RURAL INDUSTRIES RESEARCH
& DEVELOPMENT CORPORATION

Integrated Pest Management of Quandong Moth

- control of quandong moth in quandong orchards

A report for the Rural Industries Research and Development Corporation

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Foreword

For many years recognised as one of the few Australian native fruits, quandongs are now in increasing demand from bushfood outlets and specialty restaurants. Quandongs have been traditionally sourced from trees growing in the bush, but during the past ten years commercial plantings have increased, particularly in semi arid areas.

One of the major impediments to production of quality fruit is the damage caused by the quandong moth, the larvae of which feed on the flesh of fruit, severely downgrading quality. Very little is known about the biology of this moth and the possibilities for managing it in commercial orchards.

This project aims to detail the life history of the quandong moth and enable quandong growers to manage the pest in an economically and environmentally rational manner.

The IPM program recommended to growers as a result of this work includes monitoring fruit during winter and spring to detect periods of egg laying, and application of insecticide to prevent young larvae entering the fruit.

This project was funded from RIRDC Core Funds which are provided by the Federal Government and is an addition to RIRDC's diverse range of over 700 research publications. It forms part of our New Plant Products R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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Abbreviations

AQIA	Australian Quandong Industry Association
ANOVA	Analysis of Variance
C.I.	Confidence Interval
IPM	Integrated Pest Management
mg	milligrams
s^2	variance
x	mean

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Executive Summary

The native Australian quandong is in increasing demand as a unique Australian bushfood. Over the past 10 years, commercial plantings of quandongs have increased, particularly in semi-arid regions of Australia. To supply existing markets and develop new markets for their fruit, quandong growers need to be able to produce consistent quantities of high quality fruit. A major factor reducing the quality of fruit is damage caused by larvae of the quandong moth, also a native species about which little was known. Commercial growers presently use frequent applications of broad-spectrum insecticides to try to manage the pest.

The aim of the study was to detail the biology and life history of the moth and to develop management strategies that would enable growers to manage the pest in an economically and environmentally sustainable program.

Three years of field sampling were conducted at two sites in South Australia to describe the seasonal cycle of the moth. All stages of the moth were observed in the laboratory from field collected and laboratory reared material. Degree-day analysis was conducted to examine the timing of the generations of the moth and the accuracy of the predictions were compared to observed data. Field trials were conducted to examine spray timing for the currently used insecticide and to examine alternative insecticides. Surveys were conducted for natural enemies of the moth, particularly specific parasitoid wasps.

There are 3 – 4 generations of the quandong moth in South Australia each year. The summer generations occur during flowering and larvae feed on the reproductive parts of the quandong flowers. The autumn-winter generation occurs during fruit development and larvae feed on the kernel and seed coat of developing fruit. The spring generation occurs during fruit maturity and larvae feed on the flesh of fruit.

There are four larval instars of the quandong moth. The most damaging instar is the fourth and it is the one with which quandong growers are most familiar. The earlier instars are much smaller and more cryptic than the fourth, blending in well with the kernel and flesh of quandongs.

Larvae feed on the reproductive parts of flowers but because the natural shedding of flowers is high, damage during this period is not significant. Damage caused by larvae of the autumn-winter generation causes fruit to drop from trees. However, a large proportion of dropped fruit is not damaged by quandong moth larvae. Other factors such as natural thinning, wind or stress cause fruit drop and larval damage will not cause yield loss unless it exceeds the rate of natural drop. The majority of larvae that drop inside fruit are able to complete their development and give rise to the adults that lay the eggs of the spring generation. Collecting and destroying fallen fruit may help to reduce populations in the subsequent generation. Larvae feeding on the flesh of quandong fruit cause the most severe damage. This damage directly reduces the quality of fruit at harvest, and in severe cases fruit may be completely unsuitable for consumption.

A modelling program was used to predict the timing of the generations of quandong moth. Known dates of egg incidence were used as inputs and the model was used to accurately predict the date on which eggs of the next generation would be present. Predictive modelling was a valuable tool to examine the timing of quandong moth generations and determine the seasonal cycle of the moth.

The field trial on spray timing examined whether the efficacy of applications of the currently used broad-spectrum insecticide could be improved by improving timing of applications. The results indicated that efficacy could be increased with accurate timing. Two applications timed to coincide with the start of the autumn-winter and spring generations respectively, were as effective as monthly applications of the same insecticide. The field trial on alternative insecticides tested several insecticides.

The trial identified tebufenozide (Mimic®) as a promising candidate for management of the quandong moth. Mimic® reduced the incidence of larvae and the severity of damage equally as well as monthly applications of the currently used broad-spectrum. Accurate timing of applications of Mimic® is critical as it must reach young larvae before they enter fruit. Application needs to be made for a minor use permit before it can be recommended. In an IPM program specific insecticides are very valuable because they do not harm beneficial insects in the orchard.

Monitoring, insecticides, conserving natural enemies and good orchard hygiene should all form part of an integrated pest management program for the quandong moth. Monitoring for eggs of the moth and only employing insecticides when the moth is present at damaging levels will result in more judicious use of broad-spectrum insecticides. Reduced use of insecticides will conserve the populations of generalist and specific natural enemies of the moth and decrease the risk associated with sustained and frequent use of broad-spectrum insecticides. The inclusion of insecticides that are specific to moths will also aid in conserving populations of beneficial insects and restore the ecological balance where it has been disrupted by sustained use of broad-spectrum insecticides.

A fact sheet to aid quandong growers in identifying stages of quandong moth and other insects in quandong orchards has been prepared in colour hard-copy, and is also available for posting on websites.

1. Introduction

The quandong, *Santalum acuminatum* (Santalaceae) is a native Australian fruit occurring naturally in the arid regions of all the mainland states of Australia (Cribb, 1974). The trees are tolerant of drought and salinity (Sedgley, 1982) and will grow and bear fruit in semi-arid conditions and under irrigation (Grant, 1978). Trees can reach 5-6 m in height, and take between 3 and 5 years to begin bearing fruit (Sedgley, 1982). Flowering occurs from October to March, with fruit ripening in the following August to November depending on the region in which the tree is located. The mature fruit is generally red, spherical, 20-30 mm in diameter and has cream to white flesh. Australian aboriginals have eaten the flesh and kernels of quandongs for many years, and in more recent times European settlers have discovered the fruit. The flesh may be consumed raw, but fruit from some trees has an acidic taste and sweetness can vary greatly between trees (Grant, 1978). When harvested the fruit are generally halved, de-stoned and the flesh is either processed immediately, or stored as a dehydrated or frozen product. Australian aboriginals also used the kernel for medicinal purposes (Black, 1965).

Quandongs are primarily marketed as a unique Australian bush food and there is huge potential for developing both domestic and international markets. As of November 1999, there were approximately 45 000 quandong trees in plantation in Australia, with 20 000 of those producing fruit. The net harvest of quandongs in 1999 was 25 tonnes of dried de-stoned fruit, consisting of four grades valued at approximately $1.4 million (Table 1).

Table 1: Grades, quantity and value of dried, de-stoned quandong fruit from 1999 harvest in Australia.

Grade	Production (tonnes)	Value (A$, 1999)
Processing	16	565 000
Manufacturing	5	275 000
Premium vacuum packed	2	180 000
Primary value added	2	350 000
Total	**25**	**1 365 000**

Source: Gordon-Mills, 2000

In order to expand existing markets, and develop new markets for their product, growers need to be able to produce consistent supplies of high quality fruit. One of the major factors that reduces the quality of fruit is damage caused by larvae of the quandong moth, *Paraepermenia santaliella* Gaedike (Lepidoptera: Epermeniidae). The Australian Quandong Industry Association (AQIA) has identified management of the quandong moth, as the industry's primary research need. Currently, fruit grown and harvested for commercial use is graded according to the level of larval damage and frass in the flesh and the presence of quandong moth larvae. Undamaged fruit brings the highest return on the market and often fruit with a small amount of quandong moth damage is unable to be sold as a premium product. In 1999, high quality unprocessed fruit sold for the equivalent of $90/kg, compared to $35/kg for low quality processing grade fruit. Prior to this study, no research had been conducted on the biology, ecology or phenology of the quandong moth and management techniques had not been investigated. In the absence of any knowledge of the biology or population dynamics of the quandong moth, and without any monitoring techniques, growers have been forced to use broad-spectrum insecticides to reduce the damage caused by the quandong moth.

2. Objectives

The aims of this project were to:

- detail the biology of the moth, including a description and duration of all stages in the life cycle;
- examine the seasonal history of the moth, particularly the location of each stage in the field and the number of generations each year in relation to the developmental stages of the quandong tree;
- develop monitoring strategies for predicting outbreaks and targeting controls;
- survey natural enemies and other beneficial insects and secondary pests and identify and catalogue them;
- survey any varieties of quandong trees demonstrating resistance to the quandong moth and examine the mechanisms of resistance;
- trial potential management strategies both in the laboratory and the field.

3. Biology of quandong moth

3.1 Introduction

Prior to this study there were only very brief descriptions of the adult quandong moth published and only general traits of the family had been reported (Common, 1990). No descriptions of the eggs or larvae of the moth had been published, and the number of larval instars had not been determined. The majority of quandong growers were only familiar with the mature larva seen in the flesh of mature fruit, and were unable to recognise either the eggs or the adults of the moth. For pest management it is important to describe all the stages in the life cycle of the moth, to determine the total number of larval instars and to identify the most damaging stages. Observations on all stages of the moth were made in the laboratory with both field collected and laboratory-reared material.

3.2 Materials and Methods

Repeated attempts were made at developing an artificial media for larval rearing. Fresh quandong fruit was also used throughout the study as a food source for larvae. Length and width measurements for all stages were made using a stereo microscope fitted with an eyepiece micrometer. The head capsule widths of 956 larvae collected from field sites at Quorn and Sedan, South Australia were measured to determine the number of instars. A frequency distribution of head capsule widths was compiled and the mean head capsule width of larvae in each instar calculated. Observations were conducted to determine how far a neonate larva would travel on the surface of a fruit, and for how long it would wander before beginning feeding. Pupal weights were recorded 48 hours after formation using a Microbalance LM-600 (Beckman RIIC Limited). Various artificial substrates and stages of the host plant were trialled to stimulate oviposition by females in the laboratory. The effect of food on the longevity of male and female moths was examined in the laboratory. The rate of development of the egg, pupal and adult stages of the moth was recorded over a range of temperatures.

3.3 Results

3.3.1 The Egg

The egg is oval, with a cream coloured and textured chorion when first laid. After approximately three days at 24°C the colour changed to pale yellow. One day before hatch, the head capsule of the developing embryo became visible through the chorion as a darkened area at one end of the egg. Infertile eggs developed to the yellow but then desiccated and the embryo did not develop any further. The chorion of hatched eggs was translucent white with a textured surface, retained the oval shape and the hole at one end through which the neonate larva emerged was visible. The length and width of eggs was 0.35 ± 0.002mm and 0.20 ± 0.001mm (n = 102), mean ± SE, respectively. In the culture room at 24°C, eggs took an average of 6.2 ± 0.15, mean ± SE, days to hatch.

Quandong moth eggs were observed on flowers, newly formed, semi-mature fruit and mature fruit in the field. On open flowers, eggs were primarily laid next to or under the anthers and were mainly found late in the flowering period, when no nectar remained in flowers. Eggs were also observed on the stems of unopened flower buds and concealed in between the flower bud and the remnants of the bract. When mated female moths in the laboratory were given flower buds and opened flowers for oviposition sites, they laid eggs on the same parts of the flowers as found in the field. On fruit, the vast majority of eggs were laid in the calyx, next to the remnants of the anthers and in the crevices between the perianth lobes. Females seemed to prefer trees bearing fruit with closed calyces that provided protection to the developing eggs.

3.3.2 The Larva

The quandong moth has four instars. The mean head capsule widths are 0.12, 0.22, 0.38 and 0.56mm for 1st through 4th instars respectively. The first 3 instars are pale yellow with a dark brown head capsule. The early 4th instar is grey with a pale brown head capsule, and the late 4th instar is red with a pale brown head capsule. Both field and laboratory observations suggest that the 3rd and 4th instars are the most damaging larval stages.

Emergent larvae chewed a hole in one end of the egg but did not feed on the chorion after hatching. The first instar traveled on the surface of the fruit from the calyx towards the centre of the fruit. The majority of the larvae observed began feeding within five minutes of hatching from eggs and the entrance holes of first instars were less than 1mm in diameter. The distance of the larval entrance holes from the centre of the calyx, was 6.7 ± 0.7mm, mean ± 95% C.I. Within approximately 15 minutes of commencing feeding, the larvae began to deposit frass on the surface of the fruit, and had completely burrowed into the fruit within two hours.

When a mature quandong moth larva feeding inside a fruit on a tree is ready to pupate, it chews an exit hole in the fruit, and drops to the ground. If the fruit has already dropped from the tree, the larva probably chews an exit hole and crawls directly to the leaf litter to pupate. The current results suggest that few, if any, larvae pupate on the tree or descend to the ground via the trunk. Therefore, management techniques employing trunk banding and entomogenous nematodes as used for larval codling moth [Kaya, 1984 #392], will not be effective for quandong moth.

Despite repeated attempts throughout the study an artificial media for larval rearing was not developed. Fresh quandong fruit was used as a food source for developing larvae and although at times individual generations could be reared, mass rearing was not possible because of problems with fungal contamination of fruit and other difficulties with oviposition by adults.

3.3.3 The Pupa

When first formed pupae are light brown with green wings, later progressing to a light brown colour and finally darkening to a deeper brown in the two days before they eclose. At 24°C the pupal stage lasts 9.0 ± .0.2 days, mean ± 95% C.I. There was no significant difference between the length and weight of male and female pupae. The average length and weight of pupae was 3.55±0.05mm and 1.78±0.08mg, mean ± 95% C.I., respectively.

3.3.4 The Adult

The moths are grey, with several black stripes running horizontally across their wings (Figure 3.5). The adults also have bronze coloured markings on their wings. At rest, adult quandong moths sit with both their wings and their antennae parallel against their body and with their body in an upright resting position. On some moths three or four stripes were well-defined and on other moths, only one stripe could be seen clearly. The variation in the number of stripes was not sex specific. The bronze markings were more prevalent on the dorsal surfaces of females, and on males were confined mainly to the lateral surfaces. The posterior edge of both sets of wings was fringed with hair-like scales. Female moths are significantly larger than males ($T = 2.82$, $p = 0.0056$, $df = 114$). The mean length ± 95% C.I. of male moths was 4.53 ± 0.06mm ($n = 60$) and female moths was 4.68 ± 0.09mm ($n = 49$).

The presence of food had a significant effect on the longevity of adult quandong moths ($p < 0.05$). Availability of a food source increased the survival time of both males and females by a factor of approximately three (Figure 3.6). Unfed males lived for an average of 5.3 days ($n = 28$), whereas fed males lived for 17.2 days ($n = 18$). Similarly, unfed females lived for an average of 6.3 days ($n = 30$) and fed females for 18.2 days ($n = 28$). Both sexes had approximately the same lifespan.

Female quandong moths were extremely discerning with oviposition sites. On only one occasion did a moth lay eggs anywhere other than quandong flowers or fruit in the laboratory and in that case the eggs were infertile.

4. Seasonal Cycle

4.1 Introduction

Prior to this study the number of generations of the quandong moth each year, and the synchronisation of generations with the phenology of the host tree had not been investigated. Most quandong growers were only aware of the generation of the moth corresponding to fruit maturity and generations during other stages of the year were not known. The quandong moth had only been recorded feeding on the fruit of quandong trees suggesting that the moth must survive up to five months from November to March, in most regions, without fruit. The presence of alternative hosts or a period of diapause had not been investigated for the quandong moth. Regular field sampling was conducted at two sites in South Australia beginning in July 1997, and concluding at the end of the fruiting cycle in November 2000. Degree-day calculations were used to examine the timing of generations observed in the field.

4.2 Materials and Methods

4.2.1 Number and timing of generations

The field sites were chosen because they had been regularly infested with the quandong moth in previous years and were not sprayed with any insecticides. The first field site selected was a minimally maintained orchard at Quorn, South Australia. This orchard was planted from seeds collected from the southern Flinders Ranges and Yorke Peninsula in South Australia, and from around Perth in Western Australia. At the time of sampling there were approximately 150 trees in the orchard, all about 20 years old. As the trees were planted from varying sources of seed there was variation amongst the trees in fruit size, colour and shape, leaf size and shape. Yield also varied, with some trees never fruiting, or fruiting very lightly each year and others regularly fruiting heavily. From the trees in the orchard, 11 were selected which had a history of fruiting reasonably heavily in each year. The second field site selected was at Sedan, South Australia. This site was a council reserve of approximately 1 Ha, containing upwards of 300 trees of varying ages. It is likely that there would be much less genetic variation amongst these trees as many of them are situated in small groves with new trees germinating from seed dropped from a few established trees. There are also several groves in which new trees have emerged from suckers of established trees. No prior fruiting history could be obtained for this site, so trees were selected on the basis of the number of flowers on the trees when being examined and the prevalence of quandong seeds underneath the trees from the prior year’s crop. Thirteen trees were originally selected, but between 8 and 10 were sampled on a regular basis depending on the fruit set in each year.

During flowering, the sample unit was a single flower bud, opened or closed, depending on the stage of flowering. From flowering onwards, the sample unit was a single fruit, progressing from the newly formed stage to mature fruit. Quandong growers had noted that immature fruit dropped from the trees during May-July, following fruit set (AQIA pers. comm.). Therefore, fruit samples were taken from both the trees and the ground beneath the trees, as soon as fruit began to drop and for as long as fruit drop were present on the ground. Sample units were selected at random from around the entire tree and up to a height of 2.2m.

The stage of development of the quandong flower or fruit was categorised using a rating system developed after preliminary observation of all stages of quandong fruits and flowers (see Table 5.1). The developmental stage of each sample unit was also defined in terms of size. The diameter of all units was measured using a caliper. Measurements were taken from the centre of the fruit at the widest point, perpendicular to the stem.

Flowers and fruit were examined for eggs and larvae of the quandong moth under a stereo microscope. The number of both unhatched and hatched eggs was recorded for each sample unit. Where possible, unhatched eggs were removed for rearing in the culture room. When a larva was detected, it was removed from the fruit, its head capsule width recorded, and the instar determined. The larva was then placed in a well of a rearing tray with fresh fruit to attempt to rear it to the adult stage. The number of each instar of the quandong moth present was recorded for each sample unit on each sample date.

4.2.1 Predictive modeling

Dymex is a model of a lifecycle made up of a user-defined number of life-stages and simulates the processes that influence cohorts of individuals throughout their lifecycle. It is modular-based and has components that allow development, mortality, transfer between stages and reproduction to be manipulated by the user. Outputs are presented as the number and age of individuals in a cohort at any given timestep. Meteorological data collected can be imported and the model can be designed so that physiological time is used to drive the development of individuals using degree-days. In addition, special event modules can be added at any time-step to simulate the impact of management strategies, such as insecticide application, or to examine the influence of harvest of the host plant, or periods of stress in the population. The program consists of a Builder component in which the model is constructed, and a Simulator component in which the model is run and the outputs are plotted and can be exported to other programs.

4.3 Results

4.3.1 Number and timing of generations

The patterns in egg and larval incidence in the first two years of observations at Quorn indicated at least one, possibly two summer generations of the quandong moth during the flowering period of the quandong tree. However, during the following year of field sampling, no generations were detected during flowering. In each year the summer generations were followed by an autumn-winter generation that began with a period of egg lay in mid to late April. The spring generation follows the autumn-winter generation with egg lay during early-mid September and the larvae feed on mature fruit (Figure 1).

Similarly, a summer generation was detected in each year at Sedan, followed by a period of egg lay in mid-late April to begin the autumn-winter generation. Egg lay in September marked the beginning of the spring generation, again corresponding to the period of fruit maturity. Due to a lack of fruit on the trees at Sedan in 1999, sampling ceased mid-June and re-commenced when flowers were present on the trees in mid-November (Figure 2).

The trends in egg and larval incidence are similar at Quorn and at Sedan with peaks evident during flowering, fruit development and fruit maturity in most years.

Larvae of the summer generations primarily fed singly in unopened flower buds. Larvae of the winter generation also primarily fed alone, in developing fruit. In the spring generation, many larvae fed alone, but a large proportion fed with other larvae of the same instar, up to a maximum of 11 4th instars in a mature fruit.

The estimates of rates of development obtained from laboratory constant temperature studies, along with the incidence of eggs and larvae in the field provided input for Dymex professional (CSIRO Publishing), a program used to predict the timing and number of generations of the quandong moth.

4.3.2 Predictive modelling

The first aspect of the system analysed was the development times of the immature stages of the quandong moth throughout each season. Dymex uses daily maximum and minimum temperatures to generate a daily temperature cycle based on a sine curve. The sine curve is divided into 12 two hourly segments, and degree-day estimates are then determined for each block of two hours. From this, development is estimated for each stage over the entire year. A separate simulation was run for each year at Quorn and Sedan and for each immature stage of the quandong moth. The simulations show the common pattern of decreased developmental times during summer compared to the cooler winter months, where development takes much longer (Appendix Figures 1 – 2). Overall, the temperatures at Quorn are higher throughout the year than those at Sedan, and this is reflected in the degree-day accumulations and the developmental rates of all stages of the quandong moth. Using a base temperature of 4.5°C, an average of 5155 degree-days were accumulated at Quorn and 3693 degree-days at Sedan over the three years for which data were collected.

In all but one of the three years of sampling at Quorn and Sedan, eggs were found on fruit in late April and then not again until late August-early September. To examine whether sampling had accurately detected all generations, eggs were put into the simulation on the date that eggs of the autumn-winter generation were initially detected in the field each year. The initial date of entry was used to determine the earliest date on which eggs of the next generation would be present in the population. The simulation was run and demonstrated that from eggs laid in mid-late April at Quorn and Sedan, eggs of the next generation would not be expected until late August-early September. This is mainly due to low temperatures over winter greatly reducing the developmental rate of all stages of the moth and therefore delaying the arrival of the eggs of the next generation until early in spring. To examine the incidence of generations of quandong moth during summer, eggs were put into the simulation on the first date each year that they were discovered during flowering. In those years in which eggs were not found during flowering the date that first instars were initially recorded was used with egg entry backdated 5 days from first instars. In each year, three complete generations of the quandong moth developed at Quorn and two generations developed at Sedan, from eggs laid in mid-November to mid-December.

The Dymex simulations indicated that there were differences in the number of generations possible at each of the field sites and in each of the years for which the simulations were run. The differences primarily lay in the number of generations completed during summer from eggs laid in late spring-early summer. The data show that in most years at Quorn three generations were possible and at Sedan two generations were possible, during late spring-early autumn. However, during 1997-98 at Quorn, only two generations were simulated during summer with a subsequent generation delayed until autumn and then followed by the normal autumn-winter generation. Likewise, at Sedan in 1999-2000, two generations were simulated during summer and again were followed by a complete autumn generation and then the usual autumn-winter generation. Overall, the simulations indicated that five complete generations were possible at Quorn each year, and four were possible at Sedan each year, with partial generations seen in each year at each site. These simulations were based primarily on how temperatures throughout the year influence the rate of insect development. The radical change in food source from mature fruit in spring to new flower buds in late spring to summer is not taken into account and is difficult to quantify.

From the data collected throughout this study a generalised phenology diagram for the quandong moth in South Australia was constructed (Figure 5).

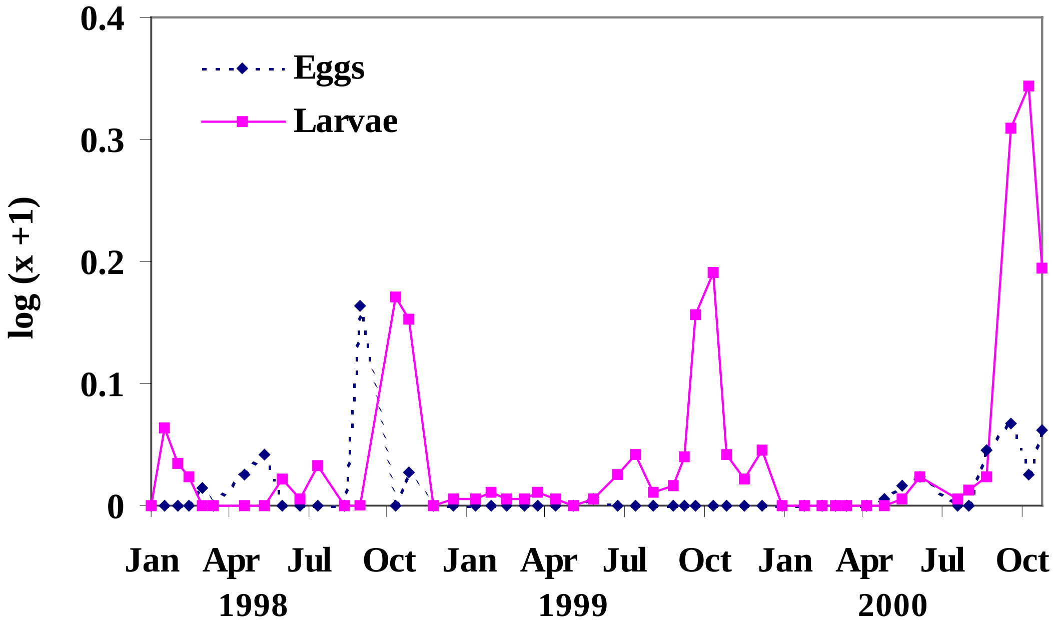

Figure 1: Incidence of eggs and larvae of the quandong moth at Quorn 1998-2000. Mean (x) numbers of eggs or larvae per sample unit plotted on a log scale.

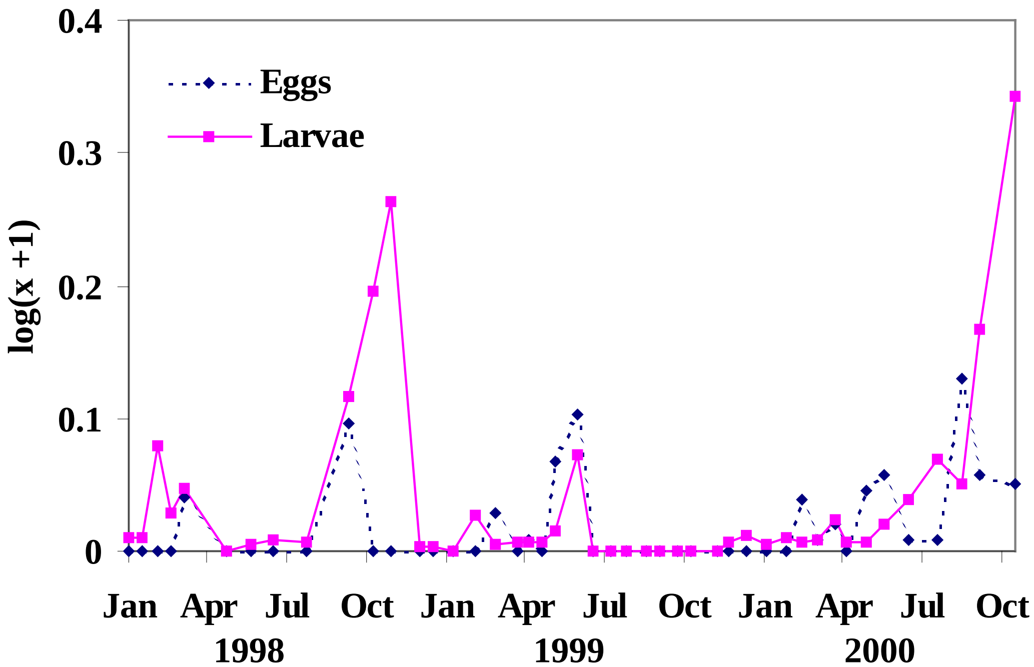

Figure 2: Incidence of eggs and larvae of the quandong moth at Sedan 1998-2000. Mean (x) numbers of eggs or larvae per sample unit plotted on a log scale.

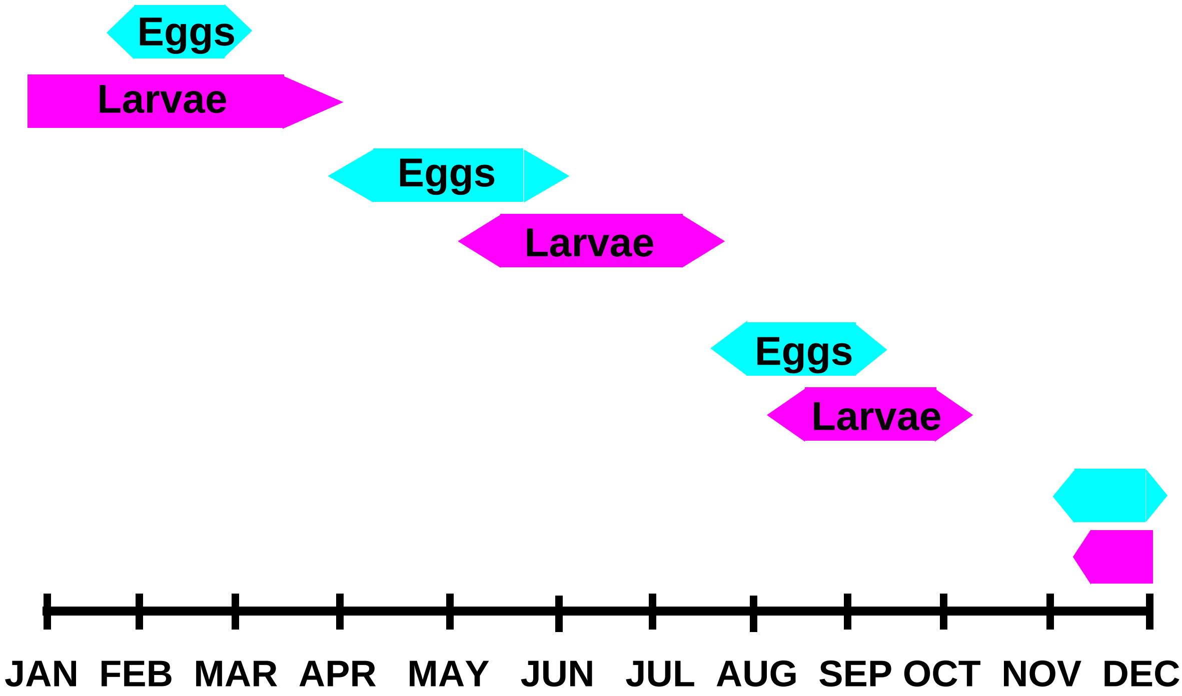

Figure 3: Generalised phenology diagram for the quandong moth in South Australia

Comparisons were made between the number and timing of generations simulated by Dymex and the data actually observed in the field (Tables 1 – 6). In each year at Quorn, the Dymex simulations indicated that a generation was expected from eggs laid in early March. It was only in 1999 that larvae of this generation might have been detected, however the data from early 1999 are ambiguous, with a consistently low incidence of larvae detected for the first six months of the year without any clear peaks. The Dymex simulations also suggested the presence of a similar generation at Sedan and the data collected are consistent with the simulation. There are several periods during the year at both Quorn and Sedan where eggs were not detected, particularly on flowers.

Throughout the regular field sampling egg counts were done on between 80-88 sample units at Quorn and 80-104 sample units at Sedan irrespective of egg density. The relationship between the mean and variance of egg counts can be used to determine the number of sample units required to detect eggs at a certain density. The relationship between the mean and variance of numbers of quandong moth eggs on both flowers and fruit is best described by Taylor's power law, $s^2 = ax^b$, where s^2 is the variance, x is the mean and a and b are coefficients derived by non-linear regression (Appendix Table 1). The results indicate that at a density of 1 egg per sample unit, 486 fruit would have to be examined to maintain an estimate within 20% of the mean.

Table 1: Comparison of oviposition dates predicted by Dymex with observed oviposition dates at Quorn 1998-99. The simulation was initiated on 21 April 1998 and run until end March 1999.

Generation	Predicted	Observed
Winter	-	21 Apr
Spring	17 Aug	2 Sep
	25 Oct	28 Oct
Summer	13 Dec	1^{st} instars 17 Dec

Table 2: Comparison of oviposition dates predicted by Dymex with observed oviposition dates at Quorn 1999-2000. The simulation was initiated on 30 April 1999 and run until end March 2000.

Generation	Predicted	Observed
Winter	-	30 Apr
Spring	21 Aug	-
	19 Oct	-
Summer	10 Dec	1^{st} instars 10 Dec

Table 3: Comparison of oviposition dates predicted by Dymex with observed oviposition dates at Quorn 2000. The simulation was initiated on 28 April 2000 and run until end of December 2000.

Generation	Predicted	Observed
Winter	-	28 Apr
Spring	3 Sep	25 Aug
	6 Nov	27 Oct
Summer	13 Dec	-

Table 4: Comparison of oviposition dates predicted by Dymex with observed oviposition dates at Sedan 1998-99. The simulation was initiated on 13 March 1998 and run until end of March 1999.

Generation	Predicted	Observed
Autumn	-	13 Mar
Winter	21 May	3rd instars -27 May
Spring	7 Oct	17 Sep
Summer	13 Dec 29 Jan	1st instars - 8 Dec 1st instars - 11 Feb

Table 5: Comparison of oviposition dates predicted by Dymex with observed oviposition dates at Sedan 1999-00. The simulation was initiated on 13 May 1999 and run until end of March 2000.

Generation	Predicted	Observed
Winter	-	13 May
Spring	24 Sep	-
Summer	3 Dec 21 Jan	1st instars - 30 Nov 1st instars - 3 Feb

Table 6: Comparison of oviposition dates predicted by Dymex with observed oviposition dates at Sedan 2000. The simulation was initiated on 4 May 2000 and run until end of December 2000.

Generation	Predicted	Observed
Winter	-	4 May
Spring	30 Sep	12 Sep
Summer	2 Dec	-

5. Damage

5.1 Introduction

Larvae of the quandong moth are present on quandong trees throughout the year, but the most obvious damage is to mature fruit and results in fruit being downgraded in quality, or in severe cases, being completely unsuitable for consumption. High larval densities had been regularly reported in mature fruit harvested from commercial orchards, wild groves and backyard trees. However, the damage caused by the other generations of the moth had not been quantified. Most quandong growers reported a period of fruit drop during the middle of the year and it was not known whether this phenomenon was due to a period of natural thinning or occurred because of feeding by the quandong moth larvae. The location and type of damage to quandong flowers and fruit was recorded throughout the year, and the implications for the yield of trees and the quality of fruit examined.

5.2 Materials and Methods

A damage rating system was developed after preliminary observations of the type of damage sustained by flowers and fruit whereby the location of damage was divided into three sites on flowers and three sites on fruit. On flowers, damage was assigned to the anthers, the stem or the central disc of the flower. With fruit, damage was assigned to the kernel, the seed coat, or the flesh. In many cases damage was present in several areas within an individual sample unit. The severity of damage was assessed using a categorical rating system, ranging from 0 – 5, where 0 was equal to no damage, and 5 was the entire area of a particular location damaged.

5.3 Results

The location of damage caused by quandong moth larvae to quandong trees differed throughout the year. In flowers, larvae primarily feed on the anthers and the central disc of the flower. In developing fruit, damage was mainly located in the kernel and the seed coat of the fruit. Once the seed coat hardened in mid-winter, the damage was restricted to the flesh of maturing fruit. In some years up to 82% of mature fruit from trees had flesh damage caused by quandong moth larvae. Wherever they feed, larvae leave frass that remains around their feeding site. In flower buds, whole buds were found filled with frass where 4^{th} instars were feeding. In developing fruit, the kernel was often filled with frass. In the flesh of fruit, the pattern of larval feeding was evident by the trail of frass left by larvae as they fed. The presence of larval frass reduces the quality of fruit, particularly at harvest.

In each year, at each site a period of fruit drop occurred during late May-late July. During this period there was a higher incidence of quandong moth larvae in dropped fruit compared to fruit remaining on the trees (Figures 4 – 5). There was a positive correlation between the number of fallen fruit sampled and the number of fruit infested with quandong moth larvae ($r = 0.40$). However, the results showed that quandong moth larvae had not damaged an average of 60% of the fruit that dropped from the trees for both sites in each year.

The period of fruit drop was investigated further at Quorn in 2000 with extra samples taken from trees having a high rate of fruit drop. The results show that the incidence of both larvae and damage was greater in fruit collected from the ground compared to those collected from the trees (Figure 6). However, like the data collected throughout the years of regular sampling, no more than 40% of the fallen fruit were damaged by quandong moth larvae. The damage in fallen fruit was primarily to the seed coat and kernel of the fruit. In contrast, the damage to mature fruit was primarily in the flesh with very little seed coat or kernel damage. Although the hardened seed coat prevented larvae from feeding in the kernel of mature fruit, all seeds were cracked to see if damage done by the winter generation of larvae was present when fruit were mature. The results demonstrated that the majority of fruit damage internally do not reach maturity (Figures 7 - 8).

In the laboratory larvae collected inside fallen fruit completed their development and emerged from the fruit to pupate inside pupation containers. In the field, fruit drop occurs during winter when temperatures would be lower and the onset of dehydration and fungal contamination would be delayed. Therefore it is likely that during the autumn-winter generation, the majority of larvae actually drop from the tree inside fruit, complete their development to the 4th instar and then chew their way out of the fruit to pupate in the leaf litter at the base of trees and give rise to adults of the spring generation of the moth.

There was a positive correlation between the instar and the severity of damage ($r = 0.49$), with 4^{th} instars causing the most severe damage. In addition, there was a positive correlation ($r = 0.39$) between the number of 4^{th} instars and the severity of damage as determined by damage ratings, with damage increasing as the number of larvae increased. The maximum number of 4^{th} instars in a single fruit was 9 and at that level there was no evidence of a decrease in damage due to crowding.

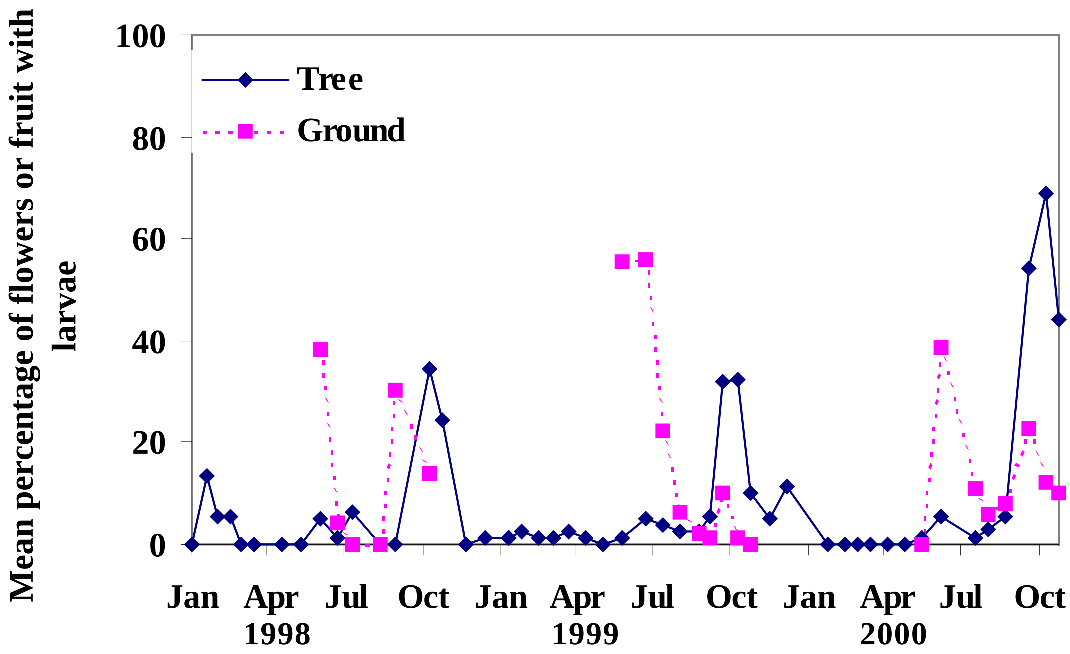

Figure 4: Incidence of quandong moth larvae in fruit collected from trees and the ground beneath at Quorn 1998-2000.

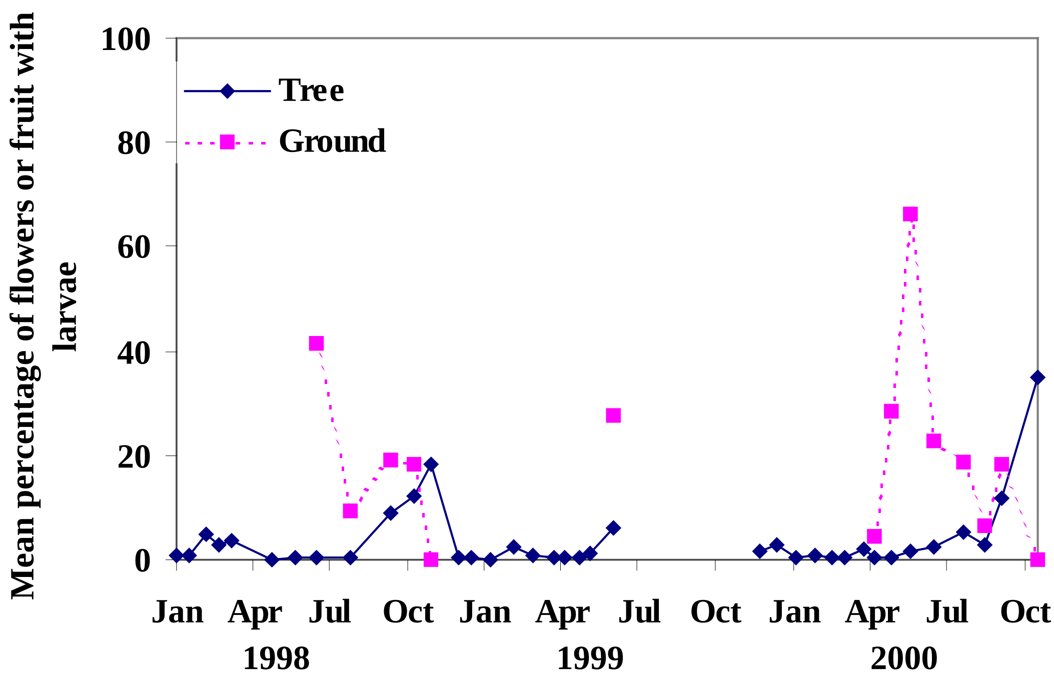

Figure 5: Incidence of quandong moth larvae in fruit collected from trees and the ground beneath at Sedan 1998-2000.

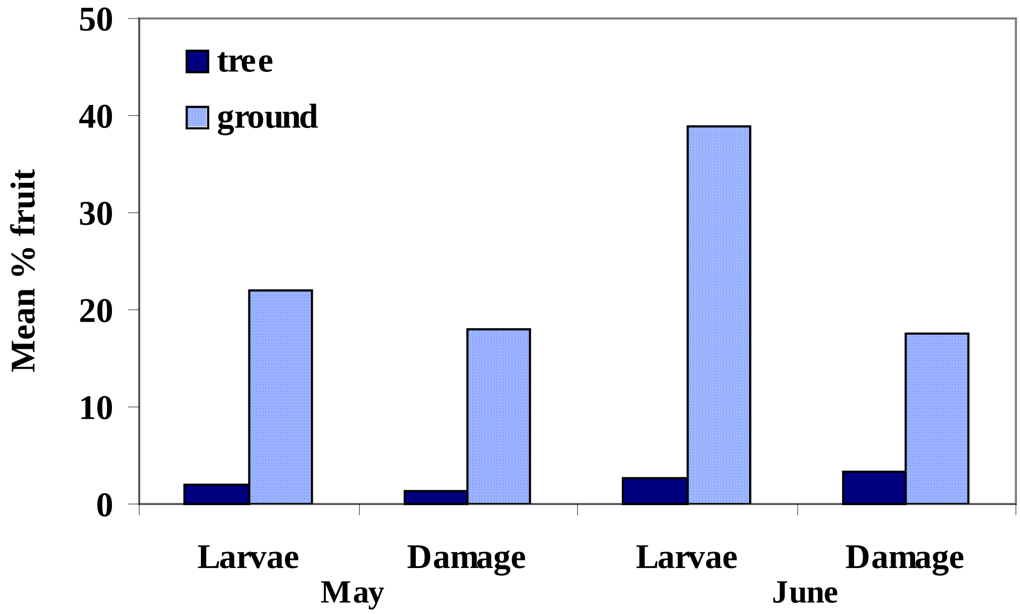

Figure 6: Percentage of fruit with quandong moth larvae or damage collected from trees and ground at Quorn 2000.

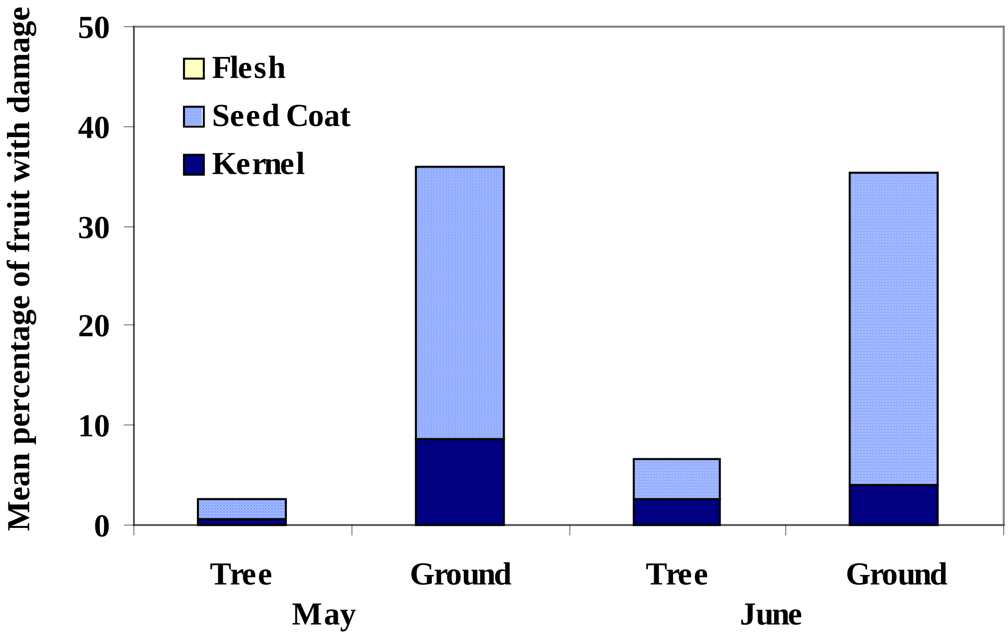

Figure 7: Location of damage to quandong fruit from trees and ground mid-year at Quorn 2000

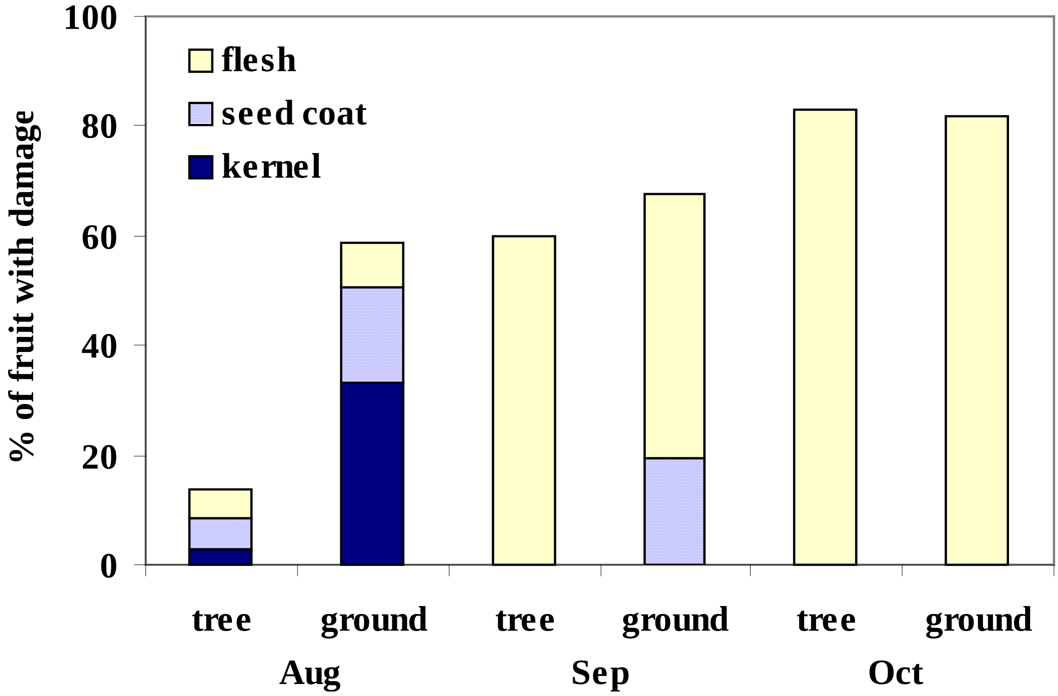

Figure 8: Location of damage in mature quandong fruit from trees and ground at Quorn in 2000

6.Management

6.1 Introduction

Integrated pest management (IPM) involves the use of a number of compatible pest management tactics. For some insect pests, several management strategies may be used simultaneously and for others different periods in the development of the host plant or the pest may require different management strategies. Techniques that are available for use in IPM include monitoring for the pest organism, insecticides, biological control, cultural methods, resistant varieties and in more recent years, genetically modified organisms. To date, the only management strategy that has been used for the quandong moth in quandong orchards is a broad-spectrum organophosphate insecticide, in many cases by calendar application. Sustained and frequent use of a broad-spectrum insecticide is not a sustainable or desirable option for management of the moth. This section outlines investigations into strategies with the potential to effectively manage quandong moth populations in a sustainable and environmentally rational manner.

6.2 Monitoring

Due to the concealed feeding behaviour of the larvae, quandong moths are only vulnerable to some management strategies for a very short period of their lifecycle. Although usually well protected inside the calyx of fruit, the eggs are the most vulnerable stage of the moth. Neonate larvae are also relatively vulnerable, but only for a very short period, as indicated by the observations on neonate larval behaviour. Thus, if management strategies such as insecticides are to be applied it is imperative that they are well timed to maximise efficacy.

Previous chapters have outlined the most damaging stages of the quandong moth and the vulnerable periods of the quandong tree. Not only is monitoring likely to be extremely difficult for growers during the flowering period, the damage that larvae cause during this period is insignificant in terms of fruit set and subsequent yield of the trees. Although, the studies on fruit drop indicated that feeding by larvae of the autumn-winter generation may not necessarily reduce yield, many larvae of this generation will contribute to the following highly damaging generation. Thus, management of this generation with is likely to be advantageous. Based on the data from field sampling, the period of oviposition that produces larvae of the autumn-winter generation commences in mid-late April. Monitoring for eggs of this generation should commence before this period with insecticides being applied as soon as eggs of the quandong moth are detected. With fortnightly sampling there were several times in this study where eggs of the autumn-winter generation were not detected but larvae were already present in fruit. Monitoring should be conducted at maximum intervals of a week and according to degree-day estimates eggs will take approximately 7-10 days to hatch during this period. Monitoring will require a hand-lens with a minimum of x10 magnification to detect egg masses. If the majority of egg masses detected are newly laid, ovicides may be applicable but for more developed eggs larvicides could be applied to target the larvae as they hatch.

Although the nature of the damage is different, the spring generation of larvae also cause a significant amount of damage to quandong fruit. At this time of the year the damage mainly reduces the quality of the fruit, rather than yield. On average eggs of the spring generation are present during early-mid September. Once again, monitoring for egg masses should be conducted with a hand-lens and management strategies implemented as soon as eggs are detected.

6.3 Chemical control

The Australian Quandong Industry Association has had a temporary registration to use dimethoate for control of quandong moth in quandong orchards 1997. Dimethoate was primarily selected for use against larvae of the quandong moth because it has systemic properties. Although dimethoate is biodegradable and undergoes rapid degradation in the environment, it is very toxic to birds, fish, aquatic invertebrates and bees. Spraying during flowering periods of the crop when bees are active is not recommended. Due to the lack of research into the biology, ecology and phenology of the quandong moth, many growers were reliant on haphazard monitoring, or calendar applications of insecticides. The systematic action of dimethoate facilitates calendar applications, however the maximum effects will be achieved if larvae are caught early to reduce the abortion of fruit from trees and the reduction in quality of mature fruit. Two field trials were conducted, the first to examine spray timing with the currently used insecticide dimethoate, and the second to investigate alternative insecticides with potential for use against the quandong moth. The results of these trials, in conjunction with information obtained on the number of timing of the generations of the moth, aim to decrease the frequency of insecticide applications and increase the effectiveness of the sprays that are applied through improved timing.

6.3.1 Materials and Methods

Both field trials were conducted at a commercial orchard of quandong trees at Whyalla, South Australia. The orchard was divided into several blocks with the grower allowing use of two blocks, with approximately 40 trees in each block. Although the trees were planted in rows, there had been a lot of seedling death in the orchard and as the grower had since moved to better yielding grafted varieties in other blocks the trees that died had not been replaced. In addition, a lot of the trees in the blocks were very low yielding and therefore not able to be used in the field trials in either year. Trees used in the trials were selected primarily on the basis of potential yield to ensure that there would be adequate fruit to sustain sampling throughout the season.

The spray timing experiment was designed as a randomised complete block design with the factor spray timing. The grower sprayed all trees initially in mid-January and then the four treatments were applied throughout the year. Single tree replicates were used, with trees randomised in each of six blocks. The treatments were sprays applied in early June only, early June and early August, early August only and an unsprayed control. All sprays were dimethoate at 75ml/100L, applied with a Solo® Knapsack sprayer. The early June and early August sprays were aimed to target the start of the autumn-winter and spring generations of the quandong moth respectively. Samples were taken from trees on 30th January, 10th March and 2nd June prior to the first spray. Although no eggs or larvae were detected in fruit on 2nd June the spray was applied as a precautionary measure as some eggs or larvae of the quandong moth may have gone undetected. The timing of the spray applied for the autumn-winter generation was also based on the previous year of data at Quorn where eggs of the generation were found in mid May. The next treatment was applied in early August and a sample taken on the 19th August as the fruit on some trees began to mature. Subsequent samples were taken from trees as fruit ripened, on the 10th and 24th September. At maturity the treatments were compared to samples taken from other trees in the orchard that had been sprayed monthly with dimethoate by the grower. Data were analysed with ANOVA and Tukey's tests to compare treatment means (Statistix®, Analytical Software, Tallahassee, Florida, U.S.A.).

The field trial examining alternative insecticides was also conducted using a randomised complete block design. The insecticides trialed were fenthion as Lebaycid®, a broad-spectrum organophosphate, fenoxycarb as Insegar® and tebufenozide as Mimic®, insect growth regulators specific to lepidoptera and dimethoate as a standard. All insecticides were applied three times throughout the trial. The first spray was applied on 15th February after detecting immature larvae in a pre-spray sample. The second spray was applied on 19th May and samples of fallen fruit were collected where possible from this date until the end of the trial. The third spray was applied on the

25th August after eggs were detected in a pre-spray sample. The sprays were timed to the beginning of the second summer generation, the autumn-winter generation and the spring generation of the quandong moth with an unsprayed control. At maturity the treatments were compared to samples taken from other trees in the orchard that had been sprayed monthly with dimethoate by the grower. Data were analysed with ANOVA and Tukey's tests to compare treatment means (Statistix®, Analytical Software, Tallahassee, Florida, U.S.A.).

6.3.2 Results

In the spray timing trial, fruit from some trees was assessed on two harvest dates in September and the results were pooled for analysis. Both the mean number of larvae per fruit and the severity of damage between treatments were analysed. For the incidence of larvae there was no significant difference between any of the spray treatments and all recorded a higher incidence of larvae than the control with the exception of early June + early August. There was no significant difference between the control and the trees that had been sprayed monthly throughout the year. For severity of damage to the flesh, the only treatment that was significantly less damaged than the control was early June + early August. Trees treated in early June and early August were not significantly different from those sprayed monthly, with the lowest levels of damage in both treatments (see Figure 8).

In the trial examining alternative insecticides, mature fruit were harvested from late August to mid October and the results were pooled for analysis of the incidence of larvae and the severity of damage. There was no significant difference in the incidence of larvae between the control and trees sprayed with fenoxycarb (Figure 9). However the level of infestation in all other treatments was as low as that in trees sprayed monthly with dimethoate. The results were very similar for the severity of damage with the exception of dimethoate, which was not significantly different from the control (Figure 10). Several larvae in fruit collected from trees sprayed with tebufenozide were deformed. When fruit drop began in 2000, a maximum of 10 fruit were collected from underneath trees where fruit had dropped. Analysis of variance showed that there was no significant difference between treatments in terms of the number of fruit dropped from trees throughout the experiment.

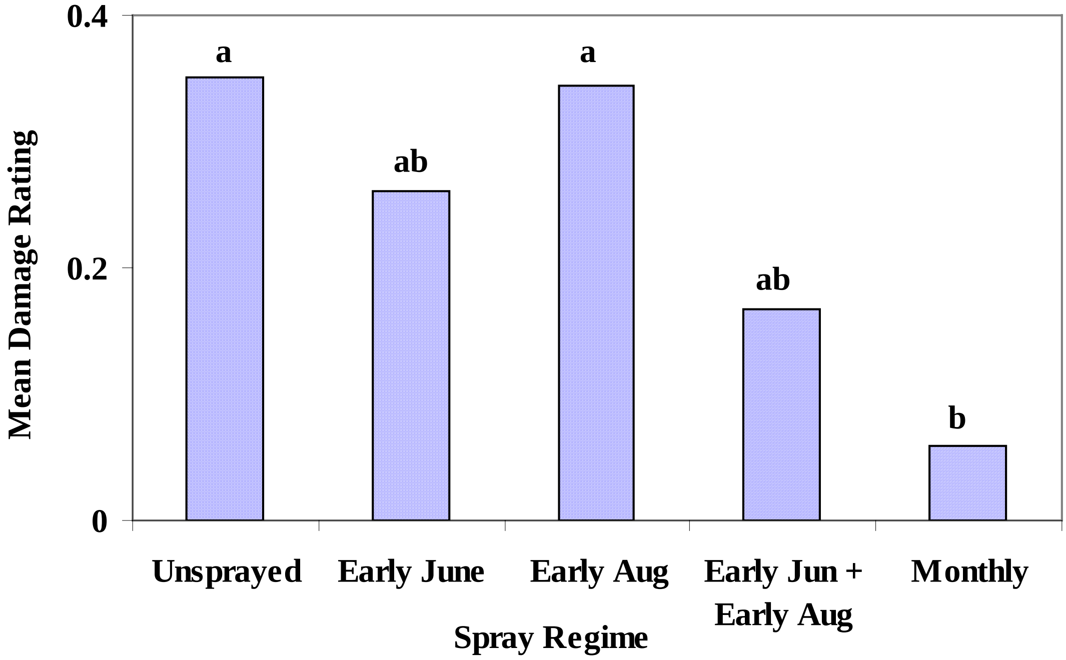

Figure 8: Severity of damage caused to mature quandong fruit by quandong moth larvae in spray timing trial with dimethoate at Whyalla 1999. Monthly = trees sprayed monthly with dimethoate by grower. Letters denote significance as determined by ANOVA and Tukey's test.

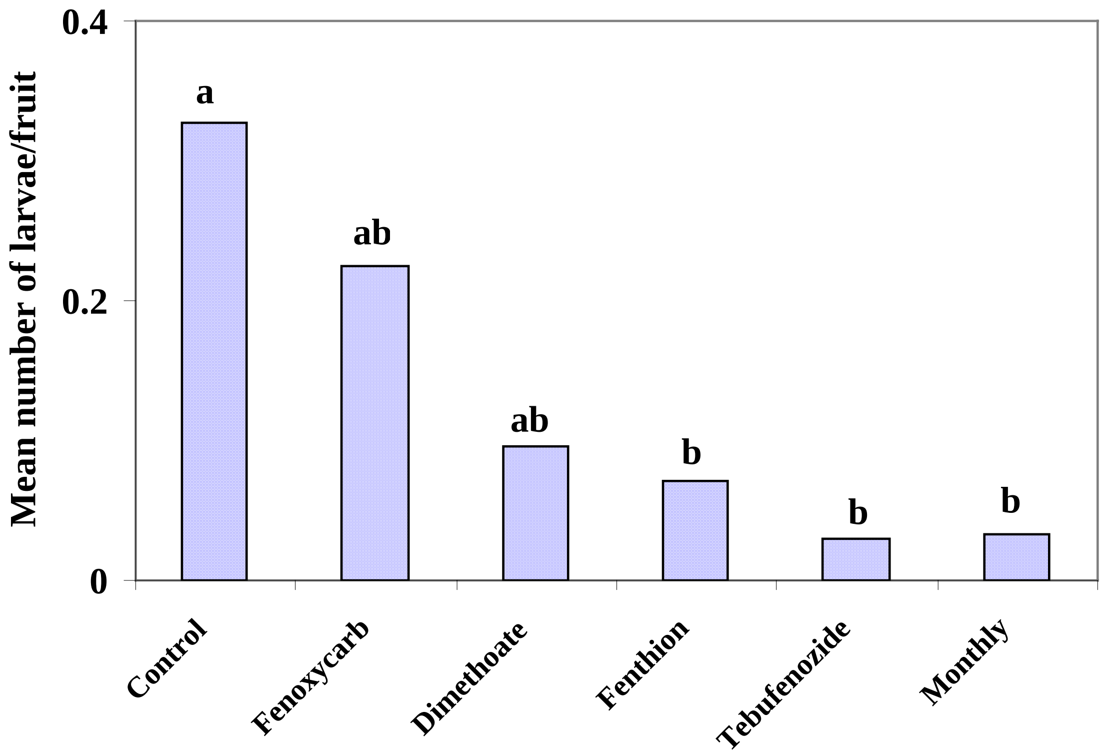

Figure 9: Incidence of quandong moth larvae in mature fruit in insecticide trial at Whyalla 2000. Insecticides were applied three times in the year and compared to monthly applications of dimethoate by the grower. Letters denote significance as determined by ANOVA and Tukey's test.

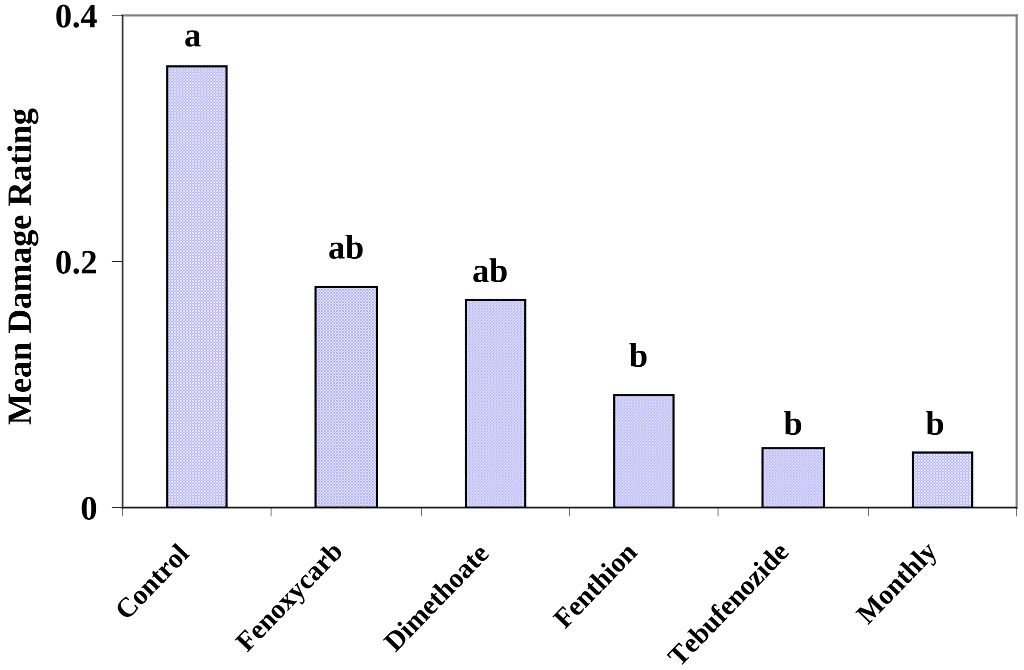

Figure 10: Severity of damage to flesh of mature quandong fruit in insecticide trial at Whyalla 2000. Insecticides were applied three times in the year and compared to monthly applications of dimethoate by the grower. Letters denote significance as determined by ANOVA and Tukey's test.

6.4 Biological Control

Native pests such as the quandong moth are expected to have specialist and generalist natural enemies already established in their ecosystem that may be only partly effective at suppressing pest populations. In addition, agricultural practices such as insecticide usage may have shifted the balance between pest and natural enemy populations such that pest species is causing economic damage. The two methods of biological control applicable in such cases are augmentation and conservation.

There were two main species of parasitoid wasps specific to the quandong moth collected during field sampling and both were in the family Braconidae. The *Chelonus* species is an egg-larval parasitoid and attacks the quandong moth in its most vulnerable stage. The *Dolichogenidea* species attacks the larvae of the quandong moth. Although both species emerge late in the final instar of the quandong moth and therefore do not prevent the larva they have attacked from feeding, they will kill the larva and reduce the numbers in subsequent generations.

It is clear that even in unsprayed orchards parasitoids are only partly effective in suppressing populations of the quandong moth. The data on the percentage parasitism at the various sites indicated that a maximum of 60% parasitism occurred during the autumn-winter generation of the quandong moth and during that generation the incidence of quandong moth larvae was relatively low. During the spring generation, the percentage parasitism was lower, approximately 40% in 1999, 20% in 2000 at Quorn and less than 2% at Sedan in 2000.

Augmentation biological control is reliant on laboratory mass-rearing large numbers of the parasitoid for release and immediate or season-long control of a pest. Because the quandong moth could not be mass reared in the laboratory, its parasitoids could not be mass reared either for evaluation in the laboratory or the field. Until such time as the quandong moth can be reared or unless a method can be found to rear its parasitoids on an alternative host, augmentative biological control will not be an option for the quandong moth.

Conservation biological control involves preserving and protecting existing populations of natural enemies through the manipulation of agricultural practices. The main factor suppressing the effectiveness of natural enemies, including parasitoids, is the use of broad-spectrum insecticides. The adoption of lepidopteran specific insecticides would help to conserve populations of all natural enemies of the quandong moth.

6.5 Cultural Control

Cultural control is most likely to have a role during the period of fruit drop by trees. This study has shown that infested fruit are aborted from trees with larvae still inside but many mature larvae are able to complete their development in fallen fruit. Collecting and destroying fallen fruit may be feasible in orchards, particularly those that are regularly maintained and small-scale.

6.6 Trapping

Several different methods were trialed for trapping adult quandong moths, including light traps and sticky traps but none were effective. Light traps were set-up at Sedan and McLaren Flat during fruit maturity, in late-September 1997 and during flowering in mid-January 1998. One male quandong moth was captured at a light trap run at Sedan during flowering in 1998. The moth was captured approximately 30 minutes after dusk. No others were captured at either site. Pheromone traps were also trialed, consisting of live females inside modified sticky traps.

None of the traps used were effective. Sticky traps were successful in catching many small Diptera but very few quandong moths. No quandong moths, male or female were captured on the live pheromone traps.

6.7 Resistance

The trees in the orchard at Quorn originated from seed collected from various sites in South Australia and Western Australia. There was a high degree of variability amongst the trees in terms of physical characteristics of leaves and fruit and in the history of fruiting and attack by the quandong moth (Powell, pers.comm.). The trees at Sedan were in a natural grove and therefore were likely to be less variable.

The severity of damage to fruit at harvest between trees and between years was compared. Analyses of variance were conducted to determine if there was a significant difference in the severity of damage between trees sampled in a year and to determine if there were significant differences between years in individual trees.

In each year at Quorn, the highest damage rating was recorded on tree 6 and in 1998 it was significantly higher than any other tree sampled. In 1999, tree 6, 2 and 11 were significantly higher than any other trees. However, in 2000, there was no significant difference between any trees. Where possible, comparisons were made between individual trees in each year. Six out of the eight trees in which comparisons were made between years had a consistent level of damage in each year. The exceptions were trees 3 and 9 with low levels of damage recorded in 1999 (Figure 11).

At Sedan, in 1998, tree 7 had a significantly higher level of damage than any other tree. In 2000, there was no significant difference between the level of damage in any trees. In three of the eight trees in which comparisons were made between years, there was a significantly higher level of damage in 1998 and the remainder were consistent across years. (Figure 12).

Overall there was a similar level of incidence and severity of damage at Quorn and Sedan. The majority of trees had a consistent level of damage in each year. Neither site had any trees with consistently low levels of quandong moth damage.

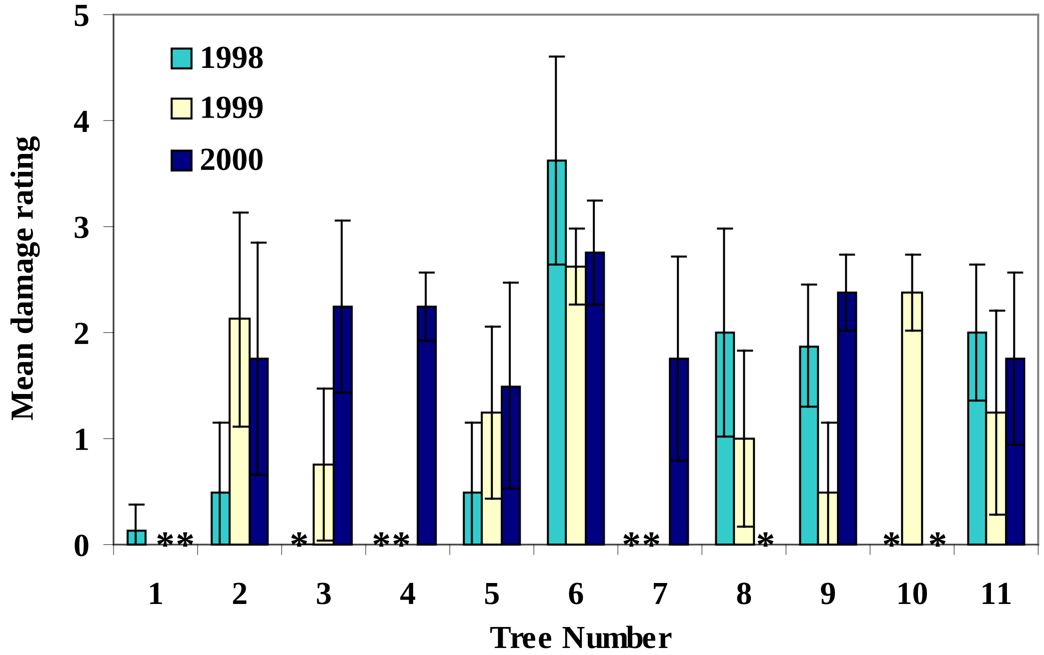

Figure 11: Comparison of severity of damage to mature quandong fruit on sample trees at Quorn 1998-2000. Bars are 95% Confidence Intervals. * = years in which data were not available.

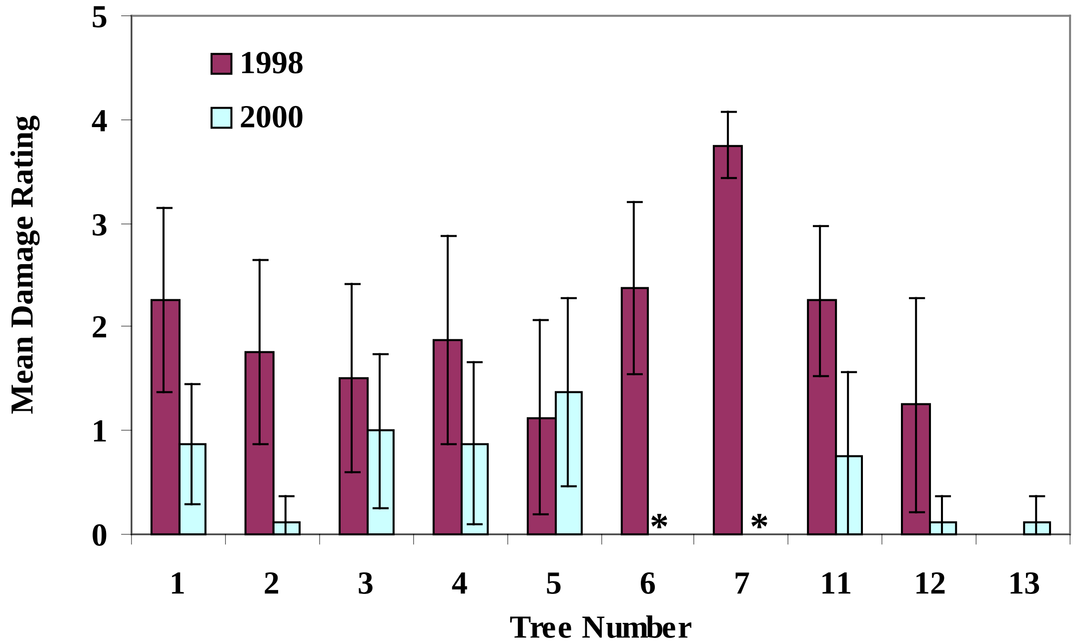

Figure 12: Comparison of severity of damage to mature quandong fruit on sample trees at Sedan 1998-2000. Bars are 95% Confidence Intervals. * = years in which data were not available.

7. Conclusions

Life cycle of quandong moth

- Developmental stages are egg, four larval instars, pupa and adult.
- At 24°C, eggs hatch 6-7 days after being laid, the duration of the larval stages is 20 days, the pupal stage lasts about 9 days and adults live up to 18 days when fed.
- Neonate larvae move 6-7mm across the surface of fruit and start feeding five minutes after hatching. The neonate channels into the fruit, leaving a minute hole. All further development is inside the fruit.
- The pre-pupa falls to the ground, often still within the fruit, and pupates in the soil
- Adults can mate within one day of emergence. Females are recorded as laying up to 85 eggs in a lifetime in the laboratory
- Adults appear to be poor fliers apparently with poor dispersal ability.

Host specificity

- Quandong moth has been recorded only from *Santalum* spp., this study reports only on the biology of quandong moth on *S. acuminatum*, but quandong moth has also been observed on fruit of sandalwood, *S. spicatum*.
- There appear to be no other hosts outside the genus *Santalum*.
- Quandong moth overcomes the absence of fruit during summer by developing within quandong flowers.
-

Seasonal cycle and host phenology

- Quandong moth has 3-4 generations per year; 1-2 generations in summer, and a winter and spring generation respectively.
- During summer, there is no fruit on trees, only flowers. The summer generation of the quandong moth live on these flowers; eggs are laid on the flower and the larvae feed on flower tissue. The number of summer generations appeared to be dependent on temperature and food quality.
- The winter generation starts with eggs laid in Autumn (April-May). By this time, the fruit is 5 - 10mm in diameter, most of which is soft kernel and little flesh. The quandong moth lays its eggs in the calyx of the fruit. Larvae eat the kernel and seed coat tissue.
- The spring generation begins with eggs laid from mid-August to mid September. By this time, the fruit is near its mature size, with several mm of flesh surrounding the hardened seed.

Damage

- Damage to flowers by the summer generation(s) is unlikely to affect yield, as quandongs flower prolifically, and normally shed large numbers of flowers.
- Damage to the immature fruit by the winter generation of quandong moth causes fruit drop, but there is also considerable drop of undamaged fruit (60% of dropped fruit were undamaged in this study). It appears that the quandong tree has evolved to produce many more flowers and fruit than it can carry to maturity, perhaps to compensate for feeding by quandong moth.
- Damage by the spring generation of quandong moths to the maturing fruit greatly reduces quality and yield.

Developing an IPM program

- Several natural enemies were found during this study, but none exerted any significant control on quandong moth. The maximum rate of parasitism recorded in this study was 60%, but this was not sufficient to reduce damage at harvest. Predation of eggs did not appear to be important, and the larvae are protected from natural enemies.
- An egg parasitoid (*Trichogramma* sp) was found to parasitise less than 1% of eggs. However, this indicates the potential to develop this species (when it is identified) for possible insectary

production, provided it can be reared on another host (a method for laboratory rearing of quandong moth could not be developed during this study).

- There did not appear to be any heritable resistance in quandong trees to quandong moth. In a quandong orchard of diverse tree genotypes, but otherwise uniform cultivation, no resistant genotypes could be identified.
- The apparent poor flight ability of adult quandong moths and the absence of bush hosts (other than *Santalum* spp.) suggest that movement of moths to commercial orchards might not be great. This suggests that orchard hygiene, particularly removing fallen fruit during winter to reduce the size of the subsequent spring generation, and in summer following harvest, will reduce the resident population of quandong moths.
- The only other intervention available to quandong growers is to use insecticides to protect fruit. To prevent larvae entering fruit, it is necessary to kill the egg or kill the larva after it hatches, but before it enters the fruit. To use this strategy, careful monitoring and timing of insecticides is necessary.
- The only chemical with a use permit (and only in South Australia) is dimethoate. However, the systemic action of this chemical makes it useful only after larvae have entered the fruit. During this study another chemical with similar action, fenthion, was found to be effective. The broad-spectrum characteristics of these chemicals and the possibility that the current review of organphosphate insecticides by the National Registration Authority may limit their use, do not make them good candidates for use in the quandong industry.
- The insect growth regulator tebufenozide was found in this study to effectively control damage at harvest. However, this is not presently registered and residue data are not presently available

Recommendations to quandong growers for control of quandong moth in orchards

- Remove fallen fruit beneath trees
- Monitor for eggs in the calices of fruit during autumn (April-May) and spring (mid August to mid September). Use a hand lens to examine fruit on trees so applications of insecticides can be timed to periods when eggs are present and neonate larvae are active.

Future work

- Residue data for tebufenozide on quandong fruit, and application for registration for Minor Use Permit.

8. Appendix

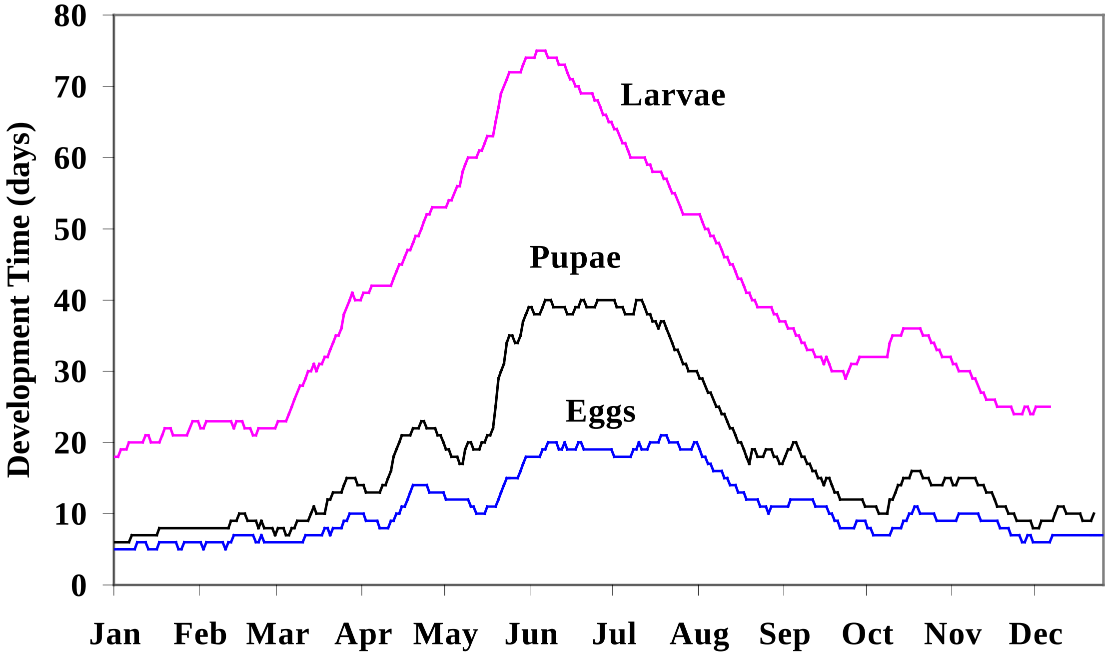

Figure 1: Developmental times of eggs, larvae and pupae of quandong moth at Quorn in 1999.

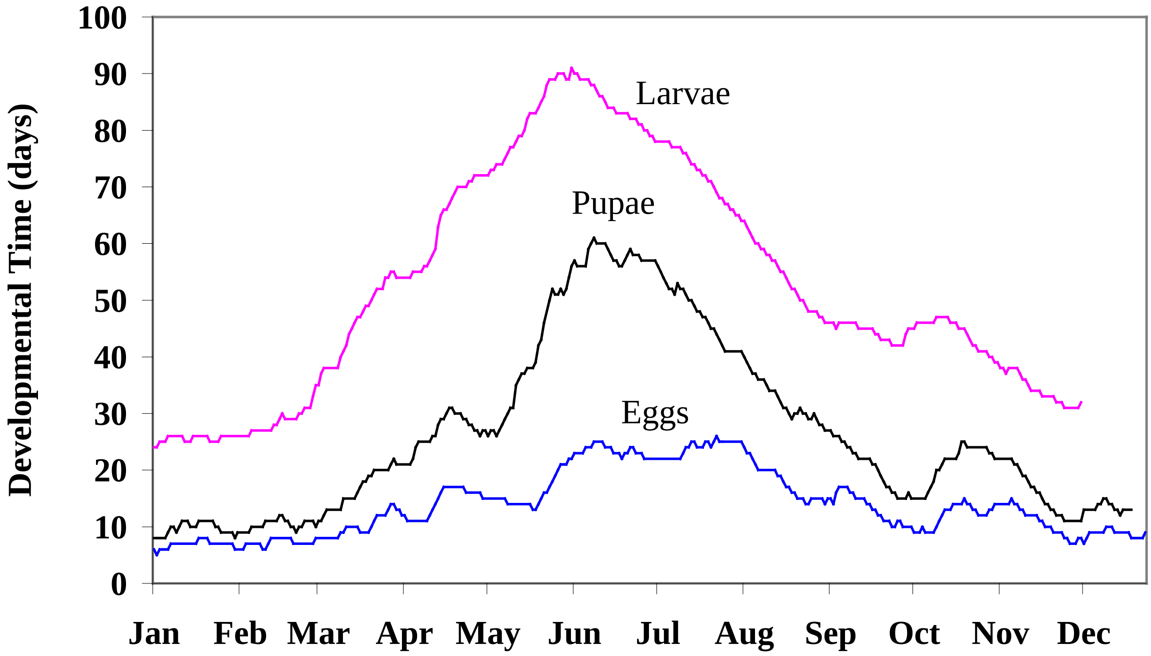

Figure 2: Developmental times for eggs, larvae and pupae of quandong moth at Sedan in 1999.

Table 1: Variances calculated from Taylor's Power Law[1] for density of quandong moth eggs on flowers and fruit. Sample sizes calculated for 20% precision level.

Mean	Variance	Sample size
0.05	0.042	422
0.1	0.174	436
0.15	0.400	444
0.2	0.720	450
0.25	1.137	455
0.3	1.651	459
0.35	2.264	462
0.4	2.976	465
0.45	3.787	468
0.5	4.699	470
0.55	5.711	472
0.6	6.825	474
0.65	8.040	476
0.7	9.357	477
0.75	10.777	479
0.8	12.299	480
0.85	13.924	482
0.9	15.653	483
0.95	17.485	484
1	19.421	486

[1]Coefficients derived from non-linear regression (SAS Analytical software); a = 19.42, b = 2.05

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