

**ASPECTS OF THE BIOLOGY AND POPULATION DYNAMICS FOR
THE INTEGRATED CONTROL OF THE MANGO SCALE
AULACASPIS TUBERCULARIS NEWSTEAD IN SOUTH AFRICA**

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ABSTRACT

Post embryonic development of the mango scale, *Aulacaspis tubercularis* Newstead, comprises of two larval instars and an imago in the female, and two larval instars, two pupal instars (prepupa, pupa), and an imago in the male. The sex of the organism can easily be determined in the first instar.

The duration of a single generation of *A. tubercularis* at simulated summer, spring and winter temperatures was 42,7, 52,5 and 68,9 days respectively. Average periods of oviposition at the same simulated conditions were 33,25, 45,69 and 28,48 days and the average number of eggs produced 203,15, 261,90 and 82,45 for summer, spring and winter respectively. Males accounted for 73% of the *A. tubercularis* population. *A. tubercularis* was found to be biparental, no parthenogenesis was found and positive phototactic behaviour was demonstrated.

Population expansion in the field began at the beginning of spring and reached a peak before midsummer. This can possibly be explained by the higher reproductive rate of the insect when reared under simulated spring conditions in the laboratory. The mango scale population peaked in August and November in Kaapmuiden and Nelspruit respectively.

The infestation of mango scale in mango trees was significantly higher in the shady south facing lower aspect than in any of the other aspects.

Generations overlapped to such an extend that all developmental stages were

found throughout the year. The long ovipositional period, which can last up to 82 days in spring, is primarily responsible for the overlapping of generations.

The only indigenous parasitoid found on mango scale in South Africa, *Aspidiotiphagus citrinus*, is density independent and therefore incapable of controlling *A. tubercularis*. A predatory thrip, *Aleurodothrips fasciapennis*, was found feeding on *A. tubercularis*. This is the first recording of this species on mango scale and in Africa.

UITTREKSEL

Post-embriëniese ontwikkeling van die mangodopluis, *Aulacaspis tubercularis* Newstead, bestaan uit twee larwale instars en 'n volwassene by die wyfie en twee larwale instars, twee pupale instars (prepapie en papie) en 'n volwassene by die mannetjie.

'n Generasie van *A. tubercularis* by gesimuleerde somer, lente en winter temperature het onderskeidelik 42,7, 52,5 en 68,9 dae geduur. Die gemiddelde duur van die eierlê-periode by dieselfde gesimuleerde toestande was 33,25, 45,69 en 28,48 dae en die gemiddelde aantal eiers wat geproduseer is 203,15, 261,90 en 82,45 onderskeidelik vir somer, lente en winter. Drie en sewentig persent van die *A. tubercularis* bevolking was mannetjies. *A. tubercularis* is biparentaal, nie-partenogeneties en het positief fototaksiese gedrag openbaar.

'n Toename in bevolking in die veld het 'n aanvang geneem in die begin van lente en 'n piek bereik voor middel somer. Dit kan moontlik verklaar word deur die groter voortplantingspotensiaal van die insek in gesimuleerde lente toestande, soos in die laboratorium aangetoon. Die mangodopluisbevolking het 'n piek gedurende Augustus in Kaapmuiden en eers gedurende November in Nelspruit bereik.

Die mangodopluisbesmetting in mangobome was betekenisvol hoër aan die skaduryke, suide- onderkant, as aan enige van die ander kante.

Generasies het tot so 'n mate oorvleuel dat al die ontwikkelingsstadia dwarsdeur die

die jaar teenwoordig was. Die belangrikste rede hiervoor is waarskynlik die lang eierleggingsperiode, wat tot 82 dae kan duur gedurende lente.

Die enigste inheemse parasitoïed wat op mangodopluis in Suid Afrika gevind is, *Aspidiotiphagus citrinus*, is digtheidsonafhanklik en gevolglik nie in staat om *A. tubercularis* te beheer nie. 'n Predatories blaaspootjie, *Aleurodothrips fasciapennis* Franklin, is op die mangodopluis gevind. Dit is die eerste rekord van dié spesie op mangodopluis asook in Afrika.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The mango scale insect, *Aulacaspis tubercularis* Newstead, is currently considered by the S.A. Mango Growers' Association to be one of the most serious problems in the mango industry. Both chemical and biological control of mango scale is high on the mango grower's association's research priority list.

Although the mango scale does not cause internal fruit damage, the cosmetic effect that it has on the fruit (Fig. 1.1) results in significant decrease in the ratio of exportable fruit and substantial financial losses for the mango grower. The scale population is small for the greater part of the year, when they can be detected on the upper surfaces of the leaves (Fig. 1.2). However, during the fruit bearing period the population increases tremendously and the scale insects migrate to the fruit where they settle. The scale insects can be rubbed off the fruit quite easily, but the marks which are left are unsightly and unacceptable to the foreign market. It is thus of utmost importance to control the scale insects before they move to the fruit, since even if they are killed on the fruit, lesions remain. Control of the scale insect is complicated by the possible negative effect of insecticide and fungicide applications against other pests and diseases, on the natural enemies of the mango scale, resulting in an unrestricted population growth of the scale.

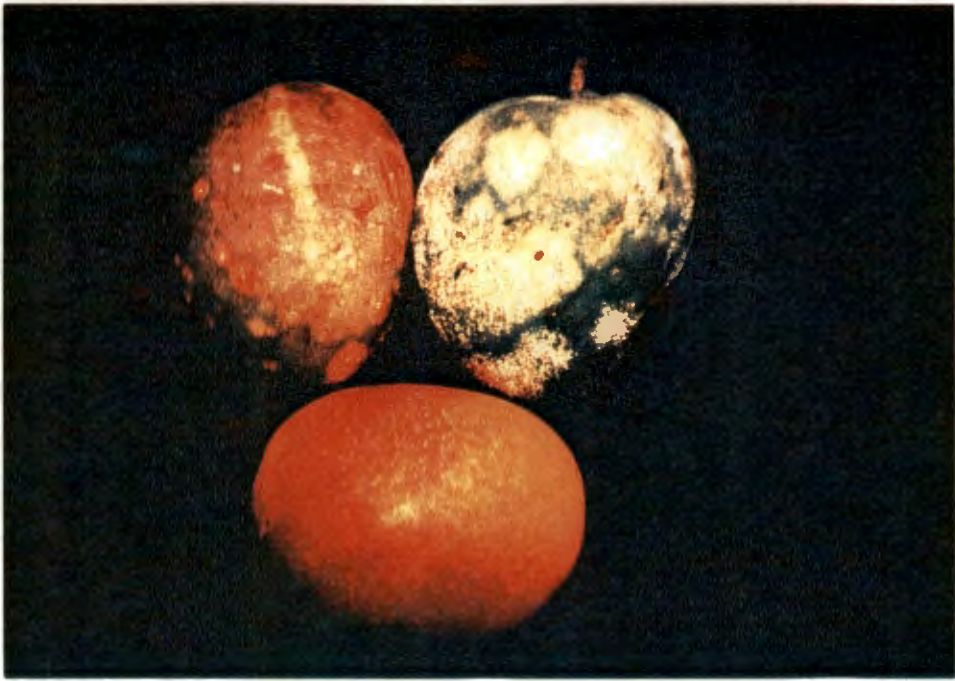


Figure 1.1 Cosmetic damage caused by *Aulacaspis tubercularis* on mango fruit.

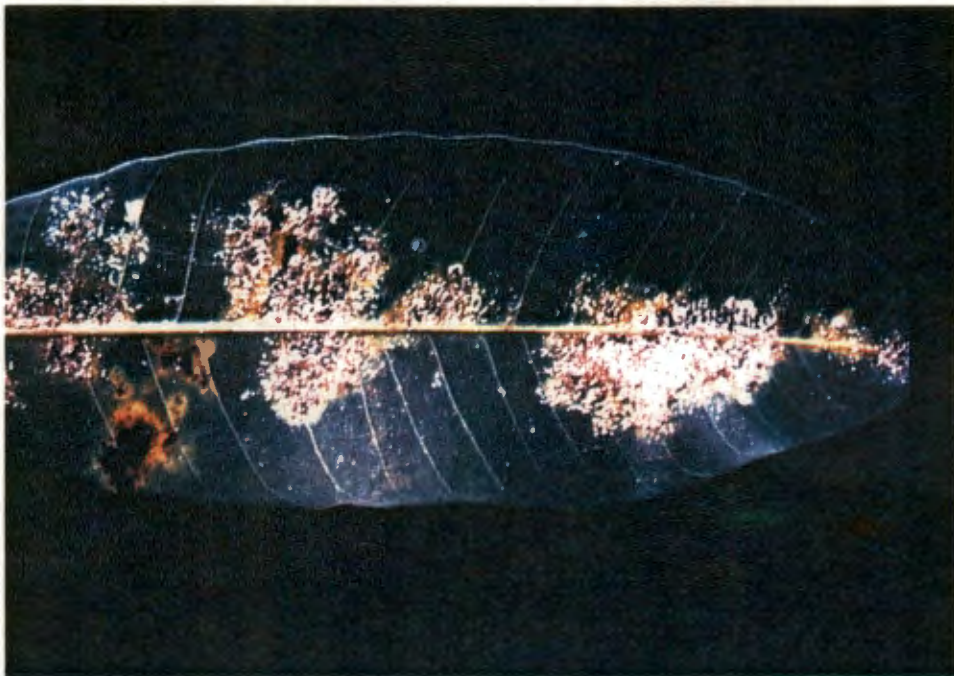


Figure 1.2 *Aulacaspis tubercularis* on the upper surface of leaves

Since the scale causes blemishes on the fruit without effecting the fruit flesh, it has only become a significant pest in South Africa during the past few years as the demand for export fruit increased. This, and the ongoing pressure to reduce the use of chemicals in mango production, has initiated an investigation into a possible biological or at least an integrated control programme for the mango scale. According to Cock (1986), knowledge of the number of generations per year, the distribution pattern, the population fluctuation and the peaks of susceptible stages to parasitism and chemical control is a prerequisite for the implementation of an integrated pest control programme. The fact that the young nymphal instars of scale insects are more sensitive to certain insecticides, especially to the insect growth regulators (Yarom, Blumberg & Ishaaya 1988, Van Duyn & Murphey 1971), confirms Cocks argument. Darvas & Varjas (1990) cited numerous examples of growth regulators affecting only certain specific growth stages of representatives of the Diaspididae. The identification of peaks of these growth stages of the mango scale could make it possible to reduce the use of chemicals by concentrating a control programme on only these stages. It is therefore the objective of this study to develop a better understanding of the biology and ecology of *A. tubercularis* with the ultimate aim to establish a viable, integrated control programme for mango pests, and in particular for the mango scale.

Although much work has been done on the chemical control of mango scale in South Africa (De Villiers & Du Toit 1981, De Villiers & Manicom 1984, De Villiers 1987, De Villiers & Manicom 1990, Viljoen & De Villiers 1987), little is known about the biology and ecology of this insect. De Villiers & Viljoen (1988) wrote a

brief article on the life cycle of *Aulacaspis tubercularis* which served as a basis for future studies, but they failed to identify and give detailed descriptions of the different instars.

1.2 TAXONOMIC OVERVIEW

The mango scale, *Aulacaspis tubercularis* Newstead, belongs to the order Hemiptera, family Diaspididae.

The scale was first described by Newstead (1906) as *Aulacaspis (Diaspis) tubercularis* on *Cinamomum zeylanicum* from Java. He made the assumption from the great numbers present on the leaves, that it was a potentially destructive species. The scale insect was renamed from time to time (Newstead 1908, Newstead 1911). Williams (1961) cited the following as synonyms of *Aulacaspis (Diaspis) tubercularis* Newstead, 1906: *Aulacaspis cinnamomi* Newstead, 1908; *Diaspis (Aulacaspis) cinnamomi* var. *mangiferae* Newstead, 1911; *Aulacaspis mangiferae* Newstead, Scott, 1952.

1.3 OCCURRENCE AND DISTRIBUTION

Uncertainty exists about the origin of the mango scale. Mohan (1989) suggests that it came from the Orient. It was probably first recorded in South Africa by Marloth in 1947 when he mentioned a grey - white, pear shaped scale insect which was becoming increasingly injurious to mangoes in the North Eastern

Transvaal. It was identified for the first time in the Nelspruit area, South Africa, in 1954 as *Aulacaspis cinnamomi* Newstead (ITSC - Nelspruit, accession no. ACH 174) when it was collected by F.J. Stoffberg. Mango scale is presently a widespread pest throughout all mango producing areas in South Africa (De Villiers, 1984). A careful literature review suggests that the mango scale is a significant pest only in South Africa and Australia (Cunningham 1989).

1.4 ECONOMIC IMPORTANCE

Although approximately twenty five insect and mite pest species have been identified on mangoes in South Africa, only five are considered economically important. They are the mango weevil (*Sternochetus mangiferae*), a complex of three fruit fly species (*Ceratitis capitata* (Wied.), *Pterandrus (Ceratitis) rosa* (Karsch) and *Pardalaspis (Ceratitis) cosyra* (Walk) and the mango scale *Aulacaspis tubercularis* Newstead (De Villiers & Labuschagne 1992). Extensive chemical control programmes are necessary in most of the mango producing areas in South Africa to control these pests.

Although the blemishes caused by the mango scale on the mango fruit are only superficial, and no harm is done to the fruit flesh, the marketability of especially export fruit, is significantly affected. The South African Mango Growers' Association published the following criteria for the export of mango fruit:

"Scale marks - pink and/or yellow discolouration caused by scale, not to

exceed 10 marks per fruit. With the understanding that individual and/or combined (concentrated) pink and/or yellow scale marks should not be larger than a R 2 - 00 coin" (Anonymous 1990).

Criteria for the local market are not as strict although the appearance of the fruit definitely affects its marketability.

Since mango scale is widely controlled with effective chemicals, the potential damage caused by the insect is difficult to determine. Pack houses give the rejection figures of fruit only after control programmes have been followed. Therefore, potential rejection figures can only be estimated by looking at the unsprayed controls in mango scale trials. Van Niekerk (1991) used the cultivar Keitt in the Letsitele valley in trials for the chemical control of mango scale. The percentage of fruit rejected because of blemishes caused by mango scale in the unsprayed controls of two trials exceeded 90%. Labuschagne & Froneman (1992) carried out similar trials in two orchards of the cultivars Fascell and Sensation, in the Friedenheim area, where the percentage fruit rejected in the unsprayed controls was 97% and 67% respectively. It must be kept in mind though, that some of these orchards were specifically selected for having high infestations of mango scale. Mr. Mike Amm, current chairman of the South African Mango Growers' Association and mango farmer in the Letsitele valley, is of the opinion that approximately 50% of the fruit in the Letsitele valley could be lost for export if mango scale is not controlled. This figure could be as high as 100% on late cultivars. The difference in price between exported and locally marketed fruit is

significant, the former fetching up to a third more per carton (J. Colyn, S A Mango Growers' Association, pers. comm. 1992).

The chemical, phentoate, is registered and widely used for the control of mango scale. The retail price for phentoate is at present R 37 / litre. The registered dose is 150 ml/ 100 l water. Between 15 and 20 litres are necessary to cover-spray an average 10 to 15 year old tree. The most common plant density for mango trees is ± 450 trees per hectare with an average production of ± 8 tons per hectare (H. Finnemore, S A Mango Growers' Association. pers. comm. 1993). Therefore, it will cost approximately R 75 to cover spray one hectare with phentoate if only one treatment is applied. The recommendation however, is two treatments per fruit season, which will bring the cost of the chemical to R 150 per hectare. According to Mr. Henry Erasmus, an experienced researcher from the firm Agricura in Tzaneen, the running cost for spray application (fuel, labour, depreciation of equipment) is R 0 - 03 per litre which amounts to R 270 per hectare mangoes. The total cost to control mango scale thus amounts to R 690 ($150 + 2 \times 270$) per hectare.

On average, the income per hectare for the 1992/93 season was $\pm$ R 12 per carton for exported fruit and R 10 per carton for locally marketed fruit (H. Finnemore, pers. comm. 1993). If mango scale were not controlled and fruit was marketed locally the loss in income would be $\pm$ R 2 - 00 per carton. Severely blemished fruit is however totally unmarketable and is not included in this calculation.

The magnitude of the potential financial loss attributed to mango scale is obvious if one considers that 612 000 cartons were exported and 3 205 000 cartons were sold locally during the 1990/91 season (Amm 1991). With most of the new plantings of mango cultivars aimed at the export market, this loss could increase dramatically in the near future. The implementation of a biological control programme could be one option to reduce the input cost and improve the quality of the fruit.

1.5 CONTROL OF *AULACASPIS TUBERCULARIS*

Control of mango scale in South Africa and abroad has centred around the use of chemicals (De Villiers & Du Toit 1981, De Villiers & Manicom 1984, De Villiers 1987, De Villiers & Manicom 1990, Viljoen & De Villiers 1987, Cunningham 1989). To date there has been no known attempt to control mango scale biologically or culturally.

1.5.1 RESISTANT CULTIVARS

Certain mango cultivars are more susceptible to mango scale infestation than others. In a study in Puerto Rico, Gallardo-Covas (1983) found that the Haden, Edward and David Haden cultivars were most susceptible to scale infestation while the Irwin and Keitt cultivars were less susceptible and Palmer the most resistant. No research on resistant cultivars has been done in South Africa, but field observations suggest that the greatest problem with mango scale infestation

occurs in cultivars of which the fruit hangs late in the season. According to Mr. M. Amm and Mr. W. Brooks from the S A Mango Growers' Association and Agricura (chemical company) respectively, the cultivar Kent is the most resistant and Zill, Sensation, Keitt and Sabre are the most susceptible to mango scale infestations (pers. comm. 1990).

1.5.2 NATURAL ENEMIES

The potential of natural enemies in the control of the mango scale is unclear. A parasitic wasp, *Aspidiotiphagus citrinus* Craw, an unidentified fly larva (Cecidomyiidae) and two predatory beetles, *Rhyzobius (Lindorus) lophanthae* Blaisdell and *Chilocorus nigritus* (F.) have been found to parasitise or prey on mango scale in South Africa. These natural enemies contribute to the natural control of the mango scale but are not effective enough to control the pest satisfactorily (Viljoen 1986). In a survey in which 1022 female mango scale insects were examined, 17,7 % were parasitised by *A. citrinus* (Schoeman 1987).

Rhyzobius lophanthae is the most important predator of *Aulacaspis tegalensis* in Mauritius and is an important biological control agent there. *Chilocorus nigritus* and *C. politus* Muls. are also common on *A. tegalensis* but are not important in its control (Williams 1970). According to Samways (1984) *Chilocorus nigritus* has been used successfully in the control of red scale on Citrus and he suggested that the value of the beetle lies in the impact it has on all stages of the scale insect.

The following natural enemies have been recorded in Pakistan on *A. tubercularis*:

Parasitoids:

Aphytis melinus DeBach

Aphytis sp.

Predators:

Pharoscymnus flexibilis (F.)

Chilocorus nigritus (F.)

Cybocephalus semiflavus Champ. (A.I. Mohyuddin, pers. comm. 1991)

A. melinus is a well known biological control agent of red scale, *Aonidiella aurantii*, on citrus in South Africa (Bedford & Grobler 1981), but has never been recorded on mango scale here. The possibility exists that the two *A. melinus* parasitoids described in Pakistan and South Africa are sibling species.

Mohan (1989) did a survey in India and noted the following natural enemies of the mango scale insect:

Parasitoids:

Aphytis sp. average 1,8 % parasitism.

Coccophagus sp. 80% parasitism in certain areas at certain times during the year.

Encarsia sp.

Encarsia citrina (*Aspidiotiphagus citrinus*) Craw

Pterptrix koebelei

Arrhenophagus chionaspidis Aurvillius

Signiphora sp.

Predators:

Chilocorus nigritus

Pharoscymnus horni Wiese

The identification of the parasitoid, *Coccophagus* sp. is probably incorrect since the genus is not known as a parasitoid of armoured scales. According to Annecke and Prinsloo (1974) *Arrhenophagus chionaspidis* was noted on various diaspidid hosts in Japan by Tachikawa (1963).

Apart from the identification of some natural enemies (some almost certainly incorrect) of the mango scale, not much research has been done on the impact of natural enemies on *A. tubercularis* populations.

1.5.3 CHEMICAL CONTROL

The current recommendation for the control of mango scale is the application of protiphos or phentoate as a full cover spray in mid October and a second spray 4 - 6 weeks later for late cultivars (De Villiers & Manicom 1990). Although good

control is achieved, natural enemy populations are probably also reduced. For this reason De Villiers (1987) did trials with mineral oil in which favourable results were obtained. However, oil treatment before flowering can have a detrimental effect on the crop size and the colour development of the fruit. Cunningham's (pers. comm. 1990) results from Queensland Australia confirm those of De Villiers (1987).

CHAPTER 2

MATERIAL AND METHODS

2.1 BIOLOGICAL ASPECTS OF *AULACASPIS TUBERCULARIS*

2.1.1 MASS REARING OF MANGO SCALE

Mass rearing of the mango scale, *Aulacaspis tubercularis* Newstead, was done for trial purposes only and was therefore done on a relatively small scale. The method of mass rearing mango scale, described by De Villiers (1990), was slightly adapted for this study.

Butternuts, *Cucurbita moschata* Duch., were used as a host for the mango scale. The butternuts were placed on vegetable racks which fitted into plastic containers (stacking bins), 450 X 300 X 180 mm in size. The reason vegetable racks were used, was to lift the butternuts off the base of the container in order to enhance air flow within the container. This was thought to delay decay of the butternuts. Containers were fitted with ventilation openings which were covered with fine gauze (organdie). De Villiers (1990) suggested that butternuts be treated with fungicides to guard against decay, but our experience showed that butternuts lasted from four to six months if the relative humidity in the container was kept low enough by ensuring a good air flow.

Initial infestation of the butternuts by mango scale was facilitated by cutting out circles of mango leaves on which individual reproducing adult female scale insects were present and placing these on the butternuts. Crawlers hatching from the adult females then settled on the butternuts. Infested butternuts were placed underneath fresh butternuts since it was believed that the crawlers are positively phototactic and would move up towards the light, thus infesting the fresh butternuts. The biggest problem encountered in the mass rearing of *A. tubercularis*, was contamination by the indigenous parasitoid, *Aspidiotiphagus citrinus*, which attacks the second instar and non -producing adult females and the second instar males. This contamination could seriously hamper the success of mass rearing *A. tubercularis*.

For the rearing of mango scale insects, De Villiers (1990) recommends an optimum growth chamber temperature and relative humidity of 25 °C and 70% respectively. It was our experience that a lower relative humidity of $55 \pm 5\%$ in the growth chambers extended the shelf life of the butternuts although the relative humidity in the containers was probably much higher than that measured in the growth chambers. Evidence in this regard is the fact that the extend of decay of the butternuts was directly proportional to the number of butternuts per container.

2.1.2 DESCRIPTION OF THE DEVELOPMENTAL STAGES

Mango scale was reared on the butternut, *Cucurbita moschata* Duch., as described in section 2.1., in an incubator with a day - night cycle of 14 and 10 hours

respectively. Temperatures were set at $26 \pm 1^{\circ}\text{C}$ and $13 \pm 1^{\circ}\text{C}$ and the relative humidity at $55 \pm 5\%$ and $75 \pm 5\%$ for day and night respectively.

Two methods were used to follow the life-cycle from egg to reproducing adult.

1. Non-toxic plastic clay (Prestik) was used to attach PVC cylinders, 30 mm high with a diameter of 40 mm, to the butternuts. The scale coverings of reproducing females were lifted and about 20 eggs were taken and placed on the butternuts in the confined areas with a fine camel hair brush. The purpose of the cylinders was to confine crawlers to a limited area to facilitate further observations.

2. A single adult female with eggs was selected on an already infested butternut and all the other scale insects manually removed with dry paper towel. Selecting such females proved to be very easy since eggs could be seen, through the scale covering, as a purple mass on the outside of the body. Similar PVC barricades were then placed around the females and the eggs were left to hatch. In both methods the barricades were removed as soon as the crawlers settled. Female insects were individually marked and separately followed through their life-cycles. The method used by Williams (1970) was used to study males. He studied *Aulacaspis tegalensis* Zhnt. males by taking daily destructive samples of individuals, to determine the duration of the developing stages. This was necessary since in males, moulting takes place beneath the scale covering, the removal of which kills the individual. All observations were done with a dissection microscope under 12 X and 25 X magnification. An ocular micrometer was used to measure

the different stages.

2.1.3 FECUNDITY, DURATION OF THE OVIPOSITIONAL PERIOD AND MORTALITY OF *A. TUBERCULARIS* AT DIFFERENT TEMPERATURE REGIMES

The duration of the ovipositional period was assessed by using two methods:

Non-producing fertilized adult females (A-), reared on butternuts at a constant temperature of $25 \pm 1^{\circ}\text{C}$, were selected out. The waxy scale coverings of the females were then carefully removed so as not to hurt them. Only females which were seen through the integument to be developing eggs, to verify that they were fertilised, were used. The scale covering of unfertilized females was attached to the body at the pygidium and in the process of removing the scale the stylet often pulled out and the female died. This was not the case in older females where the scales were loosely attached to the body. Females were examined daily, and the eggs laid were counted and removed. The mortality rate was still high and the procedure time consuming. It was consequently abandoned for a more practical method.

For all intents and purposes the emergence of young (crawlers) can be equated with the hatching of young. Since the actual hatching of eggs and duration of the ovipositional period can hardly be recorded without destroying the parent, crawler emergence is used in this discussion as synonymous with birth. Non - producing fertilized adult females (A-) reared as above were used for the purpose of this trial.

Each female was encircled by a sticky substance (Reverant) leaving an open area with a radius of $\pm 1,5$ cm around the female. The eggs were then left to hatch. Females were examined daily and the hatchlings removed. The procedure was repeated at three temperature regimes, a constant relative humidity and a day - night light cycle by using an incubator to simulate the summer, spring and winter seasons in the Nelspruit area. Mean maximum and minimum temperatures in the Nelspruit area for the last 54 years were used to determine these temperature regimes. The mean temperatures for the individual months are given in Table 2.1.

The mean long term maximum and minimum relative humidities for the last eight years in the Nelspruit area are given in Table 2.2. Maximum relative humidities exceeded 80% for all the months except of August and September during which they were only slightly below 80%. A simulated maximum relative humidity of 84% (yearly average for the last eight years) would have been ideal, but since fungus growth and decay of the butternuts prevented the completion of a generation of the mango scale on the butternuts at this humidity, the maximum relative humidity of the incubators was lowered to $75 \pm 5\%$. The lowest relative humidity possible in the incubators used was $55 \pm 5\%$. Thus the preferred minimum relative humidity of 32% (yearly average) could not be achieved. Incubators were therefore set at cycles of relative humidities for all the temperatures at $55 \pm 5\%$ and $75 \pm 5\%$ for day and night respectively. A day - night light cycle of 14 and 10 hours was used.

**Table 2.1 Mean maximum and minimum temperatures for the past 54 years in
the Nelspruit area**

		MINIMUM TEMPERATURE °C	MAXIMUM TEMPERATURE °C
JANUARY	SUMMER	18,6	29,1
FEBRUARY		18,6	29,1
MARCH		17,4	28,3
APRIL		14,5	27,0
MAY		10,0	25,3
JUNE	WINTER	6,6	23,2
JULY		6,5	23,3
AUGUST		8,7	24,9
SEPTEMBER	SPRING	11,7	26,7
OCTOBER		14,7	27,4
NOVEMBER		16,5	27,6
DECEMBER	SUMMER	17,9	28,8

The following three temperature cycles were identified: Summer: 29°C - 18°C

Spring: 26°C - 13°C

Winter: 23°C - 7°C.

Table 2.2 Mean maximum and minimum relative humidities for the past eight years in the Nelspruit area

	MAXIMUM RELATIVE HUMIDITY %	MINIMUM RELATIVE HUMIDITY %
JANUARY	86.3	39.3
FEBRUARY	87.0	39.4
MARCH	89.1	42.9
APRIL	87.9	36.9
MAY	85.4	29.9
JUNE	81.9	28.8
JULY	81.9	26.5
AUGUST	79.9	28.0
SEPTEMBER	79.0	30.3
OCTOBER	83.2	35.2
NOVEMBER	84.5	37.9
DECEMBER	85.3	41.2
AVERAGE	84.3	32.4

During the same trial the mortality rate for non - producing (A-) females, at the different temperature and relative humidity cycles was noted.

2.1.4 EFFECT OF TEMPERATURE ON THE DURATION OF THE DEVELOPMENTAL STAGES OF *AULACASPIS TUBERCULARIS*

The same day - night, and temperature cycles used to determine the duration of the ovipositional period, were used in this study. The life cycle, from egg to adult stage, of mass reared mango scales was observed at the different temperature regimes to establish the influence of temperature on the duration of the developmental stages. Individual females and groups of males were examined on every alternate day and developmental changes were noted.

2.1.5 SEX RATIO

Ovipositing adult females (A+) reared on butternuts at a constant temperature of $25 \pm 1^{\circ}\text{C}$ and a relative humidity of $55 \pm 5^{\circ}\text{C}$ were used in the study to determine the sex ratio of the mango scale. Butternuts were selected to be infested with one ovipositing (A+) female and all other scale insects were then manually removed. Each butternut was isolated in a cardboard container (250 mm X, 200 mm X 100 mm). Crawlers were left to settle for a period of ± 60 days since the ovipositional period can take that long. Butternuts were then removed and the number of males and females that settled were counted. Thirty seven maternal adult females were used in the experiment.

2.1.6 ROLE OF THE MALE

To determine whether the female scale can reproduce parthenogenetically, first and second instar females were isolated from males. Butternuts artificially infested with mango scale as described in section 2.1.1 were used. Butternuts were carefully examined and all the developmental stages except first and second instar females were removed. These butternuts were isolated in plastic containers sealed with a fine gauze (organdie) and placed in a growth chamber at a temperature of $25 \pm 1^{\circ}\text{C}$ and a relative humidity of $55 \pm 5\%$. The butternuts infested with the developing females were divided into five groups. The first group was exposed to an abundance of males immediately. The second group was exposed 14 days later, the third group 28 days later and so forth. Eventually all the groups, with the exception of the last group which were never exposed to males, were exposed to adult males at intervals of 14 days by placing them in open containers in growth chambers with an abundance of males, and fertilization could take place. The first group served as a control group since fertilization could take place as soon as the females reached sexual maturity.

2.1.7 PHOTOTAXIS

The influence of light on the direction of dispersion of the scale crawlers was examined in the laboratory by using the apparatus depicted in Figure 2.1. The apparatus consists of a cardboard box 600 mm long, 200 mm wide and 180 mm high.

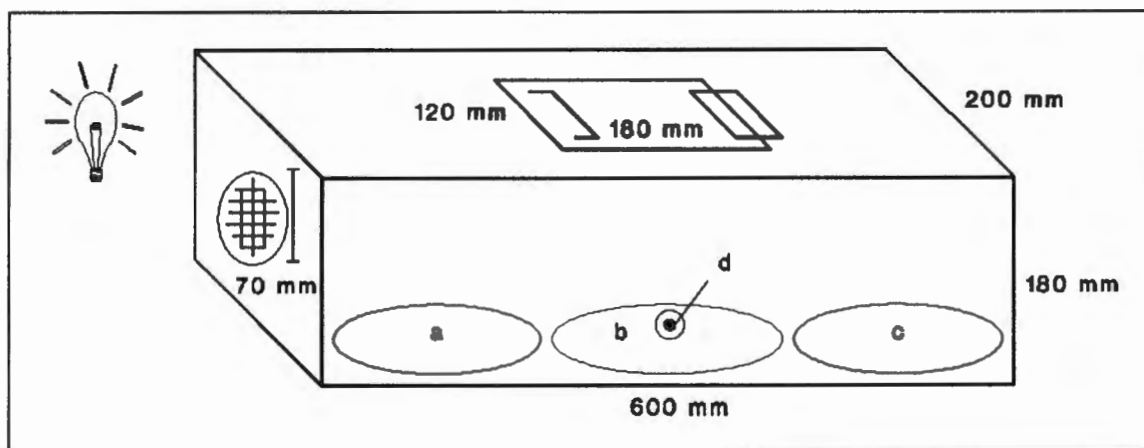


Figure 2.1 Apparatus used to examine the influence of light on the direction of dispersion of scale crawlers. Butternuts (a,b and c) laying next to each other with the infested butternut (b) in the middle. A single adult female scale (d) is indicated on the butternut (b)

At the one end is a round opening of 70 mm in diameter, sealed with fine gauze (organdie). In the centre of the roof it has a trap door of 120 X 180 mm.

A butternut infested with one producing adult scale female (A+) and two clean butternuts were placed in the box through the door so that the infested butternut lay in its length in the middle with one clean butternut on either side orientated in such a way that one was on the gauze opening side and the other on the closed end side of the infested butternut. The door was then sealed to make sure that no light could enter the box except through the round opening. The reason for sealing the round opening with organdie was to prevent wandering crawlers from escaping. The experiment was replicated ten times at a constant temperature of

25 ± 1°C and a relative humidity of 55 ± 5 %. Artificial light was provided on a day - night cycle of 14 - 10 hours. Boxes were left for a period of at least six weeks before they were opened and the butternuts examined for mango scale infestation.

The phototaxis of males was observed with the aid of emergence boxes. Developing male instars reared on butternuts were placed in the emergence boxes fitted with a transparent funnel and glass tube. The boxes were divided into a control group which was placed in a dark room and an experimental group which was placed in a room with a window through which indirect sunlight entered. The experimental boxes were orientated so that the funnels and glass tubes faced the windows. The temperature and relative humidity in both rooms were constant at 25 ± 1°C and 55 ± 5% respectively. Males were given three weeks to emerge after which the number of males collected in the tubes was compared.

2.2 POPULATION DYNAMICS OF *AULACASPIS TUBERCULARIS*

Field studies were undertaken in one or more of three orchards, two of which were in the Kaapmuiden area, 25°29’S 31°24’E, and the third on the ITSC research farm in Nelspruit, 25°27’S 30°58’E. These two geographical locations were chosen because of significant differences in climate and altitude between the regions as shown in Table 2.3.

Table 2.3 Differences in climate and altitude (m) between the Nelspruit and Kaapmuiden regions

	NELSPRUIT	KAAPMUIDEN
ALTITUDE (meters)	660	365
AVERAGE MAXIMUM TEMPERATURE (°C)	26,73	28,45
AVERAGE MINIMUM TEMPERATURE (°C)	13,48	16,91
AVERAGE MAXIMUM RELATIVE HUMIDITY (%)	85,77	87,73
AVERAGE MINIMUM RELATIVE HUMIDITY (%)	37,04	42,0

The orchards studied consisted of three different monoculture cultivars namely Peach and Keitt in Kaapmuiden and Sensation in Nelspruit. The 50 year old Peach orchard consists of large trees overlapping each other and forming dense shadows underneath. The Keitt and Sensation orchards are both 10 years old, much smaller and consequently less dense. No mango scale control has ever been applied on

any of these orchards. Only the Keitt orchard was sprayed during the last fruit season with an organophosphate, fenthion, to control the mango weevil, *Sternuchus mangiferae*. Two light, cover sprays of the chemical, one in mid October and the other two weeks later, were applied. Standard disease control programs for commercial orchards were followed throughout the duration of the study in all three orchards. The two Kaapmuiden orchards were flood irrigated while the Nelspruit orchard was irrigated by sprinklers. Fruit in the Peach, Keitt and Sensation orchards usually ripens during December, late January and late February respectively.

2.2.1 SPATIAL DISTRIBUTION WITHIN THE TREE

The first method used to determine the spatial distribution of *Aulacaspis tubercularis* entailed the sampling of eight mango leaves per tree by randomly selecting and picking two in each quadrant (N,E,S,W), the one at ± 180 cm (head height) and the other at ± 30 cm (knee height) from the ground. Eighteen randomly selected mango trees of the cultivar Sensation in the Nelspruit orchard, were sampled. Leaves were examined microscopically and all the living second instar and adult female scale insects counted. These counts were done fortnightly for a period of six months.

To verify results from the above mentioned trial, an alternative method where orchards other than the three orchards mentioned above were used. In this method five trees from five different localities and cultivars were randomly

selected. Two branches in each quadrant (N,O,S,W) of each tree were randomly selected, one at head height and the other at knee height, making sure that at least seven leaves were present per branch. Leaves were examined on the tree and only adult females were counted since the other stages were virtually impossible to detect with the naked eye. To distinguish accurately between living and dead individuals proved to be difficult. Although the intent was to count only the living females, a percentage of the count could have been dead. This would probably not have had any influence on the distribution pattern.

2.2.2 RELATIVE ABUNDANCE

The first method described to determine the spatial distribution of the mango scale was also used to determine the relative abundance of the mango scale. For this purpose counts were made in the Sensation and Peach orchards in Nelspruit and Kaapmuiden respectively. Sampled leaves were examined microscopically and all the female stages with the exception of the first instar were counted. First instar females were not counted because they could easily be missed on account of their size and distribution. Males were not counted because of their tendency to aggregate around the females which made random sampling very difficult.

2.2.3 DISTRIBUTION OF THE DEVELOPMENTAL STAGES

The method of sampling described by De Villiers (1973) was adapted and used fortnightly for 15 consecutive months from October 1992 to February 1993.

Three leaves per tree of the eighteen randomly selected trees were collected in each of the three mentioned orchards. Only leaves that were seen to be moderately infested with mango scale were sampled. Approximately fifty leaves yielded enough scale in order to examine a total of at least 350 females and 550 males, which is the sample size to ensure a representative sample (De Villiers 1973).

Scale insects were examined microscopically by lifting, or breaking the wax scale that covers the insects, with a thin needle. This was necessary to determine the developmental stage of the insect, whether it was alive or dead and whether or not it was parasitised. Males and females were considered separately. The reason for this was the major differences in morphology and distribution pattern of the two sexes. The immature instars of the males occurred in groups consisting of large numbers of individuals, while the females were randomly scattered and occurred individually all over the leaf (section 3.6). The scattered distribution and the small size of the first instar females made them difficult to detect. Consequently they were not counted. All the female scales except the first instars were examined while only a sample of the males per leaf was examined. Male crawlers settle in large groups within a radius of 1,5 cm from the adult female after hatching (section 3.6). Only a 5 mm wide strip stretching radially from the mother, was examined.

The scale insects were divided into the following developmental stages:

<u>female</u>	<u>male</u>
first instar	first instar
second instar	second instar
pre-reproductive adult	pre pupa
reproductive adult	pupa
	adult

2.2.4 PARASITISM

2.2.4.1 Collection of natural enemies

In a survey of the natural enemies of the mango scale, mango leaves, infested with scale, were collected at the following localities:

Locality	Collection dates
Nelspruit 25°27'S 30°58'E	September 1991 to February 1993
Kaapmuiden 25°29'S 31°24'E	September 1991 to February 1993
Tzaneen 23°50'S 30°10'E	23 April 1992, 14 June 1992, 10 September 1992
Rustenburg 25°40'S 27°10'E	29 January 1993

Leaves were examined for other scale insects under a stereo microscope. Where present these were physically removed before the leaves were placed in emergence boxes. Parasitoids emerging from *A. tubercularis* were identified by Dr. G.L. Prinsloo¹.

2.2.4.2 Abundance of parasitoids

The method used to determine the distribution of the developmental stages was also used to determine the rate of parasitism of the mango scale. Only endoparasitoids were found. Parasitism was noted by separately counting parasitised scale and scale from which parasites had already emerged. Parasitised scale from which parasites had already emerged was easily identified by a small hole on the dorsal side of the insect through which the parasite had emerged.

Parasitoid larvae and pupae were only found in the second instar male, the pre-ovipositional females and second instar females. No dissection of scale insects was made to detect parasitoids in their early stage of development. Therefore, it can not be stated with certainty that parasitoids oviposited only in these stages. However, according to Bruwer (1984), *Aspidiotiphagus citrinus* attacks *Insulaspis gloverii* females only from the second to the reproductive stage.

¹ Manager: Biosystematics, Plant Protection Research Institute, P/Bag X134, Pretoria, 0001

The percentage parasitism was therefore calculated as a percentage of the "susceptible hosts", in this instance, second instar males, pre-ovipositional females and second instar females.

Parasitised individuals were initially dissected and examined for the presence of parasitoid larvae or pupae but were later easily identified by the change in their colour and size. These scales changed from a healthy yellow-orange to brown and sometimes almost black (Fig. 2.2), while the body often increased in size. An easier way of identifying parasitised scale insects was by pricking the scale insect with a thin, sharp needle and noting the colour of the body fluid. The body fluid of parasitised scale is milky white compared to the yellow of normal scale.



Figure 2.2 Healthy second instar male (a). Parasitised second instar male (b).

CHAPTER 3

RESULTS AND DISCUSSION

3.1 BIOLOGICAL ASPECTS OF *AULACASPIS TUBERCULARIS*

3.1.1 DESCRIPTION OF THE LIFE CYCLE

As is generally the case with representatives of the family Diaspididae (Kojeta 1990; Ben-Dov 1985), the post embryonic development of *Aulacaspis tubercularis* comprises two larval instars and an imago in the female, and two larval stages, two pupal instars (prepupa, pupa), and an imago in the male.

a) EGG

The egg is ovate, red-brown to purple in colour, and has an average length of 0,17 (0,16-0,19) mm and breadth of 0,07 mm.

The egg covering breaks open anteriorly on the median dorso- ventral line during hatching, and the crawler emerges head first. A conspicuous white, empty shell is left behind underneath the female scale.

b) FIRST INSTAR

Crawler stage

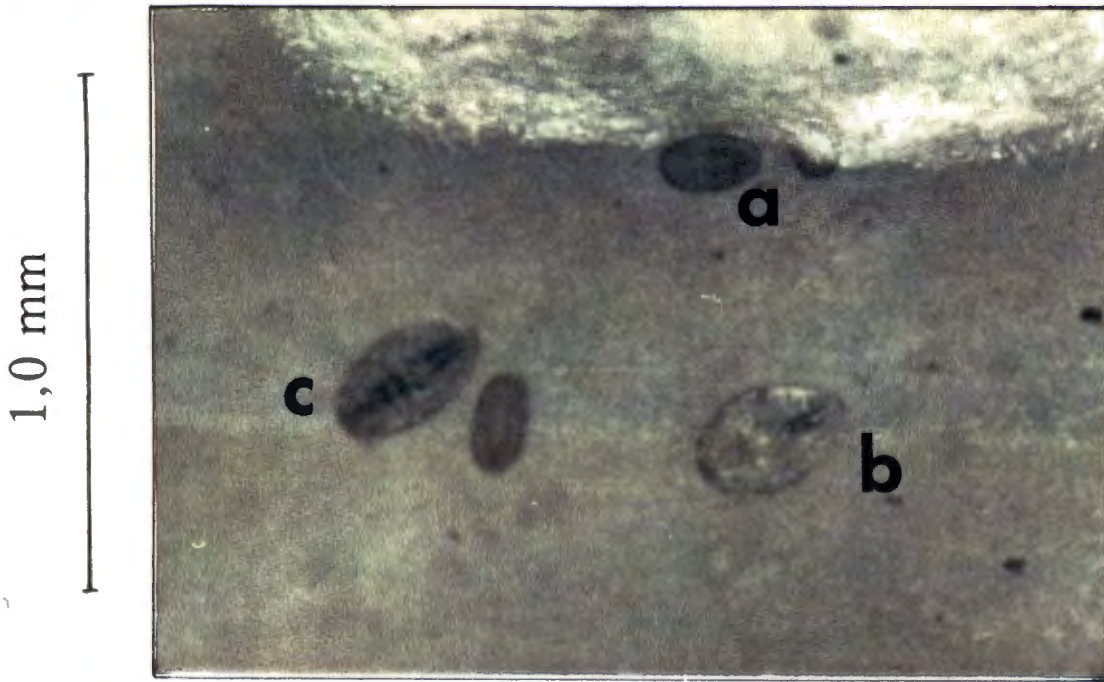


Figure 3.1 Crawler (a) first instar female (c) first instar male (b) of *Aulacaspis tubercularis*

The crawler emerges from under the female scale and normally settles within 24 hours after hatching. It is dorso-ventrally flattened, red-brown in colour, ovate, and on average 0,19 mm long and 0,10 (0,09-0,12) mm wide (Fig.3.1). Apart from the adult male, it is the only stage capable of locomotion. Dispersal of the mango scale is thus totally dependent on the crawler. Crawlers have eyes, legs, two antennae and two posterior setae. In general the males settle within close proximity to the adult female while the female crawlers settle randomly on the butternut.

Settled stage

After settling, the stylet is inserted into the host plant and the insect starts to secrete white waxy threads over itself. This species of Diaspididae is unique in that the sex of the organism can be determined at this early stage. The scale of the female sclerotises and a distinctive black median line develops dorsally during moulting of the first larval instar. The line stretches from the anterior to the posterior end. The scale of the male, develops two ridges that stretch from side to side. During this stage the insect is loosely attached to the substratum and the wax that is secreted does not form a definite covering or scale.

The male and female first instar settled stage measure on average 0,31 (0,29-0,33) X 0,20 (0,19-0,23) mm and 0,30 (0,29-0,31) X 0,18 (0,17-0,19) mm respectively.

Moulting into the next stage occurs by means of the cracking of the ventral surface of the scale along the lateral edges. The pieces of the ventral surface of the scale disintegrate while the dorsal surface of the scale is incorporated into the covering of the next instar scale.

c) SECOND INSTAR MALE

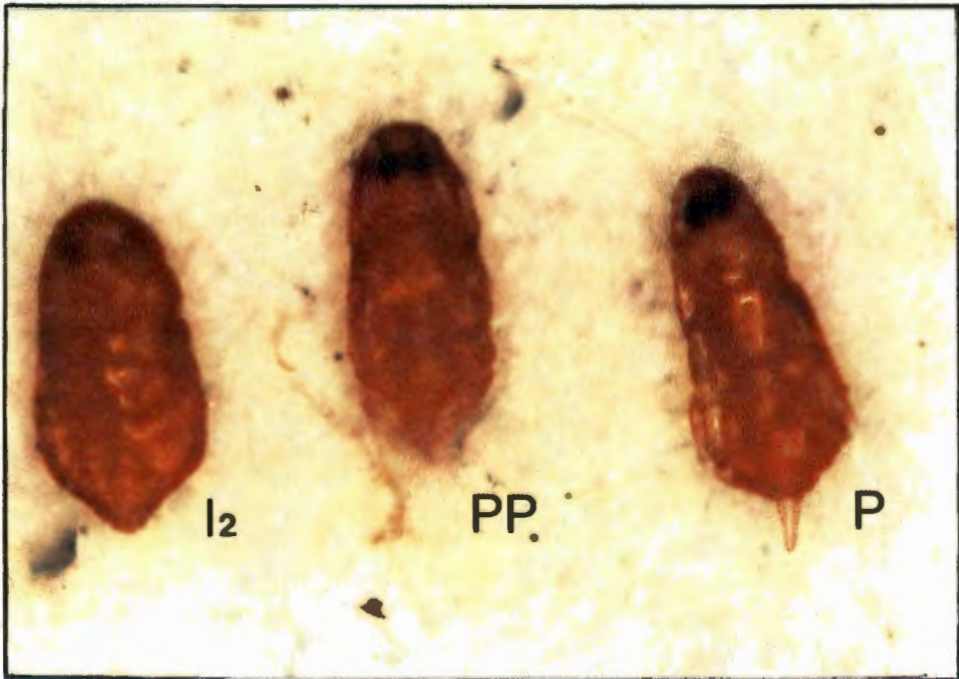
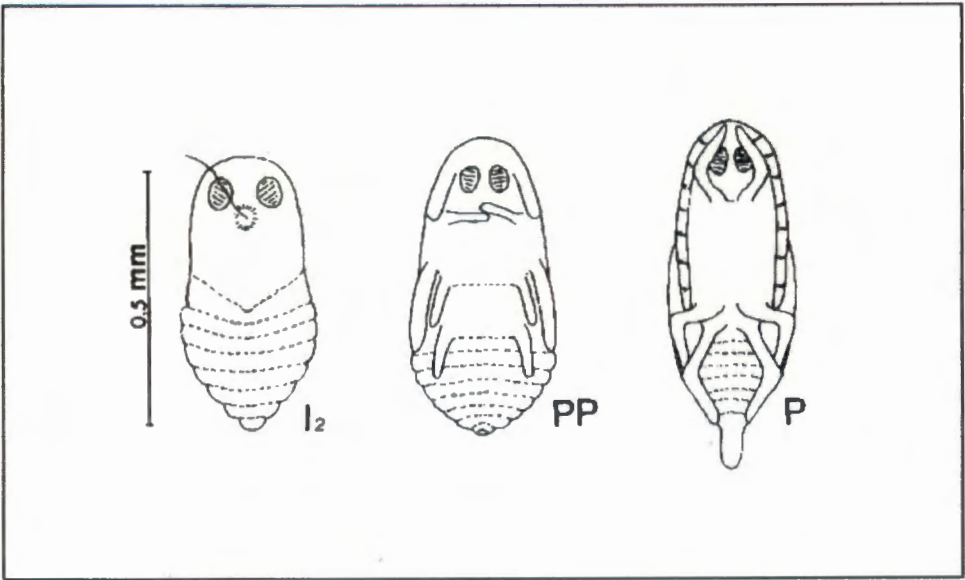


Figure 3.2 Second instar male (I_2), prepupa (PP), pupa (P) of *Aulacaspis tubercularis*

Immediately after detaching itself from the first instar scale covering the second instar begins to form its scale armour. The first sign of this scale development is three white waxy excretions which appear on the posterior aspect of the first instar scale. The tricarinate cottony wax scale under which the second and the following instars will develop, is fully formed in the second instar. The wax scale covering assumes the form of a cylindrical tube with a dorso-ventrally flattened opening at the back. Development or growth of the second instar is in a posterior direction with the anterior part remaining static. This stage has an average length of 0,55 (0,50-0,62) mm and width of 0,27 (0,26-0,29) mm. There are no rudiments of legs or other appendages (Fig.3.2). The exuvium is discarded through the opening at the posterior side of the scale during moulting and the stylet is broken off. This is the last stage during which the male feeds.

d) THIRD INSTAR MALE (PREPUPA)

External rudiments of legs and antennae become obvious (Fig. 3.2). The eyespots are more distinguishable and closer together than in the second instar and the body loses its pear shape to become more elongated. It measures on average 0,59 (0,55-0,62) mm long and 0,24 (0,21-0,26) mm wide.

e) FOURTH INSTAR MALE (PUPA)

The external rudiments of the legs and antennae are more prominent than in the prepupa and a large blunt stylus at the posterior end of the abdomen characterizes

this instar (Fig. 3.2). The exuviae of the latter two instars are expelled through the opening at the posterior end of the scale (Fig. 3.4c). The pupa and its stylus measures 0,68 (0,64-0,71) mm long and 0,24 mm wide.

f) ADULT MALE



Figure 3.3 Adult male

The adult male has two wings, is yellow to orange in colour, measures on average 0,53 mm long and 0,21 mm wide, and has long external genitalia measuring on average 0.21 mm, at the posterior tip of the abdomen (Fig. 3.3). It is unable to feed and will mate as soon as possible after emerging. Copulation takes place with the male in the superior position, allowing the copulatory organ to be inserted under the edge of the female scale.

g) SECOND INSTAR FEMALE

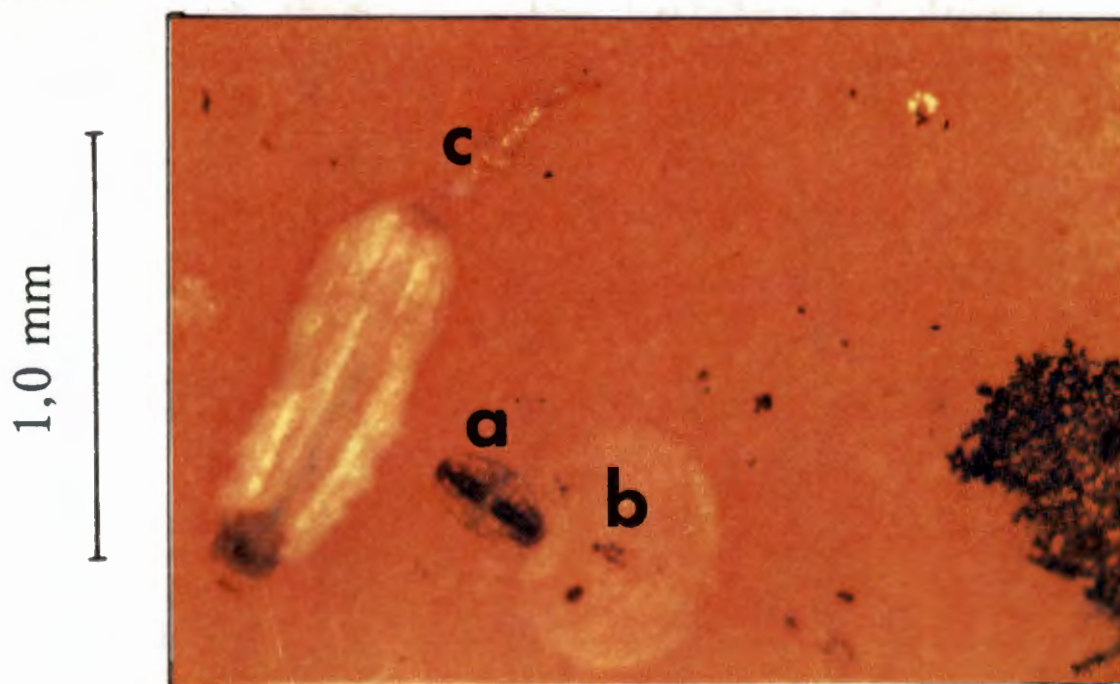


Figure 3.4 Second instar female in developing stage. First instar exuvium (a), second instar scale covering (b). Exuvium of the male pupa ejected through the posterior opening of the scale covering (c)



Figure 3.5 Second instar female in moulting stage. First instar exuvium (b), note sclerotised median line on dorsal side of the second instar female (a)

g) SECOND INSTAR FEMALE

The first sign that the first instar female is moulting, is the appearance of a white semi-circular shaped waxy excretion (the beginning of the scale) at the posterior end of the exuvium (Fig. 3.4). Growth of the body occurs in an anterior-posterior direction. It is yellow in colour but develops a sclerotised median, anterior-posterior line on the dorsal scale (Fig. 3.5), similar to that in the first instar. The body measures on average 0,70 (0,64-0,74) mm long and 0,44 (0,43-0,50) mm wide. The adult breaks through the ventral surface of the exuvium during moulting while the dorsal surface is incorporated in the adult scale covering.

h) ADULT FEMALE

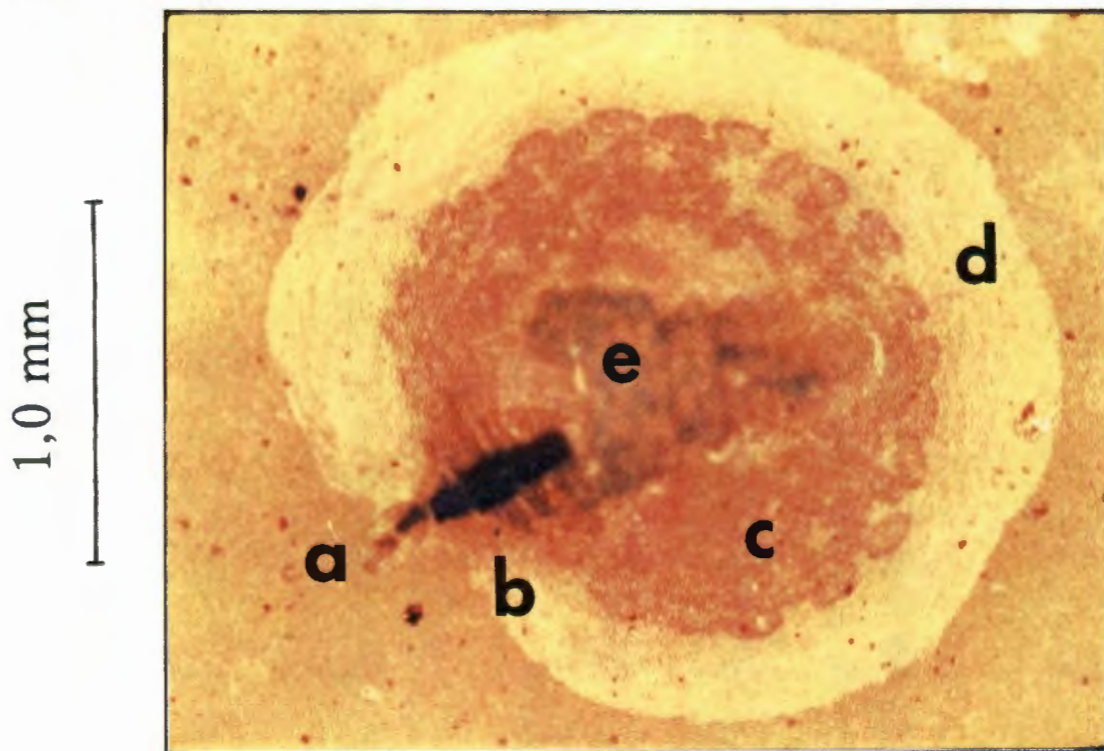


Figure 3.6 Adult female. First instar exuvium (a), second instar exuvium (b), eggs (c), scale covering (d), pear shaped body (e)

The scale of the adult is a thin circular wax layer into which both the first and second instar exuviae are incorporated and is on average 2,13 mm in diameter. The female is inseminated by the male soon after the second moult and continues to grow posteriorly while secreting the scale. The body widens posteriorly to assume its typical pear shape which is on average 1,14 (1,06-1,23) mm long and 0,66 (0,60-0,74) mm wide. In the pre-productive stage the body is yellow and the developing eggs can be seen through the integument as purple-brown spots (Fig. 3.6). The whole body changes in colour, becoming purple-brown as the developing eggs fill the body cavity. Eggs are laid under the scale in a semi-circle at the posterior end but will eventually fill the whole area under the scale.

3.1.2 FECUNDITY, DURATION OF THE OVIPOSITIONAL PERIOD AND MORTALITY OF *A. TUBERCULARIS* AT DIFFERENT TEMPERATURE REGIMES

The influence of temperature on the duration of the ovipositional period of females and the mean number of eggs per adult female is summarised in Table 3.1. The number of crawlers emerging per 48 hour period is illustrated in Figure 3.7. At all three temperature regimes, the number of crawlers emerging peaked within the first two days of egg laying (Fig. 3.7). De Villiers (1965) found that the Citrus mussel scale *Cornuaspis beckii* (Newm.) produced most of its eggs during the first few days of reproduction whereafter the number of eggs produced declined steadily until the female died of old age.

Table 3.1 The influence of temperature on the duration of the ovipositional period (days), and the mean number of eggs produced per adult female scale. The figures in brackets show variation width.

TEMPERATURE REGIMES	NUMBER OF FEMALES	MEAN NUMBER OF EGGS PER FEMALE	MEAN OVIPOSITIONAL PERIOD (DAYS)
23°C - 7°C	42	82.45 (13 - 202) <i>a</i> *	28.48 (3 - 59) <i>a</i> *
26°C - 13°C	89	261.90 (32 - 674) <i>b</i>	45.69 (25 - 82) <i>b</i>
29°C - 18°C	20	203.15 (53 - 365) <i>c</i>	33.25 (25 -43) <i>a</i>
		F = 40.00 LSD = 50.43	F = 35.36 LSD = 5.39

* Means followed by the same letter are not significantly different where P < 0,05

In order to determine the viability of the eggs, scale coverings were lifted off the females two weeks after the last crawler had emerged. All but a few of the eggs had hatched.

The observation was made that some females stopped reproducing after a few days during simulated winter conditions but did not die. Initially, such female were thought to be dead and the butternuts on which they had settled were removed. After a week or more at room temperature, however, it was observed that some of them started laying eggs again. No specific data of this phenomenon was taken but it is presumed that scale insects would eventually die if left long enough at such low temperatures.

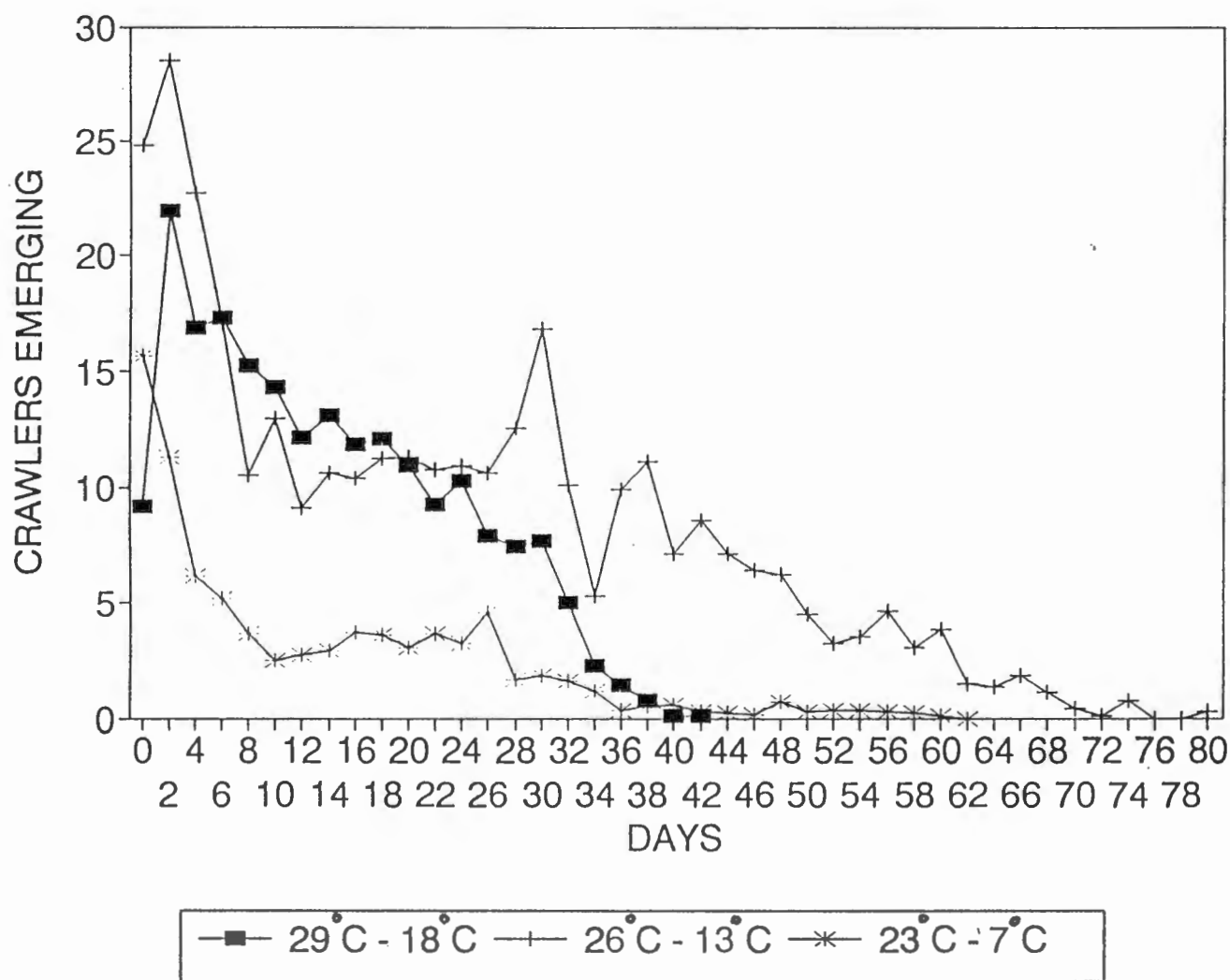


Figure 3.7 The average number of crawlers that hatched at three temperature regimes, 29°C - 18°C; 26°C - 13°C; 23°C - 7°C, as counted every second day during the reproductive period of female scales.

Diaspidids females each produce 1 - 10 eggs daily and most species produce 50 - 150 offspring per individual female, but the range has been described to extend from 10 to 600 (Kojeta 1990). Variation in reproductive potential of females within species seems to be considerable. The total number of eggs produced by adult females of *Diaspis echinocacti* Bouche, reared at a constant temperature of 27°C, was $150,8 \pm 52,5$ (Oeting 1984) thus a range of 98,3 to 203,3. Quayle (1911) noted that the number of offspring of Red scale, *Chrysomphalus (Aonidiella) aurantii* Mask., varied from 30 to 143 with an average of 55 for each scale during a period that varied from 13 to 63 days during September and October in California. This was considered by the author as a fair average for the active reproductive period. In laboratory studies done at $25 \pm 0,5^{\circ}\text{C}$ and $70 \pm 5\%$ relative humidity, Tashiro and Beavers (1968) found that the total crawler production of *A. aurantii* varied from 102 to 479 with a mean of 352 per female while the reproductive period ranged from 10 to 25 weeks. The same tendency of variation in reproductive potential was shown in this study in all three temperature regimes used (Table 3.1).

It must be noted that the host on which scales are reared could have a dramatic influence on the fecundity of the insects. De Villiers (1965) found that the Citrus mussel scale produced between 171,9 and 88,14 crawlers per female depending on the host used. Bruwer (1985) noted the same tendency while mass rearing the Long mussel scale, *Insulaspis gloverii* (Packard). Thus results can not be extrapolated to field situations without reservation, but they do give an idea of tendencies that could be expected. If chemical control of the scale insect is aimed

at controlling the crawler stage, the timing of the spray programme could be very critical since the majority of the crawlers hatch within the first few days of the reproduction period.

The results in Table 3.1 and Figure 3.7 could help to explain the fluctuation in field populations of the mango scale. The lowest reproductive rate occurred during the simulated winter conditions while the highest occurs during simulated spring which would predict high population growth during spring and a sharp decline in population during winter.

The noted mortality of non - producing adult females at the three simulated temperatures is given in Table 3.2. It again predicts a decline in the field population during winter and an increase during spring. According to Abdelrahman (1974) the mortality of developmental stages of *Aonidiella aurantii* vary markedly in accordance with their varying tolerances to extreme cold and heat. This is probably also true for the mango scale.

Table 3.2 Mortality of non - producing adult females (A-) of the mango scale at three day - night temperature cycles

TEMPERATURE CYCLE	NO. OF FEMALES	PERCENTAGE MORTALITY
29°C - 18°C	25	16
26°C - 13°C	105	7
23°C - 7°C	76	46

3.1.3 EFFECT OF TEMPERATURE ON THE DEVELOPMENTAL STAGES OF *AULACASPIS TUBERCULARIS*

The rate of development and the number of generations per year may vary substantially in a particular species in different climatic regions. Climatic conditions, particularly temperature, humidity, and rainfall, appear to be the principal controlling factors (Beardsley & Gonzalez 1975). The duration of the developmental stages of *Aulacaspis tubercularis* for the different climatic seasons in the Nelspruit area, as simulated in an incubator, is given in Table 3.3. Temperature was a significant factor influencing the mean duration of all the developmental stages except for the second instar and prepupal stage in the male. The duration of these two stages did not differ significantly in the simulated spring and summer temperatures. The difference in duration of the developmental stages tends to be more pronounced when comparing winter to spring temperatures as opposed to spring to summer temperatures, in spite of the fact that temperature intervals were equal. The total developmental period of one generation in winter, spring and summer was 68.9, 52.5 and 42.7 days respectively. Similar results were obtained by Bennett and Brown (1958) where the time span of generations of *Pseudaulacaspis pentagona* in Bermuda was 36 to 40 days during summer and 80 to 90 days in the cooler winter months. Williams (1970) observed that the duration of the life-cycle of *A. tegalensis* was 26 days at a mean minimum and maximum temperatures of 23 and 31°C respectively and 53 days at a mean minimum and maximum temperature of 19.3 and 24.8°C respectively. It is thus obvious that temperature has an effect on the duration of the developmental period

and consequently on the population fluctuation. This phenomenon is also evident in field observations, as dealt with later in this study.

The pre-adult developmental periods of males and females of *A. tubercularis* take virtually equally long so that sexual maturity in the same generation occurs concurrently (Table 3.3). Interbreeding among a females offspring is therefore possible. The slight differences in duration that were noted between the pre-adult developmental periods of the males and females in this study can possibly be ascribed to the method used to determine the duration of the period in the males. In this method variance was inevitably bigger. Williams (1970) similarly found that the pre- adult growth of the males and females of the sugar cane scale insect, *Aulacaspis tegalensis*, was of equal duration.

Table 3.3 Mean duration (in days) of the developmental stages of *Aulacaspis tubercularis* in an incubator simulating the temperature differences of the seasons on a day-night cycle of 14h:10h. The temperature regimes used were: 23 ± 1°C and 7 ± 1°C for winter, 26°C and 13°C for spring and 29 ± 1°C and 18 ± 1°C for summer. The relative humidity was kept constant at 75 ± 5% and 55 ± 5% for day and night respectively.

MALE DEVELOPMENTAL STAGES				
STAGE	TEMPERATURE (°C)	n	MEAN DURATION (DAYS)	LSD
EGG	23 - 7°C	37	15.6	0.70
	26 - 13°C	50	12.9	
	29 - 18°C	21	10.3	
1 INSTAR	23 - 7°C	15	15.6	1.08
	26 - 13°C	12	12.4	
	29 - 18°C	12	9.9	
2 INSTAR	23 - 7°C	15	8.9	0.89
	26 - 13°C	12	4.9 ^a	
	29 - 18°C	12	5.0 ^a	
PREPUPA	23 - 7°C	15	2.4	0.43
	26 - 13°C	12	1.8 ^a	
	29 - 18°C	12	1.6 ^a	
PUPA	23 - 7°C	15	9.5	0.62
	26 - 13°C	12	4.1	
	29 - 18°C	12	3.1	
PRE-ADULT DEVELOPING PERIOD	23 - 7°C	15	52.0	1.3
	26 - 13°C	12	36.1	
	29 - 18°C	12	29.9	

continued:

Table 3.3 (continue)

FEMALE DEVELOPMENTAL STAGES				
STAGE	TEMPERATURE (°C)	n	MEAN DURATION (DAYS)	LSD
EGG	23 - 7°C	37	15.6	0.67
	26 - 13°C	50	12.9	
	29 - 18°C	21	10.3	
1 INSTAR	23 - 7°C	37	17.1	0.81
	26 - 13°C	50	12.6	
	29 - 18°C	21	11.1	
2 INSTAR	23 - 7°C	37	25.3	0.79
	26 - 13°C	50	15.2	
	29 - 18°C	21	11.1	
PRE-ADULT DEVELOPING PERIOD	23 - 7°C	37	58.0	1.32
	26 - 13°C	50	40.7	
	29 - 18°C	21	32.6	
PRE-OVIPOSITIONAL, ADULT PERIOD (A-)	23 - 7°C	37	16.5	0.67
	26 - 13°C	50	12.0	
	29 - 18°C	21	10.00	
DEVELOPMENTAL PERIOD OF ONE GENERATION	23 - 7°C	37	68.9	3.61
	26 - 13°C	50	52.5	
	29 - 18°C	21	42.7	

* values followed by the same letter are not significantly different according to Fishers protected LSD test, where $P < 0.05$

3.1.4 SEX RATIO

Investigations into the possibility of using the female sex hormone or sterility techniques for pest control are dependent on information on the sex ratio of the insect. Therefore, the sex ratio of the mango scale was investigated.

The sex ratio (prevalence of males as a % of the adult population) of many sexually reproducing armoured scale insects is about 50% but there are individual reports of strongly biased sex ratios (Nur 1990). The sex ratio of *Aulacaspis tegalensis* is about 1 : 1 (Williams 1970). In the California red scale, *Aonidiella aurantii* Mask., bisexual reproduction is obligatory with the sexes also occurring in equal proportions (Flanders 1951). Published data on sex ratios in biparental armoured scales indicates that even within a given species considerable variation frequently occurs. Sex ratios may also vary between seasons and individual females within a given population may yield progeny of widely varying sex ratios in some species. The factors which determine sex ratio are as yet unknown (Beardsley & Gonzalez 1975), but Hughes - Schraeder (1948) suggested that sex may be determined by weak genetic factors which are easily overridden by environmental influences.

In this study the sex ratio of *Aulacaspis tubercularis* was shown to be strongly male-biased with on average 73% of the offspring being males (Table 3.4). This result was confirmed by casual field observations. Bennett & Brown (1958) observed that the sex ratio of *Pseudaulacaspis pentagona* Targ. was close to 50% in undisturbed females but maternal aging prior to mating increases the sex ratio

in favour of the males. An extensive literature study by Nur (1990) confirms that a delay in mating of adult females of several species caused an increase in the sex-ratio (proportion of males). This however seems to be the norm rather than the exception for *A. tubercularis* since males were in abundance during all the developmental stages in the growth chambers.

Table 3.4 The sex ratio of *A. tubercularis* determined under controlled laboratory conditions where adult females were reared on butternuts at $25 \pm 1^{\circ}\text{C}$ and a relative humidity of $55 \pm 5\%$

NO. OF MATERNAL ADULT FEMALES	TOTAL NO. OF MALE OFFSPRING	MEAN NO. OF MALE OFFSPRING	TOTAL NO. OF FEMALE OFFSPRING	MEAN NO. OF FEMALE OFFSPRING	% MALES
37*	6320	170,8	1708	46,2	72,97

* The minimum number of samples (adult females) was determined to be 20 by using $n = (t.s/D.x)^2$ (Southwood 1978)

For all but three of the experimental maternal adult females observed, the sex ratio was in favour of the males.

3.1.5 ROLE OF THE MALE (EFFECT OF MATING)

According to Brown (1965) three types of sexuality are seen in diaspidid species namely bisexuality, unisexuality (reproduction by female parthenogenesis) and dimorphic sexuality (both bisexual and unisexual strains in a species). The majority of the Diaspididae are bisexual, although several species occur as both bisexual and parthenogenetic races and others are known only in the parthenogenetic state. This is corroborated in a summary by Brown (1965) of 131 species of the diaspidids where only 21 were found to be parthenogenetic after examining females for the presence of sperm. Nur (1990) argues that this figure could be out of proportion since the frequency of unisexual (uniparental) forms are significantly higher among diaspidid pests and the species examined by Brown (1965) include a disproportionately large number of pests.

The results obtained in this trial show that *Aulacaspis tubercularis* can only reproduce sexually (Fig. 3.8). The arrows in Figure 3.8 show when each group of virgin females was exposed to males in order to allow fertilization to take place. In the first group the females were never separated from males. The females were all producing eggs within approximately four weeks. It must be emphasized that fertilization can only take place in adult females and that some of the females in the group were still in the first and beginning of the second instars. Development to adulthood could take two weeks which would imply that females started producing eggs within two weeks after fertilization. The same phenomenon can be seen in all the other groups except the last two, where virgin females were

either exposed to males late in their development, or not at all. The group that was never exposed to males, and consequently not fertilized, never produced eggs and all but a few were dead within 12 weeks.

Williams (1970) similarly observed that *Aulacaspis tegalensis* females which were prevented from mating did not lay eggs. They did however develop a scale covering identical to those of fertilized females. In some instances scale development in females of the family Diaspididae is influenced if they are prevented from mating. The white peach scale, *Pseudaulacaspis pentagona* produces an extra covering to the side of the typical scale already present and moves from under the original scale if prevented from mating. Unmated females never laid eggs (Bennett & Brown 1958; Van Duyn & Murphey 1971). Movement from under the scale covering was observed in *A. tubercularis* in almost all the females that were prevented from mating but no extra scale covering was produced. Thin loose threads covering the tip of the abdomen but never the whole body, were however produced by the females. Moving from under the scale covering could be an attempt to be more accessible to males.

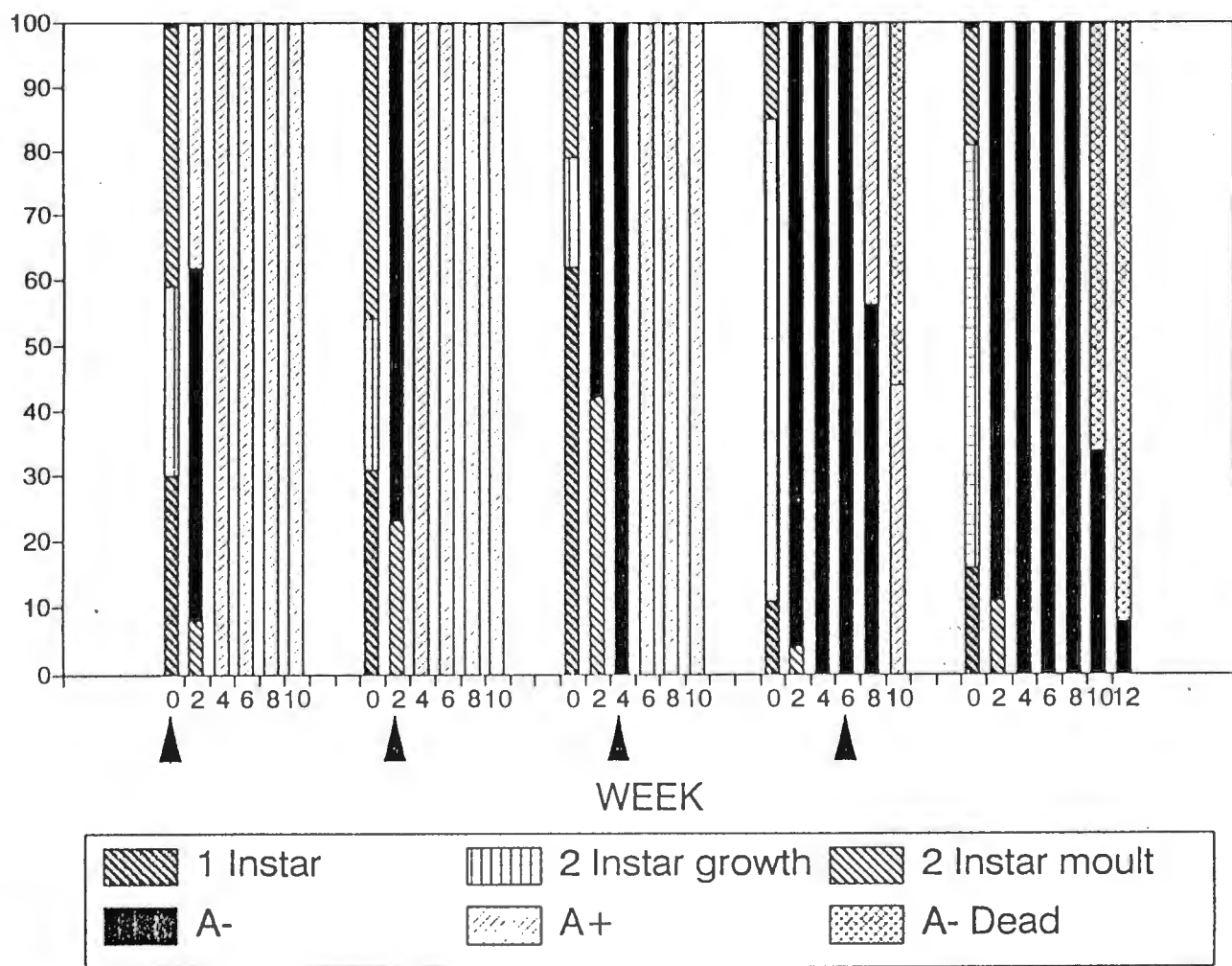


Figure 3.8 The influence of fertilization on fecundity determined by exposing virgin females to males at different times in their development. The time of exposure (fertilization) is shown by the arrows

3.1.6 PHOTOTAXIS

Crawlers are the only stage of the armoured scales capable of locomotion, other than adult males, which cannot initiate new infestations by themselves. The crawler is therefore the principal stage enabling dispersal of the species. McClure (1990b) quotes substantial literature describing the influence of various environmental factors on the pattern of spatial distribution of diaspidids within and among their host plants. Factors mentioned are: size of trees, varieties, sex of the scale insect and weather. Infestations also vary between trunks, branches and fruits. According to Beardsley & Gonzalez (1975) dispersal of armoured scale crawlers is accomplished mainly by active wandering and by wind. After an extensive literature survey they came to the conclusion that light appears to be the major factor influencing the direction of wandering in scale crawlers. In a comprehensive study on the dispersal of the sugar-cane scale *Aulacaspis tegalensis*, Greathead (1972) found that hatching crawlers move upwards and towards the light, but downwards in the dark. The results in Table 3.5 confirmed that the same tendency to move towards the light is true for mango scale crawlers. Ninety percent of the female crawlers moved in the direction of the light source and 83,5 % of the male crawlers orientated themselves to face the light source. The effect was more explicit for the females since they moved further away from the mother, while the males settled in clusters within close proximity of the mother. None of the male crawlers settled on the neighbouring butternuts. The majority of the female crawlers (80,9 %) settled on the same butternut as the mother organism but 9,9 % settled on the neighbouring butternut closest to the

light source. Only one female out of a total of 467 settled on the butternut on the dark side. It is therefore obvious that female crawlers move away from the mother and that the female crawlers are the principal group responsible for the distribution of the scale.

Table 3.5 The effect of light on the direction of movement of crawlers of *Aulacaspis tubercularis*

NO. OF A+ FEMALES	FEMALE OFFSPRING				MALE OFFSPRING			
	LIGHT	MIDDLE'		DARK	LIGHT	MIDDLE		DARK
		LIGHT	DARK			LIGHT	DARK	
1	3	79	3	0	0	0	0	0
2	0	7	0	0	0	108	31	0
3	4	33	11	1	0	0	0	0
4	2	0	0	0	0	39	11	0
5	14	72	3	0	0	148	41	0
6	9	30	0	0	0	94	12	0
7	0	4	0	0	0	210	34	0
8	0	13	2	0	0	175	45	0
9	12	84	8	0	0	4	0	0
10	2	56	15	0	0	302	40	0
TOTAL	46	378	42	1	0	1080	214	0
%	9.9	80.9	8.9	0.2	0	83.5	16.5	0

Three butternuts were used, one on the side where the light filtered in, one in the middle and one on the dark side. The one in the middle was divided into a side facing towards the light and a dark side.

The results of the trial where the phototaxis of the males was examined were so clear that a detailed explanation is unnecessary.

No males were observed in the tubes from the boxes that were kept in the dark while almost all the males from the boxes that were exposed to light, moved in the direction of the light source and accumulated in the glass tubes. They are therefore strongly positive phototaxis.

Other environmental factors influencing the distribution of the mango scale were not dealt with in this study. Available literature however suggests that wind is one of the most important natural dispersal mechanisms of scale insects and it is believed that it plays a major role in the dispersal of *A.tubercularis*. Greathead (1990) believes that clean crops at distances of tens of kilometres from the sources can be infested by crawlers of certain species transported by wind and that some species are specifically adapted for wind dispersal.

3.2 POPULATION DYNAMICS OF *AULACASPIS TUBERCULARIS*

3.2.1 SPATIAL DISTRIBUTION WITHIN THE TREE

The spatial distribution of mango scale within a tree is given in Table 3.6. A careful examination of the data depicted in Table 3.6 shows significant differences among some of the aspects of the tree, during certain times in the evaluation period. Statistical analysis of the data gathered fortnightly for a period of six months, was complicated by the population fluctuation from season to season and the patchy grouping of the insects on the leaves.

A better idea of the spatial distribution is gained in Figure 3.9 which shows the same data, but as accumulated figures. It is evident that the scale is much more abundant on the lower, south facing aspect of the tree. The most likely reason for this distribution pattern is the temperature differences between the various aspects of the tree. The south facing lower aspect is constantly in the shade while the north facing upper aspect is constantly in the sun. Bodenheimer (1951) stated that the shady centre of the tree is the preferred natural environment of the red scale *Aonidiella aurantii* Mask. His results were confirmed by Carroll and Luck (1984). They came to the conclusion that low densities of *A. aurantii* were related to direct sunlight during hot weather.

Table 3.6 The mean number of female mango scales counted over a period of six months after transformation by $\log (x + 3)$. Significant differences are depicted by the letters following the mean values. NU - north facing upper aspect; NL - north facing lower aspect; EU - east facing upper aspect; EL - east facing lower aspect; SU - south facing upper aspect; SL - south facing lower aspect; WU - west facing upper aspect; WL - west facing lower aspect

DATE	NU	NL	EU	EL	SU	SL	WU	WL
18/09/92	1.10 c	1.21 bc	1.10 c	1.34 ba	1.19 bc	1.44 a	1.10 c	1.36 ba
02/10/92	1.12 c	1.28 b	1.14 cb	1.17 cb	1.18 cb	1.46 a	1.12 c	1.28 b
16/10/92	1.12 c	1.24 bc	1.13 c	1.37 ba	1.17 c	1.42 a	1.13 c	1.19 c
30/10/92	1.12 e	1.46 bdc	1.15 ed	1.43 ba	1.72 edc	1.69 a	1.12 e	1.49 bac
13/11/92	1.28 c	1.21 cb	1.28 c	1.21 b	1.29 c	1.77 a	1.24 cb	1.42 b
21/11/92	1.19 d	1.47 ba	1.25 dc	1.37 bdc	1.22 bdc	1.53 a	1.22 bdc	1.45 bac
11/12/92	1.13 c	1.47 b	1.13 c	1.38 cb	1.39 cb	1.76 a	1.29 cb	1.39 cb
24/12/92	1.14 b	1.35 ba	1.13 b	1.32 a	1.14 b	1.21 ba	1.15 b	1.12 b
08/01/93	0.19 c	1.13 bac	1.28 bac	1.28 bac	1.12 bc	1.29 a	1.19 c	1.29 ba
24/01/93	1.15 ba	1.17 ba	1.20 ba	1.21 ba	1.14 ba	1.26 a	1.12 b	1.13 b
19/02/93	1.27 ba	1.23 a	1.17 ba	1.22 ba	1.19 b	1.15 ba	1.13 ba	1.19 b
05/03/93	1.19 b	1.12 ba	1.19 b	1.20 a	1.12 ba	1.26 ba	1.14 ba	1.20 a

* For each date, values followed by the same letter do not differ significantly where $p < 0,05$ after transformation of the values by $\log (x + 3)$

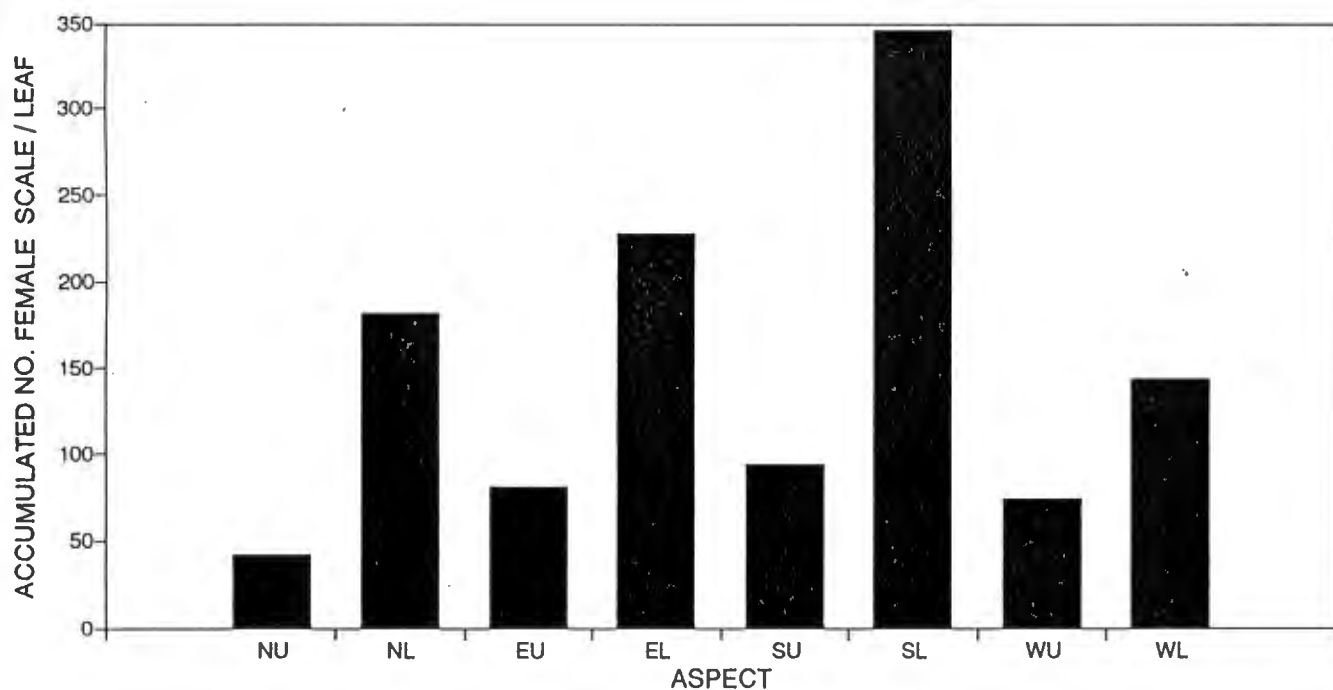


Figure 3.9 The spatial distribution of mango scale *A. tubercularis* in a tree. NU - north facing upper aspect; NL - north facing lower aspect; EU - east facing upper aspect; EL - east facing lower aspect; SU - south facing upper aspect; SL - south facing lower aspect; WU - west facing upper aspect; WL - west facing lower aspect

It is evident from Figure 3.9 that mango scale were more abundant on the east than on the west facing aspect of the tree. This tendency can possibly be explained in terms of the above mentioned literature. Although the east and west facing aspects of the tree get the same amount of direct sunlight the air temperature during the morning is lower than that during the afternoon. The combined effect of the higher air temperature and the direct sunlight could therefore explain the lower infestation on the west facing aspect.

Similar results were obtained in the follow-up trial in which five different orchards were examined as given in Table 3.7. The lower and specifically the south facing aspects had a much higher infestation of mango scale than any other aspect.

These results could have important implications. Firstly, research trials could be re-designed to monitor only the highly infested aspect of the tree, thus saving time and effort. Secondly, chemical spray programmes could be adapted to concentrate on the highly infested aspect of the tree. Trials should however be done to verify these assumptions.

Table 3.7 Spatial distribution of the mango scale *Aulacaspis tubercularis* in five orchards given as the average number of scale per leaf

ASPECT	AVERAGE NUMBER OF SCALE PER LEAF					
	MALELANE	MALELANE	FRIEDENHEIM	FRIEDENHEIM	NELSPRUIT	AVERAGE
	SENSATION	KEITT	SENSATION	FASCELL	SENSATION	
NORTH UPPER	0.02	0.64	0.07	1.76	0.57	0.61
NORTH LOWER	0.1	0.48	1.83	2.68	0.28	1.02
SOUTH UPPER	0.19	0.5	0.09	3.02	0.93	0.94
SOUTH LOWER	0.88	0.68	4.39	4.35	3.29	2.72
WEST UPPER	0.29	0.38	0.17	0.7	0.28	0.36
WEST LOWER	0.43	0.5	2.08	2.9	0.83	1.35
EAST UPPER	0.47	0.46	0.28	1.16	2.13	0.90
EAST LOWER	1.56	0.6	1.16	5.8	2.26	2.28
TOTAL	3.94	4.24	10.07	22.37	10.57	

3.2.2 RELATIVE ABUNDANCE

Climatic factors, in particular temperature and humidity, affect nearly every aspect of the life of an armoured scale insect and play a major role in the dynamics of diaspidid populations (McClure 1990a). In this study the relative abundance of *A. tubercularis* was examined. Figures 3.10 and 3.11 show the average number of females per leaf as well as the average fortnightly maximum and minimum temperatures of two areas, Nelspruit and Kaapmuiden.

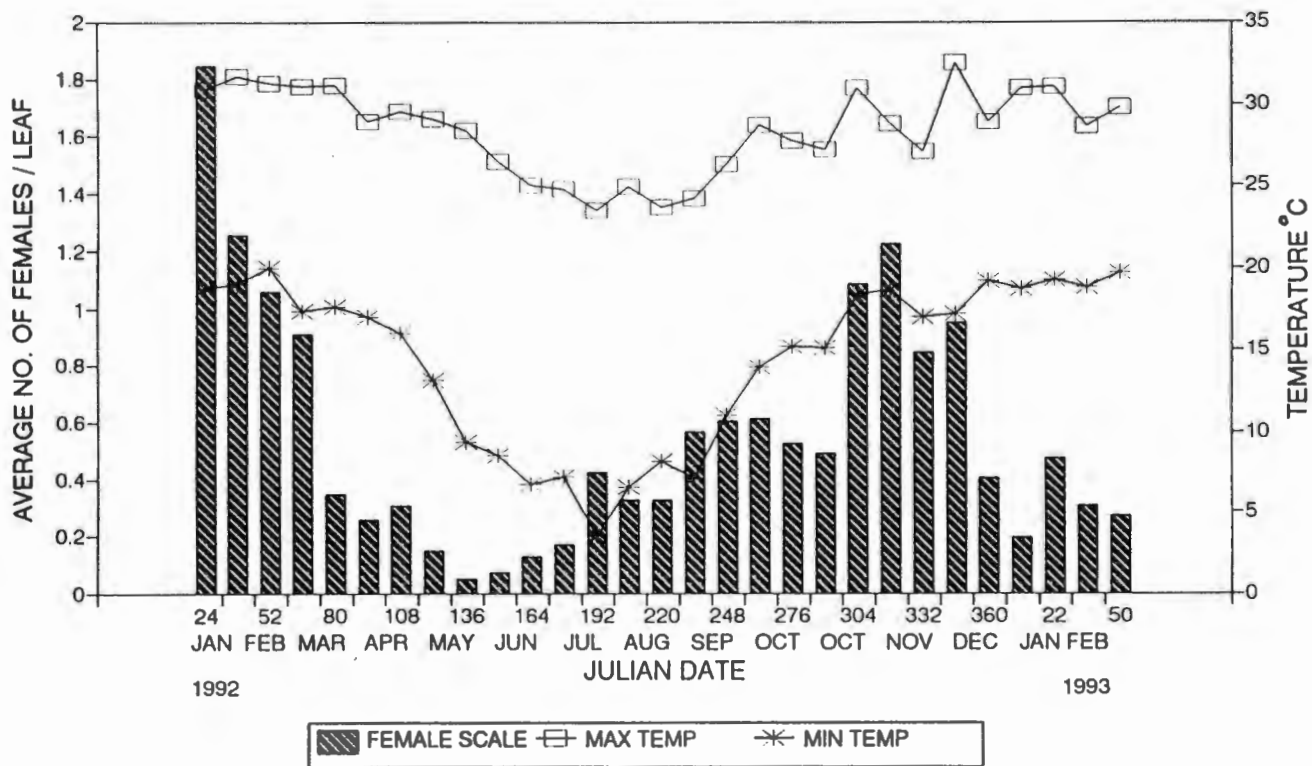


Figure 3.10 Population fluctuation of 2nd instar, A- and A+ females of *Aulacaspis tubercularis* in a mango orchard in Nelspruit

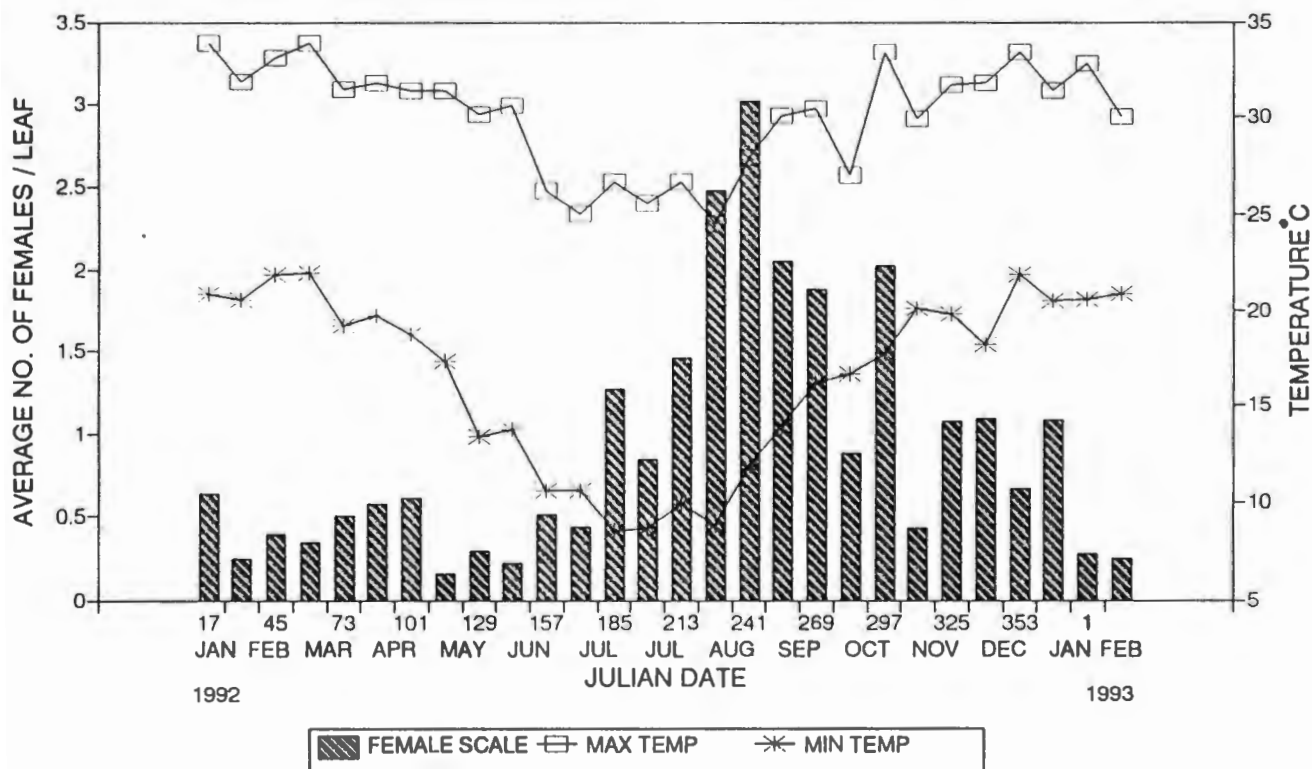


Figure 3.11 Population fluctuation of 2nd instar, A- and A+ females of *Aulacaspis tubercularis* in a mango orchard in Kaapmuiden

Table 3.8 Mean maximum and minimum temperatures and mean number of female scales per leaf for the Nelspruit and Kaapmuiden areas as used in Figures 3.10 and 3.11

NELSPRUIT				KAAPMUIDEN			
DATE	MEAN MAX TEMP. (°C)	MEAN MIN TEMP. (°C)	MEAN NO. OF SCALES / LEAF	DATE	MEAN MAX TEMP (°C)	MEAN MIN TEMP. (°C)	MEAN NO. OF SCALE / LEAF
JAN '92	30.9	18.7	1.85	JAN '92	33.9	20.9	0.69
FEB '92	31.7	19.0	1.26	JAN '92	31.9	20.6	0.25
FEB '92	31.3	20.0	1.06	FEB '92	33.1	21.9	0.39
MAR '92	31.1	17.4	0.91	FEB '92	33.9	22.0	0.35
MAR '92	31.2	17.6	0.35	MAR '92	31.5	19.2	0.5
APR '92	28.9	17.0	0.26	MAR '92	31.8	19.7	0.57
APR '92	29.5	16.0	0.31	APR '92	31.4	18.7	0.61
MAY '92	29.1	13.1	0.15	APR '92	31.4	17.3	0.16
MAY '92	28.4	9.3	0.05	MAY '92	30.2	13.4	0.29
MAY '92	26.5	8.5	0.07	MAY '92	30.6	13.8	0.22
JUN '92	25.0	6.7	0.13	JUN '92	26.2	10.6	0.51
JUN '92	24.8	7.2	0.17	JUN '92	25.1	10.6	0.44
JUL '92	23.5	3.5	0.42	JUL '92	26.7	8.5	1.26
JUL '92	24.9	6.5	0.33	JUL '92	25.6	8.7	0.84
AUG '92	23.7	8.2	0.33	JUL '92	26.7	9.9	1.46
AUG '92	24.2	7.1	0.57	AUG '92	24.5	8.8	2.48
SEPT '92	26.3	11.0	0.60	AUG '92	27.9	11.9	3.02
SEPT '92	28.7	13.9	0.61	SEPT '92	30.1	13.9	2.05
OCT '92	27.7	15.2	0.53	SEPT '92	30.5	16.2	1.88
OCT '92	27.2	15.1	0.49	OCT '92	27.0	16.6	0.88
OCT '92	31.0	18.4	1.08	OCT '92	33.4	17.7	2.03
NOV '92	28.8	18.6	1.22	NOV '92	29.9	20.1	0.43
NOV '92	27.1	17.0	0.85	NOV '92	31.7	19.8	1.07
DEC '92	32.5	17.2	0.95	NOV '92	31.8	18.2	1.09
DEC '92	28.9	19.2	0.40	DEC '92	33.4	21.9	0.67
JAN '93	31.0	18.7	0.19	JAN '93	31.4	20.5	1.08
JAN '93	31.1	19.3	0.48	JAN '93	32.8	20.6	0.27
FEB '93	28.6	18.8	0.31	FEB '93	30.0	20.9	0.25
FEB '93	29.8	19.7	0.27				
AVERAGE	28,4	14,4	0,56		30,2	16,5	0,92

The data depicted in Figures 3.10 and 3.11 is repeated in Table 3.8 to facilitate the comparison of the two areas. The population density in Kaapmuiden was much higher throughout the year than in Nelspruit (Table 3.8). The age and size of the data trees could probably have had an influence on the difference in population size. Nelspruit with a lower average temperature had population peaks in late January and in the beginning of November (Figure 3.10). Kaapmuiden in turn had one major population build up about two months earlier, at the end of August (Figure 3.11). It is possible, however, that there could have been a first peak earlier in January or December in Kaapmuiden. The most probable explanation for the decline in population during the summer months in Kaapmuiden, is the mango scale's low tolerance for high temperatures. No empirical data on the effect of extreme temperatures on mango scale is available, but it was observed that the mortality of laboratory reared mango scale insects was extremely high when temperatures in rearing chambers exceeded 30°C which occurred during breaches in temperature control. Bodenheimer (1951) investigated the difference between body temperature of the red scale and leaf surface temperature, and found that the average temperature difference was 13,4°C when leaves were in the sun. The average difference between the body temperature of scales and leaves in natural shade was less marked at 6,3°C. In both of these cases the body temperature of the scale exceeded that of the leaf surface. This could explain the population decline in Kaapmuiden at the beginning of October, after which, for a period of seven months, the average maximum temperature nearly always exceeded 30°C (Table 3.8). A population increase was only witnessed when the average maximum temperature dropped to below 30°C. The same tendency is

demonstrated in Nelspruit (Figure 3.10) where the high temperatures in January probably resulted in the steep decline in the mango scale population. This was again seen after the first spell of high temperatures in October and November.

Abdelrahman (1974) found that differential tolerance among development stages of *Aonidiella aurantii* to low temperature was the main factor determining its distribution and abundance in the field. This could also explain the situation in the Nelspruit population, where the lower temperatures may have postponed the population build-up. Laboratory experiments (Table 3.1) confirmed that the lowest reproductive rate occurred during the simulated winter conditions while the highest reproductive rate occurred during simulated spring.

The effect of growth flushes of the host tree on the population fluctuation was not specifically examined. According to Schroeder (1993), leaf growth flushes during the 1991/1992 season in the Sensation orchard in Nelspruit occurred in September and again in February - March. There does seem to be a correlation between the September flush and the mango scale population increase in Nelspruit during August - September of that year (Figure 3.10). Insufficient data is available however to confirm this.

The population peaks of *A. tubercularis* in August and November in Kaapmuiden and Nelspruit respectively, coincide with the setting of the fruit. Since scale crawlers must be prevented from migrating from the leaves to the fruit, this would probably be the most critical time in a control programme for the mango scale.

The continuous availability of the scale throughout the year would on the other hand be a distinct advantage in the establishment of imported natural enemies.

3.2.3 DISTRIBUTION OF THE DEVELOPMENTAL STAGES

Figures 3.12 to 3.17 demonstrate the temporal distribution of the different developmental stages of *A. tubercularis* in three different orchards.

No distinct generations could be identified from the results obtained in this study as presented in Figures 3.12 to 3.17, because of the overlapping of generations.

Two principal reasons are probably responsible for this overlapping. The first is that the ovipositional period is long enough to allow the first offspring of an adult female to reach sexual maturity and start reproducing while she herself is still reproducing. The duration of the ovipositional period was found to be as long as 82 days (Table 3.1) at a day -night cycle of 26°C - 13°C, while the average duration of the life cycle (egg to egg) determined under the same conditions, was 52,3 days (Table 3.3). The average ovipositional period (A+ stage) was 45.69 days long (Table 3.1) which was considerably longer than the 12,6, 15,2 and 12,0 days of the first instar, second instar and pre-ovipositional adult stages (A -) respectively (Table 3.3). This also explains the high relative abundance of the A+ stage if compared to the other developmental stages. Similarly, Williams (1970) found that the long oviposition period caused considerable overlapping of generations of *Aulacaspis tegalensis* (Zhnt.).

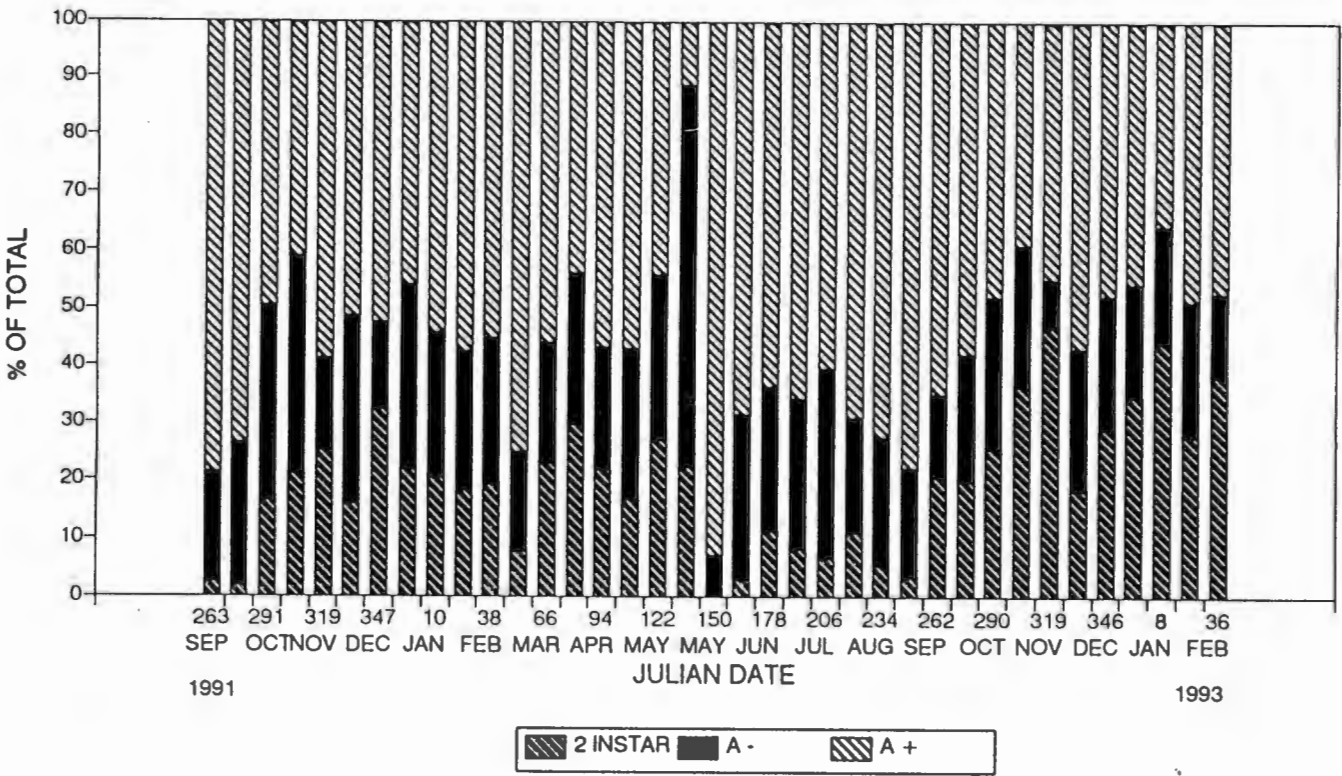


Figure 3.12 Female instar distribution of *Aulacaspis tubercularis* at Nelspruit on cultivar Sensation for the periods September 1991 to February 1993

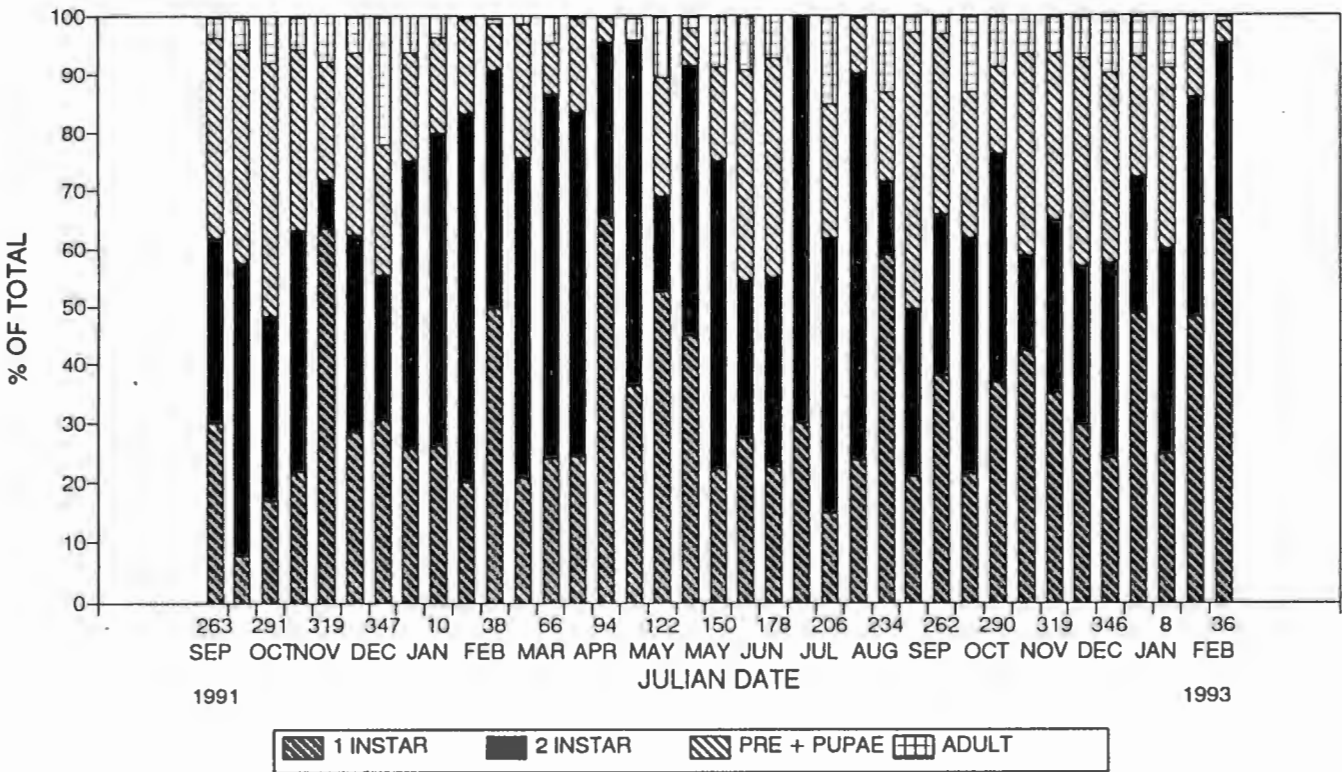


Figure 3.13 Male instar distribution of *Aulacaspis tubercularis* at Nelspruit on cultivar Sensation from September 1991 to February 1993

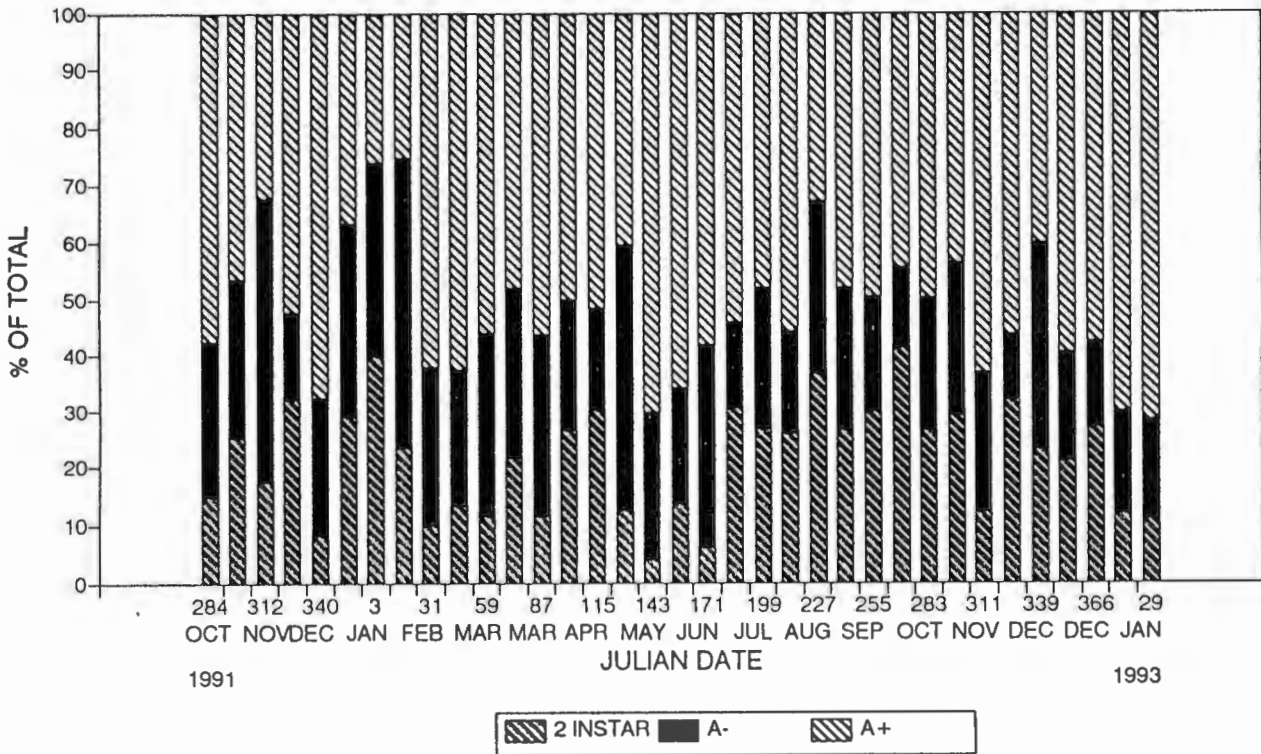


Figure 3.14 Female instar distribution of *Aulacaspis tubercularis* at Kaapmuiden on cultivar Peach from October 1991 to January 1993

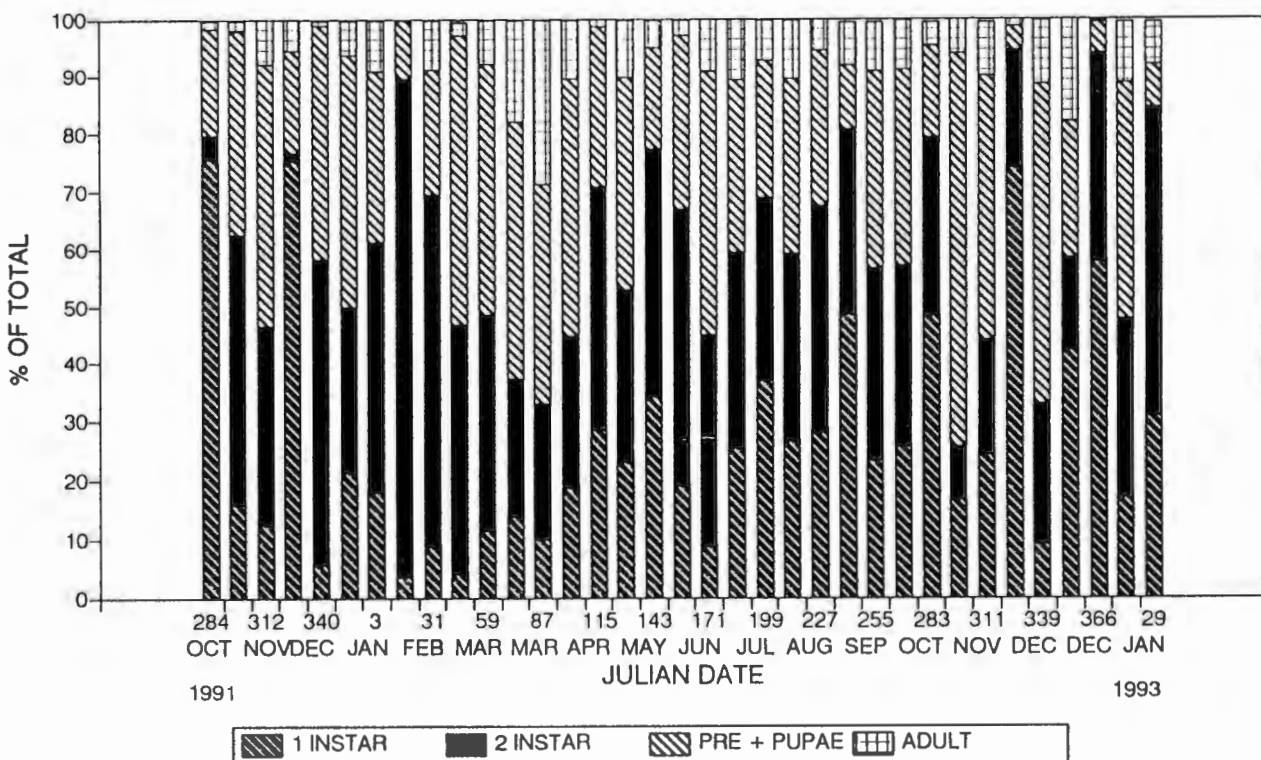


Figure 3.15 Male instar distribution of *Aulacaspis tubercularis* at Kaapmuiden on cultivar Peach from October 1991 to January 1993

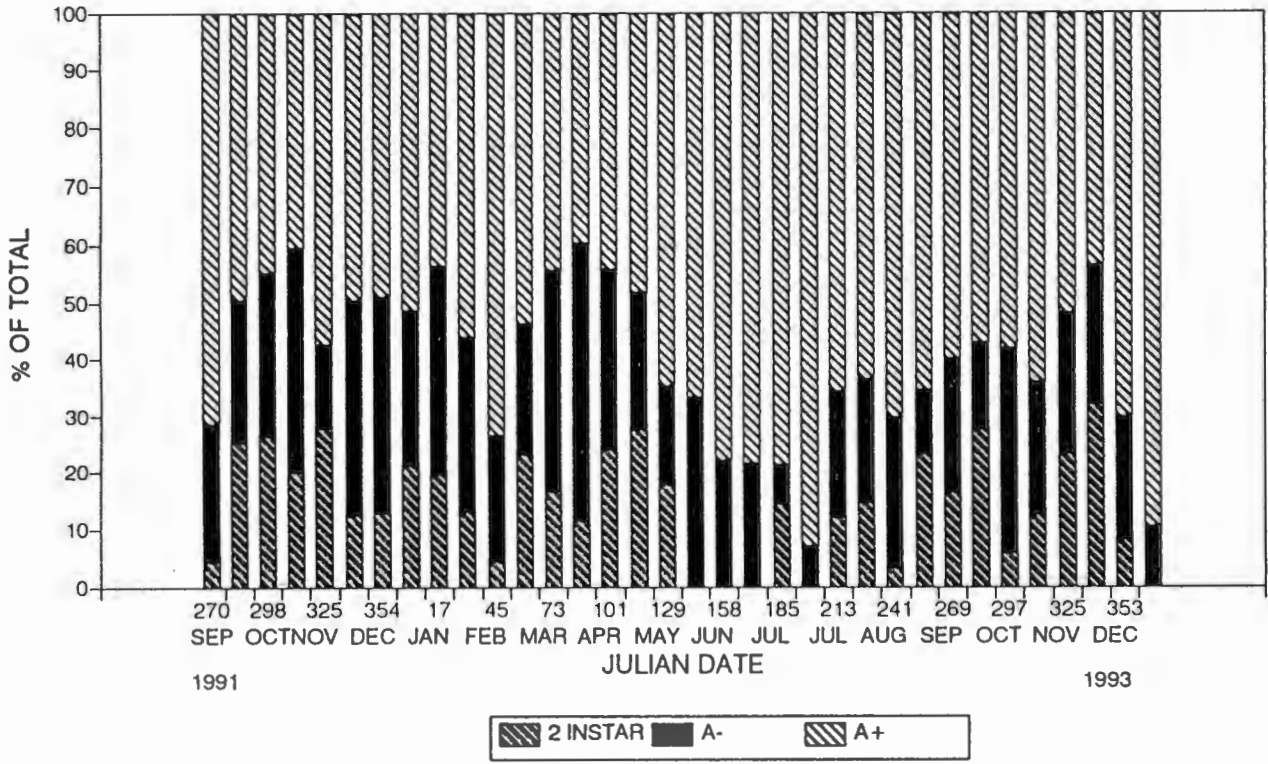


Figure 3.16 Female instar distribution of *Aulacaspis tubercularis* at Kaapmuiden on cultivar Keitt from September 1991 to December 1992

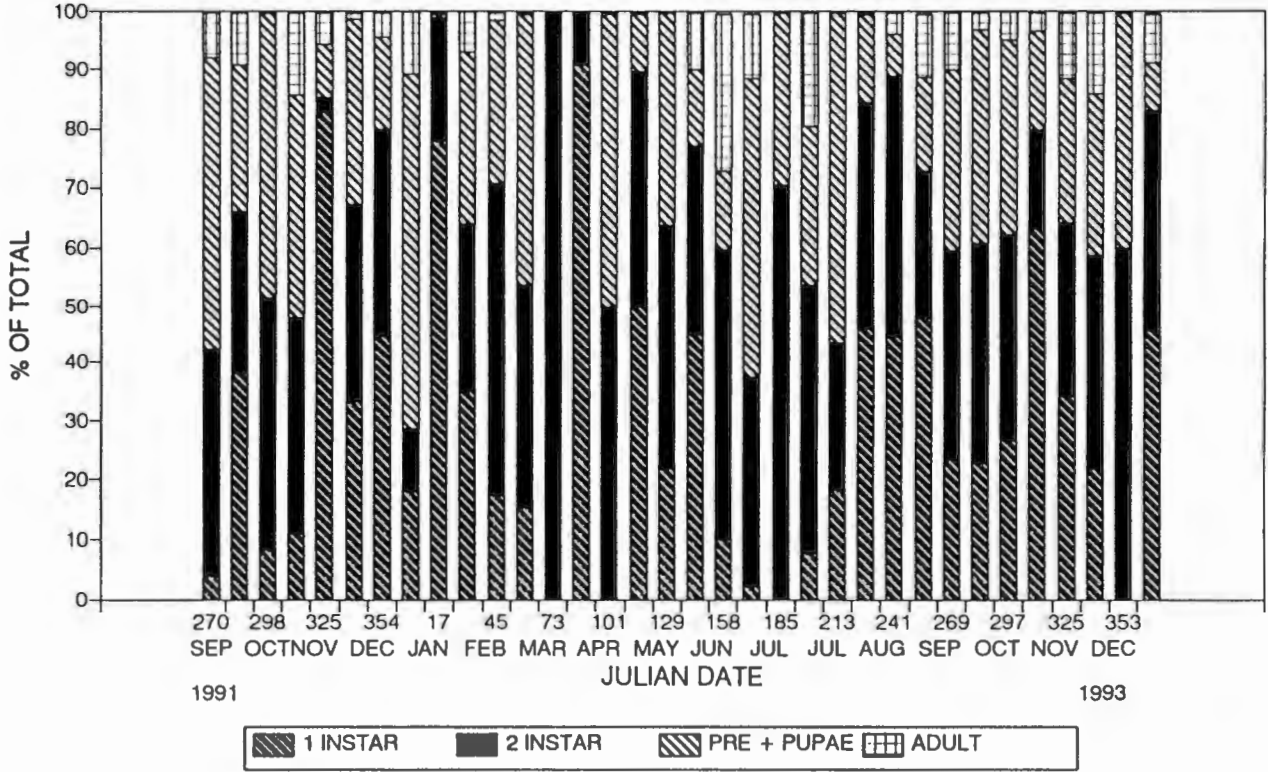


Figure 3.17 Male instar distribution of *Aulacaspis tubercularis* at Kaapmuiden on cultivar Keitt from September 1991 to December 1992

In addition to the long ovipositional period, the pre-ovipositional period could be prolonged to approximately 42 days (Figure 3.8) if fertilisation did not take place, which would cause further overlapping of generations.

It is important to be able to predict the time when the crawler population is at its peak as the crawler stage is generally accepted to be the most susceptible to chemical control. It is clear, however, that overlapping of generations makes such a prediction virtually impossible. Casual field observations seem to suggest a peak crawler population in early spring. This could be due to the increase in the total population at this time and therefore also of the crawlers. The ratio of crawlers to the other developmental stages needs to be measured rather than absolute numbers to clarify this point.

The continuous presence throughout the year of all the developmental stages, is a major advantage for the implementation of a biological control programme, in that a complex of parasitoids can be simultaneously accommodated and new parasitoids can be established at any time of the year.

3.2.4 PARASITISM

3.2.4.1 Collection of natural enemies

The only mango scale parasitoid species found in the survey was *Encarsia citrina* Craw, previously identified in 1986 as *Aspidiotiphagus citrinus* Craw (Viljoen

1986).

A predatory thrip was found and identified as *Aleurodothrips fasciapennis* Franklin. This is probably the first recording of it as a predator on mango scale, though this species has been recorded as a predator on a number of other Diaspidid scales outside of Africa (Lewis 1973).

Two predatory beetles, *Rhyzobius lophanthae* and *Chilocorus nigritus* have often been noticed predating on mango scale.

3.2.4.2 Abundance of parasitoids

The percentage parasitism as determined by counts of parasitoid pupae and larvae as well as by counts of emergence holes in scales collected at Nelspruit and Kaapmuiden is illustrated in Figures 3.18 to 3.23. The data gathered by counting the emergence holes tends to be accumulative and does not give a correct indication of the rate of parasitism. The rest of this discussion will therefore only deal with counts of parasitoid pupae and larvae. Peak periods of parasitism by *A. citrinus* on *A. tubercularis* are evident from the results given in Figures 3.18 to 3.23.

The period of parasitism for both male and female scale in the Nelspruit area stretched from January to June reaching a peak in May - June. In Kaapmuiden the peak period was between April and July for female scale and rather erratic for male

scale. In both localities the period of highest parasitism by *A. citrinus*, seemed to be from May to June. The percentage of parasitism in the Nelspruit area was found to be as high as 80% while the percentage parasitism in the Kaapmuiden area was generally lower. Parasitism of the male scales tended to be higher than that of the female scales. Cock (1988) noted that clumped distributions of pests are more heavily parasitized than randomly distributed populations, as a result of the searching behaviour of parasitoids. The immature stages of the male mango scale tend to aggregate around the female (section 3.6). Schoeman (1987) noted that 17,7% of the 1022 female, *A. tubercularis* scale insects he examined were parasitized by *A. citrinus*. He unfortunately did not mention the duration and time of his study.

Even though the percentage parasitism in this study was relatively high, the parasitoid was not effective enough in controlling *A. tubercularis*.

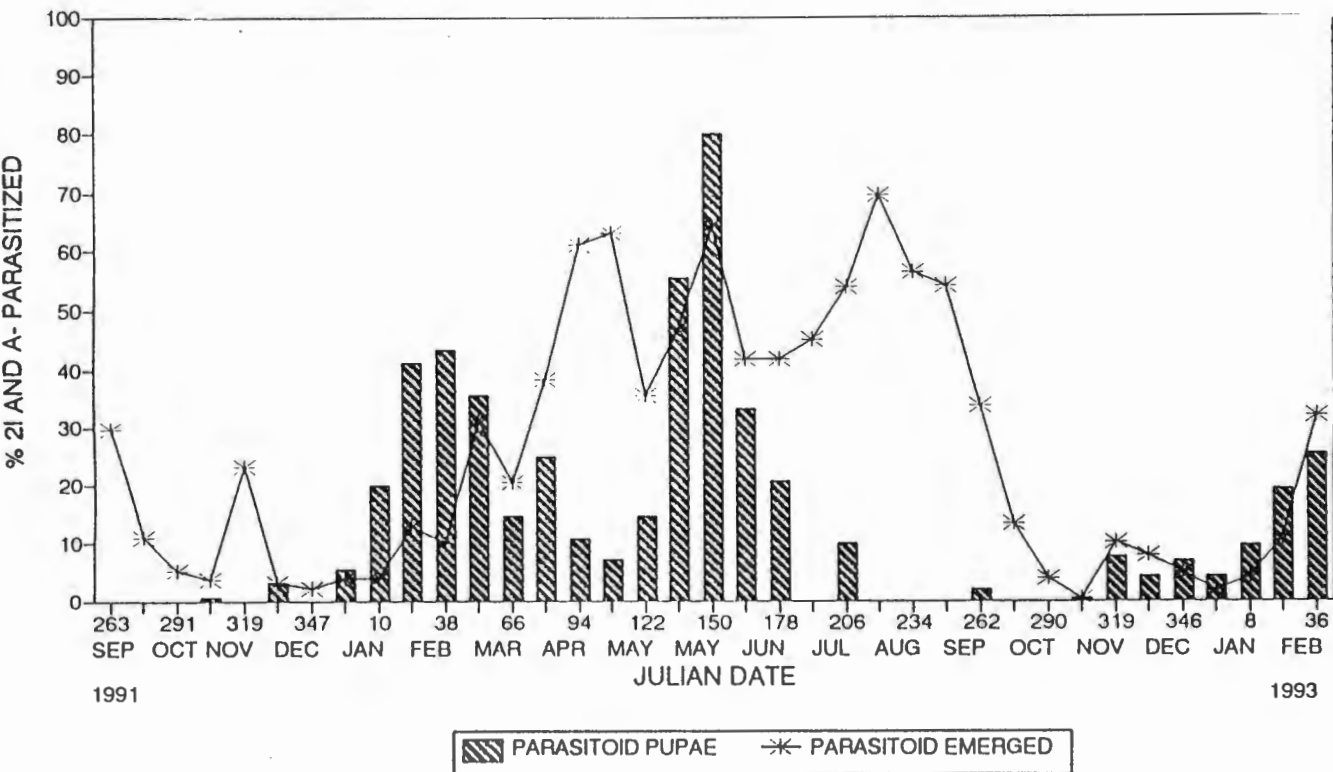


Figure 3.18 The percentage 2nd instars and A- females of *Aulacaspis tubercularis* parasitised by *Aspidiotiphagus citrinus* on mango trees of the cultivar Sensation in Nelspruit

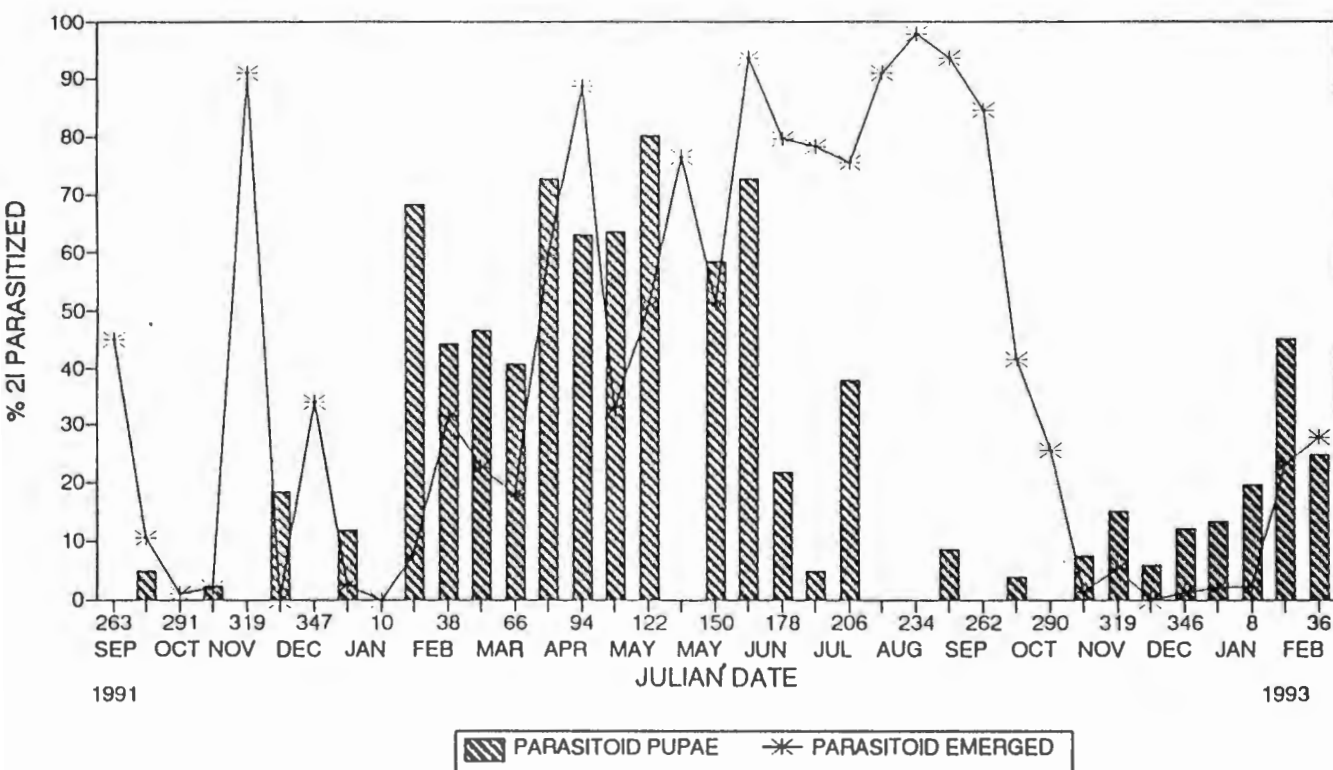


Figure 3.19 The percentage 2nd instar males of *Aulacaspis tubercularis* parasitised by *Aspidiotiphagus citrinus* on mango trees of the cultivar Sensation in Nelspruit

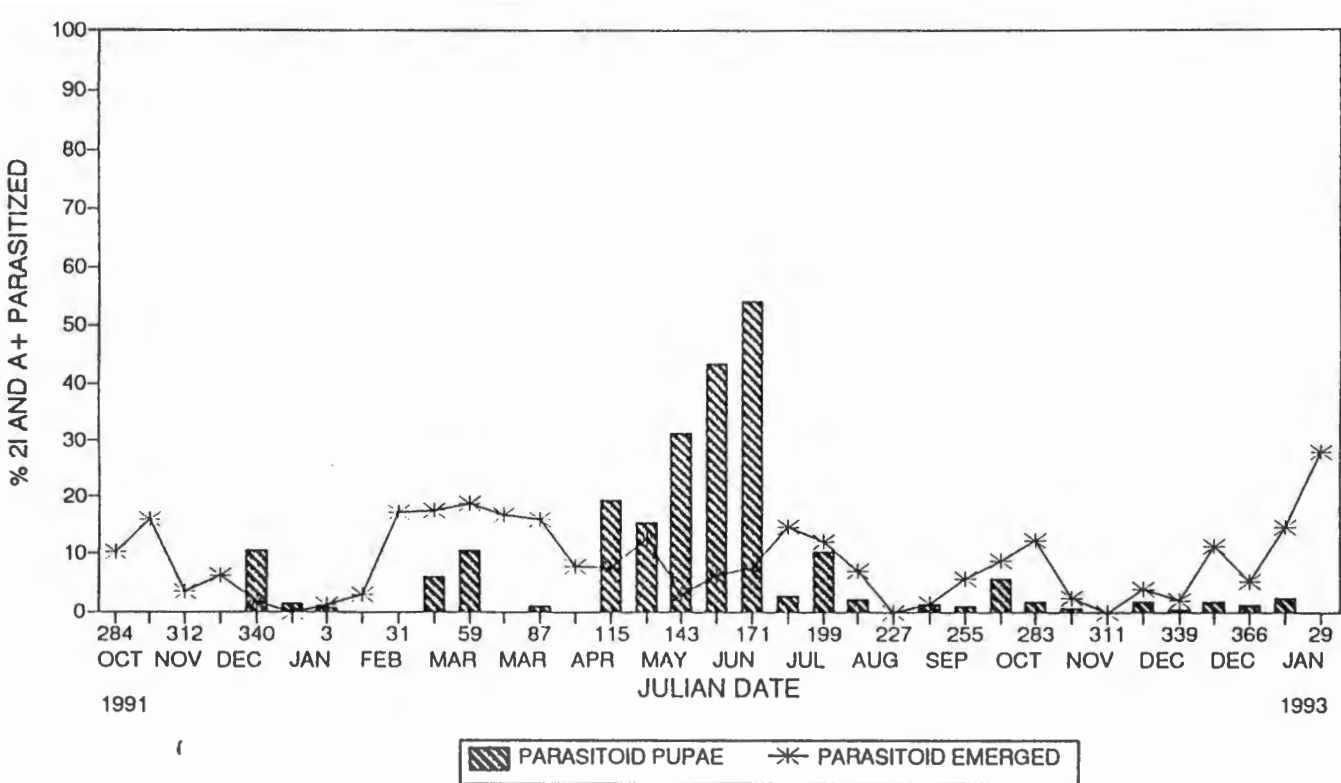


Figure 3.20 The percentage 2nd instars and A- females of *Aulacaspis tubercularis* parasitised by *Aspidiotiphagus citrinus* on mango trees of the cultivar Peach in Kaapmuiden

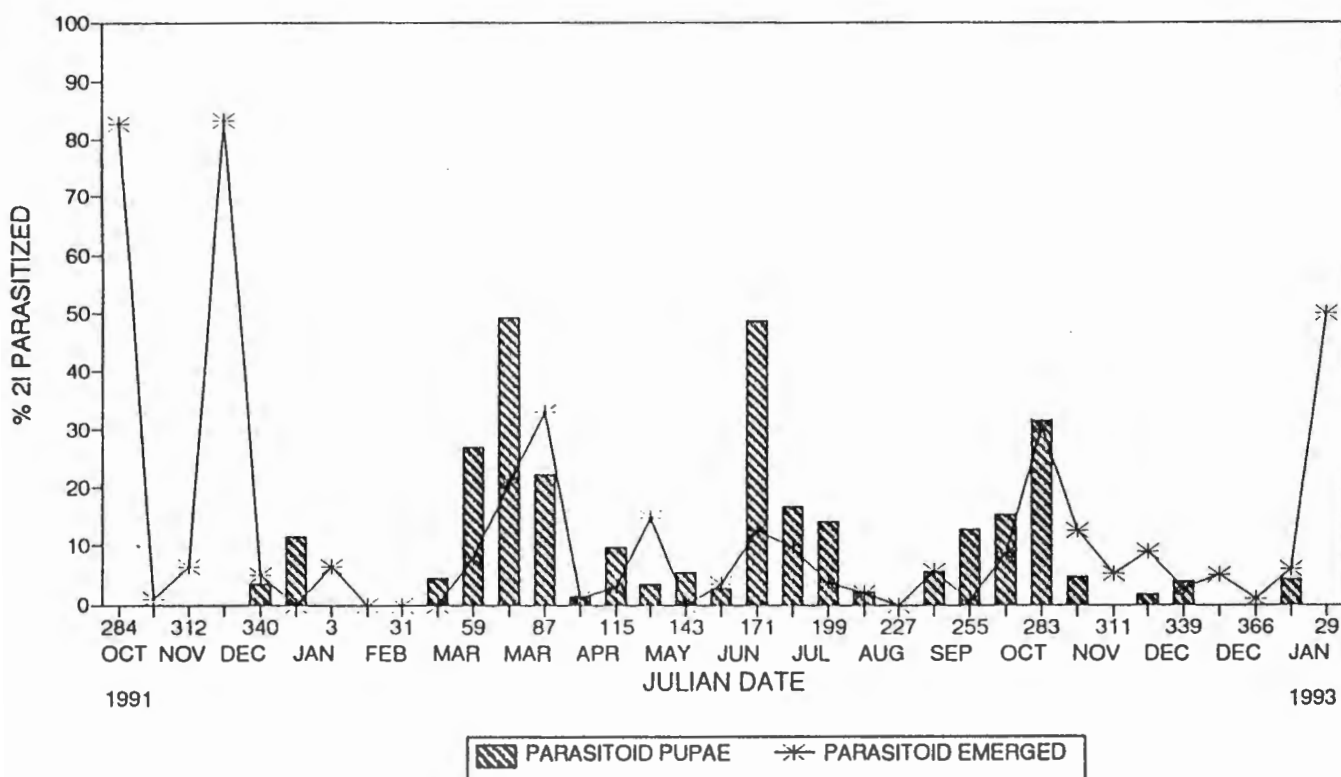


Figure 3.21 The percentage 2nd instar males of *Aulacaspis tubercularis* parasitised by *Aspidiotiphagus citrinus* on mango trees of the cultivar Peach in Kaapmuiden

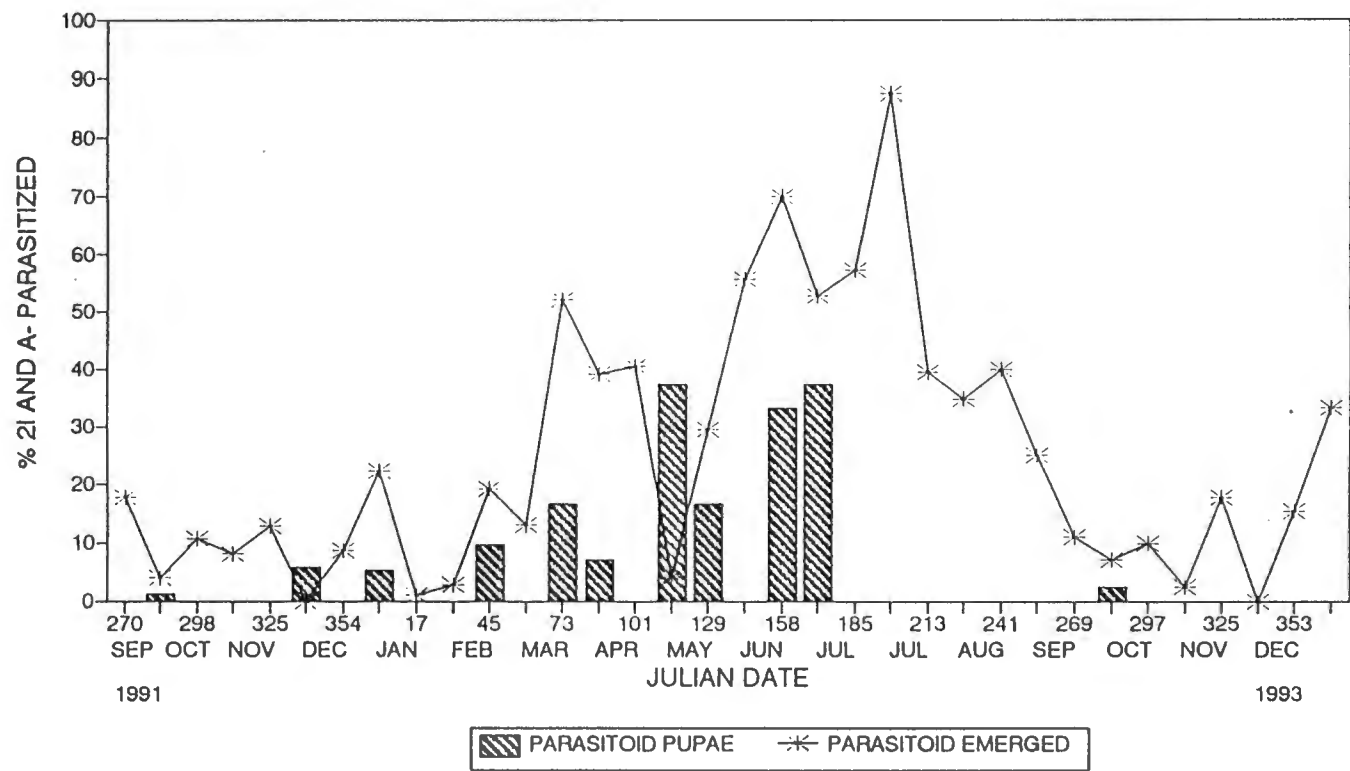


Figure 3.22 The percentage 2nd instars and A- females of *Aulacaspis tubercularis* parasitised by *Aspidiotiphagus citrinus* on mango trees of the cultivar Keitt in Kaapmuiden

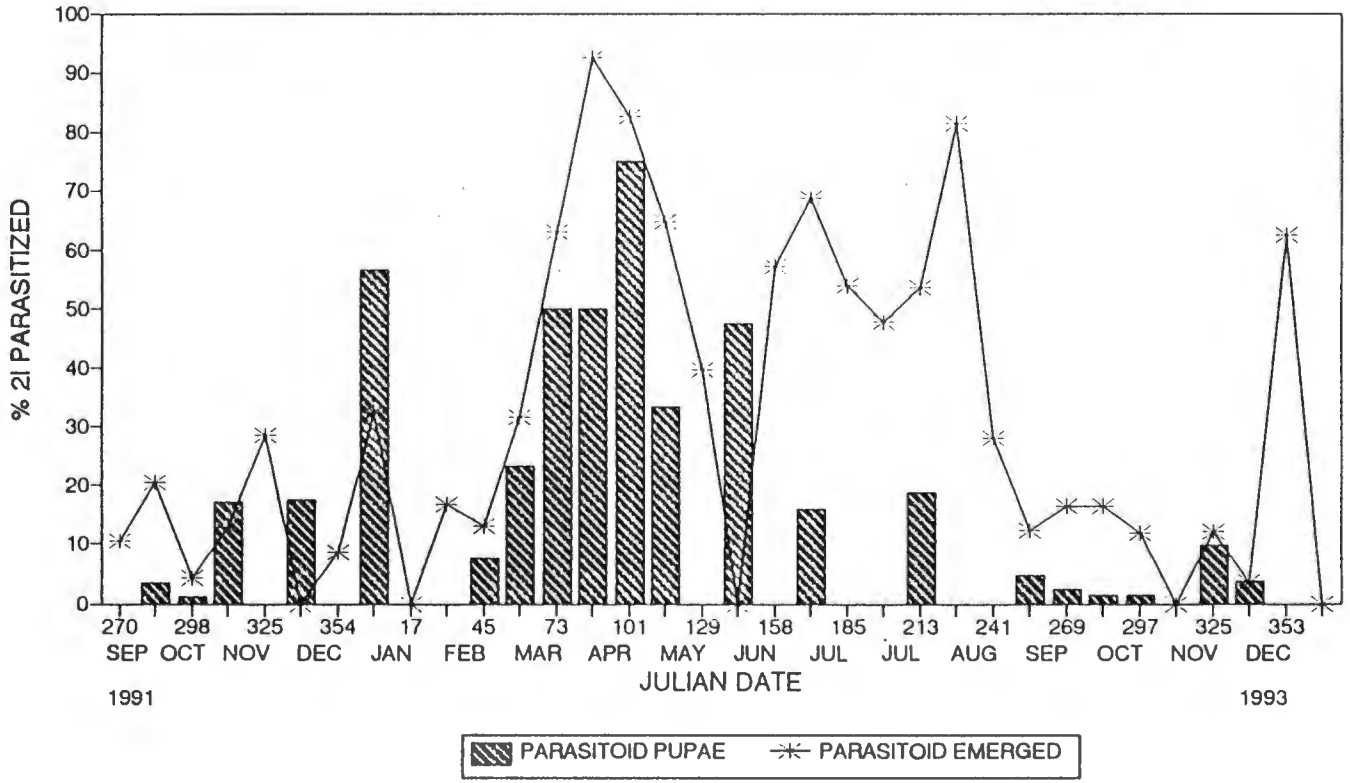


Figure 3.23 The percentage 2nd instar males of *Aulacaspis tubercularis* parasitised by *Aspidiotiphagus citrinus* on mango trees of the cultivar Keitt in Kaapmuiden

If the population fluctuation of *A. tubercularis* (Figures 3.10 and 3. 11) is compared with the percentage parasitism (Figures 3.18 to 3.23), it is obvious that a peak of parasitism is followed by a population peak of the mango scale. The assumption can therefore be made that *A. citrinus* is unable to control the mango scale population sufficiently. This situation is better illustrated in Figures 3.24 and 3.25 where the relationship between scale density and % parasitism is illustrated. The scale density in both areas is virtually inversely proportionate to the percentage parasitism by *A. citrinus*. Although the effect of parasitism on the mortality rate of the mango scale is relatively small, the combined effect of predators and the parasitoid could be significant. This postulate is however beyond the scope of this study. To determine the combined effect of the natural enemies could prove to be very difficult, since the waxy scale which covers the developing and adult stages of *A. tubercularis* is, unlike many of the other Diaspidid scales, relatively brittle. The scale covering disintegrates in a relatively short period to such an extent that no predator feeding marks can be seen on the scale covering. An estimation of the impact that other natural enemies have on the scale population, could be made by either noting the absolute number of each of these enemies feeding on the mango scale or by exclusion experiments whereby all the natural enemies are excluded from parasitising the mango scale. This was not done in this study, but needs attention before a biological control programme can be implemented.

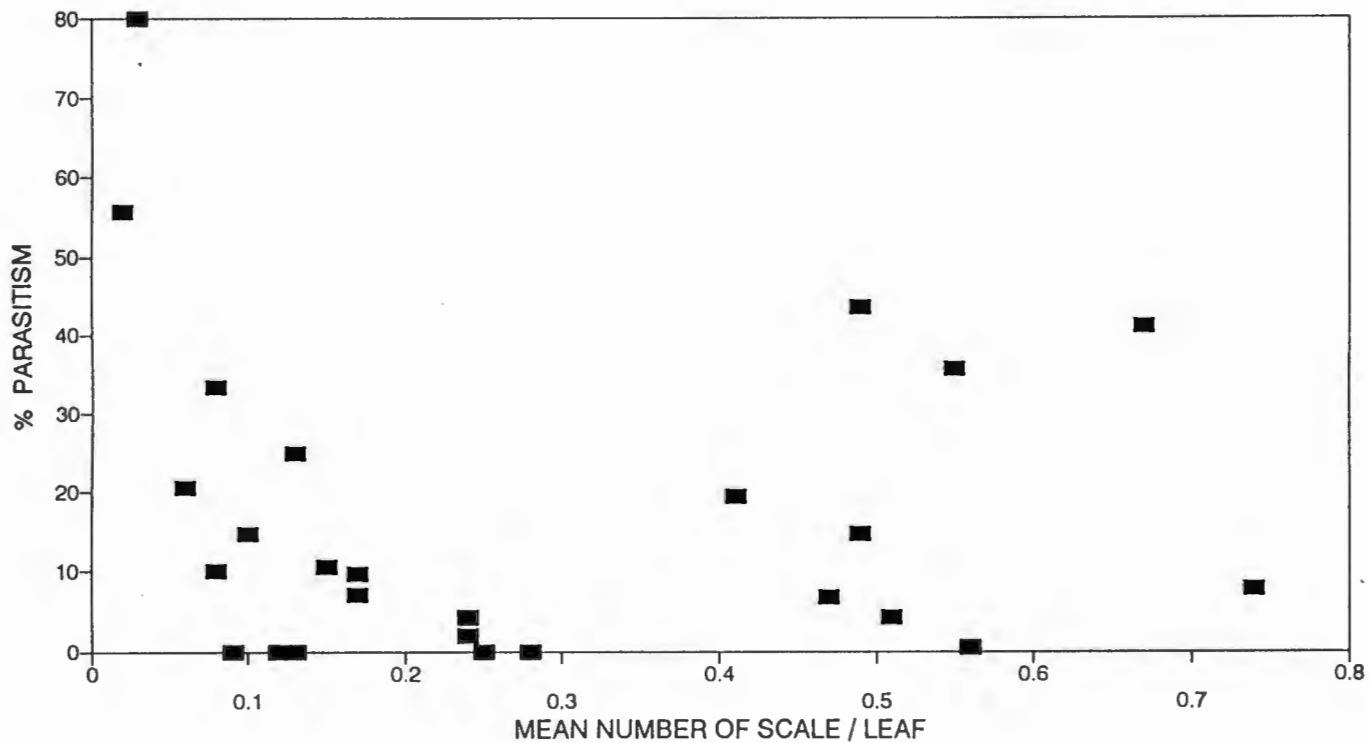


Figure 3.24 Density dependence of *Aspidiotiphagus citrinus* at Nelspruit on its host *Aulacaspis tubercularis*

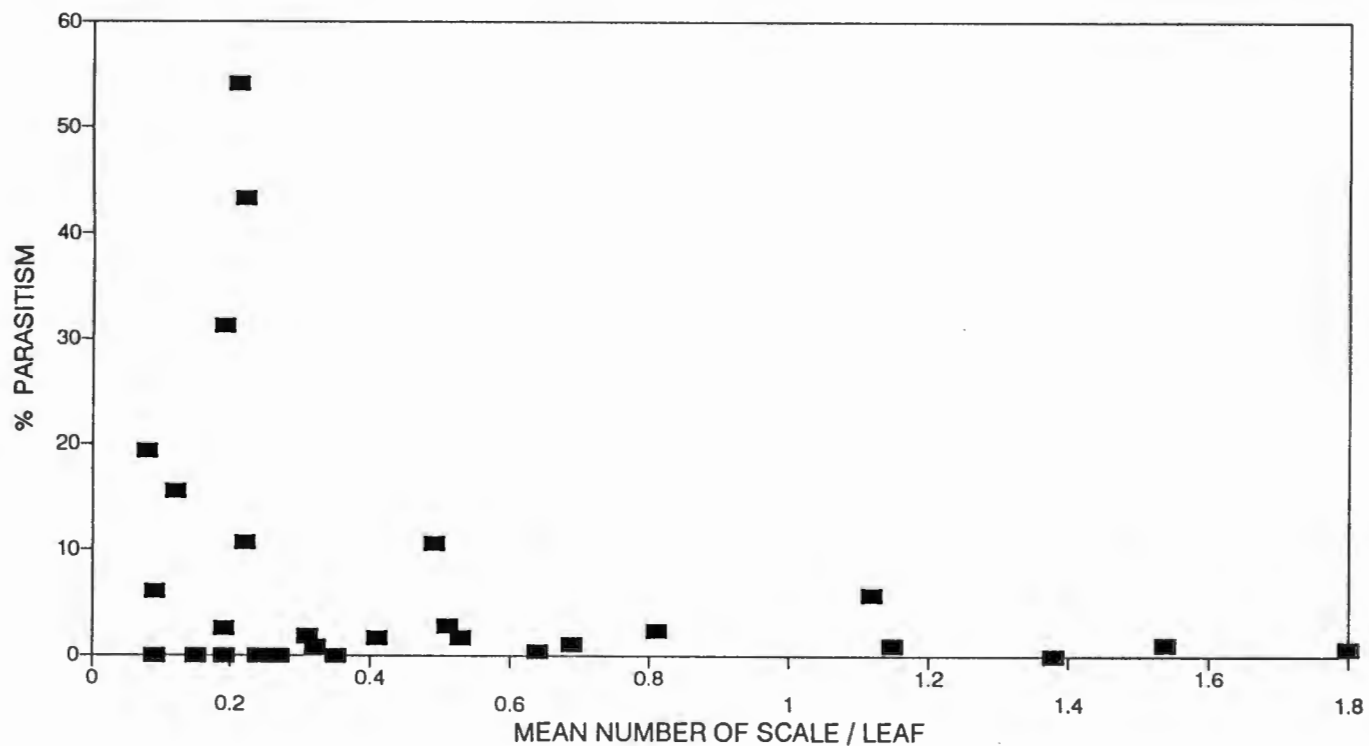


Figure 3.25 Density dependence of *Aspidiotiphagus citrinus* at Kaapmuiden on its host *Aulacaspis tubercularis*

SUMMARY AND CONCLUSIONS

The mango scale *Aulacaspis tubercularis* Newstead was reared on butternuts and studied microscopically. Post embryonic development of *A. tubercularis* comprises of two larval instars and an imago in the female, and two larval instars, two pupal instars (prepupa, pupa), and an imago in the male. The sex of the organism can easily be determined in the first instar. The scale of the female sclerotises and a distinctive black median line develops dorsally during moulting.

The duration of a single generation of *Aulacaspis tubercularis* at simulated summer, spring and winter temperatures was 42,7, 52,5 and 68,9 days respectively. Average periods of oviposition at the same simulated conditions were 33,25, 45,69 and 28,48 days and the average number of eggs produced 203,15, 261,90 and 82,45 for summer, spring and winter respectively. Males accounted for 73% of the *A. tubercularis* population. *A. tubercularis* was found to be bisexual, no parthenogenesis was found and positive phototaxic behaviour was demonstrated.

Population expansion in the field began at the beginning of spring and reached a peak before midsummer. This can be explained by the higher reproductive potential of the insect in spring, as shown in the laboratory. The mango scale population peaked in August and November in Kaapmuiden and Nelspruit respectively.

The infestation of mango scale in mango trees was significantly higher in the shady

south facing lower aspect than in any of the other aspects.

Generations overlapped to such an extent that all developmental stages were found throughout the year. The long ovipositional period which can last up to 82 days in spring is primarily responsible for the overlapping of generations.

The only indigenous parasitoid found on mango scale in South Africa, *Aspidiotiphagus citrinus*, is density independent and thus incapable of controlling *A. tubercularis*. A predatory thrip, *Aleurodothrips fasciapennis*, Franklin was found feeding on *A. tubercularis*. This species has never before been recorded on mango scale or in Africa.

In conclusion the following suggestions can be made regarding control of the mango scale:

- 1- A chemical control program, where only the south facing lower aspect of trees is sprayed should be tested and compared to the registered full cover spray.
- 2- No chemicals should be sprayed during the peak period of parasitism (January to June).
- 3- Definite peaks of crawler activity do not exist and scouting for crawlers would serve no purpose in the timing of chemical spray programmes for mango scale.
- 4- The obvious lack of parasitoids on mango scale makes it important to search for a variety of density dependent parasitoids. The continued availability of all the scale stages should be advantages in the establishment of such parasitoids.

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