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# **Studies on the Mango-Ecosystem in Papua New Guinea with special reference to the ecology of *Deanolis sublimbalis* Snellen (Lepidoptera, Pyralidae) and to the biological control of *Ceroplastes rubens* Maskell (Homoptera, Coccidae)**

Thesis
Submitted in fulfillment of the requirements for the Doctor degree
in agriculture (Dr. agr.)
Fachbereich Agrarwissenschaft, Ökotrophologie und Umweltmanagement der
Justus-Liebig-Universität Gießen

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Gießen, February 2004

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# Table of content

# 1. General introduction

The mango (*Mangifera indica* L.) (Anacardiaceae) originated in southeast Asia and its cultivation is estimated to have begun at least 4000 years ago in India (DeCandolle, 1884), where the fruit is a very important cultural and religous symbol. This high esteem applies to all parts of Asia, where it is considered to be the “king of fruits” (Purseglove, 1972). The mango is the most important fruit in Asia, and currently ranks fifth in total production among major fruit crops worldwide after bananas, citrus, grapes and apples. Between 1971 and 2002, the worldwide production of mango has increased by over 100 % - in 2002 the production was estimated to be around 25.75 million tons (FAO Statistical Database, 2003).

Mangos are a very important component of peoples diet in many less developed countries of the tropics and subtropics. In regions of the world with low living standards and serious nutritional deficiencies, their attractiveness and flavour have also enhanced the quality of life (Litz, 1997).

In Papua New Guinea (PNG), when in season, mangos not only play an essential part of the daily diet but also contribute significantly to the income of subsistence farmers and other local producers who sell the fruit on the daily markets. Mangos like the local variety “Rabaul” sell for Kina 2.00 which is equivalent to € 0.50. A lot of money, considering the fact that the monthly minimum wage is about K 120.00 (= € 30.00). Nevertheless, the current production cannot keep up with the consumer demand. The reasons for this are manifold but related. Most of the mangos are grown in household gardens, some in small orchards at subsistence level and only a few in plantation form. Cultural practices like pruning and chemical and/or biological pest control that would lead to an increased production, are therefore only rarely known or used. Instead, the production and quality is low. On the other hand, the PNG Government is seeking to increase the cultivation of crops and fruits like mango in order to become export commodities. For the export market fruit quality has to be very stringent. This requires the production of healthy and clean fruit.

In PNG, insects pests are considered as one of the main factors contributing to the production and quality losses in mango. But so far little is known about their biology, or their or their natural enemies – basic informations which are required to develop appropriate control measures or to apply already existing and proven methods. This is essential for the production of healthy fruit and, which will, eventually be the key for the issue of export and import licences.

To avoid overlapping and to give a better overview, the following work is divided into four chapters with every chapter having its own introduction and summary.

- Chapter 1 covers the collection and identification of predatory arthropods in mango by pitfall traps and the beating method, and discusses their potential role in the control of insect pests.
- Chapter 2 provides an overview of relevant insects pests on mango in the Central Province of PNG, and discusses their significance and potential control methods.
- Chapter 3 describes the work conducted on the biological control of the pink wax scale *Ceroplastes rubens* (Homoptera, Coccidae) with the introduced parasitoid *Anicetus beneficus* (Hymenoptera, Encyrtidae).
- Chapter 4 provides information on the biology of the red banded mango caterpillar *Deanolis sublimbalis* (Lepidoptera, Pyralidae), and discusses potential control methods.

## 2. The mango tree

### *Botany*

According to Kaur et al. (1980) the mango tree is believed to have evolved as canopy layer in the tropical rainforest of southeast Asia. Mature trees attain heights of up to 30 m and can survive for more than hundred years. The tree is an arborescent evergreen tree with alternate, oblong ovate leaves that are spirally arranged.

Young leaves are characteristically pink to red in colour but become dark green and leathery during development. Older leaves are 12 – 15 cm in length. The inflorescence is erect and widely branched with hundred of small flowers. The flowers are pink to red in colour and 6 – 8 mm in diameter. Both female and male flowers are found within a single inflorescence. The pollination is done by insects, in particular flies (Singh et al., 1962; Jiron & Hedström, 1985).

***Cultivation***

*Mangifera indica* is the most important out of 69 species belonging to the genus *Mangifera*. According to Cañizares Zayas (1982) another 15 species are cultivated but their distribution and use is restricted to southeast Asia. The species *M. minor*, *M. monandra* and *M. similis* are seen as having great potential for an extended cultivation (Gruezo, 1992). *M. odorata* is widely grown in the humid lowlands of southeast Asia in areas unsuitable for *M. indica*.

***Growth and reproductive development***

Mangos grow best in the warm climates of the tropics and subtropics. Temperatures between $24^{o}$ and $28^{o}$ C are considered to offer the optimum conditions (Krishnamurti et al., 1961). A minimum annual rainfall of 1000 mm is required for growth and development, although the tree is able to resist dry periods for months. Extreme humid conditions and temperatures under $0^{o}$ C are less tolerated.

The development of mango buds is strongly influenced by temperature (Ravishankar et al., 1979; Schaffer et al., 1994). Night temperatures between $8^{o}$ and $15^{o}$ C in combination with daytime temperatures below $20^{o}$ C typically induce flowering (Ou, 1980; Núñez-Elisea & Davenport, 1994). In the absence of cool temperatures in the tropics, mango trees produce flowers following a drought of 6-12 weeks or more (Pongsomboon, 1991), although it is believed that the primary impact of water stress is to prevent vegetative flushing. Vegetative shoots develop in warm, humid conditions ($30^{o}$ C day, $25^{o}$ C night).

***Varieties***

The most important variety of *M. indica* in Australia is „Kensington Pride". Other worldwide important varieties are: „Alphonso, Haden, Kent, Mulgoba, Pathiri, Neelam, Raspuri and Totapuri" (Kranz, 1981). In PNG, the local variety „Rabaul" is widely distributed and very much in demand.

## 3. Study sites

Seven sites were selected for this study, five sites in the Central Province and one in the Morobe and Eastern Highlands Provinces, each. Details of the sites are given below.

The Central Province is at the south of Papua New Guinea and has an average annual rainfall from 1000 – 1200 mm. The rainy season in this province usually commences by the end of November and lasts until March/April with the dry season occupying the remaining months. The flowering of mango trees starts in July and lasts to the end of August or early September. Fruits are harvested from October through until the mid of December.

Studies on the biology of the red banded mango caterpillar *Deanolis sublimbalis* (Lepidoptera, Pyralidae), on arboreal and predatory arthropods and the survey of important mango pests were conducted in the Central Province, whereas the studies on the biological control of the pink wax scale *Ceroplastes rubens* (Homoptera, Coccidae) included also one location in the Eastern Highlands Province as well as one in the Morobe Province.

***Mango Plantation of the Livestock Development Cooperation at Launakalana***

Launakalana is approximately 120 km to the west of of Port Moresby in the Central Province. The plantation consists of about 3000 mango trees with Kensington Pride being the dominant variety and accounts for 80 % of all trees. Other varieties are: Glenn, Totapuri, Nam Doc Mai, Large Apple, Banana Calo, Irwin and Cedrine.

The first trees (approximately 700) were planted in 1994 and plantings of similar numbers continued during the following years. No synthetic or biological insecticides have been used so far since number of insect pests were insignificant and did not require any action. In contrast, anthracnose (*Colletotrichum gloeosporioides*) is a major disease, attacking fruits as well as flowers and flowering shoots and therefore is responsible for most of the production losses. To control the fungus, the fungicides Dithane (Mancozeb) and Kocide (Copperhydroxide) are regularly applied. In general, the plantation is in a poor condition due to management and maintenance problems. During the last two years, only 200 out of 3000 trees bore fruit. The problem with anthracnose further developed because of non-weeding between the rows increasing the humidity and thus enhancing the distribution of the disease.

***Laloki Agricultural Research Station***

The Laloki Agricultural Research Station of the National Agricultural Research Institute is located about 25 km to the northeast of Port Moresby. A small mango orchard (variety Kensington Pride) of about 70 trees was established in 1998 but most of the trees failed to develop because of constant flooding and drying of this area. On and around the station there are about 30 - 40 fully grown mango trees of local varieties. No pesticides have been applied to control fungal diseases or insect pests.

***Mango Plantation of the Pacific Adventist University (PAU)***

This orchard is situated about 25 km to the northwest of Port Moresby. About 300 trees were planted in the 1980’s and another 120 in the early 1990’s. The main variety is Kensington Pride. Small numbers of other varieties like Banana Calo, Irwin, Glen and Large Apple have also been planted. In the past few years the orchard has been poorly maintained and as a consequence yields have decreased significantly. No dominant insect pest has been identified so far and consequently no insectides were applied. To control anthraknose, the orchard was regularly sprayed with fungicides.

***Tahira Mango Plantation***

Tahira is located about 35 km to the east of Port Moresby. The plantation is divided into 2 smaller orchards with the older one, which was established in 1984/1985, containing about 220 trees. The younger consists of about 110 trees, which were planted in the early 1990's. The main varieties are Kensington Pride, Irwin and Glen. The orchard formerly belonged to the Department of Agriculture and Livestock, but for the last eight years it is privately owned and well maintained. No pesticides have been applied for at least eight years.

***Sorgheri Citrus Plantation***

The Sorgheri plantation is located 70 km to the northeast of Port Moresby at an altitude of about 600 m. The orchard contains about 4000 citrus trees. No studies were conducted this at this location; it served only as a release site for the parasitoid *Anicetus beneficus*.

***Erap Agricultural Research Station***

This research station lies in the lower Markham Valley in the Morobe Province of PNG. The rainfall averages from 1200 – 1400 mm annually with the rainy season lasting from May to November. The orchard contains about 80 mature mango trees with the dominant variety being Kensington Pride. It served as a site for the collection of *Ceroplastes rubens* and determination of parasitization levels and identification of parasitoids only.

***Highlands Agricultural Research Station, Aiyura***

This research station is located in Eastern Highlands Province at an altitude of 1360 m. The annual rainfall varies between 1900 and 2200 mm with the rainy season from November to May. Since no mango trees grow at this altitude, pink wax scales have been collected from avocado trees and checked for presence of parasitoids.


**Figure 1:** Location of study sites in Papua New Guinea

Legend:

1. Laloki Agricultural Research Station
2. Mango orchard of the Pacific Adventist University (PAU)
3. Tahira mango plantation
4. Sorgheri citrus plantation
5. Launakalana mango plantation
6. Erap Agricultural Research Station
7. Highlands Agricultural Research Station, Aiyura

# 4. Studies on arboreal and epigeal predatory arthropods in two mango orchards in the Central Province of Papua New Guinea

## 4.1 Introduction and objectives

Predators play a significant role within the biological control of insect pests (Hassan et al., 1993; Howarth, 1991; Smith et al., 1997; deBach, 1974) and their importance was recognized very early (Clausen, 1962; Basedow, 1973; deBach, 1974).

Within the predatory arthropods Hymenoptera (Formicidae), Coleoptera (Coccinellidae, Carabidae, Staphylinidae) and Araneae are considered as important control agents of insect pests (Basedow & Bernal-Vega, 2001; Baliddawa, 1985; Berube & Parella, 1993; Clausen, 1962, 1978; van den Bosch et al., 1982).

In case of ants, their first utilization in pest control dates back 1700 years, when in Southern China weaver ant nests (*Oecophylla smaragdina*) were gathered, sold and placed in citrus trees to combat insect pests (Hölldöbler & Wilson, 1990). The practice still continues today (Huang & Yang, 1987). Studies by Peng et al. (1995) showed that in Northern Australia *O. smaragdina* significantly reduced the numbers of four important insect pests in cashew: *Amblypelta lutescens*, *Anigraea ochrobasis*, *Helopeltis pernicalis* and *Penicillaria jocosatrix*. In PNG and the Solomon Islands *O. smaragdina* was recorded effectively regulating the populations of the coconut bug *Amblypelta coccophaga* and the cacao pests *Amblypelta theobromae*, *Pantorhytes plutus* and *Pseudodoniella laensis* (Brown, 1959; Szent-Ivany, 1961; Greenslade, 1971).

In Africa the species *Oecophylla longinoda* is an important predator of the mirid *Pseudotheraptus wayi*, thus significantly reducing the damage by two pathogens transmitted by this pest (Hölldöbler & Wilson, 1990). *O. longinoda* is known to feed on *Distantiella theobromae* in Ghana (Collingwood, 1971). In PNG, the crazy ant *Anoplolepis longipes* was identified as an effective predator of *Pseudodoniella laensis* in cacao and later also mass-reared and released to control *Pantorhytes* spp. (Szent-Ivany, 1961).

Within the Coleoptera the most important predators belong to the families Coccinellidae, Carabidae and Staphylinidae (Krieg & Franz, 1989). Both adults and larvae are predatory. The first successful examples of biological control with ladybird beetles date back over 100 years when the Australian species *Rodolia cardinalis* and *Cryptolaemus montrouyzieri* were introduced to California for the control of the cottony cushion scale *Icerya purchasi* and the citrus mealybug *Planococcus citrii*, respectively (deBach, 1974; Malapatil et al., 2001). *Cryptolaemus montrouzieri* as many other coccinellid species (e.g. *Rhyzobia lophantae* for the control of different diaspidids) are now commercially produced (EPPO – Database, 2003; Hassan et al., 1993). The importance of carabids and staphylinids for biological pest control in agriculture and forestry was recognized early. The first successful use was the introduction of the carabid *Calosoma sycophanta* to North America in the 19$^{th}$ century to reduce the increasing populations of various caterpillars, particularly *Lymantria dispar* (Trautner & Geigenmüller, 1987; Krieg & Franz, 1989). Other important predatory carabids can be found in the genera *Bembidion*, *Agonum*, *Pterostichus*, *Amara* and *Harpalus* (Thiele, 1977). The majority of Staphylinidae are predators, although some species within the subfamilies Omalinae and Aleocharinae live on plant material like flowers or are parasitic. Important predatory species can be found in the genus *Staphylinus*, *Philontus*, *Paederus* and *Tachyporus* (Kollat-Palenga & Basedow, 2000).

Spiders are predatory, carnivorous arthropds. Their prey very largely consists of insects including beneficials. However, despite this fact spiders are considered as important antagonists of insect pests (Nyffeler, 1982; Sunderland et al., 1987). It was calculated that in annual crops and meadows up to 2 kg of fresh insect biomass per hectar and year are consumed by spiders; or even to 200 kg in fallows and forests. In some cases over 1000 aphids were recorded in one net (Fortmann, 1993). These figures explain, why spiders can have a great impact on insect populations and, in particular, on pest populations.

In Papua New Guinea epigeal and arboreal predatory arthropods in mango have not yet been identified, and their role and importance as antagonists of mango pests remains unclear. The following study was therefore undertaken to collect and identify predatory arthropods in mangos by pitfall traps and the beating method and to assess their role in controlling insect pests, particularly pink wax scale (*Ceroplastes rubens*) and the red banded mango caterpillar (*Deanolis sublimbalis*).

## 4.2 Material and methods

### 4.2.1 Study sites

Predatory arthropds were collected at the PAU and the Launakalana orchard.

### 4.2.2 Predator catches

#### 4.2.2.1 Epigael predatory arthropods

To determine the diversity and frequency of epigael predatory arthropods thirty pitfall traps (white plastic cups with 11 cm in diameter) were placed at a distance of ten meters at each study site. The pots were filled up to a third with 1 % formalin. A few drops of dishwashing liquid were added to reduce surface tension. The distance to the edges of each orchard was 25 m. As a protection against rain and dirt, wooden covers were placed over the traps. Catches with pitfall traps will contain primarily epigeal predatory arthropods, in particular beetles (Coleoptera: Caribidae and Staphylinidae), spiders (Araneae), ants (Hymenoptera: Formicidae), crickets (Orthoptera: Gryllidae) and centipedes (Chilopoda).

#### 4.2.2.2 Arboreal predatory arthropods

The diversity and abundance of arboreal predatory arthropods was determined by using the beating method. In contrast to pitfall traps, figures obtained with the beating method indicate the number of individuals per $m^2$. Thirty trees were randomly picked at each monitoring date and five branches per tree were beaten with a wooden stick. Each branch was beaten three times. To collect the insects, an insect net (42.5 cm in diameter) was placed under each branch. The bottom of the net was cut open to attach a plastic cup (11 cm in diameter). The cup was filled with 1 % formalin. The insides of the net were brushed after beating to collect those insects which did not immediately fall into the catching fluid. The beating method will catch spiders, ants, ladybird beetles (Coccinellidae), Heteroptera, Neuroptera and Mantodea.

### 4.2.3 Study period

The arthropods were collected during October, November and December 2000. During this period at each study site the barber traps were emptied five times at an interval of two weeks. The arboreal insects were collected at the same dates.

### 4.2.4 Identification of insects

The identification of the genera of ants was done using the keys by Shattuck (1999) and Hölldöbler & Wilson (1990). The genera of carabids and subfamilies of staphylinids were identified by using the key of Trautner & Geigenmüller (1997). Coccinellidae and Lycidae were identified by Dr A. Slipinski (CSIRO, Australia). The spiders were identified to family status by using the keys of Kaston (1975) and Roberts (1995). Heteroptera were identified to family status. Dermaptera, Mantodea, Neuroptera, Orthoptera (Gryllidae) and Chilopoda were not further identified. The insect collection of the National Agricultural Research Institute (NARI) in Port Moresby served as a reference collection.

## 4.3 Results

### 4.3.1 Epigeal predatory arthropods

#### 4.3.1.1 Occurrence and composition

In total 3539 epigeal predatory arthropods were collected, which included 1529 individuals from the PAU orchard and 2010 individuals from the Launakalana orchard (Table 1). The most dominant order were Hymenoptera with 2772 specimens captured, which was 78.33 % of all collected predators. Araneae were second most numerous with 524 captured individuals (14.80 %). Coleoptera, Dermaptera, Orthoptera and Chilopoda were only found in low numbers (1.61 %, 0.17%, 2.85 % and 1.30 % of the total percentage, respectively).

**Table 1:** Number of predatory epigeal arthropods caught with pitfall traps in two mango orchards in the Central Province of Papua New Guinea.

| Location | PAU | | | | | |
|---|---|---|---|---|---|---|
| | **Orders of predatory arthropods and number of individuals collected** | | | | | |
| **Sampling date** | **Coleoptera** | **Dermaptera** | **Hymenoptera** | **Orthoptera** | **Chilopoda** | **Araneae** |
| 15.10.00 | 5 | | 233 | 22 (12) | 6 | 75 |
| 29.10.00 | 16 | | 139 | 15 (6) | 4 | 50 |
| 12.11.00 | - | 1 | 481 | 37 (20) | 10 | 106 |
| 26.11.00 | 3 | | 69 | 18 (6) | 6 | 35 |
| 10.12.00 | 2 | 1 | 138 | 9 (5) | 2 | 37 |
| **Total** | **26** | **2** | **1060** | **101** | **28** | **303** |
| Location | Launakalana | | | | | |
| **Sampling date** | **Coleoptera** | **Dermaptera** | **Hymenoptera** | **Orthoptera** | **Chilopoda** | **Araneae** |
| 16.10.00 | 13 | | 391 | 17 (7) | 7 | 83 |
| 30.10.00 | 3 | | 442 | 26 (11) | 1 | 49 |
| 13.11.00 | 3 | 3 | 462 | 24 (14 | 3 | 44 |
| 27.11.00 | 1 | | 297 | 13 (5) | 3 | 20 |
| 11.12.00 | 1 | 1 | 120 | 6 (1) | 4 | 25 |
| **Total** | **21** | **4** | **1712** | **86** | **18** | **221** |
| **Total No. both locations** | **47** | **6** | **2772** | **187** | **46** | **524** |

Leg.: Number in brackets is the number of collected individuals that were juveniles.

#### 4.3.1.2 Araneae

In total 524 spiders were collected, including 303 individuals from the PAU orchard and 221 from the Launakalana orchard (Table 1). Spiders of the family Lycosidae were most frequent: in total 274 (183 at Pau, 91 at Launakalana) were captured. This is equivalent to 52.30 % of all spiders collected (Table 2). Linyphiid spiders were second most numerous, a total 80 individuals or to 15.27 % of all spiders collected were captured with the pitfall traps. Spiders of the families Heteropodidae, Clubionidae and Gnaphosidae were also frequently captured at both sites but in lower numbers than Lycosidae and Linyphiidae. Dysderidae were present in PAU catches (16 individuals) but were absent in

Launakalana. Spiders of the several other families were also collected but only in very low numbers (Table 2).

**Table 2:** Number of spiders (Araneae) caught with pitfall traps in two mango orchards in the Central Province of Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| PAU | **15.10.00** | **29.10.00** | **12.11.00** | **26.11.00** | **10.12.00** | **Total** |
| F. Agelenidae | | | 1 | | | **1** |
| Anyphaenidae | | | 1 | | 6 | **7** |
| Clubionidae | 5 | 1 | 3 | 1 | 1 | **8** |
| Dysderidae | 1 | | 8 | 4 | 3 | **16** |
| Gnaphosidae | | | 4 | 5 | 1 | **10** |
| Heteropodidae | 4 | 5 | 5 | 3 | 2 | **19** |
| Linyphiidae | 5 | 3 | 8 | 3 | 13 | **32** |
| Liocraniidae | | 4 | | | | **4** |
| Lycosidae | 59[1] | 31[2] | 66[3] | 17 | 10 | **183** |
| Mimetidae | | | 2 | | | **2** |
| Oonipidae | | | | | 1 | **1** |
| Oxyopidae | 1 | | 1 | | | **2** |
| Pisauridae | | 2 | 1 | | | **3** |
| Salticidae | | 2 | 4 | 1 | | **7** |
| Theridiosomatidae | | 2 | | | | **2** |
| Zodariidae | | | 1 | 1 | | **2** |
| **Total** | **75** | **50** | **106** | **35** | **37** | **303** |
| **Launakalana** | **15.10.00** | **30.10.00** | **13.11.00** | **27.11.00** | **11.12.00** | **Total** |
| F. Anyphaenidae | 1 | | | | | **1** |
| Clubionidae | 8 | 12 | 10 | 1 | 3 | **33** |
| Gnaphosidae | 1 | 8 | 6 | | | **15** |
| Heteropodidae | 8 | 2 | 3 | | 3 | **16** |
| Linyphiidae | 9 | 9 | 13 | 9 | 8 | **48** |
| Liocraniidae | | | | 1 | | **1** |
| Lycosidae | 53[1] | 14 | 9 | 5 | 10 | **91** |
| Salticidae | 2 | 1 | | | | **3** |
| Scyotidae | 1 | | | | | **1** |
| Thomisidae | | 2 | | 2 | | **4** |
| Zodariidae | | 1 | | | 1 | **2** |
| Mygalomorphae | | | 2 | | | **2** |
| **Total** | **83** | **49** | **45** | **20** | **25** | **222** |

Legend: [1] includes 25 juveniles, [2] includes 11 juveniles, [3] includes 47 juveniles, [4] includes 36 juveniles

### 4.3.1.3 Coleoptera

In total 47 beetles from 2 families (Carabidae and Staphylinidae) were collected, 26 at the PAU orchard and 21 at Launakalana (Table 3). Carabidae were fare less abundant than staphylinids, only 1 individual each from three different genera (*Glycia*, *Microlestes* and *Tachys*) were recorded. 44 individuals were identified as staphylinids, including 4 specimens collected as larvae. Staphylininae were most numerous (13 specimens). Paederinae (10 specimens) and Aleocharinae (10 specimens) were also collected in numbers, while other subfamilies were represented only in very low numbers or totally absent.

**Table 3:** Number of predatory beetles (Coleoptera) caught with pitfall traps in two mango orchards in the Central Province of Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| PAU | **15.10.00** | **29.10.00** | **12.11.00** | **26.11.00** | **10.12.00** | **Total** |
| **F. Carabidae** | | | | | | |
| *Microlestes* sp. | 1 | | | | | **1** |
| *Tachys* sp. | | 1 | | | | **1** |
| **F. Staphylinidae** | | | | | | |
| Aleocharinae | 1 | 3 | | 1 | | **5** |
| Omalinae | | 1 | | | | **1** |
| Osoriinae | | 1 | | | 1 | **2** |
| Oxyelinae | | 3 | | | | **3** |
| Paederinae | | 5 | | 1 | 1 | **7** |
| Staphylininae | 3 | 1 | | 1 | | **5** |
| larvae | | 1 | | | | **1** |
| **Total** | **5** | **16** | | **3** | **2** | **26** |
| **Launakalana** | **15.10.00** | **30.10.00** | **13.11.00** | **27.11.00** | **11.12.00** | **Total** |
| **F. Carabidae** | | | | | | |
| *Glycia* sp. | | | | | 1 | **1** |
| **F. Staphylinidae** | | | | | | |
| Aleocharinae | 4 | | 1 | | | **5** |
| Paederinae | | 2 | 1 | | | **3** |
| Staphylininae | 7 | 1 | | | | **8** |
| Tachyporinae | | | 1 | | | **1** |
| larvae | 2 | | | 1 | | **3** |
| **Total** | **13** | **3** | **3** | **1** | **1** | **21** |

### 4.3.1.4 Hymenoptera

All specimens of Hymenoptera collected were from the family Formicidae. In total 2772 ants were sampled (1060 individuals at the PAU orchard and 1712 at the Launakalana orchard). This number is equivalent to 78.33 % of all predatory arthropods collected by pitfall traps. Twenty three genera of ants were identified with the majority belonging to the subfamilies Formicinae, Myrmicinae and Ponerinae (Table 4).

The most dominant species at PAU was the weaver ant *Oecophylla smaragdina* (subfamily Formicinae) with 161 individuals or 15.19 % of all specimens at this site (Table 4). Other species within this subfamily (*Anoplolepis* sp., *Camponotus* sp. and *Paratrechina* sp. were also collected in high numbers (65, 105 and 42 individuals, respectively) but crazy ants (*Anoplolepis*) were only encountered at one sampling date. The species *Iridomyrmex* sp. (subfamily Dolichoderinae) were second most numerous at this site (156 individuals): *Tapinoma* sp. was also frequently caught (107 individuals). Within the subfamily Myrmicinae the species *Leptothorax* sp., *Meranoplus* sp., *Monomorium* sp., *Pheidole* sp., and *Tetramorium* sp. were most numerous (41, 48, 62, 96 and 82 specimens, respectively). *Odontomachus* sp. and *Pachycondyla* sp. were the most dominant species within the subfamily Ponerinae (65 and 30 individuals, respectively).

At Launakalana *Pheidole* sp. was most dominant ant, 797 individuals were caught in the pitfall traps (Table 5). This is equivalent to 49.77 % of all ant specimens captured at this site. *Leptothorax*, *Tetramorium* and *Monomorium* were regularly encountered (140, 47 and 39 individuals, respectively) but *Meranoplus* sp. was virtually absent (2 specimens). At Launkalana the crazy ant *Anoplolepis* sp. was the second most frequent ant with 357 individuals. The species *Oecophylla smaragdina* and *Paratrechina* sp. were also regularly caught at this location (126 and 64 specimens, respectively), while *Camponotus* sp. was only caught in low numbers (9 specimens).

The genera *Iridomyrmex* and *Tapinoma* (subfamily Dolichoderinae) were less frequent at Launakalana (11 and 4 individuals, respectively). *Odontomachus* sp. and *Pachycondyla* sp. occured in similar numbers as at PAU (36 and 27, respectively). Ants of the genus Hypoponera were collected at one date (31 specimens) but were absent at PAU (Table 4).

**Table 4:** Number of ants (Formicidae) caught with pitfall traps at the PAU orchard in the Central Province, Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| PAU | 15.10.00 | 29.10.00 | 12.11.00 | 26.11.00 | 10.12.00 | **Total** |
| Sf. Dolichoderinae | | | | | | |
| **Iridomyrmex** | 24 | 18 | 79 | 22 | 13 | 156 |
| **Tapinoma** | 61 | | 46 | | | 107 |
| Sf. Formicinae | | | | | | |
| **Anoplolepis** | | | | | 65 | 65 |
| **Camponotus** | 31 | 11 | 19 | 11 | 33 | 105 |
| Oecophylla | 77 | 42 | 40 | 12 | | **161** |
| Paratrechina | 5 | 1 | 33 | 3 | | **42** |
| Polyrachis | | | 2 | | | **2** |
| Prenolepis | | | 9 | | | **9** |
| Prolasius | | | 5 | | | **5** |
| Sf. Myrmicinae | | | | | | |
| Cardiocondyla | 3 | | | | | **3** |
| Colobostruma | | | 1 | | | **1** |
| Leptothorax | | | 41 | | | **41** |
| Meranoplus | 6 | 6 | 33 | 1 | 2 | **48** |
| Monomorium | 3 | 17 | 37 | | 5 | **62** |
| Pheidole | 3 | 13 | 33 | | 6 | **55** |
| Quadristruma | | | 1 | | | **1** |
| Solenopsis | | 1 | 11 | | | **12** |
| Tetramorium | 8 | 8 | 54 | 1 | 11 | **82** |
| **Sf. Ponerinae** | | | | | | |
| Anochetus | | | 6 | | | **6** |
| Odontomachus | 6 | 14 | 31 | 14 | | **65** |
| Pachycondyla | 5 | 8 | 9 | 5 | 3 | **30** |
| **Sf. Pseudomyrmecinae** | | | | | | |
| Tetraponera | 1 | | 1 | | | **2** |
| Total | **233** | **139** | **481** | **69** | **138** | **1060** |

**Table 5:** Number of ants (Formicidae) caught with pitfall traps at the Launakalana orchard in the Central Province, Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| **Launakalana** | 15.10.00 | 29.10.00 | 12.11.00 | 26.11.00 | 10.12.00 | **Total** |
| **Sf. Dolichoderinae** | | | | | | |
| *Iridomyrmex* | 5 | | 6 | | | 11 |
| *Tapinoma* | 4 | | | | | 4 |
| **Sf. Formicinae** | | | | | | |
| *Anoplolepis* | 18 | 6 | 15 | 231 | 87 | 357 |
| *Camponotus* | 2 | 3 | 4 | | | **9** |
| *Oecophylla smaragdina* | 25 | 19 | 13 | 48 | 21 | **126** |
| *Paratrechina* | 24 | 28 | 7 | 1 | 4 | **64** |
| *Prolasius* | 6 | 3 | | | | **9** |
| **Sf. Myrmicinae** | | | | | | |
| *Cardiocondyla* | 1 | | | 4 | 2 | **7** |
| *Leptothorax* | | 81 | 59 | | | **140** |
| *Meranoplus* | | | 2 | | | **2** |
| *Monomorium* | 20 | 10 | 17 | | | **47** |
| *Pheidole* | 235 | 261 | 301 | | 2 | **797** |
| *Quadristruma* | | | | | | |
| *Solenopsis* | | | | | | |
| *Strumigenys* | 1 | | 1 | | | **2** |
| *Tetramorium* | 5 | 8 | 9 | 13 | 4 | **39** |
| **Sf. Ponerinae** | | | | | | |
| *Anochetus* | | | | | | |
| *Hypoponera* | 31 | | | | | **31** |
| *Odontomachus* | 12 | 14 | 10 | | | **36** |
| *Pachycondyla* | | 10 | 17 | | | **27** |
| *Rhytidoponera* | 2 | | | | | **2** |
| **Sf. Pseudomyrmecinae** | | | | | | |
| Tetraponera | | | 1 | | | **1** |
| **Total** | **391** | **442** | **462** | **297** | **120** | **1712** |

#### 4.3.1.5 Gryllidae (crickets) and Chilopoda (centipedes)

Crickets and centipedes were present in pitfall traps at each sampling date and each location. In total,187 crickets and 46 centipedes were caught (Table 1).

### 4.3.2 Arboreal predatory arthropods

#### 4.3.2.1 Occurrence and composition

In total 2975 arboreal predatory arthropods were collected, 1645 individuals at the PAU orchard and 1330 individuals at the Launakalana orchard (Table 6). The total number corresponds to a figure of 9.33 ind./m$^2$. Single figures were: PAU (10.32 ind./m$^2$), Launakalana (8.34 ind./m$^2$). The most dominant order were Hymenoptera with 2260 specimens captured accounting for 75.97 % of all arboreal predators. Araneae were second most numerous with 619 captured individuals (20.80 %). Coleoptera were found in higher numbers than with pitfall traps (89 individuals = 2.99 %). Catches of Dermaptera, Heteroptera (Reduviidae and Nabidae), Mantodea and Neuroptera were insignificant (0.03 %, 0.10 %, 0.03 % and 0.03 % of the total percentage, respectively).

**Table 6:** Number of arboreal predatory arthropods caught with the beating method at two mango orchards in the Central Province of Papua New Guinea.

| Location | PAU | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Orders of predatory arthropods and number of individuals collected** | | | | | | |
| **Sampling date** | **Coleoptera** | **Dermaptera** | **Heteroptera** | **Hymenoptera** | **Mantodea** | **Neuroptera** | **Araneae** |
| 15.10.00 | 8 | | | 184 | | | 69 |
| 29.10.00 | 13 | | | 438 | | | 54 |
| 12.11.00 | 8 | | | 403 | | | 76 |
| 26.11.00 | 4 | 1 | 2 | 154 | | | 27 |
| 10.12.00 | 7 | | 1 | 192 | | | 4 |
| **Total** | **40** | **1** | **3** | **1371** | | | **230** |
| Location | Launakalana | | | | | | |
| **Sampling date** | **Coleoptera** | **Dermaptera** | **Heteroptera** | **Hymenoptera** | **Mantodea** | **Neuroptera** | **Araneae** |
| 16.10.00 | 20 | | | 206 | | | 72 |
| 30.10.00 | 13 | | | 137 | | 1 | 131 |
| 13.11.00 | 4 | | | 219 | | | 83 |
| 27.11.00 | 4 | | | 126 | | | 28 |
| 11.12.00 | 8 | | 1 | 201 | 1 | | 75 |
| **Total** | **49** | | **1** | **889** | **1** | **1** | **389** |
| **Total No. both locations** | **89** | **1** | **4** | **2260** | **1** | **1** | **619** |

#### 4.3.2.2 Araneae

Catches with the beating method were significantly higher than with pitfall traps. In total 619 spiders (1.94 ind./m$^2$) were collected, 230 at the PAU orchard and 389 at the Launakalana orchard (Table 6). These figures correspond to 1.44 spiders/m$^2$ for the PAU orchard and 2.44 spiders/m$^2$ for the Launakalana orchard. Spiders of the family Salticidae were most frequent with a total 234 (104 at Pau, 230 at Launakalana) captured. This is equivalent to 37.80 % of all arboreal spiders collected. Theridiosomatid spiders were second most numerous, in total with 121 individuals, which accounted for 19.55 % of all arboreal spiders. Spiders of the families Araneidae, Clubionidae, Linyphiidae and Thomisidae were also frequently captured at both sites but in lower numbers than Salticidae and Theridiosomatidae. Spiders of the several other families were found but only in very low numbers (Table 7). Araneid spiders, which did not fall into the net, were collected by hand.

**Table 7:** Number of spiders (Araneae) caught with the beating method at two mango orchards in the Central Province, Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| **PAU** | **15.10.00** | **29.10.00** | **12.11.00** | **26.11.00** | **10.12.00** | **Total** |
| F. Araneidae | 2 | | 8 | | 1 | **11** |
| Clubionidae | 2 | 2 | 11 | 2 | 1 | **18** |
| Gnaphosidae | 2 | | | | | **2** |
| Linyphiidae | | | 7 | 1 | | **8** |
| Lycosidae | | 1 | | | | **1** |
| Philodromidae | 2 | | | | | **2** |
| Pisauridae | | | | | | |
| Salticidae | 22 | 28 | 35 | 19 | | **104** |
| Segestriidae | | | | | | |
| Selenopidae | | 1 | | | | **1** |
| Tethragnathidae | 4 | 3 | | | | 7 |
| Theridiidae | 1 | | 2 | | | **3** |
| Theridiosomatidae | 29 | 14 | 13 | 4 | | **60** |
| Thomisidae | 1 | 5 | | 1 | 2 | **9** |
| Uloboridae | 4 | | | | | **4** |
| **Total** | **69** | **54** | **76** | **27** | **4** | **230** |
| **Launakalana** | **16.10.00** | **30.10.00** | **13.11.00** | **27.11.00** | **11.12.00** | **Total** |
| F. Araneidae | 5 | 6 | 9 | 5 | 6 | **31** |
| Clubionidae | 7 | 5 | 7 | 2 | 8 | **29** |
| Heteropodidae | 1 | | 1 | 2 | 3 | **7** |
| Linyphiidae | 6 | 14 | 6 | 2 | 3 | **31** |
| Liocraniidae | | | 1 | | | **1** |
| Lycosidae | 2 | | 2 | | 1 | **5** |
| Oxyopidae | | | 1 | | 1 | **2** |
| Philodromidae | 3 | 2 | | | 5 | **10** |
| Pisauridae | 2 | | | | | **2** |
| Salticidae | 26 | 42 | 27 | 15 | 30 | **140** |
| Segestriidae | 1 | | | | | **1** |
| Tethragnathidae | | | 1 | | 3 | 4 |
| Theridiidae | | | 1 | | | **1** |
| Theridiosomatidae | 16 | 19 | 17 | 1 | 8 | **61** |
| Thomisidae | 3 | 35* | 5 | 1 | 1 | **45** |
| Uloboridae | | 8 | 5 | | 5 | **18** |
| **Total** | **72** | **131** | **83** | **28** | **75** | **389** |

Legend: * includes- 26 juveniles

#### 4.3.2.3 Coleoptera

A total of 89 predatory beetles were captured with the beating method; 40 at the PAU orchard and 49 at the Launakalana orchard (Table 8). The total number corresponds to a figure of 0.28 ind./$m^2$ (0.25 ind./$m^2$ at PAU and (0.31 ind./$m^2$ at Launakalana). Ten specimens were caught as larvae of coccinellids and therefore could not be further identified. The majority of the adult beetles belonged to the family Coccinellidae (69 specimens). Within this family *Telsimia* sp. was the dominant species with 50 individuals, which accounted for 63.30 % of all arboreal beetles collected. A single specimen of the following species were recorded: *Harmonia testudinaria*, *Harmonia* sp., *Chilocorus* sp. and *Scymnodes* sp. Species of the tribe Scymnini were second most frequent with 10 individuals caught. *Trichalus* sp. (Lycidae) was recorded from both study sites (3 and 4 specimens, respectively). Staphylinidae (3 specimens) were only caught at Launakalana (Table 8).

#### 4.3.2.4 Hymenoptera

All specimens of Hymenoptera collected belonged to the family Formicidae. In total 2260 ants (7.09 ind./$m^2$) were sampled (1371 (8.60 ants/$m^2$) at the PAU orchard and 889 (5.58 ants/$m^2$) at the Launakalana orchard) (Table 9), which represents 75.96 % of all specimens collected by the beating method. Thirteen genera of ants were identified with the majority belonging to the subfamilies Formicinae and Myrmicinae.

The most dominant species at both locations was the weaver ant *Oecophylla smaragdina* (subfamily Formicinae). In total 2087 specimens were collected (1299 at PAU and 788 at Launakalana), which accounts to 92.35 % of all ants captured with the beating method. Other species collected within this subfamily belonged to the genera *Camponotus*, *Paratrechina*, *Prenolepis* and *Prolasius* (Table 9). No species of the subfamily Ponerinae were collected with the beating method at both study sites.

Member of the subfamily Dolichoderinae (*Iridomyrmex*, *Tapinoma*) were present in catches at Launakalana but only at one sampling date, each. No species of Dolichoderinae were recorded from PAU catches. Members of the subfamily Myrmicinae were only seldomly sampled. The most frequent one was *Crematogaster* sp. with 41 specimen in total. Catches of other genera (*Cardiocondyla*, *Meranoplus*, *Monomorium* and *Tetramorium* were insignificant ( 0.53 %, 0.04 %, 0.04 % and 0.04 %, respectively). One individual of *Tetraponera* (subfamily Pseudomyrmicinae) was collected at Launakalana.

**Table 8:** Number of predatory beetles caught with the beating method at two mango orchards in the Central Province, Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| **PAU** | 15.10.00 | 29.10.00 | 12.11.00 | 26.11.00 | 10.12.00 | **Total** |
| **F. Coccinellidae** | | | | | | |
| *Chilocorus* sp. | | | | 1 | | **1** |
| *Ileis galbula* | | 1 | | | | 1 |
| Scymnini | | 1 | 2 | | | 3 |
| *Telsimia* sp. | 6 | 11 | 6 | 1 | 6 | **30** |
| Larvae | 2 | | | | | **2** |
| **F. Lycidae** | | | | | | |
| *Trichalus* sp. | | | | 2 | 1 | **3** |
| **Total** | **8** | **13** | **8** | **4** | **7** | **40** |
| **Launakalana** | 16.10.00 | 30.10.00 | 13.11.00 | 27.11.00 | 11.12.00 | **Total** |
| **F. Coccinellidae** | | | | | | |
| *Harmonia testudinaria* | 1 | | | | | **1** |
| *Harmonia* sp. | | | 1 | | | **1** |
| *Ileis galbula* | | | | 2 | 2 | 4 |
| *Scymnodes* sp. | | | | | 1 | **1** |
| Scymnini | 5 | 1 | | | 1 | **7** |
| *Telsimia* sp. | 9 | 9 | | 2 | | **20** |
| Larvae | 3 | 3 | | | 2 | **8** |
| **F. Lycidae** | | | | | | |
| *Trichalus* sp. | | | 3 | | 1 | **4** |
| **F. Staphylinidae** | | | | | | |
| Omaliinae | 1 | | | | | **1** |
| Oxytelinae | 1 | | | | | **1** |
| Steninae | | | | | 2 | **1** |
| **Total** | **20** | **13** | **4** | **4** | **8** | **49** |

**Table 9:** Number of ants caught by the beating method at two mango orchards in the Central Province, Papua New Guinea.

| **Location** | **No. of individuals collected at each sampling date** | | | | | |
|---|---|---|---|---|---|---|
| **PAU** | 15.10.00 | 29.10.00 | 12.11.00 | 26.11.00 | 10.12.00 | **Total** |
| **Sf. Formicinae** | | | | | | |
| *Oecophylla smaragdina* | 140 | 429 | 397 | 148 | 185 | **1299** |
| *Paratrechina* | 18 | | | | | **18** |
| *Prenolepis* | | | | | 4 | **4** |
| *Prolasius* | | 4 | | 6 | 3 | **13** |
| **Sf. Myrmicinae** | | | | | | |
| *Cardiocondyla* | 8 | | | | | **8** |
| *Crematogaster* | 17 | 5 | 4 | | | **26** |
| *Meranoplus* | | | 1 | | | **1** |
| *Monomorium* | | | 1 | | | **1** |
| **Sf. Pseudomyrmecinae** | | | | | | |
| *Tetraponera* | 1 | | | | | **1** |
| **Total** | **184** | **438** | **403** | **154** | **192** | **1371** |
| **Launakalana** | 16.10.00 | 30.10.00 | 13.11.00 | 27.11.00 | 11.12.00 | **Total** |
| **Sf. Dolichoderinae** | | | | | | |
| *Iridomyrmex* | | 9 | | | | 9 |
| *Tapinoma* | | | 42 | | | 42 |
| **Sf. Formicinae** | | | | | | |
| *Camponotus* | | 1 | | 5 | | **6** |
| *Oecophylla smaragdina* | 206 | 113 | 164 | 115 | 190 | **788** |
| *Paratrechina* | | 2 | | | 10 | **12** |
| *Prenolepis* | | | 5 | | | **5** |
| *Prolasius* | | 2 | | 5 | | **7** |
| **Sf. Myrmicinae** | | | | | | |
| *Cardiocondyla* | | | 4 | | | **4** |
| *Crematogaster* | | 9 | 4 | 1 | 1 | **15** |
| *Tetramorium* | | 1 | | | | **1** |
| **Total** | **206** | **137** | **219** | **126** | **201** | **889** |

## 4.4 Discussion

The method of sampling insects by beating branches with the insects falling into a collecting funnel was particularly developed to determine damage thresholds in IPM-orientated orchards (Fortmann, 1993). But not all species within the arboreal fauna can be recorded with this procedure. Flying insects or species fixed to the plant are only seldomly collected. Catches with sweeping the net through the foliage are recommended to catch these flying insects and to complement the beating method but this procedure was not applied since tests showed that the net was frequently caught within the twigs and branches, which allowed the insects to escape. In contrast, barber traps are particularly suited to collect epigeal predatory arthropods like spiders, ants and carabids.

Both orchards were not sprayed with synthetic insecticides so that the recorded numbers reflect the natural populations of predatory arthropods.

### 4.4.1 Epigeal and arboreal Araneae

Spiders were the second most numerous group in pitfall traps and in catches with the beating method in both mango orchards, thereby underlining their importance as antagonists of insect pests in perennial plants.

In general, most of the spiders caught were hunting spiders, in particular Lycosidae and Salticidae, although web building spiders of the family Theridiosomatidae were also frequently captured. Web spiders remain on or around the web to wait for prey to be caught by the web. They are not active hunters. Captures of web builders with pitfall traps are therefore considerably less since falling into these traps requires movement. In case of bigger web spiders, in particular Araneidae, it was observed that beating of the branches with a wooden stick did not detach the spiders from the web. In contrast, smaller spiders (Theridiosomatidae) immediately lost contact with the web and fell into the catching device.

In net catches with the beating method Salticidae (jumping spiders) were most numerous. Salticidae are the biggest family within the Araneae with over 4000 species and most of the species occur in warmer climates (only 75 species are recorded from Europe) (Roberts, 1995). They are extremely active in warm and sunny weather. These conditions were prevailing on the sampling dates and certainly contribute to the high abundance of salticids. Jumping spiders were less numerous in pitfall traps. This is mainly due to the fact that their movement and catch of prey is by jumping and therefore avoiding getting caught in these traps. Theridiosomatidae were second most numerous in net catches. Only one genus occurs in Europe, the most in the tropics.

Thomisidae, Araneidae, Clubionidae and Linyphiidae were also frequently caught at both locations with the beating method. The great diversity in colour of Thomisidae relates to their exploitation of a wide variety of habitat. Species which are brown can generally be found on the ground and on the bark of trees, but those bright in colour are found on shrubs and trees (Jones, 1985). The majority sit and wait for prey and only a few are active hunters, which explains why they were seldomly caught in pitfall traps. Clubionidae are hunting spiders and occur at ground level but also higher up on bushes and trees (Roberts, 1995), and were therefore frequently caught in pitfall traps and in net catches with the beating method. Linyphiidae occur in habitats ranging from leaf litter to moss and grass, low and high vegetation and were regularly caught with both methods applied. Little is known about their biology but the majority spin tiny webs (Roberts, 1995). In field studies in Germany and in the Philippines, linyphiids were frequently collected in pitfall traps (Basedow, 1993, 1998).

Members of the family Lycosidae were most abundant in pitfall traps and second most in general. All lycosids are hunting spiders and occur mostly at ground level but also occasionally on low vegetation. No catches were therefore recorded with the beating method.
Basedow (1993, 1998) obtained similar results in field studies in Germany and the Philippines. Due to their habitat and numerosity and the fact that many species hunt during nighttime, they could play important role in the control of *Deanolis sublimbalis* (RBMC), in particular when larvae drop to the ground to reach the pupation sites in the bark of the trees. None of the web builders is considered as important in the control of RBMC, although orb spinners, in particular Araneidae, could occasionally catch adult RBMC in flight.

### 4.4.2 Epigeal and arboreal Coleoptera

***Carabidae***

The low abundance of carabids in pitfall traps is probably related to the dry and dusty conditions and the soil types (Ustropepts and Ustorthents) prevailing in the coastal areas of the Central Province. These soils are shallow, low in organic matter and during the rainy season often seriously flooded. These conditons do not favour a high abundance of carabids. Results from field trials in Panama and in the Philippines showed similar low numbers of Carabidae (Basedow & Bernal-Vega, 2001; Basedow, 1993). However, carabids are known to be very effective predators. They are extremely mobile and fast and even a low number can contribute to the reduction of larvae of Lepidoptera, in particular of the red banded mango caterpillar *Deanolis sublimbalis* (RBMC), which have to move over the ground to reach their pupation sites in the bark of the mango trees. The species *Glycia* sp., *Tachys* sp. and *Microlestes* sp. prefer sandy soils, with the latter often found in areas exposed to sunlight and poor in vegetation (Trautner & Geigenmüller, 1987).

***Staphylinidae***

In general, numbers of Staphylinidae were very low. In contrast to the conditions in the Central Province, most species prefer humid habitats in vicinity to the ground which explains the low abundance in particular of Oxytelinae, Paederinae and Tachyporinae. Only two species of Omaliinae were captured; one with the pitfall trap and one with the beating method. A higher abundance is to be expected during mango flowering in July and August, since most Omaliinae do feed on flowers and are not predatory. Aleocharineae are the most numerous subfamily within the staphylinids and were second numerous in this study. Aleocharinae are active in and on the ground, which explains why all of the specimens were captured in pitfall traps and none with the beating method. Species of the genus *Aleochara* are rather regarded as parasitoids, since the larvae are parasitic on pupae of Diptera, although the adults are polyphagous predators (Fortmann, 1993). Species of the Staphylininae were most numerous in this study. This subfamily includes important predatory species like *Staphylinus* sp. and *Philontus* sp.

A similar low frequency of staphylinids was also recorded in field investigations in the Philippines with pitfall traps in cabbage (Basedow, 1993). All predatory staphylinids prefer adults and larvae of Diptera as diet. A significant contribution by these predators to the control of RBMC is therefore not expected.

***Lycidae***

Like *Trichalus* sp. most species of Lycidae are found in the tropics. Only eight species are found in Europe. The adults live on flowers while the larvae live in rotten wood, and are predacious on other insects and larvae. Due to different habitats, there is no effect of these predators on the abundance of RBMC.

***Coccinellidae***

Predacious coccinellids have a wide range of food. Apart from feeding on Homoptera and phytophagous mites, they also prey on eggs and young instars of Lepidoptera, Coleoptera and Hymenoptera, Nematocera and Thysanoptera. The larvae always prey on the same prey as the adults. With no suitable food present, adult coccinellids are able to starve for quite some time or, more important,  switch to a different food substitute, whether this is of insect or plant origin (pollen and nectar) (Hodek, 1973).

The number of coccinellids in net catches with the beating method is dependent on the occurrence and abundance of prey insects and/or inflorescenses of the randomly choosen branches of the selected mango trees. The samples were taken during the fruiting period of mango. For ladybird beetles to be present, branches, leaves or fruits had to be infested with scales, aphids or mites. With both food sources absent, numbers of coccinellids are expected to be very low.

Target pests of *Chilocorus* beetles are mainly hard scales (*Aonidiella*, *Aspidiotus*) but they also occasionally feed on coccids and aphids (Smith et al., 1997). The adults lay cylindrical eggs beneath the cover of the prey. As the eggs hatch, the larvae feed on the scale.

Species of the genus *Harmonia* can be frequently seen feeding on aphids but also on scales and psyllids (Smith et al., 1997). *H. testudinaria* feeds mainly on *Aphis* spp.

*Scymnodes* sp. are mainly aphidophagous but as *Harmonia* switch to other homopteran food sources, if the main prey is absent. *Toxoptera odinae* was frequently recorded on mango and could therefore be the primary food source for *Scymnodes* species.

*Telsimia* species are very small insects (1mm in size) and feed primarily on eggs and newly hatched nymphs of diaspidids but if absent also attack coccids and aphids.

All the recorded species do not feed primarily on coccids. A significant effect on the occurrence of pink wax scales by these species is therefore not expected. In addition, ladybird beetles mainly feed on coccids during early nymphal development (crawlers and 1. instars). With the later secretion of wax, coccids are less visited by predators. Predation of RBMC eggs by coccinellids may occasionally happen but is not an important factor in the control of this pest, since the eggs are difficult to locate under dried sepals, and eggs of Lepidoptera in general are only a secondary food source for coccinellids.

*Ileis galbula* is not a predator but a fungus eating ladybird beetle, and therefore does not feed on *Ceroplastes rubens*. The species is very fast moving and an active flyer. Both adults and larvae feed on fungi, in particular on black mould.

In general, the results showed that predatory carabids and staphylinids were low in numbers but it is expected that they are more frequent under different conditions (soil, climate). In case of coccinellids, no specific predator of *Ceroplastes rubens* was recorded but those identified could play an important role in the control of *Aulacaspis tubercularis*, *Toxoptera odinae* and phytophagous mites.

### 4.4.3 Epigeal and arboreal Hymenoptera

Formicidae were most numerous in both collecting methods since they form, in contrast to other predatory arthropods, large colonies. It can therefore be assumed that due to their numerosity ants are very important in the control of insect pests in mango. However, not all species are predators. Others are scavengers, seed harvesters, honeydew collectors, while some, due to their aggressive behaviour, can eliminate other insect species or become household pests like fire ants (*Solenopsis invicta*). To determine the status of the ants collected, a detailed look into their biology is required. Special attention is paid to their role as potential control agents of RBMC. The effect of honeydew collecting ants on the establishment of *Anicetus beneficus* and the control of *Ceroplastes rubens* is further discussed in chapter 6.

***Dolichoderinae***

*Iridomyrmex* is one of the largest genera within the subfamily Dolichoderinae. Most species are general scavengers with the nests located in the soil (Shattuck, 1999). They were therefore frequently collected in pitfall traps. Since they also occasionally attend aphids and coccids, they were also collected with the beating method but only in low numbers. *Tapinoma* ants are mainly nocturnal and their nests are found in wide range of sites in or close to the soil (e.g. under rocks, in rotten or dead wood) and were therefore more abundant in pitfall traps. However, *Tapinoma* species have a preference of honeydew and were collected with the beating method at one occasion, while visiting a branch infested with aphids or coccids. Due to their behaviour both genera are insignificant in the control of RBMC. For the control of *C. rubens*, the presence of *Tapinoma* could prove rather harmful since workers were observed visiting pink wax scale populations for the collection of honeydew. Their attendance is assumed to disturb the parasitization process by *Anicetus beneficus* and therefore to reduce the effectiveness of this parasitoid (see chapter 6).

***Formicinae***

The results showed a significant higher diversity of ants in pitfall traps than in catches with the beating method. This effect has to be attributed to the high abundance of weaver ants (*Oecophylla smaragdina*) at both study sites. Nearly every tree was inhabited with this species. Their nests are always build in trees or shrubs and indiviual colonies can become very large (Shattuck, 1999). They are a very aggressive and dominant species - intruders will be attacked immediately. Field trials in Kenya showed that only a few ant species, which do not display an aggressive behaviour can coexist with weaver ants on the same tree (Hölldöbler & Wilson, 1990). Other species, such as *Camponotus*, common species in Asia and Australia, are never found on the same trees as the *Oecophylla* (Hölldöbler, 1983). Weaver ants are mainly diurnal and forage both on vegetation and on the ground, which explains the catches in pitfall traps. However, during daytime workers identified the pots as traps and did not fall into these traps.

As explained in chapter 7, the effect of *O. smaragdina* on the occurrence of RBMC is rather insignificant. They were not recorded attending *Ceroplastes rubens* and therefore did not disturb the establishment of the parasitoid *Anicetus beneficus* but frequently attended populations of *Saissetia* sp. and *Parasaissetia* sp.

Individuals of *Anoplolepis* were only collected in pitfall traps, probably because nests of this species were built in the soil and workers foraged on the ground only. However, nests may be found on trees as well (Shattuck, 1999). They are predators and were used as a part of integrated pest mangagement programs (Way & Khoo, 1992), but they are nowadays not recommended due to their aggressive behaviour and negative ecological impact. In the Solomon Islands it was observed that with the introduced species *Anoplolepis longipes* the species diversity of ants fell sharply (Greenslade, 1971).

Nests of *Camponotus* are found in a wide range of sites (from soil to trees). They are scavengers as well as predators and attend Homoptera for honeydew (Briese & Macauley, 1981). They are diurnal as well as nocturnal species with the latter possibly having an effect on RBMC. The effect on *Ceroplastes rubens* is discussed in chapter 6.

Species of *Paratrechina* were abundant in pitfall traps, since they can form large colonies in open soil or under rocks (Shattuck, 1999), and predation of RBMC may therefore occasionally happen.

***Myrmicinae***

There were only a few catches of Myrmicinae with the beating method. Most numerous were species of the genus *Crematogaster*. They are generalist predators but also attend Hemiptera for the collection of honeydew. Their nests are found in a range of sites including soil, and arboreally in trunks and twigs (Shattuck, 1999). Since nests can contain thousands of workers, predation on RBMC will occur if larvae cross the trails. *Pheidole* was most common in pitfall traps. Within this genus there are general predators and scavengers but others are considered as pests like the harvester ants which feed on seeds. *P. megacephala* is known to have adverse effects on the native insect fauna due to its aggressive behaviour (Hölldöbler & Wilson, 1990). To determine the status of the specimens collected, an identification to species level is required. The same applies to *Monomorium* and *Tetramorium*, since species within this genera are very diverse in size and habits, ranging from scavengers and predators to seed harvesters (Briese & Macauley, 1981). Species of *Leptothorax* are mainly zoophagous but occasionally also collect honeydew and sometimes are phytophagous (Seifert, 1996). Their nests are mainly built in the soil, in rotten wood and under rocks, and probably due to this fact were only caught in pitfall traps. In case of *Meranoplus*, regurlarly collected in traps at the PAU orchard, most species are generalist scavengers but some specialise on seeds (Shattuck, 1999).

***Ponerinae***

Within the subfamily Ponerinae, most of the species build their nests in and on the ground (under rocks and in rotten wood) and foraging generally takes place on the ground. This could explain why no species were collected with the beating method. Since all species are predacious with some being very large and conspicuous, larvae of RBMC are certainly a food source for these ants.

### 4.4.4 Gryllidae and Chilopoda

Gryllids were as nearly four times more numerous in pitfall traps than predatory carabids and staphylinids. Within this family there are species, which feed on plants like the australian species *Teleogryllus commodus* and the citrus leafeating cricket *Tamborina australis* (Jacobs & Renner, 1988; CSIRO, 1991; Smith et al., 1997). Other species are predators, in particular within the genus *Oecanthus*, which thrive upon a diet of insect food only. Aphids and scales are most frequently attacked by the tree inhabiting forms. One nymph of an undetermined species is reported of having consumed up to 900 individuals of the San José Scale each day (Fulton, 1915). *O. latipennis* and *O. niveus* feed particularly on aphids of the genus *Phylloxera* (Clausen, 1962). To determine the status of crickets caught in pitfall traps in the Central Province of PNG, an identification to genus/species level is required.

Chilopoda (centipedes) are very agile, generalist predators. They forage in and on the ground and their diet mainly consists of Collembola, Diptera and aphids (Fortmann, 1993). Larvae of RBMC will therefore only be occasional prey. In comparison, numbers of centipedes were similar to those of predatory beetles.

## 4.5 Conclusion

The frequency, abundance and diversity of predators in mango orchards in the Central Province of PNG proved to be very high. The composition of arboreal predatory arthropod was thereby strongly different from the epigeal one. In case of spiders, Salticidae (jumping spiders) and Theridiosomatidae were most frequent in catches with the beating method but Lycosidae (wolf spiders) and Linyphiidae (money spiders) were most dominant in pitfall traps. In particular Lycosidae, can considerably contribute to the control of RBMC.

Within arboreal predators, Coccinellidae were obviously most frequent. The identified species do no primarly feed on soft scales but could play an important role in the control of diaspidids and aphids. Further studies are necessary to determine their role in the control of these pests, in particular *Aulacaspis tubercularis* and *Toxoptera odinae*. In pitfall traps, Carabidae and Staphylinidae were identified as predatory beetles but their numbers were very low and presumably do not play an important role in the control of RBMC.

Due to the dominant and aggressive behaviour of the weaver ant, *Oecophylla smaragdina*, the diversity in ants was significantly lower in net catches with the beating method than in pitfall traps. It is debatable, whether these ants should be considerered as beneficial in mango and citrus. In cashew, where bugs like *Helopeltis* and *Amblypelta* are major pests, their presence is promoted, since they significantly contribute to their control and do not disturbe the harvest of fruits. In contrast, bugs are considered as minor pests in citrus and mango and the presence of weaver ants is not required and should not be encouraged. Their role in the control of RBMC is rather insignificant and, additionally, they cause an increment of soft scales and aphids (*Saissetia*, *Toxoptera*) and are a nuisance when the fruits are harvested. In general, an elimination of weaver ant populations in these cultures is recommended but is difficult to achieve. The ant diversity in pitfall traps was much higher with *Pheidole* being most frequent. Within this genus there are general predators but also seed harvesters and an identification to species level is therefore required.

Results from other studies indicate that predatory spiders, beetles and ants are very susceptible to synthetic insecticides and numbers are greatly reduced in commercial plantations. It is therefore advisable not to encourage the use of such insecticides in PNG orchards. Instead, the application of biological insecticides such as neem, which is less harmful to predatory arthropods, should be promoted.

## 4.6 Summary

Epigeal and arboreal predatory arthropods in mango (*Mangifera indica*) were collected with pitfall traps and by the beating method at two sites in the Central Province of Papua New Guinea.

Thirty pitfall traps at each site were emptied five times at an interval of two weeks during mango fruiting for the collection of epigeal arthropods. Thirty trees (5 branches/tree) at each site were randomly selected for the collection of arboreal insects with the beating method. This method was applied five times at an interval of two weeks during mango fruiting.

The number of individuals caught in pitfall traps (3539) was higher than in catches with the beating method (2975).

**Epigeal predatory arthropods** belonged to the following orders/families:

Coleoptera (Carabidae, Staphylinidae)

Hymenoptera (Formicidae)

Orthoptera (Gryllidae)

Dermaptera

Araneae

Chilopoda

Carabidae and Staphylinidae were caught only in low numbers (47 in total). Numbers of staphylinids were significantly higher than ground beetles.

The highest frequency was in ants (2772 ind.) with *Pheidole* spp. and *Oecophylla smaragdina* being most numerous. The first species is a predator while within the latter genus there are scavengers, predators and seed harvesters. Identification to species level is therefore required to determine the feeding habitat of the species collected.

Spiders were second most numerous (524 ind.). Within these predators Lycosidae were most frequent (274 ind.) followed by Linyphiidae (80 ind.). Spiders of the families Clubionidae, Gnaphosidae and Heteropodidae were also regularly collected but in lower numbers than the first two.

Numbers of Gryllidae (187 ind.) were about four times higher than Coleoptera.
Numbers of Chilopoda (46 ind.) were similar to predatory beetles.

**Arboreal predatory arthropods** belonged to the following orders/families:

Coleoptera (Coccinellidae, Staphylinidae, Lycidae)

Dermaptera

Hymenoptera (Formicidae)

Heteroptera

Mantodea

Neuroptera

Araneae

Numbers of Coloeptera (89 ind. = 0.28 ind./m$^2$) were higher than in pitfall traps. The majority belongs to the family Coccinellidae (79 ind.). Within this family *Telsimia* sp. was the dominant species (50 ind.). *Telsimia* species feed primarly on eggs and nymphs of diaspidids. All individuals (6) of Lycidae were identified as adults of *Trichalus* sp. Only the larvae of Lycidae are predatory.

The highest abundance was in ants (2260 ind. = 7.09 ind./m$^2$) with *Oecophylla smaragdina* being most numerous (2087 ind.). Twelve other genera (mainly Formicinae and Myrmicinae) were identified but numbers were insignificant. Although *O. smaragdina* is a generalist predator, their presence in mango orchards is not desired and elimination is recommended.

Spiders were second most numerous (619 ind. = 1.94 ind./m$^2$). Within these predators jumping spiders (Salticidae) were most frequent (244 ind.) followed by Theridiosomatidae (121 ind.). Spiders of the families Araneidae, Clubionidae, Linyphiidae and Thomisidae were also regularly collected but in lower numbers than the first two. The beating method proved to be unsuitable for collecting bigger, web building spiders, in particular Araneidae.

Catches of Dermaptera, Heteroptera (Reduviidae, Nabidae), Neuroptera and Mantodea were insignificant.

**Figure 2:** Nest of the weaver ant *Oecophylla smaragdina* (Formicidae) in a mango tree

**Figure 3:** Workers of the weaver ant *Oecophylla smaragdina* (Formicidae)

# 5. A survey on the occurrence and importance of mango pests in the Central Province of Papua New Guinea

## 5.1 Introduction and objectives

The mango tree (*Mangifera indica*) is attacked by a variety of insects and diseases. Galan (1990) reported over 350 insect species as pests of mango, while Peña and Mohyuddin (1997) recorded about 260 species of insects and mites as pests of mango with 41 % attacking the leaves, 28 % the fruits, 12 % the flowers, 11 % the buds and 8 % the branches and trunks.

According to Peña (1993) key pests like fruit flies, seed weevils, tree borers and mango hoppers require annual control treatments, while other pests like aphids and scales generally occur at subeconomic level but can become serious pests by the overuse of synthetic insecticides against a major pest and the significant reduction of beneficial insects.

The insects pest of mango worldwide have been listed by Laroussilhe (1980), Tandom & Verghese (1985) and Veerish (1989). Pests of mango in Australia have been published by Bagshaw et al. (1989), in the USA by Peña (1993), in Pakistan by Mohyuddin (1981) and in Israel by Wysoki et al. (1993).

In Papua Neu Guinea (PNG) mango pests have not been studied yet and their status remains unclear. The following study was therefore undertaken to obtain data on insects pests of mango and their significance in the Central Province of PNG.

The selection of the insect pests listed below was done by using the following criteria:

- The significance of insect pests of mango in the southeast Asian and Pacific region.
- The authors observations on the occurrence and abundance of insect pests at different sites in the Central Province of PNG.

1. Fruit piercing moths (Lepidoptera)

   *Othreis fullonia* Clerk, *Othreis materna* Linnaeus, *Eudocima salaminia* (Cramer) (Noctuidae, Catocalinae)

2. Mango blossom feeders (Lepidoptera)

   *Cosmostola* sp. near *laesaria* Walker (Geometridae, Geometrinae)

   *Gymnoscelis* sp. near *imparatalis* Walker (Geometridae, Larentiinae)

   *Gymnoscelis* sp. (Geometridae, Larentiinae)

   *Nanaguna breviuscula* Walker (Nolidae, Sarrothripini)

3. Mango leafminer

   *Acrocercops* spp. (Lepidoptera, Gracillariidae)

4. White mango scale

   *Aulacaspis tubercularis* Newstead (Homoptera, Diaspididae)

5. Soft scales

   *Saissetia* sp., *Parasaissetia* sp. (Homoptera, Coccidae)

6. Mango aphid

   *Toxoptera odinae* (van der Goot) (Homoptera, Aphididae)

7. Mango leaf hoppers

   *Idioscopus clypealis* Lethierry, *I. niveosparsus* Leth. (Homoptera, Cicadellidae)

8. Mango planthoppers

   *Colgaroides acuminata*, *Colgar* sp., *Scolypopa* sp. (Homoptera, Flatidae, Ricaniidae)

9. Fruit flies

   *Bactrocera frauenfeldi* (Schiner) (Diptera, Tephritidae)

10. Pink wax scale

    *Ceroplastes rubens* Maskell (Homoptera, Coccidae)

11. Red banded mango caterpillar

    *Deanolis sublimbalis* Snellen (Lepidoptera, Pyralidae, Odontinae)

The studies on the pests *Ceroplastes rubens* and *Deanolis sublimbalis* are treated separately under chapter 6 and 7.

## 5.2. Literature review

### 5.2.1 Fruit piercing moths *Othreis fullonia*, *O. materna*, *Eudocima salamnia* (Lepidoptera, Noctuidae)

All species display a similar life cycle. As a reference, the biology of *Othreis fullonia* is described here.

***Host range***

The host range of *O. fullonia* includes many economic importants fruit and vegetable crops like bananas, guava, coffee, citrus, passionfruit, pineapple, melons and tomato (Waterhouse & Norris, 1987).

***Geographical distribution***

The moth is widely distributed throughout South East Asia, the Pacific and Africa but so far not recorded in the Americas (Waterhouse & Norris, 1987).

***Biology***

The life cycle lasts between 30 and 49 days depending on the temperature (Kumar & Lal, 1983; Waterhouse & Norris, 1987). The eggs are laid in masses of up to 100 at the underside of leaves of host plants of the larvae. The larvae develop on native wines belonging to the family Menispermaceae (Comstock, 1963). In Hawaii they feed also on *Erythrina* (Fabaceae) (Heu et al., 1985). Larvae undergo five instars within three weeks and reach up to 5 cm in length when fully grown (Tryon, 1898). The larvae are dark green and have to large spots on the second and third abdominal segment (mainly white with black centres) (Smith et al., 1997). The adults are colourful moths with brown forewings and yellow-black hindwings and fly mainly between 7.00 to 11.00 pm (Tryon, 1898). Females can live for 27 to 30 days (Kumar & Lal, 1983).

***Damage***

In contrast to other economically important pests of Lepidoptera, the damaging stage to fruit crops and vegetables is the adult moth, which penetrates the skin with the stout haustellum to feed upon the juices of the ripe fruit. The process usually takes only a few seconds leaving a hole of 2 mm in diameter (Smith et al., 1997) and characteristical sugar crystals caused by the evaporation of the juices. Secondary pests like *Fusarium* sp. and *Colletotrichum* sp. settle on attacked fruits and cause rotting (Bšnziger, 1982). The incidence of the moth is generally low but when outbreaks occur, also green fruits are attacked resulting in premature ripening and dropping of the fruits (Kumar & Lal, 1983).

***Control***

The low incidence of *O. fullonia* is generally attributed to the efficacy of natural enemies, in particular egg parasitoids of the genus *Trichogramma* and larval parasitoids of the genus *Euplectrus* (Hymenoptera: Trichogrammatidae, Eulophidae) (Heu et al., 1985).

Baptist (1944) studied the effectiveness of several cultural control methods including net catches, illumination and bagging of fruits. The first method proved to be only effective at low population density while an illumination of the orchard was considered impractical on a small scale trial. However, studies from Japan showed a significant reduction of this moth by 60 % (Nomura, 1965). Fruit bagging was only practical, when fruits hang together and were easy accessible.

A chemical control is usually done with baits treated with insecticides. The results differ. Bšnizger (1982) reported only a slight effect, while Kumar & Lal (1983) reported a sufficient control. The ineffectiveness is generally attributed to the lack of suitable baits but the search for new effective baits could be useful (Bšnizger, 1982).

**Figure 4:** *Eudocima salaminia* (Lep., Noctuidae)

### 5.2.2 Blossom feeders (Lepidoptera)

### *Cosmostola* sp., *Gymnoscelis* sp., *Nanaguna breviuscula*

The lepidopteran blossom feeders are the second most important inflorescence pests of mango (Peña & Mohyuddin, 1997). The Geometrids *Chloropteryx glauciptera* Hampson and *Oxydia vesulia* (Cramer) were reported as serious pests in Dominica by Whitwell (1993) with infestation levels averaging three larvae/inflorescence. Nafus (1991) reported the noctuid *Penicillaria jocosatrix* as a mango flower pest laying its eggs predominantly on the inflorescences or on new leaves.
In Florida the microlepidoptera attacking mango consists of the following species: *Pococera atramentalis*, *Pleuroprucha insulsaria*, *Platynota rostrana*, *Racheospila gerularia* and *Tallula* spp. with the first two species being most important. The larvae of these species feed on the inflorescence, petals and ovaries and later in the season dried flowers are webbed together to form a nest (Peña, 1993). *Nanaguna breviuscula* was commonly found on mango inflorescenses in Guam (Schreiner & Nafus, 1992). Several species of Geometridae, Lymanthridae, Noctuidae, Pyralidae and Tortricidae are known as flower feeders in Australia (Peña, 1993).

A control with insecticides is usually not necessary in Florida and Australia (Peña, 1993; Cunningham, 1989) but constant monitoring is required to detect population increases.

Schreiner (1987) showed that Dipel reduced damage by larvae but frequent spraying was necessary.

**Figure 5:** Typical damage of a mango infloresscense by larvae of lepidopteran blossom feeders

### 5.2.3 Mango leafminer *Acrocercops* spp. (Lepidoptera, Gracillariidae)

***Host range and geographical distribution***

*Acrocercops* can be found on a number of fruits as leafminers but they are also known as pod borers of cacao. This pest can be found throughout the tropics and subtropics.

***Biology***

The moths are very tiny with the hindwings fringed with long hairs. When resting, the anterior part of the body is raised and fore and mid legs are prominently displayed. Adult moth reach about 4 – 5 mm in length. The eggs are translucent and about 0.3 mm long and laid on leaves along the midrib. Hatching occurs within 2 days. The larvae produce blister-like mines in the leaves. There are usually three larval stages followed by a pre-pupa and a pupa. Pupation takes place in oval flattened cocoon, either inside or outside the mine. The whole life cycle variies between 12 – 16 days (Opler, 1974).

***Control***

There is only little information on the control of *Acrocercops* – leafminers. Control measures given, apply therefore to the citrus leafminer *Phyllocnistis citrella*. This species belongs to the same family and displays a behaviour and life cycle similar to *Acrocercops*. In Australia the following control measure is recommended (Smith et al., 1997): Apply petroleum spray oil (250-500 ml oil per 100 l water) every 6 – 10 days until the youngest leaves on the majority of flushes are 40 mm long. Petroleum sprays reduce the number of eggs, since adult moth do not like laying their eggs on sprayed surfaces. Insecticides like synthetic pyrethroids are effective in the control of larvae but not recommended, since they are disrupting the activity of natural enemies of the leafminer and other citrus pests (Smith et al., 1997).

**Figure 6:** *Acrocercops diffluella* Meyr. (Lep., Gracillariidae)

**Figure 7:** Mango leaf damaged by *Acrocercops* leafminer

### 5.2.4 White mango scale *Aulacaspis tubercularis* (Homoptera, Diaspididae)

***Host range***

The host range of *A. tubercularis* includes about 20 plants with *Citrus* sp. and *Cocos nucifera* as further important economic hosts of this pest.

***Geographical distribution***

The white mango scale is distributed throughout the tropics and subropics.

***Biology***

Adult scales can be found in masses on the upper- and underside of leaves and occasionally on the fruits. The female is white and oval and about 2 mm in diameter and has a characteristic black spot (the puparium, which is incorporated into the waxy layer). Females are only occasionally seen, since the males are more prominent. They are white and about 1 mm in length and distinctly tricarinate. The crawlers are deep bright red. The life cycle takes between 35 – 40 days for females and 23 – 28 days for males (van Halteren, 1970).

***Damage and economic importance***

The white mango scale attacks shoots and leaves, and damages the plant not only by feeding on the parenchym sap but also because of the toxitity of their saliva. The economic importance is unknown but it was already considered as an economic threat to mango in Florida with the government pursuing the possibility of biological controls (Hamon, 2002).

***Control***

The predatory thrips *Auleurodothrips fasciapennis* Franklin and the parasitoid *Aspidiotiphagus citrinus* were reported as the most important biocontrol agents of *A. tubercularis* in South Africa (Labuschagne, 1993). In Australia, two treatments with petroleum sprays at a rate of 1 % are recommended for the control of hard scales (Smith et al., 1997).

**Figure 8:** *Aulacaspis tubercularis* (males) (Homopt., Coccidae)

### 5.2.5 Soft scales *Saissetia* sp. and *Parasaissetia* sp. (Homoptera, Coccidae)

The species *Saissetia coffeae* (hemispherical scale), *S. neglecta* and *S. oleae* (black scale) and *Parasaissetia nigra* (nigra scale) have been recorded from mango (Peña & Mohyuddin, 1997; Hill, 1983).

***Host range***

The black scale attacks a wide range of commerical crops like citrus, olive and ornamentals like gardenia and oleander. Coffee is the main host of the hemispherical scale and alternative hosts include tea, citrus, guava and many other cultivated plants (Hill, 1983). In addition to mango, the nigra scale is also known to infest commercial fruits like custard apple, avocado, guava and hibiscus (Smith et al., 1997).

***Geographical distribution***

The species of *Saissetia* and *P. nigra* are widely distributed in the tropics and subtropical areas (Hill, 1983).

***Biology***

The eggs are laid underneath the carapace of the adult female and hatch into crawlers shortly afterwards (Hill, 1983). Up to 2000 eggs can be found under the body of adult *S. oleae* (Smith et al., 1997) The crawlers settle on leaves, twigs and fruit stalks. Two nymphal stages are passed before reaching adulthood. In Northern Australia there are usually 4 – 6 generations of these scales per year.

***Damage***

All species produce honeydew on which sooty mould settle, which results in a reduced photosynthesis and partly even in disfigured fruits. Leaves drop in cases of heavy infestation.

***Control***

In Australia several ladybirds including *Rhyzobius* sp., *Cryptolaemus mountrouzieri* and *Diomus* sp. are known to feed on several stages of the soft scales. Lacewing larvae (*Mallada* sp.) and scale-eating caterpillars (*Catoblemma* sp.) are also important. Parasitoids include species of the genera *Microterys*, *Encyrtus*, *Tomocera* and *Scutellista*. The scales are usually kept under control by their natural enemies and chemical treatments are not necessary. If outbreaks do occur, the use of petroleum spray oil (1 %) is recommended during early development stages, in Australia (Smith et al., 1997).

**Figure 9:** *Saissetia coffeae* (Homopt., Coccidae) (Smith et al., 1997)

**Figure 10:** *Parasaissetia nigra* (Homopt., Coccidae) (Smith et al., 1997)

### 5.2.6 Mango aphid *Toxoptera odinae* (Homoptera, Aphididae)

***Host range***

*T. odinae* is highly polyphagous. In addition to *M. indica* (Anacardiaceae) it attacks a variety of plants belonging to the families Araliceae, Caprifoliaceae, Pittosporaceae, Rubiaceae and Rutaceae (Citrus).

***Geographical distribution***

*T. odinae* is a South East Asian species with Papua New Guinea being the eastern boarder. So far it has not been found in other parts of Melanasia and Polynesia but was recently recorded in Africa (A. van Harten, pers. comm., 2002).

***Biology***

The mango aphid feeds in colonies on young growth. *T. odinae* is parthenogenetic. Both winged and wingless adults produce live offspring. The life cycle of the related species *T. aurantii* can take as little as one week with at least 25 – 30 generations a year in Australia (Smith et al., 1997).

***Damage***

*T. odinae* produces honeydew, on which sooty mould grows which reduces, in return, photosynthesis. A heavy infestation can result in deformation of flowers and drop, in a reduced fruit set and in a distortion of young leaves and twigs. This species is not known as a virus vector.

***Control***

*Lipoplexis scutellaris* and *Lysiphlebia japonica* (Hymenoptera, Aphidiidae) have been recorded as parasitoids (Stary & Gosh, 1983; Kato, 1970). In Australia, several species of ladybirds including *Coccinella*, *Harmonia*, *Coleophora* and *Scymnodes* have been recorded as predators of the related species *T. aurantii*. Syrphids and lacewing larvae are further natural enemies (Smith et al., 1997). The action level for *T. aurantii* in Australia is 25 % or more of leaf flushes infested, but it is rarely necessary to apply aphicides, since natural enemies usually provide satisfactory control.

**Figure 11:** *Toxoptera odinae* (Homopt., Aphididae) on mango inflorescense

### 5.2.7 Mango leafhoppers *Idioscopus clypealis* and *I. niveosparsus* (Homoptera, Cicadellidae)

The mango is attacked by variety of leafhoppers with *I. clypealis* and *I. niveosparus* being the most important ones in the southeast Asian region. *Amritodus atkinsoni* is another important pest but has been so far only recorded in India and Pakistan (Peña & Mohyuddin, 1997).

***Host range***

Both species are specific to mango but are also occasionally found on other plants like citrus.

***Geographical distribution***

The leafhoppers are widely distributed throughout South East Asia and the South Pacific and are found in India, Pakistan and Australia.

***Distinguishing features***

Adults of I. niveosparsus reach 4 – 5 mm in length and are dark in colouration. Adults of I. clypealis are distinctly smaller and brighter.

***Biology***

Eggs are laid singly within the young tissue of flowers and leaves. A female can lay up to 200 eggs. The nymphs undergo 4 –5 moults within 10 to 20 days to reach the adult stage. The adults reproduce only through the flowering period of mango (Sohi & Sohi, 1990) and hide during the other months in cracks and crevices of the bark. Alam (1994) showed that adults of *I. clypealis* lived up to 315 days. One to four generations of *I. clypealis* were reported in the Philipines, whereas it has five to six generations in India (Peña & Mohyuddin, 1997).

***Damage***

Due to the feeding of adults and nymphs infested flowers turn brown and dry, resulting in less fruit set. Both species produce large amounts of honeydew on which sooty mould develops reducing photosynthesis and plant growth (Peña & Mohyuddin, 1997).

***Control***

A number of insecticides like organophosphates and synthetic pyrethroids are used in the control of leafhoppers. Multiple applications are required to effectively control the pest. A control with a mixture of synthetic pyrethroids and imidacloprid proved to be very successful as it has been the case with tree injections of monocrotophos and dimethoat (Thontadarya et al., 1978; Shah et al., 1983). Smith et al. (1997) noted that infestations of citrus trees with *Empoasca smithi* worsened after spraying organophospates like methidathion and chlorpyrifos early in the season or in the previous season, killing natural enemies, which would have kept the pest under control.

A number of species have been identified as egg parasitoids (Mohyuddin & Mahmood, 1993) with *Gonatocerus* sp. (Hymenoptera: Myrmaridae) being the most important one. Others are: *Quadrastichus* sp., *Aprostocetus* sp., *Mirufens* sp. and *Centrodora* sp. Fasih and Srivastava (1990) recorded two species of chrysopids, *Chrysopa lacciperda* and *Mallada boninensis*, as predators. Despite the number of recorded parasitoids and predators, no attempt of a classical biological control of mango leafhoppers has been made (Peña & Mohyuddin, 1997).

The following entomophagous fungi are reported to attack leafhoppers:

*Beauveria bassiana* in India (Tripathi et al., 1990)
*Verticillium lecanii* in India (Viraktamath et al., 1994)
*Hirsutella versicolor* in Malaysia (Lim & Chung, 1995).

In laboratory trials, Alam (1994) recorded 100 % mortality of *I. clypealis* through infections with *Metarhizium* sp. and *Beauveria* sp. A successful control is pruning, in particular of old orchards, where tree canopy has become dense. This provides better light penetration and less humidity resulting in lower number of leafhoppers, since they prefer moist and shady sites and tend to hide in the tree canopy (Bondad, 1985). Singh (1997) reported a number of mango varieties resistent to leafhopper attack.

**Figure 12:** *Idioscopus clypealis* (20 x magnification) (Homopt., Cicadellidae)

### 5.2.8 Mango planthoppers *Colgaroides acuminata*, *Colgar* sp., *Scolypopa* sp. (Homoptera, Flatidae, Ricaniidae)

***Host range***

In addition to mango the mango planthopper *C. acuminata* has been recorded from citrus as well as *Colgar* sp. and the ricaniid *Scolypopa* sp. Other hosts include many cultivated plants and weeds.

***Geographical distribution***

*C. acuminata* is native to Australia and from there it may have been introduced into Papua New Guinea. Species of the genus *Scolypopa* are widespread throughout South East Asia.

***Biology***

The eggs of the mango planthopper *C. acuminata* are laid in masses of about 50 eggs (Smith et al., 1997). The masses are about 5 mm in diameter and have a white cap. The nymphs are pale to green white with feathery, mealy filaments. The life cycle takes about 1–2 months with 5-6 generations per year in Queensland, Australia. The eggs of

*Scolypopa* are laid in the bark of thin shoots and twigs. Like *Colgaroides* the nymphs have feathery, waxy filaments. There are five nymphal instars.

***Damage***

Both species produce honeydew on which sooty mould settles resulting in a reduced photosynthesis.

***Control***

In Australia the wasp *Achalcerinys* sp. parasitises up to 90 % of egg masses of *Colgaroides acuminata*. Species of the family Dryinidae and Strepsiptera parasitise nymphal stages. Reduviidae and spiders are known as predators. Little is known about natural enemies of *Scolypopa* (Smith et al., 1997). In Australia, the wasp *Centrodora scolypopae* has been identified as an egg parasitoid of *Scolypopa australis*. Both species are considered as minor pests in Australia. In both cases, chemical control is recommended, when 20 % or more of green twigs are infested.

**Figure 13:** *Colgar* sp. (Homopt., Flatidae)

**Figure 14:** *Scolypopa australis* (Homopt., Ricaniidae) (Smith et al., 1997)

### 5.2.9 Mango fruit fly *Bactrocera frauenfeldi* (Diptera, Tephritidae)

*Bactrocera* spp. are major pests of fruits in the eastern hemisphere (Peña & Mohyuddin, 1997). In Papua New Guinea the most common fruit fly in mango is *B. frauenfeldi*. Other species reported include *B. papayae* and *B. trivialis* (Leblanc et al., 2001).

***Host range***

The mango fruit fly is an extremely polyphagous species with records from more than 72 host plants. In addition to mango, other economically important fruit attacked include guava, cashew, avocado, papaya, almond and chestnut.

***Geographical distribution***

*B. frauenfeldi* is widespread throughout South East Asia, PNG, the Solomon Island and Micronesia. It was introduced into Australia in 1974 and is now present in Queensland from Cape York Peninsula to Townsville (Peña & Mohyuddin, 1997; Leblanc et al., 2001).

***Biology***

Eggs are laid when the female is about two weeks old. Eggs are white and about 1 mm long, and laid in batches in the fruit rind of maturing fruits. One female can lay about 25 eggs in 24 hours. While puncturing the rind, the adult pushes bacteria into the flesh.

These bacteria cause fruit decay, which results in a substrate on which the larvae feed. The eggs hatch in 2 – 3 days, and the larvae feed on the fruit pulp. More than 12 larvae can be found in one fruit. There are three larval stages. When fully grown, the larva leaves the fruit and pupates in the soil. The larvae complete their development with 10 days and the pupal stage lasts ca. 11 days. The complete life cycle takes therefore about 22 days on average (Leblanc et al., 2001).

***Damage***

The puncture of the rind is not visible at first but later the area around it yellows. Attacked fruit decay through the growth of bacteria and feeding of the larvae and, in some cases, drop prematurely.

***Control***

The most important natural enemies are parasitic wasps of the family Braconidae, subfamily Opiinae. The adult wasps use their long ovipositor to attack larvae inside the fruit. Although quite common in Queensland (Australia), they do not appear to significantly reduce fruit fly numbers (Smith et al., 1997).

Fruit fly activity is monitored with baited traps to attract male flies. These traps usually consist of plastic cylinders with the lure solution suspended inside. The solution is a mixture of the lure (Cue-lure) and malathion. The flies enter the trap, come in contact with the lure and are killed by the insecticide. The preferred method of control is baiting, since it is as effective as cover sprays with insecticides but less disruptive to natural enemies. The bait consists of yeast mixed with an insecticide and is applied every 7 days during susceptible fruit stages at a rate of 20 – 30 l/ha (Smith et al., 1997). In small scale production fallen fruits should be regularly removed and soaked in kerosene to destroy larvae.

**Figure 15:** *Bactrocera frauenfeldi* (Dip., Tephritidae)

## 5.3 Material and methods

### 5.3.1 Study sites

The studies were conducted at the following sites in the Central Province:

Laloki, PAU, Tahira and Launakalana

### 5.3.2 Determination of infestation levels

All pests, except fruit flies, were monitored three times during 2002 according to their occurrence within the mango season. At each monitoring date 15 trees per orchard were randomly choosen and checked for the presence of pests listed; at Laloki due to the lesser number of trees only 6 trees were randomly picked. This survey was conducted in accordance with the guidelines for monitoring pests in Australian Citrus.

*1. Fruit piercing moths*

- Per tree 30 fruits were checked during late season for the presence of sucking.

*2. Mango blossom feeders*

- Per tree 5 inflorescenses were checked during blossom for the presence of larvae of Lepidoptera.

*3. Mango leafminer*

- Per tree 5 young twigs with 5 leaves were checked for the presence of mines.

*4. White mango scale*

- Per tree 5 twigs with 5 leaves each were checked for the presence of the hardscale or chlorotic spots caused by their feeding.

*5. Soft scales*

- Per tree 5 green, young twigs with fruits were checked for the presence of the softscales.

*6. Mango aphid*

- Per tree 5 green, young twigs were checked for the presence of aphids.

*7. Mango leafhoppers*

- Per tree 5 inflorescenses were checked for the presence of leafhoppers.

*8. Mango planthoppers*

- Per tree 5 green, young twigs were checked for the presence of planthoppers.

*9. Fruit flies*

- 450 fallen fruits were collected from Tahira and Laloki during late season and checked for the presence of fruit fly maggots. In addition, 450 fruits were bought from local markets and also checked for the presence of larvae.

### 5.3.3 Identification of insects

The larvae of blossom feeders and leafminers were taken into laboratory and reared to adult stage. The moths were sent for identification to Scott Miller, Smithsonian Institute, Washington, USA. *Toxoptera odinae* has been identified by A. van Harten (Department of Agriculture, Jemen). All other insects were identified by the author.

## 5.4 Results

### 5.4.1 Infestation levels of mango fruits with fruit piercing moths *Othreis fullonia*, *O. materna*, *Eudocima salamnia* (Lep., Noctuidae)

No samples were taken at Launakalana since fruit set was reduced due to an earlier severe infestation with anthraknose. The highest fruit damage was recorded at Laloki on the 23rd of October with 10 out of 150 (6.66 %) showing typical signs of an attack by fruit piercing moths (Table 10). On average of the three sampling dates the highest damage with 4.66 % was calculated for the Laloki orchard. At PAU and Tahira average infestation levels were 2.66 % and 1.55 %, respectively. As Table 11 shows, the majority of the trees examined were not infested, and if, only a few fruits were attacked.

**Table 10:** Infestation levels of mango fruits with fruit piercing moths in three orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested fruit | Infestation % |
|---|---|---|---|
| PAU | 9.10.02 | 450/6 | 1.33 |
| | 23.10.02 | 450/11 | 2.44 |
| | 6.11.02 | 450/12 | 2.66 |
| | | | **Mean Value 2.14 %** |
| Tahira | 10.10.02 | 450/4 | 0.88 |
| | 24.10.02 | 450/4 | 0.88 |
| | 7.11.02 | 450/14 | 3.11 |
| | | | **Mean Value 1.62 %** |
| Laloki | 9.10.02 | 150/4 | 2.66 |
| | 23.10.02 | 150/10 | 6.66 |
| | 6.11.02 | 150/7 | 4.66 |
| | | | **Mean Value 4.66 %** |

**Table 11:** Number of mango fruits per tree attacked by fruit piercing moths in three orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total |
| PAU | 9.10.02 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/2 | 30/3 | 30/1 | 450/6 |
| | 23.10.02 | 30/- | 30/- | 30/- | 30/2 | 30/2 | 30/3 | 30/4 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 450/11 |
| | 6.11.02 | 30/- | 30/- | 30/4 | 30/- | 30/- | 30/5 | 30/1 | 30/2 | 30/- | 30/- | 30/2 | 30/- | 30/- | 30/- | 30/- | 450/12 |
| Tahira | 10.10.02 | 30/2 | 30/- | 30/1 | 30/- | 30/- | 30/1 | 30/- | 30/- | 30/1 | 30/2 | 30/- | 30/- | 30/- | 30/- | 30/- | 450/4 |
| | 24.10.02 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/2 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/2 | 450/4 |
| | 7.11.02 | 30/- | 30/2 | 30/1 | 30/2 | 30/- | 30/- | 30/- | 30/- | 30/3 | 30/2 | 30/- | 30/- | 30/1 | 30/3 | 30/- | 450/14 |
| Laloki | 9.10.02 | 30/- | 30/2 | 30/2 | 30/- | 30/- | 30/- | | | | | | | | | | 150/4 [b] |
| | 23.10.02 | 30/- | 30/- | 30/2 | 30/2 | 30/6 | 30/- | | | | | | | | | | 150/10 |
| | 6.11.02 | 30/4 | 30/3 | 30/- | 30/- | 30/- | 30/- | | | | | | | | | | 150/7 |

[a] Values for the individual trees represent the number of infested fruits out of thirty fruits per tree.
[b] The totals represent the number of infested fruits out of 450 fruits checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.2 Infestation levels of mango inflorescenses with blossom feeders (Lepidoptera), *Cosmostola* sp., *Gymnoscelis* sp., *Nanaguna breviuscula*

It has to be noted that the larvae complex existed of different species with *Cosmostola*, *Gymnoscelis* and *N. breviuscula* being confirmed as blossom feeders. Other specimens were identified as *Acrocercops*, *Eublemma* and Pyralidae. On average of the three sampling dates the highest infestation level (53.33%) was calculated for the Laloki orchard, while the levels within the other orchards varied between 43.55 % and 47.11 % (Table 12). The highest infestation was recorded at Laloki on the 15th of August with 21 out of 30 inflorescenses (70 %) infested with one or more lepidopteran larvae (Table 13). The lowest infestation level (30.66 %) was recorded at Tahira on the 14th of August.

**Table 12:** Infestation levels of mango inflorescenses with blossom feeders (Lepidoptera) in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested inflorescenses | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 75/36 | 48.00 |
| | 30.8.02 | 75/43 | 57.33 |
| | 13.9.02 | 75/27 | 36.00 |
| | | | **Mean Value 47.11 %** |
| Tahira | 14.8.02 | 75/23 | 30.66 |
| | 28.8.02 | 75/48 | 64.00 |
| | 11.9.02 | 75/27 | 36.00 |
| | | | **Mean Value 43.55 %** |
| Launakalana | 20.8.02 | 75/39 | 52.00 |
| | 3.9.02 | 75/34 | 45.33 |
| | 19.9.02 | 75/26 | 34.66 |
| | | | **Mean Value 44.00 %** |
| Laloki | 15.8.02 | 30/21 | 70.00 |
| | 30.8.02 | 30/11 | 36.66 |
| | 13.9.02 | 30/16 | 53.33 |
| | | | **Mean Value 53.33 %** |

**Table 13:** Number of inflorescenses per mango tree infested with blossom feeders (Lepidoptera) in four orchards in the Central Province, PNG.

| | Mango tree sampled [a] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 5/2 | 5/3 | 5/3 | 5/4 | 5/1 | 5/2 | 5/2 | 5/2 | 5/1 | 5/5 | 5/2 | 5/3 | 5/1 | 5/2 | 5/3 | 75/36 |
| | 30.8.02 | 5/4 | 5/4 | 5/5 | 5/3 | 5/3 | 5/2 | 5/2 | 5/2 | 5/1 | 5/3 | 5/1 | 5/4 | 5/4 | 5/3 | 5/2 | 75/43 |
| | 13.9.02 | 5/2 | 5/2 | 5/1 | 5/2 | 5/3 | 5/3 | 5/4 | 5/2 | 5/1 | 5/- | 5/2 | 5/- | 5/3 | 5/2 | 5/- | 75/27 |
| Tahira | 14.8.02 | 5/5 | 5/- | 5/2 | 5/2 | 5/2 | 5/1 | 5/- | 5/2 | 5/- | 5/1 | 5/- | 5/- | 5/2 | 5/3 | 5/3 | 75/23 |
| | 28.8.02 | 5/4 | 5/3 | 5/2 | 5/4 | 5/3 | 5/3 | 5/3 | 5/4 | 5/1 | 5/5 | 5/5 | 5/3 | 5/3 | 5/3 | 5/2 | 75/48 |
| | 11.9.02 | 5/2 | 5/1 | 5/3 | 5/2 | 5/2 | 5/2 | 5/1 | 5/2 | 5/2 | 5/2 | 5/3 | 5/- | 5/2 | 5/1 | 5/2 | 75/27 |
| Launakalana | 20.8.02 | 5/4 | 5/3 | 5/3 | 5/2 | 5/2 | 5/3 | 5/2 | 5/4 | 5/3 | 5/3 | 5/2 | 5/2 | 5/2 | 5/1 | 5/3 | 75/39 |
| | 3.9.02 | 5/2 | 5/3 | 5/3 | 5/4 | 5/2 | 5/1 | 5/- | 5/3 | 5/2 | 5/- | 5/4 | 5/5 | 5/2 | 5/1 | 5/2 | 75/34 |
| | 19.9.02 | 5/1 | 5/1 | 5/3 | 5/3 | 5/2 | 5/- | 5/- | 5/2 | 5/1 | 5/3 | 5/2 | 5/3 | 5/2 | 5/1 | 5/2 | 75/26 |
| Laloki[a] | 15.8.02 | 5/5 | 5/3 | 5/4 | 5/3 | 5/3 | 5/3 | | | | | | | | | | 30/21 |
| | 30.8.02 | 5/2 | 5/3 | 5/2 | 5/2 | 5/2 | 5/- | | | | | | | | | | 30/11 |
| | 13.9.02 | 5/1 | 5/3 | 5/4 | 5/3 | 5/3 | 5/2 | | | | | | | | | | 30/16 |

[a] Values for the individual trees represent the number of infested inflorescenses out of five inflorescenses per tree.
[b] The totals represent the number of infested inflorescenses out of 75 inflorescenses checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.3 Infestation levels of mango leaves with mango leafminer *Acrocercops* spp. (Lep., Gracillariidae)

On average of the three sampling dates the highest damage with 26.49 % was calculated for the Launakalana orchard, while the average levels within the other three orchards varied between 18.04 % and 19.73 % (Table 14). The highest damage was recorded at Launakalana on the 19th of September with 109 out of 375 leaves (29.06 %) showing mines of *Acrocercops* (Table 15). The lowest infestation level (13.60 %) was recorded at PAU on the 30th of August.

**Table 14:** Infestation levels of mango leaves with mango leafminer *Acrocercops* spp. in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested leaves | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 375/82 | 21.86 |
| | 30.8.02 | 375/51 | 13.60 |
| | 13.9.02 | 375/70 | 18.66 |
| | | | **Mean Value 18.04 %** |
| Tahira | 14.8.02 | 375/85 | 22.66 |
| | 28.8.02 | 375/63 | 16.80 |
| | 11.9.02 | 375/74 | 19.73 |
| | | | **Mean Value 19.73 %** |
| Launakalana | 20.8.02 | 375/102 | 27.20 |
| | 3.9.02 | 375/87 | 23.20 |
| | 19.9.02 | 375/109 | 29.06 |
| | | | **Mean Value 26.49 %** |
| Laloki | 15.8.02 | 150/31 | 20.66 |
| | 30.8.02 | 150/27 | 18.00 |
| | 13.9.02 | 150/26 | 17.33 |
| | | | **Mean Value 18.66 %** |

**Table 15:** Number of leaves per mango tree infested with mango leafminer *Acrocercops spp.* (Lep., Gracillariidae) in four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 25/7 | 25/4 | 25/8 | 25/2 | 25/11 | 25/2 | 25/3 | 25/4 | 25/2 | 25/12 | 25/3 | 25/4 | 25/9 | 25/6 | 25/5 | 375/82 |
| | 30.8.02 | 25/4 | 25/7 | 25/3 | 25/2 | 25/5 | 25/- | 25/4 | 25/2 | 25/- | 25/10 | 25/2 | 25/2 | 25/3 | 25/6 | 25/1 | 375/51 |
| | 13.9.02 | 25/4 | 25/5 | 25/1 | 25/7 | 25/6 | 25/5 | 25/8 | 25/6 | 25/3 | 25/7 | 25/1 | 25/8 | 25/4 | 25/3 | 25/2 | 375/70 |
| Tahira | 14.8.02 | 25/3 | 25/7 | 25/10 | 25/2 | 25/4 | 25/3 | 25/3 | 25/4 | 25/5 | 25/3 | 25/14 | 25/10 | 25/8 | 25/5 | 25/4 | 375/85 |
| | 28.8.02 | 25/7 | 25/4 | 25/8 | 25/8 | 25/2 | 25/3 | 25/3 | 25/3 | 25/3 | 25/5 | 25/4 | 25/2 | 25/5 | 25/2 | 25/4 | 375/63 |
| | 11.9.02 | 25/3 | 25/12 | 25/7 | 25/3 | 25/6 | 25/9 | 25/4 | 25/2 | 25/3 | 25/4 | 25/7 | 25/2 | 25/3 | 25/4 | 25/5 | 375/74 |
| Launakalana | 20.8.02 | 25/10 | 25/5 | 25/10 | 25/11 | 25/6 | 25/9 | 25/1 | 25/8 | 25/4 | 25/1 | 25/7 | 25/11 | 25/2 | 25/10 | 25/7 | 375102 |
| | 3.9.02 | 25/4 | 25/6 | 25/8 | 25/4 | 25/2 | 25/11 | 25/13 | 25/3 | 25/1 | 25/4 | 25/7 | 25/6 | 25/4 | 25/8 | 25/6 | 375/87 |
| | 19.9.02 | 25/7 | 25/5 | 25/10 | 25/5 | 25/4 | 25/12 | 25/10 | 25/6 | 25/4 | 25/9 | 25/10 | 25/8 | 25/6 | 25/8 | 25/5 | 375/109 |
| Laloki[a] | 15.8.02 | 25/9 | 25/3 | 25/7 | 25/2 | 25/4 | 25/6 | | | | | | | | | | 150/31 |
| | 30.8.02 | 25/3 | 25/1 | 25/9 | 25/9 | 25/1 | 25/4 | | | | | | | | | | 150/27 |
| | 13.9.02 | 25/2 | 25/7 | 25/6 | 25/3 | 25/5 | 25/3 | | | | | | | | | | 150/26 |

[a] Values for the individual trees represent the number of infested leaves out of 25 leaves per tree.
[b] The totals represent the number of infested leaves out of 375 leaves checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.4 Infestation levels of mango leaves with white mango scale *Aulacaspis tubercularis* (Homopt., Diaspididae)

On average of the three sampling dates the highest damage with 18.22 % was calculated for the Launakalana orchard while the average levels within the other three orchards varied between 6.13 % and 14.87 % (Table 16). The highest damage was recorded at Laloki on the 13th of September with 33 out of 375 leaves (22.00 %) infested with white mango scales (Table 17). The lowest infestation level (5.33 %) was recorded at PAU on the 30th of August.

**Table 16:** Infestation levels of mango leaves with *Aulacaspis tubercularis* (Homopt., Diaspididae) in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested leaves | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 375/27 | 7.20 |
| | 30.8.02 | 375/20 | 5.33 |
| | 13.9.02 | 375/22 | 5.86 |
| | | | **Mean Value 6.13 %** |
| Tahira | 14.8.02 | 375/42 | 11.20 |
| | 28.8.02 | 375/64 | 17.06 |
| | 11.9.02 | 375/27 | 7.20 |
| | | | **Mean Value 11.82 %** |
| Launakalana | 20.8.02 | 375/81 | 21.60 |
| | 3.9.02 | 375/50 | 13.33 |
| | 19.9.02 | 375/74 | 19.73 |
| | | | **Mean Value 18.22 %** |
| Laloki | 15.8.02 | 150/21 | 14.00 |
| | 30.8.02 | 150/13 | 8.66 |
| | 13.9.02 | 150/33 | 22.00 |
| | | | **Mean Value 14.87 %** |

**Table 17:** Number of leaves per mango tree infested with *Aulacaspis tubercularis* (Homopt., Diaspididae) in four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 25/- | 25/2 | 25/3 | 25/2 | 25/2 | 25/5 | 25/2 | 25/1 | 25/1 | 25/1 | 25/- | 25/5 | 25/2 | 25/- | 25/1 | 375/27 |
| | 30.8.02 | 25/4 | 25/2 | 25/1 | 25/2 | 25/2 | 25/- | 25/- | 25/2 | 25/1 | 25/1 | 25/1 | 25/- | 25/2 | 25/- | 25/2 | 375/20 |
| | 13.9.02 | 25/1 | 25/1 | 25/2 | 25/3 | 25/- | 25/1 | 25/1 | 25/4 | 25/2 | 25/2 | 25/1 | 25/3 | 25/- | 25/1 | 25/- | 375/22 |
| Tahira | 14.8.02 | 25/3 | 25/3 | 25/2 | 25/2 | 25/6 | 25/1 | 25/1 | 25/7 | 25/3 | 25/- | 25/4 | 25/- | 25/5 | 25/3 | 25/2 | 375/42 |
| | 28.8.02 | 25/1 | 25/3 | 25/- | 25/1 | 25/2 | 25/11 | 25/7 | 25/8 | 25/5 | 25/2 | 25/4 | 25/2 | 25/7 | 25/5 | 25/6 | 375/64 |
| | 11.9.02 | 25/2 | 25/3 | 25/3 | 25/1 | 25/2 | 25/- | 25/2 | 25/3 | 25/- | 25/2 | 25/3 | 25/1 | 25/2 | 25/2 | 25/1 | 375/27 |
| Launakalana | 20.8.02 | 25/4 | 25/2 | 25/5 | 25/6 | 25/3 | 25/11 | 25/10 | 25/12 | 25/5 | 25/2 | 25/- | 25/3 | 25/8 | 25/4 | 25/6 | 375/81 |
| | 3.9.02 | 25/3 | 25/- | 25/4 | 25/4 | 25/8 | 25/- | 25/3 | 25/1 | 25/2 | 25/3 | 25/5 | 25/8 | 25/3 | 25/2 | 25/4 | 375/50 |
| | 19.9.02 | 25/5 | 25/3 | 25/2 | 25/1 | 25/8 | 25/8 | 25/4 | 25/5 | 25/3 | 25/5 | 25/8 | 25/5 | 25/2 | 25/6 | 25/9 | 375/74 |
| Laloki[a] | 15.8.02 | 25/1 | 25/6 | 25/- | 25/3 | 25/7 | 25/4 | | | | | | | | | | 150/21 |
| | 30.8.02 | 25/1 | 25/5 | 25/- | 25/3 | 25/1 | 25/3 | | | | | | | | | | 150/13 |
| | 13.9.02 | 25/4 | 25/3 | 25/8 | 25/10 | 25/4 | 25/4 | | | | | | | | | | 150/33 |

[a] Values for the individual trees represent the number of infested leaves out of 25 leaves per tree.
[b] The totals represent the number of infested leaves out of 375 leaves checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.5 Infestation levels of young mango twigs with soft scales, *Saissetia* sp. and *Parasaissetia* sp. (Homopt., Coccidae)

On average of the three sampling dates the highest damage with 46.66 % was calculated for the Launakalana orchard while the average levels within the other three orchards varied between 31.1 % and 32.44 % (Table 18). The highest damage was recorded at Launakalana on the 20th of August with 42 out of 75 twigs (56.00 %) infested with soft scales (Table 19). The lowest infestation level (16.00 %) was recorded at Tahira on the 14th of August.

**Table 18:** Infestation levels of young mango twigs with *Saissetia* sp. and *Parasaissetia* sp. (Homopt., Coccidae) in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested twigs | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 75/20 | 26.66 |
| | 30.8.02 | 75/24 | 32.00 |
| | 13.9.02 | 75/29 | 38.66 |
| | | | **Mean Value 32.44 %** |
| Tahira | 14.8.02 | 75/12 | 16.00 |
| | 28.8.02 | 75/34 | 45.33 |
| | 11.9.02 | 75/25 | 33.33 |
| | | | **Mean Value 31.55 %** |
| Launakalana | 20.8.02 | 75/42 | 56.00 |
| | 3.9.02 | 75/34 | 45.33 |
| | 19.9.02 | 75/29 | 38.66 |
| | | | **Mean Value 46.66 %** |
| Laloki | 15.8.02 | 30/8 | 26.66 |
| | 30.8.02 | 30/10 | 33.33 |
| | 13.9.02 | 30/10 | 33.33 |
| | | | **Mean Value 31.11 %** |

**Table 19:** Number of young twigs per mango tree infested with *Saissetia* sp. and *Parasaissetia* sp. (Homopt., Coccidae) in four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 5/2 | 5/3 | 5/1 | 5/- | 5/2 | 5/- | 5/1 | 5/1 | 5/1 | 5/2 | 5/1 | 5/1 | 5/3 | 5/1 | 5/1 | 75/20 |
| | 30.8.02 | 5/1 | 5/2 | 5/1 | 5/1 | 5/5 | 5/3 | 5/- | 5/2 | 5/1 | 5/2 | 5/1 | 5/2 | 5/- | 5/- | 5/3 | 75/24 |
| | 13.9.02 | 5/2 | 5/2 | 5/- | 5/3 | 5/4 | 5/3 | 5/2 | 5/1 | 5/- | 5/2 | 5/3 | 5/2 | 5/2 | 5/3 | 5/- | 75/29 |
| Tahira | 14.8.02 | 5/2 | 5/- | 5/- | 5/3 | 5/1 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/2 | 5/2 | 5/- | 5/- | 5/1 | 75/12 |
| | 28.8.02 | 5/- | 5/- | 5/- | 5/4 | 5/1 | 5/3 | 5/2 | 5/3 | 5/5 | 5/2 | 5/4 | 5/2 | 5/4 | 5/3 | 5/1 | 75/34 |
| | 11.9.02 | 5/2 | 5/1 | 5/- | 5/- | 5/2 | 5/- | 5/- | 5/4 | 5/3 | 5/2 | 5/- | 5/3 | 5/2 | 5/4 | 5/2 | 75/25 |
| Launakalana | 20.8.02 | 5/4 | 5/3 | 5/4 | 5/5 | 5/2 | 5/3 | 5/4 | 5/2 | 5/1 | 5/1 | 5/4 | 5/2 | 5/2 | 5/3 | 5/2 | 75/42 |
| | 3.9.02 | 5/2 | 5/3 | 5/1 | 5/3 | 5/4 | 5/- | 5/2 | 5/2 | 5/1 | 5/3 | 5/3 | 5/4 | 5/- | 5/3 | 5/3 | 75/34 |
| | 19.9.02 | 5/3 | 5/2 | 5/3 | 5/- | 5/1 | 5/3 | 5/3 | 5/3 | 5/2 | 5/3 | 5/- | 5/- | 5/- | 5/2 | 5/4 | 75/29 |
| Laloki[a] | 15.8.02 | 5/2 | 5/- | 5/1 | 5/2 | 5/1 | 5/2 | | | | | | | | | | 30/8 |
| | 30.8.02 | 5/2 | 5/3 | 5/3 | 5/- | 5/- | 5/2 | | | | | | | | | | 30/10 |
| | 13.9.02 | 5/1 | 5/2 | 5/2 | 5/- | 5/3 | 5/2 | | | | | | | | | | 30/10 |

[a] Values for the individual trees represent the number of infested twigs out of 5 twigs per tree.
[b] The totals represent the number of infested twigs out of 75 twigs checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.6. Infestation levels of young mango twigs with the mango aphid *Toxoptera odinae* (Homopt., Aphididae)

On average of the three sampling dates the highest damage with 24.88 % was calculated for the Tahira orchard, while the average levels within the other three orchards varied between 3.11 % and 9.33 % (Table 20). The highest damage was recorded at Tahira on the 11th of September with 22 out of 75 twigs (29.33 %) infested with soft scales (Table 21). No twigs infested with aphids were recorded at Laloki on the 15th of August.

**Table 20:** Infestation levels of young mango twigs with *Toxoptera odinae* (Homopt., Aphididae) in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested twigs | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 75/8 | 10.66 |
| | 30.8.02 | 75/5 | 6.66 |
| | 13.9.02 | 75/8 | 10.66 |
| | | | **Mean Value 9.33 %** |
| Tahira | 14.8.02 | 75/14 | 18.66 |
| | 28.8.02 | 75/20 | 26.66 |
| | 11.9.02 | 75/22 | 29.33 |
| | | | **Mean Value 24.88 %** |
| Launakalana | 20.8.02 | 75/3 | 4.00 |
| | 3.9.02 | 75/2 | 2.66 |
| | 19.9.02 | 75/2 | 2.66 |
| | | | **Mean Value 3.11 %** |
| Laloki | 15.8.02 | 30/- | 0.00 |
| | 30.8.02 | 30/3 | 10.00 |
| | 13.9.02 | 30/1 | 3.33 |
| | | | **Mean Value 4.44 %** |

**Table 21:** Number of young twigs per mango tree infested with *Toxoptera odinae* (Homopt., Aphididae) in four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 5/- | 5/- | 5/- | 5/1 | 5/2 | 5/- | 5/- | 5/2 | 5/- | 5/1 | 5/1 | 5/- | 5/- | 5/1 | 5/- | 75/8 |
| | 30.8.02 | 5/2 | 5/- | 5/- | 5/1 | 5/- | 5/1 | 5/- | 5/2 | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 75/5 |
| | 13.9.02 | 5/- | 5/2 | 5/1 | 5/1 | 5/- | 5/- | 5/3 | 5/- | 5/- | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/- | 75/8 |
| Tahira | 14.8.02 | 5/- | 5/- | 5/- | 5/2 | 5/3 | 5/3 | 5/2 | 5/- | 5/- | 5/1 | 5/2 | 5/- | 5/- | 5/- | 5/1 | 75/14 |
| | 28.8.02 | 5/2 | 5/3 | 5/- | 5/- | 5/- | 5/- | 5/2 | 5/3 | 5/2 | 5/4 | 5/- | 5/- | 5/3 | 5/1 | 5/- | 75/20 |
| | 11.9.02 | 5/3 | 5/1 | 5/2 | 5/1 | 5/2 | 5/1 | 5/1 | 5/1 | 5/4 | 5/- | 5/1 | 5/2 | 5/- | 5/- | 5/3 | 75/22 |
| Launakalana | 20.8.02 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/1 | 5/- | 5/1 | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 75/3 |
| | 3.9.02 | 5/- | 5/1 | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/1 | 75/2 |
| | 19.9.02 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | 752 |
| Laloki[a] | 15.8.02 | 5/- | 5/- | 5/- | 5/- | 5/- | 5/- | | | | | | | | | | 30/- |
| | 30.8.02 | 5/- | 5/- | 5/2 | 5/1 | 5/- | 5/- | | | | | | | | | | 30/3 |
| | 13.9.02 | 5/- | 5/1 | 5/- | 5/- | 5/- | 5/- | | | | | | | | | | 30/1 |

[a] Values for the individual trees represent the number of infested twigs out of 5 twigs per tree.
[b] The totals represent the number of infested twigs out of 75 twigs checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.7 Infestation levels of mango inflorescenses with mango leafhoppers *Idioscopus clypealis* and *I. niveosparsus* (Homopt., Cicadellidae)

On average of the three sampling dates the highest damage with 64.44 % was calculated for the Laloki orchard while the average levels within the other three orchards varied between 50.22 % and 52.89 % (Table 22). The highest damage was recorded at Laloki on the 11th of September with 21 out of 30 inflorescenses (70.00 %) infested with leafhoppers (Table 23). The lowest infestation level (30.66 %) was recorded at Tahira on the 14th of August.

**Table 22:** Infestation levels of mango inflorescenses with *Idioscopus clypealis* and *I. niveosparsus* (Homopt., Cicadellidae) in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested twigs | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 75/35 | 46.66 |
| | 30.8.02 | 75/38 | 50.66 |
| | 13.9.02 | 75/43 | 57.33 |
| | | | **Mean Value 51.55 %** |
| Tahira | 14.8.02 | 75/23 | 30.66 |
| | 28.8.02 | 75/48 | 64.00 |
| | 11.9.02 | 75/48 | 64.00 |
| | | | **Mean Value 52.89 %** |
| Launakalana | 20.8.02 | 75/37 | 49.33 |
| | 3.9.02 | 75/38 | 50.66 |
| | 19.9.02 | 75/38 | 50.66 |
| | | | **Mean Value 50.22 %** |
| Laloki | 15.8.02 | 30/21 | 70.00 |
| | 30.8.02 | 30/18 | 60.00 |
| | 13.9.02 | 30/19 | 63.33 |
| | | | **Mean Value 64.44 %** |

**Table 23:** Number of inflorescenses per mango tree infested with *Idioscopus clypealis* and *I. niveosparsus* (Homopt., Cicadellidae) in four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 5/1 | 5/3 | 5/1 | 5/2 | 5/5 | 5/4 | 5/3 | 5/2 | 5/1 | 5/4 | 5/2 | 5/1 | 5/2 | 5/1 | 5/3 | 75/35 |
| | 30.8.02 | 5/2 | 5/1 | 5/4 | 5/3 | 5/4 | 5/3 | 5/2 | 5/1 | 5/2 | 5/5 | 5/4 | 5/5 | 5/- | 5/- | 5/2 | 75/38 |
| | 13.9.02 | 5/3 | 5/4 | 5/3 | 5/2 | 5/1 | 5/3 | 5/3 | 5/4 | 5/2 | 5/4 | 5/- | 5/4 | 5/5 | 5/3 | 5/2 | 75/43 |
| Tahira | 14.8.02 | 5/3 | 5/3 | 5/- | 5/- | 5/- | 5/1 | 5/2 | 5/1 | 5/- | 5/3 | 5/5 | 5/2 | 5/- | 5/1 | 5/2 | 75/23 |
| | 28.8.02 | 5/4 | 5/2 | 5/4 | 5/5 | 5/3 | 5/3 | 5/3 | 5/1 | 5/4 | 5/5 | 5/5 | 5/1 | 5/2 | 5/3 | 5/3 | 75/48 |
| | 11.9.02 | 5/4 | 5/3 | 5/2 | 5/4 | 5/3 | 5/5 | 5/3 | 5/2 | 5/4 | 5/3 | 5/1 | 5/5 | 5/2 | 5/4 | 5/3 | 75/48 |
| Launakalana | 20.8.02 | 5/2 | 5/4 | 5/2 | 5/2 | 5/1 | 5/2 | 5/- | 5/1 | 5/2 | 5/5 | 5/4 | 5/3 | 5/5 | 5/2 | 5/2 | 75/37 |
| | 3.9.02 | 5/3 | 5/3 | 5/4 | 5/2 | 5/1 | 5/- | 5/1 | 5/4 | 5/3 | 5/1 | 5/- | 5/5 | 5/4 | 5/4 | 5/3 | 75/38 |
| | 19.9.02 | 5/1 | 5/4 | 5/2 | 5/4 | 5/3 | 5/3 | 5/3 | 5/2 | 5/5 | 5/2 | 5/4 | 5/- | 5/- | 5/2 | 5/3 | 75/38 |
| Laloki[a] | 15.8.02 | 5/3 | 5/3 | 5/4 | 5/5 | 5/3 | 5/3 | | | | | | | | | | 30/21 |
| | 30.8.02 | 5/4 | 5/4 | 5/3 | 5/4 | 5/1 | 5/2 | | | | | | | | | | 30/18 |
| | 13.9.02 | 5/3 | 5/5 | 5/3 | 5/3 | 5/2 | 5/3 | | | | | | | | | | 30/19 |

[a] Values for the individual trees represent the number of infested inflorescenses out of 5 inflorescenses per tree.
[b] The totals represent the number of infested inflorescenses out of 75 inflorescenses checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.8 Infestation levels of young mango twigs with mango planthoppers, *Colgaroides acuminata*, *Colgar* sp., *Scolypopa* sp., (Homopt., Flatidae, Ricaniidae)

On average of the three sampling dates the highest damage with 19.11 % was calculated for the Tahira orchard while the average levels within the other three orchards varied between 10.66 % and 17.78 % (Table 24). The highest damage was recorded at Laloki on the 13th of September with 7 out of 30 twigs (23.33 %) attacked by planthoppers (Table 25). The lowest infestation level (4.00 %) was recorded at PAU on the 15th of August.

**Table 24:** Infestation levels of young mango twigs with *Colgaroides acuminata*, *Colgar* sp. and *Scolypopa* sp. (Homopt., Flatidae, Ricaniidae) in four orchards in the Central Province, PNG.

| Location | Collection Date | Number of infested twigs | Infestation % |
|---|---|---|---|
| PAU | 15.8.02 | 75/3 | 4.00 |
| | 30.8.02 | 75/7 | 9.33 |
| | 13.9.02 | 75/14 | 18.66 |
| | | | **Mean Value 10.66 %** |
| Tahira | 14.8.02 | 75/14 | 18.66 |
| | 28.8.02 | 75/15 | 20.00 |
| | 11.9.02 | 75/14 | 18.66 |
| | | | **Mean Value 19.11 %** |
| Launakalana | 20.8.02 | 75/8 | 10.66 |
| | 3.9.02 | 75/12 | 16.00 |
| | 19.9.02 | 75/9 | 12.00 |
| | | | **Mean Value 12.89 %** |
| Laloki | 15.8.02 | 30/6 | 20.00 |
| | 30.8.02 | 30/3 | 10.00 |
| | 13.9.02 | 30/7 | 23.33 |
| | | | **Mean Value 17.78 %** |

**Table 25:** Number of young mango twigs infested with *Colgaroides acuminata*, *Colgar* sp. and *Scolypopa* sp. (Homopt., Flatidae, Ricaniidae) in four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total [b] |
| PAU | 15.8.02 | 5/- | 5/- | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/1 | 5/- | 5/1 | 5/- | 5/- | 5/- | 5/- | 5/- | 75/3 |
| | 30.8.02 | 5/- | 5/1 | 5/- | 5/1 | 5/1 | 5/- | 5/1 | 5/- | 5/1 | 5/- | 5/- | 5/2 | 5/- | 5/- | 5/- | 75/7 |
| | 13.9.02 | 5/1 | 5/1 | 5/- | 5/- | 5/2 | 5/2 | 5/- | 5/1 | 5/1 | 5/- | 5/1 | 5/2 | 5/1 | 5/- | 5/2 | 75/14 |
| Tahira | 14.8.02 | 5/1 | 5/2 | 5/- | 5/1 | 5/2 | 5/2 | 5/- | 5/1 | 5/- | 5/1 | 5/2 | 5/1 | 5/- | 5/- | 5/1 | 75/14 |
| | 28.8.02 | 5/2 | 5/3 | 5/- | 5/2 | 5/3 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/2 | 5/1 | 75/15 |
| | 11.9.02 | 5/- | 5/1 | 5/1 | 5/- | 5/2 | 5/- | 5/1 | 5/2 | 5/1 | 5/3 | 5/- | 5/1 | 5/2 | 5/- | 5/- | 75/14 |
| Launakalana | 20.8.02 | 5/- | 5/- | 5/1 | 5/- | 5/1 | 5/- | 5/1 | 5/1 | 5/2 | 5/1 | 5/- | 5/- | 5/- | 5/1 | 5/- | 75/8 |
| | 3.9.02 | 5/1 | 5/- | 5/- | 5/2 | 5/3 | 5/- | 5/1 | 5/- | 5/- | 5/2 | 5/1 | 5/- | 5/1 | 5/1 | 5/- | 75/12 |
| | 19.9.02 | 5/- | 5/- | 5/1 | 5/- | 5/- | 5/2 | 5/3 | 5/- | 5/1 | 5/1 | 5/- | 5/1 | 5/- | 5/- | 5/- | 75/9 |
| Laloki[a] | 15.8.02 | 5/- | 5/1 | 5/1 | 5/1 | 5/2 | 5/1 | | | | | | | | | | 30/6 |
| | 30.8.02 | 5/- | 5/- | 5/- | 5/2 | 5/- | 5/1 | | | | | | | | | | 30/3 |
| | 13.9.02 | 5/2 | 5/3 | 5/- | 5/- | 5/1 | 5/1 | | | | | | | | | | 30/7 |

[a] Values for the individual trees represent the number of infested twigs out of 5 twigs per tree.
[b] The totals represent the number of infested twigs out of 75 twigs checked on the sampling date except for Laloki where only 6 trees were sampled each time.

### 5.4.9 Infestation levels of mango fruits with mango fruit fly *Bactrocera frauenfeldi* (Dipt., Tephritidae)

Out of 450 fallen fruits collected at Laloki, 63 were infested with fruit fly larvae which is equivalent to an infestation level of 14 %. At Tahira 101 out 450 fruits collected were infested (22. 44 % damage level). Out of 450 fruits collected from local markets, 2 fruits were infested with fruit fly larvae (0.44 % infestation level).

## 5.5 Discussion

### 5.5.1 Infestation levels of mango fruits with fruit piercing moths *Othreis fullonia*, *O. materna*, *Eudocima salaminia* (Lep., Noctuidae)

The results show that there is only a slight damage by fruit piercing moths. The low incidence has mainly to be attributed to the fact that plants of the family Menispermaceae, on which the larvae feed, are usually found growing in moist, forested areas. These climatic conditions are in contradiction to the predominantly dry conditions in the Central Province. In addition, Hargreaves (1936) reported that if pupation occurs under very dry conditions the adult may not be able to emerge successfully.

However, severe damages were observed in Fiji (W. Liebreights, pers. comm., 2002), and due to the more wet conditions and rainforest areas, higher infestation levels are expected in the Morobe and the Madang Province and on the Island Provinces. Surveys are required to determine the status of fruit piercing moths in these provinces and if any control measures are necessary. For PNG, cultural control methods like fruit bagging and insecticide treated baits are the primary option. Due to their habitat, a sufficient biological control of eggs or larvae is difficult to achieve.

### 5.5.2 Infestation levels of mango inflorescenses with blossom feeders (Lepidoptera), *Cosmostola* sp., *Gymnoscelis* sp., *Nanaguna breviuscula*

The species of *Cosmostola* and *Gymnoscelis* were also recorded from young foliage and/or flowers of mango and other plants in Borneo. *Nanaguna breviuscula* is also known from young foliage and mango flowers (S. Miller, pers. comm., 2003). The results show a high abundance of lepidopteran larvae but it is difficult to determine the exact damage caused by these pests since not all of the recorded species were confirmed as flower feeders and other insect pests like leafhoppers, pathogens like anthracnose and natural drop also contribute to the loss of flowers. *Acrocercops* spp. are usually leafminers and within the genus *Eublemma* there are mainly predatory species. The pyralid specimens need to be further identified. However, due to their abundance a significant contribution to the loss of flowers is expected. Further studies are therefore necessary to determine their status as mango pests. The use of synthetic insecticides will certainly reduce the populations of blossom feeders, but it has to be considered that their application could promote the infestation with leafhoppers through the reduction of their natural enemies.

### 5.5.3 Infestation levels of mango leaves with mango leafminer *Acrocercops* spp. (Lep., Gracillariidae)

With infestation levels averaging 20.75 %, control measures are required to reduce the populations of leafminer. In Australia, petroleum sprays are applied against citrus leafminer, when 10 % of the advanced flushes are infested. Higher infestation levels can be tolerated under PNG conditions, since fruits are not produced for export markets and financial input is far less. Petroleum sprays are rather preventative than curative and have a lower impact on natural enemies than synthetic insecticides. They are readily available in PNG and their use is recommended, if infestation levels are severe.

An effective control of leafminers using synthetic insecticides can be difficult because larvae and pupae are protected within the leaf, and their use in PNG orchards against these pests should not be encouraged. Instead, the use of biological insecticides such as neem, which is taken up by the plant systemically, is recommended (Basedow et al., 2002, Mudathir & Basedow, 2003). Future research activities should concentrate on the identification of effective, endemic parasitoids. The import of *Ageniaspis citricola* and *Cirrospilus quadristriatus*, effective parasitoids of the citrus leafminer *Phyllocnistis citrella*, should also be taken into consideration. It it quite like possible that these parasitoids will establish themselves on mango leafminers, too.

### 5.5.4 Infestation levels of mango leaves with white mango scale *Aulacaspis tubercularis* (Homopt., Diaspididae)

From the results it is difficult to estimate, whether the white mango scale should be treated as a serious pest or not. Control measures are certainly required for the Launakalana orchard, where infestation levels averaged 18.22 %. Petroleum sprays, which could simultaneously reduce leafminer populations, at a rate of 1 % are recommended. However, under PNG conditions, methods of biological control are the preferred option. Research activities should therefore focus on the identification and use of natural enemies. An effective parasitoid, *Aspidiotiphagus citrinus*, was already recorded in Africa (Labuschagne, 1993).

### 5.5.5 Infestation levels of young mango twigs with soft scales *Saissetia* sp. and *Parasaissetia* sp. (Homopt., Coccidae)

The results showed severe infestations with *Saissetia* and *Parasaissetia* at each study site and appropriate control measures need to be developed and applied. In contrast, in Australia these pests are usually controlled by their natural enemies and treatments are not necessary. This difference is explained by the presence of weaver ants, *Oecophylla smaragdina*, which attend the populations of these scales for the collection of honeydew. In return, the ants protect the scales against predators and parasitoids and therefore prevent a successful biological control. Similar results were obtained in Japan by Itioka & Inoue (1996), who reported that the parasitization of *Ceroplastes rubens* was frequently interrupted due to interactions with the ant *Lasius niger*. The primary control method of these soft scales should therefore be the elimination of *O. smaragdina* in infested orchards and the prevention of an introduction into new, uninfested areas, if possible. Since *O. smaragdina* is an arboreal species, sticky bands would prevent an infestation of trees and/or orchards, and eventually lead to an establishment of natural enemies and a sufficient biological control of these scales. In Australian citrus and mango, weaver ants are considered as pests and are not allowed to settle in orchards and probably explains, why *Saissetia* and *Parasaissetia* are usually controlled by their natural enemies. However, weaver ants are predators and used in China since centuries for the combat of insect pests in citrus, in particular of bugs. It is therefore suggested to monitor each orchard for the presence of pests and their significance before a suggestion is made either to eliminate or to promote the presence of weaver ants. Once the weaver ant is established, it proved to be very difficult to eliminate.

### 5.5.6 Infestation levels of young mango twigs with the mango aphid *Toxoptera odinae* (Homopt., Aphididae)

An average infestation level of about 25 % was recorded at the Tahira orchard. The action level for the related species *T. aurantii* is 25 % or more of leaf flushes infested. Immediate control measures are therefore not needed in the PNG orchards but constant monitoring is required to detect population increases. This is necessary, since weaver ants were observed visiting aphid populations for the collection of honeydew. As it is the case with soft scales, their presence could lead to a reduction of natural enemies, and eventually to an increase of the aphid populations. If required, the parasitoid species *Lipoplexis scutellaris* and *Lysiphlebia japonica* (Aphidiidae) could be introduced into PNG.

### 5.5.7 Infestation levels of mango inflorescenses with mango leafhoppers *Idioscopus clypealis* and *I. niveosparsus* (Homopt., Cicadellidae)

The mango leafhoppers *Idioscopus clypealis* and *I. niveosparsus* can be are regarded as one of the major pests of mango in the Central Province of PNG. With infestation levels averaging about 55 %, appropriate control measures need to be developed immediately and applied. Also in India, Pakistan and Western Australia these species are considered as important pests. A control with synthetic insecticides is not appropriate since multiple applications are required. This is not only too costly for PNG farmers but would also lead to developing resistance problems and the elimination of natural enemies, and eventually to increased leafhopper infestations (Smith et al., 1997). The pruning of dense canopies is so far the best option for PNG farmers, since this would result in less humidity and consequently in a lower number of leafhoppers, because they prefer moist and shady sites. So far no classical biological control agents are available (Peña & Mohyuddin, 1997),

### 5.5.8 Infestation levels of young mango twigs with mango planthoppers *Colgaroides acuminata, Colgar* sp. and *Scolypopa* sp. (Homopt., Flatidae, Ricaniidae)

In Australia, the action level is 20 % or more of green twigs are infested with planthoppers. Infestation in orchards in the Central Province of PNG were lower and taken into consideration that fruits are not produced for export markets, even higher economic damage thresholds can be tolerated. Control measures are therefore not required.

### 5.5.9 Infestation levels of mango fruits with mango fruit fly *Bactrocera frauenfeldi* (Dipt., Tephritidae)

In comparison, the Papua New Guinea Fruit Fly Project (PNGFFP), a collaborative program between the National Government and Secretariat of the Pacific Community, recorded significantly higher infestation levels of fallen mango in the East New Britain Province. 50.8 % of the fruits collected were infested with *B. frauenfeldi*. In the Central Province, 82.0 % of collected ripe carambola (starfruit) were infested with *B. frauenfeldi*. Results from this study showed less infestation both of fallen and harvested mangoes.

However, control methods are necessary. In general, mass trapping of male flies with Cue –lure and a killing agent is recommended for eradication. For small producers, fruit bagging at 55 – 60 days after induction (chicken egg size) is the appropriate method. For future exports, the establishment of heat treatment chambers (hot water immersion, 20 minutes at 49$^{o}$ C) is a prerequisite. This is an efficient method for killing all stages of fruit flies (maggots and eggs) and other insects.

## 5.6 Summary

A survey was conducted at four sites in the Central Province of Papua New Guinea to determine the occurence, abundance and importance of insect pests in mango (*Mangifera indica*). The pests, except fruit flies, were monitored three times during 2002 according to their occurrence within the mango season and to the guidelines for monitoring pests in Australian citrus. At each monitoring date 15 trees per orchard were randomly choosen and checked for the presence of pests listed; at Laloki due to the lesser number of trees only 6 trees were randomly picked. In case of fruit flies, fallen fruits and market fruits were checked for the presence of maggots.

1. Fruit piercing moths (Lepidoptera)

   *Othreis fullonia* Clerk, *Othreis materna* Linnaeus, *Eudocima salaminia* (Cramer) (Noctuidae, Catocalinae)

At each study site 30 fruits per tree were examined at each monitoring date. The infestation levels variied between 1.62 % and 4.66 % indicating that fruit piercing moths are not a serious pest in the Central Province. Their status could be different in provinces with higher rainfall and humidity, since larvae are usually found in moist forested areas.

2. Mango blossom feeders (Lepidoptera)

   *Cosmostola* sp. near *laesaria* Walker (Geometridae, Geometrinae)
   *Gymnoscelis* sp. near *imparatalis* Walker (Geometridae, Larentiinae)
   *Gymnoscelis* sp. (Geometridae, Larentiinae)
   *Nanaguna breviuscula* Walker (Nolidae, Sarrothripini)

At each study site 5 inflorescenses per tree were examined at each monitoring date. The infestation levels with lepidopteran larvae variied between 43.55 % and 53.33 %. Further studies are required to determine their status as mango pests, since not all of the larvae reared to adulthood were confirmed as blossom feeders and loss of flowers is also caused by leafhoppers and pathogens like anthracnose.

3. Mango leafminer

*Acrocercops* spp. (Lepidoptera, Gracillariidae)

At each study site 25 leaves per tree were examined at each monitoring date. The infestation levels variied between 18.04 % and 26.49 %. Control measures are required but should concentrate on the use of biological control agents like parasitoids. An effective control with contact insecticides is difficult to achieve because larvae and pupae are protected within the leaf. The use of neem is recommended.

4. White mango scale

*Aulacaspis tubercularis* Newstead (Homoptera, Diaspididae)

At each study site 25 leaves per tree were examined at each monitoring date. The infestation levels variied between 6.13 % and 18.22 %. Control measures are required for the Launakalana orchard. Petroleumsprays at a rate of 1 % are recommended but also an effective parasitoid was recorded in Africa and could be introduced.

5. Soft scales

*Saissetia* sp., *Parasaissetia* sp. (Homoptera, Coccidae)

At each study site 5 young twigs per tree were examined at each monitoring date. The infestation levels variied between 31.11 % and 46.66 %. Control measures should focus on the elimination of the weaver ant, *Oecophylla smaragdina*, which attend scale populations for the collection of honeydew. In return, the ants protect the scales from natural enemies like predators and parasitoids and prevent a successful biological control.

6. Mango aphid

*Toxoptera odinae* (van der Goot) (Homoptera, Aphididae)

At each study site 5 young twigs per tree were examined at each monitoring date. The infestation levels variied betweeen 3.11 % and 24.88 %. Immediate control measures are not required since infestation levels did not exceed the action level of 25 % (calculated for Australian growers). Weaver ants did attend aphid populations and constant monitoring is therefore required to detect increases in aphid populations.

7. Mango leafhoppers

*Idioscopus clypealis* Lethierry, *I. niveosparsus* Leth.

(Homoptera, Cicadellidae)

At each study site 5 inflorescenses per tree were examined at each monitoring date. The infestation levels variied between 50.22 % and 64.44 % and they can be regarded as one of the major pests in mango in the Central Province. A chemical control with insecticides is too costly and rather detrimental through the destruction of natural enemies. For PNG conditions, the pruning of dense canopies is recommended, because leafhoppers prefer moist and shady sites.

8. Mango planthoppers

*Colgaroides acuminata*, *Colgar* sp., *Scolypopa* sp.

(Homoptera, Flatidae, Ricaniidae)

At each study site 5 young twigs per tree were examined at each monitoring date. The infestation levels variied between 10.66 % and 19.11 %. With the action level being 20 % (for Australian growers), no control measures are required.

9. Mango fruit fly

*Bactrocera frauenfeldi* (Schiner) (Diptera, Tephritidae)

Infestation levels of fallen fruits 14 % at the Laloki site and 22.44 % at the Tahira site. Out of 450 fruits collected from local markets, only 2 fruits were infested with fruit flies. Records from the PNG Fruit Fly Project were much higher. Fruit bagging is an appropriate method for small producers. Mass trapping with baits is appropriate for eradication. Heat treatment chambers are required for future exports.

# 6. On the biological control of the pink wax scale *Ceroplastes rubens* Maskell (Homoptera, Coccidae) with the introduced parasitoid *Anicetus beneficus* Ishii & Yasumatsu (Hymenoptera, Encyrtidae)

## 6.1 Introduction and objectives

A survey of citrus pests in five plantations in the highlands of Papua New Guinea (PNG) during 1993 and 1994 showed that the pink wax scale *Ceroplastes rubens* (Homoptera, Coccidae) was a dominant pest reaching infestation levels of about 20%; one plantation owner at Hoveku in the Eastern Highlands Province considered that *C. rubens* caused yield reduction of about 30% through the production of sooty mould and inhibited photosynthesis (Yoon & Wiles, 1994).

Chemical control of scales and mealybugs with synthetic insecticides is very difficult and their effectiveness is reduced by the waxy cover of the scales. These formulations are also very disruptive to most natural enemies, and overuse can cause outbreaks of other pests (Peña, 1993). It is also known that scales develop resistance to organophosphates and carbamates in a very short time (DeBach, 1974). Alternative sprays like petroleum oil sprays are more selective, but must be used carefully to avoid phytotoxicity (Kranz et al., 1979; Smith, 1976; Sabine, 1969; Malapatil et al., 2000).

Additionally, chemical control is very costly. Smith et al. (1997) reported that in Australian Citrus complete tree wetting during spray is necessary to achieve a good control, and that at least 10,000 l of spray per hectare is required on trees over 4 m high. Hardman et al. (1992) calculated that in Queensland about 45% of spray costs (A$ 4.5 million) is saved through IPM in comparison to a chemical-only programme. Two to three times this amount is saved in New South Wales, Victoria and South Australia, giving savings Australia wide of about AUD$ 15 million annually (Furness et al., 1993).

Yoon & Wiles (1994) observed two natural enemies of pink wax scale in the heavily infested orchard at Hoveku, but they did not appear to effectively control the pest, and these and other natural enemies remained unidentified.

Since chemical control of *C. rubens* is costly and difficult, heavy outbreaks do not only cause yield reduction as experienced in the highlands, but could lead to the loss of the whole tree (Wysocki et al., 1993), and subsequently to a significant loss of income for smallholders and plantation owners. Yoon & Wiles (1994) suggested appropriate control measures including the introduction of parasitoids to effectively control pink wax scale on citrus and other crops.

In PNG, chemical control of *C. rubens* by the smallholder sector for the production of mango and citrus is not practised. This offers a situation ideal for the classical biological control of this pest - introduced natural enemies could be established without being negatively affected by the use of synthetic insecticides.

The method of classical biological control has already made a valuable contribution to the control of 29 pest scales and mealybugs in citrus in neighbouring Australia (Malapatil et al., 2000) with outstanding successes like the control of the red scale *Aonidiella aurantii* with several introduced parasitoids.

As so in PNG there are examples for a successful classical biological control of weeds and insect pests. The weeds *Salvinia molesta* and *Mimosa invisa* are now effectively controlled with the introduced curculionid *Cyrtobagus salviniae* and the psyllid *Heteropsylla spinulosa,* respectively. The sugar cane borers *Sesamia* spp. are now controlled by the braconid *Cotesia flavipes* and and the green coffee scale *Coccus viridis* is controlled with the imported parasitoid *Metaphycus baruensis* (Schuhbeck & Ngere, 2001).

The method of classical biological is based on the assumption that an introduced insect species has become a pest because antagonists, which had effectively kept it under control in its country of origin, are lacking (Daxl et al., 1994).

It is therefore an important prerequisite prior to an introduction of a natural enemy, to identify the endemic parasitoid and predator fauna and their effectiveness in controlling the particular pest (deBach, 1974; GTZ, 1994). This applies in particular for *Ceroplastes rubens* in PNG, since most of its natural enemies remained unidentified, and no detailed study has been conducted to establish their potential in controlling this pest. Furthermore, the results would avoid an unnecessary importation of an effective natural enemy if it had already been accidentally introduced.

The following study was undertaken to obtain data for an appropriate management of this pest in mango, another important host of *C. rubens*. In particular, the objectives of this study were:

- to determine infestation levels of *Mangifera indica* with *C. rubens* in the Central Province of PNG.
- to study the seasonal history of *C. rubens* in the Central Province.
- to identify endemic parasitoids in different provinces of PNG.
- to assess the effectiveness of these parasitoids in controlling *C. rubens*.
- to identify important non endemic parasitoids of *C. rubens* and evaluate their suitability for an introduction into PNG.
- to import and release effective parasitoids and control the establishment, if parasitization by endemic parasitoids is not sufficient.

## 6.2 Literature review

### 6.2.1 *Ceroplastes rubens* Maskell

*Ceroplastes rubens* was first described by Maskell in 1883 from material collected on *Mangifera indica* and *Ficus* sp. in Australia. *C. rubens* is located within the large genus *Ceroplastes*, in the tribe Ceroplastini of the subfamily Ceroplastinae. Members of this subfamily are commonly referred to as wax scales (Hodgson, 1994).

***Host range***

*C. rubens* is highly polyphagous. The host range covers more than 150 plant species. Besides mango, the pink wax scale attacks commercial important crops like citrus (*Citrus limon, C. sinensis, C. reticulata*), avocado (*Persea americana*), tea (*Camellia sinensis*), coffee (*Coffea* spp.), banana (*Musa* spp.), guava (*Psidium guajava*) and coconut (*Cocos nucifera)*. The host range in Australia has been described by Qin & Gullan (1994), in the South Pacific by Williams & Watson (1990) and worldwide by Ben-Dov (1993).

***Geographic distribution***

*C. rubens* is widely distributed around the Orient, southern Asia, Australia, India, the South Pacific, East Africa and West Indies (CABI, 1990). It occurs in some temperate regions, and is also found in greenhouses in regions with a temperate climate (Hodgson, 1994).

***Origin***

It is thought to have originated in either Africa, India or Sri Lanka (Loch, 1997). It was accidentally introduced into Australia, where it is now mainly distributed in the coastal regions (Qin & Gullan, 1994). From Australia, it subsequently spread to Japan and Hawaii (Loch, 1997). First records in Papua New Guinea date back to 1959 (Williams & Watson, 1990) but the species could have been introduced earlier.

***Morphology***

The adult female scale is protected by a hard wax covering, pink to red in colour. It is about 3-4 mm long, globular and smooth in shape, with two lobes on either side and a depression at the top.

Pink wax scale resembles the Florida wax scale *C. floridensis* and the hard wax scale *C. sinensis*. However, Florida wax scale is much paler in colour and hard wax scale is mostly white and larger than pink wax scale and has a distinguishing triangular pygidium.

***Biology***

Reproduction usually occurs without fertilization (male scales are very uncommon). The number of laid eggs is related to the size of females, which in turn is related to the level of nitrogen in the leaves. The average number of eggs per females varies between 150 and 200, although up to 900 eggs have been counted by Loch & Zanucki (1997).

Eggs hatch into crawlers, which are the only mobile stage of the pink wax scale. An infestation of other leaves and trees can therefore only happen during this stage. The crawlers are bright orange and approximately 0.4 mm long with three pairs of well developed legs, antennae and a pair of ocelli. Within 24 hours after settling along the midribs of leaves (an infestation of twigs and fruits is seldom) two longitudinal dorsal scaly waxy ridges appear. Within a further 24 hours these ridges merge, resulting in a prominent dorsal crest and the crawlers loose their appendages and eye spots. From this stage on, the scale is immobile. The crawlers have now developed into the 1$^{st}$- nymphal stage.

The permanent secretion of wax imparts the nymphs as well the adults the typical purple colour. In the 2$^{nd}$- nymphal stage anterior, median and posterior pairs of lateral marginal bluntly pointed white wax processes are evident (Blumberg, 1934). In the third stage the accretion of wax on the dorsum results in partial submergence of the anterior and median processes. The posterior processes, on the other hand, enlarge. Within the adult stage this posterior pair tend to become lost in extending dorsum, although still visible (Blumberg, 1934).

The life cycle of the pink wax scale is about 2.5 – 3 months in the highlands of PNG but it is longer during the dry season (Yoon & Wiles, 1994). In Southern Queensland there are two generations a year, while in more southern states in Australia like Victoria and New South Wales there is usually only one generation each year (Smith, 1976).

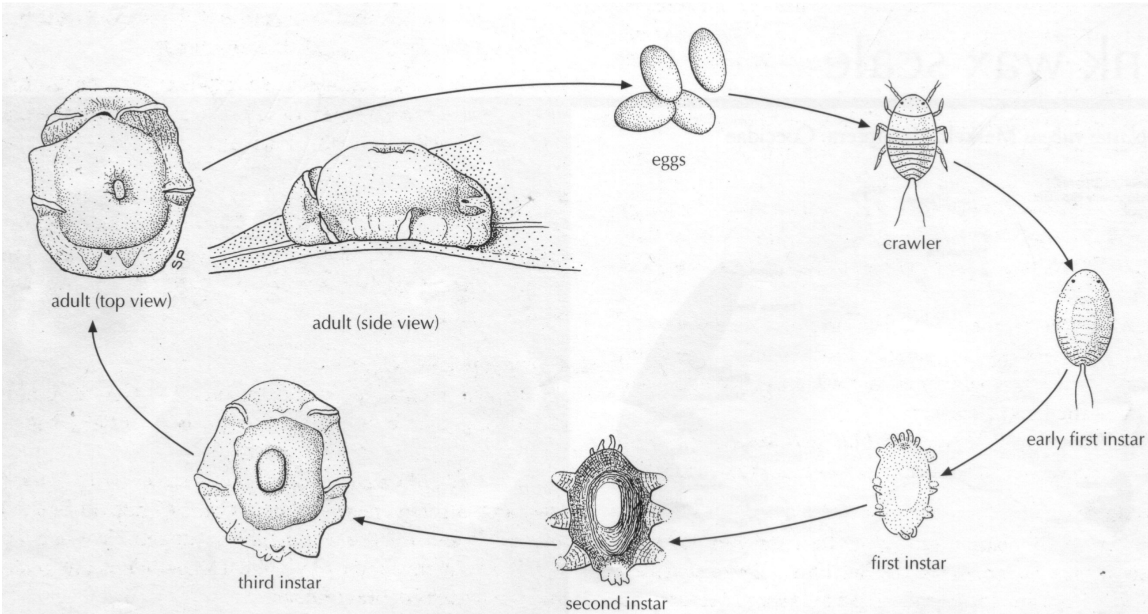


**Figure 16:** Life cycle of *Ceroplastes rubens* (Smith et al., 1997)

**Figure 17:** *Ceroplastes rubens* (Homop., Coccidae) on mango leaf

***Damage***

*C. rubens* occurs on leaves and twigs but is most commomly found along the midrib on both surfaces of the leaves. Like all other soft scales *C. rubens* produces honeydew and as a result sooty mould can be high on both fruit and leaves, which reduces photosynthesis, resulting in less carbon assimilation and consequently a lower yield and reduced fruit quality (Escalante, 1974). A heavy infestation results in a smaller leaf size, chlorosis on attacked leaves, early leaf drop and subsequently causes death of twigs, branches and occasionally the whole tree (Wysocki et al., 1993).

***Yield reduction and economic damage threshold***

There are no data on infestation levels of *C. rubens* on mango in PNG. However, there is some information on the infestation levels on citrus, another important host of this pest. Yoon & Wiles (1994) monitored the infestation of five citrus orchards for insect pests in the highlands of PNG. *C. rubens* was found to be a significant pest, particular in one plantation where 71.5 % of all monitored leaves were infested. The owner considered the yield reduction to be about 30 %. In another orchard pink wax scale infested on average 12.6 % of the leaves; in the three remaining the infestation was considerably lower (1.5 %, 4.3 % and 5.5 %, respectively).

In Australia, *C. rubens* has been considered as a major pest in citrus since its first rating by Summerville (1934) and Brimblecombe (1936). In Japan this pest was rated third on the list of important citrus pests provided by Tachikawa (1949). Since the detection of the parasitic wasp *Anicetus beneficus* on the island of Kyushu and the subsequent release on other islands and into Australia, this pest is now considered to be of lower importance in both countries but outbreaks can still occur. Action is only required when more than 5% of the leaves are infested. The Australian Citrus Grower Association recommends in this case the application of petroleum sprays when highly susceptible young scales line the midribs of outer foliage.

### 6.2.2 Natural enemies of *Ceroplastes rubens*

The use of natural enemies to control insect pests is a better alternative than the use of synthetic insecticides (deBach, 1974; Stechmann, 1990; Rosen & deBach, 1992; Andrews et al., 1992; Amend & Basedow, 1997). This particularly applies to the islands in the South Pacific where most of the insect pests are not indigenous and have been introduced. Thus, the method of a classical biological control within an IPM – Programme is of great importance for this part of the world (Stechmann, 1990; Waterhouse, 1992).

Waterhouse and Sands (2001) compiled a list of endemic natural enemies of *C. rubens* in Australia, and Yasumatsu & Tachikawa (1949) compiled a list of endemic and introduced parasitoids occurring in Japan. Their biology is described below (Table 26 & 27).

**Table 26:** Endemic parasitoids and predators of *Ceroplastes rubens* in Australia, (Waterhouse & Sands, 2001).

| Species | Stage of host |
|---|---|
| **Neuroptera** | |
| **Chrysopidae** | |
| *Mallada signata* | L 1,2,3 |
| *Mallada* sp. | |
| **Coleoptera** | |
| **Coccinellidae** | |
| *Cryptolaemuus montrouzieri* | L 2,3 |
| *Diomus* sp. | |
| *Diomus notescens* | |
| *Halmus chalybeus* | L 1,2,3 |
| *Harmonia conformis* | L 1,2 |
| *Rhyzobius ventralis* | E; L 1,2 |
| *Scymnus* sp. | L 1 |
| *Serangium bicolor* | L 1,2 |
| *Serangium maculiegerum* | L 1,2 |
| **Lepidoptera** | |
| **Noctuidae (predatory)** | |
| *Catoblemma dubia* | L 2,3; A |
| *Catoblemma* sp. | |
| **Thysanoptera** | |
| **Phlaeothripidae (predatory)** | |
| **Hymenoptera (parasitic)** | |
| **Aphelenidae** | |
| *Coccobius athrithorax* | L 3 |
| *Coccophagus ceroplastae*[a] | L 3 |
| *Encarsia citrina* | L 3 |
| *Euryischomyia flavithorax* | |
| *Myionecma* sp.[a] | L 3; A |
| **Encyrtidae** | |
| *Cheiloneurus* sp.[a] | L 3; A |
| *Coccidocnotus dubiusa* | L 3; A |
| *Diversinervus* sp. | |
| *Metaphycus* sp. | A |
| *Metaphycus varius* | L 3; A |
| *Microterys* sp. ? *australicus* | A |
| **Eulophidae** | |
| *Aprostocetus* sp. | L 3; A |
| **Pteromalidae** | |
| *Moranila californica* | A |

legend: L 1 – 3 = larval stages, A = adult, E = egg, [a] = hyperparasitoid

**Table 27:** List of recorded parasitoids of *Ceroplastes rubens* in Japan, (Yasumatsu & Tachikawa, 1949).

| Family | Species | Status Endemic (E)/ Imported (I) |
|---|---|---|
| **Aphelenidae** | *Aneristus (Coccophagus) ceroplastae* | I |
| | *Aphytis* sp. | |
| | *Casca* sp. | |
| | *Coccophagus hawaiiensis* | I |
| | *Marietta* sp. | |
| **Encyrtidae** | *Anabrolepis bifasciata* | E |
| | *Anabrolepis extranea* | |
| | *Cerapteroceroides japonicus* | E |
| | *Cheiloneurus ceroplastis* | |
| | *Microterys kotinsky* | I |
| | *Microterys okituensis* | E |
| | *Microterys speciosus* | E |
| **Eupelmidae** | *Eupelmus* sp. | |
| **Pteromalidae** | *Scutellista cyanea* | I |
| | *Tomocera (Moranila) californica* | I |

### 6.2.2.1 Parasitoids

The use of parasitoids plays a very important role in the control of various scales and mealybugs in Australian citrus (Malapatil et al., 2000). Excellent examples of this significance is the control of the red scale *Aonidiella aurantii* with the imported encyrtid *Comperiella bifasciata* and the introduction of the wasp *Leptomastix dactylopii* for the control of *Planococcus citri*.

***Aphelenidae***

The genus *Aphytis* contains a wide range of species of which some are very important in the control of hardscales. The ectophagous species *A. holoxanthus*, *A. lepidosaphes* and *A. lignanensis* have been introduced into Australia to successfully control *Chrysomphalus aonidum*, *Lepidosaphes beckii* and *Aonidiella aurantii* (Malapatil et al., 2000). Occasionally these parasitoid species can be reared from soft scales like *Ceroplastes*.

In addition to *C. rubens* species of the genus *Casca* have been reared from *Aonidiella aurantii*, *A. citrina* an *Chrysomphalum* sp. (Noyes, 1998).

Within the genus *Coccobius* there are species including *C. athrithorax* which is parasitic on pink wax scales, and also attacks hardscales and mealybugs. *Coccobius fulvus* is a commercially produced primary parasitoid of the diaspidids *Aulacaspis* sp. and *Lepidosaphes beckii* (Noyes, 1998).

The genus *Coccophagus* is widely spread in the tropics and the species are generally primary parasitoids of the coccid genera *Ceroplastes*, *Saissetia*, *Coccus* and *Pulvinaria* (Compere, 1936). Sands (1984) and Smith (1986) reported that the species *C. ceroplastae* is a primary parasitoid of *Ceroplastes rubens* in Australia. Noyes (1998) notes that following scales are also parasitized by this wasp: *Ceroplastes floridensis, Coccus hesperidum, C. pseudomagnolarium, C. viridis, Parasaissetia nigra, Pulvinaria polygonata, Saissetia coffeae* and *S. oleae*.

In Australia, *Encarsia citrina* attacks primarly the hard scales *Aonidiella aurantii, A. citrina, A. orientalia, Chrysomphalus aonidum, Lepidosaphes beckii* and *Unaspis citri* (Smith et al., 1997). *Ceroplastes rubens* as well as the species *Coccus hesperidum* and *Parlatoria pergandii* are secondary hosts (Noyes, 1998).

The species *Euryischomyia flavithorax* parasitises mainly soft scales of the genera *Ceroplastes*, *Coccus* and *Saissetia* but was also frequently recorded on *Pulvinaria urbicola* (Malapatil et al., 2000).

All species within the genus *Marietta* are known as hyperparasitoids (Clausen, 1962; Noyes, 1998). In addition to *Ceroplastes rubens*, species of *Marietta* have also been reared from several soft and hard scales, including *Parasaissetia* and *Quadraspidiotus*.

One species of *Myiocnema* was identified as a hyperparasitoid of *C. rubens* in Australia

(Loch, 1997). *M. comperei* is known as a hyperparasitoid of *Coccus viridis* and *Saissetia oleae* (Noyes, 1998).

***Encyrtidae***

Species of *Anabrolepis* are known as parasitoids of hardscales like *Aonidella* and *Aspidiotus*. Noyes (1998) listed only *C. rubens* as a coccid host within this genus.

*Ceraptoceroides japonicus* has been reared from several coccids including *C. rubens* and species of the genera *Pulvinaria*, *Phenacoccus* and *Coccus* (Noyes, 1998).

Species of the genus *Cheiloneurus* are hyperparasitoids of wasps parasitising Homoptera, in particular Dryinidae, Aphelenidae and Encyrtidae (Noyes, 1998).

Species of the genus *Coccidocnotus* are hyperparasitoids of parasitoids of Homoptera. *Coccidocnotus dubius* was recorded in New Zealand parasitising the following species: *Moranila californica* and *Aphobetus* sp. (Pteromalidae). In Queensland this species was the most frequent hyperparasitoid reared from nymphal and adult stages of *C. rubens* (Loch, 1997).

Species within the genus *Diversinervus* are primary parasitoids of the soft scales genera *Ceroplastes, Coccus, Parasaissetia, Saissetia* and *Pulvinaria*. Noyes (1998) provided a complete list of the parasitized species.

Most of the species within the genus *Metaphycus* are gregarious endoparasitoids of soft scales (Viggiani & Mazzone, 1980; Viggiani & Guerrieri, 1988), but were also recorded from hard scales (*Aonidiella*) and white flies (*Bemisia tabaci*). A few of them are known as hyperparasitoids (Noyes, 1998).

Species of the genus *Microterys* are distributed worldwide and are solitary as well as gregarious parasitoids of scales (Prinsloo, 1984). Noyes (1998) provided a full list of all recorded hosts.

***Eulophidae***

Species of the genus *Aprostocetus* (*Tetrastichus*) are known as ecto- and endoparasitoids attacking larval and egg stages of Coccoidea and Lepidoptera as well as egg predators and hyperparasitoids (Noyes, 1998). Loch (1997) recorded *Aprostocetus* sp. (subgroup *ceroplastae*) as emerged from nymphs and adults of *Ceroplastes rubens* in Queensland. Noyes (1998) and Sands et al. (1986) recorded this species also from *C. destructor*, *C. floridensis* and *C. sinensis*.

***Eupelmidae***

The genus *Eupelmus* shows a great diversity in habit; some are strictly primary external parasitoids, others are obligatory hyperparasitoids, while some are egg predators and endoparasitoids. The host range is extremly wide including various orders of insects (Clausen, 1962).

***Pteromalidae***

A few species of the genus *Moranila* are known as hyperparasitoids and egg predators but the majority are primary parasitoids (Noyes, 1998). *Moranila californica* is distributed worldwide and an important primary parasitoid of the soft scales *Ceroplastes floridensis* and *C. rubens* (Berry, 1995).

*Scutellista cyanea* is an egg predator of coccoid scales but develops as an external parasitoid, when eggs are unavailable (Clausen, 1962). There preferred hosts are species of the genus *Ceroplastes* and *Saissetia* but it has also been occasionally reared from several other genera, inlcuding *Parasaissetia*, *Phaenococcus* and *Coccus* (Clausen, 1962; Noyes, 1998).

#### 6.2.2.2 Effectiveness of parasitoids of *Ceroplastes rubens*

In Australia, the natural endemic parasitoids are commonly associated with immature stages of *C. rubens* but these alone were not effective in reducing scale infestations to acceptable levels (Smith, 1976; Waterhouse & Sands, 2001). A number of unsuccessful attempts were made during the early part of the 20th century to control *C. rubens* by introducing parasitoids, including some for the control of other scale insects, from Hawaii, Japan and China (Wilson, 1960).

Later investigations by Loch (1997) showed that parasitism levels only reached about 6% for vulnerable stages of the pink wax scale. Most common were the introduced species *occophagus ceroplastae* and the native encyrtid *Metaphycus varius*. *Moranila californica* and the introduced species *Scutellista caerulea* (Pteromalidae), and *Diversinervus elegans* (Encyrtidae) emerged from *Ceroplastes rubens* only at low rates.

Since the introduction of *C. rubens* into Japan in 1897, this scale had developed into a very serious pest of citrus and tea. Due to the wide host range of more than 150 plants, the populations of this pest infesting the non-economic plants are sources of new infestations of commercially important crops (Yasumatsu, 1969). This fact, the difficulty of controlling *C. rubens* with chemicals and the low effectiveness of endemic parasitoids, stimulated the introduction of several parasitic Hymenoptera during the years 1932 and 1938 from Hawaii and California. Four species, *Aneristus* (*Coccophagus*) *ceroplastae*, *Microtery kotinsky*, *Tomocera* (*Moranila*) *californica* and *Scutellista cyanea* were introduced and released at Nagasaki, but without success.

#### 6.2.2.3 Pathogens

The fungi *Fusarium oxysporum*, *Gibberella fujikuroi* and *Verticillium lecanii* can infect pink wax scale in high density populations under humid conditions (Smith et al., 1997).

### 6.2.3 The pink wax scale parasitoid *Anicetus beneficus* Ishii & Yasumatsu (Hymenoptera, Encyrtidae)

Between 1942 and 1946 researchers recorded a significant reduction of pink wax scale populations on the island of Kyushu in Japan. Subsequent studies by

Yasumatsu & Tachikawa (1949) demonstrated that this was related to the parasitization of this pest with an encyrtid first identified as *Anicetus annulatus* Timberlake, then revised as a new race of *Anicetus ceroplastis* Ishii, but later described as the new species *Anicetus beneficus* Ishii & Yasumatsu.

The results showed that at locations were *A. beneficus* was present parasitism reached levels between 1.47 % and 49.11 %; the mean being 20.19 %. At locations were *A. beneficus* was not recorded, parasitism levels variied only between 0.00 % and 0.87 % (Yasumatsu & Tachikawa, 1949). The mass rearing of *A. beneficus* and its subsequent release into dense populations of *C. rubens* in other areas and on other islands, where this beneficial was absent, proved to be very successful. Since then pink wax scales are difficult to find and are considered only as a minor pest in citrus (Yasumatsu, 1951, 1953, 1958, 1969; Noda et al., 1982).

In 1955, *A. beneficus* was first imported into Australia but a culture was not established, and the parasitoid was not released (Wilson, 1960). However, the continuing success of *A. beneficus* in Japan induced the reimportation in 1976 and a subsequent release at 60 sites in southern Queensland in 1977. Successful control at monitored sites was achieved in an average of 2.5 years (Smith, 1986). At one site the population of pink wax scales was reduced within 3.5 years from 320 scales to 2 adult scales per 100 leaves. At another location the population decreased from 45 scales per 100 leaves to about zero within a year (Smith, 1986), with *A. beneficus* being the most common parasitoid accounting up to 81 % of the emerged parasitoids (mean = 67 %).

A subsequent study by Loch (1997) on the natural enemies of *C. rubens* on umbrella trees (*Schefflera actinophylla*) showed parasitism levels averaging only 12.4 %. *A. beneficus* was the dominant parasitoid, accounting for 47.5 % of parasitised adults and 22.5 % of parasitised nymphs of *C. rubens*. Hyperparasitization of pink wax scale parasitoids with the native encyrtid *Coccidocnotus dubius* was frequent, averaging of 37.4 % of both adult and immature hosts, but it is not known whether *C. dubius* develops on *A. beneficus* in addition to other primary parasitoids (Loch, 1997).

According to Noyes (1998) *A. beneficus* was reared from the following other hosts: *Ceroplastes actiniformis, C. floridensis*, *C. japonicus*, *C. pseudoceriferus* and *C. sinenis*. But D. Sands and D. Smith (pers. comm., 2001) seriously doubt it parasitises these species. In Australia this parasitoid has never been reared from other hosts than *C. rubens*.

***Origin***

The origin of this parasitoid is possibly Africa or South China based on the assumption that *C. rubens* is endemic to Africa or that the parasitoid has been introduced from China into Japan during the second World War (Hirose et al., 1990).

***Morphology***

The body of the female is about 1.5 mm in length and orange yellow in colour. The legs are yellow with whitish areas and the base of the gaster is dark brown. The ocelli are red, and the genae have a transverse black band extending between maxillary base and antennal sockets. The antennae are lamellate. The male is black and about 1 mm length with femur and tibia of the hind leg dark brown with yellow joints. The other legs are generally yellow.

***Biology***

*Anicetus beneficus* is a solitary endoparasitoid. Loch (1997) recorded a sex ratio of 80 % females to 20 % males, while Tachikawa (1958) recorded an equal ratio between females and males. In Japan only one generation of *C. rubens* develops within a year whereas *A. beneficus* is bivoltine. The first generation attacks 1$^{st}$- and 2$^{nd}$- instar nymphs of pink wax scale in June and the second generation parasitises 3$^{rd}$- instar nymphs and adults in September (Noda et al., 1982). But adults are the preferred stage for parasitization.

The time required for a female to oviposit depends on the thickness of the wax cover and therefore on the development stage of the scale (Noda et al., 1982). On average the oviposition period lasted 220 seconds for 1$^{st}$- instars and about 790 seconds for adult scales. In case of instars, the ovipositor is inserted above the anal tubercle, and in adults to the anterior of the apex.

Laboratory trials by Noda et al. (1982) showed that female *A. beneficus*, when released, moved by walking and hopping from leaf to leaf but hardly flew. Female parasitoids easily located pink wax scale populations when released on the same twig but no distinct behaviour of the host habitat finding was observed. No data are available on the fecundity of female *A. beneficus* wasps.

**Figure 18:** The pink wax scale parasitoid *Anicetus beneficus* (Hym., Encyrtidae)

### 6.2.4 The correlation of honeydew producing Homoptera with ants

Within the Homoptera there are many species known to produce honeydew and to have a mutualistic relationship with ants collecting the honeydew (Way, 1963; Buckley, 1987; Hölldöbler & Wilson, 1990; Itioka & Inoue, 1996). In this symbiosis ants collect honeydew for feeding the brood and in return protect them against their natural enemies (Way, 1963; Addicott, 1984, 1986; Bristow, 1984). Strickland (1947) and Kunkel (1973) demonstrated that ants render a hygienic service to the colonies of Homoptera by constantly removing large quantities of sugary material. Partly, they also provide protection from weather by building protective shelters (Way, 1963; Maschwitz et al., 1985). El-Ziady & Kennedy (1956) and Banks & Nixon (1958) showed that the presence of ants stimulated aphids to grow and mature more rapidly.

#### 6.2.4.1 The effect of ants on the biological control of homopteran pests

In contrast to the beneficial effect of ants as predators of insect pests, it has been suggested that the interactions between ants and homopterans could reduce the effectiveness of natural enemies when used as control agents of honeydew-producing homopteran pests (Buckley & Gullan, 1991; Haines & Haines, 1978; Nechols & Seibert, 1985).

Itioka & Inoue (1996) studied the effect of ants on the degree of parasitization of *Ceroplastes rubens* by the encyrtid *Anicetus beneficus*. The authors observed that the ovipositional behavior was frequently interrupted due to interactions with the ant *Lasius niger*, which was attending the scale. Results of ant-exclusion experiments showed that ant attendance caused a significant decrease in the percentage parasitism and consequently an increase of the host populations. Further studies revealed that under natural conditions in which generalist ant species attended the host aggregations, the pest populations remained at a high level. The authors therefore concluded that ant-attendance reduces the effectiveness of *A. beneficus* as a control agent of the pink wax scale.

## 6.3 Material and methods

### 6.3.1 Study sites

The study was conducted at five sites in the Central Province and at one site in the Morobe Province and the Eastern Highlands Province, each.

### 6.3.2 Population dynamics of *Ceroplastes rubens*

#### 6.3.2.1 Seasonal history

The number of pink wax scale generations per year in the Central Province were checked in 2001 and 2002 at Laloki and Tahira by continuously observing the appearance of new first instars on infested trees.

### 6.3.3 Infestation levels of mango leaves with *Ceroplastes rubens*

The levels of infestation of mango trees with *C. rubens* were monitored three times at two weakly interval during August and September 2000 at Launakalana, PAU, Tahira and Laloki. Fifteen trees were randomly chosen at each monitoring date at the first three locations while at Laloki, due to the small number of trees, only six were chosen. On each tree 25 mature leaves (5 randomly selected twigs each with 5 leaves) were checked for the presence of the pest. This survey was conducted in accordance with the guidelines for monitoring scales in Australian Citrus (Smith et al., 1997).

### 6.3.4 Endemic parasitoids of *Ceroplastes rubens*

It is fundamental that before an introduction of parasitoids and predators into a country is made that the endemic beneficial insects are accuretaly identified and their potential in controlling the specific pest is determined (deBach, 1974; Daxl et al., 1994). To do this, pink wax scales were collected from various locations in PNG to determine percentage of parasitism and to identify the parasitoids.

#### 6.3.4.1 Determination of parasitization levels of *Ceroplastes rubens*

Mango leaves infested with pink wax scales were randomly collected from August 2000 until February 2001 at an interval of about 10 days. Nine samples were taken at the Laloki, PAU, Tahira, Launakalana and Aiyura locations and 12 samples were taken at

Erap. These samples were checked for the presence of parasitoids using the following method:

a. Adults, late $2^{nd}$- instars and $3^{rd}$- instar scales were counted and removed from the leaves. Younger stages were not recorded since no emergence of parasitoids will occur during these stages.

b. Parasitised scales from which parasitoids had not emerged yet were individually kept in glass vials (1 x 5 cm, top closed with cotton wool) for 4 weeks in the laboratory ($24^{o}$ C; 60-65 % RH) to allow parasitoids to emerge (gregarious parasitoids were recorded separately).

c. The vials were checked every 3 days for the presence of parasitoids. If present, the vials were placed into a freezer to immobilize and collect the wasps.

d. Scales that were not obviously parasitised were placed in petri dishes on wet filter paper to enhance survival of the scales, and allow for any parasitoids to develop and emerge.

e. After 4 weeks all parasitised scales from which no parasitoids emerged were dissected, parasitoids extracted and counted. If possible dead specimens were identified.

f. The degree of actual parasitization at each sampling date was calculated by:

$$y = NCS/NPS \times 100$$

with NCS being the number of collected scales vulnerable to parasitization and NPS the number of parasitised scales.

### 6.3.4.2 Parasitoid identification

The endemic parasitoids of *C. rubens* were identified to the genus by using the key of Malapatil et al. (2001) "An illustrated guide to the parasitic wasps associated with scale insects and mealybugs in Australia". In case of uncertainty, specimens were sent to the Natural History Museum, London, and identified by J. Noyes.

### 6.3.5 The importation of *Anicetus beneficus*

Both females and males of *A. beneficus* were reared at the QDPI Agricultural Research Station at Maroochydoore (Queensland, Australia) from pink wax scales collected from citrus orchards in the vicinity of the station. The parasitoids were checked by AQIS (Australian Quarantine Service) and NAQIA (National Agricultural Quarantine and Inspection Authority, PNG) before being brought to the insectary at the entomological laboratory at Kilakila, Port Moresby. Since host specifity of *A. beneficus* to *Ceroplastes rubens* was testified by D. Smith (DPI Maroochydoore, Queensland) and their health and identity checked by both Quarantine Authorities, the Department of Environment and Conservation (PNG) approved an immediate release into the field but restricted release sites to the Central Province.

#### 6.3.5.1 Release of *Anicetus beneficus*

The consignments consisted of adults of *A. beneficus* with an approximate ratio of 8 : 1 (females to males). The parasitoids were sent to PNG on the following dates and after being checked by NAQIA released at the following sites (Table 28 & 29):

**Table 28:** Number of imported adult *A. beneficus* and release sites in the Central Province, PNG.

| Date | Release Site | Approximate No. of parasitoids |
|---|---|---|
| 19.3.2002 | Laloki | 350 |
| 28.3.2002 | Tahira | 300 |
| 28.3.2002 | PAU | 200 |
| 5.4.2002 | Tahira | 250 |
| 5.4.2002 | Laloki | 200 |
| 22.4.2002 | Sorgheri | 400 |
| **Total** | | **1700** |

**Table 29**: Total number of *A. beneficus* released at location sites.

| Location | Approximate No. of parasitoids (total) |
|---|---|
| Laloki | 550 |
| Tahira | 550 |
| PAU | 200 |
| Sorgheri | 400 |

*A. beneficus* was released directly into populations of *C. rubens* on three heavily infested trees each at each Tahira, Laloki and PAU, although pink wax scale populations at PAU collapsed in September 2001 and only few live scales were observed. At Sorgheri, the parasitoids were evenly spread throughout the orchard since pink wax scale populations were not recorded at an earlier visit, although infestations were recorded by the owner.

#### 6.3.5.2 Establishment of *Anicetus beneficus*

To determine a successful establishment of *A. beneficus*, pink wax scale infested leaves were taken from trees at Tahira and Laloki on the following dates:

4 x in August and September 2002, and 1 x in February 2003

The scales were checked for the presence of parasitoids applying the same method as described under 6.3.3.1. Additionally, random samples were taken from infested trees at which no parasitoids have been released. No samples were taken from PAU and Sorgheri.

### 6.3.6 The attendance of *Ceroplastes rubens* by honeydew collecting ants

Mango leaves infested with pink wax scales were regularly checked for the presence of ants. If present, ants were collected and identified to the genus by applying the identification keys of Hölldöbler & Wilson (1990) and Shattuck (1999).

### 6.3.7 Statistical analysis

The results were statistically analysed with ANOVA (1-way analysis of variance) and then tested for significance at p = 5 % and 1 % with the t-test.

## 6.4 Results

### 6.4.1 Population dynamics of *Ceroplastes rubens*

#### 6.4.1.1 Seasonal history

In the Central Province there are three generations of pink wax scales per year.
The first generation develops from Mid-January to Mid-February, visible by the settlement of $1^{st}$ -instars on new flush, while $1^{st}$- instars of the second and third generation can be seen during April and September, respectively.
The duration of the life cycle varies with the season, during rainy season (November to April) the generation requires about 2.5 – 3 months but it is longer during the dry season, lasting up to 5 months. Since the emergence of crawlers is a continuing process, $1^{st}$- and $2^{nd}$- instars of the new generation and living adults of the previous generation were present on a same leaf. Also $3^{rd}$- instars, adults and occasionally $2^{nd}$- instars of the same generation were recorded on one leaf.

### 6.4.2 Infestation levels of mango leaves with *Ceroplastes rubens*

The highest level of infestation of *C. rubens* was recorded at Tahira with on average 6.4 % of the leaves infected. The lowest level with an average infestation of 3.82 % was observed at Launakalana, while at PAU and Laloki on average 6.31 % and 5.60 % of monitored leaves were infested with the pest, respectively. Results of statistical analysis (ANOVA) showed no significant differences between the four locations.

At each site a few trees were heavily infested and did not bear any fruit as a consequence while the majority were not infested (Table 30). At Tahira 7 out of 45 checked trees were attacked by *C. rubens*. On four of the infested trees infestation levels varied between 8 % and 12 %, while at the remaining 3 infested trees levels varied between 82 % and 100 %. The same number of trees infested with the pink wax scale was recorded at PAU. As at

Tahira, four trees had low infestation levels (8 % - 16 %), whereas at the other 3 trees infestation was severe with levels of 68 %, 80 % and 88 %, respectively.

At Launakalana the pest was recorded on 9 out of 45 trees. The percentage of infestation generally varied between 4 % and 16 %, however two trees were significantly higher infested by *C. rubens* with 40 % and 56 % of the leaves infested. At Laloki, pink wax scale was recorded from 3 trees with infestation levels varying between 56 % and 92 %.

During August and September 2001 it was observed that both populations on heavily infested trees at Launakalana and PAU collapsed and that only a few live scales were seen on these trees from there on. The same observations were also made on infested mango trees at Erap in the Morobe Province.

**Table 30:** Infestation levels of *Mangifera indica* with the soft scale *Ceroplastes rubens* at four locations in the Central Province, PNG.

| | | Mango tree sampled[a] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total No. infested leaves | Infes-tation % |
| Tahira | 23.8.00 | **25/2** | **25/3** | 25/- | 25/- | 25/- | 25/- | **25/2** | **25/2** | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/9 | 2.4 |
| | 7.9.00 | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/- | 0.0 |
| | 22.9.00 | 25/- | 25/- | 25/- | 25/- | **25/20** | **25/25** | **25/18** | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/63 | 16.8 |
| | | | | | | | | | | | | | | | | | | Mean Value 6.4 |
| PAU | 23.8.00 | 25/- | 25/- | 25/- | 25/- | 25/- | **25/2** | **25/3** | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/5 | 1.33 |
| | 7.9.00 | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/- | 0.0 |
| | 22.9.00 | **25/22** | **25/17** | **25/20** | 25/3 | 25/4 | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 37566 | 17.6 |
| | | | | | | | | | | | | | | | | | | Mean Value 6..31 |
| Launa-kalana | 22.8.00 | 25/- | 25/- | 25/- | 25/- | **25/2** | **25/3** | **25/1** | **25/2** | 25/- | **25/10** | **25/14** | 25/- | 25/- | 25/- | 25/- | 375/32 | 8.53 |
| | 4.9.00 | 25/- | 25/- | **25/4** | **25/2** | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/6 | 1.6 |
| | 18.9.00 | **25/2** | **25/2** | **25/1** | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | 375/5 | 1.33 |
| | | | | | | | | | | | | | | | | | | Mean Value 3.82 |
| Laloki[b] | 23.8.00 | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | | | | | | | | | | 150/- | 0.0 |
| | 7.9.00 | 25/- | 25/- | 25/- | 25/- | 25/- | 25/- | | | | | | | | | | 150/- | 0.0 |
| | 22.9.00 | **25/14** | **25/23** | **25/20** | 25/- | 25/- | 25/- | | | | | | | | | | 150/57 | 16.8 |
| | | | | | | | | | | | | | | | | | 450/57 | Mean Value 5.60 |

[a] Values for the individual trees represent the number of infested leaves out of 25 leaves per tree.
[b] At Laloki only 6 trees were sampled each time due to the low number of trees.

### 6.4.3 Endemic parasitoids of *Ceroplastes rubens*

#### 6.4.3.1 Determination of parasitization levels of *Ceroplastes rubens*

In total 23546 $2^{nd}$- and $3^{rd}$- instars and adult pink wax scales were collected. The majority at Erap (9569 scales), partly because samples were taken on three more occasions than at the other locations, and also because leaves were taken from old, mature trees with infestation levels averaging about 90 %, thus allowing to collect a high number of pink wax scales.

At Tahira and Laloki 1517 and 831 scales, respectively, were collected and checked for parasitoids. At these sites *C. rubens* only occurred on younger trees (2 –3 years old) which do not have many leaves. To maintain populations of *C. rubens* fewer leaves and pink wax scales were collected at each date than were collected from older trees at other sites. However, infestation levels on these trees were as significant and were similar to those at Erap. As at Erap, samples from PAU and Launakalana were taken from mature trees with high levels of pink wax scale infestations. 3715 and 5759 scales, respectively, were collected at these sites.
Out of the total number of 23546 scales collected, 455 showed presence of parasitoids with the majority being in the pupal stage. A few others were collected as larvae and others as dead adults which were not able to emerge from the host.

The highest degree of parasitization of pink wax scales averaged over the survey period, (August 2000 to February 2001), was recorded at Laloki with 3.05 % parasitization and the lowest at Launakalana with 1.19 % of vulnerable pink wax scales stages being parasitised. However, the highest level of parasitism (9.76 %) was recorded for one sampling date at Aiyura. At the other locations parasitization levels varied between 1.48 % and 2.83 % (Table 31). The results of the statistical analysis (ANOVA) showed no significant differences at LSD (5 %) between the locations.
As Table 31 shows, parasitization levels generally declined at the locations in the Central Province from October onwards, while remaining steady in the other provinces.

The highest percentage of emergence of adult parasitoids at the sites in the Central Province occurred during the months September and October but declined during later months with most of the parasitoids found dead within the host. At Erap in the Morobe Province and Ayiura (Eastern Highlands Province) parasitoids continuously emerged during the collection period with only a slight decline recorded from samples taken at Aiyura.

**Table 31:** Levels of parasitization of susceptible stages of *Ceroplastes rubens* at different localities in PNG.

| Location | Date | No. of scales collected | No. of parasitised scales | No. of scales with emerged parasitoids | No. of scales with non emerged parasitoids | Percentage Parasitization/ Mean Value |
|---|---|---|---|---|---|---|
| **PAU** | 8.9.2000 | 233 | 5 | 3 | 2 | 2.15 |
| | 15.9.2000 | 895 | 24 | 20 | 4 | 2.68 |
| | 22.9.2000 | 790 | 9 | 6 | 3 | 1.14 |
| | 29.9.2000 | 190 | 7 | 6 | 1 | 3.68 |
| | 13.10.2000 | 165 | 2 | - | 2 | 1.21 |
| | 1.11.2000 | 175 | 1 | 1 | - | 1.14 |
| | 23.11.2000 | 416 | 2 | - | 2 | 0.48 |
| | 5.12.2000 | 357 | 1 | - | 1 | 0.28 |
| | 12.12.2000 | 524 | 3 | - | 3 | 0.57 |
| **Total** | | **3715** | **54** | **36** | **18** | **1.458 %** |
| **Tahira** | 8.9.2000 | 123 | 2 | 2 | - | 1.62 |
| | 15.9.2000 | 141 | 5 | 4 | 1 | 4.25 |
| | 22.9.2000 | 96 | 4 | 3 | 1 | 4.17 |
| | 29.9.2000 | 172 | 6 | 4 | 2 | 4.07 |
| | 13.10.2000 | 244 | 2 | 2 | - | 0.82 |
| | 1.11.2000 | 214 | 1 | 1 | - | 0.47 |
| | 23.11.2000 | 168 | 2 | 1 | 1 | 1.19 |
| | 5.12.2000 | 82 | - | - | - | 0.00 |
| | 12.12.2000 | 277 | 5 | 1 | 4 | 1.81 |
| **Total** | | **1517** | **27** | **18** | **9** | **2.04 %** |
| **Laloki** | 8.9.2000 | 78 | 3 | 2 | 1 | 3.85 |
| | 15.9.2000 | 112 | 5 | 5 | - | 6.25 |
| | 22.9.2000 | 57 | 2 | 1 | 1 | 3.51 |
| | 29.9.2000 | 201 | 5 | 3 | 2 | 2.49 |
| | 13.10.2000 | 122 | 3 | 2 | 1 | 2.45 |
| | 1.11.2000 | 87 | 1 | 1 | - | 1.15 |
| | 23.11.2000 | 62 | 2 | - | 2 | 3.22 |
| | 5.12.2000 | 30 | 1 | - | 1 | 3.33 |
| | 12.12.2000 | 82 | 1 | - | 1 | 1.22 |
| **Total** | | **831** | **23** | **14** | **9** | **3.05 %** |

**Table 31 continued:** Levels of parasitization of susceptible stages of *Ceroplastes rubens* at different localities in PNG.

| Location | Date | No. of scales collected | No. Of parasitised scales | No. of scales with emerged parasitoids | No. of scales with non emerged parasitoids | Percentage Parasitization/ Mean Value |
|---|---|---|---|---|---|---|
| **Launakalana** | 5.9.2000 | 544 | 12 | 9 | 3 | 2.20 |
| | 20.9.2000 | 939 | 11 | 7 | 4 | 1.17 |
| | 27.9.2000 | 652 | 1 | 1 | - | 0.15 |
| | 5.10.2000 | 830 | 24 | 19 | 5 | 2.89 |
| | 20.10.2000 | 435 | 2 | - | 2 | 0.46 |
| | 2.11.2000 | 921 | 23 | 15 | 8 | 2.50 |
| | 22.11.2000 | 588 | 3 | - | 3 | 0.51 |
| | 30.11.2000 | 398 | 1 | - | 1 | 0.25 |
| | 7.12.2000 | 482 | 3 | - | 3 | 0.62 |
| **Total** | | **5759** | **80** | **51** | **29** | **1.19 %** |
| **Erap** | 18.8.2000 | 1073 | 25 | 21 | 4 | 2.33 |
| | 22.8.2000 | 815 | 34 | 32 | 2 | 3.82 |
| | 26.8.2000 | 1146 | 50 | 46 | 4 | 4.36 |
| | 1.11.2000 | 1202 | 8 | 6 | 2 | 0.66 |
| | 10.11.2000 | 1583 | 13 | 8 | 5 | 0.82 |
| | 15.11.2000 | 833 | 11 | 11 | - | 1.32 |
| | 23.11.2000 | 348 | 15 | 14 | 1 | 4.31 |
| | 5.12.2000 | 710 | 15 | 13 | 2 | 2.11 |
| | 14.12.2000 | 193 | 14 | 12 | 2 | 7.25 |
| | 24.12.2000 | 377 | 8 | 8 | - | 2.12 |
| | 2.1.2001 | 933 | 14 | 10 | 4 | 1.50 |
| | 8.1.2001 | 356 | 12 | 11 | 1 | 3.37 |
| **Total** | | **9569** | **219** | **192** | **27** | **2.83 %** |
| **Aiyura** | 20.12.2000 | 497 | 8 | 6 | 2 | 1.61 |
| | 27.12.2000 | 158 | 1 | 1 | - | 0.63 |
| | 3.1.2001 | 153 | 2 | 1 | 1 | 1.31 |
| | 10.1.2001 | 344 | 8 | 7 | 1 | 2.33 |
| | 17.1.2001 | 101 | 3 | 2 | 1 | 2.97 |
| | 241.2001 | 164 | 16 | 14 | 2 | 9.76 |
| | 31.1.2001 | 391 | 6 | 3 | 3 | 1.53 |
| | 7.2.2001 | 159 | 3 | - | 3 | 1.89 |
| | 14.2.2001 | 188 | 5 | 2 | 3 | 2.66 |
| **Total** | | **2155** | **52** | **36** | **16** | **2.74 %** |
| **Total No. all locations** | | **23546** | **455** | **347** | **108** | **2.22 %** |

### 6.4.3.2 Parasitoid identification

Out of the 455 parasitised scales 347 showed a complete life cycle of the parasitoids with the emergence of adult wasps, while 108 parasitoids were unable to complete their life cycle and died as pupae or as adults within the scale. Parasitoids which were still in their pupal stages and apparently alive after the monitoring period of weeks were counted as "scales with non emerged parasitoids" (Table 31). Out of the 347 parasitised scales emerged 395 adult wasps. This difference is explained by the occurrence of gregarious parasitoids (Table 32 & 33).

Species of the following genera were found as parasitoids of *Ceroplastes rubens*:

| | |
|---|---|
| *Aprostocetus* sp. | (Eulophidae) |
| *Cheiloneurus* sp. | (Encyrtidae) |
| *Coccidocnotus* sp. | (Encyrtidae) |
| *Coccophagus* sp. | (Aphelenidae) |
| *Diversinervus* sp. | (Encyrtidae) |
| *Metaphycus* sp. | (Encyrtidae) |
| *Microterys* sp. | (Encyrtidae) |
| *Moranila* sp. | (Pteromalidae) |

Individuals of the genus *Aprostocetus* (*Tetrastichus*) were the most numerous with 97 identified individuals responsible for 27.95 % parasitism of vulnerable stages of *C. rubens* (Table 32). *Aprostocetus* were only present at Erap, while no species of this genus were recorded from other locations (Table 33). All wasps emerged as solitary parasitoids of *C. rubens*.

Two adults of *Cheiloneurus* sp. emerged from parasitised scales collected at Erap but were not recorded from other locations.

Parasitoids of the genus *Coccidocnotus* were not found in the Central Province but were recorded at Erap and Aiyura. In total 16 individuals emerged as hyperparasitoids from pink wax scales. In three cases this species displayed gregarious behaviour with 2 adult wasps emerging from a single scale. Specimens were sent to NHM, London, for identification and were determined by J. Noyes as *Coccidocnotus* sp. near *dubius* (Girault) differing from the species *dubius* by having a relatively shorter ovipositor.

In total 76 adults of *Coccophagus* sp. were reared from parasitised pink wax scales accounting for 21.90 % of the total parasitization of *C. rubens*. All wasps emerged as solitary parasitoids. The greatest number of individuals (44) was recorded from infested leaves collected at Erap in the Morobe Province, whereas none of this species emerged from samples taken at Aiyura in the Eastern Highlands Province. Only a few individuals were recorded from the study sites in the Central Province.

*Metaphycus* sp. were the second most numerous parasitoids identified (84) but responsible only for 11.53 % of the total parasitization of susceptible pink wax scale stages due to their gregarious behaviour. This behaviour was recorded from all wasps emerging from *C. rubens* with 2 adults per scale being most common. An emergence of 3 adult wasps from a single scale was observed in four cases. Except from the Eastern Highlands Province, *Metaphycus* sp. were found in both other provinces.

*Microterys* sp. were collected from all locations but were most frequent at Erap in the Morobe Province. In total 64 wasps were reared as solitary parasitoids from pink wax scales; no gregarious behaviour was recorded. Specimens were sent to NHM, London, for further identification and were determined by J. Noyes as *Microterys* sp. near *garibaldia* (Girault).

All species of *Moranila* emerged as solitary parasitoids from *C. rubens*. No individuals were reared from leaf samples taken at Aiyura (Eastern Highlands Province), but were present at all other locations. In total 49 wasps were recorded corresponding to 14.12 % of the total parasitization of pink wax scales.

**Table 32:** Number of parasitoid species reared from parasitised *C. rubens* and percentage of total parasitism (2.22 %).

| Species | Number of parasitised scales | Number of parasitoids reared from the scales | Percentage Parasitism |
|---|---|---|---|
| *Aprostocetus* sp. | 97 | 97/97 | 27.95 % |
| *Cheiloneurus* sp. | 2 | 2/2 | 0.58 % |
| *Coccidocnotus* sp. | 16 | 16/12[a] | 3.46 % |
| *Coccophagus* sp. | 76 | 76/76 | 21.90 % |
| *Diversinervus* sp. | 7 | 7/7 | 2.02 % |
| *Metaphycus* sp. | 40 | 84/40[a] | 11.53 % |
| *Microterys* sp. | 64 | 64/64 | 18.44 % |
| *Moranila* sp. | 49 | 49/49 | 14.12 % |
| **Total** | **347** | **395** | **100 %** |

[a]- gregarious behaviour recorded

**Table 33:** Identified genera and number of individuals of endemic parasitoids of *Ceroplastes rubens* in three Provinces of PNG.

| | | Identified genera of parasitoids and number of individuals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Date** | **Aprostocetus** | **Coccophagus** | **Cheiloneurus** | **Coccidocnotus** | **Diversinervus** | **Metaphycus** | **Microterys** | **Moranila** | **Total** |
| **PAU** | 8.9.2000 | | 1 | | | 1 | | 1 | | **3** |
| | 15.9.2000 | | 5 | | | 1 | 21 (9x2;1x3) | 4 | | **31** |
| | 22.9.2000 | | | | | | 4 (2x2) | | 4 | **8** |
| | 29.9.2000 | | | | | | 4 (2x2) | 3 | 1 | **8** |
| | 13.10.2000 | | | | | | | | | |
| | 1.11.2000 | | | | | | 2 (1x2) | | | **2** |
| | 23.11.2000 | | | | | | | | | |
| | 5.12.2000 | | | | | | | | | |
| | 13.12.2000 | | | | | | | | | |
| | **Total** | **-** | **6** | **-** | **-** | **2** | **31** | **8** | **5** | **52** |
| **Tahira** | 8.9.2000 | | | | | | | 1 | 1 | **2** |
| | 15.9.2000 | | 2 | | | | 2 (1x2) | | 1 | **5** |
| | 22.9.2000 | | 3 | | | | | | | **3** |
| | 29.9.2000 | | | | | 1 | 2 (1x2) | 1 | 1 | **5** |
| | 13.10.2000 | | 1 | | | | | | 1 | **2** |
| | 1.11.2000 | | | | | | | 1 | | **1** |
| | 23.11.2000 | | | | | | | | 1 | **1** |
| | 5.12.2000 | | | | | | | | | |
| | 12.12.2000 | | 1 | | | | | | | **1** |
| | **Total** | **-** | **7** | **-** | **-** | **1** | **4** | **3** | **5** | **20** |
| **Laloki** | 8.9.2000 | | 2 | | | | | | | 2 |
| | 15.9.2000 | | 1 | | | | 4 (2x2) | 2 | | 7 |
| | 22.9.2000 | | | | | | | | 1 | 1 |
| | 29.9.2000 | | | | | | | 1 | 2 | 3 |
| | 13.10.2000 | | 1 | | | | | 1 | | 2 |
| | 1.11.2000 | | 1 | | | | | | | 1 |
| | 23.11.2000 | | | | | | | | | |
| | 5.12.2000 | | | | | | | | | |
| | 12.12.2000 | | | | | | | | | |
| | **Total** | **-** | **5** | **-** | **-** | **-** | **4** | **4** | **3** | **16** |

**Table 33 continued:** Identified genera and number of individuals of endemic parasitoids of *Ceroplastes rubens* in three Provinces of PNG.

| | | Identified genera and number of individuals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Date** | **Aprostocetus** | **Coccophagus** | **Cheiloneurus** | **Coccidocnotus** | **Diversinervus** | **Metaphycus** | **Microterys** | **Moranila** | **Total** |
| **Launa-kalana** | 5.9.2000 | | 5 | | | | 4 (2x2) | | 2 | **11** |
| | 20.9.2000 | | | | | 1 | 3 (1x3) | 2 | 3 | **9** |
| | 27.9.2000 | | | | | | | 1 | | **1** |
| | 5.10.2000 | | 5 | | | 2 | 9 (3x2,1x3) | 6 | 2 | **24** |
| | 20.10.2000 | | | | | | | | | |
| | 2.11.2000 | | 4 | | | | 2 (1x2) | 6 | 4 | **16** |
| | 22.11.2000 | | | | | | | | | |
| | 30.11.2000 | | | | | | | | | |
| | 7.12.2000 | | | | | | | | | |
| | **Total** | **-** | **14** | **-** | **-** | **3** | **18** | **15** | **11** | **61** |
| **Erap** | 18.8.2000 | 16 | 1 | | | | 2 (1x2) | | 3 | **22** |
| | 22.8.2000 | 29 | 1 | | | | 4 (2x2) | | | **34** |
| | 26.8.2000 | 44 | | | | | 2 (1x2) | | 1 | **47** |
| | 1.11.2000 | | | | 1 | | 3 (1x3) | | 4 | **8** |
| | 10.11.2000 | 1 | 2 | | 1 | | 4 (2x2) | | 2 | **10** |
| | 15.11.2000 | | 2 | | 4 (2x 2) | | 2 (1x2) | | 6 | **14** |
| | 23.11.2000 | 2 | 9 | | 1 | 1 | | | 1 | **14** |
| | 5.12.2000 | | 7 | 2 | | | 4 (2x2) | | 2 | **15** |
| | 14.12.2000 | 2 | 4 | | | | | 1 | 5 | **12** |
| | 24.12.2000 | 1 | 3 | | | | 6 (3x2) | | 1 | **11** |
| | 2.1.2001 | 2 | 6 | | | | | 2 | | **10** |
| | 8.1.2001 | | 9 | | 1 | | | 1 | | **11** |
| | **Total** | **97** | **44** | **2** | **8** | **1** | **27** | **4** | **25** | **208** |

Legend: figures in brackets (3x2) – three scales with 2 parasitoids each.

**Table 33 continued:** Identified genera and number of individuals of endemic parasitoids of *Ceroplastes rubens* in three Provinces of PNG.

| | | Identified genera of parasitoids and number of individuals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Date** | **Aprostocetus** | **Coccophagus** | **Cheiloneurus** | **Coccidocnotus** | **Diversinervus** | **Metaphycus** | **Microterys** | **Moranila** | **Total** |
| **Aiyura** | 20.12.2000 | | | | | | | 6 | | **6** |
| | 27.12.2000 | | | | | | | 1 | | **1** |
| | 3.1.2001 | | | | | | | 1 | | **1** |
| | 10.1.2001 | | | | 1 | | | 6 | | **7** |
| | 17.1.2001 | | | | 1 | | | 1 | | **2** |
| | 24.1.2001 | | | | 5 (2x2, 1x1) | | | 11 | | **16** |
| | 31.1.2001 | | | | 1 | | | 2 | | **3** |
| | 7.2.2001 | | | | | | | | | |
| | 14.2.2001 | | | | | | | 2 | | **2** |
| | **Total** | **-** | **-** | **-** | **8** | **-** | **-** | **30** | **-** | **38** |
| **Total No. locations** | | **97** | **76** | **2** | **16** | **7** | **84** | **64** | **49** | **395** |

Legend: figures in brackets (3x2) – three scales with 2 parasitoids each.

### 6.4.4 The importation of *Anicetus beneficus*

#### 6.4.4.1 Establishment of *Anicetus beneficus*

Female parasitoids were monitored for several hours after the releases to determine if susceptible pink wax scale stages were attacked by the parasitoid. These visual observations showed that *A. beneficus* not only attacked adults but also $2^{nd}$- and $3^{rd}$-instars. From samples taken in August and September 2002, five and six months after the release, respectively, female and male *A. beneficus* emerged.

#### 6.4.4.2 Determination of parasitization levels of *Ceroplases rubens* after the release of *Anicetus beneficus*

In autumn 2002 and spring 2003 in total 452 pink wax scales vulnerable to parasitization were collected (272 at Laloki and 180 at Tahira) with 56 scales showing presence of parasitoids (Table 34). The hightest level of parasitization (27.42 %) was recorded at Tahira in September 2002 with the average being 22.15 % (Table 34). No pink wax scales were collected at Tahira in February 2003, as no new populations were visible neither on old nor on new leaves.

In comparison, the degree of parasitization of *C. rubens* at Laloki averaged only 5.45 % with the highest level of 7.32 % recorded in August 2002. Pink wax scale populations were still present in February 2003 and parasitization averaged 6.78 %.

The results of statistical analysis (ANOVA) showed significant differences in the percentage of parasitism at LSD = 1 % between Tahira and Laloki.

The level of parasitization at Laloki increased from 3.05 % before the release of *A. beneficus* to 5.45 % after the release (difference significant at LSD = 5 %). At Tahira the level increased by 20.11 % from 2.04 % to 22.15 % with this difference being significant at LSD = 0.1%.

**Table 34:** Parasitization levels of *Ceroplastes rubens* after the release of the parasitoid *Anicetus beneficus*.

| Location | Date | **Number of scales collected** | **Number of parasitised scales** | **Number of scales with emerged parasitoids** | **Number of scales with non emerged parasitoids** | **Parasitization %** |
|---|---|---|---|---|---|---|
| Laloki | 6.8.02 | 39 | 2 | -- | 2 | 5.13 |
| | 15.8.02 | 26 | 1 | 1 | -- | 3.85 |
| | 29.8.02 | 41 | 3 | 3 | -- | 7.32 |
| | 12.9.02 | 48 | 2 | 2 | -- | 4.17 |
| | 11.2.03 | 118 | 8 | 7 | 1 | 6.78 |
| **Total** | | **272** | **16** | **13** | **3** | **Mean Value 5.45 %** |
| Tahira | 6.8.02 | 57 | 9 | 9 | -- | 15.79 |
| | 14.8.02 | 38 | 9 | 9 | -- | 23.68 |
| | 29.8.02 | 23 | 5 | 3 | 2 | 21.74 |
| | 11.9.02 | 62 | 17 | 13 | 4 | 27.42 |
| | 11.2.03 [(x)] | -- | -- | -- | -- | -- |
| **Total** | | **180** | **40** | **34** | **6** | **Mean Value 22.15 %** |
| **Total number both locations** | | **452** | **56** | **47** | **9** | **Mean Value both locations 13.80 %** |

### 6.4.4.3 Parasitoid identification after the release of *Anicetus beneficus*

Out of the 56 parasitised scales 47 showed a complete life cycle of the parasitoids with the emergence of adult wasps, while 9 parasitoids were unable to complete and died as pupae or as adults within the host (Table 34). Out of these 47 scales emerged 48 adult wasps with one parasitoid showing gregarious behaviour (Table 35).

Th most dominant parasitoid at both locations was *A. beneficus* accounting for 46.15 % of all parasitoid species at Laloki and for 79.41 % at Tahira (Table 35). Out of the 34 individuals of *A. beneficus* recorded, 30 were female and 4 were males, which is approximate to a ratio of 88 % females and 12 % males. No *A. beneficus* were recorded from trees at which no releases had been made.

**Table 35:** Number of adult parasitoids reared from parasitised scales collected at Laloki and Tahira and percentage of total parasitism (13.80 %) after release of *Anicetus beneficus*.

| **Species** | **No. of adults reared from parasitised scales** | **Percentage Parasitism** |
|---|---|---|
| *Anicetus beneficus* | 33/33 | 68.75 % |
| *Aprostocetus* sp. | -- | -- |
| *Cheiloneurus* sp. | -- | -- |
| *Coccidocnotus* sp. | -- | -- |
| *Coccophagus* sp. | 3/3 | 6.25 % |
| *Diversinervus* sp. | 3/3 | 6.25 % |
| *Metaphycus* sp. | 2/1* | 4.16 % |
| *Microterys* sp. | 3/3 | 6.25 % |
| *Moranila* sp. | 4/4 | 8.33 % |
| **Total** | 48/47 | 100 % |

* - gregarious behaviour recorded

The second most common parasitoid after *A. beneficus* was the solitary endoparasitoid *Moranila* sp. with 4 individuals (Table 35). Three parasitoids of *Coccophagus*, *Microterys* and *Diversinervus* emerged from pink wax scales, respectively, with the first two genera found at both locations, while *Diversinervus* was only reared from samples taken at Tahira. Species of *Aprostocetus*, *Cheiloneurus* and *Coccidocnotus* were not recorded during this survey (Table 36).

**Table 36:** Identified genera and number of indivuals of parasitoids of pink wax scales after the release of *Anicetus beneficus*.

| | | Identified genera and number of individuals | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Location** | **Date** | **Anicetus beneficus** | **Coccophagus** | **Diversinervus** | **Metaphycus** | **Microterys** | **Moranila** | **Total** |
| Laloki | 6.8.02 | | | | | | | |
| | 15.8.02 | | | | | | | |
| | 29.8.02 | 2 | | | | 1 | | **3** |
| | 12.9.02 | 1 | | | | | 1 | **2** |
| | 11.2.03 | 3 | 2 | | | 1 | 2 | **8** |
| **Total** | | **6** | **2** | - | - | **2** | **3** | **13** |
| **Tahira** | 6.8.02 | 7 | 1 | 1 | | | | **9** |
| | 14.8.02 | 6 | | 2 | 2 (1x2) | | | **10** |
| | 29.8.02 | 3 | | | | | | **3** |
| | 11.9.02 | 11 | | | | 1 | 1 | **13** |
| | 11.2.03[(x)] | | | | | | | |
| **Total** | | **27** | **1** | **3** | **2** | **1** | **1** | **34** |
| **Total No. locations** | | **33** | **3** | **3** | **2** | **3** | **4** | **48** |

Legend: figures in brackets (1x2) – 1 scale with 2 parasitoids.

### 6.4.5 Further natural enemies of *Ceroplastes rubens*

A fungus, probably *Verticillium lecanii*, was recorded during the wet season at Launakalana attacking pink wax scales.

### 6.4.6 The attendance of *Ceroplastes rubens* by honeydew collecting ants

The following ant species were observed visiting pink wax scale populations:

| | |
|---|---|
| *Camponotus* sp. | (Formicidae, Formicinae) |
| *Tapinoma* sp. | (Formicidae, Dolichoderinae) |

A species of *Camponotus* was recorded visiting pink wax scales on one tree at the Tahira Orchard. It was never observed on the other trees infested with *C. rubens* nor was it recorded at Laloki. Workers of *Tapinoma* were frequently collected from infested trees at Laloki but were not present at Tahira. In general, few ants were seen visiting *C. rubens* colonies.

## 6.5 Discussion

### 6.5.1 Population Dynamics of *Ceroplastes rubens*

#### 6.5.1.1 Seasonal history

The conditions in the Central Province allow *C. rubens* to develop three generations a year compared to two generations in Southern Queensland and one in Japan (Smith, 1976; Yasumatsu & Tachikawa, 1949). Yoon & Wiles (1994) recorded a similar life cycle of 2.5 – 3 months in the Highlands of PNG also with a longer life cycle during the dry season but exact number of generations were not determined.

The finding that live scales of two generations were present at the same time is in accordance with the observations by Blumberg (1934) in Australia, who also recorded an overlapping of the generations.

Three generations of *C.rubens* a year result in a more rapid infestation of other leaves and trees, and therefore pose a bigger threat to mango and citrus growers in PNG than in Australia and Japan, where it has been stated an important pest although a lower number of generations occurs.

### 6.5.2 Infestation levels of mango leaves with *Ceroplastes rubens*

The infestation levels of mango with *C. rubens* in the Central Province at the locations Tahira, PAU and Laloki only slightly exceeded the recommended action level of more than 5 % infested leaves in Australian Citrus at three locations, while at Launakalana infestations remained below that level. Yoon & Wiles (1994) also observed infestation levels below 5 % in three citrus plantations while only one site (Hoveku, Eastern Highlands Province) showed a heavy infestation with pink wax scales.

If applying the action level of 5 % in PNG, three mango orchards in the Central Province would require treatment against *C. rubens* but it must be considered this level was estimated for Australian producers, who cannot sell fruits affected with sooty mould on both domestic and export market, and in general have much higher production costs. In contrast, costs for producing mango and citrus in PNG are far lower and fruits with sooty mould sell for the same price on local markets as apparently healthy ones. This level is therefore not applicable for local producers, and higher infestation levels can be tolerated. However, trees with infestation levels of about 70 % as observed at the study sites need treatment since this will result in no fruit setting and consequently in a significantly loss of income, particularly for small holders.
If PNG is to export mango and citrus, action levels then have to be calculated for producers who intend to sell their fruits to international markets.

At each location most of the trees examined were free of pink wax scales, while only a few were infested. The slow dispersal of *C. rubens* within these orchards, as also observed by Yoon & Wiles (1994), has to be attributed to the high mortality of crawlers due to predation and natural circumstances like heavy rainfall events which kill most of the crawlers by washing them off the leaves (D. Smith, pers. comm, 2001). It has also to be considered that crawlers settle within 48 hours after hatching and that their main means of dispersal is by wind, so for any effective dispersal to take place, windy conditions have to prevail during the short period that the crawlers are active.

The collapse of the populations on heavily infested trees at Launakalana, PAU and Erap is most probably related to the coverage of nearly every leaf with sooty mould and that therefore trees were not longer able to photsynthesise and to produce nutrients on which the scales live on. This assumption is underlined by the fact that unlike other trees only a few new flushes were recorded on these formerly heavily infested trees.

### 6.5.3 Parasitization levels of *Ceroplastes rubens*

The calculated figures indicate low percentages of parasitism of the vulnerable stages (the 2nd- and 3rd instars and adults) of *C. rubens* but it has to be considered that only the actual parasitization that is – the presence of parasitoid stages (larvae, pupae, adults) within the scales at each sampling date – was recorded.
These values, however, do not represent the total number of scales attacked and killed by the parasitoids. This number has to be estimated much higher but has not been calculated for the following reasons:

- First instars were not checked for parasitoids, since adult wasps will not emerge at this stage but parasitization does occur, as it is the case with the first generation of the bivoltine *A. beneficus*, which parasitise 1. instar pink wax scales. To calculate parasitization of these instars, scales have to be dissected and checked under the microscope for the presence of hymenopteran eggs.
- Parasitised scales with emergence holes of adult wasps were not taken into account, since it is sometimes difficult to distinguish between these holes and

holes created by the feeding of predators. And more importantly, scales of the previous generation stick to the leaves even when the new generation is already present and scales turn black just before the emergence of adult wasps. This makes it impossible to differentiate between dead scales of the present and the previous generation.

The results of parasitization levels of *C. ruben*s from the three different provinces do not differ significantly (LSD = 5 %) and varied only between 1.48 % and 3.05 % (mean 2.2 %), although it has to be noticed that samples at Aiyura were taken from avocado and not from mango trees, which could have an impact on the degree of parasitization.

In Australia, Loch (1997) recorded average parasitization rates of *C. rubens* of 6 % (without *A. beneficus*) but it must be considered that introduced species like *Scutellista caerula*, *Diversinervus elegans* and *Coccophagus ceroplastae* attributed to the higher level when compared with the results from PNG. The figures from this study are slightly higher than by Yasumatsu & Tachikawa (1949) from Japan, who recorded parasitization rates of endemic and introduced parasitoids between 0.% and 0.87 %. But the authors calculated the actual parasitization on the emergence of parasitoids only and did not count larvae or pupae which could not complete metamorphosis.

### 6.5.4 Endemic parasitoids and their significance as control agents of *Ceroplastes rubens*

The results indicate that species of the genus *Anicetus* did not occur as parasitoids of *C. rubens* in PNG. This is in accordance with the findings by Wilson (1960) and Loch (1997) in Australia who did not record species of *Anicetus* as endemic parasitoids of pink wax scales. Although the following species *Coccobius atrithorax*, *Encarsia citrina*, *Euryschomia flavithorax*, *Myiocnema* sp. and *Scutellista caerulea* were not recorded from *C. rubens* in PNG, they could still be present since they emerged only in very low numbers from pink wax scales in neighbouring Australia.

In comparison to the study by Loch (1997), *Aprostocetus* sp. was far more abundant at one site in PNG than in Australia, where 2.9 % of pink wax scales were parasitised by this species. In PNG, it was only recorded at Erap and was absent at the other locations. Further collections should be made to establish its presence in other provinces, and specimens should be sent for species identification since the genus *Aprostocetus* contains a large number of species, which display different biological behaviours. The interaction with the host could be as an endoparasitoid as well as a hyperparasitoid.

Two species of *Cheiloneurus* sp. were recorded from the Morobe Province but were absent in the others. This result can be attributed to the much larger number of scales collected at this location and therefore, they could still be recorded in other provinces. Since this genus contains hyperparasitoids only, further identification is required to establish if this species will settle as a hyperparasitoid of *A. beneficus*.

Species of *Coccidocnotus* were not recorded in the Central Province and only present in low numbers in the other provinces. Loch (1997), however, recorded *C. dubius* as the most common hyperparasitoid emerging from pink wax scale in Australia. This difference may be explained by the fact that the endemic species were identified as *Coccidocnotus* sp. near *dubius* and that *C. dubius* mainly settled as an hyperparasitoid of *A. beneficus.* Since all species of *Coccidocnotus* are known as hyperparasitoids, care should be taken to avoid spreading them into the Central Province and it should also be subsequently investigated if this endemic species will act as an hyperparasitoid of *A. beneficus* in PNG.

*Coccophagus* sp. accounted but for 21.90 % of all endemic parasitoids in PNG and played a far more important role than *C. ceroplastae*, an introduced species from Hawaii, which was responsible only for 3.5 % parasitization of pink wax scales in Australia (Loch, 1997). In Japan, Yasumatsu and Tachikawa (1949), also noted low levels of parasitism by the introduced species *Coccophagus hawaiiensis* with only 5 out 1870 reared individuals belonging to this species.

*Diversinervus* sp. was insignificant in the control of *C. rubens* in all parts of PNG as was the case in Australia, where only the species *D. elegans*, introduced for the control of the white wax scale *C. destructor*, was occasionally reared from *C. rubens* (Loch, 1997).

*Metaphycus* sp. was the second most common endemic parasitoid of vulnerable pink wax scale stages but counted only for 11.53 % parasitization due to gregarious behaviour. This behaviour was also observed in the native species *Metaphycus varius* in Australia where Loch (1997) recorded up to seven adult wasps emerging from a single adult scale.

The species *Microterys okituensis* and *M. speciosus* accounted only for 0.59 % and 0.29 % parasitization of *C. rubens*, respectively, in studies by (Yasumatsu & Tachikawa, 1949). Similar low levels (0.1 %; *Microterys* sp.) were recorded in Australia by Loch (1997). In comparison, *Microterys* sp. was the fourth most common parasitoid of pink wax scale in PNG.

In general the results show that endemic parasitoids do not play an important role in controlling this pest and for an introduction of effective parasitoids as suggested by Yoon & Wiles (1994) is needed.

### 6.5.5 The importation of *Anicetus beneficus*

#### 6.5.5.1 Establishment of *Anicetus beneficus*

The numbers of parasitoids sent by the Australian Authorities variied with every consignment, since parasitised pink wax scales were field collected. The months of March to April and October to November are the peak periods for the emergence of *A. beneficus* in Australia coinciding with the presence of adults and new instars of the next generation on infested leaves. The appearance of new generations of *C. rubens* in the Central Province slightly differs from the period in Australia. This means there are fewer vulnerable pink wax scale stages that can be parasitised when *A. beneficus* from Australia are available for release in the Central Province. This could cause a delay in or prevent a successful establishment of this parasiotid.

However, both sexes emerged from samples taken in August and September 2002 and February 2003.

#### 6.5.5.2 Parasitoids and parasitization levels of *Ceroplastes rubens* after the release of *Anicetus beneficus*

Although *A. beneficus* was released at four locations, samples were only taken from Laloki and Tahira, since the populations on highly infested trees at PAU ceased and pink wax scales were only seldom found on other trees. It is recommended to check for the presence of *A. beneficus* at this site when more pink wax scales are present. At Sorgheri releases were made, although no scales were seen but could have been overlooked, and samples should be taken once pink wax populations are identified. If *A. beneficus* did not establish, fresh releases should be undertaken at this site. No releases were made at Launakalana since pink wax scale populations had also collapsed at this site.

With the establishment of *A. beneficus* at Laloki the degree of parasitization increased by 2.40 % and at Tahira by 20.11 % (Table 34). This is considerably less to the findings by Smith (1986) in Australia who recorded parasitization levels up to 81 % in citrus. However, results by Loch (1997) revealed that parasitization only averaged 12.4 % on umbrella trees.

As Table 36 shows, *A. beneficus* immediately became the most numerous parasitoid at both Tahira and Laloki and parasitization rates were significant greater (LSD = 1 %) to the ones recorded before the release of the parasitoid. In February 2003 no new generations of *C. rubens* were seen on the trees at Tahira at which *A. beneficus* was released, which indicates the effectiveness of this parasitoid. On the other hand, no *A. beneficus* were recorded from trees at which they were not immediately released. But it is known that adults are not strong flyers and move rather by walking and hopping (Noda et al., 1981), which results in a slow dispersion rate within an orchard. Yasumatsu (1953) indicated that populations of this parasitoid may disperse a distance of 2000 meters within two years.

In general, it has to be considered that samples were taken only at a short period after the release of *A. beneficus*. The results therefore only indicate that conditions are favourable for a permanent establishment. As also outlined before, the seasonal history of *C. rubens* in the Central Province slightly differs from that in Australia. High percentages of parasitism by *A.beneficus* immediately after release can therefore not be expected. To determine the effectiveness of this parasitoid, samples should be taken several years after release as it has been the case with the studies by Smith (1986) and Loch (1997) in Australia. This would allow *A. beneficus* to settle and adjust to the specific conditions, and parasitization rates would be then more accurate.

### 6.5.6 The effect of ant attendance on the establishment of *Anicetus beneficus*

*C. rubens* produces honeydew irrespective of the existence of ants unlike other species who provide honeydew when tapped by ants (Itioka & Inoue, 1996). This probably explains the rare visits of *C. rubens* colonies by ants, in particular by *Oeocophylla smaragdina*, the most numerous ant at all locations. *O. smaragdina* was only recorded attending populations of *Saissetia* sp. and *Parasaissetia* sp.

Workers of *Tapinoma* are general scavengers but have a preference for honeydew and often attend aphids or coccids (Shattuck, 1999). They were found in high numbers attending pink wax scale populations at Laloki. This could explain the low number of emerged *A. beneficus* and therefore the lower degree of parasitization of *C. rubens* observed at Laloki in comparison to Tahira where no ants of this genus were found, and parasitization rates were considerably higher. Similar results were obtained by Itioka and Inoue (1996) from in field and laboratory trials in Japan, where the attendance of pink wax scale populations by *Lasius niger* caused a decrease in percentage parasitism and thus reduced the effectiveness of *A. beneficus*. Species of *Tapinoma* are not dominant ants and once more aggressive species like *Oecophylla smaragdina* move into this area, the smaller *Tapinoma* will be attacked and forced to leave this area (Hölldöbler & Wilson, 1990). If in one orchard *C. rubens* is a dominant pest and parasitization is disturbed by *Tapinoma*, it is recommended to deliberately introduce *O. smaragdina* into this area in order to reduce *Tapinoma*. As a result, parasitoids of the pink wax scale would be less disturbed during parasitization thus leading to higher numbers of *A. beneficus* and eventually higher parasitization rates. *O. smaragdina* has not been observed visiting populations of *C. rubens*.

Workers of *Camponotus* are one of the most common groups of ants in Australia (Shattuck, 1999). They are general scavengers and predators and attend Hemiptera for honeydew (Briese & Macauley, 1981). They were seen only occasionally and in very low numbers visiting pink wax scale populations at Tahira and probably had a minimal effect on the establishment of *A. beneficus*.

## 6.6 Conclusion

The results showed that endemic parasitoids of *C. rubens* were not effective in the control of this pest, which led to the importation of the successful pink wax scale parasitoid *Anicetus beneficus* Maskell (Hymenoptera: Encyrtidae). This parasitoid was first discovered in Japan and introduced into Australia in 1976. The wasp established itself and proved to be very effective. *A. beneficus* was released at four locations in the Central Province of PNG. The parasitoid was successfully established at two locations and levels of parasitization immediately increased. A further distribution into other areas of the province and into other provinces of PNG is therefore recommended.

## 6.7 Mass production of *Anicetus beneficus* and distribution into other provinces

Since the initial number of *A. beneficus* imported were low and no mass rearing has been established in PNG so far, further imports of *A. beneficus* are needed to establish a mass rearing and to distribute this parasitoid into other provinces of PNG.

It is recommended to establish pink wax scale populations on suitable host plants like

*Eugenia* spp. (Myrtaceae) in greenhouses at the research stations at Aiyura (Eastern Highlands Province), Bubia (Morobe Province) and at the National Agricultural Insect Collection (Kilakila, Central Province), in order to rear sufficient numbers of *A. beneficus* for releases and further research activities.

Establishment of this parasitoid in the other provinces has to be checked immediately on the next generation of *C. rubens* to determine a successful settlement. Parasitization levels should be determined several years after establishment to allow *A.beneficus* to settle and adjust to the specific conditions in the provinces.

### 6.8 Recommendations for future research activities

In order to assess the effectiveness of *Anicetus beneficus* in the control of *Ceroplastes rubens*, it is necessary to undertake the following research activities:

- Determine fertility rates of female *A. beneficus* in relation to the different development stages of the scale.
- Identify ratio of female to male parasitoids.

These studies have to be conducted in laboratory trials at Kilakila before the distribution into other provinces. The results should indicate how many scales are parasitised by a single female and which ratio is appropriate for a mass production of this parasitoid. The results should then be used as a guideline for other mass rearing centers and future field releases of *A. beneficus.*

- Identify hyperparasitoids settling on *A. beneficus* and the effect on parasitism.

To determine hyperparasitism, it is necessary to dissect pupae of *A. beneficus* for presence of other pupae, to rear and identify hyperparasitoids and compare the results from different provinces. This is important, since results showed that hyperparasitoids like *Coccidocnotus* were not present in the Central Province.

- Determine the effect of ants on the establishment of *A. beneficus*.

It is also necessary to check at different locations for ants visiting populations of *C. rubens* and assess their impact on parasitism by *A. beneficus*. Identify ants and compare results of parasitism, where there are populations of ants and where ants are absent.

## 6.9 Summary

A study was conducted in three provinces of Papua New Guinea to determine damage by the pink wax scale *Ceroplastes rubens* as well as to identify endemic parasitoids, parasitization levels, and to evaluate the necessity and possibility of a classical biological control with an introduced parasitoid.

*Seasonal history*
In the Central Province there are three generations of pink wax scales per year. The duration of the life cycle varies with the season, during rainy season (November to April) the generation requires about 2.5 – 3 months but it is longer during the dry season, lasting up to 5 months.

*Infestation levels*
The highest level of infestation of mango with the pink wax scale was recorded at one site in the Central Province with an average infestation of 6.40 %. Other levels were 6.31 %, 5.60 % and 3.82 %, respectively.

*Parasitization levels*
Levels of parasitization of vulnerable pink wax scale stages variied between 1.19 % and and 3.05 %.

*Endemic parasitoids*

In total 347 parasitoids emerged from pink wax scale samples. Species of the following genera were found as parasitoids of *Ceroplastes rubens*:

| | |
|---|---|
| *Aprostocetus* sp. | (Eulophidae) |
| *Cheiloneurus* sp. | (Encyrtidae) |
| *Coccidocnotus* sp. | (Encyrtidae) |
| *Coccophagus* sp. | (Aphelenidae) |
| *Diversinervus* sp. | (Encyrtidae) |
| *Metaphycus* sp. | (Encyrtidae) |
| *Microterys* sp. | (Encyrtidae) |
| *Moranila* sp. | (Pteromalidae) |

*Aprostocetus* sp. was most numerous but was only encountered at Erap in the Morobe Province and its status remains unclear. *Coccophagus* sp., *Metaphycus* sp., *Microterys* sp. and *Moranila* sp. were also found in higher numbers. Numbers of *Cheiloneurus* sp. and *Diversinervus* sp. were insignificant. The hyperparasitoid *Coccidocnotus* sp. was found in low numbers in the Morobe and Eastern Highlands Province only.

*Import of Anicetus beneficus (Hymenoptera, Encyrtidae)*

The pink wax scale parasitoid *Anicetus beneficus* was imported from Australia and released at four sites in the Central Province.

*Parasitization levels of C. rubens after the release of A. beneficus*

The parasitization levels recorded from two study sites six respectively twelve months after release showed that parasitization increased significantly, with *A. beneficus* being the most frequent parasitoid.

*The effect of ant attendance of C. rubens on the establishment of A. beneficus*

Workers of *Tapinoma* (Dolichoderinae) were frequently collected from infested trees at Laloki but were not present at Tahira.

It is assumed that their presence is partly responsible for the lower degree of parasitization and number of *A. beneficus* at Laloki.

*Mass rearing of A. beneficus and distribution into other provinces*

It is recommended to establish pink wax scale populations on suitable host plants like *Eugenia* spp. in greenhouses at the research stations in different provinces of PNG in order to rear sufficient numbers of *A. beneficus* for releases and further research activities.

*Future research activities*

To achieve an efficient control of *C. rubens* by *A. beneficus* in PNG the following research activities have to be undertaken:

- Determine fertility rates of female *A. beneficus* in relation to the different development stages of the scale.
- Identify ratio of female to male parasitoids.
- Determine bivoltine behaviour under PNG conditions.
- Identify hyperparasitoids settling on *A. beneficus* and the effect on parasitism.
- Determine the effect of ants on the establishment of *A. beneficus* at other sites.

# 7. Studies on the biology of the red banded mango caterpillar *Deanolis sublimbalis* Snellen (Lepidoptera, Pyralidae) and its natural enemies

## 7.1 Introduction and objectives

The first records of the red banded mango caterpillar (RBMC) *Deanolis sublimbalis* Snellen (Lepidoptera: Pyralidae, Odontinae) in Papau New Guinea (PNG) date back to 1936 when specimens were collected at Kokoda in the Oro Province and it was recorded again in 1959 and 1963 in the Western Province and Port Moresby, respectively. It is nowadays widely distributed throughout the mainland and islands of PNG.

Although infestation levels of 40 – 50 % were recorded in the Philippines (Tipon, 1979) and greater than 20 % in the Port Moresby area (PNG) (Waterhouse, 1998), very little is known on the biology of this pest, and there are only few references to it in the literature. A review by Waterhouse (1998) showed 19 literature references in regard to RBMC but only a few contained information on the population dynamics, life history and control measures, and the results presented differ significantly.

In India, Sengupta & Behura (1955, 1957) recorded pupation inside the fruit, while in the the Philippines larvae were reported to pupate in earthern cocoon covered with soil particles (Golez, 1991). So far, RBMC has only been recorded from *Mangifera indica*, *M. odorata*, *M .minor* and *Bouea burmanica* but it is not known if this pest attacks other hosts, in particular when mangos are not in season (Peña & Mohyuddin, 1997).

Only a few natural enemies of RBMC are known and no specific data are available on parasititization and predation levels and only one study dealt with a chemical control of this pest.

In order to develop an effective managament strategy for *D. sublimbalis,* it is essential to collect more information on the seasonal history of this pest, to search for natural enemies and to determine whether any of them are likely to be promising for biological control (Waterhouse, 1998).

The following study was therefore undertaken to obtain the basic information required for the development of an appropriate management technique for this pest. In particular, the objectives of this study were:

- The determination of infestation levels of *Mangifera indica* with *D. sublimbalis* in the Central Province of PNG.
- To study life history and behaviour of *D. sublimbalis*
- To search for other host plants of *D. sublimbalis*
- To identify natural enemies and evaluate their effectinevess in controlling *D. sublimbalis*.

## 7.2 Literature review

### 7.2.1 *Deanolis sublimbalis* Snellen

*Deanolis sublimbalis* was first described by Snellen in 1899 from specimens collected in Celebes (Sulawesi) (Indonesia). It was long known as *Noorda albizonalis* Hampson 1903 or *Autocharis albizonalis* (Hampson) but was revised to *D. sublimbalis* because of the priority of the description by Snellen (Waterhouse, 1998).

***Geographical distribution***

*D. sublimbalis* is a southeast Asian insect species. It is believed to have evolved in the India-Burma region, since this is regarded as the origin of *M. indica* (Waterhouse, 1998). It is now widely distributed throughout this region (India, Burma, Thailand, China, Brunei, Philippines, Indonesia and Papua New Guinea) and recently detected for the first time on mainland Australia but so far has not been recorded in Pakistan, Nepal and Malaysia.

***Host range***

In addition to being recorded from *M. indica*, *D. sublimbalis* has also been recorded from from *M. odorata* and *M. minor* in PNG and from *Bouea burmanica* in Thailand (Waterhouse, 1998; Beller & Bhenchitr, 1936). All species belong to the family Anacardiaceae. Golez (1991a) tested the fruits of cashew, chico, jackfruit, papaya, santol, sineguela and star apple for suitability as alternate hosts but all specimens died within the first larval stage except cashew, which is also in the Anacardiaceae family, where larvae survived up to the third instar.

***Morphology***

The full grown *D. sublimbalis* larva is about 2 cm long and brightly banded in white and dark red with a blackish head and tail. A change in colour to bright green indicates the pre-pupal stage. The forewings of the adult moth are greyish in colour and about 15 mm long with a sharply marked darker fawn outer border. The hindwings are similar in colour but more transparent (Fenner, 1987). The dorsal thorax and abdomen are brown with yellow markings. The ventral sides of the head, thorax, palpi and tarsi are shining white (Fenner, 1987). The adult male can be distinguished from the female by having an expanded dark brown hairy tibia of the mesothoracic leg (Golez, 1991a).

***Biology***

Eggs of the RBMC are oval, 3 – 4 mm in size and waxy white. They are laid in groups from one to four eggs near the apex of the fruit and sometimes laid under the sepals or in small crevices in the fruit (Fenner, 1987; Golez, 1991a). Oviposition occurs from 55 days after flower induction and continues throughout the season (Golez, 1991a). The larvae hatch after an incubation period of 3 to 4 days and pass through five instars within 14 to 20 days. Newly hatched larvae stay together and bore into the fruit near where the eggs were laid. If later instar are crowded and competing for food and space, some leave by suspending themselves on silken threads, facilitating the transfer to other fruits, and also to the litter and soil where the pupation takes place (Waterhouse, 1998). First and second instars feed on the pulp and later stages in the seed. As many as 11 first instars may be found in a single fruit, although in later stages there is commonly only one larvae per fruit.

As a result of the feeding, liquid exudes from the skin at the mouth of the tunnel and accumulates at the tip of the fruit. It darkens quickly and shows up as a black conspicuous spot (Fenner, 1987). Infected fruits burst at the apex and have longitudinal cracks. Mango fruits of all sizes are attacked, which often leads to a premature fruit drop.

The larval stage is followed by a pre-pupal stage lasting about 2 to 3 days with pupation taking place inside earthen cocoons or in debris under the tree (Golez, 1991a). Studies in India, however, showed that the larvae generally pupate in the fruit, with the adult moth emerging through the borehole (Sengupta & Behura, 1955, 1957). The pupal stage lasts from 9 to 14 days. Adult lives for about 9 days so that life cycle varies between 28 and 40 days. The adults are nocturnal and spend most of the day resting on leaves in the trees (Golez, 1991a). They are only seldomly attracted to artificial light sources (Fenner, 1987).

**Figure 19:** Fully grown larva ( ca. 2 cm in length) of *Deanolis sublimbalis* (Lep., Pyralidae) in mango fruit

#### 7.2.1.1 Infestation levels and yield reduction

There is very little data available on infestation levels of mango with the RBMC. In the Philippines, Tipon (1979) recorded a reduction in yield of about 40 to 50 % in years of serious infestation. Golez (1991a) recorded fruit infestation up to 12.5 % in the Guimaras Province in the Philippines. In Papua New Guinea infestation levels of more than 20 % were observed around Port Moresby (Waterhouse, 1998).

#### 7.2.1.2 Natural enemies

Leefmans & van der Vecht (1930) recorded no parasitoids in their studies on RBMC in Java. Golez (1991a) recorded the egg parasitoids *Trichogramma chilonis* and *T. chilotreae* (Hym., Trichogrammatidae) parasitoids in the Luzon Province but no parasitoids were detected samples taken in the Guimaras Province (Philippines) with dry, dusty and windy conditions. The evaniid *Evania appendigaster* (Hym., Evaniidae) was reared as larval/pupal parasitoid (Golez, 1991b) but Fenner (1997) points out that this needs further confirmation, since Evaniidae are known as parasitoids of cockroach eggs. *Carcelia* sp. (Diptera, Tachinidae) was reared as a larval parasitoid of RBMC at Rabaul (PNG) (Waterhouse, 1998).

The larvae become susceptible to predation as they leave the fruit in order to pupate in the soil (Golez, 1991). The vespid *Rhychium attrisium* was identified as the most important predator in the Guimaras Province (Philippines) Golez (1991a), contributing to the high percentage of larval disappearance in the field. The wasp is abundant in summer on warm and sunny days.

In laboratory trials in Indonesia larvae were attacked by a fungus (Leefmans & van der Vecht, 1930).

**Table 37:** List of recorded predators and parasitoids of *Deanolis sublimbalis*, (Waterhouse, 1998).

| Species | Location | Reference |
|---|---|---|
| *Carcelia* sp.<br>Dipt., Tachinidae | Rabaul, (PNG) | Waterhouse, 1998 |
| *Trichogramma chilonis*, *Trichogramma chilotreae*<br>Hym., Trichogrammatidae | Philippines | Golez, 1991a |
| ***Evania appendigaster***<br>Hym., Evaniidae | Philippines | Golez, 1991b |
| ***Rhychium attrisium***<br>Hym., Vespidae | Philippines | Golez, 1991b |

#### 7.2.1.3 Chemical control

Golez (1991a) tested five insecticides at recommended rates for their suitability as control agents of RBMC. The insecticides were applied at 60, 75, 90 and 105 days after fruit induction. The most effective insecticides used were deltamethrin and cyfluthrin followed by azinphos-ethyl and fenvalerate. Carbaryl was least effective.

## 7.3 Material and methods

### 7.3.1 Infestation levels of mango fruits with *Deanolis sublimbalis*

Monitoring of the damage by RBMC was done approximately every 10 days throughout the mango fruiting. Samples were taken in 2000 from the orchards in Laloki, Launakalana and PAU and in 2001 from the Tahira orchard.

On each monitoring date 15 trees per orchard were randomly choosen and 30 fruits per tree were checked for the presence of RBMC – boreholes; at Laloki due to the small number of trees only 6 trees were randomly picked at each date.

### 7.3.2 Studies on the seasonal history and biological behaviour

#### 7.3.2.1 Oviposition

Fruits, leaves and twigs were regularly checked for oviposition sites and number of eggs laid during the 2001 season at Laloki, PAU and Tahira.

#### 7.3.2.2 Pupation sites

***Soil and Litter***

The upper layer of soil (5 cm) and the litter under two heavily infested trees at Tahira and one at Laloki were checked on a monthly basis from October to December 2001 during mango fruiting for the presence of pre-pupae and pupae of *D. sublimbalis*. At each sampling time, ten $m^2$ around each tree were randomly choosen by placing a frame (1 x 1 m) on the surface. The covered area was then searched for pupae of Lepidoptera. If found, pupae were taken into the laboratory and placed on a layer of sawdust in plastic vials (3.5 x 10cm) to allow emergence of adults.

***Fruits***

Fruits both on the tree or fallen were inspected visually for the presence of boreholes. Those with boreholes were examined for the presence of lepdiopteran pupae. If found, pupae were taken into the laboratory and placed on a layer of sawdust in plastic vials (3.5 x 10cm) to allow emergence of adults. Sampling was done on a regular basis during the 2001 mango season at Laloki, PAU and Tahira.

***Trees***

During the 2002 mango season the bark on the trunk and branches of infested trees at Tahira and Laloki were regularly checked for the presence of pre-pupae and pupae of *D. sublimbalis*. The pupal stages were collected and taken into the laboratory where they were placed in a layer of sawdust in plastic vials (3.5 x 10cm) to allow the emergence of adults.

#### 7.3.2.3 Behaviour during mango off-season

To study the behaviour during the period when there are no mango fruit on the trees, the bark on the trunk of infested trees at Tahira and Laloki were examined towards the end of the 2002 mango season for the presence of pre-pupae and pupae of *D. sublimbalis*. In total 100 pupation sites were located and marked, and again visited during off-season in March 2003 to check the cocoons for emergence holes of adult moths.

In addition, 100 prepupae and pupae were collected towards the end of the mango season 2002 and taken into the laboratory where they were placed on a layer of sawdust in plastic vials (3.5 x 10cm) to determine emergence of adults during off-season.

#### 7.3.2.4 General observations in the field

During the mango fruiting season, additional observations on the biology of *D. sublimbali*s were undertaken to answer the following questions:

1. Is there more than one RBMC borehole per fruit ?
2. On which part of the fruit are boreholes found ?
3. Is cracking of the fruit a typical sign of an RBMC attack ?
4. Is the black spot – an accumulation of liquid – at the bottom of the fruit a conspicuous symptom for a RBMC infested fruit ?
5. Does an infestation with RBMC cause premature fruitdrop ?

### 7.3.3 Determination of host plants other than *Mangifera*

#### 7.3.3.1 Field search

Fruits of the following trees were regularly monitored for boreholes and the presence of RBMC larvae during their fruiting seasons:

*Spondias* spp. (umbrella apple, yellow and purple mombins), Anacardiaceae

*Anacardium occidentale* L. (cashew), Anacardiaceae
*Syzigium* spp. (water apples), Myrtaceae

In addition, trees of *Mangifera minor* and *M. odorata* were visited to confirm earlier findings that these species are hosts for RBMC (Waterhouse, 1998).

#### 7.3.3.2 Laboratory trials (feeding study)

To determine the suitability of the fruits *Anacardium occidentale* L. and *Syzigium* spp. as alternate hosts for *D. sublimbalis*, transparent plastic boxes (12 x 6 cm) were filled with a 2 cm layer of sawdust, which had been previously sterilized. To allow ventilation, the top of the boxes were closed with insect gauze. Field collected 1$^{st}$- and 2$^{nd}$ instars of RBMC were placed in the boxes (5 larvae per box) and provided with fruits of the test plants. Hundred larvae were tested for each plant species. The survival rate was calculated on the basis of larvae pupated.

### 7.3.4 Natural enemies of *D. sublimbalis*

#### 7.3.4.1 Parasitoids

To identify larval/pupal parasitoids of RBMC, larvae were collected in the field and kept singely in transparent plastic vials (10 x 3.5 cm) in the laboratory at an average temperature of 24$^{o}$ C and 60 – 70 % relative humidity. The bottom of the vials was filled with a 2 cm layer of sawdust, which had been previously sterilized. To allow ventilation, the vials were closed with insect gauze. The vials were regularly observed for presence of parasitoids and larvae were reared to the adult stage. Pupae from which no adult moth emerged, were dissected and checked for parasitoids.

To identify egg parasitoids of RBMC, eggs were collected in the field and singely kept in the laboratory (24$^{o}$ C, 60 – 70 % RH) in glass vials (1 x 5cm) until hatching of the larvae or the emergence of parasitoids. The bottom of the vials was filled with moistened cotton wool to enhance parasitoid emergence and the mouth was closed with cotton wool to allow ventilation.

#### 7.3.4.2 Pathogens

To identify bacteria, fungi or viruses attacking RBMC, field collected larvae were kept in the laboratory using the same method as described for the idenfication of larval/pupal parasitoids and regularly checked for typical signs of viruses and bacteria attacks or the presence of fungal spores/mycelium.

#### 7.3.4.3 Predators

Predators were collected using the beating method and pitfall traps at Launakalana and PAU. In addition, visual observations were made when visiting the study sites. The detailed results have been presented and discussed in chapter 4.

### 7.3.5 Statistical analysis

The results were statistically analysed with ANOVA (1-way analysis of variance) and then tested for significance at LSD 5 % and 1 % with the f-test.

## 7.4. Results

### 7.4.1 Infestation levels of mango fruits with *Deanolis sublimbalis*

The lowest level of infestation (3.36 %) was recorded at Launakalana while the highest was found at Tahira with on average 23.18 % of the fruit with RBMC-boreholes (Table 38). Levels at PAU and Laloki were 4.71 % and 11.86 %, respectively. The statistical analysis showed significant differences at LSD 1 % between all results except for the comparison of PAU and Launakalana.

As Table 39 shows most of the trees examined at the PAU, Launakalana and Laloki sites were not infested and those that were infested had a very low level of infestation, only. However, two trees at Laloki were heavily infested with 33.33 % respectively 60 % of the fruit showing RBMC-boreholes. At Tahira the situation was different. Nearly every tree showed symptoms of an RBMC–attack and several trees were highly damaged with levels reaching 76.60 %.

Mango fruits in all stages of development were attacked but marble sized fruit were preferred sites for oviposition, and therefore more frequently attacked by RBMC larvae than mature fruits.

**Table 38:** Infestation levels of mango fruits with *Deanolis sublimbalis* at four orchards in the Central Province, PNG.

| Location | Collection Date | Number of fruit examined | Number of infested fruit | Infestation % |
|---|---|---|---|---|
| PAU | 17.8.2000 | 450 | 13 | 2.88 |
| | 1.9.2000 | 450 | 26 | 5.77 |
| | 11.9.2000 | 450 | 33 | 7.33 |
| | 15.9.2000 | 450 | 35 | 7.77 |
| | 29.9.2000 | 450 | 31 | 6.88 |
| | 13.10.2000 | 450 | 22 | 4.88 |
| | 20.10.2000 | 450 | 18 | 4.00 |
| | 1.11.2000 | 450 | 20 | 4.44 |
| | 10.11.2000 | 450 | 11 | 2.44 |
| | 22.11.2000 | 450 | 3 | 0.66 |
| **Total** | | **4500** | **212** | **Mean Value 4.71** |
| Launakalana | 5..9.2000 | 450 | 16 | 3.55 |
| | 20.9.2000 | 450 | 20 | 4.44 |
| | 27.9.2000 | 450 | 18 | 4.00 |
| | 5.10.2000 | 450 | 12 | 2.66 |
| | 12.10.2000 | 450 | 12 | 2.66 |
| | 2.11.2000 | 450 | 15 | 3.33 |
| | 22.11.2000 | 450 | 13 | 2.88 |
| **Total** | | **3150** | **106** | **Mean Value 3.36** |
| Laloki | 5.9.2000 | 150 | 12 | 8.00 |
| | 25.9.2000 | 150 | 34 | 22.66 |
| | 3.10.2000 | 150 | 14 | 9.33 |
| | 11.10.2000 | 150 | 21 | 14.00 |
| | 25.10.2000 | 150 | /8 | 5.33 |
| **Total** | | **750** | **89** | **Mean Value 11.86** |
| Tahira | 24.8.2001 | 450 | 122 | 27.11 |
| | 4.9.2001 | 450 | 177 | 39.33 |
| | 19.9.2001 | 450 | 110 | 24.44 |
| | 28.9.2001 | 450 | 73 | 16.22 |
| | 12.10.2001 | 450 | 82 | 18.22 |
| | 23.10.2001 | 450 | 62 | 13.77 |
| **Total** | | **2700** | **741** | **Mean Value 23.18** |

**Table 39:** Degree of RBMC infestation of mango trees at four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total |
| PAU | 17.8.2000 | 30/- | 30/- | 30/3 | 30/1 | 30/2 | 30/- | 30/- | 30/5 | 30/- | 30/- | 30/2 | 30/- | 30/- | 30/- | 30/- | 450/13 |
| | 1.9.2000 | 30/4 | 30/- | 30/- | 30/8 | 30/- | 30/- | 30/6 | 30/5 | 30/- | 30/- | 30/2 | 30/- | 30/1 | 30/- | 30/- | 450/26 |
| | 11.9.2000 | 30/3 | 30/9 | 30/2 | 30/7 | 30/- | 30/- | 30/- | 30/- | 30/7 | 30/- | 30/- | 30/- | 30/1 | 30/6 | 30/- | 450/33 |
| | 15.9.2000 | 30/- | 30/10 | 30/- | 30/- | 30/3 | 30/- | 30/- | 30/6 | 30/8 | 30/- | 30/4 | 30/- | 30/- | 30/2 | 30/2 | 450/35 |
| | 29.9.2000 | 30/- | 30/- | 30/- | 30/11 | 30/- | 30/- | 30/- | 30/12 | 30/- | 30/- | 30/5 | 30/- | 30/- | 30/- | 30/3 | 450/31 |
| | 13.10.2000 | 30/- | 30/- | 30/8 | 30/3 | 30/- | 30/- | 30/2 | 30/- | 30/3 | 30/- | 30/- | 30/- | 30/4 | 30/2 | 30/- | 450/22 |
| | 20.10.2000 | 30/2 | 30/- | 30/4 | 30/7 | 30/- | 30/- | 30/- | 30/5 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 450/18 |
| | 1.11.2000 | 30/- | 30/- | 30/2 | 30/4 | 30/- | 30/- | 30/5 | 30/- | 30/- | 30/- | 30/- | 30/6 | 30/- | 30/3 | 30/- | 450/20 |
| | 10.11.2000 | 30/3 | 30/- | 30/4 | 30/- | 30/2 | 30/- | 30/2 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 450/11 |
| | 22.11.2000 | 30/3 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 450/3 |
| | | | | | | | | | | | | | | | | | |
| Launakalana | 24.8.2000 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | --** |
| | 5.9.2000 | 30/2 | 30/- | 30/- | 30/7 | 30/- | 30/- | 30/4 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/3 | 30/- | 30/- | 450/16 |
| | 20.9.2000 | 30/4 | 30/3 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/6 | 30/4 | 30/- | 30/- | 30/- | 30/- | 30/3 | 30/- | 450/20 |
| | 27.9.2000 | 30/- | 30/- | 30/- | 30/- | 30/8 | 30/9 | 30/- | 30/1 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 450/18 |
| | 5.10.2000 | 30/2 | 30/- | 30/- | 30/4 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/5 | 30/1 | 30/- | 30/- | 30/- | 450/12 |
| | 12.10.2000 | 30/- | 30/- | 30/- | 30/- | 30/6 | 30/3 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/- | 30/3 | 450/12 |
| | 2.11.2000 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/7 | 30/2 | 30/1 | 30/- | 30/- | 30/3 | 30/- | 30/- | 30/2 | 30/- | 450/15 |
| | 22.11.2000 | 30/- | 30/4 | 30/- | 30/3 | 30/- | 30/- | 30/- | 30/- | 30/- | 30/3 | 30/- | 30/- | 30/3 | 30/- | 30/- | 450/13 |
| | | | | | | | | | | | | | | | | | |

[a] Values for the individual trees represent the number of the fruit with rbmc-boreholes out of thirty fruit examined per tree.
** No fruits present.

**Table 39 continued:** Degree of RBMC infestation of mango trees at four orchards in the Central Province, PNG.

| | | Mango tree sampled [a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Date | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total |
| Laloki | 11.9.2000 | 30/- | 30/5 | 30/7 | 30/- | 30/- | 30/- | | | | | | | | | | 150/12 |
| | 25.9.2000 | 30/- | 30/18 | 30/10 | 30/- | 30/- | 30/6 | | | | | | | | | | 150/24 |
| | 3.10.2000 | 30/5 | 30/4 | 30/- | 30/- | 30/- | 30/5 | | | | | | | | | | 150/14 |
| | 11.10.2000 | 30/7 | 30/- | 30/3 | 30/4 | 30/4 | 30/- | | | | | | | | | | 150/18 |
| | 25.10.2000 | 30/6/ | 30/2 | 30/- | 30/- | 30/- | 30/- | | | | | | | | | | 158/8 |
| | 1.11.2000 | -- | -- | -- | -- | -- | -- | | | | | | | | | | --** |
| | | | | | | | | | | | | | | | | | |
| Tahira | 24.8.2001 | 30/7 | 30/21 | 30/15 | 30/- | 30/8 | 30/19 | 30/12 | 30/5 | 30/- | 30/10 | 30/7 | 30/12 | 30/3 | 30/- | 30/2 | 450/122 |
| | 4.9.2001 | 30/4 | 30/2 | 30/9 | 30/8 | 30/14 | 30/23 | 30/8 | 30/25 | 30/16 | 30/7 | 30/3 | 30/14 | 30/22 | 30/18 | 30/4 | 450/177 |
| | 19.9.2001 | 30/10 | 30/6 | 30/4 | 30/12 | 30/13 | 30/- | 30/12 | 30/6 | 30/14 | 30/5 | 30/6 | 30/2 | 30/11 | 30/9 | 30/- | 450/110 |
| | 28.9.2001 | 30/8 | 30/7 | 30/4 | 30/3 | 30/- | 30/12 | 30/6 | 30/2 | 30/8 | 30/4 | 30/7 | 30/- | 30/8 | 30/4 | 30/- | 450/73 |
| | 12.10.2001 | 30/5/ | 30/7 | 30/3 | 30/4 | 30/3 | 30/15 | 30/4 | 30/12 | 30/5 | 30/- | 30/- | 30/8 | 30/- | 30/7 | 30/9 | 450/82 |
| | 23.10.2001 | 30/10 | 30/- | 30/4 | 30/3 | 30/7 | 30/- | 30/6 | 30/6 | 30/3 | 30/2 | 30/5 | 30/- | 30/- | 30/10 | 30/6 | 450/62 |

[a] Values for the individual trees represent the number of the fruit with rbmc-boreholes out of thirty fruit examined per tree.
** No fruits present.

### 7.4.2 Seasonal history and biological behaviour

#### 7.4.2.1 Oviposition

In total, 156 egg laying sites were found and their location on the tree and number of eggs were recorded. The eggs were laid in small crevices on the peduncle, on non fruiting vegetative branches close to the fruit, at the peduncle at the base of the fruit and in small crevices (preferably dried anthraknose spots) on the fruit itself. Marble sized fruit were preferred sites for oviposition, while only a few eggs were recorded on mature fruits. No eggs were recorded on the leaves. As Table 40 shows the majority of the eggs (69.87 %) were laid at the peduncle at the base of the fruit covered with dried sepals. Uncovered eggs laid at the same spot accounted for 17.95 %, while only a few were found at the other spots. Preferably eggs were laid in groups of two (Table 41), although single egg-laying and bigger egg masses (up to 14 eggs) were also recorded. Eggs are oval, 0.3 – 0.5 mm in size and covered with a waxy layer. They are white when freshly laid but turn pinkish when getting older.

**Table 40:** Oviposition sites of *Deanolis sublimbalis*

| Oviposition Site | No. of egg masses recorded | Percentage % |
|---|---|---|
| Base of peduncle covered with dried sepals | 109 | 69.78 |
| Base of peduncle (uncovered) | 29 | 18.59 |
| Peduncle | 9 | 5.77 |
| Non fruiting vegetative branch | 6 | 3.85 |
| Fruit | 3 | 1.92 |
| Total | 156 | 100 % |

**Table 41:** Sizes of egg masses of *Deanolis sublimbalis*

| No. of eggs per egg mass | No. of oviposition sites | Percentage % |
|---|---|---|
| 1 | 20 | 12.82 |
| 2 | 49 | 31.41 |
| 3 | 26 | 16.66 |
| 4 | 25 | 16.03 |
| 5 | 16 | 10.26 |
| 6 | 5 | 3.21 |
| 7 | 5 | 3.21 |
| 8 | 2 | 1.28 |
| 9 | 5 | 1.92 |
| 10 | 2 | 1.28 |
| 11 | 2 | 1.28 |
| 12 | -- | -- |
| 13 | -- | -- |
| 14 | 1 | 0.64 |
| Total | 156 | 100 % |

#### 7.4.2.2 Pupation sites

No pre-pupae or pupae of *D. sublimbalis* or any other lepidopteran species were found in the surface layer of soil or in the litter at either locations. One pupa was found in a litter pile with mango fruits, leaves and twigs but no adult emerged. An identification was therefore not possible. No pre-pupae or pupae of *D. sublimbalis* were found in the fruit.

Pre-pupae and pupae of *D. sublimbalis* were found in the bark on the trunks of every RBMC infested tree examined at both locations. To pupate, the larvae bored deep in to the bark (1-2 cm) and closed the entrance hole with chewed bark particles, which left them completely invisible. Other pupation sites were deep crevices in the bark. The identification was simple, since many of them were found in the pre-pupal stage, in which the larvae turn bluish.

#### 7.4.2.3 Behaviour during mango off-season

When the pupation sites were visited again in March 2002, no holes in the cocoons were visible. This indicates that none of the pupae had emerged as adult moths. Out of the 100 pupae taken into laboratory, no adult moth emerged during the off-season of mango.

#### 7.4.2.4 General observations in the field

RBMC larvae usually enter the fruit through one borehole, which is typically made into the lower half of the fruit. Boreholes close to the peduncle are not caused by RBMC but by another caterpillar, probably *Cryptoblabes* sp.

Cracking is not typical sign for a RBMC attack. Fruits cracking occurs in mature fruit, probably through physiological reasons before RBMC attack. Although the black spot at the bottom of the fruit – an accumulation of liquid – is associated with RBMC infestation, it is also caused by any insect piercing or boring into the fruit like the fruit piercing moth *Othreis fullonia* or *Cryptoblabes* sp.

The observations showed that RBMC attack does not necessarily result in a fruitdrop. In particular younger and therefore smaller fruits infested tend to remain on the tree and do not fall to the ground because of RBMC damage.

### 7.4.3 Determination of host plants other than *Mangifera*

#### 7.4.3.1 Field search

No larvae of *D. sublimbalis* have been found in the fruits of *Spondias* spp., *Anacardium occidentale* and *Syzigium* spp. In addition, no boreholes were found in any of the above species. *Bouea burmanica* does not occur in PNG and its geographical distribution is restricted to Burma, Thailand and China (pers. comm, E. Gideon, 2003). Fruits of the species *Mangifera minor* and *M. odorata* were attacked by RBMC.

#### 7.4.3.2 Laboratory trials (feeding study)

All larvae fed with fruits of *Syzigium* spp. did not complete metamorphosis and died within the larval stage. Five out hundred larvae supplied with cashew as a diet completed the larval stage and pupated.

### 7.4.4 Natural enemies of *D. sublimbalis*

#### 7.4.4.1 Parasitoids

In total 1355 larvae and 923 eggs were collected and no parasitoids emerged from these larvae and eggs.

#### 7.4.4.2 Pathogens

In total 547 larvae were collected in the field and kept in the laboratory to observe for possible attacks by pathogens. No signs of bacteria, virus or fungi infections were recorded in the larvae.

#### 7.4.4.2 Predators

The most abundant predator at each location was the weaver ant *Oecophylla smaragdina* but this species was not observed predating on eggs or larvae of *D. sublimbalis*. The same applies to ladybird beetles (Coccinellidae) which were collected by the beating method but were not observed feeding on RBMC (see chapter 4). Two vespids were seen in the PAU orchard but their status as predators of RBMC was not determined.

## 7.5 Discussion

### 7.5.1 Infestation levels of mango fruits with *Deanolis sublimbalis*

The results confirm the data of Waterhouse (1998) who reported RBMC infestation levels of more than 20 % in the Port Moresby area, and underline the importance of RBMC and the need for an appropriate control of this pest. It can be assumed that infestation levels are higher since infested fruit dropped to the ground were not taken into account.

The fact that most of the trees examined at PAU, Launakalana and Laloki had low levels of infestation or were not affected by RBMC indicates that spreading of this pest within an orchard is slow. The pest spreads on the tree first and from there on to other trees. The results from Tahira show once the pest is established within an orchard and if no effective control measures are taken, damage can be severe.

The infestation levels decreased towards the end of the season – mature fruits were far less attacked than marble sized ones. This is mainly due to the fact that smaller fruit do not provide sufficient food for the larva to develop. One single RBMC larva will infest therefore a number of smaller fruits before having developed in to the final instar (Golez, 1991a), while mature usuall fruit provide enough food for the larva to develop.

Other reasons for the preference of young fruits can be:

a. that adults leave the mango orchards at the end of the season and move to other host plants as which the results from host studies suggest, is unlikely or

b. that *D. sublimbalis* undergoes facultative diapause with numbers diminishing when the season finishes and less fruits are available for oviposition.

### 7.5.2 Seasonal history and biological behaviour

#### 7.5.2.1 Oviposition

Eggs of *D. sublimbalis* are very difficult to find in particular when laid under dried fruit sepals at the peduncle at the base of the fruit. Locating eggs at these spots requires close examination with forceps and hand lens. Where fruits hang together and show signs of RBMC attack, eggs will possibly be found only at one of these fruits. The infestation of the other fruits is done by larvae which leave the oviposited fruit due to competition for food and space.

The preferred oviposition site is at the base of the peduncle under dried sepals. This could also explain the absence of egg parasitoids, although this is more likely because RBMC is an introduced species in PNG with no natural enemies established.

The finding that marble sized fruits are preferred sites for oviposition has clearly to be related to the reason mentioned earlier – that *D. sublimbalis* undergoes facultative diapause with numbers diminishing towards the end of the season, when less fruits are available for oviposition.

#### 7.5.2.2 Pupation sites

The first trials were conducted to confirm the findings by Golez (1991a) in the Philippines and Sengupta & Behura in India (1955, 1957), who recorded pupae in the litter and soil and in the fruits, respectively. No pupae were found at any of these locations indicating that behaviour in the Philippines and India could differ from that in PNG. However, the observations that larvae pupate inside the bark or in deep crevices are supported by the recent results of Sujatha & Zaheruddeen (2002) from India who reported the same findings. Provided that *D. sublimbalis* is monophagous on mango, a pupation in the soil or in the fruit makes it difficult to explain what triggers the end of the diapause and occurrence of adults at the beginning of a new season. But it is safe to assume that the end of the diapause, when pupating in the bark, is iniated by physiological changes within the tree itself. In addition, during the rainy season flooding at the study sites was frequent thus reducing any survival chances of pupae in the soil and litter. Considering these facts, it has to be stated that pupae found in the litter and in the fruits were misidentified and not kept until the emergence of adult stages, which would have allowed an accurate identification.

### 7.5.2.3 Behaviour during mango off-season

The results that during the mango off-season no holes were observed in the cocoons and consequently no adult emerged support the hypothesis that *D. sublimbalis* is monophagous on mango in PNG. Otherwise empty cocoons should have been found, which would confirm emergence of adults during the mango off-season.

### 7.5.3 Determination of host plants other than *Mangifera*

The field search concentrated on plants belonging to the same family (Anacardiaceae) as mango and on water apples *Syzigium* spp. (Myrtaceae). In particular fruit of *Spondias* trees were regularly checked, since they start fruiting at the end of the mango season but even on trees close to mango no fruits with RBMC larvae were found.
In laboratory feeding trials all larvae fed with *Syzigium* died and only a few survived when fed with cashew. This shows that these trees are not hosts of *D. sublimbalis*.
In general, the results confirm the assumption that the genus *Mangifera* is the only host plant in PNG and that *D. sublimbalis* goes into diapause, when mango is not in season.

### 7.5.4 Natural enemies of *D. sublimbalis*

The result that no larval parasitoids have been found is in line with findings by Golez (1991a), who also recorded no larval parasitoids during studies in the Philippines. The only record comes from PNG, where one single *Carcelia* sp. (Tachinidae) was reared (Waterhouse, 1998). In this regard it has to be noted that larval/pupal parasitoids do not play an important role in the control of RBMC and fruitborers in general, since larvae bore into the fruit immediately after hatching, and in this concealed habitat they are less susceptible to parasitization.

Two egg parasitoids, *Trichogramma chilonis* and *T. chilotreae*, were recorded in the Philippines (Golez, 1991) but no parasitization levels were calculated, and no recommendations were made for further research on the control of *D. sublimbalis* with

Trichogrammatidae. It has therefore to be assumed that the author did not consider this species as important control agents of RBMC. Since no egg parasitoids were recorded in this study, it can be stated stated that parasitization of eggs is seldom and if, only at random. The low incidence can be related to the following reasons:

a. the oviposition site: hymenopteran parasitoids are unable to locate the eggs and
b. *D. sublimbalis* is an introduced species in both countries (PNG and Philippines) and no endemic parasitoids have established themselves on this pest.

The weaver ant *Oecophylla smaragdina* was the most frequent predator at each location but obviously not an important natural enemy of *D. sublimbalis*, since it was observed that on trees at Laloki and Tahira weaver ants were abundant but RBMC infestation was high. In addition, fruits with typical signs of RBMC were frequently recorded in the vicinity of smaller food nests of *O. smaragdina* again indicating that weaver ants are not efficient predators of RBMC. This ineffectiveness can be related to different daytime activities. According to B. Hölldöbler (pers. comm., 2002), *O. smaragdina* is mostly diurnal, while *D. sublimbalis* movement is probably nocturnal as no larvae were observed leaving the fruit during the day either to pupate or to move to other fruits.

## 7.6 Conclusion

The red banded mango caterpillar *Deanolis sublimbalis* proved to be a serious pest of mango in the Central Province of Papua New Guinea. With no effective natural enemies present and considering the fact high infestation levels have been reported from other countries, further research on biological, chemical and cultural control is urgently needed in order to reduce the occurrence of this pest.

## 7.7 Recommendations for the control of *D. sublimbalis*

To achieve an effective control of *D. sublimbalis*, high priority should be given to the following research activities:

***Search for natural enemies of D. sublimbalis within the centre of origin of M. indica***

Results from Indonesia (Leefmans & van der Vecht, 1930), the Philippines (Golez, 1991a) and from this study show that so far there are no efficient natural enemies of RBMC. Waterhouse (1998) noticed that the origin of *M. indica* is believed to be the India-Burma region and it might be inferred that *D. sublimbalis* evolved also within this region. This means that this pest is an introduced species to the regions where studies have been conducted and therefore only a few natural enemies are present.

Thus further research for antagonists (parasitoids, predators, fungi, bacteria and viruses) of RBMC should concentrate on the region of origin. If found and introduced to PNG, possible interactions between any parasitoids and predators of RBMC and *Oecophylla smaragdina* have to be investigated.

***Biological control***

Trichogrammatidae are very important egg parasitoids and worldwide used in the control of lepidopteran pests (Hassan et. al., 1984, Langenbruch & Hassan, 1984, Nagaraja, 1987, Klemm & Schmutterer, 1993). Although Golez (1991a) did not consider using the method of mass rearing and inundation of the species *Trichogramma chilonis* and *T. chilotraeae*, which were identified as egg parasitoids of RBMC, it is quite possible that this method will prove very effective in the control of RBMC. In Germany, the species *Trichogramma dendrolimi* and *T. cacoeciae* are commercially produced and successfully used in the control of the codling moth *Cydia pomonella*, which displays a life cycle similar to RBMC (Hassan et al., 1993). It is therefore recommended to utilize the mass rearing station of *Trichogramma* at Sulikon Farms in the Morobe Province of PNG, which has been established by an GTZ/DED/NARI – Project to combat the corn borer *Ostrinia furnacalis* – for the production of *T. chilonis* and/or *T. chilotreae*. The station facilities allow to produce a sufficient number of individuals for the conduct of laboratory and field trials.

***The effect of sticky bands around the tree trunks as barriers for RBMC – larvae***

Since the results show that larvae pupate in the bark of the tree trunks, field studies should be carried out to determine the effect of sticky bands on pupation. It is quite possible that these bands reduce pupation and emergence of adults. In addition, sticky bands would prevent infestation of trees with weaver ants, which could interfere with the establishment of possible natural enemies.

***Fruit bagging***

Fruit bagging – fruits are covered with paper bags - is a recommended method for smallholders in PNG to prevent attack by fruit flies and if applied at early fruit stage could also prevent attack by RBMC.

***Variety trials***

Studies should be carried out to investigate if there are preferred varieties for adult RBMC to oviposite. The planting of different varieties (early and late varieties) in one orchard should be avoided.

***Chemical control***

There is only a short period within the life cycle of the RBMC to achieve a good control with synthetic insecticides: the stage of the first instar between hatching from the egg and boring into the fruit.

The results on chemical control of RBMC in the Philippines provided by Golez (1991a) showed that four applications of pyrethroids like deltamethrin and cyfluthrin during the fruiting season were most effective in controlling this pest but important trial data like spraying equipment, trees per treatment, control treatment, RBMC reduction in % and in comparison to the control as well as statistical analyis are missing. This field trial is therefore not repeatable and the results cannot serve as a guideline for mango growers.

It is therefore necessary to undertake new and accurate laboratory and field trials to evaluate the efficiency of insecticides in the control of RBMC in order to develop an appropriate spraying programme. Since RBMC is polyvoltine, the spraying scheme should include insecticides of different groups to avoid resistance problems.

The development of a spraying programme applies in particular to Australian producers, who are threatened by an establishment of RBMC on this continent. In PNG, appropriate spraying equipment and a wide range of synthetic insecticides are not available. And, even more important, most of the mangos produced grow on large trees in the gardens of smallholders and subsistence farmers, which makes it impossible to cover the whole tree with the common knapsack sprayer.

Since effective biological measures are not known yet, it is recommended for local producers to apply cultural methods like fruit bagging and the use of sticky bands as barriers for larvae.

***Pheromone development***

Since it is very likely that *D. sublimbalis* produces a sex pheromone (Waterhouse, 1998), identification and synthesis would greatly enhance the monitoring of this pest.

## 7.8 Summary

A study was conducted at four sites in the Central Province of Papua New Guinea to determine infestation levels and biological behaviour of the red banded mango caterpillar *Deanolis sublimbalis* (RBMC) and to identify natural enemies for the development of potential biological control strategies.

*Infestation levels of mango fruits with D. sublimbalis*

The highest level of infestation was recorded at Tahira Plantation with on average 23.18 % of the fruits being damaged. The highest level recorded was 76.60 % at one tree. Average levels at other study sites variied between 3.36 % and 11.86 %.

*Oviposition sites*

The majority of the eggs are laid at the peduncle and covered with dried sepals but sometimes without the coverage. Occasionally they are found on the fruiting branch. Oviposition on the fruit is very seldom. Eggs are normally laid in small masses (2-4), althoug single eggs and bigger egg masses were also recorded. Eggs are oval, 0.3 – 0.5 mm in size and white when freshly laid but turn pinkish as they get older.

*Pupation sites*

No pre-pupae or pupae of were found in the upper layer of soil, in the leaf litter or fruit. Instead, pre-pupae and pupae were found in the bark itself or in deep crevices.

*Behaviour during mango off-season*

Pupation sites in the bark of infested trees were marked at the end of the 2002 mango season and again visited in March 2003 to determine an emergence of adult moths. No adult moths emerged out of the cocoons indicating that larvae undergo a diapause and *Mangifera* is the only host.

*Determination of host plants other than Mangifera*

In field studies, no larvae have been found in the fruits of *Spondias* spp., *Anacardium occidentale* L. and *Syzygium* spp., but *Mangifera minor* and *M. odorata* were confirmed as hosts for RBMC. In laboratory trials, all larvae fed with fruits of *Syzygium* died within the larval stage. Only five out of hundred larvae supplied with cashew as a diet completed the larval stage and pupated. This indicates again that *Mangifera* is the only host.

*Natural enemies*

No larval or egg parasitoids as well as insect pathogens were recorded. Two nest of vespids were encountered in one orchard but their role in the control of RBMC was not further investigated. The weaver ant *Oecophylla smaragdina* was the most frequent predator but did not play an important role in the control.

*Recommendations for further research*

The red banded mango caterpillar *Deanolis sublimbalis* proved to be a serious pest of mango in the Central Province of Papua New Guinea. With no effective natural enemies present, since it is not native to PNG, further research on biological, chemical and cultural control is urgently needed in order to reduce the occurrence of this pest. To achieve an effective control, the following research activities should be given high priority:

- Search for natural enemies in countries within the centre of origin of *M. indica.*
- The effect of sticky bands around the tree trunks as barriers for RBMC larvae.
- The effect of fruit bagging on oviposition and fruit infestation.
- Field trials to determine preferred varieties for oviposition.
- The development of an effective spraying programme with synthetic
- and biological insecticides.
- The detection and development of a sex pheromone.

## 8. The mango ecosystem in PNG

The ecosystem mango orchard can be characterised as an "unripe system" (van Emden, 1975). Without human interference it would finally develop to an ecosystem, which would be near to the natural habitat (Tischler, 1990). Such system, the culmination of a successive ecological development, is called the "stabilised final stage" or "climax" (Odum, 1983).

In Papua New Guinea (PNG), most of the mangos (*Mangifera indica*) are grown in household gardens. The cultivation in orchards/plantations is uncommon, and only recently a few mango plantations have been established on the mainland and the islands. It can therefore be stated that the mango orchards are still under development to a new part of PNG ecosystems. An increment of the species diversity is part of this process (van Emden, 1975). But there is also the risk that this excessive competition could have negative impacts on the stability of the system (Watt, 1965).
This process also implies that there is only a limited knowledge about the cultivation of mango in general and how to attain an "ecosystem mango orchard", which is suitable to PNG and sustainable. It is therefore imperative that growers, researchers and extension workers develop a thorough knowledge and understanding how to grow mango. A successful management of insect pests, pathogens and weeds is thereby a fundamental part of a sustainable production of mango in orchards and plantations.

However, in PNG only a few insecticides, fungicides and herbicides are available. They are expensive and often inadequate for the control of insect pests, fungi and weeds in mango, and in contradiction to a sustainable "ecosystem mango orchard" in PNG. Instead, biological and cultural control methods should be the preferred option.
In case of insect pests, most of the species in the South Pacific are not indigeneous and have been introduced (Stechmann, 1990). Since *M. indica* is not endemic to PNG, it is safe to assume that the majority of the insect pests of mango have also been introduced. Important natural enemies, which would have possibly kept the relevant pests under the economic damage threshold in the area of origin, are therefore missing. This allows, in

particular when mangos are grown in plantation form, the introduced species to develop into serious pests. However, the ecosystem "mango orchard" is still developing and chemical control with synthetic insecticides is usually not practised. As outlined before, this offers a situation not only an ideal for the classical biological control of *Ceroplastes rubens* but also of other introduced pests with no effective enemies present. If established, as it was the case with *Anicetus beneficus* show, they could significantly contribute to the control of the pest making insecticide treatments rarely necessary. If so, biological insecticides like neem should be preferred.

In case of pathogens, anthracnose (*Colletotrichum gloeosporioides*) is the major threat for local mango growers. The variety \`Kensington Pride\`, introduced from Australia, is moderatly susceptible to anthracnose and bacterial spot. In PNG, although, under more wet and humid conditions, this variety is heavily attacked by this fungus as experienced at the Launakalana orchard. Effective fungicides, which would control the fungus, are not available on the PNG market. Instead, an effective option for sustainable system is the distribution of varieties moderately resistant to this pest. Crane & Campbell (1994) reported that there are several varieties with these characteristics, including the variety ´Glenn\`, which has already been planted at several study sites in PNG.

A feature of many introduced weeds has been the speed at which they have occupied suitable habitats throughout the islands of PNG (Henty & Pritchard, 1982). As so, the introduced species *Rottboellia exaltata* (Poaceae) and *Cyperus rotundus* (Cyperaceae), have already been collected from mango orchards in the Central Province. A regular control of these weeds is necessary but difficult to achieve with herbicides and their use should not be promoted. Instead, a suitable option for PNG growers is regular cutting and cultivation during hot and dry weather.

Applying these measures and recommendations will result in a high quality of fruit at lower cost. It will also be kinder to the environment, healthier and safer for farmers and, eventually, lead to a sustainable "ecosystem mango orchard" in PNG.

## 9. Abstract

***Studies on epigeal and arboreal and predatory arthropods in two mango orchards in the Central Province of Papua New Guinea***

Predatory arthropods were studied by the beating method and pitfall trapping in two mango orchards in the Central Province of Papua New Guinea (PNG). Both orchards were not sprayed with synthetic insecticides during or before the study period. Formicidae were the most numerous group within the epigeal and the arboreal arthropods (2772 and 2269 ind., respectively). The weaver ant, *Oecophylla smaragdina*, was the most abundant species within the arboreal arthropods. *Pheidole* spp. was most frequent in pitfall traps. Spiders were the second most numerous group (524 and 619 ind., respectively). Lycosidae were predominant in pitfall traps and Salticidae in net catches with the beating method on the trees. In the barber traps, Carabidae and Staphylinidae were only present in low numbers (47 ind.). Coccinellidae were the most numerous family within the arboreal predatory beetles (89 ind.). *Telsimia* sp. accounted for 63 % of the ladybird beetles. Crickets were frequently collected in pitfall traps (187 ind.).

***A survey on the occurrence and importance of mango pests in the Central Province of Papua New Guinea***

A survey was conducted at four sites in the Central Province of Papua New Guinea to determine the abundance and importance of nine insect pests in mango. The pests, except fruit flies which were monitored by fallen fruits, were monitored three times during 2002 according to their occurrence within the mango season. Out of these pests, the white mango scale *Aulacaspis tubercularis*, (Homopt., Diaspididae), the mango leafminer *Acrocercops* spp. (Lep., Gracillariidae), the leafhoppers *Idioscopus clypealis* and *I. niveosparsus* (Homopt., Cicadellidae), the soft scales *Saissetia* sp. and *Parasaissetia* sp. (Homopt., Coccidae) and the fruit fly *Bactrocera frauenfeldi* (Dip., Tephritidae) proved to be serious pests. Appropriate control measures, in particular biological and cultural methods, are proposed. Infestation levels with fruit piercing moths *Othreis fullonia, O. materna*, *Eudocima salaminia* (Lep., Noctuidae), aphids *Toxoptera odinae* (Homopt., Aphididae), blossom feeders *Cosmostola* sp., *Gymnoscelis* sp., *Nanaguna breviuscula*

(Lepidoptera) and planthoppers *Colgaroides acuminata*, *Colgar* sp., *Scolypopa* sp. (Homopt., Flatidae, Ricaniidae) were lower. Appropriate control measures are recommended but not immediately required.

***On the biological control of Ceroplastes rubens (Homopt., Coccidae) with the introduced parasitoid Anicetus beneficus (Hym., Encyrtidae)***

A study was conducted in three provinces of Papua New Guinea to determine damage by the pink wax scale *Ceroplastes rubens* and to identify endemic parasitoids and parasitization levels in order to evaluate the necessity and possibility of a classical biological control with an introduced parasitoid. Infestation levels with the pink wax scale variied 3.82 % and 6.40 %. The parasitization levels variied between 1.19 % and 3.05 %. Out of the nine endemic parasitoids identified, *Aprostocetus* sp. (Hym., Eulophidae) was the most frequent one. The pink wax scale parasitoid *Anicetus beneficus* (Hym., Encyrtidae) was imported from Australia and released at four sites in the Central Province in March/April 2002. The establishment was controlled at two sites six resp. twelve months after release. Parasitization levels increased significantly (from 3.05 % to 5.45 % at Laloki and from 2.04 % to 22.15 % at Tahira). At both sites, *A. beneficus* was the most frequent parasitoid. The parasitization process at the Laloki site was disturbed by the ant *Tapinoma* sp.

***Studies on the biology of Deanolis sublimbalis (Lep., Pyralidae) and its natural enemies***

A study was conducted at four sites in the Central Province of Papua New Guinea to determine infestation levels and biological behaviour of the red banded mango caterpillar *Deanolis sublimbalis* (RBMC). Eggs and larvae were collected to identify natural enemies and to develop potential control strategies. Infestation levels of mango fruits variied between 3.36 % and 23.18 %. The eggs are mainly found at the peduncle covered with dried sepals. Pupation takes place inside the bark of the mango tree. No other plants than *Mangifera* spp. were confirmed as hosts in laboratory and field studies. The pest goes into diapause during mango off-season. No egg or larval parasitoids were recorded. Control measures like sticky bands are an appropriate method to prevent pupation in the bark. A spraying scheme needs to be developed for commercial producers. It is further recommended to search for potential natural enemies in the centre of origin of *M. indica*.

# 10. Zusammenfassung

## 10.1 Untersuchungen zur Abundanz baumbewohnender und epigäischer Raubarthropoden in zwei Mangoplantagen in der Central Province von Papua Neu Guinea

Baumbewohnende und epigäische Raubarthropoden-Arten und deren Abundanz wurden anhand der Klopfmethode und mittels Barberfallen an zwei Standorten in der Central Province von Papua Neu Guinea bestimmt.
Dazu wurden während der Mango-Saison an jedem Standort die Barberfallen in einem Abstand von 2 Wochen jeweils 5x entleert. Zur gleichen Zeit erfolgte die Sammlung der baumbewohnenden Raubarthropoden. Dazu wurden je Standort 30 Bäume selektiert und je Baum 5 Zweige in ein Netz abgeklopft.

Die Gesamtindividuenanzahl in Barberfallen (3539) war höher als Fänge mit der Klopfmethode (2975).

**Epigäische Raubarthropoden** konnten folgenden Ordnungen bzw. Familien zugeordnet werden:

Coleoptera (Carabidae, Staphylinidae)
Hymenoptera (Formicidae)
Orthoptera (Gryllidae)
Dermaptera
Araneae
Chilopoda

Innerhalb der epigäischen Raubarthropoden stellten die Ameisen die größte Gruppe dar (2772 Ind.). Die Arten *Oecophylla smaragdina* und *Pheidole* spp. waren am häufigsten vertreten. Die erste Art ist räuberisch, während es innerhalb der Gattung *Pheidole* sowohl Prädatoren als auch Samenfresser gibt; eine Bestimmung bis zur Art ist daher erforderlich.

Spinnen stellten die zweitgrößte Gruppe dar (524 Ind.). Innerhalb dieser waren die Familien Lycosidae (Wolfsspinnen) (274 Ind.) und Linyphiidae (Baldachinspinnen) (80 Ind.) am häufigsten vertreten. Spinnen aus den Familien der Clubionidae, Gnaphosidae und Heteropodidae wurden regelmäßig gefangen, aber in erheblich geringerer Anzahl als die beiden erstgenannten Familien.

Die Anzahl der Carabiden und Staphyliniden war gering (47 Ind.). Die Anzahl der Staphyliniden war signifikant größer als die der Laufkäfer.
Die Anzahl der gefangenen Grillen war ca. 4 mal höher als die der Coleopteren.
Die Anzahl der Chilopoden (46) war nahezu identisch zu der Anzahl der räuberischen Käfer.

**Baumbewohnende Raubarthropoden** konnten folgenden Ordnungen bzw. Familien zugeordnet werden:

Coleoptera (Coccinellidae, Lycidae, Staphylinidae)
Dermaptera
Hymenoptera (Formicidae)
Heteroptera
Mantodea
Neuroptera
Araneae

Innerhalb der baumbewohnenden Raubarthropoden stellten die Ameisen die größte Gruppe dar (2260 Ind.). Die Weberameise *Oecophylla smaragdina* war am häufigsten vertreten (2087 Ind.). Zwölf weitere Gattungen, hauptsächlich aus den Unterfamilien Formicinae und Myrmicinae, wurden bestimmt, doch deren Individuenanzahl war äußerst gering.

Spinnen stellten die zweitgrößte Gruppe dar (619 Ind.). Innerhalb dieser Ordnung waren die Familien Salticidae (Springspinnen) (214 Ind.) und Theridiosomatidae (121 Ind.) am häufigsten vertreten. Spinnen aus den Familien Araneidae, Clubionidae, Linyphiidae und

Thomisidae wurden regelmäßig gefangen, aber in signifikant geringer Anzahl als die beiden erstgenannten Familien. Die Klopfmethode erwies sich als ungeeignet zur Sammlung großer, netzbildender Spinnen wie Araneiden.

Die Anzahl räuberischer Käfer war höher (89 Ind.) als in Barberfallen. Am häufigsten konnten Coccinelliden (79 Ind.) gefangen werden. Innerhalb dieser Familie war *Telsimia* sp. (50 Ind.) die dominante Art. *Telsimia* – Arten ernähren sich primär von Eiern und Nymphen von Diaspididen (Deckelschildläusen), aber attackieren auch Schild- und Blattläuse. Lycidae wurden als Adulte gefangen, sind aber nur im Larvenstadium räuberisch. Alle 6 Individuen gehören zur Gattung *Trichalus*.

Ohrwürmer (Dermaptera), räuberische Wanzen (Reduviidae und Nabidae) als auch Florfliegen (Neuroptera) und Mantodea (Fangschrecken) wurden nur in äußerst geringer Anzahl gefangen.

## 10.2 Untersuchungen zum Vorkommen von Mangoschädlingen und deren Bedeutung in der Central Province von Papua Neu Guinea

Das Vorkommen von Mangoschädlingen und deren Bedeutung wurde an vier Standorten in der Central Province von Papua Neu Guinea (PNG) untersucht. Jeder Schädling wurde entsprechend des jeweiligen Auftretens innerhalb der Mangosaison dreimal bonitiert. Je Standort wurden 15 Bäume selektiert und die Präsenz der Schadinsekten erfasst; am Standort Laloki aufgrund der geringeren Anzahl an Bäumen wurden jeweils nur 6 Bäume ausgesucht. Der Befall mit Fruchtfliegen wurde gesondert bonitiert.

1. Fruchtstechermotten (Lepidoptera)

   *Othreis fullonia* Clerk, *Othreis materna* Linnaeus, *Eudocima salaminia* (Cramer) (Noctuidae, Catocalinae)

Je Standort wurden pro Baum 30 Früchte untersucht. Die Schadhöhen variierten zwischen 1.62 % and 4.66 %. Dies zeigt, dass Fruchtstechermotten in der Central Province keine bedeutenden Schädlinge sind. In Provinzen mit höherem Regenfall und

Luftfeuchten sind stärkere Schäden zu erwarten, da die Larven feuchte Regenwaldstandorte bevorzugen.

2. Mango – Blütenfresser (Lepidoptera)

*Cosmostola* sp. near *laesaria* Walker (Geometridae, Geometrinae)

*Gymnoscelis* sp. near *imparatalis* Walker (Geometridae, Larentiinae)

*Gymnoscelis* sp. (Geometridae, Larentiinae)

*Nanaguna breviuscula* Walker (Nolidae, Sarrothripini)

Je Standort wurden pro Baum 5 Blütenstände untersucht. Die Schadhöhen variierten zwischen 43.55 % and 53.33 %. Es ist daher anzunehmen, dass diese Motten wichtige Schädlinge sind. Es muss jedoch berücksichtigt werden, dass der Verlust von Blüten auch von anderen Schädlingen wie Cicadelliden und von pathogenen Pilzen wie Anthraknose verursacht wird. Weitere Untersuchungen sind daher notwendig, um exakte Schäden und Verluste durch diese Schadinsekten zu bestimmen.

3. Mangoblattminierer

*Acrocercops* spp. (Lepidoptera, Gracillariidae)

Je Standort wurden pro Baum 25 Blätter untersucht. Die Schadhöhen variierten zwischen 18.04 % and 26.49 %. Bekämpfungsmaßnahmen sind erforderlich, sollten sich in PNG aber auf die Anwendung von Nützlingen konzentrieren. Larven und Puppen sind innerhalb des Blattes gegen Kontaktinsektizide geschützt. Systemisch aufgenommene Wirkstoffe, auch botanischer Art (Neem), können dagegen ausreichende Wirkung erzielen.

4. Weisse Mangodeckelschildlaus

*Aulacaspis tubercularis* Newstead (Homoptera, Diaspididae)

Je Standort wurden pro Baum 25 Blätter untersucht. Die Schadhöhen variierten zwischen 6.13 % and 18.22 %. Bekämpfungsmaßnahmen sind für den Standort Launakalana erforderlich. 1 % -ige Petroleumapplikationen sind in Australien empfohlen. Ein wirksamer Parasitoid wurde in Afrika entdeckt und könnte eingeführt werden.

5. Schildläuse

*Saissetia* sp., *Parasaissetia* sp. (Homoptera, Coccidae)

Je Standort wurden pro Baum 5 grüne, junge Zweige untersucht. Die Schadhöhen variierten zwischen 31.11 % and 46.66 %. Bekämpfungsmaßnahmen sollten sich auf die Eliminierung der Weberameise, *Oecophylla smaragdina*, richten, die diese Schildlauspopulationen zur Sammlung von Honigtau besucht. Im Gegenzug werden die Schildläuse gegen natürliche Feinde wie Prädatoren und Parasitoide geschützt. Eine wirksame Kontrolle durch endemische Nützlinge wird dadurch verhindert.

6. Mangoblattlaus

*Toxoptera odinae* (van der Goot) (Homoptera, Aphididae)

Je Standort wurden pro Baum 5 grüne, junge Zweige untersucht. Die Schadhöhen variierten zwischen 3.11 % and 24.88 %. Sofortige Bekämpfungsmaßnahmen sind nicht erforderlich, da die Schadschwellen in Höhe von 25 % (berechnet für australische Anbauer) nicht überschritten wurden. Weberameisen besuchten die Blattlauskolonien; regelmäßiges Monitoring ist daher erforderlich, um etwaige Anstiege der Blattlauspopulationen rechtzeitig zu erkennen.

7. Mangoblattzikaden

*Idioscopus clypealis* Lethierry, *I. niveosparsus* Leth.

(Homoptera, Cicadellidae)

Je Standort wurden pro Baum 5 Blütenstände untersucht. Die Schadhöhen variierten zwischen 50.22 % and 64.44 %. Diese Zikaden sind daher zu den wichtigsten Mangoschädlingen in der Central Province zu zählen. Eine Bekämpfung mit Insektiziden ist aufgrund der Vielzahl notwendiger Spritzungen und der gleichzeitigen Reduktion der Nützlingsfauna für PNG nicht zu empfehlen. Als kulturelle Maßname wird ein regelmäßiger Schnitt der Baumkronen empfohlen, da die Zikaden feuchte und schattige Seiten bevorzugen.

8. Mangobaumzikaden

*Colgaroides acuminata*, *Colgar* sp., *Scolypopa* sp.

(Homoptera, Flatidae, Ricaniidae)

Je Standort wurden pro Baum 5 grüne, junge Zweige untersucht. Die Schadhöhen variierten zwischen 10.66 % and 19.11 %. Bekämpfungsmaßnahmen sind nicht erforderlich, da die Schadschwellen in Höhe von 20 % (berechnet für australische Anbauer) nicht überschritten wurden.

9. Mangofruchtfliege

*Bactrocera frauenfeldi* (Schiner) (Diptera, Tephritidae)

Bei heruntergefallenen Früchten konnte ein Befall von 14 % bzw. 22.44 % festgestellt werden; bei Marktfrüchten war der Befall erheblich geringer (0.44 %). Das Eintüten der Früchte als auch der Einsatz von Lockstoff-Fallen sind geeignete Bekämpfungsmethoden. Zum Export von Obstfrüchten, ist eine Heisswasserbehandlung von Früchten notwendig, durch welche alle Stadien von Fruchtfliegen abgetötet werden.

## 10.3 Zur biologischen Bekämpfung der roten Schildlaus *Ceroplastes rubens* (Homopt., Coccidae) mit dem eingeführten Parasitoiden *Anicetus beneficus* (Hym., Encyrtidae)

Ziele der Untersuchungen waren folgende:

- Ermittlung der Schildlausgenerationen im Jahresverlauf.
- Ermittlung der Befallsstärken.
- Bestimmung der endemischen Parasitoide und Parasitierungsgrade.
- Prüfung der Möglichkeit einer klassischen biologischen Bekämpfung mit einem eingeführten Parasitoiden und Etablierung desselben.

Die Untersuchungen beeinhalteten Standorte in drei Provinzen von PNG.

*Jahreszyklus von C. rubens*

In der Central Province von PNG treten pro Jahr drei Generationen auf. Der Lebenzyklus ist jahreszeitenabhängig. Während der Regenzeit (November bis April) dauert dieser zwischen 2.5 und 3 Monaten, in der Trockenzeit bis zu 5 Monaten.

*Schadbefall*

Der höchste Befall (6.40 %) konnte an einem Standort in der Central Province festgestellt werden. Die Schadbefälle an den weiteren Standorten variierten zwischen 3.82 % und 6.31 %.

*Parasitierungsgrade*

Die Parasitierungsgrade der bevorzugten Schildlausstadien variierten vor der Einfuhr von *Anicetus beneficus* zwischen 1.19 % und 3.05 %.

*Endemische Parasitoide*

Insgesamt konnten 347 Parasitoide identifiziert werden, die folgenden Gattungen zugeordnet werden konnten:

| | |
|---|---|
| *Aprostocetus* | (Eulophidae) |
| *Cheiloneurus* | (Encyrtidae) |
| *Coccidocnotus* | (Encyrtidae) |
| *Coccophagus* | (Aphelenidae) |
| *Diversinervus* | (Encyrtidae) |
| *Metaphycus* | (Encyrtidae) |
| *Microterys* | (Encyrtidae) |
| *Moranila* | (Pteromalidae) |

*Aprostocetus* sp. war der häufigste Parasitoid, konnte aber nur am Standort Erap in der Morobe Provinz festgestellt werden. Identifizierung bis zur Art ist notwendig, da der Status (Primär- oder Hyperparasitoid) unklar ist. *Coccophagus* sp., *Metaphycus* sp., *Microterys* sp. und *Moranila* sp. konnten auch in größerer Anzahl bestimmt werden; die Anzahl von *Cheiloneurus* sp. und *Diversinervus* sp. war dagegen sehr gering. Der

Hyperparasitoid *Coccidocnotus* sp. konnte in geringer Anzahl in der Hochland- und der Morobe Provinz festgestellt werden, nicht aber in der Central Province.

*Die Einführung des roten Schildlausparasitoiden Anicetus beneficus*

*A. beneficus* wurde in 2002 aus Australien eingeführt und an mehreren Standorten mit je 200 bis 550 Individuen in der Central Province freigelassen.

*Parasitierungsgrade nach der Freilassung von A. beneficus*

An zwei Standorten konnte nach sechs als auch nach zwöf Monaten ein signifikanter Anstieg der Parasitierung von *C. rubens* festgestellt werden. *A. beneficus* war jeweils der häufigste Parasitoid.

*Der Einfluss von Ameisen auf die Etablierung von A. beneficus*

Arbeiterinnen von *Tapinoma* (Uf. Dolichoderinae) wurden am Standort Laloki häufig beim Besuch von *C. rubens* zur Sammlung von Honigtau beobachtet, nicht aber am Standort Tahira. Die geringeren Parasitierungsgrade am erstgenannten Standort sind höchstwahrscheinlich auf die Präsenz dieser Ameisen zurückzuführen.

*Empfehlungen zur Massenzucht und Freilassung von A. beneficus*

Der Wirt *C. rubens* ist auf geeigneten Wirtspflanzen wie *Eugenia* spp. (Myrtaceae) auf den landwirtschaftlichen Forschungsstationen in den verschiedenen Provinzen von PNG zu züchten, um sowohl die Ausbreitung von *A. beneficus* in anderen Landesteilen sicherzustellen als auch entsprechende Anzahl von Parasitoiden für weitere Versuche zur Verfügung zu haben.

*Empfehlungen für die weitere Forschung*

Zur Sicherstellung einer effizienten Kontrolle der roten Schildlaus durch *A. beneficus* sind folgende Versuche durchzuführen:

- Bestimmung der Parasitierungsrate von *A. beneficus* in Bezug auf die unterschiedlichen Entwicklungsstadien von *C. rubens*.
- Bestimmung des zur Aufzucht optimalen Geschlecherverhältnisses.

- Bestimmung des bivoltinen Verhaltens von *A. beneficus* unter den Bedingungen in PNG.
- Bestimmung der Hyperparasitoide und deren Einfluss auf die Parasitierungsleistung von *A. beneficus*.
- Bestimmung der Wirkung von Ameisen zur Ansiedlung und Parasitierungsleistung von *A. beneficus*.

## 10.4 Untersuchungen zur Biologie des Mangofruchtbohrers *Deanolis sublimbalis* (Lep., Pyralidae) und über dessen natürliche Feinde

Ziele dieser Untersuchungen waren folgende:

- Beschreibung der Biologie von *D. sublimbalis* (RBMC) in Papua Neu Guinea.
- Ermittlung der Befallsstärken und der Wirtspflanzen.
- Suche nach natürlichen Feinden.
- Entwicklung von Bekämpfungsstrategien.

Die Untersuchungen wurden an vier Standorten in der Central Province von PNG durchgeführt.

*Schadbefall von Mangofrüchten*

Der höchste durchschnittliche Befall (23.18 %) konnte am Standort Tahira verzeichnet werden; der höchste Einzelbefall lag bei 76.60 %. An den anderen Standorten variierte der durchschnittliche Befall zwischen 3.36 % und 11.86 %.

*Ort der Eiablage*

Die Mehrheit der Eier wird am Fruchtansatz unter getrockneten Blütenblättern abgelegt. Teilweise findet eine Eiablage ohne diese Bedeckung oder am Fruchstiel statt. Eine Ablage auf der Frucht konnte nur sehr selten festgestellt werden. Die Grösse der Eigelege beträgt in der Regel 2 – 4 Eier, obwohl auch eine Einzelablage als auch Gelege mit bis zu 14 Eiern festgestellt wurden. Die Eier sind anfänglich weisslich; im Laufe der Entwicklung wechseln sie aber die Farbe und werden rötlich.

*Ort der Verpuppung*

In den Früchten als auch im Boden und der bodennahen Auflage konnten keine Puppen von RBMC als auch anderer Lepidopteren festgestellt werden. Dagegen konnten die Puppen in Bohrlöchern in der Rinde als auch in tiefen Rindenritzen festgestellt werden.

*Verhalten ausserhalb der Mango – Saison*

Die Verpuppungsorte in der Rinde wurden markiert und ausserhalb der Mango – Saison auf Schlupflöcher von adulten Motten bonitiert. Es konnten keine Schlupflöcher festgestellt werden. Dieses Verhalten deutet darauf hin, dass *Mangifera* – Arten die einzigen Wirtpflanzen sind.

*Bestimmung weiterer Wirtspflanzen*

Ausser *Mangifera indica*, *M. odorata* und *M. minor*, konnten in Felduntersuchungen keine weiteren Wirtspflanzen verzeichnet werden. In Laboruntersuchungen starben alle Larven, die mit *Syzigium* gefüttert wurden und nur wenige überlebten eine Ernährung mit Cashew – Früchten als Nahrungssquelle. Diese Resultate und auch Ergebnisse anderer Untersuchungen zeigen, dass *Mangifera* – Arten  die einzige Wirtspflanzen sind.

*Natürliche Feinde*

Es konnten in den Untersuchungen weder Larval- oder Eiparasitoiden noch Insektenpathogene festgestellt werden. Die Weberameise, *Oecophylla smaragdina*, war der häufigste Prädator, spielte aber in der Bekämpfung von RBMC keine Rolle.

*Entwicklung von Bekämpfungsstrategien*

Der Mangofruchtbohrer *Deanolis sublimbalis* erwies sich als bedeutender Schädling im Mangoanbau in der Central Province von PNG. Da keine wirksamen natürlichen Feinde zur Verfügung stehen, sind weitergehende Forschungsarbeiten zur biologischen, chemischen und kulturellen Kontrolle von RBMC dringend notwendig. Diese sollten beinhalten:

- Die Suche nach natürlichen Feinden im Ursprungsgebiet von *M. indica*.
- Untersuchungen zur Wirkung von Leimringen.

- Untersuchungen zur Wirkung der Eintütens von Früchten.
- Feldversuche zur Feststellung der zur Eiablage bevorzugten Mangosorten.
- Entwicklung eines effizienten Spritzprogramms mit biologischen und synthetischen Insektiziden.
- Bestimmung und Entwicklung von Sexualpheromonen.

## 10.5 Das Mango – Ökosystem in PNG

Van Emden (1975) bezeichnete landwirtschaftliche Systeme wie Mango-Plantagen als unreife Systeme. Ohne menschliche Einwirkung würden sich diese Systeme zu einem Ökosystem entwickeln, mit einem für den jeweiligen Standort entsprechenden Bewuchs (Tischler, 1990). Ein solches System, als Folge einer sukzessiven Entwicklung, bezeichnet man auch als stabile Endgemeinschaft oder “Klimax” (Odum, 1983).

In Papua Neu Guinea (PNG) wächst der Grossteil der Mangobäume in den Gärten der einheimischen Bevölkerung; einen Anbau in Plantagenform gibt es erst seit wenigen Jahren und er ist bisher nur vereinzelt vorzufinden. Das Ökosystem \`Mangoplantage\` als Teil des Gesamtsystems in PNG befindet sich daher erst in der Entwicklung. Diese bezieht steigende Artendiversität ein (van Emden, 1975). Dadurch erhöht sich aber auch die Gefahr, dass eine übermässige Konkurrenz entsteht, die negativ auf die Stabilität wirkt (Watt, 1965).

Diese Entwicklungsphase bedingt zudem, dass bisher nur wenige Kenntnisse zum Anbau der Mango in Plantagenform im allgemeinen und zur Entwicklung eines Ökosystems \`Mango Plantage\` vorhanden sind, welches für die Verhältnisse in PNG geeignet und nachhaltig ist. Eine erfolgreiche Bekämpfung von Insektenschädlingen, Pathogenen, Ungräsern und Unkräutern ist dabei ein wichtiger Bestandteil.

Auf den Einsatz von synthetischen Pestiziden, die üblicherweise in der Schädlingsbekämpfung eingesetzt werden, sollte dabei aus folgendem Grund verzichtet werden: Pestizide sind teuer in PNG und diejenigen, die auf dem Markt erhältlich sind,

sind in der Regel breitwirksame Pestizide. Eine nachhaltige und ökonomische Bewirtschaftung des "Ökösystems Mango-Plantage" in PNG ist damit nicht zu verwirklichen.

Zur nachhaltigen Etablierung dieses Ökosystems ist die Anwendung biologischer und kultureller Bekämpfungsmassnahmen aus folgenden Gründen die geeignetere Alternative:

1. Laut Stechmann (1990) sind die meisten der Schadinsekten im Südpazifik nicht einheimisch. Da die Mango selbst nicht endemisch ist, ist davon auszugehen, dass die meisten der Schädlinge ebenfalls importiert worden sind. Wichtige natürliche Feinde, die die jeweiligen Schädlinge unter der ökonomischen Schadensschwelle halten können, fehlen daher. Daher können sich, wie im Fall von *Ceroplastes rubens* und *Deanolis sublimbalis*, die eingeführten Arten zu bedeutenden Schädlingen entwickeln. Eine klassische biologische Bekämpfung, d.h. die Nachfuhr eines Nützlings aus dem Ursprungsland des Schädlings, hat sich bereits im Fall von *C. rubens* mit dem eingeführten Parasitoiden *Anicetus beneficus* als sehr wirkungsvoll herausgestellt und sollte daher auch für die anderen Schadinseken in Mango die primäre Bekämpfungsmassnahme darstellen.

2. Im Fall von Krankheiten ist die Anthraknose, hervorgerufen durch den Pilz *Colletotrichum gloeosporioides*, die wichtigste Krankheit. In den Plantagen ist die australische Sorte `Kensington Pride`die am häufigsten angebaute, aber auch sehr anfällig gegenüber diesem Pilz. Aber auch hier stehen ökölogisch geeignetere Massnahmen als der Einsatz von Fungiziden zur Verfügung. Crane & Campbell (1994) berichten von mehreren Sorten, die eine Teilresistenz aufweisen. Die bereits in PNG zum Teil angebaute Sorte `Glenn` besitzt diese Eigenschaft und sollte daher bevorzugt werden.

3. Auch im Fall von Ungräsern und Unkräutern sind viele keine einheimischen Pflanzenarten. Henty & Pritchard (1982) berichten, dass ca. 35 % der Arten eingeschleppt worden sind. Die Arten *Rottboellia exaltata* (Poaceae) and *Cyperus rotundus*

(Cyperaceae) konnten bereits in den vorhandenen Mangoplantagen festgestellt werden. Auch hier wäre, unter den gegebenen Bedingungen, eine Bekämpfung mit Herbiziden ökologisch und ökonomisch nicht sinnvoll. Regelmässige Mahd ist dagegen die günstigere und sinnvollere Alternative.

Die Anwendung der vorgeschlagenen Massnahmen wäre ein wichtiger Schritt zur Etablierung eines nachhaltigens "Ökosystems Mango-Plantage" in PNG.

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**Appendix**

1. Aiyura Agricultural Research Station

Monthly Rainfall Data: 1981-1995 (Nr = not recorded)

| **Year** | **1981** | **1982** | **1983** | **1984** | **1985** | **1986** | **1987** | **1988** | **1989** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **Avg** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 272 | 383 | 312 | 77 | 291 | 281 | 374 | 149 | 222 | 280 | 315 | 233 | 297 | 225 | 265 | 265.07 |
| Feb | 302 | 262 | 217 | 65 | 221 | 176 | 74 | 216 | 213 | 155 | 398 | 365 | 201 | 108 | 253 | 215.07 |
| Mar | 127 | 340 | 190 | 302 | 128 | 180 | 254 | 197 | 194 | 104 | 136 | 295 | 136 | 237 | 388 | 213.90 |
| Apr | 279 | 219 | 125 | 164 | 188 | 241 | 177 | 70 | 256 | 179 | 99 | 286 | 150 | 294 | 144 | 207.30 |
| May | 40 | 169 | 250 | 219 | 100 | 76 | 75 | 82 | 218 | 147 | 100 | 133 | 91 | 249 | 144 | 139.53 |
| Jun | 151 | 154 | 160 | 63 | 97 | 143 | 38 | 143 | 66 | 167 | 68 | 71 | 107 | 77 | 87 | 106.13 |
| Jul | 100 | 23 | 49 | 101 | 100 | 44 | 71 | Nr | 58 | 79 | 83 | 107 | 81 | 106 | 65 | 71.13 |
| Aug | 168 | 74 | 132 | 98 | 107 | 96 | 5 | 137 | Nr | 110 | 146 | 106 | 24 | 160 | 72 | 95.67 |
| Sep | 130 | 31 | 78 | 60 | 150 | 82 | 46 | 126 | 55 | 275 | 367 | 34 | 32 | 94 | 109 | 111.27 |
| Oct | 94 | 80 | 209 | 253 | 170 | 79 | 24 | 0 | 233 | 177 | 445 | 122 | 176 | 55 | 122 | 149.27 |
| Nov | 162 | 108 | 208 | 150 | 242 | 199 | 101 | 122 | 153 | 209 | 219 | 52 | 185 | 112 | 166 | 159.20 |
| Dec | 352 | 163 | 227 | 382 | 111 | 90 | 174 | 171 | 141 | 237 | 253 | 306 | 437 | 202 | 338 | 238.93 |
| | | | | | | | | | | | | | | | | |
| **Tot** | **2177** | **2006** | **2157** | **1934** | **1905** | **1687** | **1413** | **1411** | **1808** | **2118** | **2307** | **2110** | **1917** | **1948** | **2392** | **1872.47** |
| **Avg** | **181** | **168** | **180** | **161** | **159** | **141** | **118** | **118** | **151** | **177** | **192** | **178** | **178** | **162** | **199** | **156.04** |

2. Pacific Adventist University

Monthly Rainfall Data: 1996 – 1998

| **Year** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1996 | 185 | 270 | 127 | 205 | 230 | 3 | 82 | 4 | 9 | 121 | 100 | 294 | 1630 |
| 1997 | 210 | 175 | 154 | 6 | 33 | 1 | 24 | 6 | 20 | 0.0 | 0.0 | 93 | 722 |
| 1998 | 198 | 222 | 275 | 119 | 132 | 2 | 53 | 5 | 14 | 61 | 50 | 194 | 1324 |
| Aver | 198 | 222 | 185 | 110 | 133 | 2 | 53 | 5 | 14 | 60 | 50 | 194 | 1225 |

3. Launakalana

Monthly Rainfall Data: 1999, 2000, 2002 (Nr = not recorded)

| **Year** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1999 | 93 | 116 | 164 | 203 | 159 | 32 | Nr | 118 | Nr | 109 | 96 | 166 |
| 2000 | 212 | 181 | 209 | 313 | Nr | 373 | 35 | 131 | 62 | 22 | 42 | 101 |
| 2002 | 31 | 150 | 42 | 20 | 27 | 165 | 156 | 41 | 33 | 198 | 79 | 9 |
| Aver | 112 | 149 | 138 | 179 | 93 | 221 | 91 | 97 | 48 | 110 | 72 | 92 |

4. Erap Agricultural Research Station

Monthly Rainfall Data: 1985 – 2002

| **Year** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 157 | 22 | 162 | 96 | 121 | 80 | 100 | 308 | 41 | 22 | 178 | 146 | 1433 |
| 1986 | 218 | 136 | 277 | 231 | 15 | 53 | 43 | 65 | 48 | 217 | 58 | 155 | 1516 |
| 1987 | 195 | 97 | 200 | 139 | 19 | 12 | 4 | 9 | 59 | 8 | 9 | 171 | 922 |
| 1988 | 239 | 173 | 178 | 104 | 28 | 41 | 116 | 105 | 100 | 156 | 28 | 106 | 1374 |
| 1989 | 133 | 222 | 154 | 157 | 101 | 109 | 10 | 43 | 48 | 40 | 77 | 278 | 1372 |
| 1990 | 179 | 71 | 121 | 270 | 53 | 80 | 47 | 45 | 94 | 75 | 133 | 137 | 1305 |
| 1991 | 267 | 245 | 120 | 93 | 48 | 79 | 51 | 52 | 94 | 77 | 132 | 137 | 1395 |
| 1992 | 124 | 191 | 178 | 118 | 76 | 4 | 235 | 132 | 8 | 62 | 78 | 133 | 1339 |
| 1993 | 198 | 86 | 80 | 45 | 4 | 98 | 49 | 9 | 23 | 2 | 100 | 289 | 983 |
| 1994 | 133 | 124 | 95 | 101 | 106 | 15 | 104 | 121 | 276 | 77 | 4 | 198 | 1354 |
| 1995 | 278 | 74 | 175 | 108 | 95 | 171 | 54 | 204 | 81 | 80 | 57 | 210 | 1587 |
| 1996 | 152 | 61 | 98 | 28 | 143 | 27 | 36 | 41 | 55 | 105 | 88 | 77 | 911 |
| 1997 | 28 | 145 | 50 | 43 | 22 | 2 | 38 | 40 | 57 | 104 | 89 | 76 | 694 |
| 1998 | 204 | 213 | 227 | 25 | 33 | 99 | 160 | 44 | 81 | 119 | 219 | 186 | 1610 |
| 1999 | 40 | 115 | 52 | 122 | 57 | 65 | 13 | 71 | 30 | 69 | 62 | 185 | 881 |
| 2000 | 235 | 89 | 205 | 34 | 140 | 167 | 190 | 172 | 18 | 74 | 106 | 275 | 1705 |
| 2001 | 31 | 132 | 106 | 77 | 24 | 147 | 98 | 46 | 30 | 4 | 71 | 161 | 926 |
| 2002 | 129 | 163 | 292 | 59 | 45 | 115 | 92 | 19 | 45 | 54 | 38 | 95 | 1146 |
| **Aver** | **162** | **128** | **153** | **100** | **63** | **76** | **80** | **85** | **66** | **75** | **85** | **166** | **1240** |

## Table ii: Arthropod pests in mango (*M. indica*) (Peña & Mohyuddin, 1997)

| Order | Family | Species | Geographical Distribution | Plant Part attacked |
|---|---|---|---|---|
| Acari | Eriophyidae | *Aceria mangiferae* (Sayed) | 9,10 | Bud |
| | | *Cisaberoptus kenyae* Keifer | 13 | Leaf |
| | | *Metaculus mangiferae* Ahiah | 1,6 | Bud |
| | Tarsonemidae | *Polyphagotarsonemus latus* (Banks) | 6 | Bud |
| | Tenuipalpidae | *Brevipalpus phoenicus* Geijkes | 6 | Leaf |
| | Tetranychidae | *Oligonychus coffeae* (Nietner) | 1 | Leaf |
| | | *O. mangiferae* Rahman & Sapra | 9,13 | Leaf |
| | | *O. punicae* (Hirst) | 2,8 | Leaf |
| | | *O. yothersi* McGregor | 6 | Leaf |
| | | *Tetranychus bimaculatus* Harv. | 8 | Leaf |
| | | *T. cinnabarinus* Bdv. | 13 | Leaf |
| | | *T. telarius* (L.) | 7 | Leaf |
| | | *T. tumidus* Banks | 6 | Leaf |
| Coleoptera | Bostrichidae | *Apate monachus* Boheman | 8 | Trunk |
| | Cerambycidae | *Batocera rubus* (L.) | 9 | Trunk |
| | | *B. rufomaculata* De Geer | 13 | Trunk |
| | | *Indarbela quadrinotata* (Walker) | 9 | Trunk |
| | | *Stenodontes downesi* (Hope) | 4 | Leaf |
| | | *Macrotoma* spp. | 4 | Trunk |
| | | *M. scutellaris* Germar | 13 | Trunk |
| | Chrysomelidae | *Bassereus brunipes* | 6 | Leaf |
| | | *Crimissa cruralis* Stal | 4 | Leaf |
| | | *Diabrotica balteata* LeConte | 6 | Leaf |
| | | *Monolepta lepida* Reiche | 13 | Leaf |
| | Curculionidae | *Anthonomus* sp. | 8 | Bud |
| | | *Artipus floridanus* Horn | 6 | Leaf |
| | | *Deporaus marginatus* Pascoe | 9 | Leaf |
| | | *Diaprepes abbreviatus* (L.) | 9 | Leaf |
| | | *Pachneus* spp. | 6 | Leaf |
| | | *Rhynchaenus mangiferae* Marshall | 9 | Leaf |
| | | *Sternochetus mangiferae* (F.) | 1,4,5,7,8,9,10 | Fruit |
| | Scarabeidae | *Cotinis nitida* (L.) | 6 | Flower |
| | | *Euphoria sepulcralis* (L.) | 6 | Flower |
| | | *E. limbata* (L.) | 6 | Flower |
| | | *Macraspis* sp. | | Leaf |
| | | *Phyllophaga* sp. | | Leaf, root |
| | Scolytidae | *Hypocryphalus mangiferae* St. | 4,6 | Trunk, root |
| | | *Stephanoderes* spp. | 6 | Trunk |
| | | *Xyleborus saxesini* Eichoff | 6 | Fruit |
| | Tenebrionidae | *Epitragus* sp. | | Leaf |
| Diptera | Cecidomyiidae | *Dasineura amaramanjae* Grover | 9 | Bud |
| | | *Procontarinia matteiana* K. & S. | 9 | Leaf |

| Order | Family | *Species* | Geographical Distribution | Plant Part attacked |
|---|---|---|---|---|
| Diptera | Cecidomyiidae | *P. mangiferae* Grover | 3,7 | Leaf |
| | | *P. schreineri* Harris | 10 | Leaf |
| | | *Erosomyia indica* Grover & Prased | 9 | Flower |
| | | *E. mangiferae* Felt | 8 | bud |
| Diptera | Loncheidae | *Lonchaea* sp. | 4 | Fruit |
| Diptera | Tephritidae | *Anastrepha* spp. | 4 | Fruit |
| | | *A. distincta* Greene | 4 | Fruit |
| | | *A. fraterculus* (Wiedemann) | 4 | Fruit |
| | | *A. ludens* (Low) | 2,4 | Fruit |
| | | *A. obliqua* (Macquart) | 8 | Fruit |
| | | *A. pseudoparalella* (Loew) | 4 | Fruit |
| | | A. serpentina (Wiedemann) | 2,4,6 | Fruit |
| | | *A. striata* Schiner | 2,4,6 | Fruit |
| | | *A. suspensa* (Loew) | 2,6 | Fruit |
| | | *Bactrocera aquilonis* (May | 1 | Fruit |
| | | *B. carveae* (Kapoor) | 7 | Fruit |
| | | *B. correcta* (Bezzi) | 7 | Fruit |
| | | *B. cucurbitae* (Coquillett) | 7,9 | Fruit |
| | | *B. dorsalis* (Hendel) | 7 | Fruit |
| | | *B. facialis* (Coquillett) | 10 | Fruit |
| | | *B. frauenfeldi* (Schiner) | 1,7,10 | Fruit |
| | | *B. froggatti* (Bezzi) | 10 | Fruit |
| | | *B. incisa* (Walker) | 7,10 | Fruit |
| | | *B. kirki* (Froggatt) | 10 | Fruit |
| | | *B. latifrons* (Hendel) | 7 | Fruit |
| | | *B. melanota* (Coquillett) | 10 | Fruit |
| | | *B. neohumeralis* (Hardy) | 1 | fruit |
| | | *B. occipitalis* (Bezzi) | 7 | Fruit |
| | | *B. opiliae* (Drew & Hardy) | 1 | Fruit |
| | | *B. passiflorae* (Froggatt) | 10 | Fruit |
| | | *B. psidii* (Froggatt) | 10 | Fruit |
| | | *B. trilineola* Drew | 10 | Fruit |
| | | *B. tryoni* (Froggatt) | 10 | Fruit |
| | | *B. tuberculata* (Bezzi) | 7 | Fruit |
| | | *B. versicolor* (Bezzi) | 7 | Fruit |
| | | *B. zonata* (Saunders) | 7,9,10 | Fruit |
| | | *Ceratitis anonae* Graham | 3 | Fruit |
| | | *C. capitata* (Wiedemann) | 12,13 | Fruit |
| | | *C. catoirii* Guerin-Meneville | 3 | Fruit |
| | | *C. cosyra* (Walker) | 5 | Fruit |
| | | *C. flexuosa* (Walker) | 3 | Fruit |
| | | *C. rosa* Karsch | 3 | Fruit |
| | | *Dirioxa confusa* (Hardy) | 1 | Fruit |
| | | *D. pornia* (Walker) | 1 | Fruit |
| | | *Cochliomya macellaria* (Fabricius) | 6 | Bud |
| | | *Toxotrypana curvicauda* Gerst. | 2,4,6,8 | Fruit |
| Hemiptera | Coreidae | *Amblypelta lutescens* (Distant) | 1 | Fruit |
| | | *A. nitida* Stal | 1 | Fruit |
| | | *Pseudotherapterus wayi* Brown | 3 | Fruit |
| | | *Veneza stigma* (Herbert) | 4 | Fruit |

| Order | Family | *Species* | Geographical Distribution | Plant Part attacked |
|---|---|---|---|---|
| Hemiptera | Miridae | *Daghbertus fasciatus* (Reuter) | 6,8 | Bud |
| | | *Rhinacloa* spp. | 6,8 | Bud |
| | Pentatomidae | *Brochymena* sp. | 6 | Leaf |
| | | *Plautia affinis* Dallas | 1 | Leaf |
| | | *Stenozygum coloratum* (Klug) | 13 | Fruit ? |
| | Scutelleridae | *Symphillus caribbeanus* Kirk. | 6,8 | Fruit |
| Homoptera | Acanalonidae | *Acalonia latifrons* (Cockerell) | 6 | Bud, fruit, leaf |
| | Aleyrodidae | *Aleurocanthus woglumi* (Asby) | 2,4,5,6 | Leaf |
| | | *Aleurodicus dispersus* Russell | 6 | Leaf |
| | Aphididae | *Aphis craccivora* Koch | 13 | Leaf |
| | | *A. fabae* Scopoli | 13 | Leaf |
| | | *A. gossypii* Glover | 13 | Leaf |
| | | *A. spiraecola* Patch | 13 | Leaf |
| | | *Toxoptera aurantii* B. & F. | 6,8 | bud, fruit |
| | Asterolecanidae | *Asterolecanium pustulans* Cockerell | 6,13 | Leaf |
| | Cicadellidae | *Amrasca splendens* Ghauri | 1,3,7,9 | Leaf |
| | | *Amritodus atkinsoni* Leth. | 9 | Leaf |
| | | *A. brevistylus* Viraktamah | 9 | Leaf |
| | | *Busoniomimus manjunathi* Virak. | 9 | Leaf |
| | | *Chunrocerus niveosparsus* Leth. | 10 | Flower, leaf |
| | | *Empoasca* spp. | 13 | Leaf |
| | | *Idioscopus anasuyae* Virak. | 9 | Flower |
| | | *I. clavosignatus* Maldonado | 9 | Flower, leaf |
| | | *I. clypealis* Leth. | 7,9 | Flower |
| | | *I. decoratus* Viraktamah | 9 | Flower, leaf |
| | | *I. jayashirae* Viraktamah | 9 | Flower, leaf |
| | | *I. nagpurensis* Pruthi | 9 | Flower |
| | | *I. niveosparsus* Leth. | 7,9 | Flower, leaf |
| | | *I. nigroclypeatus* Melich | 9 | Flower, leaf |
| | | *I. spectabilis* Viraktamah | 9 | Flower, leaf |
| | | *Rabela tabebuia* (Dozier) | 6 | Leaf |
| | | *Scaphytopius* sp. | 6 | Leaf |
| | Cixiidae | *Myndus crudus* VanDuzee | 6 | Leaf |
| | Coccidae | *Ceroplastes cirripediformis* Comst. | 6 | Leaf |
| | | *C. floridensis* Comstock | 6,13 | Leaf |
| | | *C. rubens* Maskell | 1,3,6,7,8,9,10 | Leaf |
| | | *C. rusci* (L.) | 13 | Leaf |
| | | *Coccus acutissimus* (Green) | 6 | Leaf |
| | | *C. elatensis* Ben-Dov | 13 | Leaf |
| | | *C. hesperidum* L. | 13 | Leaf |
| | | *C. mangiferae* Green | 3,4,5,6,7 | Leaf |
| | | *C. moestus* De Lotto | 8 | Leaf |
| | | *C. viridis* (Green) | 6 | Leaf |
| | | *Eucalymnatus tessellatus* (Signoret) | 6 | Leaf |
| | | *Kilifa acuminata* (Signoret) | 6 | Leaf |

| Order | Family | Species | Geographical Distribution | Plant Part attacked |
|---|---|---|---|---|
| Homoptera | Coccidae | *Milviscutulus mangiferae* (Green) | 13 | Leaf, fruit, twig |
| | | *Philephedra tuberculosa* N. & G. | 6 | Bluete |
| | | *Protopulvinaria pyriformis* Cock. | 13 | Leaf |
| | | *P. mangiferae* (Green) | 5 | Leaf |
| | | *Pulvinaria psidii* Mask. | Pantrop. | Leaf |
| | | *Saissetia oleae* (Bernard) | 13 | Leaf |
| | | *S. neglecta* DeLotto | 8 | Leaf |
| | | *Vinsonia stellifera* (Westwood) | 4 | Leaf |
| | Diaspididae | *Aonidiella aurantii* (Maskell) | 13 | Leaf |
| | | *A. orientalis* (Newstead) | 13 | Leaf |
| | | *Aspidiotus destructor* (Signoret) | 4,6,7 | Leaf |
| | | *Aulacaspis tubercularis* Newstead | 1,3,4,5,6,7,8 | Leaf |
| | | *Chrysomphalum aonidum* L. | 6,13 | Leaf |
| | | *C. dyctiospermi* (Morgan) | 4,5,6,8 | Leaf |
| | | *Fiorina fiorinae* T. | 6 | Leaf |
| | | *Hemiberlesia lataniae* (Signoret) | 6,13 | Leaf |
| | | *Howardia biclavis* (Comstock) | 6 | Twig |
| | | *Ischnaspis longirostris* (Signoret) | 4,6 | Leaf |
| | | *Lindingaspis floridana* Ferris | 6 | Leaf |
| | | *L. ferrisi* Mckenzi | 9 | Leaf |
| | | *Morganella longispina* (Morgan) | 6 | twig |
| | | *Parlatoria* spp. | 6 | Leaf |
| | | *Phenacaspis cockerelli* (Cooley) | 4 | Leaf |
| | | *P. dilatata* (Green) | 1 | Leaf |
| | | *P. sandwichensis* (Fulloway) | 10 | Leaf |
| | | *Pinnaspis strachani* (Cooley) | 3,6 | Leaf |
| | | *Pseudaulascapis cockerelli* (Cooley) | 6 | Leaf |
| | | *Pseudaonidia trilibitiformis* (Green) | 4,6 | Leaf |
| | | *Radionaspis indica* Marlatt | 6 | Leaf |
| | | *Selanaspidus articulatus* (Morgan) | 4 | Leaf |
| | | *Unaspis citri* | 4 | Twig |
| | Flatidae | *Colgaroides acuminata* (Walker) | 1 | Flower, leaf |
| | Margarodidae | *Drosicha stebbingii* Stebb. | 9 | Leaf |
| | | *D.mangiferae* Green | 9 | Leaf |
| | | *Icerya seychellarum* Westw. | 3,7,9 | Leaf |
| | Ortheziidae | *Orthezia* spp. | 4 | Leaf |
| | Pseudococcidae | *Pseudococcus adonidum* (L.) | 3,4,5,9 | Leaf, , fruit |
| | | *P. elisae* Borkhsenius | 10 | Leaf |
| | | *P. longispinus* (Targioni) | 8 | Bud |

| Order | Family | *Species* | Geographical Distribution | Plant Part attacked |
|---|---|---|---|---|
| Homoptera | Pseudococcidae | *Rastrococcus invadens* Williams | 3,5 | Bud, leaf, fruit |
| | | *R. spinosus* (Robinson) | 9 | Bud, leaf, fruit |
| | Psyllidae | *Apsylla cistellata* Buckton | 9 | Leaf |
| Hymenoptera | Apidae | *Trigona* sp. | 2 | flower |
| | Formicidae | *Atta* sp. | 2 | Leaf |
| Isoptera | Termitidae | *Coptotermes acinaformis* Frogg. | 1 | Trunk, root |
| | | *C. formosanus* Shiraki | 10 | Trunk |
| | | *Microcerotermes biroi* (Desneux) | 1 | Trunk |
| | | *Microtermes obesi* Holmgren | 9 | Trunk |
| | | *Neotermes insularis* (Walker) | 1 | Trunk |
| | | *Nisutitermis graveolus* (Hill) | 1 | Trunk, root |
| | | *Odontotermes lokanadi* C. & T. | 9 | Trunk |
| | | *O. gurdaspurensis* Holmgren | 9 | Trunk |
| | | *O. wallonensis* (Wasmann) | 9 | Trunk |
| | | *O. obesus* (Rambur) | 9 | Trunk |
| | | *O. horai* R. & C. | 9 | Trunk |
| | | *Termes cheeli* (Mjober) | 1 | Trunk |
| Lepidoptera | Arctiidae | *Diacrisia obliqua* (Walker) | 9 | Leaf |
| | | *Lymire edwardisii* (Grots) | 6 | Leaf |
| | Coreuthidae | *Eccopsis praecedens* Wism. | 3 | Fruit |
| | | *Lobesia vanillana* (Joann.) | 3 | Fruit |
| | Ctneuchidae | *Syntomeidaepilais jucundisima* | 6 | Bud |
| | Gracillaridae | *Marmara* sp. | 6 | Fruit |
| | | *Acrocerops* sp. | 1 | Leaf |
| | Gelechiidae | *Thiotrina godmani* (Wals.) | 8 | Bud |
| | Geometridae | *Oxydia* spp. | 6 | Fruit |
| | | *O. vesulia* (Cramer) | 8 | Fruit |
| | | *Pleuroprucha insulsaria* Guen. | 6 | Bud |
| | | *Chloropteryx glauciptera* Hampson | 8 | Bud |
| | | *Thalassodes dissita* | 9 | Leaf |
| | Limacodidae | *Latoia lepida* Cram. | 7,9 | Leaf |
| | Lymanthriidae | *Lymanthria marginata* | 9 | Leaf |
| | Megalopygidae | *Megalopyge defoliata* Schs. | 6 | Leaf |
| | | *M. lanata* (Ramen) | 4 | Leaf |
| | Noctuidae | *Alabama argillacea* (Hb) | 8 | Fruit |
| | | *Chlumetia transversa* Walker | 7,9 | bud |
| | | *Gonodonta* spp. | 8 | Fruit |
| | | *G. pyrgo* (Cramer) | 8 | Fruit |
| | | *Othreis fullonia* (Clerck) | 1,10 | Fruit |
| | | *O. materna* (L.) | 8 | Fruit |
| | | *O. tyrannus* Guen. | 1 | Fruit |
| | | *Penicillaria jocosatrix* Guen. | 10 | Leaf |
| | Pyralidae | *Davara caricae* (Dyar) | 8 | Bud |
| | | *Deanolis sublimbalis* Sn. | 7,9 | Fruit |
| | | *Pococera atramentalis* Lederer | 6,8 | Bud, fruit |
| | | *Tallula* sp. | 6 | Fruit |
| | Saturniidae | *Nataurelia zambesiana* L. | 3 | Leaf |

| Order | Family | *Species* | Geographical Distribution | Plant Part attacked |
|---|---|---|---|---|
| Lepidoptera | Tortricidae | *Aethes* sp. | 1,8 | Bud |
| | | *Amorbia aequiflexa* Meyrick | 8 | Bud |
| | | *Cosmetra anthophaga* Diakonoff | 3 | Fruit |
| | | *Episimus transferrana* Walker | 8 | Bud |
| | | *Platynota rostrana* (Walker) | 6 | Bud, fruit |
| Orthoptera | Acrididae | *Anacridium melanorhodon* Walker | 3,5 | Leaf |
| Thysanoptera | Paleothripidae | *Leptothrips sangularis* Hood | 6 | Bud |
| | Tripidae | *Frankliniella* spp. | 8 | Bud |
| | | *F. bispinosa* (Morgan) | 6 | Bud |
| | | *F. fusca* (Fitch) | 6 | Bud |
| | | *F. kelliae* Sakimura | 6 | B ud |
| | | *F. occidentalis* (Pergande) | 13 | Bud |
| | | *Heliothrips hemorroidalis* B. | 6,13 | Bud |
| | | *Scirtothrips mangiferae* Priesner | 13 | leaf |
| | | *Selenonthrips rubrocinctus* (Giard) | 2,3,4,6,7,10 | leaf |
| | | *Retithrips syriacus* Mayet | 13 | leaf |
| | | *Thrips palmi* Karny | 6 | Bud |
| | | *T. florum* Schmetz | 6 | Bud |

**Geographical distribution areas**: 1 = Australia, 2 = Central Amerika, 3 = East Afrika, 4 = South America, 5 = West Afrika, 6 = North America, 7 = Southeast Asia, 8 = Caribbean, 9 = India and Pakistan, 10 = South Pacific, 11 = Spain, 12 = cosmopolitan, 13 = Israel.

**Acknowledgements**

First, I would to like to thank Prof. Dr. Basedow for accepting my phd thesis and for the assistance and support given. I also gratefully acknowledge the willingness of Prof. Dr. Honermeier to act as the second supervisor.

Special thanks to the Australian Quarantine and Inspection Services (AQIS) for their financial support of the "red banded mango caterpillar project" and to Dan Smith for his invaluable assistance to the importation of the parasitoid *Anicetus beneficus* from Australia to Papua New Guinea and for the permission to use the images and photographs on page 45, 46, 52 and 86.

Many "cheers" to Dr. Mark Johnston (ACNARS) for editing `my english`, and the valuable comments and remarks he made.

Thanks to Rob Mayer (DPI, Queensland) for assisting in the completion of the statistical analysis, to Scott Miller (Smithsonian Institute, Washington) for the identification of Lepidoptera and to A. Slipinski (CSIRO, Canberra) for the identification of Coleoptera.

And, finally, I would like to thank the National Agricultural Research Institute (NARI) of Papua New Guinea and their staff, in particular Mark Ero and Ana Kawi, who tolerated "bighead Stefan" for such a long time.

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