka and Nissan Islands, 1–6 May 2017

As established at the initial briefing meetings (Nov/Dec 2016) at Keravat, NARI staff member Godfrey Hannet (native to Nissan Island) undertook inspections on Nissan and Buka Islands in 2015/2016 and GW was not found.

Fidelis Hela revisited these localities on Nissan and Buka in May 2017. Survey for GW presence was undertaken on mainland Buka, and two small islands offshore from Buka, Petatch and Matsungan islands, which are on route to Nissan Island. Nissan Island was resampled on this trip.

There was no sign of GW damage on all the trees checked on mainland Buka and Petatch, Matsungan and Nissan islands. All trees were healthy with heavy nut set. Several villages on Nissan Island were visited, where elite galip seeds were originally sourced. Juvenile trees on Nissan Island, roughly the same age (8-9 yrs) as those planted at Keravat, were extensively examined. A number of traits were found in common between the elite varieties on Nissan and Keravat, including the height of the first branch (ca. 1.5 m from the base of the trees) and dense canopy cover.

Duke of York Island, 16-18 June 2017

Because GW was reported Duke of York island in 1881 we considered it critical to resample it during the current SRA. Fidelis Hela undertook a trip to Duke of York Island in June 2017 and surveyed for GW at Maren, Urakukur, Kabilomo, Kibil, Molot, Urakuk and Butlivuan villages. These villages had both local and elite galip trees but there was no sign of GW damage.

6.5 Assessment of damage to elite galip plantation plots (Keravat)

We established long term monitoring sites at Keravat to determine the following: (1) are there tree response variables associated with GW attack (e.g., canopy cover, leaf wilt and necrosis); (2) is tree age a determinant of tree mortality; (3) is there an increase in GW infestation over time and between blocks; (4) does the position of a galip tree within a block affect GW attack; (5) what period of time is required between GW colonisation and tree death; (6) can galip trees recover from GW attack.

Fidelis Hela undertook a survey of NARI Keravat blocks prior to arrival of the Australian team in November 2016, reporting attributes of each Keravat block and GW damage in 10 of 12 blocks (see Table 4).

Our Nov/Dec 2016 survey confirmed that all blocks of galip elite at Keravat are now affected by GW, with block 206, the furthest from the other blocks, being the last to show signs of attack. Block 309, with a combination of local ‘Vimmy’ and West New Britain (WNB) galip varieties GW was free as of June 2017 (Fidelis Hela, pers. comm.).

No.	Block No.	Total Area (Hectares)	Main Crops Planted	Other Crops Present	Remarks
1	104*	4.7	Cocoa, galip	Food crops	near KC
2	106*	2.7	Balsa, galip	Coconuts	Office, GLGH
3	107*	5.0	Balsa, galip		
4	203*	7.3	Cocoa, coconuts, galip		
5	206⁺		Cocoa, galip		nr guesthouse
6	305*	5.4	Cocoa, galip	Coconuts, food crops, fruits, nuts, moringa	
7	308*	10.1	Cocoa, galip	Food crops	
8	309	7.9	Cocoa, galip		Local 'Vimmy' and WNB
9	402*	10	Cocoa, galip	Balsa	
10	405*	5.8	Galip	Food crops	
11	406*	5.1	Cocoa, galip	Food crops	
12	407*	5.2	Galip	Food crops	Staff housing area

Table 4. Galip experimental block number, location, biological attributes and total hectares at NARI Keravat. Asterisk refers to GW damage (data from Fidelis Hela, NARI, November 2016). * symbol indicates recent (late 2016) spread of GW attack.

Sampling protocol

Six of the NARI Keravat experimental blocks were established as reference sites for long-term monitoring (e.g. Figure 37). Blocks #203, 206, 305, 308, 405 and 406 were sampled. A randomised block design was implemented and 8 trees per block trees labelled and sampled. These sites have thus far been sampled twice, first between 30 Nov and 3 Dec 2016, and again between 20 to 22 Mar 2017.

Prof. Cassis and Dr Reid designed and implemented the sampling design. They undertook the survey with Fidelis Hela and two assistants in Nov/Dec 2016. They trained the NARI staff in the collection of response variables and a spreadsheet was established for the digitisation of data.

Response variables measured are based on literature for other pestiferous wood-boring beetles (USDA–APHIS 2011) and include common stress response indicators in trees and signs of wood borer activity and tree damage that may make trees more susceptible to weevil attack. See Appendix 9.6 for data collection information.

Figure 37. Block #206 reference site at NARI Keravat fieldstation.

Results and discussion

Tree characteristic data for 48 trees were gathered in December 2016 to examine whether there were any correlations between GW infestation and physical tree characteristics and responses. Initial variables included in the analysis were tree age, tree position, tree height, diameter at breast height (DBH), canopy cover, leaf flush, leaf curl, epicormic shoots, and bark scaling. A logistic regression was performed in R (version 3.2.4) to determine the effect of tree age, tree position, tree height, diameter at breast height, and epicormic shoots on weevil occurrence. Variables were removed stepwise (by highest p-value) from the model to prevent over-fitting. Tree age (z-value -2.141; $p = 0.0323$) and height (z-value -3.025; $p = 0.00249$) were found to be significant, with DBH approaching significance (z-value 1.653; $p = 0.09836$); the intercept was also significant (z-value 2.176; $p = 0.02955$). Older and taller trees appear to be less susceptible to weevil infestation.

A t-test in R determined that leaf flush and leaf curl responses did not differ between GW infested and non-GW infested trees (leaf flush: $p = 0.6511$; leaf curl: $p = 0.8369$).

Canopy cover is negatively correlated with number of GW exit holes, however, the lack of fit of the linear regression indicates that more samples need to be analysed before canopy cover can be used as an indication of GW infestation ($p < 0.01$, adjusted $r^2 = 0.1474$).

6.6 Knowledge gaps

Knowledge gaps have been identified in our understanding of GW (*Ectatorhinus magicus*) and galip (*Canarium indicum*) biology in PNG, and the impact of GW on the viability and development of the galip industry. The following gaps are considered an impediment to addressing the outbreak of GW in PNG.

GW taxonomy, genotypes and distribution

The phenotypic and genotypic variation, distribution, lifecycle and host range of GW are poorly to modestly known. GW is rare in existing collections and although we have accumulated a substantial number of specimens through this SRA project, our sample is restricted to ENB and Madang Province. This hampers our understanding of the distribution, genetic and phenotypic variability of GW. There is no DNA sequencing or genotyping of GW (there are no records in GENBANK).

Although we established that GW is definitively *Ectatorhinus magicus*, including its valid membership of the genus, is it unknown if there are significant population/genotypic differences within GW or if there are possible cryptic species. At present GW has a disjunct distribution, which would suggest genetic differentiation between populations, but inadequate sampling makes such a conclusion premature.

We have established that GW overlaps geographically with *C. indicum* in lowland forests of northern PNG and ENB, but have not detected it in the outer islands, including Buka and Nissan Islands, where *C. indicum* naturally occurs. Moreover, there are records of GW at higher altitudes than those of *Canarium indicum*, which warrants a search for alternative host plants.

Further survey work is needed across the range of *Canarium indicum*, to understand the parameters driving GW distribution. This needs to be undertaken in conjunction with a study of *C. indicum* varieties, in wild and cultivated habitats, as well as survey of other cultivated and wild *Canarium* species. Further, the lack of recovery of GW from New Ireland and Duke of York during this SRA project supports an extended survey program in the outer islands.

GW life history

There are key life history attributes of GW that have not been elucidated, including oviposition sites and egg laying, the 1st larval instar, lifecycle length, voltinism, adult feeding, and natural enemies.

We have not successfully reared GW *ex situ* in the laboratory or in caged experiments in the field. We were unable to establish a ‘natural’ or artificial diet that would promote metamorphosis between larval instars, and from pupa and adult. Alternative rearing techniques need to be developed; the strategies for rearing *Vanapa oberthuri* and *Pantorhytes* spp. need to be adapted for GW. This lack of rearing success has prevented us from detecting potential natural enemies, including parasitic tachinid flies and/or parasitic Hymenoptera.

The population dynamics and voltinism is poorly understood, with almost no knowledge existing across its distributional range. The fact that we detected GW in Nov/Dec (ENB) and Apr/May (Madang) indicates multivoltinism. However, it is unknown if GW has quiescent or diapause periods, or if generation number or timing is influenced by latitude and/or altitude. We are also uncertain about adult GW feeding preferences, and although we suspect petiole grazing on galip, this has not been confirmed by observation. Dispersal rates and patterns of GW remain to be determined.

Galip taxonomy, genotypes and distribution

Canarium indicum has a long and complex history of use, cultivation, and movement of wild progenitors and cultivated varieties in PNG (Kennedy and Clarke 2004). It is thought to be one of the oldest domesticated food trees in the South Pacific and there are many 'local' varieties that are undoubtedly artificially selected for and likely follow local migration patterns and trade within PNG. However, there have been no DNA studies or genotyping of any of these local varieties or of the species of *Canarium* (Cornelius 2012, Weeks 2008).

Canarium indicum is one of approximately 20 species of *Canarium* in PNG, including three other species that have been domesticated. It has not been reported in the literature if hybridisation exists between *Canarium* species or *C. indicum*. As stated above, there are two formally recognised varieties of *C. indicum*, which are morphologically distinct, and we were unable to resolve phenotypic differences between 'local' and elite varieties in the field.

Genotypic variability is known to be a factor in the susceptibility of forest trees to insect attack (Wylie and Speight 2012, Newton et al. 1999). It is therefore critical that a study of *Canarium indicum* and GW genetics are undertaken concurrently. This would include a baseline assessment of the genetic diversity of the elite varieties (Nissan and Buka) in comparison to 'local' varieties and wild populations.

Other factors associated with GW attack

As well as genotypic variability, there are other biotic and abiotic factors to consider with insect pest attack, in particular tree vigour and size (Wylie and Speight 2012, Zas et al. 2008). Future research needs to take into account plantation and village conditions, cultivation practices, tree stressors such as waterlogging, physically induced damage to trees (e.g., machete marking, harvesting methods) and silvicultural practices (e.g., planting densities, mixed cropping).

The long term monitoring plots need to be followed through time, and experimental manipulations are required to test alternative hypotheses about the impact of GW on tree health. Our study established a correlation between DBH and tree age and GW attack, and less so with canopy cover, but these data are preliminary, and data collection needs to be extended geographically and to a broader genotypic sample.

Susceptibility to GW attack in the galip elite variety

It is unknown if the intrinsic attributes of the elite galip varieties are more susceptible to GW attack or if the current outbreak is heavily influenced by silvicultural practices, including intensive cultivation over the last decade in the Gazelle Peninsula. Also, we were only able to make limited observations on the effect of GW on 'local' galip, with our data being limited by a smaller sample size in comparison to the Keravat blocks. Moreover, the Keravat plots of the elite varieties are of the same age class (8-9 years) and it is unknown if their survivorship is enhanced by greater age/DBH. In our Madang survey we did not detect evidence of galip morbidity or mortality, and in nearly all cases tree age and DBH was greater than investigated in ENB.

Even if it can be established that GW is not present in the natural range of the elite varieties, there is insufficient evidence to hypothesise that their translocation to the natural range of GW makes them more susceptible. The tree attributes of the elite varieties such as secondary compounds, heartwood attributes and immune response also need to be investigated.

Control measures and containment

The insect pest management of GW needs to be addressed urgently in the epicentre of the outbreak in the Gazelle Peninsula. Comparison within this part of ENB and outlying areas indicate that GW is spreading geographically and tree morbidity and mortality is on the increase within the epicentre. This is having a devastating effect on the development of the galip industry, and puts at risk the investment of Australian and PNG governments.

There are financial, control effectiveness and environmental considerations that may limit insecticide use. Limited preliminary trials at NARI Keravat indicate some success with insecticide root injection, although GW reinfestation did occur. However, these NARI trails were not replicated, and fully resourced and designed trails are necessary to assess the efficacy of systemic insecticides and if they can be included in an IPM program.

The IPM program for cocoa weevils - *Pantorhytes* spp. - major pests of cocoa in PNG, needs to be reviewed, especially as galip is being mixed cropped with cocoa. The cocoa weevil is also challenging to control and the IPM strategy for them includes the creation of a favourable environment, monitoring and hand removal of adults, spot treatment of insecticides to larval tunnels, and introduction of antagonistic ant colonies (Smith 1981).

Filling all the above knowledge gaps will enable the development of an appropriate IPM strategy for GW, to include breeding and cultivation of pest resistant varieties, silvicultural practices to promote tree health and vigour, cultural controls (minimise machete wounds), and biological controls (e.g., ants, parasitoids) and spot use of insecticides.

Entomological capacity

The dearth of entomological capacity at Keravat is a hindrance. There are dedicated, knowledgeable and experienced personnel but a lack of early career entomologists, resources and infrastructure, and competing responsibilities of existing staff, are limiting what NARI can achieve in addressing the pest emergence of GW. To deal effectively with the GW outbreak, dedicated NARI staff need to be resourced and directed fulltime to GW, particularly over the next four years.

The loss of the Keravat insect collection has led to a slower response time to positively identify this pest and potential natural enemies. Establishing a new reference agricultural insect collection would increase local capacity to identify insect pests and would greatly increase capacity for locally based research.

6.7 Communication and knowledge sharing

Communication strategy and outcomes

- We have developed a fact sheet (Appendix 9.1) in English and promoted its distribution in English and local languages to galip stakeholders to assess the presence of GW and its pest status across PNG.
- We have developed a poster for the 2017 PNG Plant Protection conference (Appendix 9.2).
- Two scientific publications are in preparation: (1) Forest entomology paper reporting the emergence of GW as a pest of galip in PNG (led by Prof. Cassis); and (2) Taxonomy paper on the identity of GW (led by Dr Reid).
- GW information was distributed in local languages on radio, television, mobile networks and at local markets in Madang Province. This was promulgated by NARI and the Madang Provincial administration. This resulted in 12 farmers contacting the team about the presence of GW attack.
- We have communicated the impact and spread of GW, and outcomes of the current project with key public service agencies (NARI, NAQIA, DEC), industry peak groups (e.g., Cocoa Board, Forestry), non-government agencies (Binatang Research Centre), universities (e.g., UNRE, UPNG, Unitech), extension officers and small landholders.
- Prof. Cassis and Dr Reid had extensive meetings and undertook a fieldtrip to Vimmy plantation with Dr John Moxon (PPAP); the latter was instrumental in the development of galip and is mix cropping it with cocoa in PNG.
- We have communicated with Dr Amanda Mararuai of NAQIA to discuss exchange of information on GW, including the delimiting survey.
- Prof. Cassis contacted Prof. Helen Wallace of the University of Sunshine Coast to discuss outcomes of the work.
- Prof. Cassis has maintained ongoing communication with Tony Bartlett and Carl Menke at ACIAR.

Knowledge sharing and capacity building

- Capacity building about GW and methods for assessing its life history, damage and spread was undertaken at NARI Keravat during the ENB trip.
- Fidelis Hela at NARI Keravat first discovered the impact of GW and has shown dedication and initiative to address the GW problem. Throughout the SRA has been trained in the measurement of response variables, GW dissection, and rearing techniques. Two NARI Keravat cadets have also been trained during the SRA.
- Dr Sim Sar has been strongly committed to research on GW and the implementation of the SRA project. He is gravely concerned about the impact of GW and sees it as a high priority for NARI. This has resulted in an open and collegiate collaboration with unhindered exchange of information and methods to be applied.
- The Provincial Governor of Madang and his staff were instrumental in undertaking the Madang fieldtrip, and the Australian team briefed them, and trained four of their staff in GW detection.

7 Conclusions and recommendations

7.1 Conclusions

Identity and life history of GW

We have confirmed that the GW in ENB and Madang are conspecific with *Ectatorhinus magicus* (Figure 4), belonging to the subtribe Ithyporina, tribe Ithyporini, subfamily Molytinae, family Curculionidae ('true weevils'). This identification is based on phenotypic characters only, and an absence of genotypic data, precludes assumptions about the homogeneity of this species or the absence of cryptic species across its range in PNG.

We conclude that GW is a multivoltine wood-boring weevil species that specialises on *Canarium indicum*. The lifecycle is thought to include egg, four larval instars, pupa and adult, although we were unable to detect the egg and first instar. Entire GW development appears to be on *Canarium indicum*, and no alternative hosts were detected. The larvae tunnel in the cortical layers and heartwood of galip, and form pupal cells in the heartwood. Adults emerge through the larval tunnels, mate on galip and are thought to feed on galip petioles. The larvae can ringbark a tree causing significant mortality or partly ringbark a tree causing decline in health, including loss of canopy cover and presumably photosynthetic and reproductive capacity. GW adults are highly camouflaged and are difficult to detect. GW larvae are confirmed by the presence of exit tunnels and tree resin.

Distribution and spread of GW

The 1996 ACIAR galip report indicated no major pests of galip. French (2006) reported in the grey literature that GW was a minor pest of galip. However, from 2015 to the present GW has emerged a pest of great concern. NARI and other stakeholders have expressed major concern about its impact on ENB plantations and its spread potential in PNG. The SRA project confirms that this emerging pest is having a catastrophic impact on the fledgling galip industry, and will only worsen if it remains unchecked. Further, the uniform age class and low genetic diversity of the galip elite plantings in the Gazelle Peninsula places plantations that are currently GW free at high risk.

Several of the NARI/NAQIA 2015 delimiting survey sites were revisited and damage was found to have increased. The extent of geographic spread of GW in ENB could not be determined with confidence, because of the scope of the SRA. However, within the Gazelle Peninsula new blocks were infected relative to the 2015 NARI/NAQIA delimiting survey, particularly in the Keravat experimental blocks. It was confirmed that GW is now established in plantations across the central Gazelle region, particularly in the Agmark plantation at Vunapau, as well as Keravat, Mandres and Vunapalading. Localities (Cleanwara, Ramandu, Vimmy) distant from the Keravat/Vunapau GW epicentre showed no evidence of GW attack.

A review of the literature, historical collection event data and our survey in Madang establishes GW as widespread in lowland rainforest in the northern provinces of PNG and the Bismarck Archipelago. The SRA UNSW/AM survey of Madang found the first presence of GW in the province (low density, ca. 5%), in local galip varieties. GW was not found to be adversely affecting the tree health of larger trees (1.2–2.5 m DBH). The SRA NARI survey of Bougainville (Nissan and Buka), from which the elite galip varieties were sourced, provides evidence that these sites are GW free. Also, GW was not recovered by the SRA NARI survey of Duke of York island, from which it was first reported in 1881. There are no records of GW from West Papua, Vanuatu or the Solomon Islands.

Susceptibility to GW attack

Elite varieties of *Canarium indicum* were selected for breeding and cultivation, based on nut to shell ratio and reproductive output. Elite galip seedlings were grown at Keravat, ENB, with 200-250,000 seedling produced, of which 110,000 seedlings were distributed on ENB, in particular the Gazelle Peninsula (89%). Smaller samples were distributed in New Ireland, Manus, Lae (>200 trees) and minor distributions to Port Moresby, West New Britain and Madang have been made. Numbers of elite galip seedling distributed in Madang are unknown at this stage.

The galip elite trees in ENB smallholdings and plantations appear to be particularly susceptible to GW attack. Where other local varieties of galip are found growing alongside GW affected elite galip, the local varieties appear to be less affected (Vudal UNRE) or show no sign of GW attack (West New Britain variety, Keravat block #309). The Cleanwara and Ramandu plantations comprise extensive elite galip holdings and are considered to be at great risk. It is noteworthy that the Vimmy plantation contains a mix of varieties and trees of greater age (>DBH) and may be more resilient to GW attack.

A better understanding of the genotypes of both GW and galip, as well as GW host range, life history and attack mechanism/triggers, as well as tree stressors and susceptibility, will inform the development of an IPM approach for GW management. Further understanding of the distribution of GW and galip will allow for better selection of areas for galip plantations.

We conclude that the GW is in a classical outbreak phase and is an immediate threat to the development and long-term viability of the galip nut industry. Further, galip is highly significant to PNG as a food source and in their customs, and the impact of GW has broader social implications that also need to be explored through social science research.

7.2 Recommendations

Previous ACIAR research (Wallace et al., 2016) has identified the significant benefits of growing galip to the PNG economy; in particular to rural livelihoods and food security, through income generation for smallholders to its commercialisation on a broader scale.

The UNSW SRA FST/2016/013 project has established that GW is in an outbreak phase in ENB, causing catastrophic galip loss, and is a major threat to the socioeconomic development of this native tree species.

We recommend urgent action to address the emergence of GW as a pest of galip nut in PNG. The scale of the problem is so great in ENB that it could result in the loss of the galip industry in the short to medium term. Economic losses are already catastrophic, such as the near total loss of the Agmark plantation in the Gazelle Peninsula.

We recommend ongoing and multidisciplinary research on the GW problem, including the introduction of control trials over the next four years. As part of this research, we suggest an urgent stakeholder meeting to be held in Keravat (ENB) within the coming six months.

Using entomological, genetic, ecological and social science approaches, we recommend implementation of the following research activities.

1) Determining genetic diversity and estimates of dispersal of galip and Galip Weevil (GW).
   - (a) Genotyping of GW across PNG, focusing on ENB wild and cultivated galip.
   - (b) Determining sources, rate and direction of dispersal.
   - (c) Determining susceptibility of *Canarium* genotypes to GW attack.

2) Enhanced studies on the biology and ecology of the GW.
   - (a) Finalising studies on life cycle and other biological attributes of GW.
   - (b) Sampling of alternative hosts and determining host breath of GW.
   - (c) Collection and identification of natural enemies.

3) Establishing insectary at Keravat and lab rearing of GW and natural enemies.
   - (a) Climate controlled insectary established.
   - (b) Development and testing of artificial diets and ongoing rearing of GW.

(c) Rearing of natural enemies from lab reared GW.

4) Long term monitoring and determination of galip response variables.
   (a) Long term monitoring of GW absence/presence in PNG.
   (b) Monitoring of tree response variables at Keravat experimental plots.
5) Spatial analysis of galip weevil.
   (a) Species modelling of distribution of GW based on historical records of GW and bioclimatic data.
   (b) Species modelling of wild and domesticated *Canarium indicum*, and putative alternative hosts (focusing on Burseraceae and Anacardiaceae).
6) Control trials.
   (a) Systematic insecticide trials.
   (b) Alien and native ant trials.
   (c) Natural enemy trials.
7) Capacity building.
   (a) GW monitoring in entomological and ecological methods training.
   (b) GIS and species modelling training.
   (c) GW integrated pest management training.
8) Build baseline data on socio-economic and socio-cultural impacts of GW.
   (a) Assess impacts of GW as understood within different stakeholder groups.

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8.2 List of publications produced by project

- East New Britain Trip Report (submitted to ACIAR on Dec 24 2016)
- GW Fact Sheet (Appendix 9.1)
- GW Information Poster for conference presentation (Appendix 9.2)
- Nov/Dec trip report to ACIAR (submitted Dec 24 2016).
- Two scientific publications on taxonomy and forest entomology (in preparation).

9 Appendices

9.1 Appendix 1: GW fact sheet

This fact sheet has been prepared for distribution stakeholders across PNG. This poster has also been designed to display at markets and information stalls.

Fact Sheet

GALIP WEEVIL OF PAPUA NEW GUINEA

The Galip Weevil (GW), *Ectatorhinus magicus*, is native to Papua New Guinea and attacks galip trees, *Canarium indicum*. GW occurs in mainland PNG, from East Sepik to Oro Province, and East New Britain. There is an outbreak of this species in East New Britain and its pest status in PNG is being determined.

Symptoms of GW damage

Symptoms of attack are most marked in young trees, that are <10 years old or <80cm diameter at breast height. Severely attacked trees show loss of canopy from a distance, with dead or dying branches. Close inspection reveals weeping holes, with large amounts of resin released. The resin hardens and turns white on exposure to air and needs to be scraped off to reveal the GW damage underneath. Attack sites are commonly found on the trunk below the first branch.

Identification of GW

The adult GW is large, 2-3cm long, barrel-shaped, has a long thin rostrum (snout) and long strongly flexed legs. All dorsal (top) parts are mottled tan and creamy white intermixed with small black areas (more so in females). There is an obvious pale cross midway along the elytra (forewings). The GW larva is creamy white with a brown head that is half buried in the thorax, and has almost black mandibles. It lacks obvious eyes and legs and the thoracic spiracles (breathing holes) are greatly enlarged compared with the abdominal spiracles. The pupa is creamy white and has a long rostrum.

Adult

Larva

Biology of GW

Adults are thought to feed on leaf petioles in the tree canopy before mating. Egg-laying is unknown. Fecund (with fertilised eggs) females contain 4-5 mature eggs. There may be 4 larval instars (three have been found). The development period, egg to adult, is unknown, but likely to be at least several months. Adults are found on the tree trunk or under leaves of vines climbing the trunk. Larvae form tunnels and feed on wood, and are usually deep inside the trunk but may occur in surface tunnels, especially if feeding at soil level. Pupae are found in an oval cell within the trunk, wrapped in shredded strips of wood.

Report it

Contact Dr Sim Sar and Mr. Fidelis Hela at NARI (sim.sar@nari.org.pg, (fidelis.hela@nari.org.pg), Dr Chris Reid at the Australian Museum (Chris.Reid@austmus.gov.au) or Prof. Gerry Cassis at the University of New South Wales (gcassis@unsw.edu.au).

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9.2 Appendix 2: GW poster

This poster has been prepared for the 2017 PNG Plant Protection Association conference.

THE GALIP WEEVIL OUTBREAK IN EAST NEW BRITAIN: A NATIVE BEETLE CAUSING MORTALITY OF GALIP TREES

Gerry Cassis[1], Chris Reid[2], Fidelis Hela[3] and Sim Sar[3],

1 – Evolution & Ecology Research Centre, University of New South Wales, 2 – Research and Collections Division, the Australian Museum.

3 - National Agricultural Research Institute

In 2015 Galip Weevil (GW), *Ectatorhinus magicus*, a native of Papua New Guinea, was found destroying galip trees, *Canarium indicum*, in East New Britain (ENB). A follow-up NARI/NAQIA delimiting survey in October 2015, highlighted the extent of GW damage in the Gazelle Peninsula at that time, with over 90% tree mortality at multiple sites. UNSW and Australian Museum were contracted by ACIAR to conduct a fact finding study in 2016/2017 in collaboration with NARI. Two field surveys were conducted, in ENB (26 November–6 December 2016) and Madang district (3-11 April 2017). In ENB the outbreak of the GW was found to have spread in the Gazelle Peninsula, with the Agmark plantation at Vunapau considered to be the epicentre of the outbreak. The Madang survey resulted in the discovery of GW in local varieties of galip, but was not in an outbreak phase nor causing tree mortality.

Symptoms of GW damage

Symptoms of attack are most marked in young trees, that are <10 years old or <80cm diameter at breast height. Severely attacked trees show loss of canopy, with dead or dying branches. Close inspection reveals weeping holes, with large amounts of resin released. The resin hardens and turns white and needs to be scraped off to reveal the GW damage underneath. Attack sites are mostly found on the trunk below the first branch.

Identification of Galip Weevil

The adult GW is large, 2-3cm long, barrel-shaped, has a long thin rostrum (snout) and long strongly flexed legs. All dorsal (top) parts are mottled tan and creamy white intermixed with small black areas (more so in females). There is an obvious pale cross midway along the elytra (forewings). The GW larva is creamy white with the brown head half buried in the thorax, and has almost black mandibles. It lacks obvious eyes and legs and the thoracic spiracles (breathing holes). The pupa is creamy white and has a long rostrum.

Adult

Larva

Biology of GW

Adults are thought to feed on leaf petioles in the tree canopy. Egg-laying is unknown. Fecund (with fertilised eggs) females contain 4-5 mature eggs. There may be 4 larval instars (three have been found). The development period, egg to adult, is unknown, but likely to be at least several months. Adults are found on the tree trunk or under leaves of vines climbing the trunk. Larvae form tunnels and feed on wood, and are usually deep inside the trunk but may occur in surface tunnels, especially if feeding at soil level. Pupae are found in an oval cell within the trunk, wrapped in shredded strips of wood.

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9.3 Appendix 3: East New Britain site survey summary (UNSW/NARI/AM)

Field notes for the resampling of the 2015 delimiting survey sites, as follows:

Locality 1. Vimmy Plantation, East New Britain. 28 Nov 2016. 4.40884 S 152.25044 E 167 m. Resampling of 2015 delimiting survey site. There was no evidence of GW attack. Stressed trees were found on the road in, adjacent to the roadside, but did not exhibit GW occurrence. Stressed trees displayed reduced canopy. Stress was due to waterlogging (NARI staff pers. com.)

Locality 2. Vunapau (also known as Vunarakan), Block #3, (Agmark). 28 Nov 2016. 4.32852S 152.07571E, 168m. Resampling of 2015 delimiting survey site. More or less all trees dead or dying. Extensive exit holes, canopy reduced and dead trees, some with bark fallen off (i.e. dead for some considerable time). Two out of eight trees had epicormic roots at base of trunk. One dead standing tree had extensive bark beetle (scolytine) damage, with subcortical galleries and bostrichid beetle attack in horizontal tunnels. Other subcortical insects, including two species of bark bugs (family Aradidae). These non-GW insects are interpreted as secondary infestations post-GW attack. One tree with root insecticide treatment is putatively showing recovery.

Locality 3. Vunapalading 2, 29 Nov 2016. 4.37764S 151.94289, 79 m. Resampling of 2015 delimiting survey site. Small farmer holding. Elite galip intercropped with banana, various fruit trees; extensive ground cover, including sweet potato. *Glarisidia* as shade tree. Galip ca. 3 years old with 10-20 cm DBH. All trees severely damaged, with greatly reduced canopy. Average of three GW exit holes per tree for ten trees investigated; also evidence of older exit holes. No green tree ants present. Farmer reported extensive GW damage throughout holding. GW larvae collected.

Locality 4. Mandres 1. 29 Nov 2016. 4.35624S 151.92267E, 31 m. Resampling of 2015 delimiting survey site. Small famer holding. Elite galip intercropped with cocoa, with sweet potato understorey; also *Glarisidia*, coconut and betel nut. Site with some waterlogging. No green tree ants present. Female farmer reported 100 elite galip trees planted. For six years galip were healthy; in 2015 80 galip trees died, remainder now dying. GW adult collected.

Locality 5. Mandres 2. 29 Nov 2016. 4.34455S 151.91287E, 26 m. Resampling of 2015 delimiting survey site. Small holding. Farmer not present. Plantation with mature elite galip trees, intercropped with cocoa and banana; also, *Glarisidia* and ground cover of grasses and sweet potato. Galip trees taller and more mature than Mandras 1. 80% of galip trees with GW attacked. Some trees were dead. Possible recovery of previously attacked trees. Green tree ants present. Canopy of galip trees denser than Mandras 1, less wilting and less necrosis. Two GW larvae collected.

Locality 6. Vunapalading 1. 29 Nov 2016. 4.37021S 151.98361, 53 m. Resampling of 2015 delimiting survey site. Elite galip plantation intercropped with cocoa; extensive closed canopy, with little ground cover, extensive cocoa leaf litter; on edge of *Balsa* plantation. Extensive damage on elite galip trees, much of galip dead or dying. Green tree ants present. Many elite galip trees with old GW exit holes, huge amount of mixed frass and exudate on ground. GW adults and larvae collected.

Locality 7. Vudal block, near Natural Environment University. 29 Nov 2016. 64.34809S 151.99718E, 27m. Resampling of 2015 delimiting survey site. Galip trees extensively intercropped with mostly cocoa. Mixed local and elite varieties of galip. Tree height >5 m, with local variety much taller than elite varieties. Extensive GW damage on elite varieties. Local variety at first thought to be free of GW attack with healthy looking trees (DBH range ca. 150-180, ca. 90% canopy cover, no sign of leaf wilt or necrosis. Further inspection revealed GW larva (probably 3rd instar) at base of tree with mix of larval frass and tree exudate in soil. Closer inspection revealed larvae in exit holes up to 2.5m.

Locality 8. Cleannwara, Site #1. 2 Dec 2016. 4.25104S 151.84204E, 10m. Resampling of 2015 delimiting survey site. Large scale planting of elite galip variety, intercropped with cacao. Twelve trees inspected. No evidence of GW damage. Trees planted in 1999. Minor termite damage found, with one branch dead with empty subcortical tunnels, probably cerambycid beetle(s). Mature mango inspected, no GW damage detected.

Locality 9. Ramandu, Site #1. 2 Dec 2016. 4.23963S 151.84114E, 21m. Resampling of 2015 delimiting survey site. Elite galip intercropped with cacao. Twelve galip trees inspected. No GW damage detected. Minor termite damage found.

Locality 10. Ramandu, Site #2. 2 Dec 2016. 4.23617S 151.84029E, 12m. Resampling of 2015 delimiting survey site. Elite galip intercropped with cacao, galip very healthy. Ten galip trees inspected. No GW damage detected. Minor termite damage found. Green tree ants common. Two galip trees observed that had been smothered by vines and had lost some canopy, so resembling attacked trees from a distance,

Locality 11. Ramandu, Site #3. 2 Dec 2016. 4.234625S 151.84657E, sea level. Resampling of 2015 delimiting survey site. Elite galip intercropped with cacao. Twelve galip trees inspected. No GW damage detected. Galip very healthy.

Locality 12. Vunapau (also known as Vunarakan), Block #1. 3 Dec 2016. 4.32996S 152.027326W, 164 m. Resampling of 2015 delimiting survey site. Block #1 was also visited on 28 Nov 2016 during current survey (= Locality 2 above). Galip intercropped with cocoa; widespread dead cocoa from *Pantorhytes* feeding. Most extensive elite variety plantings examined in the Gazelle Peninsula. About 100% severely damaged to dead trees. Multiple GW tunnels on most trees, mostly below first branch, resulting effectively in ring-barking of trees. Last larval instars found at base of trees, partly emerging from tunnels, when disturbed rapidly retreating within trunk. Two GW infested trees were felled and dissected. Tunnels commencing on inside of cambium, extending to heartwood of tree. Damage to both phloem and xylem. Tunnels were extensive, including into heartwood, with pupal cells found, lined with wood strips. Canopy exhibiting petiole grazing, from possible GW adult feeding. Width of grazing strips match width across mandibles of GW adults. Manager of Vunarakan plantation observed tree damage by GW in 2012; this was not reported to NARI at that time. GW larvae collected.

Locality 13. Vunapau (also known as Vunarakan), Block #3, Site #1. 3 Dec 2016. 4.33353S 152.07898, 161 m. Mostly as in Locality 12. 100% of elite galip severely damaged or dead. GW larvae collected.

Locality 14. Vunapau (also known as Vunarakan), Block #3, Site #2. 3 Dec 2016. 4.33486S 152.07687E, 163 m. Mostly as in Localities 11 and 12. 100% of elite galip severely damaged or dead. GW larvae collected. Two GW larvae were observed in the same tunnel. First observation of GW larval tunnel in branch of trees.

Locality 15. Vimmy Plantation. 3 Dec 2016. 4.41568S 152.2473E, 170 m. Resampling of 2015 delimiting survey site. Close to Locality 1. Mix of galip varieties, mostly local variety examined. Galip trees very healthy with no GW damage found. Minor damage caused by termites.

Locality 16. Keravat NARI, interface of blocks #308 and #309. 3 Dec 2016. Note GPS readings to be provided by NARI staff. Block #309 was uniformly planted with a West Britain galip variety; trees were very tall and healthy, with minor termite tunnelling observed. No GW damage seen. Block #308 was planted exclusively with elite galip variety. Trees were much smaller and exhibited extensive GW damage. The two blocks were separated by 5m and there was no evidence of colonisation of block #309 from #308.

9.4 Appendix 4: Madang site survey summary (NARI/UNSW/AM)

Field notes from the galip survey in Madang Province, 4-8 April 2017, with notes on galip trees examined:

Day 1: South Coast, Madang - 4 Apr 2017

Locality 1. Erima, Astrolabe Bay, 5.41940S 145.73036E, 6m.1 large tree, c2m DBH, fluted trunk, termites.

Locality 2. Erima (Maru hamlet), 5.41016S 145.72902E, 10m. 3 trees, 70cm DBH (ridged), 50cm DBH (ridged), 35cm DBH (smooth, planted from Saidor), with termites. One tree (70cm DBH) was damaged (large area of bark removed) with secondary scolytine attack & termites.

Locality 3. Erima (Hagui hamlet), 5.40614S 145.71294E, 18m. 1 large tree, c3m DBH, 1 small tree, c65cm DBH, 1 tree, c1m DBH.

1 mountain sp of galip [ie different sp of *Canarium*] with large leaves and a very large nut, 75cm DBH [according to Simon & Tomatil: this species from Adelbert Mtns (Madang Prov.), up to 900m; tastes same, much lower yield]

Locality 4. Gogol, 5.34707S 145.70982E, 11m. 3 trees, c1m DBH, termite trails, planted from seeds from Saidar

Talking with Simon & Tomatil & Rex: Saidar, Karkar & Manum Islands are the original sources for galip in region. But Long Island is settled by West New Britain islanders and they brought galip from there.

Day 2: Bogia District - 5 Apr 2017

Locality 5. Rurunat, Bogia, 4.45223S 145.37849E, 9m. 1 tree, 1.2m DBH, local variety, badly damaged at base (bark cut off 1/3); cerambycid burrows in wood of dead area.

Locality 6. Medebur, Bogia, 4.46298S 145.40965E, 6m. 1 tree planted c1974, only 1.5m DBH [because of regular trimming], healthy; next to larger 'walnut' (v similar leaves).

Locality 7. Nr Medebur, Bogia, 4.47166S 145.41768E, 12m. 2 young trees, c40cm DBH, slightly ribbed, clean.

Locality 8. Toto, Bogia, 4.47928S 145.42134S, 7m. 1 very sick tree, 1m DBH, large scar at base exposing dead wood, canopy loss c50%, scolytines, termites, hard fungus in dead area. 1 large 'hela' nut tree dying, leaves almost peltate. Opposite side of road, 1 tree 1.2m DBH healthy except termites; 1 tree 2.5m DBH healthy except termites. All trees local varieties

Locality 9. Ulingan, Bogia, 4.49703S 145.41727E, 11m. 2.5m DBH healthy, buttress roots; 1.2m DBH, healthy, buttresses; 10cm DBH sapling, healthy.

Locality 11. Korak (1), Bogia, 4.51322S 145.46339E, 9m. Very large, ridged tree, 2m DBH, some sap flow from machete cuts.

Locality 12. Korak (2), Bogia, 4.52316S 145.46986E, 5m. NB 'Okari' tree = called galip locally, with large ribbed hard nut. 'Mon' tree = walnut, 1m DBH, some old sap flow from cracked trunk c3m above ground (wind damage?), termite damage, old machete cuts.

Locality 13. Tawulte, Sungkar district [Madang], 4.55415S 145.50444E, 14m. 3 trees: 40cm DBH v healthy, local variety, not much ridged. 2m DBH v healthy, c10 yrs old, old termite trail, some leaf necrosis, plus several leaves with emerged leafminer. 2.5m DBH v healthy, sap flow from machete cuts.

Locality 14. Bunabun, Sungkar, 4.58865S 145.52455E, 18m. 2 trees. 4m DBH, buttressed, termites, from Karkar. 3m DBH less buttressed, clean, from Karkar

Locality 15. Dibor, by river. 4.67039S 145.58362E 8m.

Locality 16. Tokain, village of Karkar islanders, Sungkar, 4.70660S 145.62325E, 14m. 1.2m DBH, Karkar seed, badly damaged base from fire, termites; 2.4m DBH, Karkar seed, badly damaged base from fire, termites, small patch scolytines; 1.2m DBH, Manus Id seed, rough knobbly bark, no termites; local claimed 30-40 yrs old.

Day 3: North of Madang – 6 Apr 2017

12 farmers have reported possible weevil damage in response to notices at markets, in villages and radio broadcasts

Locality 17. Mirap, Sungkar district, 4.75580S 145.66496E, 7m.

1m DBH local var, healthy, but small old fire damage at base [fires burning rubbish get a bit out of control in dry season].

Locality 18. Karkum

All trees local variety.

50cm DBH healthy, 50cm DBH healthy

1.8m DBH, strongly ribbed, healthy but with termites

1.2m DBH, ditto

2.5m DBH, ditto, but old GW hole & tunnel at 1.5m above ground (brown stained sap, pulpy fill of tunnel, with (possibly) nosodendrid beetle), tree healthy otherwise, tree locality = 4.75580S 145.66496E.

1.6m stressed tree, with large weevil sized round hole at 3m above ground with 20cm tunnel towards another hole 30cm obliquely across trunk, latter an old sappy hole (sap brown), bark surface slightly bulging between these holes, another deep hole at 2m above ground with old brown sap flow; many epicormics shoots to 1.3m, termites; difficult to assess canopy loss because adjacent to another crowding tree; location of tree – 4.76066S 145.67322E, 9m.

2.2m DBH, healthy, ribbed, termites.

A farmer (called Justin) at Karkum recognized photos, video and Chris Reid's drawing of the weevil, saw them on ends of cut branches of trees several years ago [the trees above not his trees, so some other trees]

Locality 19. Sarang 2, 4.76933S 145.68819E, -3m [!]. 1 tree, 3m DBH, large fluted, termites, local variety.

Locality 20. 1 km inland from Megiar (Sim's village), 4.81607S 145.75693E 26m.

3m DBH, large section at base dead from fire damage, with termites, cerambycid holes, (possibly) scolytines, otherwise OK, local variety.

[Large walnut, 4.5m DBH, healthy]

3m DBH, healthy, buttressed, local variety

4.5m DBH, healthy, buttressed, local variety

2m DBH, healthy, local variety

2m, DBH, old GW tunnel at 1.7m above ground, mostly internal, short 15cm tunnel on or just under surface, otherwise healthy (no epicormics), wild seeded tree; tree at 4.81555S 145.75700E, 23m

1.8m DBH healthy tree, local variety

2.5m DBH, damaged by fire long time ago, bark on one side dead up to 3m and peeling, epicormics shoots present, only 60% canopy, dead branches

2m DBH, local variety, healthy

2.2m DBH, local variety, healthy

3x saplings all 1.5-2m tall, 8-10cm DBH, planted 2016 from Keravat (described as 'hybrids'); 2 with heavy leaf damage from snub-nosed weevil eating tiny holes like alticine [location = 4.81617S 145.75621E, 20m]

Locality 21. Murumus, CCI offices, 4.96968S 145.78058E, -11m [!]. Small plantation either side of ditch, N side of site, we looked at 4 on office side (5 others on far side looked healthy from canopy); former mixed variety plantation put in by Tomatil on S side of site has been cut down. 4 galip trees:

1.8m DBH, healthy

1.8m DBH, healthy except many termites

1.3m DBH, healthy

1.5m DBH, healthy

Day 4: North and Southwest of Madang – 7 Apr 2017

Locality 22. Rempi, 5.01098S, 145.79240E, 5m. All local varieties:

45cm DBH, strongly ribbed, healthy

45cm DBH, strongly ribbed healthy

1.2m DBH, ridged, healthy

1.2m DBH, ridged, healthy except termites

Locality 23. Riwo, 5.14403S 145.79836E, 12m. All from Karkar:

1.8m, strongly ribbed, healthy, termites

2m slightly ridged, termites, healthy but small patch epicormics roots 2m above ground

40cm DBH, healthy

60cm DBH, healthy

Locality 24. 5.16062S 145.75110E, 360m. Top of hill. 2 trees:

40cm DBH, healthy

1.3m DBH, strongly ribbed, healthy

Locality 27. <u>Jahil, area 1</u>, at village, 5.24020S 145.72420E, 26m. All local varieties:

80cm DBH, healthy, termites, buttressed

1.5m DBH, healthy buttressed

1.8m DBH, healthy buttressed, planted 1984/5

<u>Jahil, area 2</u>, about 500m upstream, 5.23922S 145.72067E, 28m. All local varieties:

12cm DBH, 3m high, healthy

30cm DBH, healthy

30cm DBH, healthy

80cm DBH, healthy

70cm DBH, healthy

30cm DBH, large GW hole at 2m above ground, 80% crown, epicormics roots up to 1m above ground, situated at 5.23922S 145.72067E

1.3m DBH healthy

Jahil area 3, on slope between 1 & 2, 5.23870S 145.72220E, 12m [!].

1.2m DBH, healthy, scaly barked, local variety

Locality 28. Gum Bridge, 5.24909S 145.76479E, 15m. Local varieties:

50cm DBH, healthy

75cm DBH, healthy, termites

Locality 29. Subalulu (Tom's village), 5.40657S 145.63991E, 77m. Numerous trees:

Tree with 2 stems, each 30cm DBH, healthy

40cm DBH, healthy

3m DBH, healthy, ridged

40cm DBH, healthy

1.5m DBH, healthy, mbuttressed

2.3m DBH, healthy, scaly barked

25cm DBH, healthy = large leaved mountain species, same as at site 3

Tree with 2 stems, each 20cm DBH, healthy except termites

50cm DBH, healthy

80cm DBH, healthy

30cm DBH, healthy

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Locality 30. Jobdo, 5.26722S 145.51038E, 107m.

2.2m DBH, planted 1996, from Karkar, healthy

1.2m DBH (@ 5.26334S 145.50967E, 65m), planted 2006-8, from Rai Coast; farmer reported reduced seed crop (tree just harvested so impossible to estimate canopy); nests of fire ants on trunk; 1 adult present under Piper leaf (climber on trunk) at 1.5m high; no epicormics roots; 1 small deep weepy hole at 1m (prob with larva); 1 large hole with 15cm deep tunnel at 1.8m.

2m (at 5.26320S 145.50974E 70m) planted 2004 from Karkar; 1 adult under leaf of piper climber; 4 holes: at 30cm on buttress rib, at 50cm on buttress rib, at 1m, at 1.7m (associated with machete cuts); no epicormics roots.

Jobdo farmers recognized GWs and were familiar with them.

Also seen – Okai tree with many elongate, oval egg slits of large leafhoppers.

Locality 31. Geutar village, Barum area, 5.32467S 145.59665E, 62m.

1.2m DBH, seed from Karkar tree; small hole at 50cm with right sort of frass but apparently not going in deep – possibly a failed larval hole; otherwise healthy

90cm DBH, Karkar variety; sickly, strongly ribbed trunk, large termite nest high on trunk & canopy reduced

1.5m DBH, local variety, healthy

35cm DBH, wild species but different from Mountain Galip seen previously (nut smaller than this but larger than *C. indicum*, leaves intermediate as well); healthy, but with epicormic shoots

3.5m DBH, parent tree of the above (at edge of wild parch of forest); healthy but some decay at base between buttresses, and (possibly) Ganoderma.

20cm DBH, wild sp as above, healthy

15cm DBH, wild sp as above, healthy

1.2m DBH, Mountain Galip species (same as at as sites 3 and 29), healthy

Locality 32. Malsalu (Simon's village) [Mal = tree, salu = shade], 5.27936S 145.67009E, 160m. 2 trees:

1.5m DBH (at co-ords given), variety from Serang, on coast nr Karkum; fire ant nests, termites; 1 adult on bark in shade of Piper leaf at 2m height; hole & 15cm subcortical gallery 40cm above ground; no epicormics roots; canopy narrow but looks ok.

1m DBH, damaged by fire (about ½ base dead); but no weevil holes; fire ants, termites, epicormic shoots present.

Locality 33. Aiyab 5.28364S 145.70622E, 110m.

2.8m DBH, fire damaged at base, otherwise OK

75cm DBH, fire & machete damaged, termites, OK

90cm DBH, healthy

1.2m DBH, healthy but many termite trails

75cm DBH, healthy

80cm DBH, healthy

40cm DBH, healthy

Farmers say they recognize the GW but not convincingly.

Locality 34. Bilbil, 5.28789S 145.76408E, -11m [beside the sea!].

5m DBH, healthy except sap flow from possibly canker growth, no tunnels

40cm DBH, healthy

2.8m DBH, healthy

3.2m DBH, healthy

3.5m DBH, healthy

3.3m DBH, healthy

9.5 Appendix 5: NARI Keravat galip distribution records by district and stakeholder

The distribution data for galip elite seedlings from currently available data, ranges from 2008 to 2012, excluding 2011. Nursery stocktakes indicated the total distributed is about 200,000 and 2011 data is needed to update this. The following are summaries of the distribution records by stakeholder and district as well as the plantation shares.

Stakeholder	Qty supplied
Cocoa Coconut Research Inst.	55
ENBDC	2200
NARI	3515
Plantation	28876
Smallholder	72492
Vudal University	2200
Total	109338

LLG / District	Qty supplied
Gazelle, East New Britain	97124
Kokopo, East New Britain	5201
Pomio, East New Britain	1810
Rabaul, East New Britain	938
Buka	80
Kavieng, New Ireland	3330
Kimbe, West New Britain	10
Lae, Morobe	640
Manus	200
Port Moresby	5

Date	Name	Stakeholder	LLG / District	Qty supplied
15/10/2008	Klinwara	Plantation	Gazelle	12000
17/09/2008	Vimi (Vimmy)	Plantation	Gazelle	3150
10/06/2008	Tokiala Pltn	Plantation	Gazelle	1874
14/11/2008	CPL	Plantation	Gazelle	572
14/04/2009	Ken	Plantation	Kavieng, New Ireland	1200
	Ken	Plantation	Kavieng, New Ireland	80
22/03/2010	Agmark	Plantation	Gazelle	2000
2012	Agmark	Plantation	Gazelle	8000

9.6 Appendix 6: Response variables measured in monitoring plots at Keravat

Data for the following variables were collected for eight trees per block.

1) Block #
2) Tree #
3) Latitude
4) Longitude
5) Altitude
6) Waypoint
7) Block Row #
8) Position: Edge, Mid, Interior
9) Tree Age
10) Canopy Cover (%)
11) Tree Height (m)
12) DBH (cm)
13) Height at first branch (m)
14) Above ground exit holes (N)
15) Holes above first branch +/-
16) Base of tree exit holes (N)
17) Surface tunnels (N)
18) Tunnel exudate +/-
19) Vertical sap runs +/-
20) Knife wounds +/-
21) Bark scaling +/-
22) Fungus/bacteria +/-
23) Epicormic shoots +/-
24) Base of tree frass/exudate +/-
25) Leaf Flush +/-
26) Herbivory +/-
27) Leaf curl +/-
28) Leaf wilt +/-
29) Necrosis +/-
30) Nut +/-
31) Flowering +/-
32) Weevil Adult (N)
33) Weevil Larvae (N)
34) Green tree ants +/-
35) Other ants +/-

36) Secondary attack +/-
37) Secondary hole occupy +/-
38) Photo #
39) Observer name
40) Date and time
41) Weather
42) Block date
43) Block spacing (m)
44) Site description