RURAL INDUSTRIES RESEARCH

AND DEVELOPMENT REPORT

Ecology and Control of Fruitpiercing moths and Leaf-eating beetles in Developing Strategies for their Management in Tropical Tree Crops

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Queensland Department of Primary Industries

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Othreis fullonia piercing an apple

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Detailed Results

NON-TECHNICAL SUMMARY

The major objectives of this study were 1. To establish or improve management systems for fruitpiercing moths and leaf-eating chrysomelids through ecologically-based studies, and 2. To assess control technologies and specific areas of biology and taxonomy as a means to achieving this goal.

Fruitpiercing moths

Seasonal feeding activity of the six primary species have revealed differential relationships between crops, in intensity of activity and between localities which would allow some seasonal crop opportunism in areas other than the wet tropical coast.

The moths breed on one family of vines and have distinct preferences for particular species. The principal host plant is distributed across northern Australia and down the east coast to northern NSW. Five moth species utilise this plant to different extents and show different affinities for the various habitats in which it occurs. Breeding limitations are largely determined by the availability of new growth which is minimal during the dry season.

A complex of native parasites of fruitpiercing moths exists in Australia but has little impact on populations at the desired time.

Female moths produce an unusual *pheromone* (sex attractant) but neither its components nor activity have been established. As mating is indicated as taking place in the vicinity of the feeding site and as males considerably outnumber females feeding on any occasion *pheromones* could have considerable potential as control tools.

Physical barriers such as netting are very effective at minimising damage in addition to deterring flying foxes and birds. Increases in the recovery of marketable fruit of up to 87% have been recorded.

Elevated yellow fluorescent lights forming a barrier around blocks of fruit trees reduce moth numbers and damage by about 70%. Development costs for such a system are high and its utility may depend upon its refinement.

Studies in lychee and carambola trees have shown that fruit on trees in outer rows are more prone to attack than those on central ones. This suggests trees in a susceptible area should be planted in blocks rather than a few long rows to confine the damage.

Electrophysiological and bioassay techniques have revealed that the general 'fruity' esters produced by fruit are major components in the attraction process. However, their effectiveness as attractants depends upon their relationships to some of the other chemical volatiles (alcohols and aldehydes). The study established that moths can determine the level of ripeness of a fruit through the proportions of certain volatiles being produced. This revelation is being used as the basis for optimising the attractancy response in the development of baits for control purposes.

Leaf-eating beetles

The taxonomy of the genus *Rhyparida* was elucidated to the extent that it assisted in the determination of economic species. Studies on the economic injury caused by red shouldered leaf beetle have shown that damage to avocado flowers does not necessarily reduce fruit-set and that the beetle could act as a pollinator. The implications for reduced insecticide use at flowering are obvious.

A simulation of recurring damage to new growth on young lychee trees by black swarming leaf beetle suggested that irrespective of fertiliser application at least a year's delay in tree growth can be induced.

Management of redshouldered leaf beetle can be enhanced by monitoring activity levels with yellow sticky panels and combined with an awareness of emergence and seasonal feeding patterns, as well as crop susceptibility, more discrete and effective use of insecticides is possible.

Black swarming leaf beetle has a clearly identified feeding activity period between September and December. While bioassays have shown that the approved chemicals, except endosulfan, are effective they lack persistence and rainfastness. Efforts to improve control with feeding deterrents, controlled-release systemics, and stickers and extenders were not sufficiently successful to warrant adoption.

Some synthetic pyrethroids, which appeared to act as repellents, offered greater persistence than the approved chemicals under wet tropical conditions and, if managed properly, could reduce both spraying frequency and beetle damage in tropical tree crops.

The black swarming leaf beetle *Rhyparida discopunctulata*

BACKGROUND TO THE RESEARCH PROJECT

i) Fruitpiercing Moths

The economically important family Noctuidae (nightflying moths) is composed of a number of subfamilies of which the Catocalinae is one of the largest. This group contains the fruitpiercing moths which are represented in their most advanced form by large moths equipped with a heavily armoured proboscis which enables the penetration of the skin or rind of most fruits. Some species within this group are only capable of damaging the softer fruits while others are purely secondary feeders relying on injured skin to facilitate access to the fruit juices. Fruitpiercing moths are unusual amongst the Lepidoptera in that the adult is the pest stage. Primary damage to fruit skin allows entry of fruit rot organisms, such as the fungi *Oospora* spp. and *Fusarium* spp. and bacteria, which results in rapid breakdown and an unmarketable product. Feeding sites can provide access to fruit flies for oviposition which may then allow their development in crops not otherwise prone to attack, and therefore has quarantine implications. Damage to some fruits is not obvious for one or two days after it occurs during which time it may have been harvested, sorted and packed. Injured lychees subsequently ferment and weep through the feeding site resulting in contamination of surrounding fruit with loss of market appeal.

Fruitpiercing moths are known from most tropical and subtropical areas of the world (Banziger, 1982), but are particularly important in parts of Africa, in Asia and in the Oceanian region. They are known to attack a vast range of commercial fruits, more than 30 being documented by Cochereau (1977). Only fruits with extremely hard, pulpy or spiny skins seem immune from damage e.g. durian and mangosteen (Banziger, 1982). Even unlikely fruits such as rockmelons, capsicums and coffee are occasionally attacked which reflects the extremely cosmopolitan taste of these moths.

The French botanist, Thozet, first reported moths damaging oranges at Rockhampton in 1869. The notable Queensland entomologist, Henry Tryon, subsequently documented the principal pest species, identified some of their larval host plants and considered their control (Tryon, 1898). As fruits were attacked at night, damage levels varied between years and some other pests had a greater influence on the crops involved, fruitpiercing moth activity was overlooked or tolerated by growers for decades. The second half of this century has seen significant advances in pest control, particularly through the availability of insecticides, in contrast to the control of fruitpiercing moths which has progressed little. The acceleration in the growth of the fruit industry in the northern and eastern areas of Australia has seen the fruitpiercing moth problem escalate because these areas favour the abundance, seasonality and species diversity of these insects.

In Australia reports of extreme fruitpiercing moth damage have included the total loss of some citrus and apple crops and 80% and 50% loss of carambola and lychee crops respectively. Although these are very subjective estimates they serve to highlight the extent of the problem for some growers and the potential constraints on growing susceptible fruits successfully in significant fruitpiercing moth areas.

ii) Leaf-eating beetles

The species of concern belong to two subfamilies within the family Chrysomelidae. They include the redshouldered leaf beetle, *Monolepta australis* (Jacoby) (Galerucinae) and a number of species of the complex genus *Rhyparida* (Eumolpinae). Redshouldered leaf beetle is a small beetle (5-6 mm in length) which invades crops in dense swarms (Treverrow, 1986). Young leaves, flowers or the epidermis of fruit can suffer damage which is generally manifested quickly. Particularly susceptible crops are avocado, carambola, cashew, citrus, kenaf, macadamia, mango and sweet corn. Many ornamentals (native and exotic) are also prone to attack. Redshouldered leaf beetle is active from northern New South Wales along the east coast of Queensland and through coastal parts of the Northern Territory. *Rhyparida* spp. attack a wide range of agricultural, horticultural and ornamental crops across northern Australia. The larvae of some species can damage the roots of sugar cane and maize but it is the damage caused by adult beetles to tropical tree crops which is of most concern. Adult feeding on the growth flushes of young trees results in wilting and dieback of shoots and significant growth impairment. Occasionally fruit is attacked but such damage is usually minor. *Rhyparida discopunctulata* Blackburn (blackswarming leaf beetle) is the major economic species in the wet tropical areas of north east Queensland where crops such as lychee, longan, durian, rambutan and jakfruit are particularly susceptible.

Although considered minor pests for decades leaf-eating chrysomelids have been elevated in status as the expansion in tropical and subtropical tree fruits and nuts has gained pace. Severe flower loss due to feeding by reshouldered leaf beetle in avocados and macadamias was considered to reduce fruit-set while scarring of fruit left an unmarketable product. Although actual economic injury levels had never been ascertained the obvious nature of the damage made redshouldered leaf beetle a cause for concern. Intense and persistent swarming by blackswarming leaf beetle in young trees on the wet tropical coast has resulted in 100% of trees damaged in some instances. Many growers in this area consider this beetle their most limiting pest during the establishment of certain tree crops e.g. lychees.

The above leaf-eating chrysomelids feed mainly on the roots of grasses and legumes as larvae with breeding sites being widespread. Control is therefore confined to the adult stage and has only been achieved by reactively spraying with insecticide during beetle attacks. Non-persistent but effective chemicals are available which achieve a high kill rate. However, these chemicals lack efficacy during the hot humid conditions at the beginning of summer so that repeated applications are necessary. This in turn disrupts the activities of bees and other beneficial insects. Coupled with the inability to predict activity and the fickleness of swarming the management of these pests is difficult and in need of improvement.

OBJECTIVES OF THE RESEARCH PROJECT

General - To establish or improve management systems for fruitpiercing moths and leaf-eating chrysomelids through ecologically-based studies. To assess control technologies and specific areas of biology and taxonomy as a means to achieving this goal.

Specific a) **Fruitpiercing moths**

- To determine adult moth feeding times, feeding rates, food preferences and associations in a number of pest species;
- To assess seasonal feeding activity and breeding patterns in a range of species in north Queensland;
- To evaluate a range of larval host plants from the family Menispermaceae to identify the principal moth species/host plant associations and breeding sites;
- To test a range of monitoring and control methods for adult moths to provide growers with management options to suit crop economics; including the isolation and synthesis of pheromones, light protection systems, physical barriers and a variety of baiting or feeding decoy techniques based on the attractants in fruit;
- To cooperate with CSIRO in detailing the existing biological components of mortality in Australia;
- To publicise and extend findings to individual growers and grower groups as pertinent ones arise.

b) **Leaf-eating beetles**

- To provide a taxonomic synopsis of the economically important species of *Rhyparida*;
- To establish the extent of economic injury in relation to crop phenology in specific crops;
- To evaluate existing controls and a range of novel methodologies in the detection and suppression of beetle activity;
- To examine the adult population dynamics of a number of pest chrysomelids to improve forecasting ability. To investigate aspects of biology of these pests in the laboratory to support ecological reasoning;
- To derive interim management strategies for a number of pest species and promote their value to pertinent groups.

INTRODUCTORY TECHNICAL INFORMATION

i) Fruitpiercing moths

Some characteristics of these moths which make their control difficult and largely rule out direct insecticidal action are:

1. Activity is at night.
2. Only ripe or near ripe fruit is attacked.
3. A wide variety of fruits is susceptible.
4. Numerous moth species can be involved.
5. Primary species are relatively long-lived.
6. Breeding occurs in areas isolated from orchards.
7. Some species have a range of larval food plants.
8. Populations build up rapidly after the dry season.
9. Adults can migrate hundreds of kilometres.
10. Moths generally vacate orchards during daylight hours.

Control methods suggested or utilised in the past (Baptist, 1944) include:

a) Attracting moths into traps or with poisoned baits - A widely employed method, especially by smaller growers. As fruit or alcohol concoctions are employed as the attractant-baits they cannot compete satisfactorily with the crop odour. However, relatively recent reports in Korea (Yoon & Kim, 1977) where honey, brown sugar, vinegar and fruit juices have been used suggest damage to softer fruits by 'secondary' species can be reduced. It is quite probable that if the attractive components of ripening fruit can be established an attractant technique could have real value in minimising damage.

b) Smoking orchards to obscure/disguise attractant fruit scents - This method is largely impractical and could disrupt tree growth and fruit quality. Its value as a control method is yet to be proven.

c) Repulsion by deterrent sprays - A number of products have been tried e.g. citronella, or suggested, but none has been successful. Some products have proven to be phytotoxic.

d) Orchard sanitation - The removal of all fallen or damaged fruit is likely to reduce the number of secondary feeders that enter an orchard to feed but it is doubtful whether it would have the same effect on primary species with their predilection for ripening fruit.

e) Early harvest - This is a commonsense solution but it is not usually practical. Most tropical fruits as well as citrus do not ripen further after harvest so that picking early reduces quality and defies attempts to establish maturity standards. Growers of mangoes and papaws, which are usually harvested before becoming attractive to moths, do unwittingly benefit from this method.

f) Capture and destruction of moths at fruit by hand or net - A method still widely used by the backyarder or fruitgrower with a few valuable trees. This technique is impractical for the large commercial grower unless fruit numbers are light. Few people are willing to spend half of every night defending a crop during a fruiting season or can afford to employ someone to do it.

g) Bagging or screening fruit - This method is used widely and successfully in Asia but relies upon cheap labour and high returns for fruit. With the technology and variety of netting now available the total enclosure of trees under netting is a real option. Optimum netting size, its durability, its effectiveness and the economics of utilising such a system for fruitpiercing moth have never been ascertained.

h) Repelling moths with light - Utilization of lights which emit yellow-green wavelengths to repel moths is the technique which has offered the most potential of all those considered. Preliminary research in Japan suggested a 60% reduction in moth numbers (Nomura 1966), in South Africa 80-90% reduction (Whitehead & Rust, 1967, 1972a,b) and in Rhodesia (Zimbabwe) 98.5% reduction (Bosch, 1971). Despite the apparent value of this method and while certain specifications were offered for its use a considerable amount of information was required to confirm its effectiveness against a range of primary piercing species in tropical areas where population densities can be very high. The technique has never been developed commercially because of the logistical problems of power supply, the establishment costs of such a system and probably grower resistance to adopting something so unusual. The situation today is somewhat different with ease of access to power, good electrical technology, variable crop economics including tax considerations and time-saving desirability, so that a light protection system should be a genuine consideration.

i) Destruction of larval host plants (Banziger, 1982) - This method is not a real option in Australia because of the significant areas over which these plants occur. However, information on moth host plant preferences coupled with plant distribution data would facilitate the identification of significant breeding areas. Growers or intending growers could then be provided with a risk assessment. With information on seasonal feeding activity in the more important moth species recommendations could be made to growers on fruit or varietal selection to avoid major periods of moth activity.

An area never explored in this group of moths but one which is now more accessible is pheromone technology. To successfully utilize synthetic sex pheromones as monitoring or control tools would require a prior knowledge of species feeding activity, food preferences and seasonal abundance.

Finally, data need to be accumulated on the extent and effectiveness of existing biological controls so that an assessment can be made of their potential enhancement through introductions from other regions where these moths are not considered to be pests.

The overall aim of control strategies should be the minimisation of damage during the period when the greatest proportion of the crop is susceptible.

ii) Leaf-eating beetles

Control of leaf-eating chrysomelids is difficult or unsatisfactory for the following reasons:

1. There is no means to monitor activity.
2. Attacks are manifested quickly.
3. Feeding by some *Rhyparida* species occurs largely at night and presence is not easily detectable during the day.
4. The registered or approved chemicals are short-lived.
5. In the wet tropics insecticides lack rainfastness.
6. Breeding sites are generally isolated from adult feeding sites.
7. A range of beetle species is important but species can vary from area to area.
8. Species such as *R. discopunctulata* persist in trees in an area for weeks or even months.

Murray (1982) examined the life history of redshouldered leaf-beetle and documented recordings of major swarming periods. There is little information on species of *Rhyparida* except field observations (Cottrell-Dormer, 1926a,b) and collection records. The ecology of these beetles has never been studied and elements such as adult population dynamics are essential in establishing predictability of activity and seasonal damage risk in relation to host plant phenology.

While pheromones could be valuable as monitoring tools the lack of expertise in Coleopteran pheromone isolation in Australia makes this area a difficult one to pursue. However, coloured traps with and without chemical baits have proved attractive to related beetle species in the United States (Ladd *et al.*, 1984) and could prove of benefit as monitoring tools here.

Very little information has accrued on crop losses attributable to leaf-eating chrysomelids as the most significant damage they inflict is in pre-bearing trees or in those that are flowering. Determination of economic injury levels or damage significance needs to be accomplished so that controls for these beetles can be appropriately directed.

While the insecticides approved for use in Queensland against leaf-eating beetles do have substantial activity their relative efficacy, persistence, rainfastness and value compared to newer products require evaluation. Certain available insecticides have significant repellent action while other chemicals behave like repellents in specific circumstances, and these are worthy of assessment against these beetles. Systemic insecticides which only target pests, thereby minimising environmental concerns, offer a potential means of extending the life of a single control measure. Means of improving the rainfastness of insecticides as well as ways of changing the leaf surface characteristics to make feeding unattractive are further pursuits with potential to improve control.

Finally, to clarify the role individual species of *Rhyparida* have in disrupting horticultural activity taxonomic studies are necessary to facilitate identification.

The major aims of the current study are a) to improve the predictability of beetle activity, b) to introduce some means of early detection, and c) to maximise or extend the use of existing control measures and screen for products which outperform them.

A female specimen of the fruitpiercing moth *Othreis fullonia*

RESEARCH METHODOLOGY

i) Fruitpiercing moths

a) Host plant representatives and moth colonies

Records of the Queensland Herbarium and the CSIRO Tropical Forest Research Centre, Atherton, were consulted to ascertain the distribution and specific locality of a range of Menispermaceae. Where possible, cuttings or seeds of a number of species were obtained. These were planted in small pots in standard potting mix and held initially in a misting house or well watered glasshouse. A few whole small plants of a couple species were collected and placed directly into pots. As time progressed and plants outgrew their original pots they were repotted. Samples of five species were planted next to a block of carambola trees at Walkamin Research Station to provide leaf material to feed laboratory colonies of moths and to ensure some localised breeding of moths in the vicinity of a trial site.

Laboratory colonies of moths were initially developed by collecting adult moths from fruit then releasing them in a large cage. The cage was constructed in a glasshouse and had dimensions of 2 x 3 x 2m and was covered by 50% shadecloth. Depending on the species of moth involved the appropriate larval host plant either potted or as a cutting was introduced to the cage. Moths were provided with fruit (generally apples or carambolas) suspended from the cage roof and water in large petri dishes on the floor.

Eggs were laid on the shadecloth or host plant and were generally collected at this stage for individual experiments or to perpetuate the colony. They were held on moist filter paper in a petri dish until they hatched. First instar larvae were transferred individually to 250 ml screwtop jars and provided with soft new growth from an appropriate host plant. Food was renewed daily and at the same time faeces removed. As larvae developed and more food was required, larger more mature leaves could be used. At the cessation of feeding the prepupa was provided with tissue paper to soak up any excess moisture and enhance the pupation environment. At 24°C the pupal period took 14-17 days. At eclosion of adult moths they were introduced to the large glasshouse cage for breeding or used in experiments.

b) Adult moth feeding activity and seasonal incidence

Moths were sampled by hand from fruit for one hour on a single night each month between November 1985 and July 1989 where a ripe crop was available. Sampling took place approximately 30-60 minutes after sundown on each occasion. A single site at Kamerunga Horticultural Research Station containing carambolas was monitored throughout the period. When carambolas were not available other fruits at other sites were monitored, lychees being the most consistently surveyed. On each sampling occasion all primary piercing species were collected as well as a number of the more important 'secondary' species. Notes were kept on the number of any minor species. Primary species were identified, sexed and the females dissected to ascertain level of maturity and mating status. Associations between moth species, season and crop (mainly carambolas and lychees) were determined.

On a single occasion a carambola crop (at Kamerunga Horticultural Research Station) was monitored at 2 hourly intervals throughout the night to see whether feeding in the different species or sexes varied as night progressed.

c) Seasonal breeding activity and habitat utilization

Between 1986 and 1989 four sites in North Queensland were monitored for fruitpiercing moth utilisation mainly of *Tinospora smilacina* (Snake Vine) (Fig. 1) but of other Menispermaceae too where they occurred. Three forms of *T. smilacina* are recognised by Fay (1987) and three sites contained one of these forms in a distinct habitat and a fourth included two forms in adjacent vegetation. Habitat I (Form I) was coastal rainforest between Bingal Bay and Mission Beach, Habitat II (Forms I & II) was foreshore scrub on sand and adjacent closed swamp forest at Wangetti Beach (45 kms north of Cairns), Habitat III (Form II) was rocky, grassy foreshore at Buchans Point (20 kms north of Cairns) and Habitat IV (Form III) was open monsoonal woodland on a granite escarpment 10 kms NW of Dimbulah. Monthly hourly sampling at each site included a rating of plant growth characteristics and the collection of all larvae of primary piercing moth species. Larvae were taken to the laboratory for determination of instar or holding of 1st instars until moulting to 2nd so that species could be ascertained. Data were interpreted in terms of the moth species seasonal breeding activity, their utilization of different habitats, their affinities for different forms of *T. smilacina* and the significance of different habitats in terms of their contribution to the pest problem.

d) Larval nutrition and host plant preferences

Field observations were supported by laboratory experiments with *Othreis fullonia* in which some host preferences and larval nutritional requirements were ascertained.

Experiment 1 - Consumption and utilization of 3 species of Menispermaceae. Newly hatched larvae from a single batch of eggs were placed individually in 250 ml containers with soft new growth of either *Tinospora smilacina*, *Sarcopetalum harveyanum* or *Stephania japonica* var *timoriensis*. There were 10 larvae in each treatment. Each day headcapsule width was measured to determine instar, larval weight

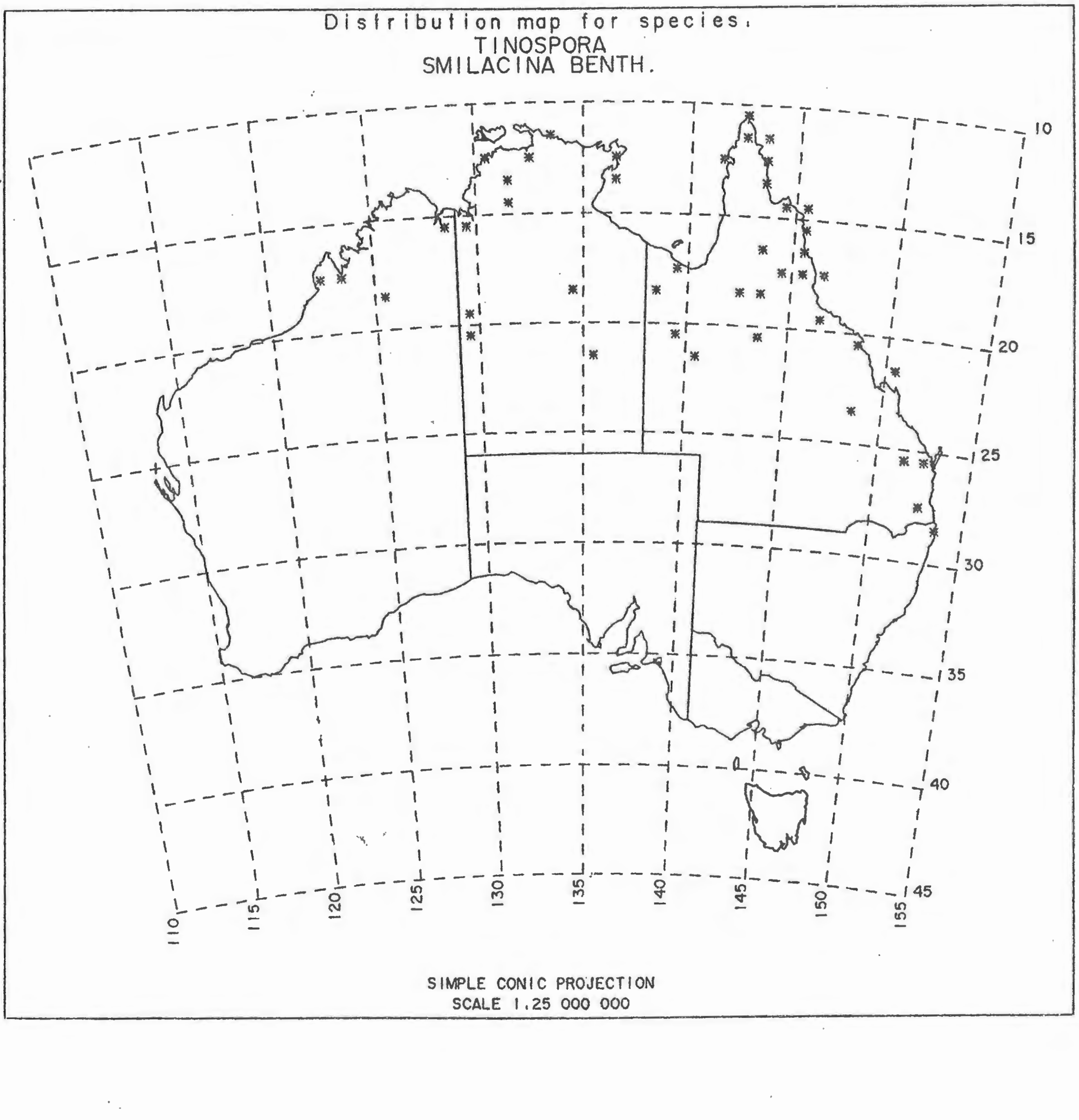


Fig. 1 - Distribution of a fruitpiercing moth larval food plant *Tinospora smilacina* in Australia.

recorded and fresh weights of faeces, uneaten leaf and replacement leaf taken. Leaves were replaced daily and changed from soft to firmer as larvae developed. Controls of leaves were kept of each plant species to ascertain moisture loss during each 24h. Apart from determining mean development rate at 24°C, level of survival and puparial weight for each treatment was recorded. The data were also used to arrive at a number of indices described by Waldbauer (1968) to examine the utilization of food. These included:

i) ECI (Efficiency of conversion of ingested food to body substance)

$$= \frac{\text{larval weight gain}}{\text{weight of food ingested}} \times 100$$

ii) AD (Approximate digestibility)

$$= \frac{\text{weight of food ingested - weight of faeces}}{\text{weight of food ingested}} \times 100$$

iii) ECD (Efficiency of conversion of digested food to body substance)

$$= \frac{\text{larval weight gain}}{\text{weight food ingested - weight of faeces}} \times 100$$

Experiment 2 - Ability to alternate feeding between plant species. Newly hatched larvae were provided with one of the 3 plant species above as in Experiment 1. Treatments included changing the plant species at the completion of the 1st instar and again at the completion of the 3rd. In two treatments larvae were fed either *T. smilacina* or *S. harveyanum* throughout their larval life. At each food change headcapsule widths were measured and puparial weights were taken 2 days after cessation of feeding. Five larvae were used for each treatment. Development times were established for each plant species through each stage.

Experiment 3 - Choice amongst a constant variety of food. The reaction of 10 larvae (held individually) to a choice of the 3 plant species used above was tested by providing sufficient food of each species so that only a single one needed to be fed on. Each 24 h leaf material left uneaten and replacement leaf was weighed for each plant species and the headcapsule widths of larvae measured. Controls of leaf mixtures were held to determine leaf moisture loss. The respiratory effects of large larvae on leaf moisture loss could not be accounted for.

Utility of a range of host plants - The ability of final instar larvae of *Othreis fullonia* (Clerck), *Othreis materna* (L.), *Othreis jordani* Holland, *Khadira aurantia* (Moore) and *Rhytia cocalus* (Cramer) to feed on a range of different Menispermaceae was tested in the laboratory. This information was combined with that obtained from the field to determine actual and probable hosts.

e) Pheromone screening and identification

Pheromone analysis was undertaken by supplying the Chemistry Department, University of Queensland, and CSIRO Division of Entomology, Canberra, with the following: 1) Probable pheromone producing glands situated in the last two abdominal segments of the female moth - on extraction these glands were immediately placed in high grade Pentane and stored in a refrigerator, 2) Tenax absorption tubes that had been exposed to female moths at night at an age when these moths were likely to be producing pheromone (2-8 days old), and 3) Live pupae so that under controlled conditions with sophisticated detection equipment CSIRO could assess if and when pheromone production was taking place. Any suspected material was assessed using a Gas Chromatograph/Mass Spectrometer. Potential pheromones were explored in *O. fullonia*, *O. materna* and *R. cocalus*.

f) Survey of Indigenous Biological Control Agents

Eggs, larvae and pupae of a number of primary piercing species were collected from a range of host plants at different sites each year between 1985 and 1990. This material was screened for parasitoid presence to establish a) moth species/parasitoid species interactions and prevalence, and b) seasonal activity. Material was documented and sent to a number of different authorities for identification.

g) Evaluation of the enclosure of trees under netting

Two types of netting were assessed: a) Anti-hail mesh, a 3 x 8 mm netting which provides 15% shade, and b) Birdban 40, a white disposable netting with 40 mm diameter hole at full stretch. In cooperation with a grower the anti-hail mesh was assessed by totally enclosing rows of carambola trees and evaluating the reduction in production losses. The Birdban (courtesy of Beau Lyons, Polynet Industries, Townsville) was assessed by placing it over a small fruit tree with ripe fruit in a large flight cage and then releasing moths to determine the extent they penetrated this barrier.

h) A light protection system

In cooperation with the Far North Queensland Electricity Board an experimental area was developed on Walkamin Research Station on the Atherton Tableland in which blocks of carambola trees were surrounded by poles carrying yellow fluorescent tubes (median wavelength 580 millimicrons) at 4m elevation. There were 4 blocks each containing 20 trees of 5 varieties (Arkin, B2, B10, Fwang Tung and Thai Knight) arranged similarly. One or two blocks could function on any night, the remainder acting as controls.

In order to achieve the light intensity recommended by Bosch (1971) initial experiments were all conducted with 2 x 40 watt lights per pole. At a pole distance of 9½ - 12m light intensity was measured as 0.2 lux in the centre of a block and $\geq$ 3.4 lux in the light barrier. In the non-illuminated blocks residual light ranged from 0 - 0.8 lux (see Results).

The effectiveness of the light system in deterring moth feeding was evaluated in two ways: 1) By assessment of damage inhibition, and 2) By assessment of moth presence. The first method involved enclosing clusters of fruit in paper bags prior to ripening. When the bulk of fruit were considered ripe and moth populations were adequate bags were removed and fruit exposed for 4 consecutive nights. During this time the number of moths and damaged fruit were recorded in the illuminated and dark blocks. Moths were sampled for one hour from 2100 hours for the first 3 nights. The second method involved sampling of moths on six occasions between March and June for one hour per night from light protected and unprotected trees.

i) Development of attractant-based control systems

In assessing the attractive properties of fruit to fruitpiercing moths both the volatile (chemical) and non-volatile characteristics need to be assessed. 1 - Non-volatile characteristics - A series of surveys in lychee and carambola orchards were undertaken to determine whether attacked or untouched fruit displayed differences in a range of non-volatile characteristics. Up to 50 fruit were sampled on a single night, half of which were observed being damaged by primary piercing species and half were adjacent untouched fruit. Data recorded included the height of the fruit on the tree, the trees position in the orchard, fruit weight, % fruit moisture, softness (derived from a penetrometer reading), colour, % Brix (% soluble solids = sugars) and pH.

2 - Volatile components of fruits - The attractive components of fruit odour can be elucidated in a variety of ways, including electroantennogram studies and a range of bioassay techniques e.g. artificial fruits and wind tunnel studies. Many hundreds of volatile chemicals emanate from the many fruits attacked by fruitpiercing moth. However, scrutiny suggested that there were some chemicals (or related types) which are common to most fruits, and particularly ones which impart either a "fruity" or a "green" note rather than those which provide specific fruits with their characteristic odours. The initial approach to fruit odours therefore was one of examining moth response to some of these general chemical volatiles to determine whether there is a fundamental attraction process which could be exploited in formulating standardised commercial baits. Electroantennogram studies - an electroantennogram unit was developed (after Roelofs, 1984) incorporating ground and recording electrodes, X 100 amplifier (Mütronix, Cairns) and Tektronix 2201 Digital Storage Oscilloscope. Procedures used to test responses largely followed those

utilized in assessing pheromones. A puff of air containing the volatile is introduced into a constant stream of purified air which passes over the excised moth antenna. The electrical signal produced passes through saline to the recording electrode. Changes in test conditions and deterioration in the response from an antenna over time require that the volatiles being assessed are interspersed with a standard chemical. Nevertheless, a single antenna could be utilized effectively for 30 - 40 minutes. Test volatiles (supplied by Ajax Chemicals, Aldrich Chemical Company, Inc., BDH Chemicals Ltd and the Sigma Chemical Company) were prepared in a standard quantity of paraffin oil and held on a strip of filter paper in an ampule/pipette prior to delivery. Details of specific experiments are provided in the Results. Bioassays - The electroantennogram technique is particularly useful for rapidly ascertaining the response of insects to a large number of volatile chemicals. However, it is not a 'stand-alone' technique and bioassays are required to verify findings and to accommodate a range of behavioural considerations. With fruitpiercing moth bioassays could be undertaken in olfactometers or windtunnels, or by utilizing traps or 'artificial' fruits. The latter approach was chosen and experiments conducted in a cage environment. Artificial fruits were created by adding volatiles or juices to a 1.75% agar suspension in 25 ml cups, coloured with food dye to facilitate confirmation of moth feeding. After approximately 3 hours the mixture had cooled and set and could be removed from the cups. If necessary, the 'fruits' could be fitted with wire stems to permit hanging. Individual experiments with artificial fruits are described in the Results.

ii) Leaf-eating beetles

a) Taxonomic studies on the genus *Rhyparida*

This work has been undertaken by Mr R.I. Storey. Research has included the examination of types from various Australian museums, literature surveys and the development of keys based largely on the extensive collection material available from North Queensland. The utility of the DELTA system of computer generated descriptions and keys has also been investigated, a system designed for large and difficult genera such as *Rhyparida*. Discussions were also held with Dr C. Reid (Australian National University) on the composition of the genus.

b) Evaluation of feeding significance and economic injury

1 - *Monolepta australis* in avocados - Avocado Foliage - Beetles were confined in gauze sleeves on branches exhibiting new growth at densities of 1 beetle/5 leaves, 1 beetle/3 leaves and 1 beetle/leaf. They were provided with water and left 7 days before determination of damage.

- Avocado flowers - This study was conducted at Kairi Research Station on the Atherton Tableland. Four avocado trees 6 - 7 m high were used - two cv. Fuerte and two cv. Hass avocado trees were separated by a lychee tree along a single row. Tree management was minimal in that no chemical pesticides or fertilizers were applied and irrigation was irregular.

Method 1. Sleeves of fine cloth gauze were placed over randomly selected flower panicles (1-4/sleeve) when the first flowers opened. Panicles were caged at 2 m above ground level on both row-sides of a tree. As each tree approached peak flowering either 10 *M. australis*, 10 flower-feeding *Plecia amplipennis* Skuse or no insects were placed within the sleeves. A 10 ml vial (with wick) of water was placed in each sleeve containing insects. A minimum of two replicates were established for each treatment on each tree. At the same time sleeves were removed from panicles to be exposed to all flower-visiting insects. Five replicates were maintained on each side of a tree for this treatment. Fruit-set was assessed in all treatments after three weeks.

Method 2. M. australis activity at the site was monitored from pre-flowering to post-fruit set by placing flat-surfaced, yellow double-sided traps (20 x 25 cm coated in Tanglefoot^R) in four positions (N, S, E & W) at 2 m height in each tree. Counts of beetles caught were completed every 7 $\pm$ 1 days, together with a rating of flowering intensity on a 1 (lowest) to 3 (highest) scale. The traps were cleaned with kerosene and recoated with Tanglefoot^R at frequent intervals to maintain an efficient trapping surface.

About 6 months post-flowering mature fruit were counted by selecting 4 positions on each row-side of a tree: 1 at 5 m height (central), 2 at 3.5 m (peripheral) and 1 at 2 m (central). A steel pole with an incomplete one metre cubed frame attached was used to count the number of fruit at each position for a total of eight counts per tree. Fruit production in 4 equivalent-sized cv. Fuerte in a commercial orchard 20 km distant where few *M. australis* were present at flowering was recorded similarly.

2 - *Rhyparida discopunctulata* - Leaf condition and type - A laboratory experiment was used to examine the ability of beetles to cause damage to new or mature leaf in avocado, guava and *Eucalyptus torelliana*.

A single leaf and beetle were introduced to a 250 ml jar after the leaf surface area and weight had been recorded. There were 5 replicates of each treatment and after 2 days leaf surface area and weight were again taken to ascertain % loss. Change in leaf characteristics in the absence of beetles was assessed by maintaining controls.

Growth impairment in lychees - A glasshouse experiment was used to ascertain the importance of *Rhyparida* damage to rate of tree growth in lychees (Tai So). Small lychee trees in pots were subjected to removal or retention of each growth flush and the implementation or not of a fertilizer (potassium nitrate) regime. The experiment was conducted over an 18 month period with assessments of change in height and canopy dimensions made at approximately 6 month intervals.

c) Damage levels and pattern of beetle attack in the field

A row of 2 - 3 year old lychee trees (mainly Mauritius) was examined after persistent attacks by *R. discopunctulata* in the Mulgrave Valley, south of Cairns. Data collected were an estimate of the level of damage in each tree (based on a 5 category rating system) and variation in damage through the row.

d) Evaluation of traps for *Monolepta*

A range of traps was tested in flowering avocado trees to determine whether any would be acceptable for monitoring *Monolepta* activity. Traps included 1) Window traps based on cross-attached perspex panels, 2) Bait traps using lures of eugenol or indole, and 3) Yellow panels covered with Tanglefoot[R]. Efficacy was established by comparing catches from traps held for a set period at a number of positions (on a rotation basis).

e) Efficacy of approved insecticides and some unregistered products

The efficacy, rainfastness and residual activity of a number of insecticides against *R. discopunctulata* was assessed in bioassays. Chemicals were applied to new growth on lychees and left in the field for one day and six days post-application. Another treatment included rain 24 hours after insecticide application and just prior to testing. Treated leaves were placed in 250 ml containers with 10 beetles/container, and assessed after 15, 24 and 40 hours for number of beetles alive, moribund and dead. There were 3 replicates of each "no rain" treatment and 2 of each "rain" treatment. Assessment also included a leaf damage rating of 1) None 2) Minimal 3) Moderate and 4) Considerable. Controls were maintained of beetles with untreated leaves. The specific products and rates assessed are presented in the results.

f) Assessment of new chemical control techniques

1 - Feeding inhibitors for *Monolepta*.
Two products were assessed for their ability to inhibit feeding by *M.*

australis on avocado foliage, to see whether they had potential when applied systemically. Phenoxyacetic acid (dissolved in acetone) and phenoxyethanol were applied at rates of 0.01, 0.05 and 0.1%, each treatment receiving a single leaf and 10 beetles. Treatments were left 24 hours before being assessed for % damage.

2 - Stickers and extenders to enhance control.
Products including Ulvapron (petroleum oil/antievaporant-carrier), Bond (synthetic latex, surfactant), Agridex (non-ionic surfactant) and Velsicol (48% polyisobutylenes) were tested alone, in combination or with carbaryl to ascertain whether rainfastness could be improved, the rate of chemical loss reduced or the leaf surface characteristics changed so that inhibition of beetle feeding could be enhanced to the point where it was superior to that achieved by carbaryl alone. The combinations and rates of product used are provided in the results, with both *M. australis* and *R. discopunctulata* being assessed.

3 - Controlled-release formulations of systemics to specifically target leaf-feeders.
A range of systemic insecticides in controlled-release form were applied pre-and post-planting to small lychee trees in pots by incorporation around the root zone. The formulation (of phorate, carbosulfan and carbofuran) and rates are given in the Results. Bioassays involved confining 10 *R. discopunctulata* with 2 new leaves from a treatment in a 250 ml jar for 48 hours. Leaves were tested at 4, 7.5 and 12 weeks after insecticides were introduced to the soil.

g) Population dynamics of adult beetles

Light traps (using mercury vapour lamps) were maintained on the Atherton Tableland (10 kms NW Kairi) and wet tropical coast (20 kms W Innisfail) between August 1985 and May 1989. The Tableland trap was located at the interface of bushland and an avocado orchard while the Coastal trap was placed adjacent to rainforest and numerous lychee trees. Continuous collections were obtained from the Tableland site over this period while intermittent collections occurred on the wet coast. All species of *Monolepta* and *Rhyparida* were sorted from each catch, usually representing a 7 day period.

For each catch period the data collected for *Monolepta australis* and *Rhyparida discopunctulata* included 1) numbers of beetles, 2) their sex-ratio, 3) the level of ovarian development in 20 females dissected per collection, and 4) the number and type of parasitoids present. Ovaries were rated into one of eight categories, from negligible development to complete development with fully-developed eggs present. Numbers of fully developed eggs were counted.

From the data accumulated information was obtained on changes in seasonal abundance in each species, estimates of seasonal breeding activity, parasitoid influences on longevity, fecundity and abundance of beetles and abundance/crop phenology relationships.

Risk assessment (feeding intensity) can be gauged from changes in the numbers of beetles with a corresponding change in the average level of ovarian development. For example, a rapid increase in abundance coupled with rapidly increasing maturity would constitute increased feeding activity and a high risk situation. The above data were organised accordingly and periods of high risk identified for both *M. australis* and *R. discopunctulata*.

The redshouldered leaf beetle *Monolepta australis*

DETAILED RESULTS

i) Fruitpiercing moths

a) Adult moth feeding activity and seasonal incidence

Table 1 presents the results of seasonal sampling of the primary moth species for the period 1985 - 1989. *O. fullonia* was particularly common in lychees in November but remained relatively abundant right through the wet season until May. *O. jordani* was mainly active between February and July. *O. materna* was in evidence through the entire year though not particularly abundant in coastal areas. The other species were more common between April and July than at other times. Late February to early June is evidently the major period of activity for primary species in North Queensland.

Table 1. **Mean number of fruitpiercing moths recorded each month from fruit at various localities (mainly on the wet tropical coast) between 1985 and 1989**

Species	J	F	M	A	M	J	J	A	S	O	N	D	Mean
O. fullonia	3.3	6.0	5.2	6.7	4.0	0.5	0.3	0	0	0	10.7	6.0	3.6
O. materna	0	0.5	2.3	0.8	0.8	0.5	0.8	0.3	0	0	1.8	0	0.7
O. jordani	1.3	4.0	6.3	8.4	8.8	5.5	3.3	0	0	0	0.8	0.3	3.2
R. cocalus	0	0.3	0.3	0.8	0.3	1.0	1.0	0	0	0	0	0	0.3
E. salaminia	0	0.3	1.3	2.3	4.3	1.5	1.5	1.0	0	0	0.8	0	1.1
K. aurantia	0	0	0.3	2.3	4.3	1.5	1.0	0	0	0	0	0.7	0.8
Total primary	4.6	11.1	15.7	21.3	22.5	10.5	7.9	1.3	0	0	14.1	7.0	9.7
Others	10.3	17.5	8.5	11.6	11.3	6.0	2.3	4.0	0	0	10.6	17.8	8.3

Table 2 examines the incidence of fruit-piercing moth activity on the Wet Tropical Coast as opposed to Tableland areas. Overall activity on the coast was about twice that on the Tablelands. While *O. fullonia* and *O. jordani* were the major species on the coast *O. materna* and *O. fullonia* were essentially the only ones of note on the Tablelands of the 3 species recorded there.

Table 2. A comparison of fruitpiercing moth activity between the Wet tropical coast and Tablelands in carambola crops sampled at comparable dates between February and June

	Mean no. per sample	
Species	Wet Coast	Tablelands
O. fullonia	11.0	2.8
O. materna	0.5	6.5
O. jordani	6.3	0
R. cocalus	0	0
E. salaminia	1.5	0.3
K. aurantia	0.8	0
TOTAL	20.1	9.6

Table 3 looks at the variation in moth activity through the night and reveals a significant reduction in moth feeding as night progressed. It is evident that beyond midnight feeding activity is of less importance.

Table 3. Variation in the numbers of moths feeding on carambola fruit throughout the night

Species	1830 h	2030 h	2230 h	0030 h	0230 h	0430 h
O. fullonia	3	3	5	2	3	1
O. materna	1	1	4	0	0	0
O. jordani	5	1	2	1	0	1
E. salaminia	2	2	2	0	2	1
K. aurantia	3	1	0	1	1	0
Total primary	14	8	13	4	6	3
Others	11	4	7	2	5	1

Regression of no. primary species on time Y = 15 - 2X (r=0.81*)

Table 4 considers the ratio of males to females taken at fruit and the reproductive condition of the latter. Males outnumbered females by 3.7 times in the total sample of 315 moths. Of the females caught 62.7% contained spermatophores and fully developed eggs while 31.3% were not mated and had developing ovaries.

Table 4. Sex-ratio of primary fruitpiercing moths collected at fruit and the reproductive condition of females

Males	Females			
	Ovaries not fully developed		Ovaries fully developed	
	Not mated	Mated	Not mated	Mated
248	21	1	3	42

Table 5 examines the association between the primary species and a number of crops sampled between 1985 and 1989. *O. fullonia* was by far the most important species feeding on lychees in North Queensland. *O. fullonia* and *O. jordani* were the main species recorded from carambolas. *O. fullonia* was the most important species overall but the importance of *O. materna* on these crops increased with distance away from the coast or rainforest areas.

Table 5. Relative numbers of primary fruitpiercing moths caught during regular monitoring of fruits in North Queensland between November 1985 and July 1989

	Lychees	Carambolas	Citrus & other
O. fullonia	91	122	31
O. jordani	3	129	13
O. materna	7	41	1
E. salaminia	3	42	3
R. cocalus	0	11	3
K. aurantia	0	33	1

b) Seasonal breeding activity and habitat utilization

As sampling was only undertaken once a month and several factors could have biased the actual numbers of larvae recovered presence and absence data are more pertinent to ascertain plant utilization. Fig. 2 illustrates the % frequency of presence of each moth species in each habitat for each month. *O. fullonia* utilized all habitats although Habitat III was occupied most often. Breeding on *T. smilacina* occurred distinctly between November and March. *O. materna* also utilized all habitats with Habitat I the least frequently occupied. January to April was its major period for breeding which continued at low levels through the remainder of the year. *R. cocalus* predominated in rainforest although it utilized those habitats containing Form II of *T. similacina* during maximum breeding between February and May. *O. jordani* and *K. aurantia* can be considered rainforest species (Habitat I). *O. jordani* bred on *Tinospora* throughout the year but *K. aurantia* only rarely (Fig. 2).

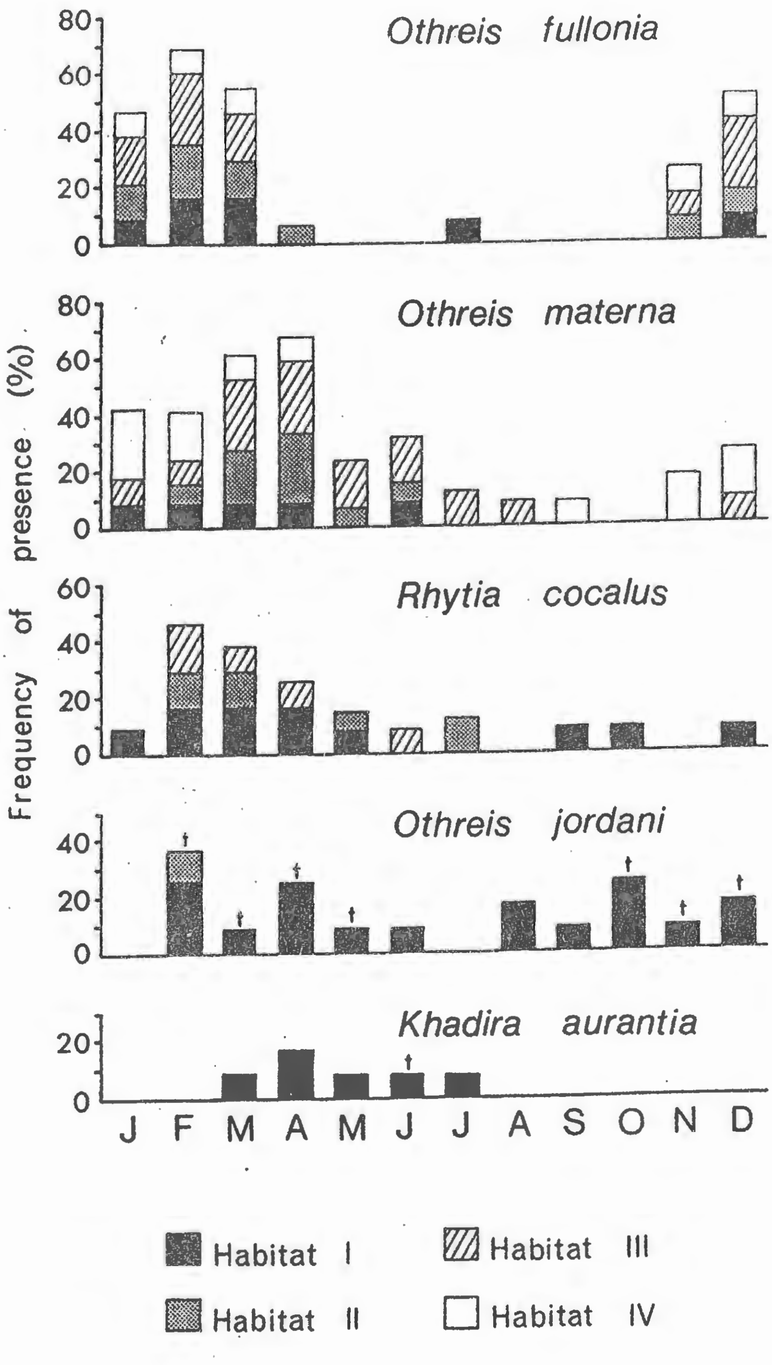


Fig. 2 - Frequency of utilization of different habitats for breeding by various fruitpiercing moth species († = sampling occasions when larvae of *O. jordani* and *K. aurantia* were collected from *T. smilacina* - see text for details).

Fig. 3 provides information on the changes in the proportions of new and mature leaf in the 3 forms of *T. smilacina* throughout the year, fruiting and flowering patterns and % occupancy by fruitpiercing moth larvae. Form I appeared to sustain some moth breeding throughout the year although February to April, and to a lesser extent December/January and May, were the major occasions. Form II, which is semi-deciduous through the dry season with little or no new growth between June and October, was occupied most frequently between December and April. Flowering and fruiting in this form is a wet season phenomenon and contrasts in this respect with the other two forms. Leaf material was entirely absent between June and mid-October in Form III while November to February was the most utilized period.

The degree of interaction between moth species within habitats was ascertained using a variation of Sorensen's co-efficient (modified) (after Southwood, 1978). The formula uses number of occurrences rather than number of individuals, with +1 indicating complete cohabitation and -1 complete separation.

Co-efficient of association, $C'_{AB} = \frac{[a-(b+c)]}{n}$

where a = no. occurrences of A + B together
b = no. occurrences of A alone
c = no. occurrences of B alone
n = total no. occurrences with a species present

Absences are not included as this could simply reflect an absence of plant material (e.g. Form III) which would bias co-efficients between habitats. Data were analysed for each species against each other species within a habitat, and for a species against all other species where 3 or more occurred in a habitat. In Habitat I analysis also included occasions when larvae were found on host plants other than *T. smilacina* (Fig. 2). The data are presented in Fig. 4. For Habitat I, all co-efficients involving one to one species comparisons were negative and ranged from -0.36 to -1.0. Where a species interaction with all remaining species was considered the level of association rose to +0.08 (with all host plants considered) or -0.14 (only *T. smilacina* considered). For Habitat II, all associations were negative with -0.40 being the highest co-efficient. The interaction between all species was substantially greater than between any two species (-0.2 to -0.54) in Habitat III. In Habitat IV where only *O. fullonia* and *O. materna* occurred the co-efficient of association was -0.17.

c) Larval nutrition and host plant preferences

Experiment 1 - Larval feeding in *O. fullonia* was completed in 16-19 days on *T. smilacina*, 21 - 24 days on *S. harveyanum* and 23 - 33 days on *S. japonica* (Fig. 5). Instars varied from 5 - 6 on *T. smilacina* (100% survival), 5 on *S. harveyanum* (90% survival) and 5 - 7 on *S. japonica* (30% survival). Puparial weights were heaviest in those fed *T. smilacina*, reaching up to 2.12 g 3 days after cessation of feeding.

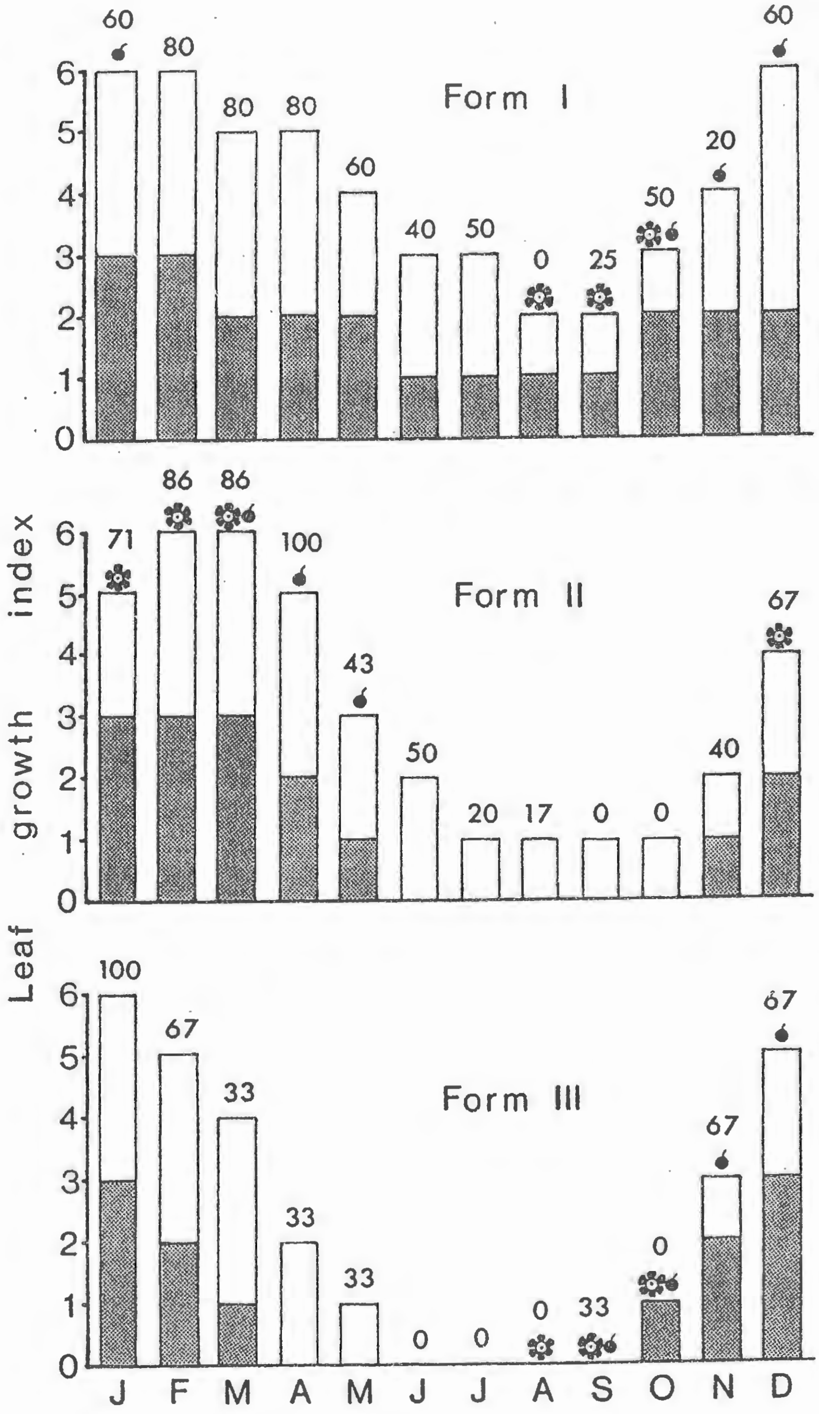


Fig. 3 - Seasonal phenology of the three forms of *T. smilacina* in north Queensland - Shaded bars = new growth, Open bars = mature leaf. Numbers above each bar = % occurrence of larvae.

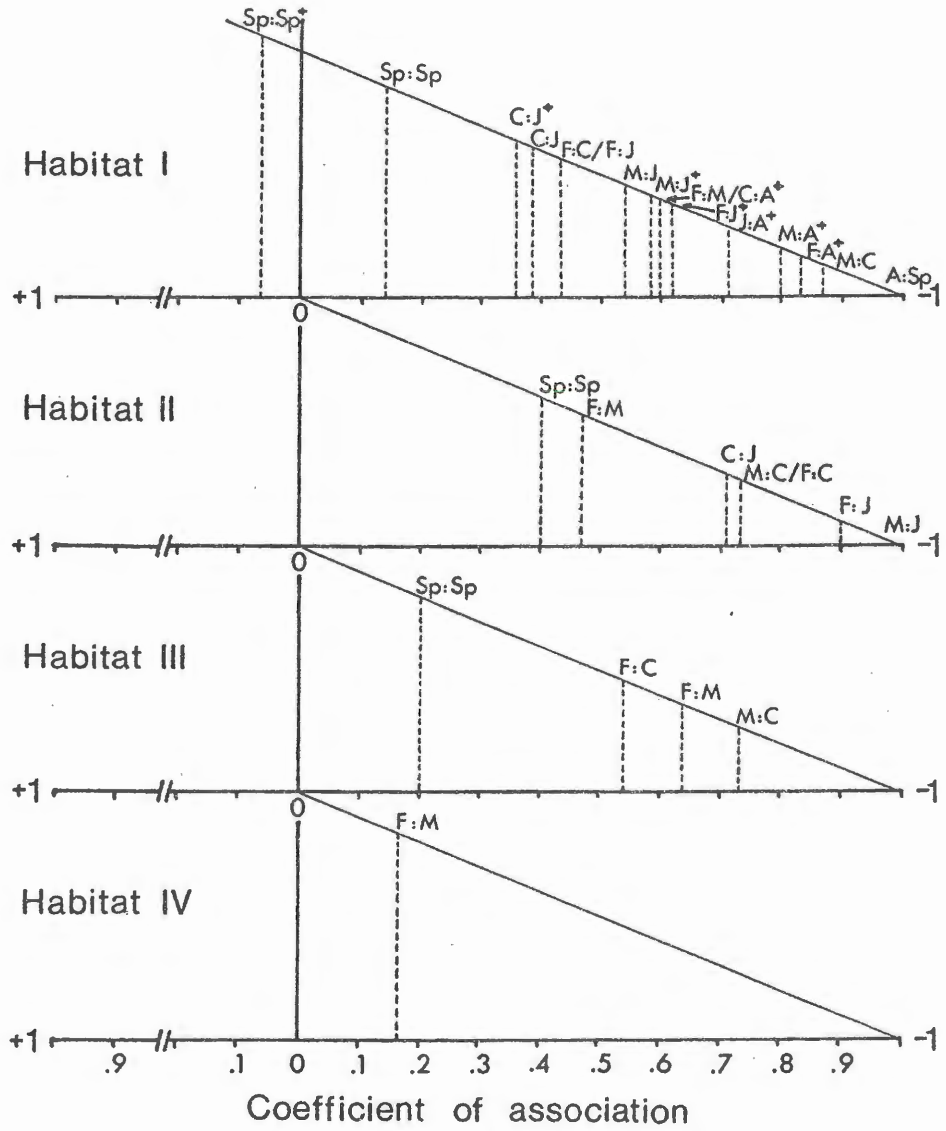


Fig. 4 - Coefficients of association between species of fruitpiercing moth in 4 habitats. (Sp = any species, F = *O. fullonia*, M = *O. materna*, C = *R. cocalus* J = *O. jordani*, A = *K. aurantia*) - Superscript + indicates all host plants.

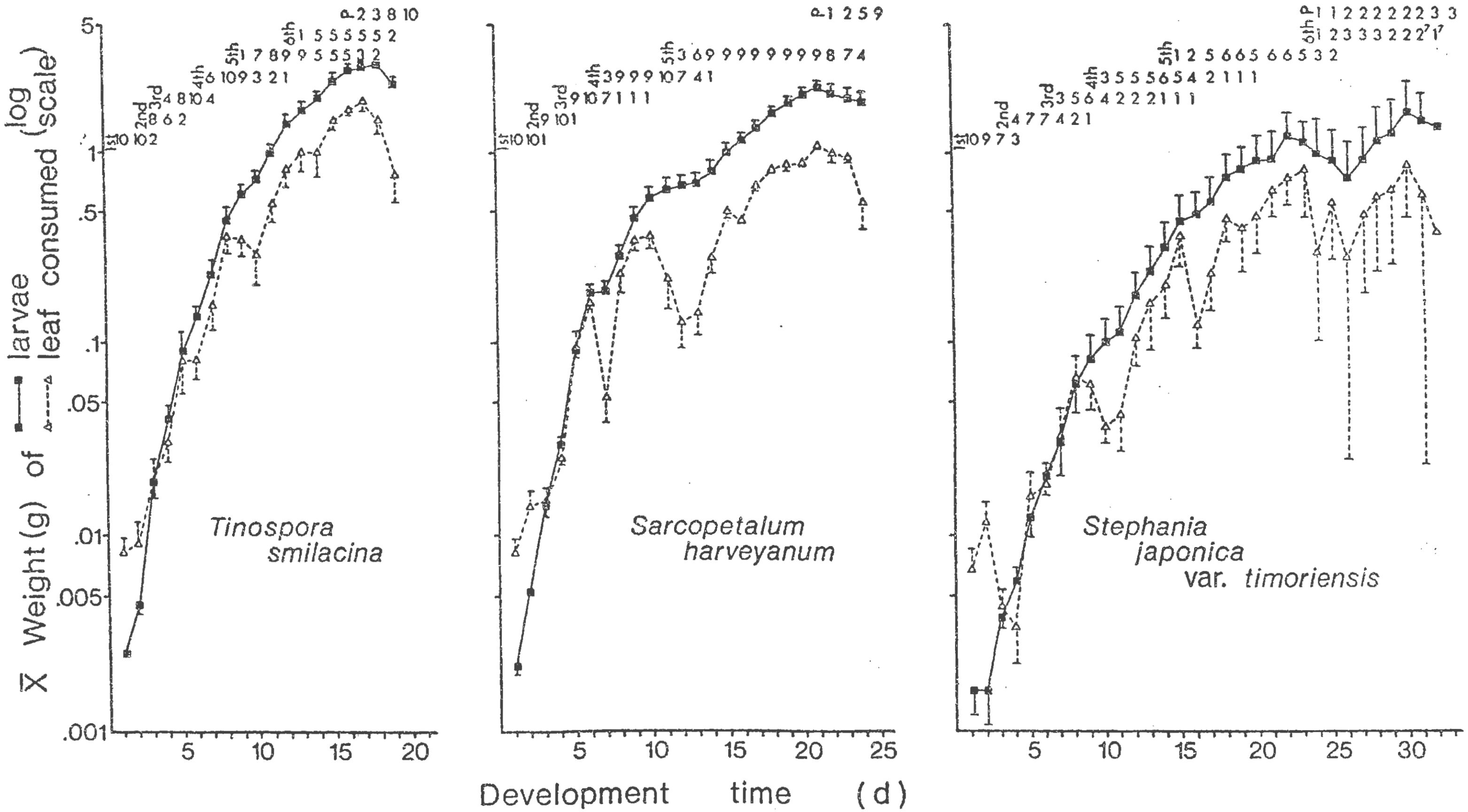


Fig. 5 - Development of larvae of *O. fullonia* on 3 different host plants. The number of surviving larvae in each instar each day are given together with their mean weight and the mean quantity of leaf consumed. Vertical lines indicate standard errors.

Efficiency of conversion of ingested food to body substance (ECI) - for wet weight of leaves and assumed constant consumption rate ECI in *O. fullonia* peaked at 73.5 in the 2nd instar for *T. smilacina* (Table 6). For *S. harveyanum* and *S. japonica* it peaked in the 2nd and 3rd instars respectively at 58.9 and 40.5. For each instar ECI's for *T. smilacina* exceeded those for the other species, and those for *S. harveyanum* exceeded those for *S. japonica* except for the 5th instar.

Approximate digestibility (AD) - In general, AD decreased from 1st to final instar, differing little between plant species for the 1st and 2nd instars (Table 6). For the 3rd and 4th instars AD was highest for *T. smilacina*.

Efficiency of conversion of digested food to body substance - In all cases ECD's for the 1st instars were substantially lower than for all other instars. For larvae fed *T. smilacina* the ECD's in the 1st and 2nd instars were considerably higher than those for the other species (Table 6). For larvae provided with *S. harveyanum* and *S. japonica* ECDs peaked during the 4th instar. *O. fullonia* fed *S. japonica* showed the greatest variation in ECD through the larval stadia.

Table 6. Digestiblity and efficiency of conversion of *Tinospora smilacina*, *Sarcopetalum harveyanum* and *Stephania japonica* var. *timoriensis* by larvae of *Othreis fullonia* at a constant rate of consumption

Instar	E.C.I.			A.D.			E.C.D.		
	Ts	Sh	Sj	Ts	Sh	Sj	Ts	Sh	Sj
1ST	42.0	29.3	21.6	79.5	82.5	70.6	55.3	36.2	34.7
2ND	73.5	58.9	37.8	67.2	65.0	60.2	109.9	91.3	63.3
3RD	61.9	48.9	40.5	69.1	52.5	44.9	90.8	93.2	93.8
4TH	48.7	40.1	38.6	53.8	41.0	36.0	91.0	97.9	108.0
5TH	31.0	20.9	25.1	33.8	28.7	28.4	96.5	88.4	93.4
6TH	22.3	-	19.1	29.3	-	28.8	96.4	-	72.9

Experiment 2 - Larvae fed *T. smilacina* in the 1st instar completed this stage sooner and achieved larger 2nd instar HWs (1.01 - 1.04 mm) than those fed either *S. harveyanum* (0.92 - 0.98 mm) or *S. japonica* (0.88 - 1.00 mm) (Fig. 6). The mortality recorded during the 1st instar was 0% for *T. smilacina,* 7% for *S. harveyanum* and 60% for *S. japonica* At the completion of the 3rd instar those larvae that had fed on *T. smilacina* as their second food, irrespective of their first, attained the largest HWs (2.72 - 2.80 mm) for the mixed food groups. These however were smaller and took more time to achieve than the average HWs recorded for larvae fed *T. smilacina* for all three instars. Irrespective of the food experienced during the first 3 instars those larvae finally exposed to *T. smilacina* completed development soonest and achieved the greatest puparial weights (2.29 -

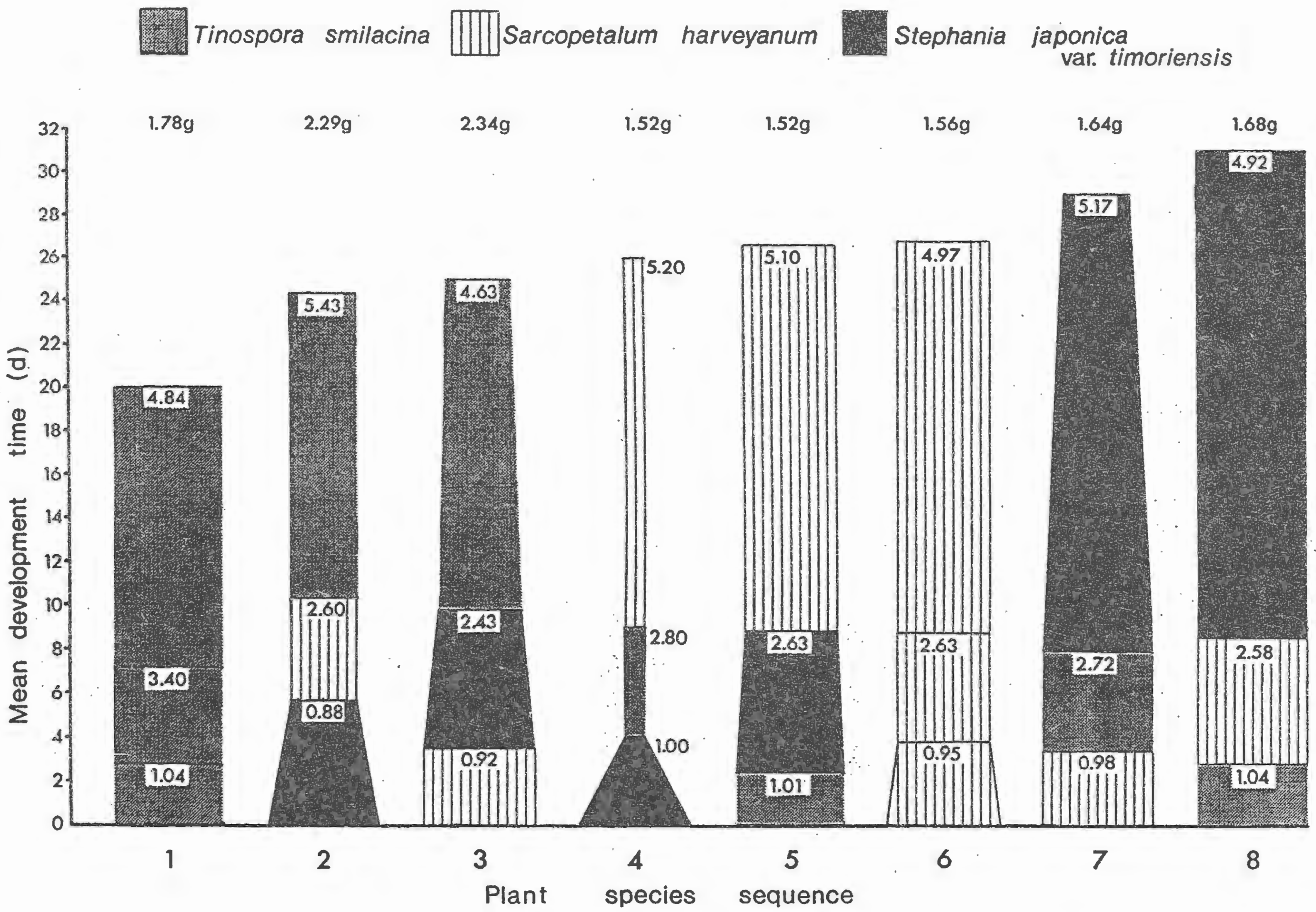
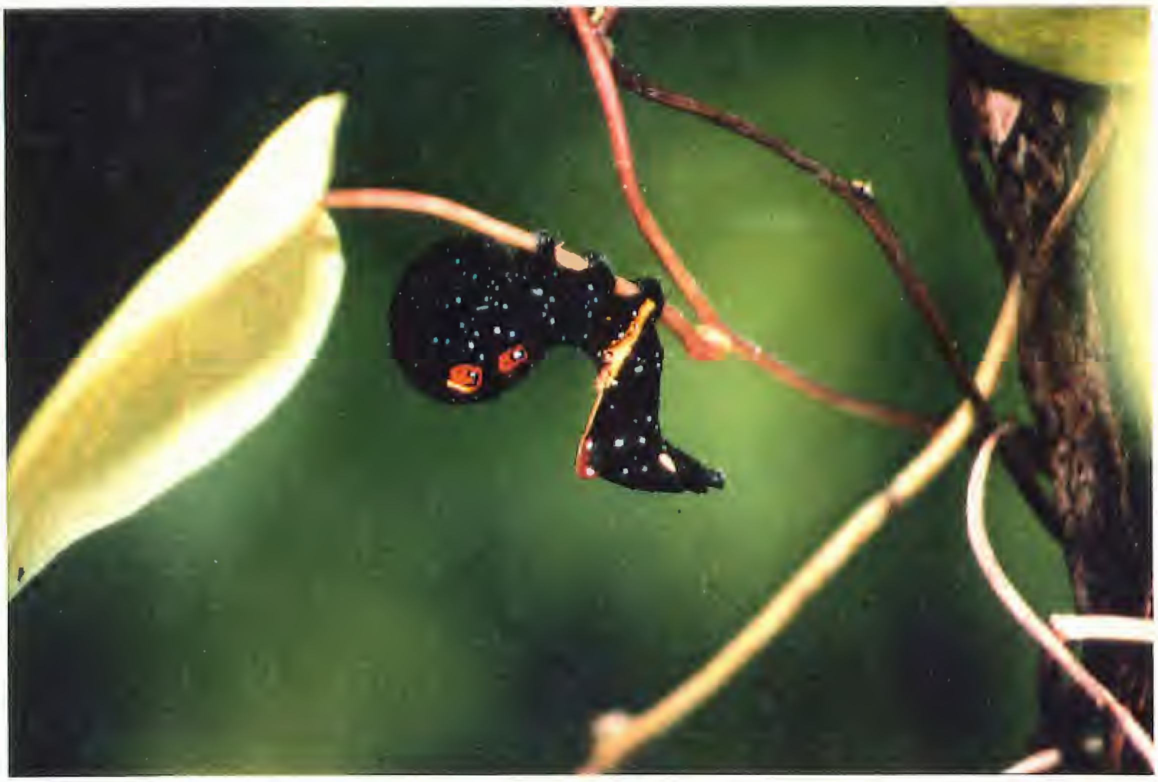


Fig. 6 - Development of larvae of *O. fullonia* when provided with a food change after the 1st and 3rd instars. The values associated with each bar indicate mean head capsule widths for 2nd, 4th and final instars while the 2-day mean puparial weights are given above each bar. Decreasing bar width corresponds to decreasing survival.

The rainforest form of *Tinospora smilacina*, a major fruit piercing moth larval food plant



Larva of the fruit piercing moth *Khadira aurantia*

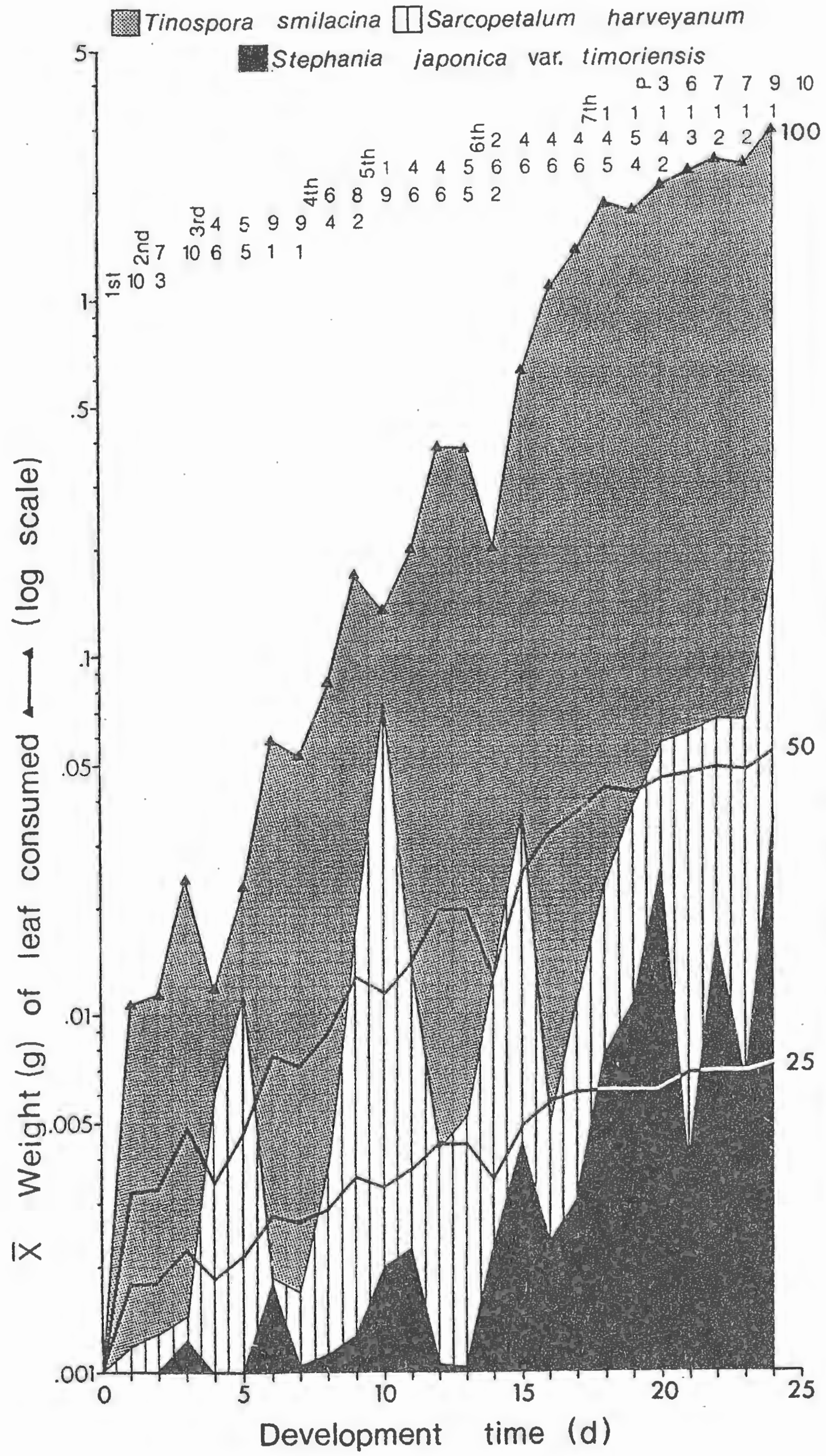


Fig. 7 - Development of the larvae of *O. fullonia* offered a choice of food. The numbers of larvae in each instar each day are given and the mean weight of leaf consumed. The right hand axis indicates the percentage of each plant species eaten each day.

2.34 g). Those larvae fed *S. japonica* for the final instars took longest to complete development. Feeding species other than *T. smilacina* to larvae for the first 3 instars increased development time by approximately 20%.

Experiment 3 - For the first 3 days of larval development >80% of food selected was *T. smilacina* (Fig. 7). From then until day 15 feeding alternated between a high proportion of *T. smilacina* (>75%) and a high proportion of *S. harveyanum* (>75%). *S. japonica* contributed <20% of the diet on any day to day 15 by which time larvae were in 5th and 6th instars. From day 15 *S. japonica* contributed a greater proportion of the food eaten, occasionally >40%. Consumption of *T. smilacina* was ≥50% during final development.

Utility of a range of host plants - Table 7 lists the moth species associations with Menispermaceae in the field in North Queensland and probable and possible alternate hosts determined by laboratory feeding responses. *O. fullonia* fed on all host plants tested, although it was only recorded breeding on less than a third of these. *K. aurantia* was the next most cosmopolitan feeder and obviously utilizes a range of species for breeding. *O. jordani* fed on several genera while *O. materna* and *R. cocalus* fed only on species of *Tinospora*. *Eudocima salaminia* (Cramer), the only primary species of moth that doesn't feed on *T. smilacina*, is known only from *S. japonica* in North Queensland, though it is said to occasionally feed on *S. harveyanum* (Sands and Schotz, 1989).

d) Pheromone screening and identification

Some unsaturated hydrocarbons were identified from a number of species, including *O. materna*, which may be pheromone components. However, these were novel compounds with bigger than usual molecules (e.g. C_{16} - C_{18}) which suggested low volatility. No marked biological activity has been demonstrated for these materials so far.

e) Survey of indigenous biological control agents

Table 8 presents the details of a very cursory survey of the native parasites of fruitpiercing moths in north Queensland. Two and possibly three species of *Telenomus* were recorded from eggs, as well as at least one *Trichogramma* sp. An *Ooencyrtus* sp., which appears to be related to one from PNG, was bred from the eggs of *O. fullonia* collected near Mareeba. All egg parasite material was forwarded to the CSIRO Long Pocket Laboratories for cataloguing but no specific names have yet been issued. In general the egg parasites were most active from the end of the wet season. Larval parasites included two species of tachinid fly and a eulophid wasp. Predators observed attacking eggs or larvae included ants, a *Chrysopa* sp., a lygaeid bug and spiders.

Table 7. Larval Food Plants (Menispermaceae) of some Fruitpiercing Moth Species in N. Queensland

	Othreis fullonia	*Othreis materna*	*Othreis jordani*	*Rhytia cocalus*	*Khadira aurantia*
Recorded feeding on (in the field)	*Tinospora smilacina* (all forms) *Sarcopetalum harveyanum* *Legnephora moorei* *Tiliacora australiana*	*Tinospora smilacina* (all forms)	*Tinospora smilacina* (Form I) *Pycnarrhena novoguineensis*	*Tinospora smilacina* (Forms I & II)	*Tinospora smilacina* (Form I) *Legnephora moorei* *Sarcopetalum harveyanum* *Stephania japonica* var. *timoriensis*
5th instars have eaten (in the lab)	*Carronia protensa* *Hypserpa decumbens* *Hypserpa laurina* *Hypserpa reticulata* *Pachygone longifolia* *Pachygone ovata* *Pycnarrhena novoguineensis* *Stephania bancroftii* *Stephania japonica* var. *discolor* *Stephania japonica* var. *timoriensis* *Tinospora angusta*	*Tinospora angusta*	*Tinospora smilacina* (Forms II & III) *Tinospora angusta* *Hypserpa laurina* *Pachygone ovata*	*Tinospora smilacina* (Form III) *Tinsopora angusta*	*Tinsopora smilacina* (Forms II & III) *Tiliacora australiana* *Hypserpa laurina* *Pycnarrhena novoguineensis* *Stephania bancroftii* *Stephania japonica* var. *discolor*
5th instars have tasted (in the lab)	N/A	-	*Carronia protensa* *Legnephora moorei* *Sarcopetalum harveyanum*	-	*Carronia protensa* *Pachygone ovata* *Tinospora angusta*

Table 8. Collections of egg and larval parasites of fruitpiercing moths in North Queensland during the study

Species	Host	Collection date	Site
Egg parasites			
Trichogramma sp.	*O. fullonia*	19/7/86	Mareeba
Telenomus sp. 1	*O. materna*	19/3/87	Wangetti Beach
Telenomus sp. 1	*O. materna*	14/4/87	Wangetti Beach
Trichogramma sp.	*O. jordani*	21/9/87	Mission Beach
Telenomus sp.?	*O. materna*	18/2/88	NW Dimbulah
Telenomus sp. 1	*O. materna*	26/7/88	Wangetti Beach
Telenomus sp.?	*O. jordani*	26/7/88	Mission Beach
Telenomus sp. 2	*P. imperialis*	23/8/88	Mission Beach
Ooencyrtus sp. nov.	*O. fullonia*	?/5/89	via Mareeba
Telenomus sp. 1	*O. fullonia*	?/16/90	via Mareeba
Larval parasites			
Exorista sorbillans	*E. salaminia*	8/4/86	Ella Bay
Euplectrus sp.	*R. cocalus*	30/7/87	Wangetti Beach
Carcelia sp.	*R. cocalus*	21/9/87	Wangetti Beach

f) Evaluation of the enclosure of trees under netting

Complete coverage of carambola trees with 3 x 8 mm anti-hail mesh increased the recovery of marketable fruit by up to 87%. Birdban 40 reduced the incidence of fruitpiercing moth damage but at least a third of the moths were able to penetrate the mesh.

g) Light protection system

The trial area and light intensity readings are shown in Fig. 8. In the assessment of damage inhibition 14 moths were detected in the protected trees and 31 in the unprotected ones. This equated to 13% of fruit clusters with damage in protected trees and 40% in unprotected ones (Table 9). Only 5% of ripe fruit were damaged in the illuminated block compared to 18% in the non-illuminated. On the six occasions between March and June when moth activity was monitored significantly fewer primary piercers occurred in the illuminated area (av = 0.09/tree) than in the non-illuminated one (av. = 0.39/tree) ($F = 10.76^{**}$)(Table 10). However, several genera generally regarded as secondary e.g. *Achaea* and *Ophiusa*, were distributed relatively evenly across both protected and unprotected areas ($F = 0.59$ ns).

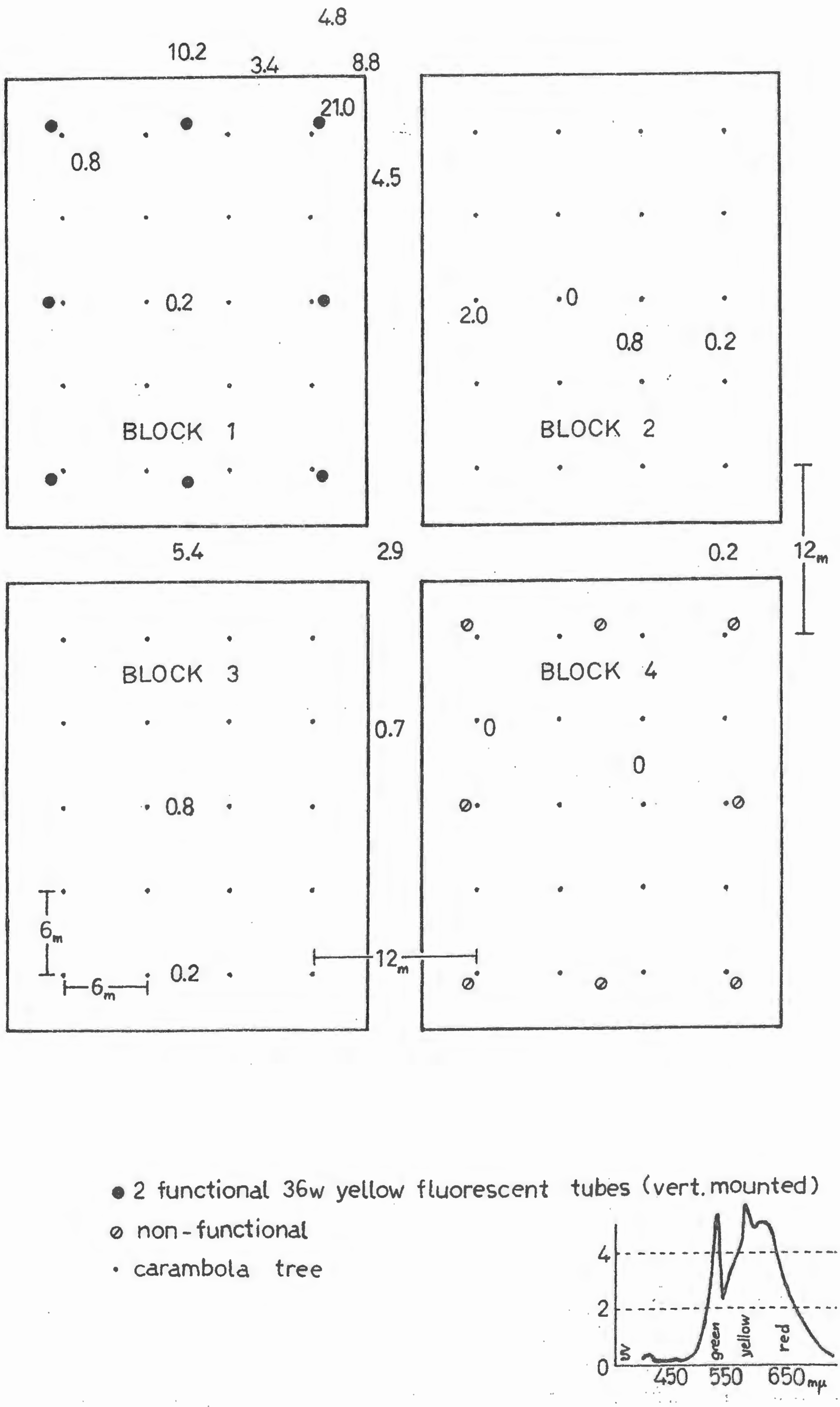


Fig. 8 - Light trial area at Walkamin Research Station. Functional lights and positions are indicated together with light readings (in lux) throughout the entire area. The wavelength profile for the yellow tubes is also given.

Table 9. Efficacy of light barriers in the protection of fruit against fruit-piercing moth

	Protected fruit	Unprotected fruit
Total no. ripe fruit examined	80	124
Total no. moths caught*	14	31
Mean no. feeding punctures/ripe fruit	0.10	0.34
Total % of clusters with damaged fruit	13	40
% ripe fruit with damage	5	18

* 1 h sampling from 2 100 h for the first 3 of 4 nights

h) Development of attractant-based control systems

1 - Non-volatile characteristics of attractive fruit

Of the characteristics assessed for lychees (Table 11) only the position of the trees was significant, with fruit in border rows being attacked most often. In general, only a single variety (mainly Tai So) was ripe on any sampling occasion. In carambolas, where mixtures of varieties were sampled moths apparently selected the ripest fruits on any occasion (Table 12). Significant differences in attacked and untouched fruit were recorded in colour, % Brix, pH and size.

2 - Volatile components of fruits

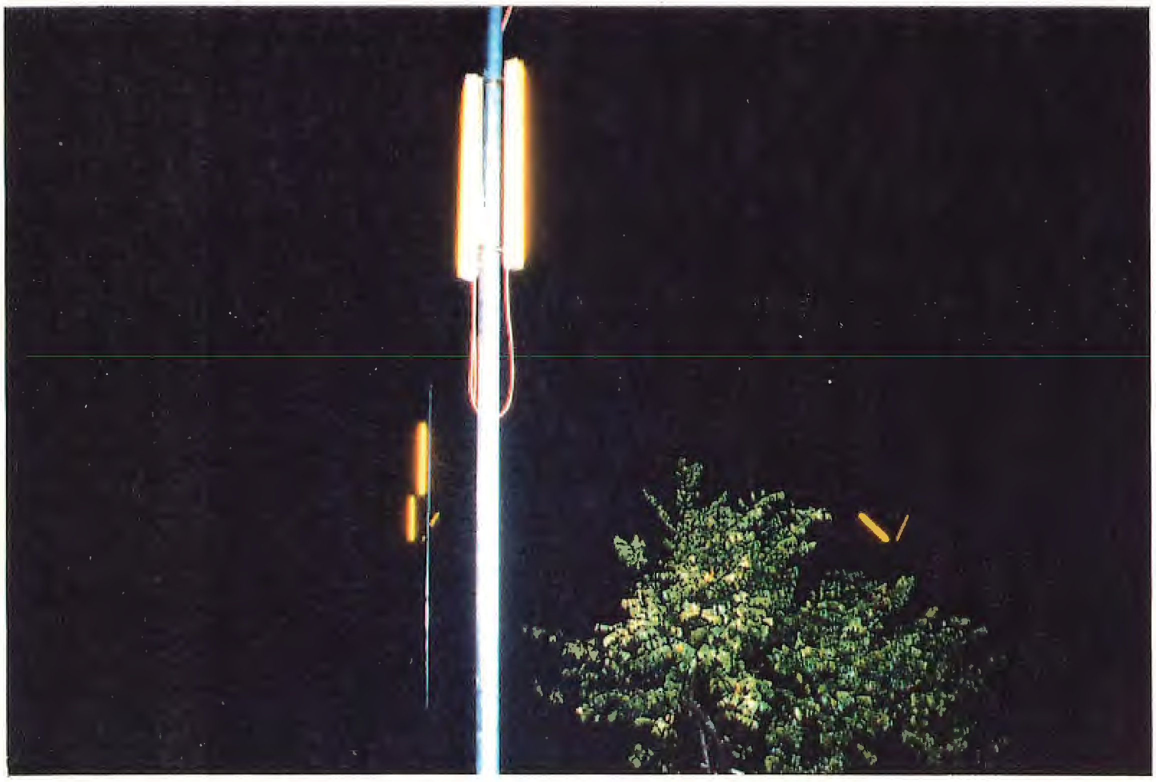
<u>Electroantennogram studies</u> - Response to a range of individual volatiles - Immature unfed and mature fed *O. fullonia* and *O. materna*, including both males and females, were tested for their responses to 15 volatiles represented by esters (6), alcohols (4), aldehydes (3), an aromatic and a terpene hydrocarbon. The volatiles were prepared in quantities of 0.025 (conc. 10^{-3}) and 2.5 μl (conc. 10^{-1}). The chemicals used are given in Table 13 which provides data on the mean response of mature fed *O. fullonia* in millivolts and as a percentage of the standard (2.5 μl amyl acetate). The increase in response as the concentration increased from 10^{-3} to 10^{-1} varied from negligible to substantial. The fruity esters (e.g. n-butyl acetate and methyl butyrate) elicited the greatest response while the "green" alcohols (e.g. 1-hexanol) and aldehydes (e.g. trans-2-hexenal) produced intermediate reactions. Similar trends were recorded for *O. materna* and for immature unfed moths of both species (Table 14).

Response to increasing volatile levels - While in the fruity esters such as amyl acetate, n-butyl acetate and methyl butyrate there was a substantial increase in response from 0.025 to 2.5 μl, and for alcohols such as 1-hexanol and cis-3-hexen-l-ol it was smaller though still considerable, the increase from 2.5 to 12.5 μl was generally negligible to minor (Table 15).

Table 10. Assessment of the impact of lights on fruit-piercing moth presence on carambola fruit

Occas. No.		% trees with		No. primary moths	
		All moth species	Primary species	Av. Per tree	Species
1	Light	0	0	0	-
	Dark	18.5	18.5	0.30	*O. fullonia* = 1 *O. materna* = 7
2	Light	7.1	0	0	-
	Dark	18.2	15.2	0.21	*O. materna* = 7
3	Light	7.1	7.1	0.07	*O. materna* = 1
	Dark	26.5	11.8	0.18	*O. fullonia* = 1 *O. materna* = 5
4	Light	85.7	7.1	0.07	*O. fullonia* = 1
	Dark	94.1	35.3	0.41	*O. fullonia* = 5 *O. materna* = 12
5	Light	?	21.4	0.21	*O. fullonia* = 2 *O. materna* = 1
	Dark	?	32.4	0.50	*O. fullonia* = 7 *E. salaminia* = 2 *O. materna* = 8
6	Light	?	21.4	0.21	*E. salaminia* = 1 *O. materna* = 2
	Dark	?	47.1	0.76	*O. fullonia* = 15 *O. materna* = 11
Paired t-test		t = -5.28 *	t = -4.75 **	t = -4.99 **	
Anovar		F = 0.59 ns	F = 6.69 *	F = 10.76 **	

The fruitpiercing moth *Othreis materna* sitting on the disposable netting 'Birdban 40'



Light protection system with yellow fluorescent tubes

Table 11. Characteristics of lychees attacked by fruit-piercing moth compared to adjacent untouched fruit (data presented as sample means)

Site	Coll. height (m)	Tree row no.	Fruit Weight (g)	% water	Softness[a]	Colour[b]	%Brix	pH	Moth species	No. fruit
1.	1.07	2.12	D-20.2	79.8	5.5	5.4	16.36	3.89	Of=24	50
	R=0-5	1-6	UD-21.6	80.0	5.4	5.1	16.32	3.90	Oj=1	
2.	1.13	1.73	D-20.7	78.2	5.8	7.5	15.67	4.13	Of=14	30
	R=0-3.5	1-5	UD-21.7	77.5	6.0	7.3	15.61	4.07	Oj=1	
3.	0.98	1.55	D-18.0	75.4	5.0	6.6	19.25	3.87	Of=19	40
	R=0-5	1-4	UD-18.3	76.7	4.9	6.6	19.03	3.84	Tr=1	
4.	1.75	1.38	D-18.9	76.6	4.6	6.1	17.65	3.79	Of=8	16
	R=0-5	1-6	UD-18.5	76.6	5.2	6.0	17.10	3.71		
5.	1.43	1.79	D-16.1	74.4	4.0	7.4	18.57	3.81	Of=13	28
	R=0-3.5	1-3	UD-15.1	79.3	3.7	7.3	17.21	3.71	Es=1	

- X^2 = 19.4 *** t=-0.51 ns t=-1.95 ns t=0.25 ns t=1.17 ns t=1.71 ns t=1.26 ns

N.B.

R = range
D = damaged
UD = undamaged

a = range of softness 0 - 10
b = range of colour 1 - 7

Table 12. Characteristics of carambolas attacked by fruit-piercing moth compared to adjacent untouched fruit (data presented as sample means)

Site	Coll. height (m)	Tree row no.	Fruit weight (g)	% water	Softness [a]	Colour [b]	%Brix	pH	Moth species	no. fruit
1.	2.06	1.35	D-93.0	91.4	9.6	3.7	6.83	3.32	Of = 20	40
	R=0-5	1-2	UD-63.4	91.4	9.5	2.6	5.49	2.95	Oj = 3	
2.	1.04	1.43	D-71.1	90.2	9.3	5.9	7.49	3.26	Of = 6	14
	R=0-3.5	1-4	UD-87.1	90.6	9.5	4.6	7.11	3.09	Es = 1	
3.	1.92	2.28	D-80.7	89.8	9.9	6.1	7.44	3.49	Of = 14	36
									Oj = 1	
	R=0-2.5	1-6	UD-59.3	90.2	9.9	3.5	6.31	2.96	Om = 2	
									Es = 2	
4.	1.10	1.50	D-93.3	89.6	9.7	6.3	8.30	3.19	Of = 17	40
									Om = 2	
	R=0-3.5	1-4	UD-73.2	90.1	9.8	3.9	7.38	2.74	Es = 2	
	-	X^2 = 14.4 *	t=3.80 ***	t=-1.77 ns	t=1.01 ns	t=6.69 ***	t=8.29 ***	t=6.21 ***		

N.B.

R = range
D = damaged
UD = undamaged

a = range of softness 0-10
b = range of colour 1-7

Table 13. Electroantennogram response of *Othreis fullonia* (mature and fed) to a range of common fruit and plant volatiles

Chemical	+Response at conc. 10^{-1}		+Response at conc. 10^{-3}	
	mV	%standard	mV	%standard
Amyl acetate*	1.14	100	0.39	36
n-butyl acetate	1.45	129	0.60	54
Ethyl butyrate	1.18	106	0.41	38
Methyl butyrate	1.31	117	0.42	40
Ethyl acetate	1.10	98	0.42	38
Methyl anthranilate	0.33	31	0.24	22
Ethanol	0.33	31	0.29	27
l-hexanol	0.90	80	0.35	31
Cis-3-hexen-l-ol	0.82	73	0.29	27
l-butanol	0.59	52	0.25	22.5
Acetaldehyde	0.30	28	0.23	21
Hexanal	0.59	52	0.26	23
Trans-2-hexenal	0.66	59	0.29	25.5
d-limonene	0.39	35	0.23	20
Eugenol	0.28	26.5	0.17	17

*indicates standard (conc. 10^{-1})
+mean of 3♀♀ 1♂ moth per chemical per concentration and 2 exposures/moth

N.B. 10^{-1} = 2.5µl of chemical in 25µl paraffin oil
10^{-3} = 2.5µl of chemical in 2.5ml paraffin oil
} 25µl of product as available odour

Table 14. Increase in electroantennogram response* of *Othreis fullonia* and *Othreis materna* as chemical concentration increased from 10^{-3} to 10^{-1}

Chemical	*O. fullonia*		*O. materna*	
	Immature Unfed (A)	Mature Fed (B)	Immature Unfed (C)	Mature Fed (D)
Amyl acetate*	64	64	67	69
n-butyl acetate	73	75	90	92
Ethyl butyrate	69	68	86	75
Methyl butyrate	80	77	95	87
Ethyl acetate	53	60	60	61
Methyl anthranilate	8	9	11	0
Ethanol	7	4	14	8
l-hexanol	56	49	41	51
Cis-3-hexen-l-ol	56	46	34	41
l-butanol	36	30	27	33
Acetaldehyde	8	7	5	6
Hexanal	47	29	33	30
Trans-2-hexenal	31	34	27	28
d-limonene	11	15	8	0
Eugenol	8	10	7	9

*increase in response based on differences recorded for individual chemicals in relation to the standard (amyl acetate) for concentrations 10^{-3} and 10^{-1}.

Paired t-tests: A vs B, t=1.23ns; C vs D, t=0.59ns; A vs C, t=0.04ns; B vs D, t=-0.43ns.

Table 15. Electroantennogram response of *Othreis fullonia* (mature and fed) to various concentrations of five volatiles of fruit

Chemical	Dose		Response	
	ml+	Conc.	mV	% standard
Amyl acetate	12.5	$10^{-0.3}$	1.53	114.5
	5.0	$10^{-0.7}$	1.47	111.0
	2.5*	10^{-1}	1.37	100.0
	0.025	10^{-3}	0.51	40.5
n - butyl acetate	12.5	$10^{-0.3}$	1.89	144.0
	5.0	$10^{-0.7}$	1.70	128.0
	2.5	10^{-1}	1.70	127.0
	0.025	10^{-3}	0.68	56.0
Methyl butyrate	12.5	$10^{-0.3}$	2.16	167.0
	5.0	$10^{-0.7}$	1.97	151.0
	2.5	10^{-1}	1.69	130.0
	0.025	10^{-3}	0.63	50.0
1 - hexanol	12.5	$10^{-0.3}$	1.22	94.0
	5.0	$10^{-0.7}$	1.10	84.0
	2.5	10^{-1}	0.98	74.0
	0.25	10^{-3}	0.65	50.0
Cis-3-hexen-1-ol	12.5	$10^{-0.3}$	1.08	84.0
	5.0	$10^{-0.7}$	1.10	86.0
	2.5	10^{-1}	1.02	78.0
	0.025	10^{-3}	0.57	45.0

* indicates standard
\+ in 25 μl of paraffin oil

Response to combinations of volatiles - Methyl butyrate, n-butyl acetate and 1-hexanol were presented individually, in pairs or all together (at 2.5 μl) to mature fed *O. fullonia* and compared against a standard (amyl acetate). The greatest response was to n-butyl acetate alone (Table 16). However, the observed response to combinations of volatiles was always greater than that expected from the sum of proportional individual responses. In particular, the addition of 1-hexanol (60%) to n-butyl acetate (40%) or to n-butyl acetate (20%) + methyl butyrate (20%) showed increases of 37% and 27% respectively over that expected.

Bioassays - Small cage tests - Tests with *O. fullonia* in 30 x 30 x 60 cm cages examined the response of moths to increasing ester concentrations, to individual vs combined volatiles and to ester combinations against a 50% carambola juice extract. Cages each contained 2 'artificial' fruits per treatment, a male and a female moth, and were replicated five times on any occasion. Table 17 provides the results in which a preference was shown for the highest concentration of esters, a combination of esters was favoured over individual volatiles and the juice extract was selected over the 'artificial' offerings.

Flight cage tests - A flight cage (2 x 2 x 3 m) was employed to test whether moths would select fruit of a particular ripeness on the basis of the ratio of the volatile chemicals they contained. Three levels of ripeness simulating mature, ripe and very ripe Kiwi fruit (after Bartley and Schwede, 1989) were prepared using 7 volatiles in different proportions. The volatiles represented 89.7 to 94.2% of those present in Kiwi fruit and esters accounted for 6.1, 58.2 and 91.9% of volatiles in mature, ripe and very ripe situations respectively. Each 'artificial' fruit contained a total of 25 μl of volatiles and were either free of or included 12.5% sucrose. Each fruit and control was replicated 4 times on any night and suspended at 2 m height in the flight cage. Fruit was separated by approximately 0.4 m. Tests included 2 male and 2 female mature *O. fullonia* or *O. materna* on a single occasion. The most frequent response was to the 'ripe' fruit (Table 18) irrespective of whether sugar was present. The 'very ripe' simulation proved the next most attractive. Some piercing was recorded on the controls which suggests a degree of orientation to hanging objects.

ii) Leaf-eating beetles

a) Taxonomic studies on the genus *Rhyparida*

A preliminary guide to the taxonomic associations of 26 species of *Rhyparida* from the Atherton Tableland was prepared to facilitate the ecological studies. Subsequent investigations using the DELTA system of computer generated descriptions and keys examined over 40 characters in 40 species. The species used were those for which names were available, and males and females of each were examined. Unfortunately, half of the characters selected (such as colour patterns, degree of punctuation) proved unsuitable for this type of plus/minus categorisation, with written description and illustration being more suitable. No new relationships between species were revealed by DELTA. Length/width ratios are useful in chrysomelid taxonomy and would need to be incorporated in descriptions, though again the DELTA system did not seem to offer any advantages over more

Table 16. Electroantennogram response of *Othreis fullonia* (mature and fed) to a number of single and combined fruit volatiles

Chemicals & Combinations+	Response			
	mV	% Standard		O-E
		Observed	Expected	
Amyl acetate (2.5)*	1.19	100	100	-
n-butyl acetate (Ba) (2.5)	1.68	141	141	-
Methyl butyrate (Mb) (2.5)	1.31	111	111	-
1-hexanol (H) (2.5)	0.72	59	59	-
Ba (1.5) + Mb (1.0)	1.59	134	129	5
Ba (1.0) + Mb (1.5)	1.52	128	123	5
Ba (1.5) + H (1.0)	1.48	124	108	16
Ba (1.0) + H (1.5)	1.50	126	92	34
Mb (1.5) + H (1.0)	1.11	93	90	3
Mb (1.0) + H (1.5)	1.11	93	80	13
Ba (1.5) + Mb (0.5) + H (0.5)	1.56	132	119	13
Mb (1.5) + Ba (0.5) + H (0.5)	1.44	122	107	15
H (1.5) + Ba (0.5) + Mb (0.5)	1.29	109	86	23

* indicates standard
+ figures in parentheses indicate quantitites in μl (delivered in 25 μl paraffin oil)

Fruitpiercing moth feeding damage to an artificial fruit

Table 17. Bioassays in small cages with field-collected *Othreis fullonia* 1) Increasing ester concentrations 2) Single vs combined volatiles 3) Esters vs juice extract

1	% response Exclusive	Shared	2	% response Exclusive	Shared	3	% response Exclusive	Shared
Control	0	0	Control	0	0	Control	0	20
0.01%	0	20	n-butyl acetate (A)	0	20	A + B	0	0
0.1%	0	0	Methyl butyrate (B)	0	0	5 esters	0	0
1%	40	20	1-hexanol (C)	0	0	Juice extract	40	20
			A + B	40	20			
			A + C	0	0			
			B + C	0	0			

1 - Equal proportions of n-butyl acetate + methyl butyrate in 25 ml baits
2 - 25 μl of each single chemical or 12.5 μl of each chemical in a combination/25 ml bait
3 - 25 μl of chemicals in equal proportion / 25 ml bait + 5.3 % sucrose
Five esters included n-butyl acetate, methyl butyrate, ethyl butyrate, amyl acetate and hexyl acetate.
Juice extract = 50% fresh carambola juice (10.6% sugar) / 25 ml bait

Table 18. Bioassay response of *Othreis fullonia* and *Othreis materna* to combinations of primary Kiwi fruit volatiles, apportioned according to degree of ripeness⁺

Chemicals	Mature % in fruit	Ripe % in fruit	Very Ripe % in fruit	Control
Acetaldehyde	1.5	6.8	0.1	-
Methylbutyrate	2.0	25.4	11.1	-
Hexanal	6.2	0.9	0.2	-
Ethyl butyrate	0.6	14.2	69.4	-
Trans-2-hexenal	76.1	25.5	7.1	-
l-hexanol	0.4	2.0	0.2	-
n-butyl acetate*	2.9	9.5	6.1	-
Total	89.7	84.3	94.2	0
Esters (%)	6.1	58.2	91.9	0
Bioassay response (%)				
- With sugar (12.5%)	0.0	71.4	50.0	25.0
- Without sugar	25.0	62.5	37.5	12.5
Mean	12.5	67.0	43.8	18.8

⁺after Bartley + Schwede (1989) J.Agr.Food Chem. 37: 1023-1025
*used instead of ethyl hexanoate
N.B. a total of 25μl of volatiles/25ml bait (0.1%)

traditional methods. Mr Storey had hoped that measurements might provide a reliable means of sexing the beetles but this was not the case. Species are quite variable, especially in colour patterns. However, it is now evident that over 200 species of *Rhyparida* exist in Australia. While division of the genus into groups or subgenera appears difficult based on external characters male genitalia offer some hope for segregating species and defining relationships. Further elucidation of *Rhyparida* taxonomy will require the input of several experts and such a project can only be considered long-term.

b) Evaluation of feeding significance and economic injury

Monolepta australis in avocados - Avocado foliage - As beetle numbers increased from 0.2 to 1 per leaf the mean % of leaves with some damage rose from 49.2 to 87.6 (Table 19). However, at 0.31 beetles/leaf only 1.4% of leaves suffered >50% damage while at 1 beetle/leaf this rose to 25.2% and would constitute economic injury.

Table 19. *Monolepta* damage to soft avocado foliage*

Beetles/sleeve	Av. no. leaves	Av. beetles/leaf	Av. % leaves with some damage	Av. % leaves with >50% damage
25	24.4	1.0	87.6	25.2
10	32.0	0.31	69.8	1.4
5	25.6	0.20	49.2	1.4

* over a 7 day period when beetle mortality ranged from 24-34% per treatment

Avocado flowers - Mean fruit-set per panicle for each tree under the various treatments is given in Table 20. Flower panicles exposed to *M. australis* only, and those with unrestricted access to insects, had very similar overall levels of fruit-set ($t = 0.12$, $p > 0.05$). Where insects were excluded from flowers, or where only *P. amplipennis* was present, fruit-set was four to five times less than in the two other treatments. Fruit-set in tree D (cv. Hass) was negligible owing to moisture stress, which induced heavy flower loss, and ultimately no mature fruit were produced (Table 20). Exclusion of tree D data from statistical analysis resulted in a significant difference in the levels of fruit-set in the *M. australis* and no insect treatments ($t = 2.35$, $p < 0.05$).

Table 20. Fruit-set in avocado trees in the presence or absence of *Monolepta australis* at flowering and the resultant production of mature fruit

Insects associated with flowers	**Mean no. fruit set/flower panicle/replicate**				
	A. cv Fuerte	**B. cv Fuerte**	**C. cv Hass**	**D. cv Hass**	**Overall mean ± SE**
M. australis alone	1.0	1.6	2.1	0.0	1.18 ± 0.45
P. amplipennis alone	0.0	1.0	0.0	0.0	0.25 ± 0.25
All insects excluded	0.5	0.5	0.2	0.0	0.30 ± 0.12
Unrestricted access	0.7	0.7	3.2	0.5	1.28 ± 0.64
Av. no. *M. australis* trapped/ flowering day	39.8	72.0	131.7	13.2	64.18 ± 25.52
Av. no. mature fruit/m^3 (unrestricted access)	7.75	7.38	11.63	0.0	8.92 ± 1.36$^+$
Co-efficient of variation	0.33	0.26	0.32	-	0.30 ± 0.02

$^+$ data for trees A, B & C only

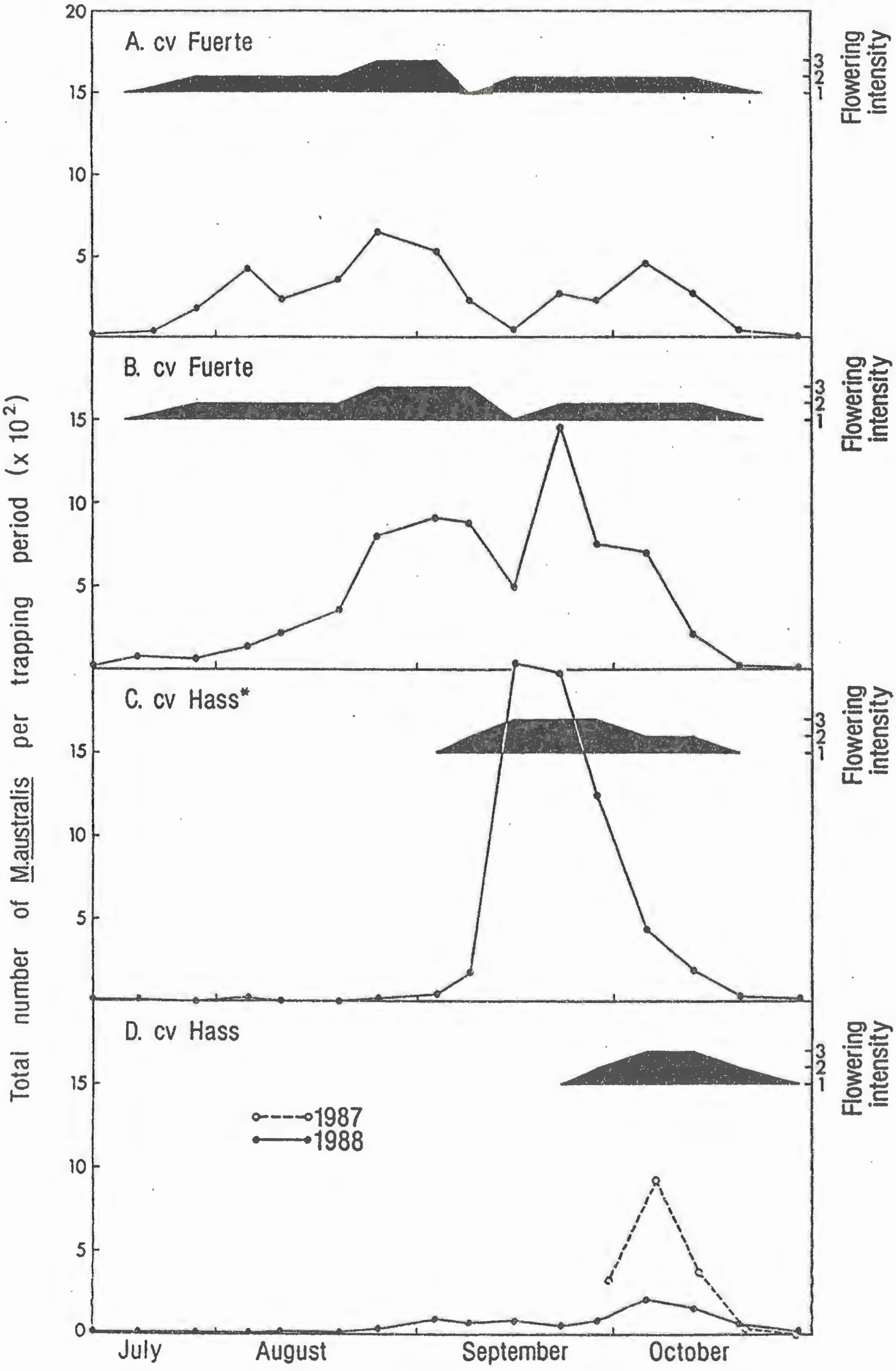


Fig. 9 - Sticky-trap catches of *M. australis* in relation to flowering intensity in four avocado trees: (a,b) cv. Fuerte; (c,d) cv. Hass.
○ - - - ○ 1987; ● ____ ● 1988.

Highest average numbers of *M. australis* per day were trapped in tree C (cv. Hass) where the flowering period was shorter than in the two trees of cv. Fuerte (A and B) (Fig. 9). Fluctuations in beetle numbers associated with individual trees virtually mirrored the intensity of flowering in those trees. The highest number of *M. australis* caught during a single trapping period was 2031 on tree C (7 - 14 September 1988) (Fig. 9). Number of mature fruit m^{-3} reached a maximum of 19 in tree C (av. = 11.6) while averaging 7.6 for the two cv. Fuerte. Commercial production of cv. Fuerte was not significantly different, at an average of 9.1 m^{-3} ($t = 1.60$, $p > 0.05$). Coefficients of variation of fruit counts were similar in the study trees (av. = 0.30) and commercial trees (av. = 0.33).

Rhyparida discopunctulata - Leaf condition and type - The % leaf loss to new growth in avocado, guava and *E. torelliana* was significantly higher ($p < 0.05$) than to mature leaves (Table 21).

Table 21. Damage to a range of leaf types caused by *Rhyparida discopunctulata*

	Av. % leaf loss+		
Foliage	New Growth	vs	Mature Leaves
Guava	7.8	*	2.4
Avocado	16.2	*	2.2
E. torelliana	11.7	*	3.3

+ caused by 1 beetle/leaf over a 2 day period
* difference significant at 5% level

Growth impairment in lychees - After 6 months the trees free of damage had increased by about one third in height and one half in canopy diameter (Table 22) irrespective of fertilizer application, whereas the damaged trees had undergone negligible growth. After 13 months all trees had grown relative to their original dimensions but in the damaged trees the increases were less than those recorded after 6 months in the undamaged ones.

c) Damage levels and pattern of beetle attack in the field

Of 21 trees scrutinised, 52% suffered damage from *R. discopunctulata* of >40% while <29% were considered to have damage levels unlikely to inhibit tree growth (Fig. 10). There was no clear pattern of damage between different trees within the row, in relation to the proximity to rainforest, to other fruit trees, to sugar cane (probable larval host) or to wind direction.

d) Efficacy of approved insecticides and some unregistered products

Table 23 presents the chemicals and rates of application against *R. discopunctulata* and assessment of their effectiveness. The approved insecticides, carbaryl and trichlorfon were very effective in the short term, with carbaryl retaining the greater effectiveness after rain. Trichlorfon did not persist over time (6 days)

Table 22. Growth Response of Young Lychee Trees in the Presence or Absence of Simulated *Rhyparida* Damage

Treatment	Av. original		Av. % of change from original in			
	Height (cm)	Canopy diameter (cm)	Height after		Canopy diameter after	
			6 months	13 months	6 months	13 months
No damage, fertilized	69.0	41.3	+ 34.8	+ 40.6	+ 48.8	+ 68.6
No damage, not fertilized	67.0	38.5	+ 30.6	+ 61.6	+ 58.4	+ 104.2
Damaged, fertilized	62.5	35.4	- 4.3	+ 18.1	+ 7.6	+ 30.6
Damaged, not fertilized	68.0	40.5	- 2.2	+ 12.9	- 16.0	+ 16.4

Rhyparida damage to terminal growth on lychee

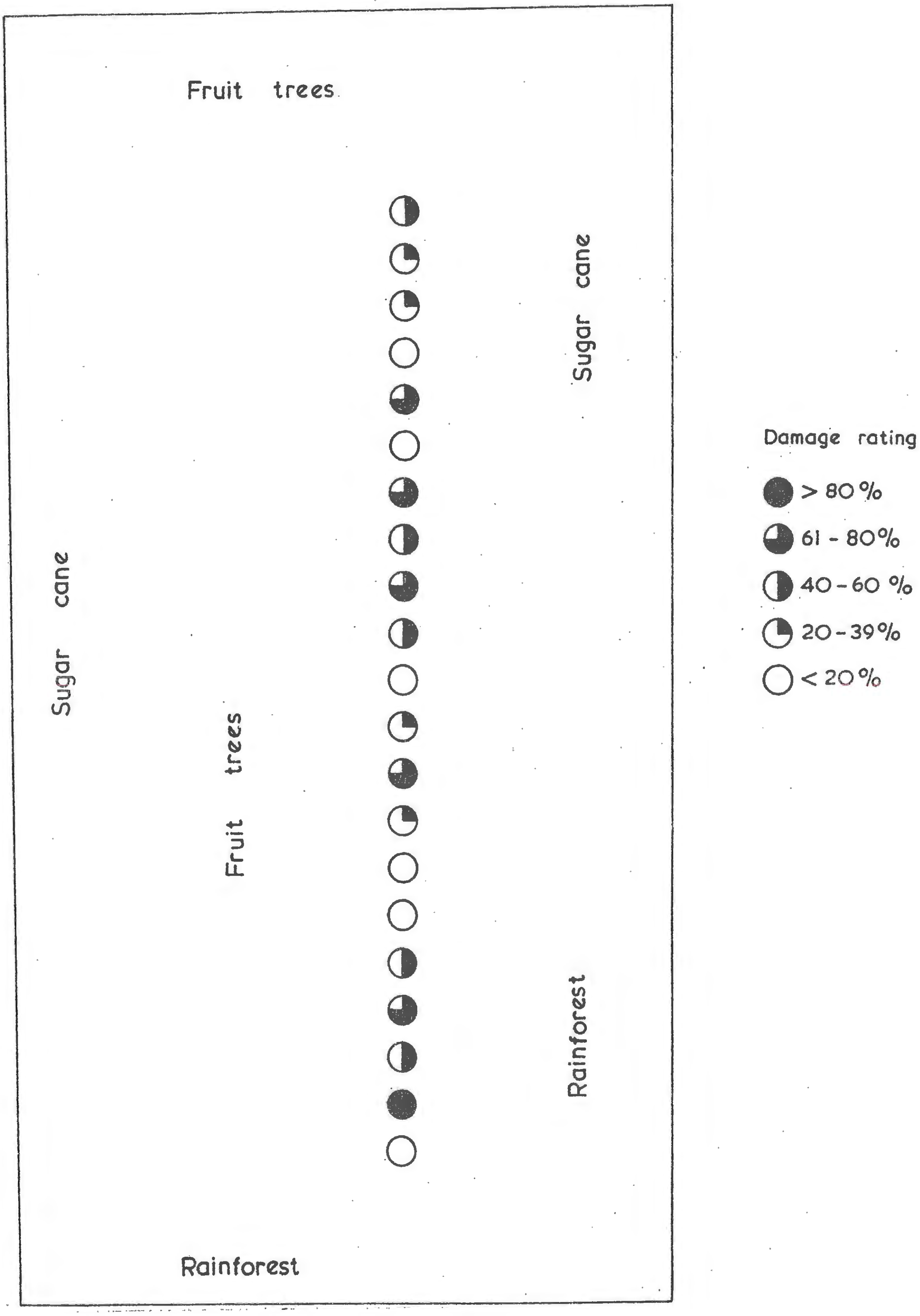


Fig. 10 - Pattern and levels of damage to new growth caused by *R. discopunctulata* in a row of young lychee trees in the Mulgrave Valley, N. Qld, in January 1987.

Table 23. Susceptibility of *Rhyparida discopunctulata* to a Range of Insecticides Applied to Lychee Foliage

Mean % in each category			1 day post application no rain		1 day post application rain	6 days post application no rain	
Treatment	Rate/s per 100 L	Assess	24 h	40 h	24 h	24 h	40 h
Cypermethrin 25g/L } Chlorfenvinphos 138g/L	400 mls	A	0	0	75	66.7	66.7
		M	16.7	10.0	15	33.7	33.7
		D	83.3	90.0	10	0	0
		Feeding	N	N	N	N	N
Deltamethrin 25g/L	50 mls	A	0	0	30	46.7	33.3
		M	93.3	93.3	70	53.3	66.7
		D	6.7	6.7	0	0	0
		Feeding	N	N	N	N	N
Endosulfan 350g/L	190 mls	A	100	100	100	100	100
		M	0	0	0	0	0
		D	0	0	0	0	0
		Feeding	Mo	Mo	Mo	C	C
Trichlorfon 625g/L	85 mls	A	6.7	3.3	90	100	96.7
		M	6.7	6.7	10	0	3.3
		D	86.7	90.0	0	0	0
		Feeding	N	N	Mo	Mi	Mi
Trichlorfon 625g/L	170 mls	A	0	0	70		
		M	10.0	3.3	20		
		D	83.3	90.0	10		
		Feeding	N	N	Mi-Mo		
Carbaryl 800g/kg	125 g	A	0	0	35		
		M	36.7	3.3	5		
		D	63.3	96.7	60		
		Feeding	N	N	N		
Methomyl 225g/L	160 mls	A	16.7	16.7	80		
		M	40.0	16.7	5		
		D	43.3	66.7	15		
		Feeding	N	N	Mi		

Categories: A = alive
M = moribund/sickly
D = dead

Feeding = None, Minimal, Moderate, Considerable
NB. All controls had 100% survival and moderate to considerable leaf damage

while endosulfan was totally ineffectual under all test conditions. The carbamate methomyl was less effective than either carbaryl or trichlorfon. Of the other unregistered products, the combination of cypermethrin and chlorfenvinphos (Barricade 'S') had similar activity to trichlorfon, irrespective of rain, and persisted only marginally better over time. Deltamethrin completely inhibited feeding but produced little mortality during the trial. The bulk of beetles appeared moribund and none recovered. Deltamethrin had reasonable rainfastness and persisted well over time.

e) Assessment of new chemical control techniques

1. - Feeding inhibitors for *Monolepta* - Table 24 indicates that while increasing the concentration of the feeding inhibitors did reduce damage levels in no treatment was it significantly less than in the controls. However, for 0.1% phenoxyacetic acid damage was significantly lower than in both treatments at 0.01%.

Table 24. Laboratory assessment of feeding inhibitors in the suppression of damage to avocado foliage by *M. australis*

Treatments	Mean % leaf damage			
	Rate of Application			
	0%	0.01%	0.05%	0.1%
Controls	28.3	-	-	-
Phenoxyacetic acid	-	35.0	18.3	11.7
2-Phenoxy ethanol	-	31.7	23.3	21.7

N.B. No beetles were dead after 24 h
LSD (5%) = 19.3

2. - Stickers and extenders to enhance control - The results presented in Table 25, for *R. discopunctulata*, have only undergone preliminary analysis but a number of inferences can be drawn. The high rate of Ulvapron + Velsicol inhibited damage as well as carbaryl in the short term. If carbaryl was added to this combination or to Bond its long term activity was marginally enhanced. None of the products improved the rainfastness of carbaryl. The results for *M. australis* were not as clear although they showed similar trends to those for *R. discopunctulata*.

3. - Controlled release formulations of systemics - After 4 weeks (post-application) no beetle deaths were recorded in any treatment (Table 26) and the levels of leaf damage were variable. After 7.5 weeks a few beetle deaths occurred in the pre-planting treatments while 50% of beetles in those post-planting treatments tested (10% phorate and 10% carbosulfan) died and the damage recorded was slight. After 12 weeks no activity was recorded against beetles.

Table 25. **Impact of stickers and extenders on feeding by *R. discopunctulata* on lychee foliage**

Treatment & Rate	1 day post application			6 days post application					
				no rain			rain		
	% D/M* beetles	% mid vein damage	% leaf damage	% D/M* beetles	% mid vein damage	% leaf damage	% D/M* beetles	% mid vein damage	% leaf damage
Control	3	44	25						
Ulvapron 20 ml/l + Velsicol 8 ml/l	8	41	46	7	58	8			
Ulvapron 40 ml/l + Velsicol 16 ml/l	7	5	2	100	18	3	14	18	10
Ulvapron 20 ml/l	8	46	46						
Ulvapron 40 ml/l	0	58	10						
Velsicol 8 ml/l	8	53	52						
Velsicol 16 ml/l	0	35	7						
Agridex 0.5 ml/l	4	82	54						
Agridex 1 ml/l	0	15	8						
Bond 1.5 ml/l	8	73	54						
Bond 3 ml/l	0	23	35						
Carbaryl 1.25 g/l	43	3	15	56	11	4	0	5	4
Carbaryl 1.25 g/l + Ulvapron 20 ml/l + Velsicol 8 ml/l				60	3	5			
Carbaryl 1.25 g/l + Ulvapron 40 ml/l + Velsicol 16 ml/l				10	0	0	0	32	8
Carbaryl 1.25 g/l + Ulvapron 20 ml/l				60	3	5			
Carbaryl 1.25 g/l + Ulvapron 40 ml/l							0	67	8
Carbaryl 1.25 g/l + Agridex 0.5 ml/l				100	5	1			
Carbaryl 1.25 g/l + Agridex 1 ml/l				100	35	15	20	32	5
Carbaryl 1.25 g/l + Bond 1.5 ml/l				93	1	3			
Carbaryl 1.25 g/l + Bond 3 ml/l				100	0	0	0	33	15
Carbaryl 1.25 g/l + Velsicol 16 ml/l				100	15	5			

* D/M - Dead/Moribund Beetles

Table 26. Impact of Controlled-release formulation of insecticides on survival and feeding of *Rhyparida* on young lychees

	Chemical conc. & granule size	Rate (g) per tree a.c.	After 4 weeks		After 7.5 weeks		After 12 weeks	
			% survival	Damage rating	% survival	Damage rating	% survival	Damage rating
	Control	-	100	2.75	100	2.50	100	2.00
PRE PLANTING	10% carbosulfan (1 mm)	1.0	100	1.25	-	-	100	1.50
	10% carbosulfan (1.5 mm)	1.0	100	1.50	80	2.00	100	1.00
	10% carbosulfan (1.5 mm)	0.5	100	2.50	-	-	100	-
	15% carbofuran (1.5 mm)	1.0	100	2.25	-	-	100	1.50
	10% phorate (1.5 mm)	1.0	100	1.75	80	3.00	100	2.00
	10% phorate (1.5 mm)	0.5	100	3.00	-	-	100	-
POST PLANTING	10% carbosulfan (1 mm)	1.5	100	2.50	-	-	100	2.50
	10% carbosulfan (1.5 mm)	1.5	100	1.50	50	1.50	100	1.75
	10% carbosulfan (1.5 mm)	0.5	100	3.00	-	-	100	-
	15% carbofuran (1.5 mm)	1.5	100	2.25	-	-	100	2.50
	10% phorate (1.5 mm)	1.5	100	1.75	50	1.00	100	2.00
	10% phorate (1.5 mm)	0.5	100	2.00	-	-	100	-

Damage rating: None = 0; Minimal = 1; Moderate = 2; Considerable = 3

f) Population dynamics of adult beetles

Monolepta australis - Fig. 11 illustrates the seasonal flight activity in adult beetles on the Atherton Tableland between 1985 and 1989. The level of activity varied between years but indicated that the major period was early December to mid April. The data indicate that there were probably two major emergences of beetles during this period. Between late June and late September there was a smaller peak in activity in any one year but on the Tablelands at least this did not represent an emergence but a resurgence corresponding to avocado (and other) flowering. Fig. 12 examines changes ovarian development in *M. australis* between 1985 and 1989. The average levels of ovarian development were lowest in summer and highest in spring, confirming December to April as the major emergence period. The results imply an increasing risk of swarming activity from December to February with a slightly reduced risk between March and May. The late winter to spring period is one of moderate activity. Co-efficients of variation for the trapping data for individual months suggest December, April and July are the least predictable in terms of activity. On the wet tropical coast where the data were less complete activity was more constant through the year and new emergences were recorded during the late winter to spring period. The incidence of parasitism by the tachinid fly, *Monoleptophaga caldwelli* Baranov, reached 33% (av. <10%) and its impact on ovarian development can be gauged from Table 27. Its effect on longevity was a reduction from a minimum average 70 days to 16 days. There was no clear seasonal pattern in the levels of parasitism.

Table 27. Ovarian development in parasitized vs non-parasitized *M. australis*

Average length of primary oocyte (mm)	Frequency*	
	Parasitized	Not parasitized
≤ 0.10	13	0
> 0.10 to ≤ 0.15	10	1
> 0.15 to ≤ 0.20	5	4
> 0.20 to ≤ 0.30	5	14
> 0.30	1	15
	Av. = 0.14 SD = 0.10	Av. = 0.29 SD = 0.09

* Sampling occasions

Fig. 11 - SEASONAL ACTIVITY IN Monolepta australis ON THE ATHERTON TABLELAND

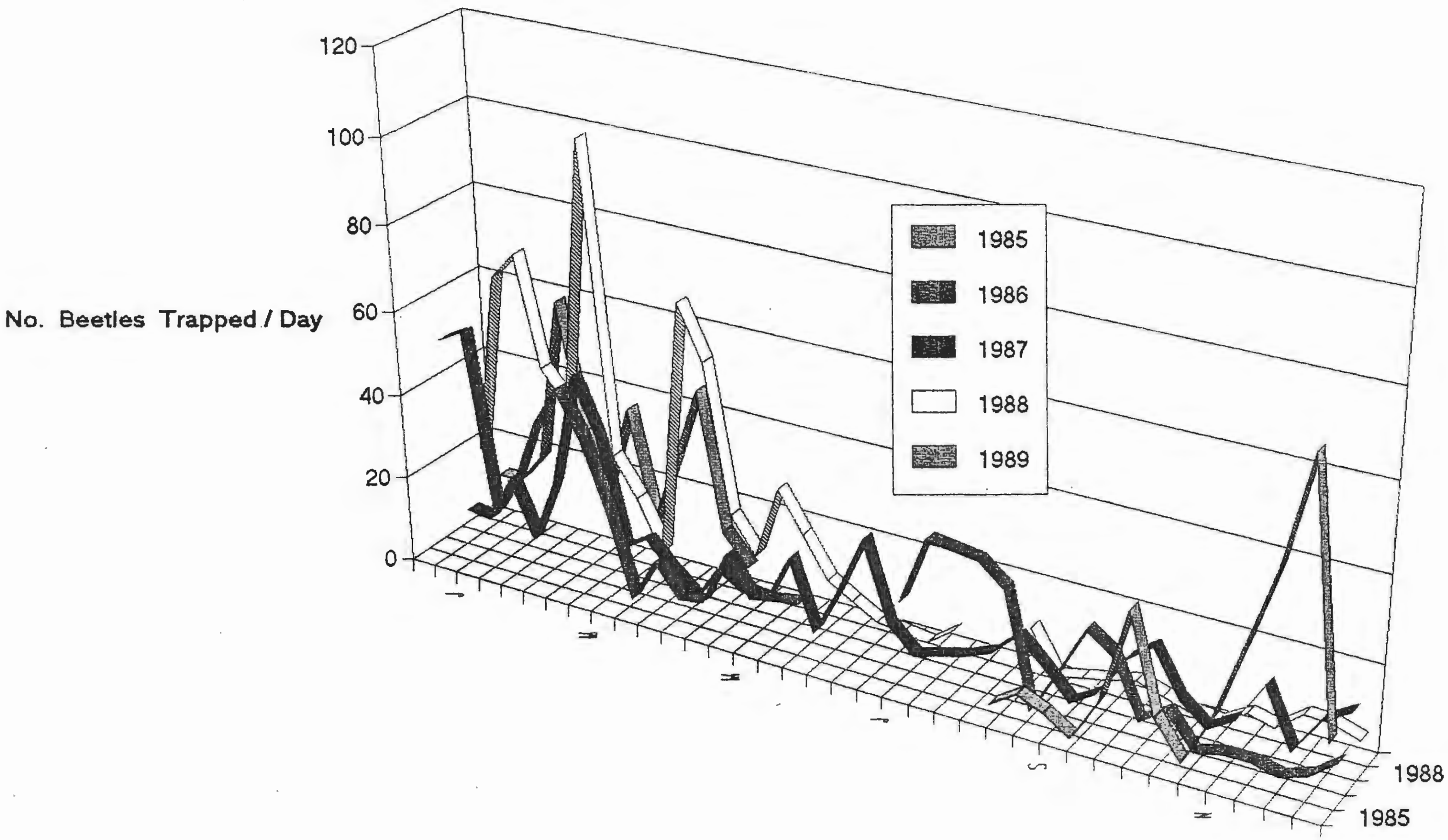
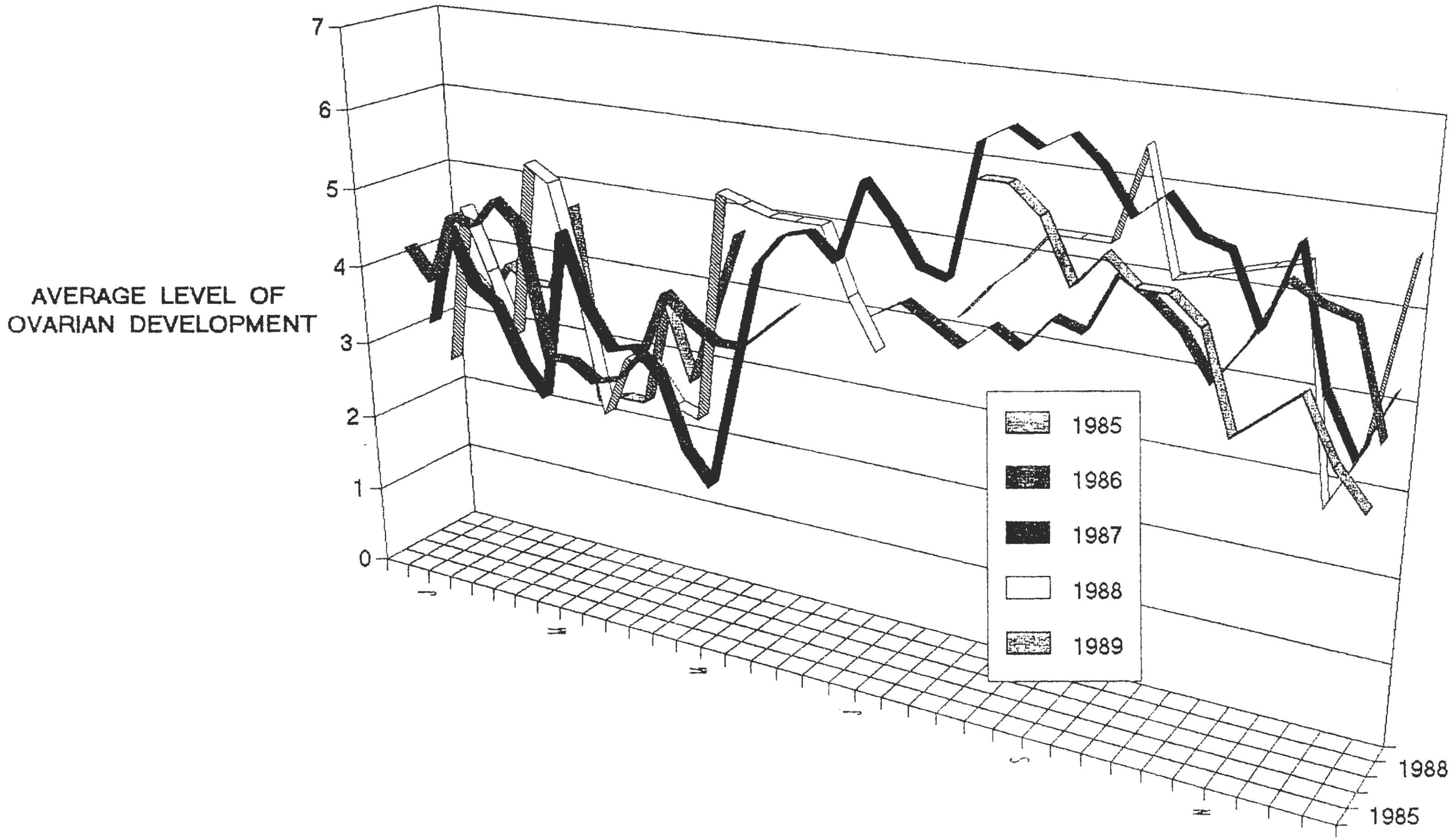


Fig. 12 - SEASONAL CHANGES IN OVARIAN DEVELOPMENT IN *Monolepta australis* ON THE ATHERTON TABLELAND



Rhyparida discopunctulata - On the Atherton Tableland this species peaked in abundance between late October and early January and between late February and April (Fig. 13). Only two generations per year were evident on the Tablelands whilst the situation on the coast was less clear. The proportion of mature beetles increased rapidly between October and December (Fig. 14) whilst those emerging in the second generation did not mature pre-winter. This clearly identifies the high risk period as September to December although co-efficients of variation suggest October and February are the least predictable months. No parasites were associated with *R. discopunctulata* in the adult stage. This species had a shorter life-span than *M. australis*.

Yellow sticky panel for monitoring activity in redshouldered leaf beetle

Fig. 13 - SEASONAL ACTIVITY IN *Rhyparida discopunctulata* ON THE ATHERTON TABLELAND

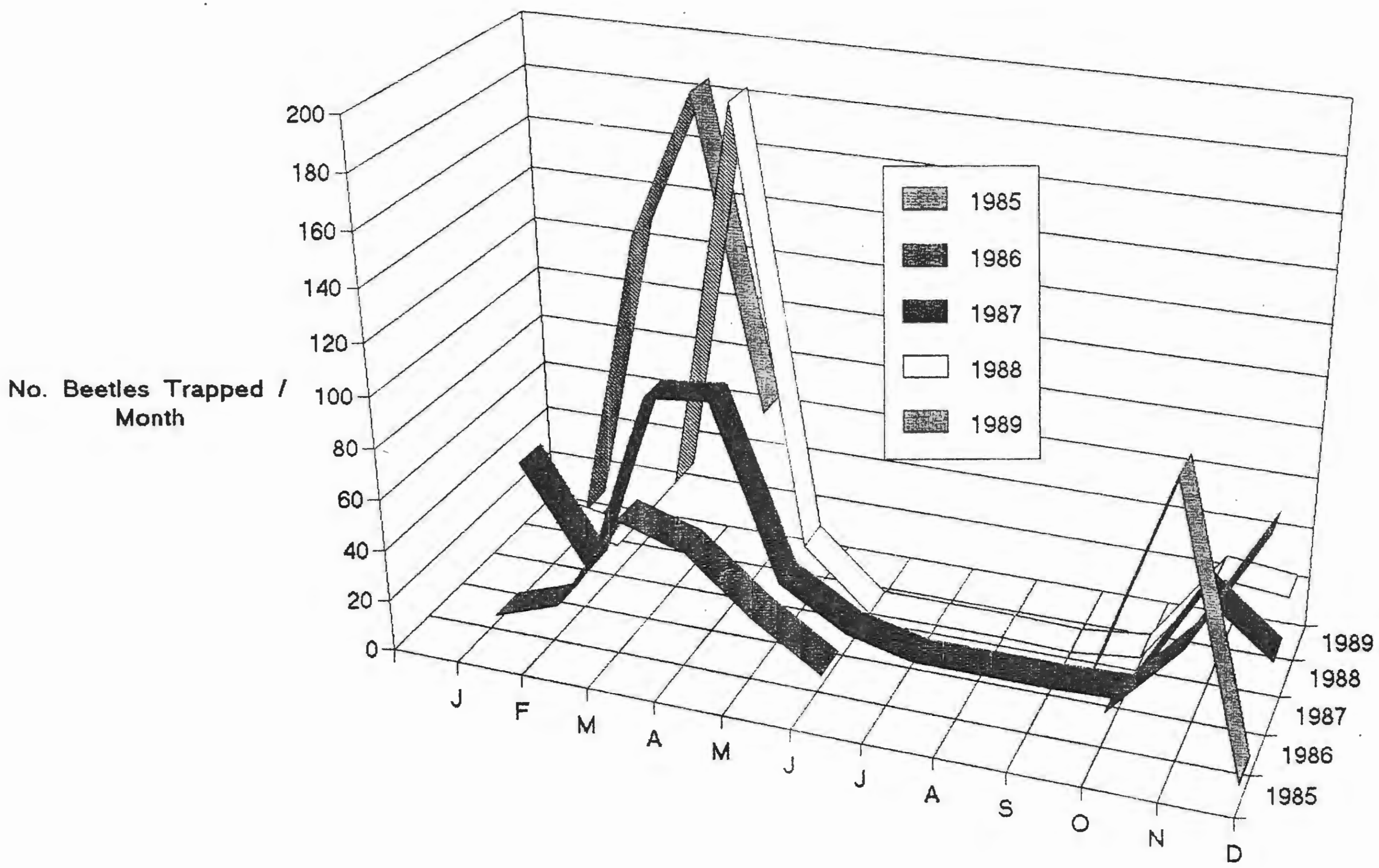
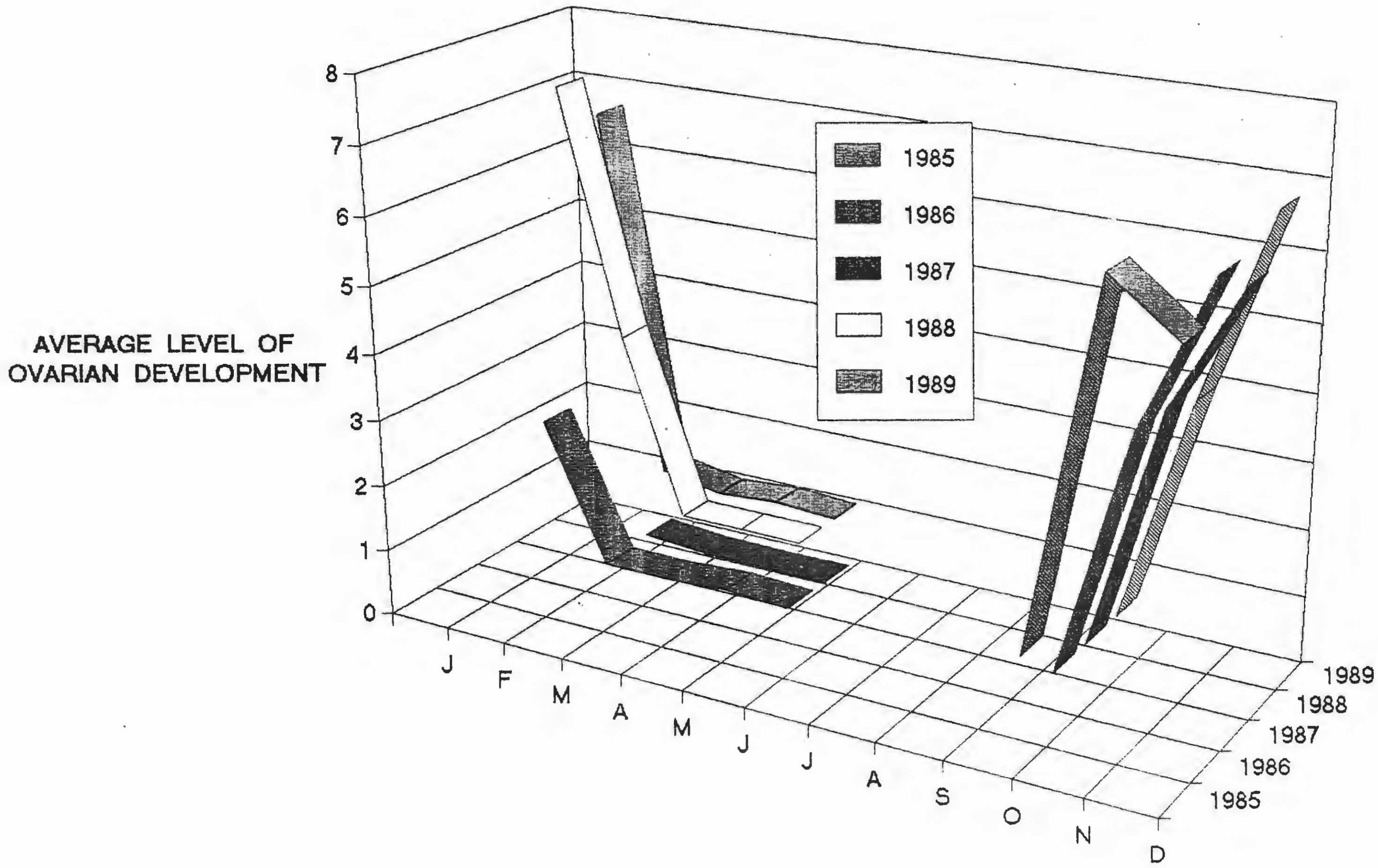


Fig. 14 - SEASONAL CHANGES IN OVARIAN DEVELOPMENT IN *Rhyparida discopunctulata* ON THE ATHERTON TABLELAND



DISCUSSION OF RESULTS

i) Fruitpiercing moths

1. *O. fullonia* is undoubtedly the most important species in north Queensland, followed by *O. jordani* in coastal areas and *O. materna* in drier and inland areas. *E. salaminia* is significant pest in SE Queensland. *Othreis iridescens* (Lucas) is a rare species never collected from fruit during the study which raises interesting questions about its habits and the limiting factors on its populations.

   The seasonal variation in species activity could be important if specific control technologies such as pheromones become available. Variation in seasonal activity and differences in species occurrences in coastal as opposed to Tableland or drier areas serve to illustrate mid-year opportunities for fruits in the latter areas which would not be available on the coast because of continued moth activity in species such as *O. jordani*. Crops such as citrus and carambolas could be grown to exploit this reduced activity in drier inland areas. With softer fruits such as grapes and carambolas however, the possibility that genera such as *Achaea, Serrodes, Ophiusa, Thyas* and *Phyllodes* can inflict primary damage, needs to be considered, as large numbers of these moths occur at times.

2. The habitat associations and host plant preferences of the primary moths provide important information on when and where certain species are active. *O. fullonia* and *O. materna* are the most cosmopolitan species in terms of habitat utilization, with *O. jordani* and *K. aurantia* the most specific. *O. fullonia* and *O. materna* may largely use Form III of *T. smilacina* for breeding in early summer which would imply a significant role by this plant in the annual build up in moth populations. The deciduousness or semi-deciduous of Forms II and III of *T. smilacina* during the dry season obviously has a great bearing on moth numbers, and particularly on *O. materna* which is host specific. This moth appears to switch its breeding to coastal areas during this time. *O. fullonia*, while capable of exploiting a number of host plants during the dry season, appears to breed with only moderate success mid-year. Breeding patterns, in general, follow moth activity patterns seasonally so that the condition of host plants, particularly the availability of soft new growth, is an important indicator of breeding potential.

   The wet tropical coast offers the greatest flexibility in host plant utilization by fruitpiercing moths and is consequently of greatest concern because of this area's preference for growing exotic fruits. Despite *O. fullonia* having a confirmed preference for *T. smilacina* it is a generalist larval feeder as are *O. jordani* and *K. aurantia*, while *O. materna, E. salaminia* and *R. cocalus* confine their feeding to virtually a single species. As *E. salaminia* and *O. materna* are probably second to *O. fullonia* in pest status Australia-wide it is interesting to speculate on the role generalist vs specialist larval feeding has in maintaining such status. An ability to utilize a number of host plants should enhance survival prospects spatially and temporally. It may offer a degree of protection against biological agents, particularly those confined to certain habitats. It could ensure continuity of breeding and improve the success of migratory populations. The success of species which are specialist feeders would appear to depend upon the host plant having an extensive distribution, probably in different habitats, covering considerable variation in climate or seasonal onset. Such specialist moths may have developed or retained a more highly refined means of locating a host plant. They may also be able to utilize a plant after it ceases to be attractive to a generalist. The substantial migratory abilities and longevity of these moths ensure that as specialists they are not at a great disadvantage in terms of maintaining populations and activity.

3. Although procurement of active pheromone material did not eventuate there was at least some indication that this aspect is worthy of further pursuit. The subfamily Catocalinae is poorly known in this respect but relatively recent studies in North America (Wong *et al.*, 1985) have revealed that at least one member produces an unusual compound with some of the characteristics of the material analysed from fruitpiercing moths. Pheromones appear to hold particular promise as a control method given the almost 4:1 ratio of males to females feeding at fruit. This phenomenon should be exploited as much as possible.

4. The existing biological controls operating on fruitpiercing moth populations in Australia are quite extensive but their impact is relatively minor. It is important that potential exotic agents which could suppress moth populations early in the season be fully explored. CSIRO have identified species in PNG which have proven effective against *O. fullonia* in Western Samoa (Sands, Pers. Comm.) and consideration should be given to their introduction here. However, the heterogeneity of moth breeding habitats in northern Australia and the number of pest species suggest that the likelihood of a dramatic impact on moth populations is remote.

5. Enclosure of fruit in bags or trees under netting should be a genuine consideration for the smaller grower with a high value crop. Mechanical exclusion with mesh also inhibits bird and flying fox feeding while bags alleviate most of the insect problems on fruit. While exclusion techniques are expensive ($4,000-5,000 per hectare for Hailguard) savings in chemical or other control costs can be substantial. A grower in the Mareeba area has adopted a bagging method to protect late mango varieties from damage and this fruit is then sold on the export market. The disposable netting Birdban 40 is not sufficiently protective to warrant recommendation but at $5-10 per tree it could be attractive to some growers. Difficulty in handling, particularly at harvesting, and lack of durability are two major problems with this product.

6. Trials with the light protection system have shown that at low-medium population densities damage by moths can be reduced by around 72%. At variable population levels the yellow lights reduced the number of primary species feeding by 77%. At high population densities these reductions are likely to be substantially less although the above figures are similar to those suggested previously (Whitehead & Rust, 1972a,b). The inability of lights to limit activity in some other species generally considered secondary could be of concern if soft fruits were the target for protection. The costs of establishing a light protection system could run to $8,000 per hectare, depending on the number and types of poles required, the

actual number of lights used and their weatherproof housing (about $50/light). The safety conditions imposed by the electricity authorities necessitate costly requirements in terms of construction. Running costs are a minor consideration as the lights have low wattage and would only operate for a short period each year while the crop is susceptible. Further studies will examine streamlining the system in the hope that establishment costs can be cut without jeopardising its efficacy.

7. The finding that a significant proportion of attacks on fruit occur in trees in outer rows has several control implications. It suggests that susceptible fruits should be planted in blocks rather than a few very long rows so that damage is largely confined to a limited number of trees. The idea of using a "trap" or "expendable" outer crop could also be a consideration where there is a significant difference in value of this and the commercial crop. It would be particularly relevant to the placement of attractant-baits and should improve the chance of such a control technology having a substantial effect on moth numbers.

The apparent importance of the general fruity esters in the attraction process was to be expected for a number of reasons. These moths attack a wide range of fruits so it would be unlikely that odours characteristic of specific fruits (such as methyl anthranilate which is found in carambolas, some grape varieties and some mandarins) would have a major influence in the initial attraction process, though they may have a role in odour conditioning and thus the inducement to moths to remain in or near a crop. It is well documented that some of the general esters become increasingly important as fruit ripens and would provide an obvious cue for moths seeking an optimum feeding time. As we have been able to show that moths will select "fruit" and a level of ripeness solely on the basis of the volatiles being emitted illustrates the significance of odour in the attraction process. It suggests that synthetic attractants are a real possibility and we have recently shown that they can compete to some extent with fruit juices. The data indicate than an ester level of approximately 70% is probably optimal, and that the remaining chemical groups should balance this so that the attractant has a "plant" quality.

ii) Leaf-eating beetles

1. Taxonomic studies on the genus *Rhyparida* have helped confirm the species of economic importance. The genus is, however, a complex one and its taxonomic limits have not been defined so that many species remain undescribed. It will take a major effort to unravel the associations within this group to the satisfaction of those concerned with it.

2. *M. australis* at 1 beetle/new leaf can constitute an economic injury level on avocados if a tree is relatively small. Damage to leaves on large trees is of little concern and insecticidal action is generally not warranted. However, at 1 beetle developing fruit serious injury could be inflicted and it is at this stage that growers should consider countermeasures. Data on flower feeding in avocados suggests these beetles do not significantly reduce fruit-set and are probably playing a role as pollinators. In crops such as avocados and mangoes where massive numbers of flowers result in relatively few fruit the extent of insect problems at flowering are

debatable and insecticidal action often does more harm than good. In crops such as macadamias and cashews where nut-set/panicle can be considerable and flowering-eating caterpillars are perhaps more significant pests the added influence of *M. australis* could justify control measures.

3. *R. discopunctulata* had a much greater impression on new foliage as opposed to mature leaf which indicates that protection of foliage on older trees is probably not justified. However, feeding on new growth on small trees significantly retards tree development and would delay the onset of fruiting. It is these trees which need protection as growers cannot afford a year or more delay in fruit production. Patterns of *Rhyparida* attack in the field are extremely variable and must be partly a function of time of flushing in relation to beetle emergence and the response of individual trees to fertiliser application. The maintenance of tree vigour is important to both a tree's ability to cope with damage and to reducing the persistence of attacks.

4. Yellow is a highly attractive colour to many insects and proved to be for *M. australis*. Yellow sticky panels were effective monitoring tools and will have practical application for detecting *M. australis*. Relatively rapid increases in beetle numbers on panels would indicate potential feeding activity and depending on crop stage may necessitate countermeasures. Such panels are best located on windbreak trees, trees with a history of attacks or trees in outer rows so that early detection is possible. The practicality and limited cost involved in utilising a trap without a chemical attractant is a great advantage. *R. discopunctulata* has a distinctly different behaviour and none of the trap designs explored proved successful. Monitoring of this species requires manual searching beneath and between leaves as beetles 'hide' during the day.

5. The insecticides available to control *M. australis* are adequate under most circumstances. It is the prevalence of *R. discopunctulata* in wet tropical regions which creates problems with insecticidal use as persistence and rainfastness are not characteristics of the approved chemicals. Both carbaryl and trichlorfon achieve a high kill rate initially and carbaryl has limited rainfastness. Endosulfan, which has an approved use in avocados in Queensland, is totally ineffective against *R. discopunctulata*. The unregistered synthetic pyrethroid deltamethrin appeared to deter feeding although beetles continuously exposed to it did succumb. Deltamethrin displayed good persistence and reasonable rainfastness. The obvious problems in using a product such as this is the potential creation of scale and mite outbreaks due to the insecticides toxicity to beneficials. A similar product, fluvalinate, which was effective when tested against *M. australis* at 0.05-0.10 g a.i./L, does have some activity against mites and scales and has very low toxicity to hymenopterous insects.

   None of the stickers or extenders tested enhanced the rainfastness of carbaryl but some (e.g. Bond) did appear to increase persistence marginally. Combinations of Ulvapron and Velsicol which were expected to change the leaf surface characteristics did inhibit feeding in the short-term. This combination may provide an alternative treatment for growers interested in products with limited insecticidal properties.

Controlled-release formulations of systemic insecticides to specifically target leaf feeders showed some potential as a post-planting application. Unfortunately, the uptake time and eventual quantity of chemical locating in growth flushes would not be satisfactory for cost-effective control and cover sprays would still be required to minimise damage.

6. Trapping and dissection data were used to determine abundance/feeding intensity relationships in both *M. australis* and *R. discopunctulata*. This information was valuable in assessing activity risk which when aligned with a susceptible crop stage would necessitate heightened awareness by growers. For redshouldered leaf beetle the early part of the year was the period of greatest risk with February the most consistent month in this regard. Crops such as sweet corn, avocados, carambolas and other maturing fruits would be susceptible at this time. The largest emergence of *M. australis* occurs in the second generation in March/April and these beetles also pose a threat to numerous crops and ornamentals. The activity mid-year is associated with flowering in such crops as avocados and mangoes and appears to relate to the topping up of nutritional reserves to prepare females for egg-laying as the wet season approaches. This activity can be monitored to determine the likely timing of the next generation, given an average 60 day development time through the immature stages. It is apparent though that the size of the previous generation will not necessarily indicate the extent of activity in the subsequent one. Although the tachinid parasite *M. caldwelli* substantially impedes ovarian development and reduces longevity in individual beetles it seems to have a limited impact on populations and probably can't be exploited to enhance overall control.

This study on the *Rhyparida* concentrated on *R. discopunctulata*, black swarming leaf beetle, but some information was obtained on *Rhyparida dimidiata* Baly, *Rhyparida humeralis* Lea, *Rhyparida prosternalis* Lea and other species. Essentially, these species displayed similar seasonal activity to *R. discopunctulata*, although in *R. prosternalis* it was a month or so later. Other than *R. discopunctulata*, *Rhyparida* sp. 46 (a small brown species which attacks avocados in wetter areas of the Atherton Tableland) and *Rhyparida limbatipennis* Jacoby (a larger brown species which severely damages ornamentals) are the main economic species in the adult stage. The emergence of the first generation of *R. discopunctulata* coincides closely with the first summer rains which can occur anytime between late September and late December. This period is the one a greatest concern as many young fruit trees flush vigorously at this time and feeding activity in beetles is intense. The subsequent February-April generation appears not to feed significantly on the Tablelands at least so is much less important economically. Clearly, the high risk period is spring to early summer and vigilance is required at this time.

IMPLICATIONS AND RECOMMENDATIONS

i) Fruitpiercing moths

1. *O. fullonia* has been identified as the most important species in tropical coastal areas in Queensland. *O. jordani* is a significant pest in wet tropical coastal areas, especially in autumn, and *E. salaminia* in subtropical coastal areas. *O. materna* is a major pest across northern Australia in drier monsoonal areas. Differences in habitat associations and seasonal activity patterns do allow some opportunism in terms of crops grown under relatively moth-free conditions. For example, as *O. fullonia* and *O. materna* are virtually the only two species active in areas away from the wet tropical coast and as their activity declines at the end of May drier or cooler inland areas can then produce fruit e.g. citrus, when coastal areas can't without risk.

2. Major breeding areas and larval host plants for the primary moth species have been identified. *T. smilacina* is obviously a major or sole host for several moth species and its proliferation would probably see an escalation in moth populations. Reports from Thailand (Banziger, 1982) suggest that forest clearing can increase the quantity of *Tinospora* as the genus displays an edge-dwelling habit. The influence *T. smilacina* has on moth populations is particularly noticeable during the dry season when there is a shortage of new leaf material and significantly reduced numbers of moths. Rainforest or wet coastal forest presents the greatest problems for fruitgrowers because of the number of moth species it supports, the availability of alternate host plants and reduced seasonality. Host plant destruction, particularly of *T. smilacina*, is not a genuine consideration except in very localised situations, as plants are distributed over vast areas. While flea beetles occasionally attack the mature leaves of *T. smilacina* little else other than fruitpiercing moth larvae appears to eat the new growth.

3. Pheromones could potentially prove valuable control tools because of the high proportion of males recorded at fruit. The expertise is now available in North America to isolate the unusual pheromones these moths appear to possess and this aspect should be pursued. *O. fullonia* should be the initial target in any such endeavour. As good seasonal and distributional information has been obtained for most of the primary species pheromones could be appropriately directed when and where required.

4. Netting has proved a valuable and reasonably cost-effective control method and should become moreso as technology improves its field life under harsh tropical conditions. Growers in areas like the Granite Belt in southern Queensland readily accept the need for hail prevention measures so it does not seem unreasonable for growers plagued by fruitpiercing moth to follow suit. Netting has the added advantage of resisting flying foxes and birds. At least one carambola grower in north Queensland has adopted the idea of trellising his trees to facilitate complete enclosure under netting. This has other advantages for harvesting fruit and prolonging cropping life.

5. The light protection system trialled in this study reduced primary moth numbers or damage by over 70%. Relatively cheap yellow fluorescent lights perform adequately and it is mainly the support structures and wiring which elevate the cost. Further trials will determine whether fewer lights maintain effective control. It is doubtful whether any system would substantially reduced damage when moth populations are exceedingly high. The establishment costs of a light protection system could be a deterrent to growers, especially as fruitpiercing moth is the only pest controlled. However, when costs are built into the total crop development program and given tax concessions on a capital investment the economics are reasonably sound but ultimately depend on the value of the crop.

6. Attractant-based control systems will be most effective if located around the perimeters of orchards and trees planted in blocks will be easier to protect than those in long rows. The general fruity esters and their associations with the other volatiles in fruit need to be fully explored for their attractancy potential. That the primary moth species are attracted to fruit of a particular ripeness on the basis of the proportions of volatiles being emitted is an important finding and could be the cornerstone for establishing effective attractants. A system which could decoy moths from feeding would have wide application for the small and large fruit grower alike. The pursuit of attractants will continue under the umbrella of the Centre for Tropical Pest Management.

ii) Leaf-eating beetles

1. Activity in *M. australis* can be monitored effectively using yellow sticky panels. Such traps can be easily prepared by growers and coated with a sticky substance such as Temo-B1 (Pestbusters, Sth. Aust. - $22/850g tin). If used during a high risk period when the crop concerned is at a susceptible stage more discrete and efficient use of insecticides can be achieved. Nevertheless, our understanding of *M. australis* would be substantially enhanced if its swarming behaviour was fully researched.

2. The apparent lack of impact of *M. australis* at flowering in avocados, and the possible role of this beetle as a pollinator, necessitate a reappraisal of the effect of such insects in crops which achieve a low level of fruit-set from a massive flowering. Chemical control at flowering is very disruptive and any effort to avoid it should be considered.

3. *R. discopunctulata* has a clearly defined damaging period between late spring and early summer which conincides with a major growth flush in young fruit trees. However, only certain areas on the wet tropical coast are subject to the activities of this beetle and a limited number of growers are affected. The available insecticides are effective for short-term control and approval has been given to extend their use to most of the new exotics which are prone to attack. The behaviour of this beetle requires that insecticides be applied late afternoon/early evening and spray coverage complete if control is to be optimised. Only pre-bearing trees need protection.

4. The data indicate that some of the more powerful synthetic pyrethroids could offer increased persistence and improved rainfastness than currently approved products. They appear to act mainly as feeding deterrents so could perhaps be used to drive beetles onto a few sacrificial trees where they could be killed or left to feed undisturbed. To ensure that scale and mite problems were not induced a product such as fluvalinate would need to be considered. At 1 application per week of 30ml/100L, as opposed to 3 of carbaryl at 125g/100L, there would only be a marginal increase in chemical costs. Savings in labour, fuel etc. would easily outway this.

5. In wet tropical areas where tree growth is not significantly affected by temperature or day length consideration needs to be given to controlling growth flushes to avoid the maximum *Rhyparida* activity period. Whether this can be achieved adequately through fertilizer timing, pruning or use of a growth regulator such as paclobutrazol remains to be seen, but growers could certainly experiment with this approach.

DESCRIPTION OF INTELLECTUAL PROPERTY

Although a number of new or refined techniques have been developed as a result of this research project at this stage none has significant commercial value. It is unlikely that there will be sufficient demand for light protection systems to justify their commercial production although there could be a market for designing specific systems for individual situations. Further studies on attractants for fruitpiercing moth could see a product developed which may need patent protection and commercial manufacture.

Larvae of *Othreis fullonia* can show attractive colour variations

TECHNICAL SUMMARY OF DEVELOPED INFORMATION

i) Fruitpiercing moths

1. *O. fullonia, O. jordani, E. salaminia* and *O. materna* are the most important fruitpiercing moth species in Australia. The first three are more-or-less confined to coastal regions while *O. materna* ranges widely in drier and inland areas.

2. The moth species show differences in seasonal activity and associations with different fruits. However, early November to early July is the main period for moth feeding activity in north Queensland but in drier or cooler areas this is reduced to the end of May. Such areas can capitalise on this shorter season by utilising crops e.g. citrus, which mature from early winter.

3. Moths breed in a range of habitats with rainforest or wet coastal forest perhaps the most important because of the variety of host plants and reduced seasonality.

4. Of the Menispermaceous hosts *T. smilacina* is almost certainly the most significant. It supports five primary species to various degrees, two exclusively. It occurs in 3 forms which occupy different habitats widely distributed across northern Australia. The generalist larval feeder, *O. fullonia*, displays a preference for *T. smilacina*. Seasonal changes in the availability of new growth on this plant have a substantial bearing on moth populations. *E. salaminia* is the only primary moth species which doesn't eat *T. smilacina* as a larva.

5. Fruitpiercing moths evidently produce unusual pheromones based on unsaturated hydrocarbons. Neither the compounds involved nor activity have been established. Prospects for pheromone utilisation, however, look good as males outnumber females at fruit by almost 4:1. In addition, females feed before and after mating which suggests orchards or neighbouring vegetation are used as the mating site and short-range pheromones could still be effective.

6. The fruitpiercing moth complex in Australia is attacked by a range of native parasites which appear to have little impact on moth populations except at the end of the wet season.

7. Physical barriers, such as netting, are very effective means of controlling fruitpiercing moths and have the advantage of suppressing flying fox and bird feeding too. Complete enclosure of trees in rows or blocks using a product such as Hailguard is recommended and will facilitate harvesting and tree maintenance.

8. Yellow lights with a median wavelength of 580 millimicrons reduce moth numbers and damage by around 70%. As establishment costs for such a system are high the technique needs further refinement to make it available to more growers.

9. Fruit on trees in outer rows are more prone to attack than those on other trees which suggests that blocks should be used instead of long rows. This would ensure that damage is confined to fewer trees. The implications for the

effectiveness of trapping or baiting are also obvious.

10. Electroantennogram studies showed that the general 'fruity' esters elicited the highest response of the volatile chemicals tested. Bioassays with 'artificial fruits' revealed that moths respond differentially to levels of ripeness on the basis of the proportions of volatiles being produced. An ester proportion of about 70% appears optimal. This information is fundamental to developing attractant baits.

ii) Leaf-eating beetles

1. Monitoring redshouldered leaf beetle can be achieved using yellow sticky panels in windbreak trees, fruit trees with a history of attacks or trees in outer rows. Rapid increases in beetle numbers indicate when countermeasures should be taken.

2. Redshouldered leaf beetle does not necessarily reduce fruit-set in avocados by feeding on the flowers and may play a role as a pollinator. It is suggested that in those fruit trees that produce massive number of flowers which result in relatively few fruit *M. australis* probably does little harm and may help reduce the energy drain on trees through flower thinning.

3. *Monolepta* activity at flowering in spring can be used to determine the probable timing of the subsequent generation, given an average 2 month life cycle in summer. This information, when combined with that on crop susceptibility, should heighten a grower's awareness.

4. *R. discopunctulata* has distinct seasonal feeding activity between late September and late December and new growth on pre-bearing fruit trees in susceptible areas must be protected or development can be delayed by a year or more.

5. The chemicals approved for use against *Rhyparida* in Queensland, carbaryl and trichlorfon are effective but are short-lived and not sufficiently rainfast in the wet tropics. Endosulfan is totally ineffective. Nevertheless, carbaryl and/or trichlorfon have received approval for use on newer exotics like jackfruits, marangs, rambutans, durians, grumichamas and chempedak as an interim measure.

6. Synthetic pyrthroids, such as deltamethrin and fluvalinate, are effective against leaf-eating beetles and seem to act as feeding deterrents. They persist better than the approved chemicals and if scale and mite control is not jeopardised they may be of value in wet tropical situations.

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DISCLAIMER

Chemicals referred to in the text were made available for experimental purposes only and cannot be used against insect pests unless registered under the Agricultural Standards Act or without the approval of the Agricultural Requirements Board, and then use must conform with the Agricultural and Veterinary Chemicals Control Act.

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