MANGO INDUSTRY BIOSECURITY PLAN
THREAT-SPECIFIC CONTINGENCY PLAN

RED BANDED MANGO CATERPILLAR

COMMON NAME:	red banded mango caterpillar
SCIENTIFIC NAME:	*Deanolis sublimbalis* Snellen, 1899
ORDER:	LEPIDOPTERA
FAMILY:	Pyralidae
SUBFAMILY:	Odontiinae
SYNONYMS:	mango fruit borer mango seed borer red banded borer *Deanolis albizonalis* (Hampson) *Autocharis albizonalis* (Hampson) *Noorda albizonalis* Hampson

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ACRONYMS

ACIAR	Australian Centre for International Agricultural Research
AMIA	Australian Mango Industry Association
DPI&F	Department of Primary Industries and Fisheries (Queensland)
IATA	International Aviation Transport Authority
NAQS	Northern Australia Quarantine Strategy
NARI	National Agricultural Research Institute (Papua New Guinea)
NAQIA	National Agriculture and Quarantine Inspection Authority (Papua New Guinea)
NPA	Northern Peninsula Area (Cape York, Queensland)
NSW	New South Wales
NT	Northern Territory
PNG	Papua New Guinea
PQA	Pest Quarantine Area
QLD	Queensland
RBMC	red banded mango caterpillar
WA	Western Australia

BACKGROUND

Red banded mango caterpillar (RBMC) is a threat to Australia‟s mango industry. It is a pest of mango fruit in all stages of fruit development, feeding on both the flesh and the seed. There are only four known hosts, all of which belong to the plant family Anacardiaceae. Mango (*Mangifera indica*) is the only host of economic importance, and the only host in Australia. RBMC is distributed throughout most of Southeast Asia and Papua New Guinea (PNG) and has been spreading through the Torres Strait islands since 1990. It was detected on mainland Australia, near the tip of Cape York Peninsula in October 2001. Since August 2001 Cape York Peninsula from just north of Coen has been a defined quarantine area for a number of targeted plant pests, including RBMC. Movement restrictions for mango plants and fruit within and from this quarantine area are in place.

Until relatively recently the scarcity of literature about RBMC suggested that it is generally a pest of little concern. However surveys in the Philippines and PNG have found infestation rates of 40-55% (Tipon 1979 in Golez 1991, Pinese 2005).

Even very low numbers of RBMC would be highly problematic for commercial mango producers in Queensland (Qld). Chemical control would be difficult because the caterpillar feeds internally on the fruit, and the likelihood of finding effective biological control agents is unclear. Additionally, confirmation of the presence of RBMC in production areas is likely to lead to the imposition of national and international quarantine restrictions.

Host Range

Anacardiaceae: mango (*Mangifera indica*); Kuini (*Mangifera odorata*) in PNG and Indonesia; *Mangifera minor* a wild fibrous mango found in PNG; and *Bouea burmanica* in Thailand (Kalshoven 1981, Waterhouse 1998, Krull 2004, Tenakanai *et al*. 2006).

Part of commodity affected

Fruit

BIOLOGY

Identification

Larvae

The larva is quite distinctive; its body is covered with alternating red and white bands, with a black „collar" on the first segment (see Fig. 1 & 2). The head is brown or black. The caterpillar commonly grows to 2 cm in length (Fenner 1997). Mango seed weevil larvae can also be found in mango seed causing similar damage to RBMC however for field assessment these larvae have no red banding.

Figure 1. RBMC larval instars (largest larva 10mm) (J.Royer)

Figure 2. RBMC larvae tunnelling into mango seed (fruit length 40mm, larval length approx 13mm) (R.Yarrow)

Prepupae and pupae

Prepupae turn a blue to green colour on the white bands (Krull 2004) (see Fig. 3). When pre-pupal stage is reached the larvae stop feeding and display minimal mobility (Tenakanai *et al*. 2006).

Figure 3. RBMC prepupa in mango tree bark, Somerset (S.Foulis, M.Stanaway).

The pupa is encased in a spun cocoon which may incorporate soil particles or bark particles, and is 11-12 mm long (Leefmans & van der Vecht 1930). Pupae are pale brown and gradually turn dark brown as they age (Tenakanai *et al*. 2006).

Adults

The adult is a plain greyish/fawn coloured pyralid moth, with „beak like" mouthparts typical of this moth family (see Fig. 4 & 5). A more complete description of the adult moths is provided by Fenner (1997): „The adult moths have wings of a shining bluish-fawn colour with a well marked darker border and a narrow, dark streak across the end of the forewing cell. Forewing length is about 13mm. Hind wing colouration is similar and the wings are held beside the body when the moth is resting, so that its shape is evenly triangular. The head and rather slender body are brown with creamy yellow markings and there are shining white scales on the tarsi and undersides of the thorax, head, and palps. The sexes are alike in appearance, except that the mid-leg of the males has a dark brown tibial scale brush which is lacking in females." Further detail is provided by Leefmans & van der Vecht (1930). Gibb *et al*. (2006) also state that males can be identified by an abdomen that extends beyond the hind wings.

Figure 4. Adult moth of RBMC (forewing length 13mm) (J. Ismay)

Figure 5. Male adult moth of RBMC on pheromone trap sticky mat, showing hind wing (R.Yarrow)

Symptoms

RBMC larvae feed on mango fruit in all stages of fruit development. First and second instar caterpillars feed just beneath the skin surface, tunnelling towards the seed. Later instars feed on the seed itself. Secondary pests such as bacteria and fruit flies may then invade the fruit. Damaged fruit can fall from the tree prematurely (Kalshoven 1981, Waterhouse 1998). Krull (2004) observed in PNG that mango fruit of all sizes were attacked, but marble sized fruit were preferred sites for oviposition and therefore more frequently infested. Infestation levels decreased towards the end of the season with mature fruit being attacked far less than marble sized fruit. Krull (2004) inferred that this is mainly due to the fact that marble sized fruit provide insufficient food for development therefore larvae need to move through several small fruit to get the same amount of food as a large fruit.

The first sign of a RBMC infestation is the presence of a sap stain running from the caterpillar"s entry hole and collecting on the drip point at the fruit apex (see Fig. 6 & 7). The sap darkens over time and becomes very noticeable (Fenner 1997). The entry site of early instars may be marked by the development of a pale brown ring, with a dark dot in the centre (Sengupta & Behura 1955, Butani 1979). The larvae usually enter through one hole, typically laid in the lower half of the fruit (Krull 2004). In the NPA, DPI&F staff observed that the entry hole is always surrounded by frass, regardless of size of larvae or size of fruit being attacked.

Figure 6. RBMC infested mangoes showing the sap stain running from the caterpillars entrance hole to the fruit apex (J. Ismay)

Figure 7. Small RBMC infested mangoes from Somerset (smallest fruit 35mm) (M.Stanaway, S.Foulis)

In the Philippines, infestation of fruit by RBMC was observed to occur as early as 45 days after flowering (egg size fruit), with the infestation level continuing to increase until the fruit were mature. The greatest damage was observed on medium sized fruit, 75-85 days after flowering. Peak abundance in the Philippines was observed in March and April (Golez 1991). In India RBMC is recorded as attacking fruit from marble size to maturity (Zaheruddeen & Sujatha 1993). This observation was confirmed by DPI&F staff in the NPA. Krull (2004) noted that RBMC attack does not necessarily result in fruit drop, particularly with younger fruit.

Life History

(see Fig. 8)

Eggs

Krull & Basedow (2006) found that oviposition occurs at the base of the peduncle covered with dried sepals 70% of the time. Oviposition will less commonly take place on the base of the peduncle without sepals (19%), and rarely on other parts of the peduncle (6%), non fruiting vegetative branches (4%) and fruit (2%). Dori (1997, in Waterhouse 1998) and Tenakanai *et al*. (2006) also report that eggs were oviposited at the base of the fruit, sometimes covered by the sepals. In contrast, Golez (1991) reported that in the Philippines eggs were oviposited in masses at the fruit *apex*, but later stated that this was "providing protection from the rain and concealing it from natural enemies", which would be expected to occur at the fruit base under the calyx. Eggs are usually laid in groups of two, though single egg laying and egg masses containing up to 14 eggs are recorded (Krull & Basedow 2006). Eggs are oval 0.3 - 0.5mm and covered in a waxy layer. They are white when freshly laid but turn pinkish in 2-3 days (Krull 2004, Tenakanai *et al*., 2006). Oviposition can occur as early as 45 days after fruit set and continues up to fruit maturity (Golez 1991).

Larvae

Golez (1991) observed RBMC passing through five larval instars. After hatching, the first instar larvae bore into the fruit flesh at the apex (Sengupta & Behura 1955, Butani 1979, Golez 1991, Waterhouse 1998). Krull & Basedow (2006) reported that RBMC larvae usually entered the fruit through one borehole typically made in the lower half of the fruit. Sampling by DPI&F staff in the NPA determined that entry holes were found on any part of the fruit from the base to the apex, but usually in the lower two thirds of the fruit towards the apex.

The first two instars feed on the mango flesh, with later instars feeding on the seed (Golez 1991, Waterhouse 1998). As many as 11 larvae have been recorded in one fruit although there is often only one (Leefmans & van der Vecht 1930, Waterhouse 1998). If competition occurs between larvae in the same fruit, some individuals may leave that fruit to search for more food. Larvae move between fruits by the use of "silk" threads, lowering themselves onto new fruit (Golez 1991). Thus the tell-tale holes can be made by both newly hatched larvae and mature larvae as they move between fruits.

Pupae

Larvae leave the fruit to pupate. The pre-pupa turns a blue-green colour (Krull 2004, Trinca & Foulis 2002). Krull & Basedow (2006) found no prepupae or pupae in the fruit, soil or leaf litter in PNG, but did find prepupae and pupae in the bark of the trunks of every infested tree toward the end of the mango season. In PNG Gibb *et al*. (2006) also found numerous diapausing larvae under the bark of mango trees in November. To pupate, the larvae bored 1-2 cm into the bark and closed the entrance hole with chewed bark particles, leaving them completely invisible. Deep crevices in the bark were also used as pupation sites. There have been reports of larvae pupating inside the fruit, with the adult moth emerging through an exit hole (Sengupta & Behura 1955, Butani 1979, Golez 1991), but these are likely to be misidentification of larvae not kept till adult emergence (Krull 2004). To determine whether adult moths emerged from pupae during mango off-season, Krull (2004) inspected field and laboratory reared pupae in March (the PNG mango fruiting season is similar to northern Queensland with flowering commencing in July and fruit being harvested from October to December). No holes for adult emergence were observed, indicating that larvae undergo diapause and that *Mangifera* is the only host in PNG. If there were alternate hosts fruiting at other periods then it would be expected that the adults would emerge to utilise these hosts (Krull collected other fruit in Anacardiaceae in PNG and found that RBMC would not feed or develop in them).

In cage breeding trials in PNG, a small proportion of pupae produced adult moths only after pupating for several months, reinforcing the occurrence of a pupal diapause. This would allow RBMC to synchronise its life cycle with the seasonal fruiting cycle of its host (Fenner 1997). Pinese (2005) also confirmed that mature larvae diapause under mango tree bark. When pupation occurs in the bark, it is assumed that the end of diapause is initiated by physiological changes within the tree itself (Krull 2004).

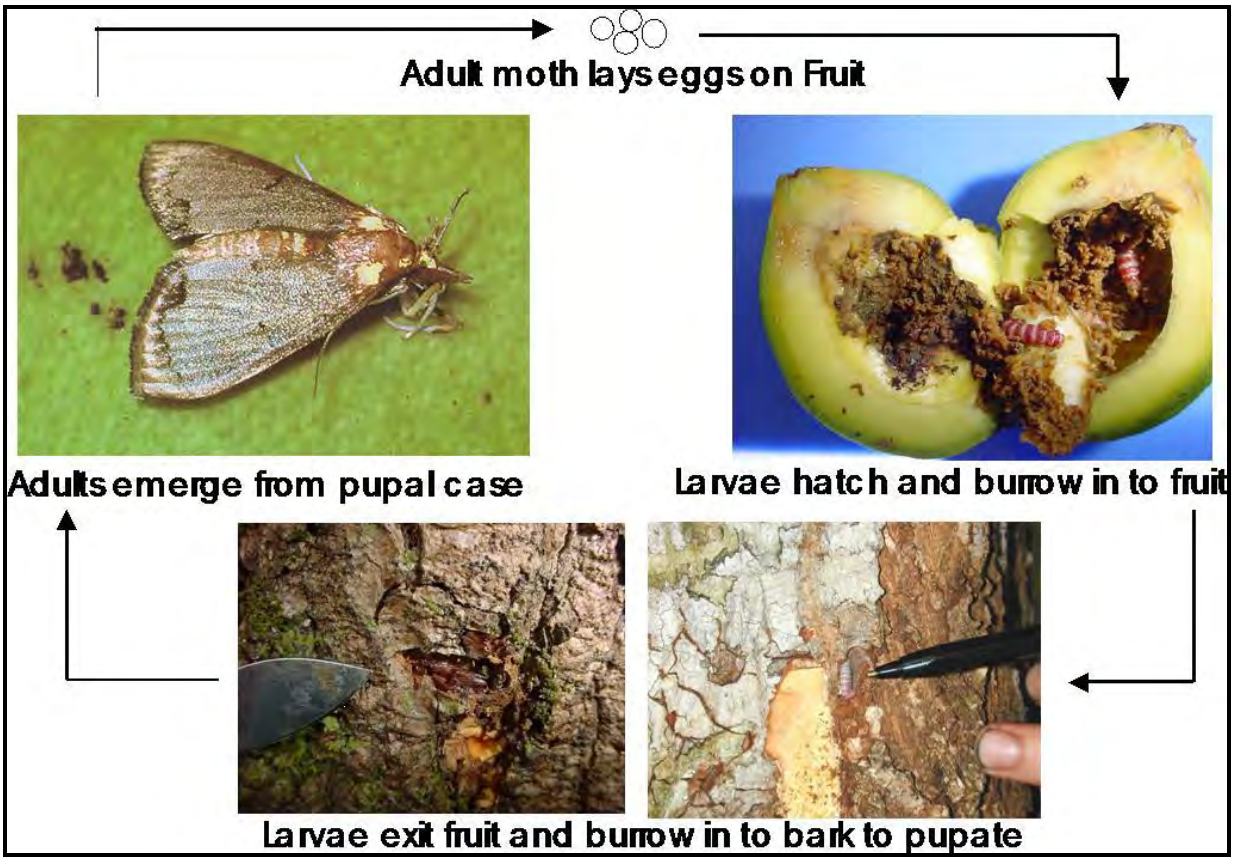

Figure 8. RBMC lifecycle (photos J.Ismay and DPI&F staff)

Adults

Golez (1991) recorded that adults are generally nocturnal, spending most of their time resting under leaves on the host tree during the day. He also noted that gravid females prefer to oviposit on fruit protected from full light, implying that some egg laying activity occurs during the day. Gibb *et al*. (2007) took pheromone gland extracts from 24-72 hour old actively calling females, at 2-3 hours into the scotophase. This infers that mating takes place within 1-3 days from emergence and females call at night.

Sujatha and Zaheruddeen (2002) found that the moths were “very sluggish and fly only a short distance indicating limited scope for adult migration” and suggested that this could account for slow spread of the pest to other mango growing regions, however “sluggish” and “short distance” weren‟t quantified. See Adult Dispersal, p11 for further discussion of dispersal in Australia.

Development Times

Development times may vary between host species, and some cultivars of mango may be preferred over others (Golez 1991).

	(Golez 1991):	(Tenakanai *et al.* 2006):
Egg	3-4 days	8-12 days
1st – 5th instar	14-20 days	11-21 days
Pre-pupa	2-3 days	4-14 days
Pupa	9-14 days	5-20 days
Adult	8-9 days	3-9 days
TOTAL	28-41 days	41-55 days

From the available records it seems logical that population peaks coincide with the peak fruiting times of available hosts.

Gibb *et al*. (2006) observed that catches of male adults in pheromone traps in PNG coincided with the onset of flowering, indicating that adult emergence may be triggered by tree phenology. In 2005, mango flowering in PNG occurred in June-July, and again in October-November. The first RBMC moths were trapped in mid July, with trap catches peaking in late September and late October and declining by December (see Fig. 9). In 2004, Gibb *et al*. (2006) set traps baited with females in mid October, but it was clear from declining numbers of males that they had only caught the end of the RBMC flight for 2004, with the last moth catches occurring in November 2004 (see Fig. 10). Yarrow and Chandler (2007) set pheromone traps in the NPA from early October 2006 to mid November 2006, with trap catch significantly declining by mid November. In Queensland mangoes usually have one flowering per season, which may occur between July and September depending on the region and annual climate variation. Based on the study by Gibb *et al*. (2006), and Yarrow and Chandler (2007) it would be also expected that in Queensland RBMC moths would be active from approximately July to December.

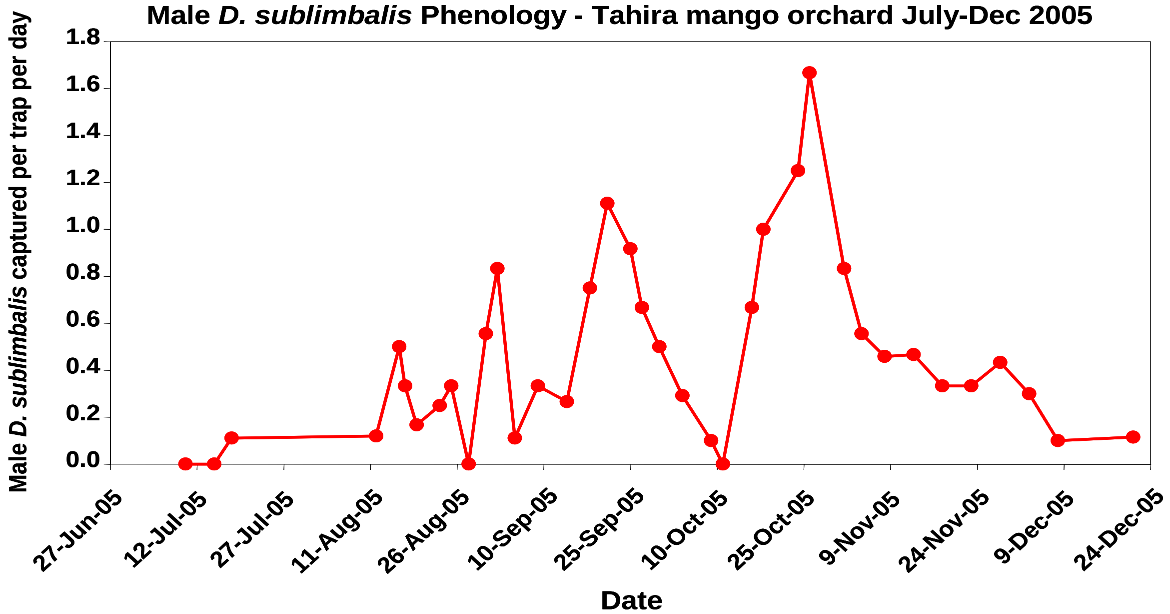

Figure 9. Male *Deanolis sublimbalis* flight phenology at Tahira mango orchard, Central Province, Papua New Guinea from 8 July to 21 December, 2005 (Gibb *et al.* 2006) (Graph courtesy of HAL)

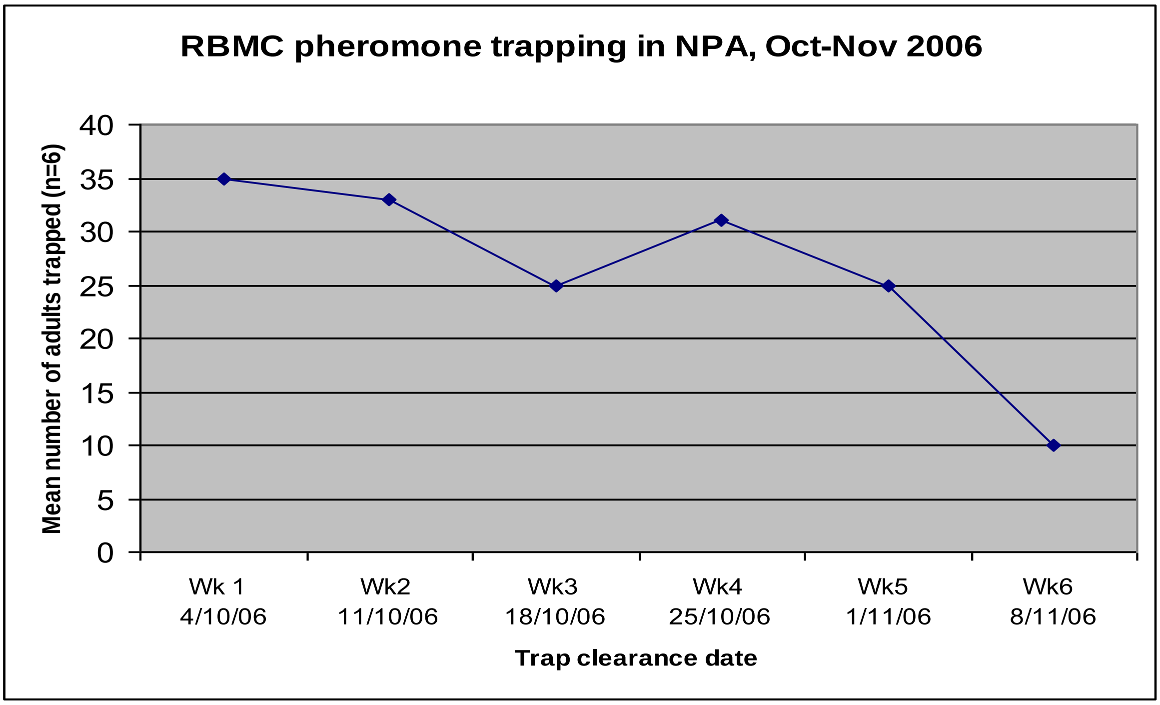

Figure 10. Pheromone trap catches at Lockerbie, NPA October- November 2006 (DPI&F)

Dispersal

Latitudinal & climatic distribution

RBMC is recorded as a serious pest of mangoes in the Indian province of Andhra Pradesh (Zaheruddeen & Sujatha 1993) which is bisected by the latitude line 17°N and has a tropical climate similar to Far North Queensland. Waterhouse (1998) records specimens from the British Natural History Museum collected from Darjeeling which bisects latitude 27°N and has average annual temperatures of 2^{0}C (min) to 19^{0}C (max)* (BBC 2005). This indicates that RBMC would most likely thrive in the Mareeba/Dimbulah production areas which are at latitude 17°S, and could survive climatically as far south as Hobart, were mangoes able to be grown there. All mango production areas in Australia could potentially be affected, including Kununurra and Carnarvon in Western Australia (WA); Katherine and Darwin in the Northern Territory (NT); Atherton Tablelands, Burdekin, Rockhampton, Bundaberg and the Sunshine Coast in Queensland; and the Far North Coast of New South Wales.

*Well adapted to tropical and subtropical lowlands, mature trees can withstand temperatures as low as 3.9°C for a few hours with injury to leaves and small branches. Young trees may be killed at -1.5°C. Flowers and small fruit may be killed if the temperature falls below 4.4°C for a few hours. No significant difference in cold resistance among mango varieties or types has been observed in Florida (Crane & Campbell 1994).

Adult dispersal

In the most recent review of the NAQS target list, RBMC was categorised as having a high potential for colonisation (NAQS 2003). In PNG, Krull (2004) found that RBMC spreads on the original tree first and then onto other trees, indicating that spread within an orchard is slow. RBMC has already shown that it can readily colonise an area through natural dispersal of adults when sufficient hosts are present. The rate and pattern of spread in the NPA indicates that the pest is spreading naturally there at the average rate of seven kilometres per year

(Royer 2008), rather than through human assisted transport (see Fig. 11). Continued spread at this rate would not be expected as a natural buffer zone occurs between the Jardine River and the outstation of Cockatoo Creek 60km south where no mangoes are known to grow. This natural buffer zone could prevent further spread through natural flight dispersal.

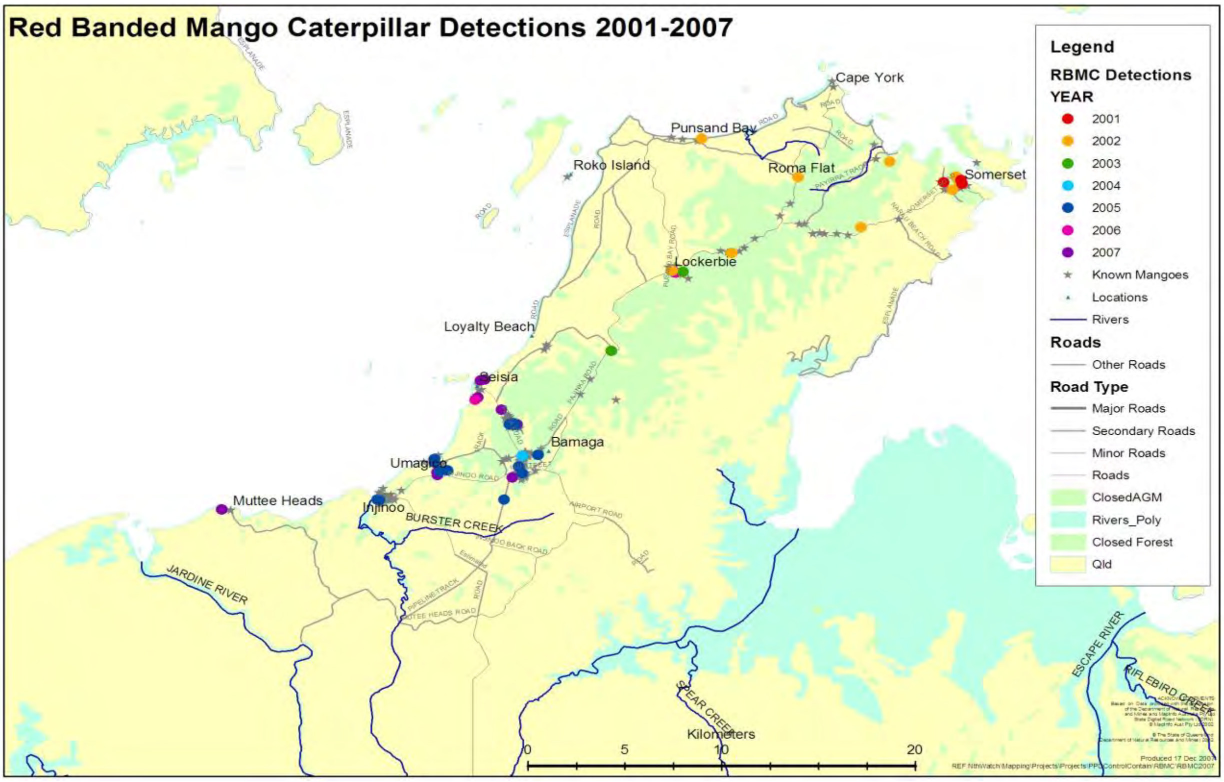

Figure 11. Spread of RBMC in the Cape York Northern Peninsula Area 2001-2007

In the NPA, only mangoes within populated community areas, on roadsides and campsites are generally surveyed as they are at higher risk of human assisted pest movement, and readily accessible. The actual density of mangoes in this area is unknown as there are large tracts of dense rainforest. From local knowledge and some surveillance forays into the forest, it is known that mangoes are scattered through the rainforest, but have not been mapped. From available satellite imagery it isn"t possible to differentiate between mango trees and surrounding rainforest due to limited colour variation in canopy. Any inference on adult flight ability from data gathered in the NPA would be incomplete as only accessible roadside/camp area mangoes were surveyed.

It is unknown whether moths are capable of dispersing over long distances when assisted by wind. In the Torres Strait RBMC has spread large distances between islands, however it remains unknown whether this has been the result of wind assisted movement of adults or human assisted movement of larvae in infested fruit (see Fig. 12).

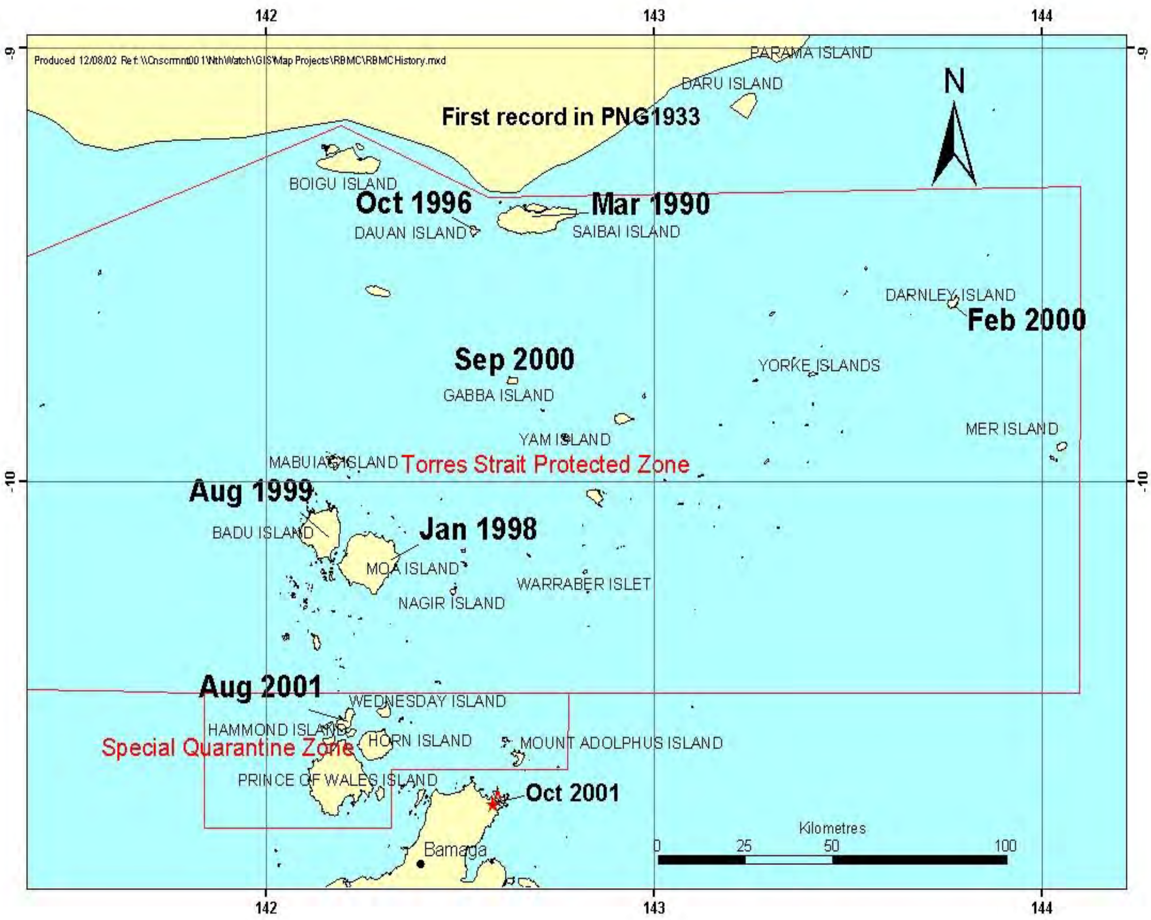

Figure 12. Spread of RBMC through Torres Strait and to Somerset on the Qld mainland

Transport of infested fruit

Due to the aforementioned rate of spread in the NPA and the natural buffer zone south of the Jardine River, the risk of human-assisted movement is probably a greater concern. All fruit found to be infested with RMBC in the NPA by DPI&F staff have shown some external signs of damage, which would render infested fruit a less likely target to be carried for human consumption. However, there have been anecdotal reports of locals in the NPA collecting green mango fruit and later discarding it at some distance when they have discovered it to be infested. The risk of RBMC eggs being carried on fruit not exhibiting damage would appear to be low. In PNG Krull (2004) found that only a small proportion of the eggs (1.92%) were laid on the fruit, the rest being laid on the peduncle or branch. Where eggs were laid on the fruit, they were most often on marble sized fruit or in crevices such as anthracnose spots on fruit, with only a few eggs recorded on mature fruits. Fruit with these characteristics are less likely to be transported for eating.

On the other hand, the first 3-4 days of initial RBMC infestation (first larval instar) may be less obvious and these fruits could potentially be carried for human consumption, risking spread of the pest. Mangoes are present throughout the settled areas of Cape York Peninsula and North Queensland, and there are hundreds of uninhabited sites where feral mangoes have established. Some of these feral sites are popular as camping and fishing spots. People travelling from the NPA to other parts of Queensland could potentially move non-symptomatic infested fruit further south in Queensland or to mango growing regions on the Atherton Tablelands and the Burdekin (approximately 800 km and 1400 km from the NPA respectively), which are easily within 2-3 days drive. To mitigate this risk, a quarantine area has been established north of 13^0 45" S in Queensland to restrict the spread of RBMC (see Fig. 13). Under the *Plant Protection Regulation 2002* a person must not, without an inspector"s approval, move a live mango caterpillar or mango plant (a) from a parcel of land in the pest quarantine area to another parcel of land in the area or (b) into or out of the pest quarantine area. The Coen Information and Inspection Centre enforces controls on the movement of mango fruit and plant material south (see Fig. 14).

RBMC could colonise a new area if infested fruit were transported and discarded near another mango tree. More than one larva may be present in one fruit (Waterhouse 1998), thus one fruit may nurture sufficient male and female moths to allow a population to establish. Larvae can complete their lifecycle, from egg to adult, in 28-41 days (Golez 1991, Krull 2001). In laboratory studies conducted by Golez (1991) and Sujatha and Zaheruddeen (2002), RBMC was successfully reared on picked mango fruit and seed; however they did not state whether mango fruit was replaced to ensure freshness.

Potential scenarios for successful spread of RBMC by movement of infested fruit include:

a) infested fruit is picked and then discarded under another fruiting mango tree with enough fallen fruit for the larvae to move to and be able to complete its larval cycle (presuming it needs other fresh fruit to be able to do so); or
b) infested fruit is discarded under another mango tree which does not have any fallen fruit and the caterpillar can complete the larval stages on the transported fruit.

Either scenario is dependent on the ability of the larva to climb up the trunk of the tree to pupate, and it is not known whether RBMC has this capacity. Thriving RBMC were found in fallen fruit in the NPA. Golez (1991) found that “movement is accomplished by suspending itself in a thread like secretion which facilitated transfer from one fruit to another, and full grown larvae likewise leave the fruit and drop to the ground to pupate”. Predation of larvae by a vespid wasp after falling to the ground was also observed. Although only trunk pupation was found by Krull & Basedow (2006), Golez"s (1991) observation of the larvae dropping to the ground may indicate that the larvae are capable of moving from the ground to the trunk to pupate.

ESTIMATED IMPACT ON PRODUCTION, TRADE, ALLIED INDUSTRIES AND NATIVE ECOSYSTEMS

Mango Production

RBMC is limited to Southeast Asia and Australasia, including India, Burma, Thailand, Vietnam, China, Indonesia, the Philippines, PNG, and now Australia. It has been recorded as a pest in all these countries except Burma and north-east India where the mango probably evolved (Mukherjee 1997). It is possible that RBMC evolved with mango in its natural area and later became a pest as it spread out of its native area.

Pinese (2005) found yield losses averaging 55% in Port Moresby, Central Province and East New Britain. All mango cultivars were attacked including Kensington Pride which suffered losses of 50%, indicating that RBMC has the potential to be a serious pest of commercial and non-commercial mangoes in Australia (where Kensington Pride is the most important commercial cultivar). There are other records of yield losses of up to 40-50% in the Philippines (Tipon 1979, in Waterhouse 1998 p109), up to 20% in the Port Moresby area (Dori 1997, in Waterhouse 1998 p109), 23% in PNG"s Central Province (Krull 2004). Fenner (1997) also states that infestation levels in PNG of 20% or more are not unusual. Surveys in three Philippines provinces in 1985 found a mango infestation rate of between 7.8 and 12.5%. In the following season the infestation rate increased to between 13.1 and 17.4% (Golez 1991), however it is unclear whether pesticide treatments trialled in this study were applied in the same sites where abundance assessments were made.

Mangoes are grown in Queensland, the Northern Territory, Western Australia and New South Wales. Even very low numbers of RBMC would be highly problematic for commercial mango producers. Chemical control would be difficult because the larvae feed internally on the fruit, and oviposition is usually on the peduncle covered with dried sepals (Krull 2004). Systemic insecticides are only absorbed into the sap stream of plants, with uptake of the insecticide by insects being dependent on intake of plant sap, and are therefore only effective against sap feeders (Fenemore 1982). It would be difficult to effectively spray to kill eggs, as they are mostly laid under the calyx. Little is known about potential biological control agents. Additionally, the confirmation of the presence of RBMC in production areas is likely to lead to the imposition of national and international quarantine restrictions. RBMC should therefore remain a priority quarantine pest.

Cost of routine control

In a recently completed ACIAR project on RBMC four synthetic pesticides were trialled on Kensington Pride mango trees in a commercial orchard in PNG. Of the pesticides tested, only the neonicotinoid thiacloprid (Calypso®) was efficacious and reduced damage to almost nil. Chlorpyrifos (Lorsban 500EC®), tebufenozide (Mimic®), methidathion (Supracide®) were also evaluated. Methidathion and tebufenozide were equal to the untreated control, while chlorpyrifos treated trees had increased levels of damage compared to the untreated control (which may be due to removal of the weaver ant (*Oecophylla smaragdina*), a possible biocontrol agent for eggs and first instar larvae (Zalucki & Kuniata 2006).

Trade implications

Annual mango production in Australia was 77 000 metric tonnes in 2004/5 with approximately 71% going to the fresh domestic market, 29% to processing and 4% for fresh export (Holmes 2006) (see Fig. 12). The estimated value of production is $100M (AMIA 2006). Queensland is the main producing state with 60% of the national harvest in 2004/2005 (Holmes 2006). Long term growth trends indicate that Australian production is growing at 8% per annum. In recent years the demand for fresh and processed mangoes has increased (AMIA 2006).

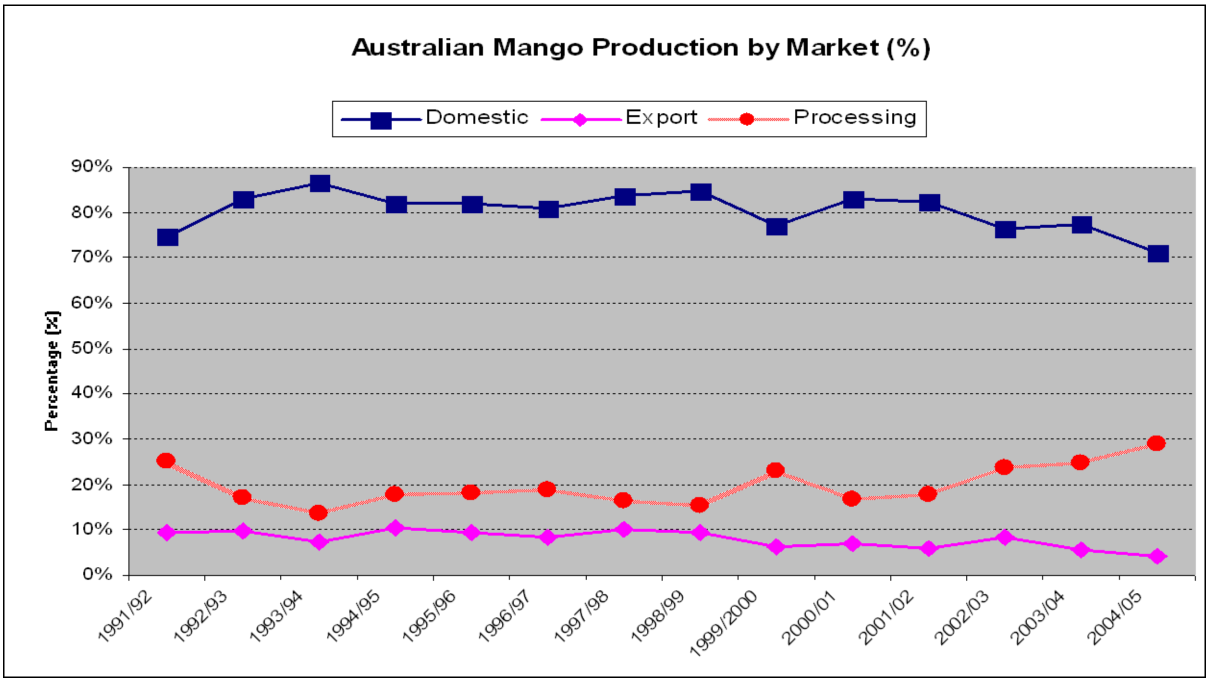

Figure 12. Proportion of Australian mangoes going to domestic, export and processing markets 1991-2005 (Holmes 2006)

The five main varieties of mangoes grown in Australia are Kensington Pride (= Bowen), R2E2, Keitt, Kent Palmer and Brooks. Small numbers of other cultivars are also grown in Qld, NT and WA. Kensington Pride accounts for almost 80% of production in Queensland.

Due to the wide geographical distribution of growing regions, combined with the use of early and late maturing varieties the majority of mangoes are harvested for eight months of the year in Australia, from September to April. However 50% of mango production occurs in December. Fluctuations of up to 44% have been known due to irregular flowering (PHA 2005).

Table 1. Harvest seasons for principal production regions (AMIA 2006)

Kununurra WA	October - November
Northern Territory	Late September - November
Queensland	Mid November - February/March
Northern New South Wales	Late January - March
Carnarvon WA	Late December - Early February
Gingin WA	February - March

Export Markets

Australia's major mango export markets for 2004/2005 were (with percentage of market): Hong Kong (27%), Singapore (22%), Japan (17%), Europe (10%), Middle East (9%), United Arab Emirates (UAE) (7%), Malaysia (7%), Asia Other (0.6%), and New Zealand (0.5%) (Holmes 2006). China has just opened up as a new export market in 2007-2008. Any restrictions imposed by importing countries for RBMC would be dependent on several factors. These include whether the country commercially produces mangoes, if the country already has

RBMC, and what treatments the importing country will accept. One possible post harvest disinfestation treatment is the use of irradiation of fruit to kill eggs and first instar larvae.

Markets likely to remain unaffected:

- Singapore and Hong Kong have no market access restrictions as they have no mango production areas. Combined, these markets accounted for 47% of exports in 2004/2005 (Holmes 2006).

Countries listed on the AMIA website (2006) as having phytosanitary requirements for exporting mangoes from Australia are: Japan, Saudi Arabia, UAE, Malaysia, New Zealand, China.

- Japan has approved Kent, Keitt Palmer, R2E2 and Kensington mangoes for export from Australia. Fruit quality inspections for fruit fly are required. Japan grows mangoes in southern districts, though not commercially (FAO 2003), and does not have RBMC.
- United Arab Emirates - UAE grows mangoes commercially, does not have RBMC, and has existing restrictions for mango seed weevil (MSW) (FAO 2003, AMIA 2006).
- Malaysia grows mangoes commercially, does not have RBMC, and has existing restrictions on MSW (FAO 2003, AMIA 2006).
- New Zealand requires mangoes to be irradiated at a minimum 250 Gray for fruit fly (AMIA 2006). It does not commercially grow mangoes.
- China has recently approved Australian mango exports and has the potential to be a major market. China has existing restrictions for MSW (mandatory vapour heat treatment) and requires pre-export inspections (AMIA 2006). RBMC is present in the Yunnan province of China.

Domestic Markets

Over 70% of mango production goes to the domestic market with an estimated value of $60-80M. Queensland produces 80% of Australia‟s mangoes. The main domestic markets are Brisbane, Sydney, Melbourne and Adelaide (DPI&F 2007b).

Possible impacts on the domestic market of a detection of RBMC in or near a mango production area are as follows:

Quarantine restrictions

All mango growing states and territories are likely to impose quarantine restrictions on the entry of risk items such as plants and fruit. However the impact on export to WA would be negligible (from Queensland at least) due to the state‟s restrictions for mango seed weevil (Tree 2006 pers. comm.). Were RBMC to enter mango production areas, the affected state jurisdiction would likely consider establishing a quarantine area, with restrictions on movement of risk items from and within the area. The greatest impact on the domestic market is likely to be felt in restrictions that may be imposed by NSW. This is due to the presence of the mango industry in that state and the large volumes of fruit exported to NSW from other mango producing areas.

Post harvest disinfestation treatments

Post harvest chemical treatments are unlikely to be effective given that the pest bores into the fruit seed. No chemical treatments are currently known. Irradiation may be viable but testing (likely to take a year) would be required. NT would consider allowing entry of fruit certified as Vapour Heat Treated (VHT), and inspected (Tree 2006 pers. comm.). Hot water treatment may also be acceptable if shown to be effective. Again this would require trials taking at least a year. Mareeba has a VHT facility. For movement of plant material and seed into the NT, NT plant quarantine has indicated that planting material would require treatment, such as a cover spray with e.g. bifenthrin to treat for adults with seed needing to be de-husked and inspected (Tree 2006 pers. comm.).

Emergency chemical registration

Any application for a permit to use certain chemicals for RBMC control would need to be submitted to the Australian Pesticides and Veterinary Medicines Authority. If a pesticide is already registered for a similar use, and information is available on application rates, suitability of the pesticide and background for necessity of the emergency registration, then granting of the permit can be completed very quickly. However, if the previous set of circumstances is not met then processing the application for an emergency use permit could take much longer (Tree 2006 pers. comm.). There are two chemicals currently registered for mango seed weevil and/or RBMC. Reslin® (a.i.bioresmethrin and piperonyl butoxide) is registered under a limited use permit in WA for the control of insect pests of mangoes, including RBMC, mango seed weevil, mango pulp weevil. Actara® (a.i. thiamethoxam) is registered in Qld and other states for control of mango seed weevil (DPI&F 2007a).

Environmental impact

Alternate hosts, *Mangifera odorata, M. minor* and *Bouea burmanica* are not known to be present in Australia hence there would be no environmental impact through damage to these species (Fagg 2005).

Some testing on other Anacardiaceae as potential hosts has been conducted by Krull (2004), and Pinese (2005) in PNG. Anacardiaceae is a small family with only 13 species in Australia. No host specificity testing has been conducted on these species so it is not known whether they could be used as alternate hosts by RBMC. However, their fruit are not physically similar to mango, being much smaller and less fleshy so it is unlikely that they would host RBMC.

The only other known non-economic impact would be on backyard and feral mangoes used for food by the general public. These trees are generally very large and chemical sprays would be unsuitable. Recommendations made by Krull (2004) that could be applicable for householders include:

- Sticky bands around the tree trunks as barriers for RBMC larvae to pupation.
- Bagging fruit with paper bags.

MANAGEMENT/CONTROL OPTIONS

It is recommended that any decision to eradicate be based on the circumstances of each particular incursion. In the event of an incursion into a production area, the procedure outlined in PLANTPLAN (PHA 2007) should be followed. Any attempt at eradication will likely involve the use of chemical controls as no other effective methods are available.

An Australian Centre for International Agricultural Research (ACIAR) funded joint DPI&F/NARI/NAQIA project, (CP/2002/013) *Biology, damage levels and control of red-banded mango caterpillar in Papua New Guinea and Australia* was undertaken in PNG from 2003-2006. The project aimed to provide accurate information about the pest‟s biology and options for its control. At the conclusion of the project an effective pheromone was identified by staff at HortResearch New Zealand and was tested extensively in PNG, and later in the NPA. An effective chemical control option (thiacloprid) was also identified as part of the ACIAR project.

Of four chemicals trialled in PNG during the project, thiacloprid was identified as the only effective chemical control option, reducing RBMC damage to almost nil. Data on application rates, frequency and timing have not yet been released. Registration of this chemical requires efficacy data (available from the ACIAR trial) and residue data. Obtaining residue data requires conducting the proposed spray regime (see Chemical Control p19), harvesting the fruit and having it analysed at a laboratory for spray residue. This process normally takes about a year.

There are currently no known RBMC resistant mango varieties. Little work has been conducted on biological control. Chemical control of RBMC is likely to be the preferred short term management option. However the investigation and importation of biological controls should be considered in the long term as a means of suppressing RBMC populations in feral mangoes and organic orchards.

No other information on eradication is available from the literature and no eradication attempts have been recorded, other than the unsuccessful DPI&F attempt at eradication in the NPA in 2001-2002 using host removal through stag horn pruning of trees. Emphasis in the available literature is on chemical or biological control.

Chemical Control

There is only a short period within the lifecycle of RBMC to achieve good control with synthetic insecticides - the first instar stage between hatching from the egg and boring into the fruit. Control with ovicides is problematic as eggs are usually laid on the peduncle under dried sepals (Krull 2004), making access for the chemical to the eggs difficult.

Of four synthetic pesticides tested in PNG, only thiacloprid (Calypso) showed good efficacy and protected fruit from infestation, reducing RBMC damage to almost nil. Other chemicals trialed which proved ineffective were Lorsban (chlorpyrifos), Supracide (methidathion) and Success (spinosad).

Thiacloprid is currently registered in all states for control of codling moth on pome fruit and oriental fruit moth on stone fruit. Codling moth has a similar lifecycle to RBMC. For codling moth (*Cydia pomonella*, Tortricidae) the recommended application of thiacloprid is as follows “Apply a total of 4 sprays at 14 day intervals commencing at egg lay of the first generation as indicated by monitoring. Apply thoroughly to ensure complete coverage. Do not apply more than 4 sprays per season”. Rates of 37.5ml/L are recommended (DPI&F 2007a). Methidathion (Supracide), is registered for use in mangoes in Queensland against mango seed weevil. However it is recommended as a cover foliar spray to kill adult seed weevil.

From previous research the only record of effective chemical control is from Golez in the Philippines (1991) „Insecticidal application at 60, 75, 90 and 105 days after (fruit) induction were needed to continuously protect the trees from the borer.‟ The most effective pesticides evaluated were the pyrethroids deltamethrin[1] and cyfluthrin[2]. Fenvalerate[3], azinphos-ethyl[4], and carbaryl[5] also reduced RBMC populations, but not as effectively (Golez 1991). Of these chemicals, only carbaryl (which Golez (1991) found to be the least effective), is currently registered for use in mangoes in Queensland.

[1]Deltamethrin is registered in Queensland for the control of heliothis moth in cotton and other crops; rutherglen bugs and leafhoppers in sorghum; on cut flowers to control thrips, weevils, flower beetle; and for a range of exports in domestic, export and timber situations (DPI&F 2007a).

[2]Cyfluthrin is registered in Queensland for the control of fire ants in potted plants (QDPI&F 2007a).

[3]Fenvalerate is not registered in Queensland, but esfenvalerate is registered for the control of heliothis moth in celery (DPI&F 2007a).

[4]Azinphos-ethyl is not registered in Queensland, but azinphos-methyl is registered for the control of white fringed weevil in *Duboisia* sp., and for the control of various moths on stone fruit and nashis (DPI&F 2007a).

[5]Carbaryl is registered in Queensland on mangoes for the control of mango leafhopper codling moth, light brown apple moth, cabbage white butterfly, caterpillars, certain leaf eating insects, green vegetable bugs, fig leafhopper, flattid planthoppers, and pink wax scale. It is also registered for use on a number of other crops (DPI&F 2007a).

Pheromones

An effective pheromone lure has been identified by Hortresearch in New Zealand (NZ) and trialed in the field in PNG as part of the RBMC ACIAR project. In the PNG trial the lure trapped hundreds of male moths and was significantly more attractive than virgin female moths, catching six times more moths than caged virgin females. This lure can now be used for routine trapping of male moths and has the potential to be used for mating disruption (Gibb *et al*. 2007). Initial testing suggested the lure was effective for at least four weeks in the field under tropical conditions (Gibb *et al*. 2006). Gibb *et al*. (2007) note that further work needs to be done on trap type, lure matrices (instead of rubber septa), mating behaviour, dispersal, and lure attractancy range (see Research and Development p28).

Over a one week period in December 2005, trapping was conducted in the NPA by Bruno Pinese in collaboration with DPI&F Biosecurity Queensland staff, but attracted only a few adult RBMC. This was likely to have occurred because the trapping was carried out too late in the season, after mating had occurred.

Trapping conducted in PNG from June to December 2005 indicates that moth activity coincides with mango flowering and fruiting. Male *D. sublimbalis* moths were first captured in mid July (first mango flowering June-July) and were present throughout the mango season with a decline in numbers by December. The rate of moth capture increased during the season with peak numbers trapped during the second mango flowering in October-November (Gibb *et al*. 2006) (see Fig.9).

In October 2006 staff from DPI&F Biosecurity conducted further testing of the pheromone at Lockerbie Station in the NPA, a site known to be heavily infested with RBMC. The pheromone was tested over a period of six weeks from the 4th October til the 15th November (see Fig. 10). Yarrow and Chandler (2006) suggested that trap clearance needed to be weekly to fortnightly in tropical areas to minimise degradation of trap catches.

In its current form the lure impregnated septum used with a delta trap and sticky mat can be used as a supplementary early warning tool. However it is currently not known whether pheromone trapping can detect RBMC when visual surveillance for larvae cannot. As pheromone traps can be set for weeks, it does offer better temporal surveillance, whereas visual surveillance captures a picture of damage at one point in time. The lure"s distance of attraction is not yet known, so it is premature to make assumptions about pheromone trapping offering better spatial coverage for surveillance. Based on current data (Gibb *et al*. 2006) its most likely application is in determining the commencement of moth emergence and possible timing for first application of pesticide. With the time taken from moth emergence to mating and egg laying being currently unknown, this may be of limited benefit for spray scheduling.

Natural enemies

Two species of egg parasitoids, *Trichogramma chilonis* and *T. chilotraeae* (Trichogrammatidae), were recorded as egg parasites of RBMC in the Philippines by Golez (1991), however the rate of parasitism was not commented on. The eggs of RBMC are the only stage of the life cycle that are openly vulnerable to parasitism. Trichogrammatidae are very important egg parasitoids and are used worldwide in control of lepidopteran pests (Hassan *et al*. 1984, Najaraja 1987, Kelmm & Schmutter 1993 in Krull 2004, p154). *Trichogramma* wasps have been used to control caterpillar pests in a range of horticultural and field crops throughout Australia. Adult female *Trichogramma* sp. wasps lay their eggs into those of the moth pests. When the wasp egg hatches, the larva devours the developing caterpillar inside the moth egg. Pests targeted by trichogrammatid wasps include *Heliothis* sp., codling moth, oriental fruit moth, fruit stem borer (pecan stem girdler), macadamia flower caterpillar, cabbage moth, light brown apple moth and loopers (Bugs for Bugs 2005) and codling moth *Cydia pomonella.* Codling moth has a similar life cycle to RBMC (Krull 2004). Krull (2004) recommended utilizing the mass rearing station of *Trichogramma* sp. in the Morobe Province of PNG for laboratory and field trials. In his 2004 trials he found no emergence of parasitoids from a collection of over 2200 pupae and larvae. This could be because RBMC is an introduced species in PNG with no natural enemies established. *Trichogramma pretiosum* and *Trichogramma carverae* are produced by Bugs for Bugs Mundubbera Qld, and *Trichogrammatoidea cryptophlebiae* are produced by Bio Resources Pty Ltd Mount Samson Qld. Trichogrammatids should be investigated for use against RBMC in Australia.

Krull & Basedow (2006) observed in PNG that the weaver ant *Oecophylla smaragdina* was an abundant predator but did not feed on eggs or larvae of RBMC. Coccinellidae also did not feed on RBMC eggs.

Other less promising records of natural enemies include:

- A single tachinid (*Carcelia* (*Senometopia*) sp.) was reared from a RBMC larva in PNG (Dori 1997, in Waterhouse 1998, p109)
- A larval predator *Rychium attrisimum* (Vespidae) in the Philippines, preys on larvae which are moving between fruits or which have recently dropped to the ground for pupation (Golez 1991)
- A fungal pathogen was recorded attacking RBMC larvae in the laboratory in Indonesia (Leefmans & van der Vecht 1930), but was not identified. In a later study, out of 547 larvae kept in the laboratory no signs of attack from pathogens was seen (Krull 2004).

Krull (2004) recommends that further research into natural enemies (parasitoids, predators, fungi, bacteria and viruses) of RBMC should focus on the centre of origin, India and Burma.

Cultural Control

Cultural control methods suggested by Krull (2004) which could be considered for large urban grown trees include:

- Sticky bands around the tree trunks as barriers for RBMC larvae to pupation. The bands would also prevent the weaver ant (*Oecophylla smaragdina*) which could predate on natural enemies of RBMC
- Bagging fruit with paper bags.

These methods are not suitable for large scale commercial production.

QUARANTINE ZONES, MOVEMENT CONTROLS AND RISK MITIGATION MEASURES

Quarantine and containment

A Pest Quarantine Area (PQA) for RBMC is established on Cape York Peninsula from just north of Coen (see Fig. 13). Restrictions on the movement of all mango fruit are in place. The *Plant Protection Regulation 2002* prohibits the movement of mango plants (including fruit) within and from the PQA.

If an infestation of RBMC was found ***outside*** the PQA, properties immediately affected would be quarantined. A Restricted Area (RA) would then be established, with the extent and boundaries of the RA dependent on a number of factors. These factors would include the length of time the pest has been present, likely rate of pest spread, the availability of hosts and the availability of surveillance data.

As an example of this, the average rate of spread of RBMC in the NPA is 7 km per year (Royer 2008). However, mangoes in the NPA are scattered through the rainforest and communities. If an incursion occurred in a mango production area the rate of spread could be faster or slower due to the higher density and availability of host material.

<u>Restrictions would be imposed on the movement of risk items, including plants and fruit, within and from the RA.</u>

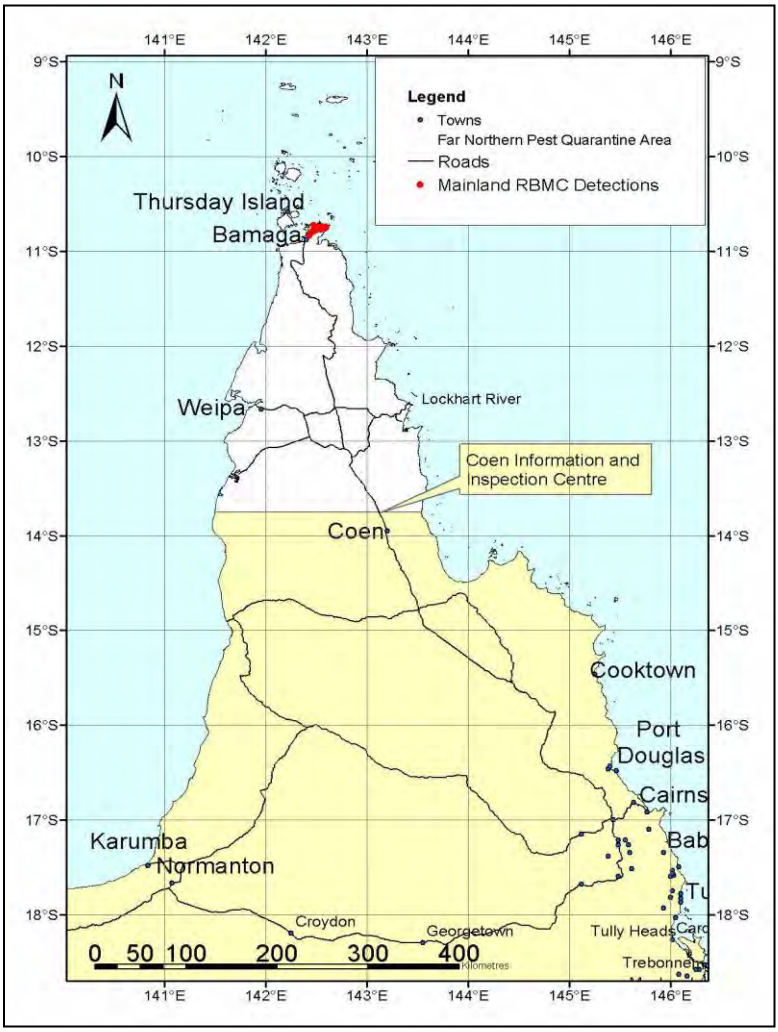

Figure 13. Far Northern Pest Quarantine Area on Cape York, Queensland

The boundary of the RA should be changed as needed after conducting delimiting surveys (see Incursion Delimiting Surveillance p25). All movement of mango fruit or plants from the PQA should cease immediately. All efforts should be made to trace fruit or plant movements to and from the RA, and to examine any such fruit or plants for signs of RBMC where practicable. See Trade Implications – Domestic Markets p17 for detail on post harvest treatment options.

Once the incursion has been delimited a Pest Quarantine Area (PQA) should be established that includes a buffer area from the outermost detections. Again the size of the buffer area would be subject to the consideration of various factors including prevailing winds, the opportunity for natural and human assisted spread into the buffer area and the availability of surveillance data from the area.

Further surveillance should be conducted in the buffer area at the beginning and prior to the end of each mango fruiting period.

Public Awareness

Raising awareness of this pest is important to gain public cooperation in preventing further spread and assist in early detection of new infestations.

Queensland DPI&F undertakes the following public awareness campaign:

NPA communities

- recommendations on how to manage the pest – regular inspection for damaged fruit and destruction through bagging, burning, burial
- an awareness campaign through local radio and press.

Cape York Peninsula (CYP) travellers

- display at the Coen Information and Inspection Centre (CIIC), including posters, pamphlets and RBMC caterpillar specimens in ethanol, two pages in the DPI&F booklet "Biosecurity on the Cape – Everybody"s Business" (2006), note in information kit
- signage – 20 signs are in place throughout the CYP from Mt Molloy north
- radio messages at major CYP centres
- CIIC continues to inspect and prevent movement of mangoes out of the PQA.

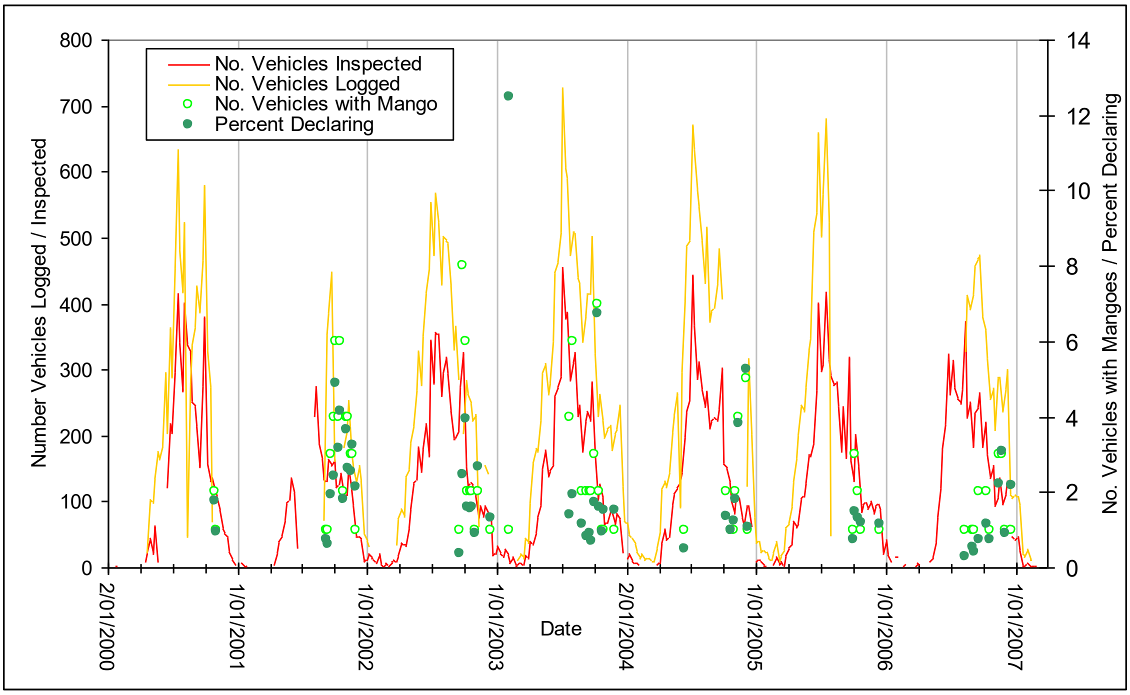

Figure 14. Coen Information and Inspection Centre - number of vehicles travelling south carrying and declaring mangoes.

Mango Growers

- public awareness campaign for growers on the Atherton Tablelands, talk at AMIA meeting, poster on RBMC pheromone trapping at Sixth Mango Industry Conference
- article in Mango Matters newsletter
- leaflets distributed to mango packing sheds.

General Public

- RBMC mentioned in many media releases, radio interviews and TV interviews about surveillance and plant health
- awareness material for RBMC always promoted at garden shows, field days, school talks
- members of the public actively encouraged to look for and report this pest to DPI&F.

In the event of an incursion into a mango production area a copy of the Quarantine Notice should be sent to all growers in the affected areas and advertised in the relevant local newspapers.

SURVEILLANCE

Early Warning Surveillance

General surveillance to detect RBMC should be conducted as part of regular plant pest surveys. DPI&F"s Plant Biosecurity program has a surveillance target list of high priority pests which includes RBMC. Regular surveillance for this pest has been conducted by scientific staff on Cape York Peninsula since the detection in 2001. Delimiting surveys have been conducted in 2001 (two), 2002 (two), 2003 (one), 2004 (one), 2005 (one) 2006 (one) and 2007 (one). This is supplemented by additional Cape and Gulf surveillance during the mango season. In addition, regular surveys have been conducted in urban areas of Cairns, Townsville and

Mackay and the mango production areas of the Atherton Tablelands, Ayr and Bowen. These surveys have been conducted since 1999. Plant Health Inspectors based in Innisfail, Townsville, Rockhampton, Bundaberg, Nambour, Brisbane and Toowoomba have been trained in surveillance for RBMC and conduct surveillance as part of the urban survey program as well as opportunistically during the course of their normal inspectorial duties. Biosecurity Queensland has developed a plant health survey procedure. The procedure includes a field note with RMBC surveillance instructions (see Appendix 1. DPI&F Red Banded Mango Caterpillar Field note).

Incursion Delimiting Surveillance

Commercial or non-commercial detection

If RBMC is detected outside a production area the following delimiting survey protocol is suggested:

1. Survey fruiting mangoes (fruits 3cm long and upwards) at 30 points* in a 1km radius from the initial detection**
2. Survey fruiting mangoes at 50 points between 1 and 5 km from the detection
3. Survey fruiting mangoes at 50 points between 5 and 20 km from the point of detection.

* a point = up to 5 adjacent trees.

** Spread the distribution of the points evenly, though this may not be possible in instances where mangoes are patchy or at low densities. GIS should be used to ensure even coverage, and to log progress and detection sites.

Surveillance methodology

Obtain mapping data that identifies land use, land ownership, mango growers, or previous survey data identifying presence of mango trees. Prior to conducting the survey, maps of the area should be generated with approximate locations to be surveyed overlaying mango presence data (if known). Divide the survey zone (e.g. 1km zone) into quadrants. Teams of two should each be assigned specific quadrants to survey.

Sampling method

Search for any fruit exhibiting signs of damage, such as sap stains or black marks. Thin slices of fruit should be cut from the caterpillar entry point to detect early instar larvae that have not yet burrowed to the seed. The fruit should eventually be cut open to dissect the seed. If no fruit are present then check under the bark for the presence of pre-pupa. See Appendix 2 for further discussion of sampling techniques.

Essential information to collect at each survey location includes:

- **GPS reading:** Teams should calibrate each unit before setting out each day and be trained in correct use. Track log function should be used to track team progress and act as a back up should way points be incorrect for a particular location. The GPS waypoint and GPS unit identifying code should both be listed for each survey site.
- **Address:** Addresses should be taken in full. Street numbers and rural property numbers must be used where possible. Additional landmarks or directions should be documented where the site may be difficult to locate again. If surveying a commercially producing property, the trading name should be documented.
- **Number of hosts present:** The number of trees on a residential property should be counted. For commercial properties the area under commercial mango production should be stated with the approximate number of trees stated if known.

- **Number of trees inspected**: List the number of trees inspected.
- **Mango fruit inspected:** State the total number of fruit inspected (note fruit inspected when looking for sap marks or holes is not the same as fruit cutting). Unmarked fruit is not likely to contain RBMC infestation.
- **Mango fruit cut and examined internally:** State the number of fruit that have been cut and examined internally.
- **Survey Team:** List personnel who conducted the site survey.
- **Date:** Include the date/s the property is visited for inspection.

Mudmap: mudmaps of commercial properties should be drawn to illustrate planting blocks – any infested blocks should be clearly identified.

Mark location of infested trees or where samples have been taken with a GPS waypoint and record on the visit sheet. Flagging tape should be used to mark the tree and the end of the row (in an orchard).

Additional surveillance notes

- If RBMC is detected in a commercial orchard that block should be considered infested. Surrounding blocks should be surveyed to determine extent of infestation on the property.
- Any infestations detected should be reported to the surveillance coordinator as soon as a property is completed. Surveillance effort should be re-evaluated at the end of each day to determine where detections have been made and where the surveillance effort should be focussed the following day.
- Surveillance teams should rendezvous at the surveillance base each morning before setting out for surveillance. They should be given a map and properties to cover to continue the delimiting effort in a logical and efficient manner.

WPHS

Sun exposure, snakebite, dehydration, uncooperative growers etc should be covered and a brief strategy developed for each. If angry growers are encountered staff should leave the property and refer to the surveillance coordinator.

Public Liaison

A media officer is generally placed in State Pest Control Headquarters (SPCHQ). The officer works with the media spokesperson to provide regular updates to the media. No response staff should talk to the media at all unless directed to by the SPCHQ media officer.

Staff Induction

All surveillance staff should be trained in surveillance prior to collecting data. Staff should be briefed on surveillance methodology, symptoms of RBMC, data recording, sample labelling, sample traceability (chain of evidence), conduct on properties and workplace health and safety issues. Staff entering properties should be trained as Plant Health Inspectors under the *Plant Protection Act 1989*, or be accompanied by a staff member who has completed this training.

DIAGNOSTICS AND LABORATORIES

Preservation of samples being sent for specialist identification

- Samples should be collected into vials containing 70% ethanol.
- Ethanol exceeding 70% is a class 3 flammable liquid (Post Guide 2005). "Australia Post accepts in the post an alcoholic beverage of 70% (or less) alcohol by volume, contained in primary receptacles of less that 5 litres".
- Specimens for DNA analysis should be collected into 95% ethanol. As ethanol above 70% is a class 3 flammable substance, packaging of specimens must meet stringent postage and freight packaging requirements specified by IATA 650. Specimens would also need to be packed by suitably qualified staff according to these requirements.
- Ensure the lid of the vial is secure and wrap in absorbent material and place in a secondary larger plastic container. Place the packed specimens in a cardboard mailing box with padding. Address to the entomologist with sender"s name on the back. Clearly write "Insect Specimens" on the front.
- Contact the entomologist to ensure they will be there to receive the sample (see Diagnostic Laboratories below), and can replenish the ethanol on receipt.
- **Send samples by overnight courier. Do not send them in the post.** All consignment notes must be retained and filed for tracing of sample movement. A register of consigned samples should be kept at the Local Pest Control Centre (LPCC) and as samples are received by diagnostic service providers the LPCC should be contacted and the samples signed off as having arrived. Any unaccounted for samples should be followed up by LPCC staff on the day that they were supposed to reach the lab.

Diagnostic Laboratories

The following entomologists should be consulted for diagnosis of suspect RBMC:

Dr Marianne Horak
CSIRO Entomology
GPO Box 1700
Canberra ACT 2601

e-mail : marianne.horak@csiro.au
phone : 02 6246 4259
fax: 02 6246 4264

Jane Royer
Dept Primary Industries & Fisheries
21 Redden St,
PO Box 652
CAIRNS QLD 4870

email: jane.royer@dpi.qld.gov.au
phone: 07 40573640
fax: 07 40573690

Primary identification of caterpillars can be conducted in Cairns however confirmation by PCR analysis should be conducted by Dr Horak on any specimens collected outside of the Cape York RBMC PQA.

RESEARCH AND DEVELOPMENT

Further research would aid effective use of pheromone traps for mass trapping, monitoring or mating disruption and timing of spray treatments. Areas of additional research were identified in the review of the RBMC ACIAR project (Zalucki & Kuniata 2006), and by DPI&F staff in the course of surveillance work.

- Further work, over at least a full year, is required to determine what initiates and terminates diapause and how this relates to tree phenology. Foam trunk traps were used in PNG, but these were still in development and yielded little data. Traps could be set at different heights on trunks and pre-pupae/pupae monitored over a year in tandem with capturing data on mango tree phenology.
- Dispersal and mating behaviour need to be studied to determine what initiates adult spread, if males and females have multiple matings (as this would affect attempts at mating disruption), and time after adult emergence til egg laying for timing of sprays.
- Determine whether larvae pupate on branches or just the trunk, and if larvae drop from fruit to the trunk, or to the ground first and crawl up the trunk - this would affect any cultural controls such as placing barriers around mango trunks to prevent pupation.
- Work is needed to estimate losses over a season. This was done on one occasion in PNG as part of the ACIAR project, and by Krull (2001) in PNG over a season. However, no data were captured on number of larvae and instar stage in each fruit, and size of fruit and fruit abundance at time of sampling.
- Compare pheromone trapping with other sampling methods (fruit cutting for larvae, or bark inspection for pupae), to determine most effective monitoring method through seasons. In order to generate meaningful data on insect presence, activity or abundance, various monitoring methods need to be assessed over time and preferably in different places. Additionally pheromone traps compete with calling females and their effectiveness will vary with the timing in the season.
- The effective distance of lure attraction needs to be assessed to determine trap density required for application in monitoring, mass trapping or mating disruption. A trial to assist in determining this will be conducted as part of an ACIAR project in Indonesia in 2009.
- Determine most effective trap type (delta or bucket) to avoid trap saturation and ensure specimen integrity is maintained.
- Determine optimal trap placement (height and relation to wind direction).
- Field longevity of the pheromone needs to be further studied.
- Comparison of red rubber septa with other lure matrixes would be useful.
- Obtain efficacy data for thiacloprid, and progress its registration.
- Obtain residue data for thiacloprid. To do this, we need to use the proposed spray regime, harvest the fruit and conduct laboratory analysis for chemical residues. This could take a year.
- Trialling disinfestation treatments, particularly irradiation – developing an appropriate irradiation treatment would take approximately a year.

Notable research outcomes from the 2003-2006 ACIAR-funded RBMC project in PNG include:

- Average level of infestation was 55% of fruit.
- Confirmation that mature larvae diapause under mango bark. Preliminary catches of adult moths appear to indicate that emergence may be triggered by tree phenology, in particular the onset of flowering, but this observation requires confirmation.

- A pheromone was developed that was significantly more attractive to male RBMC than caged virgin females.
- The insecticide Thiacloprid (Calypso®) was field tested and proven to reduce RBMC damage to almost nil.

Further research into effective trichogrammatid egg parasitoids is also recommended.

DESTRUCTION/ERADICATION

The feasibility of eradication of an incursion outside of the existing PQA should be considered by the relevant technical advisory panel. Eradication is likely to be only considered feasible if the incursion is found to be small and isolated and there is an effective means of control and prevention of spread. Pheromone trapping and intensive surveillance of fruit and bark should be conducted in a substantial buffer zone around the incursion, so that there is a high level of confidence in the limited presence of the pest. Density of surrounding host material should also be taken into account to allow for escape of the pest at very low (undetectable) levels. Pathway of introduction should also be examined to determine whether an infestation is likely to be isolated rather than a detection that is part of a natural spread continuum.

Eradication by habitat destruction was attempted with the first Australian mainland detection at Somerset. All known mango trees in the infested zone were either staghorn-pruned (pruned to the first fork) to prevent them from fruiting for at least two seasons, or injected with herbicide to kill them. This eradication attempt was unsuccessful. When it was conducted, available information in the literature indicated that the larvae pupated in the soil or leaf litter. As it is now known that pupation takes place in the bark and the pupa diapause when the trees aren"t fruiting, staghorn pruning is now considered an ineffective option. The area where the infestation occurred is remote forest with many feral mango trees spread through it, so even if staghorn pruning were an effective option on infested trees it would be a near impossible task to locate all mango trees in this area. Eradication would be difficult in remote areas of north Queensland, as feral mango trees are widespread through most areas.

Planning and pre-treatment of affected site and disinfestation

Mechanical pathways

Vehicles should not be parked under or near mango trees. Any chainsaws, or other equipment should be thoroughly checked on entry and exit from site to avoid spreading the pest.

Effective chemicals

There is insufficient information as yet on the efficacy of chemicals (thiacloprid) to determine whether eradication through this means is feasible. If an incursion were to occur in a mango production areas then this would require consideration. Chemical treatments are unlikely to be effective in urban or feral areas due to the large size of the trees.

Boundary definition

Intensive surveillance of fruit and bark of all hosts should be conducted in a 20 km buffer zone around the infestation before seriously considering an eradication effort.

Removal and destruction

Disposal biosecurity

As RBMC pupate in the bark, total host destruction is recommended on site. Host material should not be removed from the site and should be burnt as soon as practical to destroy any diapausing pupae. This may only be feasible in commercial areas with smaller mango trees.

Confirming eradication

Final approval of a Pest Free Area (PFA) at a national level should be based on evidence that meets both national and international quarantine standards.

If eradication appears to have been achieved then a program of regular surveillance in the known infested area and buffer zone should continue for a further two years before declaring area freedom. Infested areas targeted for eradication should be surveyed for presence of RBMC for two years after host destruction. As host material would now be absent from the direct vicinity pheromone traps should be used to attract any adults that may have spread to nearby mango trees.

- Pheromone trapping – the density of pheromone trapping to effectively monitor for RBMC presence remains unknown. Trials to assist in determining this will be conducted as part of an ACIAR project in Indonesia in 2009. Trapping should be conducted for two years after the last known RBMC has been found, within a 20 km buffer around the eradication zone.
- Surveillance for larvae in fruit and pre-pupae in bark should be conducted in a 15 km buffer zone 3 times per year, during fruiting season, for two years.

TECHNICAL DEBRIEF AND ANALYSIS FOR STAND DOWN

Refer to section 2.4 of PLANTPLAN for detail of the stand down phase of the national emergency in more detail.

Eradication unsuccessful/unfeasible

If eradication of RBMC is not considered feasible or cost beneficial, efforts should move to controlling pest spread, investigating long-term control methods and movement restrictions. An example scenario would be if RBMC was detected in a large area surrounded by a reasonable density of host material (such as a production area). Control through chemical sprays and pheromone trapping/mating disruption could be used, in addition to movement restrictions to prevent further spread of the pest. Refer to PLANTPLAN.

Area-wide management strategies coordinated by industry bodies assisted by DPI&F would assist in reducing population reservoirs.

Integrated pest management strategies should also be investigated to avoid over- reliance on pesticides and potential pest resistance.

Technical recommendations for ongoing pest management

Management advice

Where eradication is unsuccessful, government agencies and industry will require technical analysis from experts to guide decisions on containment and control.

Containment

Refer to Quarantine Zones/Movement Controls p22. Appropriate warning and information signs would need to be in place to prevent movement of infested fruit by the general public.

Control/Management

Refer to Management/Control Options p18. Long term control strategies will need to be established such as longer term registration of chemicals.

Industry adaptation strategies

Certain domestic and international markets are likely to be affected with an ineradicable incursion into a production area. Longer term market loss mitigation strategies should include:

- Investigation into unsourced foreign markets that do not have restrictions on RBMC (non-mango growing countries), working in with market access staff from state and federal agencies.
- Research into postharvest disinfestation treatments to determine efficacy treatments such as vapour heat treatments, irradiation and chemical dips.

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Appendix 1. DPI&F Red Banded Mango Caterpillar Field note

RED BANDED MANGO CATERPILLAR

Surveillance Technique: Examine fruit on trees and ground from marble size up for signs of sap exudation. Cut fruit in thin slices around any holes, then cut through seed.

Number of plant items to sample: Visually inspect at 50% of the easily visible fruit on the tree for any black marks or sap stains. Remove the fruit from the trees, using extendable cutters if necessary, and cut the fruit as above.

Sampling period: During mango fruiting season. Peak period September to December.

Organism: *Deanolis sublimbalis* Snellen (Lepidoptera:Pyralidae)

Hosts: Mango (*Mangifera* spp.)

Distribution: Torres Strait, Northern Peninsula Area of Cape York Peninsula, Papua New Guinea, Indonesia (Java), Philippines, Thailand, India

Nearest location to Australia: Torres Strait and Northern Peninsula Area of Cape York Peninsula (under official control)

Biology: The adult moth lays eggs mainly on the peduncle, sometimes covered by the sepals or deposited in small crevices in the fruit. Upon hatching, larvae tunnel towards the seed, feeding on fruit pulp, but causing the most damage within the seed. Fruit are attacked at various stages of development from marble size up, and damage renders fruit unsuitable for consumption. Boring may cause secondary infection by other organisms, commonly resulting in fruit drop. Egg stage 3-4 days, larval period 14 days, pupal period 14 days. Generally only one larva per fruit, but up to 11 have been found. Larvae reach 2 cm in length and have characteristic red and white bands with a dark brown to black head. Causes high yield losses in mangoes.

Signs/symptoms: Sap burns at point of entry and characteristic sap-runs down the fruit. Holes may be apparent at the fruit surface. Cutting the fruit including the seed will expose caterpillar if still present. Caterpillar has distinctive red and white bands across abdomen. Large amounts of frass (excreta) often present in seed.

How to collect samples: Collect any caterpillars and place in 70% ethanol together with pencil written label.

Diagnostic laboratory: All regions: Send samples directly via post: Jane Royer, Biosecurity, DPI&F, PO Box 652, Cairns Qld 4870

Further information contact: Diagnostic entomologist, Cairns Biosecurity Plant Health Laboratory tel 07 40573640; mobile 0427 131 490; email Jane.Royer@dpi.qld.gov.au

Appendix 2. Sampling Techniques for RBMC

Fruit cutting
Select fruit with signs of damage. First look for dark sap stains on the skin, then inspect the fruit to ensure the stain is not due to sap run from stalk damage.

Small fruit less than 6cm should be cut with a pocket knife in thin slices from the entry hole on the skin towards the seed. On small fruit early instars are often found directly under the skin. The seed can then be chopped open to look for RBMC.

Larger fruit over 6 cm can be cut in half to look for RBMC in the seed. However once fruit gets over a certain size (approx. 11 cm) the seed can become very hardened and virtually impossible to cut.

Bark inspection
This is a secondary surveillance tool that can be used if a tree is not fruiting. With a sturdy pocketknife prise back chunks of bark and look for the prepupa. Pupa are more difficult to diagnose but can be collected for DNA analysis.

Sweep netting
It should be noted that efforts are better concentrated on larval detection which allows for easier and cheaper diagnosis. Sweep netting is a tertiary surveillance technique to detect adults when trees are not fruiting or to collect adults on known infested trees for reference purposes (one should be aware that fees would be attached to a positive diagnosis for adults).

Sweep the tree for the presence of adults. Collect into a killing jar, leave the specimen in until dead then transfer to a specimen jar with a bit of tissue paper. Freeze as soon as possible, and leave at room temperature only for as long as it takes to express post to an entomologist.

Other methods
Light trapping methods are not recommended as it is labour intensive and involves sorting through many moths that would be attracted to light during a night.